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MURRUMBIDGEE ECOLOGICAL MONITORING PROGRAM

PART 3: MURRUMBIDGEE PUMP STATION

AUTUMN 2011

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List of Abbreviations

ACT	Australian Capital Territory
ACTEW	ACTEW Corporation Limited
AFDM	Ash Free Dry Mass (periphyton)
ALS	Australian Laboratory Services
ANZECC	Australian and New Zealand Environment and Conservation Council
ANOVA	Analysis of Variance (statistics)
APHA	American Public Health Association
ARMCANZ	Agriculture and Resource management Council of Australia and New Zealand
ARI	Average Recurrence Interval
AUSRIVAS	Australian River Assessment System
BACI	Before After Control Impact
CI	Confidence Interval
CMA	Catchment Management Authority
DO	Dissolved Oxygen
EC	Electrical Conductivity
ECD	Enlarged Cotter Dam
EIS	Environmental Impact Statement
EPA	Environmental Protection Authority
GL/a	Gigalitres per annum
GPS	Global positioning system
IBT	Inter-Basin Water Transfer
M2C	Murrumbidgee to Cotter
M2G	Murrumbidgee to Googong
MEMP	Murrumbidgee Ecological Monitoring Program
ML/d	Megalitres per day
NATA	National Association of Testing Authorities
NMDS	Non-metric Multidimensional Scaling (statistics)
NSW	New South Wales
NTU	Nephlelometric Turbidity Units
QA	Quality Assurance
QC	Quality Control
SD	Standard Deviation
TN	Total Nitrogen
TP	Total Phosphorus

Executive Summary

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River, near the Cotter Road bridge. The MPS is adjacent to the Cotter Pump Station which used to have an abstraction capacity of 50ML/d, however the MPS upgrade has increased pumping capacity to Stromlo Water Treatment Plant to 100ML/d, with a total design capacity of 150ML/d.

The upgraded infrastructure also includes a recirculating flow from Murrumbidgee River to the base of the Enlarged Cotter Dam. This will provide environmental flows of up to 40ML/d to the lower Cotter River reach during the construction of the enlarged Cotter Dam (ECD). The program is referred to as the Murrumbidgee to Cotter (M2C) project. This Murrumbidgee Ecological Monitoring program (MEMP) does not monitor the effects of M2C, as this is currently being undertaken by others.

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

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

The key aims of this sampling run were to:

1. *Collect macroinvertebrate community data, upstream and downstream of the MPS*
2. *Provide ActewAGL with river health assessments based on AUSRIVAS protocols at the key sites that could potentially be impacted by construction works and operation of the MPS upgrade*
3. *Collect baseline periphyton data to assist in the characterisation of seasonal and inter-annual temporal variability, and*
4. *Report on water quality upstream and downstream of the MPS*

This report presents the results from biological sampling of the Murrumbidgee River for the monitoring of the MPS in autumn 2011. Sampling was completed in May 2011 and was based on the AUSRIVAS sampling protocols. Sampling was extended to include multiple replicates from each site and specimens were identified to genus level, instead of family level. The reasons for these variations were to a) establish estimates of the within–site variability prior to the commencement of pumping; and b) improve the ability of the monitoring program to detect subtle changes in the macroinvertebrate assemblages in response to water abstraction impacts.

Macroinvertebrate community composition, periphyton assemblages and water quality were monitored from five sites on the Murrumbidgee River, two upstream and three downstream of the Murrumbidgee Pump Station (MPS).River flows and rainfall for the sampling period were recorded at ALS gauging stations located at Lobb's Hole (410761: upstream of the MPS) and Mt. MacDonald (410738: downstream). Baseline physico-chemical water quality parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded at each of the five sites at the time of the biological sampling. Additionally, grab samples were taken from each site for verification of in-situ data and nutrient analysis.

Macroinvertebrates were sampled in the riffle and edge habitats where available. Both habitats were sampled to provide a more comprehensive assessment of each site. (Sampling was undertaken on 4th and 5thMay2011.

Periphyton samples were collected using the in-situ syringe method. In addition to this technique, qualitative assessments of the estimated substrate coverage by periphyton and filamentous green algae were also conducted.

The key results from the autumn 2011 sampling of the MPS indicate that:

1) *During the autumn period, there were no abstractions from the MPS to the Stromlo Water Treatment facility suggesting that variation in any of these indicators is likely a function of other environmental parameters unrelated to the MPS operation or infrastructure works. However, flows between 25-46ML/d were diverted on a daily basis to the base of the Cotter Dam since February 4th to provide environmental flows to the lower Cotter reach during the ECD construction. Stop-logs were removed from the Cotter Dam wall in mid-April and this increased flows in the lower Cotter reach from approximately 90ML/d to 530 ML/d over a one week period, which contributed to 52% of the Murrumbidgee flow downstream of the confluence over the latter part of April.*

2) *For the majority of the water quality parameters, there was no difference between upstream and downstream sites. Total Nitrogen and Total Phosphorus were above the ANZECC guideline values at both sites upstream of the MPS and one site immediately downstream of the Cotter River confluence. Despite this, these concentrations tended to dissipate downstream, which may be influenced by additional flow entering the Murrumbidgee River from the Cotter River. Further evidence for this can be found from the slightly lower EC concentrations, downstream of the Cotter confluence. Dissolved oxygen varied slightly between locations, but this is attributed to variations in the time of day at which the samples were taken.*

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

4) *There was no evidence for differences in chlorophyll-a concentrations or Ash Free Dry Mass (AFDM) – measures of algal productivity - between upstream and downstream locations.*
Compared to the autumn 2010 sampling results the concentration levels of chlorophyll-a were very similar. Comparatively, the concentrations of AFDM are markedly reduced this season. This difference in concentration levels is likely due to the preceding high flow period during March and an increase in flows from the Cotter River occurring approximately two weeks before sampling occurred. It has previously been found that floods and higher flow velocities reduce the AFDM and silt content of the periphyton more than they do to the chlorophyll-a concentrations.

5) *While sampling was not possible in spring 2010 due to high flows for extended period, there has been a notable improvement in the condition of the riffle habitat assemblages based on the AUSRIVAS modelling information. The increased abundance of EPT taxa in the riffle*

habitat and the step up from BAND B to BAND A suggests that since autumn 2010, prolonged periods of high flow over spring and again in early March may have had the beneficial effect of removing fine sediment build up in the substrate and by doing so, improved habitat availability and quality for taxa that rely on clean and diverse substrates.

6) *There was a high degree of similarity amongst the riffle macroinvertebrate communities (all sites were grouped together at 70% similarity) indicating the influence of similar environmental conditions leading up to the sampling run. In the absence of any pumping or construction related work on the MPS the similarity amongst sites and locations is not surprising given the similarities in substrate, vegetation and land-use seen between these sites. At 75% similarity, the downstream sites formed a single group and the upstream sites formed individual groups. These subtle differences are due to changes in the dominance of certain taxa as opposed to their absence. The downstream sites had a higher abundance of Baetid mayfly's which might indicate that the additional flow entering the Murrumbidgee River from the Cotter confluence facilitates a higher number of these taxa by increasing habitat availability and quality.*

7) *The edge habitat remained at BAND B at all sites, which despite the improvements in the riffle assessments, resulted in overall site assessments equivalent to autumn 2010 (i.e. BAND B). The reasons for this are probably linked again to the flushing flows of spring and early autumn, where several ubiquitous taxa may have been washed away under the higher flow conditions. Furthermore, it is feasible that their habitat (i.e. submerged logs, macrophytes and detritus) had the same fate, resulting in slower recruitment rates and more variable edge habitat leading to patchy distributions of even the more common taxa, and therefore less taxa being collected by the AUSRIVAS model.*

From our current sampling design is it evident that flow is highly influential in shaping the macroinvertebrate community structure. High flow results in a reduction in the estimated abundances of specific groups of taxa such as Ephemeroptera: Plecoptera and Trichoptera (EPT) and free-living edge taxa which are otherwise ubiquitous throughout the sampled reaches. There has been little change in the number of taxa collected throughout this baseline period, suggesting a high degree of resilience in the macroinvertebrate communities, despite being exposed to a highly variable range of daily flows.

The resistance and resilience of the macroinvertebrate fauna to any potential impact resulting from the (up to) 100 ML/d abstraction from the MPS are likely to depend on a) the timing of the abstractions and b) the duration that flows are abstracted. Macroinvertebrate communities are likely to be at their most vulnerable in summer and autumn when Murrumbidgee base flows are at their lowest levels; and if flows are artificially lowered through ongoing water abstractions during these months we could expect to see some initial changes in water quality and loss of some of the more sensitive EPT taxa. At this point however, our knowledge is limited to natural variations occurring in the system without the operation of the MPS.

1 Introduction

The Murrumbidgee Ecological Monitoring Program (MEMP) was set up by ACTEW Corporation to evaluate the potential impacts of water abstraction from the Murrumbidgee River. It is being undertaken as part of the ACT Water Supply security infrastructure upgrade. The proposed timeline was initially to undertake sampling in spring and autumn over a three year period commencing in spring 2008, however this has been extended until 2012. The MEMP is currently being project managed by ActewAGL.

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

Part 1: Angle Crossing (intake point for Murrumbidgee to Googong-M2G transfer)

Part 2: Burra Creek (discharge point for M2G abstraction)

Part 3: Murrumbidgee Pump Station

Part 4: Tantangara to Burrinjuck

This report focuses on Part 3: Murrumbidgee Pump Station.

The Murrumbidgee Pump Station (MPS) is located just downstream of the Cotter River confluence with the Murrumbidgee River. It is adjacent to the Cotter Pump Station which used to abstract up to 50ML/d, contributing to the water supply for the ACT. The recently upgraded Murrumbidgee Pump Station has increased the abstraction capacity from the Murrumbidgee River to 100ML/d via the MPS, with a design capacity of 150ML/d. The upgraded infrastructure will also provide a recirculating flow of up to 40ML/d from the Murrumbidgee to the base of the Enlarged Cotter Dam (ECD), providing environmental flows to the lower Cotter reach during the construction of the ECD. This project is referred to as Murrumbidgee to Cotter (M2C) transfer. The MEMP project does not aim to monitor the effects of the M2C transfer, but rather provides a characterisation of the baseline condition prior to that project coming on line.

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

The increase in abstraction at the Murrumbidgee Pump Station (MPS) may place additional stress on the downstream river ecosystem. This monitoring program has been established to monitor the condition of the Murrumbidgee River in terms of water quality and ecological condition at key sites both upstream and downstream of the extraction point (MPS). Monitoring will eventually extend to the period after the proposed abstractions are implemented and data collected in that phase will be compared with those collected as part of this study.

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

1.1 Project objectives

The objective of the MPS monitoring program is to provide ACTEW with seasonal assessments of river health affected by the operation of the upgraded Murrumbidgee Pump Station under the requirements of Actew's licence to abstract water (# WU67, section D6).

Specifically, the aims of the project are to:

1. Meet Actew's monitoring obligations under the requirements of its licence to abstract water;

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

3. Obtain baseline macroinvertebrate, water quality and periphyton data for eventual use in the assessment of whether or not the proposed abstractions from the MPS are impacting the ecology and ecological "health" of the Murrumbidgee system downstream of the MPS. This study will also provide ACTEW with river health assessments based on AUSRIVAS protocols at the key sites concerning the operation and the works associated with the upgrade of the MPS.

1.2 Project scope

The current ecological health of the sites monitored as part of the Murrumbidgee Pump Station (MPS) monitoring program is estimated using AUSRIVAS protocols for macroinvertebrate community data; combined with a suite of commonly used biological metrics and descriptors of community composition. The scope of this report is to convey the results from the autumn 2011 sampling run. Specifically, as outlined in the MEMP proposal to ACTEW Corporation (ALS, 2011), this work includes:

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

1.3 Rationale for using biological indicators

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

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

2 Methods and Materials

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

Sampling of riffle and edge habitats was carried out in order to provide a comprehensive assessment of each site. The monitoring of both habitats potentially allows the program to isolate flow related impacts from other disturbances. The reasoning behind this is that each habitat is likely to be affected in different ways. Riffle zones, for example, are likely to be one of the first habitats affected by low flows and water abstractions (Boulton, 2003; Dewson *et al.*, 2007; Smakhtin, 2001), 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.

2.1 Study sites

Site selection was based upon the recommendations outlined in ACTEW's licence to take water #WU67 section D6 Site names and locations are given in Table 1 and shown in Figure 1, with photos in Plates 1 and 2). Prior to sampling, comprehensive site assessments were carried out, including assessments of safety, suitability and granted access from landowners. As outlined in this document, there are no suitable reference sites in the proximity for this assessment, so a before – after / control – impact (BACI) design (Downes *et al.*, 2002) was adopted based on sites upstream of the abstraction point serving as control sites and sites downstream of the abstraction / construction point serving as impact sites. Baseline monitoring carried out as part of this study will serve as the 'Before' period for this assessment.

Table 1. Sampling site locations and details

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

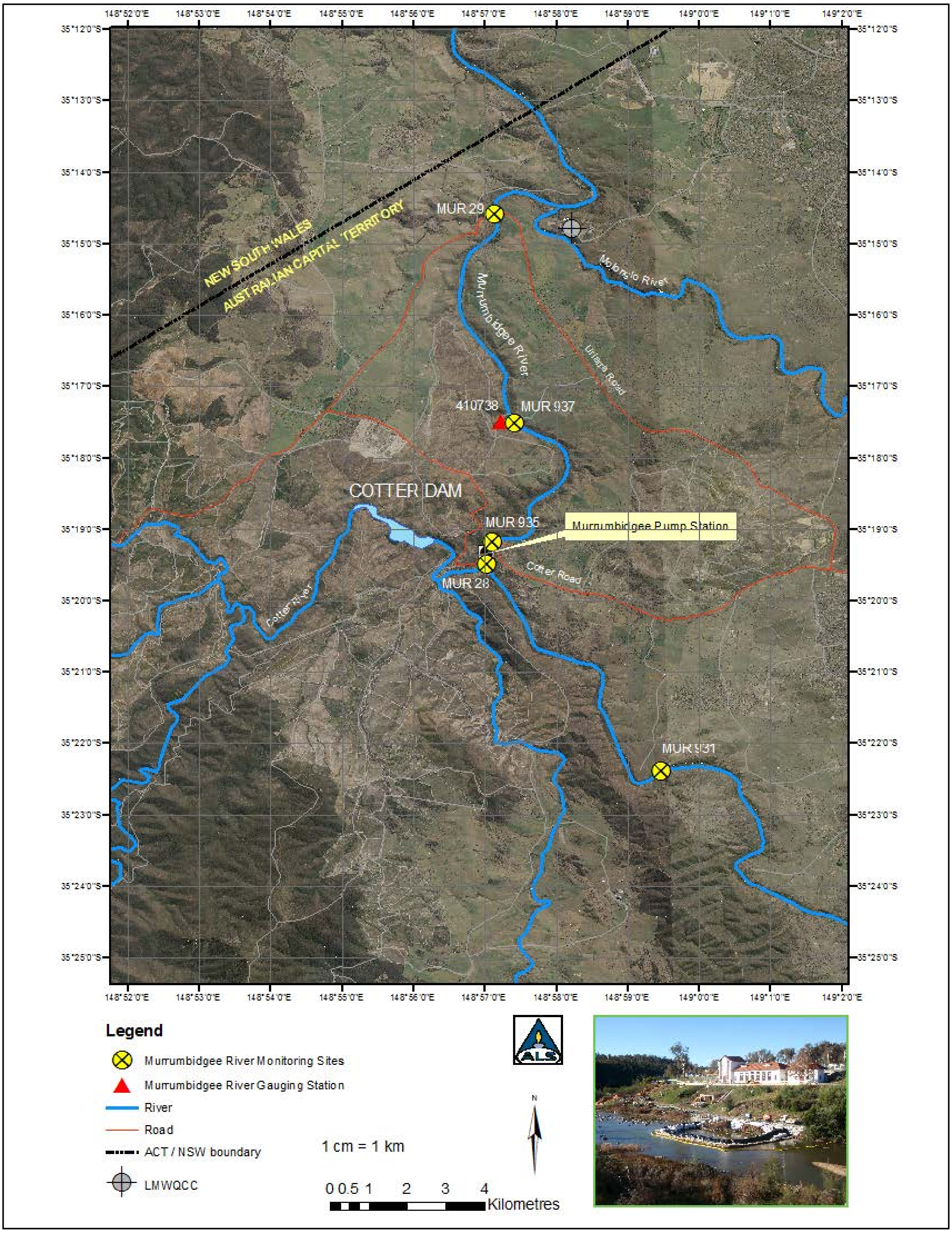

Figure 1. Location of the monitoring sites and gauging stations for the MPS monitoring program

Note: Lobbs Hole gauging station (410761) is located approximately 25 km upstream of MUR 931

MUR 931. Looking downstream

MUR 931. Facing across stream to true left bank

MUR 28. Facing upstream

MUR 28. Looking downstream towards Cotter Bridge

Plate 1. Monitoring sites upstream of the Murrumbidgee Pump Station

MUR 935. Looking upstream to Cotter Road Bridge

MUR 935. Diminishing wetted width

MUR 937. Riffle habitat, looking upstream

MUR 937. Looking downstream

MUR 29. Riffle habitat looking downstream

MUR 29. Flood damage to riparian zone

Plate 2. Monitoring sites downstream of the Murrumbidgee Pump Station

2.2 Hydrology and rainfall

River flows and rainfall for the sampling period were recorded at ALS gauging stations at Lobb's Hole (410761, ~25km upstream of MUR 931), Mt. MacDonald (410738, ~5km downstream of the MPS) and the Cotter River at Kiosk (410700, just downstream of the Cotter Dam).

Site locations and codes are given in Table 2.

Table 2. Stream flow and water quality monitoring site locations.

Site Code	Location/Notes	Parameters*	Latitude	Longitude
410700	Cotter @ Kiosk	WL, Q	S -35.3240	E 148.9417
410738	M'bidgee River @ Mt. MacDonald	WL, Q	S -35.2917	E 148.9565
410761	M'bidgee River @ Lobb's Hole	WL, Q, pH, EC, DO, Temp, Turb	S -35.5384	E 149.1013
570985	M'bidgee River @ Lobb's Hole	Rainfall	S -35.5375	E 149.1021

Note: WL = Water Level; Q = Rated Discharge; EC = Electrical Conductivity; DO = Dissolved Oxygen; Temp = Temperature; Turb = Turbidity

2.3 Water quality

Baseline physico-chemical parameters including temperature, pH, electrical conductivity, turbidity and dissolved oxygen were recorded at each sampling site using a multiprobe Hydrolab® Minisonde 5*a* Surveyor.

The Surveyor was calibrated in accordance with ALS QA procedures and the manufacturer's requirements prior to sampling. Additionally, grab samples were taken from each site in accordance with ACT AUSRIVAS protocols (Coysh *et al.*, 2000) for Hydrolab® verification and nutrient analysis.

All samples were placed on ice, returned to the ALS laboratory and analysed for nitrogen oxides (total NOx), total nitrogen (TN) and total phosphorus (TP) in accordance with the protocols outlined in APHA (2005). Collectively, this information on the water quality parameters will assist in the interpretation of the biological data and in its own right provide a basis on which to gauge ecosystem changes linked to changes in flow at these sites once the MPS is operational.

2.4 Macroinvertebrate sampling

Riffle and edge habitats were sampled for macroinvertebrates (May 4th and 5th) and analysed using the ACT autumn riffle and edge AUSRIVAS (Australian River Assessment System) protocols (Coysh, *et al.*, 2000). At each site, two samples were taken from the riffle habitat (flowing broken water over gravel, pebble, cobble or boulder, with a depth greater than 10 cm; (Coysh, *et al.*, 2000) using a framed net with 250 µm mesh size. Sampling began at the downstream end of each riffle. The net was held perpendicular to the substrate with the opening facing upstream. The stream bed directly upstream of the net opening was agitated by vigorously kicking, allowing dislodged invertebrates to be carried into the net by the current. The process continued, working upstream over 10 metres of riffle habitat. Samples were then preserved in 70% ethanol, clearly labelled with site code and date, then stored on ice and placed in a refrigeration unit until laboratory sorting commenced.

The edge habitat was also sampled according to 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 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.

2.5 Periphyton

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

The five sampling sites selected for this project (Table 1) were sampled for periphyton in autumn in conjunction with the macroinvertebrate sampling. All periphyton (i.e. adnate and loose forms of periphyton, as well as organic/inorganic detritus in the periphyton matrix) samples were collected using the *in-situ* syringe method similar to Loeb (1981), as described in Biggs and Kilroy (2000).

A 1 m wide transect was established across riffles at each site. Along each transect, 12 samples were collected at regular intervals, using a sampling device of two 60 ml syringes and a scrubbing surface of stiff nylon bristles covering an area of ~637 mm^2. The samples were divided randomly into two groups of 6 samples to be analysed for Ash Free Dry Mass (AFDM), and chlorophyll-a. Samples for Ash Free Dry Mass and chlorophyll-a analysis were filtered onto glass filters and frozen. Sample processing followed the methods outlined in APHA (2005).

2.6 Data analysis

Data were analysed using both univariate and multivariate techniques using the software R ver.2.10.1. (R Development Core Team, 2008) and PRIMER v6 (Clarke and Gorley, 2006). Details of these analyses are provided below.

2.6.1 Water quality

Water quality parameters were examined for compliance with ANZECC & ARMCANZ (2000) water guidelines for healthy ecosystems in upland streams. Trend analyses of water quality parameters will be conducted at the end of the baseline collection period.

2.6.2 Macroinvertebrate communities

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

Processing of the aquatic macroinvertebrate samples followed the ACT AUSRIVAS protocols. Briefly, in the laboratory, the preserved macroinvertebrate samples were placed in a sub-sampler, comprising of 100 (10 X 10) cells (Marchant, 1989). The sub-sampler was then agitated to evenly distribute the sample and the contents of randomly selected cells removed. Macroinvertebrates from each selected cell were identified to genus level. Specimens that could not be identified to the specified taxonomic level (i.e. immature or damaged taxa) were removed from the dataset prior to analysis.

For the ACT AUSRIVAS model, all taxa were analysed at the family level except Chironomidae (identified to sub-family), Oligochaeta (class) and Acarina (order). Animals were identified using taxonomic keys listed in Hawking (2000). All animals within the cell were identified. Data was entered directly into electronic spread-sheets to eliminate errors associated with manual data transfer.

Non-metric multidimensional scaling (NMDS) was performed on the macroinvertebrate community data following the initial cluster analysis. NMDS is a multivariate procedure that reduces the dimensionality of multivariate data by describing trends in the joint occurrence of taxa and aids with interpretation. The initial step in this process was to calculate a similarity matrix for all pairs of samples based on the Bray-Curtis similarity coefficient (Clarke and Warwick, 2001). For the macroinvertebrate data collected during this survey, the final number of dimensions is reduced to two. How well the patterns in the 2-dimensional NMDS plot represents the multivariate data is indicated by the stress value of each plot. The stress level is a measure of the distortion produced by compressing multidimensional data into a reduced set of dimensions and will increase as the number of dimensions is reduced. Stress can be considered a measure of "goodness of fit" to the original data matrix (Kruskal, 1964), and when near zero suggests that NMDS patterns are very representative of the multidimensional data. Stress greater than 0.2 indicates a poor representation (Clarke and Warwick 2001).

An analysis of similarities (ANOSIM) was performed on the data to test whether macroinvertebrate communities were statistically different upstream and downstream of the proposed discharge point. Sites were unable to be nested with location in the two-way design due to a lack of replication at several of the sites. Instead, a one-way analysis examined the differences between location (up and downstream of the MPS, using site as the unit of replication).

The similarity percentages (SIMPER) routine was carried out on the datasets only if the initial ANOSIM test was significant (i.e. $P<0.05$), to examine which taxa were responsible for, and explained the most variation among statistically significant groupings. This procedure was also used to describe groups (i.e. which taxa characterised each group of sites) (Clarke and Warwick, 2001).

2.6.3 AUSRIVAS assessment

AUSRIVAS is a prediction system that uses macroinvertebrates to assess the biological health of rivers and streams. Specifically, the model uses site-specific information to predict the macroinvertebrate fauna expected (E) to be present in the absence of environmental stressors. The expected fauna from sites with similar sets of predictor variables (physical and chemical characteristics influenced by non-human characters, e.g. altitude) are then compared to the observed fauna (O), and the ratio derived is used to indicate the extent of any impact (O/E). The ratio derived from this analysis is compiled into bandwidths (i.e. X, A-D; Table 3) which are used to gauge the overall health of a particular site (Coysh *et al.* 2000). Data is presented using the AUSRIVAS O/E 50 ratio (Observed/Expected score for taxa with a >50% probability of occurrence) and the previously mentioned rating bands (Tables 3).

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

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

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

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

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

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

2.6.5 Periphyton

The raw Chlorophyll-a and Ash Free Dry Mass (AFDM) data were converted to estimates of concentrations and biomass (per square metre) respectively, following the methodology outlined in Biggs and Kilroy (2000).

These data were used to test for differences between upstream-control locations versus downstream impact locations. Log transformed Chlorophyll-a and raw AFDM data were fitted to a mixed effects, nested analysis of variance (ANOVA). Site was nested within location and was treated as a random effect and location was considered a fixed effect. For the purposes of graphical visualisation, raw data are presented.

2.7 Macroinvertebrate quality control procedures

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

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

All procedures were performed by AUSRIVAS accredited staff.

2.8 Licenses and permits

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

ALS field staff maintain current ACT AUSRIVAS accreditation.

3 Results

3.1 Summary of sampling and river conditions

Autumn sampling was completed on the 4th and 5th of May. Mean daily flows recorded at the time of sampling at 410761:Lobb's Hole (closest upstream station to MUR 931) and 410738:Mt. MacDonald (at MUR 937) were 225 ML/d and 352 ML/d respectively. In this round of sampling, flow conditions were stable for much of autumn due to low rainfall throughout April, despite March having higher than average rainfall. There was limited edge habitat at MUR 28 and MUR 29 which meant that only one edge sample was possible at these sites (Table 4). Air temperatures of the sampling period ranged between 6°C and 16°C and weather conditions were fine.

There was a notable absence of emergent and submergent macrophytes across all sites. Although the amount of sand in the riffles appears to have declined since the floods, there are currently some thick mats of periphyton and fresh silt deposits which have probably developed during this low flow period following the floods in spring. The thick mats of periphyton growth were especially prolific along the retreating margins at MUR 935 and MUR 937.

Table 4. Macroinvertebrate samples collected during the autumn sampling run

Site	Edge	Riffle
MUR 931	2	2
MUR 28	1	2
MUR 935	2	2
MUR 937	2	2
MUR 29	1	2

3.2 Hydrology and rainfall

March was the wettest month in autumn with 99.2 mm of rainfall recorded at Lobb's Hole, which is a slight decrease on last season ALS (2010), but almost twice the long term average for March (51.8mm). There were 23 wet days for the season, averaging 7.7 per month. The rainfall for the whole autumn period was 126.8mm with the highest event of 54.8 mm in mid-March. Rainfall and flow is shown in Figure 2.

This high level of rainfall in mid-March produced 55% of March's rainfall and resulted in a flow peak of 4290 ML/d at Lobb's Hole and 3880 ML/d at Mt. MacDonald, showing a localised peak at Lobb's Hole, which tended to dissipate downstream (Figure 2a). These events had annual recurrence intervals (ARI) of 1.5yr and 1.25yr respectively. Rainfall and flow data are summarised in Table 5. Flows downstream of the Cotter Dam ranged from 48.8 – 573 ML/d during autumn. The highest flows occurred during April, the increase in flows during the latter part of the month ranged from 439 to 494 ML/d (Figure 3) and contributed to approximately 52% of the Murrumbidgee Flow downstream of the confluence between 20th-26th of April.

The Murrumbidgee pump station was commissioned for operation in 2010. From February 4th to June 30th 2011, the MPS has been continuously diverting between 25 - 46 ML/d to the base of the Cotter dam from February 4th – June 30th, providing an environmental flow release during the construction of the ECD. Additionally, water from the Bendora gravity main has been released via the Bendora scour valve, upstream of the Cotter Bridge adjacent to MUR 28. Water is being released into the Murrumbidgee River to minimise spilling of Bendora Dam during the ECD construction, downstream at the Cotter Dam. A flow of 110 ML/d was released continuously from the scour valve from May 19th – June 8th, thereby not coinciding with the autumn 2011 sampling run (see Figure 2).

In the third week of April, a small section of the flashboards (or stop-logs) that were installed to a height of 2m above the spillway on the Cotter Dam wall, to increase the storage capacity during ECD construction, were removed for a week to reduce the high water level providing additional buffering capacity during a critical construction phase.

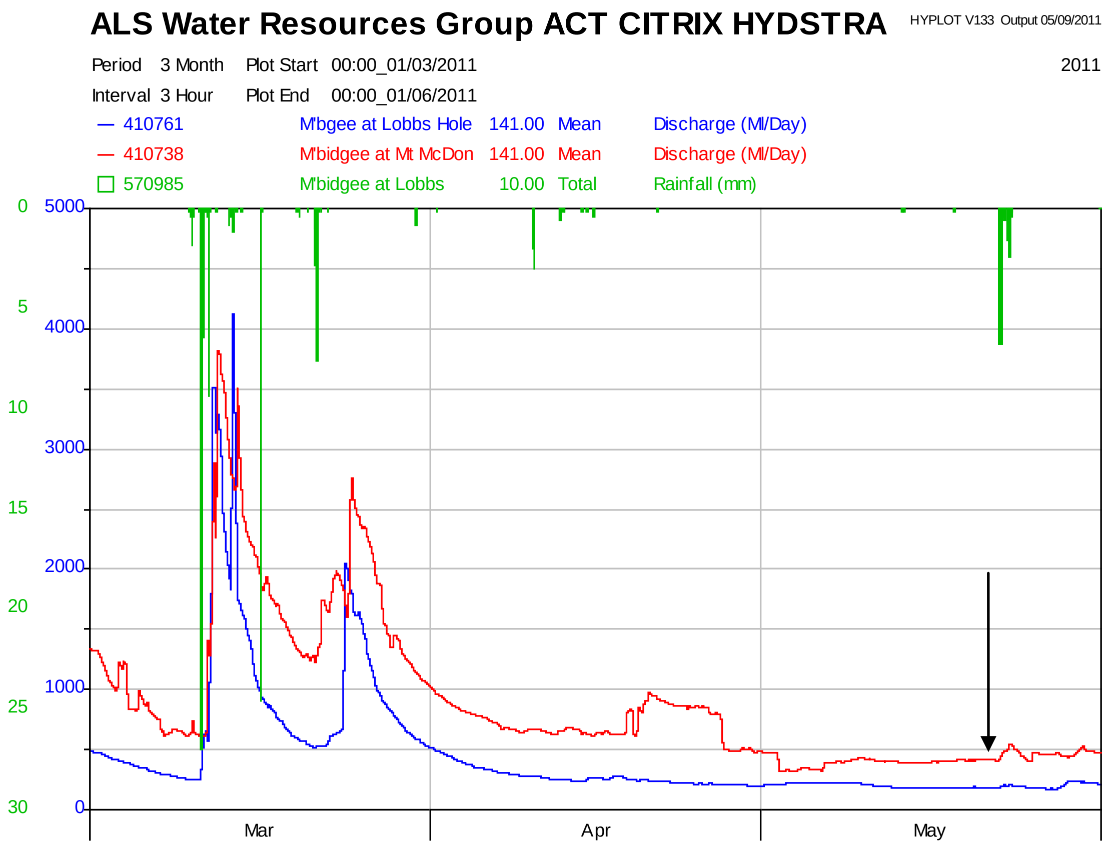

Figure 2. Autumn hydrograph of the Murrumbidgee River at Lobb's Hole (410761) and Mt. MacDonald (410738). Total rainfall was recorded at the Lobb's Hole station. The arrow indicates the date the 110ML/d release from the Bendora Gravity main commenced, via the scour valve – adjacent to MUR 28.

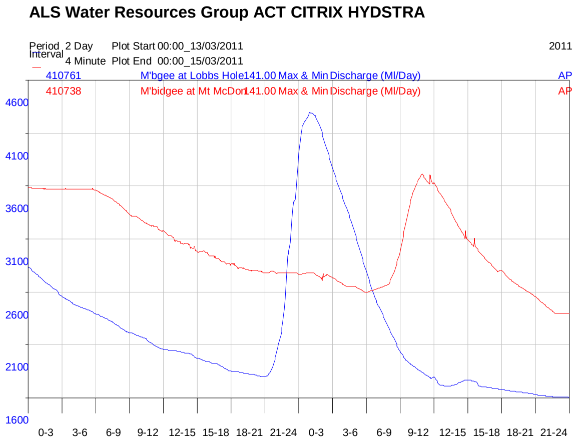

Figure 2a. Zoomed in view of Figure 2. for13-14 March indicating downstream dissipation of flow from Lobb's Hole(blue line) to Mt. MacDonald(red).

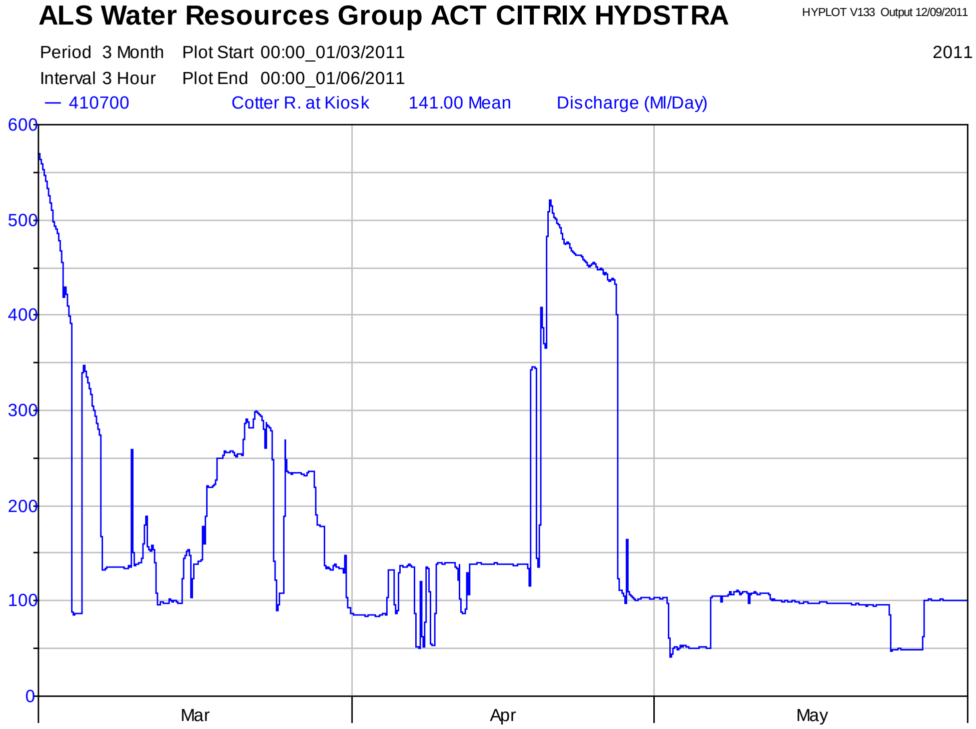

Figure 3. Hydrograph for the Cotter River downstream of Cotter Dam (410700) for autumn 2011.

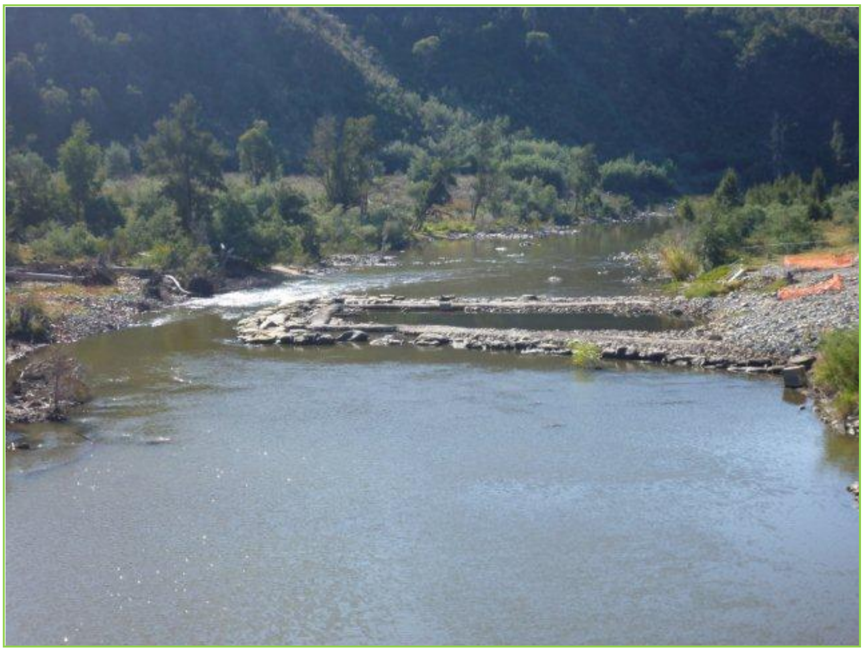

Plate 3. The Murrumbidgee River viewed from the Cotter Road bridge.

Top: looking downstream with Coffer dam in the mid-ground and; Bottom: looking upstream. Mean daily flow at the time these photographs were taken (5/05/2011) was 352 ML/d at the Mt. MacDonald gauging station (410738).

Table 5. Monthly flow and rainfall statistics for autumn 2011 at Lobb's Hole (410761) and Mt. MacDonald (410738).

Station	Lobb's Hole (410761)		Mt. MacDonald (410738)
	Rainfall Total (mm)	Mean Flow (ML/d)	Mean Flow (ML/d)
March	99.2	862.2	1524.0
April	7.2	276.3	728.8
May	20.4	201.0	418.1
Autumn	**126.8 (42.3/mth)**	**448.9**	**890.3**

3.3 Water quality

The pH data is missing for the majority of the autumn period from Lobb's Hole due to a probe failure, with a significant delay in spare component availability from the supplier. However, all other parameters where logged correctly.

Mean monthly water quality values are given in Table 6. The data shows that all continuously recorded physic-chemical parameters were within ANZECC & ARMCANZ guidelines for the autumn period. The one exception was the turbidity level during a period in March, which corresponds to a period of increased flow due to a number of consecutive rainfall events (refer Figure 2).

The overall patterns in the continuous water quality data show a gradual decline in the water temperature (Figure 4). This corresponds to the decline in ambient temperatures which were decreasing towards the beginning of winter. The turbidity was consistently low other than the aforementioned period during March. Throughout the autumn period EC steadily increased, with the exception of a period during late March-early April where there was a distinct drop (Figure 4) due to a rainfall flushing event.

The results from the grab samples are given in Table 7 and show there is currently no evidence to suggest the MPS upgrade is having any negative affect upon the key water quality parameters. There is a noticeable decrease in the turbidity readings downstream of the pump station with readings also indicating super saturation of DO downstream of MPS. There is also an evident increase in pH from upstream to downstream sites, with the furthest site downstream (MUR 29) on the upper limit of the ANZECC & ARMCANZ guidelines (highlighted in yellow in Table 7).

Nitrogen oxides were below detectable levels at all sites. Total phosphorus concentrations exceeded the ANZECC & ARMCANZ guidelines at both upstream sites and one downstream site (MUR 935) measuring 0.03 mg/L, with the remaining two sites on the upper limit. Total nitrogen concentrations exceeded the ANZECC & ARMCANZ guidelines at all sites measuring 0.27 mg/L, except site MUR 29 which was on the upper limit of the guidelines. The remaining parameters were similar across all sites (Table 7).

Table 6. Monthly water quality statistics from Lobb's Hole (410761)

All values are means. Monthly maximum turbidity values are in parentheses. Dissolved Oxygen is expressed as mean monthly minimums and maximums

Station	Lobb's Hole (410761)				
Analyte	Temp.	EC	pH	Turbidity	D.O. (% Sat.)
March	20.2	118.7	7.98	188 (965)	93-97
April	15.3	114.2	NA	5 (18)	96-98
May	10.3	124.1	NA	5 (30)	95-98
Autumn	**15.2**	**119**	**7.98**	**66 (965)**	**94-97**

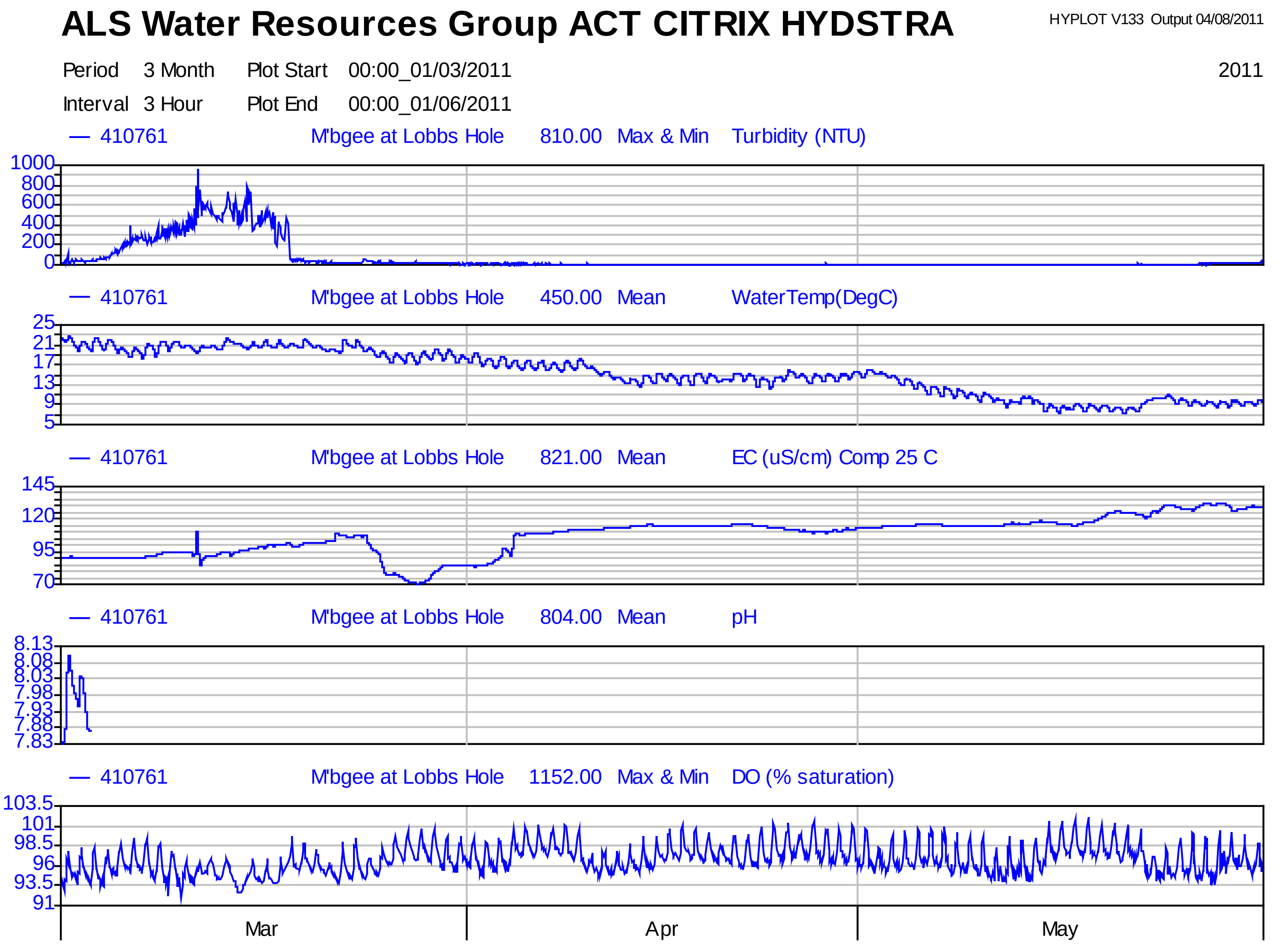

Figure 4. Continuous water quality record from Lobb's Hole (410761) for autumn 2011

Table 7. Water quality results for autumn 2011.
ANZECC & ARMCANZ (2000) guidelines are in brackets in the heading row in bold.
Orange cells indicate values outside guidelines. Yellow cells indicate values are on the cusp of the upper limit of the guideline.

Location to MPS	Site	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)	Alk.	NOx (mg/L) [0.015]	Nitrate (mg/L)	Nitrite (mg/L)	Ammonia (mg/L)	TP (mg/L) [0.02]	TN (mg/L) [0.25]
Upstream	MUR 931	09.30	13.3	110.1	6.5	11	7.6	97.3	10.3	47	<0.01	<0.01	<0.01	0.04	0.03	0.27
	MUR 28	12.00	13.9	111.6	6.9	11	7.8	100.2	10.5	48	<0.01	<0.01	<0.01	0.04	0.03	0.27
Downstream	MUR 935	13.30	14.3	112.1	6	10	7.9	106.0	11.0	48	<0.01	<0.01	<0.01	<0.01	0.03	0.27
	MUR 937	16.05	14.8	114.6	4.3	9	7.9	109.1	11.2	48	<0.01	<0.01	<0.01	<0.01	0.02	0.27
	MUR 29	15.05	15.7	107.3	5.4	6	8.0	103.9	10.4	49	<0.01	<0.01	<0.01	0.01	0.02	0.25

3.4 Periphyton

Chlorophyll-a concentrations showed less site to site variation than in previous sampling events (ALS, 2009 & 2010) (Figure 5). The highest concentrations (119,240 µg/m^{-2}) were detected at MUR 28, upstream of the Murrumbidgee Pump Station, while the lowest value (3775 µg/m^2) was detected downstream of the pump station at MUR 29. Average concentration upstream of the MPS was 35,110 ± 20,063 µg/m^2 (95% CI) compared to an average of 31,602 ± 20,063 µg/m^2 (95% CI) downstream.

Despite the slightly higher average upstream, they were determined to be not significantly different between locations ($F_{1,3}$ = 0.016; P=0.91; Table 8). Compared to previous sampling runs, the main differences appear to be a wider range of values at MUR 937 including higher maximum values at that site.

The average periphyton ash free dry mass (AFDM) for the upstream sites was 6,999 ± 2,397 mg/m^2 (95% CI) compared to 6,396 ± 22,620 mg/m^2 (95% CI) downstream of the MPS (Figure 6). These values were not significantly different between locations ($F_{1,3}$ = 0.32; P=0.61; Table 8). The highest value was recorded at MUR 937, which is consistent with our field observations, where "thick mats of periphyton observed across the transect; with evidence of decomposing *Juncus* sp. and *Myriophyllum* sp. throughout the slow sections of the riffle" (Taylor, *Pers. Obs*. 2011). There was a moderate relationship between chlorophyll-a concentrations and AFDM (R=0.44), however the strength of this relationship suggests that the chlorophyll-a component of the AFDM was low.

Table 8. One-way nested analysis of variance results for chlorophyll-a and ash free dry mass densities

Response	Source	DF	F-value	P-value
Chlorophyll-*a* (log)	Location	1	0.016	0.91
	Site [Location]	3	1.468	0.25
	Residual	29		
AFDM (log)	Location	1	0.321	0.61
	Site [Location]	3	3.065	0.047
	Residual	29		

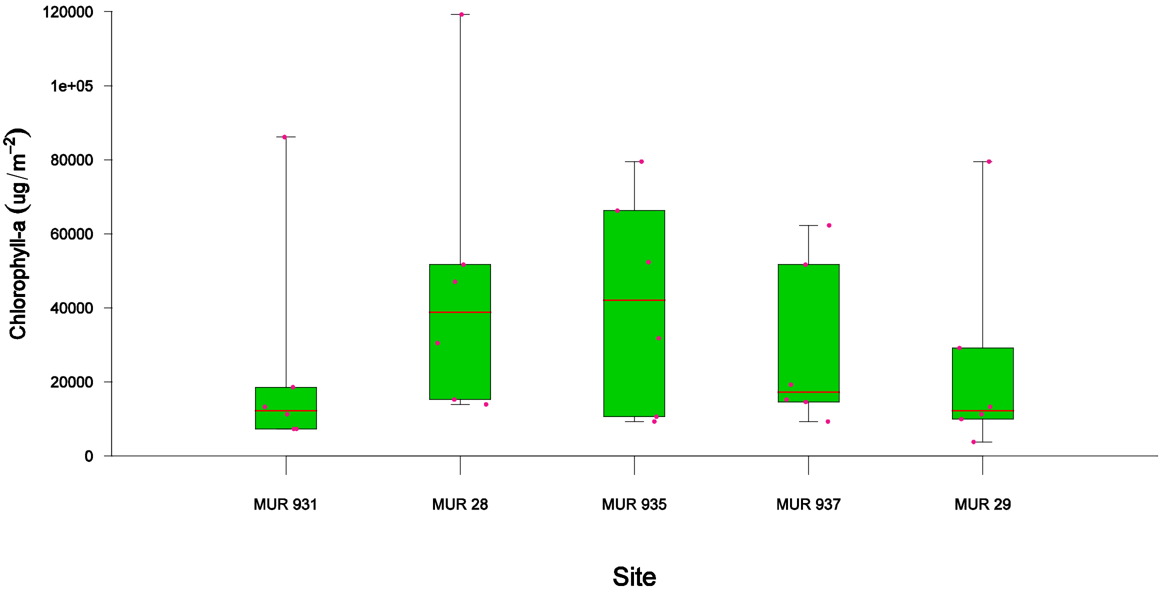

Figure 5. Periphyton chlorophyll-a concentrations from upstream and downstream of the MPS

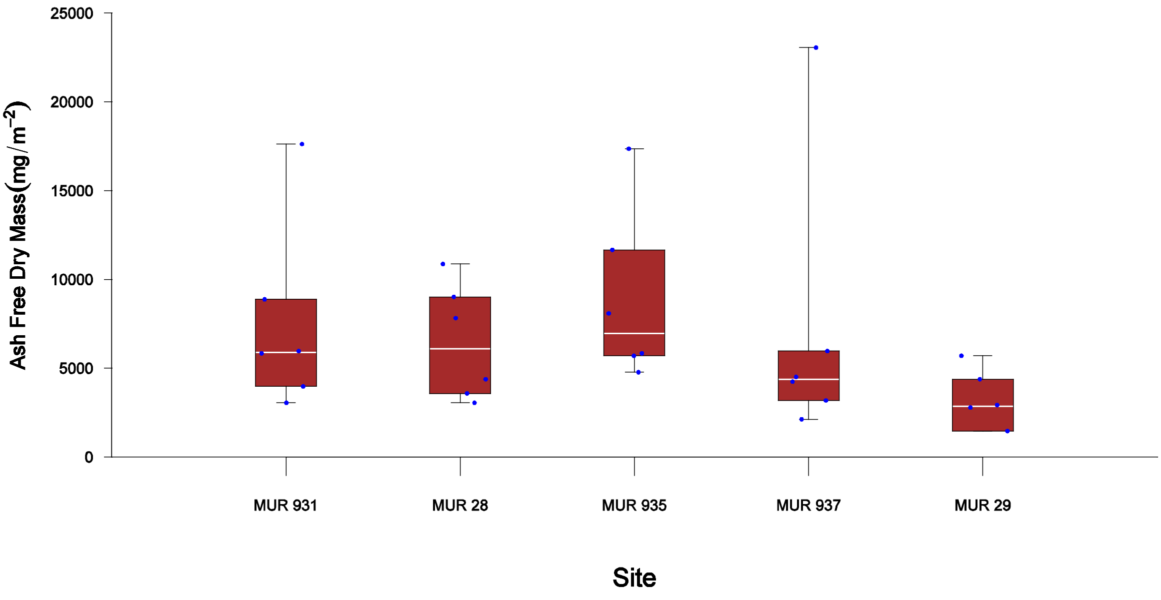

Figure 6. Periphyton Ash Free Dry Mass (AFDM) from upstream and downstream of the MPS

Strip chart values in blue (above) and red (top) represent raw data points.
See APPENDIX A for an explanation on how to interpret box and whisker plots.

3.5 Macroinvertebrate communities

3.5.1 **Patterns in community structure**

3.5.1.1 Riffle

Macroinvertebrate assemblages collected from riffle habitats showed a high degree of similarity between sites (Figure 7). All sites are grouped within the 70% similarity ellipses derived from the cluster analysis (Figure 8) suggesting a high degree of taxonomic similarity among all sites. At 75% similarity, the main group is subdivided into three sub groups; one main group, which contains all of the downstream sites (MUR 935, MUR 937 and MUR 29) and a further two groups which contain samples of each of the upstream sites (MUR 28 and MUR 931). ANOSIM results show that although there appears to be some separation of the grouping factor “location” in the NMDS plot (Figure 8), the difference is not statistically significant (R=0.83; P=0.10).

There was little variation in taxonomic richness values amongst all of the sampling sites (Figure 9). Family richness ranged from 20 at MUR 931 to 23 at MUR 935. MUR 28 had the highest number of genera at 31, while the lowest occurred at MUR 931. Overall, there were five dominant taxonomic groups included a combination of tolerant and sensitive taxa. In no particular order these taxa included Oligochaetes (SIGNAL-2), Hydropsychidae (SIGNAL=6), Baetidae (SIGNAL=5), Chironominae (SIGNAL=3) and Simuliidae (SIGNAL=5). The dominant taxa recorded in this round of sampling suggests a shift in the macroinvertebrate composition compared to autumn 2010, where the dominant groups were all Oligochaetes or Dipterans, which contributed up to 75% of the total estimated abundances amongst sites. Due the high Bray-Curtis similarity scores between sites, the difference between the main group and the two upstream groups is largely due to differences in the rank-abundances of the five main taxonomic groups mentioned above rather than the presence/absence of any specific taxa. For example, whereas the main group is dominated by Baetidae (SIGNAL =5) and Simuliidae (SIGNAL=5), the upstream group(s) are characterised by Hydropsychidae and Chironomidae (SIGNAL=3).

The difference in this sampling run to the previous sampling run in autumn 2010; is the high relative contribution of sensitive taxa in the group “EPT” compared to the tolerant group (Figure 10). The relative abundance of sensitive taxa was, for the most part, higher than the relative abundances of tolerant taxa. The exception was at MUR 931where 45% of the community was made up of EPT taxa, compared to 50% tolerant taxa, which was due to a 30-40% increase in the proportion of Chironomids compared to the other sites.

3.5.1.2 Edge

Edge samples showed a similar pattern to previous sampling runs in that the Bray-Curtis similarity measure is lower than the riffle habitat. In this study, all edge samples form one group at 50% similarity and at 60 % the samples form five groups which contain samples from their respective sampling sites. There is one exception to this, where MUR 29 and half of the MUR 935 samples form a group (Figures 11 & 12).

There is no evidence of a location effect based on the edge samples from the ANOSIM (R=0.75; P=0.10), although the moderately large R-value does indicate that most samples among groups are more similar to one another than samples between groups. This can be seen to a certain degree in the NMDS plot (Figure 11) but the position of MUR 935 and the high amount of within site variation maybe limiting the ability to detect a location affect based on the analysis of similarity. The number of macroinvertebrate families ranged from 18 at MUR 29 to 25 at MUR 935. Genus richness was notably higher at MUR 931 (38) compared to the other sites, which ranged from 25 at MUR 29 to 29 at MUR 935. Corixidae (SIGNAL=2), Chironominae (SIGNAL=3) and Caenid Mayflies were the dominant groups in the edge macroinvertebrate assemblages.

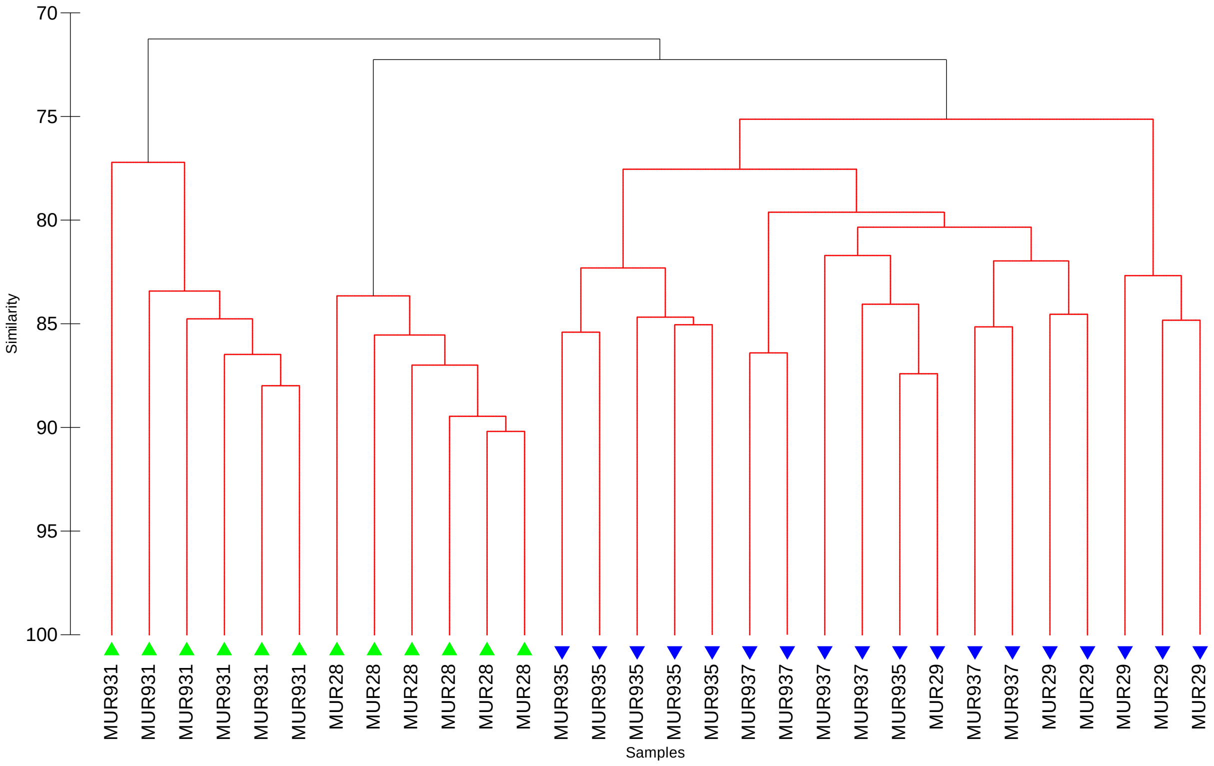

Figure 7. Cluster analysis of riffle samples from autumn 2011. Green circles are upstream of the MPS, blue squares are downstream

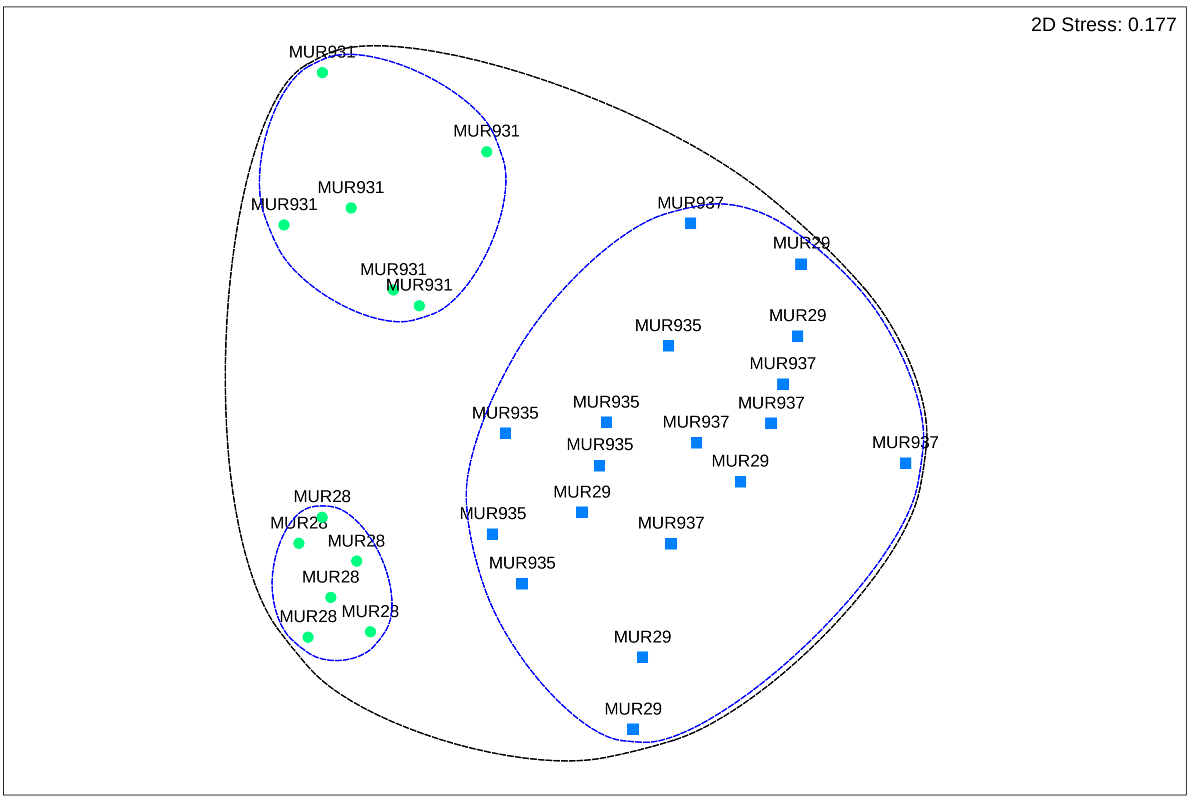

Figure 8. NMDS plot of riffle samples taken in autumn 2011. Green circles are upstream of the MPS, blue squares are downstream. Ellipses represent the 70% similarity (black) and 75% (blue) groups superimposed from the cluster analysis.

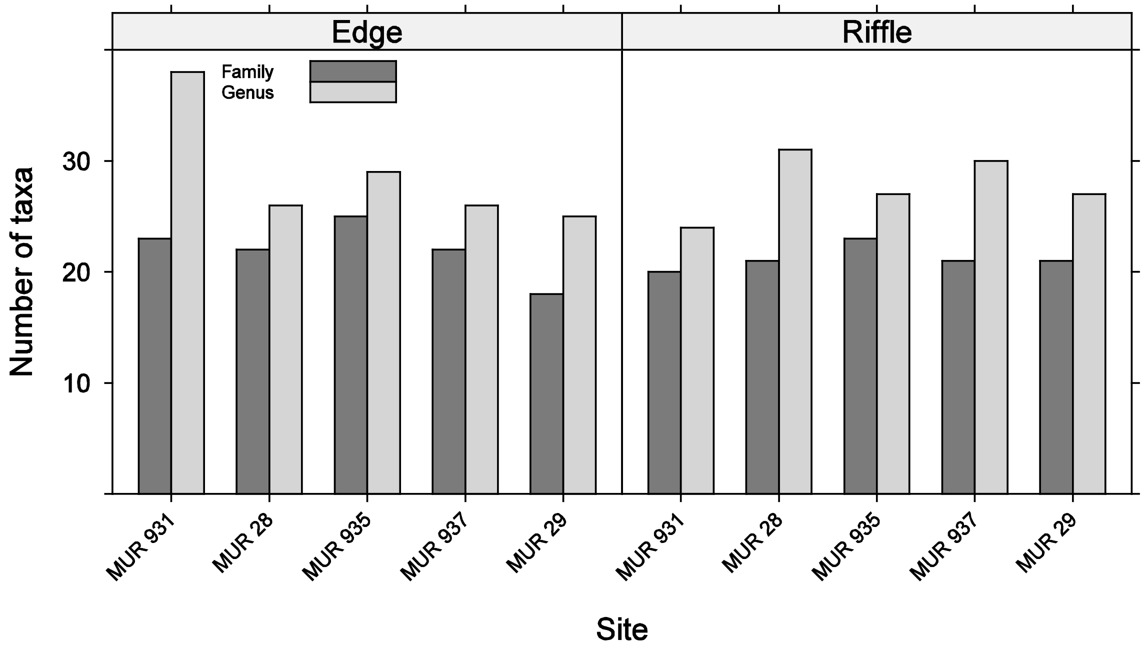

Figure 9. Family and genus richness from riffle and edge habitats

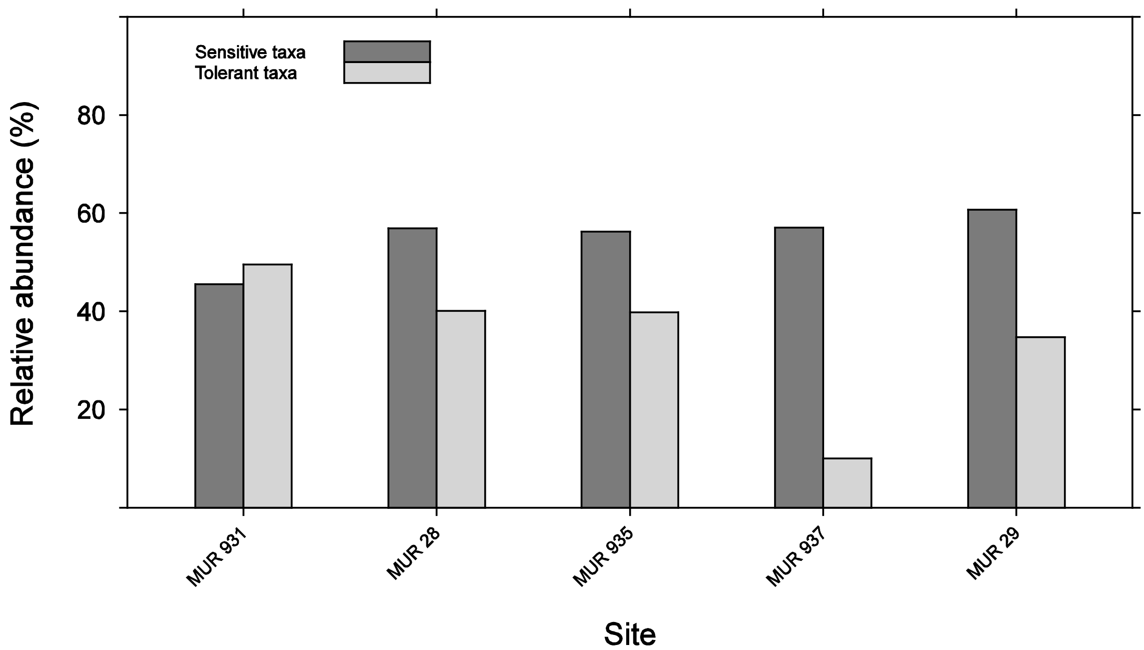

Figure 10. Relative abundance of sensitive (EPT) and tolerant taxa.

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

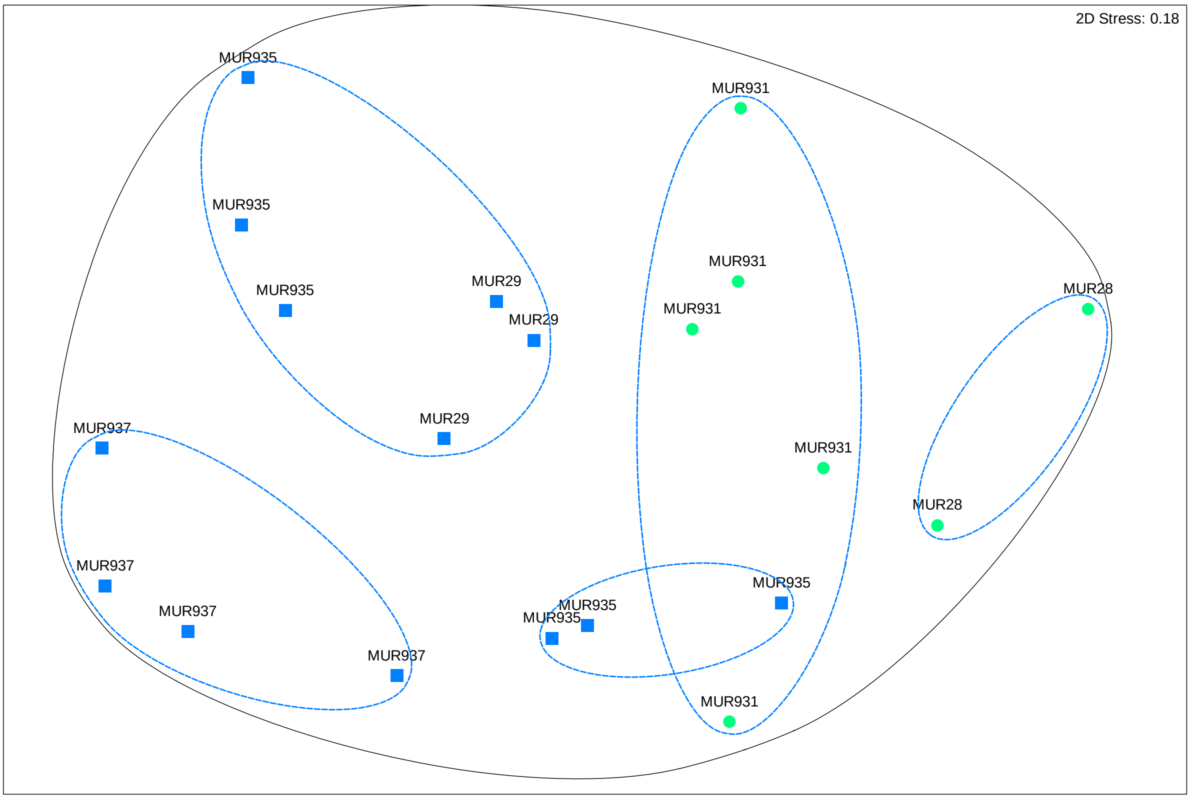

Figure 11. NMDS plot of edge samples taken in autumn 2011. Green circle points are upstream of the MPS, blue square points are downstream. Ellipses represent the 50% (black) and 60% (blue) similarity groups superimposed from the cluster analysis

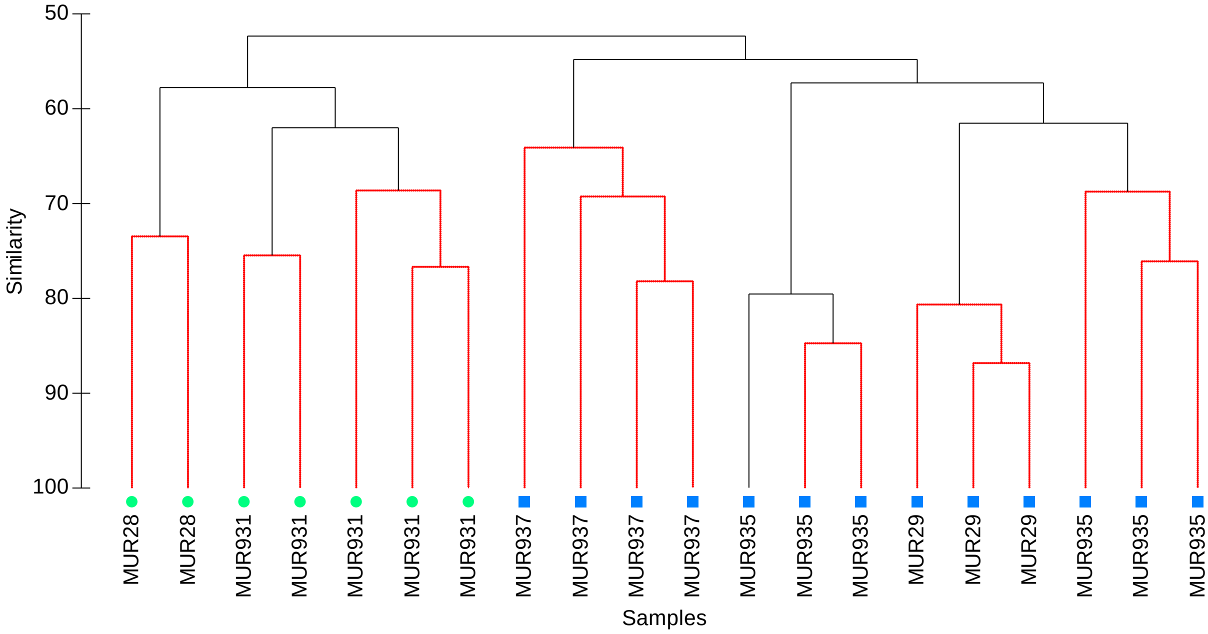

Figure 12. Cluster analysis of edge samples from autumn 2011. Green circles are upstream of the MPS, blue squares are downstream

3.5.2 AUSRIVAS assessment

The results for the AUSRIVAS scores for each of the sites, including individual replicates, are given in Table 9.

Average O/E 50 scores were slightly higher upstream (mean=1.00; n=12) than downstream (mean=0.96; n=18), but were not statistically different between locations ($F_{1,3}$=4.20; P=0.13) (Table 10). The riffle habitat at all of the sampling sites were close to reference (BAND A). This represents an improvement of the AUSRIVAS ecological health of the riffle at all sampling sites, compared to the autumn 2010 assessment.

The BAND A assessment given to each riffle habitat is the result of the presence of one additional macroinvertebrate family at each site compared to autumn 2010. The identity of this family varies from site to site; but there is a much higher occurrence of the sensitive “riffle beetle” family (Elmidae: SIGNAL = 7) compared to previous sampling runs. In this study, Elmidae were found in 75% of the riffle samples compared to 14% in 2010. The frequency of Gripopterygidae (SIGNAL=8) and Tipulidae (SIGNAL=5) also increased in the riffle samples (APPENDIX B). Gripopterygidae were missing from all samples in autumn 2009 and 2010, while in the current study, taxa from this family were recovered from 20% of samples. It should be noted however, that Gripopterygidae were not collected at MUR 937 or MUR 29 and this is consistent with all previous sampling runs.

The overall health assessments determined by the AUSRIVAS modelling suggest all sites are BAND B and this is due to the largely unchanged edge habitat assessments from this study. All the edge habitats were considered to be significantly impaired (BAND B; Table 9), suggesting fewer taxa collected than were expected by the model, based on the habitat and physico-chemical variables. There was also no difference in the O/E 50 scores between locations as determined by the mixed-effects ANOVA model ($F_{1,3}$=0.00; P=0.98) (Table 11).

Compared to previous assessments, the only change was seen at MUR 29 which shifted from BAND A in autumn 2010 to BAND B in the current study. This result is again due to the absence of one family, which pushed the O/E 50 score just below the BAND A threshold. The missing family was Hydroptilidae (SIGNAL=4), which was collected at two out of three of the MUR29 replicate sites, and indeed was only missing from two other site samples (APPENDIX B). Other missing taxa from the edge samples included Conoesucidae (SIGNAL =7); Synlestidae (SIGNAL =7) and Planorbidae (SIGNAL=2), all which were missing from all the samples taken in this study. In the case of Conoesucidae, this family has yet to be collected in the lower reaches of the Murrumbidgee River during the course of the MEMP and Synlestidae has rarely been collected.

SIGNAL-2 scores for the riffle habitat increased slightly upstream of the MPS since autumn 2010. Upstream of the MPS the average score was 4.56 compared to 4.48 downstream and 4.2 in autumn. In both instances this probably reflects slight changes in the frequency of occurrence of the sensitive Gripopterygidae and Elmidae at the upstream location as discussed above. These slight differences in SIGNAL scores between locations were not statistically different ($F_{1,3}$ = 3.32; P=0.16); nor were they different for the edge samples ($F_{1,3}$ = 2.76; P=0.19) which showed the downstream to have slightly higher averages (mean = 4.43; n=13) compared to the upstream samples (mean =4.3; n=7).

Table 9. AUSRIVAS and SIGNAL-2 scores for autumn 2011

Location to MPS	SITE	Rep.	SIGNAL-2		AUSRIVAS O/E score		AUSRIVAS band		Overall habitat assessment		Overall site assessment
			Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	
UPSTREAM	Mur 931	1	4.50	4.55	0.89	0.86	A	A	A	B	B
	Mur 931	2	4.56	4.20	1.00	0.78	A	B			
	Mur 931	3	4.90	4.00	1.11	0.62	A	B			
	Mur 931	4	4.56	4.42	1.00	0.93	A	A			
	Mur 931	5	4.56	4.20	1.00	0.78	A	B			
	Mur 931	6	4.56	4.20	1.00	0.78	A	B			
	Mur 28	1	4.90	4.45	1.11	0.85	A	A	A	B	B
	Mur 28	2	4.25	4.38	0.89	0.62	A	B			
	Mur 28	3	4.25		0.89		A				
	Mur 28	4	4.90		1.11		A				
	Mur 28	5	4.56		1.00		A				
	Mur 28	6	4.67		1.00		A				
DOWNSTREAM	Mur 935	1	4.56	4.20	1.00	0.78	A	B	A	B	B
	Mur 935	2	4.90	4.55	1.11	0.85	A	A			
	Mur 935	3	4.25	4.75	0.89	0.93	A	A			
	Mur 935	4	4.67	4.50	1.00	0.62	A	B			
	Mur 935	5	4.25	4.44	0.89	0.70	A	B			
	Mur 935	6	4.56	4.22	1.00	0.70	A	B			
	Mur 937	1	4.56	4.18	1.00	0.86	A	A	A	B	B
	Mur 937	2	4.56	4.50	1.00	0.78	A	B			
	Mur 937	3	4.25	4.20	0.89	0.78	A	B			
	Mur 937	4	4.25	4.50	0.89	0.62	A	B			
	Mur 937	5	4.56		1.00		A				
	Mur 937	6	4.56		1.00		A				
	Mur 29	1	4.25	4.64	0.89	0.86	A	A	A	B	B
	Mur 29	2	4.56	4.45	1.00	0.86	A	A			
	Mur 29	3	4.25	4.50	0.89	0.78	A	B			
	Mur 29	4	4.56		1.00		A				
	Mur 29	5	4.88		0.89		A				
	Mur 29	6	4.25		0.89		A				

Table 10. One-way nested analysis of variance results for O/E 50 and SIGNAL-2 scores from the **riffle** samples

Response	Source	DF	F-value	P-value
O/E 50	Location	1	4.20	0.13
	Site [Location]	3	0.64	0.56
	Residual	29		
SIGNAL - 2	Location	1	3.32	0.16
	Site [Location]	3	0.31	0.82
	Residual	29		

Table 11. One-way nested analysis of variance results for O/E 50 and SIGNAL-2 scores from the **edge** samples

Response	Source	DF	F-value	P-value
O/E 50	Location	1	0.000	0.98
	Site [Location]	3	0.494	0.69
	Residual	29		
SIGNAL - 2	Location	1	2.766	0.19
	Site [Location]	3	0.968	0.43
	Residual	20		

4 Discussion

Construction work on the Murrumbidgee Pump Station (MPS) was completed in 2010. There was no pumping from the Murrumbidgee River to the Stromlo Water Treatment Plant during the 2010/2011 financial year (R. Pratt, *Pers. com.* September 6th 2011) although the water reticulation component to provide the lower Cotter reach with environmental flows, has been operational since February 2011. The sampling conducted in autumn 2011 is the fourth sampling run undertaken by ALS (formally Ecowise Environmental). The focus for MPS is on aquatic fauna, periphyton and water quality at five sites based on the recommendations in ACTEW's licence to take water (WU67 section D6).

4.1 Water quality

Water quality samples were collected alongside the biological samples in early May (4th and 5th). The results show no evidence of a location effect, which would indicate a potential impact by the works associated with the construction and early operation of the MPS, including M2C. Since the autumn sampling run in 2010 the total nitrogen concentrations across all sites have reduced, although all but one site are still above ANZECC & ARMCANZ (2000) guideline values. On the other hand, total phosphorus concentrations have increased since autumn 2010 at the three most upstream sites, with these sites now outside the ANZECC & ARMCANZ (2000) guidelines. The higher nutrient concentrations upstream of the MPS compared to the downstream sites (except MUR 935, refer Table 7) is probably due to the dilution effect of the Cotter River confluence which also accounts for the small reduction in electrical conductivity at the downstream sites.

Turbidity was the only other parameter to exceed the guidelines during the autumn period. The exceedance levels occurred in March, due to a number of consecutive rainfall events, however by late March the turbidity returned to within the guideline values of 2-25 NTU. The remaining water quality parameters showed a high degree of similarity among all sites. There were slight changes in dissolved oxygen (as mg/L and % saturation), which are attributed to the variation in the sampling times as DO varies during the day because of photosynthesis mechanisms.

4.2 Periphyton

There was no significant difference in either chlorophyll-a concentrations or AFDM between upstream and downstream locations (refer Table 8). In comparison to the autumn 2010 sampling results the concentration levels of chlorophyll-a were very similar, while comparatively the concentrations of AFDM are markedly reduced this season. This difference in concentration levels is likely due to the preceding high flow period during March, and an increase in flows during April (approximately two weeks before sampling occurred, although this would only have affected sites downstream of the Cotter River confluence). It has previously been found that floods and higher flow velocities reduce the AFDM and silt content of the periphyton more than they do to the chlorophyll-a concentrations (Jowett and Biggs, 1997)

ALS (2010) reported that site MUR 937 generally showed the lowest concentrations for both chlorophyll-a and AFDM, however this sampling run has resulted in site MUR 29 showing the lowest concentrations of AFDM and both MUR 29 and MUR 931 having lower concentrations of chlorophyll-a. Although there are differences in chlorophyll-a and AFDM concentrations, the variations between sites have remained consistent with previous seasons.

4.3 River health and patterns in macroinvertebrate communities

There was a high degree of similarity amongst the riffle macroinvertebrate communities (all sites were grouped together at 70% similarity) indicating the influence of similar environmental conditions leading up to the sampling run; and consequently we found no evidence to suggest that there were community differences between upstream and downstream locations of the MPS. In the absence of any pumping or construction related work on the MPS the similarity amongst sites and locations is not surprising given the similarities in substrate, vegetation and land-use practices between these sites. The geographic range of these sites also substantiates these similarities given that there is little variation in altitude, geology or other physical features which influences the distribution of macroinvertebrate communities (Allan, 2004; Clarke *et al.*, 2008; Cummins, 1974; Downes *et al.*, 2000; Hynes, 1975).

Another possible explanation for the high degree of overlap in the macroinvertebrate communities, as suggested by Lake (2000), is that the high flow events such as those seen over spring 2010 and in March 2011, act as a "reset" mechanism for benthic communities. This would have had the effect of weakening any site to site and/or location effects that would have pre-existed prior to the high flow events. In their study looking at point source impacts from an effluent release, Ortiz and Puig (2007) found that after obvious location differences in water quality, taxonomic richness and the absence of certain EPT taxa downstream of effluent, a series of high flow events effectively homogenised the macroinvertebrate communities and water quality variables so that the effect size of the point source impact either vanished or was reduced. This scenario fits the present study despite the absence of pre-existing location impact from the MPS.

There was a subtle difference between locations at the 75% similarity threshold which show all of the downstream sites forming a single group (refer Figure 7). These subtle differences in the macroinvertebrate communities are due to changes in the dominance of certain taxa as opposed to their absence. The downstream sites had a higher abundance of Baetid mayfly's which might indicate that the additional flow entering the Murrumbidgee River from the Cotter confluence facilitates a higher number of these taxa by increasing resources, habitat availability and/or quality. This is supported by the fact that during the latter part of April, when the stop-logs were removed from the Cotter Dam wall, the additional flow contributed to 52% of the total flow, albeit for a short period of time.

Brittain and Saltveit (1989) showed that under high flow conditions, Baetidae increased in abundance compared to sites with lower base-flows while Malmqvist and Englund (1996) investigated the impacts of flow alterations on mayflies and found that abundances of mayflies in general were significantly lower at sites with lower flow and that Baetids became sparser in response to flow reductions. It is unclear at this stage if the flows from the Cotter do account for this subtle difference between the upstream and downstream communities, since other interacting factors such as algae standing crops, and other food resources are also important considerations, However, based on our periphyton biomass analysis, there do not appear to be clear differences between locations that would account for the almost ten-fold increase in the estimated Baetid abundance.

While sampling was not possible in spring 2010 due to high flows, there has been a notable improvement in the condition of the riffle habitat assemblages based on the AUSRIVAS modelling. Riffle habitats in this sampling run were all assessed as BAND A (close to reference, refer Table 9) which is an improved assessment since the previous assessment for the MPS in autumn 2010. During autumn 2010 all sites were assessed as BAND B (significantly impaired), which was due to the absence of three specific taxa: Elmidae (SIGNAL =7); Gripopterygidae (SIGNAL=8) and Tipulidae (SIGNAL =5) from various sites and samples. During this sampling run, while not collected in high numbers, the more frequent occurrence of these taxa does imply that conditions at the sampling sites related to the MPS program have benefited from the flushing flows over spring and March as discussed for Baetidae above.

In past sampling runs, Elmidae and Gripopterygidae in particular have been absent or very rare in the kick samples, despite being predicted with high probability by the AUSRIVAS model. Gripopterygidae, it was thought were absent due to background water quality and habitat conditions, while Elmidae it was thought, were missing because of unfavourable flow conditions during previous sampling runs. Both taxa exhibit qualities that make them useful indicators for flow and water quality related monitoring programs. Elmidae in particular are considered to be good indicators of flow variation (Brooks *et al*., 2011) because of their affinity for fast flowing, clear and high oxygenated water (Gooderham and Tsyrlin, 2005). *Dinotoperla* spp. (Gripopterygidae) on the other hand can be found in slower moving water, but are considered to be highly sensitive to poor water quality. The presence of these taxa is probably related to the removal of fine sediment deposits in the riffle habitat from substrate mobilisation and increased near-bed velocities.

Despite improvements in the riffle habitat, the overall site assessments place the condition of these monitoring sites in the BAND B category. The reason for this is due to the classification of the edge samples, which display an overall higher degree of variability not only in the macroinvertebrate assemblages (refer Figure 11) but also in the range of AUSRIVAS O/E 50 scores. The edge habitat remained at BAND B at all sites, resulting in overall site assessments equivalent to autumn. The reasons for this are probably linked again to the flushing flows of spring and March, where several ubiquitous taxa may have been washed away under the higher flow conditions. Furthermore, it is feasible that their habitat (i.e. submerged logs, macrophytes and detritus) had the same fate, resulting in slower recruitment rates and more variable edge habitat resulting in patchy distributions of even the more common taxa, and therefore less taxa being collected than were predicted by the AUSRIVAS model.

Although after periods of high flow events, free living taxa such as Corixidae (SIGNAL=2) have been found to be completely absent from some sites in other components of the MEMP project, they show high resilience in that they reappear after periods of stable flows, which is deemed to be a desirable quality of a healthy ecosystem (Davies et al., 2010). Indeed, from both riffle and edge samples, we have found that during the MPS project, there has been little change in the number of taxa collected throughout this baseline period. The fact that taxonomic richness has been consistent throughout the course of this project suggests that irrespective of how the relative abundance of certain groups reacts to changes in flow, there is a considerable amount of resistance to change within the Murrumbidgee macroinvertebrate populations.

Based on the MPS sampling program to date, it is expected that the resistance and resilience of the macroinvertebrate fauna to any potential impact resulting from the (up to) 100 ML/d abstraction from the MPS is likely to depend on:

a) the timing of the abstractions; and

b) the duration that flows are abstracted.

Macroinvertebrate communities are likely to be at their most vulnerable in summer and autumn when Murrumbidgee base flows are at their lowest levels, and if flows are further lowered through ongoing water abstractions during these months, we could expect to see some changes in water quality and a potential loss of some of the more sensitive EPT taxa. At this point however, our knowledge is limited to natural variations occurring in the system without the operation of the MPS.

5 Conclusion

The following conclusions are drawn from the autumn 2011 sampling run:

- Water quality results from this study were similar amongst all sampling sites. It was found that Total Phosphorous concentrations dissipated downstream of the Cotter River confluence which suggests a noticeable dilution factor from the Cotter River contributing flow. Additional sampling from the Cotter River may support this result.
- There has not been any water abstraction from the MPS to the Stromlo water treatment facility during the 2010/11 financial year which removes the potential influence of MPS, aside from completion of infrastructure works and removal of the Murrumbidgee coffer dam wall. It is therefore likely that the variation amongst the edge macroinvertebrate communities and the subtle sub-structuring of the riffle assemblages is due to the antecedent high flow events leading up to this sampling run.
- There were notable improvements in the riffle macroinvertebrate communities in that there were higher estimated abundances of sensitive EPT taxa than recorded in autumn 2009 and 2010, and an increase in the frequency of Elmidae and Gripopterygidae. These contributing factors lead to BAND A assessments for each site in the riffle habitat. We attribute this to improvements in the quality of habitat and water quality which occurred after the flushing flows in spring and early autumn.
- Overall site health was considered to be BAND B ("*significantly impaired*") due to high within-site and between-site variations in the collection of predicted macroinvertebrate families. This variation is also considered to be a function of the high seasonal flows, which may have removed important habitat or altered existing habitat that may have excluded local populations.

Our predictions that were made in ALS (2011) for Angle Crossing, apply to the MPS component of the MEMP; that during winter and spring, when the proportion of flow being abstracted is low compared to base flows, there are unlikely to be any long term effect on water quality, periphyton community's or the macroinvertebrate populations. Short term effects may see some reductions in individual indicator taxa and reactive changes in water quality to hydrological disturbances. Winter and spring high flow events may provide an important natural (reset) restoration mechanism to anthropogenic disturbance.

The additional flow release from the Bendora scour valve, immediately upstream of the Cotter Rd bridge, may also prove to be beneficial, especially during periods of low base flow.

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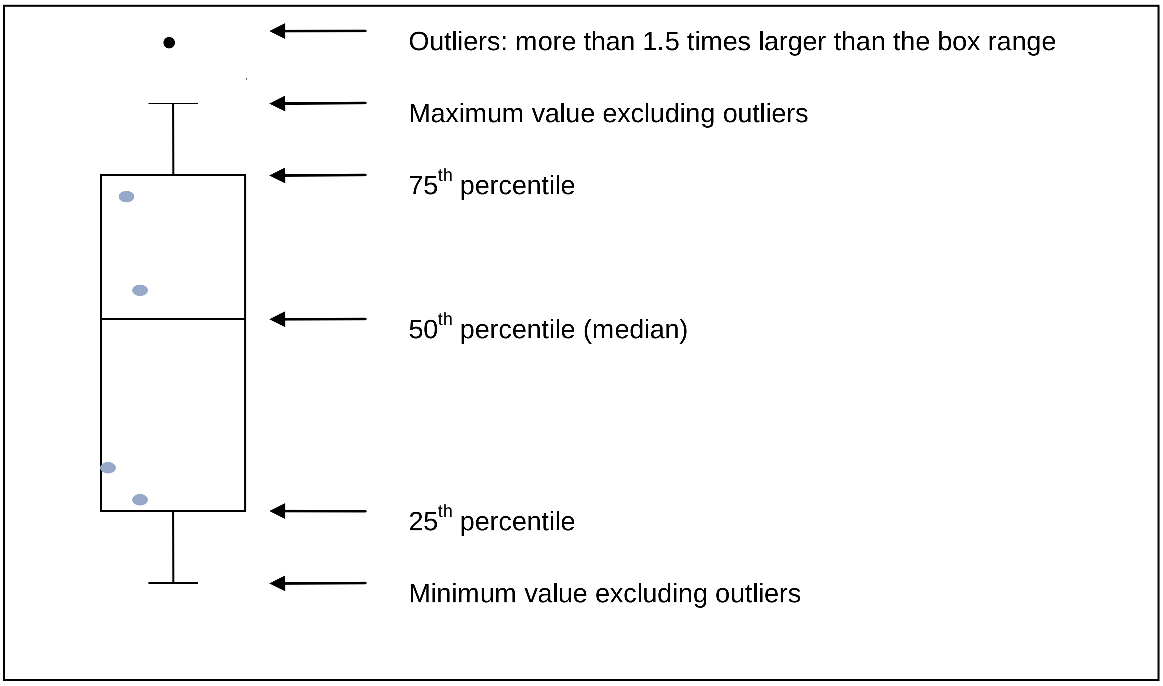
APPENDIX A

INTERPRETING BOX AND WHISKER PLOTS

Appendix A. Interpreting box and whisker plots.

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



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

APPENDIX B

TAXA PREDICTED WITH >50% PROBABILITY, BUT WERE MISSING FROM THE AUTUMN 2010 SAMPLES

Appendix B. Macroinvertebrates predicted to occur with >50% probability by the AUSRIVAS model but absent from edge samples. Number in cells represents their given probability of occurrence at a given site. Blank cells indicate collection at a given site.

Edge

Site	Taxa	Planorbidae	Oligochaeta	Elmidae	Tanypodinae	Baetidae	Orthocladiinae	Synlestidae	Leptophlebiidae	Caenidae	Gripopterygidae	Conoesucidae	Hydroptilidae	Ecnomidae	Total number of missing taxa
	SIGNAL	2	2	7	4	5	4	7	8	4	8	7	4	4	
MUR 931		*0.55*		*0.62*	*0.90*			*0.65*				*0.59*			5
MUR 931		*0.55*		*0.62*	*0.90*			*0.65*			*0.69*	*0.59*			6
MUR 931	Edge	*0.55*			*0.90*	*0.89*	*1.00*	*0.65*	*0.97*		*0.69*	*0.59*			8
MUR 931		*0.55*						*0.65*			*0.69*	*0.59*			4
MUR 931		*0.55*		*0.62*	*0.90*			*0.65*			*0.69*	*0.59*			6
MUR 28	Edge	*0.55*			*0.90*			*0.65*			*0.69*	*0.59*			5
MUR 28		*0.55*	*0.97*		*0.90*			*0.65*	*0.97*	*1.00*	*0.69*	*0.59*			8
MUR 935		*0.55*		*0.62*	*0.90*			*0.65*			*0.69*	*0.59*			6
MUR 935		*0.55*		*0.62*	*0.90*			*0.65*				*0.59*			5
MUR 935		*0.55*			*0.90*			*0.65*				*0.59*			4
MUR 935	Edge	*0.55*	*0.97*	*0.62*	*0.90*			*0.65*			*0.69*	*0.59*		*0.59*	8
MUR 935		*0.55*	*0.97*	*0.62*	*0.90*		*1.00*	*0.65*			*0.69*	*0.59*			8
MUR 935		*0.55*		*0.62*				*0.65*			*0.69*	*0.59*	*0.93*		6
MUR 937		*0.55*		*0.62*				*0.65*			*0.69*	*0.59*			5
MUR 937		*0.55*			*0.90*		*1.00*	*0.65*			*0.69*	*0.59*			6
MUR 937	Edge	*0.55*		*0.62*	*0.90*			*0.65*			*0.69*	*0.59*			6
MUR 937		*0.55*	*0.97*	*0.62*	*0.90*			*0.65*			*0.69*	*0.59*	*0.93*		8
MUR 29		*0.55*	*0.97*					*0.64*			*0.69*	*0.59*			5
MUR 29	Edge	*0.55*			*0.90*			*0.64*			*0.69*	*0.59*			5
MUR 29		*0.55*			*0.90*			*0.64*			*0.69*	*0.59*	*0.92*		6

Appendix B (cont'd). Taxa predicted to occur with ≥50% probability by the AUSRIVAS model, but not collected in the riffle habitat.

Riffle

Site	Taxa	Oligochaeta	Elmidae	Tipulidae	Gripopterygidae	Total number of missing taxa
	SIGNAL	2	7	5	8	
MUR 931	Riffle			*0.80*	*0.60*	2
MUR 931					*0.60*	1
MUR 931						0
MUR 931					*0.60*	1
MUR 931					*0.60*	1
MUR 931					*0.60*	1
MUR 28	Riffle				*0.60*	1
MUR 28			*1.00*		*0.60*	2
MUR 28			*1.00*			1
MUR 28						0
MUR 28					*0.60*	1
MUR 28			*1.00*			1
MUR 935	Riffle				*0.60*	1
MUR 935						0
MUR 935					*0.60*	1
MUR 935			*1.00*			1
MUR 935			*1.00*		*0.60*	2
MUR 935			*1.00*		*0.60*	2
MUR 937	Riffle				*0.60*	1
MUR 937					*0.60*	1
MUR 937			*1.00*		*0.60*	2
MUR 937			*1.00*		*0.60*	2
MUR 937					*0.60*	1
MUR 937					*0.60*	1
MUR 29	Riffle			*1.00*	*0.60*	2
MUR 29					*0.60*	1
MUR 29				*1.00*	*0.60*	2
MUR 29					*0.60*	1
MUR 29		*0.80*			*0.60*	2
MUR 29				*1.00*	*0.60*	2