ACTEWAGL

MURRUMBIDGEE ENVIRONMENTAL MONITORING PROGRAM

PART 4: TANTANGARA TO BURRINJUCK

SPRING 2011

The ALS Water Sciences Group is part of the Environmental Division of ALS, one of the largest and most geographically diverse environmental testing businesses in the world.

CERTIFICATE OF APPROVAL FOR ISSUE OF DOCUMENTS

Client: ActewAGL
Project Title: **Murrumbidgee Environmental Monitoring Program**
Report Title: Part 4: Tantangara to Burrinjuck
Document No: CN211063-P4--S11-R8-V4
Document Status: For Client Review
Date of Issue: 16 March 2012
Comments:

	Position	Name	Signature	Date
Prepared by:	Environmental Scientist	Zoe Lagerroth		14/03/2012
Internal Review by:	Senior Ecologist	Phil Taylor		16/03/2012
Peer Review by:				
Approved by:	Manager, Water Sciences ACT	Norm Mueller		16/03/2012

For further information on this report, contact:

Name: Phil Taylor
Title: Environmental Project Manager
Address: 16B Lithgow Street, FYSHWICK, ACT 2609
Phone: 02 62025422
E-mail: phil.taylor@alsglobal.com

Document Revision Control

Version	Description of Revision	Person Making Issue	Date	Approval
1	For Client review	Phil Taylor	15/03/2012	Norm Mueller
2	Draft Final	Phil Taylor, Josh Cox	5/04/2012	Norm Mueller
3	Final	Phil Taylor	23/04/2012	Norm Mueller

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

List of abbreviations

ACT – Australian Capital Territory
ACTEW – ACTEW Corporation Limited
ANZECC – Australian and New Zealand Environment and conservation Council
ANOSIM – Analysis of Similarities (statistics)
ANOVA – Analysis of Variance (statistics)
ARI – Annual Recurrence Interval
ARMCANZ - Agriculture and Resource Management Council Of Australia and New Zealand
AUSRIVAS – Australian River Assessment System
CPOM – Coarse Particulate Organic Matter
CRCFE – Cooperative Research Centre for Freshwater Ecology
EC – Electrical Conductivity
ECD – Enlarged Cotter Dam
EIS – Environmental Impact Statement
EPA – Environmental Protection Authority
EPT – Ephemeroptera, Plecoptera, Trichoptera
D.O. – Dissolved Oxygen
GL/a – Gigalitres per annum
GPS – Global Positioning System
LMWQCC – Lower Molonglo Water Quality Control Centre
LWD – Large Woody Debris
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)
O/E Family – Observed to Expected ratio of macroinvertebrate families
PCA – Principal Components Analysis
Q – Daily flow (ML/d)
QA – Quality Assurance
QC – Quality Control
RBA – Rapid BioAssessment
SIGNAL – Stream Invertebrate Grade Number – Average Level
SIMPER – Similarity Percentage (statistics)
TN – Total Nitrogen
TP – Total Phosphorus
Temp. Water temperature (℃)
WAE – Water Allocation Entitlement
WL – Water Level

Executive Summary

In light of the recent drought in the ACT region, ACTEW Corporation, the water utility company for the ACT, developed a water supply security program that encompassed the development of new infrastructure in order to secure long term water supply for the ACT. One of the project options put forward was the "Tantangara transfer" which involves transferring water from the Tantangara Reservoir on the upper Murrumbidgee River to the ACT via run of river flow, and then abstracting the water and transferring it to the Googong Reservoir. This provides a source of water that is less dependent on rainfall within the ACT.

The Murrumbidgee Ecological Monitoring Program was set up by ACTEW Corporation to evaluate the potential impacts of water abstraction from the Murrumbidgee River. It was designed to address concerns raised by both Government and non-Government stakeholders; and to provide ACTEW Corporation with relevant information regarding any beneficial and/or detrimental ecological effects of the abstraction. The MEMP was set up to be implemented prior to the commencement of the Murrumbidgee to Googong transfer project (M2G), allowing ACTEW to collect pre-abstraction baseline data to compare against post-abstraction data once the M2G project is in operation. The MEMP study has undertaken pre-abstraction sampling in spring and autumn since spring 2008.

There are four component areas that have been established for the MEMP. This report focuses on Part 4: Tantangara to Burrinjuck. In particular, it focuses on results of the spring 2011 macroinvertebrate sampling run.

The key aims of this sampling run were to:

a. *Increase baseline macroinvertebrate data for key sites along the Murrumbidgee River, and in doing so establish a database of the existing condition prior to any designated releases from Tantangara reservoir;*

b. *Undertake in-situ water quality sampling – including nutrient analysis as a baseline for future condition assessments;*

c. *Provide AUSRIVAS assessments of riffle and edge habitats between Tantangara Reservoir and Burrinjuck Reservoir on the Murrumbidgee River.*

The spring sampling was conducted in November 2011 at 23 sites along the Murrumbidgee River between Tantangara Dam and Burrinjuck Reservoir. The sampling run also followed an environmental flow release from Tantangara Reservoir by Snowy Hydro that reached approximately 1500 ML/d for 8 days.

During spring 2011, there was above average rainfall across the catchment which influenced the water quality results. Similar to previous sampling events, levels of Total Nitrogen and Total Phosphorus exceeded ANZECC and ARMCANZ (2000) guideline values for upland river systems at most sites. Some values of turbidity, dissolved oxygen and pH were also outside of the expected range. Low levels of electrical conductivity and turbidity were again observed just downstream of Tantangara Dam.

Water quality in the reach upstream of Cooma was, as expected, superior to that observed for the downstream reaches. Differences in water quality observed between reaches were attributed to the percentage of agricultural landuse, and impact from urban stormwater runoff and sewerage treatment plant discharge.

Based on AUSRIVAS grading, the overall assessment of the 23 Murrumbidgee River sites generally ranged from Band A (near reference condition) upstream of the ACT urban area, to Band B (significantly impaired) in and downstream of the ACT, with a Band C (severely impaired) result indicated just before Burrinjuck Reservoir. When the riffle and edge habitats are considered separately, some individual samples collected from Zone 1 (upstream of Cooma) and Zone 2 (Cooma to Angle Crossing) were Band X (more diverse than the reference). This improvement appears to be a result of increased natural flows over the previous year and the environmental flow release from Tantangara prior to the monitoring period.

Overall, the number of macroinvertebrate families and the number of sensitive macroinvertebrates was similar in the upper sections of the Murrumbidgee River between the Tantangara Dam wall and upstream of Angle Crossing. However, some sites between Point Hut Crossing and upstream of Burrinjuck reservoir showed declines in the number of sensitive taxa.

There were statistical differences in the relative abundances of sensitive Mayfly, Stonefly and Caddisfly taxa at the upper most reaches compared to all sites downstream of Cooma. Some of these taxa included highly sensitive taxa indicating that compared to sites downstream of Cooma, the upper reaches generally have high water quality and good quality habitat. These longitudinal differences in the Murrumbidgee River are attributed to downstream changes in landuse which is further influenced by several major tributaries draining agricultural/grazing and urban areas further downstream.

1 Introduction

The drought in the ACT, which began in the year 2000, progressively caused declines in the ACT's dam storage volumes to unprecedented levels. ACTEW Corporation, the major water utility company in the ACT, developed a water security program that encompassed upgrading the existing Cotter Dam, and development of new infrastructure to pump water from the Murrumbidgee River in order to secure water for the Australian Capital Territory (ACT). One of the new water security projects put forward was the "Tantangara transfer" which will involve transferring water from the Tantangara Reservoir in the upper Murrumbidgee River to the ACT via run of river flow, with the aim of providing a source of water that is less dependent on rainfall within the ACT.

In order to use water from the Tantangara Reservoir, ACTEW has commenced the construction of a river off take pumping structure, and pipeline from Angle Crossing (southern border of the ACT) to the Googong catchment. 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 flow into the Googong Reservoir. The system is designed to enable pumping of up to 100 ML/d, and is expected to be in operation by mid-2012. Abstraction will be dictated by the storage level in Googong reservoir, the level of demand for the water, and by the availability of water in the Murrumbidgee River. The abstraction infrastructure is referred to as the Murrumbidgee to Googong project (M2G). A schematic overview of the proposed operations is given in Appendix A.

Required base flows to be maintained in the Murrumbidgee River will be regulated through the *ACT Environmental Flow Guidelines (ACT Government, 2006, 2011)* and associated water licence. ACT & NSW Government agencies, and recreational and rural users in the regional Murrumbidgee River reach (both upstream and downstream of Angle Crossing), are key stakeholders in the M2G project.

The Murrumbidgee Ecological Monitoring Program was set up by ACTEW Corporation to evaluate the potential impacts of water abstraction from the Murrumbidgee River. It was designed to address concerns raised by both Government and non-Government stakeholders; and to provide ACTEW Corporation with relevant information regarding any beneficial and/or detrimental ecological effects of the project. The MEMP was set up to be implemented prior to the commencement of the M2G project, allowing ACTEW to collect pre-abstraction baseline data to compare against and post-abstraction data once the M2G project is in operation. The timeline for the MEMP study is to undertake pre-operational sampling in spring and autumn commencing in spring 2008. The current status is that the M2G project is due for completion mid-2012 after which the commissioning stage would commence and sampling would change to post-operational.

There are four component areas covered as part of the MEMP:

Part 1: Angle Crossing;

Part 2: Burra Creek (discharge point for Angle Crossing abstraction);

Part 3: Murrumbidgee Pump Station; and

Part 4: Tantangara to Burrinjuck

This report focuses on Part 4: Tantangara to Burrinjuck.

In particularly, it focuses on results of spring 2011 monitoring carried out as part of the MEMP Tantangara to Burrinjuck area study.

1.1 Objectives

The overall objectives of the MEMP are to monitor the physical, biological and water quality indicators along the length of the upper Murrumbidgee River from Tantangara to Burrinjuck reservoirs (details are given in ALS, 2011). The intention of the seasonal sampling is to establish baseline macroinvertebrate data for key sites along the Murrumbidgee River and, in doing so, establish a data base of the existing condition prior to any releases from Tantangara Reservoir. The baseline monitoring incorporates water quality monitoring (including nutrient analysis) and macroinvertebrate monitoring based on the Australian River Assessment System (AUSRIVAS) sampling and assessment framework.

With these procedures in place, ALS will be able to provide ACTEW and ActewAGL with appropriate information to further develop knowledge and understanding of environmental flows and ecosystem thresholds. The information derived from this program will also support ActewAGL's adaptive management approach to water abstraction and environmental flow provision in the ACT. Frequent assessments of the program will ensure that the monitoring program put in place has the capacity to adapt to changing environmental, social and economic conditions, with regard to ActewAGL's operational requirements.

1.2 Scope of Work

The works outlined in the proposal (ALS, 2011) included the following:

- Bi-annual sampling, in spring and autumn;
- Macroinvertebrate sampling of both the riffle and edge habitats as per ACT AUSRIVAS protocols;
- Macroinvertebrates to be identified to the taxonomic level of family;
- *In-situ* water quality measurements to be collected and analysed for physico-chemical parameters and nutrients;
- Water quality analysis to be conducted in ALS's NATA accredited laboratory.

2 Materials and Methods

2.1 Study Sites

As stated in the objectives of this program, macroinvertebrate community composition and water quality is to be monitored along the Murrumbidgee River between the Tantangara and Burrinjuck reservoirs, with the aim of obtaining baseline information about ecological condition. Ecological monitoring was conducted in accordance with ANZECC & ARMCANZ (2000) guidelines.

The upper Murrumbidgee River is impacted by a range of landuse practices throughout the catchment. Consequently, it was important to sample a sufficiently large number of sites to provide a realistic snap-shot of the current macroinvertebrate community across all existing landuse impacts. Both riffle and edge habitats were sampled, where possible, to provide a more complete picture of the macroinvertebrate community at each site.

Sites are the same as previous sampling runs and were chosen based on several criteria including:

1. Accessibility – safe and with approvals from land owners;
2. Sites which 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 water abstractions;
3. Sites which have historical ecological data sets (e.g. Keen, 2001) took precedence over "new sites" – thus allowing comparisons through time to help assess natural variability through the system.

Potential sites were identified initially from topographic maps and then visited prior to sampling to assess suitability. In total, 23 sites fulfilled the above criteria. These sites include 10 sites upstream and 13 sites downstream of Angle Crossing (ACT), locations upstream and downstream of the Lower Molonglo Water Quality Control Centre (LMWQCC) and several of the Murrumbidgee Rivers major tributaries (Table 1; Figure 1).

The sites were divided up into four macro-reaches (zones) which represent geographic or hydrological changes (Allan and Castillo, 2008) throughout the system; and obvious changes in terms of landuse, erosional processes and/or other potential anthropogenic impacts. These classifications are to some extent subjective, but are based on previous frameworks which have suggested methods for such classifications (e.g. Hynes, 1970; Frissell *et al*., 1986; Allan and Castillo, 2008). Details of the four zones are provided in Table 2.

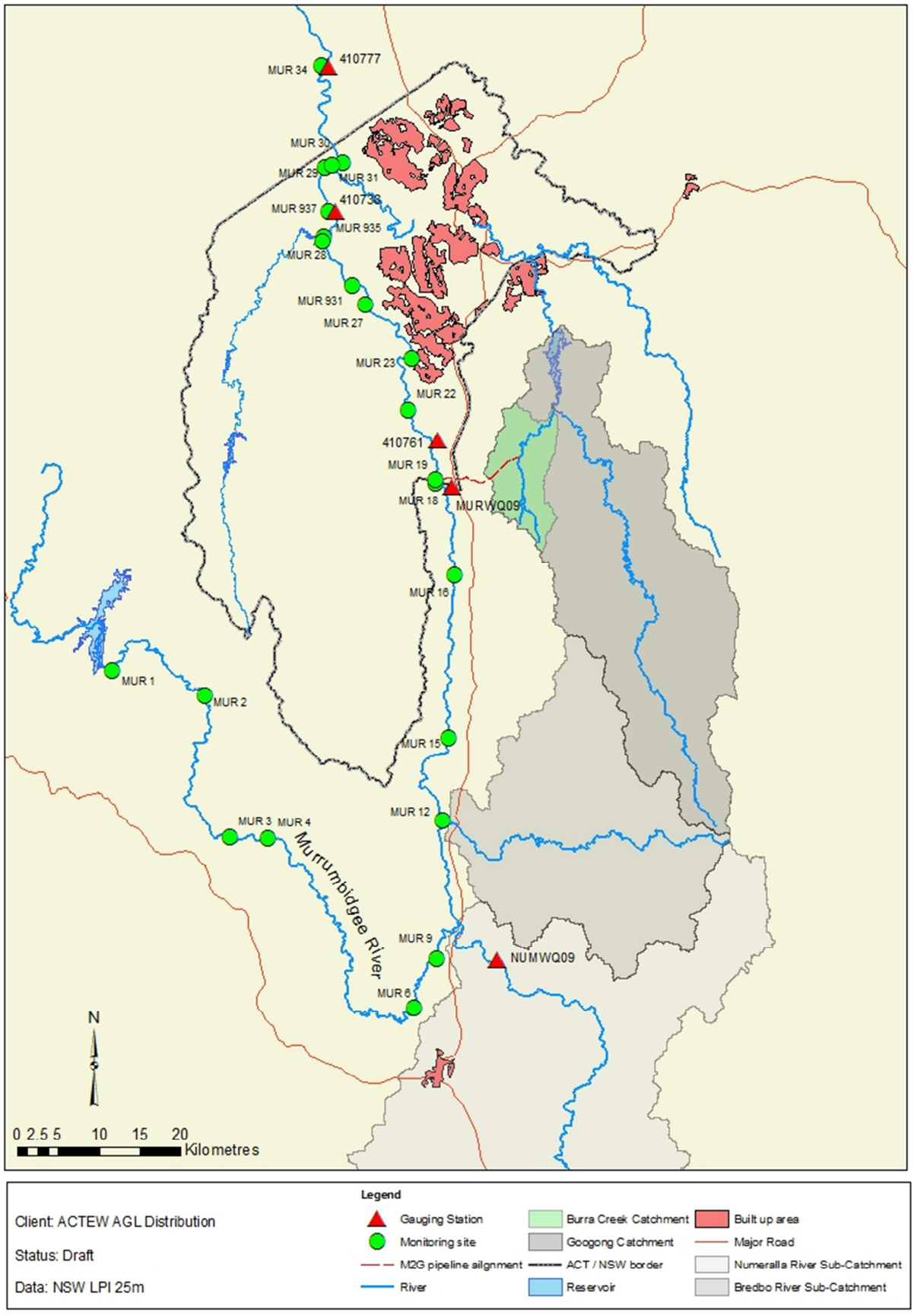


Figure 1. Location of macroinvertebrate sampling sites and continuous monitoring stations on the Murrumbidgee River

Table 1. Sampling site locations and details

Site Code	Location	Alt. (m)	Landuse	Habitat sampled
MUR 1	D/S Tantangara Reservoir	1200	Native	Riffle and Edge
MUR 2	Yaouk Bridge	1070	Grazing	Riffle and Edge
MUR 3	Bobeyan Road Bridge	968	Grazing	Riffle and Edge
MUR 4	Camp ground off Bobyon Road	968	Recreation / Grazing	Riffle and Edge
MUR 6	D/S STP Pilot Creek Road	743	Native / Residential	Riffle and Edge
MUR 9	Murrells Crossing	723	Grazing	Riffle and Edge
MUR 12	Through Bredbo township	698	Grazing / Residential / Recreation	Riffle and Edge
MUR 15	Near Colinton - Bumbalong Road	658	Grazing / Recreation	Riffle and Edge
MUR 16	The Willows - Near Michelago	646	Grazing / Recreation	Riffle and Edge
MUR 18	U/S Angle Crossing	608	Grazing	Riffle and Edge
MUR 19	D/S Angle Crossing	608	Grazing / Recreation	Riffle and Edge
MUR 22	Tharwa Bridge	572	Recreation / Grazing / Residential	Riffle and Edge
MUR 23	Point Hut Crossing	561	Recreation / Residential	Riffle and Edge
MUR 27	Kambah Pool	519	Recreation / Residential	Riffle and Edge
MUR 931	“Fairvale” ~4km U/S of the Cotter Confluence	480	Grazing	Riffle and Edge
MUR 28	U/S Cotter River confluence	468	Grazing	Riffle and Edge
MUR 935	Casuarina sands	471	Grazing	Riffle and Edge
MUR 937	Mt. MacDonald ~5km D/S of the Cotter Confluence	460	Grazing / ex-forestry/ Recreation	Riffle and Edge
MUR 29	Uriarra Crossing	445	Grazing	Riffle and Edge
MUR 30	U/S Molonglo Confluence	445	Grazing	Riffle and Edge
MUR 31	D/S Molonglo Confluence	443	Grazing	Riffle and Edge
MUR 34	Halls Crossing	393	Grazing	Riffle and Edge
MUR 37	Boambolo Road	370	Grazing	Edge

Note: U/S – upstream, D/S - downstream

Table 2. Zone structure of sites along the Murrumbidgee River

Macro-reach	Zone	Sites included	Land use
Tantangara - Cooma	1	MUR 1 - 4	Native. Reservoir within national park. Recreation. Agricultural land downstream of Yaouk
Cooma – Angle Crossing	2	MUR 6 - 18	Agriculture dominant. Some urbanization. STP present upstream of MUR 6.
Angle Crossing - LMWQCC	3	MUR 19 - 30	Residential and residential / urban development increases. Less grazing than in the Tantangara – Cooma and LMWQCC – Taemas Bridge macro-reaches
LMWQCC – Taemas bridge	4	MUR 31 - 37	Intensive agricultural landuse. Downstream of LMWQCC. Previous work has shown a marked change in water quality downstream of the treatment plant

2.1.1 Hydrology and rainfall

River flows and rainfall for the sampling period were recorded at ALS operated gauging stations located at: upstream of Angle Crossing (MURWQ09); Lobb's Hole (downstream of Angle Crossing: 410761); Mount MacDonald (downstream of the Cotter River confluence: 410738) and Halls Crossing (located at MUR 34: 410777). Gauging locations and codes are given in

Table 3. Stations were calibrated monthly and data were downloaded and verified before quality coding and storage in the ALS database. Water level data was manually verified by comparing the logger value to the manually read staff gauge value and adjusted if required. Rain gauges were also calibrated and adjusted as required. Records were stored using the HYDSTRA© database management system.

Site	Site Code	Location/Notes	Parameters*	Latitude	Longitude
1	MURWQ09	M'bidgee River, upstream of Angle Crossing	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.59070˚	E 149.1179˚
2	410761	M'bidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.53980˚	E 149.1015˚
3	410738	M'bidgee River @ Mt. MacDonald	WL, Q	S 35.29170˚	E 148.9565˚
4	410777	M'bidgee River @ Hall's Crossing	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.13277˚	E 148.9425˚

Site	Site Code	Location/Notes	Parameters*	Latitude	Longitude
1	MURWQ09	M'bidgee River, upstream of Angle	WL, Q, pH, EC, DO,	S 35.59070˚	E 149.1179˚

		Crossing	Temp, Turb, Rainfall		
2	410761	M'bidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.53980˚	E 149.1015˚
3	410738	M'bidgee River @ Mt. MacDonald	WL, Q	S 35.29170˚	E 148.9565˚
4	410777	M'bidgee River @ Hall's Crossing	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.13277˚	E 148.9425˚

Table 3. River flow monitoring locations and parameter

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

2.2 Water quality

In-situ physico-chemical parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded using a multiprobe HYDROLAB® Minisonde 5 and Surveyor meter. The Minisonde and Surveyor unit were calibrated in accordance with QA procedures and the manufactures requirements prior to sampling.

From each site, grab samples were taken in accordance with the AUSRIVAS protocols (Coysh *et al*., 2000) for HYDROLAB® verification and nutrient analysis. All samples were placed on ice, returned to the ALS laboratory and analysed for various water quality parameters in accordance with the protocols outlined in A.P.H.A (2005). Collectively, this information on the water quality parameters will assist with 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.

Care must be taken with interpreting the results of NOx, nitrate, nitrite, phosphorus and ammonia as the Level of Reporting (LOR) for these variables are 0.01. This means that some values for these analytes are censored (i.e. their values were below detectable limits) and could produce misleading results.

2.3 Macroinvertebrate sampling

Macroinvertebrate samples were collected and analysed in accordance with the ACT AUSRIVAS protocols for riffle and edge habitats (Coysh *et al*., 2000). Samples were collected using a framed net (350 mm wide) with 250 µm mesh. Riffle habitat (flowing broken water over gravel, pebble, cobble or boulder, with a depth greater than 10cm) (Coysh *et al*., 2000) 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. Edge habitat (backwaters or areas of low flow within 0.5m of the bank) was sampled by sweeping the collection net along the edge habitat at the sampling site with the operator working systematically over a ten metre section and sampling where there was overhanging vegetation, submerged snags, macrophyte beds, overhanging banks and areas with trailing vegetation. The samples were then preserved in the field using 70% ethanol in clearly labelled containers showing site codes, habitat and date information.

The purpose of this biannual seasonal report is to convey the results of the macroinvertebrate and water quality sampling from Tantangara Reservoir to Burrinjuck Reservoir in spring 2011. Several sites within this report are also key components of the three main sub-sections of the MEMP, including monitoring for the Murrumbidgee Pump Station (MPS) upgrade operation and the impact assessment of the construction and operation of the Angle Crossing pump station and pipeline, which includes the eventual discharge into Burra Creek. The sampling regime for these sub-sections differs slightly to those reported here, mainly in that replicate macroinvertebrate samples were collected for ecological assessment in the other sub-sections and a higher level (Genus) of identification was sometimes applied. This means that a more comprehensive list of macroinvertebrate taxa is likely to be captured for those sub-sections. For the Tantangara to Burrinjuck component of the MEMP, only one macroinvertebrate sample was included for each habitat type at each site and identification was only to Family level. In order to compare data from the Tantangara to Burrinjuck study to those collected as part of other study components, the first sub-sample from the first replicate macroinvertebrate sample taken at each site from those other studies was selected for inclusion in the data analysis. As a result of this process, it should be recognised that there are small discrepancies between the taxonomic inventories, taxonomic richness measurements and presence / absence of taxa reported here and those reported in relation to other sub-sections of the MEMP.

2.3.1 Sample processing

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 extracted, one at a time. Macroinvertebrates were examined under a microscope until a total of 200 animals were collected. If 200 animals were identified before a cell had been completely analysed, identification continued until all animals within the cell were identified. Macroinvertebrates present in each sample were identified to family level except for select groups such as Chironomidae (identified to sub-family), Oligochaeta (identified to class) and Acarina (identified to order). Macroinvertebrate identification was undertaken using a range of published and working keys. QA/QC procedures for macroinvertebrate sample processing are described in Section 2.4.5.

Upon the completion of macroinvertebrate identification, the samples were transferred to robust vials with evaporation-proof rubber seals for long-term archiving. Samples can be re-examined at a later date if required (e.g. if the taxonomy changes significantly during the course of a long term monitoring program).

2.4 Data analysis

2.4.1 Water quality

Principal Components Analysis (PCA) - based on Euclidean distances - was used to determine which physico–chemical variables were most strongly associated with differences among sites. PCA is a multivariate analysis technique that is commonly used on environmental data as an exploratory procedure. It compresses a set of variables – in this case water quality - into a smaller number of derived variables, called components. These components are linear combinations of the original variables that help explain as much of the variation in the data matrix as possible (Quinn and Keough, 2002); PCA summarises the data in a way which best explains the variance within the data set, and in this way it is similar to a multivariate extension of linear regression.

The output from the PCA includes a two or three dimensional plot similar to those produced by non-metric multidimensional scaling (NMDS) and a list of eigenvalues and eigenvectors. The eigenvalues represent the amount of the original variance explained by each new component and the eigenvectors are coefficients or weights that show how much each original variable contributes to each new, derived variable, or component.

Principal Components Analysis was performed in PRIMER version 6 (Clarke and Gorley, 2006) using normalised water quality variables collected in spring 2011. The analysis began with 13 variables however nitrate and nitrite records were removed from the analysis because they did not provide any information beyond that available from NOx. Dissolved Oxygen (mg/L) was also removed in favour of Dissolved Oxygen (% saturation). Some values for ammonia are censored (i.e. they could not be differentiated beyond the LOR). Thus, care must be taken when interpreting the results of the PCA in regards to differences in ammonia. However, ammonia values were included in the analysis as the raw data indicated key differences between sites. Prior to multivariate analysis, turbidity, alkalinity and electrical conductivity were log (x+1) transformed and values of NOx, total phosphorus and total nitrogen were fourth root transformed. Variables were only transformed where an improvement in “normality” was evident.

Water quality parameters were also examined for compliance with ANZECC water guidelines for healthy ecosystems in upland streams of temperate Australia (ANZECC & ARMCANZ, 2000).

2.4.2 AUSRIVAS assessment

AUSRIVAS is a prediction system that uses macroinvertebrates to assess the biological health of rivers and streams. The model uses site-specific information to predict the macroinvertebrate fauna expected (E) in the absence of environmental stressors. The expected fauna from sites with similar sets of predictor variables (physical and chemical characteristics which cannot be influenced by human activities e.g. altitude) are then compared to the observed fauna (O) and the ratio derived is used to indicate the extent of any impact (O/E). The ratios derived from this analysis are converted to Bandwidths (i.e. X, A-D; **.**

Table 4) which indicate the overall health of each site (Coysh *et al*., 2000). Data are presented using the AUSRIVAS O/E 50 ratio (Observed/Expected score for taxa with a >50% probability of occurrence base on site location and habitat conditions) 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 is based on the furthest band from reference condition from the two habitats. For example, a site that had an A assessment in the edge and a B Band in the riffle would be given an overall site assessment of B (Coysh *et al*., 2000). This approach accords with the precautionary principle.

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 expected less 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 over time and in some circumstances the inclusion of these taxa in the model might indicate false changes in the site classification; the presence or absence of these taxa might be a function of sampling effort rather than truly reflecting ecological change.

Table 4. AUSRIVAS Band-widths and interpretations for the ACT spring edge and riffle models

Band	O/E Band Width		Explanation
	RIFFLE	EDGE	
X	>1.14	>1.13	More diverse than expected. Potential enrichment or naturally biologically rich. Potential enrichment or naturally biologically rich.
A	0.86-1.14	0.87-1.13	Similar to reference. Water quality and / or habitat in good condition.
B	0.57-0.85	0.61-0.86	Significantly impaired. Water quality and/ or habitat potentially impacted resulting in loss of taxa.
C	0.28-0.56	0.35-0.60	Severely impaired. Water quality and/or habitat compromised significantly, resulting in a loss of biodiversity.
D	<0.28	<0.35	Extremely impaired. Highly degraded. Water and /or habitat quality is very low and very few of the expected taxa remain.

2.4.3 Univariate indices

Several additional metrics to the AUSRIVAS were utilised. This included: taxa abundance (the total number of animals collected); taxa richness (the number of taxa recorded in a sample – based on the applied taxonomic resolution level); EPT richness (number of Ephemeroptera, Plecoptera and Trichoptera families in a given sample); EPT relative abundance (the proportion of total abundance made up of EPT taxa); OCD relative abundance (the proportion of total abundance made up of less sensitive taxa from the Oligochaeta, Chironomidae and Diptera groups) and the Stream Invertebrate Grade Number – Average Level (SIGNAL-2) index.

SIGNAL-2 is a biotic index based on pollution sensitivity values (grade numbers) assigned to aquatic macroinvertebrate families. The sensitivity values for each family have been determined 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.

Preliminary Experimental Data Analysis (EDA) determined that the distribution of some indices appeared to deviate from a normal distribution (Appendix G). This means that the parametric ANOVA technique may produce erroneous results (Zar, 1999) and was, thus, abandoned in favour of more conservative non-parametric equivalents. For consistency, non-parametric tests were used for analysis of all univariate indices. A Mann-Whitney test was used to examine differences between two independent samples (e.g. habitats) and a Kruskal-Wallis test was used to determine differences between more than two independent samples (e.g. zones). As no suitable non-parametric multiple-comparisons technique was available, differences between groups were assessed using a modified version of Tukey's HSD (honestly significant differenced) test for factors with $k \geq 3$ levels with uneven sample sizes.

2.4.4 Macroinvertebrate communities

The macroinvertebrate data were examined separately for riffle and edge habitats, as these habitats are well known to support different macroinvertebrate taxa. All multivariate analyses were performed using PRIMER version 6 (Clarke and Gorley, 2006). Univariate statistics were performed using STATISTICA version 9 (StatSoft Inc, 1984-2010).

Non-metric multidimensional scaling (NMDS)

Non-metric multidimensional scaling (NMDS) was performed on the macroinvertebrate community data following the initial cluster analysis. NMDS is a multivariate procedure that reduces the dimensionality of multivariate data and simplifies its 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). The number of dimensions (axes) used in the NMDS procedure was based on the resultant Stress levels. Stress is a measure of the distortion produced by compressing multidimensional data into a reduced set of dimensions (i.e. it is a measure of goodness of fit of the ordination plot relative to patterns in the original data matrix) and will increase as the number of dimensions is reduced (Kruskal, 1964).

Classification

Classification or cluster analysis is a mathematical method of grouping entities according to the relative similarity of their attributes. In an ecological setting these techniques can be used to group sites according to how similar their macroinvertebrate community is. The key to this technique is the Bray-Curtis similarity matrix which is constructed from the individual similarities between all possible pairs of sites (Bray & Curtis, 1957; Clifford & Stephenson, 1975). From this matrix, a classification using Hierarchical Agglomerative Clustering is obtained and represented visually as a dendrogram. The dendrogram displays sites in groups of varying size according to the similarities between them. In other words, sites which are similar in macroinvertebrate assemblage will be grouped together on the dendrogram.

Cluster analysis can be useful in detecting patterns within complex data sets but it is not without limitations. The nature of this technique is such that linkages will often be made between sites based on chance similarities. The SIMPROF test (described below) can be used in conjunction with the cluster analysis to prevent misinterpretation of random similarities as “true” patterns.

SIMPROF (SIMilarity PROFile)

The SIMPROF test determines whether a dataset contains a “multivariate structure. It can be used as a safeguard against misinterpreting chance similarities as meaningful patterns. SIMPROF works by rearranging observations (i.e. taxa counts) across the samples to simulate random data and then recalculating the similarities between the samples. The similarities from the ‘random’ data are then compared to the similarities from the observed data. This process is replicated several times, each time with the observed data being compared to a different ‘random’ set of data. If the similarities calculated from the actual observations are found to be significantly different from those calculated from the simulated ‘random’ data then it is concluded that any pattern detected is ‘real’ and not just a chance occurrence (Clarke and Warwick, 2001). When used in conjunction with cluster analysis, the SIMPROF test will indicate meaningful clusters within the dendrogram by outlining them in red.

PERMANOVA (Permutational MANOVA)

PERMANOVA is an extension to the PRIMER multivariate software package for biological and environmental data. The PERMANOVA procedure is based on the principals of a MANOVA (multivariate analysis of variance) with some differences. The key to PERMANOVA is the use of permutation to determine differences between categorical groups. This is done by randomly rearranging the observations to different sample labels and reanalysing the data to obtain the distribution of data that may be expected “by chance” if no multivariate patterns exist. This distribution of permuted data replaces the theoretical distribution which is generally utilised by parametric statistics such as MANOVA. The calculated test statistic (pseudo F) is compared to the permutational distribution in order to determine whether the observed pattern is likely to have occurred by chance or whether there are “true multivariate patterns” within it. The use of permutation to create the null distribution means that many of the assumptions which exist for MANOVA are avoided. For example, there is no assumption that the test data follows a normal distribution. Also, there is no necessity for data cells to be equal as long as an appropriate Sum of Squares (SS) calculation method is used. PERMANOVA was used to test for differences in the macroinvertebrate communities between groups (Zones).

SIMPER (SIMilarity PERcentages)

The SIMPER routine was used to identify taxa that contributed strongly to the average dissimilarity between site groups identified from the cluster analysis (classification). SIMPER computes the average dissimilarity (Bray-Curtis) between all pairs of inter-group samples (every sample in Group 1 with every sample in Group 2 etc.) and then breaks this average down into the separate contributions from each taxon. In addition to calculating the average dissimilarity between groups, SIMPER also calculates the average similarity within a group.

BEST

BEST is a multivariate statistical technique that allows the user to evaluate the match between the community assemblage data and a set of corresponding environmental variables. It does this by determining all possible combinations of environmental variables (each on its own, each paired with one other, each paired with two others etc.) and calculating the similarities for each combination. Each matrix of environmental variable similarities is then correlated with the resemblance matrix of biotic assemblage. The BEST procedure selects the subset of environmental variables which produces the highest correlation coefficient. These variables are those which best explain the community composition seen across the sites (Clarke and Warwick, 2001). This technique was only employed where cluster (and SIMPROF) analysis suggested a difference between zones.

2.4.5 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 who had more than 100 hours of identification experience.
- When required, taxonomic experts performed confirmations of identification. Voucher specimens were also used when required.
- ACT AUSRIVAS QA/QC protocols were followed.
- 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 (i.e. data that were not identified past Order level).
- Characteristics of geological and in-stream attributes were documented according to AUSRIVAS methods. These characteristics were cross-checked between sites with similar characteristics to ensure that habitat descriptions were consistent (some of the attributes involve percentage estimates, and are subjective by definition).

2.5 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))-03.

ALS field staff maintains current ACT AUSRIVAS accreditation.

3 Results

3.1 Hydrology and rainfall

Figure 1 shows flows and rainfall during spring 2011 at the river flow monitoring sites, while total spring 2011 rainfall for all gauging stations can be found in Table 5. The hydrograph shown in Figure 1 highlights the distinct increased stable flow for approximately 10 days during October resulting from the environmental flow release from Tantangara Reservoir. There are also larger spikes in flow at the end of November due to the intense rainfall events experienced at that time.

There were a number of small events throughout the spring 2011 period with the majority of rain coming during the last week of November (Figure 1). This was the wettest November on record for Lobb's Hole which received a total of 311.2mm comprising just over 81% of the total spring rainfall in 2011 (period of record: 1974-2011). Monthly mean flows during October were the highest during spring at the three most upstream stations while the highest monthly mean flow for spring at Hall's Crossing (the furthest downstream station) was in November. September had the lowest mean flow across all stations during spring.

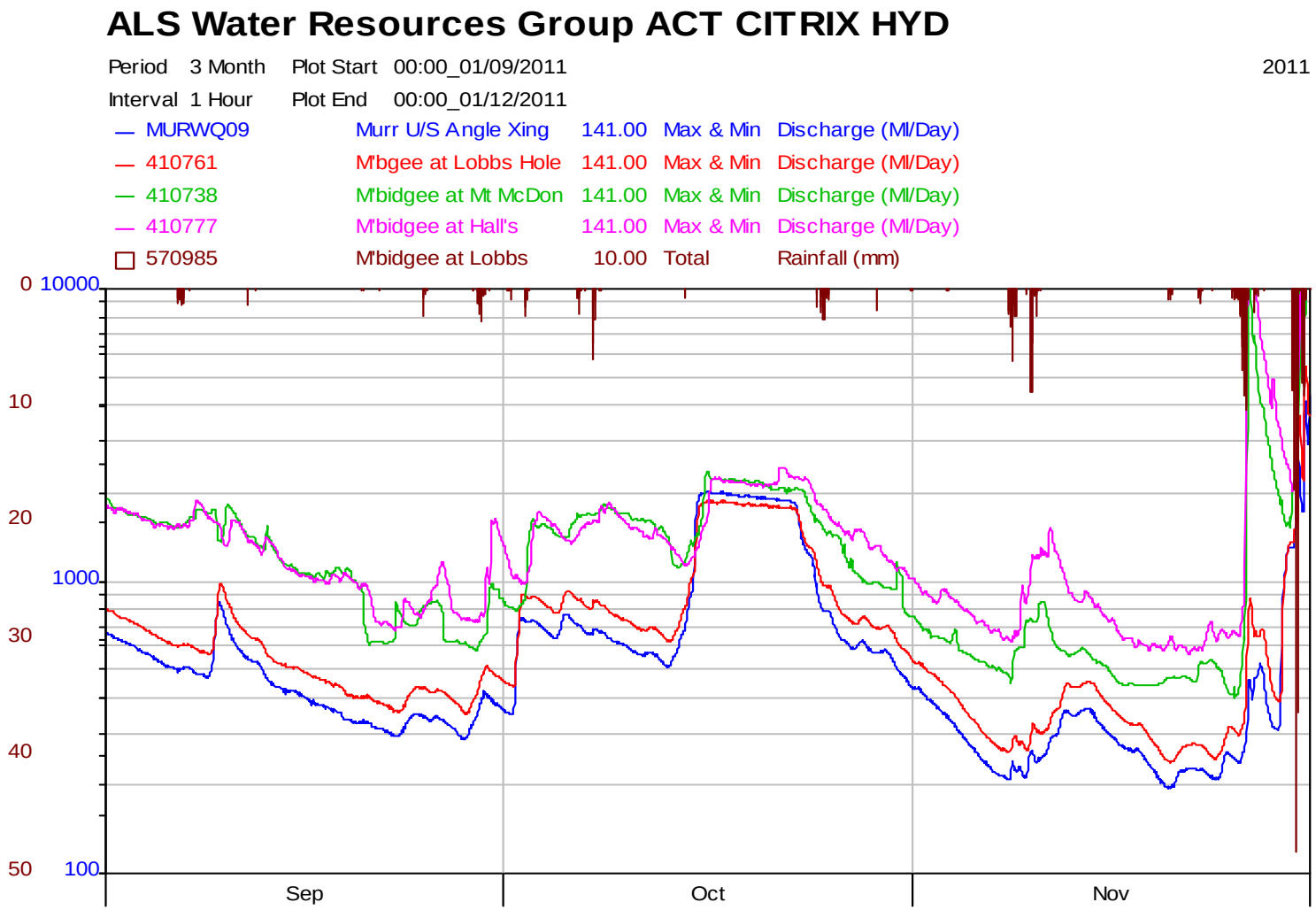


Figure 1. Spring hydrograph of the Murrumbidgee River flows and rainfall. Flow is on a log scale, rainfall in mm per hour from top down

Table 5. Average monthly flow and rainfall statistics for spring 2011

Site Location	September Average flow (ML/d)	October Average flow (ML/d)	November Average flow (ML/d)	Rainfall (mm) (spring total)
Upstream of Angle Crossing (MURWQ09)	442.0	985.0	404.3	279.6
Lobb's Hole (410761)	535.0	1051.0	500.2	382.4
Mt. MacDonald (410738)	1172	1559	1184	-
Hall's Crossing (410777)	1212	1623	1845	269.6

3.2 Water Quality

3.2.1 *In-situ* and grab samples

Water quality results recorded at the Murrumbidgee River monitoring sites in spring 2011 are presented in Table 6. These values were either analysed from grab samples (nutrients, TSS) or recorded by a probe, in-situ (dissolved oxygen (DO), pH, temperature). Temperatures ranged between 17.9˚C at MUR 1 and 24.8 ˚C at MUR 22. The level of electrical conductivity (EC), DO and turbidity were within the recommended range (ANZECC & ARMCANZ, 2000) at most sites, with three, one and four exceedances, respectively. EC was below recommended levels at MUR 1, 2 and 3, while DO readings were slightly above guidelines at MUR 4, 23, 935 and 30. During spring 2011, turbidity levels only exceeded the guideline maximum at MUR 15. There were a number of exceedances to guideline levels with regards to pH with levels above the maximum at nine of the 23 sites. Only one of these exceedances in pH level occurred in Zone 1 and pH was within the recommended range at all Zone 2 sites. TSS ranged between 3 mg/L at MUR 4 and 31 mg/L at MUR 37. Alkalinity ranged between 13 mg/L at MUR 4 and 35 mg/L at MUR 37. NO_x levels were well above the recommended range at all sites in Zone 4 while only slightly elevated at MUR 931 (Zone 3).

There were a large number of exceedances of the ANZECC & ARMCANZ guidelines (2000) for both total phosphorus (TP) and total nitrogen (TN) (Table 6). TP exceeded the guideline limit at 18 of the 23 sites with TP levels at MUR 2, 3, 4 and 937 within guideline levels and MUR 29 on the cusp of the guidelines. Total nitrogen was in exceedance of the guidelines at 20 of the 23 sites with only TN levels at MUR 3, 4 and 937 found to be within ANZECC & ARMCANZ guidelines (2000).

Table 6. In-situ and grab sample water quality results for spring 2011 ANZECC & ARMCANZ (2000) guidelines are in **red bold**. Values outside recommended guideline levels are highlighted yellow. Borderline values are highlighted in orange.

Zone	Site	Date/ Time	Temp. (℃)	EC (µs/cm)	Turbidity (NTU)	TSS (mg/L)	pH (units)	DO (% Sat.)	DO (mg/L)	Alkalinity (mg/L)	NOx (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
ANZECC Guideline Levels			N/A	**30-350**	**2-25**	N/A	**6.5-8.0**	**90-110**	N/A	**N/A**	**<0.015**	N/A	N/A	N/A	**<0.02**	**<0.25**
Zone 1: Tantangara -Cooma	MUR 1	14/11/11 11:05	17.9	**22.1**	**2**	7	7.12	98.3	7.92	18.0	0.004	0.002	<0.002	0.009	**0.026**	**0.31**
	MUR 2	14/11/11 13:40	19.8	**25.0**	**2**	5	7.51	105.5	8.33	16.0	0.004	0.002	<0.002	<0.002	0.019	**0.26**
	MUR 3	14/11/11 15:10	21.6	**29.1**	5	4	7.94	**110.0**	8.44	15.0	0.003	0.001	<0.002	<0.002	0.011	0.17
	MUR 4	14/11/11 16:20	22.2	33.1	7	3	**8.44**	**112.1**	8.60	13.0	0.004	0.002	<0.002	<0.002	0.010	0.18
Zone 2: Cooma – Angle Crossing	MUR 6	15/11/11 10:50	21.1	48.6	10	11	7.49	95.5	7.50	23.0	0.011	0.009	<0.002	0.009	**0.029**	**0.36**
	MUR 9	15/11/11 12:35	21.5	51.0	8	17	7.45	98.1	7.74	24.0	0.006	0.004	<0.002	0.003	**0.029**	**0.35**
	MUR 12	15/11/11 14:20	22.7	72.8	14	20	7.71	100.9	7.82	30.0	0.006	0.004	<0.002	0.003	**0.039**	**0.37**
	MUR 15	11/11/11 9:10	20.7	84.5	**32**	29	7.83	99.2	8.12	36.0	0.009	0.007	<0.002	0.007	**0.056**	**0.38**
	MUR 16	11/11/11 12:20	21.5	73.2	15	18	7.88	104.2	8.42	31.0	0.003	0.001	<0.002	0.007	**0.036**	**0.32**
	MUR 18	10/11/11 10:30	21.1	77.7	14	17	7.71	97.7	8.04	31.6	0.010	0.008	<0.002	<0.002	0.030	0.32

Table 6. continued

Zone	Site	Date/ Time	Temp.(℃)	EC (µs/cm)	Turbidity (NTU)	TSS (mg/L)	pH (units)	DO (% Sat.)	DO (mg/L)	Alkalinity (mg/L)	NOx (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
ANZECC Guideline levels			N/A	**30-350**	**2-25**	N/A	**6.5-8.0**	**90-110**	**N/A**	N/A	**<0.015**	N/A	N/A	N/A	**<0.02**	**<0.25**
Zone 3: Angle Crossing – LMWQCC	MUR 19	10/11/11 9:10	21.2	72.9	13	14	7.55	94.2	7.66	30.6	0.010	0.008	<0.002	<0.002	**0.030**	**0.31**
	MUR 22	7/11/11 15:20	24.8	71.5	9	11	**8.04**	108.3	8.20	31.4	0.003	0.001	<0.002	0.002	**0.027**	**0.30**
	MUR 23	11/11/11 14:50	22.7	83.0	15	20	**8.10**	**110.1**	8.68	36.0	0.003	0.001	<0.002	<0.002	**0.040**	**0.37**
	MUR 27	7/11/11 14:05	22.8	73.0	12	14	7.61	96.4	7.62	31.8	0.003	0.001	<0.002	0.002	**0.032**	**0.30**
	MUR 931	9/11/11 10:00	21.7	77.4	11	14	7.69	99.8	8.07	33.1	**0.016**	0.014	<0.002	0.014	**0.029**	**0.33**
	MUR 28	9/11/11 14:25	23.5	77.6	11	16	**8.08**	107.1	8.21	33.2	0.005	<0.002	<0.002	<0.002	**0.029**	**0.31**
	MUR 935	9/11/11 12:50	23.6	75.3	13	15	**8.07**	**110.5**	8.55	32.4	0.006	0.004	<0.002	0.002	**0.027**	**0.30**
	MUR 937	8/11/11 9:50	22.6	62.5	6	8	7.72	103.2	8.19	28.0	0.002	<0.001	<0.002	0.002	0.019	0.22
	MUR 29	10/11/11 13:15	22.5	71.2	7	13	**8.08**	109.0	8.60	29.6	0.004	0.002	<0.002	<0.002	**0.020**	**0.26**
	MUR 30	10/11/11 15:10	23.0	67.1	9	15	**8.17**	**110.6**	8.71	29.1	0.004	0.002	<0.002	0.002	**0.030**	**0.32**

Table 6. continued

Zone	Site	Date/ Time	Temp.(℃)	EC (µs/cm)	Turbidity (NTU)	TSS (mg/L)	pH (units)	DO (% Sat.)	DO (mg/L)	Alkalinity (mg/L)	NOx (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
ANZECC Guideline levels			N/A	**30-350**	**2-25**	N/A	**6.5-8.0**	**90-110**	**N/A**	N/A	**<0.015**	N/A	N/A	N/A	**<0.02**	**<0.25**
Zone 4: D/s LMWQCC to ~5km u/s Taemas Bridge	MUR 31	8/11/11 14:50	22.6	114.5	7	9	**8.08**	106.1	8.46	33.1	**1.6**	1.6	0.002	0.003	**0.034**	**1.90**
	MUR 34	16/11/11 9:20	22.6	184.7	12	20	7.94	100.4	8.05	51.0	**2.2**	2.2	0.010	0.003	**0.040**	**2.90**
	MUR 37	16/11/11 11:50	22.7	183.3	18	31	**8.20**	106.8	8.51	53.0	**1.8**	1.8	0.014	<0.002	**0.043**	**2.60**

The results of a Principal Components Analysis are shown in Figure 2 and the raw output from this analysis is provided in Appendix B. The first two principal components explained approximately 76.5% of the variation in the data which indicates that the first two principal components have been successful in condensing the information provided by the original 13 variables. The first principal component, PC1 is largely characterised by decreased levels of electrical conductivity, alkalinity, TSS, turbidity and all nutrient measurements. The second principal component, PC2, was characterised most strongly by increased pH, dissolved oxygen (% saturation) and, to a lesser extent, by decreased levels of Total Phosphorus. PC1 allows us to conclude that Zone 1 sites had lower EC, turbidity, alkalinity, TSS and nutrients compared to other sites. The furthest downstream sites (Zone 4), MUR 34 and MUR 37 exhibit the highest levels of nutrients as well as turbidity, TSS, temperature and alkalinity.

Interestingly, the four Zone 1 sites are spread across the entire PC2 axis due to the relatively low DO and pH at MUR 1 and the highest DO and pH of all sites recorded at MUR 4. The spread of sites along the PC2 axis also suggests that Zone 2 sites generally had lower pH, DO and temperature compared to Zone 3 sites.

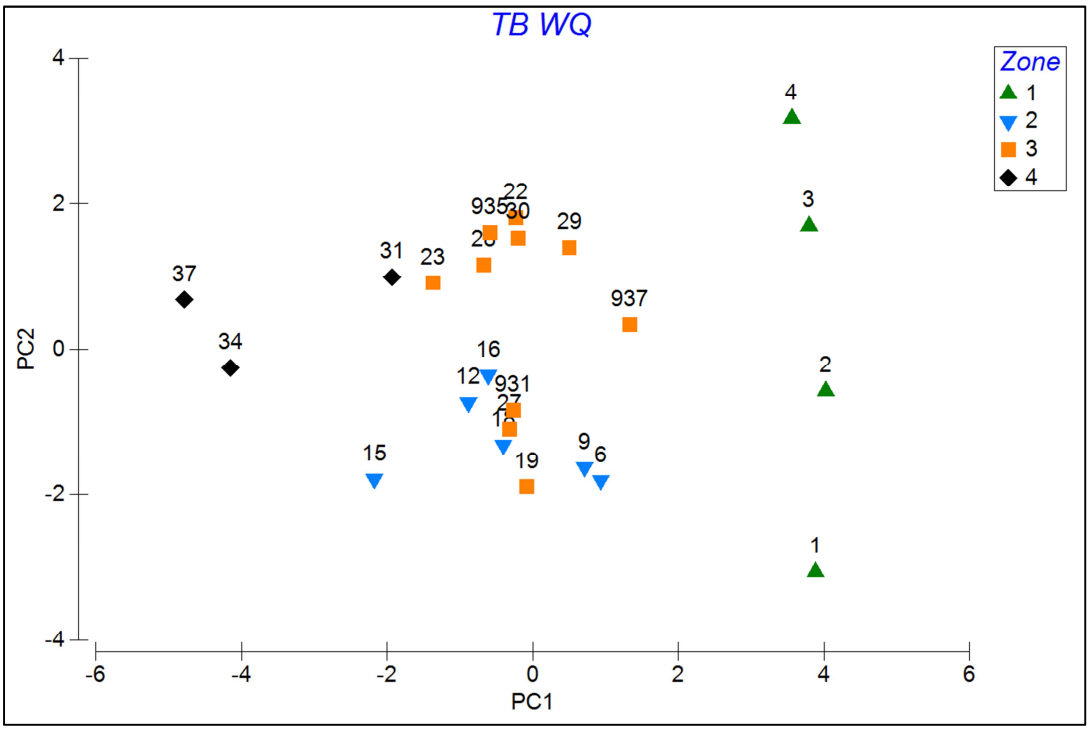


Figure 2. Correlation based Principal Components Analysis on water quality data collected in spring 2011
Numbers relate to site codes outlined in Table 1

3.2.2 Continuous water quality

The continuous trends in water quality for the three hydrological monitoring stations are captured in Figure 3, 5 and 6. During the spring period flow releases from Tantangara Reservoir silted up the turbidity and DO probes causing a loss in readings for a period of 14 and 22 days respectively at the continuous gauging station upstream of Angle Crossing (MURWQ09). During the monthly site visit the probes were cleaned out and calibrated to restore normal readings. Due to the shallow nature of this site since the 2010 flood events, probe siltation has been an on-going issue and a flow cell that pumps water from the river for sampling is being investigated. The pH probe at Lobb's Hole was giving false readings due to probe failure for a period of 24 days during September and October, until a new probe could be supplied.

The turbidity at upstream Angle Crossing and at Lobb's Hole was stable throughout the period, with the exception of a spike at the end of November. This spike was due to a number of intense rainfall events and the resulting high flow levels. Hall's Crossing showed a similar pattern, however experienced two spikes. The first spike in mid-October occurred at the end of the flow release from Tantangara Dam. This was exacerbated by the run off from a number of urban streams and the Molonglo River which flow into the Murrumbidgee River downstream of Lobb's Hole, after a small locally occurring rainfall event. The second spike was at the end of November, corresponding with the event registered by the other stations.

DO readings showed a distinct diurnal pattern across all sites with the variation becoming larger during November which can be attributed to the increased surface water temperatures. DO was generally within the ANZECC & ARMCANZ guidelines (2000) however daily means were outside guidelines for two days at upstream Angle Crossing and 16 days at Hall's Crossing. Water temperature showed a consistent increase throughout spring at all sites in accordance with ambient temperature increases towards the beginning of summer.

EC was relatively stable across all three continuous monitoring sites with some fluctuations, resulting in no exceedances of ANZECC & ARMCANZ guidelines (2000). There was also a diurnal pattern to the pH readings at Lobb's Hole and Hall's Crossing, less so at upstream Angle Crossing, with some variation between sites. Lobb's Hole consistently had a slightly increased pH over the other two sites having daily means exceeding the guidelines for 18 days compared to two days at the upstream Angle Crossing site; and no exceedances of mean daily values at Hall's Crossing.

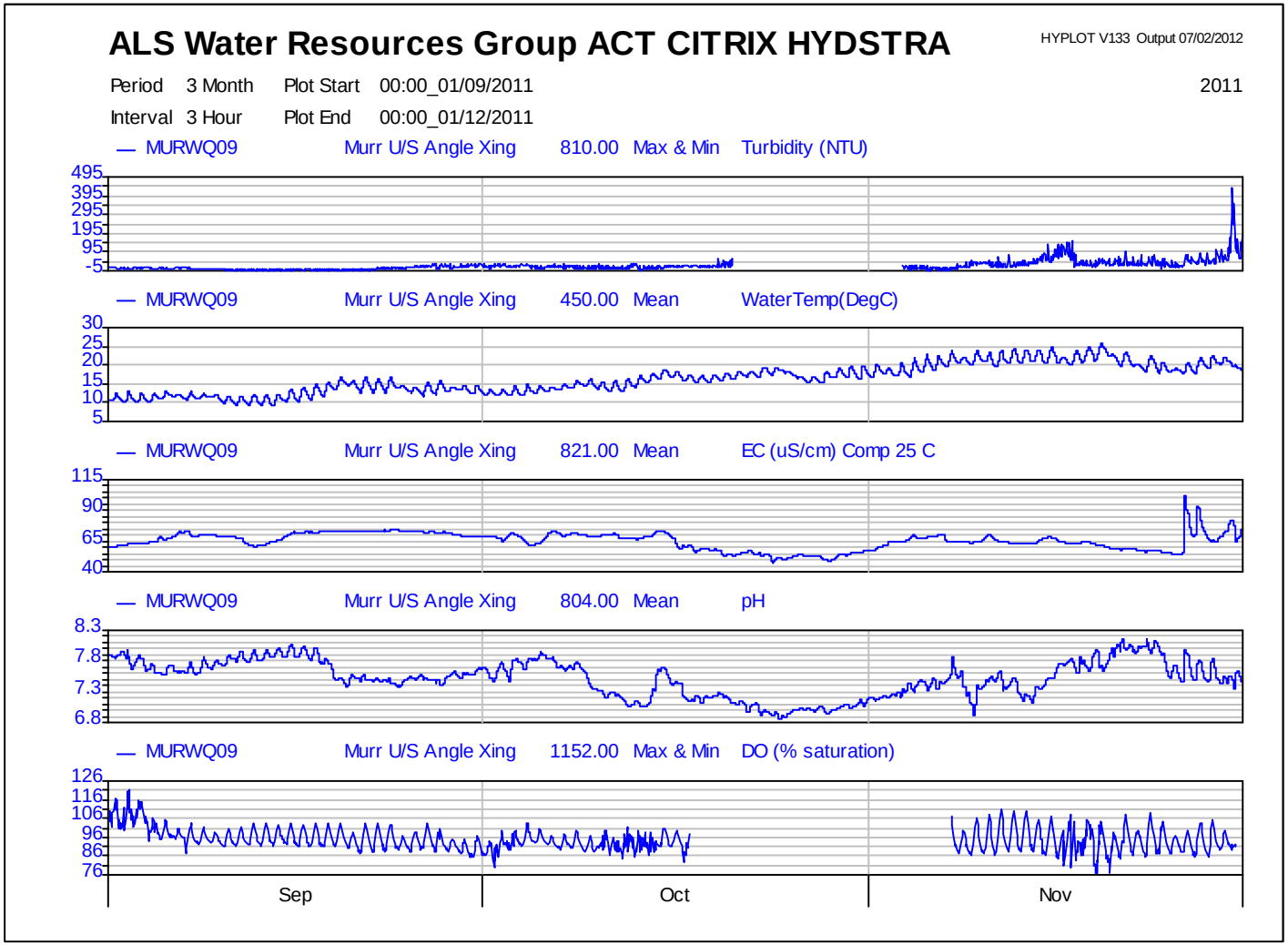


Figure 3. Continuous water quality results recorded upstream of Angle Crossing in spring 2011 (MURWQ09)

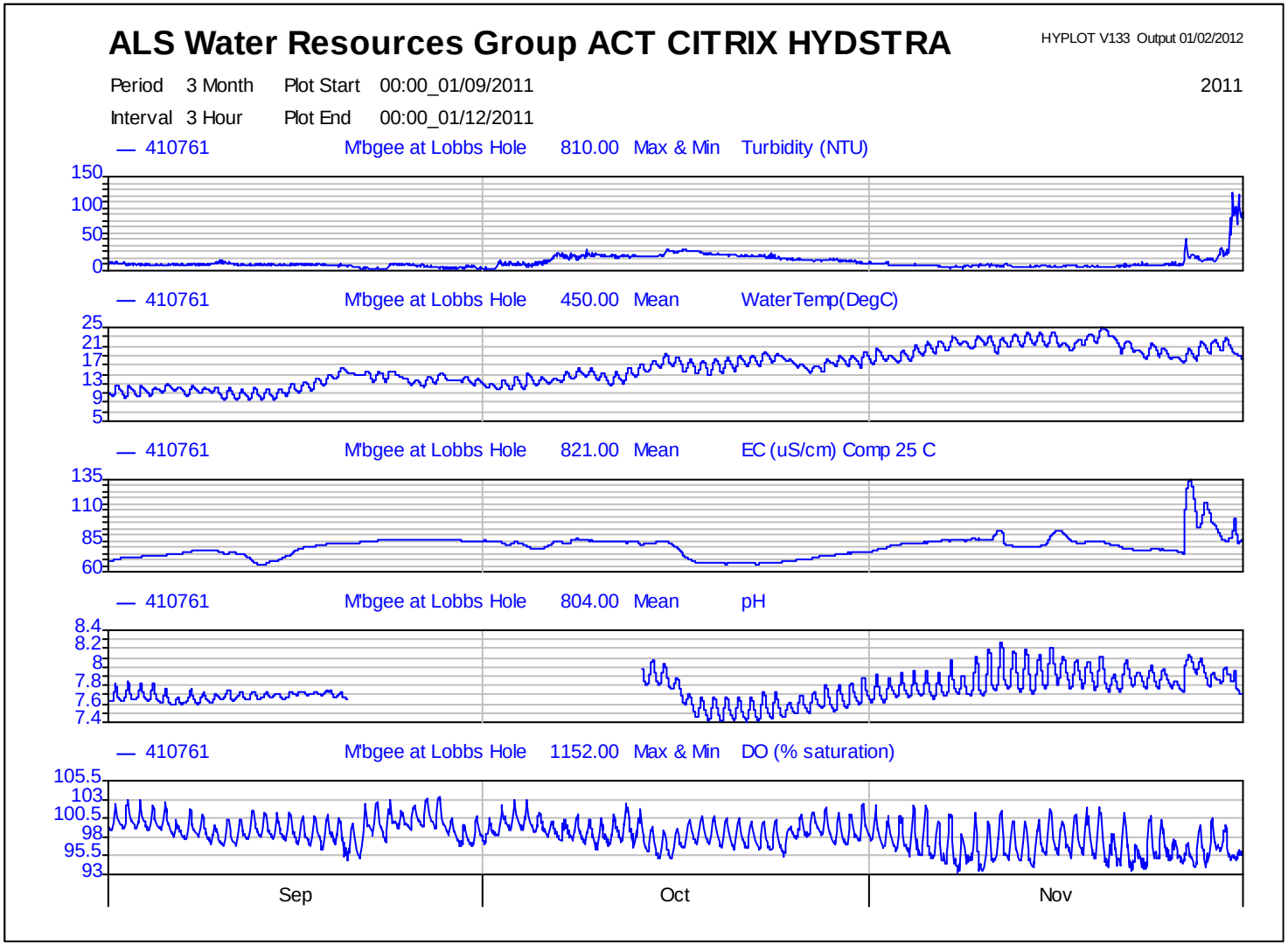


Figure 4. Continuous water quality results for Lobb's Hole in spring 2011 (410761)

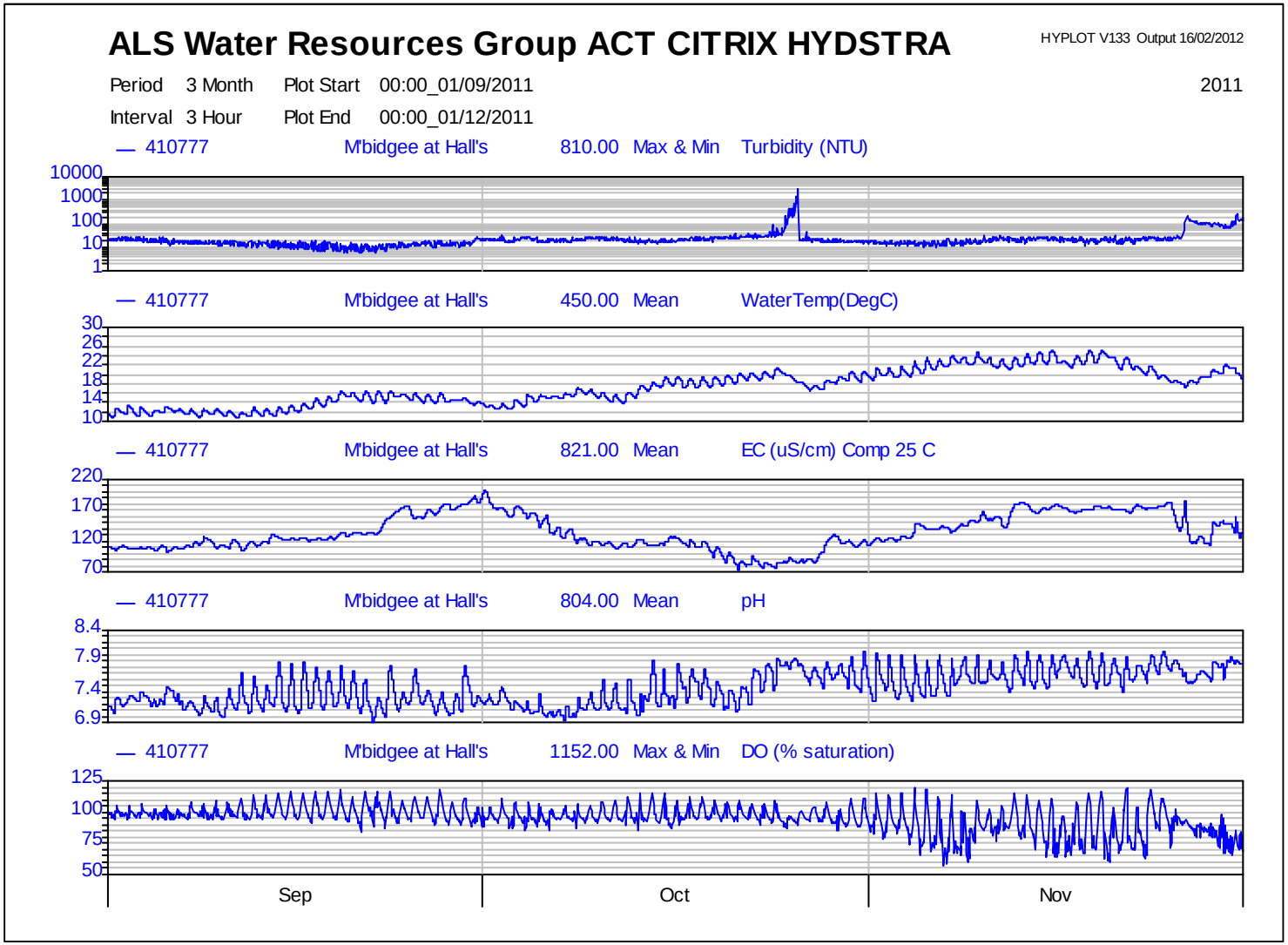


Figure 5. Continuous water quality results for Hall's Crossing in spring 2011 (410777)

3.3 Macroinvertebrate communities

PERMANOVA was used to detect significant differences in the composition of the macroinvertebrate community between habitats and zones. A significant difference (p<0.05) in the community composition was detected been edge and riffle samples (Appendix C). Thus, the data were separated by habitat prior to further analysis.

Differences in the macroinvertebrate community between sites and Zones are described in Figure 6 and Figure 7. The MDS plot (Figure 6) shows that while riffle samples from the same zone are sometimes clumped, there are several instances in which riffle samples were more similar to those collected from other zones. Overall, there is no clear separation between the zones.

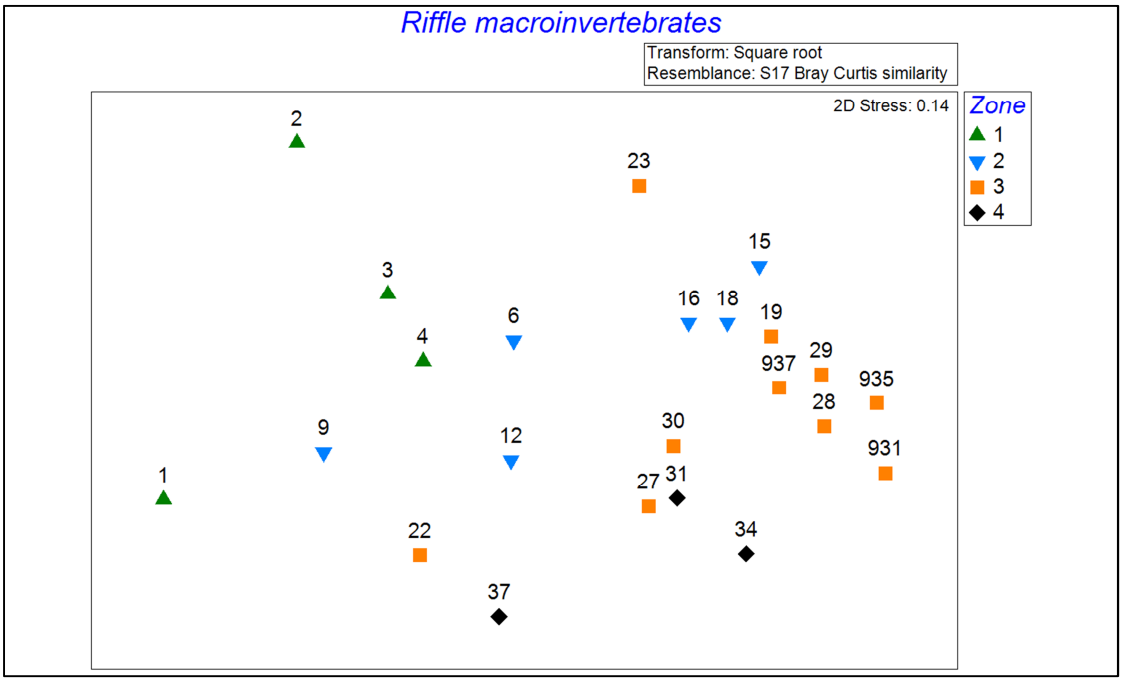


Figure 6. Non-metric multidimensional scaling of family level data for the spring 2011 riffle samples

The cluster diagram (Figure 7) closely mirrors the pattern observed in the MDS plot. Some riffle samples were clustered with others from the same zone such as MUR 2, MUR 3 and MUR 4, but these groupings were not strong. The most strongly related riffle samples are from MUR 31 and MUR 37 and these sites are from different zones. SIMPROF (indicated by the red lines) suggests that there are only two main groupings: the first is a combination of riffle samples from MUR 2, 3, 4, 9, 12, 22 and 37; the second contains the remaining samples. Both groups contain samples collected from all four zones.

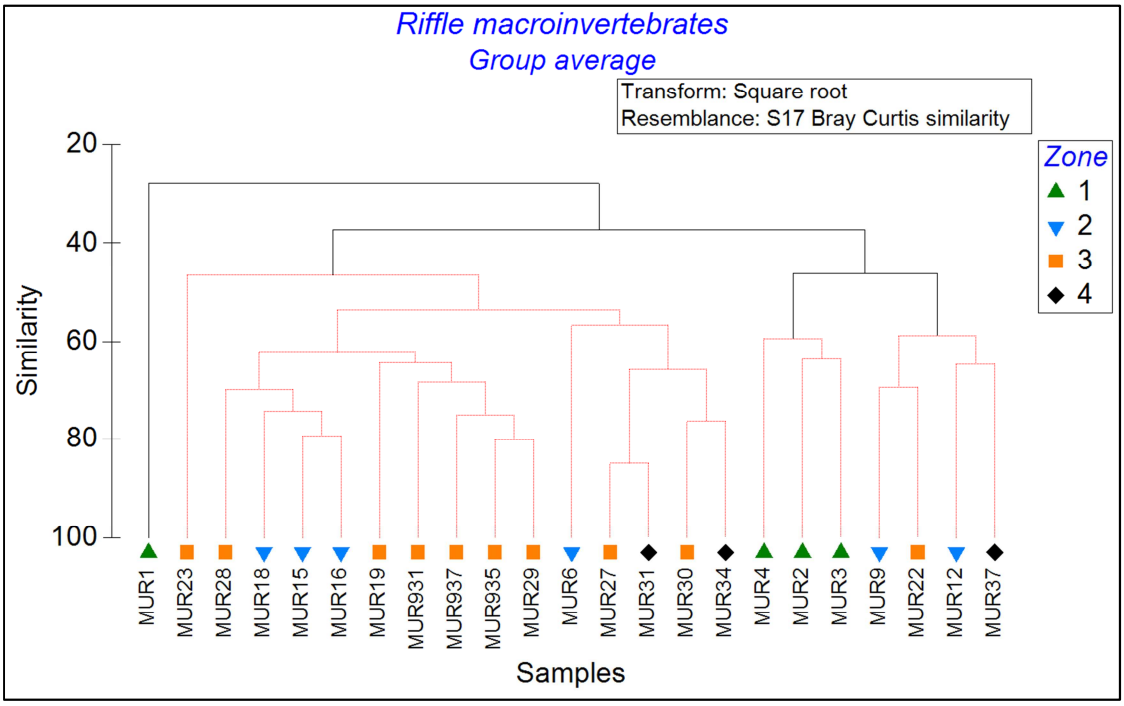


Figure 7. Cluster analysis of family level data for the spring riffle samples. Branches marked in red denote significant groupings based on SIMPROF.

PERMANOVA detected significant (p<0.05) differences in the community composition of riffle samples between zones. The results of multiple comparisons testing for pairwise differences in zones are provided in Table 7. This table indicates significant differences (p<0.05) in the macroinvertebrate riffle community between Zone 1 and the other three zones.

Table 7. p-values for multiple comparisons between Zones for riffle macroinvertebrates

Significant ***p***-values are highlighted in red (***p***<0.05).

Zone	1	2	3
1			
2	**0.02**		
3	**<0.001**	0.06	
4	**0.02**	0.04	0.12

SIMPER was used to determine the average similarity in the macroinvertebrate community between and within zones (Table 8). The similarity in community composition between zones was often higher than within zones. Similarity was generally fairly low, with no similarity (either inter-zone or intra-zone) being higher than 64.5% (Zone 1 vs. Zone 4). The lowest intra-zone similarity was between riffle samples from Zone 3 and Zone 4.

Table 8. Average similarity in riffle macroinvertebrate samples between and within zone groups

Zone	1	2	3	4
1	48%			
2	55%	58%		
3	63%	44%	60%	
4	64%	48%	39%	56%

The taxa contributing most strongly to the differences between Zone 1 samples and Zones 2, 3 and 4 are outlined in Table 9, Table 10 and

Table 11, respectively. The major difference between Zone 1 and 2 riffle samples was the increased number of Oligochaeta and Simuliidae and the decreased number of Gripopterygidae compared to Zone 1 samples.

Zone 1 and 3 and 4 differed most strongly by the increased numbers of Simuliidae and Hydropsychidae and decreased numbers of Gripopterygidae in Zone 3 and 4 compared to Zone 1 (Table 10;

Table 11).

Table 9. Major differentiating taxa between Zone 1 and Zone 2 riffle samples

Family	Av abundance		Contribution to group differences
	Zone 1	Zone 2	
Oligochaeta	10.11	24.44	8.45
Simuliidae	3.45	16.83	7.72
Gripopterygidae	20.89	10.25	6.89
Talitridae	12.42	0.00	6.53
Hydroptilidae	1.12	12.44	5.83

Table 10. Major differentiating taxa between Zone 1 and Zone 3 riffle samples

Family	Av abundance		Contribution to group differences
	Zone 1	Zone 3	
Simuliidae	3.45	50.73	18.92
Gripopterygidae	20.89	3.13	7.58
Hydropsychidae	4.64	20.15	6.67
Leptophlebiidae	16.62	3.54	5.68
Talitridae	12.42	0.00	5.27

Table 11. Major differentiating taxa between Zone 1 and Zone 4 riffle samples

Family	Av abundance		Contribution to group differences
	Zone 1	Zone 4	
Simuliidae	3.45	51.36	18.12
Gripopterygidae	20.89	0.00	9.06
Hydropsychidae	4.64	22.25	6.46
Orthocladiinae	18.12	33.84	6.42
Leptophlebiidae	16.62	3.96	5.57

The difference in the number of Simuliidae, Gripopterygidae and Hydropsychidae are illustrated in Figure 8, Figure 9 and Figure 10, respectively. These plots indicate the increased number of Simuliidae and Hydropsychidae and decreased number of Gripopterygidae in the downstream sites. In these plots, the size of the bubble indicates abundance.

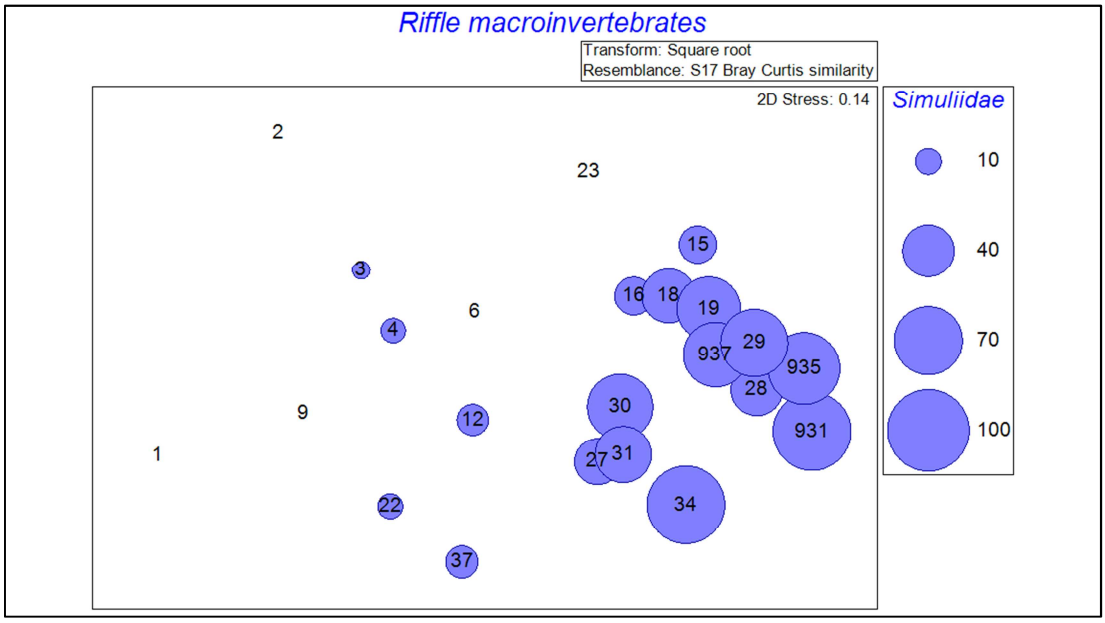


Figure 8. Bubble plot indicating relative abundance of Simuliidae between riffle samples

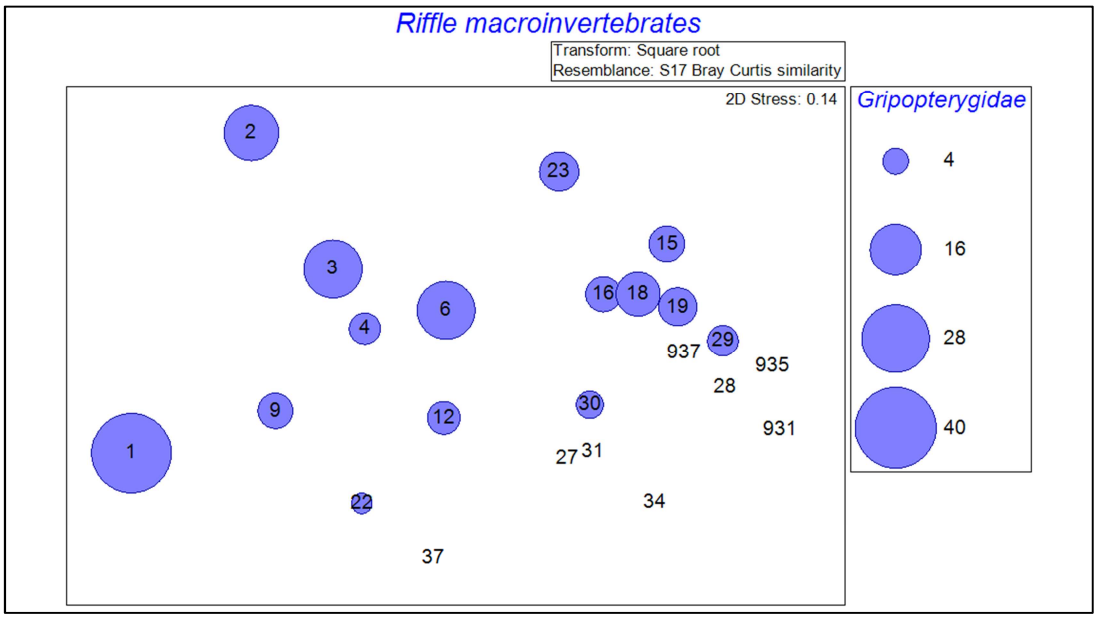


Figure 9. Bubble plot indicating relative abundance of Gripopterygidae between riffle samples

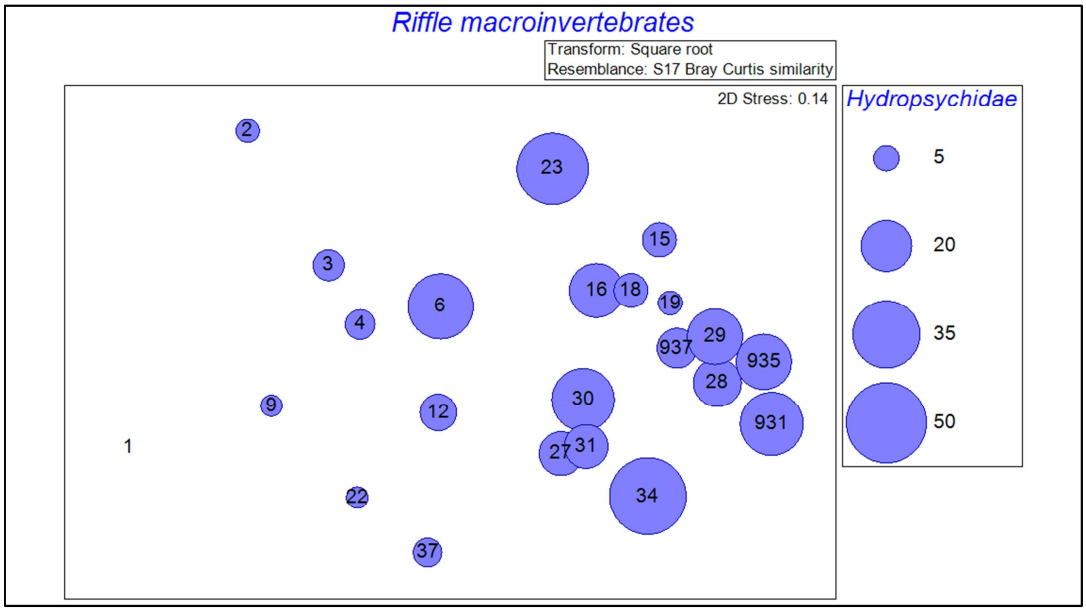


Figure 10. Bubble plot indicating relative abundance of Hydropsychidae between riffle samples

The difference in the community composition of edge samples is portrayed in Figure 11. This cluster diagram shows that some edge samples were clumped in Zone groups such as for Zone 1, but others such as Zone 3 were scattered. The stress in this plot is quite high which indicates that the multivariate pattern might be more complex than can be displayed in 2-dimensions. However, due to the large number of sites, the 3-D plot was difficult to interpret and, thus, the 2-D plot is used, with caution.

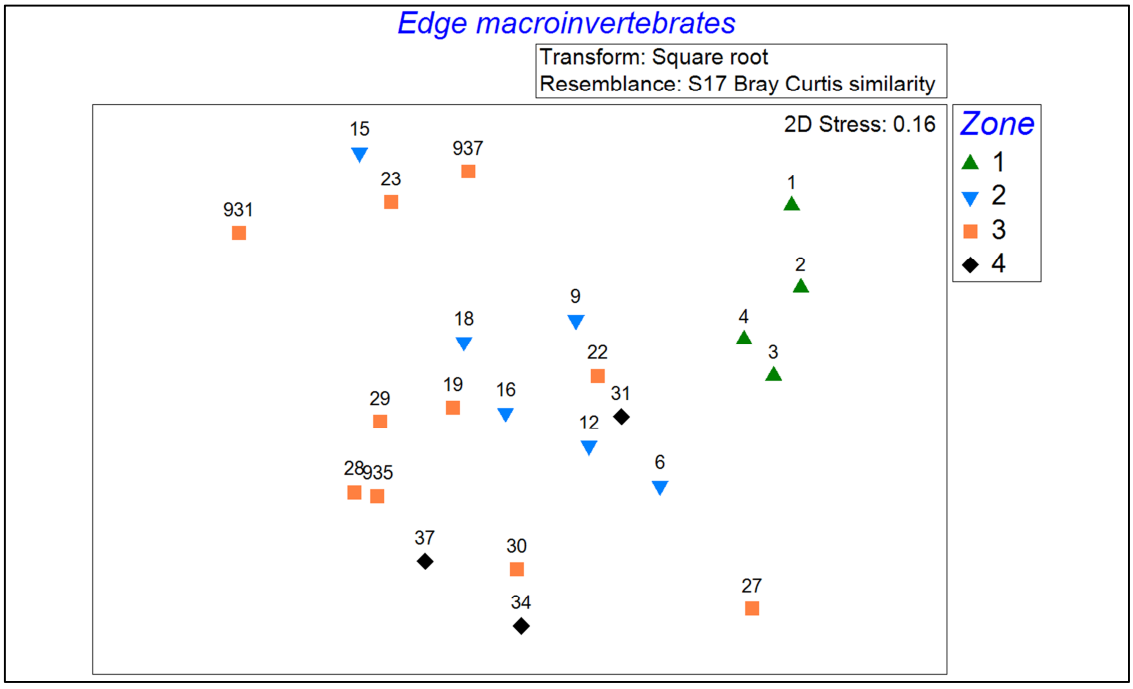


Figure 11. Non-metric multidimensional scaling of family level data for the spring edge samples

The cluster diagram (Figure 12) provides a clearer description of the similarity between samples. Similarity between edge samples was generally only around 60%, although some groups such as MUR 28 and MUR 935 were more similar. Even the four Zone 1 samples, which are clumped together on the MDS diagram, are no more than 70% similar with regards to community composition.

However, PERMANOVA indicated that there were significant (p<0.05) differences in the community between certain Zones. Table 12 indicates that the community composition of Zone 1 edge samples was significantly different to that of the other three zones. The average similarities between and within zones are provided in Table 13. As with riffle samples, the similarity between edge samples is often higher between zones than within zones. The highest average similarity was 68.41% similarity, which was observed between Zone 1 and Zone 3 samples.

The taxa most strongly differentiating between Zone 1 and Zones 2 and 3 edge samples were Talitridae, Corixidae and Oligochaeta (Table 14; Table 15). Talitridae were not collected in Zone 2 or Zone 3 samples. Higher numbers of Corixidae in Zone 2 compared to Zone 1 and a higher number again were observed in Zone 3 samples. Lower numbers of Oligochaeta were observed in Zone 2 and Zone 3 edge samples compared to Zone 1 samples.

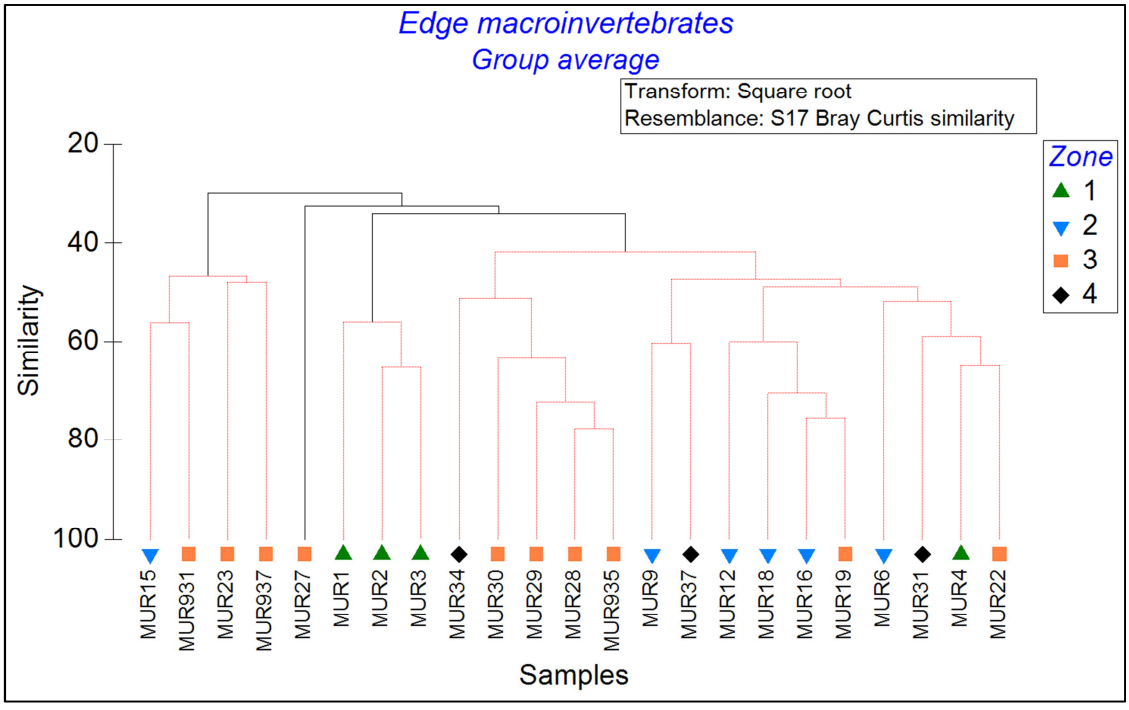


Figure 12. Cluster analysis of family level data for the spring edge samples

Branches marked in red denote significant groupings based on SIMPROF.

Table 12. p-values for multiple comparisons between Zones for edge macroinvertebrates

Significant ***p***-values are highlighted in red (<0.05).

Zone	1	2	3
1			
2	0.0052		
3	0.0007	0.22	
4	0.0292	0.06	0.12

.

Table 13. Average similarity in edge macroinvertebrate samples between and within zone groups

Zone	1	2	3	4
1	56.76%			
2	57.70%	54.00%		
3	68.41%	53.59%	43.72%	
4	67.30%	51.97%	55.82%	45.40%

The major taxa contributing to differences in edge samples between Zone 1 and 4 were Corixidae, Chironominae and Talitridae (Table 16). Chironominae and Corixidae were observed in larger numbers, on average, within edge samples from Zone 4 compared to Zone 1 samples. Talitridae were only found in Zone 1 samples, not in Zone 4 samples.

Table 14. Major differentiating taxa between Zone 1 and Zone 2 edge samples

Family	Av abundance		Contribution to group differences
	Zone 1	Zone 2	
Talitridae	14.37	0.00	10.99
Corixidae	4.34	13.71	7.48
Oligochaeta	13.76	8.85	7.05
Gripopterygidae	12.71	5.00	6.18
Chironominae	5.44	11.78	5.03

Table 15. Major differentiating taxa between Zone 1 and Zone 3 edge samples

Family	Av abundance		Contribution to group differences
	Zone 1	Zone 3	
Corixidae	4.34	26.32	14.76
Talitridae	14.37	0.00	9.38
Oligochaeta	13.76	12.30	8.21
Gripopterygidae	12.71	2.06	7.17
Orthocladiinae	11.82	12.89	5.42

Table 16. Major differentiating taxa between Zone 1 and Zone 4 edge samples

Family	Av abundance		Contribution to group differences
	Zone 1	Zone 4	
Corixidae	4.34	24.88	12.63
Chironominae	5.44	22.79	9.79
Talitridae	14.37	0.00	9.19
Gripopterygidae	12.71	0.75	7.83
Oligochaeta	13.76	9.77	6.88

The bubble plots below illustrate the change in the abundance of Corixidae and Talitridae between zones. Corixidae generally increased between upstream and downstream Zones (Figure 13). Talitridae were only observed in edge samples from Zone 1 (Figure 14). Bubble plots are not shown for Chironominae and Oligochaeta as the differences were too subtle to be effectively communicated using this technique.

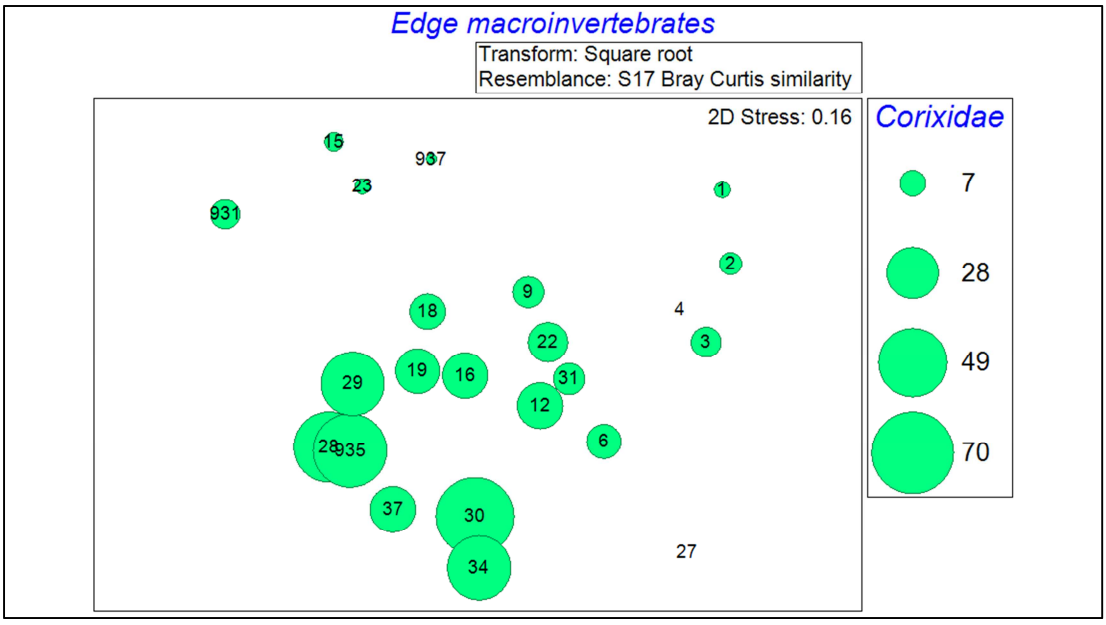


Figure 13. Bubble plot indicating relative abundance of Corixidae between edge samples

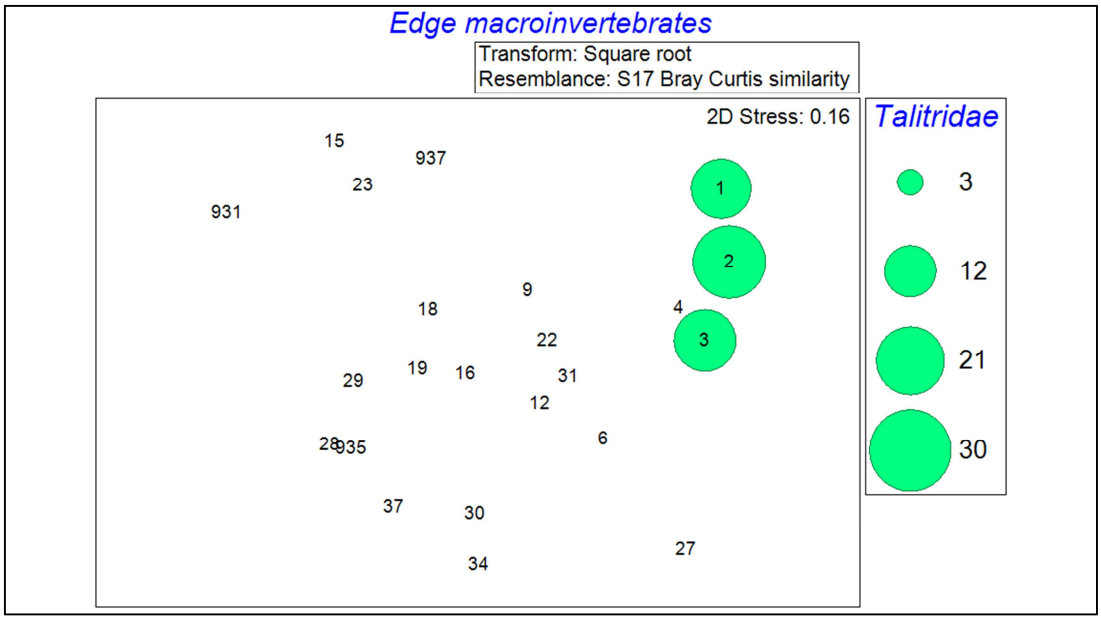


Figure 14. Bubble plot indicating relative abundance of Talitridae between edge samples

BEST analysis was conducted to identify potential links between the macroinvertebrate community assemblage and water quality. Although only one measurement was collected for each site, macroinvertebrate data were analysed separately for Riffle and Edge samples as the macroinvertebrates were seen to differ significantly between habitats. BEST calculated only a weak relationship (correlation of 0.372) between the edge macroinvertebrate community and most strongly correlated water quality variables (Appendix D). BEST analysis on riffle macroinvertebrates estimated a correlation of 0.525 between the macroinvertebrate community assemblage and alkalinity and temperature (Appendix D). The change in temperature between the sites was subtle but the change in alkalinity was more evident, as can be seen in the bubble plot below (Figure 15). This plot shows that alkalinity was lowest within Zone 1 sites and then increased between Zone 2 and Zone 4.The furthest downstream sites MUR 34 and MUR 37 appeared to have the highest levels of alkalinity.

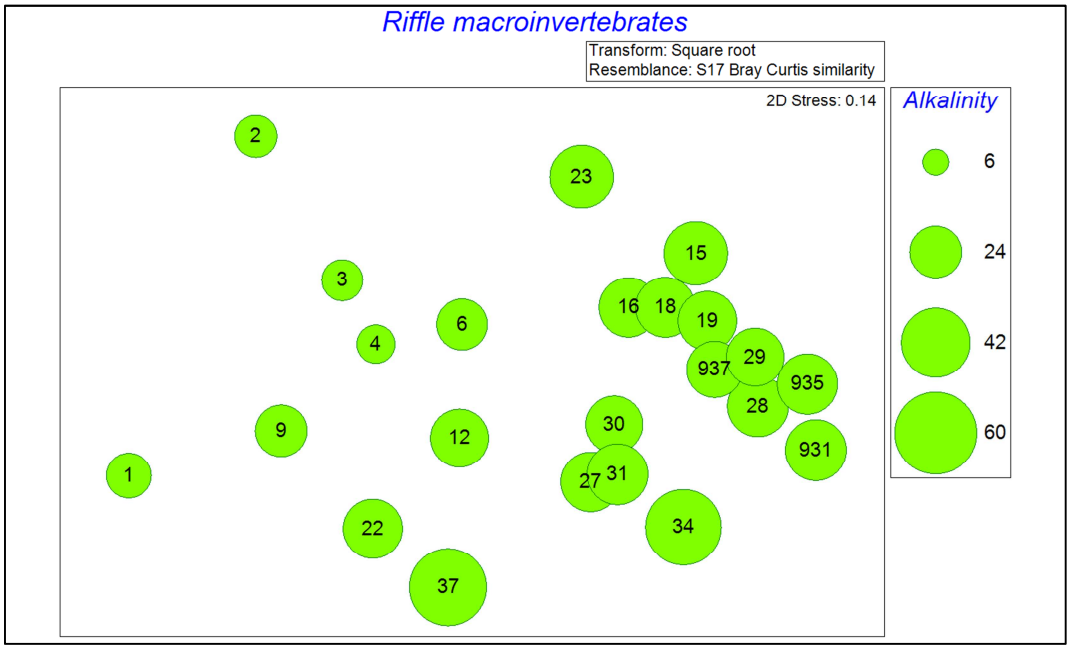


Figure 15. Bubble plot indicating changes in alkalinity between sites and Zones

3.4 Univariate indices

Table 17 outlines the results of several univariate indices related to macroinvertebrates for edge and riffle samples. Taxa richness was quite variable between sites with no clear pattern observed between Zones or Habitats. EPT taxa was generally higher in riffle samples compared to edge samples and levels appeared to be higher overall in Zone 1 and Zone 2 sites compared to the other two Zones.

Average SIGNAL-2 score in riffle samples ranged between 4.60 at MUR 27 and 5.85 at MUR 6 and in edge samples between 3.40 at MUR 34 and 5.0 at MUR 1 and MUR 3 for edge samples.

AUSRIVAS banding for the overall site assessment was either A (similar to reference), B (significantly impaired) or C (severely impaired). A grade of C (severely impaired) was only given to the furthest downstream sites MUR 34 and MUR 37 and only based on the edge sample. The riffle samples for these same sites were awarded an A and B grade, respectively. With the exception of MUR 1 and MUR 18, overall AUSRIVAS grade was generally better within Zone 1 and Zone 2 compared to sites further downstream. When examining AUSRIVAS results separately for the two habitats, some X (exceeds reference condition) grades were also observed (edge sample for MUR 2 and MUR 4 and riffle sample from MUR 15). An overall AUSRIVAS grade was not applied to MUR 34 due to the vast differences in the edge and riffle grades for this site.

Table 17. Taxa richness, AUSRIVAS Bands and SIGNAL-2 scores for spring 2011
NRA = no reliable assessment, Coloured cells indicate replicates that were nearly outside the experience of the model.

Zone	Site	Location	Richness		EPT Richness		SIGNAL- 2		AUSRIVAS O/E50 Score		AUSRIVAS Band		Overall AUSRIVAS assessment
			Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
Zone 1	MUR 1	D/S Tantangara Reservoir	15	21	5	6	5.67	5	0.63	0.99	B	A	B
	MUR 2	Yaouk Bridge	24	21	10	10	5.57	4.8	1.06	1.16	A	X	A
	MUR 3	Bobeyan Road Bridge	20	19	9	8	5.38	5	0.97	0.88	A	A	A
	MUR 4	Camp ground off Bobeyan Road	24	17	11	6	5.5	4.91	1.05	1.21	A	X	A
Zone 2	MUR 6	D/S STP Pilot Creek Road	16	16	9	5	5.85	4.2	0.97	1.11	A	A	A
	MUR 9	Murrells Crossing	21	17	10	6	5.73	4.33	1.11	1	A	A	A
	MUR 12	Through Bredbo township	16	15	7	7	5.08	4.6	1.19	1.11	X	A	A
	MUR 15	Near Colinton - Bumbalong Road	13	13	5	4	4.91	4.25	0.88	0.89	A	A	A
	MUR 16	The Willows - Near Michelago	13	16	6	6	5	4.2	0.96	1.11	A	A	A
	MUR 18	U/S Angle Crossing	14	20	7	5	5	4.5	0.85	1.11	B	A	B
Zone 3	MUR 19	D/S Angle Crossing	14	16	7	5	5.42	4.2	0.93	1.11	A	A	A
	MUR 22	Tharwa Bridge	20	16	8	7	5.25	4.6	0.95	1.11	A	A	A
	MUR 23	Point Hut Crossing	13	20	6	8	5.27	4.6	0.88	1.11	A	A	A
	MUR 27	Kambah Pool	11	13	3	6	4.6	4.33	0.79	0.66	B	B	B
	MUR 931	"Fairvale" ~4km U/S of the Cotter Confluence	13	13	5	4	4.8	4.43	0.75	0.78	B	B	B
	MUR 28	U/S Cotter River confluence	14	10	6	3	4.8	4.14	0.75	0.78	B	B	B
	MUR 935	Casuarina sands	13	10	5	3	4.78	3.5	0.67	0.66	B	B	B
	MUR 937	Mt. MacDonald ~5km D/S of the Cotter Confluence	13	16	5	6	4.73	4.5	0.82	0.89	B	A	B
	MUR 29	Uriarra Crossing	13	10	6	4	4.73	4	0.83	0.78	B	B	B
	MUR 30	U/S Molonglo Confluence	15	12	7	4	5.2	3.71	1.01	0.78	A	B	B
Zone 4	MUR 31	D/S Molonglo Confluence	13	15	5	6	4.64	4.13	0.86	0.89	A	A	A
	MUR 34	Halls Crossing	14	12	5	3	5	3.4	0.96	0.55	A	C	NRA
	MUR 37	Boambolo Road	13	10	5	2	5.3	4.2	0.79	0.55	B	C	C

The habitat from which the samples was collected, either edge or riffle, was expected to be influential on the univariate indices. Thus, separate Mann-Whitney tests were conducted for each of total abundance, overall taxa richness, EPT richness, EPT relative abundance, OCD relative abundance, SIGNAL-2 and O/E50 to determine whether levels differed significantly between edge and riffle samples. These tests indicated no significant difference (p>0.05) in overall taxa richness, EPT taxa richness or O/E50 between edge and riffle samples (Appendix H) and for this reason, data were combined across habitats for these three variables in subsequent testing between Zones. Mann-Whitney tests determined that there was a significant difference (p<0.05) in total abundance, EPT relative abundance, OCD relative abundance and SIGNAL-2 between edge and riffle samples (Appendix H).

A Kruskall-Wallis test was conducted on overall taxa richness to determine whether this metric varies significantly between the four Zones. The test indicated that there was a significant difference in taxa richness between Zones as can be seen in Figure 16. This plot shows that taxa richness in spring 2011 was highest at Zone 1 sites (20 taxa) after which richness decreased in order of Zones to a low of 10 taxa at Zone 4. The Tukey test of multiple comparisons provides pair-wise significance tests between Zones. The results of multiple comparisons testing for taxa richness (Table 18) indicates that taxa richness was only significantly (p<0.05) different between Zone 1 sites and those from Zones 3 and 4.

EPT richness was found to differ significantly (p<0.05) between Zones. Figure 17 indicates a decreasing trend in EPT richness between Zone 1 and Zone 4. The results of multiple-comparisons in Table 19 show that EPT richness was significantly higher on average at Zone 1 sites compared to sites from all other zones. There was no significant difference in EPT richness between the three furthest downstream zones.

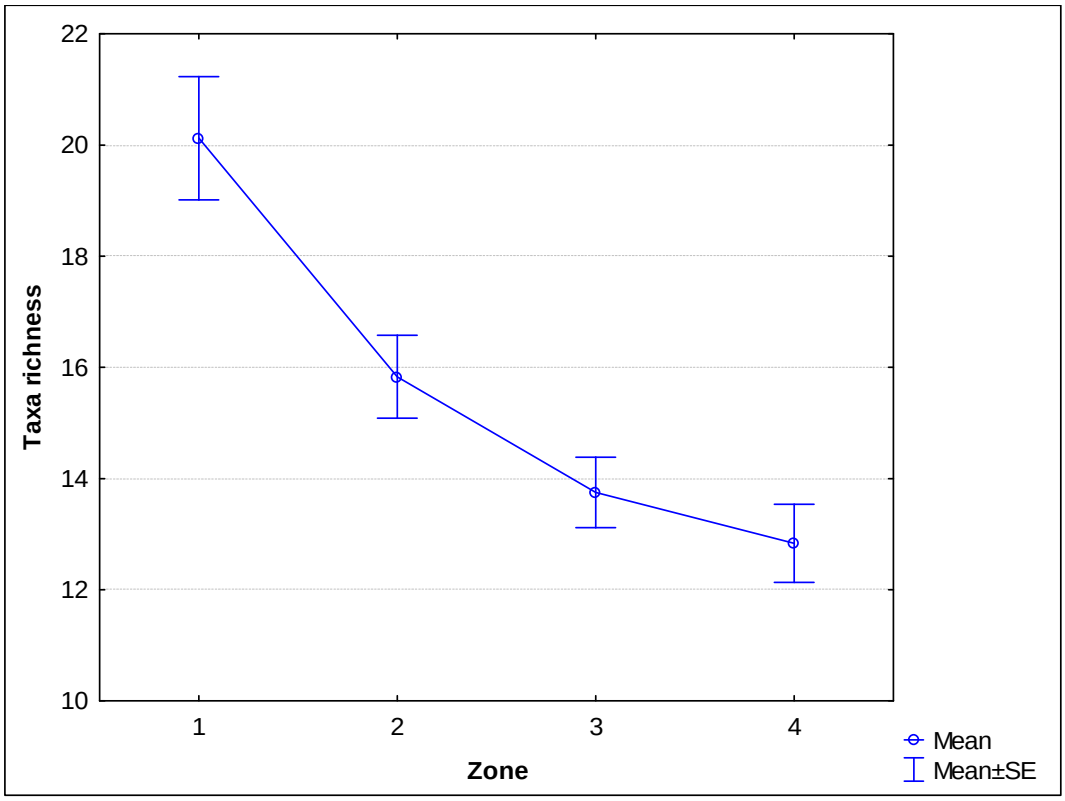


Figure 16. Means plot showing differences in Taxa richness between Zones

Table 18. Tukey's HSD post-hoc analysis of pairwise comparisons of Taxa richness between Zones

Text in red indicates significant differences (p<0.05).

Zone	1	2	3
1			
2	0.21		
3	**0.01**	0.48	
4	**<0.01**	0.17	0.71

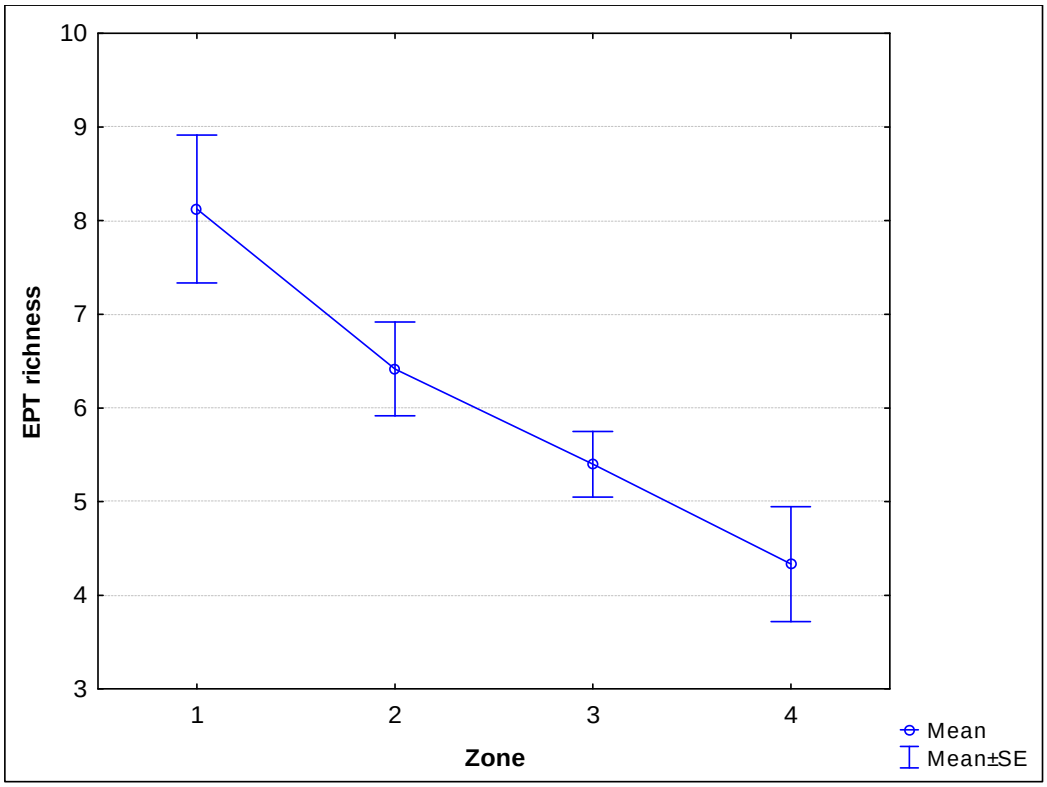


Figure 17: Means plot showing differences in EPT richness between Zones

Table 19. Tukey's HSD post-hoc analysis of pairwise comparisons of EPT richness between Zones

Text in red indicates significant differences (p<0.05).

Zone	1	2	3
1			
2	0.01		
3	<0.01	0.25	
4	<0.01	0.23	0.93

The results of a Kruskal-Wallis test indicated that O/E50 score differed significantly between Zones. The means plot in Figure 18 shows that there was little difference in O/E50 score between Zone 1 and Zone 2 sites in spring 2011, although O/E50 was reduced in Zones 3 and 4. The table of multiple comparisons (Table 20) reveals that O/E50 score was significantly lower for Zone 3 and 4 sites compared to sites within Zones 1 and 2.

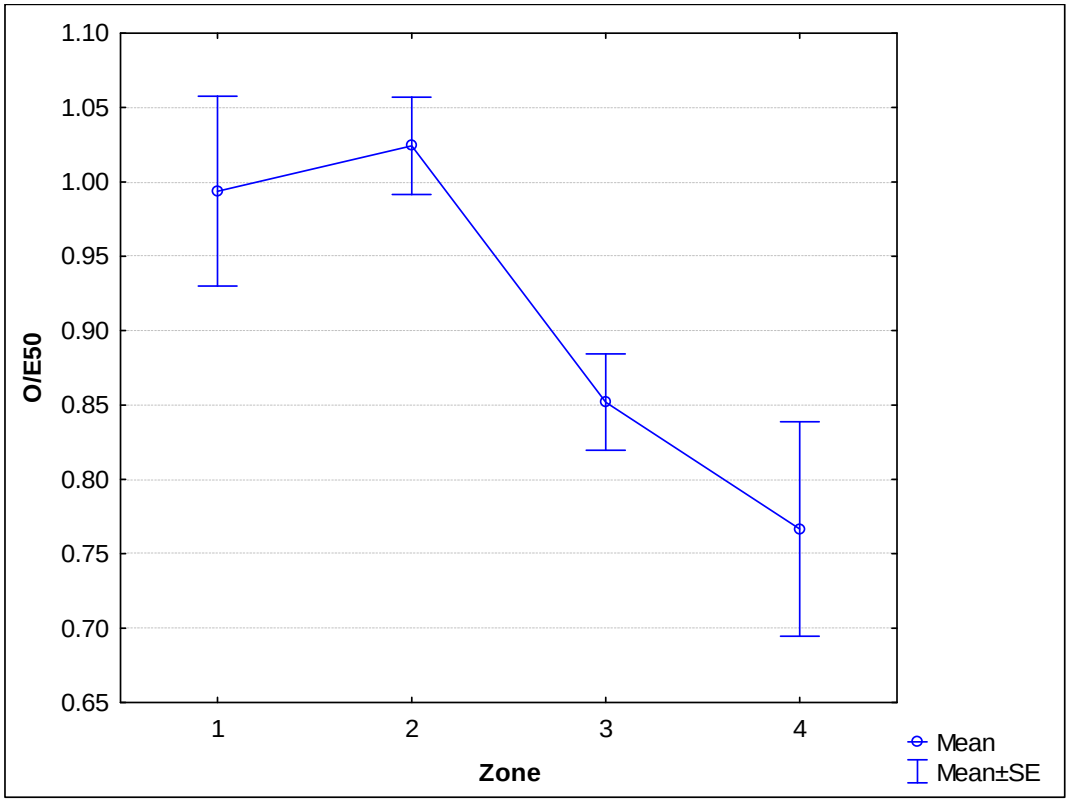


Figure 18. Means plot showing differences in O/E50 score between Zones

Table 20. Tukey's HSD post-hoc analysis of pairwise comparisons of O/E50 score between Zones

Text in red indicates significant differences (p<0.05).

Zone	1	2	3
1			
2	0.97		
3	0.23	0.03	
4	0.05	0.02	0.75

Edge samples

Due to the significant differences found in total abundance, EPT relative abundance, OCD relative abundance and SIGNAL-2 score between Edge and Riffle samples, the data were split between habitats before subsequent analysis of differences between zones. For data collected from Edge samples, no significant difference (p>0.05) was found in total abundance, OCD relative abundance or SIGNAL-2 score between Zones (Appendix I). A significant difference was found for EPT relative abundance of edge samples between one or more of the four Zones. The means the plot in Figure 19 shows that EPT relative abundance increased steadily between furthest downstream Zone 4 and furthest upstream Zone 1. The multiple comparison results in

Table 21 show that the only significant difference was between Zone 1 and Zone 4 sites.

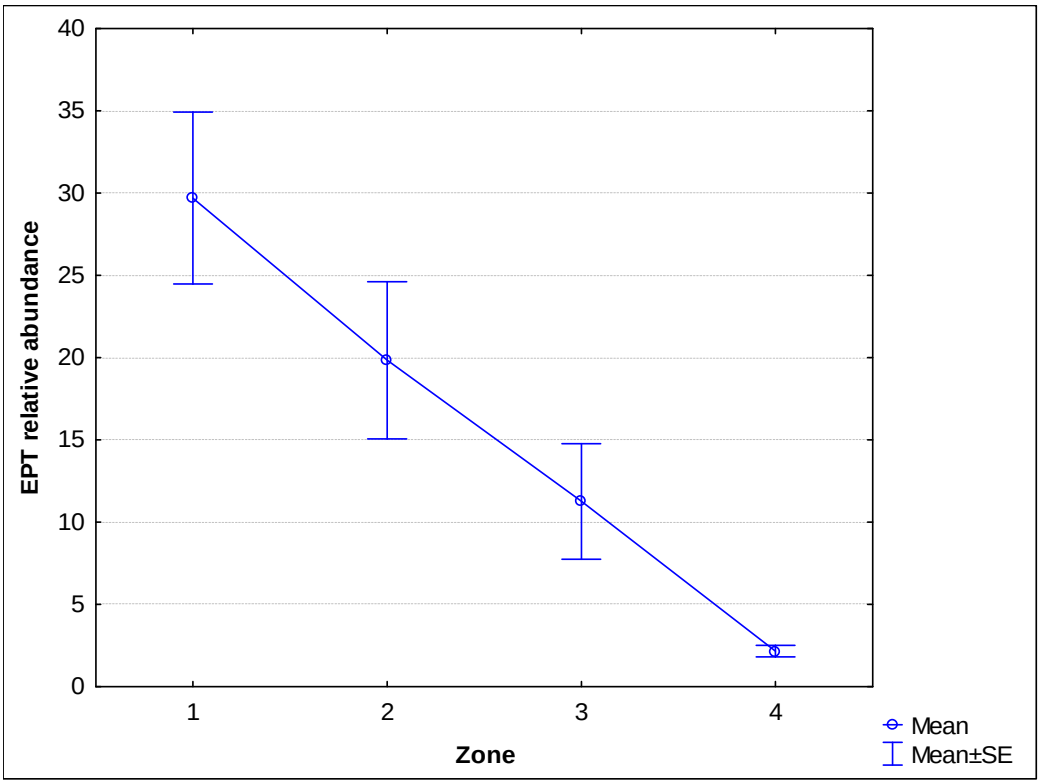


Figure 19. Means plot showing differences EPT relative abundance of Edge samples between Zones

Table 21. Tukey's HSD post-hoc analysis of pairwise comparisons of EPT relative abundance of Edge samples between Zones**.** Text in red indicates significant differences (p<0.05).

Zone	1	2	3
1			
2	0.56		
3	0.09	0.51	
4	0.02	0.20	0.72

Riffle samples

No significant difference was detected in total abundance or SIGNAL-2 score of riffle samples between the Zones (Appendix I). A significant (p<0.05) difference in both EPT and OCD relative abundance was determined between the four Zones. The difference in EPT relative abundance between Zones is illustrated in Figure 20. This plot shows an increasing trend in mean EPT relative abundance between furthest downstream Zone 4 and furthest upstream Zone 1. However, the difference in EPT relative abundance between Zone 3 and Zone seems to be less pronounced. This is confirmed by the table of multiple comparisons (Table 22) which indicates that the only significant (p<0.05) differences are between Zone 1 and Zone 4.

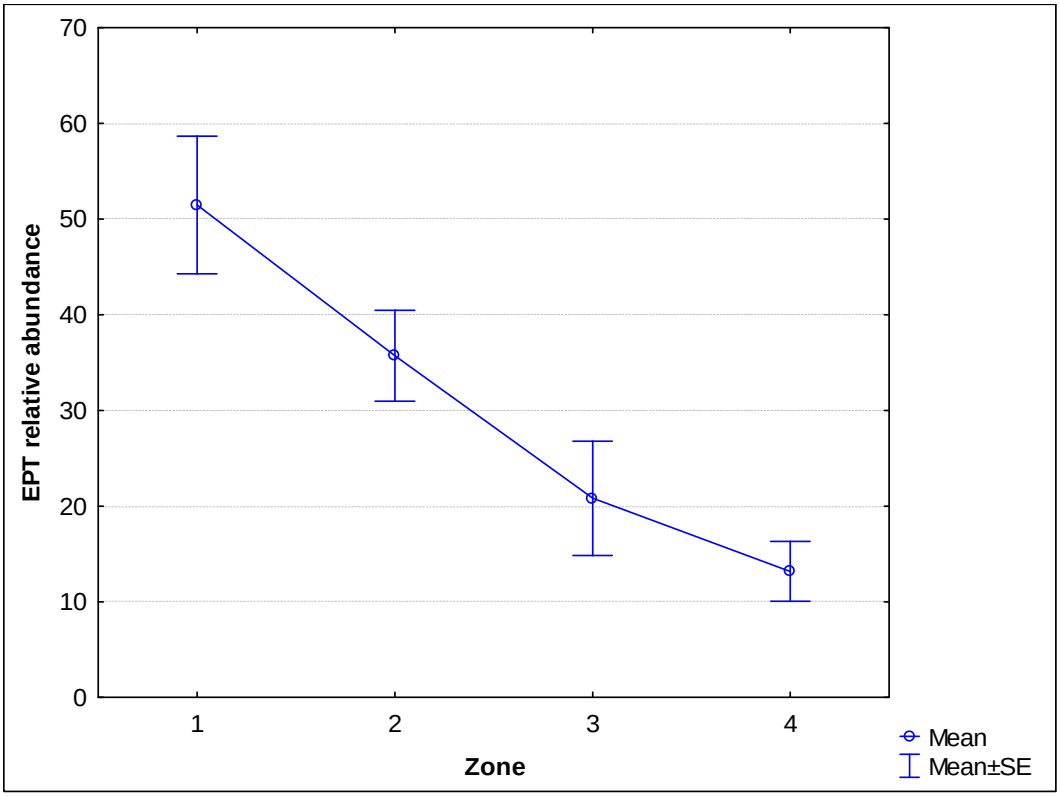


Figure 20. Means plot showing differences EPT relative abundance of Riffle samples between Zones

Table 22. Tukey's HSD post-hoc analysis of pairwise comparisons of EPT relative abundance of Riffle samples between Zones. Text in red indicates significant differences (p<0.05).

Zone	1	2	3
1			
2	0.49		
3	0.05	0.37	
4	**0.03**	0.31	0.93

The difference in OCD relative abundance detected in riffle samples between Zones can be viewed in Figure 21. This plot shows that OCD relative abundance is lowest, on average, within Zone 1 and then noticeably higher from Zone 2 to Zone 4. The multiple comparisons in Table 23 indicate that OCD relative abundance of riffle samples collected from Zone 1 were not significantly different from Zone 2 samples but was significantly different to samples collected from Zone 3 and 4.

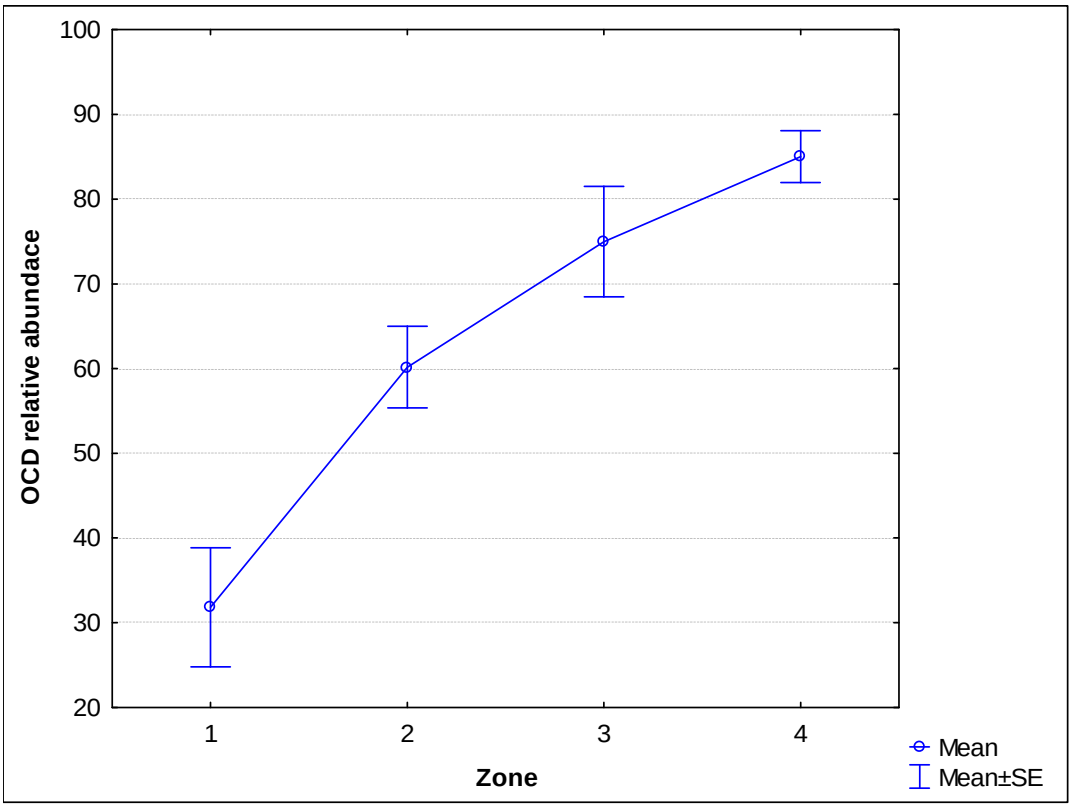


Figure 21. Means plot showing differences OCD relative abundance of Riffle samples between Zones

Table 23. Tukey's HSD post-hoc analysis of pairwise comparisons of OCD relative abundance of Riffle samples between Zones. Text in red indicates significant differences (p<0.05).

Zone	1	2	3
1			
2	0.10		
3	<0.01	0.43	
4	<0.01	0.28	0.88

The proportion of sensitive (EPT) taxa to overall taxa is displayed for edge and riffle samples Figure 22 and Figure 23, respectively. These plot show that overall richness and the proportion of richness made up of EPT taxa is quite similar between edge and riffle samples. Richness did appear to be slightly higher in Zone 1 and Zone 2 sites compared to other sites. Of the edge samples, richness (and EPT richness) was lowest at Zone 3 sites MUR 28 and MUR 935 and Zone 4 site MUR 37. For riffle samples, the lowest overall and EPT richness was observed at Zone 3 site MUR 27.

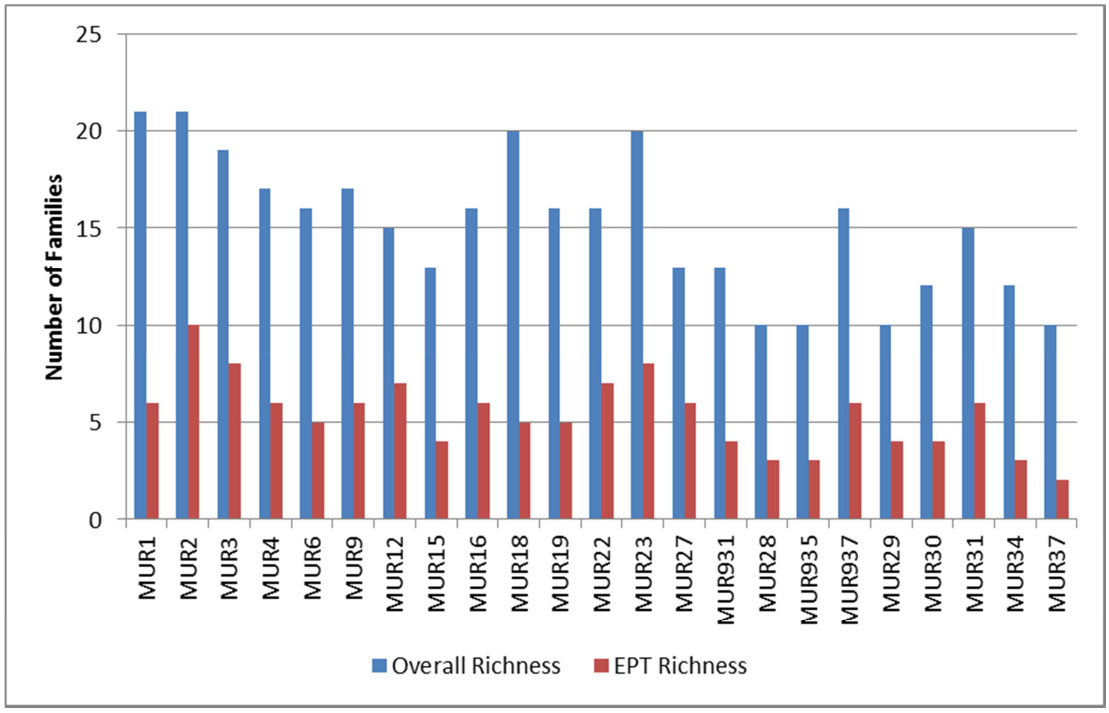


Figure 22. Number of EPT taxa compared to overall richness within edge samples

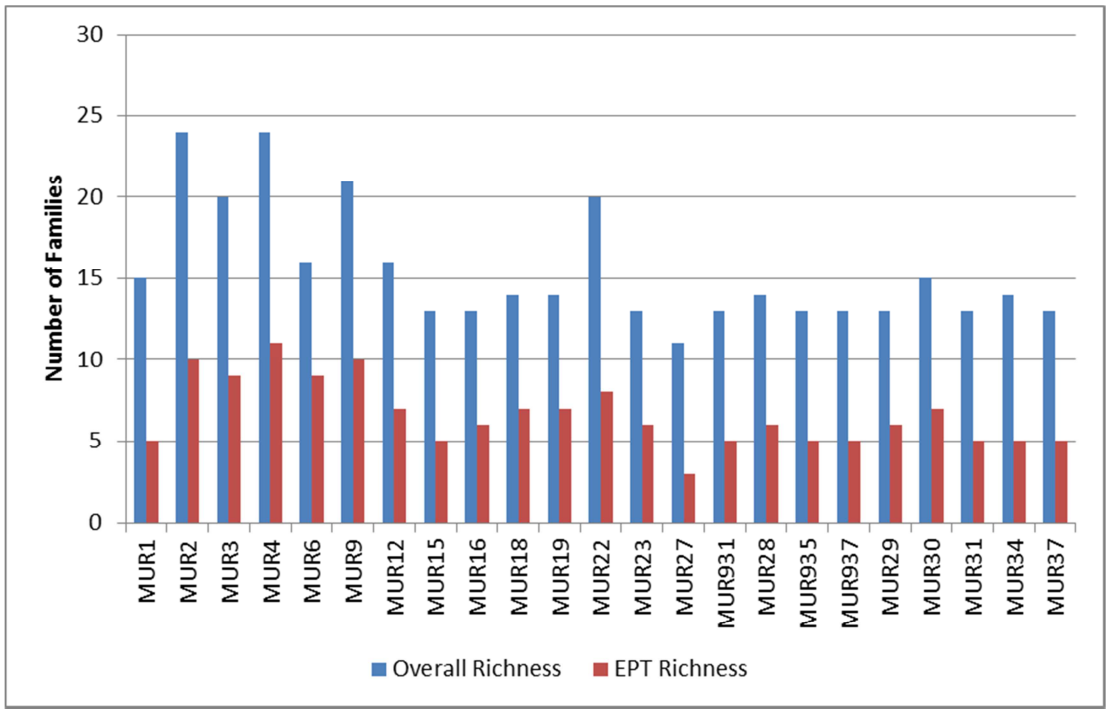


Figure 23. Number of EPT taxa compared to overall richness within riffle samples

4 Discussion

4.1 Water Quality

During spring 2011, moderate to high rainfall and the release of water from Tantangara reservoir lead to high flows throughout the sampled reaches of Murrumbidgee River.

Dissolved oxygen levels were good throughout the entire system, probably as a result of the flowing conditions and continuing rainfall. Turbidity levels, although higher than in autumn 2011, were within the guideline levels at all sites except MUR 15 (Zone 2). Based on the habitat conditions (Appendix F), there is no clear reason for the spike in turbidity at this site. At the time of spring sampling, MUR 15 was observed as having only moderate flow and no note was taken of particularly high erosion. There is also a good amount of riparian vegetation along the bank at this site which would be expected to reduce the impact of run-off. Therefore, the high turbidity reading at MUR 15 can reasonably be assumed to be a local scale disturbance, such as rainfall immediately prior to sampling, and is not expected to reflect any real impact at the site.

As with previous sampling events, water quality was noticeably different in Zone 1 when compared to the other three Zones. Nutrients were lowest within Zone 1 and sites from this zone were amongst the few at which total nitrogen and total phosphorus levels did not exceed the guideline values. EC was below the lower guideline limit at three of the four sites from this Zone.

Levels of pH were variable between sites and above the guideline maximum at some. Unlike the autumn 2011 sampling event, the exceedances in pH were not restricted to the sites furthest downstream. The increased number of exceedances for pH may be due to the increased rainfall and, thus, run-off experienced during this sampling event.

There were no major differences in water quality between Zone 2 and Zone 3 which is expected since sites within these two zones have generally similar land-use. There was, however, a noticeable increase in nutrients, EC and alkalinity downstream of the Molonglo River confluence (Zone 4 sites). This is due to the influence of the Molonglo River joining the Murrumbidgee River at this point, which also includes discharge from the Lower Molonglo Water Quality Control Centre (LMWQCC). Despite the increase of electrical conductivity in Zone 4 all sites downstream of the Molonglo River confluence were beloe the ANZECC and ARMCANZ (2000) guidelines recommended maximum level.

The multivariate principal components analysis (PCA) concurred with the assessment made from the univariate information. The Zone 1 sites were separated from the other Zones but a large amount of variation was also visible in the water quality parameters for the four Zone 1 sites. Little differentiation could be made in overall water quality between Zone 2 and Zone 3 sites but water quality at Zone 4 sites, particularly MUR 34 and MUR 37 were slightly different.

4.2 Patterns in macroinvertebrate communities

There was no clear separation in the edge or riffle macroinvertebrate community between Zones, based on visual methods. However, PERMANOVA identified significant differences in both the edge and riffle community in Zone 1 compared to the other three Zones. The taxa commonly listed as contributing most strongly to the differences in Zone 1 were Corixidae (Hemiptera; edge only), Gripopterygidae (Plecoptera; edge & riffle), Simuliidae (Diptera; riffle only), Oligochaeta (edge & riffle), Hydropsychidae (Trichoptera; riffle only) and Talitridae (Amphipoda; edge only).

The higher number of Hydropsychidae and Simuliidae at Zone 2, 3 and 4 sites has been found on previous sampling runs which has been attributed to these taxa preferring towards faster flowing water (Gooderham and Tsyrlin, 2002; Williams, 1980) and tolerating slight nutrient enrichment, which is more characteristic of the downstream sites. The number of Simuliidae increased between Zone 1 and Zone 4 in parallel to the general pattern of increasing flows throughout the catchment. Hydropsychidae were less predictable in their patterns but abundance was still generally lowest in Zone 1 and Zone 2 where flows were lower.

Higher numbers of the tolerant taxon Corixidae were observed within the edge habitat at Zone 2, 3 and 4. These taxa are able to construct an air film around the bulk of their body (Williams, 1980) which means that they do not come into close contact with the water and, thus, can live in highly disturbed systems. The decreased number of Corixidae in the upstream sites most likely reflects the improved water within these areas and increased competition at these sites by rarer, more sensitive taxa.

Talitridae were observed only at Zone 1 sites but these animals are predominantly land-based (Gooderham and Tsyrlin, 2002) and, thus, their presence in Zone 1 cannot be attributed to changes in water quality within this site.

The pattern of reducing numbers of Gripopterygidae (Plecoptera) from upstream to downstream is important as Plecoptera are particularly sensitive to organic pollution and changes in temperature (Yule, 1997). The highest numbers of these taxa were collected at MUR 1, 2 and 3, which can be explained by the lower temperatures (up to three degrees cooler than downstream sites) at these sites. Although not identified as an important factor by the multivariate analysis, the reduced electrical conductivity at Zone 1 sites may also have promoted the presence of more sensitive taxa at these sites.

Multivariate analyses linked the differences in the riffle macroinvertebrate community between sites to changing levels of temperature and alkalinity. Temperature did not vary between sites and zones in a consistent way and, thus, does not provide a useful explanation. Alkalinity, however, was noticeably lower in Zone 1 compared to other zones.

4.3 River Health (AUSRIVAS assessment & univariate indices)

Based on the AUSRIVAS assessment, overall health was generally good throughout Zone 1, 2 and 3, with most sites achieving a grade equivalent to ‘reference condition’ or ‘significantly impaired’. The impact of agricultural land-use is clear in the differences between Zones with the sites which are subjected to the most intensive agriculture receiving the lowest grade. The results of statistical analysis confirmed that AUSRIVAS O/E50 score was significantly lower in Zone 3 and 4 compared to Zone 1 and Zone 2. Despite some changes in land-use between Zone 1 and 2, there was no significant difference in O/E50, on average, between the two zones. More surprising, given the differences in water quality, was the fact that there was no significant difference in O/E50 found between Zones 1 and either Zone 3 or Zone 4.

EPT richness decreased between Zones in the direction of flow, with corresponding changes in land-use and water quality. EPT richness was significantly higher in Zone 1 than the other three zones. However, the proportion of EPT taxa to total taxa appeared to be similar between the four zones. EPT relative abundance also decreased from Zone 1 to Zone 4 but was only significantly higher in Zone 1 when compared to Zone 4. Some sites with high EPT relative abundance also had high OCD relative abundance. This is not necessarily contradictory. There is difficulty in equating these two metrics because the tolerant Oligochaeta and Diptera (including Chironomids) are opportunistic and prone to clumping where there are sufficient resources. Furthermore, the ability of OCD taxa to endure in highly disturbed environments is not a reason to expect that they will not occur in less disturbed systems. Some site conditions, such as the availability of food and habitat would be expected to encourage the presence of all types of macroinvertebrates, both sensitive and tolerant. This is noted to be the case for Oligochaeta (Gooderham and Tsyrlin, 2002). Thus the abundance scale is not comparable between EPT and OCD. In this case, the presence of EPT taxa is given precedence in the determination of ecosystem health.

From examining the raw data, there was a marked increase in abundance of Gripopterygidae in samples collected from Zone 1 and members of the moderately to highly sensitive families, Scirtidae (SIGNAL-2=6), Psepheniidae (SIGNAL-2 =6), Conoesucidae (SIGNAL-2=7), Atriplectidae (SIGNAL-2=7), Odontoceridae (SIGNAL-2=7) and Glossomatidae (SIGNAL-2=9) were only collected from Zone 1 sites. Overall, average SIGNAL-2 score did not differ significantly between Zones.

The variable results emphasise the need for multiple univariate indices when using macroinvertebrates to determine the health of an ecosystem. Despite the somewhat misleading results of the AUSRIVAS analysis and OCD relative abundance, the information added by SIGNAL-2 score and the EPT taxa leads to the overall conclusion that ecosystem health is improved, overall, within Zone 1 compared to the three other zones. Furthermore, Zone 4 sites appear to be in the poorest condition in terms of water quality and the macroinvertebrate communities.

5 Conclusions

Rainfall and flows were moderate to high throughout the spring 2011 period. Some differences in water quality were observed (compared to the previous sampling event) such as increased turbidity.

Apart from nutrients, water quality was generally within guideline values throughout the system despite the reasonably high levels of rainfall. There were only a few exceedances of DO, EC and turbidity guideline values. Exceedances of pH and nutrient guidelines were more numerous but were evident across the four zones. As per previous sampling events, water quality was noticeably higher within the upper reach of Zone 1 and the poorest water quality observed in the lower downstream reach in Zone 4.

Based on AUSRIVAS grading, the overall assessment of the 23 sites was either 'near reference condition', 'significantly impaired' or 'severely impaired'. AUSRIVAS banding was often different between Edge and Riffle samples which highlights the need for sampling both habitats. Generally, the best scores were awarded to sites in Zone 1, Zone 2 and Zone 3 and the least favourable grade was observed for Zone 4 sites. The O/E50 score (on which the band was based) provided a different result when subjected to statistical analysis. Average O/E50 did not differ significantly between zones.

Some key differences in terms macroinvertebrate community composition were found between zones. Increased numbers of Hydropsychidae and Simuliidae at the downstream sites are most likely related to the increased flows in these sections of the river. However, the most notable difference in the macroinvertebrate community in Zone 1 compared to the other zones was the observation of certain sensitive taxa, exclusively within this zone (e.g. Conoesucidae and Odontoceridae).

When considering the weight of evidence provided by the water analysis, multivariate and univariate macroinvertebrate indices, the water quality and 'ecosystem health' of Zone 1 sites is higher than that of the other Zones. Little difference was detected between Zone 2 and Zone 3 sites but the least favourable water quality and macroinvertebrate results were generally observed for Zone 4 sites. These sites are downstream of the confluence with Molonglo River and may reflect the characteristics of this system. However, these changes could also been explained by the intensive agriculture activities at Zone 4 sites.

6 References

ACT Government (2006) 2006 Environmental Flow Guidelines. Environment ACT, Canberra.

ACT Government (2011) 2011 Environmental Flow Guidelines, Draft. Environment ACT, Canberra.

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

ALS. (2011) Murrumbidgee Ecological Monitoring Program Proposal: Spring 2011 – Autumn 2012. Report for ActewAGL Distribution. Report number: CN211063-2011-020

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.

Bray, J.R., Curtis, J.T. (1957) An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs*. 27: 325-349.

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

Chessman, B.C. (2003) SIGNAL 2 – A Scoring System for Macro-invertebrate ('Water Bugs') in Australian Rivers. Monitoring River Heath Initiative Technical Report no 31, Commonwealth of Australia, Canberra.

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.

Clifford, H.T. & Stephenson, W. (1975) An Introduction to Numerical Classification. Academic Press, New York.

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

Frissell, C.A., Liss, W.J., Warren, C.E. & Hurley, M.D. (1986) A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management*, 10, 199-214.

Gooderham, J. & Tsyrlin, E. (2002) The Waterbug Book: A guide to the freshwater macroinvertebrates in temperate Australia, CSIRO Publishing, Victoria.

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

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.

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

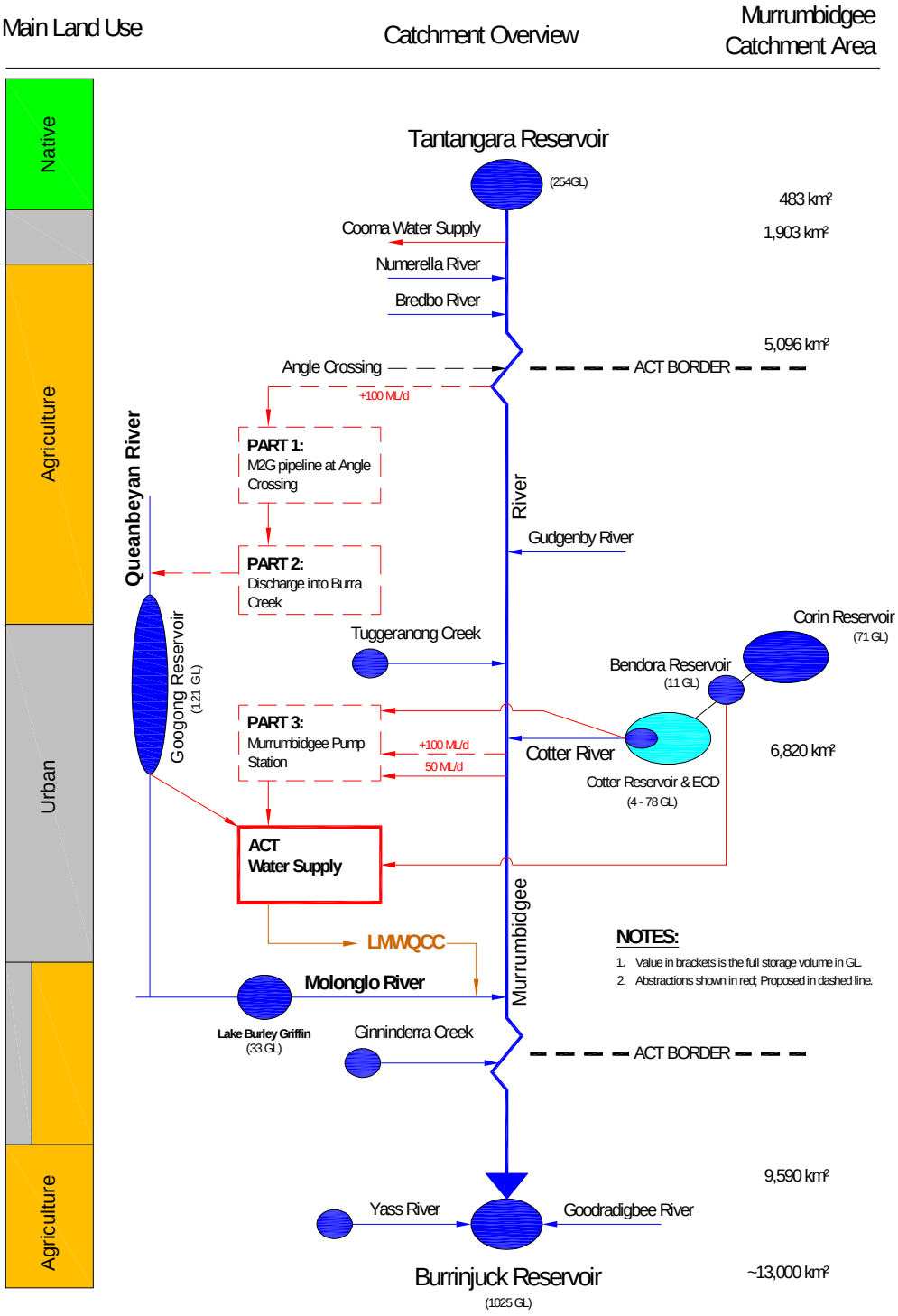
Quinn, G.P. & Keough, M.J. (2002) *Experimental Design and Data Analysis for Biologists*.

William, W.D. (1980) *Australian Freshwater Life*. MacMillan Publishers Australia Pty Ltd, South Yarra.

Yule, C. (1997) *Identification guide to the Stonefly nymphs of New South Wales & Northern Australia*. Australian Water Technologies Pty Ltd, West Ryde.

Zar, J.R. (1999). Biostatistical Analysis: 4th Edition. Prentice-Hall, Inc., New Jersey.

Appendix A - Schematic representation of the Murrumbidgee Catchment and ACTEW's major water projects


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

Appendix B - Principal Components Analysis of water quality variables

PCA

Principal Component Analysis

Data worksheet
Name: Data6
Data type: Environmental
Sample selection: All
Variable selection: All

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	5.21	52.1	52.1
2	2.44	24.4	76.5
3	1.47	14.7	91.1
4	0.402	4.0	95.1
5	0.303	3.0	98.2

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Temp	-0.209	0.447	0.231	0.655	0.212
EC	-0.427	0.069	-0.031	0.212	-0.057
pH	-0.156	0.574	0.044	-0.266	-0.318
D.O (% Sat.)	0.040	0.588	-0.015	-0.496	0.391
Turbidity	-0.340	-0.017	0.414	-0.146	-0.654
Alkalinity	-0.421	-0.047	0.058	0.139	0.305
Total Nox	-0.287	0.039	-0.614	0.015	-0.187
TP	-0.355	-0.286	0.124	-0.343	0.280
TN	-0.325	-0.006	-0.549	-0.044	-0.006
TSS	-0.375	-0.188	0.274	-0.221	0.254

Appendix C -
PERMANOVA output

PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: Resem1
Data type: Similarity
Selection: All
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Habitat	Fixed	2
Zone	Fixed	4

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Habitat	1	16751	16751	6.8173	0.0001	9933
Zone	3	23564	7854.7	3.1966	0.0001	9874
HabitatxZone	3	10258	3419.5	1.3916	0.0639	9858
Res	38	93373	2457.2			
Total	45	1.5004E5				

Details of the expected mean squares (EMS) for the model

Source	EMS
Habitat	1*V(Res) + 18.824*S(Habitat)
Zone	1*V(Res) + 10.667*S(Zone)
HabitatxZone	1*V(Res) + 5.3333*S(HabitatxZone)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Habitat	1*Habitat	1*Res	1	38
Zone	1*Zone	1*Res	3	38
HabitatxZone	1*HabitatxZone	1*Res	3	38

Estimates of components of variation

Source	Estimate	Sq.root
S(Habitat)	759.38	27.557
S(Zone)	506.02	22.495
S(HabitatxZone)	180.43	13.432
V(Res)	2457.2	49.57

PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: ResemEdge1
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 9999

Factors

Name	Type	Levels
Zone	Fixed	4

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Zone	3	13036	4345.4	2.7754	0.0002	9892
Res	19	29748	1565.7			
Total	22	42784				

Details of the expected mean squares (EMS) for the model

Source	EMS
Zone	1*V(Res) + 5.3333*S(Zone)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Zone	1*Zone	1*Res	3	19

Estimates of components of variation

Source	Estimate	Sq.root
S(Zone)	521.2	22.83
V(Res)	1565.7	39.569

PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: ResemEdge1
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 9999

Factors

Name	Type	Levels
Zone	Fixed	4

PAIR-WISE TESTS

Term 'Zone'

Groups	t	P(perm)	Unique perms
1, 2	1.9694	0.0045	210
1, 3	2.2971	0.0015	1001
1, 4	2.063	0.0302	35
2, 3	1.1489	0.232	5694
2, 4	1.2961	0.0629	84
3, 4	1.2697	0.1274	286

Denominators

Groups	Denominator	Den.df
1, 2	1*Res	8
1, 3	1*Res	12
1, 4	1*Res	5
2, 3	1*Res	14
2, 4	1*Res	7
3, 4	1*Res	11

Average Similarity between/within groups

	1	2	3	4
1	56.757			
2	38.413	48.391		
3	27.068	42.455	40.729	
4	32.701	43.118	38.147	45.4

PERMANOVA

Permutational MANOVA

Resemblance worksheet
Name: ResemRiffle2
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Type	Levels
Zone	Fixed	4

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Zone	3	11857	3952.3	3.3512	0.003	998
Res	19	22408	1179.4			
Total	22	34265				

Details of the expected mean squares (EMS) for the model

Source	EMS
Zone	1*V(Res) + 5.3333*S(Zone)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Zone	1*Zone	1*Res	3	19

Estimates of components of variation

Source	Estimate	Sq.root
S(Zone)	519.93	22.802
V(Res)	1179.4	34.342

PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: ResemRiffle2
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Unrestricted permutation of raw data
Number of permutations: 999

Factors

Name	Type	Levels
Zone	Fixed	4

PAIR-WISE TESTS

Term 'Zone'

Groups	t	P(perm)	Unique perms
1, 2	1.6988	0.027	208
1, 3	2.646	0.002	612
1, 4	1.9031	0.037	35
2, 3	1.4814	0.08	943
2, 4	1.4886	0.059	84
3, 4	1.2997	0.121	277

Denominators

Groups	Denominator	Den.df
1, 2	1*Res	8
1, 3	1*Res	12
1, 4	1*Res	5
2, 3	1*Res	14
2, 4	1*Res	7
3, 4	1*Res	11

Average Similarity between/within groups

	1	2	3	4
1	48.991			
2	40.754	52.483		
3	30.449	49.8	54.811	
4	35.413	46.07	52.246	56.029

Appendix D -
BEST analysis – output

BEST

Biota and/or Environment matching

Data worksheet
Name: Data2
Data type: Environmental
Sample selection: All
Variable selection: All

Resemblance worksheet
Name: ResemEdge1
Data type: Similarity
Selection: All

Parameters
Rank correlation method: Spearman
Method: BIOENV
Maximum number of variables: 5
Resemblance:
Analyse between: Samples
Resemblance measure: D1 Euclidean distance

Variables
1 Temperature (˚C)
2 Electrical Conductivity (µS/cm)
3 pH
4 D.O (mg/L)
5 D.O (% Sat.)
6 Turbidity (NTU)
7 Alkalinity
8 Total NOx (mg/L)
9 Nitratrate (mg/L)
10 Total Phosphorus (mg/L)
11 Total Nitrogen (mg/L)
12 TSS (mg/L)
13 TKN (mg/L)

Best results

No.Vars	Corr.	Selections
2	0.372	6,7
1	0.361	7
3	0.355	6,7,12
2	0.354	2,7
2	0.351	7,12
3	0.348	2,6,7
3	0.347	3,6,7
4	0.345	3,6,7,12
4	0.345	1,6,7,12
1	0.345	2

BEST

Biota and/or Environment matching

Data worksheet
Name: Data3
Data type: Environmental
Sample selection: All
Variable selection: All

Resemblance worksheet
Name: ResemRiffle2
Data type: Similarity
Selection: All

Parameters
Rank correlation method: Spearman
Method: BIOENV
Maximum number of variables: 5
Resemblance:
Analyse between: Samples
Resemblance measure: D1 Euclidean distance

Variables
1 Temperature (˚C)
2 Electrical Conductivity (µS/cm)
3 pH
4 D.O (mg/L)
5 D.O (% Sat.)
6 Turbidity (NTU)
7 Alkalinity
8 Total NOx (mg/L)
9 Nitratrate (mg/L)
10 Total Phosphorus (mg/L)
11 Total Nitrogen (mg/L)
12 TSS (mg/L)
13 TKN (mg/L)

Best results

No.Vars	Corr.	Selections
2	0.525	1,7
3	0.488	1,7,12
3	0.483	1,3,7
4	0.475	1,3,7,12
3	0.473	1,2,7
3	0.458	1,7,13
4	0.452	1-3,7
4	0.452	1,2,7,12
3	0.451	1,7,10
4	0.451	1,2,7,13

Appendix E - Expected taxa for riffle and edge habitats: spring 2011

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

Taxa	Sphaeriidae	Oligochaeta	Acarina	Elmidae	Psephenidae	Tipulidae	Simuliidae	Tanypodinae	Baetidae	Leptophlebiidae	Caenidae	Gripopterygidae	Notonemouridae	Hydrobiosidae	Glossosomatidae	Conoesucidae	Calocidae	Total number of missing taxa
SIGNAL2	**5**	**2**	**6**	**7**	**5**	**5**	**5**	**4**	**5**	**8**	**4**	**8**	**6**	**8**	**9**	**7**	**9**	
MUR1						0.54	0.57	0.84	0.76		0.74		0.64	0.60	0.60		0.59	**9**
MUR2							0.60							0.61				**2**
MUR3				0.97		0.70								0.62		0.78		**4**
MUR4					0.62									0.62				**2**
MUR6					0.66		0.65	0.58										**3**
MUR9					0.67		0.64											**2**
MUR12	0.60																	**1**
MUR15				0.93				0.69		0.85				0.50	0.56	0.51		**6**
MUR16				0.94	0.52									0.51	0.57	0.52		**5**
MUR18				0.95	0.60	0.63								0.56	0.68	0.64		**6**
MUR19			0.81		0.57			0.65							0.64	0.60		**5**
MUR22					0.53			0.68						0.52	0.59	0.55		**5**
MUR23					0.51		0.73	0.70						0.50	0.55	0.51		**6**
MUR27					0.53				0.65	0.86		0.89		0.52	0.58	0.54		**7**
MUR931			0.83		0.65			0.60		0.96		0.96		0.60	0.76	0.75		**8**
MUR28				0.96	0.64			0.59				0.95		0.59	0.75	0.72		**7**
MUR935					0.67			0.58		0.96	0.89	0.97		0.61	0.79	0.77		**8**
MUR937				0.97	0.65							0.96		0.60	0.77	0.75		**6**
MUR29				0.96	0.62					0.94				0.59	0.73	0.72		**6**
MUR30	0.61							0.83										**2**
MUR31					0.56					0.89		0.91		0.54	0.64	0.60		**6**
MUR34	0.56							0.80				0.83						**3**
MUR37		1.00			0.53			0.68				0.91		0.54	0.61	0.59		**7**

Appendix E (cntd.) - Taxa expected, but not collected in the edge habitat. The number in each cell is the probability of collection

Taxa	Oligochaeta	Acarina	Ceratopogonidae	Tanypodinae	Baetidae	Leptophlebiidae	Caenidae	Corixidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
SIGNAL2	**2**	**6**	**4**	**4**	**5**	**8**	**4**	**2**	**8**	**6**	
MUR1					0.68		0.84				**2**
MUR2		np									**0**
MUR3		0.50	0.62				0.92				**3**
MUR4								np			**0**
MUR6		np				0.82					**1**
MUR9					0.62					0.88	**2**
MUR12		np	0.65								**1**
MUR15			0.65	0.97		0.83					**3**
MUR16						0.82					**1**
MUR18					0.62						**1**
MUR19						0.82					**1**
MUR22		np	0.65								**1**
MUR23			0.65								**1**
MUR27			0.65	0.97		0.82		0.53		0.88	**5**
MUR931	1.00		0.65		0.62	0.82					**4**
MUR28			0.65	0.97	0.62				0.62		**4**
MUR935			0.65	0.97	0.62	0.82			0.62		**5**
MUR937			0.65	0.97						0.88	**3**
MUR29			0.65	0.97		0.82				0.88	**4**
MUR30		np	0.65	0.97		0.82			0.62		**4**
MUR31			0.65		0.62	0.82					**3**
MUR34		np	0.65	0.97	0.62	0.82	0.94		0.62		**6**
MUR37	1.00		0.65		0.62		0.94		0.62	0.88	**6**

np= not predicted

Appendix F - Site descriptions

Appendix F - Site descriptions

Site	Photo	Site Characteristics	Site Notes
MUR1		D/S Tantangara Reservoir Stream width: 5m Landuse: Native Forest / Native Grassland Riparian Zone Width: 30m Native Vegetation: 90% Point Source Pollution: Potential from the bridge	Low flow, trout observed at site, recent clearing of dead eucalypts upstream of bridge from channel and banks though still remain downstream of bridge, erosion evident on right hand bank
MUR2		Yaouk Bridge Stream width: 11m Landuse: Native forest / Grazing Riparian Zone Width: 2.5m Native Vegetation: 30% Point Source Pollution: Potential from the bridge	Moderate flow
MUR3		Bobeyan Road Bridge Stream width: 45m Landuse: Grazing Riparian Zone Width: 0m Native Vegetation:15% Point Source Pollution: Potential from the bridge	Moderate flow, adult damselflies observed at site, main areas of erosion are around the bridge and at an electricity pole on the right hand bank
MUR4		Camp ground off Bobeyan Road Stream width: 10m Landuse: Grazing / Recreational Riparian Zone Width: 30m Native Vegetation: 70% Point Source Pollution: Potential from the bridge	Moderate flow, small areas of erosion

MUR6		D/S STP Pilot Creek Road Stream width: 15m Landuse: Grazing / Recreational / Residential Riparian Zone Width: 15m Native Vegetation: 50% Point Source Pollution: Cooma Treatment Plant	Moderate flow, removal of willows overhanging riffle habitat since previous spring, evidence of stock trampling on banks with direct access to river channel, moderate levels of erosion on right hand bank possibly due to instability since willow removal, some erosion on left hand bank due to stock
MUR9		Murrells Crossing Stream width: 26m Landuse: Grazing / Residential Riparian Zone Width: 1m Native Vegetation: 15%	Moderate flow, recent bank slumps downstream of bridges on the right hand bank, most river shading caused by bridges, less intense erosion on left hand bank upstream of bridges with stock present on bank
MUR12		Through Bredbo township Stream width: 35m Landuse: Grazing / Recreational Riparian Zone Width: 5m Native Vegetation: 20% Point Source Pollution: None	Moderate flow. some small eroded areas on both banks
MUR15		Bumbalong Road Stream width: 11m Landuse: Grazing / Residential Riparian Zone Width: 10m Native Vegetation: 40%	Moderate flow, extensive edge habitat, good riparian vegetation alongside riffle habitat, fox cub present at site when we arrived

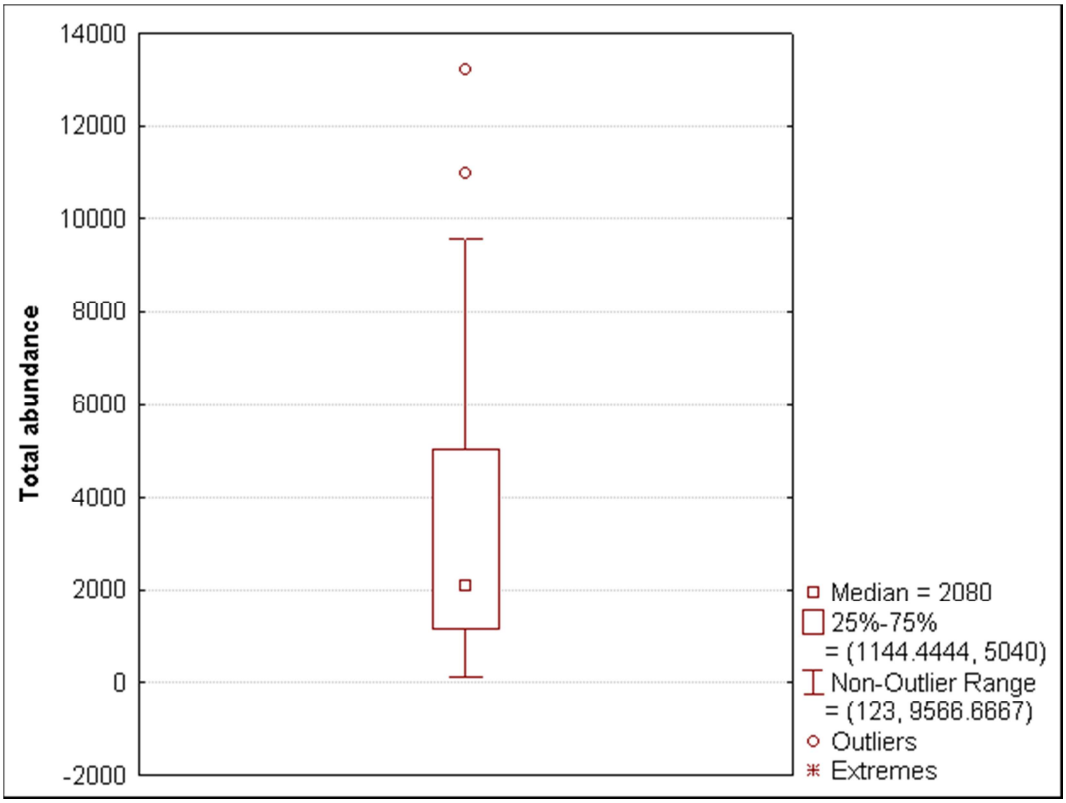
MUR16		The Willows, near Michelago Stream width: 35m Landuse: Native Forest / Grazing Riparian Zone Width: 30m Native Vegetation: 80%	Moderate flow, high proportion of natives compared to other sites
MUR18		U/S Angle Crossing Stream width: 20m Landuse: Grazing / Recreational Riparian Zone Width: 7m Native Vegetation: 60%	Moderate flow, vegetation growing on protruding bars on left hand bank, erosion evident on far left hand bank
MUR19		D/S Angle Crossing Stream width: 32m Landuse: Grazing / Recreational / Industrial Riparian Zone Width: 12.5m Native Vegetation: 35% Point Source Pollution: Crossing, Construction of M2G	Moderate flow, heavy rain during sample collection creating extensive silt runoff from adjacent dirt roads, very little periphyton with some tufts of filamentous green algae, extensive colonisation of the submerged macrophyte Myriophyllum sp.
MUR22		Tharwa Bridge Stream width: 35m Landuse: Riparian Zone Width: 16m Native Vegetation: 10% Point Source Pollution: Bridge, Construction	Low flow, reconstruction of Tharwa Bridge impacting upon site with increased sediment being deposited downstream of the bridge, silt fences in place, construction blocking access to usual edge habitat

MUR23		Point Hut Crossing Stream width: 8m Landuse: Grazing / Recreational / Residential Riparian Zone Width: 12.5m Native Vegetation: 60% Point Source Pollution: Potential from the bridge	Moderate flow, scales on right hand bank, established vegetation on bar in centre of channel creating river braid
MUR27		Kambah Pool Stream width: 80m Landuse: Native Forest / Recreational Riparian Zone Width: 25m Native Vegetation: 50%	Moderate flow, sediment along edges highly pungent with anaerobic scent, possibly high decay of organics, iron bacteria present in patches, some rubbish along banks and in pockets of riffle zone, water murky, some new Phragmites sp. growth
MUR931		Fairvale, 4km U/S of the Cotter River confluence Stream width: 24m Landuse: Native Forest / Grazing / Residential / Commercial Riparian Zone Width: 22.5m Native Vegetation: 40%	Moderate flow, no aquatic vegetation present allowing considerable terrestrial species encroachment on banks, abundance of riffle habitat
MUR28		U/S Cotter River confluence Stream width: 35m Landuse: Ex-Forestry / Commercial / Industrial Riparian Zone Width: 12.5m Native Vegetation: 40%	Moderate flow, Cotter River confluence directly downstream of riffle site

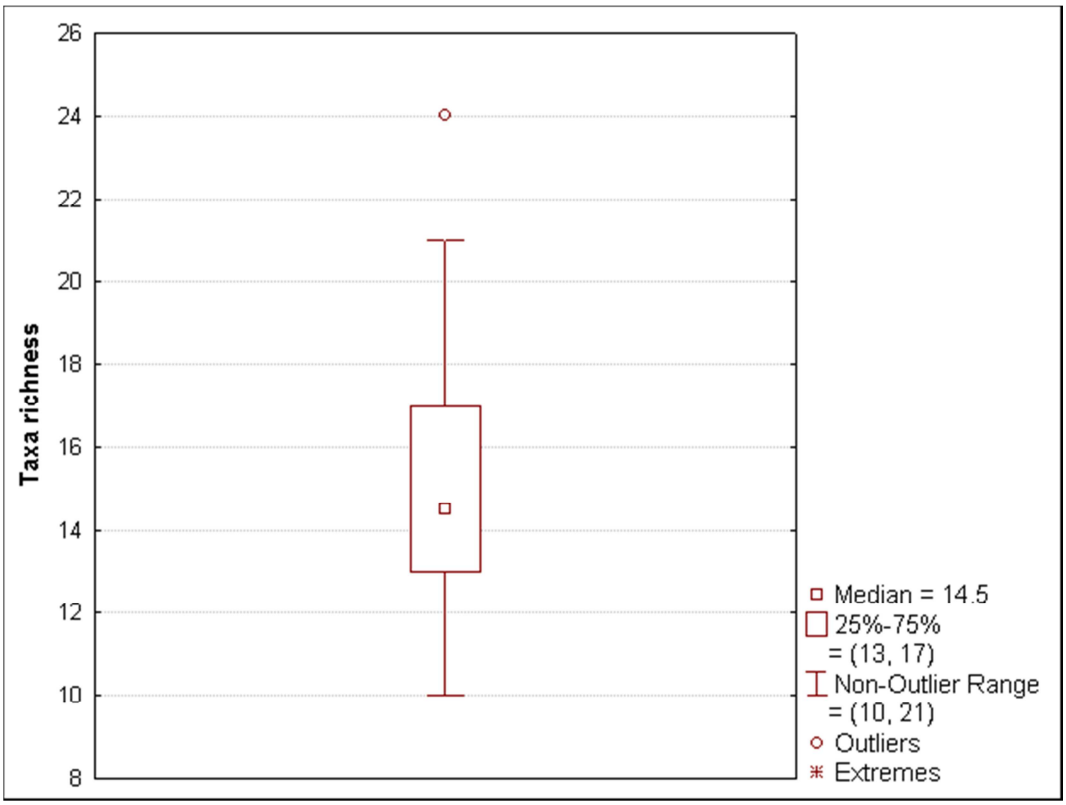
MUR935		Casuarina Sands Stream width: 32m Landuse: Ex-Forestry / Commercial / Recreational Riparian Zone Width: 17.5m Native Vegetation: 40% Point Source Pollution: Bridge	Moderate flow, chance of eroded sediment from steep hills on left hand bank entering river
MUR937		Mt. MacDonald, 5km D/S of the Cotter River confluence Stream width: 40m Landuse: Native Forest / Grazing / Commercial Riparian Zone Width: 30m % Native Vegetation: 35m Point Source Pollution: None	Moderate flow, iron bacteria on surface, large riffle area, very little edge habitat available to sample
MUR29		Uriarra Crossing Stream width: 45m Landuse: Grazing / Recreational Riparian Zone Width: 7.5m % Native Vegetation: 20m Point Source Pollution: Bridge	Moderate flow, water quality parameters measured at upstream riffle due to inundation of usual site by increased flow, extensive woody debris strewn across channel particularly directly downstream of the bridge, established vegetation on sand bars, carp present around edge habitat, very limited edge habitat with what is available in poor quality
MUR30		U/S Molonglo River confluence Stream width: 40m Landuse: Grazing / Recreational Riparian Zone Width: 30m % Native Vegetation: 50% Point Source Pollution: None	moderate flow, two fisherman at site catching carp, high level of weed infestation on banks, established vegetation on bar on the right hand bank

MUR31		D/S Molonglo River confluence Stream width: 49m Landuse: Native Forest / Grazing / Commercial Riparian Zone Width: 30m Native Vegetation: 10%	Moderate flow, surrounding steep hills with erosion evident, many upturned trees baring their roots to the flow increasing sediment entry to the river
MUR34		Halls Crossing Stream width: 16m Landuse: Grazing / Residential / Recreational Riparian Zone Width: 20m Native Vegetation: 50% Point Source Pollution: Potential from the bridge	Moderate flow, small areas of bank erosion, fish present at site, terrestrial plants encroaching on the river
MUR37		Boambolo Road Stream width: 12m Landuse: Grazing Riparian Zone Width: 16m Native Vegetation: 40% Point Source Pollution: None	Usual riffle inundated by water from Burrinjuck Reservoir, iron bacteria seepage present, previous height in dam has killed all macrophytes and has since reduced revealing large bare bars and banks, the saturation and weakening of banks from the higher water levels has caused large areas of bank erosion, fish present at site

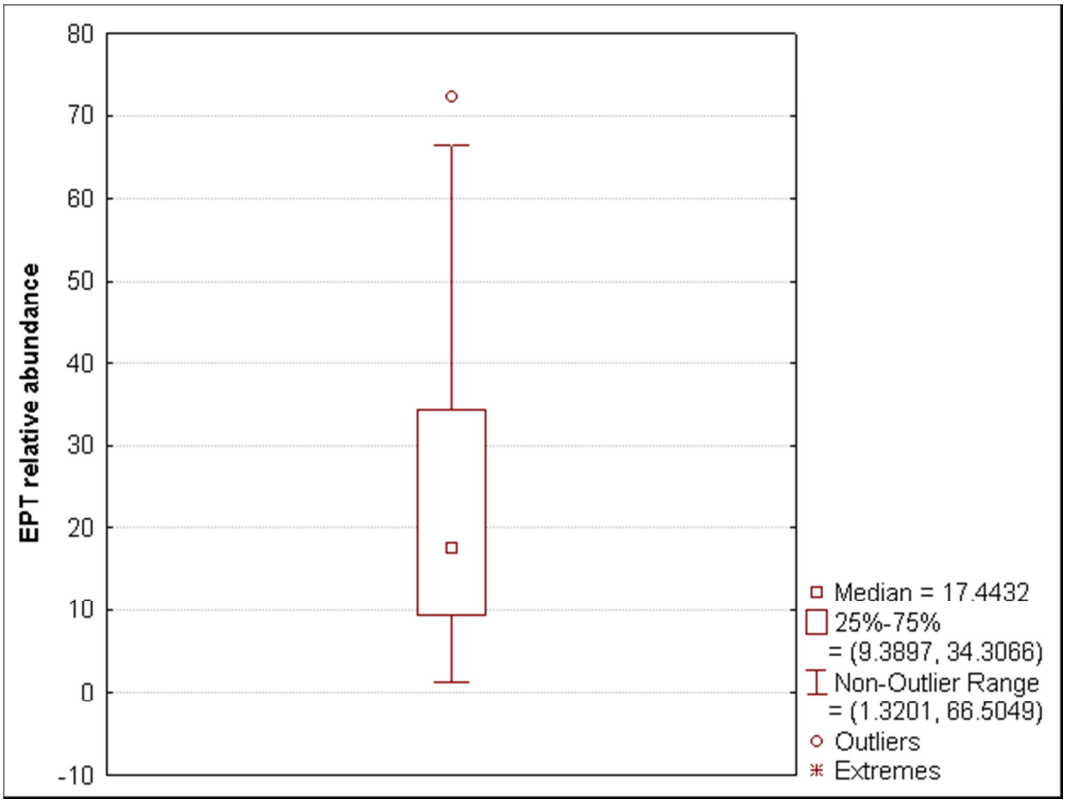
Appendix G -
Box and Whisker plots



Appendix G - Box and whisker plot of Total abundance indicating deviation from normal distribution



Appendic G (cntd.) - Box and whisker plot of Taxa richness indicating deviation from normal distribution



Appendic G (cntd.) - Box and whisker plot of EPT relative abundance indicating deviation from normal distribution

Appendix H -
Mann-Whitney output – Edge vs. Riffle

Appendix H - Mann-Whitney test between habitats. Highlighted p-values are significant at $p<0.05$

	Rank Sum	Rank Sum	U	Z	Valid N	*p*-value
Total abundance	379.00	702.00	103.00	-3.53704	23	**0.000243**
Taxa richness	542.50	538.50	262.50	0.03295	23	0.965299
EPT richness	459.50	621.50	183.50	-1.76852	23	0.074990
EPT relative abundance	423.00	658.00	147.00	-2.57039	23	**0.009222**
OCD relative abundance	418.00	663.00	142.00	-2.68024	23	**0.006511**
Av SIGNAL-2	313.00	768.00	37.00	-4.98700	23	**0.000000**

Appendix I -
Kruskal-Wallis output – between Zones

Combined Edge & Riffle

Kruskal-Wallis ANOVA by Ranks; Taxa richness Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 46) =19.45907 p =0.0002			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	8	314.5	39.31
2	12	329.5	27.46
3	20	354.0	17.70
4	6	83.0	13.83

Kruskal-Wallis ANOVA by Ranks; EPT richness Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 46) =12.25619 p =0.0066			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	8	281.5	35.19
2	12	319.5	26.63
3	20	404.5	20.23
4	6	75.5	12.58333

Kruskal-Wallis ANOVA by Ranks; O/E50 Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 46) =13.83685 p =0.0031			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	8	242.5	30.31
2	12	391.5	32.63
3	20	362.0	18.10
4	6	85.0	14.17

Edge data

Kruskal-Wallis ANOVA by Ranks; Total abundance Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =.6304348 p =0.8894			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	46.0	11.50
2	6	62.0	10.33
3	10	130.0	13.00
4	3	38.0	12.67

Kruskal-Wallis ANOVA by Ranks; EPT relative abundance Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =10.79130 p =0.0129			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	76.0	19.00
2	6	88.0	14.67
3	10	102.0	10.20
4	3	10.0	3.33

Kruskal-Wallis ANOVA by Ranks; OCD relative abundance Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =2.285870 p =0.5152			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	41	10
2	6	88	15
3	10	103	10
4	3	44	15

Kruskal-Wallis ANOVA by Ranks; Av SIGNAL 2 Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =7.258911 p =0.0641			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	75.0	18.75
2	6	59.0	9.83
3	10	125.0	12.50
4	3	17.0	5.67

Riffle data

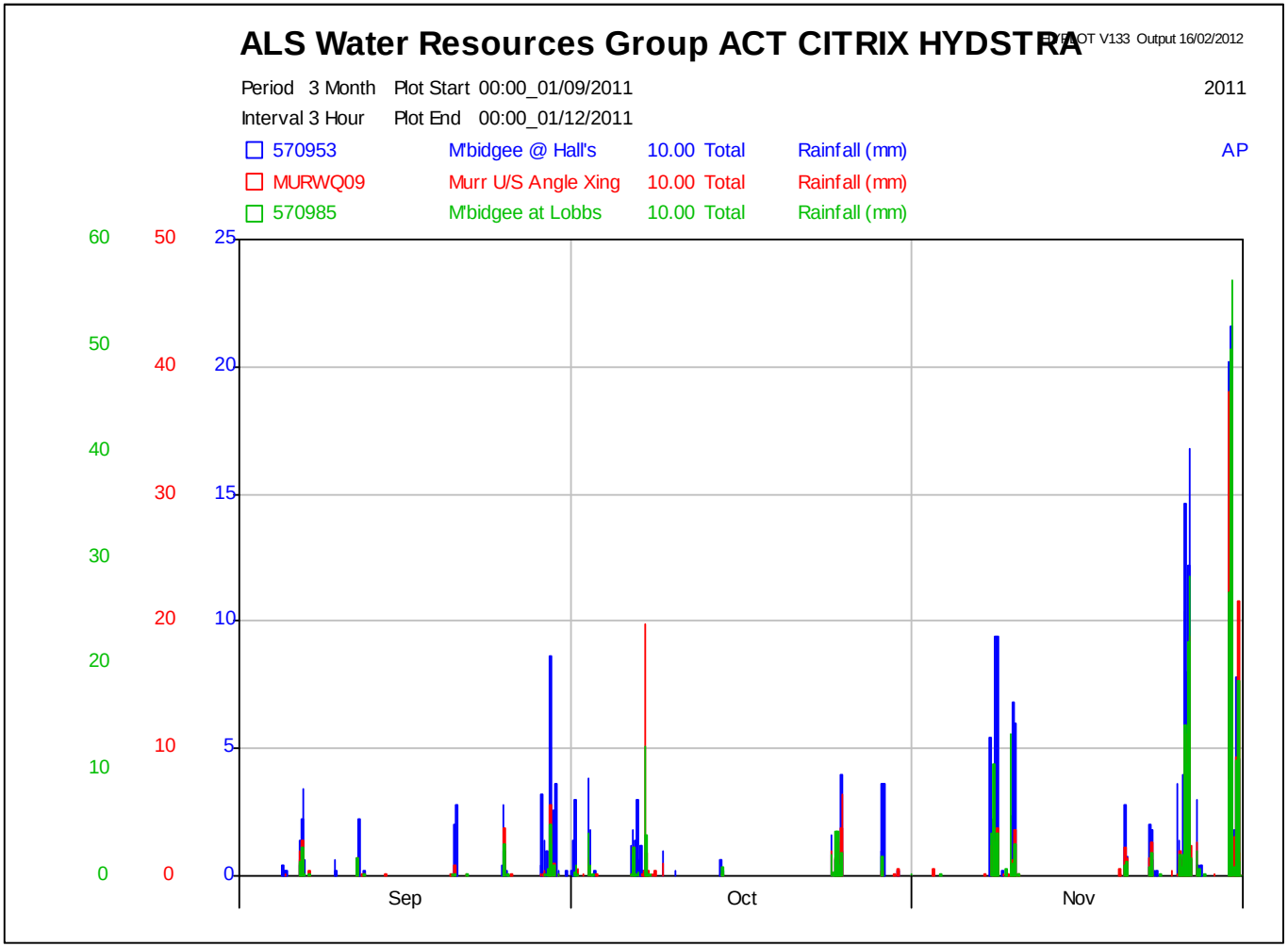
Kruskal-Wallis ANOVA by Ranks; Total abundance Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =5.374394 p =0.1463			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	28.0	7.00
2	6	56.0	9.33
3	10	151.0	15.10
4	3	41.0	13.67

Kruskal-Wallis ANOVA by Ranks; EPT relative abundance Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =11.65435 p =0.0087			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	76.0	19.00
2	6	97.0	16.17
3	10	86.0	8.60
4	3	17.0	5.67

Kruskal-Wallis ANOVA by Ranks; OCD relative abundance Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =12.78949 p =0.0051			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	15.0	3.75
2	6	52.0	8.67
3	10	152.0	15.20
4	3	57.0	19.00

Kruskal-Wallis ANOVA by Ranks; Av SIGNAL-2 Independent (grouping) variable: Zone Kruskal-Wallis test: H (3, N= 23) =2.415644 p =0.4907			
Zone	**Valid N**	**Sum of ranks**	**Mean rank**
1	4	62.0	15.50
2	6	82.0	13.67
3	10	103.0	10.30
4	3	29.0	9.67

Appendix J - Rainfall



Appendix J - Rainfall totals during the spring period at Halls Crossing (570953), upstream Angle Crossing (MURWQ09) and Lobb's Hole (570985)