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MURRUMBIDGEE ECOLOGICAL MONITORING PROGRAM

ANNUAL REPORT

2010-11

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CERTIFICATE OF APPROVAL FOR ISSUE OF DOCUMENTS

Client: **ActewAGL Distribution**
Project Title: Murrumbidgee Ecological Monitoring Program
Report Title: MEMP Annual Report 2010-11
Document No: CN 211063-AR-1011-002
Document Status: FINAL
Date of Issue: 29 December 2011
Comments:

	Position	Name	Signature	Date
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Document Revision Control

Version	Description of Revision	Person Making Issue	Date	Approval
1	For client review	Norm Mueller	08/12/2011	NM
2	Final	Norm Mueller	15/12/2011	NM
3	Minor changes to Final	Norm Mueller	29/12/2011	NM

EXECUTIVE SUMMARY

The Murrumbidgee Ecological Monitoring Program (MEMP) commenced in 2008. The project is being undertaken by ALS Water Resources Group for ActewAGL to establish baseline river data prior to the commissioning of, and during initial operation of, the Murrumbidgee to Googong (M2G) transfer project and the Murrumbidgee Pump Station.

Baseline data is being collected for the Murrumbidgee River from Tantangara Dam to Burrinjuck Reservoir, and for Burra Creek as the discharge point for M2G. This report is a summary of work undertaken during the 2010-11 financial year focusing on the M2G components, with additional analysis of the seasonal ecological variability.

Parameters being monitored in the Murrumbidgee River and Burra Creek (Googong catchment) for the MEMP with monitoring timelines are:

- Streamflow and water quality, undertaken continuously;
- Macroinvertebrates and periphyton, undertaken each spring and autumn;
- Freshwater fish survey, completed annually;
- Riparian and in-stream vegetation characteristics prior to M2G commissioning, and;
- Streambed and sediment movement (geomorphological) characteristics prior to M2G commissioning.

Key results for the 2010-2011 rainfall and streamflow data are:

- Annual rainfall in the Murrumbidgee River and Burra Creek catchments was above average with 1070mm received at Angle Crossing.
- Murrumbidgee River flow volume at Lobb's Hole, downstream of Angle Crossing, was slightly above average at 312GL (292GL average).
- Burra Creek flow volume at Burra Rd, was significantly above average at 8.9GL (1.4GL average), primarily due to storm events in September, October, and December 2010.
- The largest storm event (highest Average Recurrence Interval, ARI) was in Burra Creek on 9 December 2010 which reached a peak of 25,400ML/d (294m^3/s) having a probability of 1 in 70 years ARI.
- The peak flow in the Murrumbidgee River at Lobb's Hole was 32,400ML/d (375m^3/s) which had a probability of approximately 1 in 4 years ARI.

Water quality varied significantly during storm events but was generally within the ANZECC(2000) guideline values, except for nutrients (total nitrogen and phosphorous) and turbidity, which were almost always above the guideline. This, in conjunction with other favourable conditions, led to significant algae growth in the system after the storm events.

Using the AUSRIVAS ecological indicators for river health showed that the system responded well to the increased flow with many riffle regions (fast flowing water) of the Murrumbidgee River improving from Band B to Band A. The pool areas (edges) generally deteriorated in the short term as many of the bugs would most likely have been washed downstream during the storm events, but will recover.

Biological indicators show strong seasonal variably, in part due to aspects of life histories and non-biological changes (such as temperature), but also show significant reactions to high and low flows in spring and autumn respectively.

The fish survey of Murrumbidgee River found one Macquarie Perch, two Trout Cod, and three Murray Cod in the vicinity of Angle Crossing. Although these are low numbers, it was the first time in 20 years that Murray Cod have been caught in fish surveys at this location.

The key **recommendations** from the program include:

Overall:

- Continuation of the monitoring components in accordance with the EIS and approved sub plans for the Operation Environmental Management Plan (OEMP) for M2G;

Macroinvertebrate sampling:

- Undertaking of hyporheic zone (subsurface) surveys within the Burra Creek catchment prior to M2G operation to increase knowledge of the mechanisms used by bugs during periods of low to zero flow. This would improve the prediction of the affect that pumping will have on macroinvertebrates and also the quality of ground water sources;
- Undertake at least one season of summer and winter macroinvertebrate sampling to reduce the knowledge gap in the seasonal variation within Burra Creek as pumping may occur year round;
- Undertake a desktop review of potential specific indicator species, and then monitor them, to provide more detailed information with regards to flow variation affects and future flow related projects and environmental flow requirements.

Fish monitoring:

- The presence of threatened fish species at, and upstream of, the abstraction point should be considered for the management scheme of M2G;
- A monitoring program for the intake egg screen should be developed to determine its impact upon the larvae of threatened species;
- Implement trials to assess fish responses to various flow regimes within Burra Creek following the commencement of M2G operation;
- Repeat the fish survey of Burra Creek following the summer period to determine whether there are any shifts in species diversity.

M2G project impact

There was no detectible difference in aquatic or water quality data during the year that could be attributed to any construction impact from the M2G project.

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1. Chapter 1 – Introduction

The Annual Report is a summary of the monitoring and analysis undertaken for ActewAGL under the Murrumbidgee Ecological Monitoring Program (MEMP) during the 2010-2011 financial year. It also includes analysis of the seasonal differences between the spring and autumn macroinvertebrate sampling data. The monitoring components are on the upper Murrumbidgee River and Burra Creek (Googong Reservoir catchment). This program involves the assessment of areas potentially impacted by the new ACT Water Security infrastructure projects.

Parameters being monitored include:

- Streamflow and water quality;
- Macroinvertebrates and periphyton;
- Freshwater fish;
- Riparian and in-stream vegetation characteristics; and
- Streambed and sediment movement (geomorphological) characteristics.

This program establishes baseline river health indices based on seasonal assessments, which will assist in determining the accuracy of Environmental Impact Assessments (EIA) and for regulatory licencing requirements.

The MEMP is divided into four component areas:

- Part 1: Angle Crossing (M2G project)
- Part 2: Burra Creek (M2G project)
- Part 3: Murrumbidgee Pump Station
- Part 4: Tantangara Dam to Burrinjuck Reservoir

Macroinvertebrate and periphyton monitoring and reporting for each component area is undertaken each spring and autumn, and commenced in spring 2008. Other parameters are to be assessed prior to the commissioning of, and during the operation of, the infrastructure projects.

1.1 Background of major projects

ACTEW Corporation introduced a water security program in 2007 and is currently building additional infrastructure to improve the future water supply security for the residents of Canberra and Queanbeyan.

The new water security projects include:

- A new 78GL Cotter Dam called the Enlarged Cotter Dam (ECD) just downstream of the existing 4 GL Cotter Dam;
- Murrumbidgee Pump Station (MPS): adjacent to the existing Cotter Pump station to increase pump capacity from ~50ML/d to 150ML/d (nominally 100ML/d);
- Murrumbidgee to Googong transfer pipeline (M2G): from Angle Crossing just within the ACT's southern border to Burra Creek in the Googong Dam catchment, at up to 100ML/d;
- Tantangara Reservoir release for run of river flow to the M2G abstraction point at Angle Crossing.

Increasing water abstractions from the Murrumbidgee River could have several impacts on water quality, riparian vegetation, riverine geomorphology and the aquatic ecology of the system. Some beneficial ecological effects could be expected in the reaches downstream of Tantangara Reservoir and in Burra Creek (downstream of the discharge point) under the proposed flow release regime, including increased habitat availability for native fish species. The increased flow in those locations is also likely to favour flow dependent macroinvertebrates and improve surface water quality.

The key aims of the MEMP are:

- to determine whether or not, and to what extent, abstraction from Murrumbidgee River is affecting the maintenance of healthy aquatic ecosystems within the river or impacting Burra Creek, in terms of biological communities;
- to determine whether or not, and to what extent, abstraction of water at Angle Crossing is impacting riverine habitat through changes in sediment movement;
- to determine whether or not, and to what extent, abstraction of water at Angle Crossing is impacting riverine habitat through changes in flow;
- to establish baseline information regarding water quality, the structure of macroinvertebrate communities, and ecosystem health throughout the upper Murrumbidgee catchment;
- to establish baseline and operational information on water quality and streamflow, macroinvertebrate communities, fish, riverine vegetation and geomorphology, relating to aquatic systems impacted by the water abstraction and discharge (M2G);
- to monitor water quality between Tantangara and Burrinjuck, and also within Burra Creek, which will establish normal annual and seasonal variation so that any changes resulting from the operations of abstraction and release are identified.

The frequency, monitoring locations and resolution of the monitoring on the Murrumbidgee River and Burra Creek will differ between the components as changes occur at different spatial and temporal scales. This monitoring program is designed to be adaptive. Through the reporting of data and results, liaison with the client and technical advisory groups, it may be decided that certain monitoring methodologies need to be changed or adapted to enhance the outcomes of the program.

1.2 Environmental flows and the 80th:90th percentile rule

Under the current licence agreement (ACTEW's Licence to take water, December 2008), flows in the Murrumbidgee River at the Cotter Pump Station must be maintained at 20ML/d during any stage of water restrictions (www.actew.com.au). When these restrictions do not apply, flows must be maintained at the 80th or 90th percentile flow, depending on the time of year. The 80:90 rule has been applied to hydrological modelling of the Murrumbidgee River at Angle Crossing for the M2G operational plan; and was based on data collected from the Lobb's Hole gauging station. Specifically the 80th percentile flow applies from November to May and the 90th percentile from June through to October (Figure 1.1).

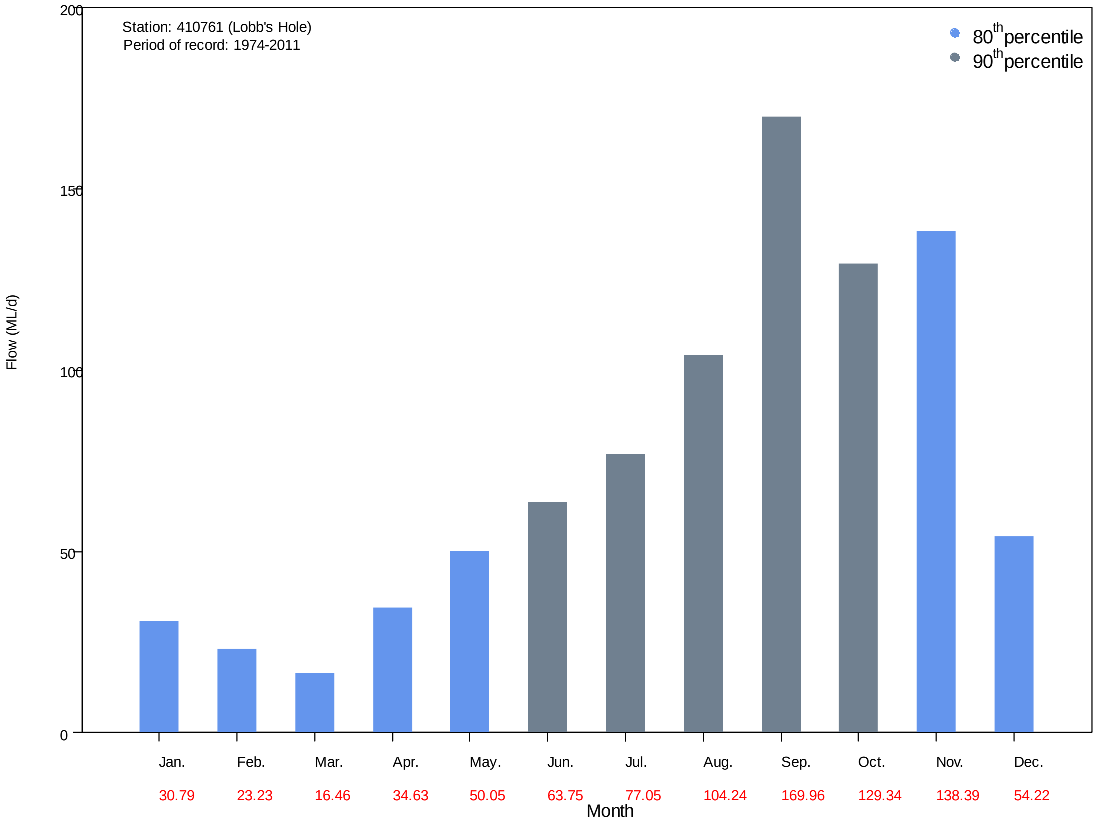

Figure 1.1 – Environmental flow values for the operation of the M2G project

Note: Flow data are current to 1/11/2011. Monthly values in red are megalitres per day (ML/d) and are based on continuous daily flow data from the Lobb's Hole gauging station (410761) since its commencement of operation in 1974.

As can be seen from the figure above, the lowest flows in the Murrumbidgee River occur in summer and autumn. The 80th percentile flows from November to May are less than the 90th percentile flows except for November. It is during these low flow months that abstraction from the Murrumbidgee River is likely to have the most significant impact, as the proportion of the abstraction rate to the baseflow is the greatest.

2. Chapter Two – Stream Flow

2.1 Sites

River level and rainfall data for the sampling period were recorded at ALS gauging stations which are located at the sites and codes as given in Table 2.1. Sites that existed prior to the commencement of the MEMP project have rating tables established to convert water level into flow data. The new sites (MURWQ09 and NUMWQ10) are being rated for flow through a series of gauging's being undertaken over time.

Stations are calibrated monthly and data are downloaded and verified before storage on the database where it is quality coded. Data records are stored in the HYDSTRA© database management software.

Table 2.1 – River flow monitoring locations and parameters

Status	Site Code	Location	Parameters#	Latitude	Longitude
Existing	410777 (570953)	M'bidgee River @ Hall's Crossing	WL, Q, pH, EC, DO, Temp, Turb. (Rainfall)	S 35.1328	E 148.9425
Existing	410738	M'bidgee River @ Mt. McDonald	WL, Q	S 35.2917	E 148.9553
Existing	410761 (570985)	M'bidgee River @ Lobb's Hole (D/S of Angle Crossing)	WL, Q, pH, EC, DO, Temp, Turb. (Rainfall)	S 35.5398	E 149.1002
Existing	410774 (570951)	Burra Creek D/S Burra Rd	WL, Q, pH, EC, DO, Temp, Turb. (Rainfall)	S 35.5425	E 149.2279
Existing	410781	Queanbeyan River U/S of Googong Reservoir	WL, Q, pH, EC, DO, Temp, Turb.	S 35.5222	E 149.3005
New for MEMP	MURWQ09	M'bidgee River U/S Angle Crossing	WL, pH, EC, DO, Temp, Turb, Rainfall	S 35.3533	E 149.0705
New for MEMP	NUMWQ09	Numerella River @ Chakola Road	WL, pH, EC, DO, Temp, Turb, Rainfall	S 36.1010	E 149.1891

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

In addition to the in-situ monitoring sites above, individual water grab samples were collected during the spring and autumn macroinvertebrate sampling program to assess water quality. Additional intermediate and storm event based samples were also collected to help define the variability in the key parameters analysed (Appendix 3: Table A3.3). Water Quality results for continuous data and grab samples are covered in Chapter 3.

2.2 Rainfall and Streamflow Results

A summary of the monthly rainfall during the 2010-11 financial year is given in Table 2.2. Burra recorded the lowest rainfall at 616.4mm, with the highest being surprisingly nearby at Lobb's Hole with 1072mm. This variability indicates the spatial nature of rainfall for these catchment areas. On several occasions it appeared that the increase in streamflow was underestimated by the rainfall recorded, suggesting that the storm cells were not completely picked up by the rainfall gauging network.

Table 2.2 – 2010-2011 Monthly Rainfall Totals (mm)

SITE	JUL 2010	AUG 2010	SEP 2010	OCT 2010	NOV 2010	DEC 2010	JAN 2011	FEB 2011	MAR 2011	APR 2011	MAY 2011	JUN 2011	ANNUAL TOTAL
Numeralla (NUMWQ09)	14.4	25.4	10.8	57.6	114	82.6	25.2	119.0	165.2	2.0	33.2	4.4	653.8
Angle Crossing (MURWQ09)	51.2	69	83.2	132.6	136.3	284.8	82.8	116.0	73.8	9.4	22.2	9.6	1071
Lobb's Hole (570985)	52.2	74.5	87.2	151.2	133.4	198.2	98.6	142.0	99.2	7.2	20.4	8.4	1073
Hall's Crossing (570953)	95.6	87.2	85.2	94.4	194.5	114.8	48.6	125.0	43.0	16.8	50.8	20.2	976.1
Burra (570951)	41.4	46.2	52.0	62.4	64.4	53.8	58.5	56.4	50.7	46.0	44.4	40.4	616.4
Mean Lobb's Hole 1975-2011	59.1	48.6	56.5	65.5	75.1	62.4	65.6	61.1	51.9	45.1	42.7	46.0	679.6

Note: Rainfall site numbers of pre-existing sites (sites 5709..) are different from streamflow site numbers.

The rainfall data for Lobb's Hole indicates that the rainfall in 2010-11 was approximately 60% higher than the long term average. Angle Crossing had the highest monthly rainfall in December 2010 with the monthly value of 284.8mm being over four times higher than the long term average for the area. Burra Creek had a significant streamflow event in December 2010, however the majority of rainfall was localised to the upper parts of the catchment in the Tinderry Nature Reserve.

As a result of above average rainfall the subsequent runoff volumes were also above average.

A summary of the annual volume of flow in each of the catchments is given in Table 2.3 below.

Table 2.3 – July 2010- June 2011 Annual Flow

Location / Site No.	Mean Annual Flow (Period of record) (GL)	Mean Flow last 10 yrs: 2001-11 (GL)	2010-11 Annual flow (GL)	Years since 2010/11 flow last exceeded
Murrumbidgee River (410761-Lobb's Hole)	292 (since 1974)	119	312	12
Queanbeyan River (410781)	39.6 (since 1990)	23.3	125.3	Highest on record
Burra Creek (410774)	3.5 (since 1986)	1.42	8.9	22

It can be seen that the 2010-11 annual flow for each of the river systems was above average with the Queanbeyan River and Burra Creek flow volumes being approximately three times the long term Mean Annual Flow. The 2010-11 annual flow volumes in Queanbeyan River and Burra Creek were over five times the average annual flow that occurred during the previous 10 years. These flows enabled Googong Reservoir to easily fill and overtop. In fact the annual flow volume from Queanbeyan River itself into Googong was above the total storage capacity of the reservoir (total inflow to Googong would be the addition of 410781, 410774 and an allowance of the immediate catchment of the reservoir).

A storm event on 9 December 2010 did cause flooding of low lying areas in Queanbeyan downstream (approximately a 1:15 year ARI flood event). Googong had reached full supply level the previous week. At the start of July 2010 Googong Reservoir was at 49% capacity. It reached 80% capacity on 26 October, and overtopped (100%) on 3 December 2010. At the end of June 2011, Googong was still at 100% capacity.

Stream discharge duration curves for the year, and previous historical data are given in Appendix 2: Figure A2.1. These plots provide the percentage time that specified flows were exceeded and allow a comparison between 2010-11 flow rates and historical flows.

Discharge plots in three monthly segments for the year are provided in Appendix 2: Figure A2.2. The highest events during the year occurred in September, October, and December 2010.

Seasonal discharge plots relating to the macroinvertebrate sampling are provided in the Autumn and Spring Macroinvertebrate reports (ALS, 2010a, 2010b, 2011a, 2011b).

There were several significant flow events during the year that exceeded a 1 in 1 year Average Recurrence Interval (ARI) event. The key events that occurred in the Murrumbidgee River and Burra Creek are given in Table 2.4. The Average Recurrence Interval (ARI) is based on historical data. For Burra Creek there were 5 events that peaked at over 100ML/d, however the elevated daily mean flow lasted for several days. The most significant event occurred in Burra Creek on 9 December 2010 with an estimated recurrence interval of 1 in 70 years. The historical record is only from 1985 and the ARI estimate should therefore be considered with caution with the short period of record taken into consideration. It is known from gauging sites in the ACT that high flows in the region occurred in the 1950's and 1970's.

Table 2.4 – 2010 to 2011 key flow events and probabilities

Location / Site No.	Event Date	Peak Flow (m3/s)	Peak flow (ML/d)	ARI*
Murrumbidgee River (410761-Lobb's Hole)	4/9/2010	77	6,650	1:1.5 yr
Events> 5,000 ML/d	15/10/2010	184	15,900	1:2.5 yr
	3/12/2010	264	22,800	1: 3 yr
	9/12/2010	375	32,400	1:4 yr
Burra Creek (410774)	19/8/2010	1.2	100	< 1: 1 yr
Events > 100 ML/d	4/9/2010	13.2	1,140	< 1: 1 yr
	15/10/2010	35.6	3,080	1: 3 yr
	3/12/2010	38.3	3,310	1: 3 yr
	6/12/2010	1.9	164	< 1: 1 yr
	9/12/2010	294	25,400	1: 70 yr
	3/02/2011	3.6	310	< 1: 1 yr

Note: ARI- Average Recurrence Interval based on period of record data to July 2011 using a Log Pearson III analysis.*

The M2G project has been designed with five pumps producing approximate transfer capacities of 20, 40, 65, 92, and 100ML/d once the system has been commissioned. As an indication of the number of days that Burra Creek has been at these flow levels naturally during the year Table 2.5 has been produced. It indicates that 100ML/d was exceeded on 15 days throughout the year. The days reflect the higher flows as a result of the 7 storm events indicated in the previous table.

Table 2.5 – Burra Creek Flow frequency based on M2G pump levels

No. Pumps operating	Burra Creek Flows	Winter Jul-Aug 2010 Jun 2011	Spring 2010	Summer 2010/11	Autumn 2011	Total for 2010-2011
1	Days >= 20 ML/d	2	12	13	3	**30**
2	Days >= 45 ML/d	1	8	12	2	**23**
3	Days >= 65 ML/d	0	8	11	1	**20**
4	Days >= 92 ML/d	0	7	10	0	**17**
5	Days >= 100 ML/d	0	6	9	0	**15**

2.3 Discussion

The main cause of the significant rainfall events has been attributed to a strong La Nina (significantly negative Southern Oscillation Index: Australian Bureau of Meteorology website). This La Nina event has continued into the latter part of 2011 and it is expected that the 2011-12 annual rainfall and flow volumes will also be above average.

Higher river flows such as the 2010-11 values have not been seen in the catchments for at least 12 years and closer reflect average annual flows than the drought conditions experienced over the last ten years.

Streamflow data indicates that the 100ML/d abstraction capacity from the M2G project was exceeded in 2010-11 in Burra Creek for 15 days, or 4% of the time. The 50th percentile flow was 2.7ML/d. In the previous 10 years to the 2010, Burra Creek exceeded 100ML/d on only 20 occasions (average 2 days per year).

The significant event in Burra Creek on 9 December 2010 (1:70 yr ARI) also caused significant erosion of in-stream vegetation and re-created pools that had largely disappeared over the previous 15 or so years. These high flow events can also have significant impact on geomorphology, riverine vegetation, and macroinvertebrate and fish habitat.

3. Chapter Three – Water Quality

3.1 Sites

Water quality is measured in-situ at four sites on the Murrumbidgee River, one site on Queanbeyan River and one site on Burra Creek, as indicated previously in Table 2.1. In-situ probes are multi parameter probes (Temperature, Dissolved Oxygen, pH, Electrical Conductivity, and Turbidity) installed inside a conduit for protection, with the end of the pipe perforated to allow water to flow past the sensor units.

The key sites for the Murrumbidgee River are upstream and downstream of the Murrumbidgee to Googong (M2G) abstraction point at Angle Crossing. The existing streamflow site 5.6 km downstream at Lobb's Hole (410761) had in-situ water quality added to it in 2009, with a new water quality site 2.0 km upstream of Angle Crossing (MURWQ09) also installed in 2009. The Numeralla site (NUMWQ09) was installed to obtain water quality data from one of the main upstream tributaries. The site at Halls Crossing (410777) is 15 km downstream of the northern ACT border and also provides water quality data for water leaving the ACT.

In addition to the in-situ probes samples were taken by hand (grab samples) during the macroinvertebrate sampling runs in spring and autumn, with additional individual samples also taken during or after storm events.

3.2 Results

The in-situ water quality data is stored on the ALS data management system and is readily accessible by ActewAGL. Analysis results from the grab samples are stored in the ActewAGL water data warehouse. A typical water quality trend plot during an event is indicated in Figure 3.1. The plot looks busy but indicates the expected variability of individual sensor readings during an event, in this case the large event that occurred in Burra Creek on 9 December 2010.

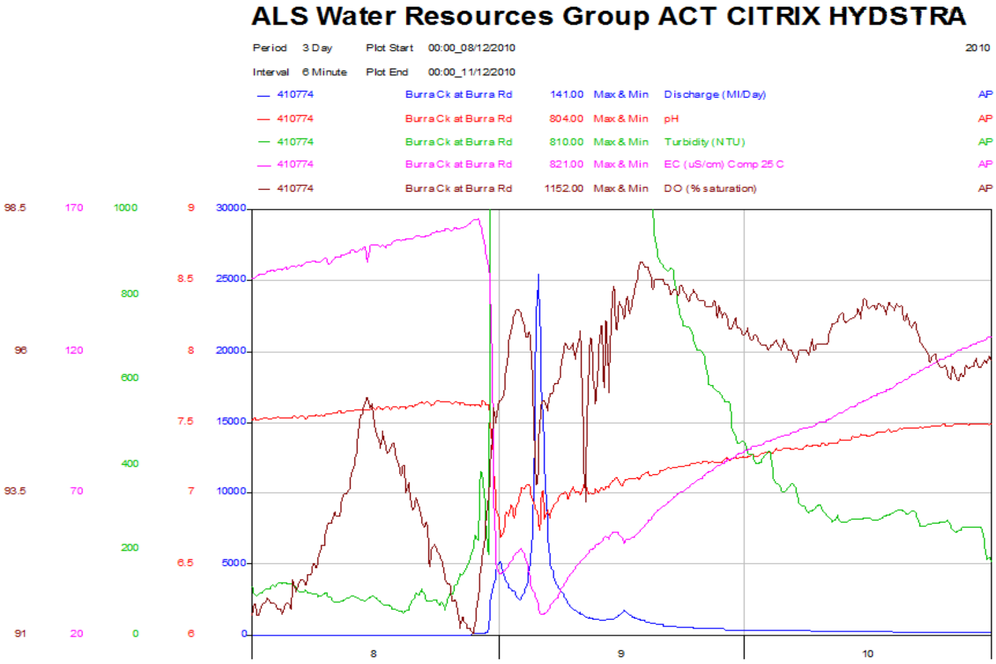

Figure 3.1 – Water quality trend in Burra Creek during 9 December 2010 high flow event

Expected changes during a rainfall runoff event are:

- Turbidity (green line) typically escalates to very high levels (above 1000 NTU) due to the amount of fine sediment transported in initial rainfall runoff, and decreases again after the peak of an event;
- Electrical conductivity (magenta line) is usually linked to salts from the groundwater contribution which becomes diluted with surface water runoff, decreasing the EC quickly during an event, and then increasing gradually again as the groundwater proportion increases;
- Level of pH (red line) if slightly alkaline, will generally reduce to ~7 or below, as rainfall is slightly acidic, and then gradually increase again as flows .
- Dissolved oxygen levels (brown line) usually increase during an event due to flow turbulence allowing oxygen to be more readily dissolved. The peak occurring on 8 December is a typical daily variation due to photosynthesis of aquatic plants/algae.

It is important to recognise that the point in time at which water samples are taken during and after an event can therefore significantly impact the results obtained. This is supported by grab samples that were taken on Burra Creek from the peak of an event on 15 October 2010, which emphasises the variability made above. The discharge plot and water quality results can be seen in Appendix 3: Figure A3.1. In addition to the in-situ data trends it also shows the significant reduction in suspended solids(TSS), total nitrogen(TN), and total phosphorous(TP) after the peak discharge. Therefore it is important to take this into account during any data interpretation and assessment.

To obtain baseline and event data for water quality, grab samples were taken during the spring and autumn macroinvertebrate sampling runs and were analysed for the usual physico-chemical and nutrient parameters with results provided in Appendix 3: Tables A3.1 and A3.2 for spring and autumn respectively. The results that exceed the ANZECC (2000) guidelines are also highlighted. The additional grab sample results are provided in Appendix 3: Table A3.3.

The benefit of the spring and autumn sampling runs is that they need to avoid rainfall affects occurring within two weeks prior to the sampling run. Therefore this data provides a good basis for establishing the baseline water quality during those seasons. Several plots of the results for different parameters are provided in Appendix 3: Figures A3.2 to A3.5.

Plots for the in-situ data throughout the year for Angle Crossing or Lobb's Hole, and in Burra Creek are provided in Appendix 3: Figures A3.6 to 3.15. Percentage duration curves have been plotted for Angle Crossing and Burra Creek for the parameters of Turbidity and pH in Appendix 3: Figure3.16, and for EC and Temperature in Appendix 3: Figure 3.17.

There was no detectible difference in the data that could be attributed to any construction impact from the M2G project.

3.3 Discussion

The key result from the water quality data is that the indicators for nutrients, typically total nitrogen and total phosphorous, were almost always above the ANZECC guideline values. This typically meant that with the cleared stream conditions created by the storm events in 2010 and subsequent additional light and heat in the water column, algae was able to quickly establish in many of the pools within Burra Creek and within the river system.

As expected turbidity increased dramatically in the short term during storm events and can take days or weeks to settle back to low background levels.

4. Chapter Four – Ecological Indicators

4.1 Introduction

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 four indices of community condition: the AUSRIVAS index (Appendix 4.1), the Signal-2 index, taxonomic richness and the richness of the Ephemeroptera, Plecoptera, and Trichoptera (or EPT index) were used as part of this study to assess river health. A summary of the AUSRIVAS index results for Spring 2010 and Autumn 2011 for both Angle Crossing and Burra Creek is also included in Appendix 4.1.

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 valuable indicator of river health.

Changes in total periphyton biomass and/or the live component of the periphyton (as determined by chlorophyll-*a*) can vary with changes in flow volume, so these variables are often used as indicators of river condition in relation to monitoring the effects of flow regulation, environmental flow releases or water abstraction impacts (Biggs, 1989; Whitton and Kelly, 1995; Biggs *et al*., 1999). Water abstractions from the Murrumbidgee River 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.

4.2 Methodology

Details of the seasonal sampling design and statistical methodology are provided in detail in the spring and autumn reports (ALS, 2011a, 2011b, 2011c). For this component of the MEMP, the univariate and multivariate data used in all seasonal reports were re-analysed to incorporate the seasonal variation in each data set. These methods are described below.

4.2.1 Data Analysis

Separate univariate analyses were performed on 1) taxonomic richness; 2) EPT richness and 3) Signal-2 scores using linear mixed effects models to test for location and season differences. Season and Location were treated as fixed effects, while site and replicate were considered to be random effects nested within the fixed factor –site. For these analyses, data transformations were not required because the assumptions of normality and equal variances were met for the residuals of each response variable. Chlorophyll-a and AFDM from the periphyton samples met these assumptions after being log-transformed. Linear models were constructed using the lmer function in the lme4 package (Bates *et al*., 2011), a statistical package available in the R software package (R Development Core team 2011).

Seasonal and location differences in the whole macroinvertebrate community assemblages were tested for using permutational analysis of variance models (PERMANOVA+) for each component of the MEMP. PERMANOVA is a routine for testing multivariate responses (i.e. macroinvertebrate community structure) to one or many independent variables). PERMANOVA has similarities to the analysis of similarity (ANOSIM) approach that has been used throughout the seasonal MEMP data analysis procedure, and when there is a single factor, will produce varied results. PERMANOVA was used here because it achieves variance partitioning allowing it to analyse more complex experimental designs than ANOSIM (Anderson and Ter Braak, 2003; Alvarez and Peckarsky, 2005; Anderson *et al*., 2008).

PERMANOVA models were run separately for the Angle Crossing, Burra Creek and Tantangara to Burrinjuck datasets. Each test was based on Bray-Curtis similarity coefficients and was derived from 9999 permutations. Data were 4th root transformed prior to the construction of the similarity matrices to down weight the influence of highly abundant taxa.

4.4 Results and Discussion

4.4.1 Part 1 – Angle Crossing

Average flows recorded at Lobb's Hole for the spring period were 50% higher than autumn (888 ML/d and 446ML/d respectively) with the flow from spring to autumn shown in Figure 4.1. The impact of these higher flows is reflected in the results in the spring seasonal report (ALS, 2010a).

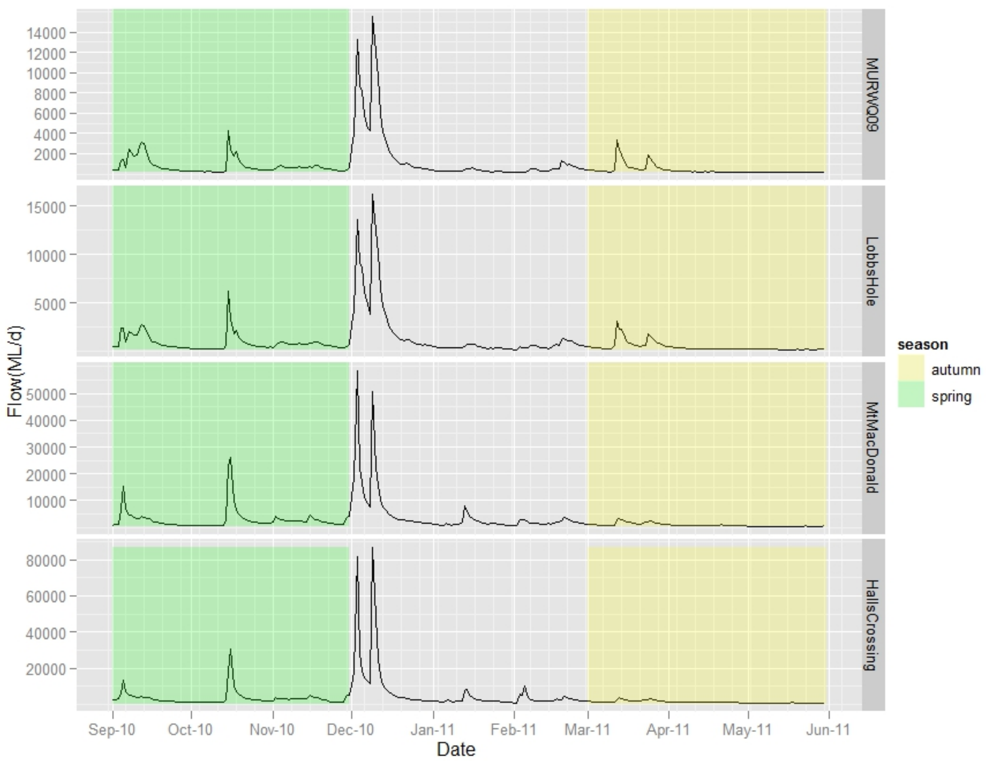

Figure 4.1 – Spring and autumn hydrograph from key sites in the Murrumbidgee Ecological Monitoring Program Note: differences in the scales of the y-axis

There was no significant difference detected in either chlorophyll-a or AFDM concentrations between upstream and downstream locations even though average chlorophyll-a concentrations were higher among the downstream sites in spring and autumn (Figure 4.2, and values in Appendix 4.2). The higher mean concentrations downstream of Angle Crossing are largely due to the results from Point Hut Crossing (MUR 23) in spring, but in autumn the influence of Point Hut Crossing was negligible because concentrations were considerably lower than all previous sampling runs. The reason for this is unclear, because this site has consistently higher concentrations of both chlorophyll-a and AFDM than the four sites upstream which is likely due to the more frequent spillages from Point Hut Pond.

These spills are likely to deliver nutrients at a more constant rate because of the urbanised catchment. However, ALS suspects that because some of the larger substrate fractions were scoured from the riffle, there was less stable substrate for high rates of algal growth. Further, it may have also been due to a limited nutrient supply from Point Hut Pond since there were no runoff events for 40 days leading up to the autumn sampling event.

In spring there was a strong negative relationship between current velocity and AFDM & Chlorophyll-a concentrations, indicating a decrease in concentrations with increasing flow. In contrast the Chlorophyll-a concentrations in autumn showed a positive relationship with flow, which appears to contradict the spring data. The explanation for these contrasting results, however, is that biomass accrual has been found to be greatest at medium velocities when nutrient uptake and gaseous exchange is maximised. Under these conditions filamentous growth appears to exceed the flow related scouring which generally occurs during periods of higher flow.

Mean Chlorophyll-a concentrations were significantly higher in autumn compared to spring, which is an indication that despite higher nutrient concentrations in the runoff during spring, the more frequent, higher magnitude flows (Figure 4.2) is keeping algal growth in check with frequent disturbances (Biggs and Stokseth, 1996; Biggs, 2000).

While there were strong seasonal patterns in the chlorophyll-a data, the same patterns were not seen in the AFDM data, where there was not a consistent pattern between seasons or locations (Figure 4.2). This data shows a marked increase in AFDM between locations in spring, thought these differences were not statistically different. The contrasting results may be an indication that although the average Chlorophyll-a concentrations in spring were very similar (indicating a similar live component), the >50% increase in AFDM downstream may reflect accumulating organic material that has been scoured during high flow events during spring and thus accumulating downstream.

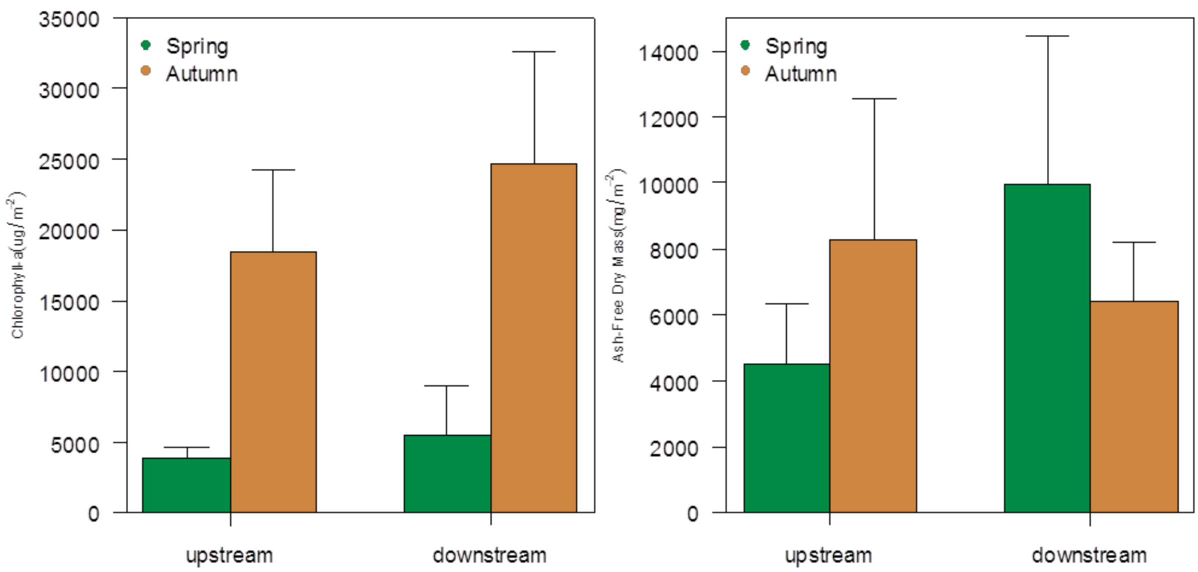

Figure 4.2 – Average Chlorophyll-a (left) and Ash Free Dry Mass upstream and downstream of Angle Crossing Error bars are 95% Confidence intervals (n=18 for each group mean)

The macroinvertebrate analyses indicate a strong seasonal influence on the community composition and the univariate indices.

Comparisons of the AUSRIVAS assessment between autumn and spring for the Angle Crossing component show that for the riffle sites four of the six sites (66.6%) showed no change in their assessment from spring to autumn while one site (16%) showed an improvement (directly downstream of Angle Crossing) and one site (16%) decreased (MUR 23 - Point Hut Crossing moved from BAND A to BAND B) (Appendix 4.4). For the edge habitat, two sites had “no reliable assessment” in spring and one site was not sampled, this meant that comparisons between seasons were only possible at three sites. Of these, one site had no change (MUR 23 – Point Hut Crossing) and two showed and improvement (MUR 16 and MUR 19).

The reason for the decline in the AUSRIVAS BAND at MUR 23 in autumn was due to a single taxa (Simuliidae: SIGNAL=5); this taxa was present in all the other replicates taken from this site. These taxa are usually highly ubiquitous and abundant and therefore the AUSRIVAS assessment should be approached with some degree of caution. Improvements in the autumn AUSRIVAS assessment were attributed to improved habitat conditions (i.e. through the removal of fine sediments, especially from the riffle habitat) and a more stable flow regime. High flows in spring reduced the number of EPT taxa and total richness taxa downstream of Angle Crossing (Figure 4.3; values in Appendix 4.5). There was no location effect on the Signal-2 scores, but the higher values recorded in spring indicate that while taxonomic richness tended to be lower, the sensitivity of the taxa was higher in spring than in autumn (Figure 4.3; values in Appendix 4.5). The lower richness indices between locations in spring suggest that increase flow volume with increasing catchment area may have more impact upon the resistance of certain taxa during these conditions. The physical characteristics of MUR 19 immediately downstream of Angle Crossing has featured in previous discussion regarding the lowered richness and EPT taxa (ALS, 2010a, 2011a) because of its proximity to the low level crossing, which is flanked by two dirt roads. Sediment delivery during runoff events (Plate 4.1) may reduce the number of taxa (especially EPT taxa) which are sensitive to silt and respond by relocating via downstream drift.

Plate 4.1 - Angle Crossing, showing turbid runoff from the right hand (indicated by the arrow) and from the left hand side

The PERMANOVA tests on the whole community assemblages show a highly significant difference between seasons for both the riffle and edge communities (Appendix 4.7). There was no significant difference between locations for either the riffle or the edge communities. The NMDS plots show the seasonal effect (Figures 4.4 and 4.5) which can be seen by the clustering and separation of the communities. The absence of any location effect can also be interpreted in these plots by the interdispersal of upstream and downstream sites within each seasonal cluster without any clear pattern. This is more prominent in autumn however, whereas in spring there appears to be a separation of the farthest downstream communities forming their own group (i.e. MUR 19 and MUR 23).

During spring, there appears to be higher separation of groups which is likely due to higher flows over this period causing the displacement of certain taxa due to the higher velocities exerting higher sheer stress on the macroinvertebrates. Despite this seasonal impact, once flows stabilise over the summer and autumn months, there seems to be a recovery of EPT taxa and total community richness (Figure 4.3). It is clear from our current sampling design that flow is highly influential on shaping the macroinvertebrate community structure. It is apparent that high flow events in spring can result in a reduction in the estimated abundances of specific groups of taxa such as Ephemeroptera: Plecoptera and Trichoptera (EPT) and free-living edge taxa that are otherwise ubiquitous throughout the sampled reaches. In autumn, when base flows tend to be lower, but more stable, there is generally an increase in EPT abundances, but this is largely due to proliferation of moderately-tolerant Trichoptera taxa and a marked decrease in the number of sensitive mayfly taxa.

We have found little change in the number of taxa collected throughout this baseline period which has encapsulated a range of flows in the range: 35 ML/d – 630ML/d. The fact that taxonomic richness has been consistent throughout the course of this project suggests that irrespective of how the estimated relative abundance of certain groups and when certain taxa are absent from some sites reacts to changes in flow, there is a considerable amount of resistance within the Murrumbidgee macroinvertebrate populations. And although after periods of high flow events, some free living taxa have been completely absent from some sites, they show high resilience, which is deemed to be a desirable quality of a healthy ecosystem (Davies *et al*., 2010).

When the Murrumbidgee River was sampled in autumn 2009 at 72ML/d, and in autumn 2010 at 36 ML/d, there were reductions in the absolute numbers of the more sensitive taxa, but there was little evidence of taxa being removed completely. The exception to this was Elmidae (Coleoptera) which was notably absent during autumn during low flows. Brooks *et al*. (2011) have suggested, that Elmidae may provide a useful indicator taxa for low flow impacts. Other taxa that could prove useful indicators of low flow impacts include Tipulidae, Leptophlebiidae and to a lesser extent Gripopterygidae.

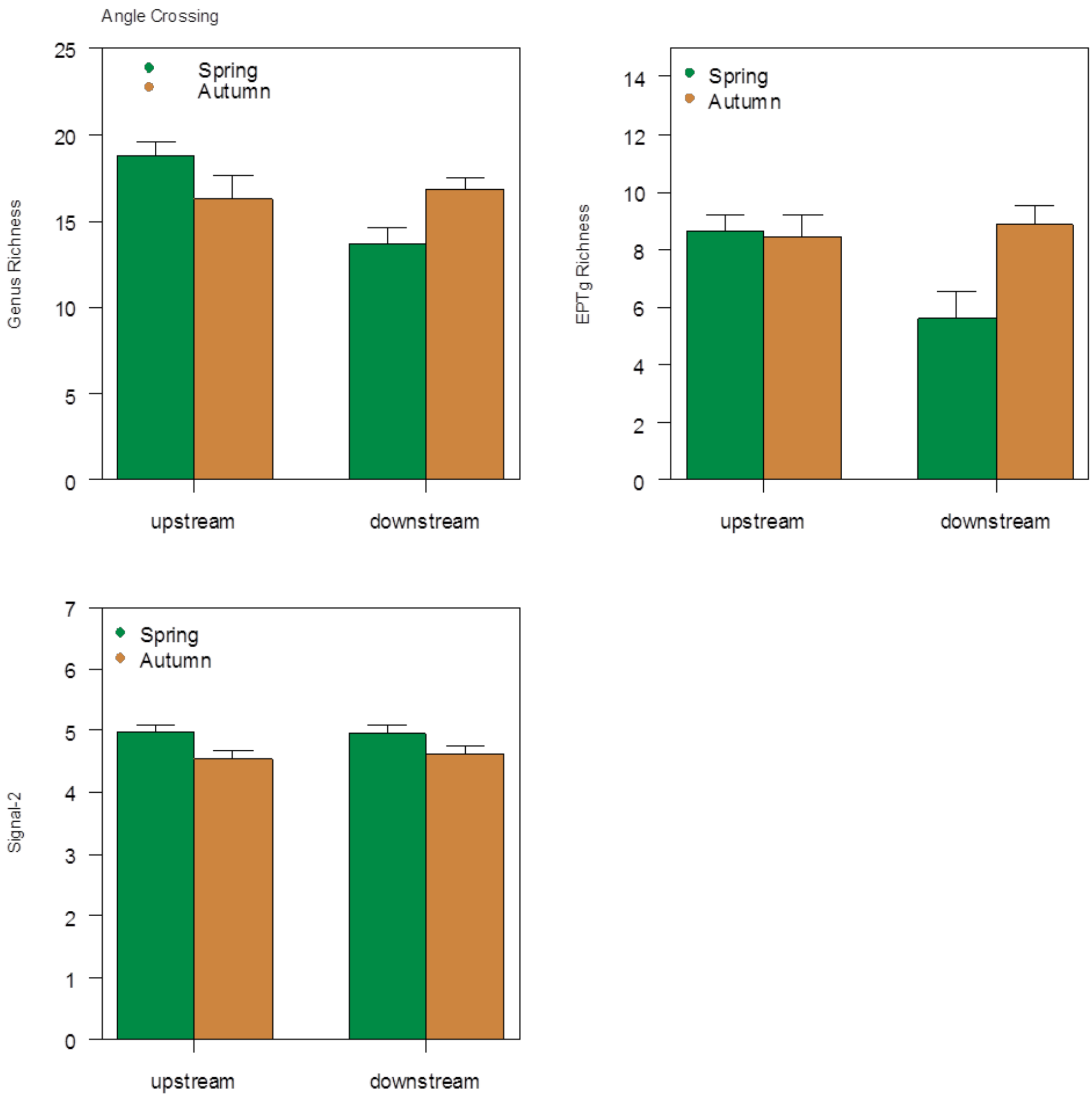

Figure 4.3 – Average macroinvertebrate indices for autumn and spring and up and downstream of Angle Crossing
Error bars are 95% Confidence intervals (n=6 for each group mean).

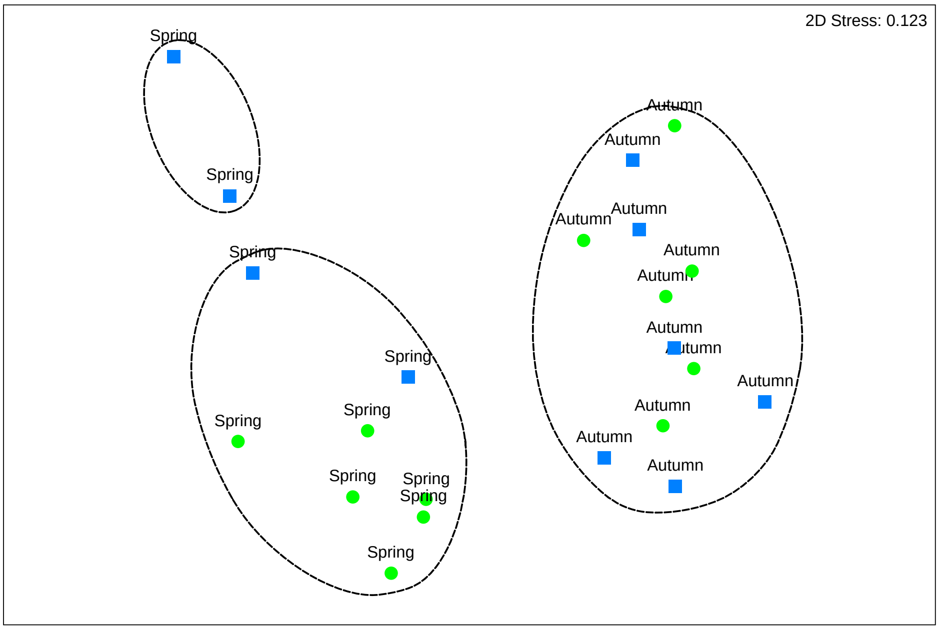

Figure 4.4 – Non-metric multidimensional scaling of genus level data from spring and autumn riffle samples
Ellipses represent the 65% similarity groups
Blue squares indicate sites downstream of Angle Crossing; green circles are sites upstream of Angle Crossing

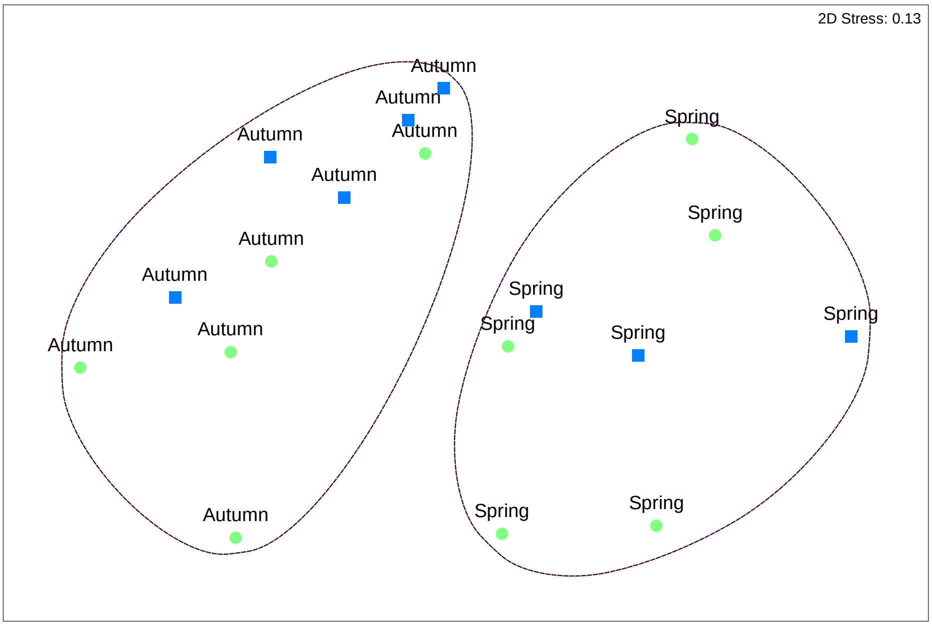

Figure 4.5 – Non-metric multidimensional scaling of genus level data from spring and autumn edge samples
Ellipses represent the 55% similarity groups
Blue squares indicate sites downstream of Angle Crossing; green circles are sites upstream of Angle Crossing

4.4.2 Part 2 – Burra Creek

Flow conditions in autumn 2011 were similar to those seen for the spring 2010 sampling run, with low base flows and limited riffle habitat at sites upstream and downstream of the outlet pipe at Williamsdale Road Bridge (Figure 4.6).

We found no significant location differences in chlorophyll- a or AFDM concentrations in spring or autumn; however there was a highly significant difference between seasons for chlorophyll-a and AFDM concentrations (Figure 4.7; values in Appendix 4.2) at the upstream sites in Burra Creek and the Queanbeyan River control site. Downstream of Williamsdale Road there was no seasonal difference detected for either biomass estimate. The lower chlorophyll-a concentrations in spring are probably related to the higher average base flows and more frequent flow-related disturbances. The reason that there is no seasonal change downstream of Williamsdale Rd is unclear; although one submission is that the more frequent number of deep pools downstream of the proposed discharge point (e.g. Plate 4.2) may act as a buffer against the impacts of seasonal high flow events and thus lessen the scouring impact at these downstream sites.

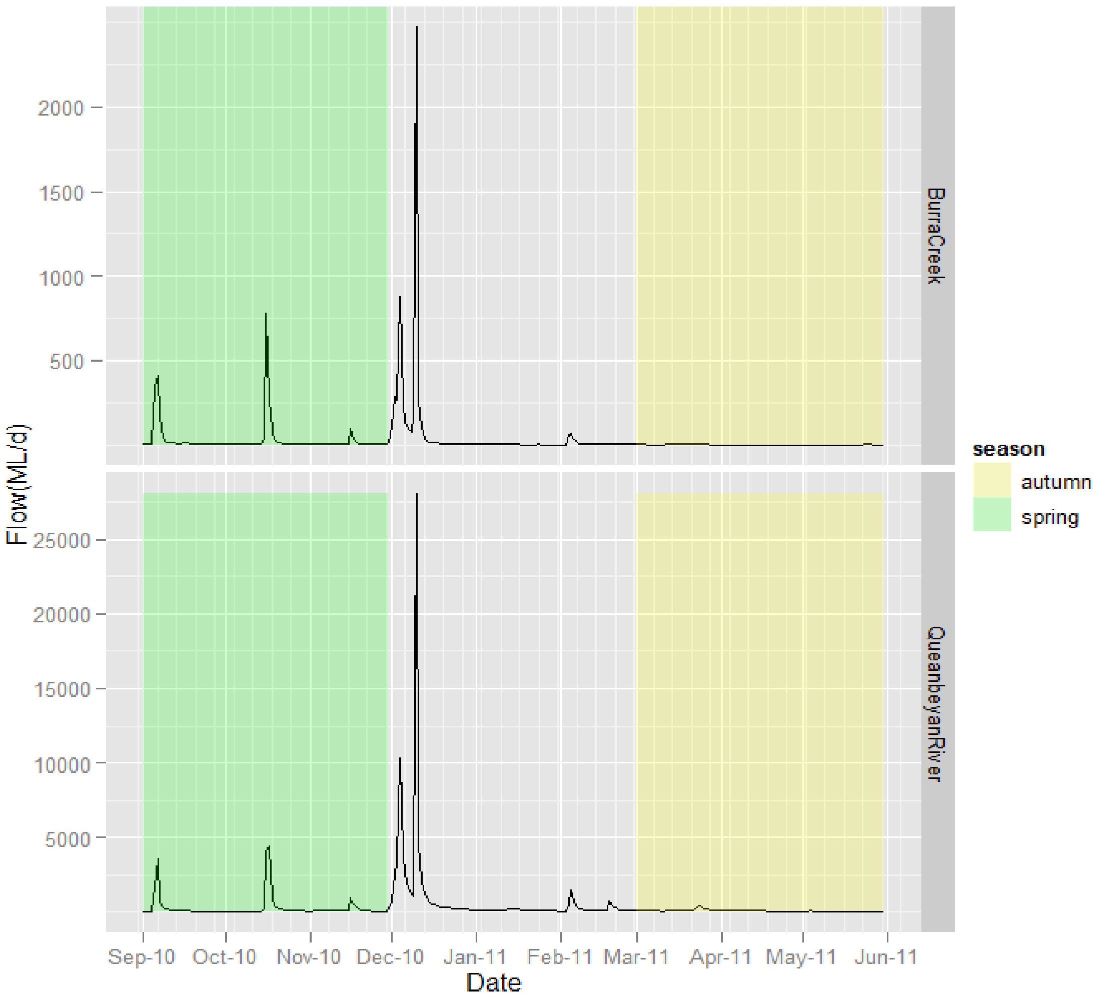

Figure 4.6 – Spring and autumn hydrograph for Burra Creek and the Queanbeyan River
Note the difference scales on the y-axis

Plate 4.2 – Deep pools downstream of the Williamsdale Road discharge point (left: BUR 2a – downstream of Burra Road weir and; right: BUR 2c upstream of London Bridge)

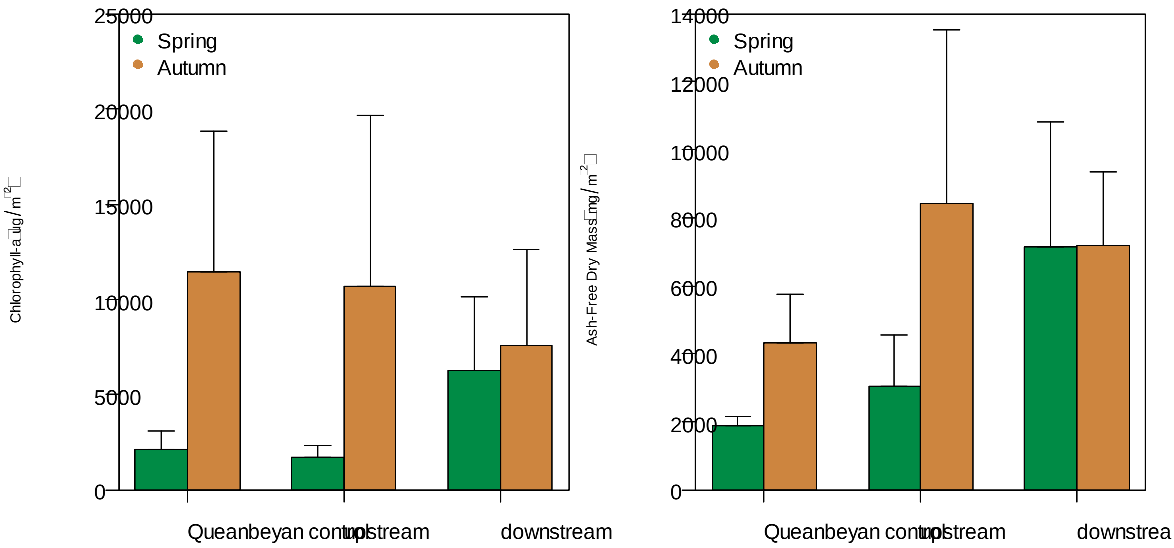

Figure 4.7 – Average Chlorophyll-a (left) and Ash Free Dry Mass upstream and downstream of the Burra Creek outlet at Williamsdale Rd and the Queanbeyan River control site
Error bars are 95% Confidence intervals

A number of riffle samples could not be taken due to lack of habitat (i.e. BUR 2a and 2b) in spring and inundation by Googong Dam levels (BUR 3) in autumn (Appendix 4.4). The edge habitat at BUR 3 decreased from BAND A to BAND B between autumn and spring and BUR 2a was assessed as BAND C (severely impaired). Aside from these assessments all of the other sites were assessed as BAND B and there were no changes at these sites between seasons. The poor assessment given to BUR 2a is likely due to the lack of habitat and low diversity substrate, which was predominantly sand with large amounts of silt.

The analysis of the univariate metrics derived from the macroinvertebrate community data shows a highly significant increase in EPT taxa in autumn compared to spring (Figure 4.8). While members of this group are often prefer faster flowing water, which is usually associated with spring, the more stable conditions during autumn, may promote higher diversity within the group because longer periods between disturbances promotes higher diversity (Lake, 2000).

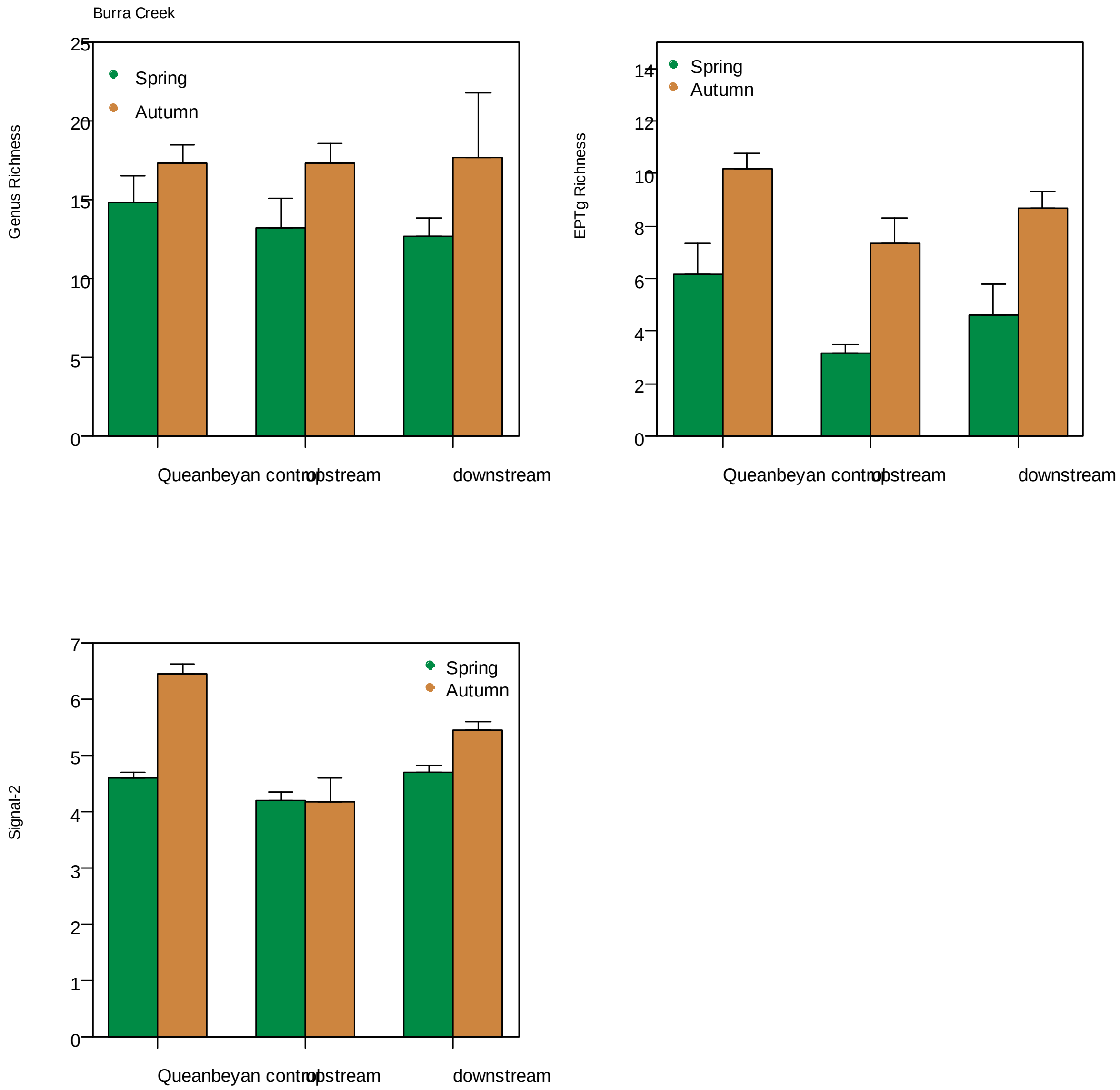

Figure 4.8 – Average macroinvertebrate indices for autumn and spring and upstream and downstream of the Burra Creek discharge point

Error bars are 95% Confidence intervals (n=6 for each group mean)

PERMANOVA tests of the whole community composition indicate a strong seasonal separation of the samples (Appendix 4.7). For the edge communities there was a significant season and location difference. The location difference exists between the Burra sites and the Queanbeyan Control site but not between the Burra Creek locations (i.e. upstream and downstream of Williamsdale Rd) (Figure 4.9). There was also a highly significant seasonal effect on the edge samples (Figure 4.10). There appears to be a separation of locations within each season, but because of the low number of samples collected during spring and autumn these differences were not considered to be statistically significant.

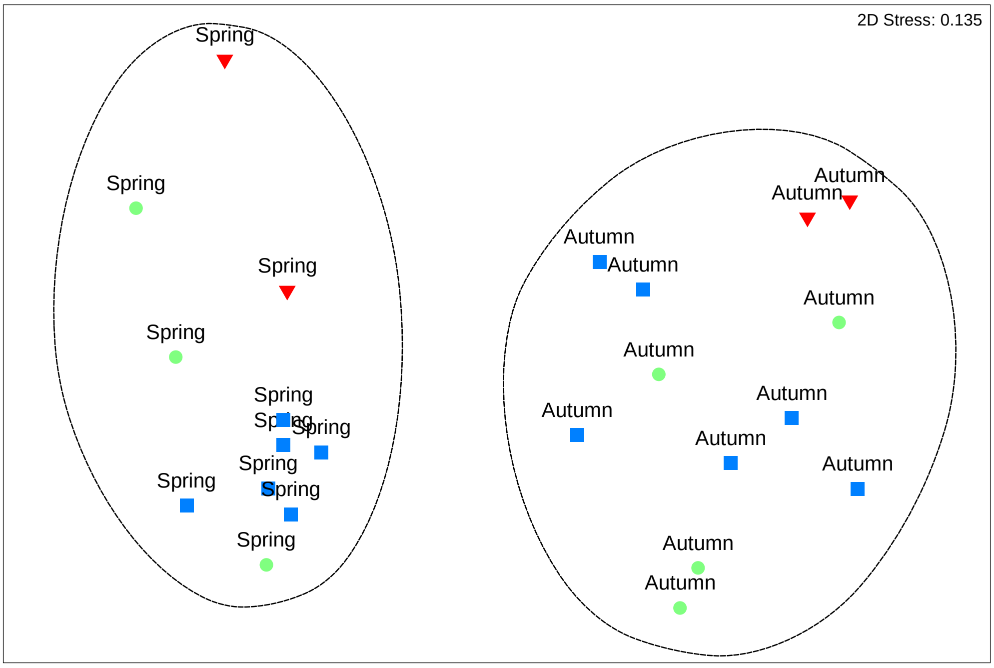

Figure 4.9 – Non-metric multidimensional scaling of genus level data from spring and autumn riffle samples. Ellipses represent the 40% similarity groups
Blue squares indicate sites downstream of Williamsdale Road; green circles are sites upstream of Williamsdale Road and red triangles show the Queanbeyan River samples

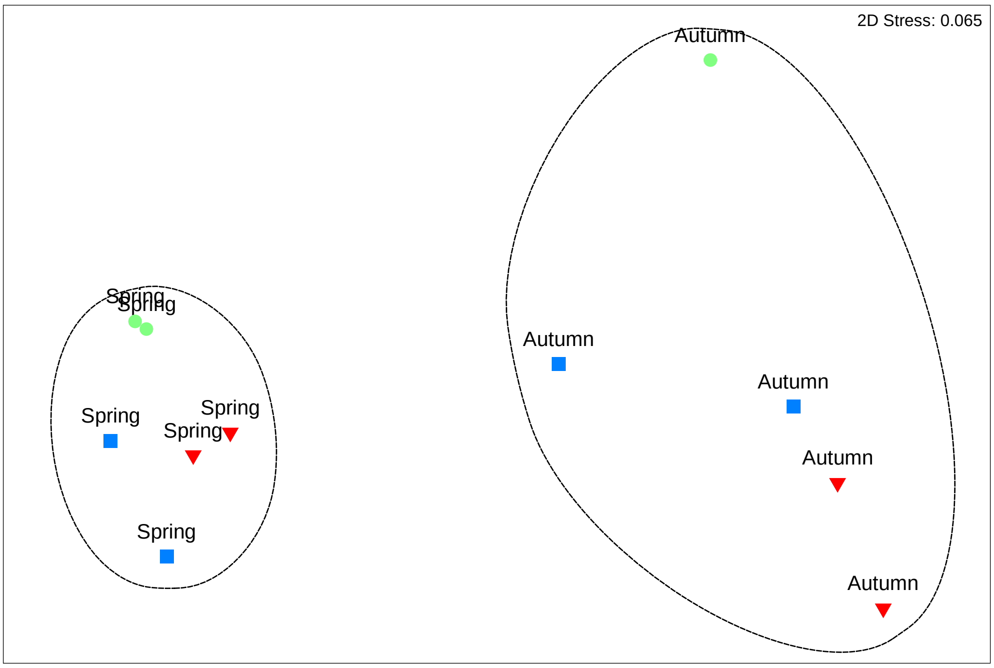

Figure 4.10 – Non-metric multidimensional scaling of genus level data from spring and autumn edge samples. Ellipses represent the 50% similarity groups
Blue squares indicate sites downstream of Williamsdale Road; green circles are sites upstream of Williamsdale Road and red triangles show the Queanbeyan River samples

The riffle samples in spring were characterised by opportunistic taxa that quickly colonise disturbed environments. Some of these taxa require clean substrate and have been shown to be highly abundant and dominate community composition in the Murrumbidgee River samples. Spring samples were collected two weeks after a high flow event in both the Burra Creek and Queanbeyan River catchments. The AUSRIVAS recommended sampling period after high flow events is 4 weeks which limits sampling opportunities, so it is feasible that the lower univariate metric values (Appendix 4.6) reflect the short period of time since the disturbance.

The results of the spring and autumn sampling runs highlight the strong seasonal dynamics in the Burra Creek and Queanbeyan River. High flows in spring had and overriding impact on the concentration levels of chlorophyll-a and AFDM and the macroinvertebrate communities. The M2G project is unlikely to have an impact on the ecological processes during high flow events but may increase the frequency of moderate flow disturbances and increase both the baseflow and permanence ratio in Burra Creek which we predict will change the structure of the Burra Creek macroinvertebrate communities downstream of the discharge weir, so that they resemble the communities at the nearby perennial Queanbeyan river.

4.4.3 Part 3 – Murrumbidgee Pump Station

Due to high flows in the lower reaches of the Murrumbidgee catchment (downstream of the Cotter Confluence), biological sampling was not undertaken for the MPS component in spring 2010 (ALS, 2010*c*).

The key results from the autumn 2011 sampling run show that:

- 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. 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;

- 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 macroinvertebrate community assemblages based on the AUSRIVAS modelling information since the previous autumn sampling run (2010).

- There was a notable increase in estimated relative abundance and number of EPT taxa in the riffle habitat and the improvement 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;

- 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;

- 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

From our current sampling design is it evident that flow is highly influential in shaping the macroinvertebrate community structure. High flow produces 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.

4.4.4 Part 4 – Tantangara to Burrinjuck

Part 4 of the MEMP involves the collection of single replicate samples from both the riffle and edge habitat from 23 sites situated from Tantangara Reservoir to approximately 2km upstream of the Burrinjuck Reservoir delta region. The sites are divided into four macro-reaches (zones) which represent geographic or hydrological changes (Allan and Castillo, 2008) throughout the system; and obvious changes in terms of landuse, erosional processes and/or other potential anthropogenic impacts (Table 4.1). These classifications are to some extent subjective, but are based on previous frameworks which have suggested methods for such classifications (e.g. Allan and Castillo, 2008; Frissell *et al*., 1986).

Table 4.1 - Zone structure of sites along the Murrumbidgee River

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

The results from the AUSRIVAS assessment (Appendix 4.4) indicate that for the autumn period the majority of the riffle samples resulted in BAND A assessments. The majority of sites show no change since spring 2010 while three sites (MUR19, MUR 27 and MUR 29) showed improvements. MUR 3 and MUR 23 had a decline in their AUSRIVAS health assessment. MUR 3 (located at Bobeyan Road bridge near Adaminaby) shifted from BAND A in spring to BAND C (severely impaired) in autumn indicating that many of the taxa expected to occur were absent from the sample. The reason for this isolated impact is unclear but there was a considerable amount of stock movement in and around this site in autumn, with stock waste scattered along the margins. This is likely to be influencing the water chemistry at this site, especially during runoff events. However our water quality sampling is not always detecting these changes.

The edge samples had fewer sites with BAND A assessments (34%) and the majority of these were in the upper reaches of the Upper Catchment. The exceptions were MUR 18, 19 and 30 all of which have quality edge habitat with considerable depth and comparatively good riparian cover. The BAND B assessments are likely due to poorer quality habitat among the various sites, which tend to fluctuate in their depth and generally have poor trailing bank vegetation and poor macrophyte populations and diversity. This last point was particularly evident in autumn 2011 when it was noted how severe the scouring had been on macrophyte stands throughout the catchment.

Taxonomic richness (family level) differed only between zones and had no significant seasonal element to the variation displayed in the data (Figure 4.11; Table A4.10 Appendix 4.5). In contrast, EPT richness was lower in spring for Zone 2-3 compared to Zone 1. Signal-2 scores were higher in Zone 1 compared to Zones 2-3, which did not differ from one another and were not different between seasons.

These results suggest that there is a strong spatial element to the distribution of sensitive EPT taxa and whole community richness. The upper reaches above Cooma tend to have a greater diversity of more sensitive taxa (as indicated by the Signal-2 values) and while the seasonal variability can be seen in Figure 4.11, which tends to show lower diversity in spring (this is probably in response to increased flows) the seasonal fluctuations within each zone are minimal compared to the differences between zones. Owing to the preference of many of the more sensitive taxa requiring cool, clear water, the higher diversity within Zone 1 is not surprising. Although there is no data for Zone 4 ion spring, the autumn results indicate a decline in the mean richness and Signal-2 values progressively downstream, which can be related to changes in elevation, land use and catchment area.

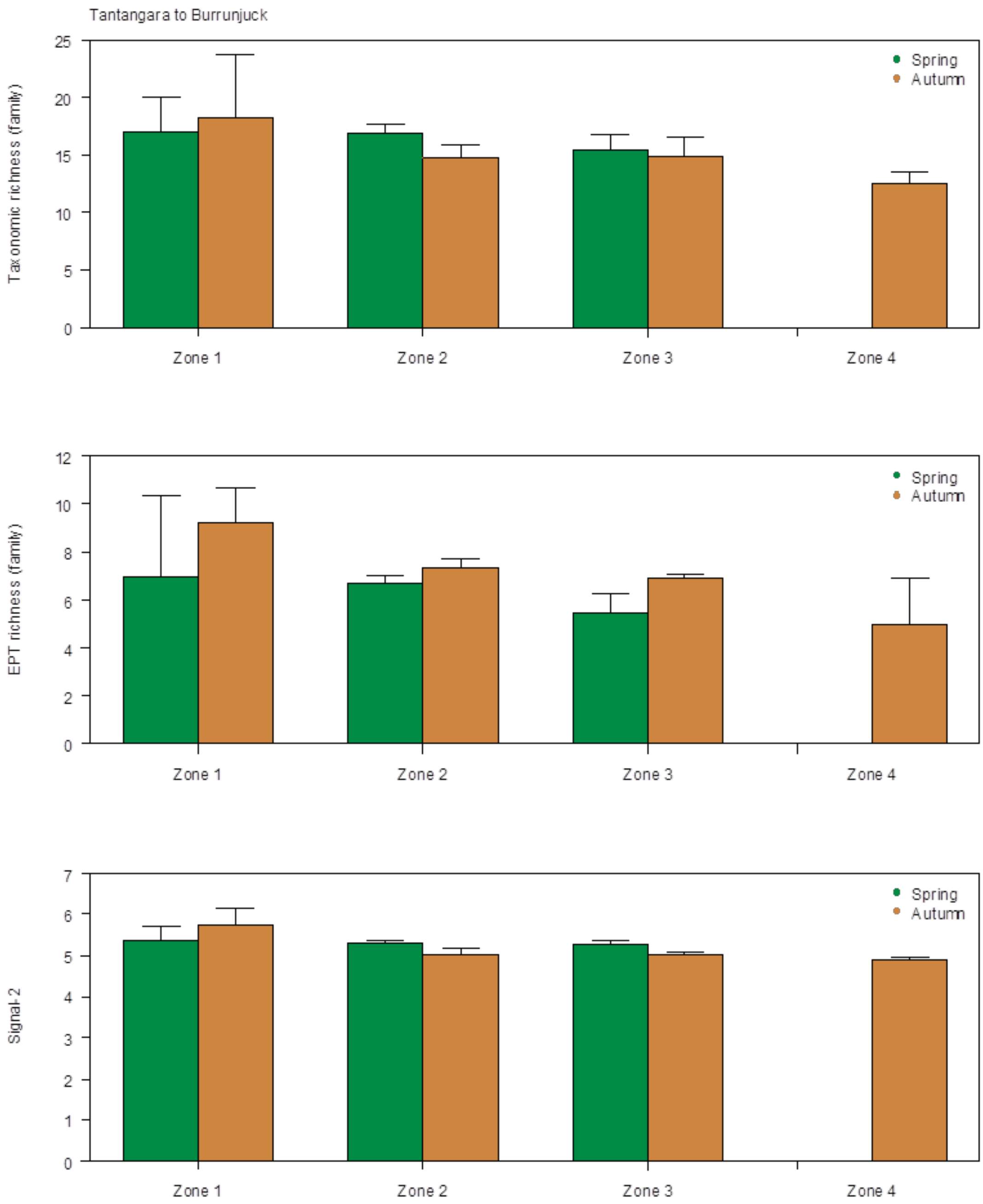

Figure 4.11 – Average macroinvertebrate indices for autumn and spring from Tantangara to Burrinjuck Error bars are 95% Confidence intervals

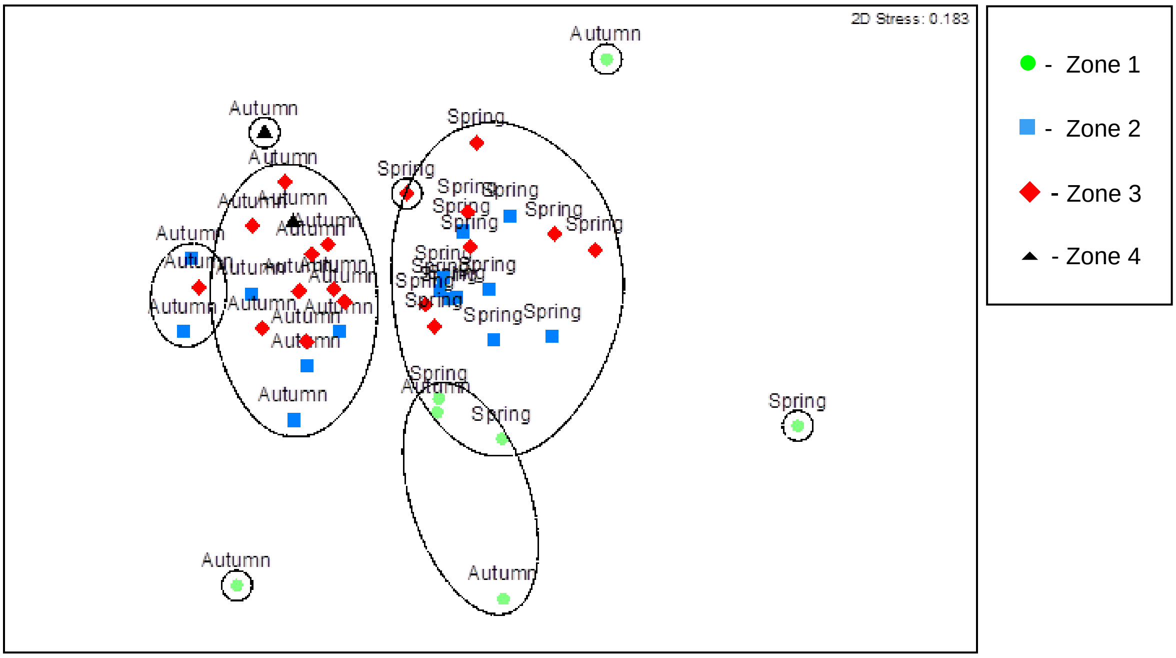

Figure 4.12 – Non-metric multidimensional scaling of family level data from spring and autumn riffle samples Ellipses represent the 55% similarity groups

The results from the multivariate analysis for the whole macroinvertebrate communities support the univariate analyses interpretation (Figure 4.12).

The edge NMDS plot shows a similar seasonal separation of sites, but the most notable difference is the higher degree of variation among the zones (Figure 4.13) which is an indication of the more complex and therefore highly variable habitat within each zone. Over and above this within-zone variation, PERMANOVA results indicate a strong seasonal change in community structure (indicated by the separation of the two main groups and a highly significant zonation effect (indicated by the separation of zones within each season).

Irrespective of the season, there is an obvious separation of sites in Zone 1 compared to Zones 2 and 3 which tend to group closely together. This indicates a high degree of similarity between these zones caused by similar macroinvertebrate community assemblages. The separation of the Zone 1 sites is largely due to the occurrence and higher numbers of flow and water quality sensitive taxa at these sites. Some of these taxa drop out of the samples below Cooma and others become less abundant as they are replaced by more tolerant taxa such as Chironomids and Simulids.

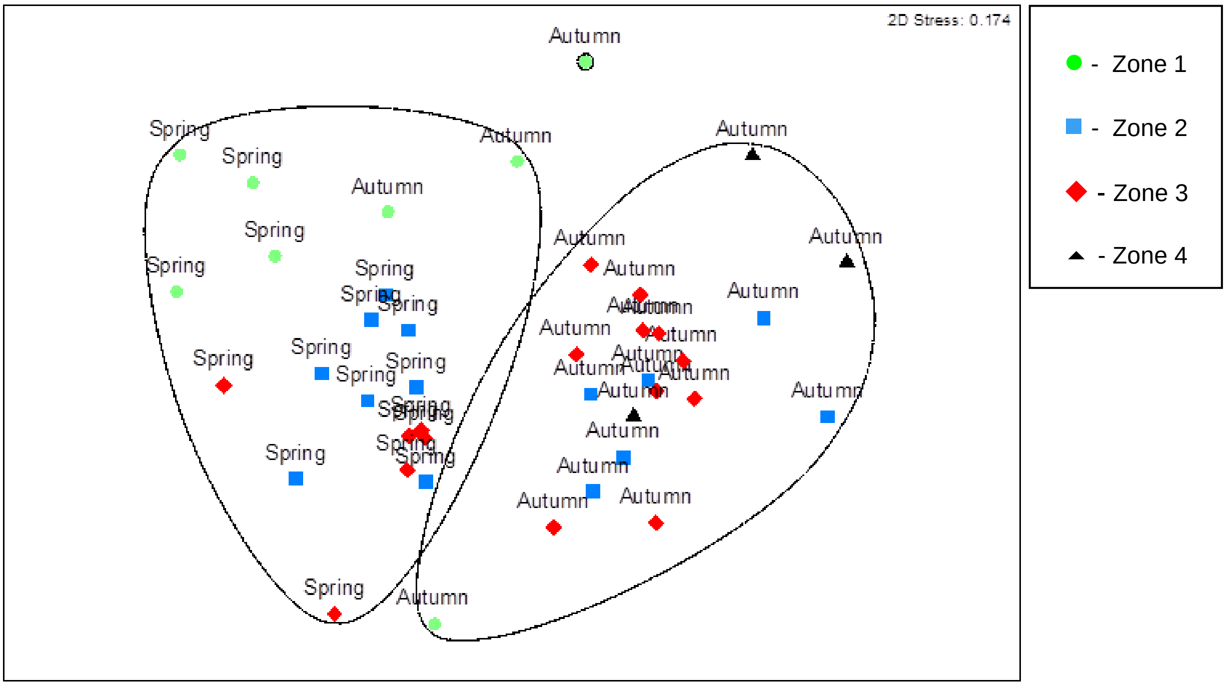

Figure 4.13 – Non-metric multidimensional scaling of family level data from spring and autumn edge samples Ellipses represent the 48% similarity groups

4.5 Conclusions

Seasonal varaibility was the overiding influence on most of the biological indicators considered in this program. The seaonal aspect is a function of changes in ambient and surfacne water temperature and life cycle patterns in various macoinvertbrate taxa (Hynes, 1970).

It is clear from our current sampling design that flow is highly influential in shaping the macroinvertebrate community structure. It is apparent that high flow events in spring can result in a reduction in the estimated abundances of specific groups of taxa such as Ephemeroptera: Plecoptera and Trichoptera (EPT) and free-living edge taxa that are otherwise ubiquitous throughout the sampled reaches. There has been little change in the number of taxa collected throughout this baseline period, which has encapsulated a range of flows from 35 ML/d to 630ML/d.

It is predicted that during winter and spring, when the proportion of flow being abstracted is low compared to predicted seasonal base flows, that there are unlikely to be any long term effects on water quality, periphyton communities or the macroinvertebrate populations. Short term effects may include some reductions in individual indicator taxa and reactive changes in water quality to hydrological disturbances, but as long as there is a period of stable flows following these disturbances, the system should return to a state similar to that seen before the disturbance.

During summer and autumn, it is expected that detrimental changes in water quality may occur when flows are less than 80 ML/d due to reduced flushing of the riverine environment and greater nutrient uptake by algae during extended periods of low baseflow. Water temperature is also likely to increase during periods of low flow, which will in turn influence D.O., pH, and algal growth.

If river flows are artificially maintained at or near the 80^{th}:90^{th} percentile flow level through ongoing water abstractions, we could expect to see a deterioration in water quality which would then begin to reduce the abundance and occurrence of sensitive macroinvertebrate taxa over the longer term and increase the relative abundance and frequency of pollution tolerant taxa.

This may have repercussions to fish populations which also rely on healthy macroinvertebrate populations as a food resource and may have particular preferences for certain macroinvertebrate taxa as a food source.

In Burra Creek we have already suggested that the M2G project is unlikely to have an impact on ecological processes and macroinvertebrate community structure during high flow events but may increase the frequency of moderate flow disturbances and increase both the baseflow and permanence ratio in Burra Creek. This, we predict will change the structure of the Burra Creek macroinvertebrate communities downstream of the discharge weir, as hydrological shifts away from the currently intermittent nature of Burra Creek towards a more perennial system is likely to result in significant changes in the community structure and function of these sites.

4.6 Recommendations

An additional challenge of the M2G project is to relate what we already know to what we can expect in terms of biological changes under the 80^{th}:90^{th} pumping rules. To address these challenges we recommend the following:

- The continuation of AUSRIVAS monitoring as suggested in the EIS. In doing so the data obtained from this program are likely to encompass a broader range of flow patterns which will allow firmer predictions to be established in relation to the operation of M2G;

- In previous reports ALS have recommended undertaking the hyporheic zone (HZ) surveys within the Burra Creek catchment prior to the operation of M2G. The proposed M2G transfer has the potential to change the substratum, surface water quality, geomorphology, riparian vegetation and potentially the groundwater quality within the system which could in turn impact upon the hyporheic fauna. It is recommended to undertake a pilot program collecting baseline survey data of the hyporheic community at each site, but at least obtaining one set of data prior to M2G commissioning. This information will allow ACTEW to make more informed decisions regarding this component of the ecosystem, but would mean an expansion to the scope of the project to include such sampling. Currently this recommendation has not been supported by ActewAGL;

- The current program has limitations in that the biannual (spring and autumn) sampling regime may be too broad (i.e. changes may not be picked up for several months) to isolate specific flow-related impacts at the various discharge levels intended as part of the M2G project. Further, there is currently a knowledge gap as to the seasonal variability within Burra Creek outside of the current autumn/spring sampling regime. Winter and summer monitoring should ideally be incorporated in the operational phase monitoring program, given that pumping could be occurring year round. An operational monitoring program proposal was submitted to ActewAGL Distribution which outlines a two stage approach to monitoring the responses of macroinvertebrate communities (ALS, 2011d). Currently this recommendation has not been supported by ActewAGL;

- The MEMP project incorporates a range of metrics (i.e. AUSRIVAS, Signal-2, Taxa Richness) to assist in the characterisation of specific sites and whether there are relationships of these metrics to the flow regime. One of the problems with this method is that each metric relies on the combination of several or all members of the macroinvertebrate community and these results can vary in space and time without necessarily being a function of the environmental factor of interest (in this case flow).

A desirable outcome of the adaptive management component of this program would be to isolate specific taxa that are shown (statistically) to respond to specific flow thresholds. This would provide another line of evidence to support the analysis and interpretation of the seasonal reporting component. This information would also provide a platform for future flow related projects supported by ActewAGL. This additional analysis is currently out of the scope of the current program, but would benefit the MEMP in the mid to long term, especially during the operation of the M2G project.

5 Chapter Five – Fish Monitoring

5.1 Introduction

The fish monitoring was undertaken by the ACT Government, Conservation Planning and Research for ALS environmental as a key component of the MEMP baseline monitoring. The following sections are a summary of the source documents prepared for the MEMP by Beitzel *et al*., (2010 & 2011).

The Murrumbidgee River reportedly has one of the most degraded fish communities within the Murray-Darling Basin (Davies *et al*., 2008). However, the area is still known to provide adequate habitat for a number of threatened species. These species include the Trout Cod (*Maccullochella macquariensis*), Macquarie Perch (*Macquaria australasica*), Silver Perch (*Bidyanus bidyanus*), Murray Cod (*Maccullochella peelii peelii*) and Two-spined Blackfish (*Gadopsis bispinosus*). There are several recreational fishing targets within the reach, which include the Murray Cod and the Golden Perch (*Macquaria ambigua*). Other native species within the reach include the Australian Smelt (*Retropinna semoni*), Western Carp Gudgeon (*Hypseleotris klunzingeri*) and Mountain Galaxias (*Galaxias olidus*) (Lintermans, 2002).

Alien fish species are well established in the Murrumbidgee River including European Carp (*Cyprimus carpio*), Goldfish (*Carassius auratus*), Redfin (*Perca fluviatilis*), Gambusia (*Gambusia holbrooki*) and Oriental Weatherloach (*Misgurnus anguillicaudatus*). Rainbow trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) are found at higher elevations closer to Tantangara Dam and are recreational fishing targets along with Redfin and to some extent European Carp (Lintermans, 2002).

Numerous studies have been completed with regards to the fish communities of the Upper Murrumbidgee River such as those by Lintermans (2002), Gilligan (2005), ACT Government (2007) and Davies *et al*. (2008). A number of threats and potential threats to the fish communities of the Upper Murrumbidgee River were identified and are listed below (Lintermans, 2002; ACT Government, 2007; ACT Government, 2010):

- Loss of natural flow regime (flow volume, variability, seasonality and thermal regime);
- Loss of in stream and riparian complexity (reduced amounts of large woody debris, increased base load sediment and exotic/cleared riparian plant communities;
- Competition, predation and disease from alien fish;
- Poor water quality;
- Barriers to fish passage;
- Overfishing.

It is possible that some of these threats will be exacerbated by the extraction of water from Angle Crossing.

The aims of the fish monitoring is to:

- Assess the fish community of the Upper Murrumbidgee River;
- Confirm the presence of threatened fish species in the Upper Murrumbidgee River; and
- Provide a baseline for a monitoring program on the fish community of the Upper Murrumbidgee prior to the implementation of the Murrumbidgee to Googong Water Transfer Project.

5.2 Methodology

Nine sites were surveyed as part of this program, consisting of four sites upstream the Angle Crossing (water abstraction point), one site at Angle Crossing and four sites downstream of the Angle Crossing. Details of the sites surveyed, survey effort, location and survey data is shown in Table 5.1 (Site location map for both Murrumbidgee River and Burra Creek provided in Appendix 5).

Full detail of the electrofishing techniques, biomass calculations and data analysis are given in the source document, provided to ALS by Beitzel *et al*., (2011).

Table 5.1 – Location of sampling sites and sampling effort (Source: Beitzel *et al*. (2011))

Site Name	Date	Boat EF* Shots	Previous Data Available	Location in Relation to Angle Crossing
Kissop's Flat	31/5/11	12	Yes	95 km upstream
Scottsdale	7/6/11	12	No	37.5 km upstream
Lawler Rd	6/5/11	12	No	13.5 km upstream
Boat Hole	10/5/11	10	Yes	1 km upstream
Angle Crossing	24/5/11	10	No	key location
Tharwa Sandwash	2/6/11	12	Yes	7 km downstream
Point Hut	14/6/11	12	Yes	18.5 km downstream
Kambah Pool	15/3/11	12	Yes	29 km downstream
Casuarina Sands	3/3/11	12	Yes	42.5 km downstream

*EF - Electrofishing

5.3 Results – Murrumbidgee River

A total of 188 fish were caught across all sites. Five species caught were native, with three of these considered to be threatened and also four exotic species across all sites. All fish caught are shown in Table 5.2. Of note is the dominance of Carp surveyed at all the monitoring sites (Mean fish lengths are in Appendix 5).

Table 5.2 – Number of fish caught by site (Source: Beitzel *et al*. (2011))

	Kissop's Flat	**Scottsdale**	**Lawler Rd**	**Boat Hole**	**Angle Crossing**	**Tharwa Sandwash**	**Point Hut Crossing**	**Kambah Pool**	**Casuarina Sands**	**Overall**
Carp*	6	15	13	6	15	18	6	40	13	132
Golden Perch						1	1	3	2	7
Goldfish*			1		2		2	1		6
Macquarie Perch	3			1						4
Murray Cod				1	2	2		2		7
Oriental Weatherloach*					1	1				2
Redfin*						10		1	3	14
Trout Cod					1			1		2
Western Carp Gudgeon								7	7	14

* introduced species

The composition of fish biomass is shown in Figure 5.1. The total biomass is dominated by carp at every site while native species comprise between 0 and 30 percent depending upon the site. For example, native fish were absent at both Scottsdale and Lawler Rd.

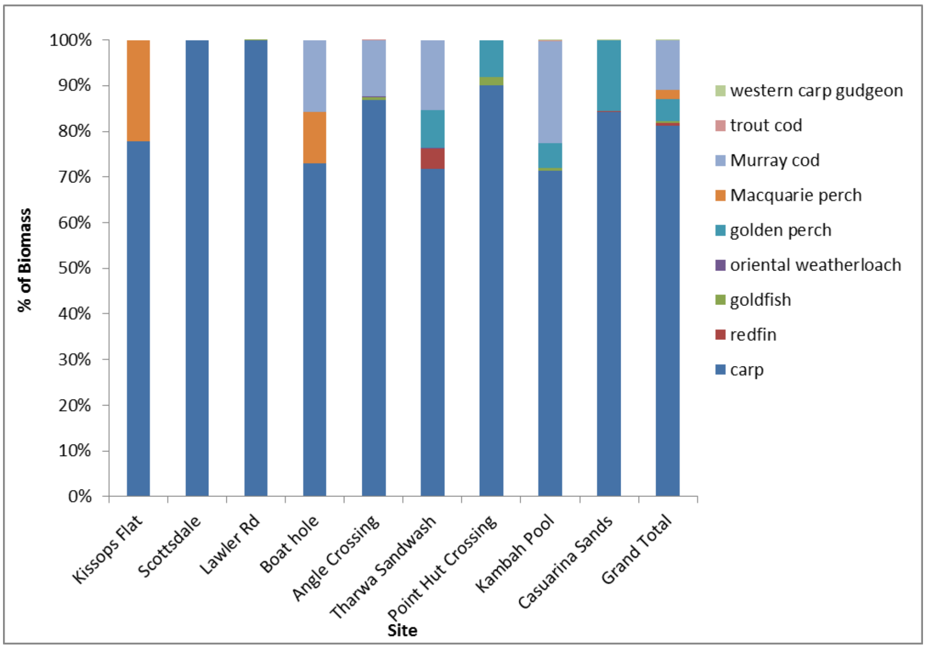

Figure 5.1 – Percentage composition of calculated biomass for each site (Source: Beitzel *et al*. (2011))

5.4 Results – Burra Creek

During the sampling period a total of 72 fish were caught across four of the five monitoring sites. There were no fish were captured or seen at Burra Rd.

Two native species were recorded at both Queanbeyan River sites (Flynn's Crossing and Gelignite Crossing) (Table 5.3). Introduced species were not captured or observed at Flynn's Crossing. All fish that were captured within Burra Creek were introduced species, with a high abundance of redfin. Two introduced species which were found within the Murrumbidgee system: Carp and Oriental Weatherloach, are currently not present in the Burra Creek system.

Table 5.3 – Number of fish caught by site (* denotes native species) (Source: Beitzel *et al*. (2011))

Site	Flynns Crossing	Gelignite Crossing	Burra Road	Limestone Crossing	London Bridge	Total
	Queanbeyan River		Burra Creek			
Eastern gambusia					1	1
Goldfish				4	1	5
Mountain galaxias*	19	5				24
Rainbow trout		1				1
Redfin				29	11	40
Western carp gudgeon*	1					1
Total	**20**	**6**	**0**	**33**	**13**	**72**

5.5 Discussion

This study was the first time that Trout Cod have been recorded at Angle Crossing since stocking was transferred to Kambah Pool in 2006. The fish's caudal length of 118mm indicates that the fish was approximately 1-2 years old (Douglas and Brown, 2000). This may represent the first natural spawning of stocked trout cod at Angle Crossing, if another sub adult and juvenile trout cod is recorded at Angle Crossing, it may be considered for otolith examination to determine whether it is a natural recruit or a stocked hatchery fish.

The collection of three Murray Cod from the Angle Crossing and Boat Hole sites is the first collection of this species upstream of Gingerline Gorge in over 20 years. These were recorded between 440 and 480mm meaning they are approximately 3-5 years old (Rowland, 1998). The origin of these fish is unknown but the main possibilities are natural upstream expansion through Gingerline Gorge, downstream movement from NSW stockings, illegal stockings or loss from farm dams. Gingerline Gorge has been generally thought to be the upstream extent of the Murray cod populations in the Murrumbidgee river for the previous 40 years (ACT Government, 2007). This indicates a possibility for the establishment of a breeding population of Murray cod upstream of Gingerline Gorge in the near future.

The possibility of natural breeding of both Murray and Trout cod at and upstream of Angle Crossing, raises potential impacts of M2G extraction to affect drifting larval and juvenile stages. The monitoring of the egg screen used will be able to determine whether the pumping is causing mortality to larval and juvenile threatened species, as well as confirming the presence of a breeding population at or upstream of Angle Crossing.

It is possible that the environmental flow releases from Tantangara Dam may improve the fish community through increased habitat availability. It is possible that improvements in habitat for Macquarie perch will be made by clearing of sediment from the riffle habitats prior to the breeding season. It is hoped that the populations of Two-spined Blackfish above Yaouk will benefit through the clearing of sediment.

When comparing this survey to the same survey undertaken at the same time 2010 by Beitzel *et al*. (2010), it is apparent that Kissop's Flat, Scottsdale, Point Hut and Kambah Pool are similar in species abundance and composition. The difference in the Angle Crossing and Boat Hole sites is the appearance of both Murray Cod and Trout Cod. The dominance of carp at all sites was consistent among both surveys. This year's survey registered two additional introduced species, which were not recorded in 2010 (i.e. Goldfish and the Oriental Weatherloach). Although in 2010 the number of Australian Smelt recorded was only six, their absence from the current survey was disappointing.

Macquarie Perch were recorded at Angle Crossing for the second year in a row after an absence from this site since 2004, although they were absent from the upstream site at Lawler Rd, where they were recorded last year. This population of Macquarie Perch within the upper Murrumbidgee may be quite significant, as it has recently been discovered through genetic investigations by Farrington *et al*. (2009) that they may be distinct from other local populations within the Cotter and Queanbeyan Rivers. They suggest that there is some level of genetic structure within the Upper Murrumbidgee population which possibly indicates a barrier between populations which is rarely crossed or separated breeding stocks. This could be important for the management of Macquarie Perch in the Upper Murrumbidgee River.

There is the possibility that some of the fish species recorded in this survey, both native and introduced, may react to changes in flow regime created by the M2G water transfer during low flow periods. This may change available habitat and water condition, which may have effects upon movement and breeding among some species. Due to the current high level of Googong Reservoir, it is likely that when the M2G scheme is commissioned, there will be no need to supplement the water supply for several years. This will still result in the regular start-up of pumps for maintenance, probably on a monthly basis. This will provide the perfect opportunity to assess the effectiveness of the egg screen, with examination for fish eggs and larval impingement included as part of the recommended screen monitoring.

The maintenance operation of the pumps creates another issue for Burra Creek, with the likely elevation of pH during the first few years. The holding time in the pipes between maintenance periods will significantly increase the pH (likely to be up to approximately 9.5-10). This is planned to be reduced to below 8.0 at the discharge point by dosing the water with CO_2 at the mini-hydro location. However, this may deoxygenate the water which could cause harm to aquatic flora and fauna in Burra Creek if sufficient re-oxygenated does not occur during discharge over the rckk strata into the creek. Monitoring needs to be set up to determine the effectiveness of this action.

5.6 Recommendations

Due to the variation in the fish communities in the surveys completed for the MEMP by Beitzel (2010 & 2011), it is recommended that the baseline surveys should be continued in 2012, where it can then link up with the ACT Government survey in 2012-2013.

While M2G is not being utilised for water supplementation for Googong Reservoir then the Murrumbidgee fish community surveys can be reduced to every second year to coincide with the ACT Government survey. Once M2G begins operation, these surveys should be conducted annually for three tofour years of low flow operation to ascertain potential impacts and guide environmental flow requirements.

The following are highlighted recommendations by Beitzel *et al*. (2011):

- The Murray cod research plan in the Sustainable Diversion Limit Plan should be altered to take into account the recording of Murray Cod at Angle Crossing and the potential for Trout Cod to be breeding in the reach. Amendments could include identifying Trout Cod from Murray Cod as part of the larval project and the consideration of Angle Crossing as a site for water quality and larval investigations;

- Although carp were dominant at all sites, there were threatened native fish species recorded at five sites. The recording of Macquarie Perch at Angle Crossing shows they're persisting in the Murrumbidgee River upstream of Tharwa. The presence of these threatened species at and above the abstraction point, should be considered for the schemes management;

- A monitoring program for the egg screen should be developed to determine the impact it will have upon the larvae of threatened species. The commissioning and maintenance phase of the M2G provides the perfect opportunity before full operation begins;

- A general fish monitoring program has been developed for Burra Creek and will be completed. The change in flow to Burra Creek means possible changes in fish abundance and distribution in this system. The monitoring of Burra Creek will also assist in the detection of carp, and whether the carp exclusion in the M2G pipeline has been successful;

- Trials should be implemented to assess fish responses to various flows following the commencement of the M2G operation. This should consider the responses of fish to the ramping up and down of flows to determine the risks of fish strandings and kills related to flow fluctuations;

- Burra Creek surveys should be repeated to capture the community structure following summer.

6 Chapter Six – Geomorphology

6.1 Introduction

Sediment movement within a channel system can be a key component to ecological river health. Macroinvertebrates do not readily populate silty beds and excessive silt can also cause disruption to survival of fish eggs after the spawning cycle. Excessive erosion in Burra Creek could also cause movement of sediment into the Googong Reservoir creating various water quality issues as sediment can be associated with elevated nutrient levels and high levels of iron and manganese.

6.2 Methodology

To assess the impact of sediment movement caused by potential additional deposition at Angle Crossing through water abstraction, and potential increased erosion within Burra Creek after discharge, surveys are proposed to be undertaken prior to the completion of the M2G transfer pipeline in mid-2012. An initial survey of several cross sections on Murrumbidgee River and Burra Creek was undertaken in 2009 and shall be reassessed in more detail in early 2012.

6.3 Results

Maps for the initial geomorphology components are presented in Appendix 6: Figures A6.1 and A6.2 for Angle Crossing and Burra Creek respectively. Since the initial surveys were undertaken there have been many storm events that have changed the instream bed morphology and riparian vegetation composition.

Photos are provided in Appendix 6: Plate A6.1 indicating:

- the immediate area below the discharge point prior to the storm events in June 2010, with significant emergent macrophyte beds;
- after two storm events with the main macrophyte vegetation removed, in November 2010;
- in June 2011, after several storm events shows the quick re-establishment of macrophytes on the bank areas.

6.4 Discussion

The potential impact on geomorphology for Angle Crossing is expected to be very low given the small volume of extraction compared to the impact of storm events. With respect to the abstraction rate of 100ML/d, a 1 in 1 year flow for Murrumbidgee River is approximately 12,000ML/d. However, Burra Creek does not have many days with flow at or above 100ML/d and the impact from the discharge point will require more detailed monitoring.

The major storm of 9 December 2010 was approximately a 1 in 70 year ARI event for Burra Creek and significantly changed the stream bed by removing in-stream vegetation and transporting sediments from many areas. This also re-created pools that had been filled in through gradual deposition over more than 20 years of low flows. Key pools shall be surveyed in 2012 prior to commissioning of M2G transfer flows. The cleared out creek channel is a resetting event that will now potentially allow fish to migrate upstream from Googong Reservoir potentially to the M2G discharge point.

7 Chapter Seven – Riparian Vegetation

7.1 Introduction

The planned water abstraction from Angle Crossing will alter the flow regime in the Murrumbidgee River, and downstream of the discharge point in Burra Creek. These modifications could affect the riverine vegetation downstream of the abstraction and discharge points in the Murrumbidgee River and Burra Creek respectively. Therefore, an understanding of the condition of the riverine vegetation at these key locations is necessary to determine whether the changes to the flow dynamics will have an impact upon these areas following the operation of the M2G project.

The quality, condition and extents of riparian vegetation are closely linked to the riverine environment (Evans, 2003). The changes in flows could lead to changes in species composition and species dominance, which will then lead to a reduction in riverine vegetation diversity. Reductions in river flow due to river regulation cause the encroachment of riparian vegetation into the channel, especially in sandy reaches and on islands.

The results from the initial surveys conducted for the Angle Crossing and Burra Creek components of the MEMP aim to assess the impacts of the water abstractions and discharges on in-channel and riparian vegetation using multiple assessment methods, to determine whether the water abstractions and discharges will have an effect, causing significant ecological changes.

7.2 Methodology

Sites comprising the Angle Crossing and Burra Creek components of the MEMP project were assessed for vegetation and habitat conditions. These sites match those used in the macroinvertebrate monitoring component and are shown on the map in Appendix 1.1. The attributes considered in this ‘baseline’ assessment are:

1) taxon richness and composition;
2) nativeness;
3) plant growth form and structure;
4) regeneration and recruitment;
5) functional groups and;
6) provision of habitat.

Assessments at each site focussed on a 100m reach of the river. Species composition and cover were established through the use of line transects, extending across the channel, with three such transects per site. These transects were generally through areas of high species diversity, and within relatively undisturbed vegetation (i.e. not adjacent to access tracks, disturbed areas or significant weed infestations that can readily change due to catchment management operations). These transects also covered the wide range of geomorphic features within the reach.

All species intercepting the line at 0.5m intervals were recorded and used to determine percentage cover of each species. Data was then extrapolated to represent each reach. Vegetation community type, species composition, abundance, distribution, dominant species, weed species, rare and threatened species, overall condition rating and representation of vegetation structure were recorded. The ‘random meander’ method was used to create a comprehensive species list for each site, and involved covering each reach in no specific pattern. This also allowed overall assessments of habitat quality and recruitment and regeneration (juveniles).

The combined data from the line transects provided the key variables to compare the similarity of the sites using both cluster analysis and multi-dimensional scaling.

Each site was given a condition rating described in Table 7.1 to assess the overall 'condition' of the vegetation and habitat at each site. Note that this assessment has not been yet been conducted on the Burra Creek survey data.

Table 7.1 – Condition categories used in flora and habitat assessments

Condition	Comments
Good	Vegetation retains a high number of indigenous species, assemblages of species and structural characteristics of the pre-European equivalent. Such vegetation has usually changed very little over time, is relatively undisturbed and displays resilience to weed invasion, due to intact ground cover, shrub and canopy layers.
Moderate	Vegetation generally retains its structural integrity, containing a moderate number of indigenous species, but has been highly disturbed, and has lost some component of its original species complement. Weed invasion is significant.
Poor	Vegetation has been subject to high levels of disturbance and has lost most of its original species. The vegetation is significantly modified structurally, and left with only a discontinuous canopy of the original tree cover, very few shrubs and very little of its original groundcover. Vegetation is dominated by exotic species, replacing much of the indigenous ground cover. Environmental weeds are dominant or co-dominant with the original indigenous species.

7.3 Results and Discussion

7.3.1 Murrumbidgee River

In the MDS plot (below), points that are close together represent samples which are similar with respects to percent cover of individual species, overall vegetation cover and percent area of open water and un-vegetated substratum. Figure 7.1 indicates that site MUR15 is distinctly different from all other sites, as is MUR16 and to a lesser extent MUR28. Sites MUR18, MUR19 and MUR23 however, appear to be relatively similar.

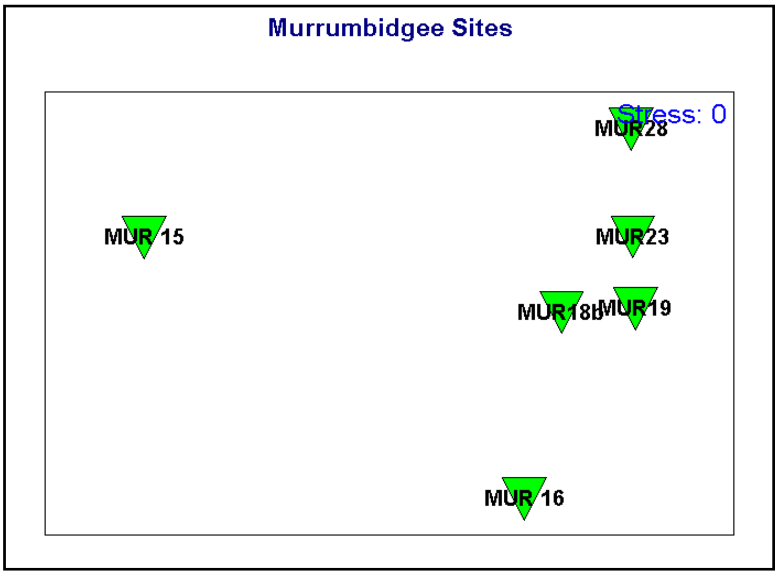

Figure 7.1 – MDS Ordination showing relative similarities of sites

Figure 7.2 presents the comparison of the six sites with regard to both the native and introduced growth forms of vegetation. The vegetation at the upstream site MUR15 was predominantly introduced species. Exotic pasture grasses and minor weeds of roadsides and grazing lands were relatively common at all other sites, except at MUR16. Bushes of blackberry and willows were also common at several sites, contributing to the cover of introduced vegetation.

The sub-canopy, shrub layer, dominated vegetation cover at all other sites. The dominant native shrubs at all sites were *Acacia dealbata, A. rubida*, *Kunzea ericoides*, *Callistemon sieberi* and *Leptospermum obovatum*. A few other species also contributed to this cover. At the upstream site MUR16, native forest trees, mainly Black Cypress (*Callitris endlicheri*) contributed to the high vegetation cover. At the downstream site MUR28, a similar high contribution was made by large groves of casuarinas (*Casuarina cunninghamiana*).

Collectively, the abundance of native grasses (mainly, *Phragmites australis* and *Paspalum distichum*) and sedges, including cumbungi (*Typha domingensis*) was somewhat similar at sites MUR18, MUR16, MUR19 and MUR23, while MUR15 and MUR28 showed less such cover.

As shown in Figure 7.2, sites MUR16 and MUR28 stand out as they are dominated by the growth forms of native trees (*Callitris endlicheri* and *Casuarina cunninghamiana*, respectively) and the diversity of the native shrubs (*Acacia dealbata*, *A. rubida*, *Kunzea ericoides*, *Callistemon sieberi* and *Leptospermum obovatum*). The native shrub growth form was generally prevalent at the other sites, with the herbaceous, ground cover growth forms also being well represented. These perennial, woody species reproduce by seeds, and depend on river flows and occasional disturbances by flooding for seed dispersal, seedling establishment and growth. In contrast, the dominant growth form at site MUR15 was herbaceous, introduced forbs and pasture grasses, which are almost exclusively annuals; hence, species dependent on profuse seed setting for survival.

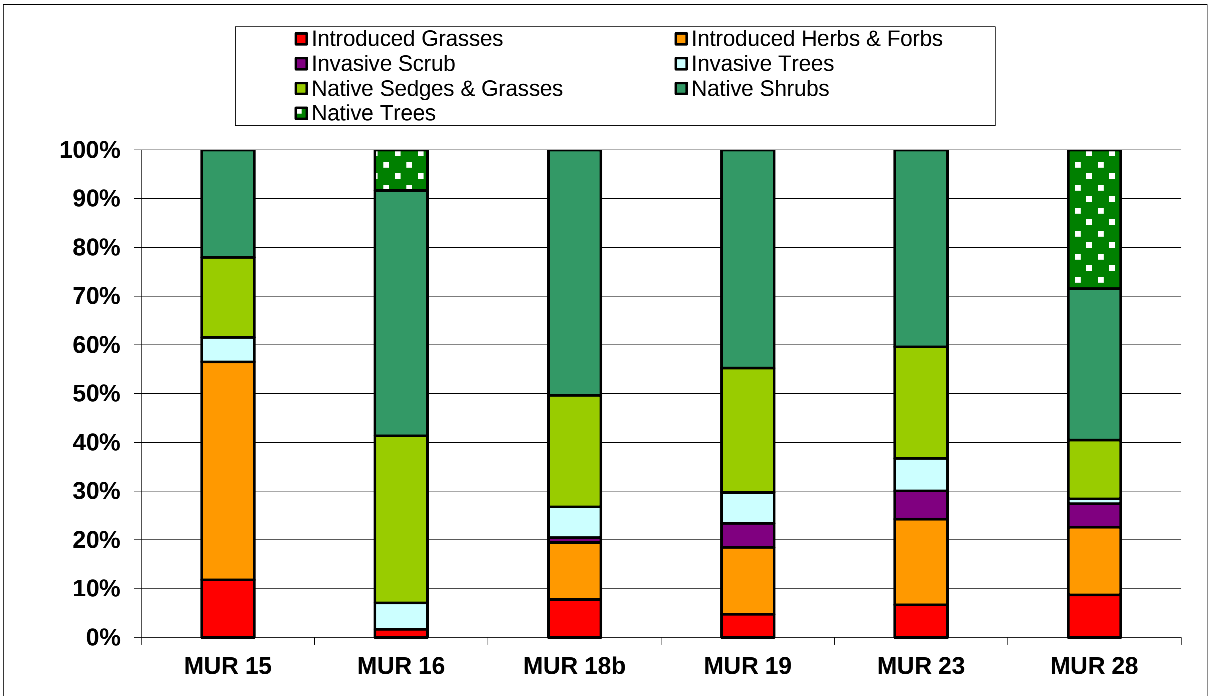

Figure 7.2 – Comparison of Growth Forms of plants at the assessed sites

Table 7.2 provides condition assessments for the vegetation and habitats of each site, in relation to the vegetation intactness, species diversity, history of disturbance, weed invasion and general health. The longitudinal variability along the reaches and the variability between banks resulted in the combination of categories.

The riverine vegetation assemblages are usually composed of species with different life forms. The variety of plant growth forms (or life forms) has been considered very important for maintaining the integrity of aquatic ecosystems. Different groups of plants, and their growth forms, contribute to the structure of the physical space by increasing the complexity of aquatic habitats.

In floodplain ecosystems, aquatic macrophyte assemblages are especially indicative of environmental variability, because they respond to longitudinal as well as transverse gradients in relation to the main river, also including flood disturbances, and/or low flow periods.

The growth forms are also important for survival of the vegetation, and also for the contributions the vegetation makes to the riverine environment. For instance, in the ground cover layer, survival mechanisms of seed-setting annuals would be different to those with perennial growth habits, which produce rhizomes, tubers and corms, or stolons and runners. Also, the canopy layers of native trees and sub-canopy layers of native, woody shrubs, provide shade for the riverine environment and habitat for certain aquatic fauna, like birds. These 'ecosystem services' are different to the services, like habitat, provided by the smaller herbaceous forms.

Table 7.2 – Summary of Habitat Assessment

Site Code	Condition	Comments
MUR 15	Poor	Vegetation has been subject to high levels of disturbance and is significantly modified structurally, few shrubs and little of its original groundcover. Vegetation is dominated by exotic species replacing much of the indigenous ground cover.
MUR 16	Good	Vegetation retains a high number of indigenous species and structural characteristics of the pre-European equivalent. The vegetation is relatively undisturbed and displays resilience to weed invasion, due to intact shrub and canopy layers.
MUR18	Moderate tending to Poor	Part of the vegetation at the site retains its structural integrity, with a number of indigenous species. However, some sections have been highly disturbed. Weed invasion of the site is significant.
MUR 19	Poor tending to Moderate	Vegetation has been subject to high levels of disturbance, and has no original tree cover, few shrubs and little of its original groundcover. Vegetation has abundant exotic species.
MUR 23	Moderate tending to Poor	Part of the vegetation at the site retains its structural integrity, with a number of indigenous species. However, some sections have been highly disturbed, and have lost some component of its original species complement. Weed invasion is significant.
MUR 28	Moderate	Part of the vegetation at the site retains its structural integrity, with a moderate number of indigenous species, but sections of the reach has been disturbed. Weed invasion is moderate.

7.4 Burra Creek

At this stage the full analysis and report of the Burra Creek vegetation survey is still in preparation. The full taxa list from this survey show in Appendix 7. From these plant lists it is apparent that the Burra Creek riparian flora is dominated by introduced species (Figure 7.3), particularly downstream of BUR 1a (which fringes the Tinderry Nature Reserve).

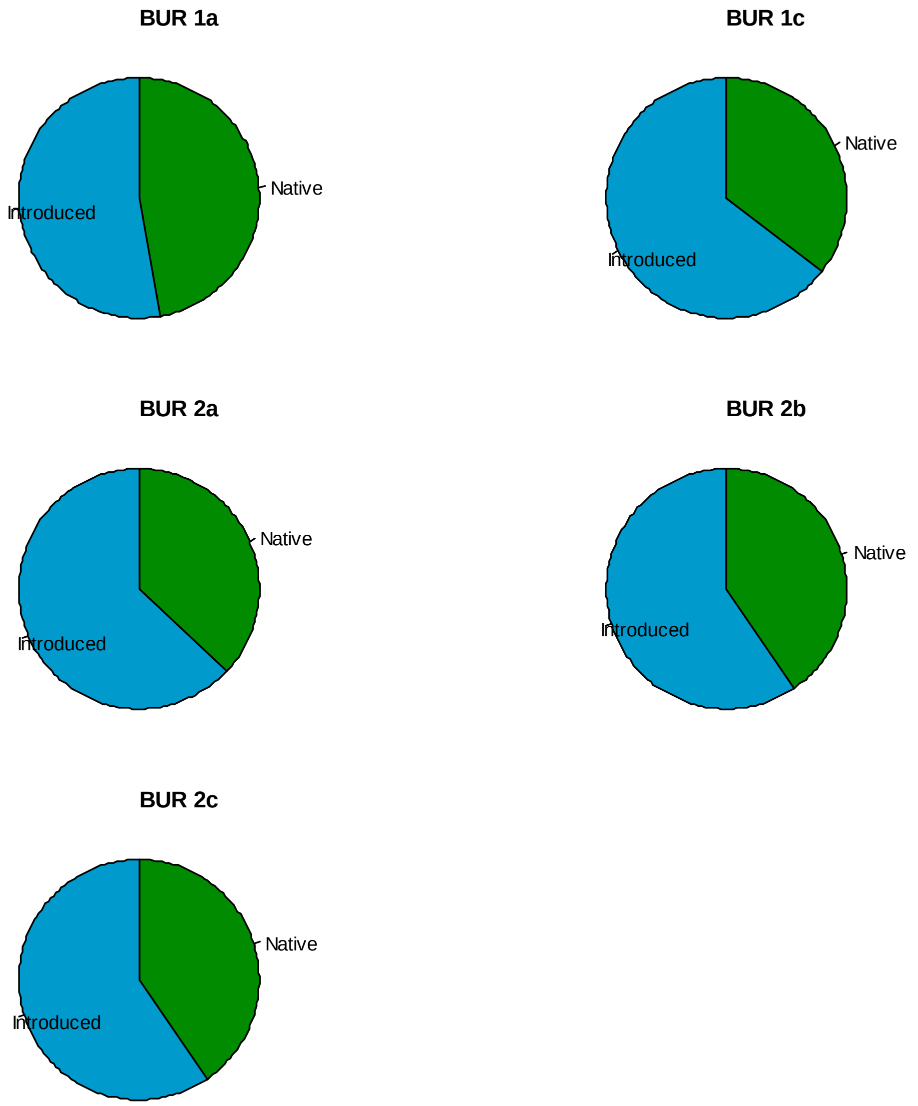

Figure 7.3 – Ratios of introduced to native plants from the Burra Creek vegetation survey 2011

7.5 Conclusions

The monitoring data collected from these baseline surveys will be compared with future monitoring at the same sites, to indicate whether 'colonising' species (pioneer trees, shrubs and herbaceous species), are invading the sites, and are likely to cause ecosystem changes.

The following are highlighted points from this pre-abstraction, baseline study:

- The vegetation at each site reflects the nature and interplay of hydrologic and geomorphic factors, which determine the composition and abundance of different species. For instance, the vegetation at the least disturbed site (i.e. MUR16) was dominated by natives, compared with the other five sites, which are subject to varying degrees of human disturbances.

- The quality of vegetation at a number of sites was rated as ‘moderate’, ‘moderate-poor’ or ‘poor’, largely reflecting the anthropogenic influences, either from adjacent farming lands, or from heavy public use of the riverine environment.

- The relatively disturbed sites, dominated by introduced herbs and forbs, reflect the sparse tree canopies or sub-canopy shrub layers, and openness of habitat. Reduced competition for light and space allows introduced herbs and forbs, which are mainly annuals, to attain high abundance in bare patches of sand and soil, following seasonal flooding. Sparse cover can also impact the available shade and habitat for macroinvertebrates and fish and increase potential for algal blooms due to increased light availability and temperature.

- Perennial herbs and forbs, including grasses and reeds (Poaceae), sedges and rushes (Cyperaceae, Juncaceae, Restionaceae) were noticeably minor components of the vegetation at the sites. In all probability, river flow fluctuations, including low and high (and fast) flows, and the depth of the water table, affect the establishment and persistence of such species in the floodplain and in the riparian ecotone. Many sedges, rushes and reeds, as well as aquatic forbs, require a permanent water source to sustain high cover, and if a shallow water table is not present, they are replaced by annuals that avoid drought through temporal escape.

- Sandy soils have less water holding capacity. In low flow periods, which could be prolonged, the sandy shorelines and sand bars may become too dry for the establishment of many riverine species. The increased sand deposition at a number of sites may favour the development of stress-tolerant species (i.e. many pioneering species) and drought resistant species. Similarly, periodic flood disturbances may preclude development of dense grasses and sedges at sites with deep water tables and narrower channels.

- The dominance of pioneering, stress-tolerant species, both native and introduced species, at a number of sites could be a result of increased stream intermittency and water table decline.

- The native vegetation in Burra Creek is predominantly native sedges and grasses. *Eleocharis sp* and *Juncus usitatus* are the dominant sedges while *Phragmites australis* (common reed) and *Paspalum distichum (*water couch) are the most common native grasses*.*

- *Kunzea ericoides* is the dominant native shrub in Burra Creek but tends to have a patchy disitribution – being less common with increased distance downstream of the Tinderry Nature Reserve. Downstream of the Tinderry Nature Reserve, blackberry dominates the margins and sub-canopy shrub layer with occasional *Acacia dealbata*

- *Gynatrix pulchella* (Hempbush) was observed prior to the large flood in December 2010 downstream of London Bridge but was not accounted for in the latest survey.

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APPENDIX 1

Site Location Map

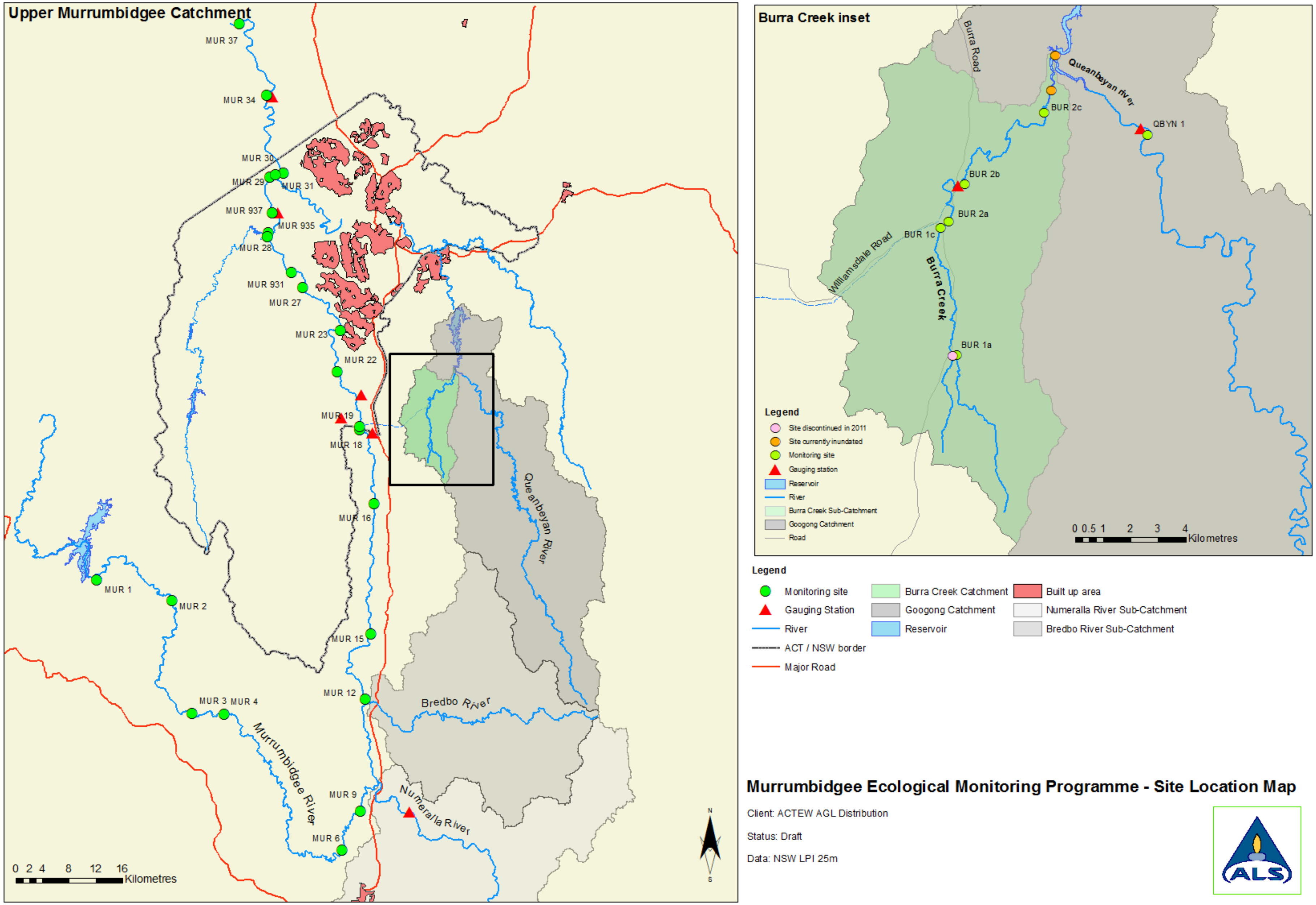


Figure A1.1 – Map of site locations on the Murrumbidgee River, Burra Creek and the Queanbeyan River

APPENDIX 2

Stream Flow Monitoring Data

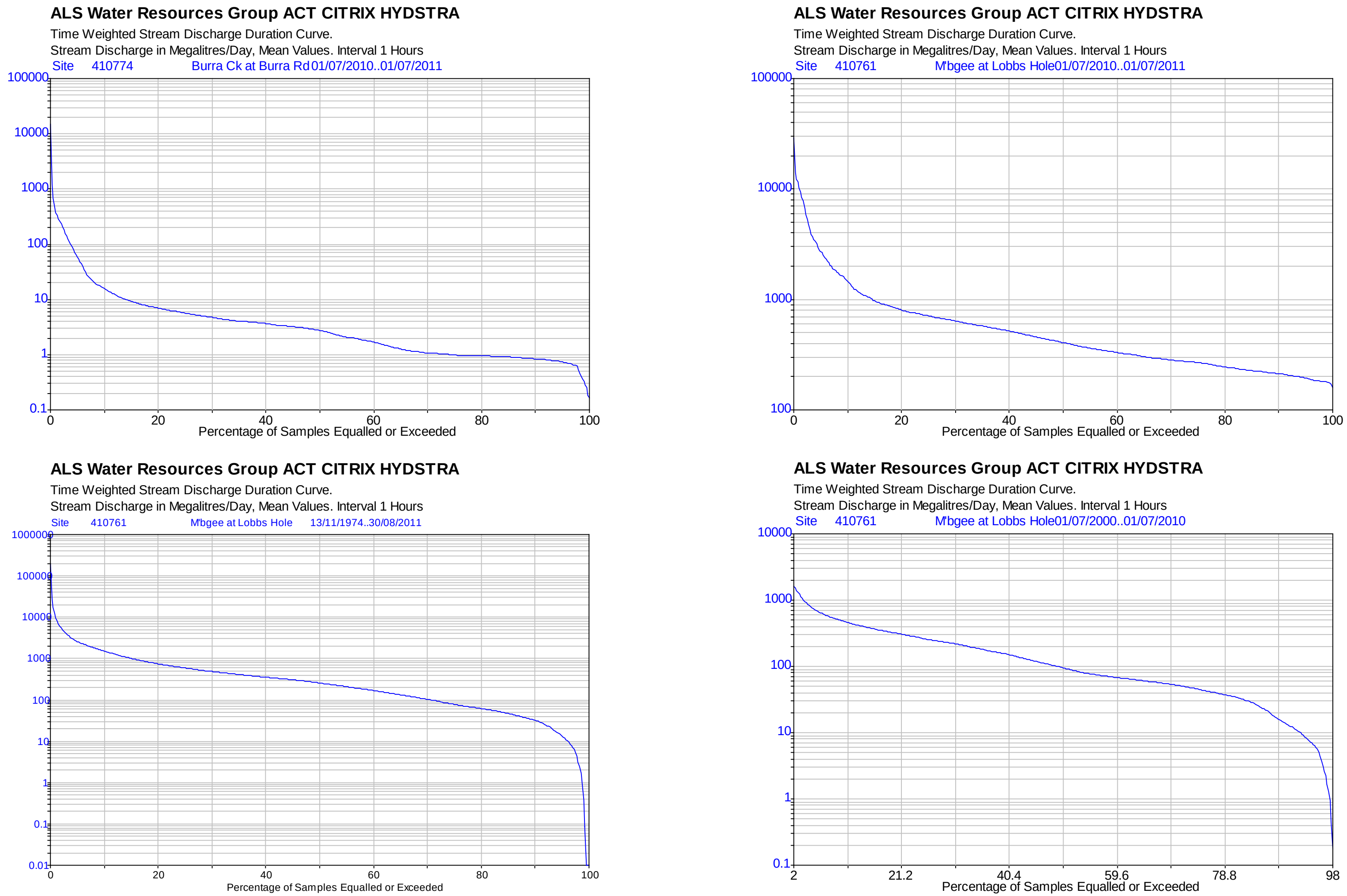
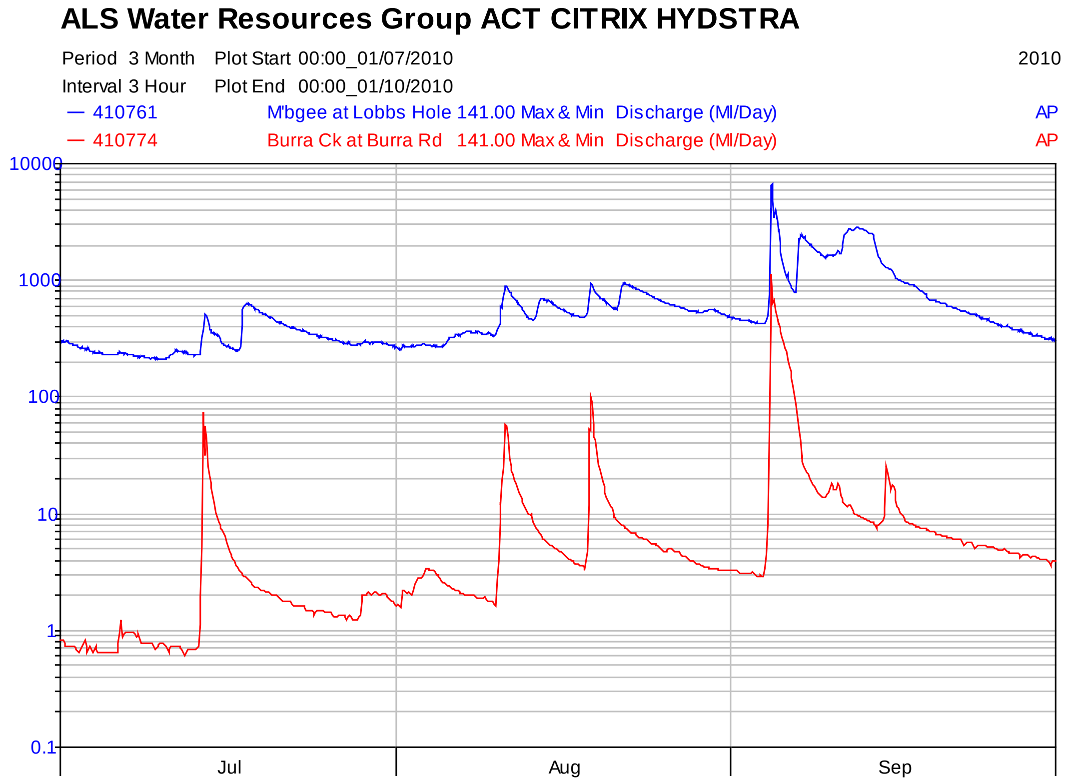


Figure A2.1 – Flow duration curves for the Murrumbidgee River and Burra Creek (2010-11 top and previous years bottom)



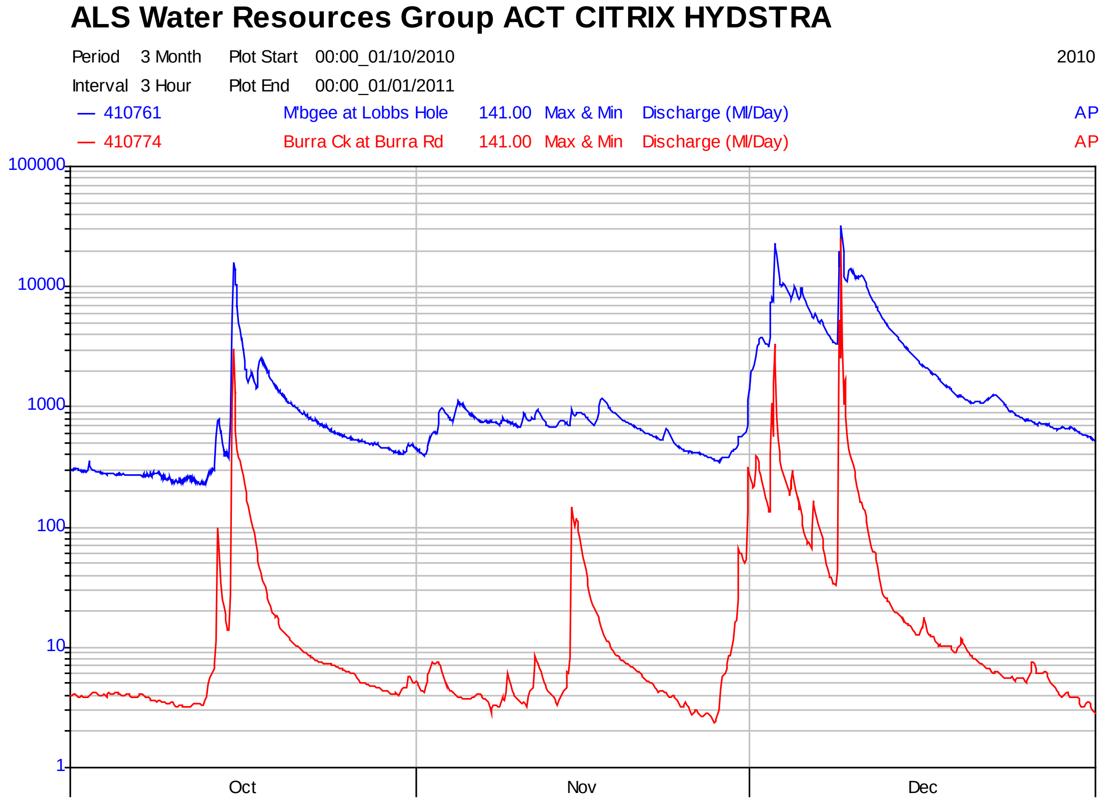
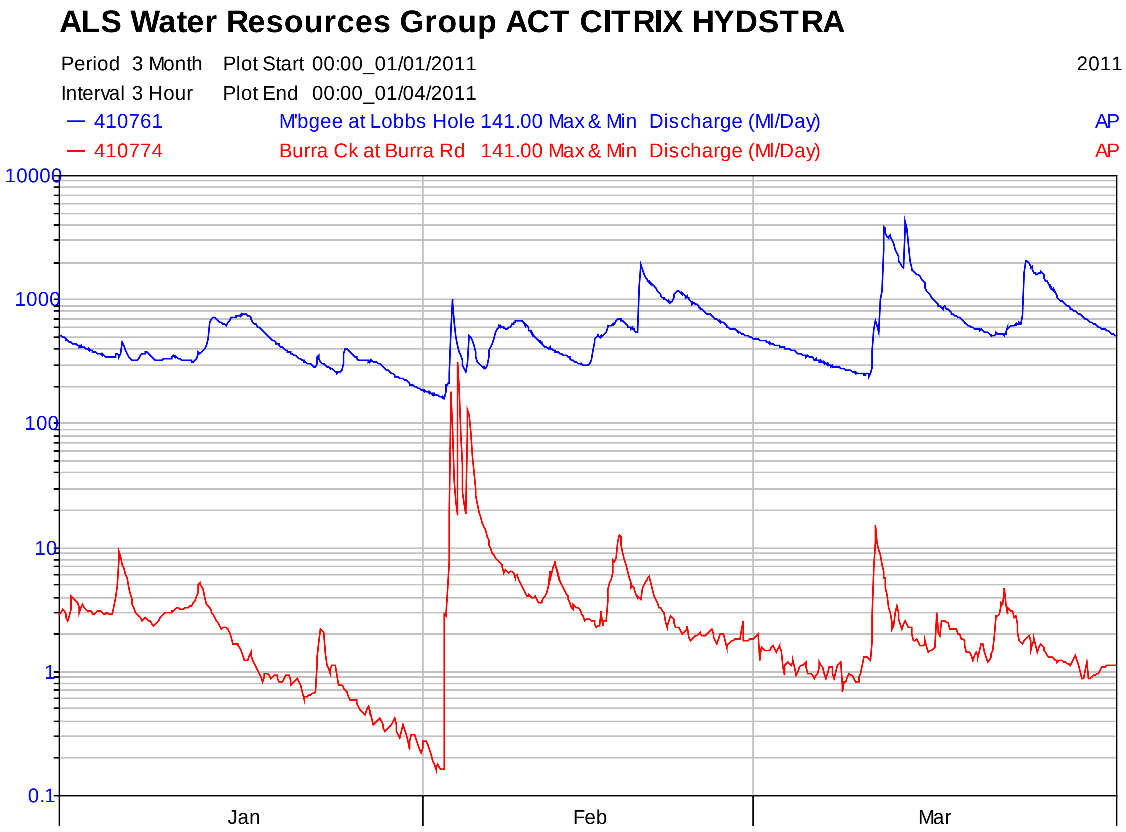


Figure A2.2 – Murrumbidgee River and Burra Creek flow **Jul-Dec 2010** (log scale)



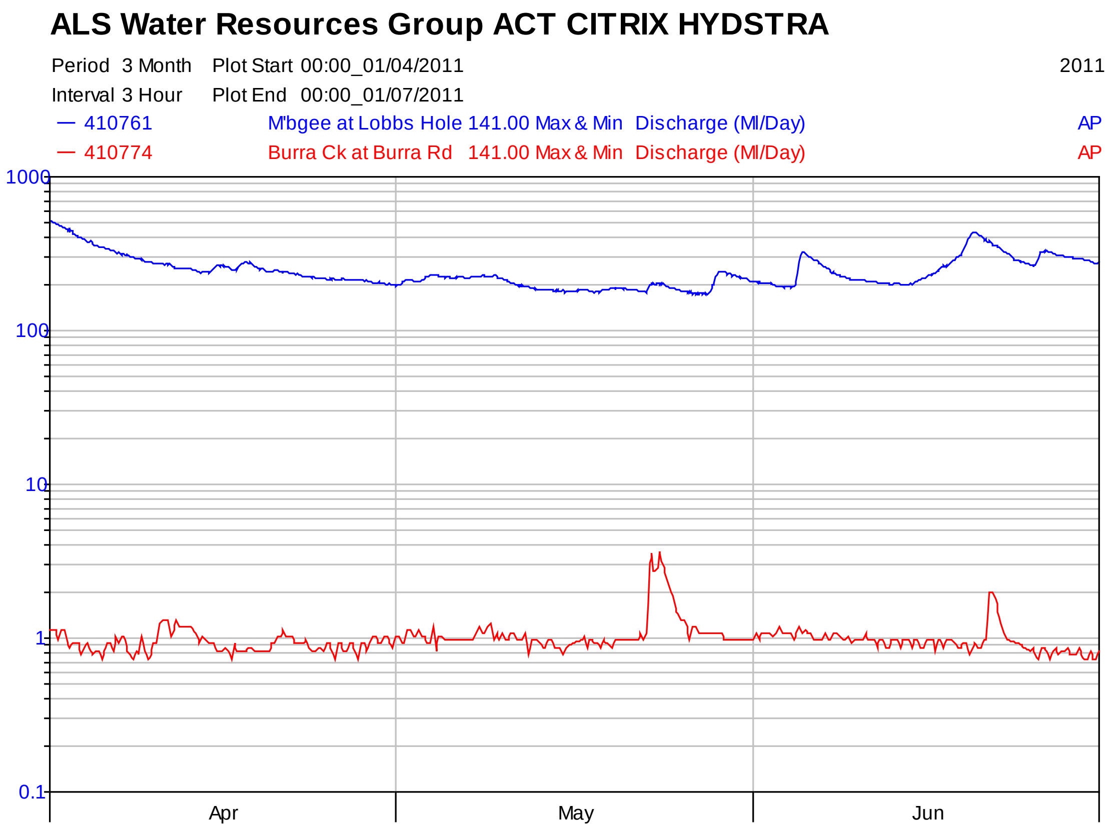


Figure A2.3 – Murrumbidgee River and Burra Creek flow **Jan-Jun 2011** (log scale)

APPENDIX 3

Water Quality Data

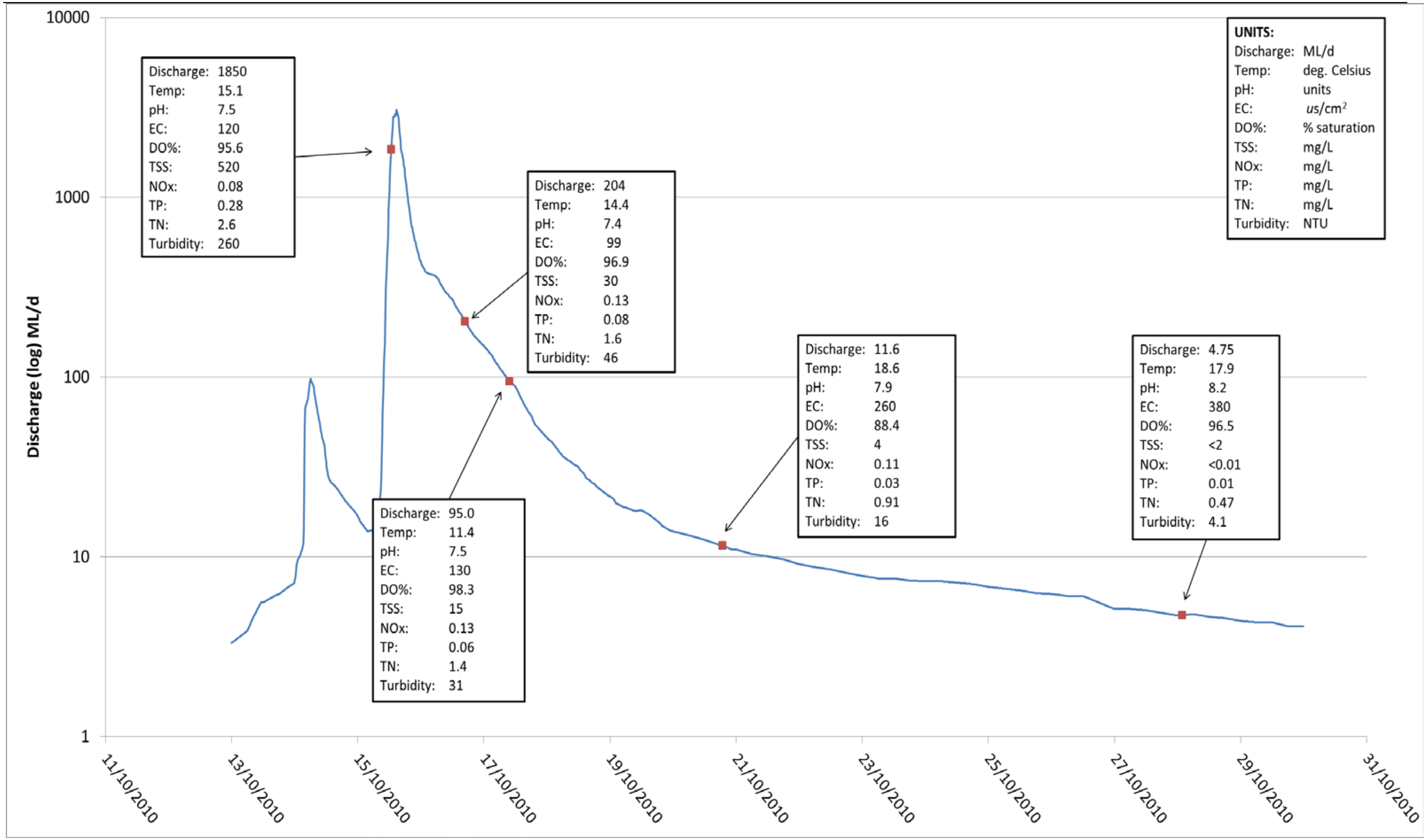


Figure A3.1 – Water quality during hydrograph recession (October 2010 high flow event: grab samples)

Table A3.1 – Water quality parameters during the Spring 2010 sampling period

Site	Date	Time	Q	Temp.	EC	Turb.	TSS	pH	D.O.	D.O.	NOx	TP	TN
Units	-	-	ML/d	°C	µs/cm	NTU	mg/L	-	% Sat.	mg/L	mg/L	mg/L	mg/L
ANZECC Guidelines		-	-	-	30-350	2-25	-	6.5-8	90-110	-	0.02	0.02	0.25
CAS1	5/11/2010	14:10		14.7	312	36	50	7.8	73.6	7.69	<0.01	0.04	0.65
BUR1	5/11/2010	13:00		13.76	90.1	6	5	7.22	86.3	9.26	0.04	0.03	0.63
BUR2A	5/11/2010	14:30		15	351.3	4	3	7.6	86.5	9.92	<0.01	0.01	0.44
BUR2B	5/11/2010	15:00	3.72	15.1	356.4	4	<2	7.67	91.3	9.42	0.01	<0.01	0.39
BUR3	5/11/2010	10:30		14.9	387.9	6	<2	8.07	84.8	8.84	<0.01	<0.01	0.35
QBYN1	5/11/2010	9:15	107	13.5	75.8	33	8	7.48	90.6	9.7	0.06	0.03	0.42
MUR1	30/11/2010	11:00		13.2	20.1	2	5	6.95	84.9	9.22	0.02	0.02	0.2
MUR2	30/11/2010	13:20		12	20.5	3	3	7.1	85.5	9.54	<0.01	0.01	0.15
MUR3	30/11/2010	15:40		13.2	28.3	9	6	6.95	87.8	9.15	<0.01	0.02	0.33
MUR4	30/11/2010	14:40		13.4	33.6	9	10	6.95	86.6	8.95	<0.01	0.03	0.39
MUR6	26/11/2010	11:00		21.2	37.4	16	29	7.2	85.7	7.82	<0.01	0.05	0.35
MUR9	26/11/2010	12:00		21.5	38	19	24	7.1	86.6	7.9	<0.01	0.05	0.32
MUR12	26/11/2010	13:00		21.9	54.2	25	35	7.3	87.6	7.95	0.02	0.07	0.42
MUR15	24/11/2010	9:50		22.2	51.4	9.8	14	6.95	89.3	8.06	<0.01	0.04	0.37
MUR16	24/11/2010	12:00		23.2	64.7	16	36	7.03	94.4	8.37	<0.01	0.05	0.51
MUR18	24/11/2010	14:30	465	24.4	69.7	10	12	7.5	99.3	8.58	<0.01	0.04	0.46
MUR19	24/11/2010	15:30		24.6	70.1	12	11	7.92	98.8	8.52	<0.01	0.04	0.46
MUR22	25/11/2010	14:30		25.4	76.5	13.9	8	7.88	100.7	8.55	<0.01	0.04	0.47
MUR23	25/11/2010	13:10		24.1	79	12	14	7.7	95.4	8.32	<0.01	0.04	0.47
MUR27	25/11/2010	11:55		24.5	82.3	11	13	7.5	94.6	8.17	<0.01	0.04	0.48
MUR931	-	-		-	-	-	-	-	-	-	-	-	-
MUR28	26/11/2010	9:00		22.1	67.7	14	11	7.32	100.1	9.06	<0.01	0.03	0.34
MUR935	-	-		-	-	-	-	-	-	-	-	-	-
MUR937	-	-		-	-	-	-	-	-	-	-	-	-
MUR29	25/11/2010	10:30	1322	23	70	15	16	7.3	98.6	8.69	<0.01	0.04	0.35
MUR30	-	-		-	-	-	-	-	-	-	-	-	-
MUR31	-	-		-	-	-	-	-	-	-	-	-	-
MUR34	-	-		-	-	-	-	-	-	-	-	-	-
MUR37	-	-		-	-	-	-	-	-	-	-	-	-

Note: Highlighted values outside ANZECC guideline values.

Table A3.2 – Water quality parameters during the Autumn 2011 sampling period

Site	Date	Time	Q	Temp.	EC	Turb.	TSS	pH	D.O.	D.O.	NOx	TP	TN
Units	-	-	ML/d	°C	µs/cm	NTU	mg/L	-	% Sat.	mg/L	mg/L	mg/L	mg/L
ANZECC Guidelines		-	-	-	30-350	2-25	-	6.5-8	90-110	-	0.015	0.02	0.25
CAS1	3/05/2011	12:00		12	415.1	3.5	4	7.9	82.9	7.62	<0.01	0.01	0.23
BUR1	3/05/2011	11:00		13.6	149.4	7	13	7.3	91.6	8.56	<0.01	0.01	0.31
BUR2A	3/05/2011	15:00		14	444.5	11	13	8.2	92.8	9.7	<0.01	0.01	0.23
BUR2B	3/05/2011	13:50	1.0	14.7	543.6	4.4	11	8.3	101.1	10.4	<0.01	0.01	0.2
BUR3	3/05/2011	9:15		14.8	296.2	14	44	8.2	87.6	8.96	0.05	0.03	0.56
QBYN1	2/05/2011	14:00	71	14.1	67.3	3	2	7.8	98.5	10.3	<0.01	0.01	0.16
MUR1	11/05/2011	11:30		4.9	27.6	1.2	2	7	89.6	11.4	<0.01	<0.01	<0.05
MUR2	11/05/2011	13:30		6.2	25.8	1.5	2	7.2	91.1	11.5	<0.01	<0.01	0.06
MUR3	11/05/2011	14:45		7.9	30.3	3	4	7.3	94.4	11.4	<0.01	0.01	0.15
MUR4	11/05/2011	15:30		7.4	36.1	5	5	7.4	92.5	11.3	<0.01	0.01	0.18
MUR6	9/05/2011	13:00		9.6	49.2	3.1	4	7.5	97.3	11.2	<0.01	0.02	0.15
MUR9	9/05/2011	14:00		10	50.8	2.6	4	7.5	95.5	10.9	<0.01	0.02	0.16
MUR12	6/05/2011	13:00		12.6	92.4	6.2	11	7.7	93.3	10.1	<0.01	0.04	0.27
MUR15	6/05/2011	11:00		12.9	97.4	6.2	10	7.7	96.6	10.3	<0.01	0.04	0.26
MUR16	9/05/2011	10:10		10.9	105.7	7.5	10	7.8	95.5	10.7	<0.01	0.03	0.28
MUR18	6/05/2011	14:00	224	12.2	107.9	5.4	10	7.8	98.8	10.7	<0.01	0.04	0.26
MUR19	6/05/2011	15:30		12.3	108.7	5.2	9	7.8	99.3	10.7	<0.01	0.03	0.27
MUR22	10/05/2011	13:35		11.7	103.4	8.6	27	7.9	102.2	11.2	<0.01	0.03	0.28
MUR23	10/05/2011	11:50		9.8	107.1	5.7	7	7.8	96.8	11.1	<0.01	0.02	0.26
MUR27	10/05/2011	10:50		10.7	109.8	5.6	8	7.9	99.8	11.2	<0.01	0.03	0.27
MUR931	5/05/2011	9:30		13.3	110.1	6.5	11	7.6	97.3	10.3	<0.01	0.03	0.27
MUR28	5/05/2011	12:00		13.9	111.6	6.9	11	7.8	100	10.5	<0.01	0.03	0.27
MUR935	5/05/2011	13:30		14.3	112.1	6	10	7.9	106	11	<0.01	0.03	0.27
MUR937	5/05/2011	16:05	339	14.8	114.6	4.3	9	7.9	109.1	11.2	<0.01	0.02	0.27
MUR29	4/05/2011	15:05		15.7	107.3	5.4	6	8	103.9	10.4	<0.01	0.02	0.25
MUR30	10/05/2011	9:00		9.5	100.5	4.6	5	7.8	96.1	11.1	<0.01	0.02	0.23
MUR31	4/05/2011	14:00		15.6	218.6	8.4	10	8.1	107.3	10.8	4.5	0.04	4.7
MUR34	4/05/2011	9:30		15.3	189.6	7.6	11	8	103.4	10.5	2.8	0.03	3.2
MUR37	4/05/2011	11:50		16.3	198	7.1	9	8	100.3	9.9	2.3	0.02	2.7

Note: Highlighted values outside ANZECC guideline values.

Table A3.3 – Main water quality parameter results from grab samples for Burra Creek, Cassidy's Creek and Queanbeyan River.

ANZECC Guideline values in column heading in red.

Site	Date	Time	Q# (ML/d)	EC (µS/cm) 30 -350	Diss. Al (mg/L)	pH (units) 6.5-8.0	TSS (mg/L)	Nox (mg/L) <0.02	TP (mg/L) <0.02	TN (mg/L) <0.25	Turb. (NTU) 2 - 25
CAS1	5/11/2010	14:00		350			50	<0.01	0.04	0.65	21
CAS1	9/02/2011	10:59		320	0.04	7.7	240	<0.01	0.09	1.3	81
CAS1	3/05/2011	12:30		430		7.9	4	<0.01	<0.01	0.23	3.5
BUR1	11/08/2010	10:00		56		6.7	31	0.06	0.06	1.2	71
BUR1	15/10/2010	13:00		45	0.62	7	1100	0.04	0.36	3.4	500
BUR1	16/10/2010	17:03		71	1.7	7.2	29	0.07	0.07	1.5	41
BUR1	16/10/2010	17:10		69	2.7	6.8	97	0.11	0.07	1.5	73
BUR1	17/10/2010	8:34		72	2.4	7	20	0.11	0.05	1.3	38
BUR1	17/10/2010	8:38		79	2.2	7.2	18	0.08	0.06	1.3	35
BUR1	20/10/2010	19:03		88	0.66	7.1	5	0.03	0.04	0.97	27
BUR1	28/10/2010	13:30		98	1.7	7.3	3	<0.01	0.03	0.65	15
BUR1	5/11/2010	13:30		100			5	0.04	0.03	0.63	13
BUR1	9/12/2010	11:27		53		6.8	790	0.03	0.13	1.6	410
BUR1	9/02/2011	10:56		100	1.5	7.4	6	0.03	0.03	0.68	15
BUR1	3/05/2011	11:00		150		7.3	13	<0.01	0.01	0.31	6.8
BUR1A	4/09/2010	18:10		46	1	7.2	390	0.12	0.19	2.1	240
BUR1A	20/10/2010	19:08		110	0.53	7.4	7	0.02	0.03	0.98	25
BUR1A	28/10/2010	13:33		150	1.2	7.8	<2	<0.01	0.02	0.6	12
BUR1A	15/06/2011	12:00		150	0.03	7.6	<2	<0.002	0.005	0.27	2.3
BUR1A	15/06/2011	12:01		410	<0.02	8.1	<2	<0.002	0.005	0.18	2
BUR1B	2/08/2011	13:05				8.3	7	<0.01	<0.01	0.2	2
BUR1C	2/08/2011	10:25				8.2	3	<0.01	<0.01	0.18	14
BUR2	4/09/2010	18:03		62	1.6	7.1	350	0.19	0.18	2.1	210
BUR2	15/10/2010	12:50		67	1	7.1	97	0.10	0.2	1.9	84
BUR2	16/10/2010	17:25		91	1.7	7.3	32	0.11	0.08	1.5	43
BUR2	17/10/2010	9:19		110	1.7	7.5	13	0.12	0.06	1.4	32
BUR2	20/10/2010	18:52		220	0.72	7.8	4	0.11	0.03	0.93	18
BUR2	28/10/2010	13:15		330	0.28	8.1	<2	0.02	0.02	0.52	7
BUR2	15/04/2011	14:15		510	<0.02	8.1	4	0.03	0.01	0.3	8.4
BUR2	20/04/2011	12:15		520	<0.02	8.1	3	0.06	0.02	0.34	11
BUR2	15/06/2011	12:00		540	<0.02	8.1	4	0.16	0.01	0.51	8.6
BUR2A	5/11/2010	14:40		400			3	<0.01	0.01	0.44	2.4
BUR2A	16/11/2010	9:55		110	0.65	7.2	10	0.03	0.06	1.4	26
BUR2A	9/12/2010	11:45		59		6.8	1200	0.13	0.16	1.8	720
BUR2A	9/02/2011	11:11		280	0.47	7.9	7	0.08	0.03	0.82	13

Site	Date	Time	Q# (ML/d)	EC (µS/cm) 30 -350	Diss. Al (mg/L)	pH (units) 6.5-8.0	TSS (mg/L)	Nox (mg/L) <0.02	TP (mg/L) <0.02	TN (mg/L) <0.25	Turb. (NTU) 2 - 25
BUR2A	3/05/2011	15:10		450		8.2	7	<0.01	0.01	0.23	11
410774	4/09/2010	17:50		77	1.3	7.1	870	0.18	0.35	3.2	500
410774	15/10/2010	12:42	1850	120	0.91	7.5	520	0.08	0.28	2.6	260
410774	16/10/2010	16:37	204	99	1.7	7.4	30	0.13	0.08	1.6	46
410774	17/10/2010	9:50	95	130	1.5	7.5	15	0.13	0.06	1.4	31
410774	20/10/2010	18:40	11.6	260	0.65	7.9	4	0.11	0.03	0.91	16
410774	28/10/2010	13:45	4.8	380	0.14	8.2	<2	<0.01	0.01	0.47	4.1
410774	15/04/2011	14:35		530	<0.02	8.3	3	<0.01	0.01	0.19	5.5
410774	20/04/2011	12:28		540	<0.02	8.2	3	<0.01	0.02	0.27	6
410774	15/06/2011	12:00		570	<0.02	8.2	2	0.01	0.009	0.21	4.8
BUR2B	11/08/2010	10:15		220		7.9	35	0.02	0.07	1.1	60
BUR2B	5/11/2010	15:00		380			<2	0.01	<0.01	0.39	3.1
BUR2B	16/11/2010	9:45		110	0.62	7.2	10	0.04	0.05	1.4	26
BUR2B	9/12/2010	10:55		67		6.9	1900	0.11	0.21	2.2	1600
BUR2B	9/02/2011	10:33		280	0.63	8	6	0.09	0.04	0.71	14
BUR2B	3/05/2011	13:30		550		8.3	4	<0.01	0.01	0.2	4.4
BUR2C	4/09/2010	17:25		120	1.1	7.4	690	0.15	0.26	2.7	390
BUR2C	15/10/2010	12:12		160	0.8	7.7	92	0.08	0.09	1.4	63
BUR2C	16/10/2010	15:47		100	1.5	7.5	31	0.12	0.08	1.5	48
BUR2C	17/10/2010	11:52		140	1.3	7.6	12	0.10	0.06	1.3	31
BUR2C	20/10/2010	18:20		260	0.44	8	4	0.04	0.03	0.82	14
BUR2C	28/10/2010	13:57		390	0.06	8.3	<2	0.02	0.01	0.48	2.2
BUR2C	9/12/2010	10:35		91		7.2	1500	0.15	0.18	1.9	1100
BUR2C	9/02/2011	10:20		310	0.47	8.1	46	0.03	0.05	0.88	25
BUR2C	15/06/2011	12:00		560	<0.02	8.4	3	0.01	0.006	0.19	2.9
BUR3	11/08/2010	10:52		370		8.1	8	<0.01	0.02	0.41	11
BUR3	5/11/2010	11:45		430			<2	<0.01	<0.01	0.35	1.8
BUR3	3/05/2011	9:15		340		8.2	44	0.05	0.03	0.56	14
QBYN1	5/11/2010	10:00		85			8	0.06	0.03	0.42	9.4
QBYN1	2/05/2011	14:00		72		7.8	2	<0.01	0.01	0.16	3
QBYN2	11/08/2010	10:46		96		7.6	23	0.02	0.05	0.66	28

Note: Highlighted values outside ANZECC guideline values.
the only site with gauged flow in 410774. Sites are in order from upstream to downstream.

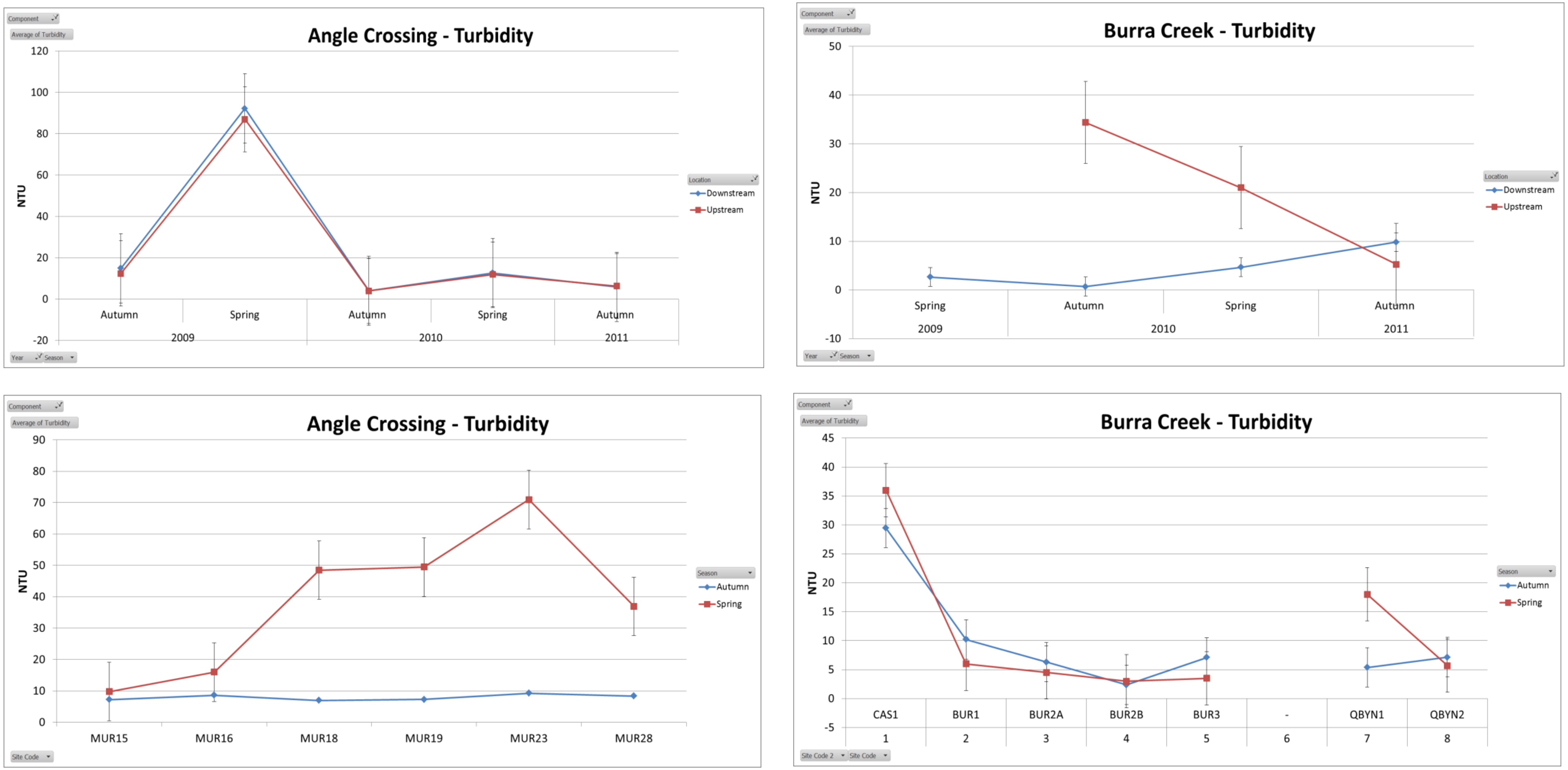


Figure A3.2 – Turbidity plots for Angle Crossing and Burra Creek

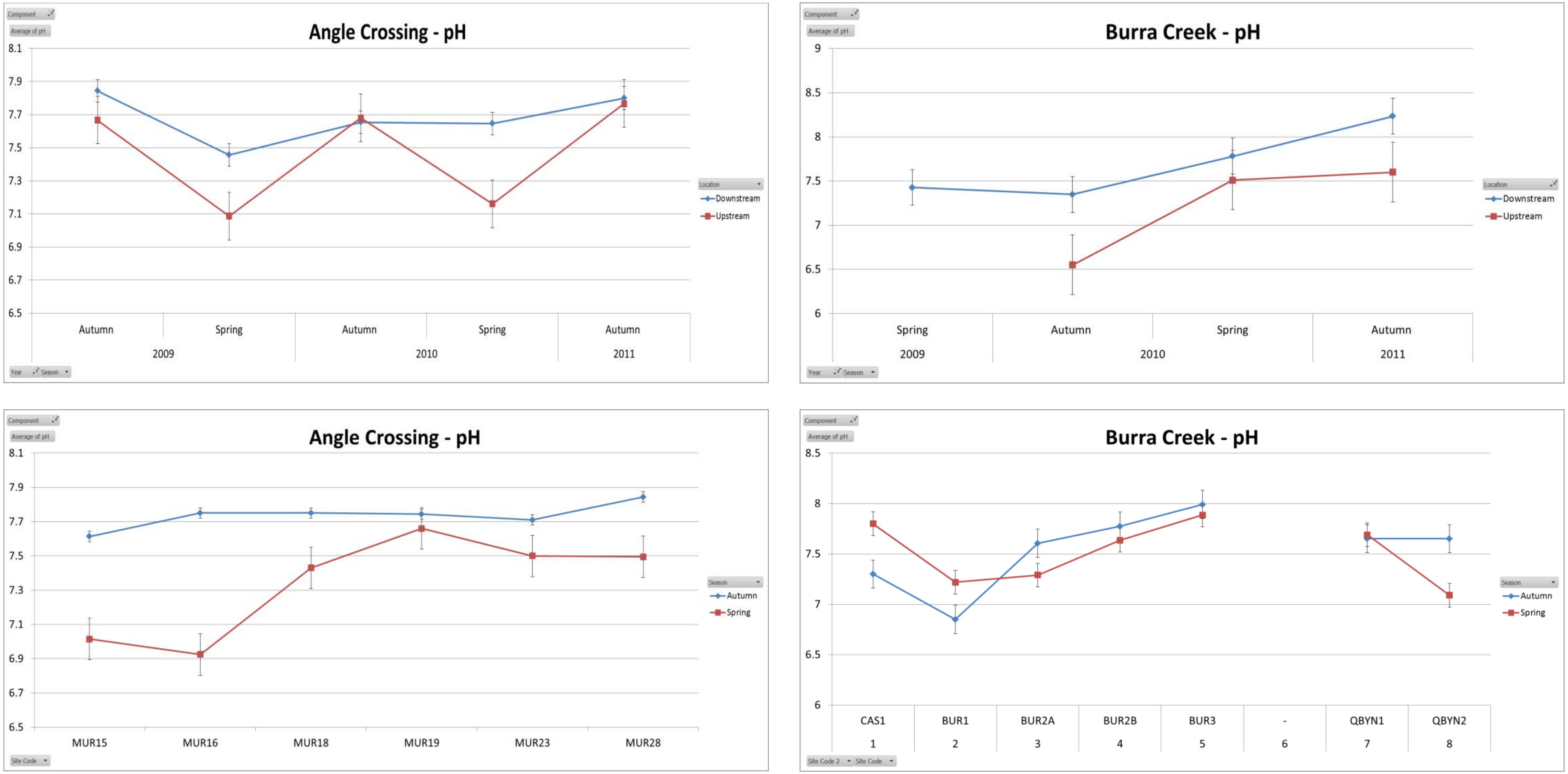


Figure A3.3 – pH plots for Angle Crossing and Burra Creek

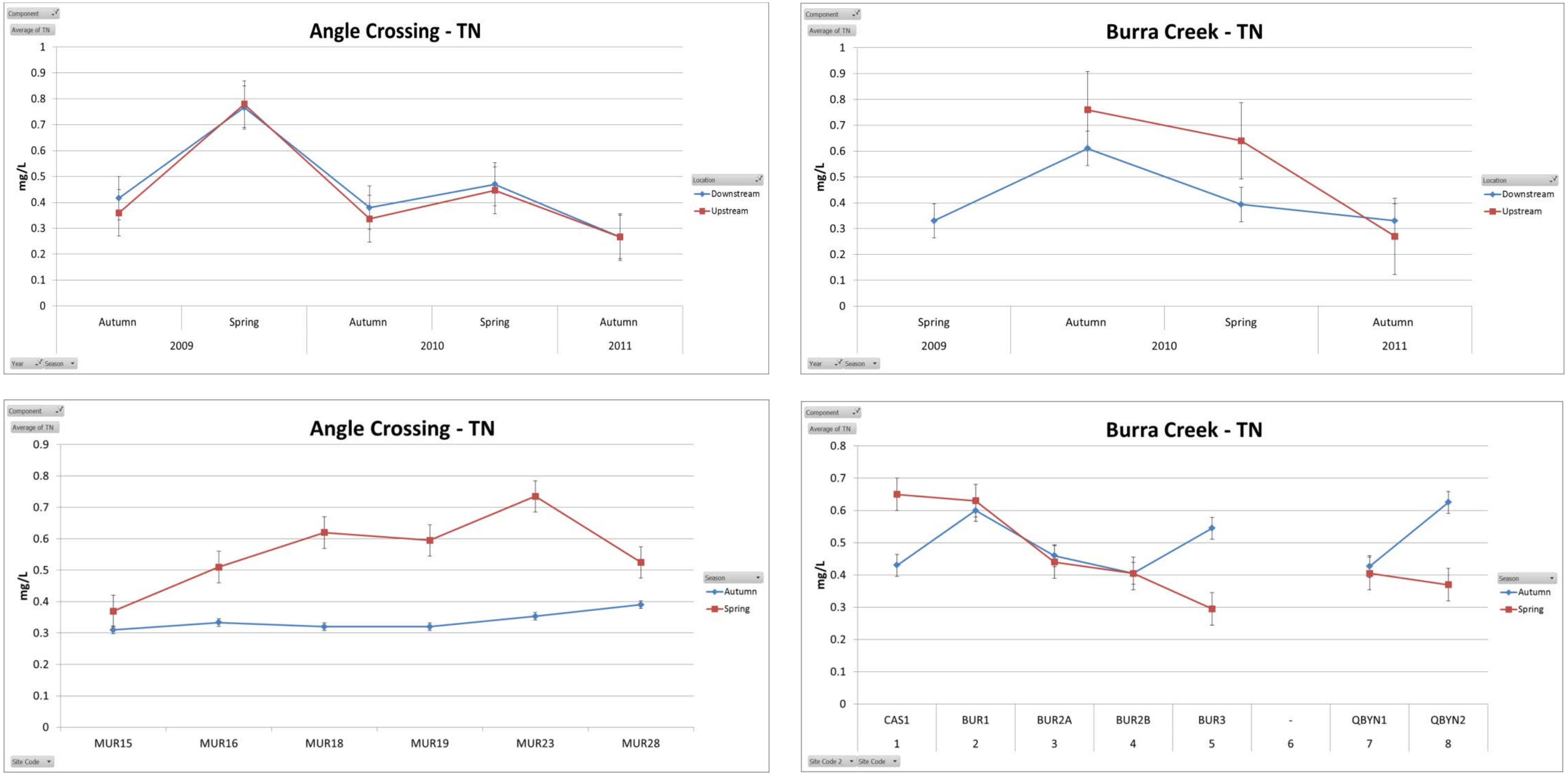


Figure A3.4 – Total nitrogen plots for Angle Crossing and Burra Creek

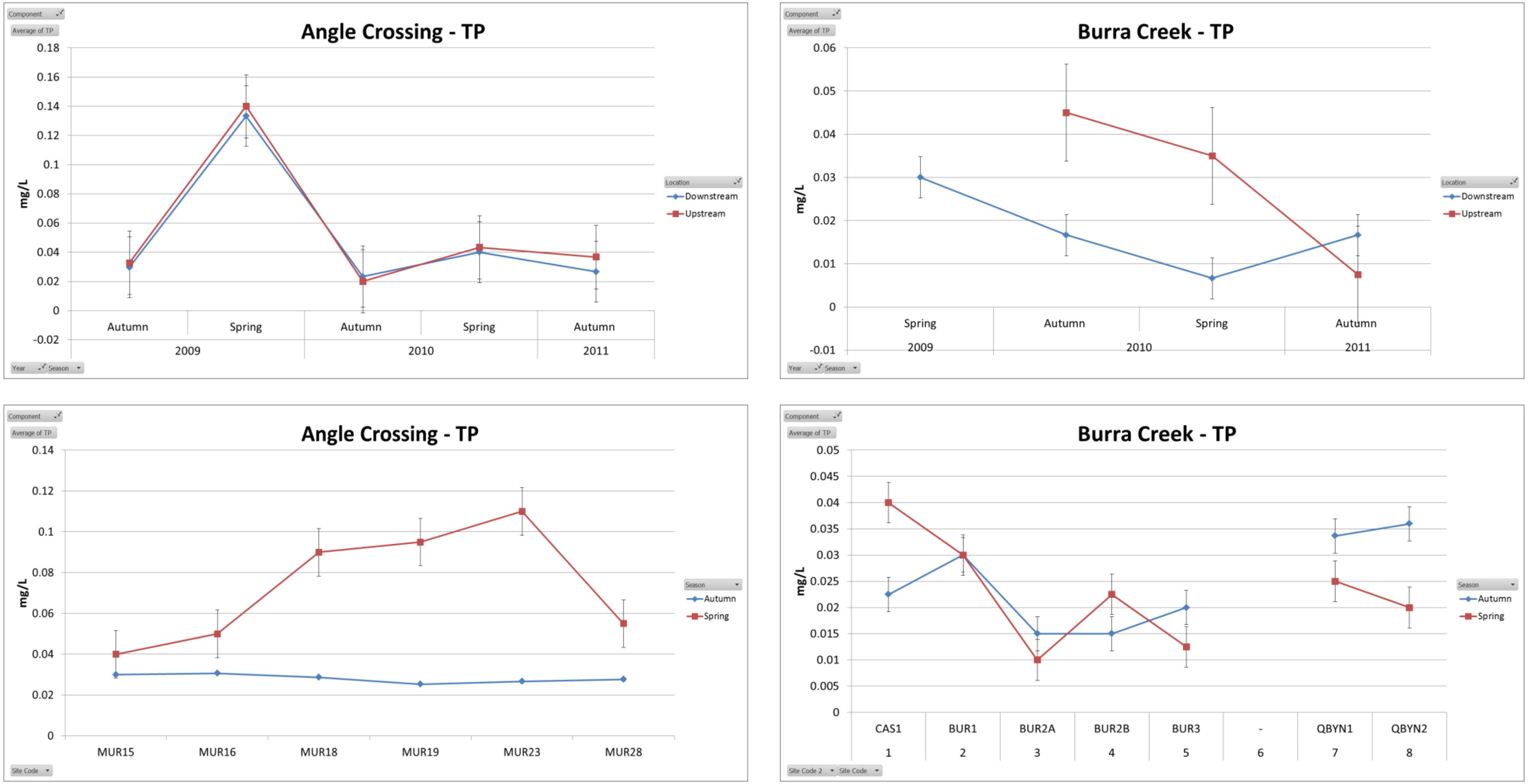
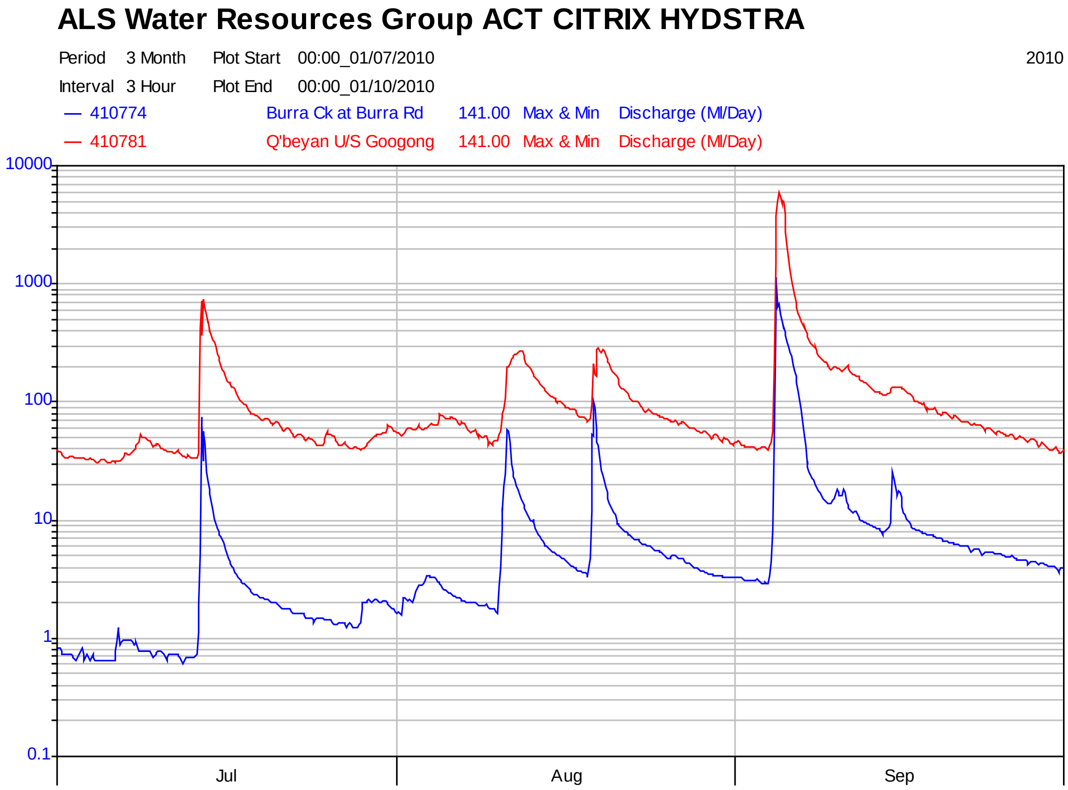


Figure A3.5 – Total phosphorus plots for Angle Crossing and Burra Creek



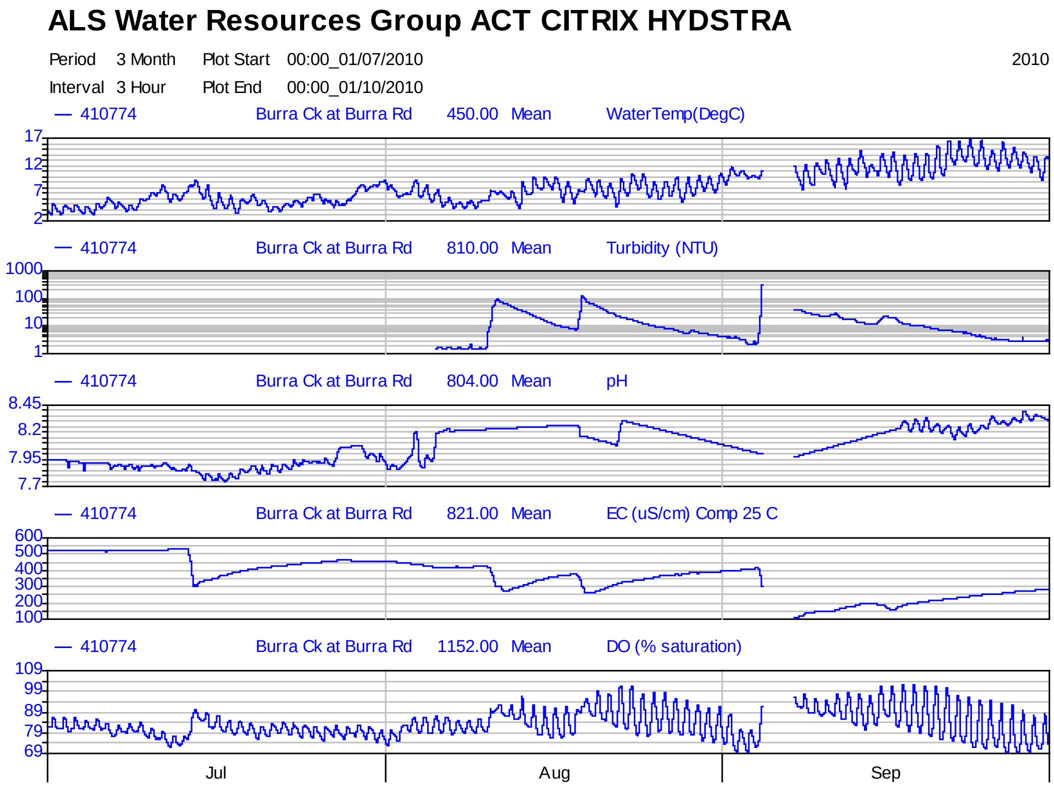
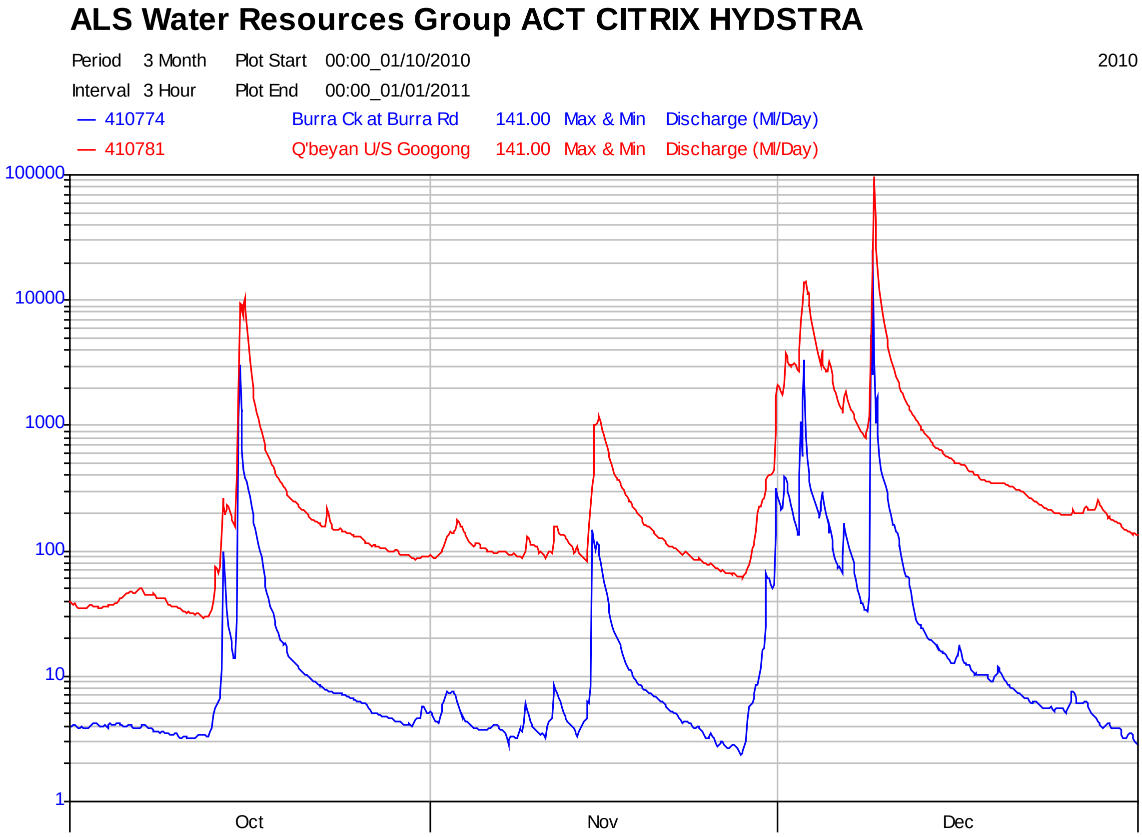


Figure A3.6 – Burra Creek discharge and in-situ water quality **Jul-Sep 2010**



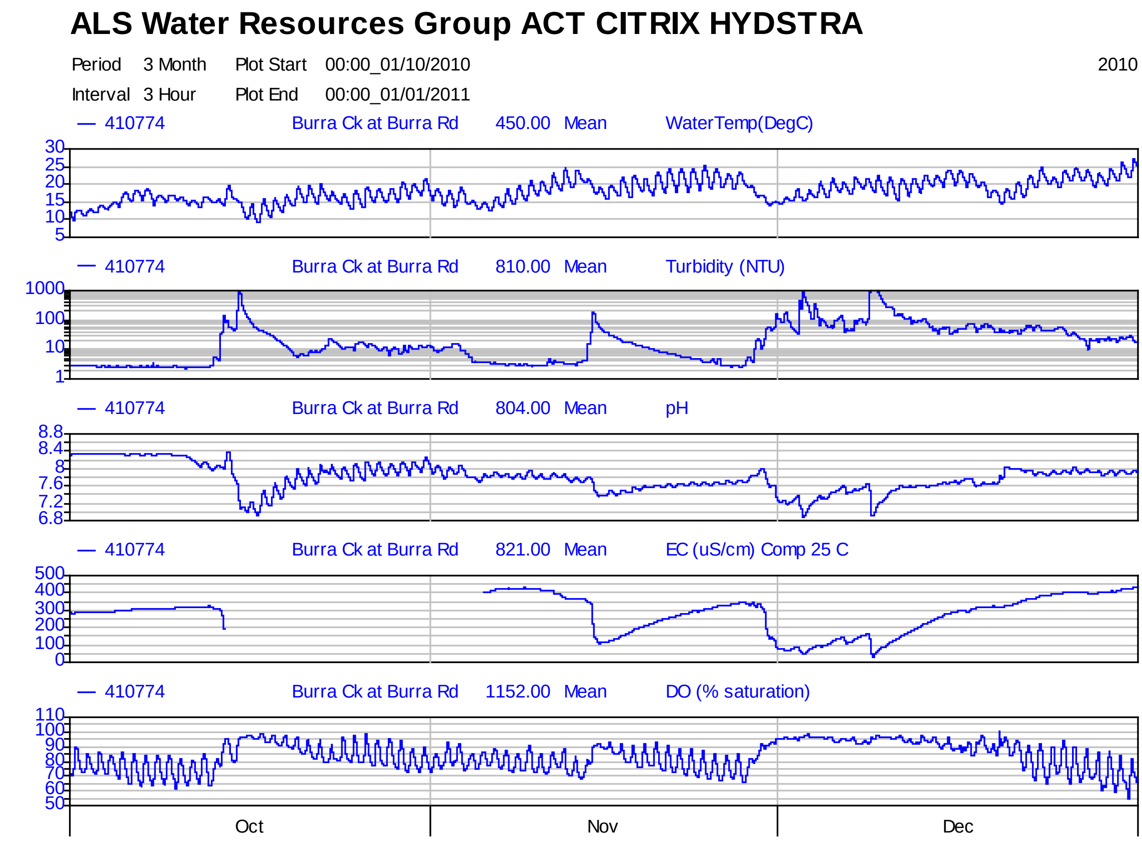
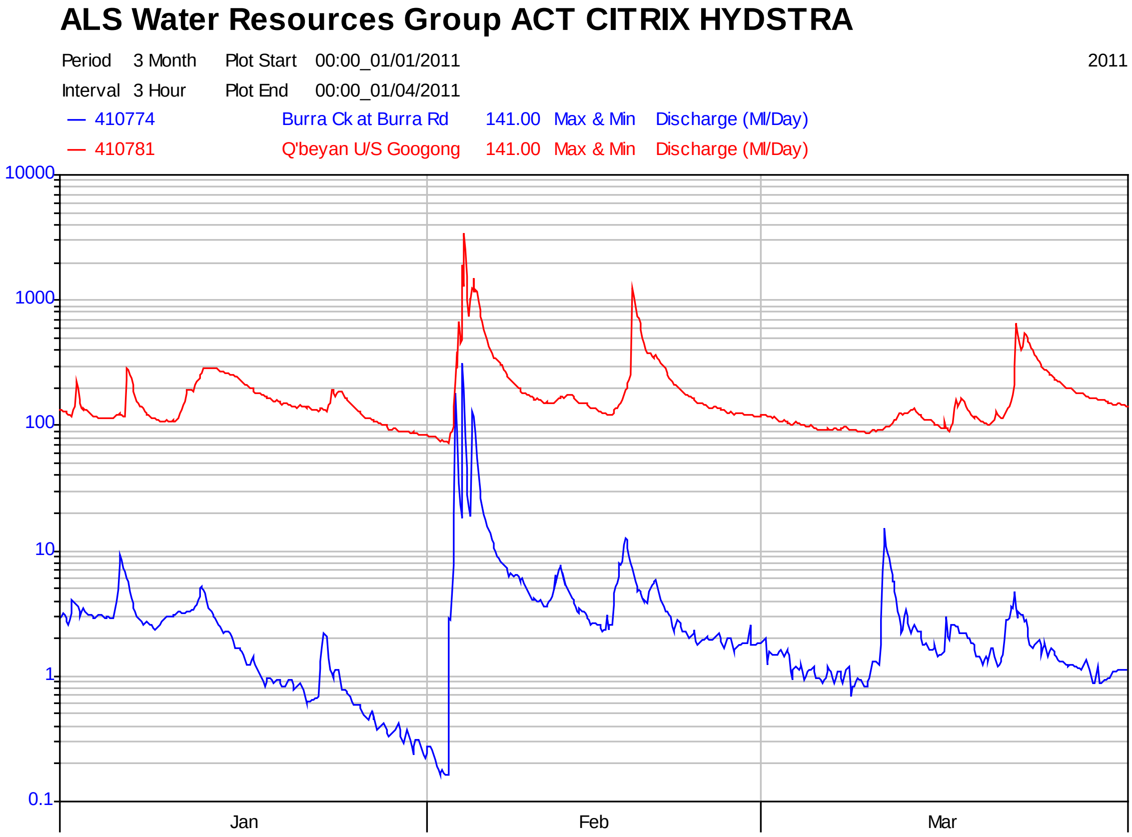


Figure A3.7 – Burra Creek discharge and in-situ water quality **Oct-Dec 2010**



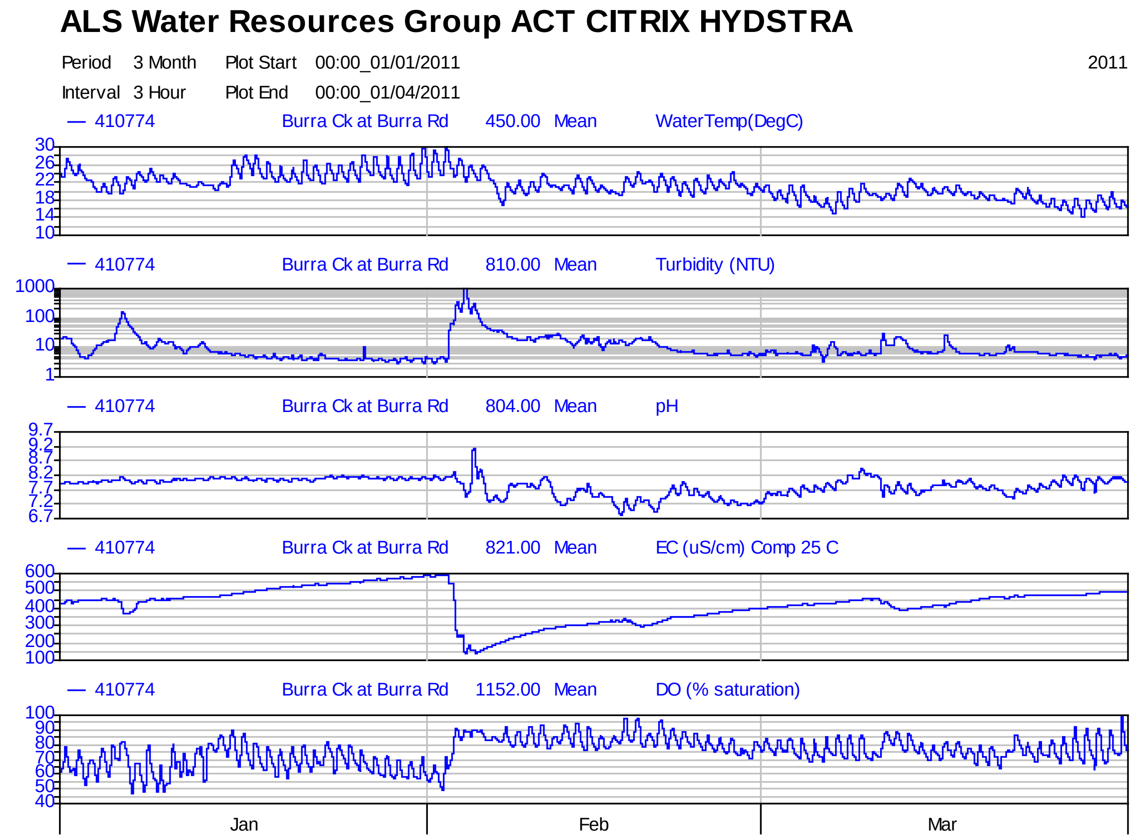
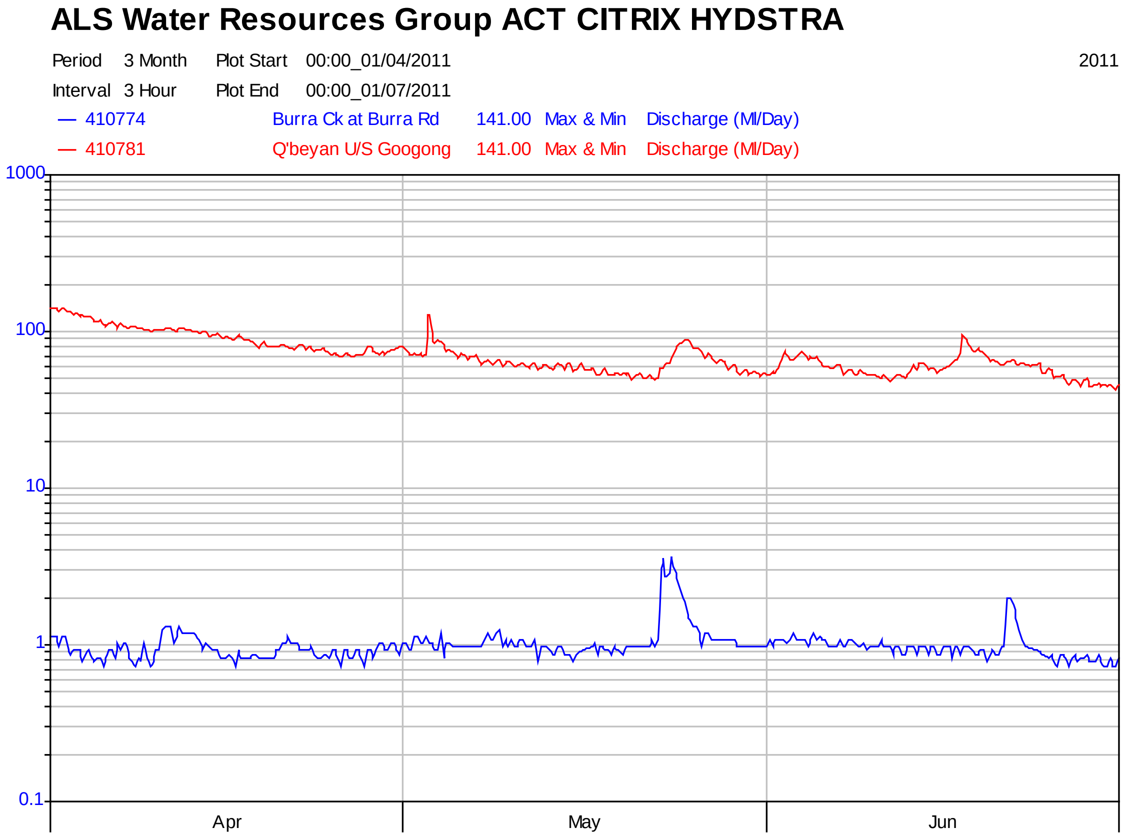


Figure A3.8 – Burra Creek discharge and in-situ water quality **Jan-Mar 2011**



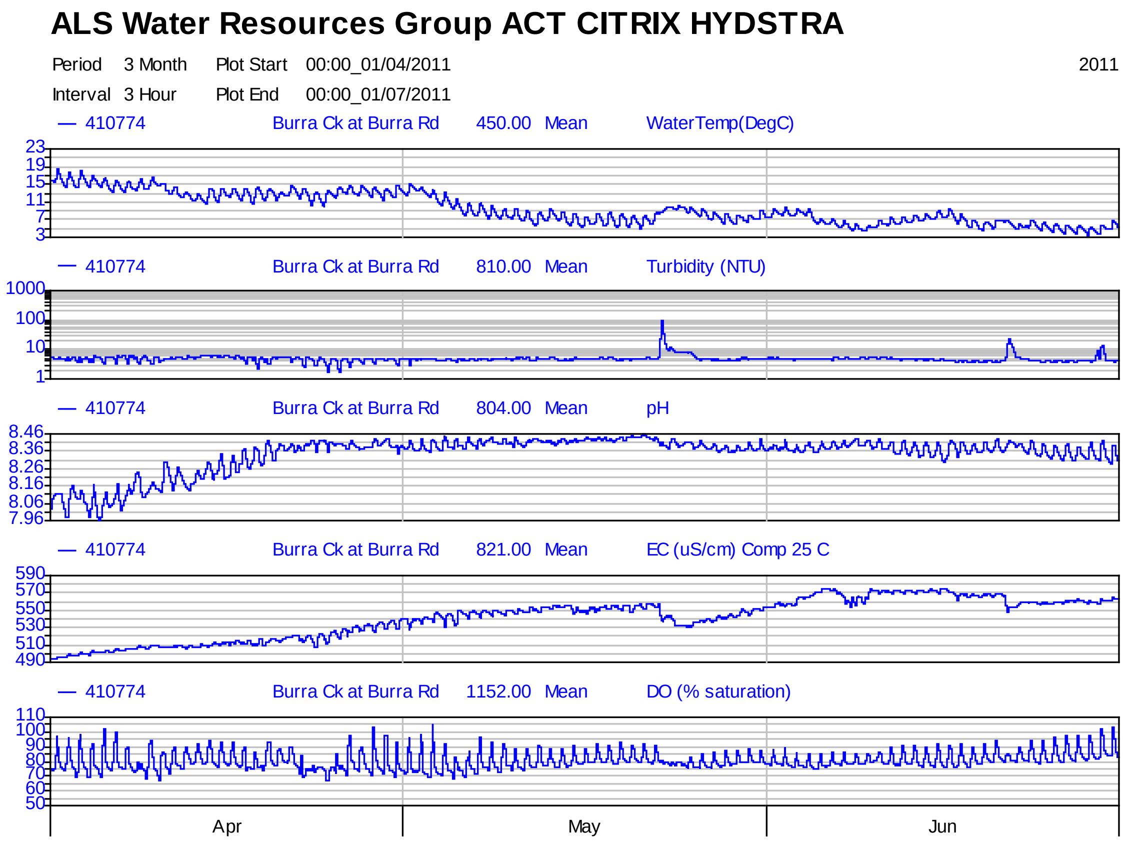
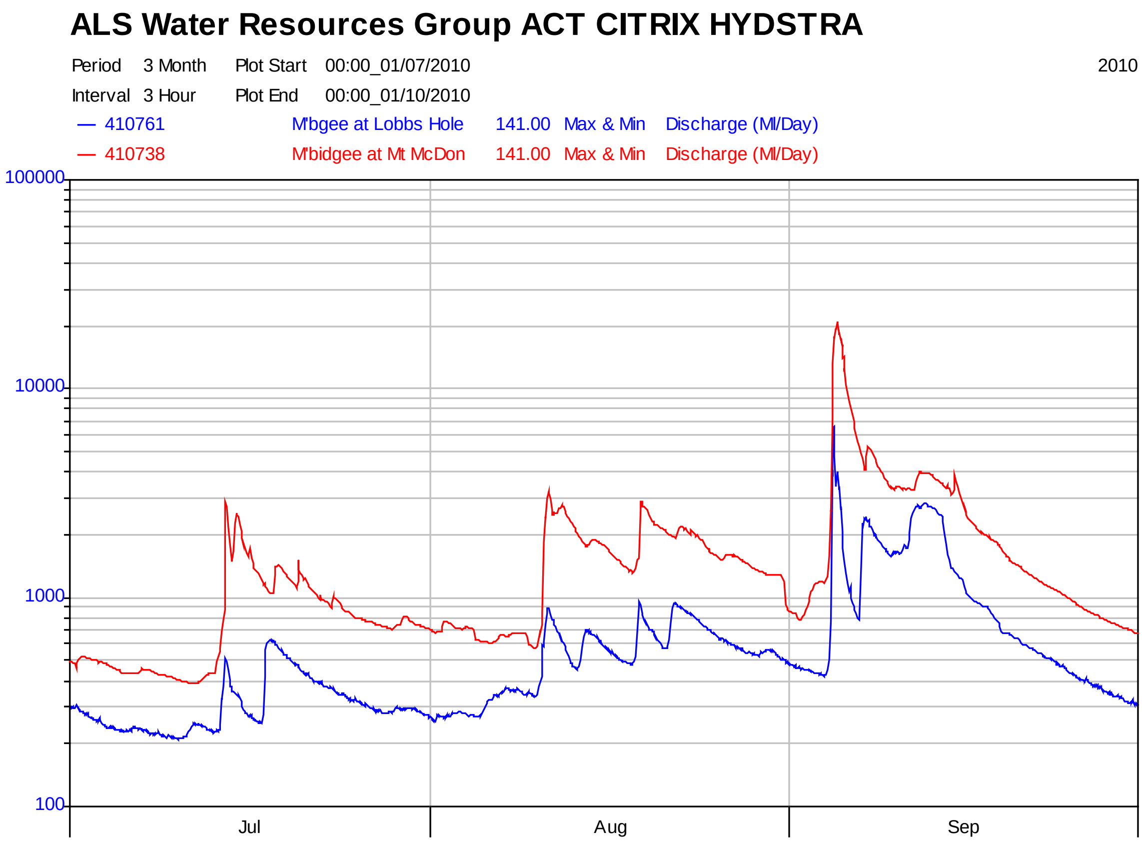


Figure A3.9 – Burra Creek discharge and in-situ water quality **Apr-Jun 2011**



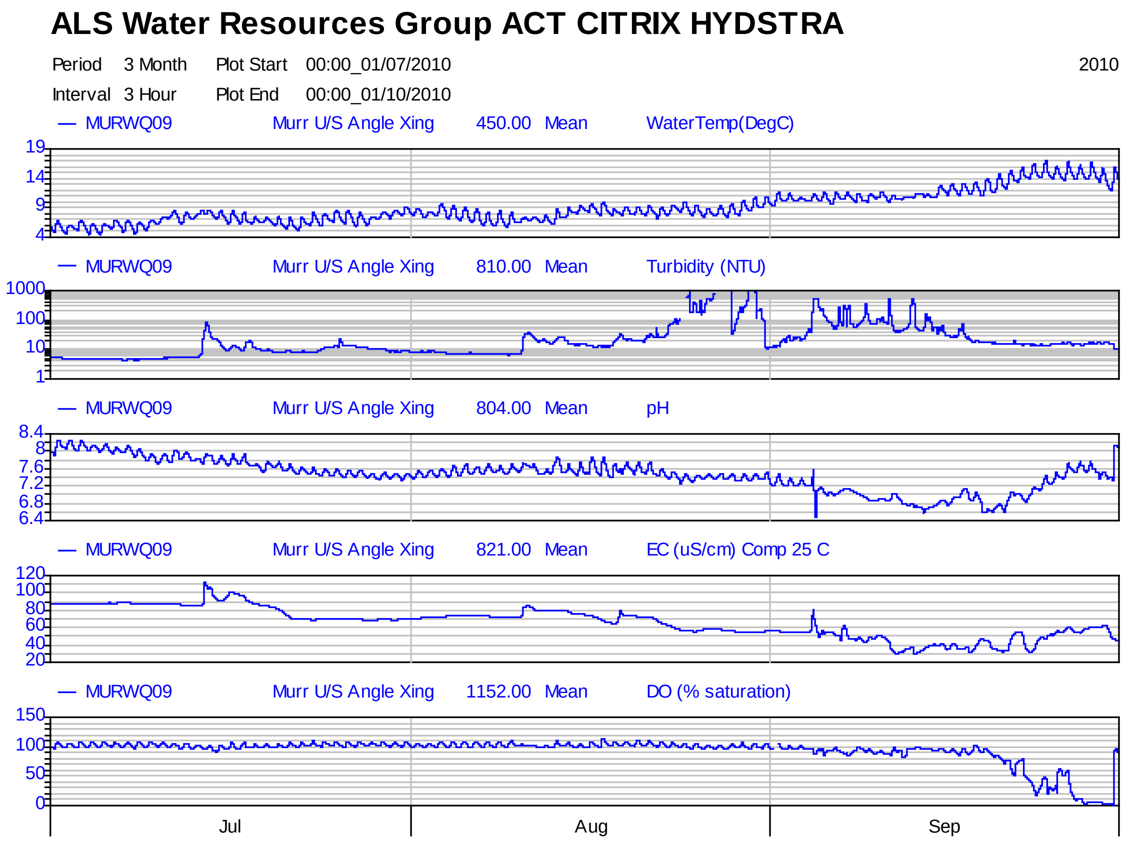
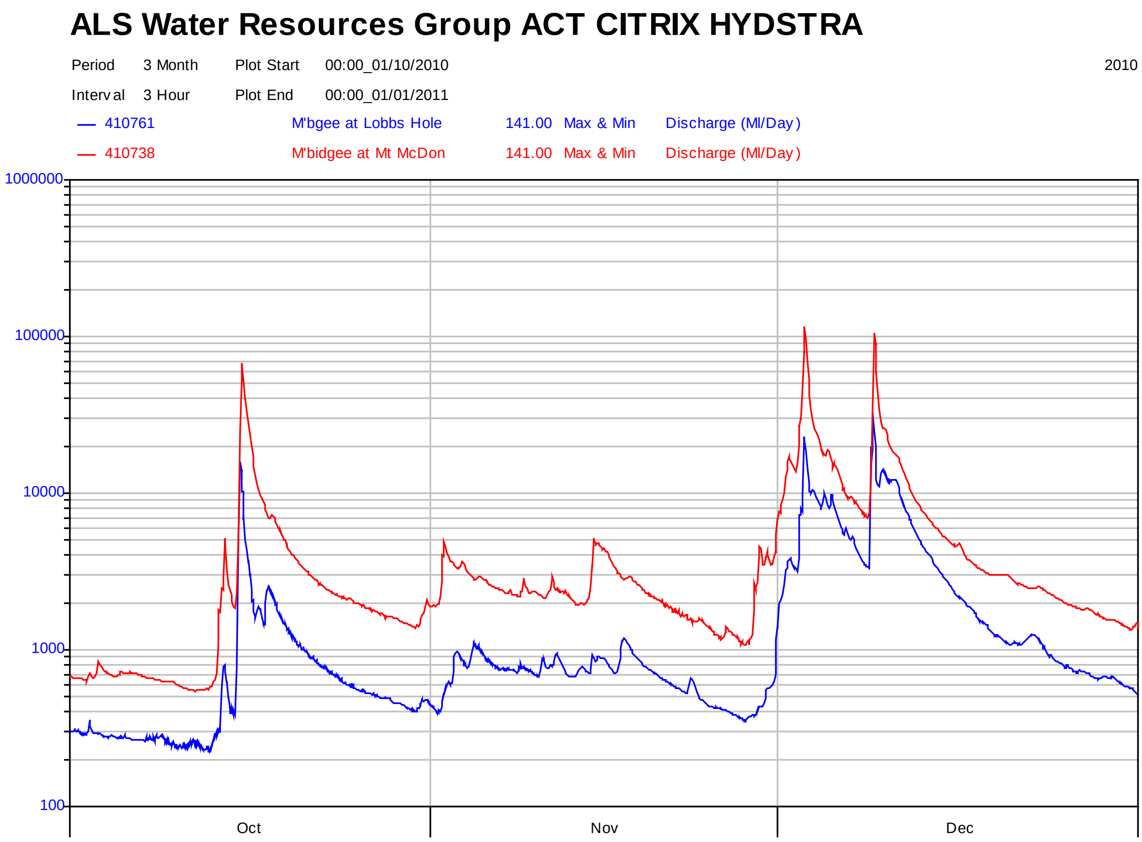


Figure A3.10 – Murrumbidgee River discharge and in-situ water quality **Jul-Sep 2010**



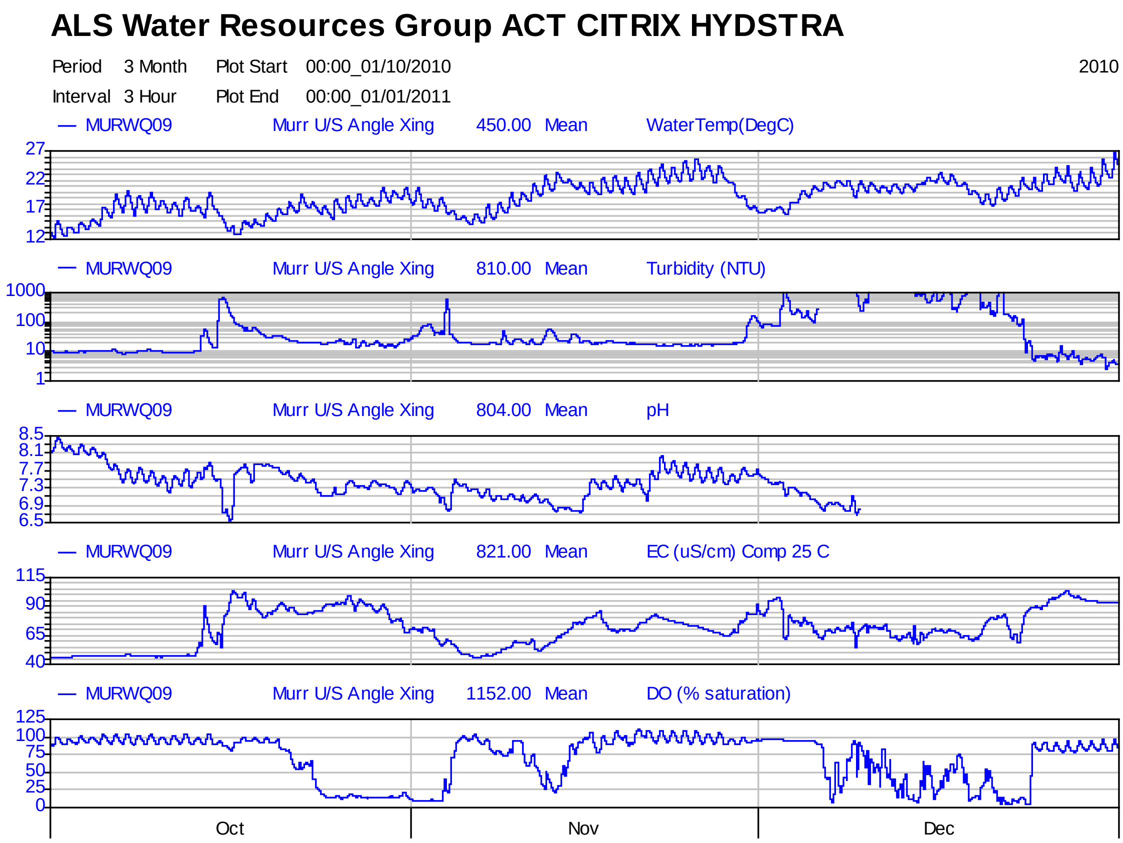
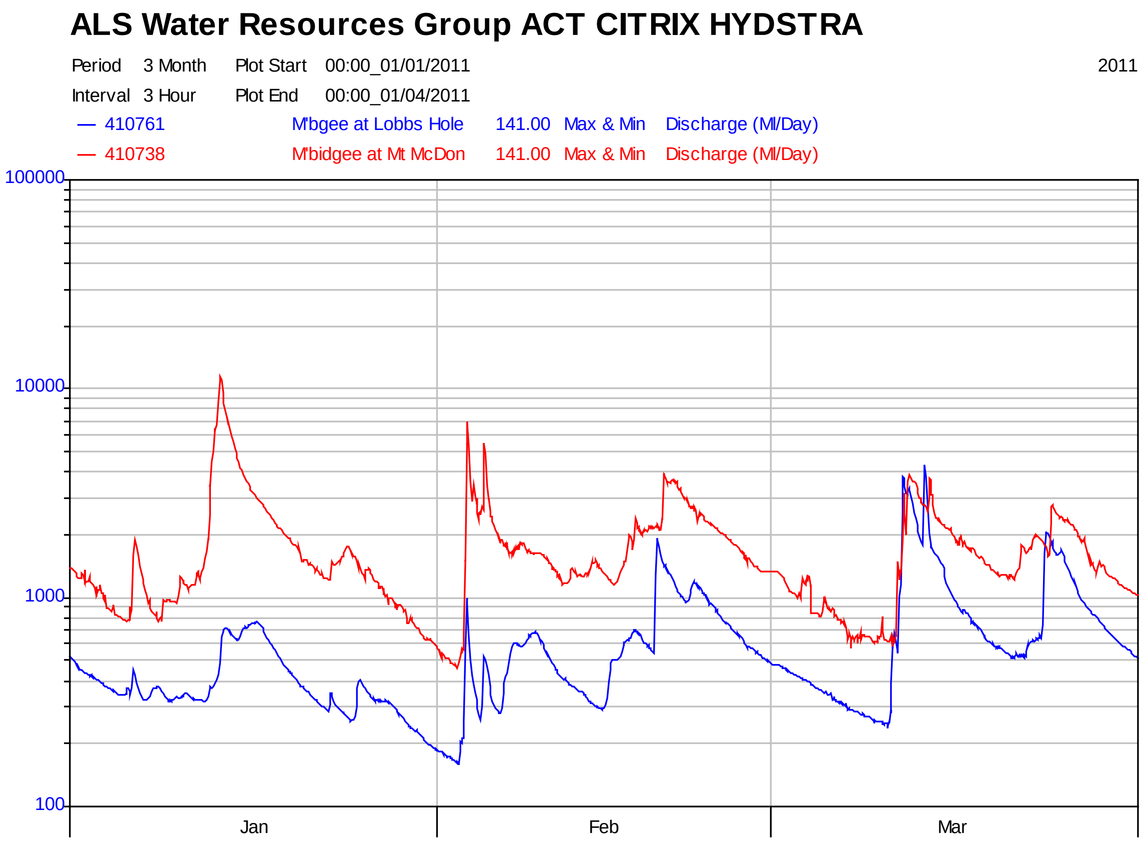


Figure A3.11 – Murrumbidgee River discharge and in-situ water quality **Oct-Dec 2010**



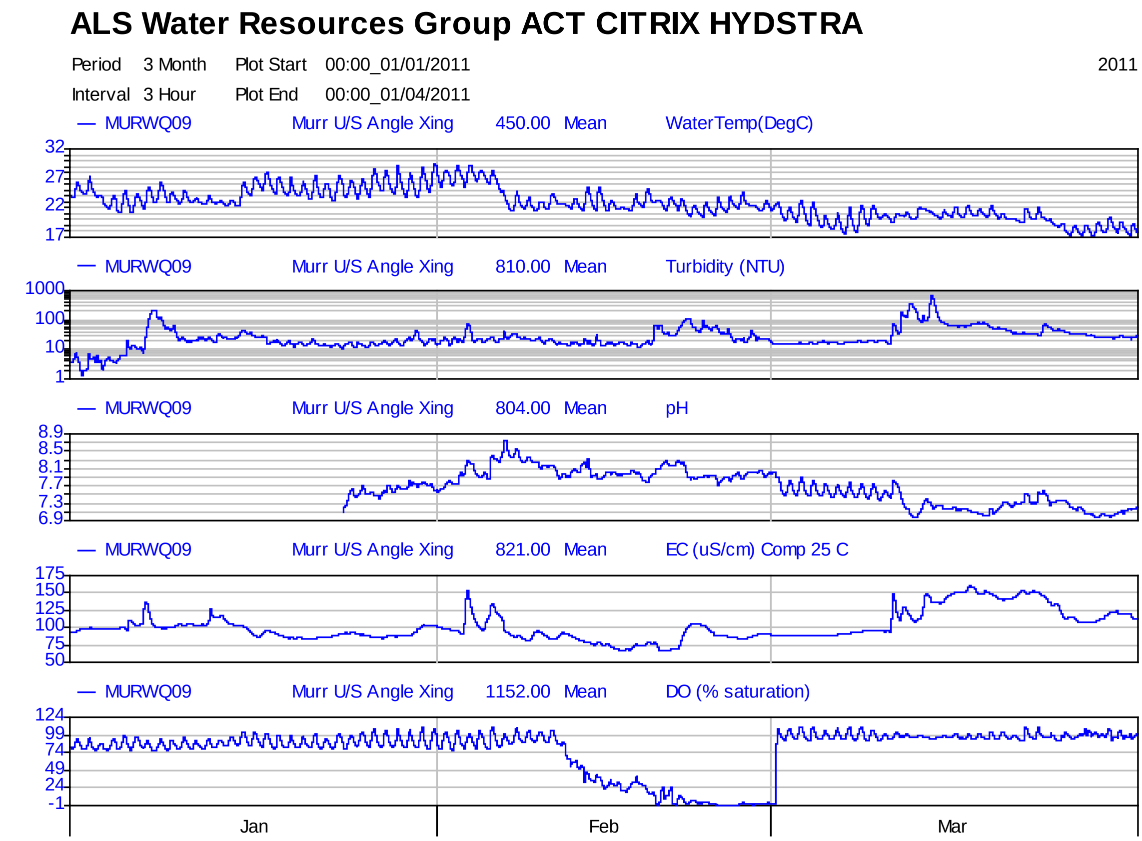
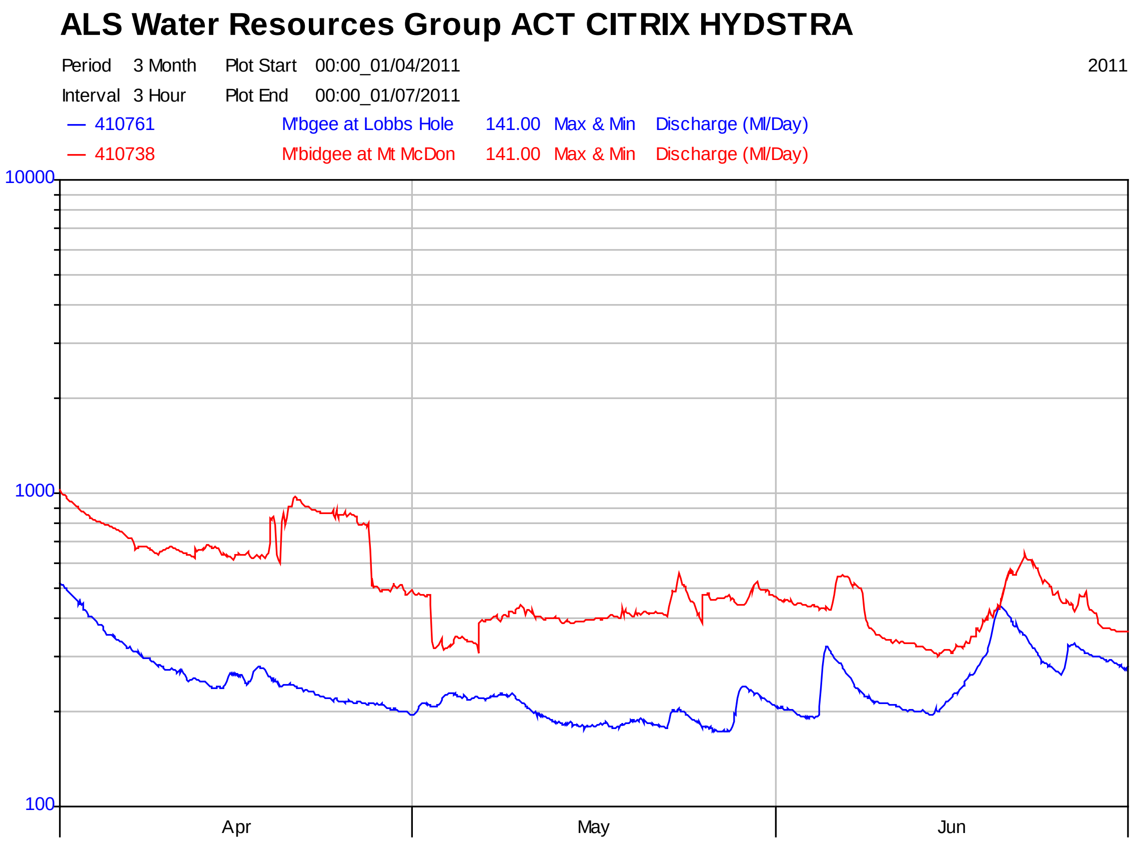


Figure A3.12 – Murrumbidgee River discharge and in-situ water quality **Jan-Mar 2011**



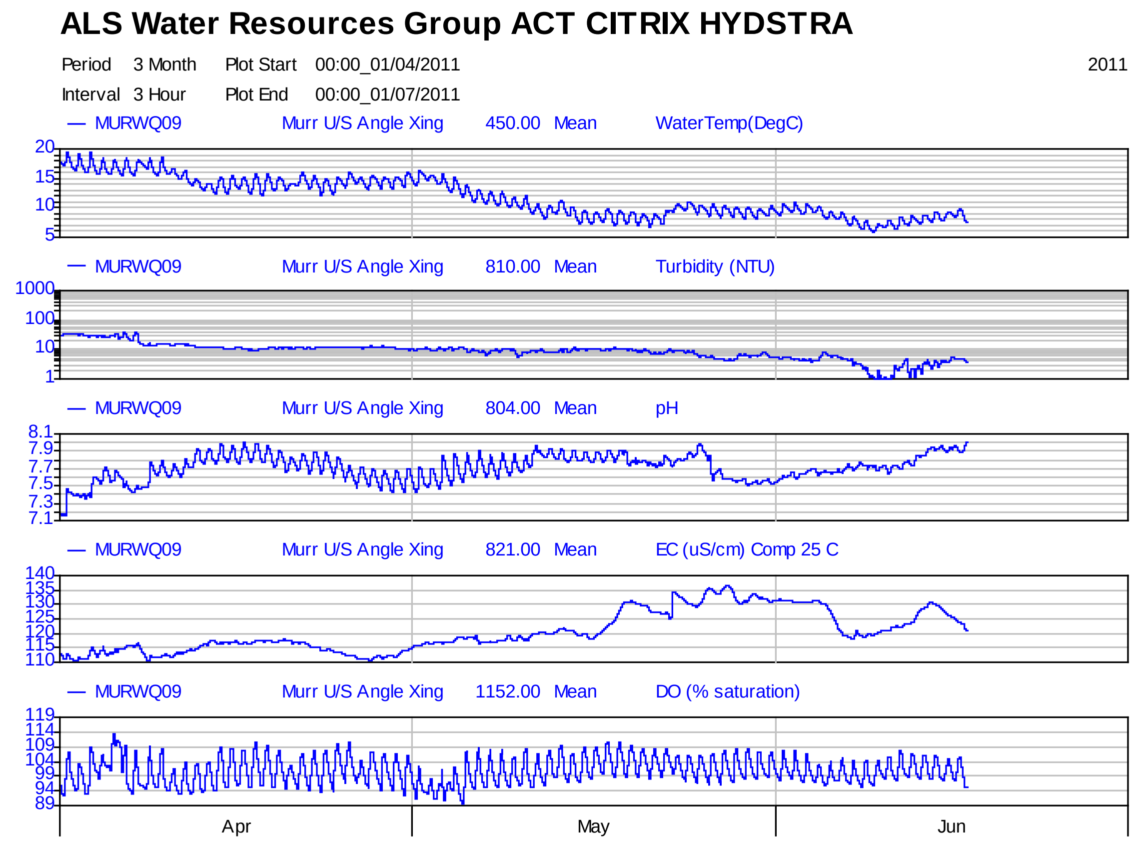
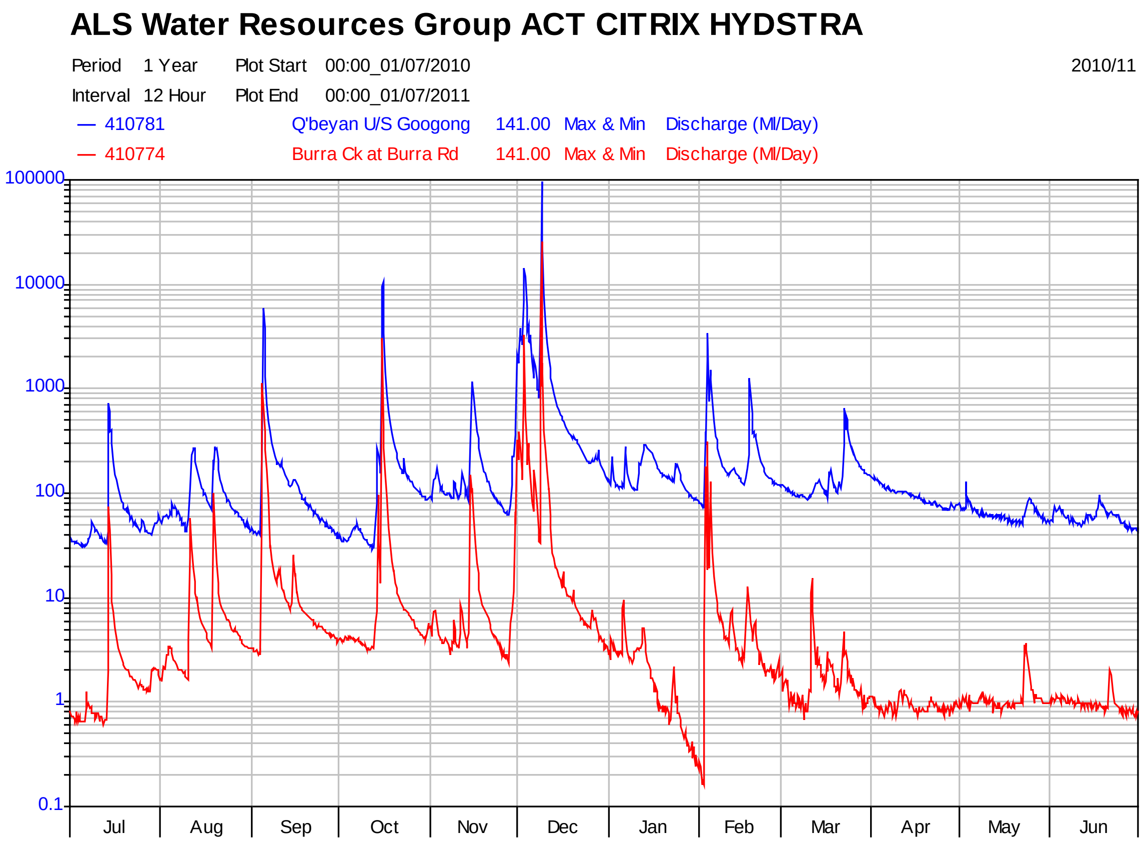


Figure A3.13 – Murrumbidgee River discharge and in-situ water quality **Apr-Jun 2011**



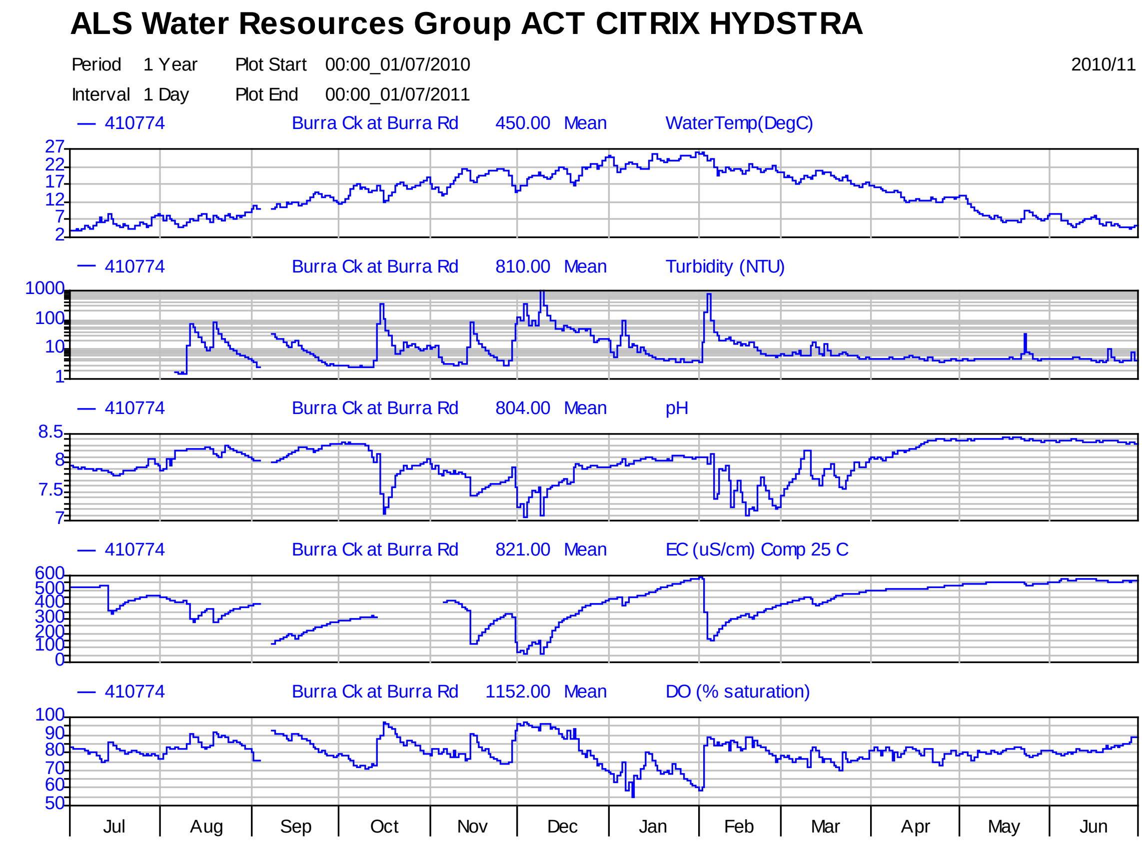
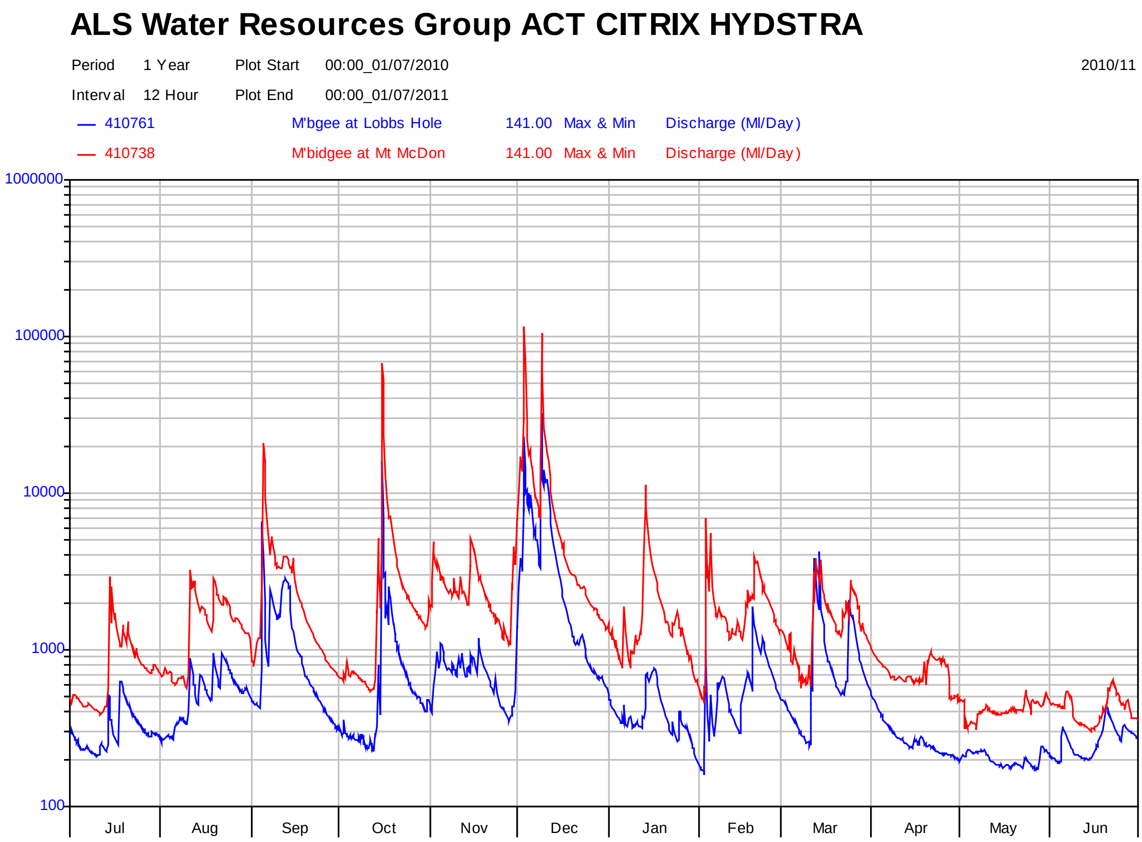


Figure A3.14 – Burra Creek discharge and in-situ water quality **2010-11**



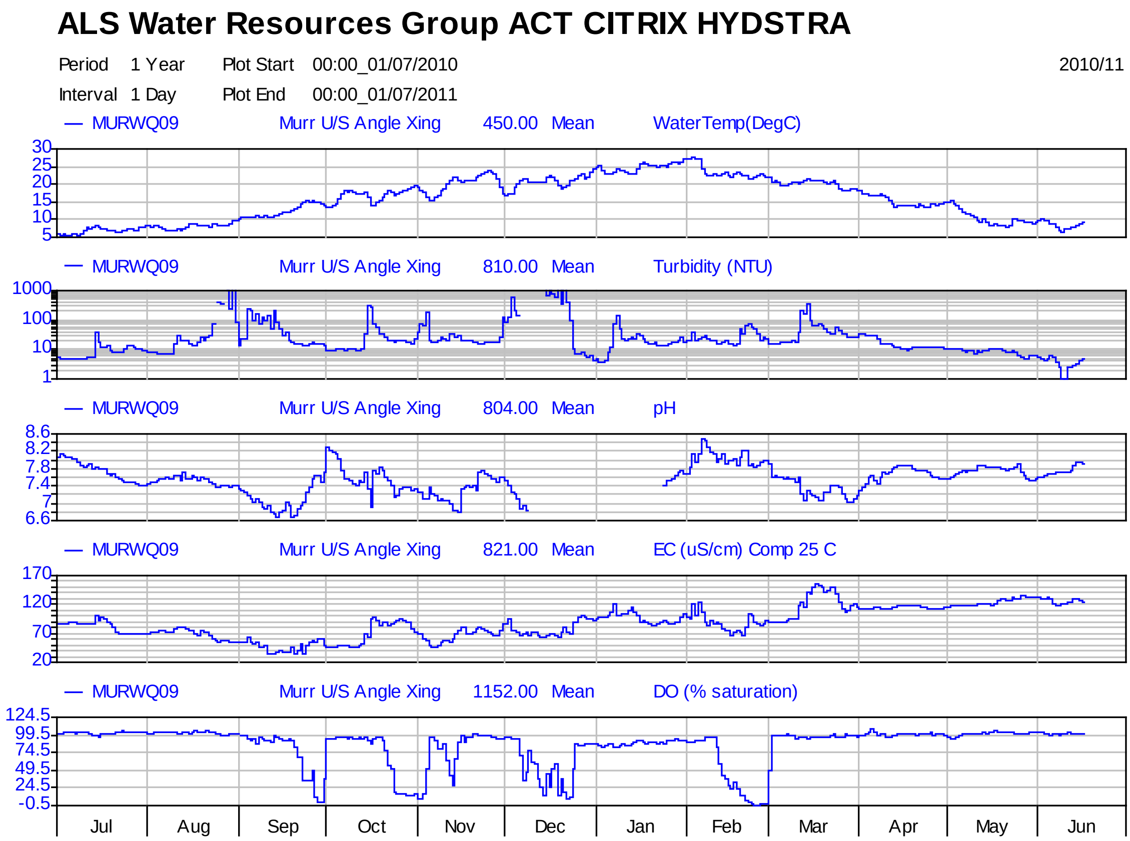


Figure A3.15 – Murrumbidgee River discharge and in-situ water quality **2010-11**

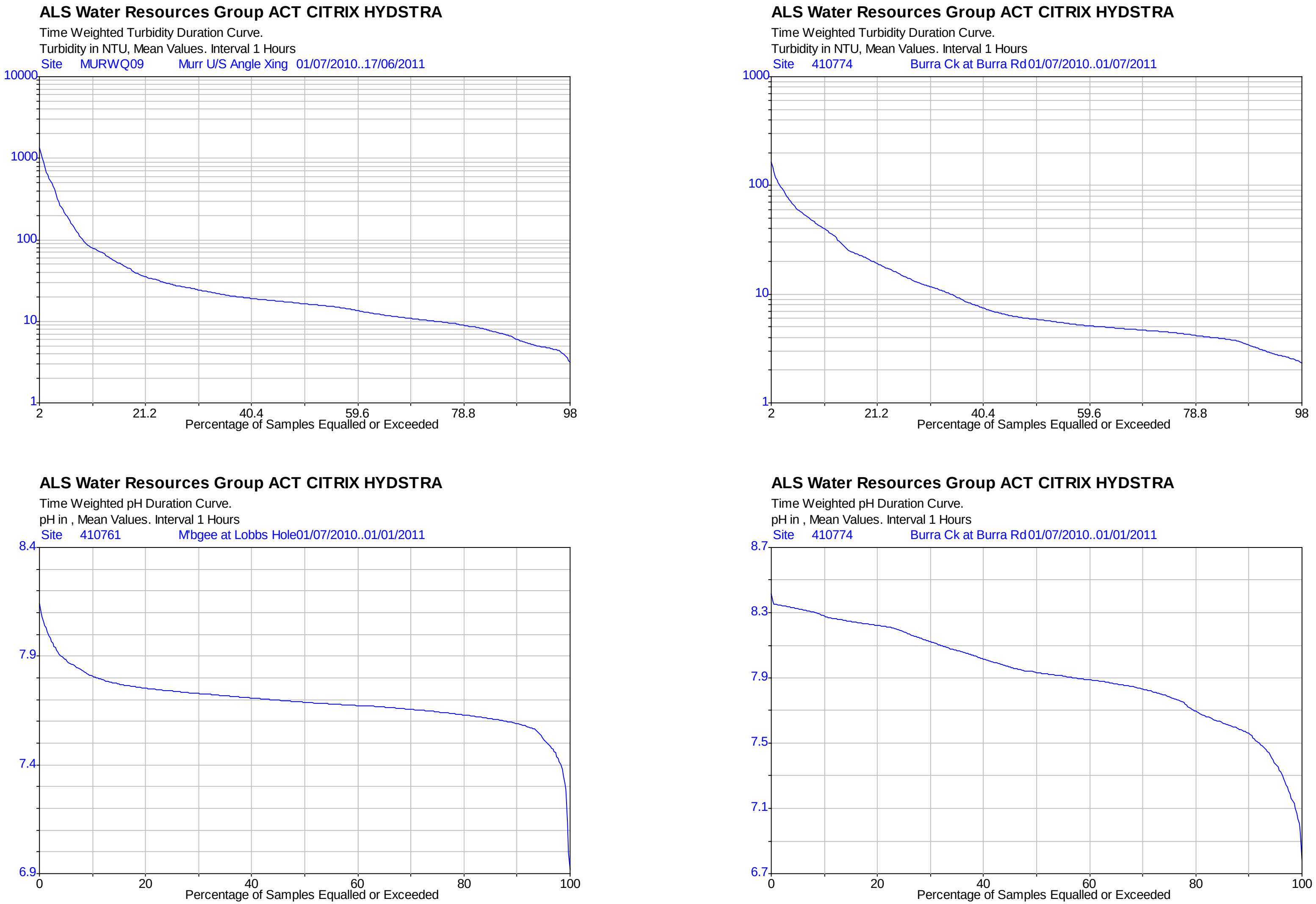


Figure A3.16 – Turbidity and pH duration plots for Burra Creek and the Murrumbidgee River

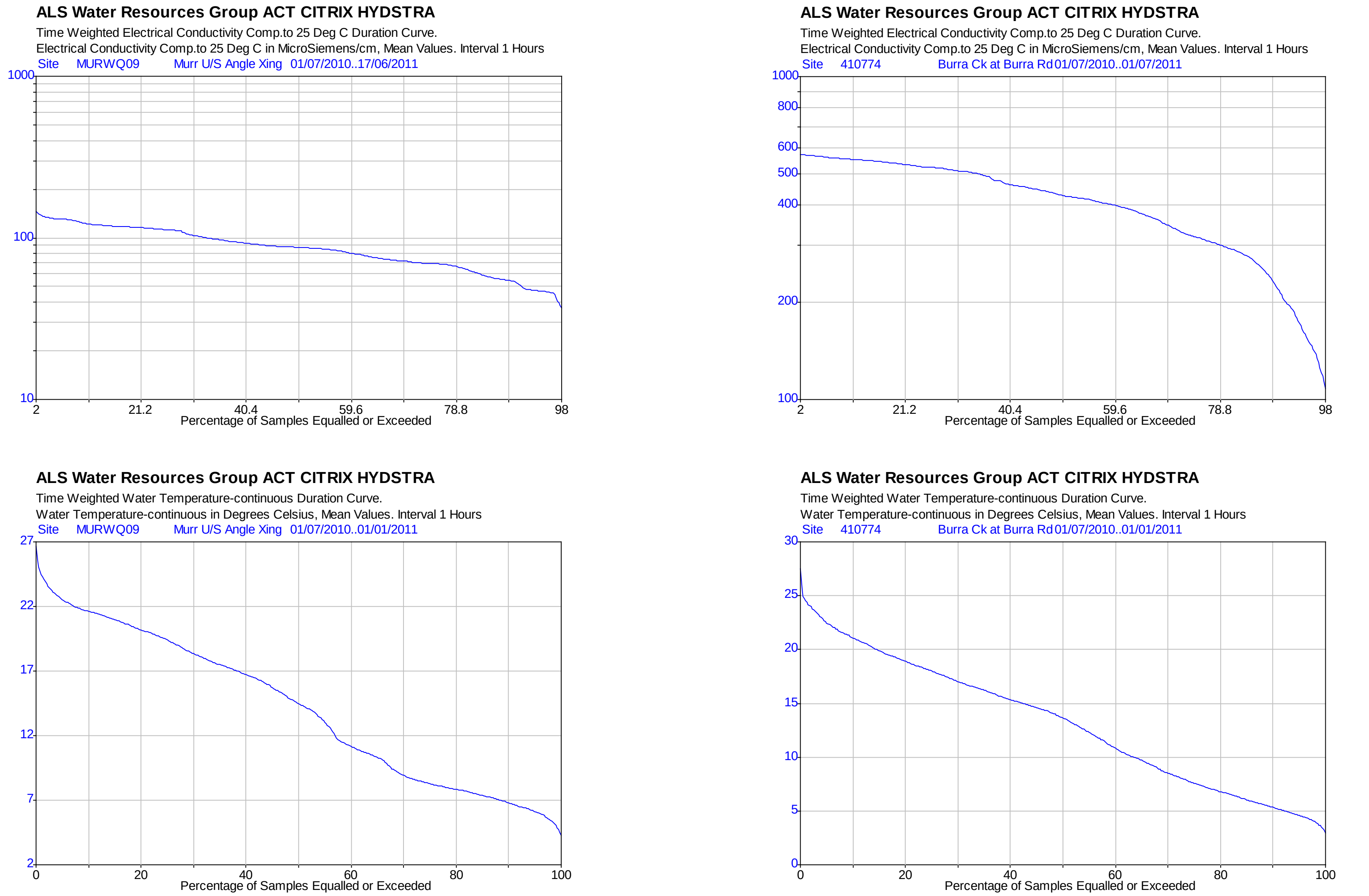


Figure A3.17 – Electrical conductivity and temperature duration plots for Burra Creek and the Murrumbidgee River

APPENDIX 4

Ecological Indicators

APPENDIX 4.1 – AUSRIVAS Band Descriptions

Table A4.1 – AUSRIVAS band descriptions for Autumn and Spring

BAND	Description	Spring		Autumn	
		Riffle	Edge	Riffle	Edge
X	More diverse than expected. Potential enrichment or naturally biologically rich.	>1.14	>1.13	>1.12	>1.17
A	Similar to reference. Water quality and/or habitat in good condition	0.86-1.14	0.87-1.13	0.88-1.12	0.83-1.17
B	Significantly impaired. Water quality and/or habitat compromised significantly resulting in a loss of biodiversity.	0.57-0.85	0.61-0.86	0.64-0.87	0.49-0.82
C	Severely impaired. Water quality and/or habitat compromised severely resulting in a loss of biodiversity.	0.28-0.56	0.35-0.60	0.40-0.63	0.15-0.48
D	Extremely impaired. Highly degraded. Water quality and/or habitat quality is very low and very few of the expected taxa remain.	0-0.27	0-0.34	0-0.39	0-0.14

Table A4.2 – Angle Crossing AUSRIVAS bands results from Autumn 2009 to Autumn 2011

Site	Site code	Location	Autumn 2009		Spring 2009		Autumn 2010		Spring 2010		Autumn 2011	
		Upstream	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge
1	**MUR 15**	Approximately 30 km U/S of Angle Crossing near Colinton;	B	B	NRA*	B	B	A	A	NRA	A	B
2	**MUR 16**	Just U/S Angle Crossing	B	B	B	B	B	A	A	C	A	B
3	**MUR 18**	500m above abstraction site	B	B	B	B	B	B	B	NRA	B	A
		Downstream										
4	**MUR 19**	D/S Angle Crossing; directly below causeway	B	B	B	B	B	B, C	B	C	A	A
5	**MUR 23**	D/S Angle Crossing; at Point Hut;	B	C	B	B	B	A, B	A	B	B	B
6	**MUR 28**	33km D/S Angle Crossing; U/S Cotter River confluence;	B	B	B	B	B		NS	NS	A	B

Table A4.3 – Burra Creek AUSRIVAS bands results from Autumn 2009 to Autumn 2011

Site	Site code	Location	Autumn 2009		Spring 2009		Autumn 2010		Spring 2010		Autumn 2011	
		Upstream	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge	Riffle	Edge
1	**Cass 1**	Cassidy Creek U/S Burra Creek Confluence	Dry	Dry	Dry	B	Dry	B	NS	B	NS	B
2	**BUR 1**	Burra Creek U/S of Cassidy creek Confluence (Upstream of discharge point)	Dry	Dry	Dry	A	C	B	B	B	B	B
		Downstream										
3	**BUR 2a***	Burra Creek D/S Williamsdale Bridge	Dry	Dry	Dry	B	Dry	B	NS	B	C	B
4	**BUR 2b***	Burra Creek D/S Burra Road Bridge	Dry	Dry	Dry	C	Dry	B	NS	B	B	B
5	**BUR 3***	Burra Creek D/S London Bridge arch	Dry	Dry	B	B	B	B	B	A	NS	A
		Control										
6	**QBN 1**	Queanbeyan River ~3km U/S Burra Creek Confluence.	B	A	B	A	B	B	B	B	B	B
7	**QBN 2***	Queanbeyan River ~1km D/S Burra Creek Confluence	C	B	B	B	B	B				

APPENDIX 4.2 – Summary Statistics for Periphyton Data

Table A4.4 – Summary statistics for Periphyton data collected in Spring 2010 and Autumn 2011

Site	Location	Component	Spring 2010						Autumn 2011					
			Chlorophyll a			AFDM			Chlorophyll a			AFDM		
			$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
Mur 15	Upstream	Angle Crossing	3080.4	2083.4	6	2119.8	984.4	6	16572.43	19792.3	6	10775.9	11562.4	6
Mur 16	Upstream	Angle Crossing	5719.2	5020.3	6	7154.5	1871.3	6	7132.4	2608.6	6	10621.4	10597.7	6
Mur 18	Upstream	Angle Crossing	2804.4	1947.9	6	4283.8	5176.8	6	31764.7	33912.2	6	3444.7	685.8	6
Mur 19	Downstream	Angle Crossing	1126.2	1211.3	6	4151.4	5040.7	6	28750.4	33180.7	6	7529.9	6032.8	6
Mur 23	Downstream	Angle Crossing	9859.5	3686.1	6	15811.63	4798.1	6	9219.17	2534.8	6	5233.4	1300.2	6
Mur 28	Downstream	Angle Crossing			0			0	36261.5	2950.8	6	6447.9	3226.5	6
Qbyn 1	Queanbeyan Control	Burra Creek	2150.7	1160.4	6	1874.7	347.1	6	11438.4	33275.6	6	4305.9	1833.4	6
Bur 1	Upstream	Burra Creek	1722.4	750.6	6	3052.5	1876.3	6	10708.6	33912.2	6	8436.5	6368.9	6
Bur 2a	Downstream	Burra Creek			0			6	11129.2	34754.1	6	7715.2	4086.4	6
Bur 2b	Downstream	Burra Creek			0			6	3985.7	36273.2	6	6665.1	3833.2	6
Bur 3	Downstream	Burra Creek	6304.4	4763	6	7141.3	4582.6	6	23137	38721.2	6			0

$\bar{x}$ = mean; SD = standard deviation; n = number of samples

APPENDIX 4.3 – ANOVA Tables for the Periphyton Analysis

Table A4.5 – ANOVA tables for periphyton analysis from **Angle Crossing and Burra Creek**

Site	Variable	Source	df	F	P
Angle Crossing	**Chlorophyll-a**	***Source***	**df**	**F**	**P**
		Season	1	28.98	<0.0001
		Location	1	0.235	0.65
		*Season*Location(Site)*	1	0.376	0.54
		Residual	62		
	AFDM				
		Season	1	2.858	0.097
		Location	1	0.400	0.561
		Season*Location(Site)	1	2.954	0.092
		Residual	62		

Site	Variable	Source	df	F	P
Burra Creek	**Chlorophyll-a**	**Source**	**df**	**F**	**P**
		Season	1	10.00	0.011
		Location	2	0.141	0.876
		Season*Location(Site)		3.051	0.097
		Residual	29		
	AFDM				
		Season	1	8.403	0.017
		Location	2	2.242	0.308
		Season*Location(Site)	2	1.247	0.332
		Residual	29		

APPENDIX 4.4 – AUSRIVAS Summary Tables, Edge and Riffle

Table A4.6 – AUSRIVAS band comparison between Spring 2010 and Autumn 2011 for the riffle habitat

Site	Location	Spring 10	Autumn 11	Change*
MUR 1	D/S Tantangara Reservoir	B (0.84)	B (0.82)	—
MUR 2	Yaouk Bridge	A (1.05)	A (0.89)	—
MUR 3	Bobeyan Road Bridge	A (0.93)	C (0.59)	↓
MUR 4	Camp ground off Bobeyan Road	NS†	A (0.95)	—
MUR 6	D/S STP Pilot Creek Road	A (1.03)	A (1.11)	—
MUR 9	Murrells Crossing	A (1.00)	A (0.89)	—
MUR 12	Through Bredbo township	A (0.90)	A (0.89)	—
MUR 15	Near Colinton - Bumbalong Road	A (1.04)	A (0.96)	—
MUR 16	The Willows - Near Michelago	A (0.97)	A (0.95)	—
MUR 18	U/S Angle Crossing	B (0.75)	B (0.78)	—
MUR 19	D/S Angle Crossing	B (0.76)	A (1.02)	↑
MUR 22	Tharwa Bridge	A (0.98)	A (1.00)	—
MUR 23	Point Hut Crossing	A (0.95)	B (0.78)	↓
MUR 27	Kambah Pool	B (0.82)	A (1.00)	↑
MUR 931	Fairvale -U/S Cotter Confluence	NS	A (1.00)	—
MUR 28	U/S Cotter River confluence	NS	A (1.00)	—
MUR 935	Casuarina sands	NS	A (0.98)	—
MUR 937	Mt. MacDonald D/S Cotter Confluence	NS	A (0.96)	—
MUR 29	Uriarra Crossing	C (0.52)	A (0.93)	↑
MUR 30	U/S Molonglo Confluence	NS	A (1.00)	—
MUR 31	D/S Molonglo Confluence	NS	A (1.00)	—
MUR 34	Halls Crossing	NS	A (0.89)	—
MUR 37	Boambolo Road	NS	NS	—
QBYN 1	Flynn's Crossing	B (0.83)	B (0.80)	—
BUR 1	Burra Creek Native (US Williamsdale Road)	B (0.67)	B (0.68)	—
BUR 2A	D/S Williamsdale Bridge	NS	C (0.62)	—
BUR 2B	D/S Burra Road Bridge	NS	B (0.78)	—
BUR 3	D/S London Bridge	B (0.76)	NS	—
CAS 1	U/S Burra Creek confluence	NS	NS	—

– NO CHANGE; ↑ IMPROVEMENT; ↓DECLINE; † NS – NOT SAMPLED; ‡NRA –NO RELIABLE ASSESSMENT

Table A4.7 – AUSRIVAS band comparison between Spring 2010 and Autumn 2011 for the edge habitat

Site	Location	Spring 10	Autumn 11	Change*
MUR 1	D/S Tantangara Reservoir	B (0.69)	A (1.06)	↑
MUR 2	Yaouk Bridge	A (1.11)	A (0.82)	—
MUR 3	Bobeyan Road Bridge	A (0.89)	A (0.81)	—
MUR 4	Camp ground off Bobeyan Road	B (0.70)	B (0.76)	—
MUR 6	D/S STP Pilot Creek Road	A (1.00)	A (0.93)	—
MUR 9	Murrells Crossing	X (1.22)	A (0.88)	↓
MUR 12	Through Bredbo township	B (0.78)	B (0.71)	—
MUR 15	Near Colinton - Bumbalong Road	NRA‡	B (0.78)	—
MUR 16	The Willows - Near Michelago	C (0.55)	B (0.73)	↑
MUR 18	U/S Angle Crossing	NRA‡	A (0.88)	—
MUR 19	D/S Angle Crossing	C (0.51)	A (0.85)	↑
MUR 22	Tharwa Bridge	A (1.00)	B (0.78)	↓
MUR 23	Point Hut Crossing	B (0.72)	B (0.76)	—
MUR 27	Kambah Pool	B (0.78)	B (0.70)	—
MUR 931	Fairvale -U/S Cotter Confluence	NS	B (0.74)	—
MUR 28	U/S Cotter River confluence	NS	B (0.62)	—
MUR 935	Casuarina sands	NS	B (0.70)	—
MUR 937	Mt. MacDonald D/S Cotter Confluence	NS	B (0.73)	—
MUR 29	Uriarra Crossing	A (0.89)	B (0.78)	—
MUR 30	U/S Molonglo Confluence	NS	A (0.93)	—
MUR 31	D/S Molonglo Confluence	NS	B (0.78)	—
MUR 34	Halls Crossing	NS	B (0.78)	—
MUR 37	Boambolo Road	NS	B (0.62)	—
QBYN 1	Flynn's Crossing	B (0.76)	B (0.75)	—
BUR 1	Burra Creek Native (US Williamsdale Road)	B (0.72)	B (0.64)	—
BUR 2A	D/S Williamsdale Bridge	B (0.70)	B (0.62)	—
BUR 2B	D/S Burra Road Bridge	B (0.76)	B (0.73)	—
BUR 3	D/S London Bridge	A (0.97)	A (0.82)	↓
CAS 1	U/S Burra Creek confluence	B (0.78)	B (0.70)	—

— NO CHANGE; ↑ IMPROVEMENT; ↓DECLINE; † NS – NOT SAMPLED; ‡NRA –NO RELIABLE ASSESSMENT

APPENDIX 4.5 – Summary Statistics for the Macroinvertebrate Univariate Metrics

Table A4.8.– Summary statistics for the macroinvertebrate univariate metrics for **Angle Crossing**

Angle Crossing		Spring 2010				Autumn 2011		
		x̄	SD	n		x̄	SD	n
Taxa richness (genus)	Upstream	18.7	1.96	18		16.2	3.04	18
	Downstream	13.6	1.72	12		16.7	1.71	18
EPT richness (genus)	Upstream	8.6	1.19	18		8.4	1.62	18
	Downstream	5.5	1.68	12		8.8	1.37	18
Signal -2	Upstream	4.98	0.2	18		4.54	0.26	18
	Downstream	4.96	0.2	12		4.62	0.28	18

Table A4.9 – Summary statistics for the macroinvertebrate univariate metrics for **Burra Creek**

Burra Creek		Spring 2010				Autumn 2011		
		x̄	SD	n		x̄	SD	n
Taxa richness (genus)	Queanbeyan Control	14.8	2.14	6		17.3	1.51	6
	Upstream	12.6	1.51	3		17.6	5.09	3
	Downstream	13.2	2.17	6		17.3	1.15	12
EPT richness (genus)	Queanbeyan Control	6.1	1.17	6		10.1	0.75	6
	Upstream	3.1	0.41	6		7.3	1.12	6
	Downstream	4.6	1.34	6		8.6	0.58	12
Signal -2	Queanbeyan Control	4.61	0.10	6		6.45	0.20	6
	Upstream	4.19	0.20	6		4.18	0.53	6
	Downstream	4.7	0.15	6		5.44	0.14	12

Table A4.10 – Summary statistics for the macroinvertebrate univariate metrics for **Tantangara to Burrinjuck**

Tantangara to Burrinjuck		**Spring 2010**				**Autumn 2011**		
		$\bar{x}$	SD	n		$\bar{x}$	SD	n
Taxa richness	Zone 1	17	2.65	3		18.2	5.56	4
	Zone 2	16.8	1.94	17		14.6	3.01	20
	Zone 3	15.3	2.8	9		14.9	1.62	9
	Zone 4			0		12.5	0.71	3
EPT richness	Zone 1	7	3	3		9.2	1.5	4
	Zone 2	6.6	0.83	17		7.3	0.98	20
	Zone 3	5.5	1.47	9		6.9	0.87	9
	Zone 4			0		5	1.41	3
Signal -2	Zone 1	5.36	0.29	3		5.72	0.45	4
	Zone 2	5.29	0.23	17		5.04	0.35	20
	Zone 3	5.26	0.24	9		5.02	0.30	9
	Zone 4			0		4.88	0.05	3

APPENDIX 4.6 – ANOVA Tables for the Univariate Macroinvertebrate Analysis

Table A4.11 – ANOVA table for the univariate macroinvertebrate analysis for **Angle Crossing**

	Source	df	F	P
Taxa Richness	Season	1	0.132	0.712
	Location	1	12.23	0.025
	Season*Location(Site)	1	25.31	<0.001
	Residual	62		
EPT richness				
	Season	1	10.31	0.003
	Location	1	1.544	0.281
	Season*Location(Site)	1	22.10	0.000
	Residual	62		
Signal-2				
	Season	1	41.34	<0.001
	Location	1	0.226	0.659
	Season*Location(Site)	1	0.198	0.755
	Residual	62		

Table A4.12 – ANOVA table for the univariate macroinvertebrate analysis for **Burra Creek**

	Source	df	F	P
Taxa Richness	Season	1	0.132	0.712
	Location	1	12.23	0.025
	Season*Location(Site)	1	25.31	<0.001
	Residual	62		
EPT richness				
	Season	1	10.31	0.003
	Location	1	1.544	0.281
	Season*Location(Site)	1	22.10	0.000
	Residual	62		
Signal-2				
	Season	1	41.34	<0.001
	Location	1	0.226	0.659
	Season*Location(Site)	1	0.198	0.755
	Residual	62		

Table A4.13 – ANOVA table for the univariate macroinvertebrate analysis for Tantangara to Burrinjuck

	Source	df	F	P
Taxa Richness	Season	1	72.45	0.001
	Location	2	3.23	0.146
	Season*Location(Site)	2	13.33	0.017
	Residual	26		
EPT richness				
	Season	1	280.01	0.001
	Location	2	0.275	0.773
	Season*Location(Site)	2	1.142	0.342
	Residual	26		
Signal-2				
	Season	1	361.21	<0.0001
	Location	2	7.23	0.047
	Season*Location(Site)	2	47.68	0.0016
	Residual	26		

APPENDIX 4.7 – PERMANOVA Tables for the Macroinvertebrate Community Analysis

Table A4.14 – PERMANOVA output for the macroinvertebrate community analyses for Angle Crossing

Angle Crossing -Riffle

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
# Se	1	4093.7	4093.7	14.861	0.01	999	0.001
# L	1	742.05	742.05	1.0246	0.532	60	0.426
# Si(# L)	4	3098.7	774.67	4.1634	0.001	999	0.001
# Sex# L	1	824.63	824.63	2.9937	0.079	998	0.035
# Si(# L)x# Se	3	826.38	275.46	1.4804	0.074	996	0.114
Res	11	2046.7	186.07				
Total	21	12324					

Estimates of components of variation

Source	Estimate	Sq.root
S(# Se)	397.73	19.943
S(# L)	1.8576	1.3629
V(# Si(# L))	168.17	12.968
S(# Sex# L)	114.41	10.696
V(# Si(# L)x# Se)	44.696	6.6855
V(Res)	186.07	13.641

Angle Crossing - Edge

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
# Se	1	5343.5	5343.5	4.8905	0.0346	9937	0.0131
# L	1	822.92	822.92	0.71776	0.7371	180	0.6398
# Si(# L)	4	5107.5	1276.9	1.7661	0.0258	9907	0.058
# Sex# L	1	1130.8	1130.8	1.035	0.4418	9939	0.428
# Si(# L)x# Se	3	3307.5	1102.5	1.5249	0.081	9892	0.1355
Res	7	5061	723				
Total	17	22273					

Estimates of components of variation

Source	Estimate	Sq.root
S(# Se)	568.26	23.838
S(# L)	-52.247	-7.2282
V(# Si(# L))	205.14	14.323
S(# Sex# L)	10.217	3.1964
V(# Si(# L)x# Se)	237.18	15.401
V(Res)	723	26.889

Table A4.15 – PERMANOVA output for the macroinvertebrate community analyses for Burra Creek

Burra Creek - Riffle

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
# Se	1	4082.4	4082.4	9.5262	0.0013	9851	0.0031
# L	2	2863.6	1431.8	0.94513	0.4024	60	0.5823
# Si(# L)	2	1694.2	847.08	1.9767	0.0332	9885	0.0954
Res	5	2142.7	428.54				
Total	10	12695					

Estimates of components of variation

Source	Estimate	Sq.root
S(# Se)	1096.2	33.108
S(# L)	-37.444	-6.1192
V(# Si(# L))	432.04	20.786
V(Res)	428.54	20.701

Burra Creek Edge

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
# Se	1	10888	10888	7.3604	0.0134	9955	0.0061
# L	2	5756	2878	1.8675	0.0185	60	0.0931
# Si(# L)	3	4639.7	1546.6	3.2669	0.0001	9913	0.0002
# Sex# L	2	2040.8	1020.4	0.69421	0.7476	9937	0.7615
# Sex# Si(# L)	3	4424.9	1475	3.1157	0.0001	9887	0.0002
Res	11	5207.4	473.4				
Total	22	35430					

Estimates of components of variation

Source	Estimate	Sq.root
S(# Se)	1023.8	31.997
S(# L)	199.12	14.111
V(# Si(# L))	287.46	16.955
S(# Sex# L)	-133.88	-11.571
V(# Sex# Si(# L))	536.56	23.164
V(Res)	473.4	21.758

Table A4.16 – PERMANOVA output for the macroinvertebrate community analyses for Tantangara to Burrinjuck

Tantangara to Burrinjuck - Riffle

PERMANOVA table of results

Pooled terms
SexSi(Zo)

Terms whose SS and df were combined

Pool	Terms
Pooled	Res + SexSi(Zo)

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Se	1	3822.5	3822.5	11.963	0.0001	9959
Zo	3	4629.8	1543.3	2.7601	0.0002	9906
Si(Zo)	18	11400	633.34	1.9821	0.0003	9837
SexZo	2	1370.6	685.32	2.1448	0.0169	9933
Pooled	17	5432	319.53			
Total	41	29745				

Estimates of components of variation

Source	Estimate	Sq.root
S(Se)	250.21	15.818
S(Zo)	130.1	11.406
V(Si(Zo))	168.19	12.969
S(SexZo)	72.255	8.5003
V(Res)	319.53	17.875

Tantangara to Burrinjuck - Edge

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Se	1	7366.1	7366.1	8.8989	0.0001	9946
Zo	3	6209.1	2069.7	2.4998	0.0002	9892
Si(Zo)	19	15732	827.98	1.0003	0.5012	9818
SexZo**	2	2633.6	1316.8	1.5908	0.068	9930
Pooled	15	12416	827.75			
Total	40	49295				
		2	15			

Estimates of components of variation

Source	Estimate	Sq.root
S(Se)	426.81	20.659
S(Zo)	152.71	12.358
V(Si(Zo))	0.13185	0.36311
S(SexZo)	93.652	9.6774
V(Res)	827.75	

APPENDIX 5

Fish Monitoring

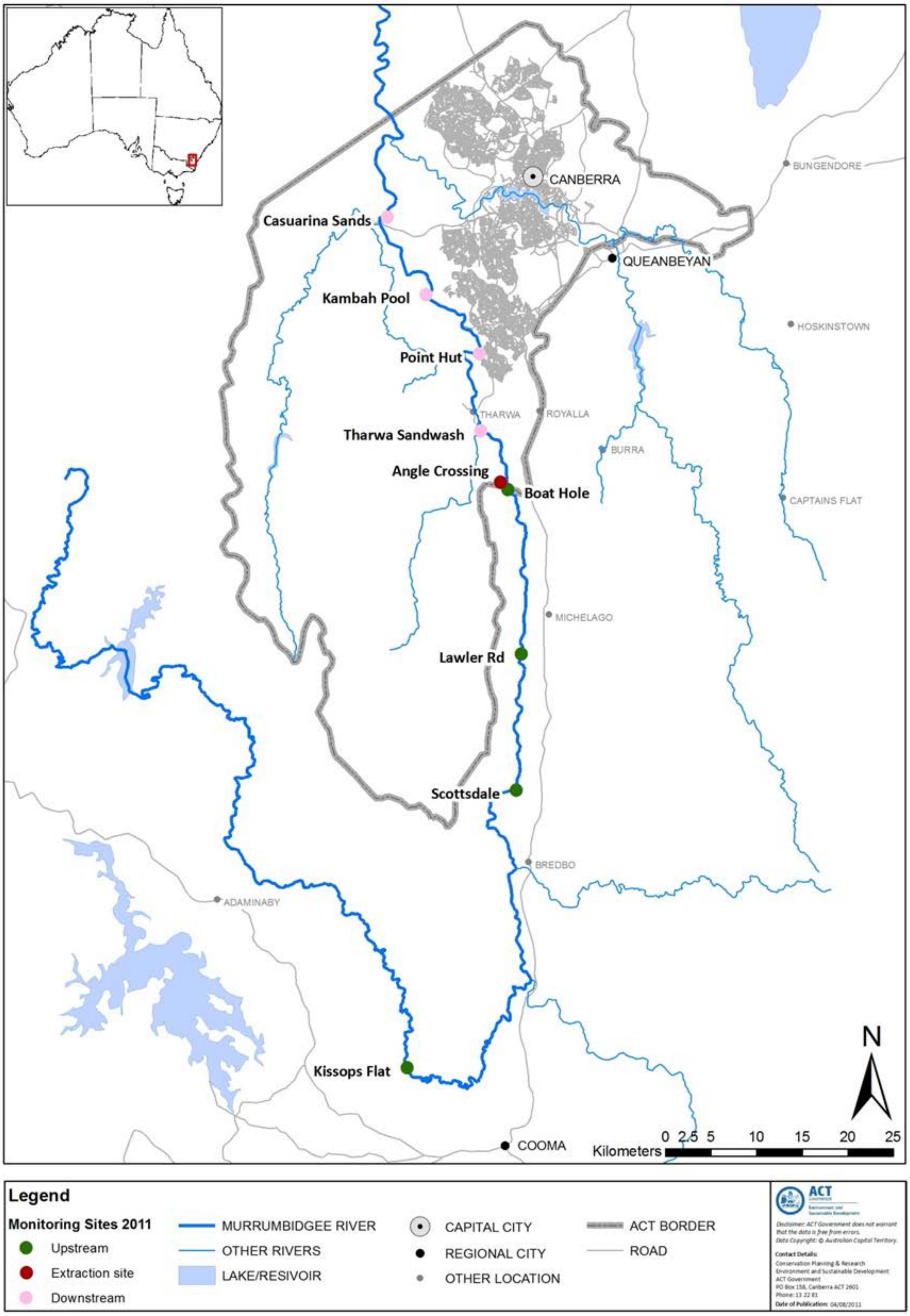


Figure A5.1 – Survey sites for the 2011 Murrumbidgee River fish monitoring (Source: Beitzel et al. (2011))

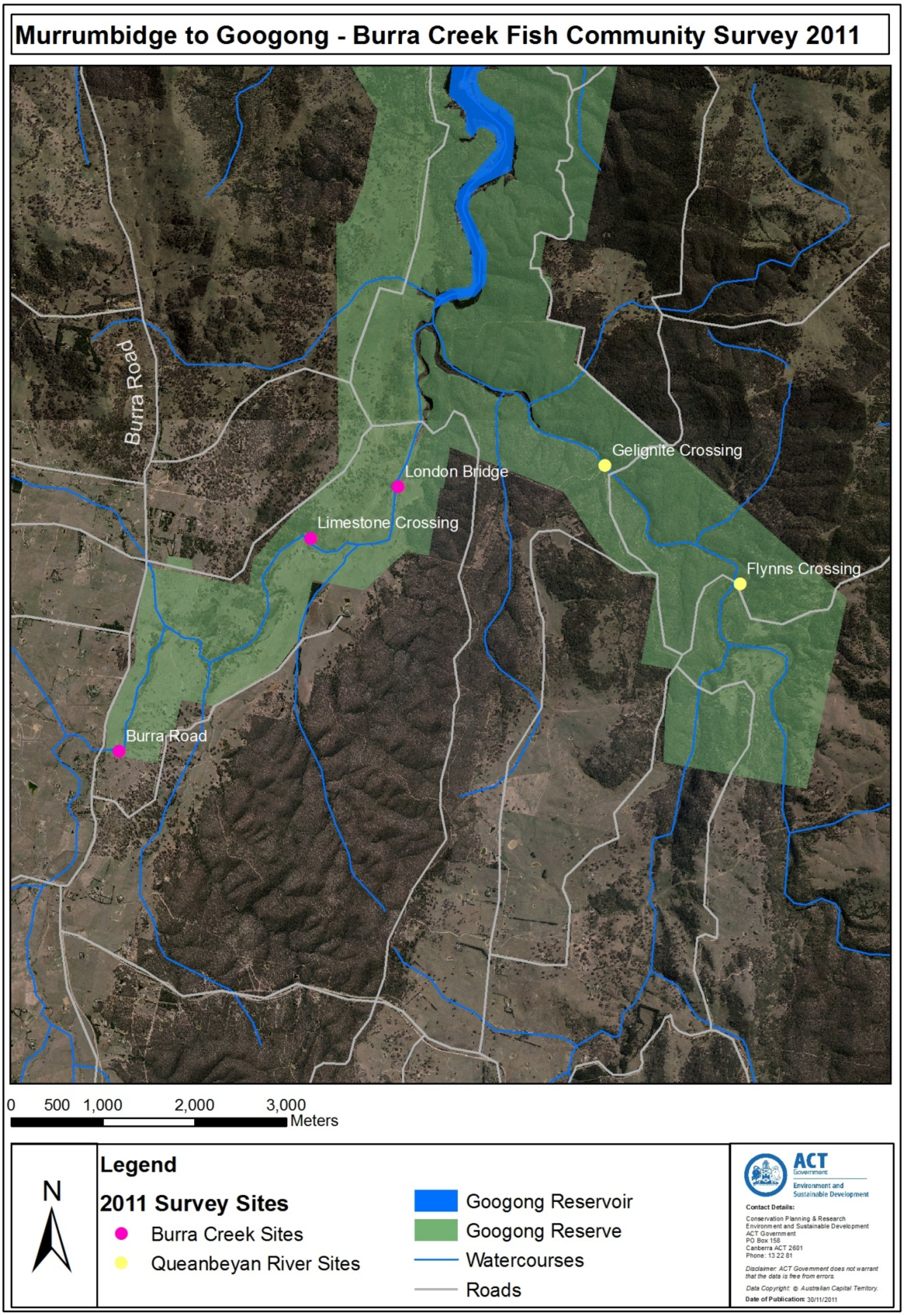


Figure A5.2 – Survey sites for the 2011 Burra Creek fish monitoring (Source: Beitzel et al. (2011))

Table A5.1 – Mean fish length (mm) caught by electrofishing during the 2011 fish monitoring at each site (Source: Beitzel et al. (2011))

	Kissops Flat	Scottsdale	Lawler Rd	Boat hole	Angle Crossing	Tharwa Sandwash	Point Hut Crossing	Kambah Pool	Casuarina Sands	Overall
carp	499 (36.5)	366 (140.2)	453 (81.4)	354 (156.5)	447 (81.6)	393 (74.8)	559 (48.4)	418 (78.2)	431 (60.5)	424 (96.8)
golden perch						470	420	396 (12.8)	425 (35.4)	418 (31.2)
goldfish			76		136 (7.1)		169 (23.3)	245		155 (56.6)
macquarie perch	370 (26.5)			350						365 (23.8)
murray cod				440	473 (3.5)	500 (63.6)		645 (452.5)		525 (204.8)
oriental weatherloach					130	130				130
redfin						184 (53.2)		94	106 (15.6)	161 (58.6)
trout cod					118			250		184 (93.3)
western carp gudgeon								39 (3.4)	36 (5.8)	38 (4.8)

Note: standard deviation in brackets

Table A5.2 – Maximum, minimum, mean length (mm) and standard error for species recorded in Burra Creek during the 2011 fish monitoring survey (Source: Beitzel et al. (2011))

Species	Max	Min	Mean	SE
redfin	223	65	99.45	5.37
mountain galaxias	100	57	72.13	2.51
goldfish	237	26	122.69	15.50
rainbow trout	221	-	-	-
western carp gudgeon	25	-	-	-
eastern gambusia	26	-	-	-

APPENDIX 6

Geomorphology

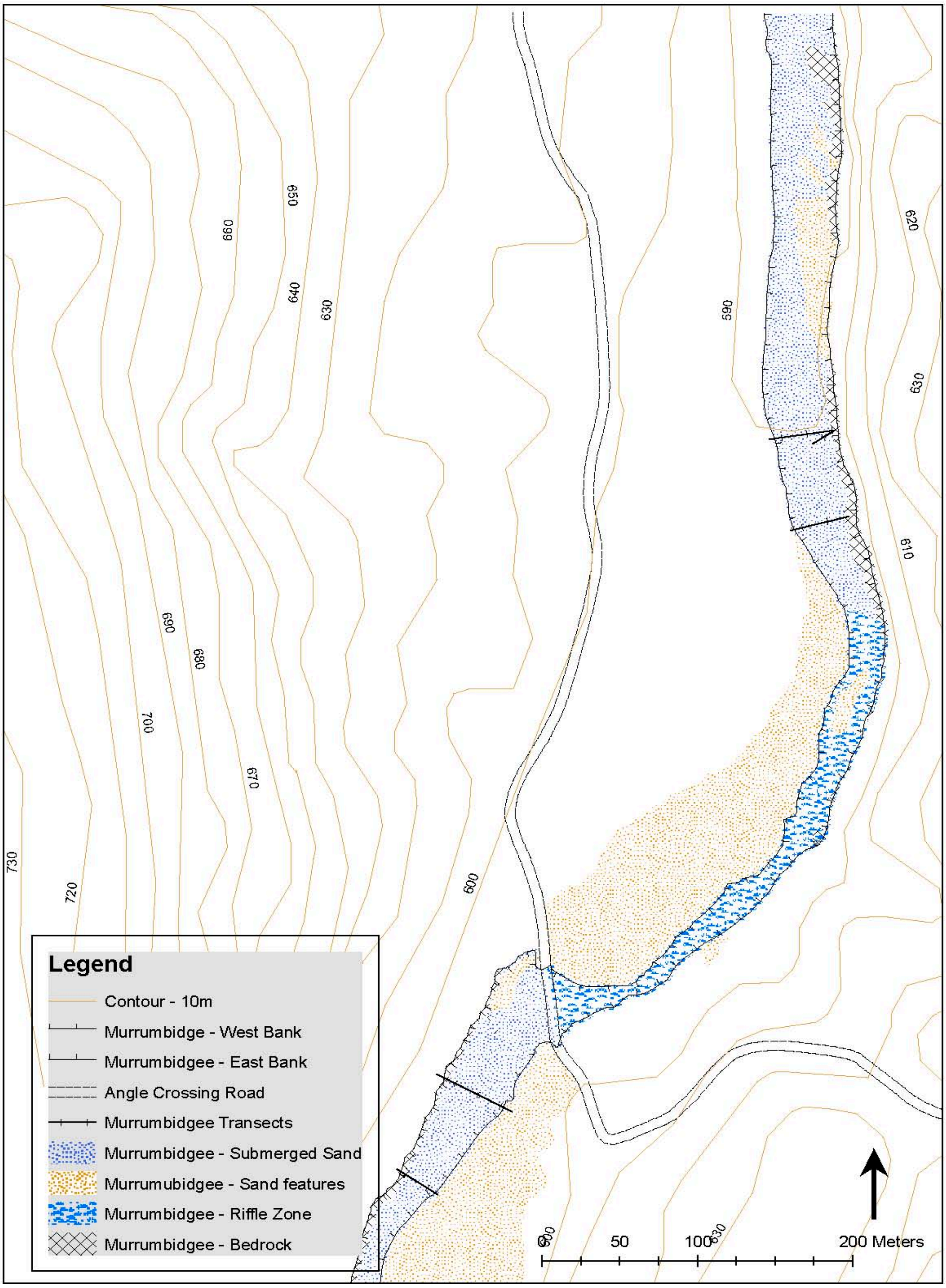


Figure A6.1 – Angle Crossing geomorphology features

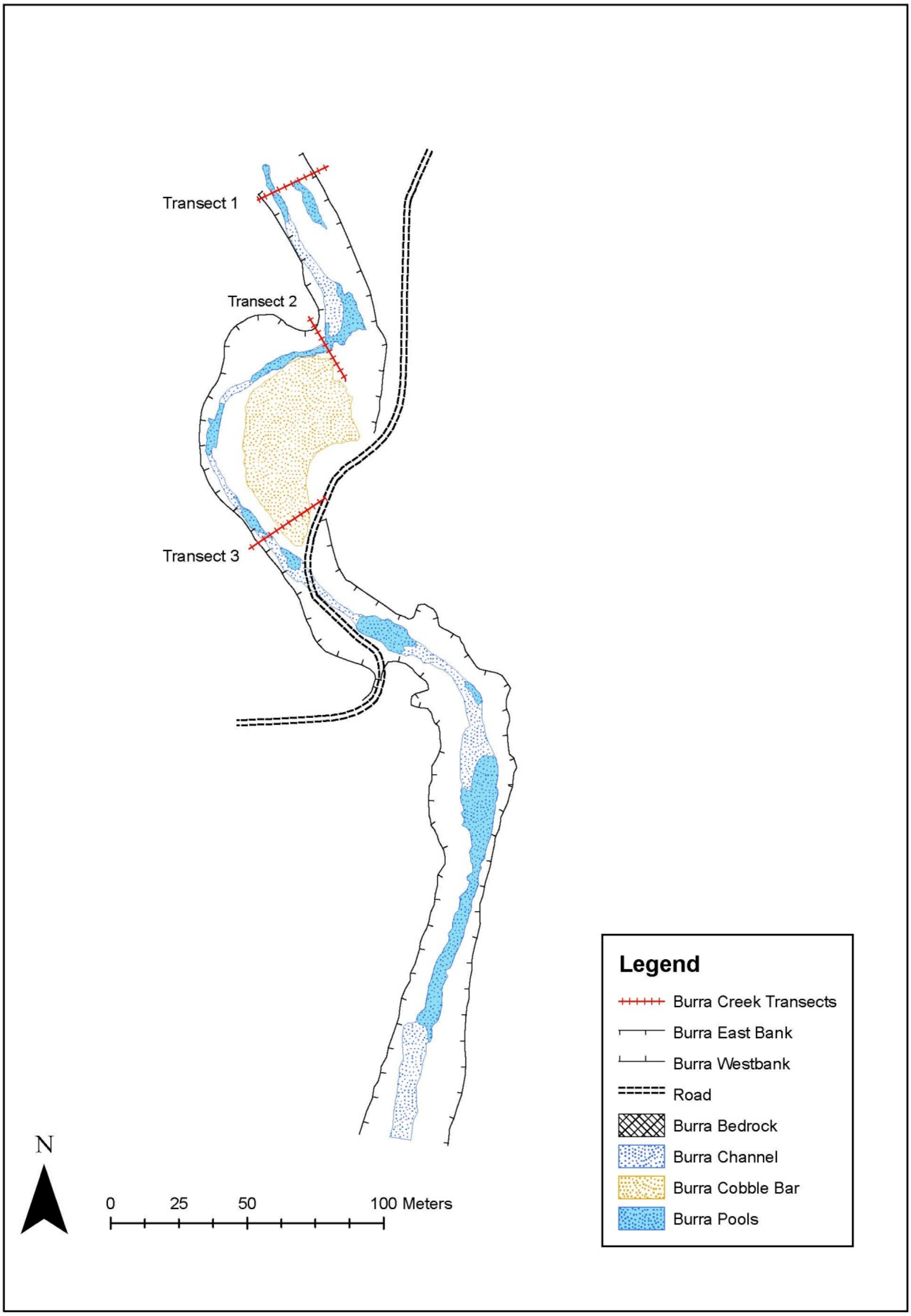


Figure A6.2 – Burra Creek geomorphology features

May 2010 – significant macrophyte dominance

November 2010 – after high flow event scour

June 2011 – macrophyte recovery

Plate A6.1 – Burra Creek downstream of Williamsdale Rd representing the variation through time

APPENDIX 7

Species Lists from the Burra Creek Vegetation Survey

Table A7.1 – Species list from the vegetation survey for Site **BUR1a**

BURRA SITE 1A	Scientific name	Common name	Plant Form	Native/ Introduced	Abundance in Riparian Zone
Asteraceae	*Cardus pycnocephalus*	Slender Thistle	Forb	Introduced	Minor
	Centipeda cunninghamii	Sneezeweed	Forb	Native	Common
	Conyza bonariensis	Fleabane	Forb	Introduced	Minor
	Cotula coronopifolia	Waterbuttons	Forb	Native	Minor
	Gamochaeta sp.	Cudweed	Forb	Introduced	Minor
	Hypochaeris radicata	Catsear	Forb	Introduced	Minor
	Taraxacum officinale	Dandelion	Forb	Native	Minor
Clusiaceae	*Hypercium perforatum*	St John's Wort	Forb	Introduced	Minor
Cyperaceae	*Carex incomitata*	Sedge	Sedge	Native	Common
	Cyperus eragrostis	Umbrella Sedge	Sedge	Native	Minor
	Eleocharis plana	Spike Rush	Sedge	Native	Common
Fabaceae	*Acacia dealbata*	Silver Wattle	Shrub	Native	Minor
	Trifolium sp.	Clover	Forb	Introduced	Minor
Juncaceae	*Juncus usitatus*	Common Rush	Sedge	Native	Common
	Juncus sp.	To be identified	Sedge	Native	Common
Myrsinaceae	*Anagallis arvensis*	Scarlet pimpernel	Forb	Native	Minor
Myrtaceae	*Kunzea ericoides*	Burgan	Shrub	Native	Dominant
Plantaginaceae	*Plantago major*	Greater Plantain	Forb	Weed	Common
Poaceae	*Eragrostis curvula*	African Love Grass	Grass	Introduced	Common
	Holcus lanatus	Yorkshire Fog	Grass	Introduced	Common
	Hordeum leporinum	Barley Grass	Grass	Introduced	Common
	Lolium perenne	Ryegrass	Grass	Introduced	Minor
	Paspalum distichum	Water Couch	Grass	Native	Minor
	Phalaris aquatica	Phalaris	Grass	Introduced	Dominant
	Poa labillardieri	Poa (River) Tussock	Grass	Native	Dominant
Polygonaceae	*Acetosella vulgaris*	Sheep Sorrel	Forb	Introduced	Common
	Polygonum prostratum	Wireweed	Forb	Introduced	Common
	Rumex crispus	Curly Dock	Forb	Native	Minor
Ranunculaceae	*Ranunculus inundatus*	River Buttercup	Forb	Native	Minor
Rosaceae	*Acaena ovina*	Sheep's Burr	Forb	Introduced	Minor
	Rosa rubiginosa	Sweet Briar	Shrub	Introduced	Minor
	Rubus fruiticosus	Blackberry	Shrub	Introduced	Minor
Scrophulariaceae	*Verbascum virgatum*	Twiggy Mullein	Forb	Introduced	Minor
Verbenaceae	*Verbena bonariensis*	Purpletop	Forb	Introduced	Minor

Table A7.2 – Species list from the vegetation survey for Site **BUR1a**

BURRA SITE 1C	Scientific name	Common name	Plant Form	Native/ Introduced	Abundance in Riparian Zone
Asteraceae	*Cardus pycnocephalus*	Slender Thistle	Forb	Introduced	Minor
	Carthamus lanatus	Saffron Thistle	Forb	Introduced	Minor
	Conyza bonariensis	Fleabane	Forb	Introduced	Minor
	Hypochaeris radicata	Catsear	Forb	Introduced	Minor
	Sonchus oleraceus	Sowthistle	Forb	Introduced	Minor
	Taraxacum officinale	Dandelion	Forb	Native	Minor
Clusiaceae	*Hypercium perforatum*	St John's Wort	Forb	Introduced	Minor
Cyperaceae	*Carex incomitata*	Sedge	Sedge	Native	Minor
	Eleocharis atricha?	Spike Rush	Sedge	Native	Common
	Eleocharis plana	Spike Rush	Sedge	Native	Common
Elatinaceae	*Elatine gratioloides*	Waterwort	Forb	Native	Minor
Fabaceae	*Trifolium* sp.	Clover	Forb	Introduced	Minor
Haloragaceae	*Myriophyllum* sp. (*aquaticum*?)	Milfoil	Forb	Native	Minor
Juncaceae	*Juncus usitatus*	Common Rush	Sedge	Native	Common
Lythraceae	*Lythrum salicaria*	Purple Loosestrife	Forb	Introduced	Common
Plantaginaceae	*Plantago major*	Greater Plantain	Forb	Introduced	Minor
Poaceae	*Eragrostis curvula*	African Love Grass	Grass	Introduced	Common
	Holcus lanatus	Yorkshire Fog	Grass	Introduced	Common
	Hordeum leporinum	Barley Grass	Grass	Introduced	Common
	Lolium perenne	Ryegrass	Grass	Introduced	Minor
	Paspalum distichum	Water Couch	Grass	Native	Minor
	Phalaris aquatica	Phalaris	Grass	Introduced	Dominant
	Poa labillardieri	Poa (River) Tussock	Grass	Native	Dominant
Polygonaceae	*Acetosella vulgaris*	Sheep Sorrel	Forb	Introduced	Common
	Polygonum arenastrum	Wireweed	Forb	Introduced	Common
	Rumex crispus	Curly Dock	Forb	Native	Minor
Rosaceae	*Acaena ovina*	Sheep's Burr	Forb	Introduced	Minor
Salicaceae	*Populus* sp.	Poplar	Tree	Introduced	Common
	Salix spp.	Willow	Tree	Introduced	Common
Scrophulariaceae	*Verbascum virgatum*	Twiggy Mullein	Forb	Introduced	Minor
Typhaceae	*Typha orientalis*	Cumbungi	Sedge	Native	Minor

Table A7.3 – Species list from the vegetation survey for Site **BUR2a**

BURRA SITE 2A	Scientific name	Common name	Plant Form	Native/ Introduced	Abundance in Riparian Zone
Asteraceae	*Cardus pycnocephalus*	Slender Thistle	Forb	Introduced	Minor
	Carthamus lanatus	Saffron Thistle	Forb	Introduced	Minor
	Conyza bonariensis	Fleabane	Forb	Introduced	Minor
	Hypochaeris radicata	Catsear	Forb	Introduced	Minor
	Sonchus oleraceus	Sowthistle	Forb	Introduced	Minor
	Taraxacum officinale	Dandelion	Forb	Native	Minor
Clusiaceae	*Hypercium perforatum*	St John's Wort	Forb	Introduced	Minor
Cyperaceae	*Carex incomitata*	Sedge	Sedge	Native	Minor
	Eleocharis atricha?	Spike Rush	Sedge	Native	Common
	Eleocharis plana	Spike Rush	Sedge	Native	Common
Elatinaceae	*Elatine gratioloides*	Waterwort	Forb	Native	Minor
Fabaceae	*Trifolium* sp.	Clover	Forb	Introduced	Minor
Juncaceae	*Juncus usitatus*	Common Rush	Sedge	Native	Common
Lythraceae	*Lythrum salicaria*	Purple Loosestrife	Forb	Introduced	Common
Plantaginaceae	*Plantago major*	Greater Plantain	Forb	Introduced	Common
Poaceae	*Avena fatua*	Wild Oat	Grass	Introduced	Common
	Eragrostis curvula	African Love Grass	Grass	Introduced	Dominant
	Holcus lanatus	Yorkshire Fog	Grass	Introduced	Common
	Hordeum leporinum	Barley Grass	Grass	Introduced	Common
	Lolium perenne	Ryegrass	Grass	Introduced	Common
	Paspalum distichum	Water Couch	Grass	Native	Common
	Phalaris aquatica	Phalaris	Grass	Introduced	Dominant
	Poa labillardieri	Poa (River) Tussock	Grass	Native	Dominant
	Phragmites australis	Common Reed	Grass	Native	Common
Polygonaceae	*Acetosella vulgaris*	Sheep Sorrel	Forb	Introduced	Common
	Rumex crispus	Curly Dock	Forb	Native	Minor
Ranunculaceae	*Ranunculus inundatus*	River Buttercup	Forb	Native	Minor
Rosaceae	*Acaena ovina*	Sheep's Burr	Forb	Introduced	Minor
	Rosa rubiginosa	Sweet Briar	Shrub	Introduced	Minor
	Rubus fruiticosus	Blackberry	Shrub	Introduced	Common
Salicaceae	*Populus* sp.	Poplar	Tree	Introduced	Dominant
	Salix spp.	Willow	Tree	Introduced	Dominant
Scrophulariaceae	*Verbascum virgatum*	Twiggy Mullein	Forb	Introduced	Minor
Typhaceae	*Typha orientalis*	Cumbungi	Sedge	Native	Minor

Table A7.4 – Species list from the vegetation survey for Site **BUR2b**

BURRA SITE 2B	Scientific name	Common name	Plant Form	Native/ Introduced	Abundance in riparian zone
Asteraceae	*Cardus pycnocephalus*	Slender Thistle	Forb	Introduced	Minor
	Conyza bonariensis	Fleabane	Forb	Introduced	Minor
	Hypochaeris radicata	Catsear	Forb	Introduced	Minor
	Sonchus oleraceus	Sowthistle	Forb	Introduced	Minor
	Taraxacum officinale	Dandelion	Forb	Native	Minor
Clusiaceae	*Hypercium perforatum*	St John's Wort	Forb	Introduced	Minor
Cyperaceae	*Carex incomitata*	Sedge	Sedge	Native	Minor
	Eleocharis atricha?	Spike Rush	Sedge	Native	Common
	Eleocharis plana	Spike Rush	Sedge	Native	Common
Fabaceae	*Trifolium sp.*	Clover	Forb	Introduced	Minor
Juncaceae	*Juncus usitatus*	Common Rush	Sedge	Native	Common
Lythraceae	*Lythrum salicaria*	Purple Loosestrife	Forb	Introduced	Common
Myrsinaceae	*Anagallis arvensis*	Scarlet pimpernel	Forb	Native	Minor
Plantaginaceae	*Plantago major*	Greater Plantain	Forb	Introduced	Common
	Veronica anagallis-aquatica	Water Speedwell	Forb	Native	Minor
Poaceae	*Avena fatua*	Wild Oat	Grass	Introduced	Common
	Eragrostis curvula	African Love Grass	Grass	Introduced	Dominant
	Holcus lanatus	Yorkshire Fog	Grass	Introduced	Common
	Hordeum leporinum	Barley Grass	Grass	Introduced	Common
	Lolium perenne	Ryegrass	Grass	Introduced	Common
	Paspalum distichum	Water Couch	Grass	Native	Common
	Phalaris aquatica	Phalaris	Grass	Introduced	Dominant
	Poa labillardieri	Poa (River) Tussock	Grass	Native	Dominant
	Phragmites australis	Common Reed	Grass	Native	Common
Polygonaceae	*Acetosella vulgaris*	Sheep Sorrel	Forb	Introduced	Common
Ranunculaceae	*Ranunculus inundatus*	River Buttercup	Forb	Native	Minor
Rosaceae	*Acaena ovina*	Sheep's Burr	Forb	Introduced	Minor
	Rosa rubiginosa	Sweet Briar	Shrub	Introduced	Minor
	Rubus fruiticosus	Blackberry	Shrub	Introduced	Minor
Scrophulariaceae	*Verbascum virgatum*	Twiggy Mullein	Forb	Introduced	Minor
Typhaceae	*Typha orientalis*	Cumbungi	Sedge	Native	Common

Table A7.5 – Species list from the vegetation survey for Site **BUR2c**

BURRA SITE 2C	Scientific name	Common name	Plant Form	Native/ Introduced	Abundance in Riparian Zone
Asteraceae	*Conyza bonariensis*	Fleabane	Forb	Introduced	Minor
	Hypochaeris radicata	Catsear	Forb	Introduced	Minor
	Sonchus oleraceus	Sowthistle	Forb	Introduced	Minor
	Taraxacum officinale	Dandelion	Forb	Native	Minor
Characeae	*Chara* sp.	Stonewort	Algae	Native	Very Common
Clusiaceae	*Hypercium perforatum*	St John's Wort	Forb	Introduced	Minor
Cyperaceae	*Carex incomitata*	Sedge	Sedge	Native	Minor
	Eleocharis atricha?	Spike Rush	Sedge	Native	Common
	Eleocharis plana	Spike Rush	Sedge	Native	Common
	Schoenoplectus validus	Sedge	Sedge	Native	Common
Fabaceae	*Trifolium* sp.	Clover	Forb	Introduced	Minor
Haloragaceae	*Myriophyllum* sp. (*aquaticum*?)	Milfoil	Forb	Native	Minor
Juncaceae	*Juncus usitatus*	Common Rush	Sedge	Native	Common
Lythraceae	*Lythrum salicaria*	Purple Loosestrife	Forb	Introduced	Common
Myrsinaceae	*Anagallis arvensis*	Scarlet pimpernel	Forb	Native	Minor
Plantaginaceae	*Plantago major*	Greater Plantain	Forb	Introduced	Common
	Veronica anagallis-aquatica	Water Speedwell	Forb	Native	Minor
Poaceae	*Avena fatua*	Wild Oat	Grass	Introduced	Common
	Eragrostis curvula	African Love Grass	Grass	Introduced	Common
	Lolium perenne	Ryegrass	Grass	Introduced	Common
	Paspalum distichum	Water Couch	Grass	Native	Common
	Phalaris aquatica	Phalaris	Grass	Introduced	Common
	Poa labillardieri	Poa (River) Tussock	Grass	Native	Common
	Phragmites australis	Common Reed	Grass	Native	Common
Polygonaceae	*Acetosella vulgaris*	Sheep Sorrel	Forb	Introduced	Common
Rosaceae	*Acaena ovina*	Sheep's Burr	Forb	Introduced	Minor
Typhaceae	*Typha orientalis*	Cumbungi	Sedge	Native	Very Common