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

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EXECUTIVE SUMMARY

BACKGROUND AND STUDY OBJECTIVE

- The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (ACT) and Queanbeyan. Ecological assessment is undertaken in spring and autumn each year to evaluate river response to environmental flow releases to the Cotter and Queanbeyan Rivers. 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.

SPRING 2016 – AUTUMN 2017 RESULTS AND CONCLUSIONS

- Discharge in the six months prior to sampling was far higher in spring 2016 than both autumn 2016 and spring 2015, largely due to above average rainfall across the region. Discharge following spring sampling was consistently low prior to the autumn 2017 sampling.
- Water quality parameters at below dam test sites were within guideline levels in spring 2016 and autumn 2017, with the exception of pH, nitrogen oxides (NO_x) and total nitrogen (TN) which were above guideline levels at two of the five test sites in spring 2016 and three of the five test sites in autumn 2017. pH and NO_x levels were also above guideline levels at two and three of the reference sites, respectively, in spring 2016. pH and total nitrogen were above guideline levels at seven and one of the reference sites, respectively, in autumn 2017. 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, except for the middle reference site on the Goodradigbee River (GM2) in spring 2016 and test site below Corin Dam and reference site above Googong Reservoir (QM1). Click here for more information
- Among the test sites, downstream of Bendora Dam was the only test site which met the environmental flow ecological objective of AUSRIVAS band A in spring 2016. The only test site to meet the environmental flow ecological objective of AUSRIVAS band A in autumn 2017 was the site downstream of Cotter Dam. Click here for more information
- Macroinvertebrate community condition at the test sites downstream of Cotter and Googong Dams is likely to have been affected by high discharge disturbance events in the months leading up to sampling in spring 2016. Whilst the site below Cotter Dam recovered in autumn 2017, however the sites below Googong Dam either remained impaired or continued to deteriorate in condition. Click here for more information

Filamentous algae cover and AUSRIVAS band scores for the test sites (green shading indicates environmental flow objective met, orange shading indicates environmental flow objective not met).

	Riffle filamentous algae cover (%)		AUSRIVAS band (O/E score)	
Site	**Spring 2016**	**Autumn 2017**	**Spring 2016**	**Autumn 2017**
CM1 (Corin Dam)	< 10	20	B	B
CM2 (Bendora Dam)	< 10	< 10	A	B
CM3 (Cotter Dam)	< 10	< 10	C	A
QM2 (Googong Dam)	< 10	15	B	B
QM3 (Googong Dam)	< 10	< 10	B	C

PROJECT RECOMMENDATIONS

No new recommendations at this stage. The below recommendation from the spring 2014 assessment is still applicable to the latest assessments given the results.

- Filamentous algae cover continues to be a problem at the site below Corin dam (possibly related to extended periods when flows are <150 ML d-1). Brief releases of a higher magnitude may be an effective management tool for controlling accumulated filamentous algae between scheduled releases, if and when required.

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 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 condition at Cotter River test sites regardless of river regulation effects. However, if Cotter and Goodradigbee River tributaries are in similar biological condition, then differences in 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 spring 2016 and autumn 2017, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments. Site summary sheets outlining the outcomes of both the spring 2016 and autumn 2017 assessments 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 2013). 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 when releases from the Cotter Dam are unavailable.

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 in spring between the 9th and 18th November 2016 (Table 1) and autumn 19th and 21st April 2017. 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.

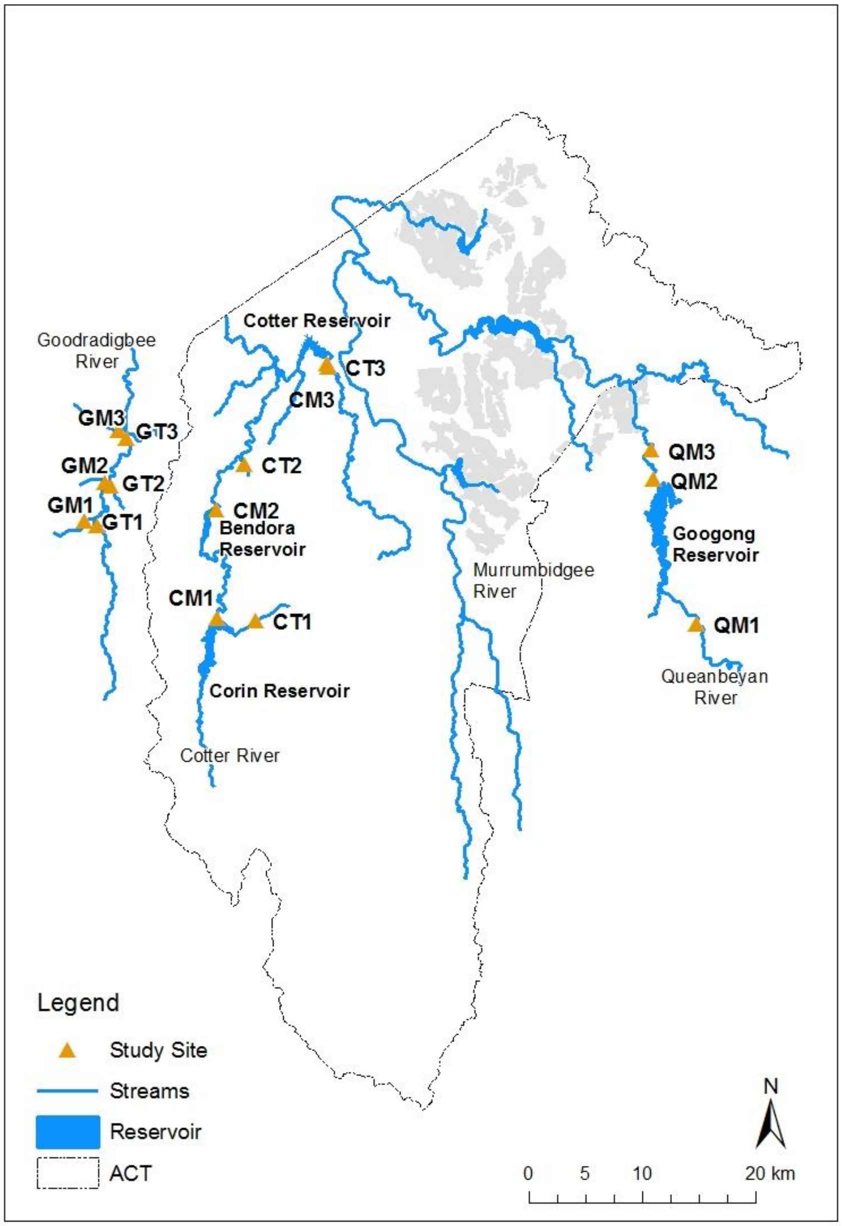


Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

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

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, pH, electrical conductivity and turbidity were measured at all sites using a calibrated Horiba U-52 water quality meter and dissolved oxygen was measured using a Hach portable DO 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 spring and the ACT autumn riffle models. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT spring and ACT autumn riffle models use 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 spring 2016 and autumn 2017, 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 60-65% 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 spring 2016 and autumn 2017 sampling at below dam sites on the Cotter and Queanbeyan Rivers was a mixture of over dam flows and operational flow requirements under environmental flow guidelines (ACT Government 2013) (Table 4). Corin Reservoir was spilling from 10th October until the 10th of November 2016. Bendora and Cotter Reservoirs had been spilling since they filled at the end of July and the start of July 2016, respectively. Googong Reservoir was spilling between early-June and mid-August and then again from early September until mid-October in 2016. There was no record of over dam flows from all the reservoirs in 2017, with all flows being exclusively operational.

Generally, a wet winter and spring resulted in an increase in discharge for most sites prior to the 2016 spring assessment. This was largely reversed for the autumn 2017 assessment where low flow conditions prevailed for the six months prior to sampling for most sites. For the spring 2016 assessment cumulative mean daily discharge at each of the below dam test sites and in the Goodradigbee River between May 2016 and the November 2016 sampling was much higher (+430 – 860%) to that of the preceding autumn 2015 assessment with the exception of CM1 which had a 23% reduction (Figure 2; Broadhurst 2016). The six months preceding the 2016 spring monitoring had a higher cumulative mean daily flow than the previous spring by 74 – 290 %. Following a wet winter and spring in 2016 there was a reduction of between 56 – 76 % in cumulative discharge in the six months prior to the autumn 2017 sampling, with the exception of CM1 which recorded a 107% increase in cumulative discharge.

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 80^{th} 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 80^{th} 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.

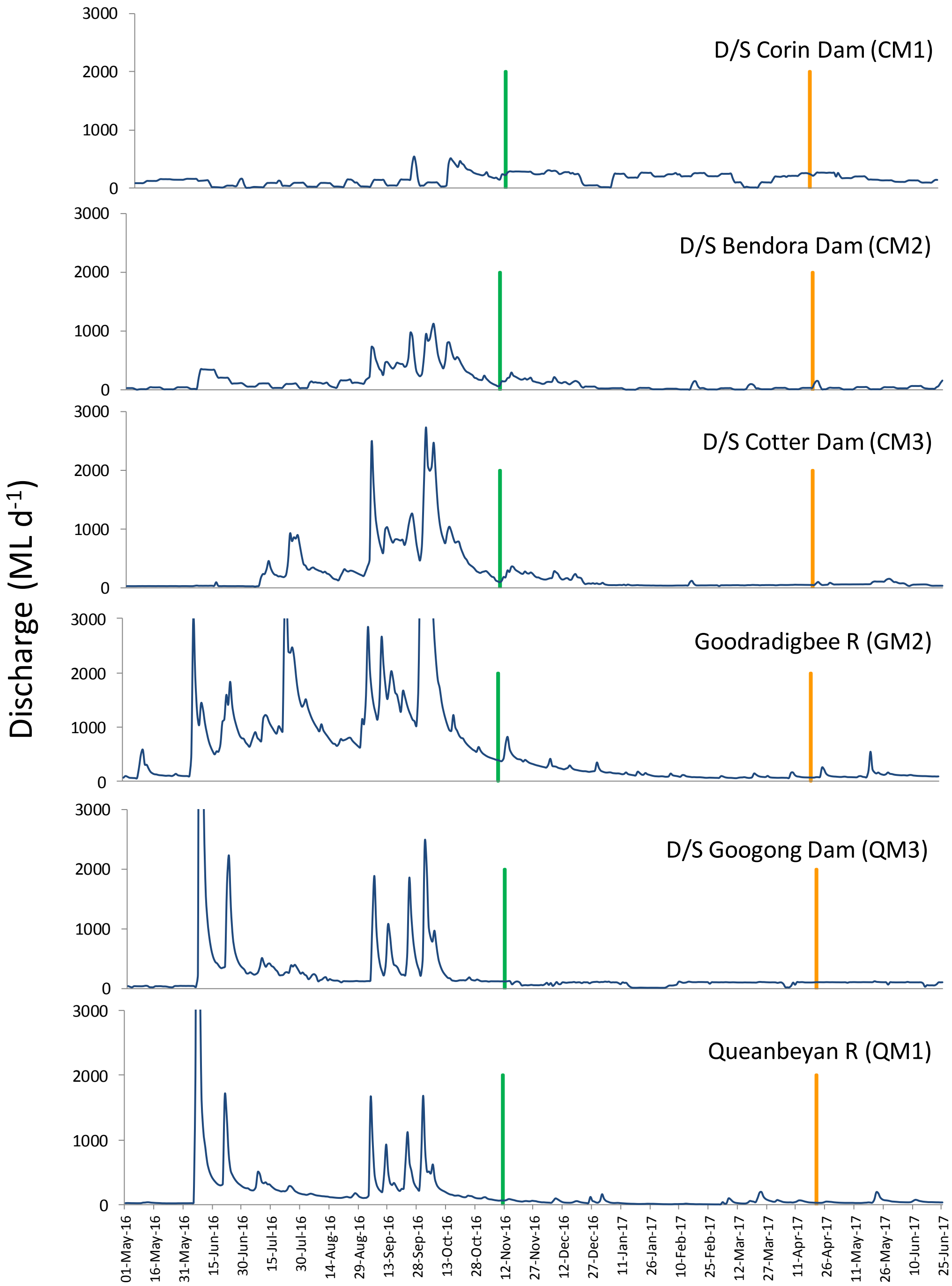


Figure 2. Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 1st May 2016 to 25th July 2017. Green bar corresponds to spring 2016 sampling and orange bar corresponds to autumn 2017 sampling. Note: Discharge at QM1 and QM3 on the 6th June 2016 peaked at 14360 and 13374 ML d^{-1}, respectively. Discharge peaked at GM2 at 6920 ML d^{-1} on the 5th of October 2016.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in spring 2016 and autumn 2017. Exceptions were pH at test sites QM2, reference sites QM1 and GM1; nitrogen oxides at test sites QM2, and QM3 and at reference sites CT3, QM1 and GT3; total nitrogen at test sites QM2 and QM3 in spring 2016 (Table 5). For the autumn 2017 assessment pH at test sites at QM2 and QM3, reference sites at CT3, GM1, GM2, GM3, GT1, GT2 and GT3; nitrogen oxides at test sites CM2, QM2 and QM3; total nitrogen at test sites QM2 and QM3 and reference site QM1 were outside guideline levels (Table 6).

Table 5. Water quality parameters measured at each of the test and reference sites in **spring 2016**. 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	16.34	20	7.63	8.74	1.0	4	0.013	0.008	0.12	0.01
	CM2	16.36	26	6.67	9.11	0.0	10	0.012	0.007	0.11	0.009
	CM3	15.31	44	7.02	9.53	0.0	12	0.011	0.009	0.13	0.01
	QM2	15.49	84	8.20	10.24	2.0	27	0.017	0.104	0.55	0.02
	QM3	16.37	86	8.16	9.69	3.7	30	0.014	0.064	0.5	0.016
Reference sites	CT1	13.66	47	7.04	8.81	0.0	20	0.012	0.015	0.110	0.018
	CT2	18.34	36	6.97	8.45	0.1	12	0.015	0.006	0.050	0.004
	CT3	19.21	81	7.82	9.26	1.6	23	0.016	0.040	0.220	0.015
	QM1	21.43	86	8.11	8.57	3.0	38	0.014	0.023	0.220	0.012
	GM1	18.2	89	8.14	8.68	1.4	44	0.017	0.010	<0.05	0.006
	GM2	15.49	81	7.98	9.31	0.9	34	0.012	0.009	<0.05	0.007
	GM3	16.49	72	7.80	9.49	1.4	28	0.012	0.011	0.060	0.008
	GT1	17.06	44	7.93	9.04	2.1	18	0.013	0.006	<0.05	0.010
	GT2	15.68	44	7.87	9.16	1.9	22	0.011	0.003	0.050	0.011
	GT3	14.71	40	7.81	9.5	4.5	18	0.012	0.019	0.080	0.012

Table 6: Water quality parameters measured at each of the test and reference sites in **autumn 2017**. 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	13.99	22	7.56	9.1	1.5	9	0.004	<0.002	0.09	0.006
	CM2	15.32	24	7.72	9.19	2.5	8	0.005	0.018	0.15	0.01
	CM3	18.57	35	7.82	9.23	2.8	10	0.004	0.007	0.14	0.009
	QM2	17.53	92	8.11	9.53	0.0	24	0.006	0.031	0.41	0.012
	QM3	17.34	93	8.25	9.66	1.1	26	0.007	0.026	0.42	0.012
Reference sites	CT1	11.25	49	7.63	9.4	1.3	22	<0.002	<0.002	0.060	0.014
	CT2	13.29	34	7.72	9.18	1.1	8	0.003	<0.002	0.050	0.004
	CT3	17.44	83	8.09	9.46	4.0	28	0.005	0.003	0.110	0.010
	QM1	14.73	85	7.89	9.2	1.3	31	0.004	<0.002	0.290	0.014
	GM1	13.96	124	8.46	10.13	0.3	46	0.002	<0.002	<0.05	0.004
	GM2	12.35	120	8.15	10.02	1.0	50	0.003	<0.002	0.060	0.006
	GM3	12.79	113	8.14	9.71	0.6	50	0.006	0.005	<0.05	0.007
	GT1	12.48	59	8.19	9.81	0.4	24	0.003	<0.002	<0.05	0.009
	GT2	11.47	70	8.14	10.08	0.1	30	0.003	<0.002	<0.05	0.007
	GT3	10.22	57	8.10	10.23	0.5	24	0.002	<0.002	<0.05	0.010

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 except for GM2 in spring 2016 and CM1 and QM1 in autumn 2017, which had 20% cover. Field observations of periphyton cover of riffle habitats were ≤10% cover at all sites in spring 2016, though this was more variable in autumn 2017 with some sites having as much as 20% cover (Table 7; Figure 3 and Figure 4).

Mean ash free dry mass concentrations differed between sites in both the spring 2016 and autumn 2017 assessments. In the spring assessment mean ash free dry mass (AFDM) was significantly greater at Goodradigbee reference site GM3 than below Bendora Dam (CM2) ($H_{6,35}$= 17.658; P = 0.007). Mean AFDM below Corin Dam (CM1) was significantly greater than below Googong Dam (QM2) and below Bendora Dam (CM2) ($H_{6,35}$=22.730; P = 0.001) in autumn 2017. Differences in AFDM between all other sites were not statistically significant for both spring 2016 and autumn 2017. (Figure 5).

Mean Chlorophyll-a concentrations differed between sites in both the spring 2016 and autumn 2017 assessments. Mean Chlorophyll-a concentrations was significantly lower at GM1 (most upstream Goodradigbee River site) compared to below Corin Dam (CM1), below Cotter Dam (CM3), below Googong Dam (QM2) and Goodradigbee reference site GM2 ($F_{6,35}$ = 4.14 P = 0.003) in spring 2016. However, mean Chlorophyll-a concentrations was significantly greater below Corin Dam (CM1) compared to below Bendora Dam (CM2), reference sites Goodradigbee

(GM1 and GM2) and below Googong Dam (QM2) and reference site Goodradigbee (GM3) was significantly greater than below Bendora Dam (CM2) ($H_{6,35}$=7.476; P=0.001) in autumn 2017. Differences in Chlorophyll-a concentrations between all other sites were not statistically significant for both spring 2016 and autumn 2017 (Figure 6).

Table 7: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from spring 2014 to autumn 2017. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat												
	Periphyton						Filamentous algae					
	Spr-14	Aut-15	Spr-15	Aut-16	Spr-16	Aut-17	Spr-14	Aut-15	Spr-15	Aut-16	Spr-16	Aut-17
CM1	10	20	20	20	<10	20	25	10	20	10	<10	20
CM2	<10	<10	<10	<10	<10	20	10	<10	<10	<10	<10	<10
CM3	75	20	25	20	<10	<10	10	<10	15	<10	<10	<10
QM2	10	<10	10	15	<10	15	10	<10	10	<10	<10	15
GM1	<10	<10	<10	<10	<10	15	<10	0	<10	<10	<10	<10
GM2	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	20	<10
GM3	<10	10	10	10	<10	10	<10	10	10	10	<10	10
QM1	10	10	40	<10	<10	20	10	10	40	25	<10	20
QM3	10	<10	<10	10	<10	15	10	<10	<10	10	<10	<10

Test sites

Reference sites

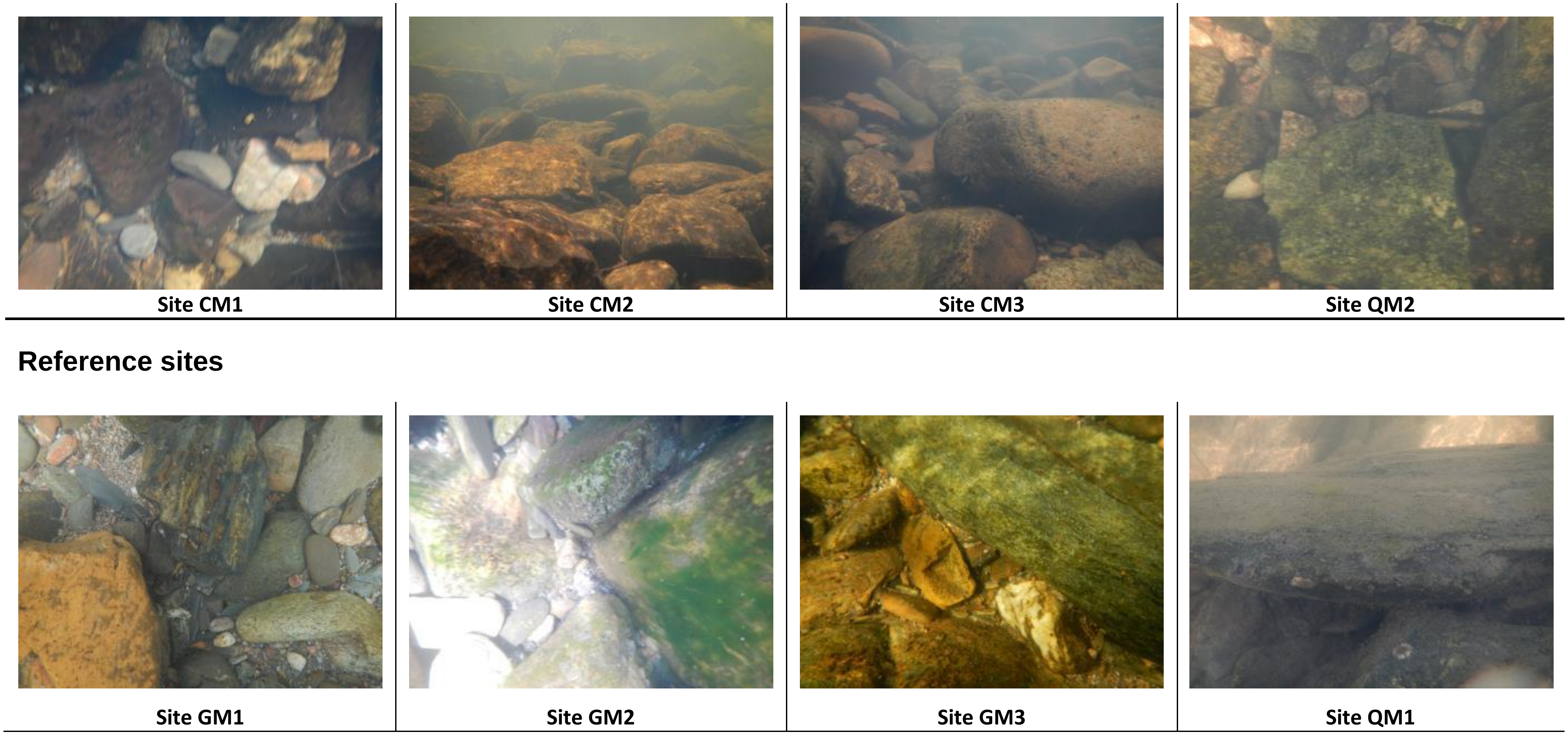
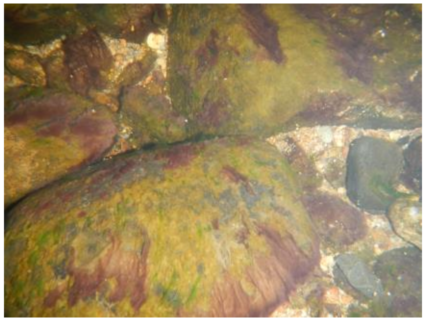


Figure 3. Filamentous algae cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in **spring 2016**.

Test sites



Site CM1

Site CM2

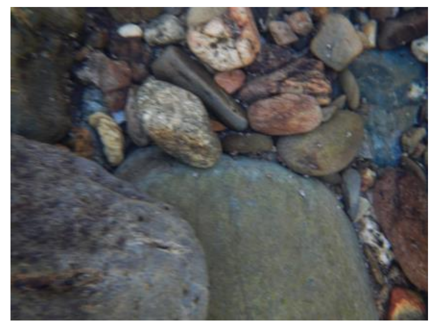
Site CM3

Site QM2

Reference sites

Site GM1

Site GM2



Site GM3

Site QM1

Figure 4: Filamentous algae cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in **autumn 2017.**

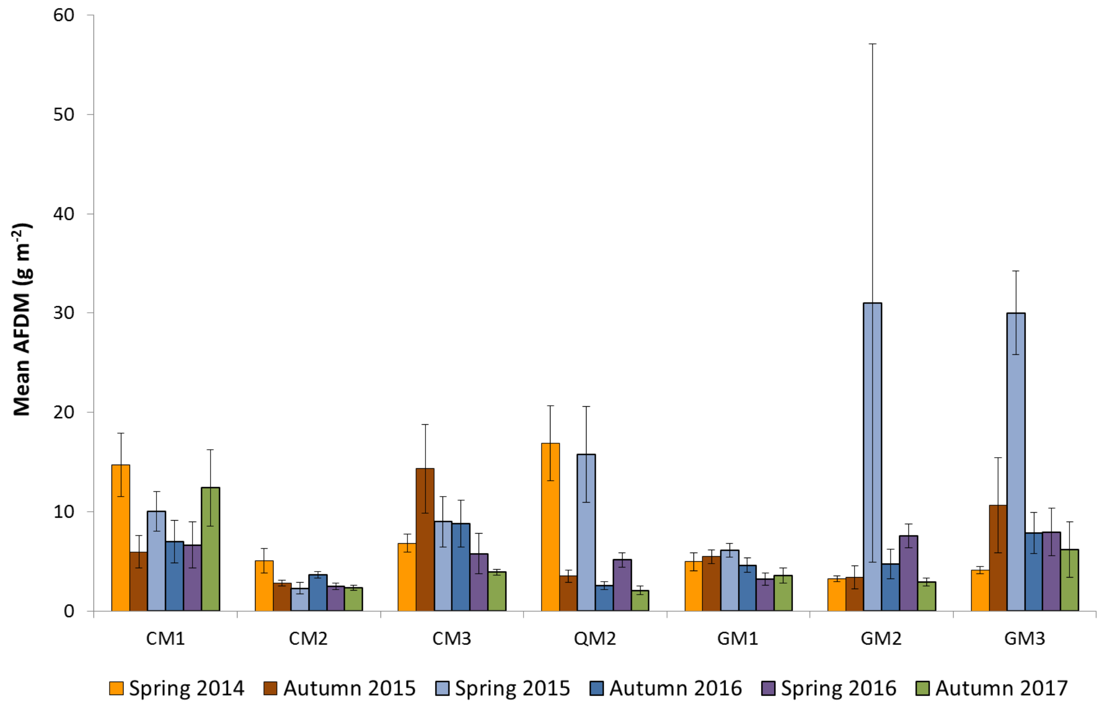


Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2014 to autumn 2017. Error bars represent +/- 1 standard error.

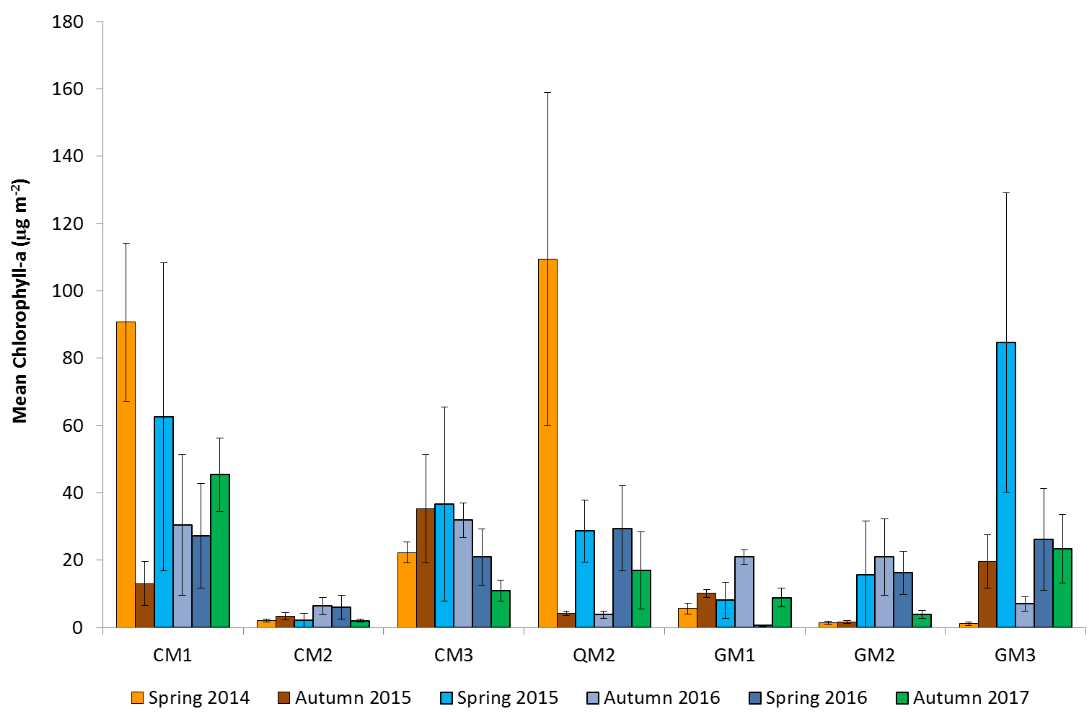


Figure 6: Mean Chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2014 to autumn 2017. Error bars represent +/- 1 standard error.

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 spring 2016 and again in autumn 2017 (Table 8).

As for six of the past seven assessments, Cotter River test site results varied in biological condition. Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in spring 2016 and autumn 2017, though its score of 0.84 in spring 2016 was just under the score of 0.86 required to be similar to reference condition (band A) (Table 8). Although CM1 remained in band B for the autumn 2017 assessment it recoded a reduction in the observed / expected score to 0.65 (just 0.01 from being assessed as band C severely impaired).

Condition of the Cotter River below Bendora Dam (CM2) was stable at band A for the past five assessments out of seven but has been assessed as significantly impaired (band B) in autumn 2017, though its score of 0.86 was just 0.02 below being assessed as band A (Table 8). Furthermore, Leptophlebiidae were predicted to occur and although they were not detected in the subsample they were detected in the whole of sample scan indicating that these taxa were present, though at low densities.

The condition of the Cotter River below Cotter Dam (CM3) was similar to reference (band A) in autumn 2017, which has increased in condition from severely impaired (band C) in spring 2016 (Table 8). Taxa missing from CM3 in spring 2016 but were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model ranged from SIGNAL grades 3 – 9 (Table 9). Two of the 10 taxa with a ≥50% chance of occurrence by the AUSRIVAS model that were not detected in the subsample was found in the whole of sample scan (Tipulidae and Hydrobiosidae Table 9).

Queanbeyan River test site QM2 was assessed as in the middle of band B (significantly impaired) for both the spring 2016 and autumn 2017 assessments. Queanbeyan River test site QM3 was assessed as significantly impaired (band B) in spring 2016 and severely impaired (band C) in autumn 2017. Both of these sites have been variable in condition over the past assessments ranging from severely impaired (band C) in autumn 2015 to similar to reference condition (band A) in spring 2014 and spring 2015, for QM2 and QM3, respectively (Table 8). This variation in biological condition was not evident at the upstream reference site on the Queanbeyan River (site QM1) which has been similar to reference condition (band A) since autumn 2014 (Table 8 and White et al 2009). Both QM2 and QM3 had an extremely high whole of sample estimated macroinvertebrate abundance compared to the reference site QM1 (approximately 4-fold see Appendix 2) in spring 2016. This was largely driven by an extremely high relative abundance of Simuliidae and Orthocladiinae, which meant that only 1% of the sample had to be processed to gain the required 200 macroinvertebrates for the AUSRIVAS model (appendix 2). Although, relative abundances of macroinvertebrates were similar between reference and test sites (Appendix 2) in autumn 2017, the relative abundance of Simuliidae and Orthocladiinae was still high for Queanbeyan River test sites QM2 and QM3. A whole of sample scan of the spring sample revealed the presence of four and five taxa expected with a ≥50% chance of occurrence by the AUSRIVAS model but not detected in the subsample for QM2 and QM3, respectively (Table 9). The taxa were Tipulidae, Psephenidae, Leptophlebiidae, Hydrobiosidae and Hydropsychidae (Table 9).

Generally reference sites were assessed as being similar to reference condition in spring 2016, with the exception of Cotter tributary site on Kangaroo Creek (CT1), which was assessed as being significantly impaired (band B) (Table 8). Four of the nine taxa expected with a ≥50% chance of occurrence by the AUSRIVAS model, but missing from sub-samples were detected in the whole of sample scan (which were Baetidae, Hydrobiosidae, Glossosomatidae and Hydropsychidae), indicating that these predicted taxa were present, but in low abundance (Table 9).

Reference site condition was more variable in autumn 2017, with site conditions ranging from significantly impaired (band B) to more biologically diverse than reference (band X) (Table 8). Reference sites CT3, QM1, GM3, GT2 and GT3 remained similar to reference (band A) in autumn 2017. The Cotter tributary site on Kangaroo Creek (CT1) scored close to a band A but remained significantly impaired (band B), though had two taxa (Psephenidae; Hydrobiosidae) detected in the whole of sample scan that were predicted with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples (Table 10). Sites CT2, GM1 and GM2 decreased their biological condition from similar to reference (band A) to significantly impaired (band B) from spring 2016 to autumn 2017 assessment (Table 8). Cooleman Creek which is a tributary to Goodradigbee River was assessed similar to reference (band A) in spring 2016, and more biologically diverse than reference (band X) in autumn 2017. In spring 2016 of the 18 taxa expected with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples, seven taxa were detected in the whole of the sample scan (Table 9), indicating these taxa were present but in low abundances. In autumn 2017 of the 21 taxa expected with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples, eight taxa were detected in the whole of the sample scan (Table 10).

Table 8: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2014 to autumn 2017.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Autumn 2017	B (0.65)	B (0.86)	A (0.89)	B (0.70)	C (0.56)	B (0.85)	B (0.71)	A (0.90)	A (0.97)	B (0.73)	B (0.67)	A (0.88)	X (1.26)	A (1.12)	A (0.97)
Spring 2016	B (0.84)	A (0.89)	C (0.51)	B (0.72)	B (0.69)	B (0.75)	A (1.07)	A (0.88)	A (1.01)	A (1.04)	A (1.04)	A (0.97)	A (1.13)	A (1.07)	A (0.88)
Autumn 2016	B (0.85)	A (0.94)	A (0.89)	B (0.84)	B (0.69)	X (1.16)	Not sampled	A (0.90)	A (1.04)	B (0.84)	A (0.97)	B (0.74)	A (1.12)	A (0.93)	A (0.97)
Spring 2015	B (0.69)	A (0.89)	B (0.66)	B (0.80)	A (1.07)	A (0.96)	X (1.15)	A (0.96)	A (1.1)	X (1.27)	A (1.04)	X (1.19)	X (0.91)	A (0.98)	A (1.21)
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)

Table 9. Macroinvertebrate taxa that were expected with a ≥ 50% chance of occurrence by the AUSRIVAS ACT spring riffle model but were missing from sub-samples for each of the study sites in **spring 2016** and their SIGNAL 2 grade indicated by an "X" (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan (which indicates taxa that were present, though at relatively low abundances).

	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Acarina	6		X								X					
Scirtidae	6						X									
Elmidae	7			X												
Psephenidae	6	X	X	X	X	X		X	X	X						
Tipulidae	5	X	X	X	X	X		X	X	X	X	X	X			X
Ceratopogonidae	4									X						
Tanypodinae	4				X	X	X				X					
Chironominae	3	X											X			X
Baetidae	5		X	X			X									
Leptophlebiidae	8			X	X	X										
Caenidae	4	X		X												
Notonemouridae	6						X									
Hydrobiosidae	8			X	X	X	X							X		X
Glossosomatidae	9	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Hydropsychidae	6	X		X	X	X	X		X	X		X	X		X	
Conoesucidae	7			X	X	X			X						X	
Calocidae	9						X									
Leptoceridae	6						X									
Total		**5**	**5**	**10**	**8**	**8**	**9**	**3**	**5**	**5**	**3**	**3**	**4**	**2**	**3**	**4**

Table 10: 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 2017** and their SIGNAL 2 grade indicated by an "X" (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan (which indicates taxa that were present, though at relatively low abundances).

Taxon Name	Signal 2 score	CM3	CM2	QM3	GM2	GM3	GT3	QM2	CM1	GT2	GT1	GM1	CT1	CT3	CT2	QM1
Hydrobiidae	4			X				X				X		X		
Ancylidae	4			X				X				X		X		
Oligochaeta	2			X	X			X								
Acarina	6			X												
Scirtidae	6								X	X					X	
Elmidae	7		X		X							X				
Psephenidae	6	X	X		X		X		X				X		X	X
Tipulidae	5		X													
Podonominae	6	X	X	X	X	X		X				X	X	X		X
Tanypodinae	4	X		X	X	X	X	X	X			X	X			
Baetidae	5								X						X	
Coloburiscidae	8								X						X	
Leptophlebiidae	8		X					X	X							
Caenidae	4				X								X		X	
Gomphidae	5			X	X	X	X									X
Hydrobiosidae	8	X		X				X	X			X	X			X
Glossosomatidae	9								X	X					X	
Hydroptilidae	4			X	X	X	X					X		X		
Hydropsychidae	6										X				X	
Conoesucidae	7	X														
Leptoceridae	6		X	X				X	X					X	X	
TOTAL		**5**	**6**	**10**	**8**	**4**	**4**	**8**	**9**	**2**	**1**	**7**	**5**	**5**	**8**	**4**

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 7, Figure 8) for both spring 2016 and autumn 2017 assessments. Tolerant OC taxa were extremely dominant (> 80%) at below dam test sites below Cotter Dam (CM3) and below Googong Dam (QM2 and QM3) (Figure 7) in spring 2016, whereas environmentally sensitive taxa were extremely dominant (>75%) in same sites in autumn 2017(Figure 8). Environmentally tolerant taxa comprised greater than 50% at Cotter River test sites CM1 and CM2 and reference tributaries CT2 and CT3 in spring 2016 (Figure 7). However, environmentally sensitive taxa comprised greater than 50% at Cotter River test sites CM1 and CM2 and reference site CT3 in autumn 2017 (Figure 8). Cotter tributary site on Burkes Creek (CT2) comprised >50% environmentally tolerant taxa in spring 2016 and autumn 2017 (Figure 7 and Figure 8). All reference sites in the Goodradigbee Catchment were dominated by environmentally sensitive taxa in both spring 2016 and autumn 2017 assessments (Figure 7, Figure 8, Figure 9 and Figure 10). In spring 2016 assessment site CM3 below Cotter Dam was dominated by large numbers of Orthocladiinae (Figure 9 and Appendix 2), whereas in autumn 2017, reference site CT2 (Burkes Creek) was dominated by Chironomidae (Figure 10). Filter feeding Simuliidae comprised > 60% of the sub-sample at Queanbeyan River test site QM3 (Figure 9 and Appendix 2) in spring 2016. Below dams tests sites had very low relative abundances of environmentally sensitive taxa Ephemeroptera, compared to reference sites (Figure 9, Figure 10 and Appendix 2) for both spring 2016 and autumn 2017.

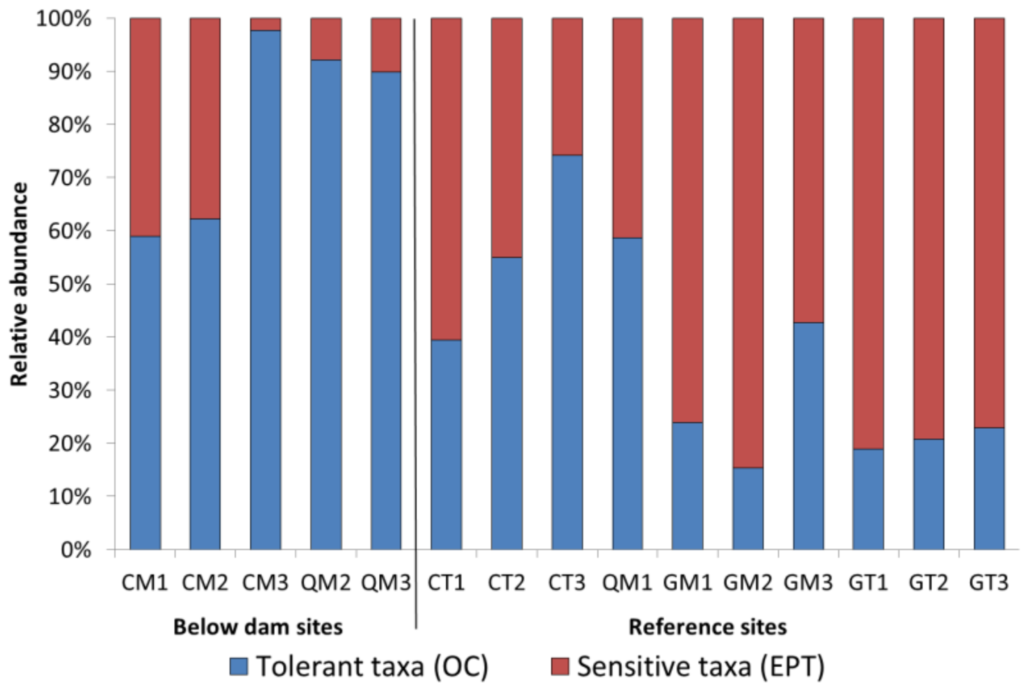


Figure 7. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **spring 2016**.

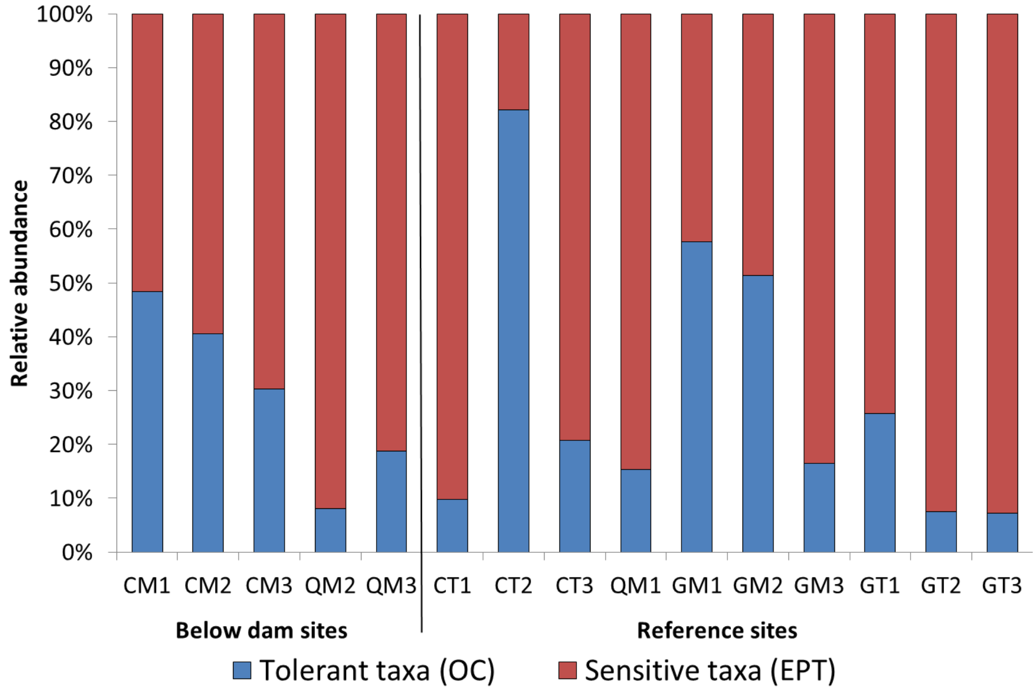


Figure 8: Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **autumn 2017**.

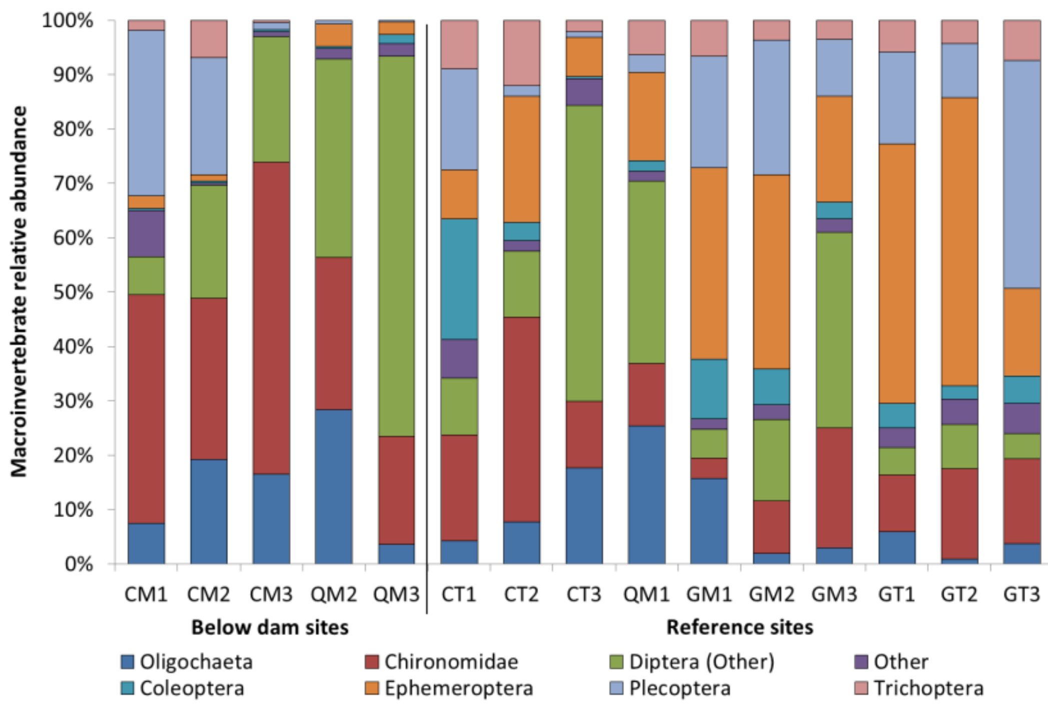


Figure 9: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **spring 2016**.

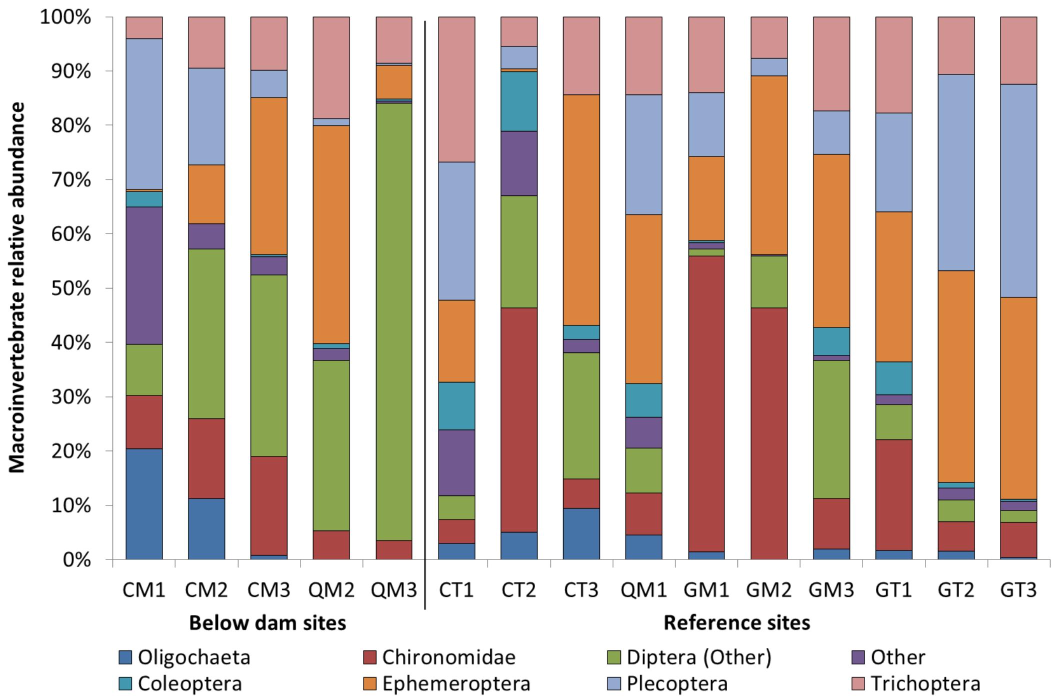


Figure 10: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **autumn 2017**.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Goodradigbee reference sites grouped out as similar to each other and different from other sites (both test and reference) for both the spring 2016 and autumn 2017 assessments, largely based on a higher relative abundance of Leptophlebiidae (Figure 11 and Figure 12). Cotter River test sites CM1 and CM3 (Below Corin and Cotter Dams, respectively) and Cotter tributary CT1 (Kangaroo Creek) had macroinvertebrate assemblages dissimilar to all other sites in spring 2016 (Figure 11). Cotter tributary CT2 (Burkes Creek) had macroinvertebrate assemblages dissimilar to all other sites in autumn 2017 and mostly driven by Acarina, Oligochaeta and Elmidae (Figure 12). Cotter River test site CM3 (Below Cotter Dam) had a higher relative abundance of environmentally tolerant Orthocladiinae and Simuliidae, a particulate filter feeder, in spring 2016 and Hydropsychidae and Simuliidae in autumn 2017 (Figure 11 and Figure 12) . In the spring 2016 assessment, Cotter River test site CM1 (below Corin Dam) was dominated by environmentally tolerant Orthocladiinae and environmentally sensitive Gripopterygidae (Figure 11; Appendix 2) and Oligochaeta and Acarina in autumn 2017 assessment (Figure 12; Appendix 2). The macroinvertebrate assemblage at test sites QM2 and QM3 (both below Googong Dam) grouped out together (Figure 11) in spring 2016 whereas these sites have grouped out together with QM1 and CT3 (reference sites) and CM3 (Cotter River test site) in autumn 2017 assessment which is driven by higher relative abundance of Hydropsychidae and Simuliidae (Figure 12).

Cotter River test site CM2 grouped out with reference sites QM1, CT2 and CT3 (Figure 11) in spring 2016 and CM1 in autumn 2017 (Figure 12).

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 more environmentally tolerant Simuliidae, Oligochaeta and Orthocladiinae at these sites compared to sites which had greater relative abundances environmentally sensitive taxa Leptophlebiidae and Gripopterygidae (Figure 11; Appendix 2) in spring 2016 assessment. The reference site Kangaroo Creek (CT1) a tributary to Cotter River had macroinvertebrate assemblage dissimilar to all other sites in spring 2016 (Figure 11) and got a diverse relative taxa abundance in autumn 2017 assessment (Figure 12; Appendix 2).

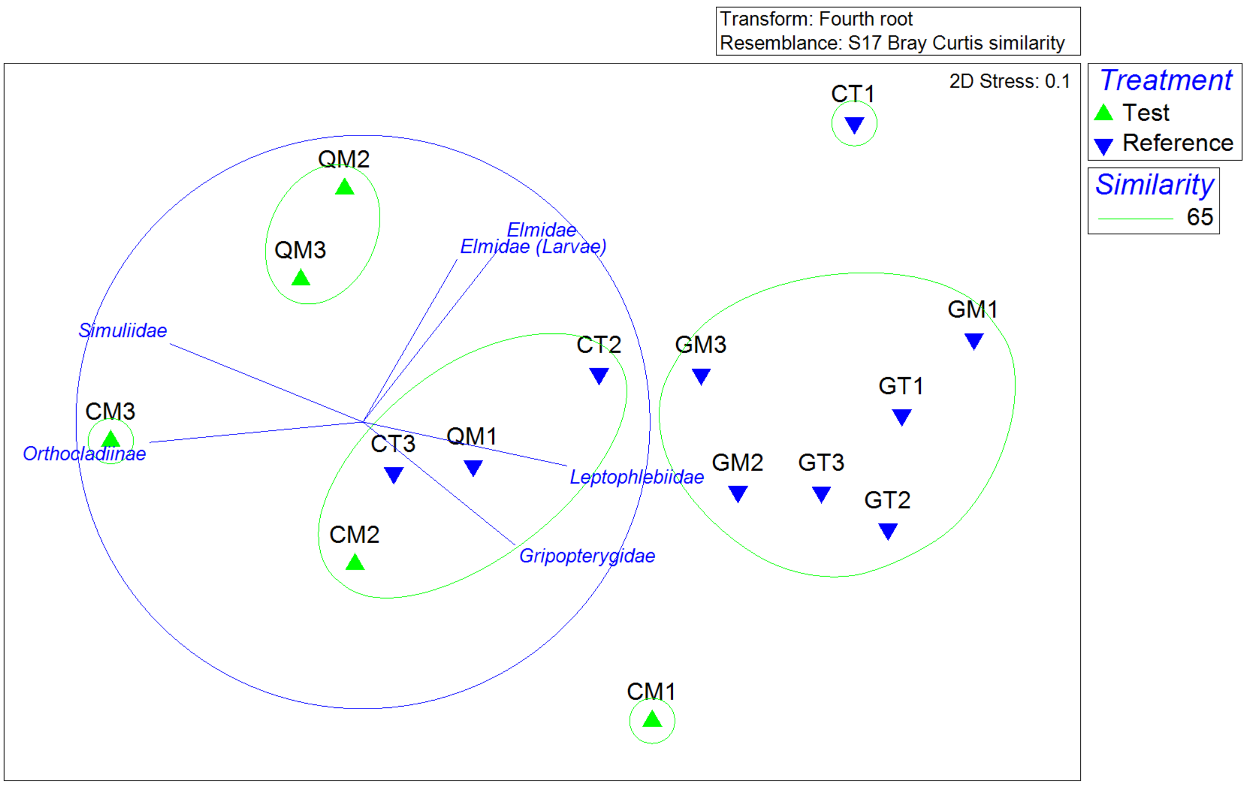


Figure 11. MDS ordination of 65% similarity between macroinvertebrate samples collected in **spring 2016** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.65 (i.e. taxa that discriminate between the groups of sites) 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.

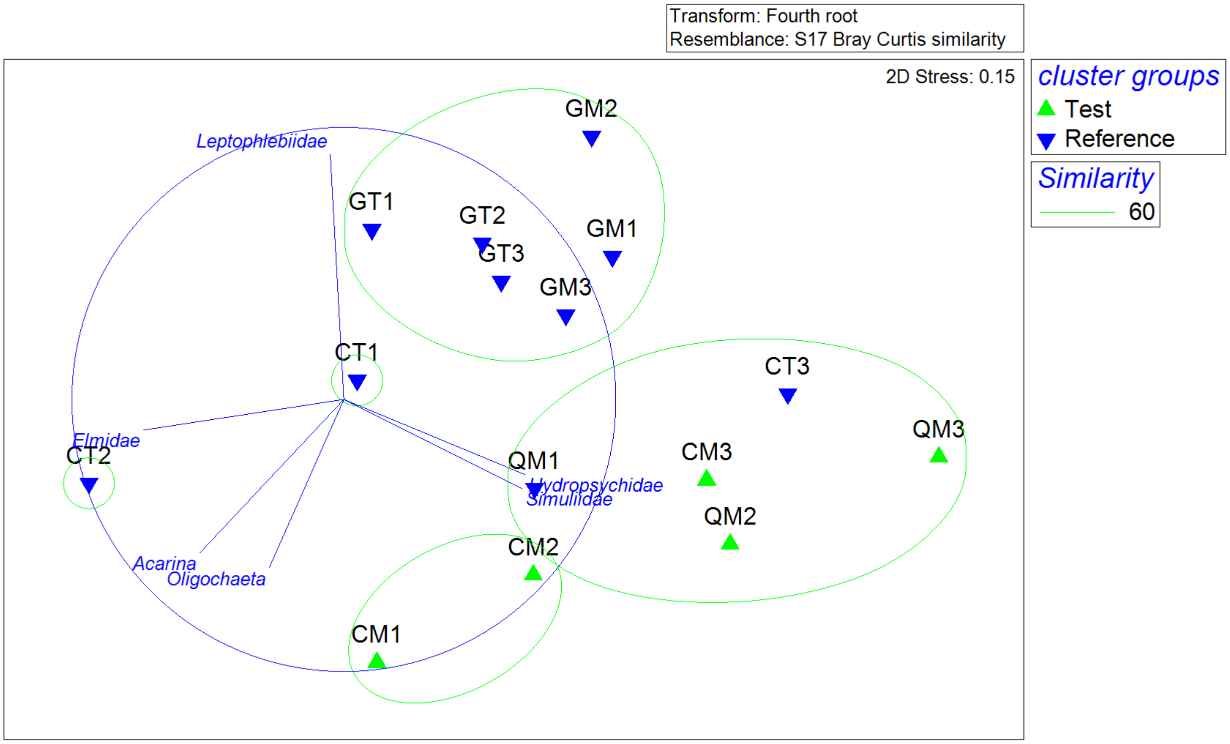


Figure 12. MDS ordination of 60% similarity between macroinvertebrate samples collected in **autumn 2017** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa that discriminate between the groups of sites) 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 across both sampling seasons (Table 5 and Table 6). Parameters outside of guideline levels for both seasons were pH, nitrogen oxides (NO_x) and total nitrogen (TN) (Table 5 and Table 6). pH was within guideline levels of 6.5-8 at all sites except for test sites below Googong Dam (QM2 and QM3) and reference sites above Googong Dam (QM1) and the most upstream reference site on the Goodradigbee River (GM1) in spring 2016 (Table 5).

Nitrogen oxides (NOx) and total nitrogen (TN) were well above guideline concentrations at test sites downstream of Googong Dam (site QM2 and QM3). Nitrogen oxides were also above guidelines at reference tributaries at Paddys River (CT3) and Bramina Creek (GT3) and reference site upstream of Googong Dam (QM1) in spring 2016 (Table 5). Total nitrogen and NOx concentrations at the test sites downstream of Googong were higher than those of the upstream reference site on the Queanbeyan River (reference site QM1) in both seasonal assessments. This could to be a result of continued high TN concentrations present in Googong Reservoir which are likely either sourced from the reservoir (release from sediments or from the breakdown of vegetative matter (Nowlin et al. 2005) or from the upstream Queanbeyan River during high flow events (during which Nitrogen can be transported into the reservoir). High Nitrogen levels and denitrification within the reservoir could be the cause of elevated NOx concentrations in outflows (Saunders and Kalff 2001). 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 except the Goodradigbee River reference site (GM2) in spring 2016 and at test site CM1 (downstream of Corin Dam) and reference site QM1 above Googong Reservoir in autumn 2017 (Table 7). This is somewhat consistent with recent 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 spring.

Although there was some significant difference in Periphyton/algae biomass between sites in both spring 2016 and autumn 2017, these differences were independent of treatment group. Periphyton/algae biomass across all sites was within the range of those measured in recent sampling (dating back to spring 2013). There were also significant differences between sites in mean Chlorophyll-a concentrations in both seasons. Chlorophyll-a concentrations were significantly lower at the most upstream site on the Goodradigee River (GM1) compared to the site immediately downstream of Googong, Corin and Cotter Dams (QM2 and CM3). This difference largely lies in the much lower than usual Chlorophyll-a concentrations at GM1, rather than above usual values at the test sites (which were not different to the other reference sites). The site below Corin Dam (CM1) had significantly higher mean Chlorophyll-a concentrations than test sites CM2 and QM2 and reference sites GM1 and GM2 in autumn 2017. The site below Corin dam has been amongst the sites with the highest Chlorophyll-a concentrations over the past few years (in particular high filamentous algae cover), which may be contributing to the impairment of the macroinvertebrate community at this site since spring 2014. Substrate with a high cover is filamentous algae provides undesirable habitat for most macroinvertebrates taxa.

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at four of the five below dam test sites in both spring 2016 and autumn 2017. For the spring 2016 assessment, this is a net decline in condition at below dam test sites as the previous two spring assessments only had impairment at three of the tests sites. With the exception of autumn 2016 (which only had three test sites with biological impairment), all other autumn samples since 2014 have recorded four of the five test sites as being biologically impaired (Table 8).

The Cotter River test site below Corin Dam (CM1) remained significantly impaired and therefore failed to meet the environmental flow ecological objective of AUSRIVAS band A in both spring 2016 and autumn 2017. The diverse macroinvertebrate community at this site combined with the AUSRIVAS score being at the upper limit of band B indicated that biological impairment was only minor downstream of Corin Dam in spring 2016 (Table 8). This site remained in band B in autumn 2017, but had a reduction in the AUSRIVAS score, so much so that it was only 0.02 from being a band C (severely impaired). The reduction in condition of the macroinvertebrate community in autumn 2017 may be disturbance related, as there were several relatively sharp increases in discharge in the weeks leading up to sampling (see site summary sheet Appendix 1).

Cotter River test sites downstream of Bendora Dam (CM2) was the only test site to achieve the environmental flow ecological objective of AUSRIVAS band A in spring 2016, and was within 0.02 of achieving it again in autumn 2017 (Table 8). This site has been assessed as band A or within 0.02 for all assessments since autumn 2014. This result, coupled with the generally low ash-free dry mass and Chlorophyll-a concentrations indicate that effects of the dam on the river at the site are being well mitigated by the environmental flow release regime.

The Cotter River test site downstream of Cotter Dam received the lowest AUSRIVAS score of all sites in spring 2016 and was the only site to be assessed as severely impaired. The macroinvertebrate community at CM3 in spring 2016 was characterised by low taxonomic richness and an extremely high percentage composition of tolerant taxa (Appendix 2, Figure 7 and Figure 9). The simplified and environmentally tolerant macroinvertebrate community present at CM3 in spring 2016 is unlikely to be a result of the operation of Cotter Dam as flows to this site have largely been unregulated since Bendora and Cotter Reservoirs filled in July 2016 (Figure 2). There was a relatively high disturbance frequency (two high discharge peaks > 2300 ML day^{-1}) in the months leading up to sampling (Figure 2 and site summary sheet Appendix 1). High discharge disturbance events have been shown to reduce macroinvertebrate density, biomass and diversity (Robinson et al. 2003; Death 2008). At the time of sampling the macroinvertebrate community may have been in a state of recovery following several large flooding events in the preceding months. This is supported by the prevalence of Simuliidae and Orthocladiinae which are early colonisers following disturbance events (Robinson et al. 2003). The absence of case building Tricopterans at CM3 further supports evidence of flood related disturbance, as cases of these taxa can be destroyed by high and turbulent velocities and shifting sediments and high mortalities can be experienced (Robinson et al. 2003). Reference sites on the Goodradigbee River also encountered several large discharge events leading up to sampling, though their macroinvertebrate communities were able to recover more rapidly. There are a number of factors that are likely to have contributed to the difference in the recovery between the site below Cotter Dam and the Goodradigbee reference sites. Firstly, as the test site is situated below a large Reservoir, recolonisation by drift from riverine macroinvertebrate communities upstream (found to be one of the main mechanisms of recolonization (Death 2008)) would have been limited compared to the Goodradigbee River whose macroinvertebrate community is not fragmented by the presence of reservoirs. It is also possible that the overall good condition of the macroinvertebrate communities at the reference sites over time has rendered them more resilient to disturbances. Generally, most macroinvertebrate communities have largely recovered from most flooding within two to four months (Death 2008), which was the case with this site (CM3) as it returned to band A in autumn 2017.

Macroinvertebrate communities at both sites downstream of Googong Dam (QM2 and QM3) were assessed as significantly impaired in spring 2016, and like the site below Cotter Dam were characterised by a prevalence of early colonisers Simuliidae and Orthocladiinae, and an absence of case building Tricopterans (see Robinson et al. 2003). It is likely that the macroinvertebrate communities at both sites are recovering following disturbances caused by high discharge in the months leading up to sampling in spring 2016. As for the Goodradigbee River reference sites, the reference site upstream of Googong Reservoir also received several large discharge disturbance events leading up to sampling, however, for similar reasons (connectivity and good macroinvertebrate community condition prior to disturbance), the macroinvertebrate community was resilient and has recovered faster than the sites situated downstream of Googong Dam (similarly to below Cotter Dam discussed above). The presence of a number of environmentally sensitive taxa in low abundances at these two tests sites in spring 2016 suggested that the recovery of the macroinvertebrate community at these two sites was underway. However, site QM3 continued to decline in condition as detected by the autumn 2017 assessment where this site was assessed as a band C (the only site in this band in autumn 2017). The driver behind this was a dominance of Simuliidae in the sample, where it made up 80% of the macroinvertebrate community counted. The dominance of a single taxa such as Simuliidae at this site may be attributable to the prevailing low flow conditions with minimal fluctuations in the six months leading up to sampling.

CONCLUSION

Water quality parameters at below dam test sites were largely within guideline levels in spring 2016 and autumn 2017, with the exception of nitrogen oxides (NO_x) and total nitrogen (TN) which were above guideline levels at two of the five test sites (sites below Googong Dam) during both assessments. Despite this nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites in spring and right on 20% at CM1 in autumn. The only test sites to achieve a band A was site CM2 (downstream of Bendora Dam) and CM3 (below Cotter Dam) in spring 2016 and autumn 2017, respectively. Macroinvertebrate community condition at the sites below Cotter Dam on the Cotter River and below Googong Dam on the Queanbeyan River appear to have been affected following several high discharge disturbance events in spring 2016, though the site at below Cotter Dam recovered in autumn 2017. Both the sites below Googong Dam have deteriorated in condition. Recolonisation at these sites may be comparatively slow compared to reference sites due to connectivity and community resilience related to macroinvertebrate community condition prior to disturbance.

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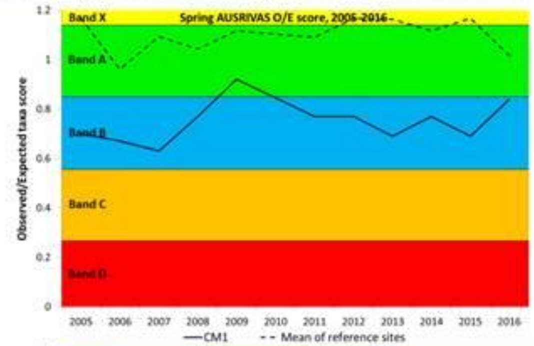
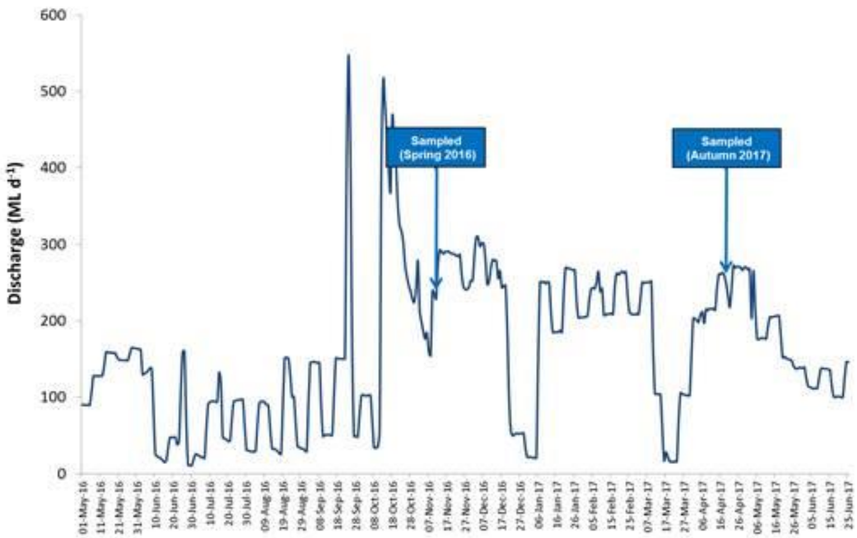
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

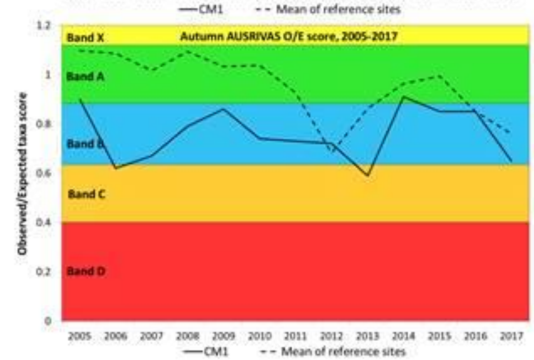
CM1 - Spring 2016 - Autumn 2017

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2016	Autumn 2017	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	10%	20%	Yes







Sampling season	Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+ (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
Spring 2016	16.34	20	7.63	8.74	1.0	4	0.013	0.008	0.12	0.01
Autumn 2017	13.99	22	7.56	9.1	1.5	9	0.004	.001	0.09	0.006

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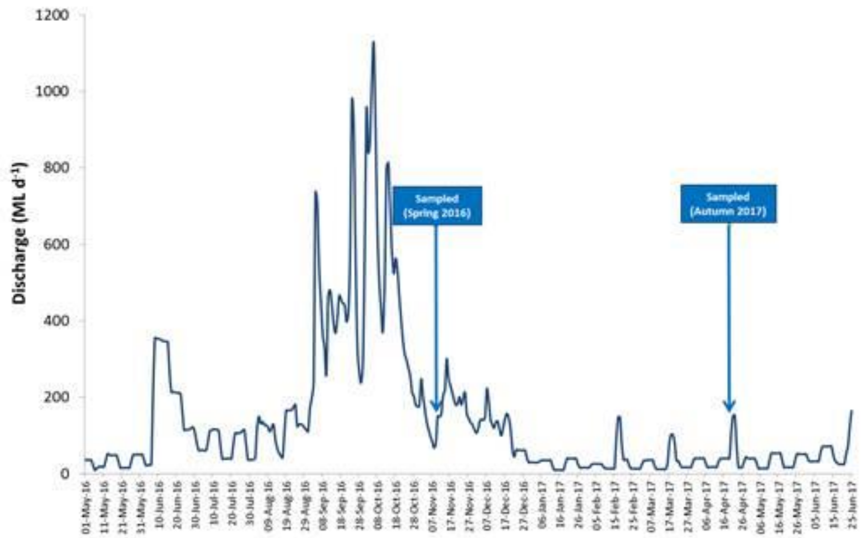
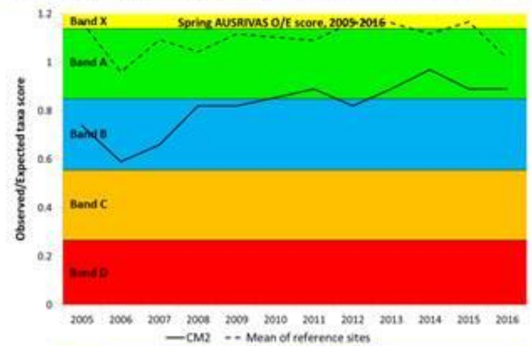
CM2

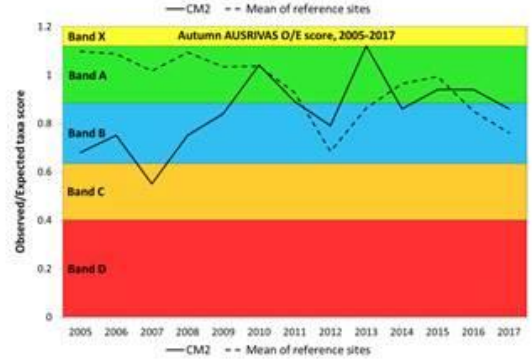
- Spring 2016
- Autumn 2017

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2016	Autumn 2017	Objective met?
AUSRIVAS band A	Band A	Band B	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes







* Denotes values outside guideline levels

Sampling season	Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
Spring 2016	16.36	26	6.67	9.11	0	10	0.012	0.007	0.11	0.0009
Autumn 2017	15.32	24	7.72	9.19	2.5	8	0.005	0.018 *	0.15	0.010

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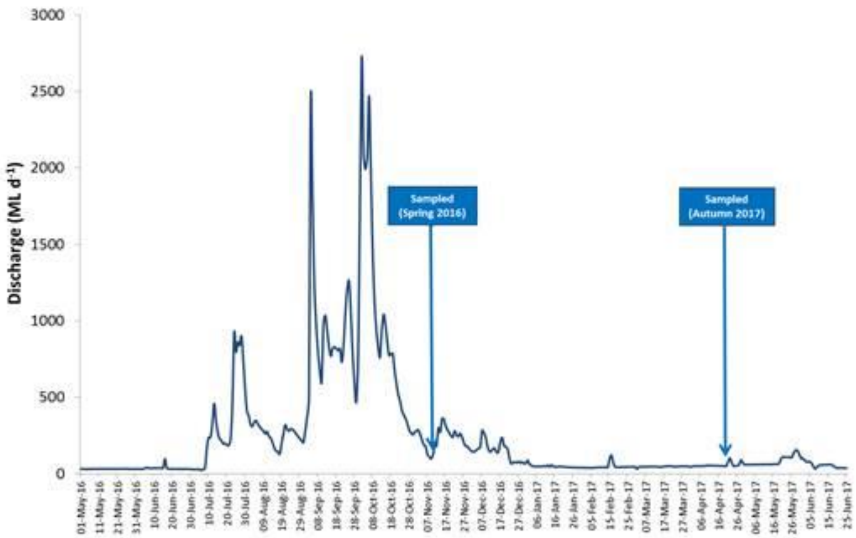
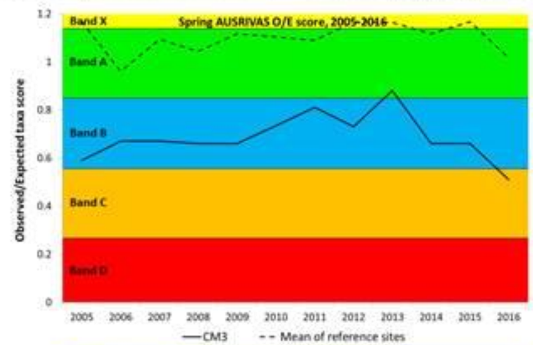
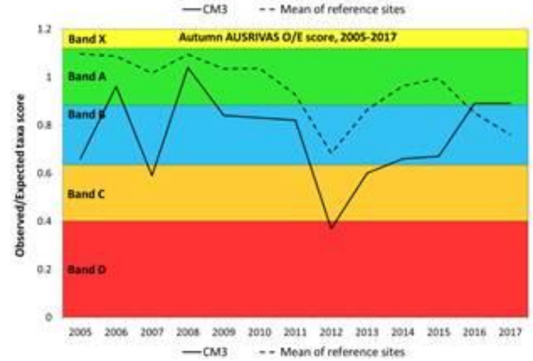
CM3 - Spring 2016 - Autumn 2017

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2016	Autumn 2017	Objective met?
AUSRIVAS band A	Band C	Band A	Yes
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





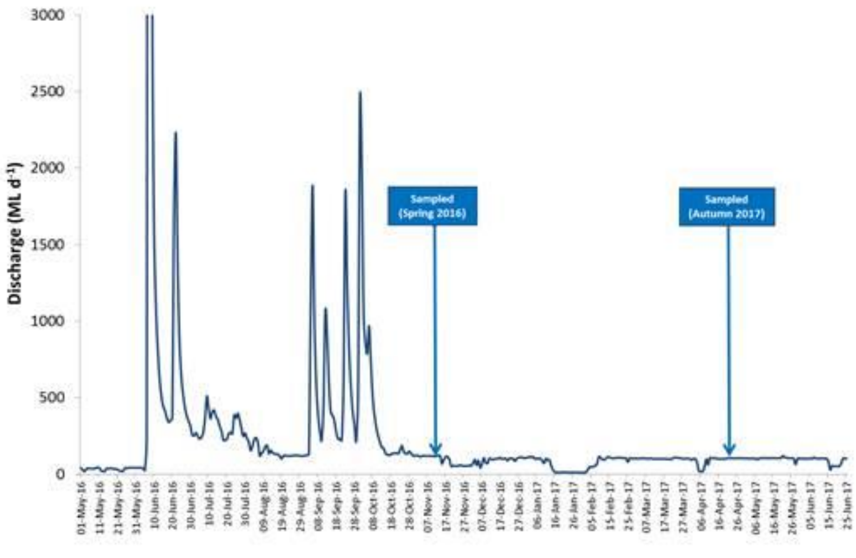


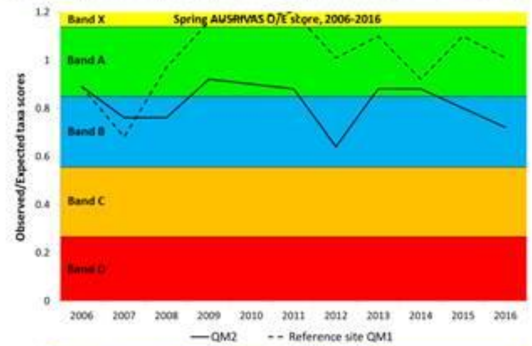
Sampling season	Temp. (^{o}C)	EC ($\mu s\ cm^{-1}$)	pH	D.O. ($mg\ l^{-1}$)	Turbidity (NTU)	Alkalinity ($mg\ L^{-1}$)	NH_4^+ ($mg\ L^{-1}$)	NOx ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
Spring 2016	15.31	44	7.02	9.53	0	12	0.011	0.009	0.13	0.01
Autumn 2017	18.57	35	7.82	9.23	2.8	10	0.004	0.007	0.14	0.009

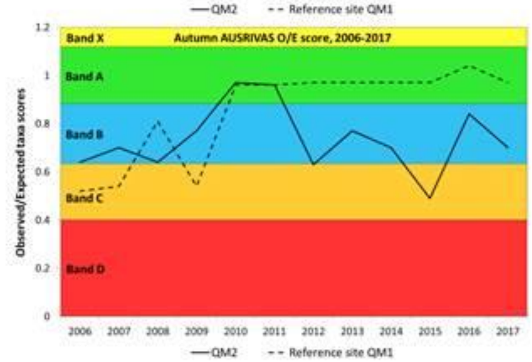
QM2 - Spring 2016 - Autumn 2017

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2016	Autumn 2017	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	<10%	<20%	Yes







* Denotes values outside guideline levels

Sampling season	Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
Spring 2016	15.49	84	8.2 *	10.24	2	27	0.017	0.104 *	0.55 *	0.02
Autumn 2017	17.53	92	8.11 *	9.53	0.0	24	0.006	0.031 *	0.41 *	0.012

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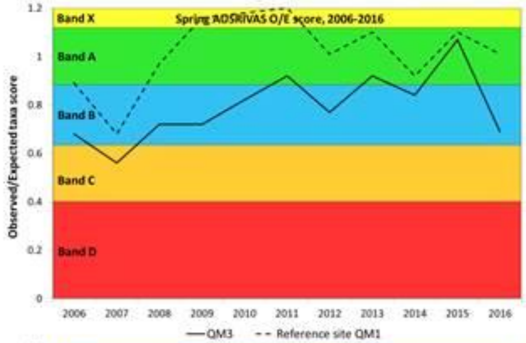
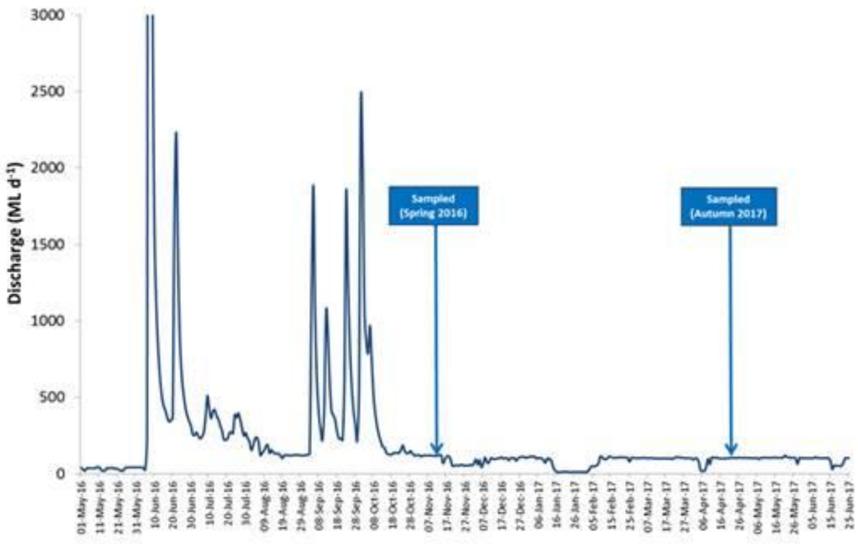
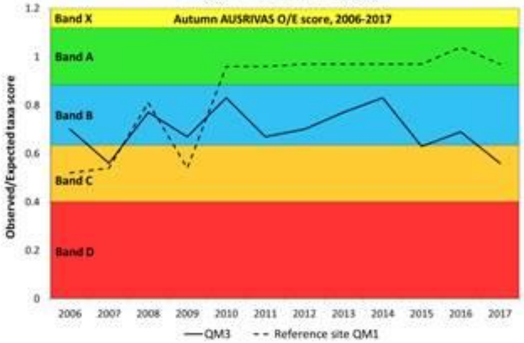
QM3 - Spring 2016 - Autumn 2017

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2016	Autumn 2017	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

Sampling season	Temp. (ºC)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
Spring 2016	16.37	86	8.16 *	9.69	3.7	30	0.014	0.064 *	0.5 *	0.016
Autumn 2017	17.34	93	8.25 *	9.66	1.1	26	0.007	0.026 *	0.42 *	0.012

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APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2016 AND AUTUMN 2017

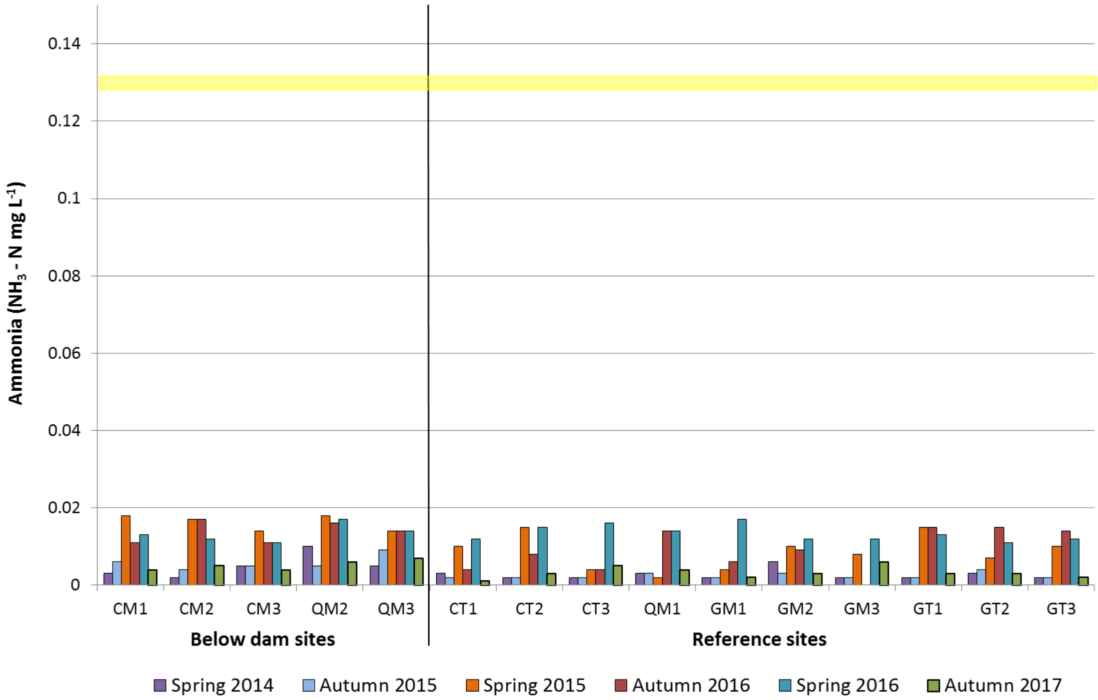
Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in spring 2016 at each of the study sites.

CLASS **Order** Family *Sub-family*	**Signal 2 Grade**	**CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**QM1**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
GASTROPODA																
Planorbidae	4						2									
Physidae		3														
OLIGOCHAETA	2	16	50	38	76	11	9	16	51	56	33	4	6	13	2	8
ACARINA	6	13		1	3	7	13	4	14	3		5	2	7	9	6
Coleoptera																
Hydraenidae				1												
Elmidae	7	1	1		1	5	46	7	1	4	7	4	5	6	3	5
Psephenidae	6						1				16	10	1	4	2	6
Diptera																
Tipulidae	5						2							8	9	
Tanyderidae	6							1								
Culicidae	1				1											
Ceratopogonidae	4	1										4		1	1	
Simuliidae	5	1	54	53	94	211	15	20	157	73	7	27	70	2	5	8
Psychodidae	3				2			1			3		1			
Athericidae	8						5									
Empididae	5	13			1			3		1	1	1	1		2	2
Aphroteniinae	8	2					4	1			1	1		12	21	28
Diamesinae	6											1	4			
Podonominae	6								1							
Tanypodinae	4	1	1	2				3	3	2		2	1	1	1	1
Orthocladiinae	4	87	64	121	70	51	34	62	29	19	5	16	39	6	6	5
Chironominae	3		12	9	5	9	3	12	2	4	2	1		4	7	
Ephemeroptera																
Baetidae	5	2			5	2		21	2	14	10	3	15	31	6	4
Coloburiscidae	8						5				15	26	4	1	5	3
Leptophlebiidae	8	3	1				11	26	17	3	32	39	19	59	78	23
Caenidae	4		2		6	5	3	1	2	19	17	9	1	14	23	5
Hemiptera																
Saldidae	1									1						
Corixidae	2			1												
Megaloptera																
Corydalidae	7	2			2							1			1	1
Odonata																
Gomphidae	5										4		1	1		3
Austropetaliidae	10		1													
Telephlebiidae	9												2			2
Plecoptera																
Gripopterygidae	8	65	56	3	2	1	39	4	3	7	40	53	21	37	21	91
Notonemouridae	6										3					
Trichoptera																
Hydrobiosidae	8	1	14					7	1	4	2	1	2		2	
Glossosomatidae	9										1					
Hydroptilidae	4	1							1	4					1	1
Philopotamidae	8						2								1	
Hydropsychidae	6		2					1			4			1		2
Polycentropodidae	7						8	2						1		
Ecnomidae	4		1	1				1	4	6						1
Tasimiidae	8						1									
Conoesucidae	8	2	1				6	14			2	7	5	6		12
Helicopsychidae	8										1				1	
Philorheithridae	8										3					
Odontoceridae	7													1	2	
Calamoceratidae	7						2								1	
Leptoceridae	6										1			4	1	
No. of individuals		214	260	230	268	302	211	207	288	220	210	215	200	220	211	217
No. of taxa		17	14	10	13	9	20	20	15	16	23	20	19	22	25	21
% of sub-sample		11	5	5	1	1	12	4	3	3	8	4	5	7	6	4
Whole sample estimate		**1945**	**5200**	**4600**	**26800**	**30200**	**1758**	**5175**	**9600**	**7333**	**2625**	**5375**	**4000**	**3143**	**3517**	**5425**

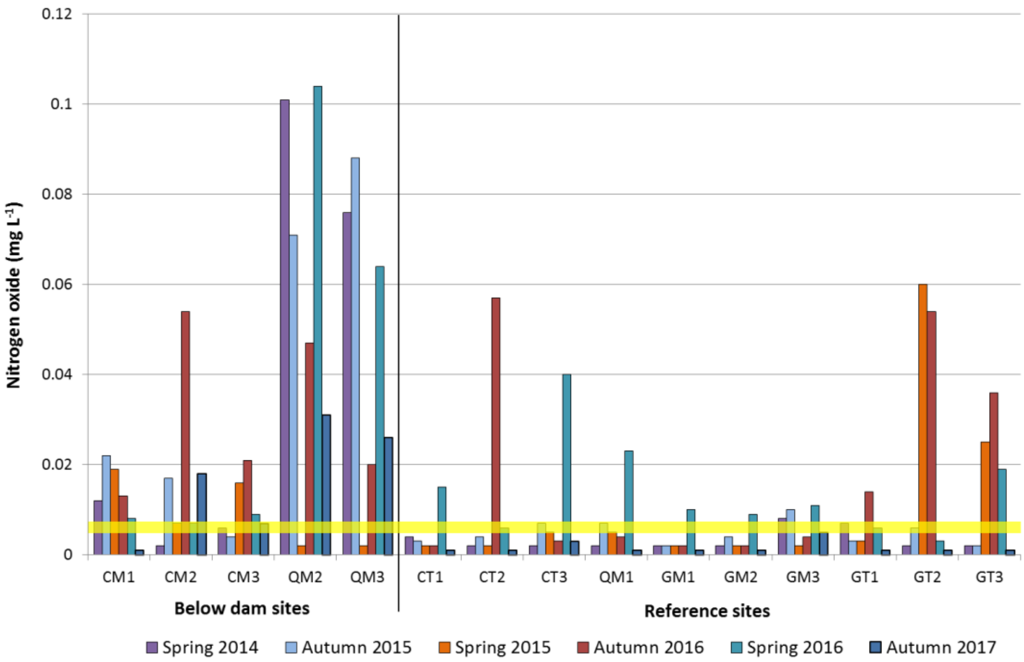
Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2017 at each of the study sites.

CLASS **Order** Family *Sub-family*	**Signal 2 Grade**	**CM3**	**CM2**	**QM3**	**GM2**	**GM3**	**GT3**	**QM2**	**CM1**	**GT2**	**GT1**	**GM1**	**CT1**	**CT3**	**CT2**	**QM1**
GASTROPODA																
Planorbidae	**4**		3						1				12		1	
PELECYPODA																
Sphaeriidae	**5**	6		1				2					1			
OLIGOCHAETA	**2**	2	26			4	1		50	5	4	7	6	19	11	11
ACARINA	**6**	1	7		1	2	3	1	60	6	4	1	9	2	25	12
Coleoptera																
Dytiscidae	**2**														1	
Hydrophilidae	**2**											1				1
Scirtidae Sp.	**6**					1					1					4
Elmidae	**7**					1	1				3		1	1	9	3
Elmidae (Larvae)	**7**	1		1		8		1	7	2	9		17	4	13	7
Psephenidae	**6**					1		1		1	1	1				
Ptilodactylidae	**10**														1	
Diptera																
Tipulidae	**5**			1	2		3	1	13	1	10	2	1		2	1
Tanyderidae Sp.	**6**												2			
Ceratopogonidae	**4**														4	1
Simuliidae	**5**	80	69	207	27	53	2	71	10	10	3	4	2	47	38	18
Psychodidae	**3**									2						
Athericidae	**8**	1			1	1					1		2		1	
Stratiomyidae	**2**												1			
Empididae	**5**		2										1			
Dolichopodidae	**3**		1								1					
Aphroteniinae	**8**						1				1				1	
Podonominae	**6**						1				2					
Tanypodinae	**4**		1							1	4			1	48	1
Orthocladiinae	**4**	29	18	7	7	4	9	8	23	2	19	9	5	9	34	9
Chironominae	**3**	15	15	2	138	16	4	4	1	14	21	265	4	1	7	9
Ephemeroptera																
Baetidae	**5**	28	16	10	5	17	21	28		40	23	7	9	68		37
Coloburiscidae	**8**					2	7			1		6	4			
Leptophlebiidae	**8**	1		2	98	43	53			79	39	56	18	13	1	3
Caenidae	**4**	41	9	4		6	6	64	1	4	2	9		5		36
Lepidoptera	**2**															1
Megaloptera																
Corydalidae	**7**								1							
Odonata																
Diphlebiidae	**6**												3	1		
Aeshnidae	**4**						1			1						
Gomphidae	**5**	1	1					2				5		1		
Telephlebiidae	**9**													1		1
Plecoptera																
Gripopterygidae	**8**	12	41	1	10	17	92	3	68	115	40	59	50		9	53
Notonemouridae	**6**										2		2			1
Trichoptera																
Hydrobiosidae	**8**		2		1	2	4			1	3			3	1	
Glossosomatidae	**9**					6	1							1		
Hydroptilidae	**4**	1	1					1	2	1	5		1			11
Philopotamidae	**8**	3		1	2					1		2	2	5		2
Hydropsychidae	**6**	16	6	21	3	6	2	36	4	1		28	5	17		21
Polycentropodidae	**7**		3													
Ecnomidae	**4**	4	8		4	11	2	5	2		1	11	2	3		
Tasimiidae	**8**						1						6			
Conoesucidae	**8**		2		5	11	19	1	2	5	18	16	39		10	1
Helicopsychidae	**8**														1	
Helicophidae	**10**										2					
Calamoceratidae	**7**				1					2	1					
Leptoceridae	**6**				8	1				23	11	13				
No. of individuals		242	231	258	313	213	234	229	245	318	231	502	205	202	218	244
No. of taxa		17	19	12	16	21	21	16	15	23	27	19	26	19	20	23
% of sub-sample		1	3	2	1	2	2	2	3	1	1	1	2	2	15	2
Whole sample estimate		**24200**	**7700**	**12900**	**31300**	**10650**	**11700**	**11450**	**8167**	**31800**	**23100**	**50200**	**10250**	**10100**	**1453**	**12200**

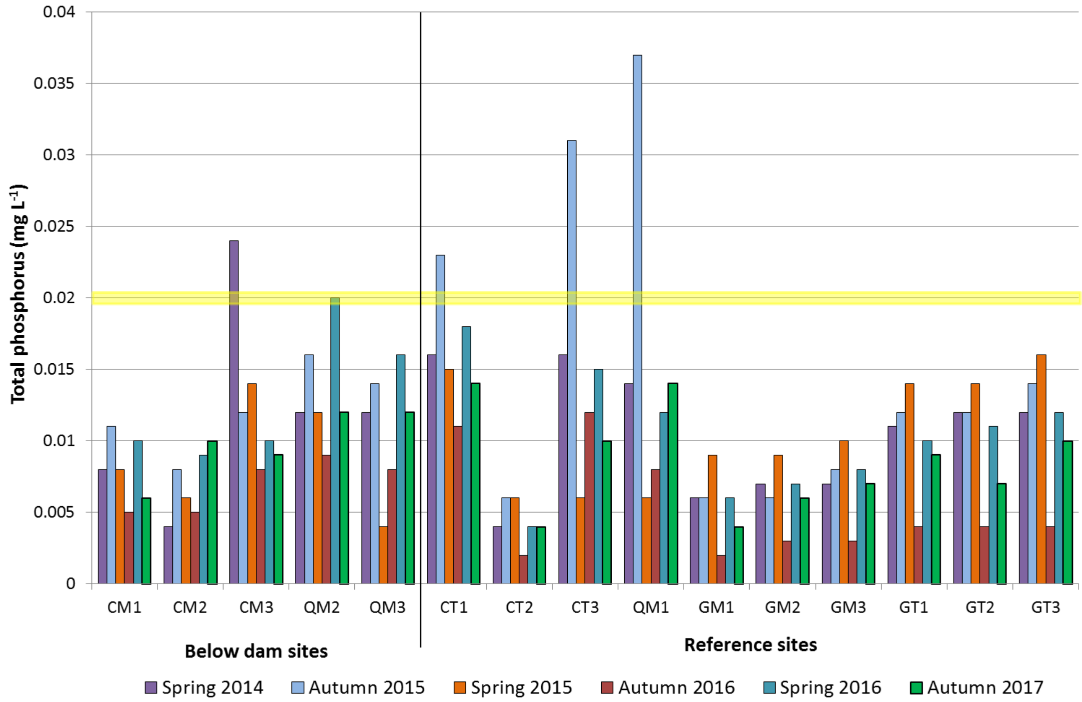
APPENDIX 3: WATER QUALITY FIGURES



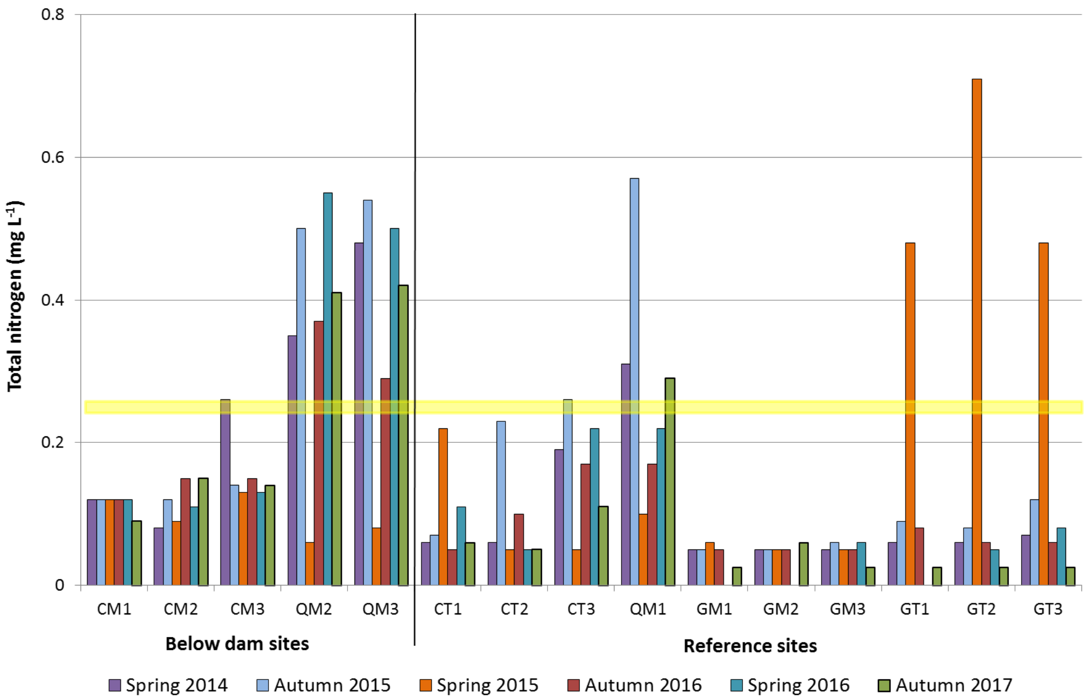
Ammonium (NH_4^+) concentration at all sites from spring 2014 to autumn 2017. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is shaded yellow.



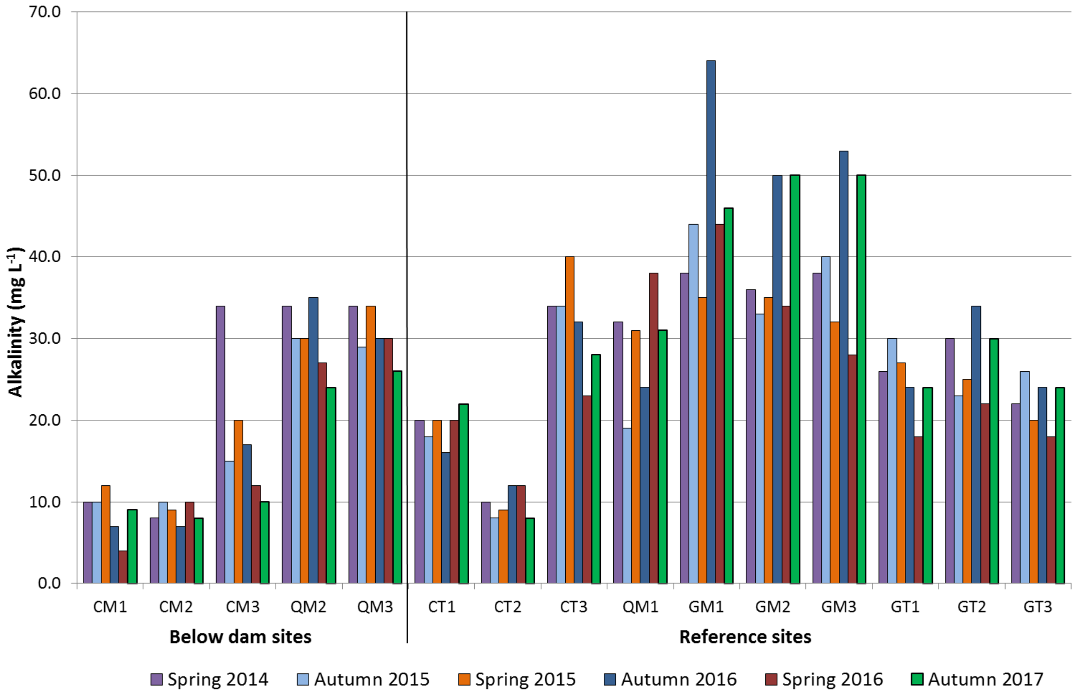
Nitrogen oxide concentrations at all sites from spring 2014 to autumn 2017. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is shaded yellow.



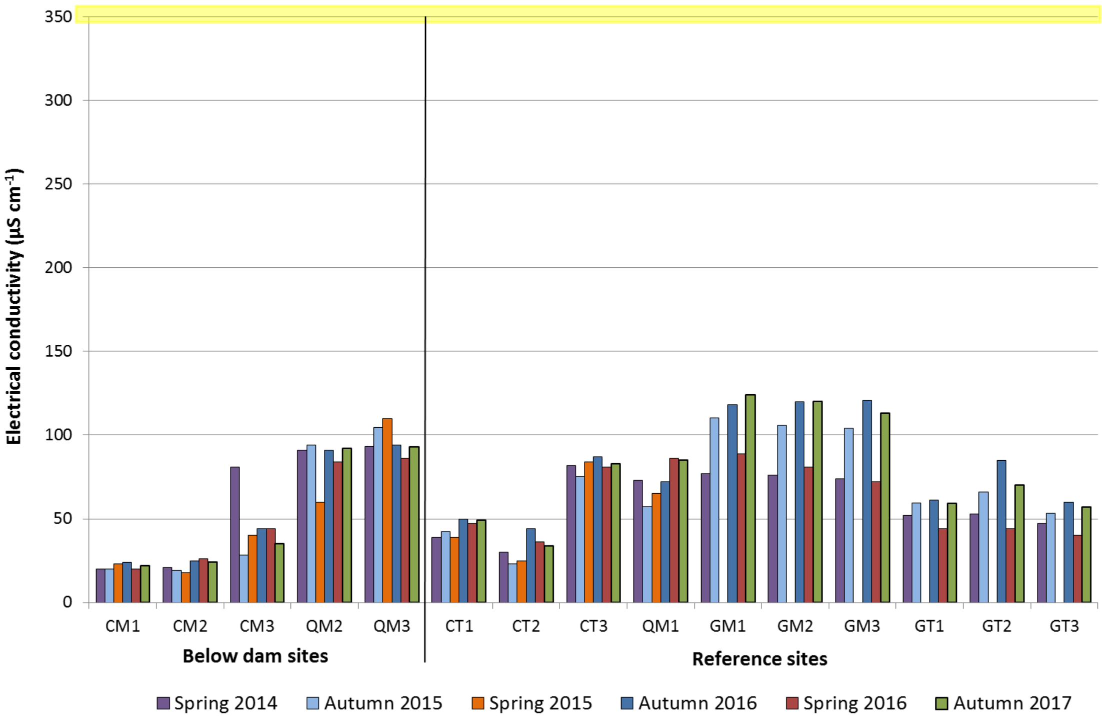
Total phosphorus concentrations at all sites from spring 2014 to autumn 2017. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is shaded yellow.



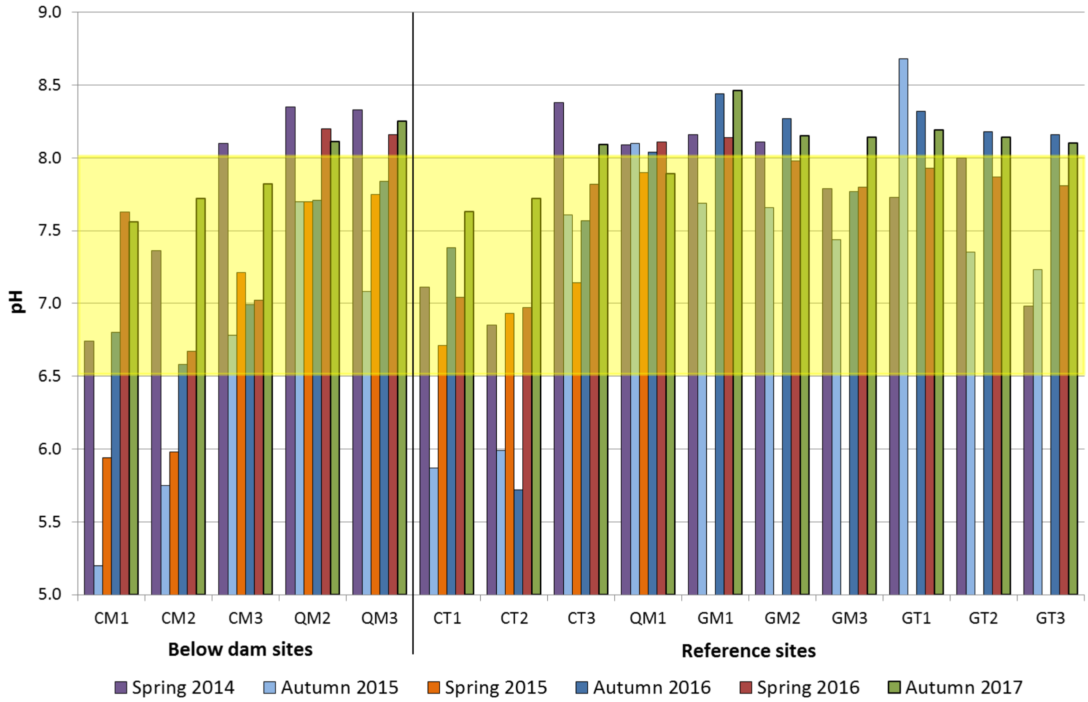
Total nitrogen concentrations at all sites from spring 2014 to autumn 2017. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is shaded yellow.



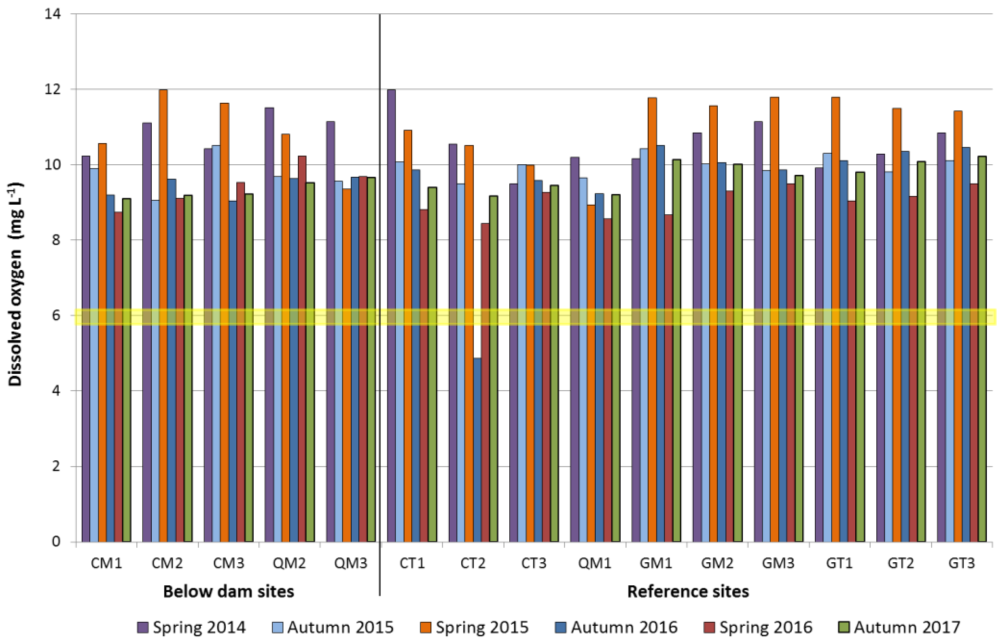
Alkalinity at all sites from spring 2014 to autumn 2017.



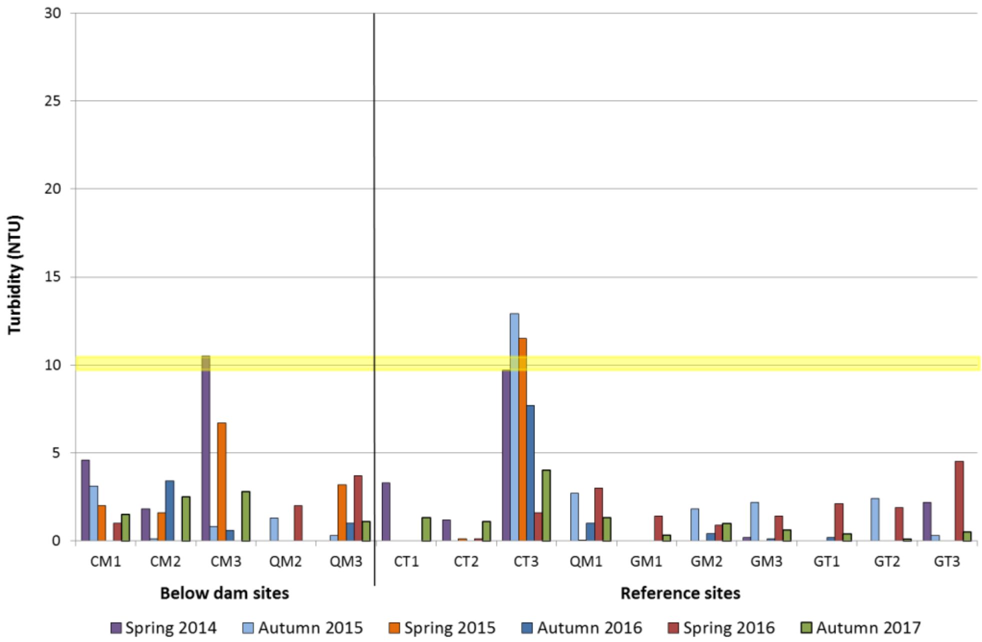
Electrical conductivity at all sites from spring 2014 to autumn 2017. The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is shaded yellow.



pH at all sites from spring 2014 to autumn 2017. The ANZECC/ARMCANZ (2000) guideline range for pH is shaded yellow.



Dissolved oxygen concentration at all sites from spring 2014 to autumn 2017. The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from spring 2014 to autumn 2017. The guideline for maximum turbidity is shaded yellow (Environment Protection Regulation SL2005-38).