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

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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. Here we present the results of assessments undertaken in spring 2017 and autumn 2018.

SPRING 2017 – AUTUMN 2018 RESULTS AND CONCLUSIONS

- Discharge in the six months prior to sampling in spring 2017 was generally lower than discharge in the six months prior to sampling in Autumn 2018 in some of the sites below Corin Dam, below Cotter Dam and Goodradigbee River. Discharge following spring sampling was consistently low prior to the autumn 2018 sampling in sites below Bendora Dam, below Googong Dam and upstream Googong Dam.
- Water quality parameters at below dam test sites were largely within guideline levels in spring 2017 and autumn 2018, with the exception of pH, nitrogen oxides (NO_x) and total nitrogen (TN) which were above guideline levels at a number of testsites. Click here for more information.
- The majority of test and reference sites met the environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats, except for the test sites downstream of Bendora Dam and immediately downstream of Googong Dam in spring 2017, and the reference site above Googong Reservoir in autumn 2018. Click here for more information
- None of the five test sites met the environmental flow ecological objective of AUSRIVAS bands in either Spring 2017 or autumn 2018. Click here for more information
- Macroinvertebrate community condition at the test sites downstream of Corin, Bendora and Cotter Dams remained in similar condition for both the sampling season (AUSRIVAS band B). The site immediately downstream of Googong Dam decreased in biological condition in autumn 2018 compared to spring 2017. Both test sites below Googong Dam either remained impaired or severely impaired. 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 2017**	**Autumn 2018**	**Spring 2017**	**Autumn 2018**
CM1 (Corin Dam)	< 20	< 20	B	B
CM2 (Bendora Dam)	< 20	< 10	B	B
CM3 (Cotter Dam)	40	< 10	B	B
QM2 (Googong Dam)	40	< 10	B	B
QM3 (Googong Dam)	< 20	< 10	B	C

PROJECT RECOMMENDATIONS

No new recommendations at this stage.

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 2017 and autumn 2018 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 2017 and autumn 2018 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 26th and 28th September 2017 (Table 1) and autumn 16th and 18th April 2018. 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.

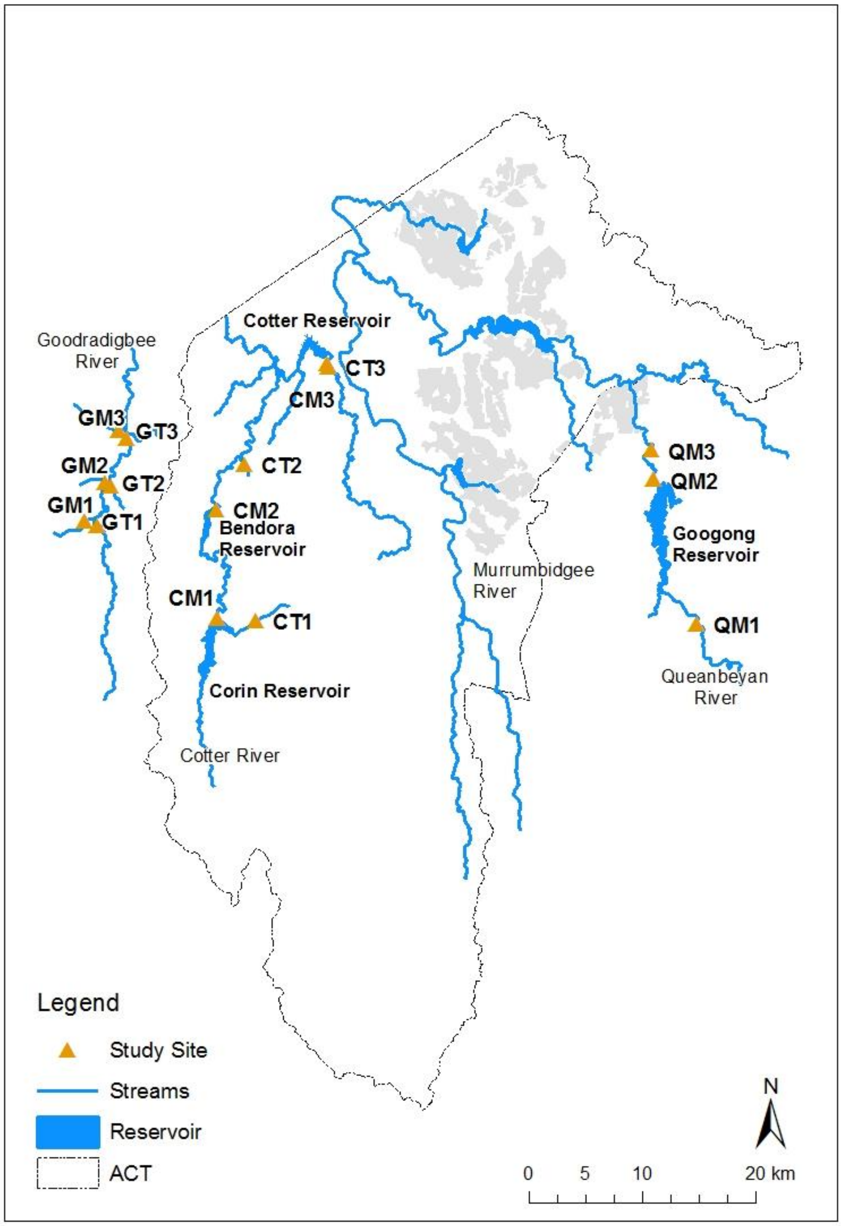


Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

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 2017 and autumn 2018, single factor Analysis of Variance (ANOVA) (SAS 9.3) was used followed by Tukey-Kramer multiple comparisons.

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 2017 and autumn 2018 sampling at below dam sites on the Cotter and Queanbeyan Rivers was dominated by regulated flow conditions prescribed by operational flow requirements under the environmental flow guidelines (ACT Government 2013) (Table 4). All below dam sites met base flow regulations, with sites below Cotter Dam and Corin Dam well in excess of operational requirements. All Dams except for Cotter Dam were below full supply level in the months leading up to sampling in both spring 2017 and autumn 2018. Cotter dam was overflowing from mid-August 2017 until early January 2018. There was a reduction in the variability of operational releases from Bendora Dam in October – November, with weekly variations reduced from 50% to 25% to prevent loss of Macquarie perch eggs and larvae.

Goodradigbee River recorded highest total discharge (85154 ML) and Queanbeyan River (Upstream Googong Dam) recorded least total discharge (13184 ML) from 16th April 2017 to 15th April 2018 (365 days). Mean daily discharge at Goodradigbee River peaked highest in the first week of December 2017 (2672.56 ML d-1) following two days of heavy rainfall totaling 93.6 mm (BOM; station number 071073). Differences in total discharges for the six months prior to sampling varied between spring 2017 and autumn 2018 sampling depending on site, with increases in total discharge for site CM1 (5.12%), CM3 (10.68%) and Goodradigbee River (3.51%) and decrease in total discharge for site CM2 (21.93%), QM2 (111.57%) and QM1 (17.70%) (Figure 2; Broadhurst, et al 2017). The greatest mean discharge at a regulated site, six months prior to sampling occurred downstream of Cotter Dam at site CM3 in both spring 2017 and autumn 2018 assessments (323 ML d-1 and 742.07 ML d-1 respectively) and the least at Bendora Dam at site CM2 in both spring 2017 and autumn 2018 assessments (13.59 ML d-1 and 8 ML d-1 respectively). The total of 536.4 mm rainfall was recorded in the catchment six months prior to sampling in spring 2017 and 605.2 mm rainfall in autumn 2018 sampling, which is more than historical rainfall 503.42 mm and 547.54 mm within 2004 - 2018 respectively (BOM; station number 070349).

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.

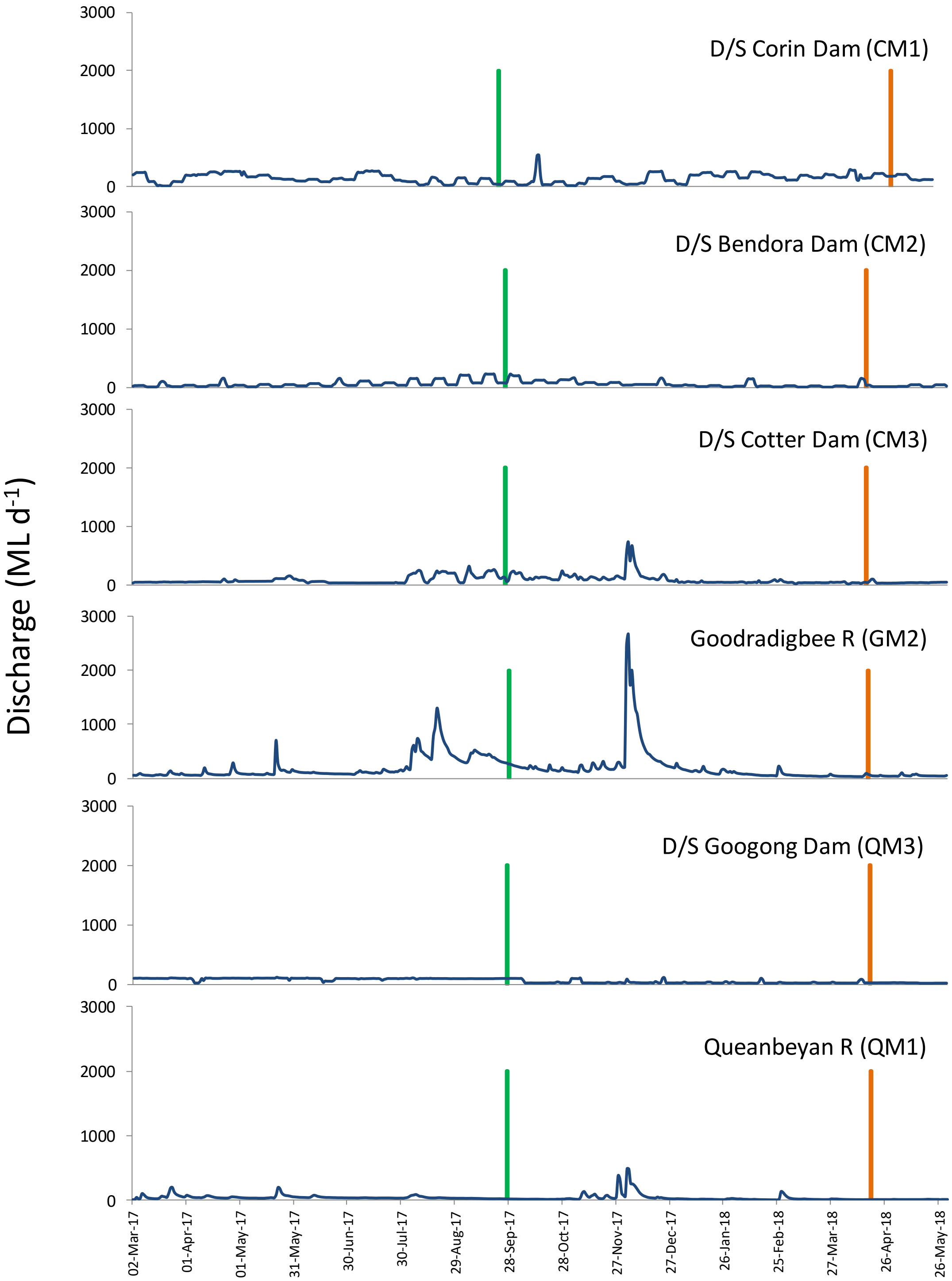


Figure 2. Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 2nd May 2017 to 31st May 2018. Green bar corresponds to spring 2017 sampling and orange bar corresponds to autumn 2018 sampling.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in spring 2017 and autumn 2018. Exceptions were pH at test sites QM2, reference sites CT3 and QM1; nitrogen oxides at test sites CM1, QM2, and QM3; total nitrogen at test sites QM2 and QM3 in spring 2017 (Table 5). For the autumn 2018 assessment pH at test sites at CM1 and CM3, reference sites at GM1; turbidity at reference site CT3; nitrogen oxides at test sites CM1 and QM2, reference site at GM3; 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 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	9.61	27	7.06	9.64	0.0	6	<0.002	0.019	0.12	0.007
	CM2	8.24	26	7.37	10.65	0.0	10	<0.002	0.005	0.1	0.006
	CM3	13.02	45	7.96	10.11	0.0	14	<0.002	0.014	0.14	0.007
	QM2	11.5	111	8.06	10.52	0.0	35	0.002	0.031	0.41	0.01
	QM3	12.53	111	7.91	10.09	0.0	30	0.004	0.024	0.42	0.011
Reference sites	CT1	8.24	54	7.38	9.67	0.0	20	<0.002	<0.002	0.05	0.015
	CT2	10.32	31	6.50	9.75	0.0	10	<0.002	0.002	<0.05	0.003
	CT3	16.04	94	8.31	9.68	1.6	30	<0.002	0.002	0.17	0.012
	QM1	13.45	115	8.02	9.48	0.0	39	<0.002	<0.002	0.22	0.011
	GM1	13.7	82	7.90	9.52	0.0	28	<0.002	0.002	0.06	0.008
	GM2	12.26	81	7.85	9.87	0.0	30	0.002	0.005	0.06	0.008
	GM3	11.97	79	7.85	9.92	0.0	30	<0.002	0.012	0.07	0.008
	GT1	12.99	57	7.82	9.29	0.0	19	<0.002	<0.002	0.07	0.011
	GT2	11.87	58	7.77	9.58	0.0	22	<0.002	<0.002	0.07	0.01
	GT3	10.8	51	7.29	10.16	0.0	20	<0.002	<0.002	0.14	0.018

Table 6: Water quality parameters measured at each of the test and reference sites in **autumn 2018**. 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	11.42	30	6.42	9.61	6.2	2	0.003	0.022	0.11	0.004
	CM2	16.22	29	6.67	8.79	1.1	10	0.022	0.013	0.13	0.006
	CM3	16.14	46	6.31	9.32	2.9	16	0.009	0.01	0.13	0.004
	QM2	18.05	121	7.54	9.49	0.1	37	0.021	0.025	0.36	0.005
	QM3	17.18	167	7.57	9.64	2.0	50	0.022	0.01	0.35	0.005
Reference sites	CT1	6.1	59	6.60	10.37	1.3	6	0.005	0.007	0.09	0.015
	CT2	NO FLOW DURING SAMPLING									
	CT3	15.52	125	7.02	9.61	12.6	46	0.018	0.007	0.15	0.014
	QM1	15.2	117	7.83	9.53	3.7	37	0.024	0.004	0.32	0.006
	GM1	15.21	134	8.07	9.61	0.0	54	0.006	0.009	0.06	0.005
	GM2	13.41	126	7.73	9.5	1.5	55	0.004	0.013	0.17	0.01
	GM3	13.33	129	7.67	9.52	1.4	55	0.019	0.019	0.08	0.006
	GT1	14.1	68	7.64	9.42	1.0	27	0.020	0.012	0.11	0.009
	GT2	12.62	82	7.73	9.61	0.9	20	0.008	0.010	0.13	0.01
	GT3	11.79	62	7.45	9.87	1.7	25	0.020	0.004	0.17	0.011

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 CM3 and QM2 in spring 2017 and reference site QM1 in autumn 2018, which had >20% filamentous cover. Field observations of periphyton cover of riffle habitats were <20% in most of the sites, except for sites CM3, QM2 and GM3 in spring 2017 and site QM1 in autumn 2018 where >20% periphyton cover has been observed (Table 7; Figure 3 and Figure 4).

Mean ash free dry mass concentrations differed between sites in both the spring 2017 and autumn 2018 assessments. In the spring 2017 assessment, mean ash free dry mass (AFDM) was significantly greater at Goodradigbee reference site (GM3) compared to all other sites except for Queanbeyan River test site QM2 ($H_{6,35}$= 19.834; P = 0.003). AFDM at Queanbeyan River test site QM2 was significantly higher than reference site GM1. In the autumn 2018 assessment, mean AFDM below Corin Dam (CM1) was significantly greater than below Bendora Dam (CM2), Cotter Dam (CM3) and Goodradigbee reference site (GM2), and below Googong Dam (GM2) was significantly greater than below Bendora Dam (CM2) and Cotter Dam (CM3) ($H_{6,35}$ = 28.976; P = 0.001). Differences in AFDM between all other sites were not statistically significant for either the spring 2017 or autumn 2018 assessments. (Figure 5).

Mean Chlorophyll-a concentrations differed between sites in both the spring 2017 and autumn 2018 assessments. In the spring 2017 assessment, mean chlorophyll-a concentrations at test site below Corin Dam (CM1) was significantly greater than

Goodradigbee reference site GM1, GM2 and GM3, below Bendora Dam CM2 and below Cotter Dam CM3; the test site below Cotter Dam CM3 was significantly greater than Goodradigbee reference site GM1 and GM2; below Googong Dam QM2 was significantly greater than Goodradigbee reference site GM1 and GM2 and Goodradigbee reference site GM3 was significantly greater than GM1 and GM2 ($F_{6,35}$ = 31.461, P = 0.001). For the autumn 2018 assessment, mean chlorophyll-a concentrations at Goodradigbee reference site GM2 and GM3 was significantly lower than test site below Corin Dam CM1 and below Googong Dam QM2 respectively ($H_{6,35}$ = 32.4, P = 0.001). Differences in Chlorophyll-a concentrations between all other sites were not statistically significant in either of the spring 2017 or autumn 2018 assessments (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 2015 to autumn 2018. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat	Periphyton							Filamentous algae					
	Spr-15	Aut-16	Spr-16	Aut-17	Spr-17	Aut-18		Spr-15	Aut-16	Spr-16	Aut-17	Spr-17	Aut-18
CM1	20	20	<10	<20	<20	<20		20	10	<10	20	<20	<20
CM2	<10	<10	<10	<20	<10	<10		<10	<10	<10	<10	<20	<10
CM3	25	20	<10	<10	40	<10		15	<10	<10	<10	40	<10
QM2	10	15	<10	15	40	<20		10	<10	<10	15	40	<10
GM1	<10	<10	<10	15	<20	<10		<10	<10	<10	<10	<10	<10
GM2	<10	<10	<10	<10	<20	<10		<10	<10	20	<10	<10	<10
GM3	10	10	<10	10	40	<10		10	10	<10	10	<10	<10
QM1	40	<10	<10	20	<20	40		40	25	<10	20	<10	40
QM3	<10	10	<10	15	<20	<20		<10	10	<10	<10	<20	<10

Test sites

Site CM1

Site CM2

Site CM3

Site QM2

Reference sites

Site GM1

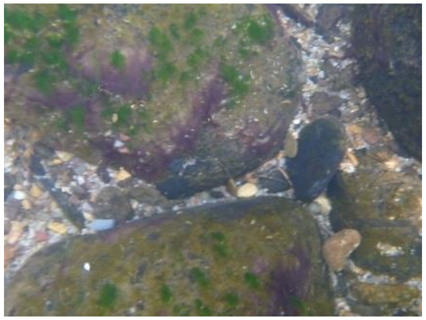
Site GM2

Site GM3

Site QM1

Figure 3. Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in **spring 2017**.

Test sites



Site CM1

Site CM2

Site CM3

Site QM2

Reference sites

Site GM1

Site GM2

Site GM3

Site QM1

Figure 4: Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in **autumn 2018.**

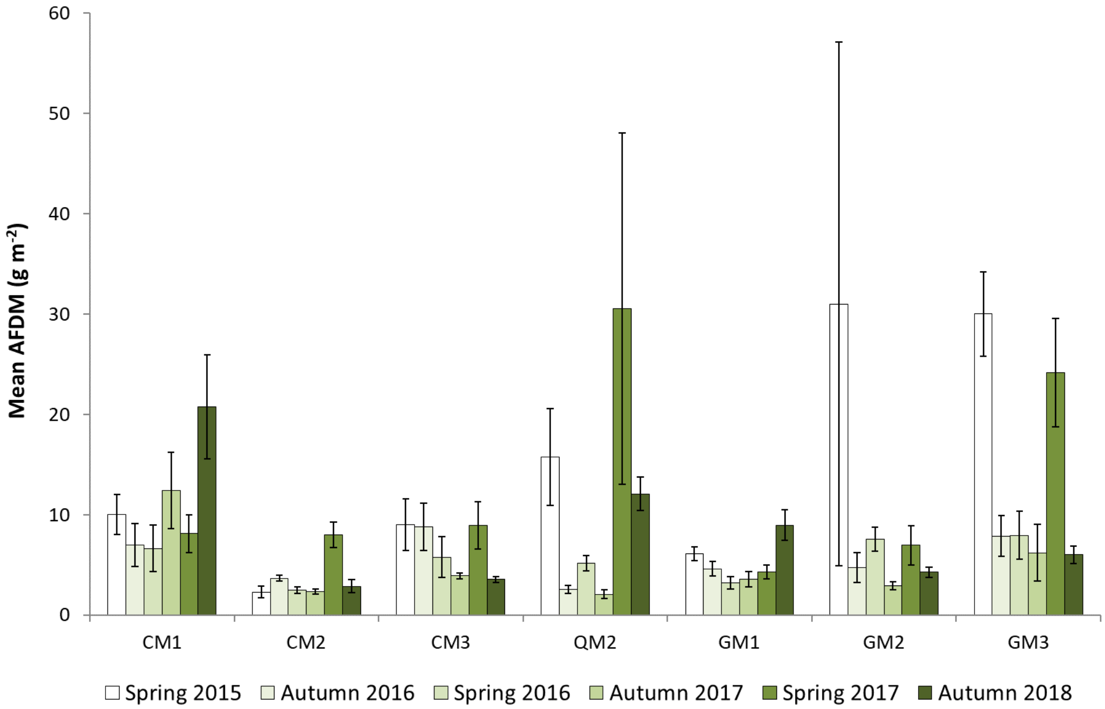


Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2015 to autumn 2018. Error bars represent +/- 1 standard error.

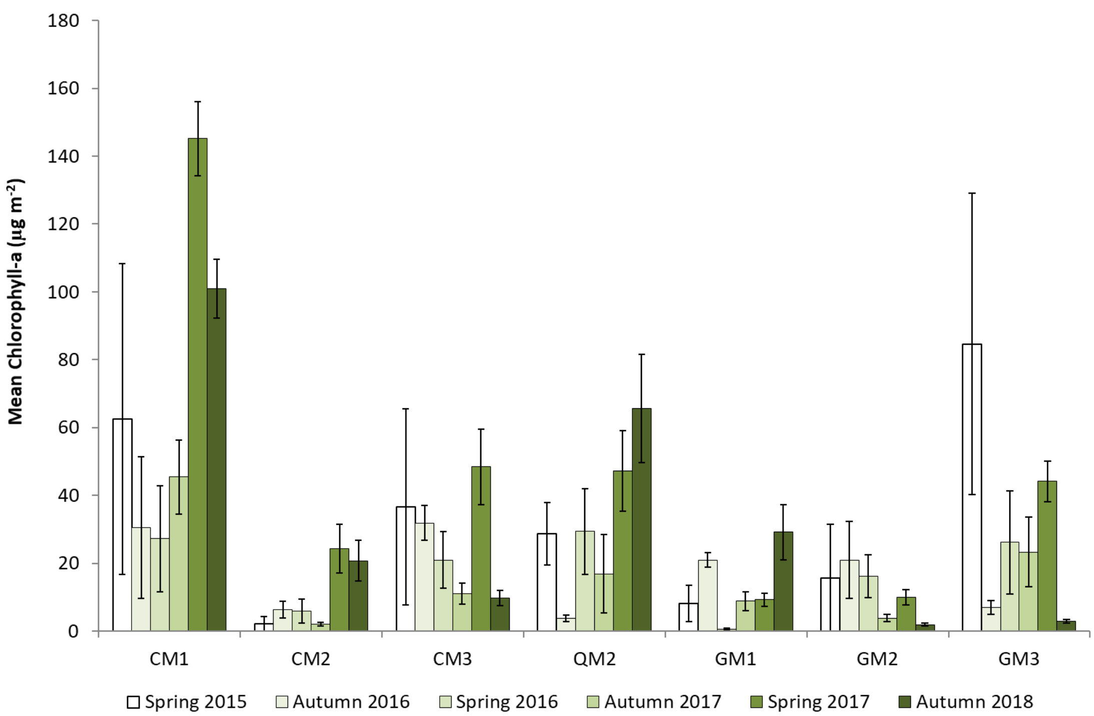


Figure 6: Mean Chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2015 to autumn 2018. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in spring 2017 and again in autumn 2018 (Table 8).

Cotter River test sites have varied in biological condition over the past seven assessments. Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in spring 2017 and autumn 2018 (Table 8). Although CM1 remained in band B for the autumn 2018 assessment, it increased in the AUSRIVAS observed / expected score (O/E) from 0.61 in spring 2017 to 0.78 (0.10 from being assessed as band A similar to reference condition) (Table 8).

Condition of the Cotter River below Bendora Dam (CM2) decreased after spring 2016 assessment and has remained at band B for the past three assessments. Although this site remained significantly impaired (band B) in autumn 2018, and it recorded in increased O/E score to 0.79 from 0.67 in spring 2017 assessment (Table 8). The macroinvertebrate community at CM2 in autumn 2018 was characterized by a high abundance of Simuliidae (Appendix 2).

The condition of the Cotter River below Cotter Dam (CM3) was significantly impaired (band B) in both spring 2017 and in autumn 2018 assessments. However, it has increased its AURIVAS O/E score from 0.73 in spring 2017 to 0.81 in autumn 2018 assessment, which is 0.07 from being assessed as band A (Table 8). Taxa missing from CM3 in spring 2017 but were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model ranged from SIGNAL grades 4 – 9. One of the seven taxa (Hydrobiosidae) was detected in the whole sample scan (Table 9), suggesting that this taxon was present, but in low abundances at this site in spring 2017. Taxa missing from CM3 in autumn 2018 but were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model ranged from SIGNAL grades 4 - 7 (Table 9). One of the six 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 Psephenidae (Table 9), suggesting that this taxon was present, but in low abundances at this site.

Below Googong Dam test site QM2 was assessed as in the middle of band B (significantly impaired) for both the spring 2017 and autumn 2018 assessments. Below Googong Dam test site QM3 was assessed as band B (significantly impaired) in spring 2017 and band C (severely impaired) in autumn 2018. QM3 has been alternating between band B and band C for the past four assessments (Table 8). This variation in biological condition was not evident at the upstream reference site on the upstream Googong Dam (QM1), which has been similar to reference condition (band A) since autumn 2015 (Table 8 and White et al 2009). Test site QM2 had a high estimated macroinvertebrate sample abundance compared to the reference site QM1 (approximately 2-fold see Appendix 2) in autumn 2018. The decrease in AUSRIVAS band score between spring 2017 and autumn 2018 for QM3 was largely driven by an extremely high relative abundance of Simuliidae, Orthocladiinae and Caenidae. (appendix 2). Relative abundance of sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera) was higher than Tolerant taxa (Oligochaeta and Chironomidae) for both test sites and reference sites in autumn 2018, where as in spring 2017 assessment, test sites CM3, QM2 and QM3 and reference site CT2 had higher relative abundance of tolerant taxa. A whole of sample scan of the spring 2017 samples of QM2 and QM3 revealed the presence of Psephenidae and Hydrobiosidae in whole sample scan but not detected in the subsample (Table 9). Both of these taxa were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model in autumn 2018, zero and one (Gomphidae) taxa expected with a ≥50% chance of occurrence by the AUSRIVAS model but not detected in the subsample for QM2 and QM3, respectively (Table 10).

Reference sites were assessed as being similar to reference condition or more biologically diverse than reference in spring 2017. In the autumn 2018 assessment, reference sites varied in biological condition from significantly impaired (band B) to more biologically diverse than reference (band X). The trend of greater biological condition of reference sites in spring compared to autumn has been consistent over the past three years of monitoring (Table 8) The sites CT1, GT1 and GT2 which are tributary to Googradigbee River were assessed as (band X) more biologically diverse than reference site and sites CT2, CT3, QM1, GM1, GM2, GM3 and GT3 were assessed as (band A) similar to reference in spring 2017. Only GT2 was assessed as (band X) more biologically diverse than reference; the sites CT1, CT3, QM1, GM1, GM3 and GT3 were assessed as (band A) similar to reference and sites GM2 and GT1 were assessed as (band B) significantly impaired in autumn 2018 (Table 8).

Reference site biological condition was more variable in autumn 2018 than spring 2017, ranging from significantly impaired (band B) to more biologically diverse than reference (band X) (Table 8). Reference site biological condition either remained similar condition between spring 2017 and autumn 2018 assessments or decreased in condition. Reference sites CT3, QM1, GM1, GM3, GT2 and GT3 did not change its AUSRIVAS band and assessed as band A (similar to reference) in both spring 2017 and autumn 2018 assessments. At least some taxa have been detected in whole sample scan that were predicted with a ≥50% chance of occurrence by AUSRIVAS model but missing from the sub-samples. Taxa detected were Tanypodinae in CT3, GM1 and GT3 and Gomphidae in CT3, GM2, GM3 and QM1 in autumn 2018and Hydrobiosidae in GM1 and GM3 and Hydropsychidae in GM1, GM3 and GT3 in spring 2017. The reference site Kangaroo Creek CT1 was assessed as more biologically diverse than reference (band X) in spring 2017 and similar to reference (band A) in autumn 2018. One (Tipulidae) out of four taxa was 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 in autumn 2018 and one out of two in spring 2017. Cooleman Creek (GT1) which is a tributary to Goodradigbee River, was assessed as more biologically diverse than reference (band X) in spring 2017, and significantly impaired (band B) in autumn 2018. Six taxa were expected with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples, with only one of these taxa (Hydrobiosidae), detected in the whole of the sample scan in autumn 2018 (Table 10) and one taxa (Hydropsychidae) in spring 2017 (Table 9), indicating these taxa were present but in low abundances. Goodradigbee River upstream of Bullflat Creek (GM2) was assessed as similar to reference (band A) in spring 2017 and significantly impaired (band B) in autumn 2018. Seven taxa were expected with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples, with two of these taxa (Elmidae and Gomphidae) detected in the whole of the sample scan in autumn 2018 (Table 10) and none out of two taxa in spring 2017 (Table 9).

Table 8: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2015 to autumn 2018. **Note:** Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

	Below dams sites					Reference sites									
	CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**QM1**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Autumn 2018	**B** (0.78)	**B** (0.79)	**B** (0.81)	**B** (0.77)	**C** (0.63)	**A** (1.00)	Not sampled	**A** (0.9)	**A** (0.96)	**A** (0.99)	**B** (0.64)	**A** (0.89)	**B** (0.87)	**X** (1.18)	**A** (0.9)
Spring 2017	**B** (0.61)	**B** (0.67)	**B** (0.73)	**B** (0.80)	**B** (0.77)	**X** (1.23)	**A** (1.00)	**A** (1.11)	**A** (1.01)	**A** (1.12)	**A** (1.11)	**A** (1.12)	**X** (1.21)	**X** (1.28)	**A** (0.98)
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)

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 2017** (Indicated by an "X") and their SIGNAL 2 grade (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**	**CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
Oligochaeta	**2**	X														
Acarina	**6**		X													
Scirtidae	**6**						X									
Elmidae	**7**		X		X	X										
Psephenidae	**6**	X	X	X	X	X		X	X						X	
Tipulidae	**5**	X														
Ceratopogonidae	**4**															X
Simuliidae	**5**															X
Tanypodinae	**4**	X		X	X	X									X	X
Baetidae	**5**	X	X	X												
Leptophlebiidae	**8**	X	X	X	X	X										
Caenidae	**4**	X						X			X					
Notonemouridae	**6**						X									
Hydrobiosidae	**8**	X	X	X	X	X		X		X		X			X	
Glossosomatidae	**9**	X	X	X	X	X										
Hydropsychidae	**6**		X					X		X	X	X	X		X	
Conoesucidae	**7**			X	X	X			X							
Total bugs		**9**	**8**	**7**	**7**	**7**	**2**	**4**	**2**	**2**	**2**	**2**	**1**	**0**	**4**	**3**

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 2018** (Indicated by an "X") and their SIGNAL 2 (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). **Note:** Site CT2 (Burkes Creek) was completely dry during sampling and macroinvertebrate could not be collected.

Taxon Name	Signal 2 score	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
Hydrobiidae	4				X	X		NO FLOW DURING SAMPLING	X	X		X				
Ancylidae	4				X	X			X	X		X				
Acarina	6					X					X					
Scirtidae	6	X												X		
Elmidae	7		X	X							X				X	
Psephenidae	6	X		X											X	
Tipulidae	5						X									
Simuliidae	5												X			
Podonominae	6		X	X	X	X	X		X	X	X	X	X		X	X
Tanypodinae	4	X	X	X			X		X	X					X	
Chironominae	3		X		X	X										
Baetidae	5	X														
Coloburiscidae	8	X														
Leptophlebiida	8				X	X										X
Caenidae	4	X									X					
Gomphidae	5				X	X			X		X	X			X	X
Gripopterygida	8		X													
Hydrobiosidae	8		X								X		X			
Glossosomatid	9	X														
Hydroptilidae	4			X		X	X					X	X			
Hydropsychida	6										X		X			
Conoesucidae	7			X									X			
Leptoceridae	6		X		X	X										

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 2017 and autumn 2018 assessments. Tolerant OC taxa were dominant (> 50%) at below dam test sites below Cotter Dam (CM3) and below Googong Dam (QM2 and QM3) and reference sites CT2 and GM3 in spring 2017 (Figure 7). In contrast, environmentally sensitive taxa were extremely dominant (>60%) in all sites in autumn 2018 (Figure 8). Environmentally sensitive taxa comprised greater than 50% at Cotter River test sites CM1 and CM2 for both spring 2017 and autumn 2018. All the reference sites in spring 2017 and autumn 2018, except for CT2 and GM3 in spring 2017, environmentally sensitive taxa comprised greater than 60% (Figure 7, Figure 8).

Cotter tributary site on Burkes Creek (CT2) comprised >50% environmentally tolerant taxa in spring 2017. However, comparison cannot be made between seasons in the absence of creek flow in autumn 2018 assessment (Figure 7 and Figure 8). All reference sites in the Goodradigbee Catchment were dominated by environmentally sensitive taxa

(Ephemeroptera and Plecoptera) in both spring 2017 and autumn 2018 assessments, except for GM3 where more of environmentally tolerant taxa (Diptera) were detected (Figure 7, Figure 8, Figure 9 and Figure 10). In spring 2017 assessment site CM3 below Cotter Dam and Below Googong Dam QM2 was dominated by large numbers of Oligochaeta and Chironomidae (Figure 9 and Appendix 2), whereas in autumn 2018 the same site has been dominated by Ephemeroptera (Figure 8 and Figure 10). Filter feeding Simuliidae comprised > 60% of the sub-sample at Queanbeyan River test site QM3 (Figure 9, Figure 10 and Appendix 2) in both spring 2017 and autumn 2018. Below dams tests sites had very low relative abundances of environmentally sensitive taxa Ephemeroptera, compared to reference sites, except for site CM1 and CM2 in spring 2017. However, environmentally sensitive taxa Ephemeroptera dominated all the below dams tests site in autumn 2018 (Figure 9, Figure 10 and Appendix 2).

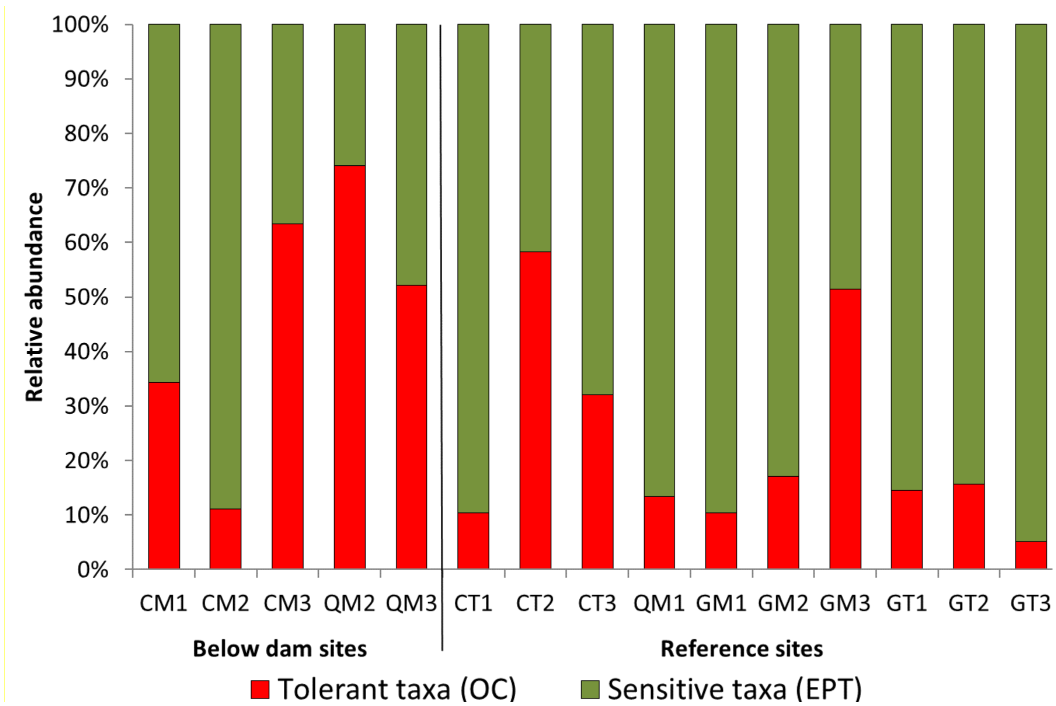


Figure 7. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **spring 2017**.

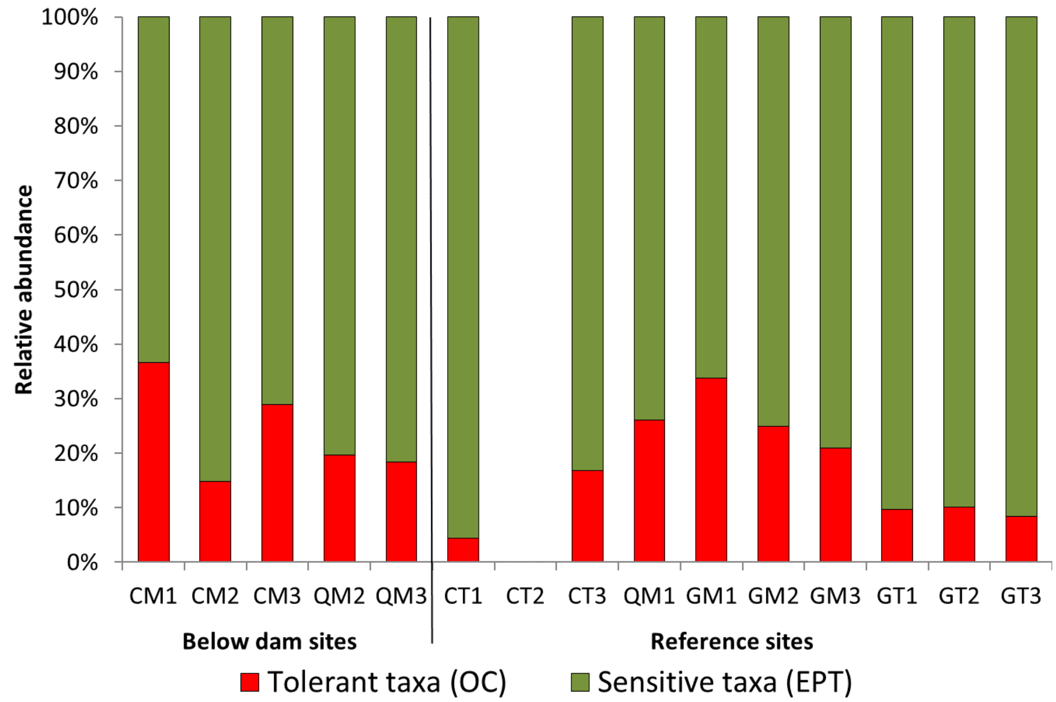


Figure 8: Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **autumn 2018**. Note: The Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

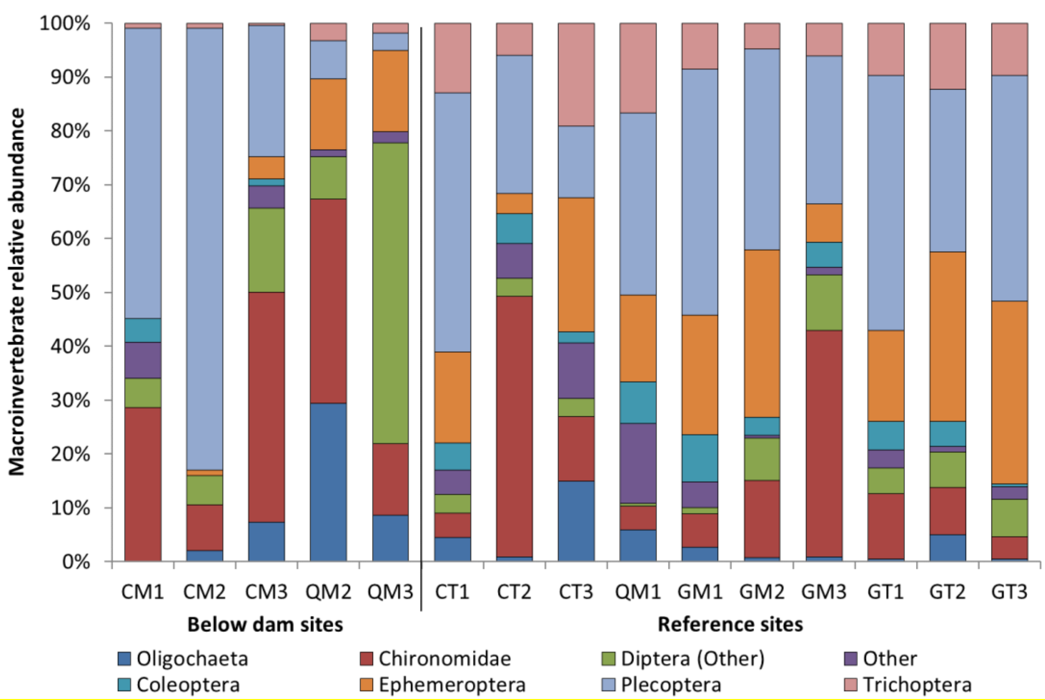


Figure 9: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **spring 2017**.

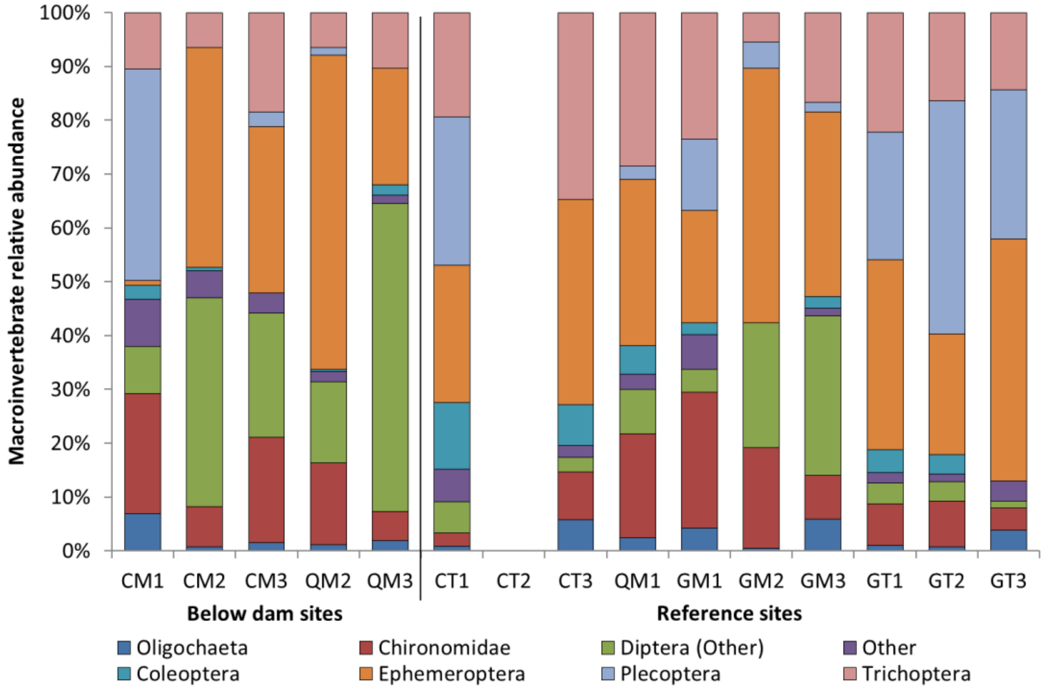


Figure 10: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **autumn 2018**. Note: The Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

In general macroinvertebrate assemblages at reference sites were similar to other reference sites and test sites similar to other test sites for both spring 2017 and autumn 2018 assessments (Figure 11 and Figure 12). The exceptions to this were sites CM1 and QM1 which were not similar to any other sites in spring 2017, and CM1 again grouped out individually in autumn 2018, whilst reference sites CT3 and QM1 grouped out with test sites in autumn 2018. Goodradigbee reference sites grouped out as similar to each other and different from other sites (both test and reference) for both the spring 2017 and autumn 2018 assessments, largely because of a higher relative abundance of Leptophlebiidae in both the assessments (Figure 11 and Figure 12). In spring 2017, all the tributaries of Cotter River (CT1, CT2 and CT3) grouped out with Goodradigbee reference sites, based on high relative abundance of Leptophlebiidae and Coloburiscidae. However, only CT1 has grouped out as similar to Goodradigbee reference sites in autumn 2018. Cotter River test sites CM1 and CM2 and upstream Googong Dam QM1 had macroinvertebrate assemblages dissimilar to all other sites in spring 2017 (Figure 11). Cotter River test site CM1 had macroinvertebrate assemblages dissimilar to all other sites in spring 2017 and autumn 2018 (Figure 12), driven by Corydalidae and Muscidae, and Orthocladiinae and Corydalidae, respectively. Cotter River test site CM3 and Queanbeyan River test site QM2 and QM3 had similar macroinvertebrate assemblages but dissimilar to other sites in spring 2017. These sites were mostly driven by Oligochaeta, Hydropsychidae and Caenidae spring 2017 (Figure 11). Cotter River test sites, Below Bendora Dam CM2 and below Cotter Dam CM3; below Googong Dam test sites QM2 and QM3; upstream Googong

Dam QM1 and Paddy's River CT3 had similar macroinvertebrates assemblage and largely driven by Caenidae and Simuliidae in autumn 2018 (Figure 12). Cotter River test site CM3 (Below Cotter Dam) had a higher relative abundance of environmentally tolerant Orthocladiinae in spring 2017 and Caenidae and Simuliidae in autumn 2018 (Figure 11 and Figure 12).

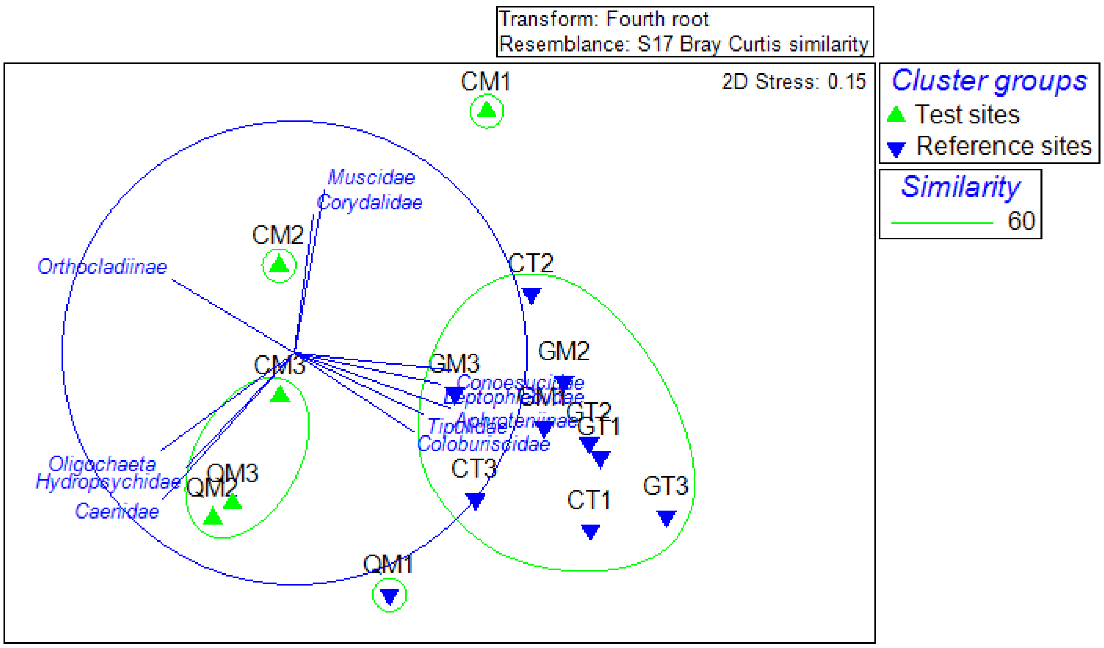


Figure 11. MDS ordination of 60% similarity between macroinvertebrate samples collected in **spring 2017** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa 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.

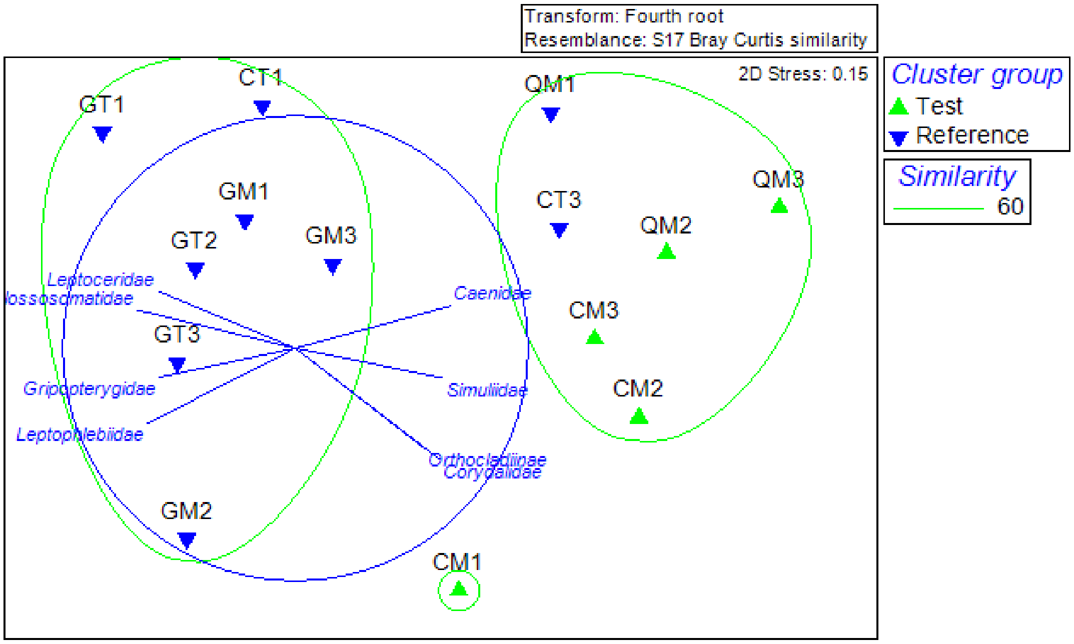


Figure 12. MDS ordination of 60% similarity between macroinvertebrate samples collected in **autumn 2018** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa 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 and nutrient levels at below dam test sites and unregulated reference sites was generally within guideline levels in both spring 2017 and autumn 2018 (Table 5 and Table 6). Deviations for pH and turbidity were rare and marginal, mostly less than 0.1 for pH and within 2.6 NTU for turbidity. These deviations are unlikely to have had an adverse effect on the biological condition of these sites.

Nitrogen oxides (NO_x), total nitrogen (TN) were exceeded at test only sites in spring 2017, but at both test and reference sites in autumn 2018. Nitrogen oxides (NOx) and total nitrogen was well above guideline concentrations at test sites below Googong Dam (QM2 and QM3) in spring 2017, though these levels had reduced in autumn 2018. 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 spring 2017 assessment. 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). However, in autumn 2018 assessment, TN concentrations were higher in QM1, which may have been triggered during high flow events. 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.

Nitrogen Oxides concentrations at the test site below Corin Dam (CM1) were marginally higher than guideline concentrations for both the assessments (Table 5, Table 6). These concentrations are within the range of concentrations for this site over the past decade (0.01 – 0.042) and would be unlikely to directly significantly alter the biological condition of this site.

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 test sites below Cotter Dam (CM3) and below Googong Dam (QM2) in spring 2017 and upstream of Googong Dam, reference site (QM1) in autumn 2018 (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 and autumn.

Although there was some significant difference in Periphyton/algae biomass between sites in both spring 2017 and autumn 2018, these differences were independent of treatment group (i.e. there was no pattern between test and reference sites). 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 spring 2017 and autumn 2018, though again these differences were independent of treatment group. Chlorophyll-a concentrations were significantly lower at the most upstream site on the Goodradigee River reference sites compared to the site immediately downstream of Googong and Corin Dams (QM2 and CM1) for both the assessment seasons. 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 both the assessment seasons. The site below Corin dam CM1 has been amongst the sites with the highest Chlorophyll-a concentrations over the past few years, which may be contributing to the impairment of the macroinvertebrate community at this site since spring 2015. Substrate with a high cover is filamentous algae provides undesirable habitat for most macroinvertebrate taxa. Recent elevated NOx levels may be contributing to higher algal productivity at this site, along with low flow variability leading up to autumn 2018 sampling.

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at all five below dam test sites in both spring 2017 and autumn 2018 and therefore failed to meet the environmental flow ecological objective of being similar to reference condition. The reasons behind each site failing to meet the objective are complex to interpret and often differ depending on site. Reference sites were generally similar to reference condition, though there was some deviation from this with several sites being more biologically diverse in spring 2017 and two sites being significantly impaired in autumn 2018 (Table 8).

The Cotter River test site below Corin Dam (CM1) remained significantly impaired in both spring 2017 and autumn 2018 assessment and has been for the past three years. Although this site remained in band B in autumn 2018, it had an increase in the AUSRIVAS score O/E, resulting in it being only 0.10 from band A (similar to reference). The increase in condition of the macroinvertebrate community in autumn 2018 compared to autumn and spring 2017 may be related to disturbance regime, as there were no large increases in discharge in the weeks leading up to sampling (see site summary sheet Appendix 1).

The Cotter River test site below Bendora Dam (CM2) remained significantly impaired in both spring 2017 and autumn 2018 (Table 8). This site has improved in AUSRIVAS O/E score between spring 2017 and autumn 2018, to be close to band A, where it had been recently assessed (autumn 2015 – spring 2016) (Table 8). This result coupled with the low ash-free dry mass and Chlorophyll-a concentrations indicate that effects of the dam on the river (such as impeding drift recolonisation) at the site are being reasonably well mitigated by the environmental flow release regime.

The Cotter River test site downstream of Cotter Dam (CM3) remained significantly impaired in both spring 2017 and autumn 2018. However, condition of the site in autumn 2018 has improved from spring 2017 from an AUSRIVAS O/E score of 0.73 to 0.81, which is 0.07 score away from being assessed as band A. The flow regime downstream of Cotter Dam was characterized by relatively high discharge during spring 2017 sampling and relative low constant discharge in autumn 2018. The low variable flow may have made conditions more suitable for environmentally sensitive taxa to thrive leading in to autumn 2018 (Belmar, et. Al. 2013). It is possible that the flow regime (be it highly variable or very stable) downstream of Cotter Dam is having an impact on the macroinvertebrate community over the past two assessments, though for differing reasons.

Macroinvertebrate communities at both sites downstream of Googong Dam (QM2 and QM3) were assessed as significantly impaired in spring 2017. In autumn 2018 assessment, QM2 has been assessed as significantly impaired and QM3 as severely impaired. These sites were characterised by a prevalence of early colonisers Simuliidae and Orthocladiinae, and an absence of case building Tricopterans (see Robinson et al. 2003) and Ephemoropterans. It is likely that the macroinvertebrate communities (Environmentally tolerant taxa) at both sites are prevalent due to presence of high periphyton cover and organic matters (leading to high nutrient levels). The presence of several environmentally sensitive taxa in low abundances at these two tests sites in spring 2017 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 2018 assessment where this site was assessed as a band C (the only site in this band in autumn 2018). 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 high peaks in discharge just before sampling and in the six months prior. These high peaks may have acted as a disturbance to the macroinvertebrate community, with early colonisers (such as Simuliidae) likely to be dominant shortly afterwards (Belmar, et. Al. 2013).

Reference sites on the Goodradigbee River 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 Goodradigbee reference sites. 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. Goodradigbee reference site GM2 and its tributary GT1 were assessed as significantly impaired in autumn 2018 (Table 8), though these sites have been alternating between band A, B and X for the past few years and they are generally in reference condition. The impaired condition observed in autumn 2018 may be as a result of natural variation or sampling variation.

CONCLUSION

Water quality parameters at below dam test sites were largely within guideline levels in spring 2017 and autumn 2018, 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 (sites below Googong Dam and Corin Dam). Despite this nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites in autumn 2018. However, in spring 2017 below Cotter Dam (CM3) and below Googong Dam (QM2) had more than 20% filamentous algae coverage of riffle habitats. None of the test sites achieved a band A in either assessment. However, there was increase in AUSRIVAS O/E score for the test sites below Corin, Bendora and Cotter Dam in autumn 2018 compared to spring 2017. Both test sites below Googong Dam decreased their AUSRIVAS band score in autumn 2018 compared to spring 2017, potentially due to disturbance by high peaks in discharge. Recolonisation following disturbance at test sites may be comparatively slow due to connectivity and community resilience related to macroinvertebrate community condition but there is a sign of recovery.

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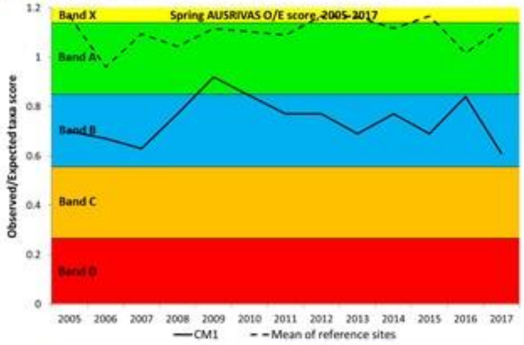
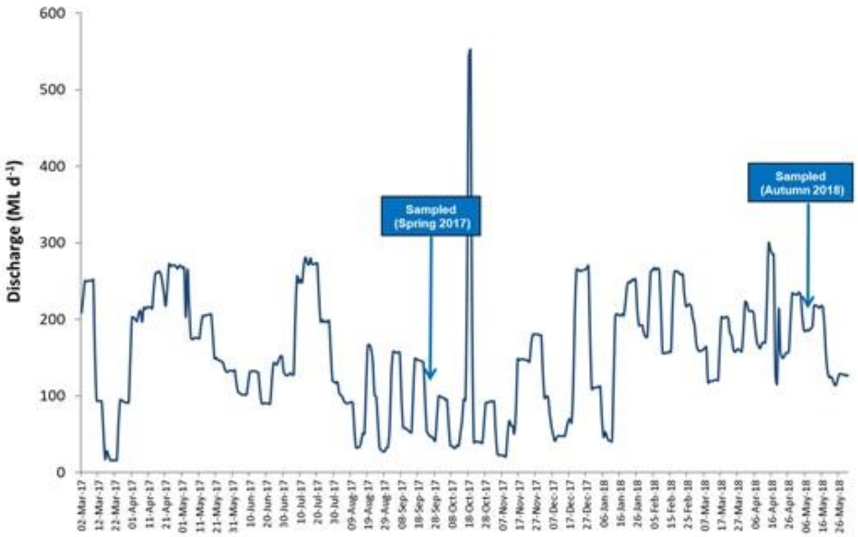
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

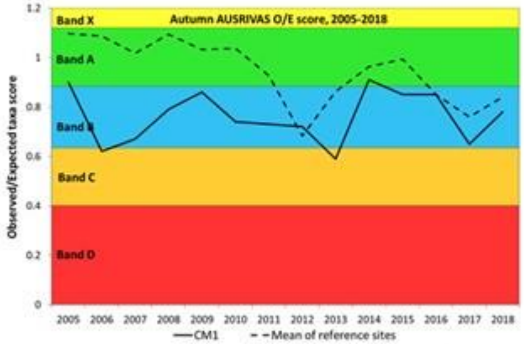
CM1 - Spring 2017 - Autumn 2018

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2017	Autumn 2018	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	<20%	<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 2017	9.61	27	7.06	9.64	0.0	6	<0.002	0.019*	0.12	0.007
Autumn 2018	11.42	30	6.42*	9.61	6.2	2	0.003	0.022*	0.11	0.004

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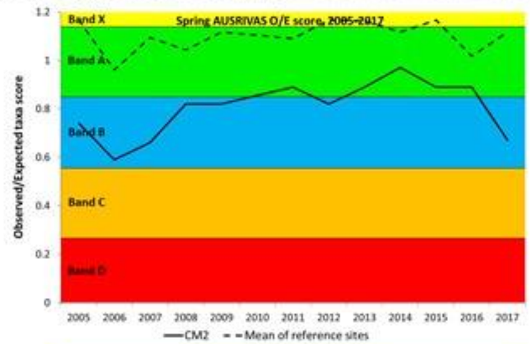
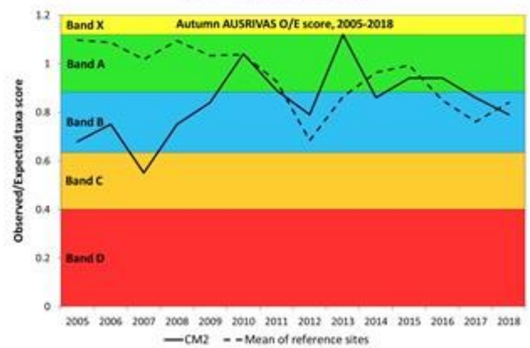
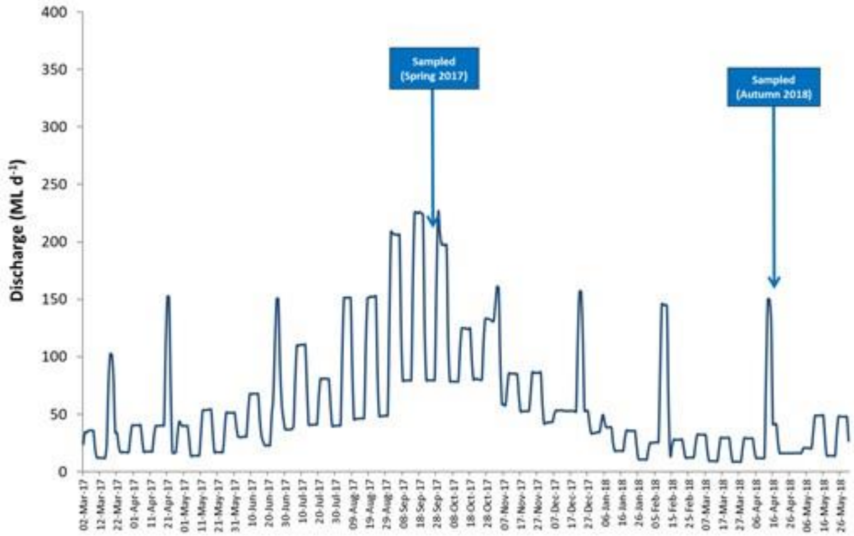
CM2 - Spring 2017 - Autumn 2018

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2017	Autumn 2018	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	<20%	<10%	Yes







Sampling season	Temp. (^{0}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 2017	8.24	26	7.37	10.65	0.0	10	<0.002	0.005	0.1	0.006
Autumn 2018	16.22	29	6.67	8.79	1.1	10	0.022	0.013	0.13	0.006

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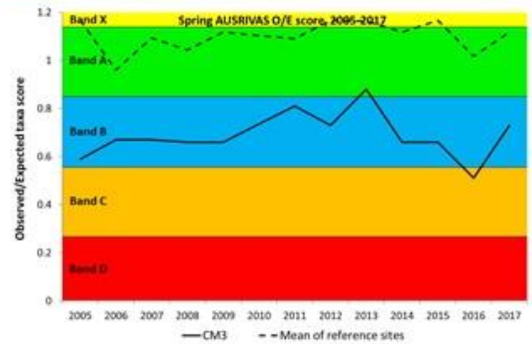
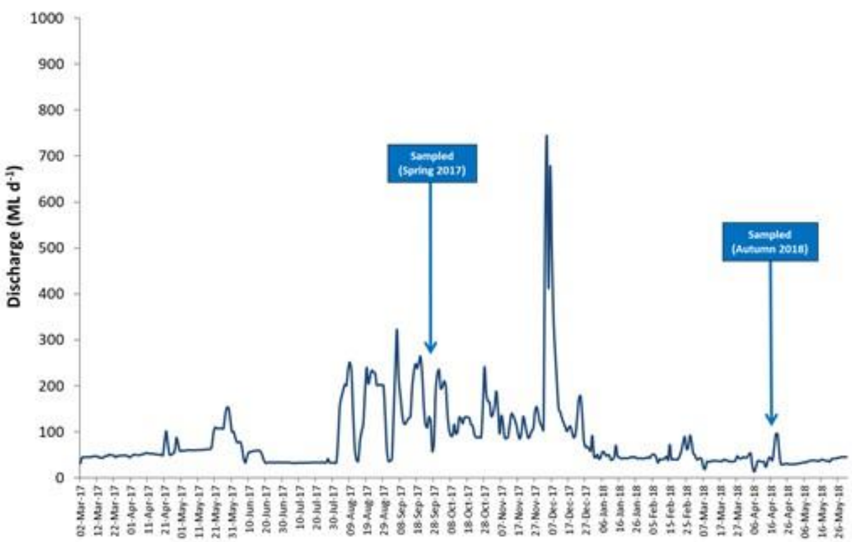
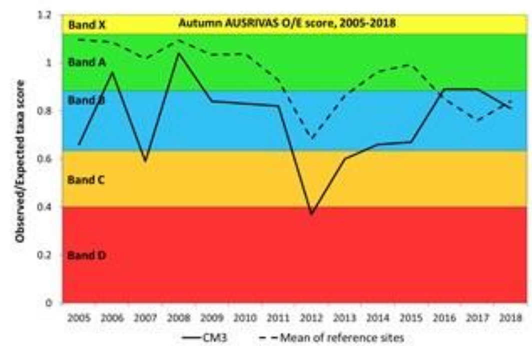
CM3 - Spring 2017 - Autumn 2018

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2017	Autumn 2018	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	40%	<10%	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 2017	13.02	45	7.96	10.11	0.0	14	<0.002	0.014	0.14	0.007
Autumn 2018	16.14	46	6.31*	9.32	2.9	16	0.009	0.01	0.13	0.004

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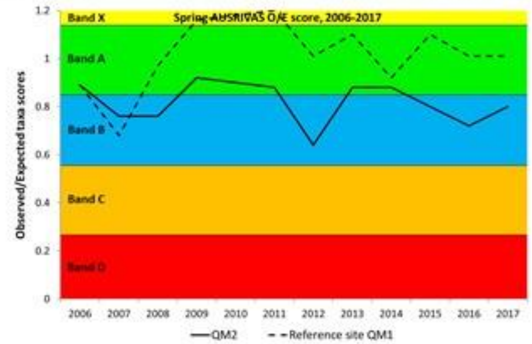
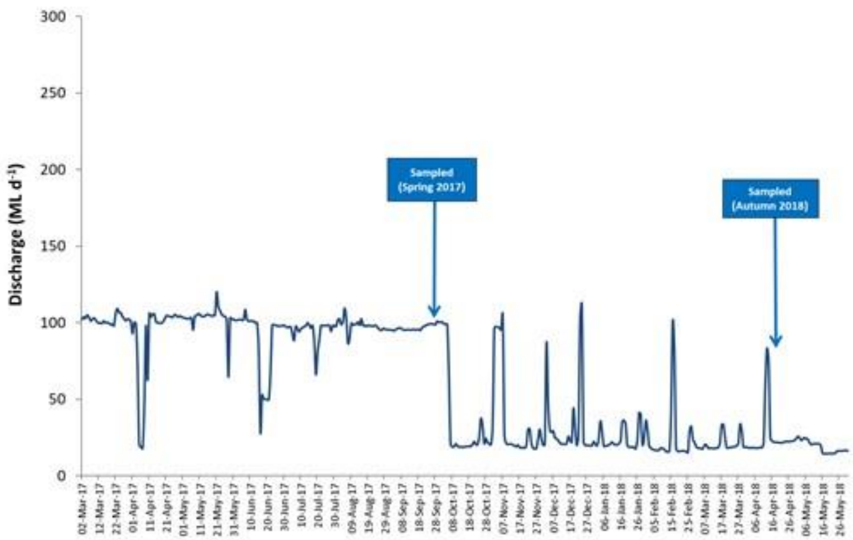
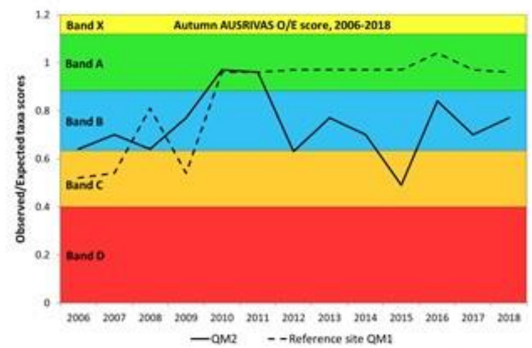
QM2 - Spring 2017 - Autumn 2018

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2017	Autumn 2018	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	40%	<10%	Yes







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 2017	11.5	111	8.06*	10.52	0.0	35	0.002	0.031*	0.41*	0.01
Autumn 2018	18.05	121	7.54	9.49	0.1	37	0.021	0.025*	0.36*	0.005

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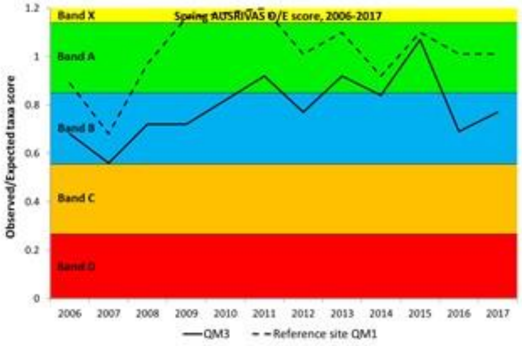
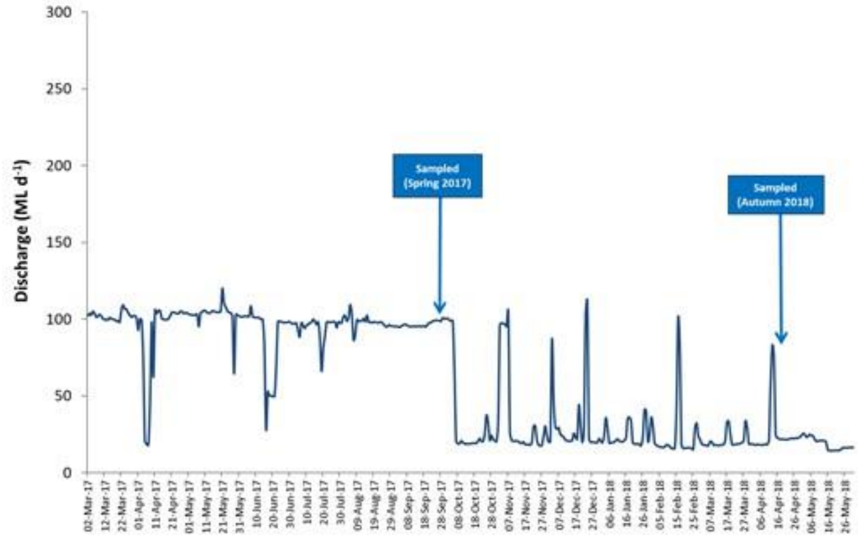
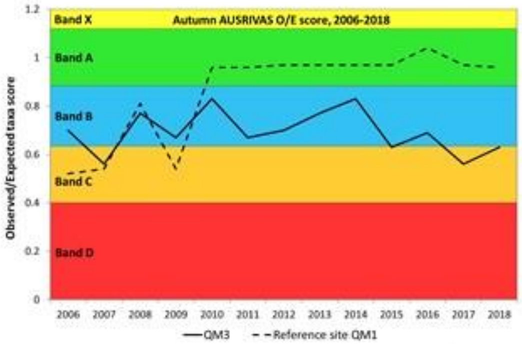
QM3 - Spring 2017 - Autumn 2018

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2017	Autumn 2018	Objective met?
AUSRIVAS band A	Band B	Band C	No
<20% filamentous algae cover in riffle habitat	<20%	<10%	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 2017	12.53	111	7.91	10.09	0.0	30	0.004	0.024*	0.42*	0.011
Autumn 2018	17.18	167	7.57	9.64	2.0	50	0.022	0.01	0.35*	0.005

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APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2017 AND AUTUMN 2018

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

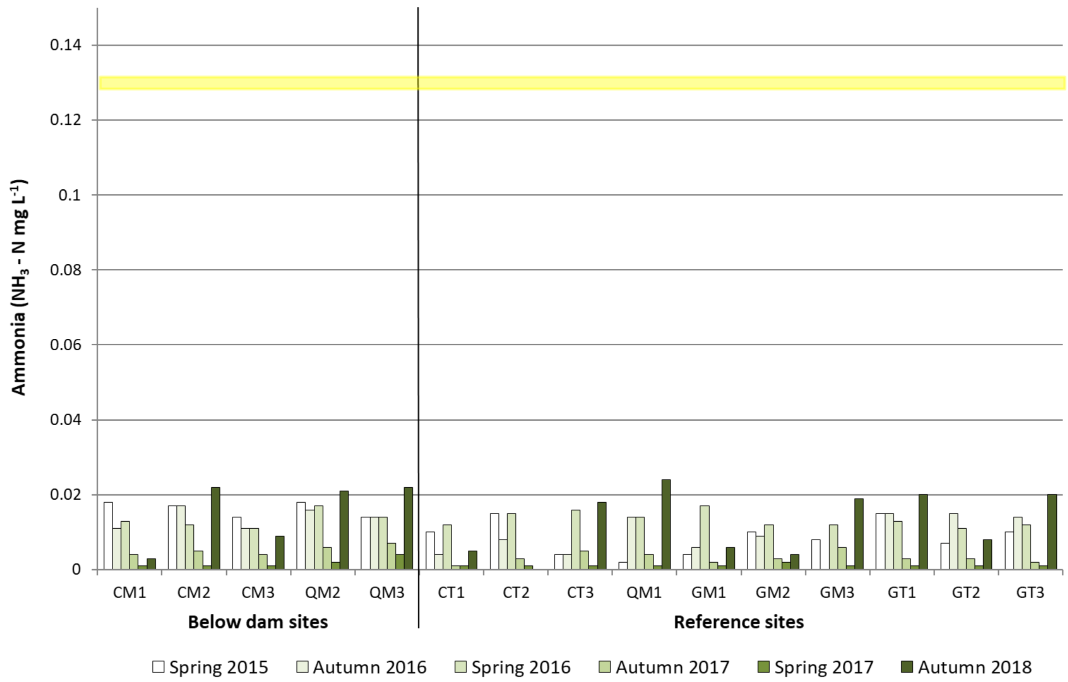
CLASS **Order** Family *Sub-family*	**Signal 2 Grade**	**Sites** **CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
GASTROPODA																
Planorbidae	**4**			1			1									
PELECYPODA																
Sphaeriidae	**5**							9		1						
OLIGOCHAETA	**2**		4	16	71	24	9	2	36	11	3	2	1	13	1	13
ACARINA	**6**	6		6	1	5	8	5	24	10	1	1	7	3	3	32
Coleoptera																
Dytiscidae	**2**						1									
Hydrophilidae	**2**									1						
Elmidae (Adult)	**7**			3			4	1	2			1	1			2
Elmidae (Larvae)	**7**	9					5	11	3	4	5	4	6	8	1	14
Psephenidae	**6**									31	7	5	4	4		1
Diptera																
Tipulidae	**5**		1	1	2	2	1	1	2	2	3	3	7	11	12	
Blephariceridae	**10**														2	
Ceratopogonidae	**4**	1						1						2		
Simuliidae	**5**	2	10	33	15	152	1	1	2	3	25	19	3	3	1	
Athericidae	**8**				1	1	3									1
Empididae	**5**	5			1		1	2	3		1			1		
Dolichopodidae	**3**						1									
Muscidae	**1**	3						2	1							
Aphroteniinae	**8**	1					3			1			4	2	6	
Podonominae	**6**								1		1		1	2		
Tanypodinae	**4**		1				1	1	1	1	1	2	3	3		
Orthocladiinae	**4**	57	14	81	91	33	2	55	25	13	42	82	12	1	1	9
Chironominae	**3**	1	2	12	1	4	3	48	2	10	9	6	5	15	2	1
Ephemeroptera																
Baetidae	**5**				6	13	3	1	14	26	8	2	6	14	10	3
Coloburiscidae	**8**			1			8				1		3		6	
Leptophlebiidae	**8**						19	7	37	53	106	9	23	55	52	3
Caenidae	**4**		2	8	26	29	4		9	11		4	3	13	5	30
Megaloptera																
Corydalidae	**7**	8		1		1				1	1				2	1
Odanata																
Gomphidae	**5**				2					7		2				
Telephlebiidae	**9**			1					1							
Plecoptera																
Gripopterygidae	**8**	111	164	53	17	9	96	55	32	185	138	59	98	79	90	75
Trichoptera																
Hydrobiosidae	**8**						1		6		2		1	2		
Glossosomatidae	**9**						1	5	34	3	4	7	1	1	2	9
Hydroptilidae	**4**		1		3	1			2				1			14
Philopotamidae	**8**						1				1				1	1
Hydropsychidae	**6**	1		1	4	4	1		1					1		9
Polycentropodidae	**7**						4		2				1			
Ecnomidae	**4**				1										1	2
Conoesucidae	**8**	1	1				9	8		22	11	5	8	6	11	2
Helicopsychidae	**8**									7				1		
Calocidae	**9**						8						1		5	
Philorheithridae	**8**											1				
Odontoceridae	**7**												1			
Calamoceratidae	**7**														1	
Leptoceridae	**6**						1		1	3			6	21		
No. of individuals		206	200	218	242	278	200	215	241	406	370	214	207	261	215	222
No. of taxa		13	10	14	15	13	28	18	23	22	20	18	25	23	21	19
% of sub-sample		6	3	5	3	2	3	4	3	4	6	3	2	4	3	1
Whole sample estimate		**3433**	**6667**	**4360**	**8067**	**13900**	**6667**	**5375**	**8033**	**10150**	**6167**	**7133**	**10350**	**6525**	**7167**	**22200**

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in **autumn 2018** at each of the study sites. **Note:** Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

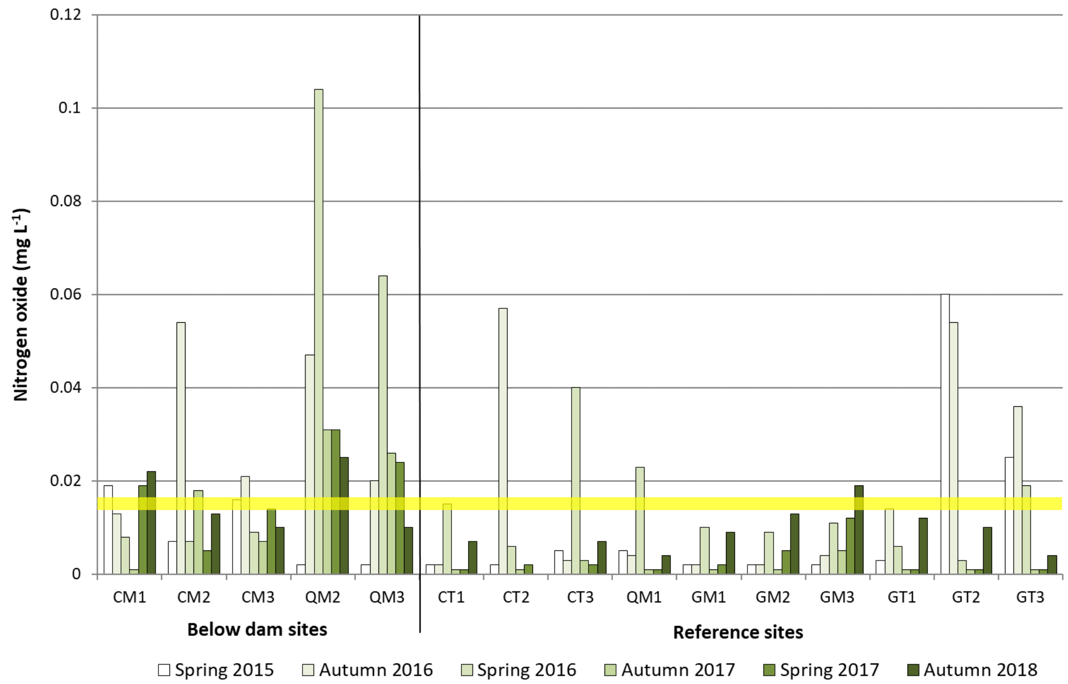
CLASS Order Family *Sub-family*	Signal 2 Grade	Sites															
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
GASTROPODA								NO FLOW DURING SAMPLING								
Planorbidae	4									4					5	
Physidae	1	1														1
PELECYPODA																
Sphaeriidae	5	1	9	3		1	13		1					1		
OLIGOCHAETA	2	16	2	4	3	5	2		13	10	1	13	2	2	9	5
ACARINA	6	13	1	1	2		2		3	3		2	4	2	3	5
Coleoptera																
Hydrophilidae	2															1
Elmidae (Adult)	7	6				1	3						2	1		2
Elmidae (Larvae)	7				1	4	24		17	1		4	5	5		8
Psephenidae	6		2				1			4		1	2	4		
Ptilodactylidae	10						2									
Diptera																
Tipulidae	5	10	2	1	5				2		1	1	5	4	1	1
Ceratopogonidae	4												1			
Simuliidae	5	6	104	60	34	149	2		2	9	46	65		3	2	15
Athericidae	8	4	2		1	1	12		2					3		
Empididae	5									1			2			1
Aphroteniinae	8						1							3	1	
Tanypodinae	4				3	2					1	1	4	1		3
Orthocladiinae	4	48	21	48	37	12	4		10	5	9	8	3	15	3	22
Chironominae	3	3		4			1		10	54	28	9	9	5	6	15
Ephemeroptera																
Baetidae	5		14	25	21	9	5		50	8	4	18	7	4	10	33
Coloburiscidae	8						22			6		6	3	1	10	
Leptophlebiidae	8	2	77	1			32		9	27	92	43	54	53	83	
Caenidae	4		23	56	133	48	3		27	8		9	9	5	4	31
Megaloptera																
Corydalidae	7	5	2	2	3	3										
Odanata																
Diphlebiidae	6								1							
Gomphidae	5			4						8				1		
Telephlebiidae	9		2									1			1	
Plecoptera																
Eustheniidae	10						1									
Gripopterygidae	8	90		7	4		66			31	10	4	49	120	66	5
Notonemouridae	6													1		
Trichoptera																
Hydrobiosidae	8	1		1	1	2	4		3	1		2		1	5	1
Glossosomatidae	9						1			3	1	2	1	1	1	
Hydroptilidae	4	4	1		1				1	1	1			1	1	17
Philopotamidae	8						16			2	1	1		5		1
Hydropsychidae	6	2	13	41	10	18	11		54	18		17		1	2	21
Polycentropodidae	7											1			5	
Ecnomidae	4	8	1	5	5	7	3		19	3	1	3	7	1	2	18
Conoesucidae	8	8	3				12			22	3	10		5	13	
Helicopsychidae	8													2		
Calocidae	9											1				
Odontoceridae	7													1		1
Calamoceratidae	7													8	1	
Leptoceridae	6	1		2					1	5	4		38	20	4	
No. of individuals		229	279	265	264	262	243		225	234	203	222	207	280	238	207
No. of taxa		19	17	17	16	14	24		18	23	15	23	19	31	23	21
% of sub-sample		6	4	3	2	3	2		2	2	1	1	2	2	1	3
Whole sample estimate		**3817**	**6975**	**8833**	**13200**	**8733**	**12150**		**11250**	**11700**	**20300**	**22200**	**10350**	**14000**	**23800**	**6900**

APPENDIX 3: WATER QUALITY FIGURES

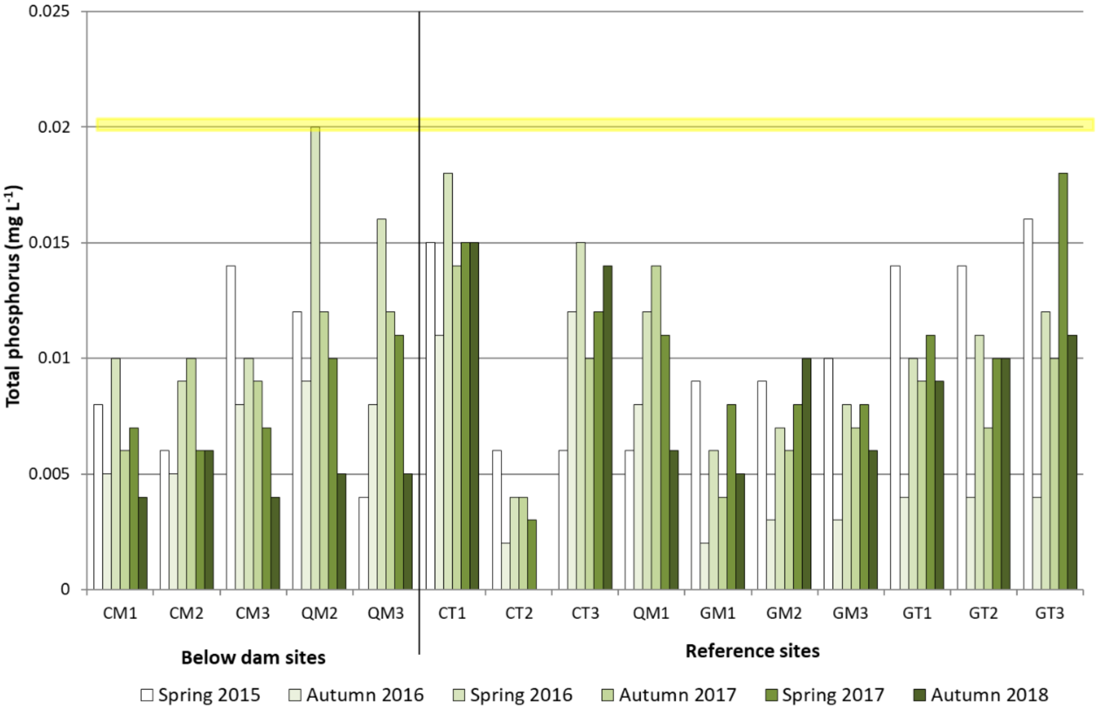
(Note: There was no flow during sampling and water samples could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).



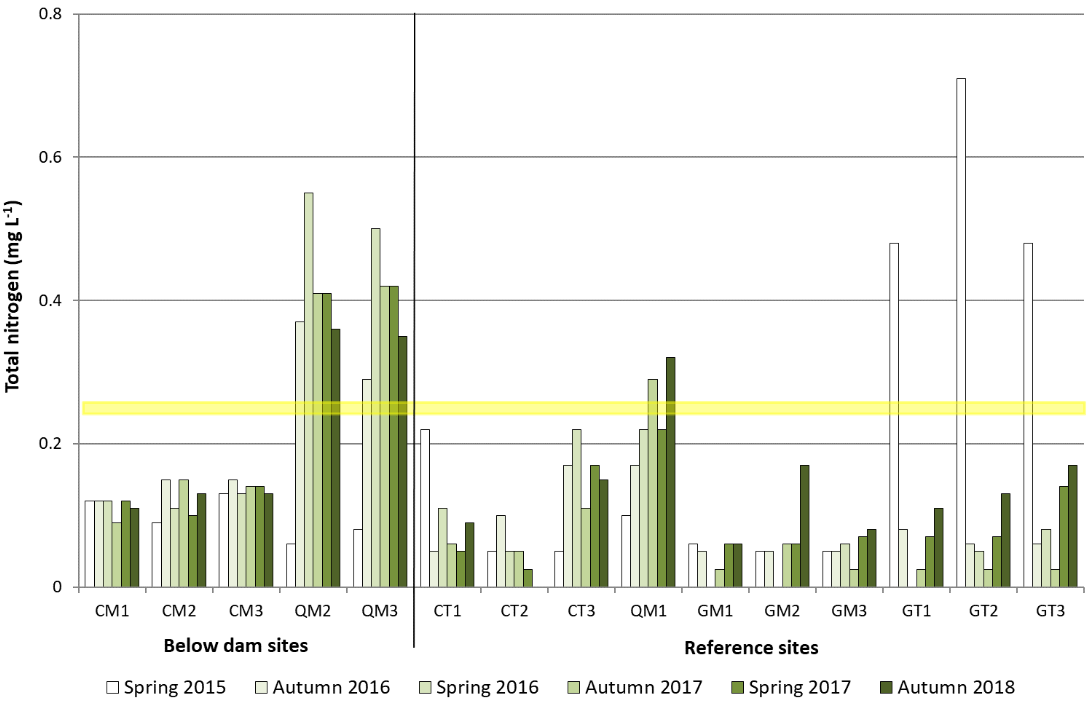
Ammonium (NH_4^+) concentration at all sites from spring 2015 to autumn 2018. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is shaded yellow.



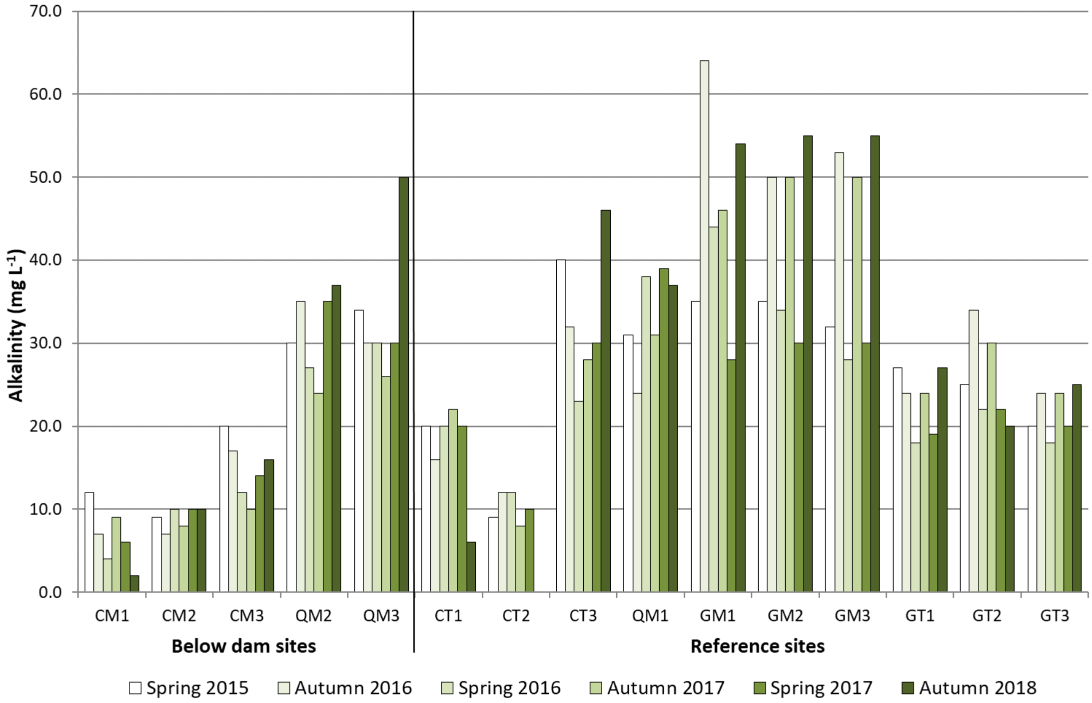
Nitrogen oxide concentrations at all sites from spring 2015 to autumn 2018. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is shaded yellow.



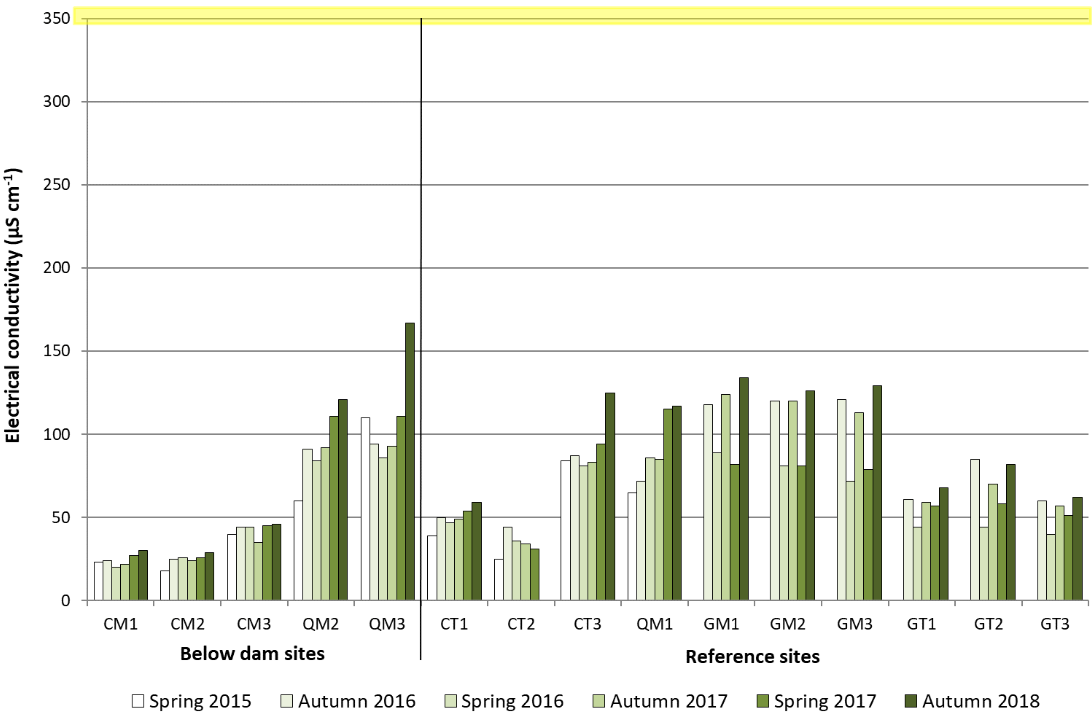
Total phosphorus concentrations at all sites from spring 2015 to autumn 2018. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is shaded yellow.



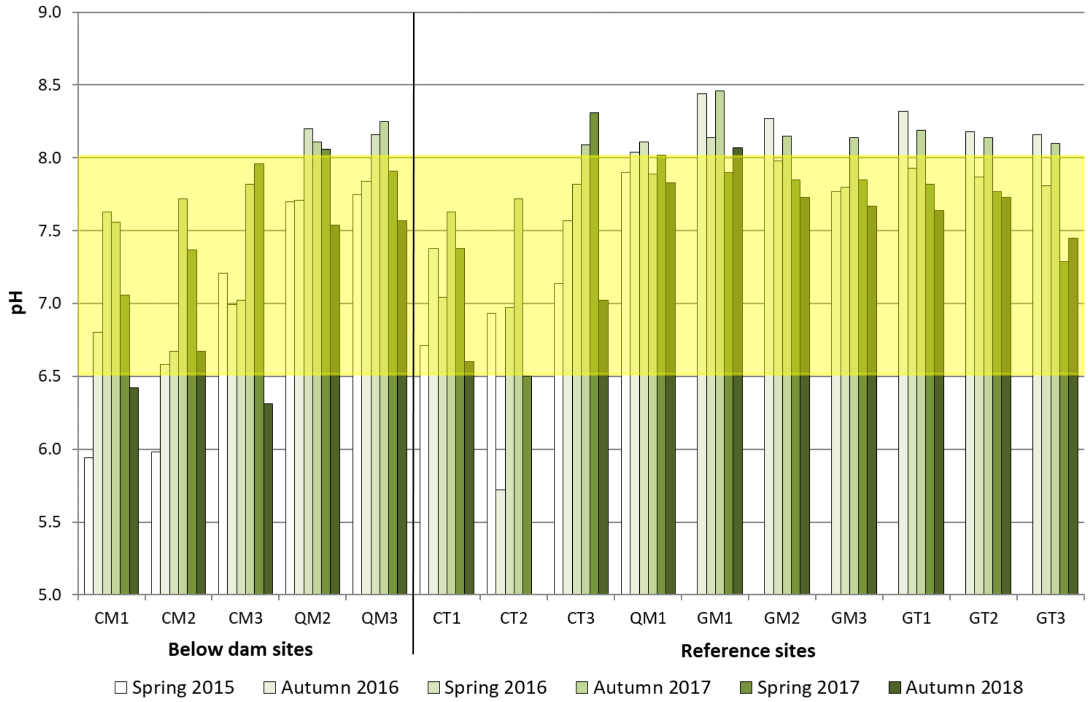
Total nitrogen concentrations at all sites from spring 2015 to autumn 2018. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is shaded yellow.



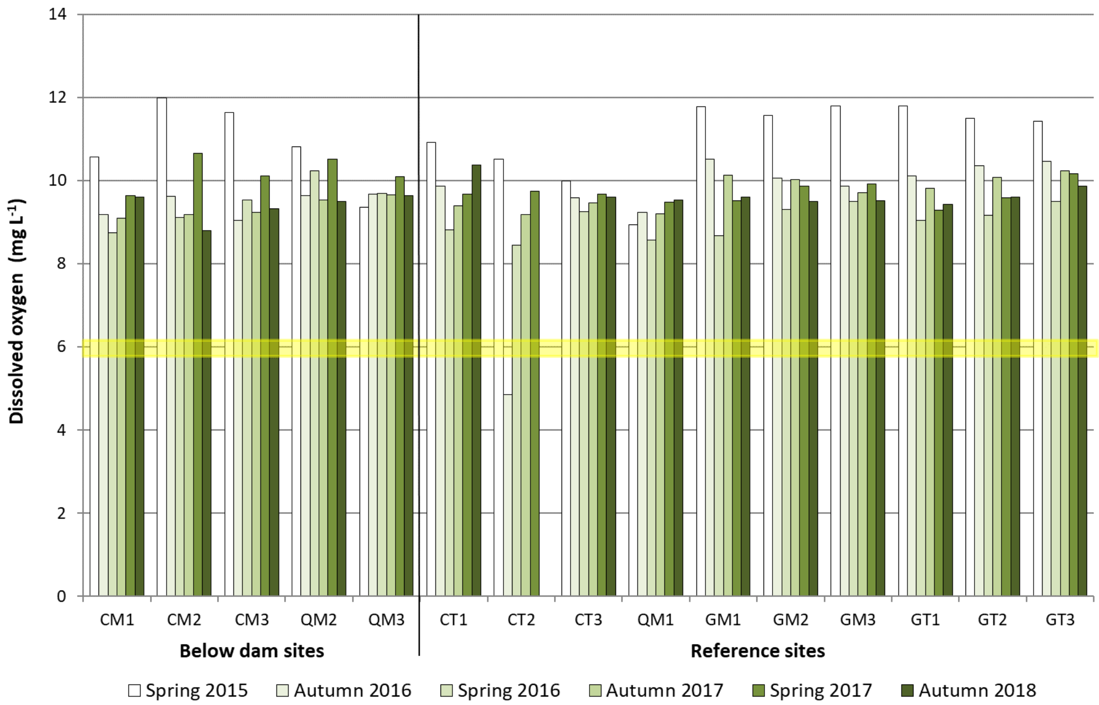
Alkalinity at all sites from spring 2015 to autumn 2018.



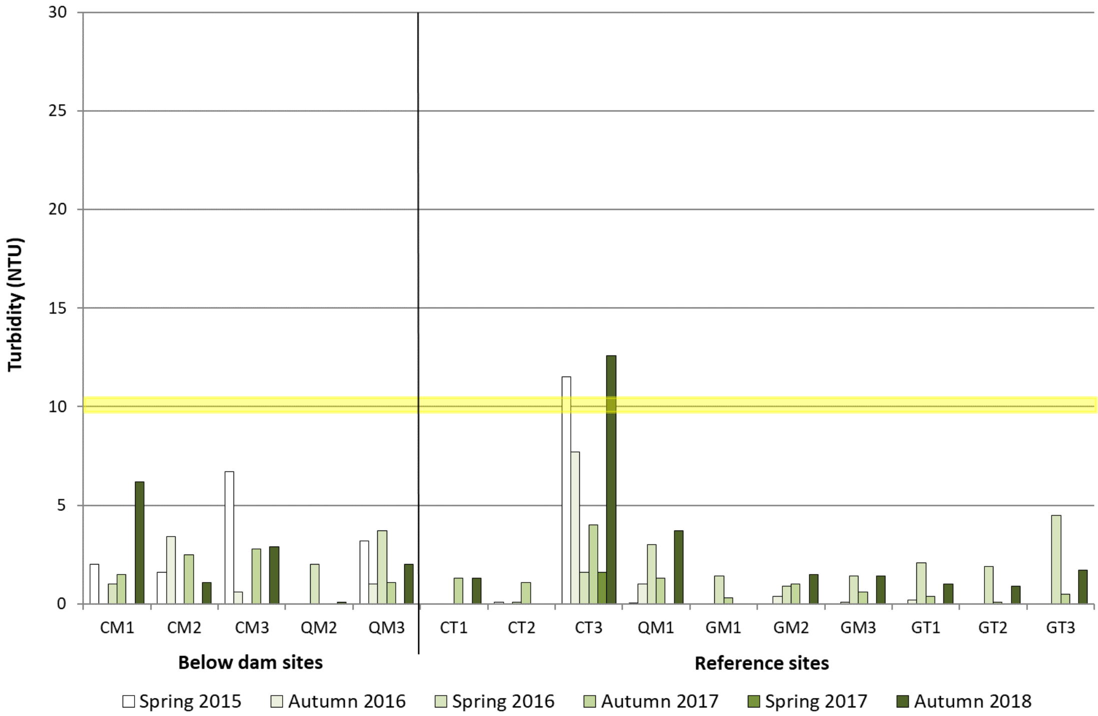
Electrical conductivity at all sites from spring 2015 to autumn 2018. The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is shaded yellow.



pH at all sites from spring 2015 to autumn 2018. The ANZECC/ARMCANZ (2000) guideline range for pH is shaded yellow.



Dissolved oxygen concentration at all sites from spring 2015 to autumn 2018. The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from spring 2015 to autumn 2018. The guideline for maximum turbidity is shaded yellow (Environment Protection Regulation SL2005-38).