CLIENTS | PEOPLE | PERFORMANCE

ACTEW Water

Murrumbidgee Ecological Monitoring Program

Part 1: Angle Crossing

Autumn 2012

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

Contents

Table Index

Figure Index

Plate Index

Appendix Index

List of Abbreviations

ACT – Australian Capital Territory

ACTEW – ACTEW Corporation Limited

AFDM – Ash Free Dry Mass (periphyton)

ALS – Australian Laboratory Services

ANOSIM – Analysis of similarities

ANOVA – Analysis of Variance (statistics)

ANZECC –Australian and New Zealand Environment and Conservation Council

APHA – American Public Health Association

ARMCANZ – Agriculture and Resource management Council of Australia and New Zealand

AUSRIVAS – Australian River Assessment System

BACI – Before After Control Impact

EC – Electrical Conductivity

EIS – Environmental Impact Statement

EPA – Environmental Protection Authority

EPT – Ephemeroptera, Plecoptera and Trichoptera taxa

GL/a – Gigalitres per annum

GPS – Global positioning system

M2G – Murrumbidgee to Googong

MEMP – Murrumbidgee Ecological Monitoring Program

ML/d – Megalitres per day

NATA – National Association of Testing Authorities

NMDS – Non-metric Multidimensional Scaling (statistics)

NSW – New South Wales

NTU – Nephlelometric Turbidity Units

PERMANOVA – PERMutational Multiple Analysis Of Variance

QA – Quality Assurance

QC – Quality Control

SIMPER – Similarity Percentages

TN – Total Nitrogen

TP – Total Phosphorus

Executive Summary

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

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

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

The key aims of this sampling run were to:

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

The key results from the autumn 2012 sampling of Angle Crossing show that:

1) At the beginning of the season in early March there were a number of large flow events down the Murrumbidgee River. The largest of these events peaked at 59,300 ML/d at the upstream Angle Crossing gauging station (41000270, previously known as MURWQ09) and 63,700 ML/d at the Lobb's Hole gauging station (410761) and represented a 1 in 8 year Average Recurrence Interval event (based on Lobb's Hole period of record data from 1974).

2) Most water quality parameters recorded at the upstream Angle Crossing site tended to be mirrored downstream at Lobb's Hole indicating that there was no detectable change to these parameters resulting from the M2G project. However, there were differences in dissolved oxygen levels between locations and this was a direct result of some large sand deposits in close proximity to the upstream Angle Crossing site. There are some ongoing issues with access to this site, but procedures are in place to rectify this and potentially move the site to a more suitable location which will not be impacted by sand movement resulting from high flow events;

3) The water quality grab sample results are consistent with previous sampling runs. The downstream gradient in electrical conductivity is weaker than in previous sampling runs and this is due to high baseflows at the time of sampling. pH tended to be outside the ANZECC and ARMCANZ (2000) guidelines but these values were only just in breach of the guidelines and were only a matter of 0.1 or 0.2 of a unit different from the upstream sites.

4) Nutrient concentrations exceeded the guideline values at all sampling locations. There was a decline in Nitrogen Oxides (NOx), Total Nitrogen (TN) and Total Phosphoros (TP) seen at MUR 23 and MUR 28 which correlated to increased Chlorophyll-a concentrations at those sites. These concentrations, while outside the ANZECC & ARMCANZ guidelines are still within the "natural" range of values recorded for this section of the Murrumbidgee River under high baseflow conditions. As flows decrease, nutrient levels should decrease;

5) AUSRIVAS results as well as the suite of univariate and multivariate analysis of the macroinvertebrate assemblages suggest a high degree of similarity between locations and amongst sampling sites. Edge and Riffle habitats were both assessed as Band B as were the overall sites assessments for this period. This combined with the comparability of taxonomic richness values to previous sampling periods suggest that despite being exposed to such a large event, recovery can be rapid although based on the estimated abundances, especially of the sensitive taxa (EPT), reaching pre-flood conditions may take longer.

The flooding event at the beginning of March has had an overriding influence upon all biological indicators being considered in this sampling run. Even though sampling occurred approximately eight weeks after the high flow event, the community composition had low abundances of sensitive EPT taxa, although taxonomic richness was comparable to previous sampling occasions indicating that although taxa are likely to be removed immediately following high flow disturbances, recolonisation of the number of taxa can occur reasonably quickly even though we can expect a delay in abundances reaching pre-flood levels. The upshot of this is that because taxonomic composition is similar to pre-flood levels, and because AUSRIVAS relies on this state (composition as opposed to abundances) the AUSRIVAS bands will provide similar assessments owing to this condition of the model.

Although there is a high degree of resistance and resilience amongst these sampling sites to various high flow disturbances, one of the key challenges now, in terms of the M2G project, is to use this to evaluate likely scenarios of biological changes under the 80:90 pumping rules. While we have data relating to high flow disturbances, situations under low flow conditions are less common. Currently the autumn 2009 sampling run is the only representation of macroinvertebrate communities in the Murrumbidgee River when base flows were under 100 ML/d.

1. Introduction

The Murrumbidgee Ecological Monitoring Program (MEMP) was set up by ACTEW Corporation to evaluate the potential impacts of water abstraction from the Murrumbidgee River.

The current time-line for the MEMP sampling covers autumn and spring sampling that commenced in spring 2008 and is current to autumn 2012.

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

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

This report focuses on Part 1: Angle Crossing, specifically the results from the autumn 2012 sampling round.

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

The system has been designed to pump up to 100 ML/d and was completed in August 2012 with commissioning in September 2012. Future water abstraction from the Angle Crossing pump station will be dictated by the Googong Reservoir's storage level, the availability of water in the Murrumbidgee River, and on EPA water quality trigger levels. The environmental flow rules for the Murrumbidgee to Googong project (M2G) have been adopted from the framework outlined in the Environmental Flow Guidelines (ACT Government, 2011). Under these flow rules, Murrumbidgee flows must be protected at the 80th percentile flow between November and May and the 90th percentile between June and October (Table 1).

Table 1. Current 80th and 90th percentile flows for Murrumbidgee River at Angle Crossing

These values are based on the period of record data (1974-2012) from Lobb's Hole gauging station (410761) and are current for flows to 31 May 2012. All values are expressed in ML/d.

Jan*.	Feb*.	Mar*.	Apr*.	May*.	Jun†.	Jul†.	Aug†.	Sep†.	Oct†.	Nov*.	Dec*.
31.3	23.6	17.2	34.6	50.0	63.6	77.0	104.3	174.8	131.9	144.0	56.3

** 80th percentile flow† 90th percentile flow*

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

1.1 Background

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

Land-use varies from National Park in the high country to agriculture and farming in the valley regions. Land use is dominated by urbanisation between Point Hut Crossing and the North Western suburbs of Canberra near the confluence with the Molonglo River. The major contributing urbanised tributary flowing into the Murrumbidgee River is Tuggeranong Creek which enters the Murrumbidgee River downstream of Point Hut Crossing.

Annual rainfall in the Upper Murrumbidgee River catchment ranges from greater than 1400 mm in the mountains, to 620 mm at Canberra, down to 300 mm in the west (B.O.M, 2012).

Prior to spring 2010, drought was the most significant impact on catchment quality within the upper Murrumbidgee catchments in recent times. During this period, more than 80% of catchments had been drought-affected since late 2002. Some of the effects of this were drought-induced land degradation increased stress on surface and groundwater resources, increased soil erosion and a shift from mixed farming and cropping, to grazing and reduced stock numbers. Since the spring of 2010, the drought broke in the ACT and surrounding NSW regions, with more frequent high flow events occurring throughout that year and an upward trend in the monthly average base flows (Figure 1).

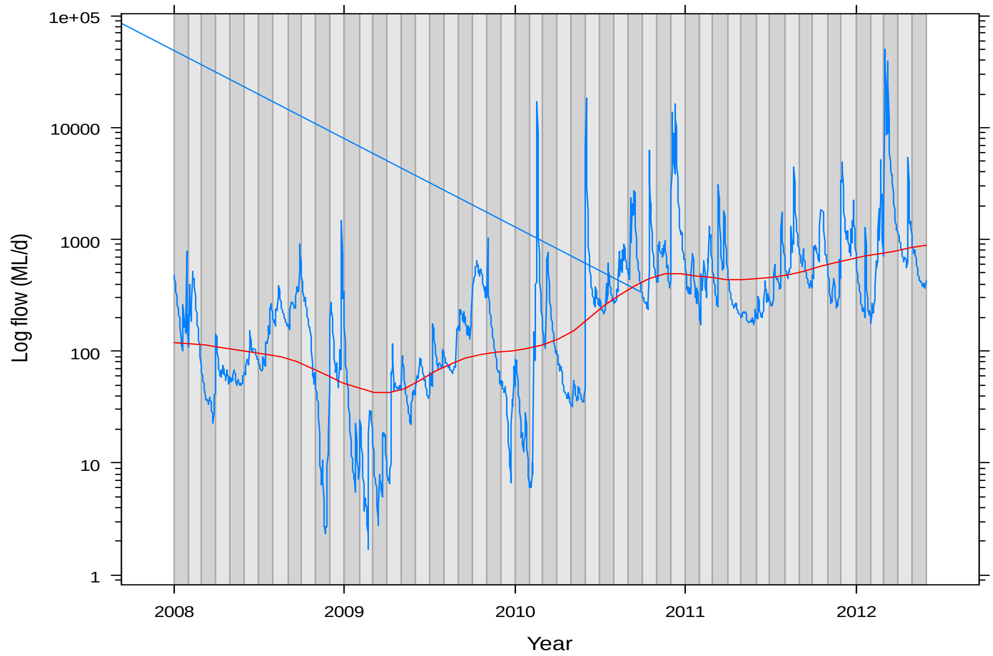


Figure 1. Hydrograph of the Murrumbidgee River at Lobb's Hole (410761) from 2008 to 31 May 2012

1.2 Project Objectives

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

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

The specific aims of this monitoring program are:

1. To determine seasonal and annual variation in water quality parameters at control and test sites before water abstractions commence, and to assist in the monitoring of water quality in the commissioning and post commissioning phases of the M2G project:
2. To determine seasonal and annual variation in periphyton communities at control and test sites before water abstractions commence, and to assist in the monitoring of river ecosystem health once the abstractions begin;
3. To determine baseline macroinvertebrate communities at test and control sites before the water abstractions commence, and to assist in the monitoring of riverine ecosystem health once the abstractions begin.

Table 2. Project objectives and estimated time frames

	Key objectives	Time frame	Outcomes
Phase 1	Obtain baseline information to include: hydrological, biological and physico-chemical water quality information. Establish spatial and temporal trends up and downstream of the existing low-level crossing that is Angle Crossing.	2009-2012	Help establish flow rules for the operation of the pump station in the M2G project. Establish biological signatures and inventories as references for changes over time.
Phase 2	Monitor the ecological responses related specifically to water abstractions from Angle Crossing to Burra Creek via the M2G pipeline	Spring 2012-	Assist in minimising ecological impacts by using baseline and indicator taxa information in relation to proposed flow rules.

1.3 Project Scope

The current ecological health of the sites monitored as part of the Murrumbidgee to Googong (M2G) monitoring program was estimated using AUSRIVAS protocols for macroinvertebrate community data, combined with a suite of commonly used biological metrics and descriptors of community composition. The scope of this report is to convey the results from the autumn 2012 sampling. Specifically, as outlined in the MEMP proposal to ACTEW Corporation (GHD, 2012) this work includes:

- Sampling conducted in autumn 2012;
- Macroinvertebrate communities collected from riffle and edge habitats using AUSRIVAS protocols;
- Macroinvertebrate samples counted and identified to the taxonomic level of genus;
- Riffle and edge samples assessed through the appropriate AUSRIVAS model;
- *In-situ* water quality measurements collected and samples analysed for nutrients in the Australian Laboratory Services (ALS) Canberra NATA accredited laboratory.

1.4 Rationale for using biological indicators

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

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

Changes in total periphyton biomass and/or the live component of the periphyton (as determined by chlorophyll-a) can vary with changes in flow volume, so these variables are often used as indicators of river condition in relation to monitoring the effects of flow regulation, environmental flow releases or water abstraction impacts (Whitton and Kelly, 1995).

Water abstractions from Angle Crossing will not affect the timing or magnitude of higher flows, but could affect conditions during the seasonal low flow period, such as increasing the nutrient availability through increased residence time, reducing scouring impacts on benthic organism and reducing surface flows over riffle habitats and thus decreasing habitat quality and availability. As changes in flow volume are expected with the proposed changes in the Murrumbidgee River water abstraction regime, periphyton biomass and chlorophyll-a are included as biological indices.

2. Materials and Methods

2.1 Study Sites

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

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

Sites were chosen based on several criteria, which included:

- Safe access and approval from land owners;
- Sites have representative habitats (i.e. riffle / pool sequences). If both habitats were not present then riffle zones took priority as they are the most likely to be affected by abstractions;
- Sites which have historical ecological data sets (eg. Keen, 2001) took precedence over new sites –allowing comparisons through time to help assess natural variability through the system. This is especially important in this program because there is less emphasis on the reference condition, and more on comparisons between and among sites of similar characteristics in the ACT and surrounds over time.

Potential sites were identified initially from topographic maps, they were visited prior to sampling and their suitability was subsequently considered. Six sites suiting the criteria mentioned above are given in Table 3, and shown in Figure 2 and Plates 1 & 2. These sites include three sites upstream of Angle Crossing (in NSW) and three sites downstream (all in the ACT).

Table 3. Sampling site locations and details

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

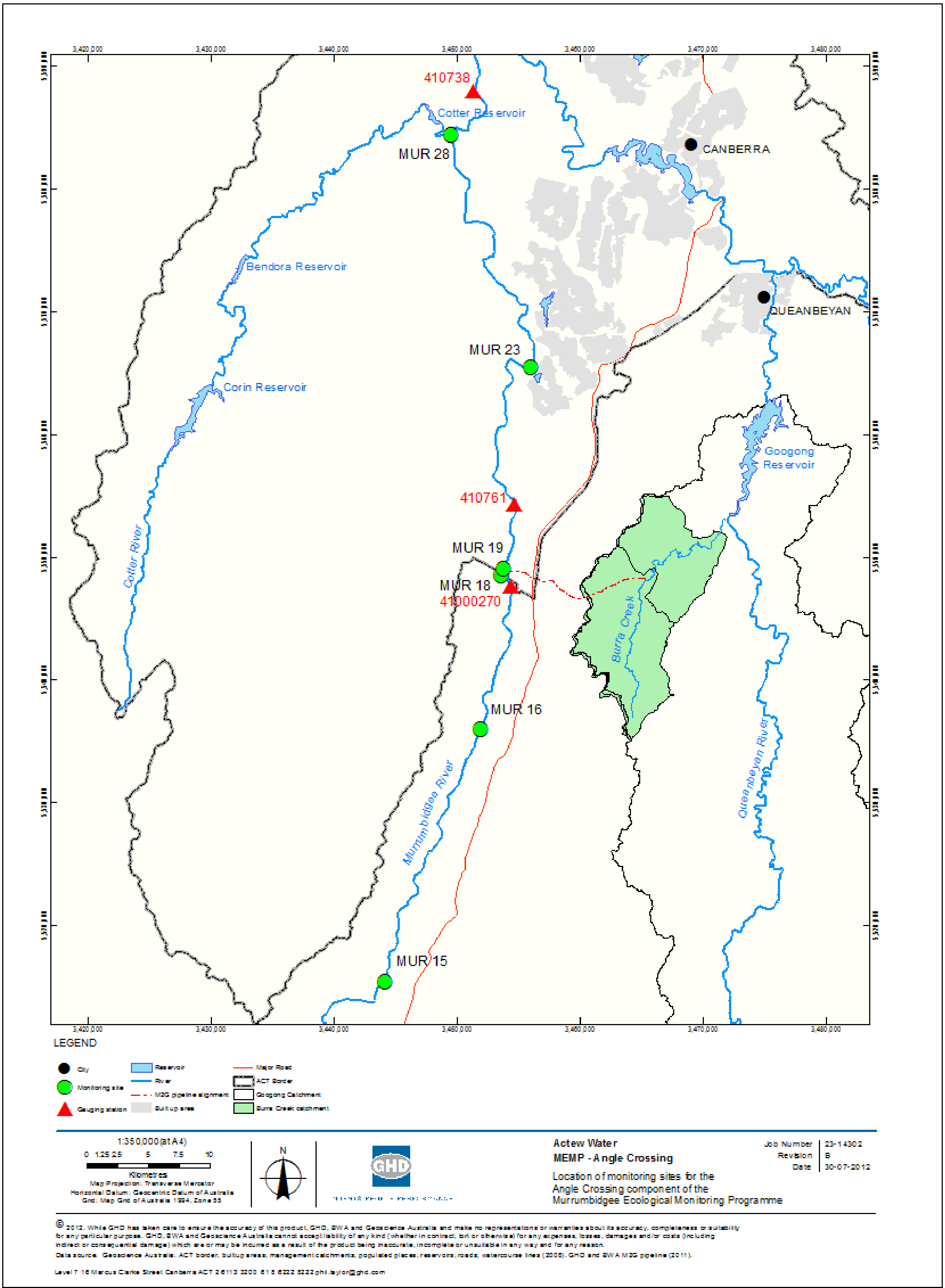


Figure 2. Angle Crossing sampling locations and gauging station

MUR 15 Looking upstream from sandbar

MUR 15 Looking upstream from riffle to sandbar

MUR 16 Looking upstream

MUR 16 Looking downstream

MUR 18 Looking upstream

MUR 18 Looking downstream

Plate 1. Photos of sampling sites upstream of Angle Crossing

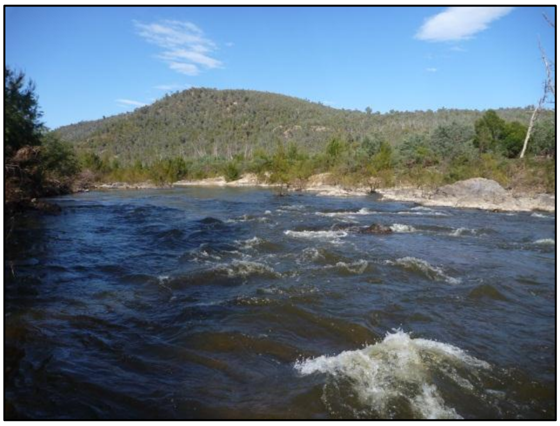
MUR 19 Looking across at the construction

MUR 19 Looking downstream

MUR 23 Looking downstream from the bridge

MUR 23 Looking upstream from the bridge

MUR 28 Looking downstream towards Cotter Rd



MUR 28 Looking upstream

Plate 2. Photos of sampling sites downstream of Angle Crossing

2.2 Hydrology and Rainfall

River flows and rainfall for the sampling period were recorded at gauging stations located at Lobb's Hole (downstream of Angle Crossing: 410761) and upstream of Angle Crossing (41000270, formerly MURWQ09). Site codes and locations are shown in Table 4 and Figure 2.

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

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

Site Code	Location/Notes	Parameters*	Latitude	Longitude
410761	M'bidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.5398	E 149.1015
41000270	M'bidgee River U/S Angle Crossing	WL, Q, pH, EC, DO, Temp, Turb, Rainfall	S 35.3533	E 149.0705

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

2.3 Water Quality

Baseline physico-chemical parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded using a multiprobe Hydrolab® minisonde 5a at sites indicated in Table 3. The Hydrolab® was calibrated following QA procedures and the manufactures requirements prior to sampling. Additionally, grab samples were taken from each site in accordance with the AUSRIVAS protocols (Coysh *et al*., 2000) for Hydrolab verification and nutrient analysis. All samples were placed on ice, returned to the ALS Canberra laboratory, and analysed for nitrogen oxides (total NOx), total nitrogen and phosphorus in accordance with the protocols outlined in APHA (2005). Collectively, this information on the water quality parameters was used to assist in the interpretation of biological data and provide a basis on which to gauge ecosystem changes potentially linked to flow reductions at these key sites following water abstractions.

2.4 Periphyton

Estimates of algal biomass were made using complementary data from both chlorophyll-a (which measures autotrophic biomass) and ash free dry mass (AFDM) which estimates the total organic matter in periphyton samples and includes the biomass of bacteria, fungi, small fauna and detritus in samples) of the periphyton samples (Biggs, 2000). The six sites shown in Table 3 were sampled for periphyton in autumn in conjunction with the macroinvertebrate sampling. All periphyton - adnate and loose forms of periphyton, as well as organic/inorganic detritus in the periphyton matrix, were collected using the in-situ syringe method similar to Loeb (1981) as described in Biggs and Kilroy (2000) (Plate 3 & 4). A 1m wide transect was established across riffles at each site. Along each transect, twelve samples were collected at regular intervals, using a syringe sampling device, based on two 60 ml syringes and a scrubbing surface of stiff nylon bristles, covering an area of ~637 mm^2. The samples were then divided randomly into two groups of six samples to be analysed for Ash Free Dry Mass (AFDM gm^{-2}), and chlorophyll-a. Samples for AFDM (gm^{-2}) and chlorophyll-a analysis were filtered onto glass filters and frozen. Sample processing follows the methods outlined in APHA (2005).

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

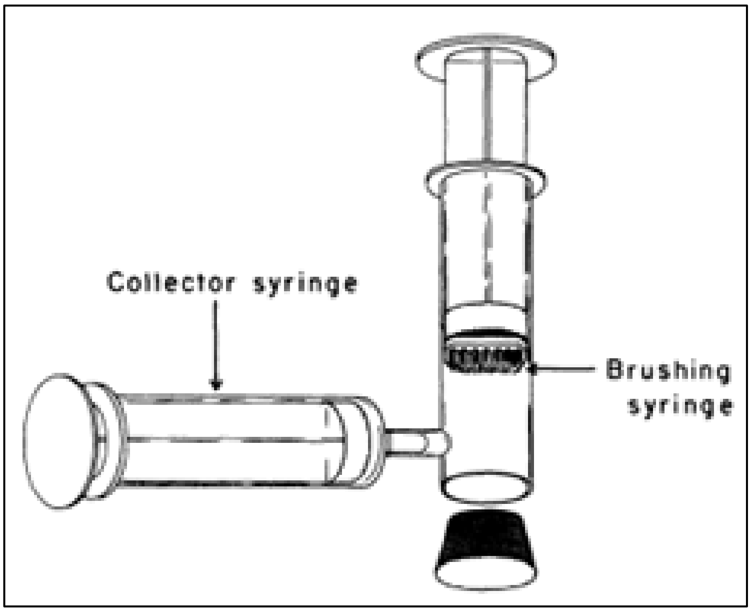


Plate 3. Diagram of the periphyton sampler (taken from Loeb, 1981)

Plate 4. Periphyton sampler being used in the field

2.5 Macroinvertebrate sampling and processing

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

Riffle and edge habitats were sampled for macroinvertebrates and analysed in strict accordance with the ACT Autumn riffle and edge AUSRIVAS (Australian River Assessment System) protocols (Coysh, Nichols, Ransom, Simpson, Norris, Barmuta and Chessman, 2000)(Coysh et al., 2000) during Autumn (1^{st} – 9^{th} May) 2012. At each site, two samples were taken (where possible) from the riffle habitat (flowing broken water over gravel, pebble, cobble or boulder, with a depth greater than 10 cm; (Nichols, Sloane, Coysh, Williams and Norris, 2000)(Nichols et al., 2000) using a framed net (350 mm wide) with 250 µm mesh size. Sampling began at the downstream end of each riffle. The net was held perpendicular to the substrate with the opening facing upstream. The stream directly upstream of the net opening was disturbed by vigorously kicking and agitating the stream bed, allowing any dislodged material to be carried into the net. The process continued, working upstream over 10 metres of riffle habitat. The samples were then preserved in the field using 70% ethanol, clearly labelled with site codes and date then stored on ice and refrigerated until laboratory sorting commenced.

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

Processing of the macroinvertebrate samples followed the ACT AUSRIVAS protocols. Briefly, in the laboratory, the preserved macroinvertebrate samples were placed in a sub-sampler, comprising of 100 (10 X 10) cells (Marchant, 1989). The sub-sampler was then agitated to evenly distribute the sample. The contents of randomly selected cells were removed and the macroinvertebrates within each cell were identified to genus level except for Chironomids (sub-family) and Oligochaeta (class). Specimens that could not be identified to the specified taxonomic level (i.e. immature or damaged taxa) were removed from the data-set prior to analysis. For the AUSRIVAS model, taxa were analysed at family level except for: Chironomidae (sub-family), Oligochaeta (class) and Acarina (order) until 200 animals were identified identification followed taxonomic keys published by Hawking (2000) (Hawking, 2000). If 200 animals were identified before a cell had been completely analysed, identification continued until the animals in the entire cell were identified. Data were entered directly into electronic spread sheets to eliminate errors associated with manual data transfer.

2.6 Macroinvertebrate quality control procedures

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

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

All procedures were performed by AUSRIVAS accredited staff.

2.7 Licence 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)).

GHD field staff maintain current ACT and NSW AUSRIVAS accreditation.

2.8 Data analysis

2.8.1 Water quality

Water quality parameters were examined for compliance with ANZECC water guidelines for healthy ecosystems in upland streams (ANZECC and ARMCANZ, 2000). This report presents results based on autumn 2012 sampling.

2.8.2 Periphyton

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

2.8.3 Macroinvertebrate Communities

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

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

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

All multivariate analyses were performed using PRIMER version 6 (Clarke and Gorley, 2006) and PERMANOVA+ (Anderson et al., 2008). Univariate statistics were performed using R version 2.15.1 (R Development Core Team, 2012).

2.8.4 AUSRIVAS Assessment

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

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

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

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

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

We conducted linear mixed effect ANOVA models separately for the riffle and edge samples to test for location differences in the univariate metrics: SIGNAL-2 scores and AUSRIVAS O/E 50 ratios. The factor, “site” (nested within location) was considered a random effect representing the river condition upstream and downstream of the proposed abstraction point; while location (up- and downstream) was considered a fixed, constant effect. Data transformations were not necessary because the model assumptions were met on all accounts. Models were constructed using lme4 (Bates et al., 2011) a statistical package applied in the R environment (R Development Core Team, 2011). For all analyses, the level of significance (alpha) was set to 5%.

Several metrics in addition to AUSRIVAS and SIGNAL-2 were used. The number of taxa (taxa richness) was counted for each site and other descriptive metrics such as the relative abundances of pollution-sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera - EPT) and, pollution-tolerant taxa, (i.e.

Oligochaeta and Chironomids) were examined at family and genus levels. Taxa richness was monitored as a means of assessing macroinvertebrate diversity. In assessing the taxonomic richness of a site, it is important to keep in mind that high taxa richness scores may, though does not always, indicate better ecological condition at a given location. In certain instances high taxa richness may indicate a response to the provision of new habitat or food resources that might not naturally occur as a result of anthropogenic activities.

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

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

3. Results

3.1 Summary of sampling conditions

The six monitoring sites were sampled on the 1st, 2nd and 9th of May[1]. Conditions were variable, with fine spells turning to persistent rain at times. Temperature ranged from 13°C to 21°C during this period. Murrumbidgee River flow was consistently dropping for the sampling period, with a small increase resulting from the rainfall event that occurred on the 2nd May while we were sampling MUR 19. The number of samples collected at each site is shown in Table 6. Plate 5 shows the Bendora Scour valve, located at MUR 28 in operation prior to sampling.

Plate 5. Bendora Main Scour during the first week of May

Table 6. Macroinvertebrate samples collected during the autumn sampling run

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

[1] There was a delay in sampling MUR 28 as the Bendora Scour valve was operational up until the 9th of May. Safe sampling is not possible during its operation.

3.2 Field Observations

All sites showed evidence of the high flow event during March with large levels of depositional material (mainly sand) found at the sites. There were also some distinct areas of scour such as the car park area at MUR 23, and areas of dead macrophytes and grasses along the edges of the channels due to the inundation. MUR 15 was sampled directly upstream of the usual riffle section due to safety issues arising from increased river depth in accessing the original site. This was due to impacts from the high flow events since the spring 2011 sampling run. The original site will be re-assessed for ongoing use during the spring 2012 sampling run. The construction works at Angle Crossing were progressing with the deconstruction of the coffer dam around the intake structure during our site visit to MUR 18 and MUR 19. Quick reference site summaries can be found in Appendix B.

3.3 Hydrology and Rainfall

At the beginning of the season in early March there were a number of large flow events down the Murrumbidgee River. The largest of these events peaked at 59,300 ML/d at the upstream Angle Crossing gauging station (41000270) and 63,700 ML/d at the Lobb's Hole gauging station (410761). Separate to this period was another small event during mid-April, which corresponded to a few short intense rainfall periods.

The flow conditions while sampling was completed were stable, with little rain recorded for this period of May. The hydrograph is presented in Figure 3 showing flow and rainfall at upstream Angle Crossing and Lobb's Hole for the autumn period. Summaries of the monthly flow and rainfall can be found in Table 7. The hydrograph for Point Hut Pond which is located at MUR 23 can be found in Appendix C.

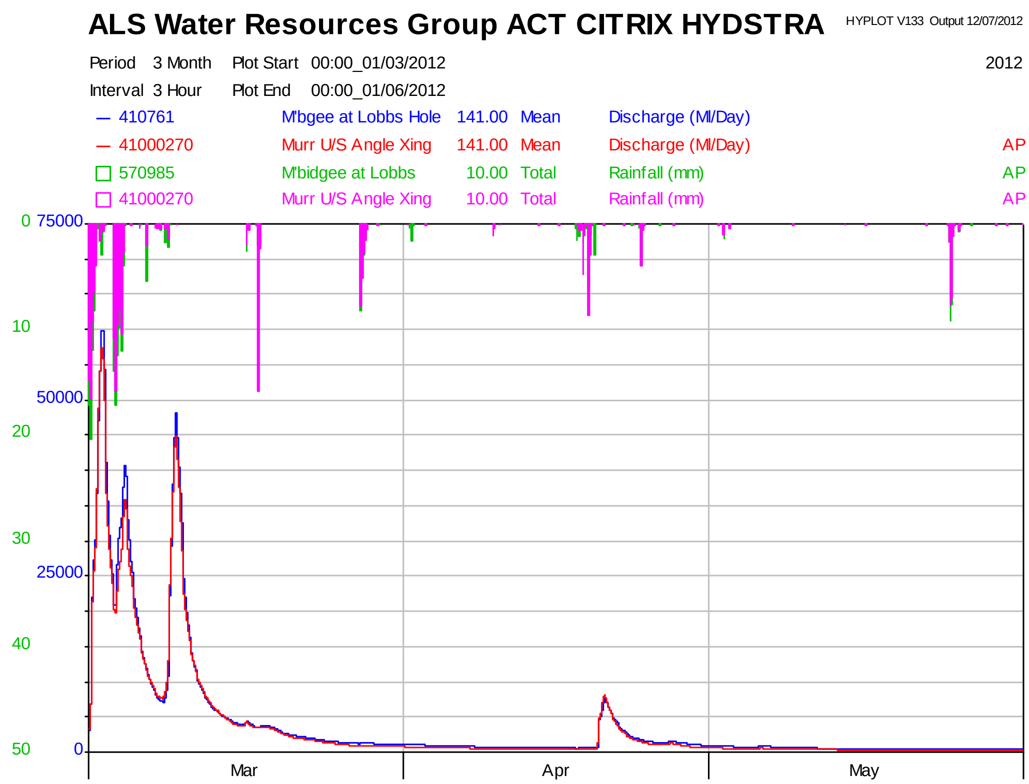


Figure 3. Autumn hydrograph of the Murrumbidgee River upstream of Angle Crossing (41000270) and downstream of Angle Crossing at Lobb's Hole (410761)

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

Site	Upstream Angle Crossing (41000270)		Lobb's Hole (410761)	
	Rainfall Total (mm)	Mean Flow (ML/d)	Rainfall Total (mm)	Mean Flow (ML/d)
March	204.2	10,400	187.0	9,810
April	24.2	1,330	29.4	1,100
May	22.8	527	22.2	367
Autumn (mean monthly)	251.2 (83.7)	4,086	238.6 (79.5)	3,759

3.4 Water Quality

3.4.1 Continuous

The pH sensor at Lobb's Hole (410761) was not-operational in March due to lightening damage from a previous electrical storm.

Comparisons of the available parameters show no indication of a location difference driven by the M2G project (Figures 4 and 5; Table 8). The logged parameters responded similarly to the high flow events of early March and mid-April; and these were the periods of lower compliance with the ANZECC and ARMCANZ (2000) guidelines ((Table 9). For example, during March and April turbidity was outside the guidelines up to 65% of the time due to high flows over this period. There were differences in the dissolved oxygen (% saturation) levels between locations and this is attributed to the March event rather than M2G because the issue was related to the upstream Angle Crossing site (41000270). Heavy silt deposits occurred adjacent to that site, which resulted in problems in the data time series at the beginning of March.

Table 8. Monthly water quality statistics from upstream (41000270) and downstream (410761) of Angle Crossing

All values are means, except dissolved oxygen (% saturation) which is expressed as mean monthly minimums and maximums. Maximum values for turbidity are in parentheses. **ANZECC guidelines are in red parentheses.**

Analyte	**Temp. °C**		**EC (uS/cm) (30-350)**		**pH (6.5-8.0)**		**Turbidity (NTU) (2-25)**		**D.O. (% sat.) (90-110)**	
	U/S	D/S	U/S	D/S	U/S	D/S[1]	U/S	D/S	U/S	D/S[2]
March	17.5	17.5	88.5	157.3	7.78	-	87.5 (919)	88.0 (1009.2)	77.9-98.6	86.3 - 96.5
April	15.6	15.8	112.8	175.1	7.61	7.96	16 (106)	8.9 (52.1)	84.5-97.3	91.3 – 96.9
May	9.7	9.8	140	184.5	7.68	8.03	10 (28)	4.25 (8.19)	95-8-100.2	93.5 – 99.3
Autumn	14.2	14.4	113.7	172.3	7.69	8.00	37	34	77.9-100.2	86.3 – 99.3

U/S –upstream; D/S – downstream [1]*does not include 2 days in April* [2]*does not include 4 days in April*

Table 9. Compliance (%) to ANZECC and ARMCANZ (2000) guideline values from the continuous gauging stations upstream (41000270) and downstream (410761) of Angle Crossing

Compliance values are expressed as the percentage of days throughout the autumn period (based on daily means) that values met the guidelines

Analyte	**EC (us/cm)**		**pH**		**Turbidity (NTU)**		**D.O. (% sat.)**	
	U/S	D/S	U/S	D/S[1]	U/S	D/S	U/S	D/S
March	100	100	91	-	35	38.7	32	96.7
April	100	100	100	39.3	86	93.3	90	100
May	100	100	100	12.9	100	100	100	100
Autumn	100	100	97	26.1	74	77	74	98.9

Note: There are currently no guidelines for water temperature [1]*does not include 2 days in April*

Table 8 shows the monthly water quality summaries for both the upstream Angle Crossing and Lobb's Hole monitoring stations. The monthly summaries at Lobb's Hole indicate a minimal number of exceedances across all monitored parameters, with the largest guideline breaches for pH and turbidity.

Table 9 indicates the percentage of daily means which are compliant with the ANZECC & ARMCANZ (2000) guidelines. Lobb's Hole has high compliance levels of > 98% for both electrical conductivity and dissolved oxygen (% saturation). However, compliance rates are reduced for turbidity with an average of 77.35%, mostly due to the event during March, while the pH compliance rate is the poorest with an average of 26.10%.

3.4.2 Grab samples & *in-situ* parameters

The results from the grab samples and in-situ water quality probes are presented in Table 10. Temperature ranged from 10.2°C at MUR 28 to 12.6°C at MUR 18. All electrical conductivity (EC and turbidity readings were within the ANZECC & ARMCANZ (2000) guidelines, while a single dissolved oxygen (DO) reading at MUR 15 was on the cusp. The pH readings indicated that all sites downstream of the construction at Angle Crossing were just above the guidelines upper limit.

Nutrient concentrations exceeded the upper limits of the guidelines at all sampling sites (Table 10), whilst total NOx recorded at MUR 28 was the only parameter to be within the recommended guidelines. These results are within the range of values that have been seen for the duration of the project and are highly comparable to the previous autumn sampling run. Total Nitrogen concentrations were almost twice as high as the previous autumn sampling run and this is this is most likely to be a function of higher base flows and more run-off throughout the catchment compared to autumn 2011.

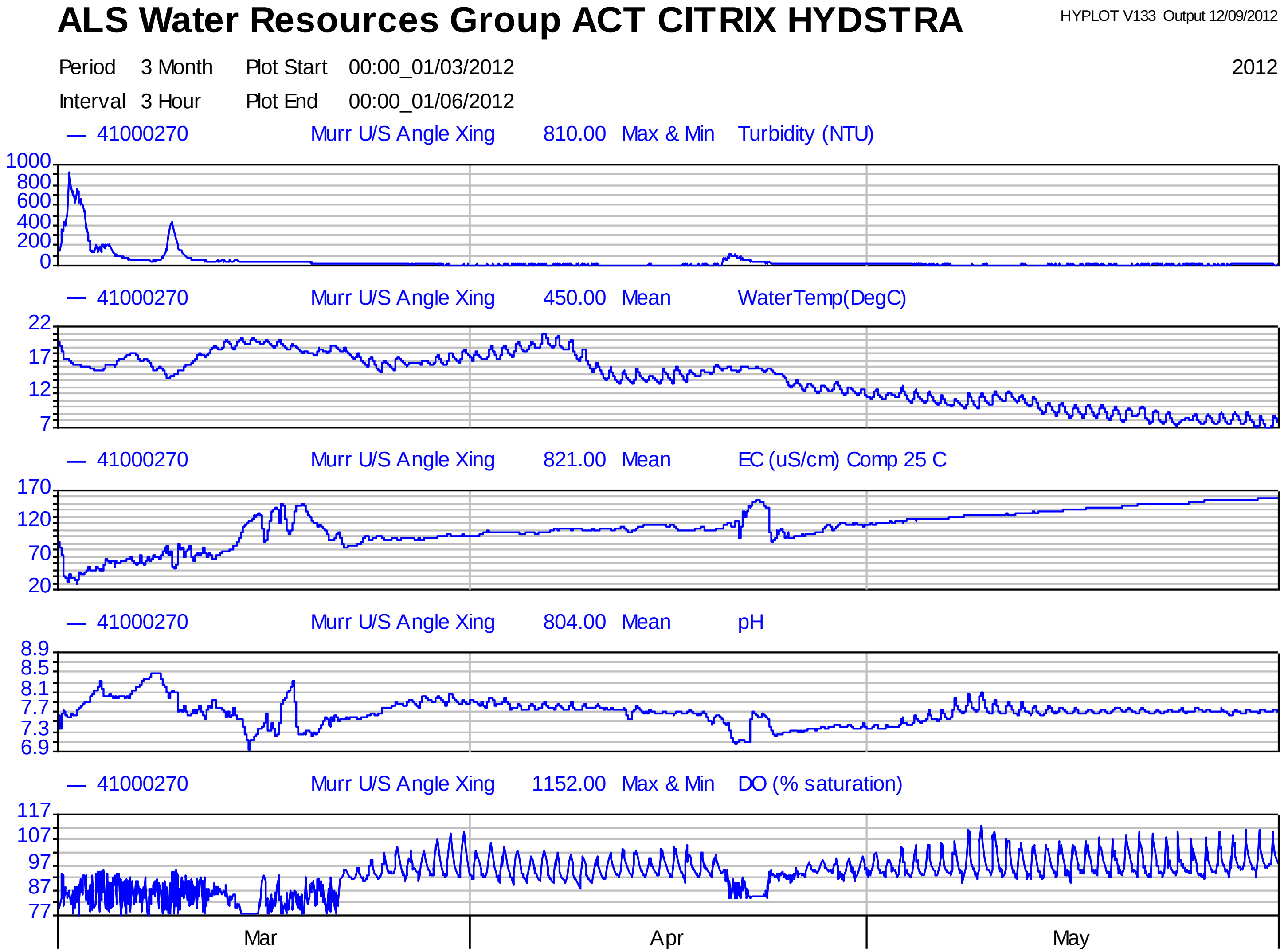


Figure 4. Continuous water quality records from upstream Angle Crossing (41000270) for autumn 2012

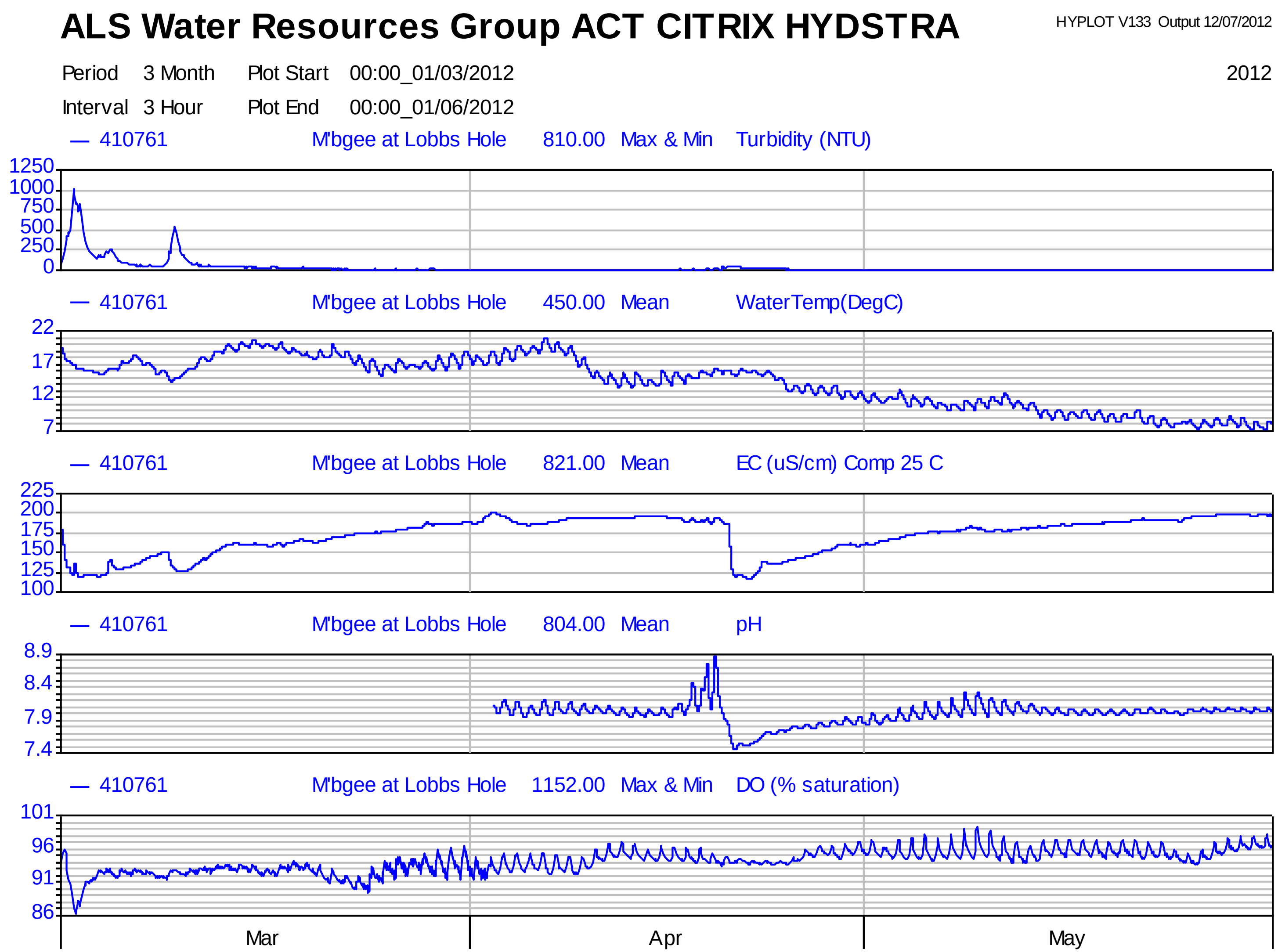


Figure 5. Continuous water quality records from upstream Angle Crossing (41000270) during autumn 2012

Table 10. In-situ water quality results from autumn 2012

ANZECC guidelines are in red parentheses, yellow cells indicate values outside of ANZECC and ARMCANZ (2000) guidelines, light orange cells indicate values which are on the cusp of the guideline

	Site	Date	Time	Temp. (°C)	EC (µs/cm (30-350)	Turbidity(NTU) (2-25)	TSS mg/L	pH (6.5-8)	D.O. (% Sat.) (90-110)	D.O. (mg/L)	Alkalinity (mg/L)	NOX (mg/L)(0.015)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L) (0.02)	TN (mg/L) (0.25)
Upstream	MUR 15	1/5/12	10.00	11.7	160	8.4	7	7.8	110.0	11.4	60	0.068	0.066	<0.002	0.011	0.041	0.50
	MUR 16	1/5/12	13.00	12.0	160	8.0	5	7.9	102.6	10.3	60	0.064	0.062	<0.002	0.008	0.037	0.49
	MUR 18	1/5/12	15.10	12.6	150	8.5	6	7.9	101.0	11.1	59	0.061	0.059	<0.002	0.009	0.037	0.49
Downstream	MUR 19	2/5/12	10.30	11.5	160	7.9	6	8.1	102.1	11.4	60	0.061	0.059	<0.002	0.007	0.036	0.48
	MUR 23	2/5/12	12.15	11.4	150	9.9	7	8.0	99.5	9.9	58	0.046	0.044	<0.002	0.004	0.034	0.44
	MUR 28	9/5/12	10.00	10.2	160	4.3	3	8.1	105.7	11.0	64	0.004	0.002	<0.002	0.005	0.022	0.33

3.5 Periphyton

The periphyton analysis for autumn 2012 shows no difference in chlorophyll-a concentrations between sampling locations ($F_{1,35}$ =1.65; *P*=0.26; Table 11). Average concentrations were highest downstream of Angle Crossing (9686 ug/m^{-2}) compared to upstream (4996 ug/m^{-2}). Chlorophyll-a was lowest at MUR 18 (95 ug/m^{-2}) (Figure 6) and supports our field observations that the substrate at MUR 18 was relatively clean compared to the other sampling sites. The highest concentrations were seen at MUR 23 (max value = 25 500 ug/m^{-2}) and are typical for this site.

Compared to the chlorophyll-a data extracted from the periphyton communities in spring, the autumn 2012 data shows no distinct longitudinal pattern, although the elevated concentrations downstream of and including MUR 23 are consistent with our previous findings.

The distribution of AFDM was somewhat consistent across sampling sites (Figure 7) showing no difference between the upstream and downstream locations ($F_{1,35}$ =2.77; *P*=0.17; Table 11) and generally less site to site variation as indicated by the non-significant random effects test.

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

Response	Source	DF	F-value	P-value
Chlorophyll-*a* (log)	Location	1	1.65	0.26
	Site [Location]	4	7.94	<0.001
	Residual	35		
AFDM (log)	Location	1	2.77	0.17
	Site [Location]	4	1.65	0.18
	Residual	35		

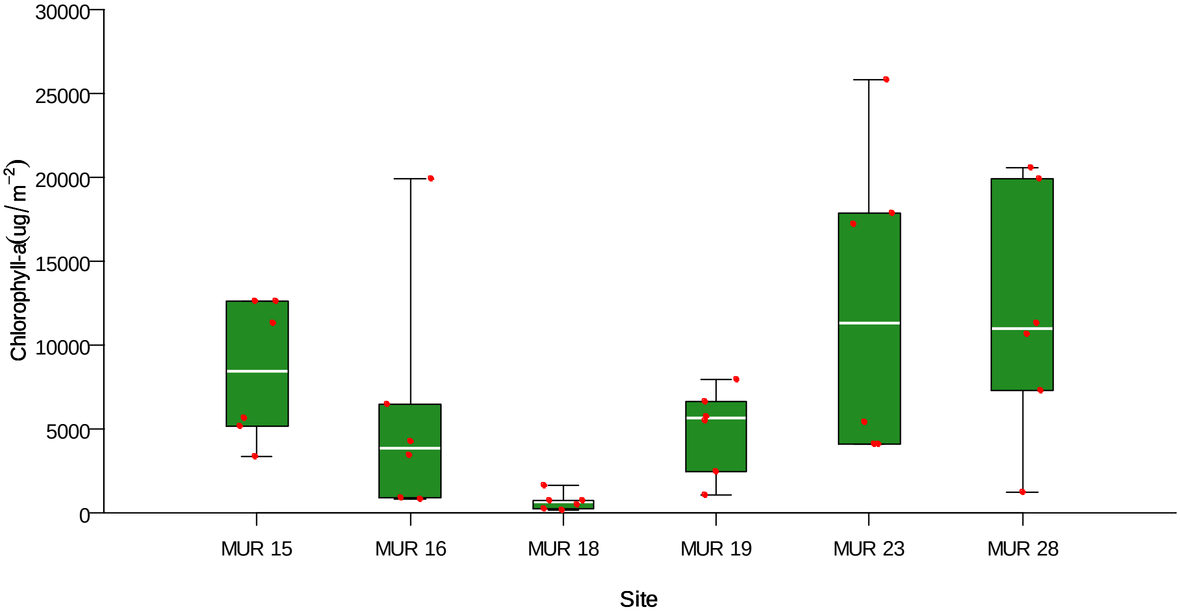


Figure 6. The distribution of Chlorophyll-a upstream and downstream of Angle Crossing

Strip chart values (in red) represent the raw data values for each site.

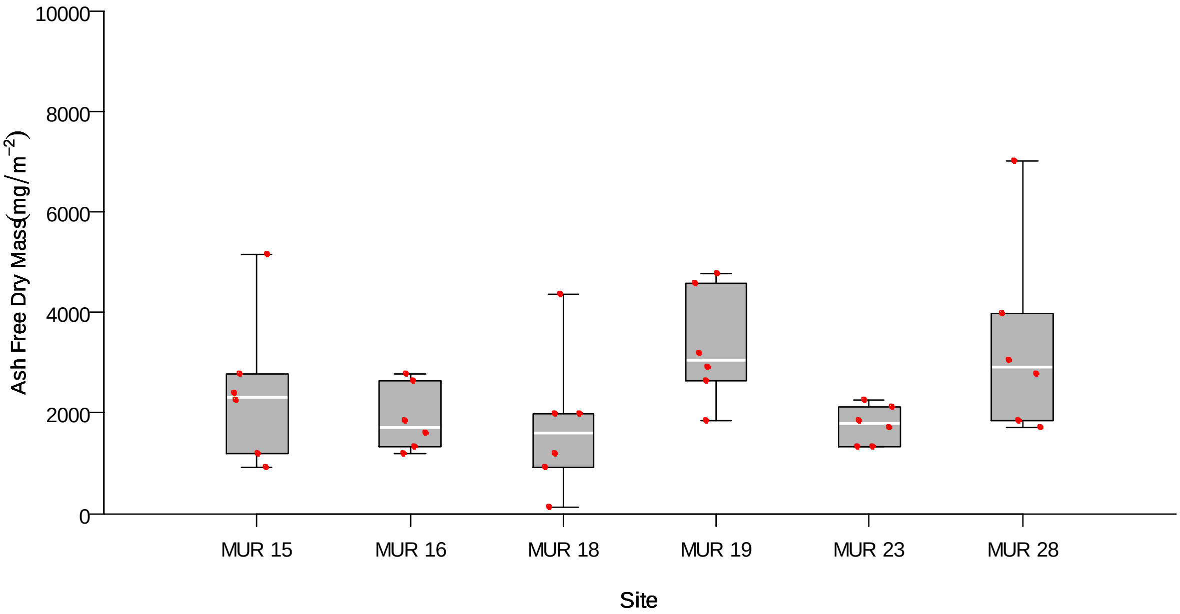


Figure 7. The distribution of Ash Free Dry Mass upstream and downstream of Angle Crossing

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

3.6 Macroinvertebrate Communities

3.6.1 Riffles

Macroinvertebrate communities showed a high degree of similarity (Figure 8), which is consistent with the previous two sampling events (spring 2011 and autumn 2011). Average similarities between sites was high (range: 71-84 %) indicating that species composition was very similar amongst sampling sites and in the context of Figure 8 - on average all of the sampling sites grouped together with 65% similarity and the results of the ANOSIM support this by indicating that there is no difference in the community compositions between upstream and downstream locations (Global R = 0.30; *P*=0.10; Appendix E). MUR 15, the farthest upstream site appears to be slightly removed from the main group and this is largely due to the absence of several taxa that were collected at all the other sampling sites; for example: Tipulidae (SIGNAL = 5); Hydrobiosidae (SIGNAL =8); and Empididae (SIGNAL = 5). The other key difference between MUR 15 and the remaining sites in the main group is the high number of Chironomidae (SIGNAL =3) which occur in abundance at an order magnitude greater than all of the other sites.

Aside from these slight differences all of the sampling sites were characterised by very high abundances of the blackfly – Simuliidae (SIGNAL=5). This family was the dominant taxa at all sites followed by Orthocladiinae (SIGNAL =4) and Chironomidae. Other taxa that characterised the riffle habitat were: Baetidae (SIGNAL =5), Caenidae (SIGNAL =4) and Hydropsychidae (SIGNAL =6) all in various orders of their importance (dominance) at a given site, but numbers of these taxa were considerably less than the Simuliidae, Orthocladiinae and Chironomidae, which explains the high relative contribution of tolerant taxa amongst sites (Figure 9).

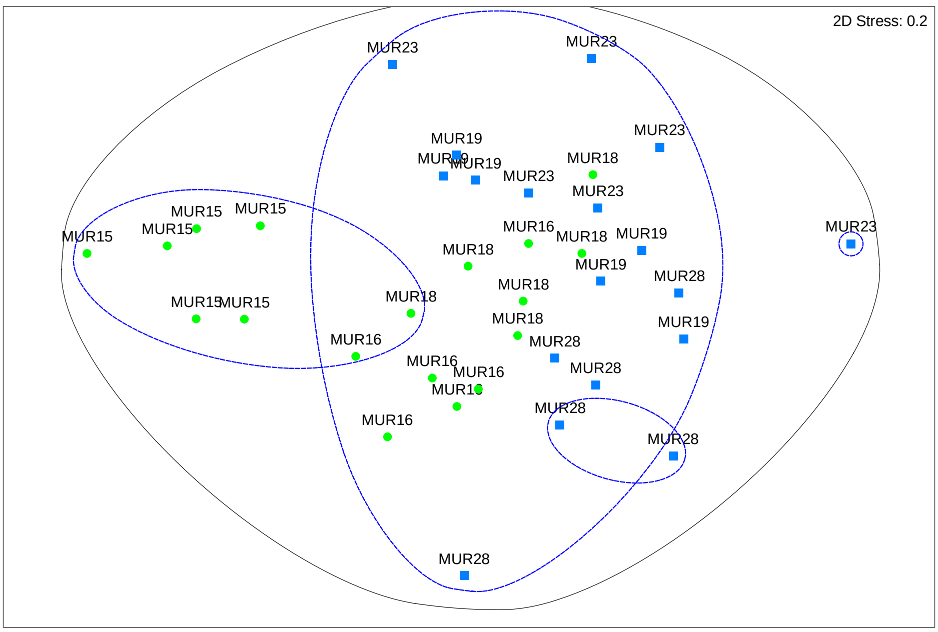


Figure 8. Non-metric multidimensional scaling ordination plot of macroinvertebrates collected from the riffle habitat

The blue ellipse represents 70% similarity groups and the outer, black ellipse represents 65% similarity groups. Green circles are upstream sites and blue squares are downstream sites.

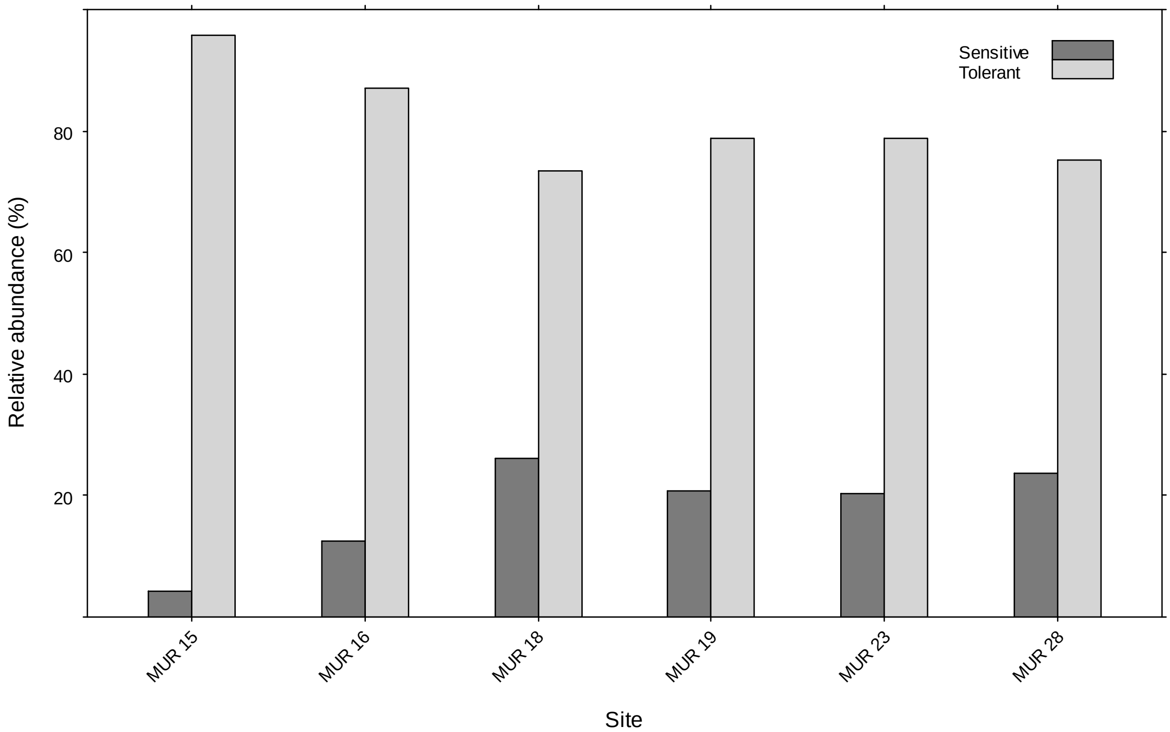


Figure 9. Estimated relative abundances of sensitive and tolerant taxa from the riffle samples

Univariate metrics concur with the multivariate data, indicating a high degree of similarity between sites in terms of total taxa richness (Figure 10) and the number of EPT taxa (Figure 11). Although there is a pattern in total richness of riffle samples, which suggests an increase from MUR 15 to MUR 23 and then slightly declines at MUR 28. Family richness in the riffle ranged from 12 at MUR 15 to 22 at MUR 23. Genus richness was also lowest and highest at MUR 15 and 23 respectively. Some taxa contributing to the relatively high number of species at MUR 23 were unique to that site in this sampling run and these include Corixidae (SIGNAL =2), which are usually confined to the edge habitat; Dugesiidae (SIGNAL =2); Hydrophilidae (SIGNAL =2) and Sphaeriidae (SIGNAL =5). EPT richness was highest at MUR 19 (immediately downstream of Angle Crossing) with ten families and 16 genera and lowest at MUR 15 where 7 families and 11 genera were collected.

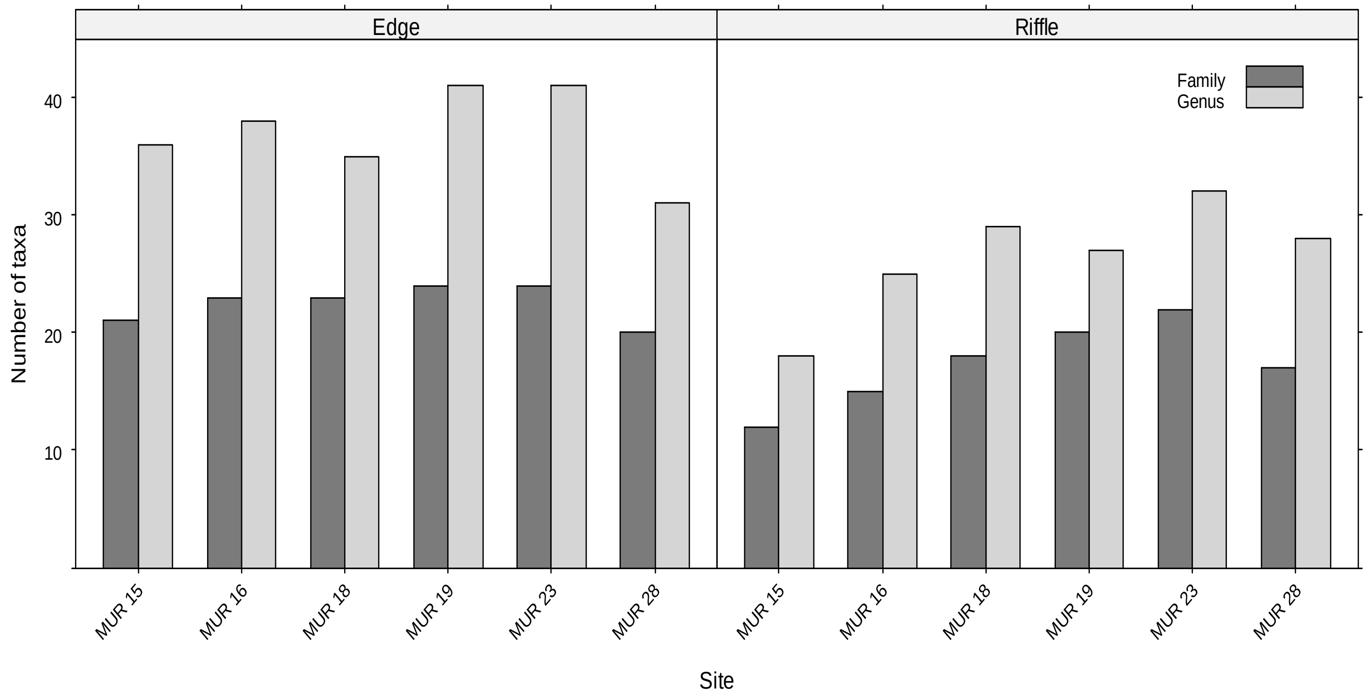


Figure 10. Taxa richness at the genus and family level collected from edge (left) and riffle (right) samples

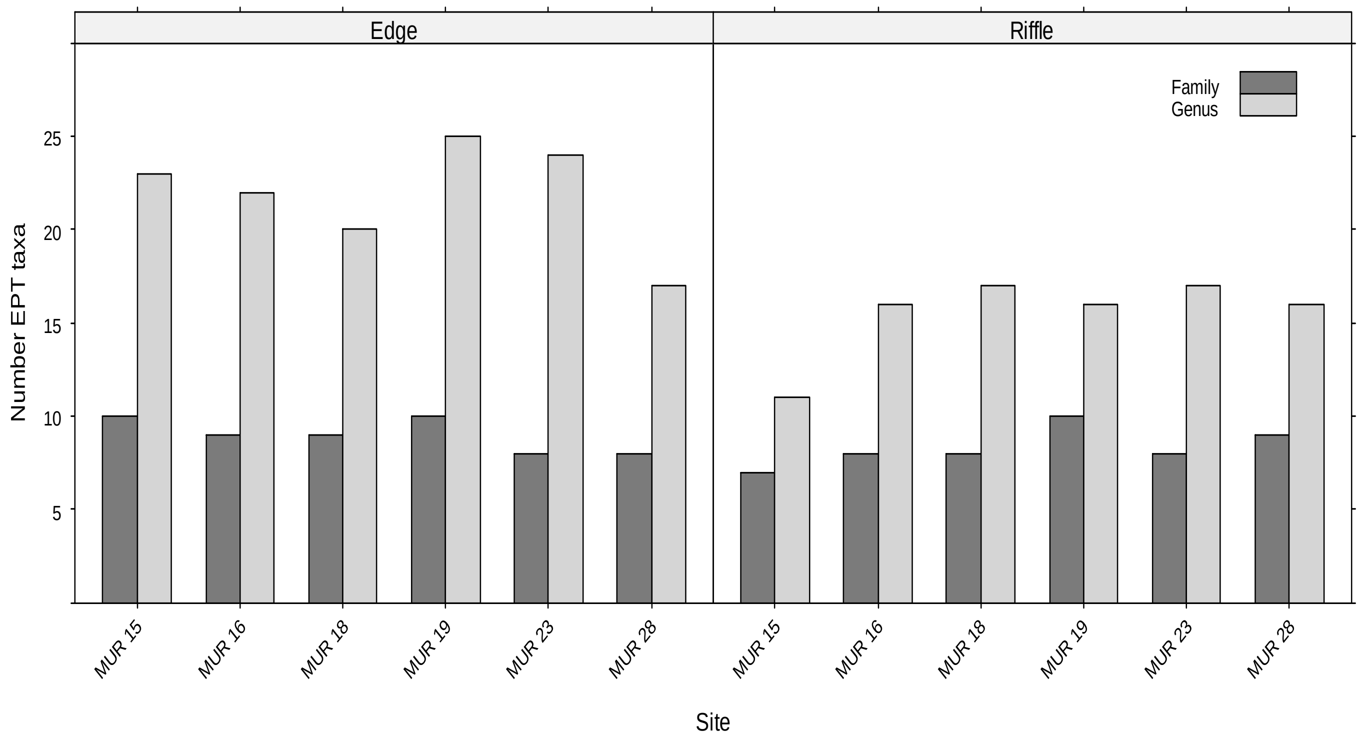


Figure 11. Number of EPT genera and families collected from the edge (left) and riffle (right) samples

3.6.2 Edges

The outcome from the edge macroinvertebrate community analysis is consistent with the riffle communities in that there is a high degree of similarity amongst sites and that MUR 15 appears to be separated from the main group and the ANOSIM results also support the hypothesis of no location difference (Global-R = - 0.07; *P*=0.80: Appendix E). The negative R value reflects the fact that some of the upstream sites (i.e. MUR 16 and MUR 18) are more similar to downstream sites than they are to other upstream sites (Figure 12). As was seen with the riffle communities, Chironominae were highly abundant at MUR 15 as were Corixidae (SIGNAL =2) and Oligochaetes (SIGNAL=2) compared to sites in the main group.

Taxonomic richness and EPT richness did not vary by any degree between MUR 15 and MUR 23 (range=21-24 families and 35-41 genera) however, as was seen in from the riffle samples, there was a decline in both total richness (Figure 10) and EPT richness (Figure 11) at MUR 28.

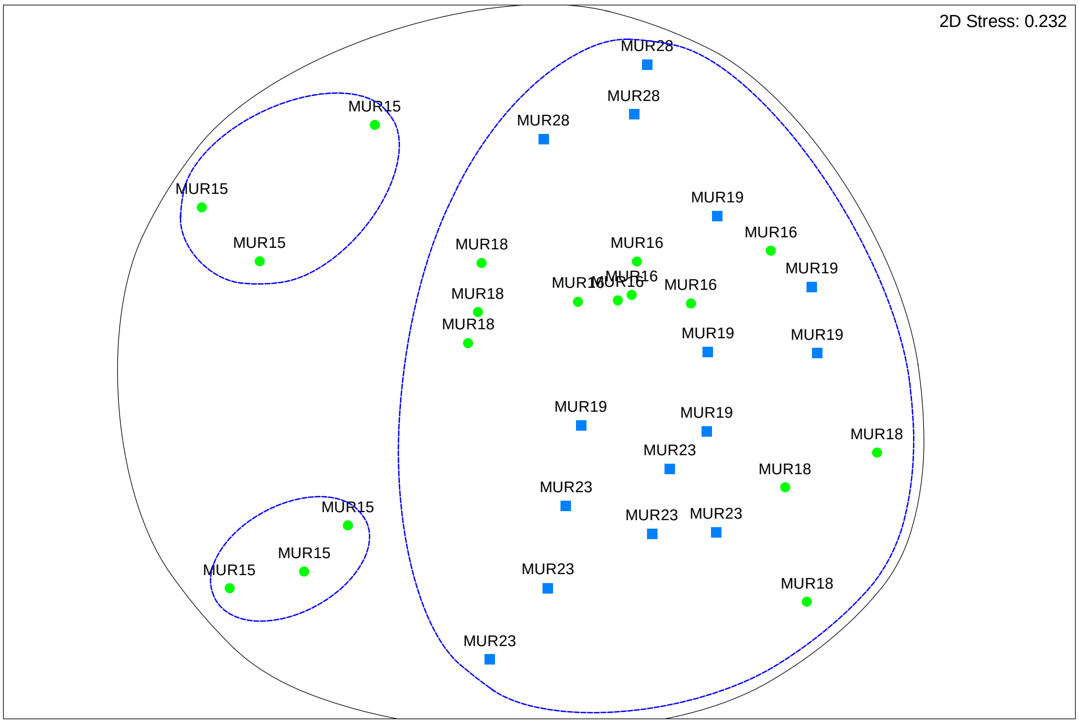


Figure 12. Non-metric multidimensional scaling ordination plot of macroinvertebrates collected from the edge habitat

The blue ellipse represents 60% similarity groups and the outer, black ellipse represents 55% similarity groups. Green circles are upstream sites and blue squares are downstream sites.

3.7 AUSRIVAS Assessment

All sites were assessed as Band B for riffle and edge habitats (Table 12). Missing taxa from the riffle habitat included Tipulidae (SIGNAL=5), Elmidae (SIGNAL =7) and Gripopterygidae (SIGNAL=8) (Appendix F). For a complete list of taxa collected refer to Appendix G. All sites ranged in the number of taxa that were missing from 1-3. Several replicates from each site were assessed as Band A (Table 12; Figure 13) of which MUR 23 had the 5 out of the 6, resulting in a significant difference between upstream and downstream sites ($F_{1,35}$ = 10.12; *P*=0.03; Table 13). There was a high amount of within site variation of the SIGNAL -2 scores (Figure 13) reflecting the range of tolerance values seen within each site. Average SIGNAL -2 scores were <4.6 for all sites, agreeing with the community descriptions in section 3.6.1 that these assemblages were dominated by moderately to highly sensitive taxa amongst all sites. Furthermore, the high degree of within site variation has resulted in no location or site differences detected from the ANOVA model ($F_{1,35}$ = 2.27; *P*=0.21; Table 13).

The number of missing taxa from the edge habitat ranged from 2, at MUR 23 to 9 at MUR 18 (Appendix F) resulting in Band B assessments at each site (Table 12). Despite the high variation in the number of missing taxa, all sites were assessed as Band B, although as with the riffle samples several of the site replicates were determined as Band A. MUR 28 was the only site to have all B assessments and this is probably a consequence of the limited habitat available at that site. Overall there was no location difference in the O/E50 scores ($F_{1,32}$ = 0.16; *P*=0.71; Table 14) or the SIGNAL -2 scores ($F_{1,32}$ = 0.84; *P*=0.41; Table 14); Figure 14 suggests that MUR 15, on average had lower SIGNAL-2 scores than the other sites.

On the whole, the overall sites assessments were the same as the previous two sampling runs (Table 15). MUR 19 dropped a Band to B from the previous two sampling runs, while MUR 16 also went from Band A in spring 2011 to Band B in this sampling round. Although in autumn 2011, MUR 16 was assessed as Band B.

Table 12. AUSRIVAS and SIGNAL scores for autumn 2012

SITE	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS band		Overall habitat assessment		Overall site assessment
		Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
Mur 15	1	4.63	4.18	0.89	0.86	A	A	B	B	B
Mur 15	2	4.14	3.50	0.78	0.63	B	B			
Mur 15	3	4.50	4.20	0.89	0.78	A	B			
Mur 15	4	4.63	4.20	0.89	0.78	A	B			
Mur 15	5	4.63	4.20	0.89	0.78	A	B			
Mur 15	6	4.14	3.78	0.78	0.70	B	B			
Mur 16	1	4.63	4.89	0.89	0.70	A	B	B	B	B
Mur 16	2	4.25	4.80	0.89	0.78	A	B			
Mur 16	3	4.25	4.73	0.89	0.85	A	A			
Mur 16	4	4.14	4.50	0.78	0.93	B	A			
Mur 16	5	4.14	4.20	0.78	0.78	B	B			
Mur 16	6	4.14	4.20	0.78	0.78	B	B			
Mur 18	1	4.14	4.20	0.78	0.78	B	B	B	B	B
Mur 18	2	4.63	3.71	0.89	0.54	A	B			
Mur 18	3	4.50	4.22	0.89	0.70	A	B			
Mur 18	4	4.14	4.22	0.78	0.70	B	B			
Mur 18	5	4.67	4.55	1.00	0.85	A	A			
Mur 18	6	4.63	4.55	0.89	0.85	A	A			
Mur 19	1	4.63	4.80	0.89	0.78	A	B	B	B	B
Mur 19	2	4.89	4.00	1.00	0.62	A	B			
Mur 19	3	4.63	4.89	0.89	0.70	A	B			
Mur 19	4	4.14	4.18	0.78`	0.85	B	A			
Mur 19	5	4.25	4.6	0.89	0.78	A	B			
Mur 19	6	4.14	4.55	0.78	0.85	B	A			
Mur 23	1	4.89	4.44	1.00	0.95	A	A	B	B	B
Mur 23	2	4.89	4.44	1.00	0.86	A	A			
Mur 23	3	4.67	4.44	1.00	0.86	A	A			
Mur 23	4	4.50	4.22	0.89	0.86	A	A			
Mur 23	5	4.50	4.25	0.89	0.76	A	B			
Mur 23	6	4.14	4.25	0.78	0.76	B	B			
Mur 28	1	4.14	4.70	0.78	0.78	B	B	B	B	B
Mur 28	2	4.50	4.44	0.89	0.70	A	B			
Mur 28	3	4.67	4.25	1.00	0.62	A	B			
Mur 28	4	4.50	NS	0.89	NS	A	NS			
Mur 28	5	4.50	NS	0.89	NS	A	NS			
Mur 28	6	4.50	NS	0.89	NS	A	NS			

NS: Not sampled as limited edge habitat available.

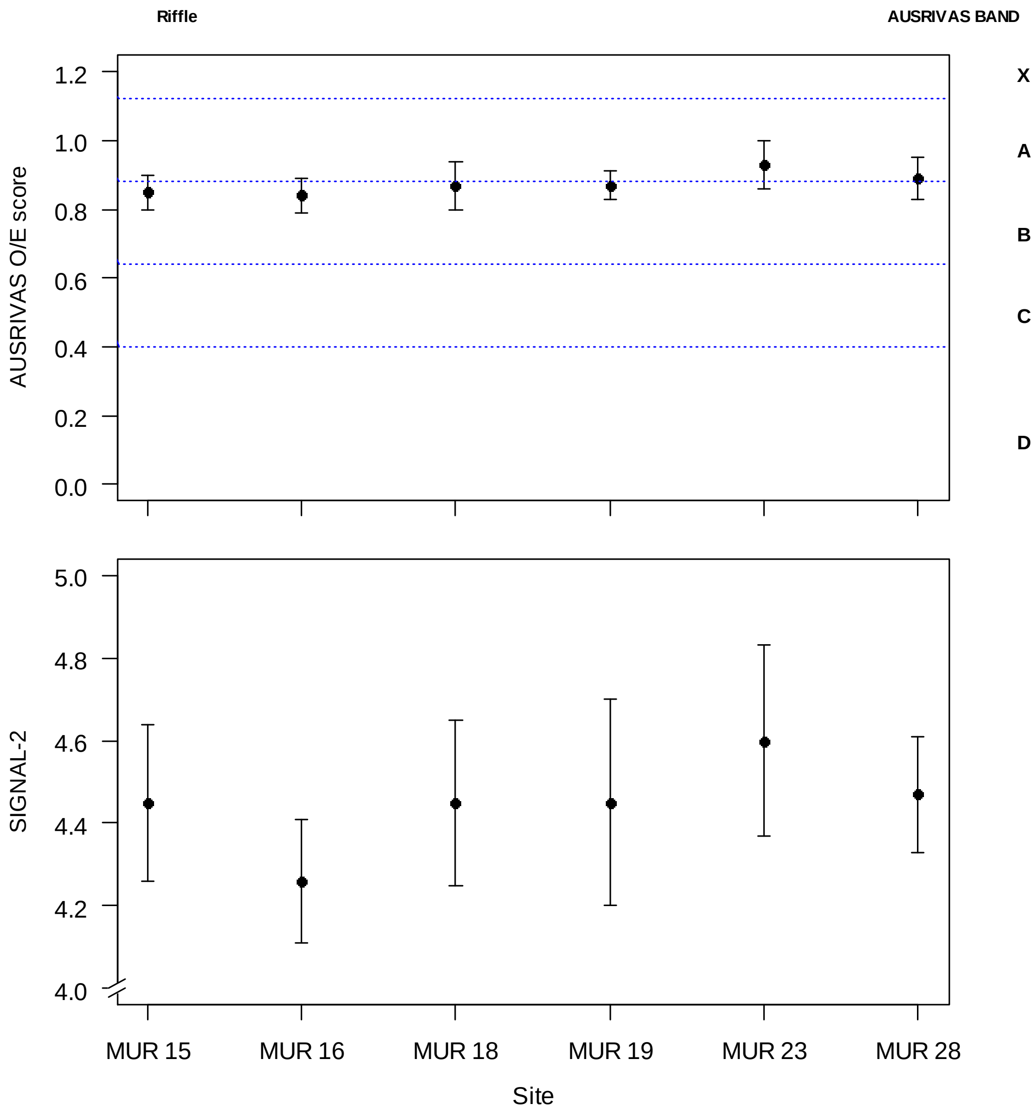


Figure 13. Average AUSRIVAS OE/50 scores (top) and average SIGNAL -2 scores* from the riffle samples

*Error bars are 95% confidence intervals

Table 13. Nested analysis of variance from the riffle samples comparing OE/50 scores and SIGNAL – 2 scores between locations

Response	Source	DF	F-value	P-value
OE/50	Location	1	10.12	0.03
	Site [Location]	4	0.53	0.71
	Residual	35		
SIGNAL -2	Location	1	2.27	0.21
	Site [Location]	4	0.92	0.46
	Residual	35		

Table 14. Nested analysis of variance from the edge samples comparing OE/50 scores and SIGNAL – 2 scores between locations

Response	Source	DF	F-value	P-value
OE/50	Location	1	0.16	0.71
	Site [Location]	4	1.85	0.14
	Residual	32		
SIGNAL-2	Location	1	0.84	0.41
	Site [Location]	4	3.09	0.03
	Residual	32		

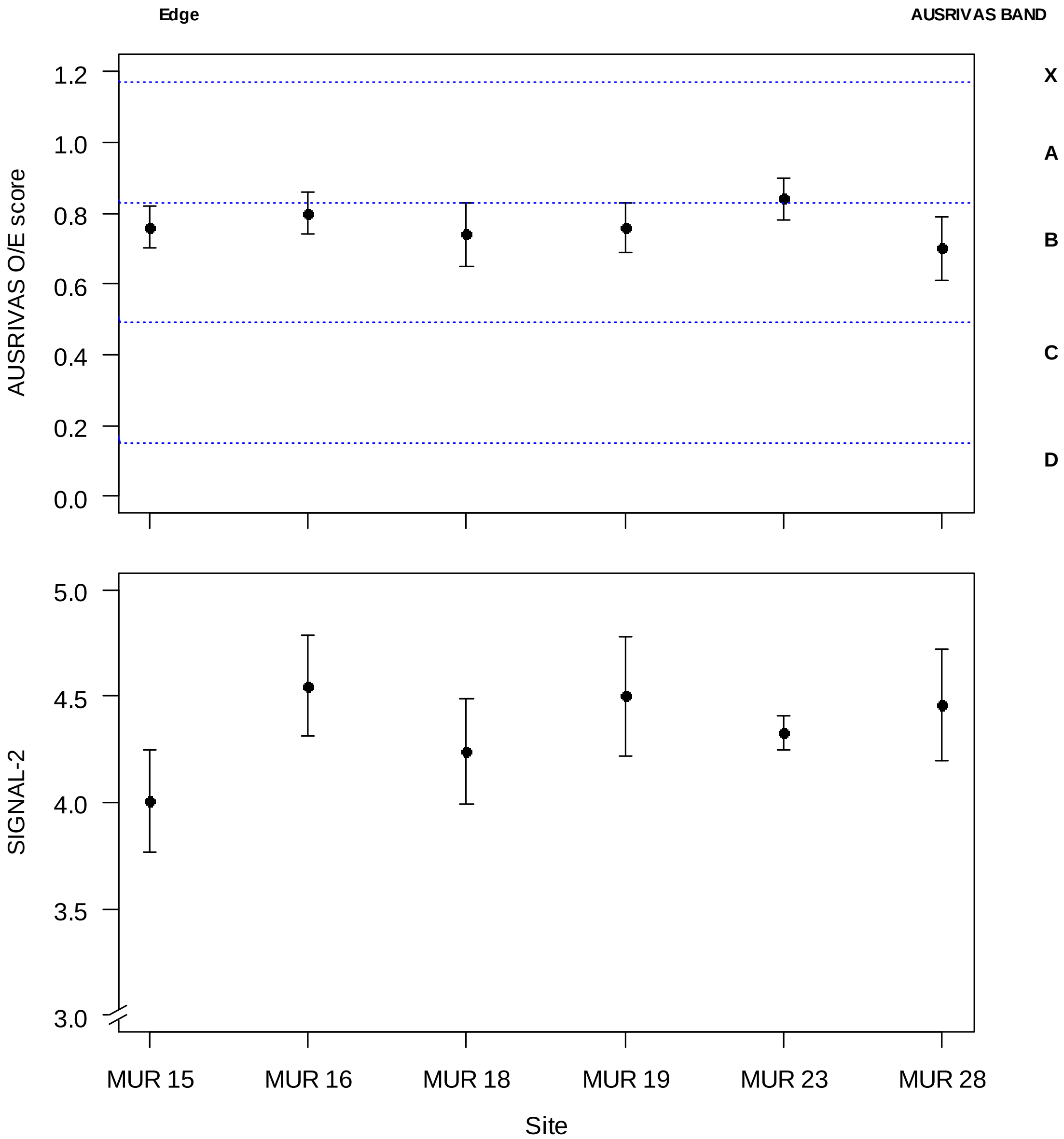


Figure 14. Average AUSRIVAS OE/50 scores (top) and average SIGNAL -2 scores* from the edge samples

*Error bars are 95% confidence intervals

Table 15. Comparisons of the current AUSRIVAS bands with previous sampling runs

Site	Autumn 2011	Spring 2011	Current (Autumn 2012)
MUR 15	**B**	**B**	**B**
MUR 16	**B**	**A**	**B**
MUR 18	**B**	**B**	**B**
MUR 19	**A**	**A**	**B**
MUR 23	**B**	**B**	**B**
MUR 28	**B**	**B**	**B**

4. Discussion

The MEMP monitoring programme aims to provide ACTEW Water with ecological assessments of sites upstream and downstream of Angle Crossing, to establish a baseline condition prior to the operation of the Murrumbidgee to Googong (M2G) project.

4.1 Water Quality and periphyton

The water quality results generally have a high level of compliance with the ANZECC & ARMCANZ (2000) guidelines for the continuous data that is available and the grab samples. There was also a distinct absence of a longitudinal gradient in the EC data that is for the most part indicative of the Murrumbidgee River. The reason for this is that during high base flow periods as was the case in autumn 2012, dilution becomes important relative to the downstream inputs of dissolved salts.

pH levels exceeded or were on the upper threshold limit of the ANZECC guidelines at the downstream sites only (Table 10) but should also be noted that the downstream sites were sampled on a different day to the upstream sites, indicating that differences in rainfall and other daily changes may have played a role in this rather than being a consequence of the location of these sites relative to Angle Crossing.

There was a large sand deposit adjacent to the water quality probe at the upstream Angle Crossing site which resulted in low dissolved oxygen readings at the beginning of March, thus resulting in low compliance values for the month. Efforts are currently being made to clear this site and potentially relocate it to help rectify this ongoing issue (Andy Cumming, *pers. comms*., April 2012).

The elevated nutrient levels which are present at all sites, exceed the guideline levels (Table 10); this is unsurprising as these concentration levels have been recorded regularly in the Murrumbidgee river since the inception of the MEMP. Land use and degraded riparian zones further upstream seem likely reasons for these elevated readings, especially given the saturated river catchments during the time of sampling.

The total nitrogen, total phosphorus and NO_X concentrations show a distinct lowering of concentrations with distance downstream indicating that a) the source of these nutrients is upstream of MUR 15 and b) nutrient uptake by primary producers. The point of most rapid decline appears to be at MUR 28, at which point NO_x concentrations fell by 90% compared to MUR 23. TP and TN concentrations declined by 35% and 25% respectively. The decline in the concentration levels to some extent correlate with increasing chlorophyll-a concentrations at MUR 23 and MUR 28 which are regularly higher than the other sites, indicating nutrient uptake through increased plant growth.

Neither the AFDM nor the Chlorophyll-a concentrations showed any location difference that may have been a result of the M2G project. Chlorophyll-a concentrations were considerably lower than they were in the same sample period in 2011. During autumn 2011 mean flow (ML/d) in the Murrumbidgee was 390 ML/d compared to autumn 2012 where average flow for autumn was 4000 ML/d, which probably resulted in the lower Chlorophyll-a concentrations in this period. AFDM was highly comparable across sample sites which is likely to be a result of the flood having the effect of “resetting” and thereby, standardising the standing crops across all sites. The differences in the Chlorophyll-a concentrations (i.e. the live component) seen across sites could represent site to site variations in suitable substrate; light penetration; riparian vegetation and channel morphology to name a few.

High flow events reduce standing crops of algal biomass through hydrologic stress and scouring through increased bed movement (Peterson, 1996). Periphyton communities are also regulated by macroinvertebrate grazers and nutrients (Murdock*, et al.*, 2011) and following flood events, grazers can be removed through scouring which ultimately changes the importance of nutrients during the recovery period with the absence of grazers regulating the growth and standing crop. Murdock et al. (2011) found that nutrients were the most important influence on algal reestablishment following a flood due to lower numbers of grazers and as already mentioned there is some evidence to suggest that increased concentrations at MUR 23 and MUR 28 are related to nutrient inputs.

4.2 Macroinvertebrate communities and AUSRIVAS assessment

Two months prior to collecting macroinvertebrate samples, peak flows at Lobb's Hole exceeded 63 000 Ml/d. High flow events tend to have a homogenizing effect on habitat condition amongst sites due to increasing connectivity and dilution effects on water quality (Thomaz*, et al.*, 2007) and because the event in early March impacted all sampling sites in this project, similar effects upon the habitats amongst sites would be expected; resulting in comparable macroinvertebrate communities between sampling sites.

Sampling sites in this study had a high degree of similarity evidenced from the relationships displayed in the NMDS ordination plots (Figures 8 & 12) and the non-significant ANOSIM result that tested for differences between locations.

The structure of the riffle habitat communities in this study is indicative of communities recovering from flow related disturbances, with all sites being characterised by moderately tolerant taxa including Simulids, Chironomids and Oligochaetes. Previous sampling runs have shown similar patterns despite the size of the high flow event in those studies being significantly smaller than the one preceding the current sampling run. The data presented in this study are also consistent with the literature which shows that recovering macroinvertebrate communities tend to be dominated by the taxa also represented here. Niemi et al. (1990) showed that generally recolonisation begins with Dipterans (e.g. Simuliids and Chironomids) followed by Ephemeroptera, Trichoptera and Plecoptera and that recolonisation times can vary significantly within each taxonomic group depending on the magnitude, duration and frequency of events.

Previous studies have found that following high magnitude flood events, macroinvertebrate communities can be reduced by up to 99% compared to pre-flood conditions (e.g. Fritz and Dodds, 2004) resulting in an initial loss of all taxonomic groups. During the recolonisation period the number of taxa tends to recover more quickly than abundances and density (Death, 2008) which helps explain why taxonomic richness in this study is comparable to autumn 2011 during a period of relatively stable flow. Estimated abundances of other groups, namely EPT (Figure 11) were considerably lower than in the previous autumn event. Death (2008) explains that recovery trajectories to pre-flood conditions generally occurs in 2-4 months but recovery may not be complete if there are further high flow events within this time period. In mid-April, the Murrumbidgee River was subjected to another small event, peaking at approximately 5000 Ml/d (Figure 3), which may have disrupted this recolonisation period, resulting in the lower EPT abundances compared to autumn 2011.

Despite the magnitude of the high flow disturbance, the Band B assessments allocated to each site are comparable to all previous sampling events (except spring 2011) indicating that even after the initial impact of the flood, the eight week period prior to sampling seems to be sufficient in the Murrumbidgee River to recover to pre flood conditions, or at least on a season by season basis.

Taxa missing but expected by the AUSRIVAS model further highlights the similarities between sampling sites in this study (Appendix F). Tipulidae (SIGNAL = 5); Elmidae (SIGNAL =7) and Gripopterygidae (SIGNAL =8) were missing from each the riffle habitat at each site and did not show any specific pattern in the presence/absence exhibited across sampling sites. The absence of these taxa may be a direct response to the magnitude of the March event and the subsequent high flow event in mid-April or as result of indirect effects such as depletion of food sources and habitat. Tipulidae, for example commonly inhabit fine sediments and prefer slower flowing water (Gooderham and Tsyrlin, 2005), this taxa was present in only 16% of the samples in this sampling run but were found in over 80% in autumn 2011, suggesting that while present their distribution was patchy and may have been limited by suitable habitat following the flood or available food sources. Similar arguments could be made for the Elmidae and Gripopterygidae, although returning to Neimi *et al.*, (1990) these two groups, which represent the Coleoptera (beetles) and Plecoptera (Stoneflies) respectively generally, are slow colonisers and the timing of which can increase as the magnitude of the flood increases.

The AUSRIVAS Bands suggest that there were no differences between sampling locations (Table 12), however the results from the ANOVA on O/E 50 scores indicates that downstream sites (from the riffle habitat model only) (Table 13) were higher on average compared to the upstream sites. The ecological significance of this result appears to be negligible based on the inventory of missing but expected taxa (Appendix F) and appears to be driven by the results from MUR 23. McBride et al. (1993) suggest that one problem with significance testing is that there is an apparent misconception that statistical significance equates to practical or ecological significance.

We support this view and suggest that, equivalence tests, which test for differences in some predetermined level of practical or ecological significance (i.e. the effect size or degree of family loss), which either: a) jeopardises the objects of the M2G project or b) can be shown to be detrimental to ecosystem functioning (Barmuta *et al.*, 2003); may be a better alternative for these analyses, especially given that as has been seen here, variation within a given bandwidth can vary enough to cause significant differences between locations, when a) the discrete assessment Bands themselves are not indicating such a difference and b) the ecological significance of such a result may not have any practical meaning.

The number of taxa missing from the AUSRIVAS edge model was higher than the riffle as was the number of expected taxa, which represents greater habitat complexity that is usually associated with the edge habitat (Appendix F). As with the riffle, Elmidae were missing from the majority of samples which again may indicate a lack of food or slow colonisation patterns. The overall patterns discussed for the riffle habitat were seen in the edges, which also showed a high degree of similarity in the community assemblages (Figure 10) and concurrence amongst sites in terms of the univariate metrics. A number of taxa predicted to occur in the edge habitat, but were missing were missing from all of/or the majority of the samples including Elmidae (present in one sample) Synlestidae and Conoesucidae (Appendix F). The latter two taxa have not been collected at these sites in the autumn to date, which may be a result of the historical land use in the catchment, since Synlestidae and Conoesucidae are both sensitive to poor water quality (SIGNAL =7) the antecedent condition in the Murrumbidgee may limit the potential to recolonise.

The macroinvertebrate community composition coupled with the univariate indices is similar to the results seen in previous sampling runs; except that these results follow a major high flow event that occurred in early March, suggesting that there is a high degree of resilience in the Murrumbidgee River to hydrological conditions. Providing that there is sufficient time between high flow events for the system to recover, it appears that it is unlikely that these taxa will be displaced permanently but may undergo periods of low abundances and shifts in the dominant taxa within that community.

5. Conclusions and Recommendations

The higher base flows in this study resulted in some dilution of water quality gradients, namely electrical conductivity. Other parameters such as the nutrients were slightly higher than background levels and there is some indication that the reduction in nutrient concentrations downstream of Angle Crossing is related to increased algal growth. For the most part the physico–chemical analytes from the water quality parameters were within the ANZECC and ARMCANZ (2000) guidelines. Nutrient concentrations were elevated, however these values still correspond to background nutrient levels within this part of the Murrumbidgee River catchment, especially during wet periods.

Continuous water quality data shows that electrical conductivity remained within the guidelines for the entire autumn period at Lobb's Hole. pH and turbidity exceeded the guidelines most frequently, and this is due to the events in March and April. Dissolved oxygen had a high level of compliance downstream of Angle Crossing; however upstream levels were low, especially during the early part of March due to sand deposits near the sensor after the high flow event.

The flooding event at the beginning of March has had an overriding influence upon all biological indicators being considered in this sampling run. Even though sampling occurred approximately eight weeks after the high flow event, the community composition had low abundances of sensitive EPT taxa, although taxonomic richness was comparable to previous sampling occasions indicating that although taxa are likely to be removed immediately following high flow disturbances, recolonisation of the number of taxa can occur reasonably quickly even though we can expect a delay in abundances reaching pre-flood levels. The upshot of this is that because taxonomic composition is similar to pre-flood levels, and because AUSRIVAS relies on this state (composition as opposed to abundances) the AUSRIVAS bands will provide similar assessments owing to this condition of the model.

Although the AUSRIVAS bands indicated that there was no difference between sampling locations, the ANOVA results on the OE/50 scores indicated a difference in means between upstream and downstream sites. After further examination of the data, it was determined that this result was driven by higher scores at MUR 23 on account of 1 family not being missing compared to the other sites, resulting in Band A assessments for some of the samples. As already discussed, the ecological significance of this result appears to be negligible based on the inventory of missing but expected taxa and we recommend the application of equivalence tests to the current study. Equivalence tests test for differences in some predetermined level of practical or ecological significance. These levels will need to be determined, but should be based on current baseline data which will allow estimates of natural variation in the O/E50 scores to be made prior to the application of this method.

6. Literature Cited

ACT Government (2011) 2011 Environmental Flow Guidelines.

Australian Government Bureau of Meteorology (2012) www.bom.gov.au

Anderson, M. J., Gorley, R. N. and Clarke, K. R. (2008) *PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods.* PRIMER-E: Plymouth, UK.

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.

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

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

Bates, D., Maechler, M. and Bolker, B. (2011) *Linear mixed-effects models using S4 classes.* R package version 0.999375-39*.* http://CRAN.R-project.org/package=lme4.

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

Cao, Y., Larsen, D.P. & Thorne, R.S.-J. (2001) Rare Species in Multivariate Analysis for Bioassessment: Some Considerations. *Journal of the North American Benthological Society*, 20, 144-153.

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

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

Clarke, K. R. and Gorley, R. N. (2006) *PRIMER v6: User Manual/Tutorial*, PRIMER-E: Plymouth.
Coysh, J., Nichols, S., Ransom, G., Simpson, J., Norris, H. R., Barmuta, L. A. and Chessman, B. C. (2000) *AUSRIVAS Macroinvertebrate bioassessment: predictive modelling manual*, CRC for Freshwater Ecology.

Death, R. G. (2008). The effects of floods on aquatic invertebrate communities, In. Lancaster, J. & Briers, R. A. (eds.), *Aquatic Insects: Challenges to Populations: Proceedings of the Royal Entomological Society's 24th Symposium*, Cromwell Press, Trowbridge.

Dewson, Z. S., James, A. B. W. and Death, R. G. (2007) A review of the consequences of decreased flow for instream habitat and macroinvertebrates. *Journal of the North American Benthological Society*, 26 (3), 401-415.

Fritz, K. M. and Dodds, W. K. (2004) Resistance and resilience of macroinvertebrate assemblages to drying and flood in a tallgrass prairie stream system. *Hydrobiologia*, **527** 99-112. ACTEW Water Murrumbidgee

GHD (2012) Murrumbidgee Ecological Monitoring Program Proposal: Spring 2011 – Autumn 2012. Proposal for ACTEW Water. Proposal number: 23-0905618.

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

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

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. (1964) Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika*, 29, 1-27.

Loeb, S. (1981) An in-situ method for measuring the primary productivity and standing crop of the epilithic periphyton community in lentic systems. *Limnology and Oceanography*, (26), 394-399.

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

McBride, G.B., Loftis, J.C. & Adkins, N.C. (1993) What do significance tests really tell us about the environment? *Environmental Management*, 17, 423-432.

Murdock, J.N., Dodds, W.K., Gido, K. & Whiles, M.R. (2011) Dynamic influences of nutrients and grazing fish on periphyton during recovery from flood. *Journal of the North American Benthological Society*, 30, 331-345.

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

Niemi, G.J., DeVore, P., Detenbeck, N., Taylor, D., Lima, A., Pastor, J., Yount, D.J. & Naiman, R.J. (1990) Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management*, 14, 571-587.

Peterson, C. G. (1996). Response of Benthic Algal Communities to Natural Physical Disturbance, In. Stevenson, J., Bothwell, M. L. & Lowe, R. L. (eds.), *Algal Ecology: Freshwater Benthic Ecosystems*, Academic Press, U.S.A.

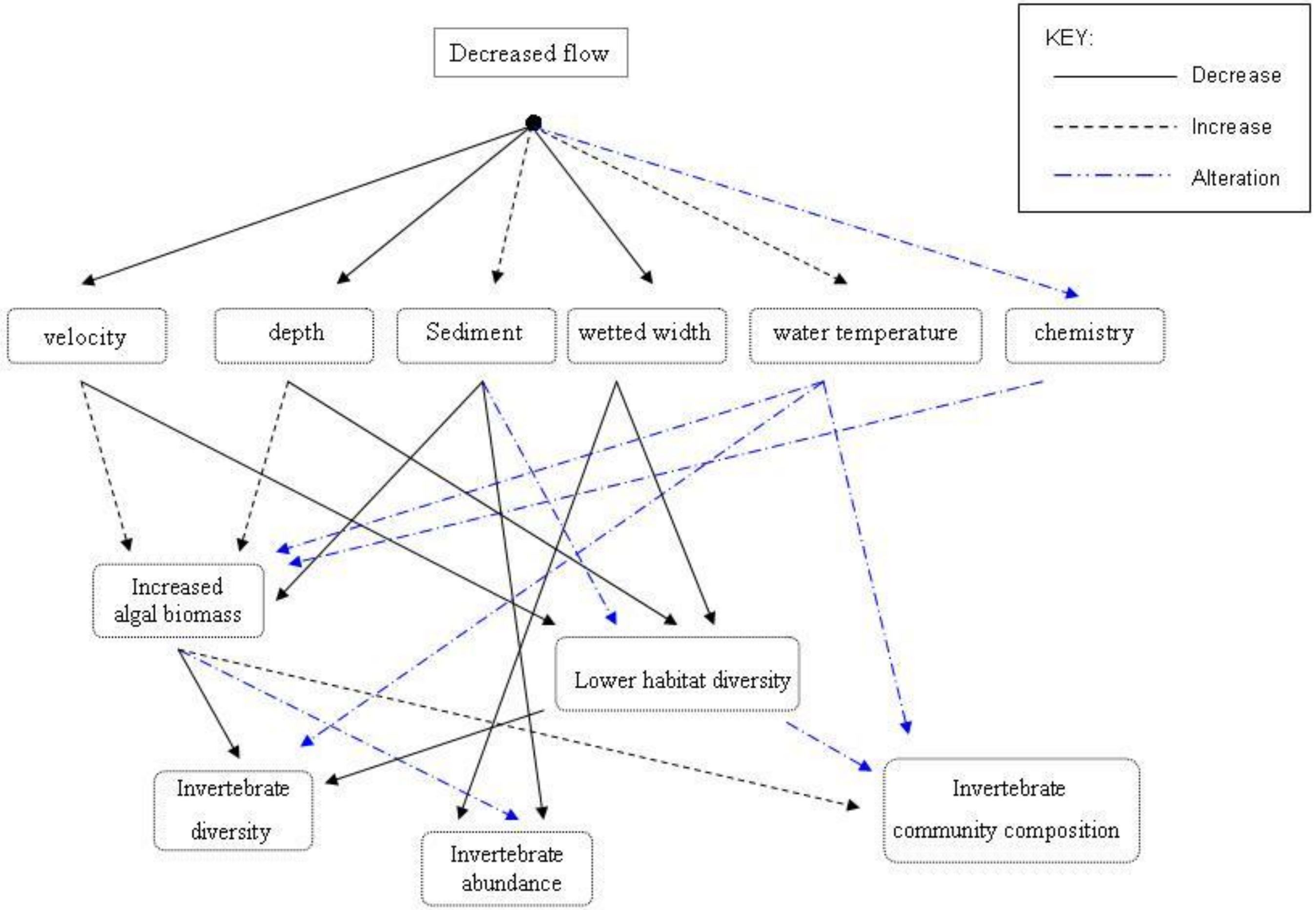
R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Thomaz, S.M., Bini, L.M. & Bozelli, R.L. (2007) Floods increase similarity among aquatic habitats in river-floodplain systems. *Hydrobiologia*, 579, 1-13.

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

Appendix A

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



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

*Reproduced with permission from the authors.

Appendix B

Site Summaries

MUR15

Bumbalong Road
1/5/2012 10:00am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	TSS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
11.7	160	8.4	7	7.8	110.0	11.4

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
60	0.068	0.066	< 0.002	0.011	0.041	0.50

Daily Flow: 770 ML/day

Recorded at the closest station (410050), located on the Murrumbidgee River at Billilingra. (Source: www.water.nsw.gov.au)

Compared to current flow:

Spring 2011: 

Autumn 2011: 

Riffle Habitat

- Sampled upstream of usual riffle due to site alteration by high flows
- Dominant substrate was sand

Dominant Taxa

- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 8)

- None

Edge Habitat

- Dominant trailing bank vegetation was blackberry and wood

Dominant Taxa

- Baetidae
- Corixidae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebidae

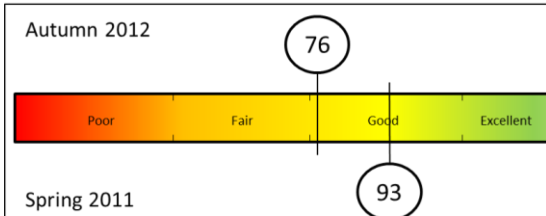
AUSRIVAS Results

	Autumn 2011	Spring 2011	Autumn 2012
Riffle Habitat	A	A	B
Edge Habitat	B	A	B
Overall Site Assessment	B	A	B

Additional Comments

- Sections of dead vegetation along the banks due to inundation
- Periphyton coverage limited due to the unstable nature of the sediment, although abundant on the small sections of stable substrate
- High levels of sand deposited on the site since Spring 2011

Site Quality Assessment



MUR16

The Willows – Near Michelago
1/5/2012 10:00am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	TSS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
12.0	160	8.0	5	7.9	102.6	10.3

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
60	0.064	0.062	< 0.002	0.008	0.037	0.49

Daily Flow: 770 ML/day

Recorded at the closest station (410050), located on the Murrumbidgee River at Billilingra. (Source: www.water.nsw.gov.au)

Compared to current flow:

Spring 2011: 

Autumn 2011: 

AUSRIVAS Results

	Autumn 2011	Spring 2011	Autumn 2012
Riffle Habitat	A	A	B
Edge Habitat	B	A	B
Overall Site Assessment	B	A	B

Riffle Habitat

- Restricted riffle zone due to high flows
- Dominant substrate was cobble

Dominant Taxa

- Simuliidae

Sensitive Taxa (SIGNAL-2 ≥ 8)

- Coloburiscidae
- Leptophlebiidae
- Hydrobiosidae

Edge Habitat

- Dominant trailing bank vegetation was native shrubs and tree's

Dominant Taxa

- Caenidae

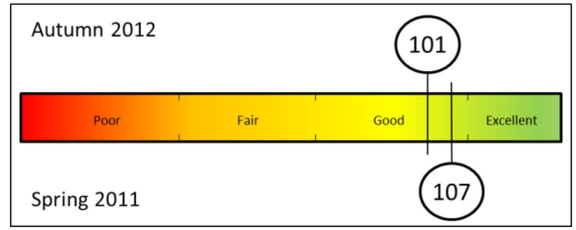
Sensitive Taxa (SIGNAL-2 ≥ 7)

- None

Additional Comments

- High level of periphyton coverage, however it is only a thin (young) layer due to scour from higher flows
- Evident lack of macrophytes which are usually present at this site, specifically *Myriophyllum sp.*

Site Quality Assessment



MUR18

Upstream Angle Crossing
1/5/2012 10:00am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	TSS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
12.4	150	8.5	6	7.9	101.0	11.1

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
59	0.061	0.059	< 0.002	0.009	0.037	0.49

Daily Flow: 570 ML/day

Recorded at the closest station (41000270), located on the Murrumbidgee River at upstream Angle Crossing.

Compared to current flow:

Spring 2011: ↓ Autumn 2011: ↓

AUSRIVAS Results

	Autumn 2011	Spring 2011	Autumn 2012
Riffle Habitat	B	B	B
Edge Habitat	A	B	B
Overall Site Assessment	B	B	B

Riffle Habitat

- Restricted riffle zone due to high flows
- Dominant substrate was cobble

Dominant Taxa

- Baetidae

Sensitive Taxa (SIGNAL-2 ≥ 8)

- Leptophlebiidae
- Hydrobiosidae

Edge Habitat

- Dominant trailing bank vegetation was macrophytes (mainly *Phragmites australis*) native shrubs

Dominant Taxa

- None

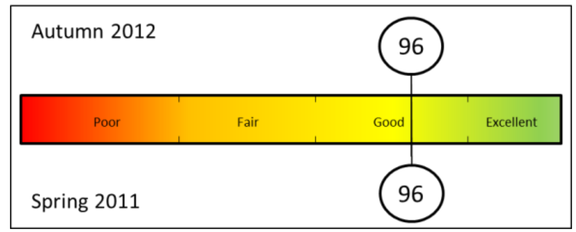
Sensitive Taxa (SIGNAL-2 ≥ 7)

- None

Additional Comments

- Sections of erosion on the left hand bank
- New braid cut through providing a new riffle section on the far side of the channel (not sampled)

Site Quality Assessment



MUR19

Downstream Angle Crossing
2/5/2012 10:30am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	TSS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
11.5	160	7.9	6	8.1	102.1	11.4

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
60	0.061	0.059	< 0.002	0.007	0.036	0.48

Daily Flow: 520 ML/day

Recorded at the closest station (41000270), located on the Murrumbidgee River at upstream Angle Crossing.

Compared to current flow:

Spring 2011:  Autumn 2011: 

AUSRIVAS Results

	Autumn 2011	Spring 2011	Autumn 2012
Riffle Habitat	A	A	B
Edge Habitat	A	A	B
Overall Site Assessment	A	A	B

Riffle Habitat

- Some deposition of sand in riffle zone
- Dominant substrate was cobble

Dominant Taxa

- Simuliidae
- Hydropsychidae

Sensitive Taxa (SIGNAL-2 ≥ 8)

- Leptophlebiidae
- Hydrobiosidae

Edge Habitat

- Some deposition of cobble and pebble material around the edge habitat
- Dominant trailing bank vegetation was native shrubs

Dominant Taxa

- Baetidae

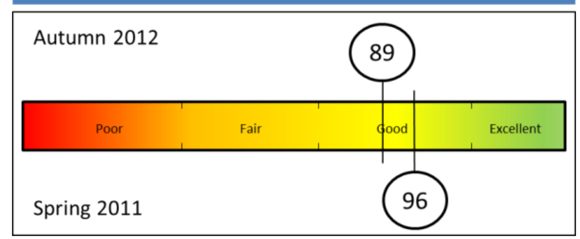
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Additional Comments

- New *Myriophyllum sp.* growth
- Periphyton coverage approximately 70%, however reduced directly downstream of the crossing
- Areas of erosion on the right hand bank
- Large levels of sand and a concrete pillar deposited on left hand bank during the March event but was cleaned up by Bulk Water Alliance prior to sampling
- Construction of the M2G uptake nearing completion with the removal of the coffer dam

Site Quality Assessment



MUR23

Point Hut Crossing
2/5/2012 12:15pm

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	TSS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
11.4	150	9.9	7	8.0	99.5	9.9

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
58	0.046	0.044	< 0.002	0.004	0.034	0.44

Daily Flow: 810 ML/day

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

Compared to current flow:

Spring 2011:  Autumn 2011: 

AUSRIVAS Results

	Autumn 2011	Spring 2011	Autumn 2012
Riffle Habitat	B	A	B
Edge Habitat	B	A	B
Overall Site Assessment	B	A	B

Riffle Habitat

- Dominant substrate was cobble

Dominant Taxa

- Simuliidae
- Baetidae
- Hydrobiosidae
- Hydropsychidae

Sensitive Taxa (SIGNAL-2 ≥ 8)

- Colobuiscidae
- Leptophlebiidae
- Gripopterygidae
- Hydrobiosidae

Edge Habitat

- Dominant trailing bank vegetation was macrophytes, wood and shrubs

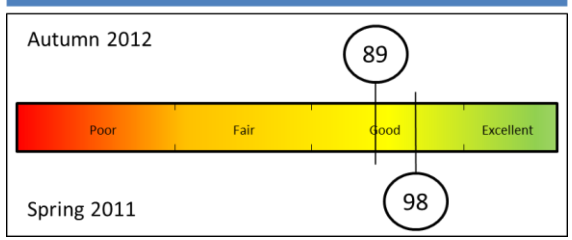
Dominant Taxa

- Baetidae
- Corixidae
- Leptoceridae

Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae
- Gripopterygidae
- Hydrobiosidae

Site Quality Assessment



Additional Comments

- Small areas of erosion on the left hand bank
- Large amounts of sand deposited around the site and within the channel
- Tree's pushed over from high flows
- High level of material scoured from the car park area

MUR28

Upstream Cotter River Confluence
9/5/2012 10:00am

Temp. (°C)	EC (µs/cm)	Turb. (NTU)	TSS (mg/L)	pH	D.O. (% Sat.)	D.O. (mg/L)
10.2	160	4.3	3	8.1	105.7	11.0

Alkalinity	NO_x (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L)	TN (mg/L)
64	0.004	0.002	< 0.002	0.005	0.022	0.33

Daily Flow:

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

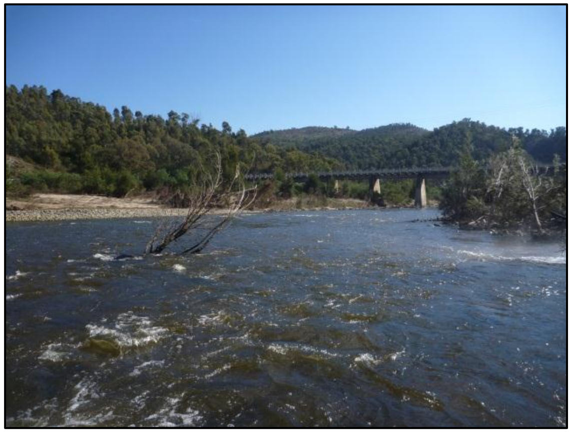
1200 ML/day
Recorded at station 410738, located on the Murrumbidgee River at Mt. MacDonald.

250 ML/day
Recorded at station 410700, located on the Cotter River at Cotter Kiosk (below the Enlarged Cotter Dam).

The high flows down the Cotter River limit the comparability of this seasons flow to that of other seasons, which is further complicated by the operation of the Bendora Scour Valve.

AUSRIVAS Results

	Autumn 2011	Spring 2011	Autumn 2012
Riffle Habitat	A	B	B
Edge Habitat	B	B	B
Overall Site Assessment	B	B	B



Riffle Habitat

- Dominant substrate was bedrock and boulder

Dominant Taxa

- Hydropsychidae

Sensitive Taxa (SIGNAL-2 ≥ 8)

- Leptophlebiidae
- Gripopterygidae
- Hydrobiosidae

Edge Habitat

- Limited edge habitat available due to scour valve, resulting in a single edge sample
- Dominant trailing bank vegetation was wood

Dominant Taxa

- Chironomidae
- Baetidae
- Leptoceridae

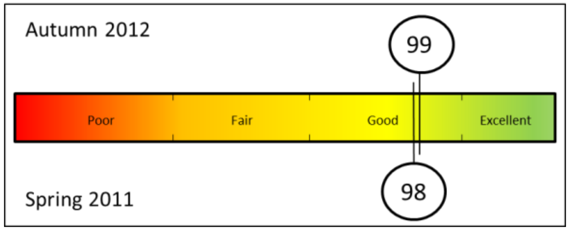
Sensitive Taxa (SIGNAL-2 ≥ 7)

- Leptophlebiidae

Additional Comments

- Bendora Scour Valve has been on for over a week, was turned down, but not completely off, for sampling
- The Murrumbidgee Pump Station is currently recirculating water down the Cotter River, downstream of the Enlarged Cotter Dam

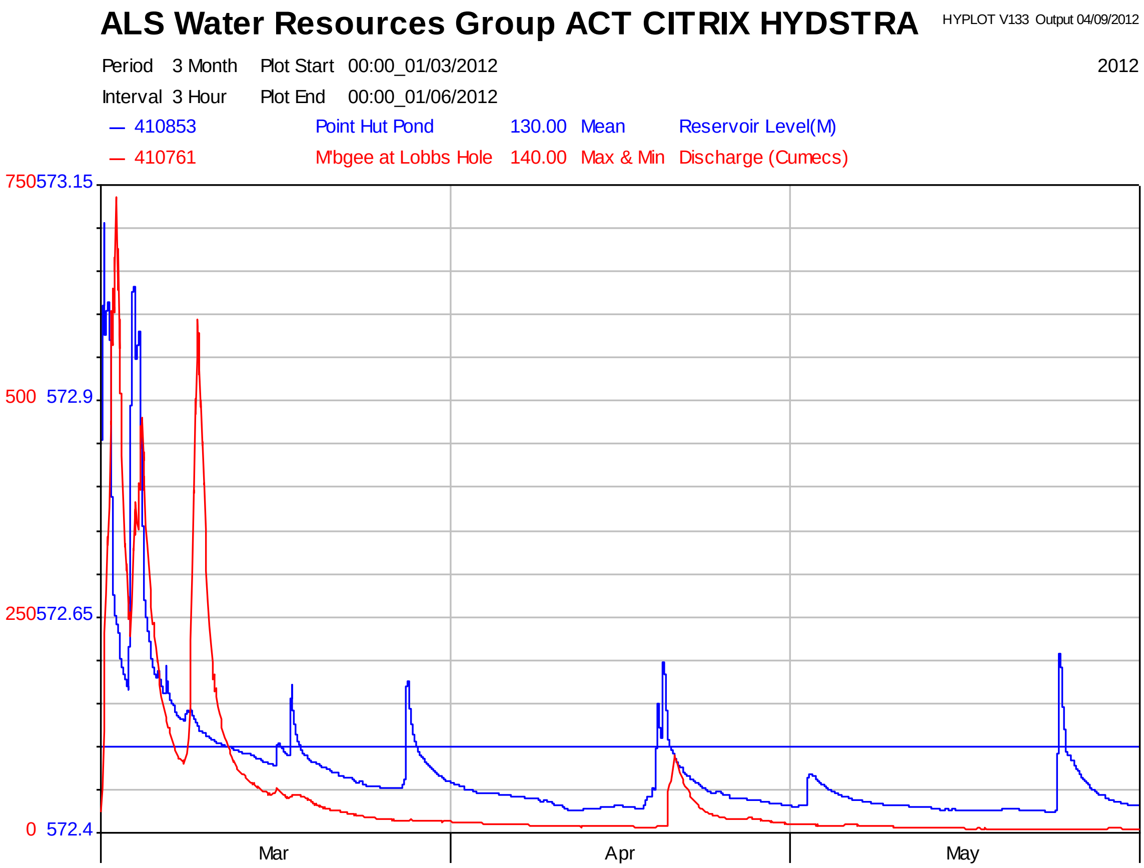
Site Quality Assessment



Appendix C

Point Hut Pond Hydrograph: Autumn 2012

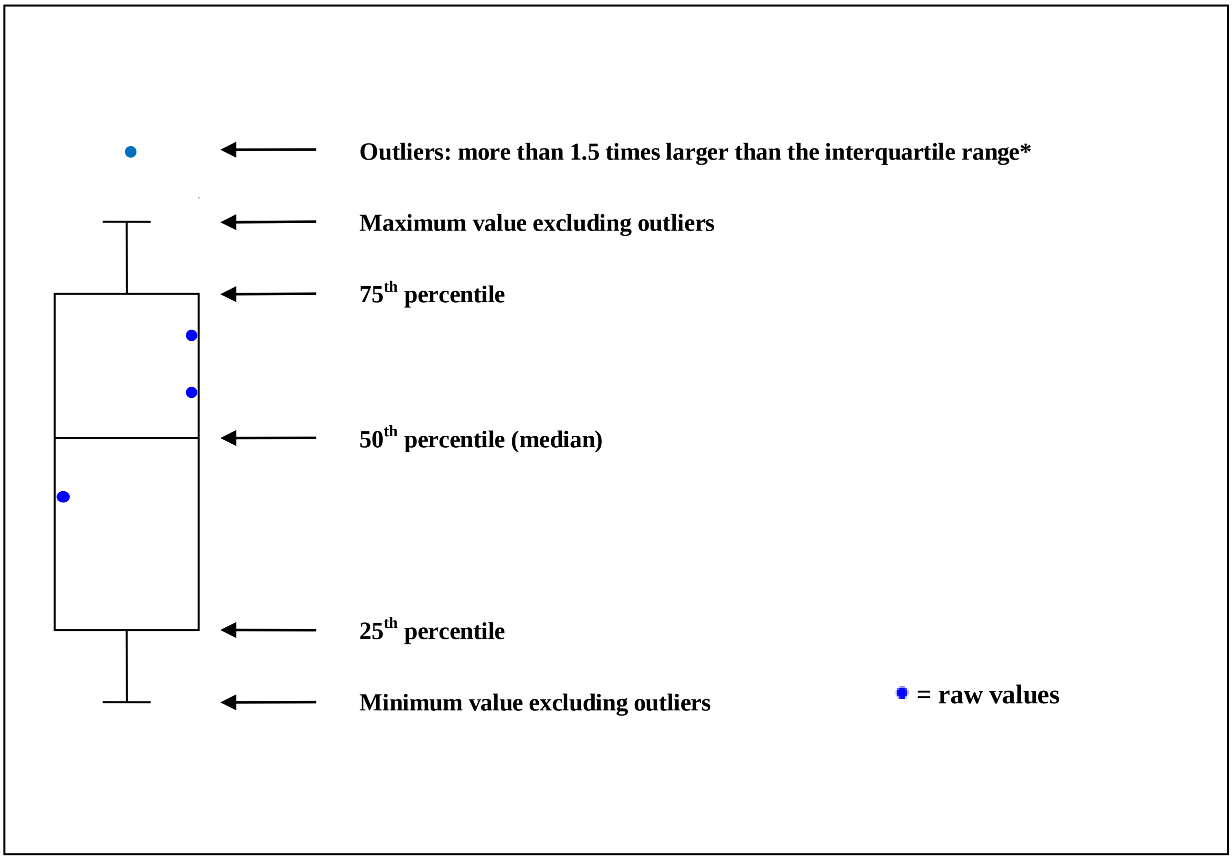
Appendix C. Point Hut Pond and Lobb's Hole Hydrograph showing mean daily flows (in Cumecs) for autumn 2012



Appendix D

Interpreting box and whisker plots

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



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

Appendix E

ANOSIM output for riffle and edge samples

RIFFLE

```
TESTS FOR DIFFERENCES BETWEEN Site Code GROUPS
(across all Location groups)
Global Test
Sample statistic (Global R): 0.584
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN Location GROUPS
(using Site Code groups as samples)
Global Test
Sample statistic (Global R): 0.296
Significance level of sample statistic: 10%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 1
```

EDGE

```
TESTS FOR DIFFERENCES BETWEEN Site Code GROUPS
(across all Location groups)
Global Test
Sample statistic (Global R): 0.598
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN Location GROUPS
(using Site Code groups as samples)
Global Test
Sample statistic (Global R): -0.074
Significance level of sample statistic: 80%
Number of permutations: 10 (All possible permutations)
Number of permuted statistics greater than or equal to Global R: 8
```

Appendix F

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

The number in each cell is the probability of collection. np = not predicted

APPENDIX F. Taxa expected, but not collected in the riffle habitat for autumn 2012

Site	Taxa	Elmidae	Tipulidae	Gripopterygidae	Total number of missing taxa
	SIGNAL	7	5	8	
Mur 15	Riffle	*1.00*	*0.80*		2
Mur 15		*1.00*	*0.80*	*0.60*	3
Mur 15			*0.80*	*0.60*	2
Mur 15		*1.00*	*0.80*		2
Mur 15		*1.00*	*0.80*		2
Mur 15		*1.00*	*0.80*	*0.60*	3
Mur 16	Riffle	*1.00*	*0.80*	*0.60*	3
Mur 16		*1.00*		*0.60*	2
Mur 16		*1.00*		*0.60*	2
Mur 16		*1.00*	*0.80*	*0.60*	3
Mur 16		*1.00*	*0.80*	*0.60*	3
Mur 16		*1.00*	*0.80*	*0.60*	3
Mur 18	Riffle	*1.00*	*0.80*		2
Mur 18		*1.00*	*0.80*	*0.60*	3
Mur 18			*0.80*	*0.60*	2
Mur 18		*1.00*	*0.80*		2
Mur 18		*1.00*			1
Mur 18		*1.00*	*0.80*		2
Mur 19	Riffle	*1.00*	*0.80*		2
Mur 19			*0.80*		1
Mur 19		*1.00*	*0.80*		1
Mur 19		*1.00*	*0.80*	*0.60*	3
Mur 19		*1.00*		*0.60*	2
Mur 19		*1.00*	*0.80*	*0.60*	3
Mur 23	Riffle		*0.80*		1
Mur 23			*0.80*		1
Mur 23		*1.00*			1
Mur 23			*0.80*	*0.60*	2
Mur 23			*0.80*	*0.60*	2
Mur 23		*1.00*	*0.80*	*0.60*	3
Mur 28	Riffle	*1.00*	*0.80*	*0.60*	3
Mur 28			*0.80*	*0.60*	2
Mur 28		*1.00*			1
Mur 28			*0.80*	*0.60*	2
Mur 28			*0.80*	*0.60*	2
Mur 28			*0.80*	*0.60*	2

APPENDIX F (cntd.). Taxa expected, but not collected in the edge habitat autumn 2012

Site	Taxa	Planorbidae	Acarina	Hydrophilidae	Elmidae	Tanypodinae	Leptophlebiidae	Corixidae	Synlestidae	Hydroptilidae	Ecnomidae	Conoesucidae	Gripopterygidae	Leptoceridae	Total number of missing taxa
	SIGNAL	2	6	2	7	4	8	2	7	4	4	7	8	6	
Mur 15	Edge	0.54	np	np	0.63		0.96		0.62			0.57			5
Mur 15	Edge	0.54	np	np	0.63		0.96		0.62		0.57	0.57	0.66	0.97	8
Mur 15	Edge	0.54	np	np	0.63	0.90			0.62			0.57	0.66		6
Mur 15	Edge	0.54	np	np	0.63	0.90			0.62			0.57	0.66		6
Mur 15	Edge	0.54	np	np	0.63				0.62		0.57	0.57	0.66		6
Mur 15	Edge	0.54	np	np	0.63		0.96		0.62		0.57	0.57	0.66		7
Mur 16	Edge	0.55	np	np	0.62	0.90		0.62	0.66		0.59	0.59			7
Mur 16	Edge	0.55	np	np	0.62	0.90		0.62	0.66			0.59			6
Mur 16	Edge	0.55	np	np	0.62			0.62	0.66			0.59			5
Mur 16	Edge	0.55	np	np	0.62				0.66			0.59			4
Mur 16	Edge	0.55	np	np	0.62				0.66		0.59	0.59	0.69		6
Mur 16	Edge	0.55	np	np	0.62				0.66		0.59	0.59	0.69		6
Mur 18	Edge	0.55	np	np	0.62				0.66		0.59	0.59	0.69		6
Mur 18	Edge	0.55	np	np	0.62		0.97	0.62	0.66		0.59	0.59	0.69	0.97	9
Mur 18	Edge	0.55	np	np	0.62	0.90			0.66		0.59	0.59	0.69		7
Mur 18	Edge	0.55	np	np	0.62				0.66	0.93	0.59	0.59	0.69		7
Mur 18	Edge	0.55	np	np	0.62	0.90			0.66			0.59			5
Mur 18	Edge	0.55	np	np	0.62	0.90			0.66			0.59			5
Mur 19	Edge	0.55	np	np	0.62	0.90		0.62	0.66			0.59			6
Mur 19	Edge	0.55	np	np	0.62	0.90			0.66		0.59	0.59	0.69	0.97	8
Mur 19	Edge	0.55	np	np	0.62	0.90		0.62	0.66		0.59	0.59			7
Mur 19	Edge	0.55	np	np	0.62				0.66			0.59	0.69		5
Mur 19	Edge	0.55	np	np	0.62	0.90			0.66		0.59	0.59			6
Mur 19	Edge	0.55	np	np	0.62				0.66		0.59	0.59			5
Mur 23	Edge	np		0.76	0.73				np		np	np	np		2
Mur 23	Edge	np		0.76	0.73	0.93			np		np	np	np		3
Mur 23	Edge	np		0.76	0.73	0.93			np		np	np	np		3
Mur 23	Edge	np	0.58	0.76	0.73				np		np	np	np		3
Mur 23	Edge	np		0.76	0.73	0.93			np		np	np	np	0.97	4
Mur 23	Edge	np	0.58	0.76	0.73	0.93			np		np	np	np		4
Mur 28	Edge	0.55	np	np				0.62	0.66	0.93		0.59	0.69		6
Mur 28	Edge	0.55	np	np	0.62			0.62	0.66		0.59	0.59	0.69		7
Mur 28	Edge	0.55	np	np	0.62	0.90			0.66	0.93	0.59	0.59	0.69		8

Appendix G
Taxonomic Inventory

Appendix G. Taxonomic inventory of the macroinvertebrate taxa collected for the riffle habitat

CLASS / Order	Family / Subfamily	Genus	MUR15	MUR16	MUR18	MUR19	MUR23	MUR28
ACARINA				■	■	■	■	■
BIVALVIA	Corbiculidae	Corbicula				■	■	
	Sphaeriidae				■			
	Sphaeriidae/ Corbiculidae						■	
Coleoptera	Dytiscidae					■	■	
	Elmidae	Austrolimnius					■	
		Coxelmis						■
		Simsonia						■
		sp.	■		■	■		■
		Stetholus						■
	Gyrinidae	Macrogyrus			■			
	Hydrophilidae						■	
Diptera	Chironominae		■	■	■	■	■	■
	Empididae			■	■	■	■	■
	Orthocladiinae		■	■	■	■	■	■
	Simuliidae	Austrosimulium	■	■	■	■	■	■
		Simulium	■	■	■			
		sp.	■	■	■	■	■	■
	Tipulidae			■	■	■	■	■
Ephemeroptera	Baetidae	Baetidae Genus 2	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Caenidae	Genus C		■	■		■	■
		sp.		■	■	■	■	■
		Tasmanocoenis	■	■	■	■	■	■
	Coloburiscidae	Coloburiscoides						■
	Leptophlebiidae	Atalophlebia						■
		Jappa	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
Hemiptera	Corixidae	Micronecta					■	
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera					■	■		
	Gripopterygidae	Dinotoperla	■	■				
		Illiesoperla					■	■
		sp.	■		■	■	■	
Trichoptera	Ecnomidae	Ecnomus		■		■		■
		sp.		■				
	Hydrobiosidae	sp.		■	■	■	■	■
		Taschorema		■	■	■	■	■
	Hydropsychidae	Asmicridea		■	■	■		
		Cheumatopsyche	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
	Hydroptilidae	Orthotrichia		■	■	■	■	
		Oxyethira	■		■		■	
		sp.			■		■	■
	Leptoceridae		■				■	
	Philopotamidae	Chimarra				■		
Turbellaria	Dugesiidae	Dugesia					■	

Appendix G (cont.). Taxonomic inventory of the macroinvertebrate taxa collected for the edge habitat

CLASS / Order	Family / Subfamily	Genus	MUR15	MUR16	MUR18	MUR19	MUR23	MUR28
ACARINA			■	■		■	■	■
BIVALVIA	Corbiculidae	Corbicula		■	■	■		
Coleoptera	Dytiscidae	Necterosoma			■			
	Elmidae	Simsonia						■
		Stetholus						■
	Gyrinidae	Macrogyrus	■		■		■	
	Hydraenidae	Hydraena		■		■	■	
Decapoda	Atyidae	Paratya		■	■	■	■	■
		sp.				■		
	Palaemonidae	Macrobrachium	■	■	■		■	
Diptera	Ceratopogonidae	Ceratopoginae				■	■	
	Chironominae		■	■	■	■	■	■
	Empididae			■	■	■	■	■
	Orthocladiinae		■	■	■	■	■	■
	Psychodidae		■	■	■	■	■	■
	Simuliidae	Austrosimulium	■	■	■	■	■	■
		Simulium	■	■				
		sp.	■	■	■	■	■	■
	Tanypodinae		■	■	■	■	■	■
	Tipulidae		■	■	■	■		■
Ephemeroptera	Baetidae	Baetidae Genus 1					■	
		Baetidae Genus 2	■	■	■	■	■	■
		Cloeon			■			■
		sp.	■	■	■	■	■	■
	Caenidae	Genus C	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
		Tasmanocoenis	■	■	■	■	■	■
	Leptophlebiidae	Atalophlebia		■	■		■	■
		Jappa		■	■	■	■	■
		sp.	■	■	■	■	■	■
GASTROPODA	Physidae	Physa					■	
Hemiptera	Corixidae	Micronecta	■	■	■	■	■	■
Odonata	Gomphidae						■	
OLIGOCHAETA			■	■	■	■	■	■
Plecoptera			■		■	■		■
	Gripopterygidae	Dinotoperla		■	■	■	■	
		Illiesoperla	■				■	
		sp.		■	■	■	■	
Trichoptera	Ecnomidae	Ecnomus	■	■	■	■	■	■
		sp.	■	■		■		
	Hydrobiosidae	sp.	■			■		
		Taschorema	■	■		■		
	Hydropsychidae	Asmicridea				■		■
		Cheumatopsyche	■	■	■	■	■	■
		sp.	■	■		■	■	■
	Hydroptilidae	Hellyethira	■				■	■
		Hydroptila	■			■	■	
		Orthotrichia	■	■	■	■	■	
		Oxyethira	■	■	■	■	■	
		sp.	■	■	■	■	■	
	Leptoceridae	Notalina	■					
		Oecetis	■	■	■	■	■	■
		sp.	■	■	■	■	■	■
		Triaenodes		■		■	■	
		Triplectides	■	■	■	■	■	

GHD

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

Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
1 Draft	Phil Taylor	Christobel Ferguson		Norm Mueller		24/09/2012
2 Draft Final	Phil Taylor	Norm Mueller		Norm Mueller	[signature]	19/10/2012
3 Final	Phil Taylor	Norm Mueller		Norm Mueller	[signature]	31/10/2012