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INSTITUTE FOR APPLIED ECOLOGY

BIOLOGICAL RESPONSE TO FLOWS DOWSNTREAM OF CORIN, BENDORA, COTTER AND GOOGONG DAMS

Autumn 2015

Report to Icon Water

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BACKGROUND AND STUDY OBJECTIVE

- The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (ACT). Ecological assessment is undertaken in spring and autumn each year to evaluate river response to environmental flow releases to the Cotter and Queanbeyan Rivers, and to meet the requirements of Licence No. WU67 – Licence to Take Water. Sites below dams are assessed and compared with sites on the unregulated Goodradigbee River and Queanbeyan River upstream of Googong Dam to evaluate ecological change and responses attributed to the flow regulation.
- This study addresses the needs of Icon Water's License to Take Water (WU67) to assess the effects of dam operation, water abstraction, and environmental flows, and to provide information for the adaptive management of the Cotter and Googong water supply catchments. This study specifically focuses on assessing the ecological status of river habitats by investigating water quality and biotic characteristics.

AUTUMN 2015 RESULTS AND CONCLUSIONS

- Water quality parameters were generally within the recommended water quality guideline levels at below dam test sites and reference sites. Nitrogen oxide and total nitrogen were above guideline concentrations at sites on the Queanbeyan River. Above guideline nitrogen oxide and total nitrogen concentrations downstream of Googong Dam are likely to be the result of the nitrogen concentrations in the catchment upstream of Googong Dam (e.g. site QM1) and this water spilling from the dam. Click here for more information
- All test and reference sites met the environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats. Click here for more information
- Site CM2 downstream of Bendora Dam was the only site which met the environmental flow ecological objective of AUSRIVAS band A; however all sites had relatively high proportions of environmentally sensitive taxa. Click here for more information
- Sites QM2 and QM3 in the Queanbeyan River downstream of Googong Dam were assessed as severely impaired by the AUSRIVAS model. This outcome reflects changes to the macroinvertebrate community brought about by a flood event prior to this assessment, and does not necessarily indicate that the presence or operation of Googong Dam is causing severe biological impairment at these sites. Click here for more information

	Within environmental flow ecological objective	Outside environmental flow ecological objective
Site	**Riffle filamentous algae cover (%)**	**AUSRIVAS band (O/E score)**
CM1 (Corin Dam)	10	B
CM2 (Bendora Dam)	< 10	A
CM3 (Cotter Dam)	< 10	B
QM2 (Googong Dam)	< 10	C
QM3 (Googong Dam)	< 10	C

PROJECT RECOMMENDATIONS

- No new recommendations at this stage. The recommendations from the spring 2014 assessment are still applicable to the autumn 2015 assessment given the results.

INTRODUCTION

Water diversions and modified flow regimes can result in deterioration of both the ecological function and water quality of Australian streams (Arthington and Pusey 2003). Many of the aquatic ecosystems in the Australian Capital Territory (ACT) are subject to flow regulation. Environmental flow guidelines were introduced in 1999 as part of the Water Resources Act 1998 and redefined in 2006 and 2013 (ACT Government 2013). The Environmental Flow Guidelines identify the components of the flow regime that are necessary for maintaining stream health, and set the ecological objectives for the environmental flow regime (ACT Government 2013). The ecological objectives for environmental flows are 1) for the Cotter and Queanbeyan Rivers to reach an Australian River Assessment System (AUSRIVAS) observed/expected band A grade (similar to reference condition) and 2) to have <20% filamentous algal cover in riffles for 95% of the time (ACT Government 2013). Ecological assessment evaluates the effectiveness of the flow regime for meeting the ecological objectives and provides the scientific basis to inform decisions about refinements to future environmental flow releases to ensure that these resources are protected.

This assessment is based on the ecological objectives of environmental flow regimes in the ACT, has been ongoing at fixed sampling sites since 2001 and is based on bi-annual assessments (autumn and spring) of macroinvertebrate assemblages, algae (periphyton and filamentous algae) and water quality. Sampling is conducted during autumn and spring of each year to evaluate the condition of river habitat downstream of dams on both the Cotter and Queanbeyan Rivers. A comparison is made with the condition of reference sites on the unregulated Goodradigbee River and the Queanbeyan River upstream of Googong Dam.

Tributaries of the Cotter and Goodradigbee Rivers are also sampled to determine whether impacts on biological condition in these rivers is being caused by catchment or river regulation effects. For example, if Cotter River tributaries are assessed in poorer biological condition than reference tributaries on the Goodradigbee River, then catchment condition may be driving instream biological conditionat Cotter river test sites regardless of river regulation effects. However, if Cotter and Goodradigbee River tributaries are in similar biological condition, then differences biological condition between Goodradigbee and Cotter River sites may be attributed to river regulation effects.

This sampling and reporting program satisfies Icon Water's Licence to Take Water (WU67) and the requirement to provide an assessment of the effects of dam operation and the effectiveness of environmental flows. The information from the assessment links into the adaptive management framework applied in the water supply catchments.

This report provides an assessment of sites downstream of the dams on the Cotter and Queanbeyan Rivers in autumn 2015, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments. Site summary sheets outlining the outcomes of the autumn 2015 assessment for each of the test sites CM1 (Corin Dam), CM2 (Bendora Dam), CM3 (Cotter Dam), QM2 (Googong Dam), and QM3 (downstream of QM2) are included as Appendix 1.

FIELD AND LABORATORY METHODS

STUDY AREA

The study area includes the Cotter and Goodradigbee Rivers, which are situated to the east and west of the western border of the ACT, respectively, and the Queanbeyan River to the east of the ACT (Figure 1). The Cotter River is a fifth order stream (below Cotter Dam) with a catchment area of approximately 480 km^2. The Cotter River is a major source of drinking water for Canberra and Queanbeyan, with the principal management outcome to ensure a secure water supply (ACT Government 2006). Conservation of ecological values of the river is an important consideration in the ongoing management of the Cotter River. The river is regulated by three dams, the Cotter Dam, Bendora Dam and Corin Dam.

The Cotter River catchment is largely free of pollutants and human disturbance aside from regulation, which provides the opportunity to study the effects of flow releases from the dams with minimal confounding from other factors often present in environmental investigations (Chester and Norris 2006; Nichols *et al.* 2006). The Murrumbidgee to Cotter pumping augmentation (M2C) project has been implemented to provide an environmental flow transfer capability (up to 40ML d^{-1}) for the Cotter River reach below Cotter Dam by pumping water from Murrumbidgee River.

The Queanbeyan River is a fifth order stream (at all sampling sites), and is regulated by Googong Dam approximately 90 km from its source to secure the water supply for the ACT and Queanbeyan. Compared to the Cotter River catchment, the Googong catchment is less protected and is therefore subject to disturbance in addition to flow regulation.

The Goodradigbee River is also a fifth order stream (at all sampling sites) and remains largely unregulated until it reaches Burrinjuck Dam (approximately 50 km downstream of the study area). This river constitutes an appropriate reference site for the study because it has similar environmental characteristics (substrate and chemistry) but is largely unregulated (Norris and Nichols 2011).

Fifteen sites were sampled for biological, physical and chemical variables between the 14^{th} and 16^{th} April 2015 (Table 1). Site characteristics including latitude, longitude, altitude, stream order, catchment area, and distance from source were obtained from 1:100 000 topographic maps. Latitude and longitude were confirmed in the field using a Global Positioning System.

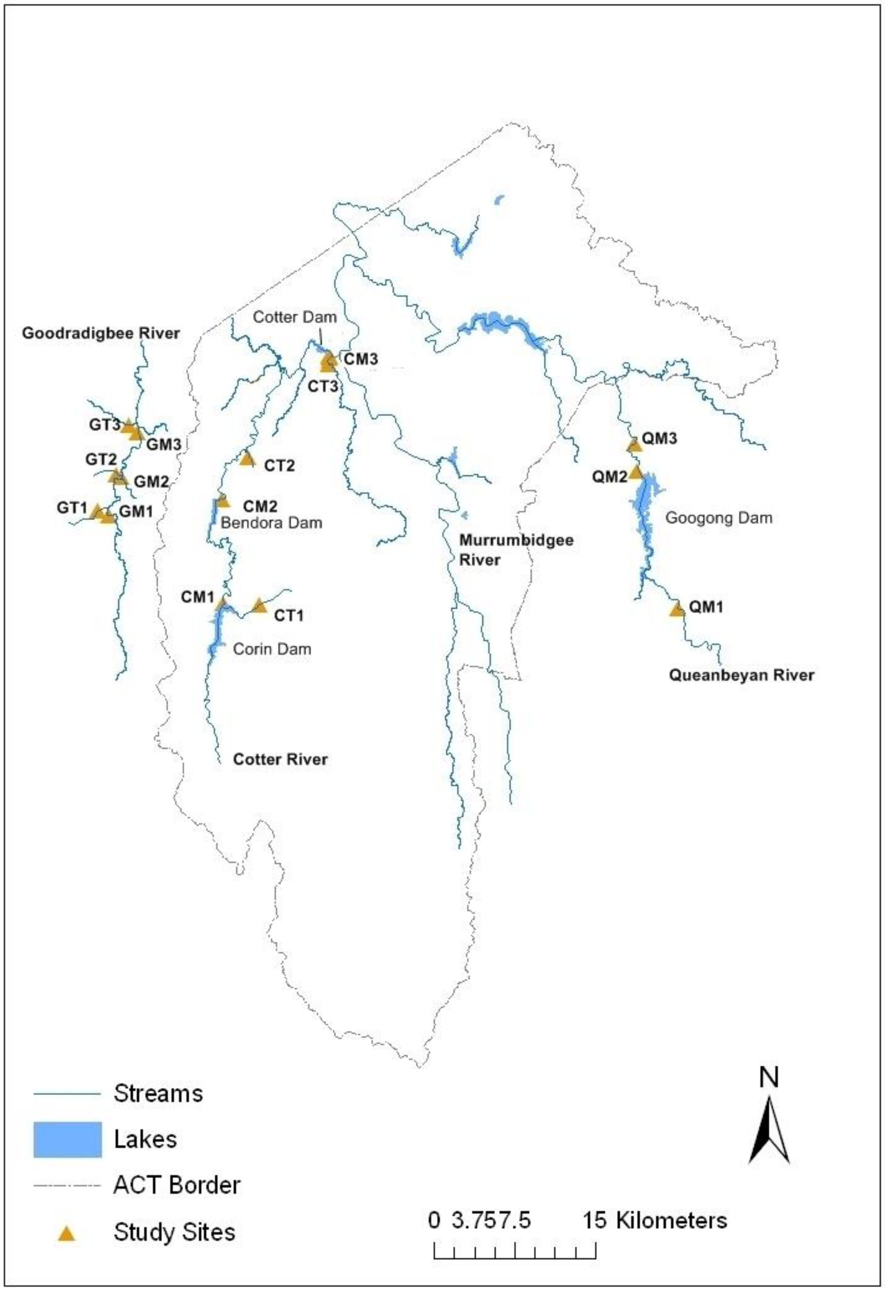

Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the below dams assessment program, autumn 2015.

Site	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500m downstream of Corin Dam	900	31	4
CM2	Cotter	500 m downstream of Bendora Dam	700	51	4
CM3	Cotter	100m upstream Paddy's River confluence	500	75	5
CT1	Kangaroo Ck	50m downstream Corin Road crossing	900	7.3	3
CT2	Burkes Ck	50 m upstream of confluence with Cotter River	680	4.5	3
CT3	Paddys	500 m upstream of confluence with Cotter River	500	48	4
GM1	Goodradigbee	20 m upstream of confluence with Cooleman Ck	680	38	5
GM2	Goodradigbee	20 m upstream of confluence with Bull Flat Ck	650	42	5
GM3	Goodradigbee	100 m upstream of Brindabella Bridge	620	48	5
GT1	Cooleman Ck	50 m upstream of Long Plain Road crossing	680	17.9	4
GT2	Bull Flat Ck	Immediately upstream of Crace Lane crossing	650	15.6	4
GT3	Bramina Ck	30 m upstream of Brindabella Road crossing	630	18	5
QM1	Queanbeyan	12 km upstream of Googong Dam near 'Hayshed Pool'	720	72	5
QM2	Queanbeyan	1 km downstream of Googong Dam	590	91.6	5
QM3	Queanbeyan	2 km downstream of Googong Dam at Wickerslack Lane	600	92.6	5

HYDROMETRIC DATA

Mean daily flow data for each of the below dam test sites (provided by Icon Water) and Goodradigbee River reference sites (obtained from the NSW Department of Primary Industries Office of Water, gauging station 410088) was used to determine changes in river flow for the months preceding sampling. Daily rainfall data for Canberra was obtained from the Bureau of Meteorology.

PHYSICAL AND CHEMICAL WATER QUALITY ASSESSMENT

Water temperature, dissolved oxygen, pH, electrical conductivity and turbidity were measured at all sites using a calibrated Horiba U-52 water quality meter. Total alkalinity was calculated by field titration to an end point of pH 4.5 (A.P.H.A. 2005). Two 50ml water samples were collected from each site to measure ammonium, nitrogen oxide, total nitrogen and total phosphorus concentrations. Samples were analysed following methods from the Standard Methods for the Examination of Water and Wastewater (A.P.H.A 2005).

Water quality guideline values for the Cotter, Googong and Goodradigbee catchments were based on the most conservative values from the Environment Protection Regulations SL2005-38 (which cover a variety of water uses and environmental values for each river reach in the ACT), and the ANZECC and ARMCANZ (2000) water quality guidelines for aquatic ecosystem protection in south-east Australian upland rivers. While comparisons with water quality guidelines are not required as part of the environmental flow guidelines, and are used only as a guide, they provide a useful tool for the protection of ecosystems (which is a primary objective of environmental flows). Only the upper guideline value for conductivity was used because concentrations below the minimum guideline level are unlikely to impact on the ecological condition of streams.

Table 2: Water quality guideline values from the Environment Protection Regulations SL2005-38* and ANZECC and ARMCANZ (2000)**. N/A *= guideline value not available*.

Measure	Units	Guideline value
Alkalinity	mg L^{-1}	N/A
Temperature	ºC	N/A
Conductivity**	µS cm^{-1}	<350
pH**	N/A	6.5-8
Dissolved oxygen *	mg L^{-1}	>6
Turbidity*	NTU	<10
Ammonium (NH_4^+)**	mg L^{-1}	<0.13
Nitrogen oxides**	mg L^{-1}	<0.015
Total phosphorus**	mg L^{-1}	<0.02
Total nitrogen**	mg L^{-1}	<0.25

PERIPHYTON AND FILAMENTOUS ALGAE

VISUAL OBSERVATIONS

Periphyton and filamentous algae visual observations within riffle habitats were recorded following methods outlined in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000, http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

ASH-FREE DRY MASS AND CHLOROPHYLL-A

Twelve replicate periphyton samples were collected at each of the Cotter and Goodradigbee River sites and site QM2 on the Queanbeyan River using a syringe sampler based on a design similar to that described by Loeb (1981). Samples from each site were measured for Ash-free dry mass (AFDM) and chlorophyll-a content in accordance with methods described in A.P.H.A (2005).

MACROINVERTEBRATE SAMPLE COLLECTION AND PROCESSING

Benthic macroinvertebrates were sampled from the riffle habitat following National River Health Program protocols presented in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000; http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

In the laboratory, preserved samples were placed in a sub-sampling box comprising of 100 cells (Marchant 1989) and agitated until evenly distributed. Contents of each cell were removed until approximately 200 animals from each sample were identified (Parsons and Norris 1996). Macroinvertebrates were identified to the family taxonomic level using keys listed by Hawking (2000), except Chironomidae, which were identified to sub-family, aquatic worms (Oligochaeta) and mites (Acarina), which were identified to class. After the ~200 macroinvertebrates were sub-sampled, the remaining unsorted sample was visually scanned to identify taxa which were not found in the ~200 animal sub-sample (Nichols *et al*. 2000). QA/QC procedures were implemented for macroinvertebrate sample processing following those outlined in Nichols *et al*. (2000).

AUSRIVAS (AUSTRALIAN RIVER ASSESSMENT SYSTEM)

AUSRIVAS predicts the macroinvertebrate fauna expected to occur at a site with specific environmental characteristics, in the absence of environmental stress. The fauna observed (O) at a site can then be compared to fauna expected (E), with the deviation between the two providing an indication of biological condition (Coysh *et al*. 2000; http://ausrivas.ewater.com.au). A site displaying no biological impairment should have an O/E ratio close to one. The O/E ratio will decrease as the macroinvertebrate assemblage and richness are adversely affected.

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT autumn riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT autumn riffle model uses a set of 12 habitat variables to predict the macroinvertebrate fauna expected to occur at each site in the absence of disturbance.

AUSRIVAS allocates test site O/E taxa scores to category bands that represent a range in biological conditions to aid interpretation. AUSRIVAS uses five bands, designated X, A, B, C, and D (Table 3). The derivation of model bandwidths is based on the distribution of O/E scores of the reference sites used to create each AUSRIVAS model (Coysh *et al.* 2000, http://ausrivas.ewater.com.au).

SIGNAL 2 GRADES

Habitat disturbance and pollution sensitivity grades (SIGNAL 2) range from 1 to 10, with sensitive taxa receiving higher grades than tolerant taxa. The sensitivity grades are based on taxa tolerance to common pollution types (Chessman 2003).

DATA ENTRY AND STORAGE

Water quality, habitat, and macroinvertebrate data were entered into an Open Office database. The layout of the database matches the field data sheets to minimise transcription errors. All data were checked for transcription errors using standard two person checking procedures. A backup of files was carried out daily.

DATA ANALYSIS

To determine if there were significant differences in periphyton AFDM and chlorophyll-a between sites in autumn 2015, single factor Analysis of Variance (ANOVA) (SAS 9.3) was used followed by Tukey-Kramer multiple comparisons. A $\log_{10}(x+1)$ transformation was applied to AFDM and chlorophyll-a data, before undertaking the ANOVAs, to ensure the data met the ANOVA assumptions.

Similarity in macroinvertebrate community structure between sites in terms of relative abundance data was assessed using the Bray-Curtis similarity measure and group average cluster analysis In PRIMER 6 (Clark and Warwick 2001). Groups in the cluster analysis were defined at 65% similarity. All data was fourth root transformed before the analysis to down weight the influence of highly abundant taxa.

Table 3: ACT autumn and spring riffle AUSRIVAS model band descriptions, band width and interpretation.

Band	Band description	Band width	Interpretation
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	**>1.12** (autumn) **>1.14** (spring)	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	SIMILAR TO REFERENCE	**0.88-1.12** (autumn) **0.86-1.14** (spring)	Water quality and/or habitat condition roughly equivalent to reference sites.
B	SIGNIFICANTLY IMPAIRED	**0.64-0.87** (autumn) **0.57-0.85** (spring)	Potential impact either on water quality or habitat quality or both, resulting in loss of taxa.
C	SEVERELY IMPAIRED	**0.40-0.63** (autumn) **0.28-0.56** (spring)	Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	EXTREMELY IMPAIRED	**0-0.39** (autumn) **0-0.27** (spring)	Extremely poor water and/or habitat quality. Highly degraded.

RESULTS

HYDROMETRIC DATA

Stream discharge in the months leading up to autumn 2015 sampling at below dam sites on the Cotter and Queanbeyan Rivers was largely determined by operational requirements and environmental flow guidelines (ACT Government 2013) (Table 4).

Total discharge at each of the below dam test sites and in the Goodradigbee River between November 2014 and the autumn 2015 sampling was generally similar (±15%) to that preceding the autumn 2014 assessment (Figure 2; Levings & Harrison 2014). The exception was at site QM2 downstream of Googong Reservoir where the total discharge was approximately 3.8 times the same period preceding autumn 2014. This resulted from above average rainfall in the upper reaches of the Queanbeyan River catchment throughout the study period. The greatest daily mean discharge (4230 ML d^{-1}) also occurred downstream of Googong Dam on 9th April 2015, one week prior to sampling.

Table 4: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams (ACT Government 2013).

Dam	Flow regime
Corin	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 ML d^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Bendora	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 ML d^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Cotter	From Murrumbidgee to Cotter (M2C) transfer: If Murrumbidgee River flow at Mt MacDonald gauging station is greater than 80 MLd^{-1}, then M2C discharges 40 MLd^{-1}. Each month, M2C discharge flow is reduced temporarily to 20 ML d^{-1} for a 36 to 46 hour period. Cotter Dam releases bimonthly flows peaking at 100 MLd^{-1} and a flow peaking at 150 ML d^{-1} between mid-July and mid-October.
Googong	Maintain base flow average of 10 ML d^{-1} or natural inflow, whichever is less. Riffle maintenance flow of 100 ML d^{-1} for 1 day every 2 months.

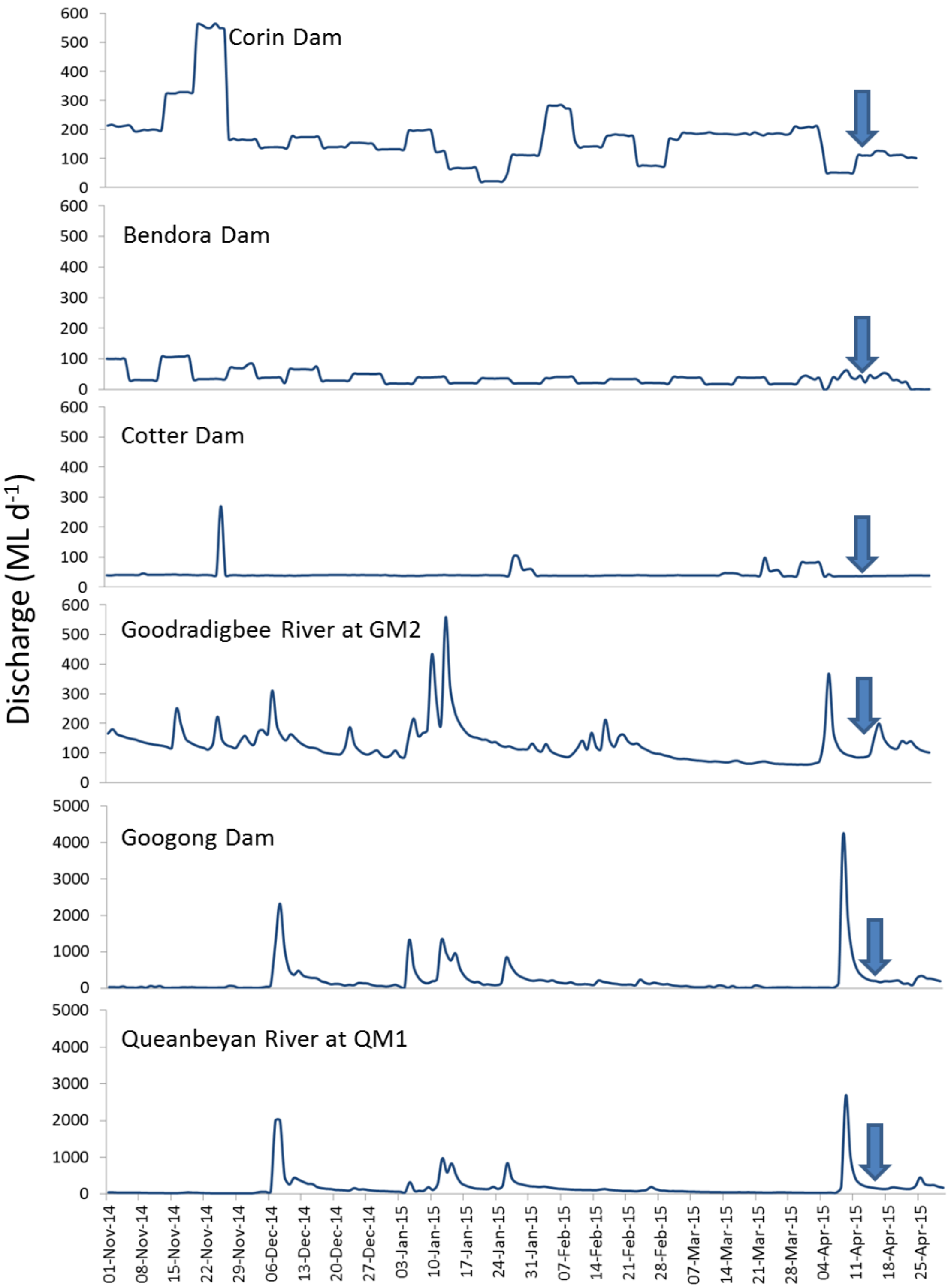

Figure 2. Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 1st November 2014 to 30th April 2015. Arrows correspond to autumn 2015 sampling dates.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in autumn 2015. Exceptions were turbidity at site CT3; nitrogen oxides at test sites CM1, CM2, QM2, and QM3; total nitrogen at test sites QM2 and QM3, and reference sites CT3 and QM1; and total phosphorus at reference sites CT1, CT3, and QM1 (Table 5).

Table 5. Water quality parameters measured at each of the test and reference sites in autumn 2015. Values outside guideline levels are shaded orange.

		Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
	Guideline level	NA	350	6.5-8	>6	<10	NA	<0.13	<0.015	<0.25	<0.02
Below dam test sites	CM1	11.8	19.6	6.6	9.9	3.1	10	0.006	0.022	0.12	0.011
	CM2	16.2	18.9	6.8	9.1	0.1	10	0.004	0.017	0.12	0.008
	CM3	15.2	28.2	6.8	10.5	0.8	15	0.005	0.004	0.14	0.012
	QM2	16.5	94	7.7	9.7	1.3	30	0.005	0.071	0.5	0.016
	QM3	15.9	104.4	7.1	9.6	0.3	29	0.009	0.088	0.54	0.014
Reference sites	CT1	9.8	42.4	6.9	10.1	0	18	0.002	0.003	0.07	0.023
	CT2	12.9	23	7	9.5	0	8	<0.002	0.004	0.23	0.006
	CT3	16.4	75.4	6.6	10	12.9	34	0.002	0.007	0.26	0.031
	QM1	14.3	57.4	6.9	9.7	2.7	19	0.003	0.007	0.57	0.037
	GM1	12.4	110.3	7.7	10.4	0	44	0.002	<0.002	<0.05	0.006
	GM2	12.8	106	7.7	10	1.8	33	0.003	0.004	<0.05	0.006
	GM3	14.7	104.2	7.4	9.9	2.2	40	0.002	0.01	0.06	0.008
	GT1	12.2	59.4	7.7	10.3	0	30	0.002	0.003	0.09	0.012
	GT2	12.9	65.8	7.4	9.8	2.4	23	0.004	0.006	0.08	0.012
	GT3	12.7	53.5	7.2	10.1	0.3	26	<0.002	0.002	0.12	0.014

FILAMENTOUS ALGAE AND PERIPHYTON

The environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats was achieved at all below dams test sites in autumn 2015. Field observations of periphyton and filamentous algae cover of riffle habitats were ≤10% cover at all sites in autumn 2015, except sites CM1 and CM3 below Corin and Cotter Dams which had a 20% cover of periphyton (Table 6; Figure 3).

Mean ash free dry mass (AFDM) was significantly greater below Cotter Dam (CM3) than below Bendora and Googong Dams (CM2 and QM2), and site GM2 on the Goodradigbee River (F=3.95; 6,35; P<0.0041). Differences in AFDM between all other sites were not statistically significant, , because of within site variability (Figure 4).

Mean chlorophyll-a concentrations were also significantly greater below Cotter Dam (CM3) and at reference site GM3 than below Bendora and Googong Dams (CM2 and QM2), and site GM2 on the Goodradigbee River (F=7.08; 6,35; P<0.0001). Differences in chlorophyll-a concentration between all other sites were not statistically significant, because of within site variability (Figure 5).

Table 6: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from spring 2012 to autumn 2015. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat													
	Periphyton							Filamentous algae					
	Spr-2012	Aut-2013	Spr-2013	Aut-2014	Spr-2014	Aut-2015		Spr-2012	Aut-2013	Spr-2013	Aut-2014	Spr-2014	Aut-2015
CM1	<10	25	10	<10	10	20		10-35	<10	80	<10	25	10
CM2	10-35	75	20	<10	<10	<10		>90	<10	20	<10	10	<10
CM3	10-35	<10	50	<10	75	20		<10	<10	<10	<10	10	<10
QM2	<10	<10	20	10	10	<10		<10	<10	<10	<10	10	<10
QM3	<10	<10	20	10	10	<10		<10	<10	<10	<10	10	<10
GM1	<10	15	<10	<10	<10	<10		<10	15	<10	<10	<10	<10
GM2	<10	<10	<10	<10	<10	<10		<10	<10	<10	<10	<10	<10
GM3	10-35	<10	10	<10	<10	10		<10	<10	15	<10	<10	10
QM1	10-35	10	<10	<10	10	10		10-35	<10	<10	<10	10	10

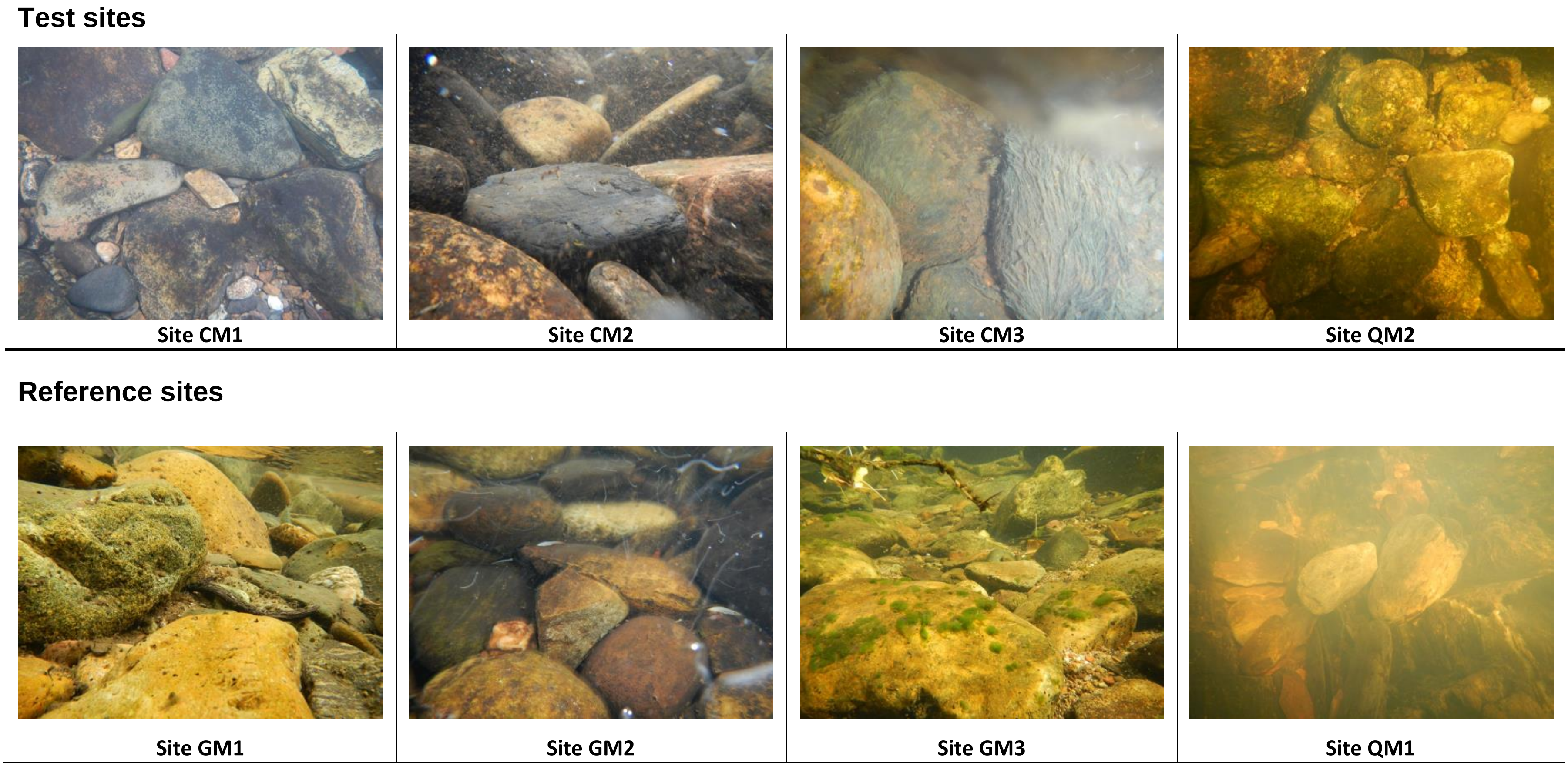

Figure 3. Filamentous algae cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in autumn 2015.

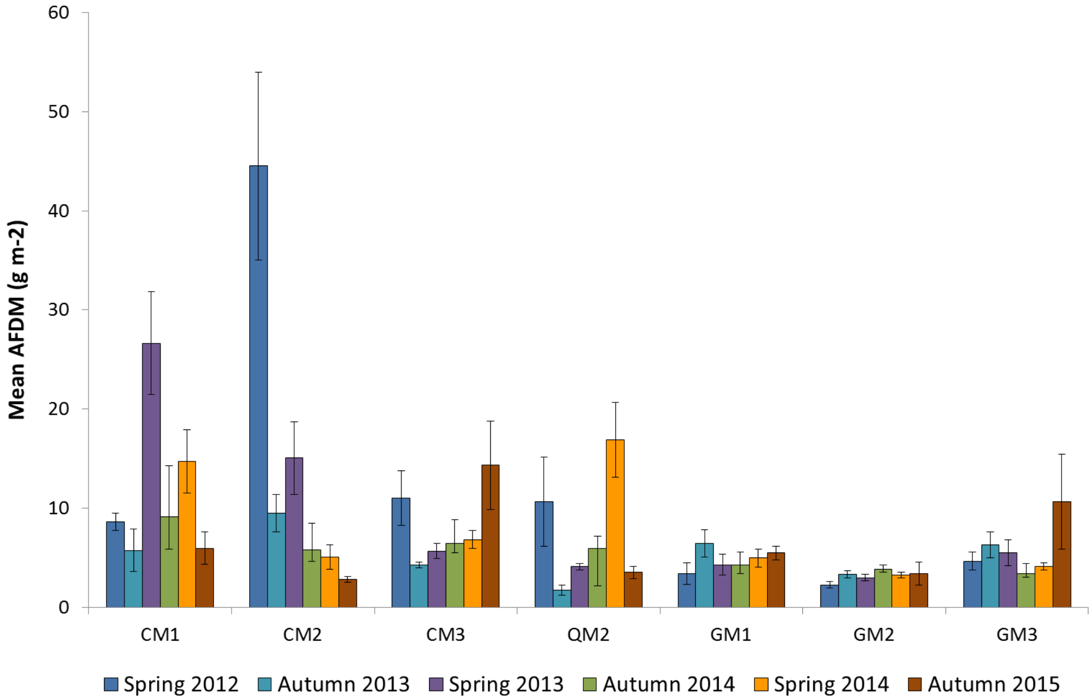

Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2012 to autumn 2015. Error bars represent +/- 1 standard error.

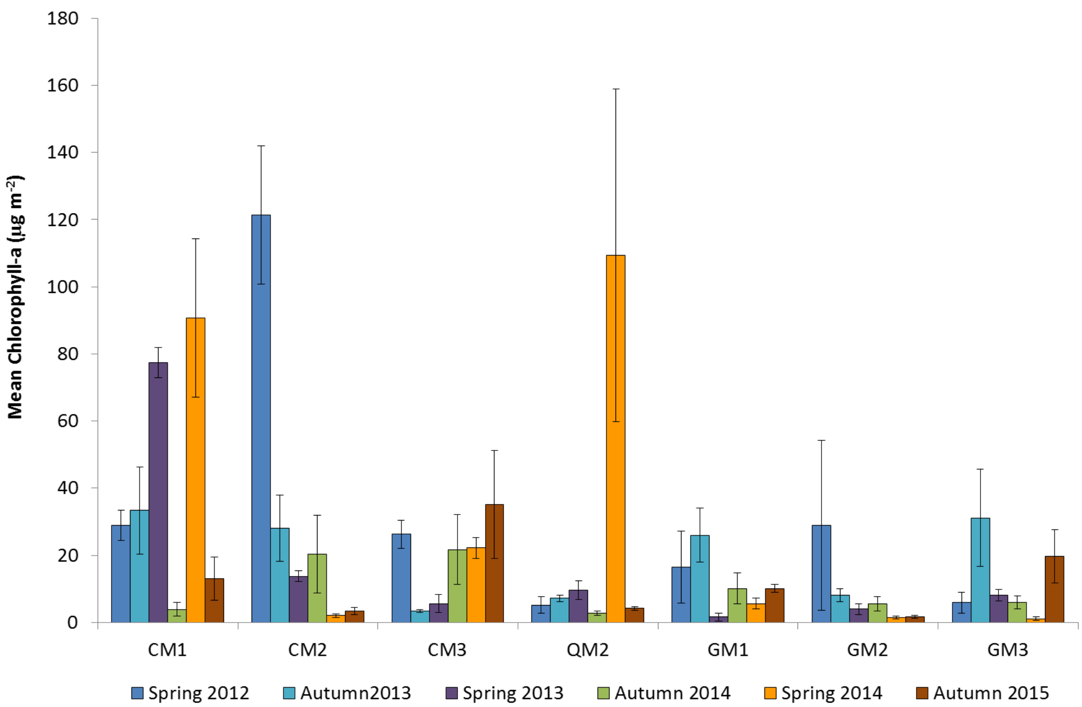

Figure 5: Mean chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2012 to autumn 2015. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites on the Goodradigbee and Queanbeyan Rivers based on AUSRIVAS assessment in autumn 2015 (Table 7).

Cotter River test sites CM1 and CM3 were assessed as significantly impaired (band B), and test site CM2 was similar to reference condition (band A) in autumn 2015. This is the same outcome for these sites as the previous assessment in spring 2014, and is consistent with previous outcomes from both spring and autumn assessments (Table 7).

Goodradigbee River reference site GM1 was assessed as biologically impaired (band B) for the first time since autumn 2012, while the two downstream sites on the Goodradigbee River (GM2 and GM3) have remained in reference condition in autumn 2015 (Table 7).

Two of the three Cotter River tributary sites (CT2 and CT3) were assessed as significantly impaired (band B), and CT1 was assessed as similar to reference condition (band A). Goodradigbee River tributary site GT1 was assessed as more diverse than reference (band X), and sites GT2 and GT3 were assessed as similar to reference condition (Table 7).

Queanbeyan River test sites QM2 and QM3 downstream of Googong Dam declined from band A (QM2) and band B (QM3) in the previous assessment to band C (severely impaired) in autumn 2015. This decline in biological condition was not evident at the upstream reference site QM1 which was assessed as band A (similar to reference condition) (Table 7). This Queanbeyan River reference site has not been assessed as biologically impaired since autumn 2009 (White et al 2009).

Taxa expected with a ≥50% chance of occurrence by the AUSRIVAS model, but missing from sub-samples are presented in Table 8. Missing taxa ranged in SIGNAL 2 grade from 2 (Oligochaeta) to 9 (Glossosomatidae). Cotter River and tributary sites CM3, CT1, CT2, and CT3; Queanbeyan River sites QM1, QM2 and QM3; and Goodradigbee River and tributary sites GM1, GM2, and GT3 had taxa identified in whole of sample scans that were missing from respective sub-samples. This indicates these taxa (Hydrobiosidae – sites QM3, CT2, GM1, and GT3; Psephenidae – sites CM3 and CT1; Gomphidae – sites QM1, QM2, CT3, GM2, and GT3; and Ancylidae– site QM2) were present, but in low abundance (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from spring 2012 to autumn 2015.

	Below dams sites					Reference sites									
	CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**QM1**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Autumn 2015	**B** (0.85)	**A** (0.94)	**B** (0.67)	**C** (0.49)	**C** (0.63)	**A** (0.93)	**B** (0.77)	**B** (0.70)	**A** (0.97)	**B** (0.81)	**A** (1.05)	**A** (1.12)	**X** (1.16)	**A** (1.05)	**A** (1.05)
Spring 2014	**B** (0.77)	**A** (0.97)	**B** (0.66)	**A** (0.88)	**B** (0.84)	**A** (1.03)	**A** (1.07)	**A** (0.96)	**A** (0.92)	**A** (1.12)	**A** (1.11)	**A** (1.12)	**A** (1.13)	**A** (0.98)	**A** (1.05)
Autumn 2014	**A** (0.91)	**B** (0.86)	**B** (0.66)	**B** (0.70)	**B** (0.83)	**A** (0.96)	**A** (0.90)	**B** (0.84)	**A** (0.97)	**A** (0.88)	**A** (1.04)	**A** (0.97)	**X** (1.19)	**A** (1.12)	**A** (1.05)
Spring 2013	**B** (0.69)	**A** (0.89)	**A** (0.88)	**A** (0.88)	**A** (0.92)	**X** (1.16)	**A** (1.00)	**B** (0.74)	**A** (1.10)	**X** (1.19)	**A** (1.11)	**X** (1.19)	**A** (1.13)	**A** (0.98)	**A** (1.13)
Autumn 2013	**C** (0.59)	**A** (1.12)	**C** (0.60)	**B** (0.77)	**B** (0.77)	**A** (1.08)	**Not sampled**	**B** (0.70)	**A** (0.97)	**A** (0.89)	**A** (0.89)	**B** (0.81)	**A** (1.01)	**B** (0.86)	**A** (1.05)
Spring 2012	**B** (0.77)	**B** (0.82)	**B** (0.73)	**B** (0.64)	**B** (0.77)	**X** (1.26)	**A** (1.12)	**B** (0.68)	**A** (1.01)	**A** (1.12)	**X** (1.26)	**A** (1.12)	**B** (0.83)	**B** (0.75)	**B** (0.68)

Table 8. Macroinvertebrate taxa that were expected with a ≥ 50% chance of occurrence by the AUSRIVAS ACT autumn riffle model but were missing from sub-samples for each of the study sites in autumn 2015 and their SIGNAL 2 grade (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan.

	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Glossosomatidae	9	X						X							X	
Coloburiscidae	8	X						X							X	
Hydrobiosidae	8		X	X	X	X		X	X		X					X
Leptophlebiidae	8				X	X					X					
Conoesucidae	7			X												
Elmidae	7			X												
Acarina	6				X											
Leptoceridae	6	X	X		X	X			X		X					
Podonominae	6		X	X	X	X	X		X	X	X		X	X		X
Psephenidae	6	X	X	X			X			X						
Scirtidae	6	X													X	
Baetidae	5			X												
Gomphidae	5			X	X	X			X	X		X				X
Simuliidae	5						X	X								
Tipulidae	5							X								
Ancylidae	4				X	X			X		X					
Caenidae	4	X			X			X								
Hydrobiidae	4				X	X			X		X					
Hydroptilidae	4				X	X			X	X		X				
Tanypodinae	4		X	X	X	X	X	X	X		X	X	X			
Oligochaeta	2													X		
Total		**6**	**5**	**8**	**11**	**9**	**4**	**7**	**8**	**4**	**7**	**3**	**2**	**2**	**3**	**3**

TAXONOMIC RELATIVE ABUNDANCE

The ratio of environmentally tolerant Oligochaeta and Chironomidae (OC) taxa to more sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was variable across all sites (Figure 6). Tolerant OC taxa were less prevalent at below dam test sites than at reference sites, with the exception of site CM3 below Cotter Dam which was the only site where OC taxa outnumbered EPT taxa (Figure 6). Filter feeding Simuliidae comprised 86% of the sub-sample at Queanbeyan River test site QM2 and 80% at QM3 (Diptera (other) category in Figure 7 and Appendix 2).

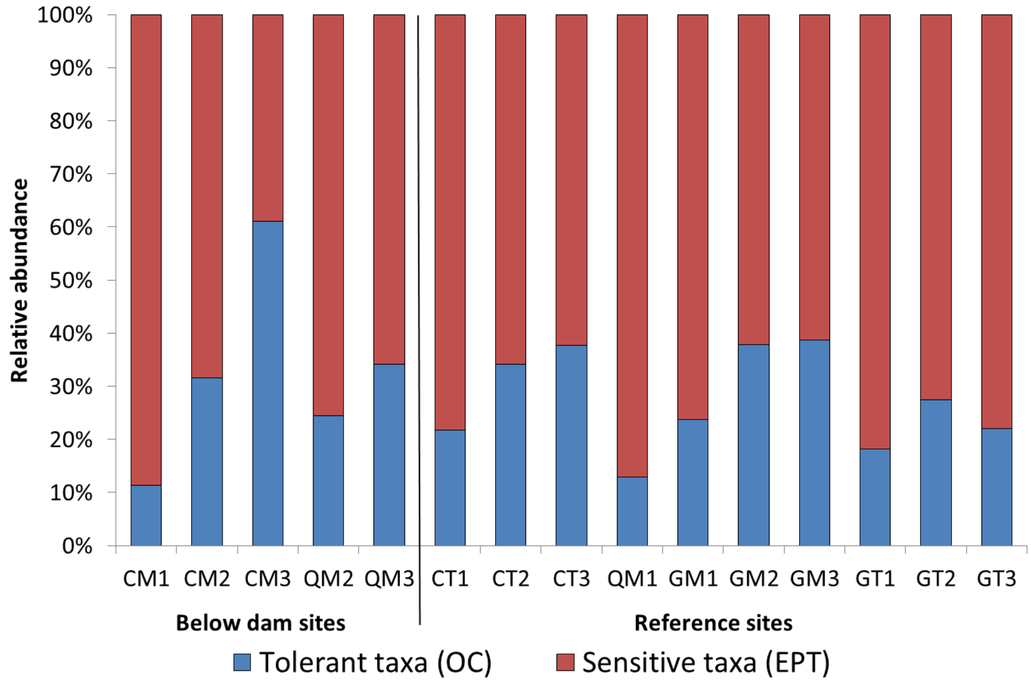

Figure 6. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in autumn 2015.

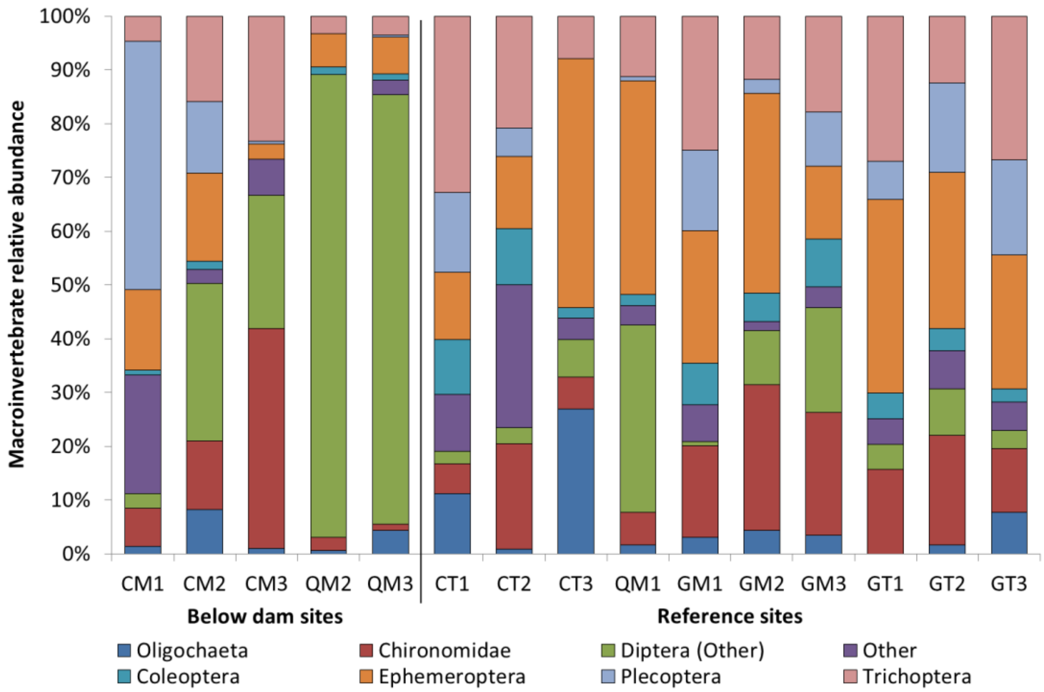

Figure 7: Relative abundance of macroinvertebrate taxonomic groups from samples collected in autumn 2015.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Cluster analysis based on the relative abundance of macroinvertebrate taxa identified seven groups of sites at 65% similarity (Figure 8). Cotter River test sites CM1 (Corin Dam) and CM3 (Cotter Dam) had macroinvertebrate assemblages dissimilar to all other sites. The macroinvertebrate assemblage at test site CM2 below Bendora Dam grouped with each of the Goodradigbee River reference sites (Figure 8).

Goodradigbee tributary sites GT1 and GT2 grouped together with the Cotter River tributary site CT1, and Goodradigbee tributary site GT3 grouped with the Goodradigbee River main channel sites. Macroinvertebrate assemblages at Cotter River tributary sites CT2 and CT3 were dissimilar to those of all other tributary sites.

Queanbeyan River test sites QM2 and QM3 had macroinvertebrate assemblages that were dissimilar to all other sites. This was primarily because of the higher relative abundance of Simuliidae taxa at these sites compared to sites which had grater relative abundances of Leptophelbiidae, Gripopterygidae, Conoesucidae, Coloburiscidae, Elmidae and Glossomatidae (Figure 8; Appendix 2).

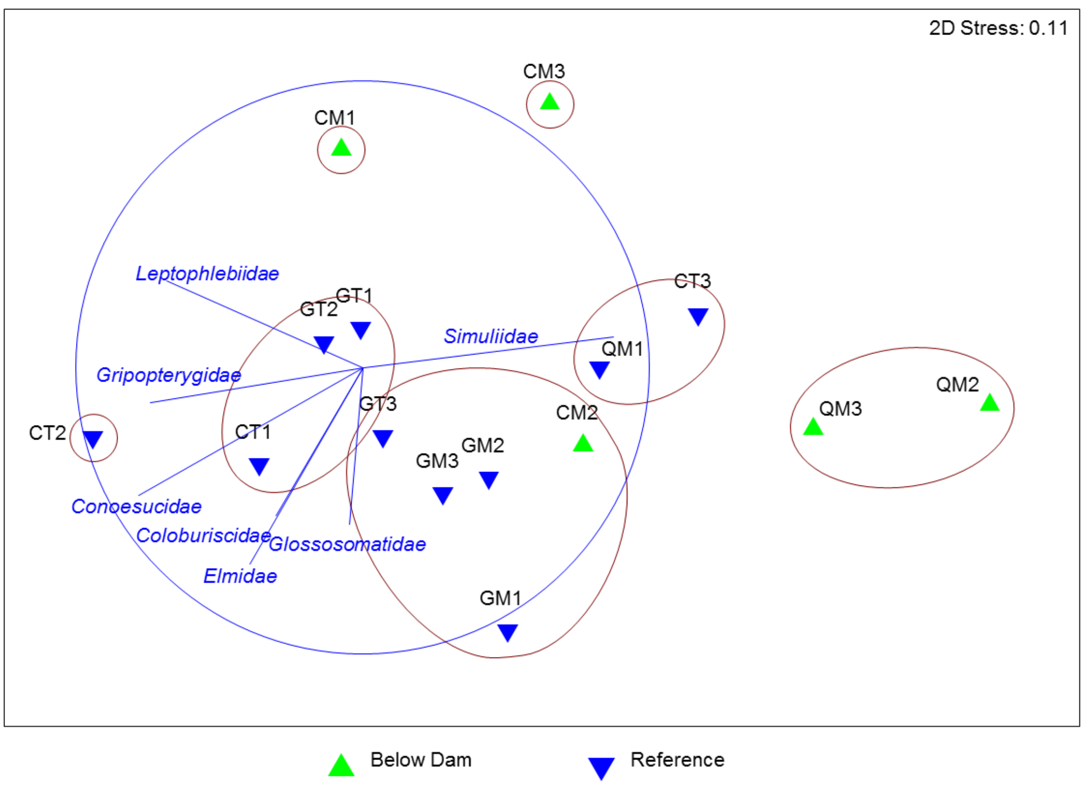

Figure 8. MDS ordination of 65% similarity between macroinvertebrate samples collected in autumn 2015 for the below dams assessment program (red oval lines). Similarity based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.7 are overlayed on the MDS ordination. The closer the blue line for each taxa is to the edge of the blue circle the greater the correlation.

DISCUSSION

WATER QUALITY

Water quality at below dam test sites and unregulated reference sites was generally within guideline levels in autumn 2015 (Table 5). Parameters outside of guideline levels were turbidity, nitrogen oxides (NO_x), total nitrogen (TN), and total phosphorus (TP) (Table 5).

Turbidity was within guideline level of 10 NTU at all below dam test sites, and only exceeded the guideline level in Paddys River at site CT3 (Table 5). Turbidity at this site (as well as TN and TP) is commonly above guideline levels as a result of instream sedimentation caused by catchment land-use.

Nitrogen oxides (NOx) and total nitrogen (TN) were well above guideline concentrations downstream of Googong Dam (site QM2 and QM3) in autumn 2015 (Table 5). NOx concentrations at these downstream test sites were approximately ten times those of inflows to Googong Reservoir from the Queanbeyan River upstream (reference site QM1), while TN concentrations were comparable to those of inflows. This is likely to be a result of high TN concentrations entering Googong reservoir from the upstream Queanbeyan River, and denitrification within the reservoir causing elevated NOx concentrations in outflows. Therefore, while elevated NOx concentrations are likely to be attributable to the presence of the reservoir, neither the high NOx or TN concentrations in outflows can be attributed to the operation or management of Googong Reservoir.

FILAMENTOUS ALGAE AND PERIPHYTON

Filamentous algae cover in riffle habitats was well below the environmental flow ecological objective of <20% cover at all sites in autumn 2015 (Table 6). This is consistent with recent autumn assessments, and indicates that the current environmental flow release strategy is effective in achieving the environmental flow ecological objective to control filamentous algae accumulation downstream of dams on the Cotter and Queanbeyan Rivers during autumn.

Periphyton/algae biomass in the riffle habitat downstream of Cotter Dam was greater than it has been in recent assessments, and was significantly greater than biomass downstream of Bendora and Googong Dams. This may be the result of low flow volumes (<150 ML d^{-1}) and variability preceding sampling which have allowed for increased periphyton/algae growth.

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at four of the five below dam test sites in autumn 2015, which is a net decline in condition at below dam test sites since the previous assessment in spring 2014, but is consistent with autumn assessments over recent years (Table 7).

Cotter River test sites below Corin and Cotter Dams (CM1 and CM3) have remained biologically impaired since the previous assessment and therefore failed to meet the environmental flow ecological objective of AUSRIVAS band A. Site CM1 downstream of Corin Dam was assessed as significantly impaired, despite having a high taxonomic richness (Appendix 2) and the greatest proportion of sensitive EPT taxa of all sites in autumn 2015 (Figure 6). The diverse and environmentally sensitive macroinvertebrate community at this site indicates that biological impairment is only minor downstream of Corin Dam, as reflected by the AUSRIVAS assessment on the upper limit of AUSRIVAS band B (Table 7).

Biological impairment downstream of Cotter Dam has been attributed to the influence of Murrumbidgee River water transferred through the M2C water recirculation pipe (Harrison & Levings 2014). However, the M2C water recirculation was not in operation at the time of the current assessment and the site has remained biologically impaired. It may therefore be low flow volumes and variability preceding sampling are driving the ongoing biological impairment at this site.

Site CM2 downstream of Bendora Dam was the only test site to achieve the environmental flow ecological objective of AUSRIVAS band A in autumn 2015 (Table 7). Despite the relatively low flows and absence of flushing flow releases in the lead up to autumn 2015 sampling, the macroinvertebrate assemblage at this site was similar to that of the three reference sites on the Goodradigbee River (Figure 8).

Site GM1 on the Goodradigbee River was assessed as significantly impaired (band B) in autumn 2015 (Table 7). This site is generally in reference condition, and in the absence of apparent stressors it is likely that this outcome was a result of natural variation. This site had a similar macroinvertebrate community assemblage to the downstream reference sites GM2 and GM3, and the Cotter River test site CM2, all of which were assessed as band A.

Two of the three Cotter River tributary sites were assessed as significantly impaired (band B) in autumn 2015 (Table 7). Site CT3 on Paddys River is influenced by land-use effects in the sub-catchment that are isolated from the Cotter River catchment, and is therefore does not provide an indication of catchment scale stressors on the Cotter River. The biological impairment of Burkes Creek (CT2) is likely to be a result of natural variation; however, this biological impairment in the Cotter River catchment, which was not evident in the Goodradigbee River catchment, means that a catchment scale stressor may be acting on the Cotter River, and biological impairment at test sites may not be solely attributed to the effect of impoundments.

Queanbeyan River test sites QM2 and QM3 below Googong Dam were both assessed as severely impaired (band C) in autumn 2015 (Table 7), and the upstream reference site was similar to reference condition (band A). Macroinvertebrate sub-samples from these sites had ratios of sensitive EPT: tolerant OC taxa similar to reference sites; however it was a numerical dominance of filter feeding Simuliidae taxa characterising the macroinvertebrate assemblages downstream of Googong Dam (QM2 – 86%, QM3 – 80%). Simuliidae adults lay desiccation resistant eggs above the water line and population increases such as this are common after flood events where large numbers of eggs hatch upon inundation. It is likely the flood event one week prior to sampling has driven the numerical dominance of this taxon, and subsequently influenced the outcome of the AUSRIVAS assessment below Googong Dam in autumn 2015. Surface water from Googong Reservoir was spilling over the dam wall for several months prior to the autumn 2015 assessment. This is likely to have caused an increased relative abundance of filter feeding taxa (such as Simuliidae and Hydropsychidae) capitalising on a high phytoplankton biomass from surface waters in the nutrient rich reservoir. A smaller flood event at these sites before the spring 2014 assessment resulted in a similar, yet less pronounced effect on the macroinvertebrate assemblages at these sites.

CONCLUSION

Water quality parameters were generally within guideline values, except for nitrogen oxides at below dam test sites, total nitrogen in the Queanbeyan River, and total phosphorus at some reference sites. Despite this nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all sites. Site CM2 downstream of Bendora Dam was the only below dam site to achieve AUSRIVAS band A assessment. The Queanbeyan River downstream of Googong Dam was assessed as severely impaired; however, this assessment is likely to reflect changes to the macroinvertebrate community brought about by a flood event prior to sampling, rather than an absence of environmentally sensitive taxa brought about by the operation and management of Googong Dam.

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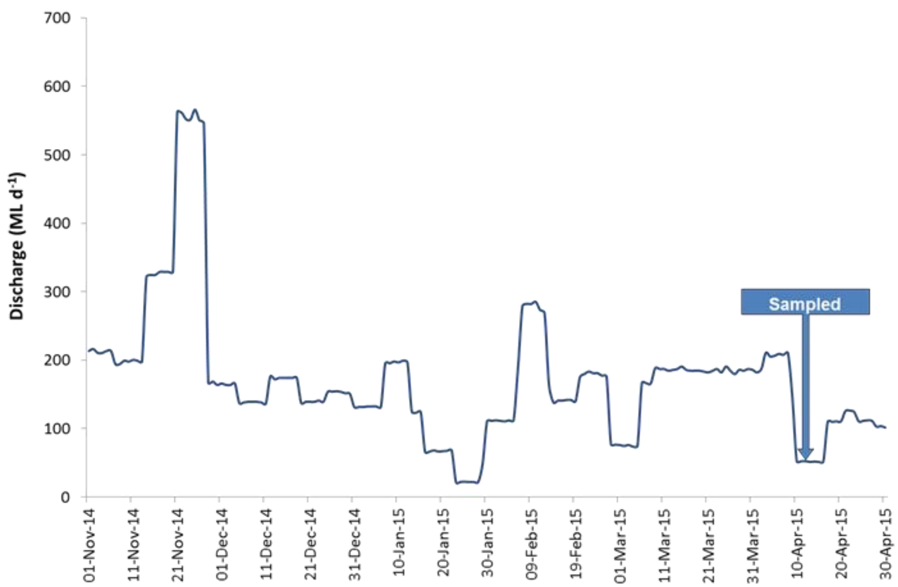
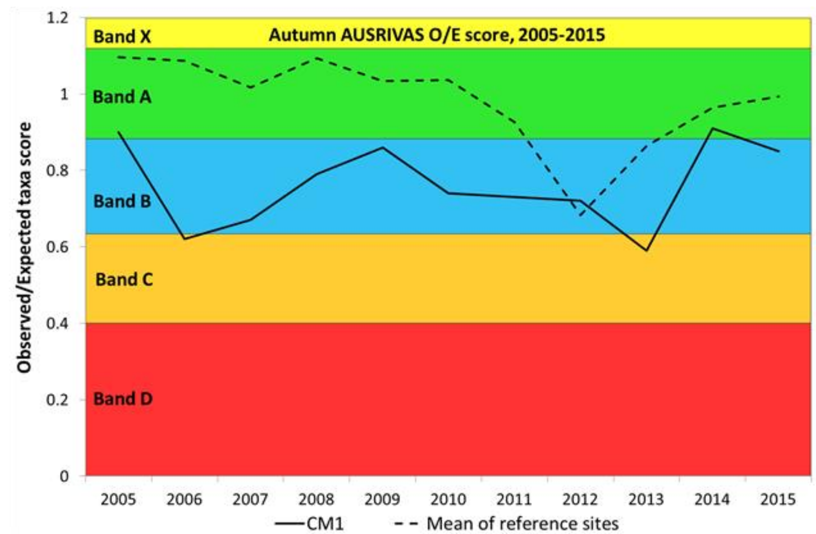
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

CM1 – Autumn 2015

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2014	Autumn 2015	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	25%	**10%**	Yes





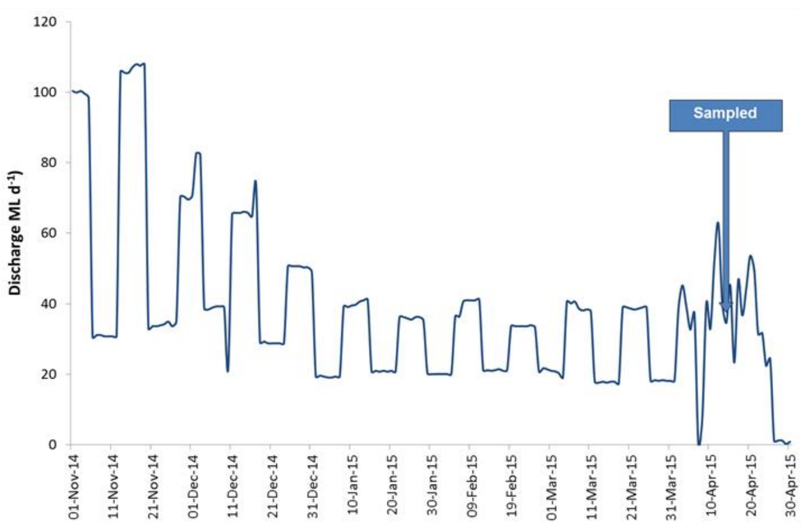
* Denotes values outside guideline levels

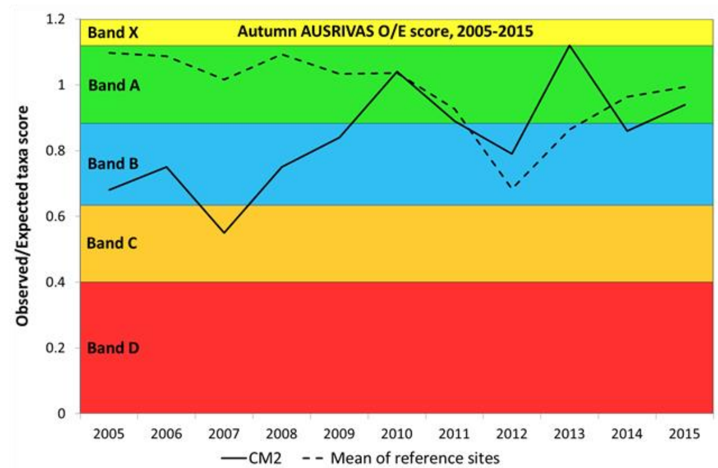
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3-N (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
11.83	20	5.20	9.9	3.1	10	0.00	0.022	0.12	0.018

CM2 – Autumn 2015

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2014	Autumn 2015	Objective met?
AUSRIVAS band A	Band A	**Band A**	Yes
<20% filamentous algae cover in riffle habitat	10%	**<10%**	Yes





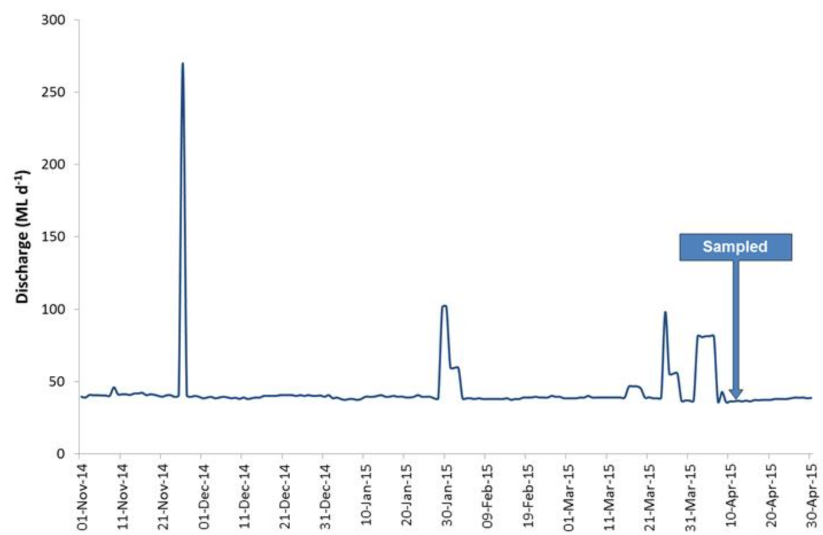
* Denotes values outside guideline levels

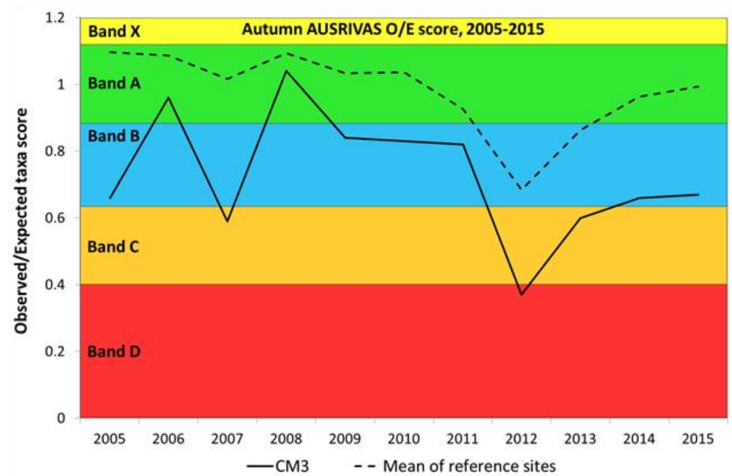
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3-N (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
16.22	18.9	5.75	9.05	0.1	10	0.004	0.017	0.12	0.008

CM3 – Autumn 2015

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2014	Autumn 2015	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**<10%**	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_3-N (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
15.21	18.9	6.78	10.52	0.8	15	0.005	0.004	0.14	0.012

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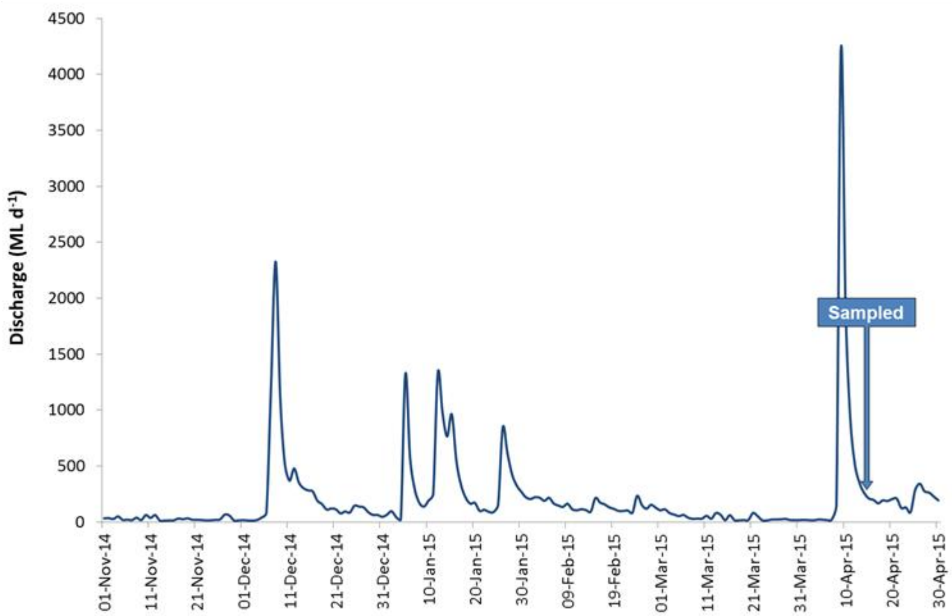
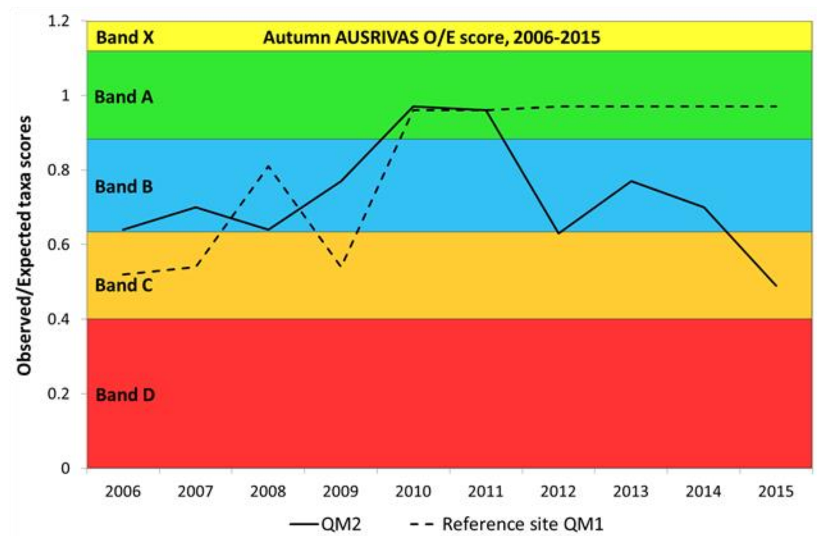
QM2 – Autumn 2015

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2014	Autumn 2015	Objective met?
AUSRIVAS band A	Band A	Band C	No
<20% filamentous algae cover in riffle habitat	10%	<10%	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3-N (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
15.52	94	7.70	9.69	1.3	30	0.005	0.071	0.50	0.016

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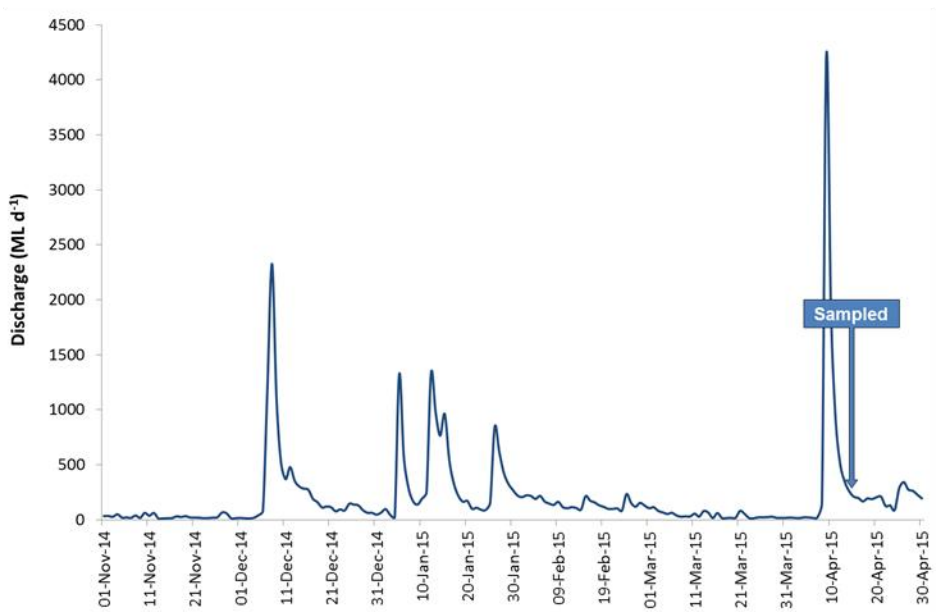
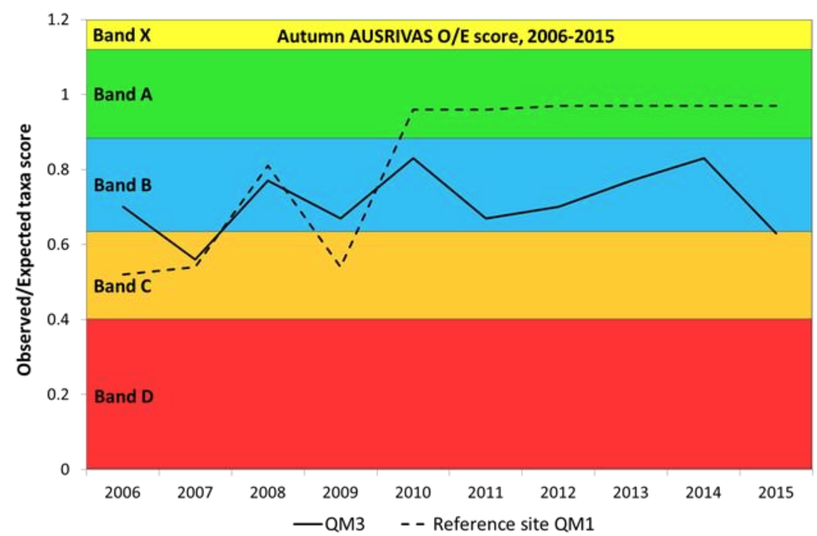
QM3 – Autumn 2015

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2014	Autumn 2015	Objective met?
AUSRIVAS band A	Band B	Band C	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





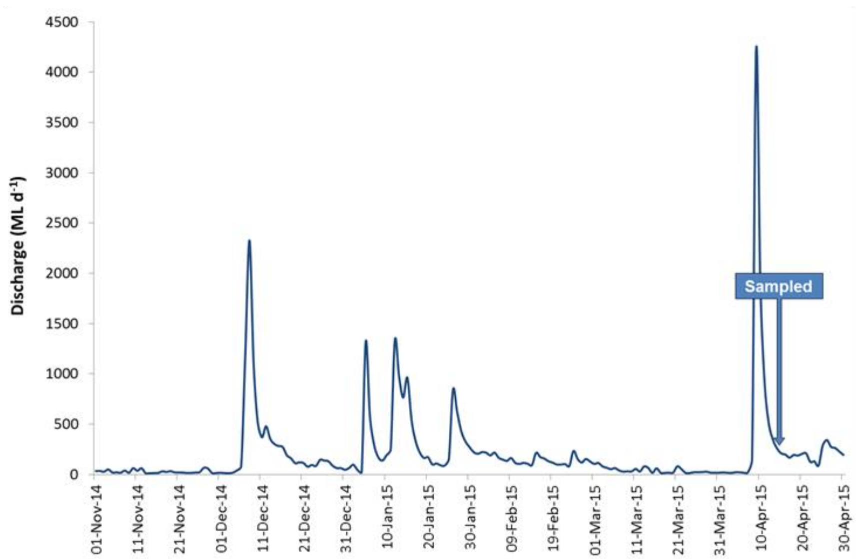
* Denotes values outside guideline levels

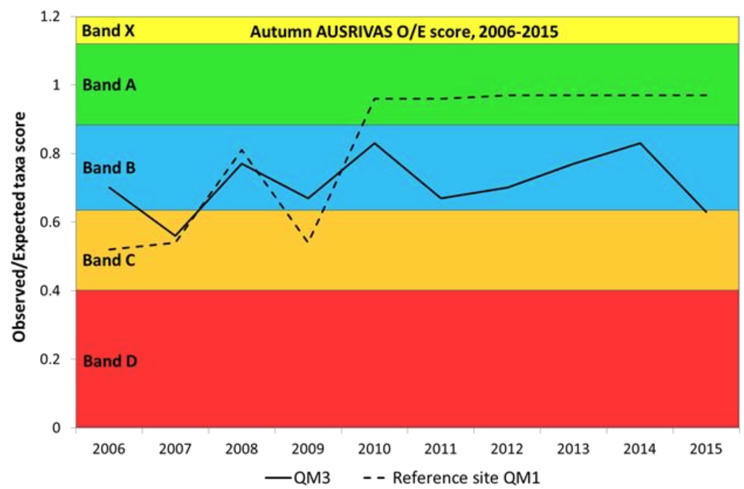
Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_3-N (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
15.92	104.4	7.08	9.57	0.3	29	0.009	0.088	0.54	0.014

QM3 – Autumn 2015

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2014	Autumn 2015	Objective met?
AUSRIVAS band A	Band B	Band C	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





* Denotes values outside guideline levels

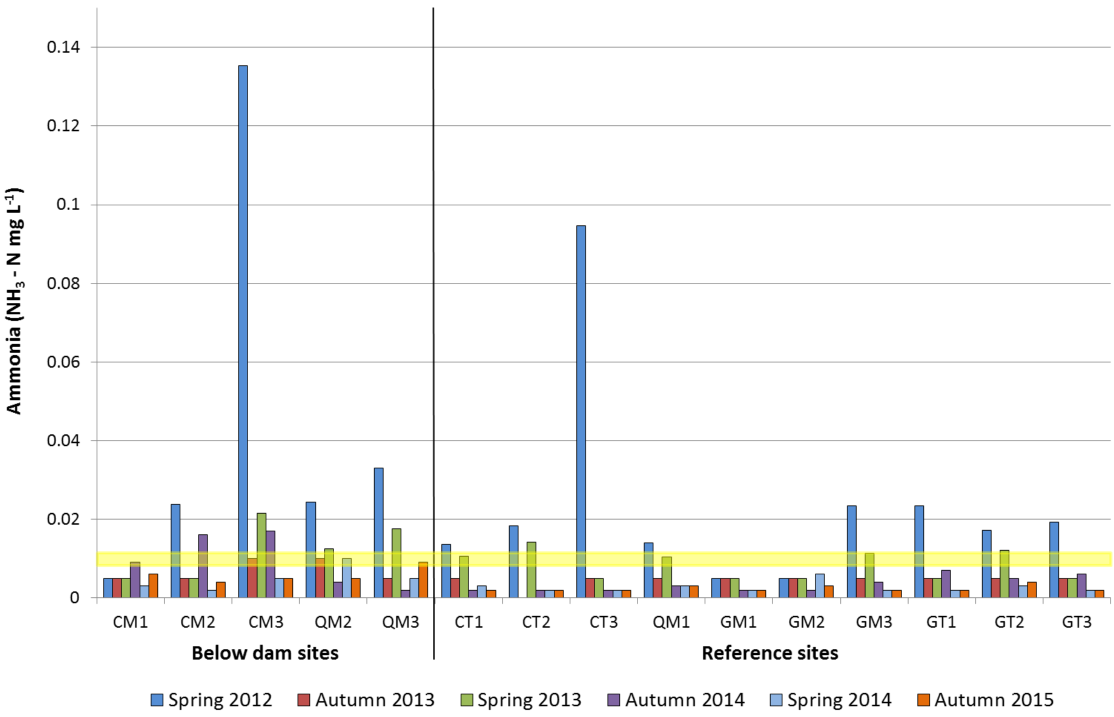
Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_3-N (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
15.92	104.4	7.08	9.57	0.3	29	0.009	0.088	0.54	0.014

APPENDIX 2: MACROINVERTEBRATE TAXA AUTUMN 2015

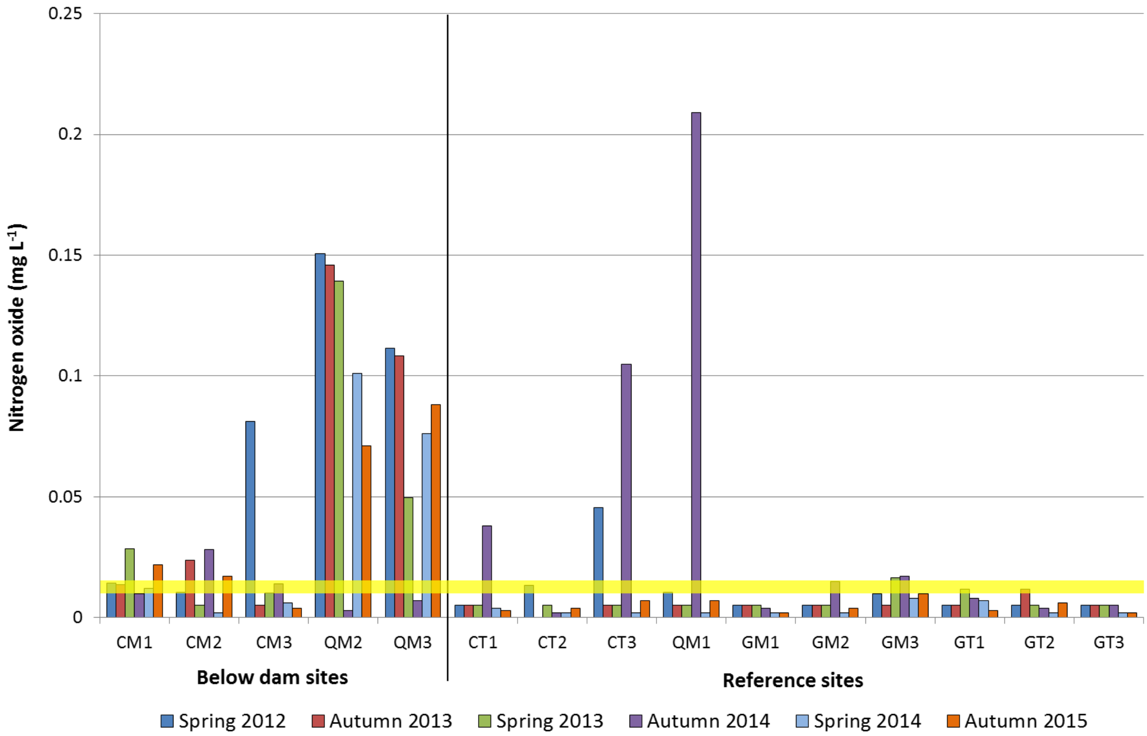
Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2015 at each of the study sites.

CLASS **Order** Family *Subfamily*	*SIGNAL 2 grade*	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
TURBELLARIA																
Dugesiidae	*2*	2						1	3						2	
Gastropoda																
Ancylidae	*4*			2			11	38				1	3		2	6
Physidae	*1*	1														
OLIGOCHAETA	*2*	3	16	2	2	11	24	2	54	4	9	10	8		4	16
ACARINA	*6*	34	4	11		7	11	22	5	9	15	3	5	10	13	5
Coleoptera																
Hydrophilidae	*2*							2							1	
Hydraenidae	*3*							1								
Scirtidae	*6*							2					1			
Elmidae	*7*	2	3		5	3	19	18	4	5	8	9	15	7	6	3
Psephenidae	*6*							1			15	3	5	3	3	2
Ptilodactylidae	*10*						3									
Diptera																
Tipulidae	*5*	1	1	3			3						2	6	5	2
Tanyderidae	*6*										1		1			
Dixidae	*7*							1								
Simuliidae	*5*	2	56	45	310	201			13	87	1	23	43	3	1	5
Athericidae	*8*	1					1									
Empididae	*5*	2		4			1	6	1					1	15	
Aphroteniinae	*8*		1				1	1						1	3	3
Podonominae	*6*							9				2				
Tanypodinae	*4*	4								1				4	7	1
Orthocladiinae	*4*	10	9	36	4	1	2	15	9	10	13	21	25	12	10	7
Chironominae	*3*	1	15	50	5	2	9	20	3	4	37	39	29	16	29	14
Ephemeroptera																
Baetidae	*5*	4	8		22	12	5	2	45	38	7	1	2	16	3	11
Coloburiscidae	*8*						7				2		2			3
Leptophlebiidae	*8*	28	1	5			14	29	9	31		78	13	56	57	26
Caenidae	*4*		23	1		5	1		39	30	63	6	15	4	10	12
Megaloptera	*0*															
Corydalidae	*7*	9		1												
Odonata																
Aeshnidae	*4*						1				1					
Gomphidae	*5*		1								4		1			
Telephlebiidae	*9*	1														
Plecoptera																
Gripopterygidae	*8*	99	25	1		1	32	12		2	44	6	24	15	40	37
Notonemouridae	*6*		1													
Trichoptera																
Hydrobiosidae	*8*	2					1			1		3	1	1	2	
Glossosomatidae	*9*										3	2	9			
Hydroptilidae	*4*	2	1	13			1	2			1		2	15		12
Philopotamidae	*8*					2	1		1	8			5		3	
Hydropsychidae	*6*	5	19	36	12	5	6	2	15	15	65	17	8	6	4	11
Polycentropodidae	*7*														1	
Ecnomidae	*4*		1			2				1				3		
Tasimiidae	*8*							4								
Conoesucidae	*8*	1	10				59	24		1	3	5	16	6	4	18
Helicopsychidae	*8*							2								12
Calocidae	*9*						1	5		1				6	4	
Calamoceratidae	*7*							6			1				2	3
Leptoceridae	*6*						2	3		1			1	20	10	
No. of individuals		214	195	210	360	252	216	230	201	249	293	229	236	211	241	209
No. of taxa		21	18	14	7	12	24	26	13	18	20	18	24	22	26	21
% of sub-sample		3	3	2	2	1	3	7	2	1	2	2	1	2	1	1
Whole sample		713	650	105	180	252	720	328	100	249	146	114	236	105	241	209

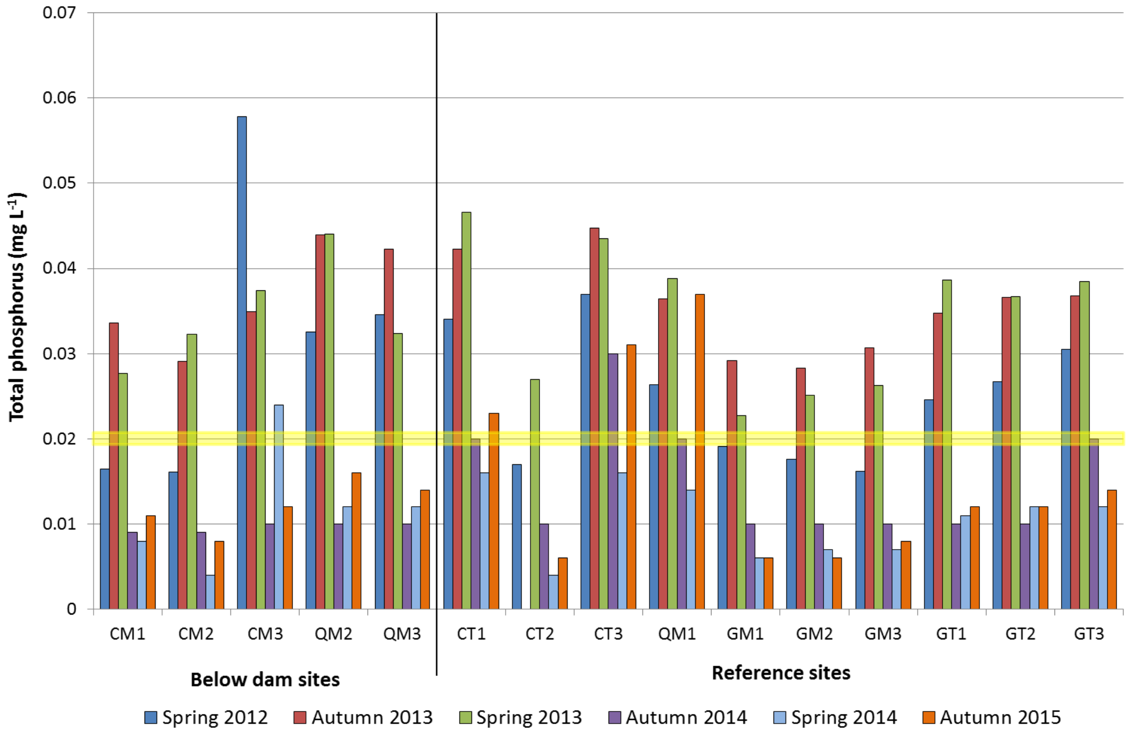
APPENDIX 3: WATER QUALITY FIGURES



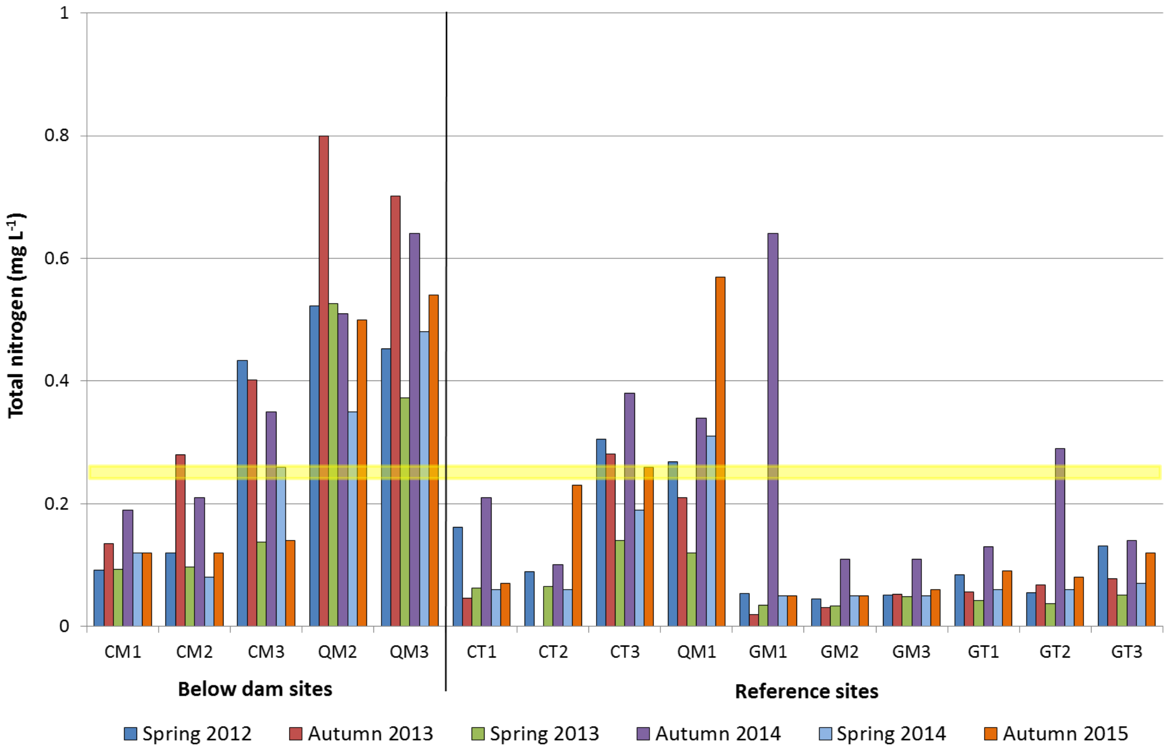
Ammonium (NH_4^+) concentration at all sites from spring 2012 to autumn 2015. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



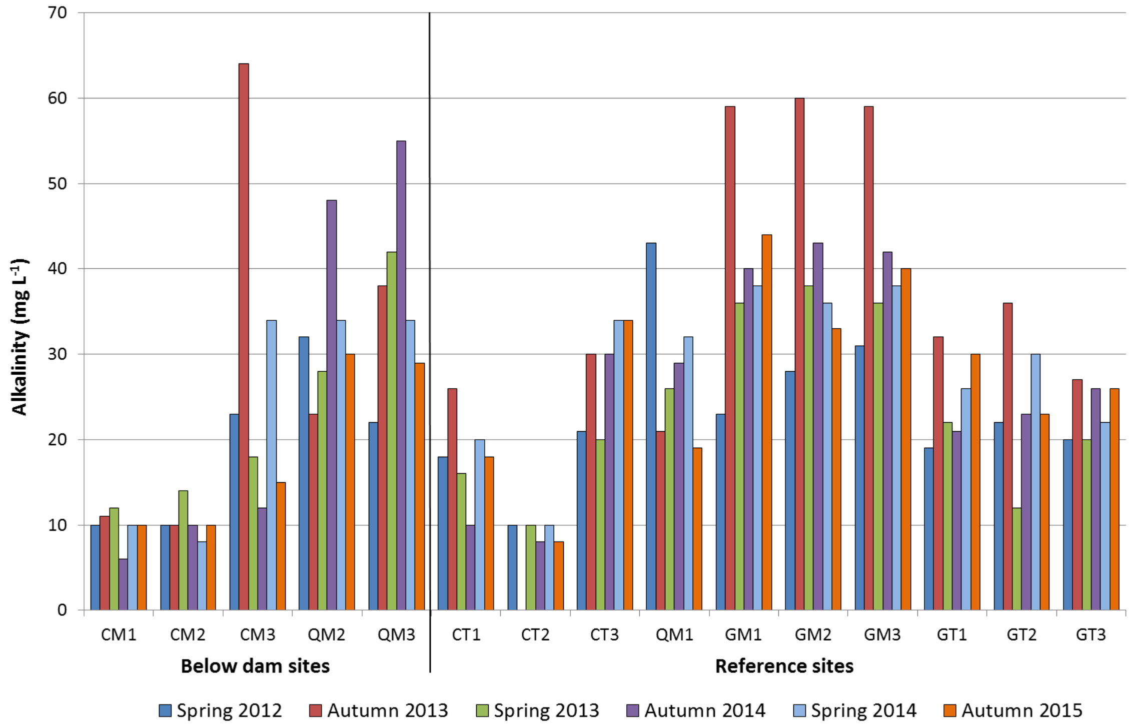
Nitrogen oxide concentrations at all sites from spring 2012 to autumn 2015. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



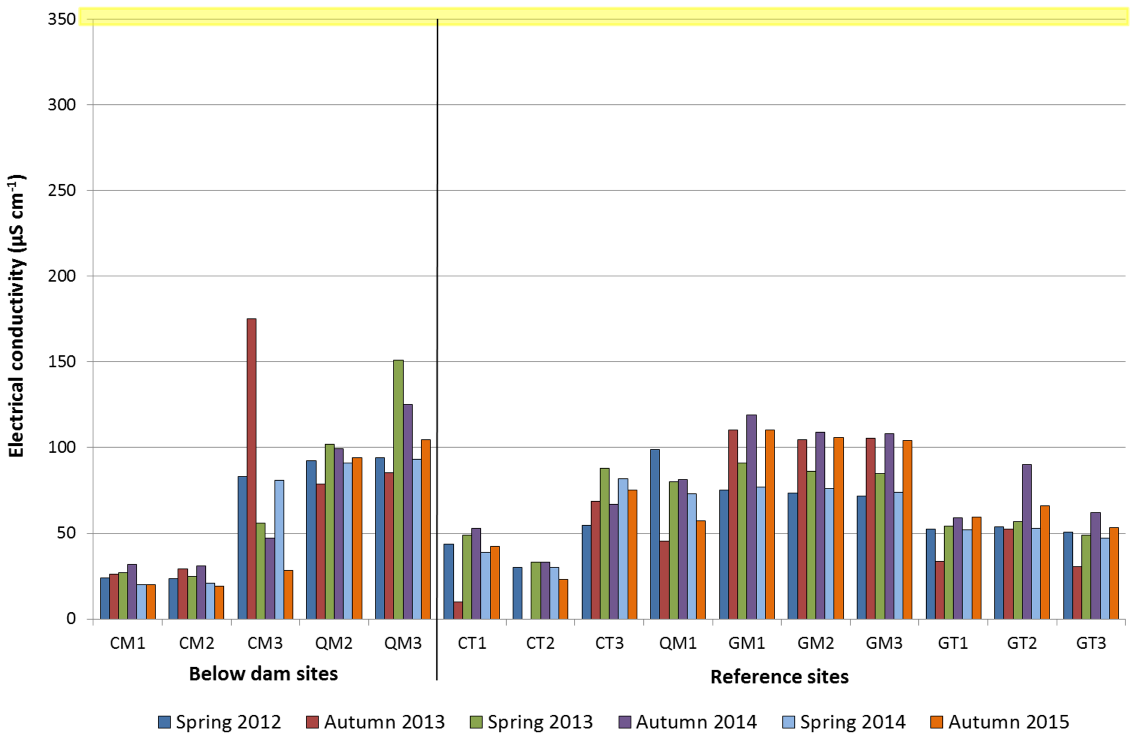
Total phosphorus concentrations at all sites from spring 2012 to autumn 2015. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



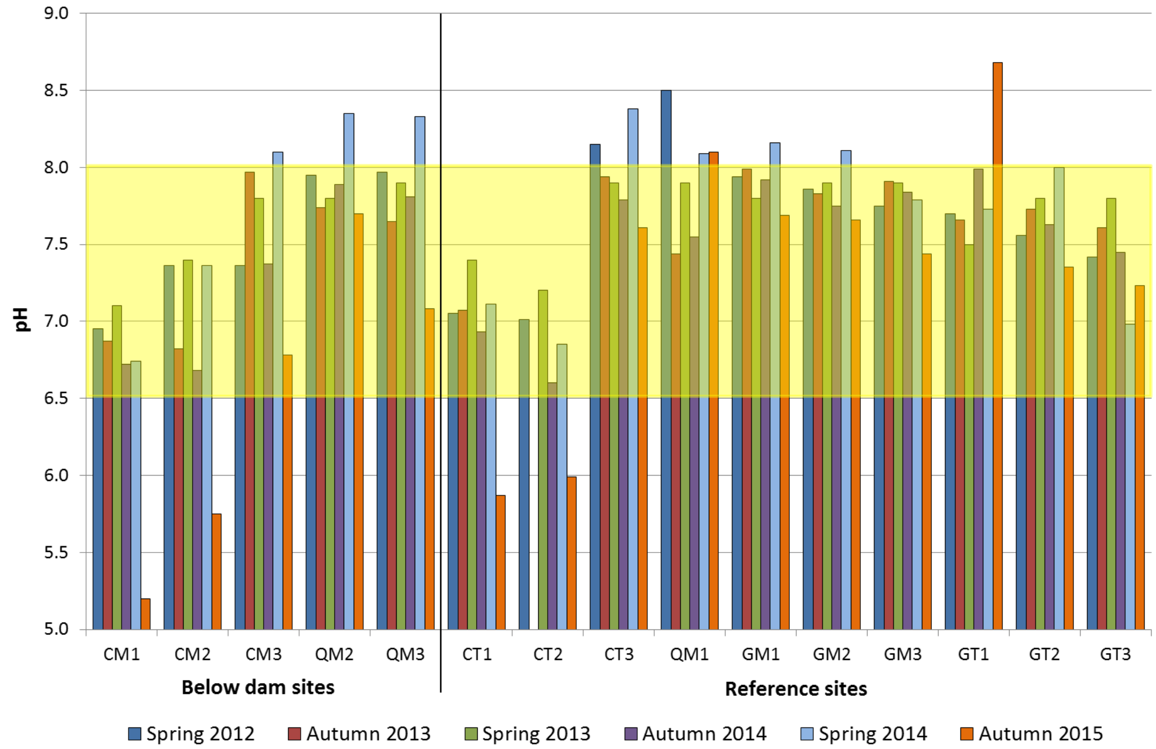
Total nitrogen concentrations at all sites from spring 2012 to autumn 2015. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



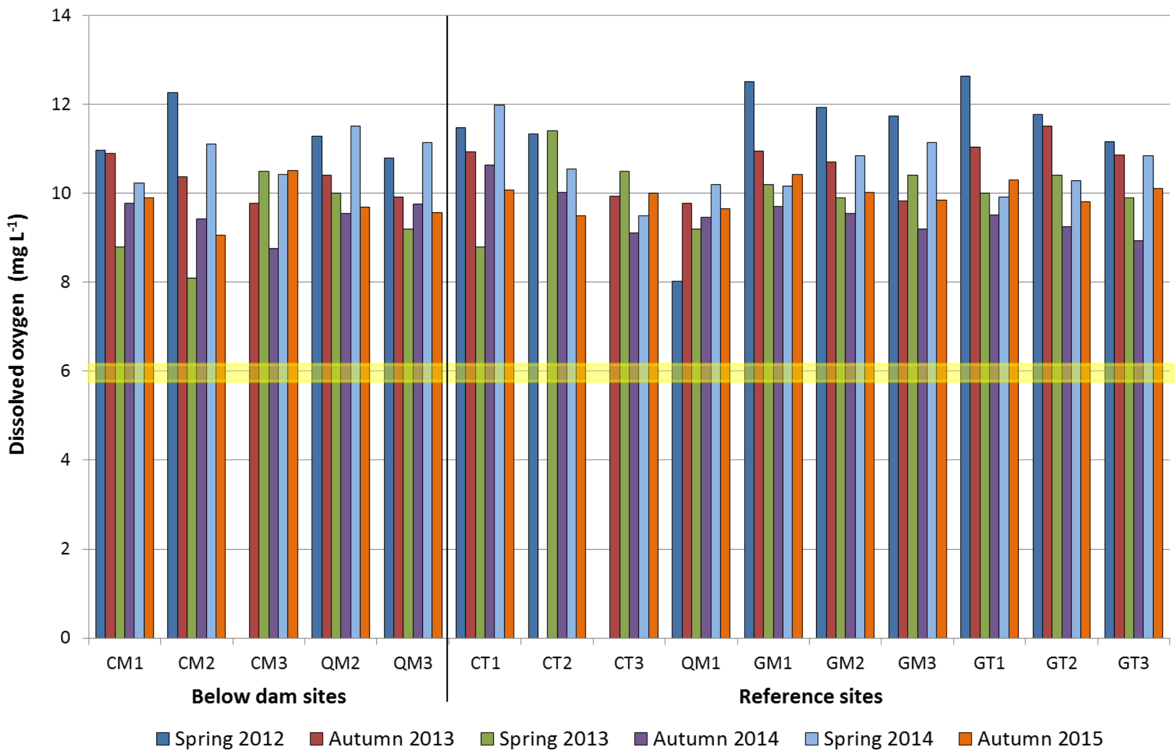
Alkalinity at all sites from spring 2012 to autumn 2015.



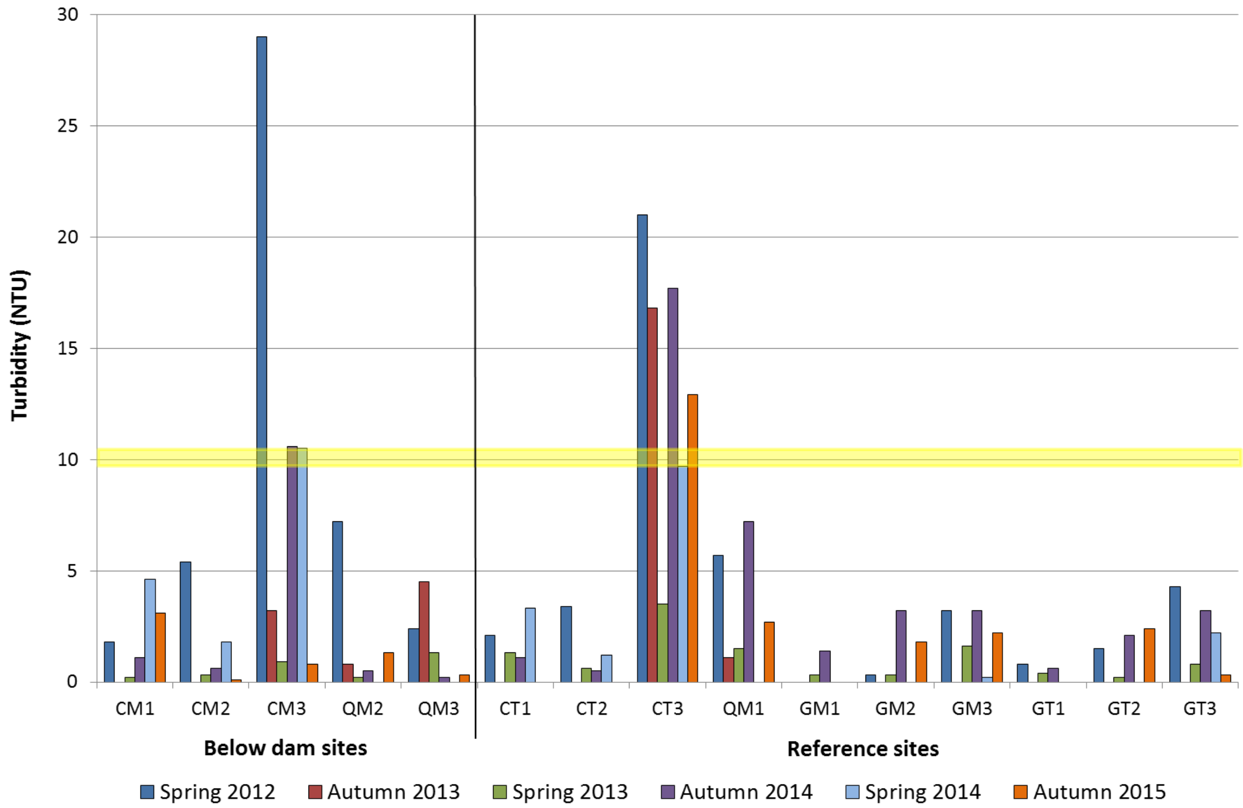
Electrical conductivity at all sites from spring 2012 to autumn 2015. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from spring 2012 to autumn 2015. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from spring 2012 to autumn 2015. The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from spring 2012 to autumn 2015. The guideline for turbidity is shaded yellow (Environment Protection Regulation SL2005-38).