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 2018 and autumn 2019.

SPRING 2018 & AUTUMN 2019 RESULTS AND CONCLUSIONS

- Total discharge in the six months prior to sampling in spring 2018 was generally higher than discharge in the six months prior to sampling in autumn 2019 in the sites below Corin Dam, below Bendora and below Googong Dam except for below Cotter Dam which had higher discharge in autumn 2019. Similarly the reference site Goodradigbee River and Queanbeyan River had higher discharge in six months prior to sampling in spring 2018 than six months prior to sampling in autumn 2019. Total rainfall six months prior to sampling was less than historical average rainfall across the entire study area in spring 2018. Rainfall was mixed across the study area leading up to sampling in autumn 2019, with dry conditions prevailing for non-Cotter Catchment sites, while the Cotter Catchment received slightly higher than average rainfall during this period.
- Water quality parameters at below dam test sites were largely within guideline levels in spring 2018 and autumn 2019, with the exception of pH, turbidity, nitrogen oxides (NO_x) total nitrogen (TN) and total phosphorus (TP) which were above guideline levels at a number of test sites. 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 site downstream of Googong Dam (QM2) in spring 2018. Click here for more information.
- There was a general decline in biological condition between spring 2018 and autumn 2019, as indicated by AUSRVAS assessments. Three out of five test sites met the environmental flow ecological objective of AUSRIVAS band A in spring 2018 and none of the five test sites met the environmental flow ecological objective of AUSRIVAS band A in autumn 2019. A number of reference sites were also impacted and reduced from band A to band B in autumn 2019. This indicates that some larger scale climatic conditions may be influencing biological condition. Click here for more information
- Macroinvertebrate community condition at the test sites downstream of Corin and Bendora Dams remained in similar condition for both the sampling season (AUSRIVAS

band B). The sites below Cotter and Googong Dams decreased in biological condition in autumn 2019 compared to spring 2018. Click here for more information

Table 1A: 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 2018**	**Autumn 2019**	**Spring 2018**	**Autumn 2019**
CM1 (Corin Dam)	< 20	<10	B	B
CM2 (Bendora Dam)	< 10	<10	B	B
CM3 (Cotter Dam)	< 20	<10	B	C
QM2 (Googong Dam)	40	<10	A	C
QM3 (Googong Dam)	<10	<10	A	B

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, 2013 and 2019(ACT Government 2019). 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 2019). 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 2019). 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 objectives are met.

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 informs 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 2018 and autumn 2019 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 2018 and autumn 2019 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 17th to 19th September 2018 and in autumn between 8th to 12th April 2019 (Table). 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.

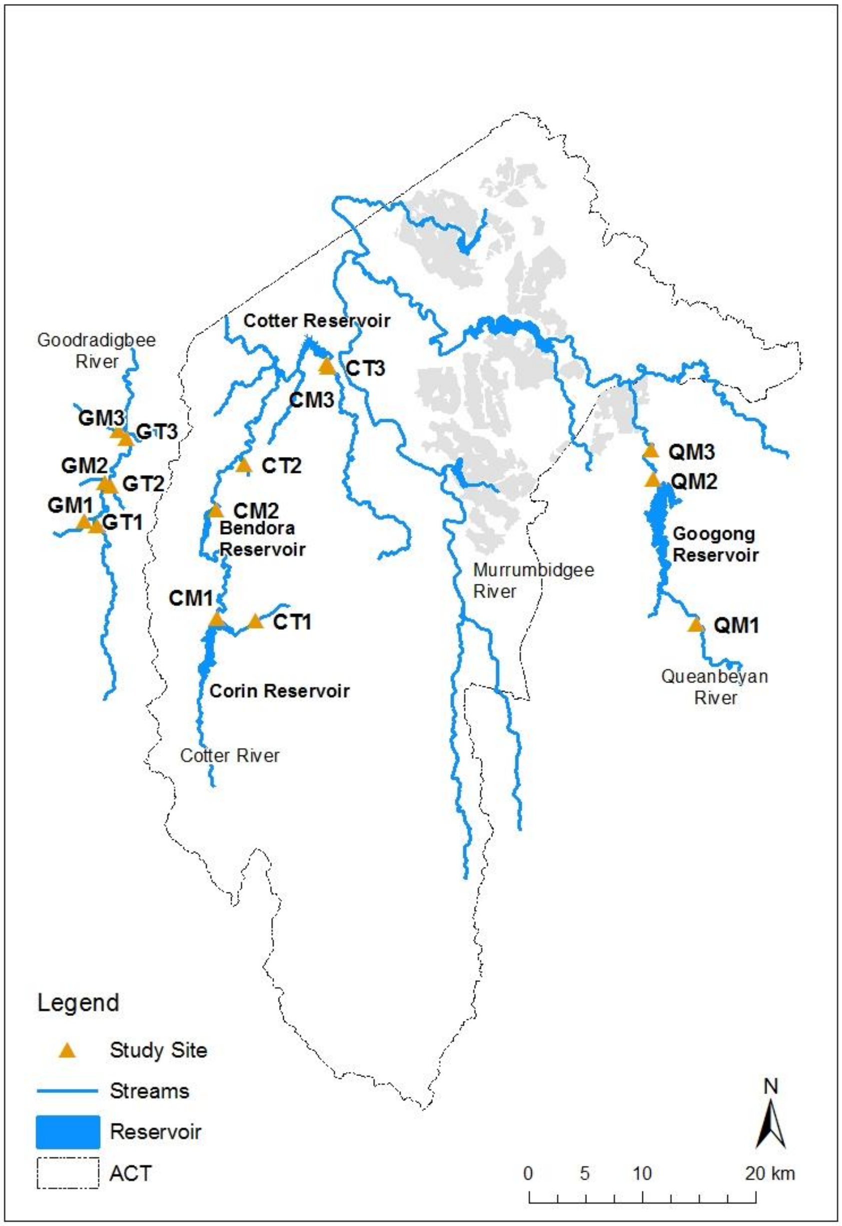


Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

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

Six 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 User's 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). 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, 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 both spring 2018 and autumn 2019 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 2019) (Table). All below dam sites met base flow regulations, with the site below Corin Dam well in excess of operational requirements (especially in spring 2018). All dams were below full supply level in the months leading up to sampling in both spring 2018 and autumn 2019. There was a reduction in the variability of operational releases from Bendora Dam in October – November 2018, with weekly variations reduced from 50% to 25% to prevent loss of Macquarie perch eggs and larvae.

Goodradigbee River recorded highest total discharge (45,488 ML) and Queanbeyan River (Upstream Googong Dam) recorded least total discharge (5,094 ML) from 6th April 2018 to 7th April 2019 (365 days). Differences in total discharges for the six months prior to sampling varied between spring 2018 and autumn 2019 sampling depending on site, with increases in total discharge for site CM3 (5.20%), Goodradigbee River (3.56%) and QM1 (52.88%) and decrease in total discharge for site CM1 (-27.03%), CM2 (-4.66%) and QM2 (-13.13%) (Figure 2). The greatest mean discharge at a regulated site, six months prior to sampling occurred downstream of Corin Dam at site CM1 in both spring 2018 and autumn 2019 assessments (300 ML d^{-1} and 615.04 ML d^{-1}, respectively) and the least at downstream of Googong Dam at site QM2 and QM3 in spring 2018 and in downstream Corin Dam at site CM1 in autumn 2019 assessments (6.44 ML d^{-1} and 1.45 ML d^{-1} respectively). A total of 359.2 mm rainfall was recorded in the Cotter River catchment in the six months prior to sampling in spring 2018 which is less than historical rainfall of 472.9 mm over the same period. The total of 604.6 mm rainfall that fell prior to the autumn 2019 assessment was more than historical rainfall of 541.7 mm from 2004 to 2019 (BOM; station number 070349). A total of 115.6 mm rainfall was recorded in the Queanbeyan River Catchment in the six months prior to sampling in spring 2018 which is less than the historical rainfall of 274.5 mm over the same period. 358.6 mm of rainfall was recorded in the six months prior to sampling in autumn 2019 which is less than the historical rainfall of 382.9 mm from 1966 to 2019 (ALS Environmental, Site 570965).

Table 4: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams (ACT Government 2019).

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.

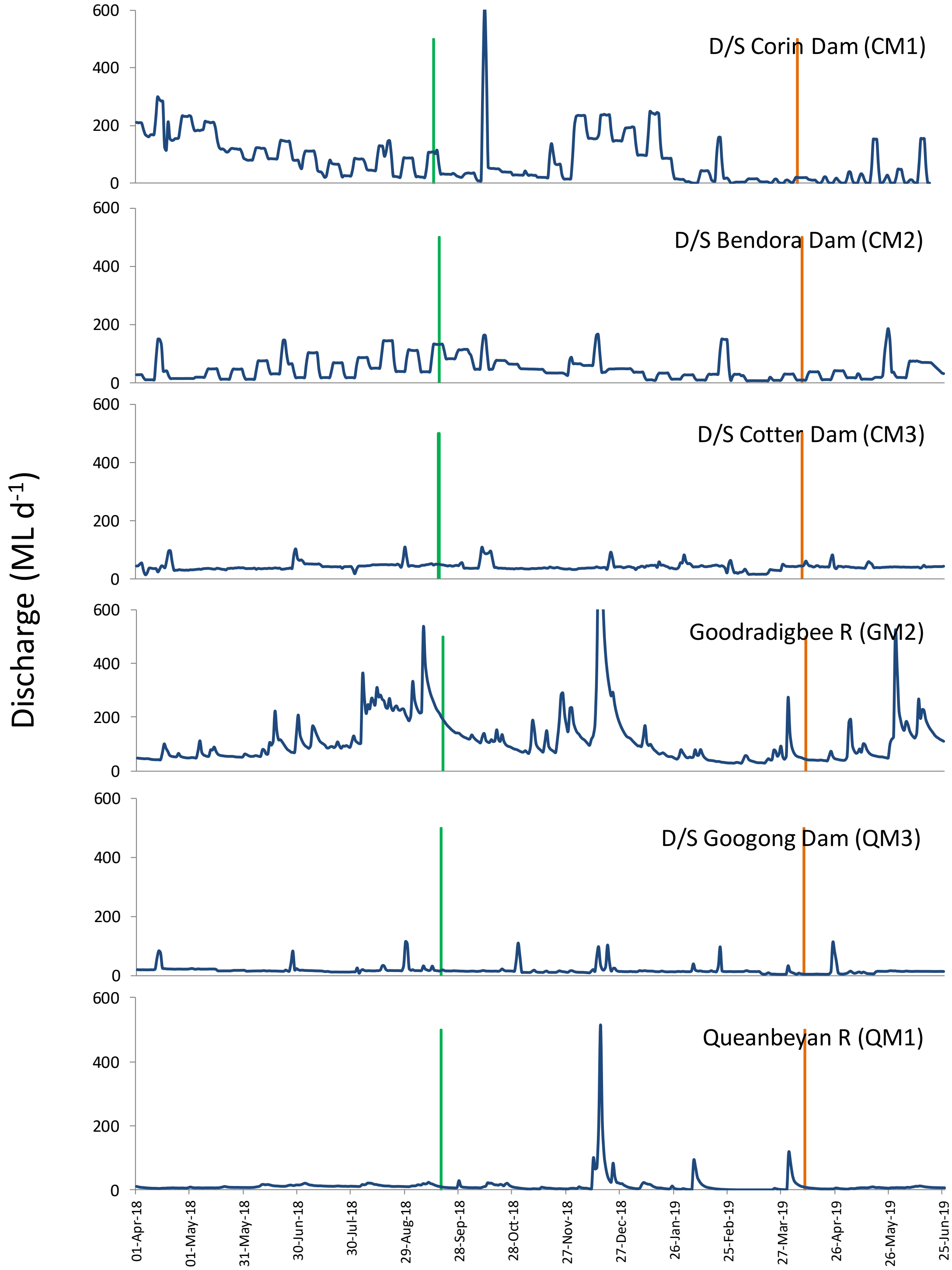


Figure 2. Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 1st April 2018 to 26th June 2019. Green bar corresponds to spring 2018 sampling and orange bar corresponds to autumn 2019 sampling.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in spring 2018 and autumn 2019. Exceptions were pH at test sites QM2, reference sites GM1; nitrogen oxides at test sites CM1; total nitrogen at test sites CM3, QM2 and QM3 and total phosphorus in test site CM3 in spring 2018 (Table). For the autumn 2019 assessment pH at test sites at CM3, QM2, QM3 and reference sites CT3, GM1, GM2, GM3, GT1, GT2 and GT3; turbidity at test site CM3, reference site CT3 and QM1; nitrogen oxides at test sites CM3; total nitrogen at test sites CM3, QM2 and QM3, reference site CT3 and QM1 and total phosphorus at test site CM3, reference sites CT3 and QM1 were outside guideline levels (Table).

Table 5. Water quality parameters measured at each of the test and reference sites in **spring 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	9.03	28	7.07	9.74	0.0	4	0.006	0.017	0.17	0.01
	CM2	7.82	26	6.80	10.72	0.0	4	0.005	<0.002	0.1	0.006
	CM3	13.3	117	7.70	10.31	7.4	8	0.007	0.002	0.29	0.023
	QM2	11.57	120	8.14	11.01	0.0	20	0.021	<0.002	0.34	0.007
	QM3	12.14	172	7.74	10.63	0.0	24	0.016	<0.002	0.35	0.009
Reference sites	CT1	6.54	59	6.75	10.28	0.0	8	0.004	<0.002	<0.05	0.016
	CT2	9.48	38	7.27	10.48	0	4	0.003	<0.002	0.05	0.004
	CT3	13.14	90	7.90	10.67	0.0	16	0.005	<0.002	0.16	0.012
	QM1	11.49	117	7.96	9.79	0.0	18	0.019	<0.002	0.19	0.008
	GM1	11.13	85	8.04	10.24	0.0	18	0.004	<0.002	<0.05	0.006
	GM2	10.1	84	6.98	10.64	0.0	18	0.003	<0.002	<0.05	0.006
	GM3	10.15	82	7.67	10.67	0.0	18	0.007	<0.002	0.05	0.006
	GT1	9.84	57	7.77	10.29	0.0	14	0.015	<0.002	0.07	0.012
	GT2	9.56	59	7.23	10.25	0.0	10	0.014	<0.002	0.06	0.009
	GT3	8.65	52	7.47	10.38	0.0	9	0.017	<0.002	0.07	0.011

Table 6: Water quality parameters measured at each of the test and reference sites in **autumn 2019**. 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	15.09	2	7.03	9.07	0.5	10	0.007	0.008	0.11	0.007
	CM2	17.88	2	7.50	8.63	1.4	10	0.009	0.012	0.12	0.007
	CM3	18.98	82	8.14	9.26	19.1	34	0.014	0.022	0.45	0.032
	QM2	18.63	89	8.23	9.1	1.0	46	0.004	0.012	0.28	0.006
	QM3	17.77	291	8.81	10.27	5.1	100	0.006	0.011	0.31	0.01
Reference sites	CT1	12.01	24	6.79	9.56	0.3	28	0.005	0.004	<0.05	0.014
	CT2	No flow during sampling on 12/04/2019									
	CT3	19.29	85	8.54	10.26	10.6	48	<0.002	<0.002	0.46	0.019
	QM1	17.01	51	7.93	NA	15.2	40	0.074	0.052	0.67	0.035
	GM1	13.63	84	8.77	10.73	0.3	58	0.008	<0.002	<0.05	0.005
	GM2	12.73	79	8.44	10.24	1.1	62	<0.002	<0.002	<0.05	0.006
	GM3	13.53	79	8.34	10.22	2.1	56	0.006	0.006	0.07	0.006
	GT1	11.66	31	8.46	10.29	1.2	30	0.007	<0.002	0.09	0.009
	GT2	9.99	41	8.30	10.81	0.8	36	0.007	0.002	0.09	0.01
	GT3	10.07	24	8.33	10.82	1.2	20	0.006	<0.002	0.09	0.008

FILAMENTOUS ALGAE AND PERIPHYTON

The environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats was achieved at all below dams test sites in both assessments except for QM2 in spring 2018. Field observations of periphyton cover of riffle habitats were <20% in most of the sites, except for sites QM2, GM3, QM1 and QM3 in spring 2018 and all sites observed <20% periphyton cover in autumn 2019 (Table ; Figure 3 and Figure 4).

Mean ash free dry mass concentrations did not differ between sites in both the spring 2018 and autumn 2019 assessments ($F_{6,35} = 1.07$, $p = 0.384$) and ($F_{6,35} = 1.74$, $p = 0.14$), respectively.

Mean Chlorophyll-a concentrations differed between sites in the spring 2018 assessment ($F_{6,35} = 7.30$, $p = 0.001$), with differences being a mix of test and reference sites. The test site below Corin Dam (CM1) had significantly greater mean chlorophyll-a concentrations (75.42 µg m^{-2}) more than CM2 ($p = 0.01$), reference site GM1 by 103.97 µg m^{-2}more ($p = 0.0001$) and GM2 by 94.19 µg m^{-2} more ($p = 0.0007$). The test site CM3 had significantly greater mean chlorophyll-a concentrations (79.39 µg m^{-2}) more than reference site GM1 ($p = 0.005$) and GM2 by 69.61 µg m^{-2} ($p = 0.02$). The reference site GM1 had significantly lower chlorophyll concentrations (65.57 µg m^{-2}) than reference site GM3 ($p = 0.04$) and test site QM2 by 65.22 µg m^{-2} ($p = 0.04$). There was no difference in mean chlorophyll concentration between sites in the autumn 2019 assessment ($F_{6,35} = 1.208$, $p = 0.325$) (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 2016 to autumn 2019. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat	Periphyton							Filamentous algae					
	Spr-16	Aut-17	Spr-17	Aut-18	Spr-18	Aut-19		Spr-16	Aut-17	Spr-17	Aut-18	Spr-18	Aut-19
CM1	<10	<20	<20	<20	<20	<10		<10	20	<20	<20	<20	<10
CM2	<10	<20	<10	<10	<20	<10		<10	<10	<20	<10	<10	<10
CM3	<10	<10	40	<10	<20	<10		<10	<10	40	<10	<20	<10
QM2	<10	15	40	<20	40	<10		<10	15	40	<10	40	<10
GM1	<10	15	<20	<10	<20	<10		<10	<10	<10	<10	<20	<10
GM2	<10	<10	<20	<10	<20	<10		20	<10	<10	<10	<10	<10
GM3	<10	10	40	<10	40	<10		<10	10	<10	<10	<10	<10
QM1	<10	20	<20	40	40	<20		<10	20	<10	40	<20	<20
QM3	<10	15	<20	<20	40	<10		<10	<10	<20	<10	<10	<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 2018**.

Test sites

Site CM1

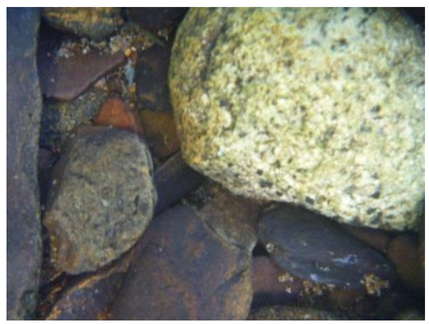
Site CM2

Site CM3

Site QM2

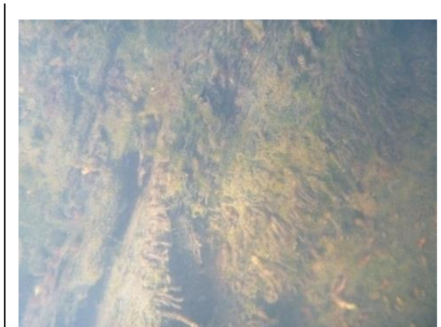
Reference sites

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 2019.**

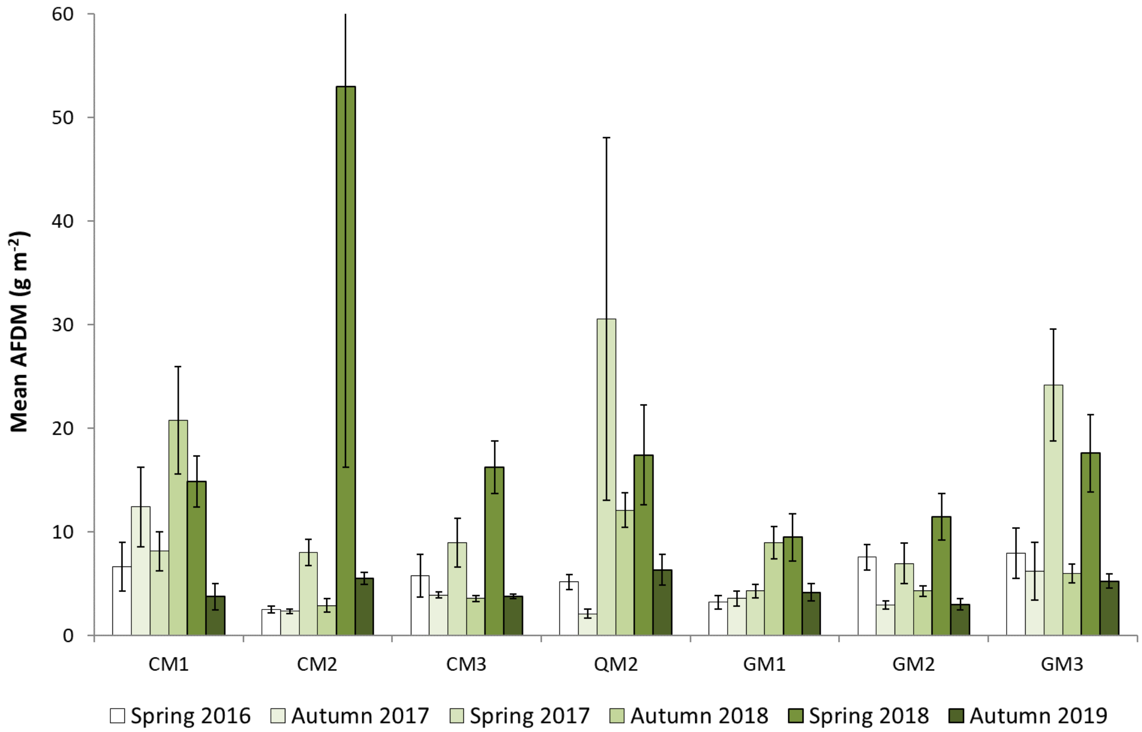


Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2016 to autumn 2019. Error bars represent +/- 1 standard error.

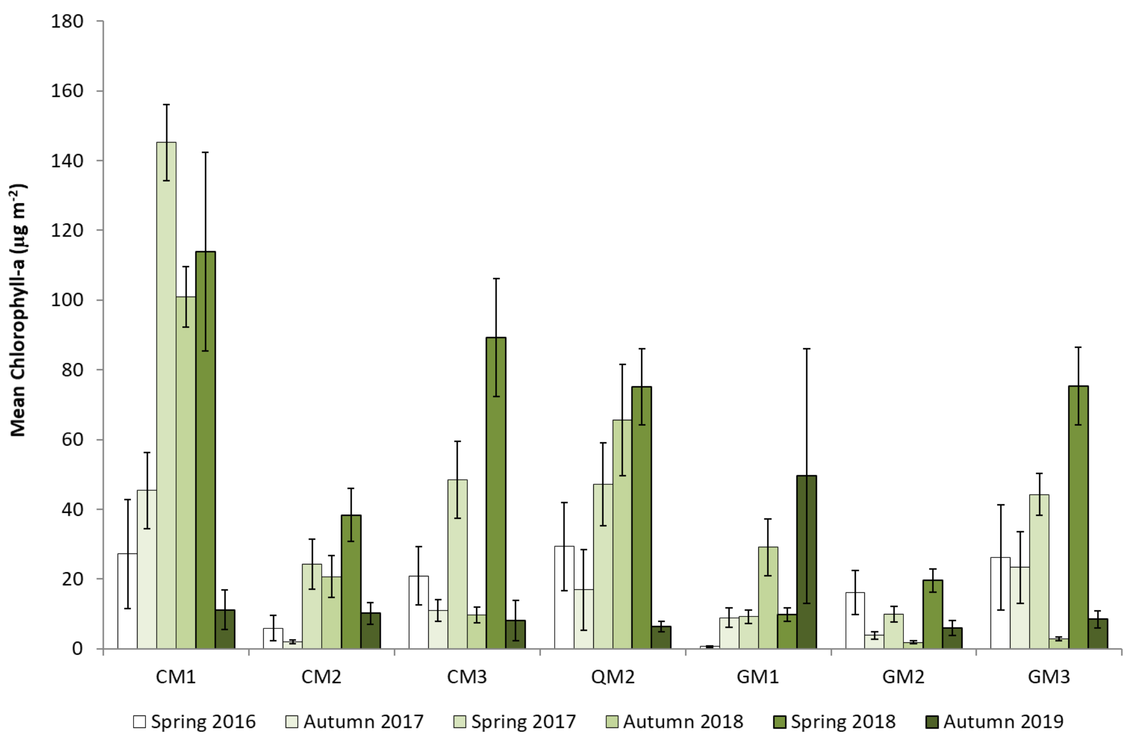


Figure 6: Mean Chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2016 to autumn 2019. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in spring 2018 and again in autumn 2019 (Table 1), though this difference was less evident in autumn 2019.

Cotter River test sites have varied in biological condition over the past eight assessments. Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in spring 2018 and autumn 2019 (Table 1). Test site CM1 remained in band B for the past eight assessments but it has increased in the AUSRIVAS observed/expected score (O/E) from 0.61 in spring 2017 to 0.85 in autumn 2019 assessment (0.03 from being assessed as band A similar to reference condition) with Conoesucidae as the most dominant macroinvertebrate community (Table 1).

Condition of the Cotter River below Bendora Dam (CM2) was assessed as band B and remained similar to spring 2018. It has remained at band B for the past five assessments. Although this site remained significantly impaired (band B) in autumn 2019, it recorded an increased O/E score to 0.79 from 0.74 in spring 2018 assessment (Table 1). The macroinvertebrate community at CM2 in autumn 2019 was characterised by a high abundance of Simuliidae (Appendix 2).

The condition of the Cotter River below Cotter Dam (CM3) was severely impaired (band C) in autumn 2019 and it has declined from being assessed as significantly impaired (band B) in spring 2018 (Table 1). Taxa missing from CM3 in spring 2018 but were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model ranged from SIGNAL grades 4 – 9. One of the eight taxa (Baetidae) predicted to have a ≥50% chance of occurrence by the AUSRIVAS model was detected in the whole sample scan (Table 2), suggesting that this taxon was present, but in low abundances at this site in spring 2018. Taxa missing from CM3 in autumn 2019 but were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model ranged from SIGNAL grades 2 - 8 (Table 2). 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 Gomphidae (Table 2), suggesting that this taxon was present, but in low abundances at this site. The decrease in AUSRIVAS band score between spring 2018 and autumn 2019 for CM3 was largely driven by an extremely high relative abundance of Simuliidae, Orthocladiinae and Caenidae. (appendix 2). However, the relative abundance of sensitive taxa (Ephemeroptera, Plecoptera and Trichoptera) was higher than Tolerant taxa (Oligochaeta and Chironomidae) in autumn 2019 assessment.

The below Googong Dam test site (QM2) was assessed as similar to reference (band A) in spring 2018 and severely impaired (band C) in autumn 2019. The below Googong Dam test site (QM3) was assessed as band A (similar to reference) in spring 2018 and band B (significantly impaired) in autumn 2019. QM3 has been alternating between band A, band B and band C for the past six assessments (Table 1). This variation in biological condition was not evident at the upstream reference site above Googong Dam (QM1), which has been similar to reference condition (band A) until the spring 2018 assessment (Table 1 and White et al 2009). However, it has been assessed as band B (significantly impaired) in autumn 2019. The decrease in AUSRIVAS band score between spring 2018 and autumn 2019 for QM2 was largely driven by an extremely high relative abundance of 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 (QM2 and QM3) and reference site QM1 in autumn 2019, whereas in spring 2018 assessment, both test and reference site had higher relative abundance of environmentally tolerant taxa. A whole of sample scan of the spring 2018 samples of QM2 revealed the presence of Hydropsychidae in whole sample scan but not detected in the subsample and zero presence in QM3 (Table 2). Gomphidae and Hydrobiosidae were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model in autumn 2019 in QM3 and zero in QM2 (Table 10).

Reference sites were assessed as being similar to reference condition or more biologically diverse than reference in spring 2018. In the autumn 2019 assessment, reference sites varied in biological condition from significantly impaired (band B) to more biologically diverse than reference (band X). The trend of better biological condition of reference sites in spring compared to autumn has been consistent over the past three years of monitoring (Table 1). The site GM1 was assessed as band X (more biologically diverse than reference) and rest of the reference sites were assessed as band A (similar to reference) in spring 2018 (Table 1). Reference site GT1 and GT3 which are tributaries to Goodradigbee River were assessed as band X (more biologically diverse than reference); site CT1, GM1 and GM2, were assessed as (band A) similar to reference and site CT3, QM1, GM3 and GT2 were assessed as band B (significantly impaired) in autumn 2019 (Table 1).

Reference sites GT1 and GT3 changed in biological condition from band A (similar to reference) in spring 2018 to band X (biologically more diverse) in autumn 2019. Site CT1 and GM2 remained similar biological condition between spring 2018 and autumn 2019 assessments. Sites CT3, QM1, GM1, GM3 and GT2 decreased their biological condition mostly from band A in spring 2018 to band B in autumn 2019, except for site GM1 which has decreased from band X to band A. Some of the 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 Psephenidae in CT3 and GT1, Baetidae in GM2 and CM3, Leptophlebiidae in CM1, and Hydropsychidae in CM1, QM2 and GT3 in spring 2018 and Hydrobiosidae in CM1, QM3 and CT1, Gomphidae in CM3, QM3, GM2, GM3 and QM1 and Coloburiscidae in GT2 in autumn 2019.

Reference site GM1 was assessed as band X (more biologically diverse than reference) in spring 2018 and changed to AUSRIVAS band to band A (similar to reference) in autumn 2019. However, a higher number of macroinvertebrates taxa were present in autumn 2019 assessment (almost by three-fold) than spring 2018. A dominant taxa were Gripopterygidae in spring 2018 and Hydropsychidae in autumn 2019 (Appendix 2).

The reference site Kangaroo Creek (CT1) was assessed as band A (similar to reference) in the both seasons. Its AUSRIVAS taxa O/E score has decreased from 1.10 in spring 2018 to 1.08 autumn 2019. However, a greater number of taxa was recorded in autumn 2019 than spring 2018 (Appendix 2). Greater environmentally sensitive taxa than environmentally tolerant taxa were detected in both seasons. The dominant macroinvertebrate community in spring 2018 was Gripopterygidae and Elmidae in autumn 2019 (Appendix2).

Cooleman Creek (GT1) which is a tributary to Goodradigbee River, was assessed as more biologically diverse than reference (band X) in autumn 2019, and similar to reference (band A) in spring 2018. Four taxa were expected with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples, with only one of these taxa (Psephenidae), detected in the whole of the sample scan in spring 2018 (Table 10) and only one taxa (Podonomidae) was expected with a ≥50% chance of occurrence by AUSRIVAS model in autumn 2019 (Table 2) and was not detected in whole sample scan, indicating these taxa were present but in low abundances.

Bramina Creek (GT3), upstream of Brindabella Road Bridge which is a tributary to Goodradigbee River was assessed as more biologically diverse than reference (band X) in autumn 2019 and similar to reference in spring 2018. The site has been dominated by Leptophlebiidae macroinvertebrate community in both the seasons. However, more macroinvertebrate communities were detected in autumn 2019 (30 taxa) than spring 2018 (24 taxa) (Appendix 2). Two taxa were expected with a ≥50% chance of occurrence by AUSRIVAS model, but missing from the sub-samples, with one of these taxa (Hydropsychidae) was detected in the whole of the sample scan in spring 2018 (Table 2) and there were no taxa missing from the sample which were expected with a ≥50% chance of occurrence by AUSRIVAS model in autumn 2019 (Table 2).

Table 1: AUSRIVAS band and Observed/Expected taxa score for each site from spring 2015 to autumn 2019. **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 2019	B (0.85)	B (0.79)	C (0.52)	C (0.63)	B (0.76)	A (1.08)	Not sampled	B (0.76)	B (0.67)	A (1.05)	A (1.04)	B (0.81)	X (1.23)	B (0.86)	X (1.28)
Spring 2018	B (0.84)	B (0.74)	B (0.66)	A (1.03)	A (1.00)	A (1.10)	Not sampled	A (1.11)	A (1.10)	X (1.19)	A (0.97)	A (1.12)	A (0.98)	A (1.13)	A (1.13)
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)

Table 2. 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 2018 and autumn 2019** (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).

Missing taxa in spring 2018																
Taxon Name	**Signal 2 score**	**CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
Oligochaeta	**2**												X	X	X	
Scirtidae	**6**						X									
Elmidae	**7**		X	X												
Psephenidae	**6**	X		X	X	X			X				X			
Tipulidae	**5**															
Simuliidae	**5**						X									
Tanypodinae	**4**	X	X	X	X	X			X			X	X			
Chironominae	**3**												X			
Baetidae	**5**	X	X	X							X					
Leptophlebiidae	**8**	X	X	X												X
Caenidae	**4**										X					
Hydrobiosidae	**8**		X	X			X			X		X				
Glossosomatidae	**9**	X	X	X	X	X					X					X
Hydropsychidae	**6**	X			X						X			X	X	
Conoesucidae	**7**		X	X		X										
Leptoceridae	**6**						X									
Total bugs		**6**	**7**	**8**	**4**	**4**	**4**	**0**	**2**	**1**	**4**	**2**	**4**	**2**	**2**	**2**

Missing taxa in autumn 2019																
Taxa	**Signal 2 Grade**	**CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
Hydrobiidae	4				X	X			X	X	X	X				X
Ancylidae	4				X	X			X	X	X	X				X
Oligochaeta	2			X												
Acarina	6				X											
Scirtidae	6	X												X		
Elmidae	7		X	X	X											
Psephenidae	6			X												
Tipulidae	5	X														
Podonominae	6		X	X	X	X	X		X			X	X			X
Tanypodinae	4		X	X	X	X			X			X				X
Coloburiscidae	8	X												X		
Leptophlebiidae	8		X													
Gomphidae	5			X	X	X					X	X				X
Gripopterygidae	8			X												
Hydrobiosidae	8	X		X	X	X	X		X					X		X
Glossosomatidae	9	X												X		
Hydroptilidae	4			X	X	X						X				X
Hydropsychidae	6		X						X							X
Conoesucidae	7		X	X										X		
Leptoceridae	6	X	X						X	X				X		
Total		**6**	**7**	**10**	**9**	**7**	**2**	**0**	**7**	**3**	**3**	**6**	**1**	**6**	**0**	**8**

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 2018 and autumn 2019 assessments. Tolerant OC taxa were dominant (> 50%) at below dam test sites below Cotter Dam (CM3) and below Googong Dam (QM2) in spring 2018 (Figure 7), In contrast, environmentally sensitive taxa (EPT) were extremely dominant (>60%) in below dams test sites in autumn 2019. However, reference site Paddy's River, upstream of Cotter River junction (CT3) and Queanbeyan River, upstream of Googong Dam (QM1) had higher environmentally tolerant taxa (OC) in autumn 2019 assessment, unlike spring 2018, where all the reference sites had dominant (greater than 50%) environmentally sensitive taxa (EPT), (Figure 7, Figure 8).

Comparison cannot be made for Cotter tributary site on Burkes Creek (CT2) between seasons in the absence of creek flow in both assessment seasons (Figure 7 and Figure 8). All reference sites in the Goodradigbee Catchment were dominated by environmentally sensitive taxa (Ephemeroptera and Plecoptera) in both spring 2018 and autumn 2019 assessments (Figure 7, Figure 8, Figure 9 and Figure 10). The reference site CT3 in Cotter River catchment and QM1 in Queanbeyan River catchment were dominated by environmentally sensitive taxa (Ephemeroptera and Plecoptera) in spring 2018 but environmentally tolerant taxa Diptera dominated the sites in autumn 2019.

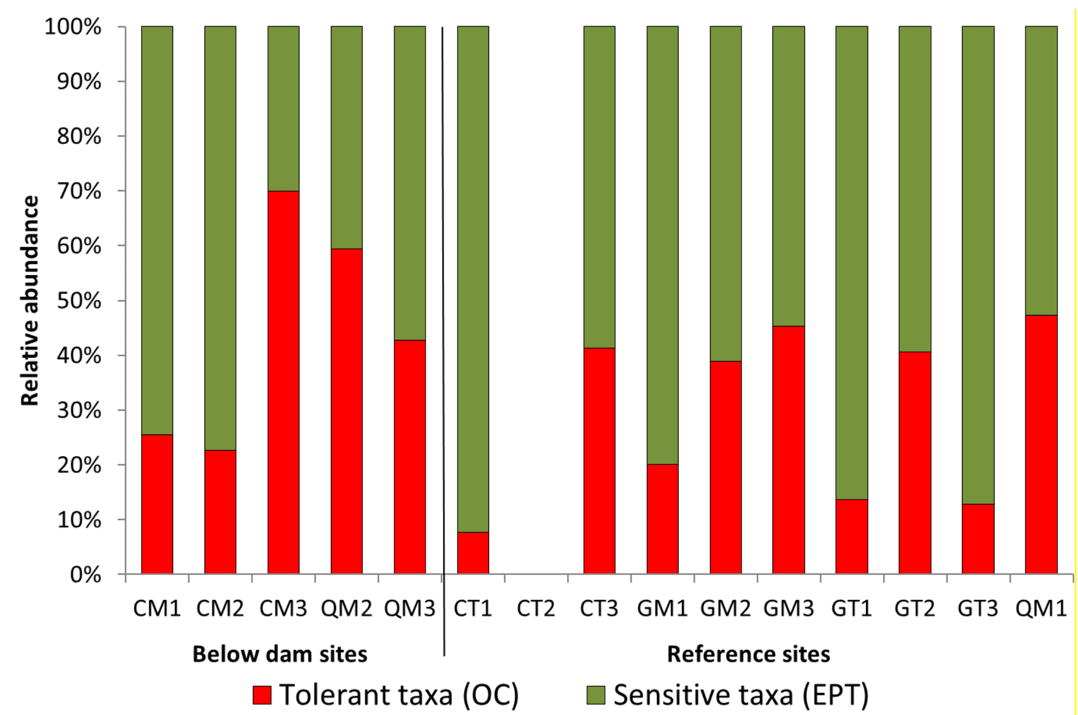


Figure 7. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **spring 2018**. Note: Burkes Creek was completely dry during sampling and macroinvertebrates could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

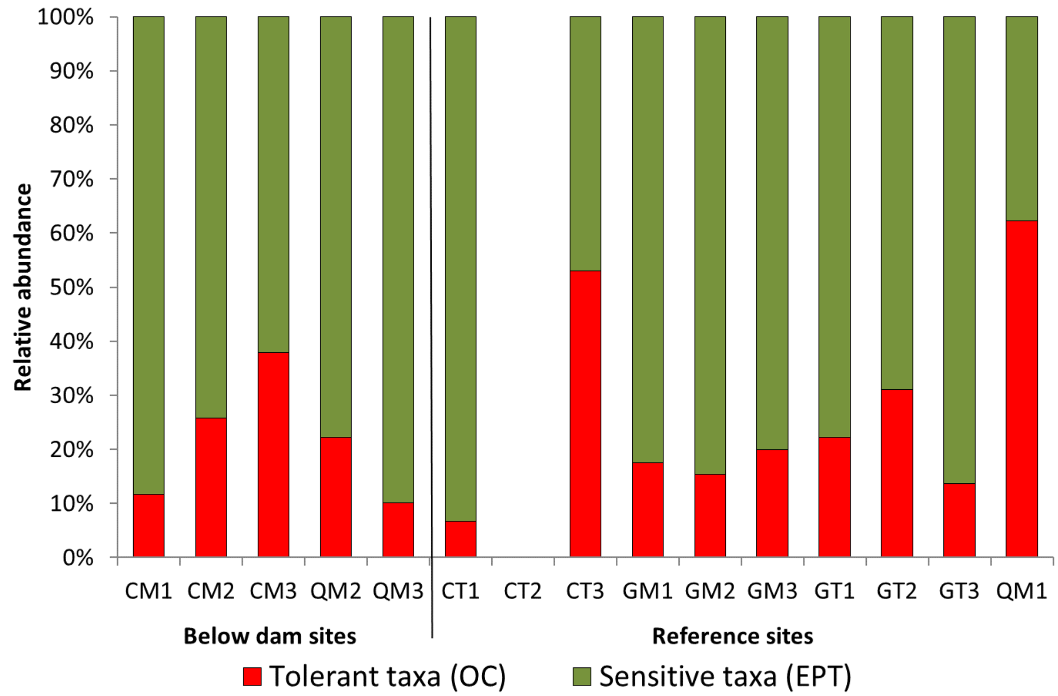


Figure 8: Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **autumn 2019**. Note: Burkes Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

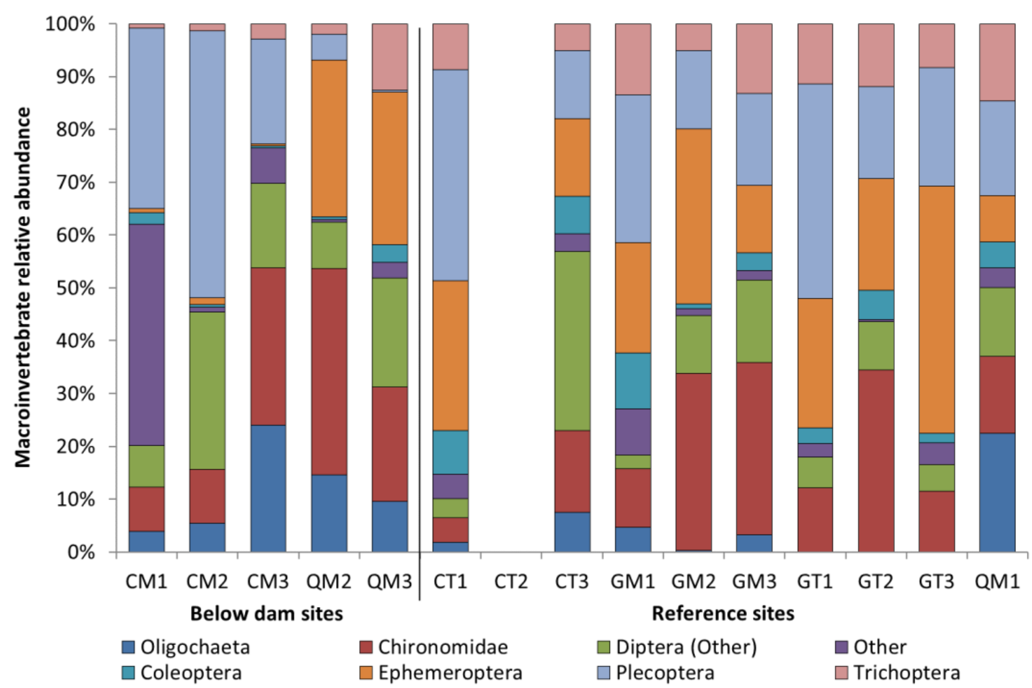


Figure 9: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **spring 2018**. Note: Burkes Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

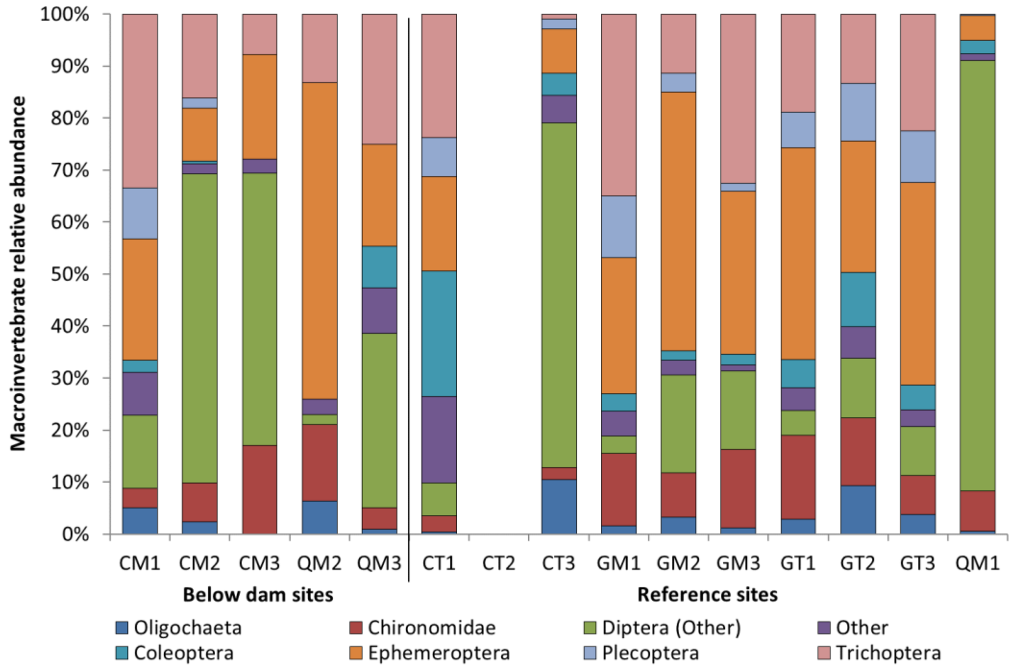


Figure 10: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **autumn 2019**. Note: Burkes Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

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 2018 and autumn 2019 assessments (Figure 11 and Figure 12).

The exceptions to this was site CM1 which was not similar to any other sites in spring 2018, and CM2 grouped out individually in autumn 2019, whilst reference sites CT3 and QM1 grouped out from test sites in autumn 2019. Goodradigbee reference sites grouped out as similar to each other and different from other sites (both test and reference) for both the spring 2018 and autumn 2019 assessments, largely because of a higher relative abundance of Leptophlebiidae in both the assessments (Figure 11 and Figure 12). In spring 2018, the tributaries of Cotter River (CT1) grouped out with Goodradigbee reference sites, based on high relative abundance of Telephlebiidae and Philopotamidae. The reference site CT3 has grouped with Queabeyan River sites primarily due to high relative abundance of Podonomidae in spring 2018 and grouped with reference site of Queanbeyan River QM1 in autumn 2019 largely due to presence of Simulidae. Queanbeyan River downstream of Googong Dam QM2 and QM3 and Cotter River downstream of Cotter Dam were grouped together mainly driven by prevalence of Caenidae in autumn 2019.

Cotter River test sites CM2 and CM3 had macroinvertebrate assemblages dissimilar to all other sites, (Figure 11) driven by Podonomidae, Corydalidae, Empididae, Lymnaeidae and Muscidae in spring 2018 and Simulidae and Caenidae in autumn 2019. Cotter River test sites CM2 and CM3 and Queanbeyan River reference site QM1 had similar macroinvertebrate assemblages but dissimilar to other sites in spring 2018 except QM1 which had similar macroinvertebrate assemblages to QM2, QM3, CT3 and GM3. However, GM3 had similar macroinvertebrate assemblages to CT1, GT1, GT2, GT3, GM1 and GM3 (Figure 11). Cotter River reference site CT3 and Queanbeyan River reference site QM1 had similar macroinvertebrates assemblage and dissimilar to all other sites which were largely driven by high relative abundance of [Simulidae] in autumn 2019. Kangaroo Creek (CT1) which is a tributary to the Cotter River has similar macroinvertebrates assemblage to all Goodradigbee River catchment sites due to prevalence of [Philopotamidae] (Figure 12).

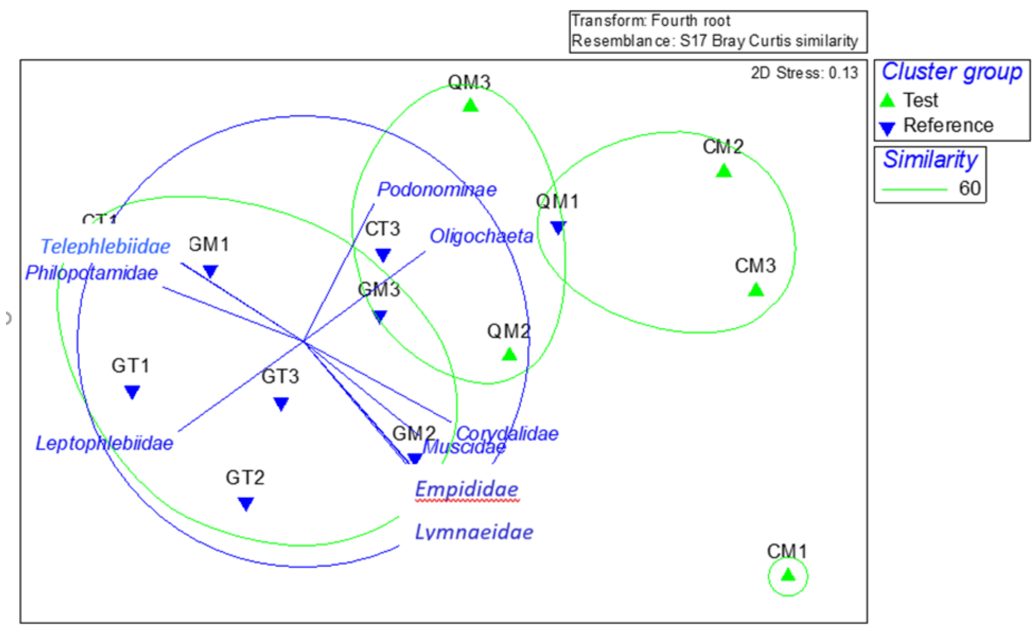


Figure 11. MDS ordination of 60% similarity between macroinvertebrate samples collected in **spring 2018** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa 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.

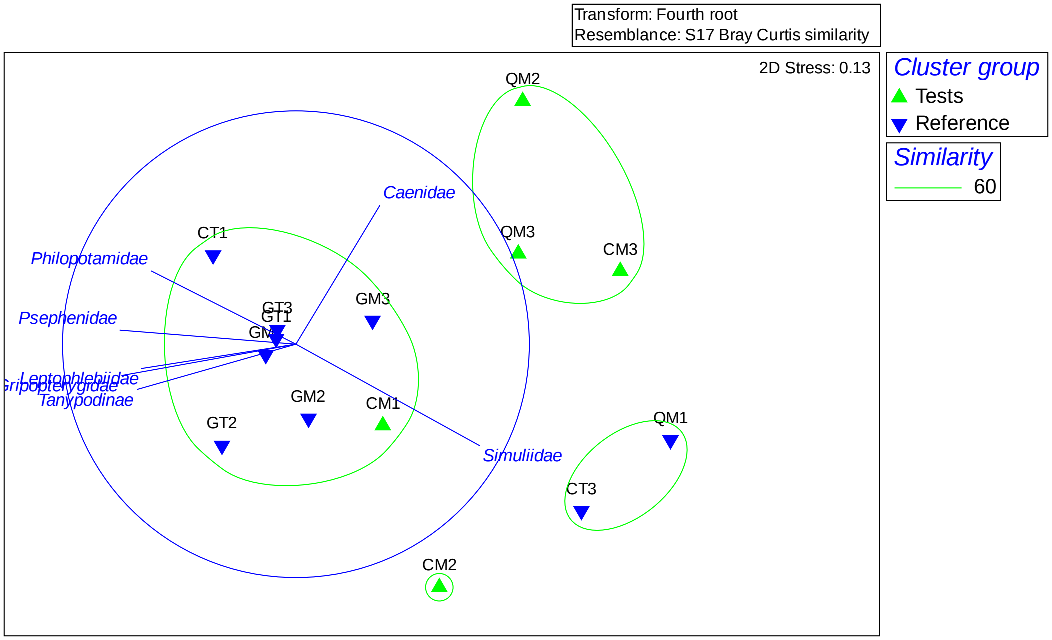


Figure 12. MDS ordination of 60% similarity between macroinvertebrate samples collected in **autumn 2019** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa 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 2018 and autumn 2019 (Table and Table). The higher than guideline pH levels assessed in autumn 2019 do not appear to be related to flow regulation and are more likely a result of equipment calibration error. Some attention to the pH at these sites in further assessments will provide further insight.

Nitrogen oxides (NO_x) had exceeded guideline concentrations only at test sites in both sampling seasons. Total nitrogen (TN) and total phosphorus (TP) were exceeded at test only sites in spring 2018, but at both test and reference sites in autumn 2019. Nitrogen oxides (NOx) was above guideline concentrations in spring 2018 at the test site below Corin Dam (CM1) but only by 0.002 mg L^{-1} above guideline concentrations. In autumn 2019, NOx was above guideline concentrations at the below Cotter Dam (CM3) site by 0.007 mg L^{-1} above guideline concentrations. Higher NO_X concentration at CM3 may be attributed to the transferred Murrumbidgee River water (M2C flow transfer) during sampling. Total nitrogen was well above guideline concentrations at test sites below Cotter Dam (CM3) and Googong Dam (QM2 and QM3) in spring 2018 as well as in autumn 2019 with additional reference sites Kangaroo Creek (CT3) and reference site of Queanbeyan River, upstream Googong Dam (QM1). Total nitrogen and nitrogen oxides 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 2018 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). High Nitrogen levels and denitrification within the reservoir could be the cause of elevated NOx concentrations in outflows (Saunders and Kalff 2001). However, in autumn 2019 assessment, TN concentrations were higher in QM1, which may have been triggered during high flow events. 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.

Total phosphorus (TP) concentrations at the test sites CM3 in both spring 2018 and autumn 2019 and reference site CT3 and QM1 in autumn 2019 were marginally higher than guideline concentrations. Higher TP concentration at CM3 may be attributed to transferred Murrumbidgee River (M2C flow transfer) and QM1 may be attributed to inputs from the surrounding catchment.

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 site below Googong Dam (QM2) in spring 2018 (Table). This is 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.

There was no difference between sites in Periphyton/algae biomass (measured as AFDM) in either assessment. Periphyton/algae biomass in spring 2018 and autumn 2019 across all sites was within the range of those measured in recent sampling (dating back to spring 2016). Mean Chlorophyll-a concentrations were significantly different between sites in spring 2018, though these differences were not related to whether a site was a test or reference site. The differences largely lie in the much lower than usual Chlorophyll-a concentrations at a reference site (GM1), likely associated with bed disturbance from pulse flows leading up to sampling. There was no significant difference in mean Chlorophyll-a concentrations in autumn 2019.

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at three of five and all five below dam test sites spring 2018 and autumn 2019, respectively. The reasons for departure from being similar to reference were site and season specific. Reference sites were generally similar to reference condition, though there was some deviation from this with one being more biologically diverse in spring 2018 and two sites in autumn 2019. There were also several sites being significantly impaired in autumn 2019 (Table 1).

The Cotter River test site below Corin Dam (CM1) remained significantly impaired in both spring 2018 and autumn 2019 assessment and has been for the past three years. Although this site remained in band B in autumn 2019, it had an increase in the AUSRIVAS score O/E, resulting in it being only 0.03 from band A (similar to reference). It is unclear what has driven the increase in condition of the macroinvertebrate community in autumn 2019, but may be a result of reduced discharge disturbance leading up to sampling, compared to previous assessments (see site summary sheet Appendix 1).

The Cotter River test site below Bendora Dam (CM2) remained significantly impaired in both spring 2018 and autumn 2019 (Table 1). This site did improved in AUSRIVAS O/E score between spring 2018 and autumn 2019, with an increased O/E score to 0.79 from 0.74, to be within 0.09 from band A (Table 1). 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 spring 2018 and severely impaired in autumn 2019. The condition of the site in autumn 2019 has declined from spring 2018 from an AUSRIVAS O/E score of 0.66 to 0.52. The flow regime downstream of Cotter Dam was characterized by relatively low constant discharge in both seasons, with water for this site being derived from the Murrumbuidgee River via the Murrumbidgee to Cotter River transfer scheme. The low variable flow and different water quality may have made conditions more suitable for environmentally tolerant taxa to thrive leading into autumn 2019 (Belmar, et. Al. 2013).

Macroinvertebrate communities at both sites downstream of Googong Dam (QM2 and QM3) decreased in biological condition from spring 2018 to autumn 2019. Site QM2 decreased from band A (similar to reference) in spring 2018 to band C (severely impaired) in autumn 2019. The site QM3 decreased from band A (similar to reference) in spring 2018 to band B (significantly impaired) in autumn 2019. Although both sites increased their relative abundance of environmentally sensitive taxa, the diversity was reduced due to the high abundance of Baetidae and Caenidae at QM2 and Hydropsychidae and Baetidae at QM3. It is likely that simplification of the macroinvertebrate community (i.e. loss of diversity) may be due to low disturbance frequency of the sites leading up to autumn 2019 sampling. The lack of disturbance is caused by drought conditions, as any pulses in discharge were captured by the Googong Reservoir as it wasn't at full supply during this period.

Four of the reference sites declined in biological condition from band A (similar to reference) to band B (significant impaired) between spring 2018 and autumn 2019. Two of these site in the reference catchment (GM3 and GT2), were only 0.07 and 0.02 in the O/E ratios from being assessed as similar to reference, respectively (and had taxa present in the whole of sample scan that were predicted to be present indicating these taxa were present, just at low abundances). The other two reference sites that declined from band A to band B were in the Cotter and Queanbeyan catchments (CT2 and QM1). Both of these sites have been assessed as band A for the past seven assessments, so their decline to band B is an anomaly. The macroinvetebrates communities at CT2 and QM1 were dominated by Simuliidae, comprising 66 and 82% of the macroinvertebrate abundances at each site, respectively. Simulidae are filter feeders and thrive when particulate matter is prevalent in the water column and disturbance is low. Low flow conditions may have contributed to the macrinvertbrate communities being dominated by simulidae at these two sites in autumn 2019,

CONCLUSION

Water quality parameters at below dam test sites were largely within guideline levels in spring 2018 and autumn 2019. Despite some increased nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites in autumn 2019 and at four of five test sites in spring 2018. Most test sites and some reference sites decreased in biological condition (either within band or across bands) between spring 2018 and autumn 2019, likely due to drought flow conditions. Test sites below Corin and Bendora Dams appear to have been somewhat protected by regulated flows and actually increased slightly in biological condition.

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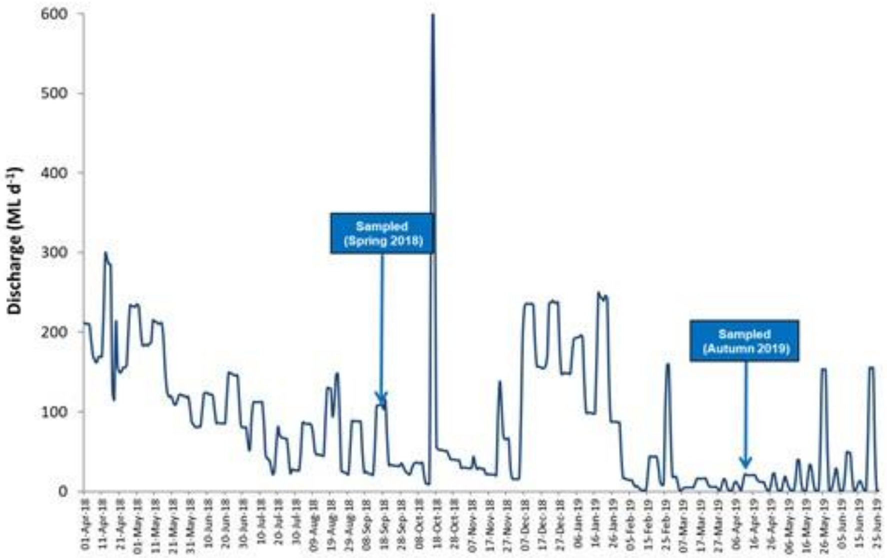
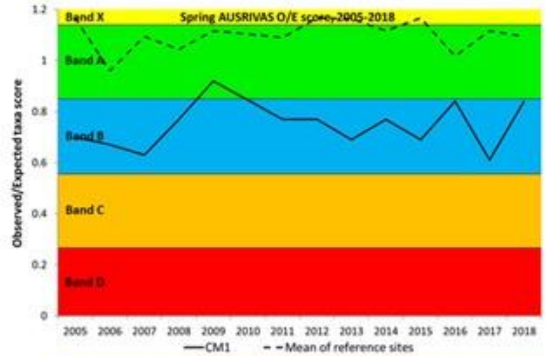
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

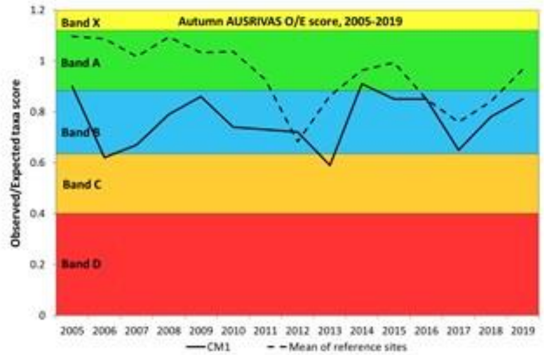
CM1 - Spring 2018 - Autumn 2019

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2018	Autumn 2019	Objective met?
AUSRIVAS band A	Band B	Band B	No in both seasons
<20% filamentous algae cover in riffle habitat	<20%	<10%	Yes in both seasons







* Denotes values outside guideline levels

Sampling season	Temp. (^oC)	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 2018	9.03	28	7.07	9.74	0.0	4	0.006	0.017	0.17	0.01
Autumn 2019	15.09	2	7.03	9.07	0.5	10	0.007	0.008	0.11	0.007

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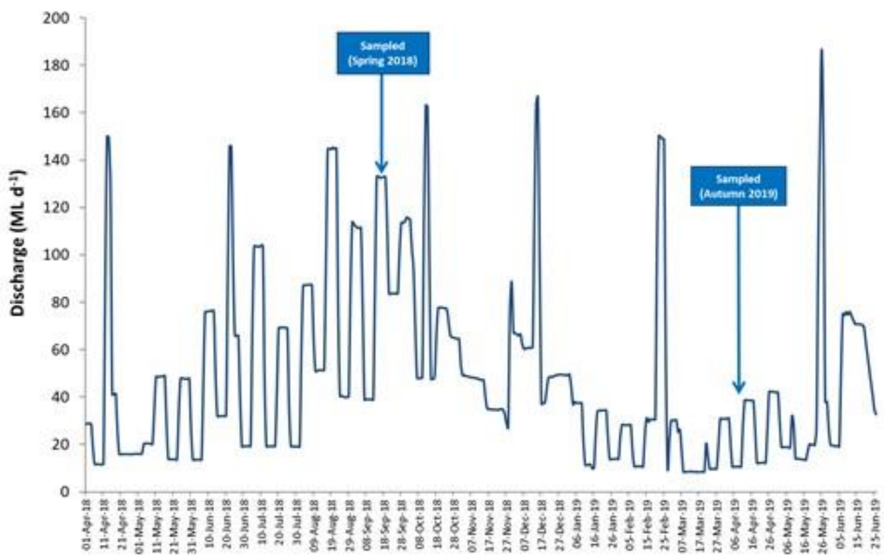
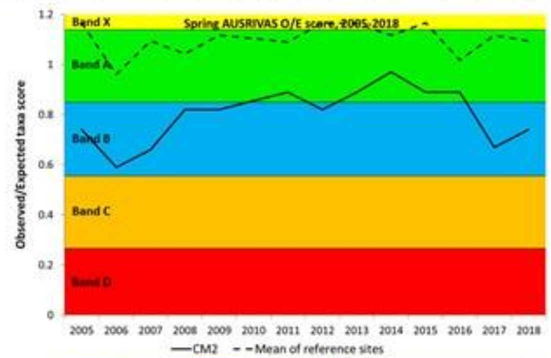
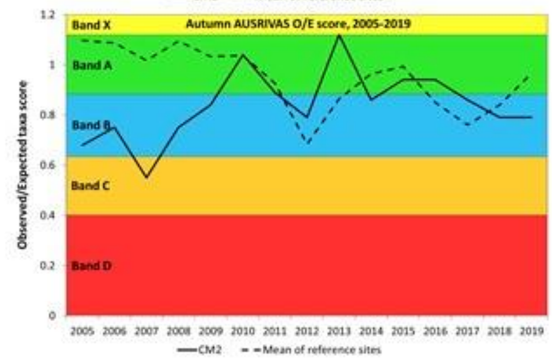
CM2 - Spring 2018 - Autumn 2019

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2018	Autumn 2019	Objective met?
AUSRIVAS band A	Band B	Band B	No in both seasons
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons







* 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 2018	7.82	26	6.80	10.72	0.0	4	0.005	<0.002	0.1	0.006
Autumn 2019	17.88	2	7.50	8.63	1.4	10	0.009	0.012	0.12	0.007

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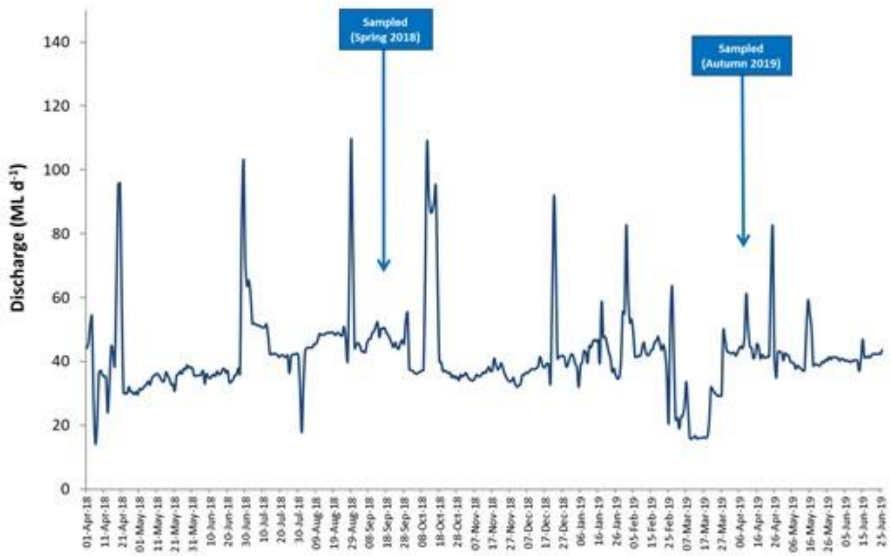
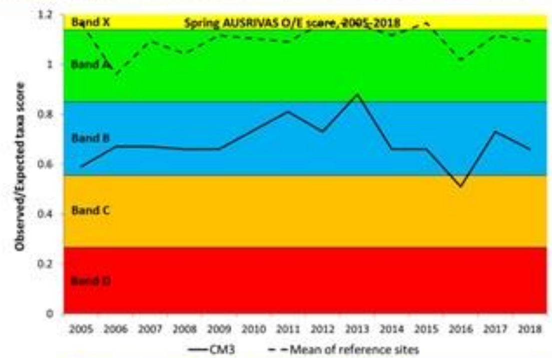
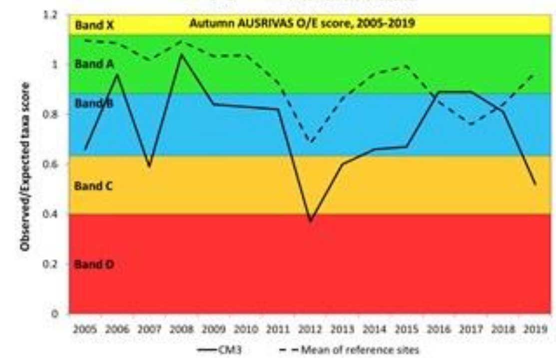
CM3 - Spring 2018 - Autumn 2019

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2018	Autumn 2019	Objective met?
AUSRIVAS band A	Band B	Band C	No in both seasons
<20% filamentous algae cover in riffle habitat	<20%	<10%	Yes in both seasons







* 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 2018	13.3	117	7.70	10.31	7.4	8	0.007	0.002	0.29	0.023
Autumn 2019	18.98	82	8.14	9.26	19.1	34	0.014	0.022	0.45	0.032

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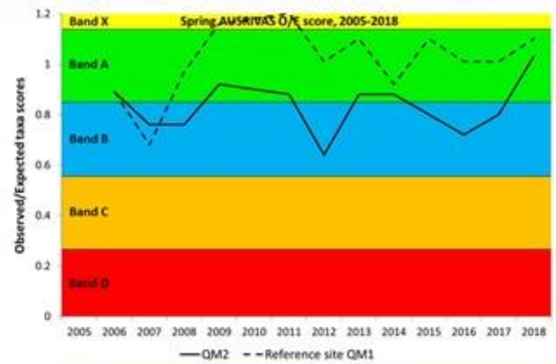
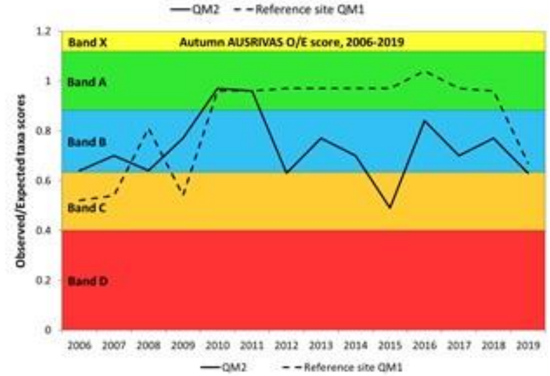
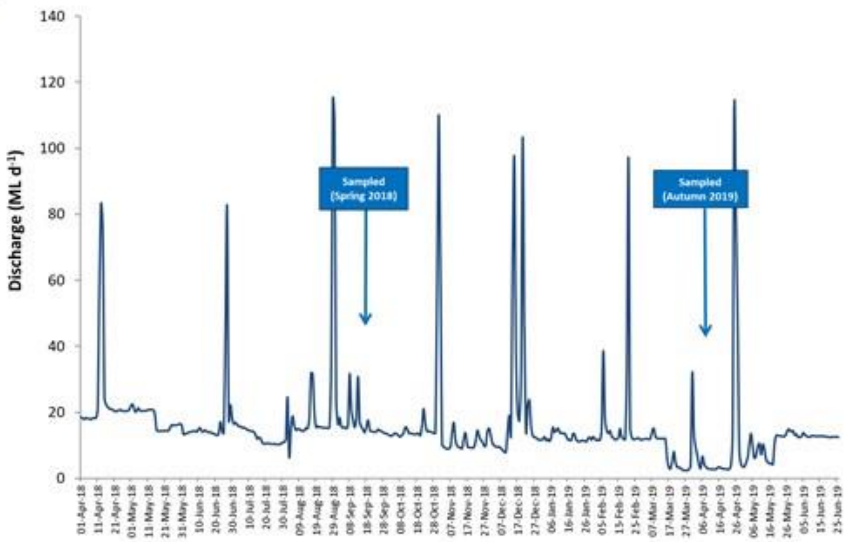
QM2 - Spring 2018 - Autumn 2019

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2018	Autumn 2019	Objective met?
AUSRIVAS band A	Band A	Band C	Yes in spring 2018 but no in Autumn 2019
<20% filamentous algae cover in riffle habitat	>20%	<10%	No in spring 2018 but yes in Autumn 2019







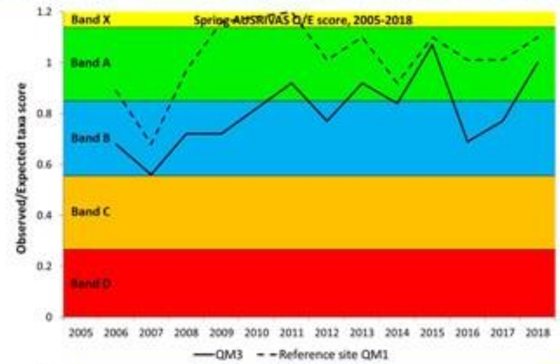
* Denotes values outside guideline levels

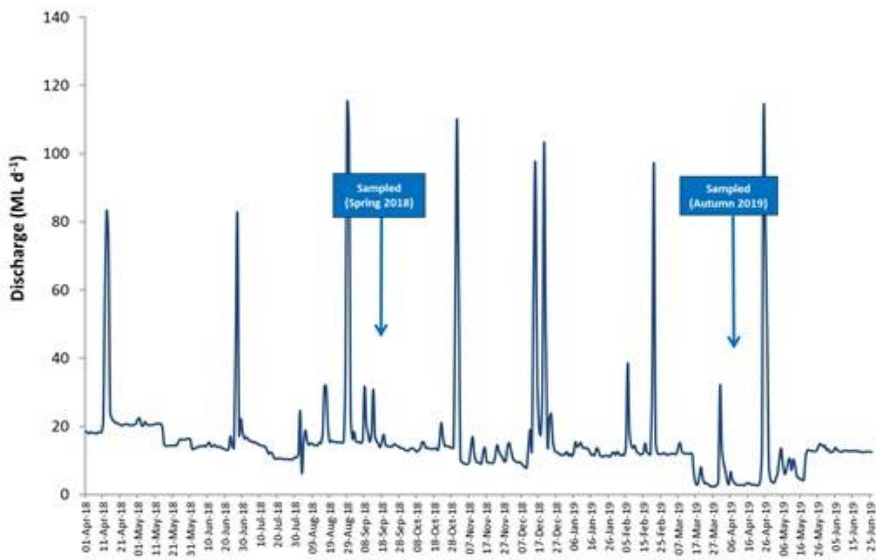
Sampling season	Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+ (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
Spring 2018	11.57	120	8.14	11.01	0.0	20	0.021	<0.002	0.34	0.007
Autumn 2019	18.63	89	8.23	9.1	1.0	46	0.004	0.012	0.28	0.006

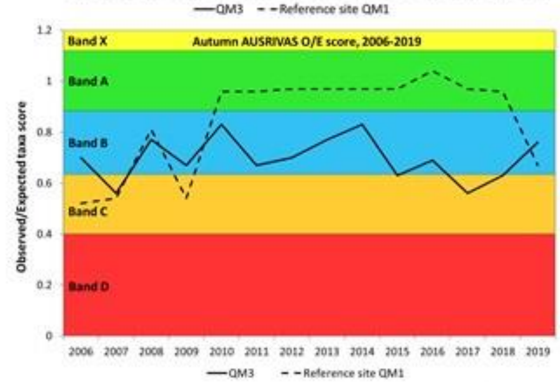
QM3 - Spring 2018 - Autumn 2019

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2018	Autumn 2019	Objective met?
AUSRIVAS band A	Band A	Band B	Yes in spring 2018 but no in Autumn 2019
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons







* Denotes values outside guideline levels

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 2018	12.14	172	7.74	10.63	0.0	24	0.016	<0.002	0.35	0.009
Autumn 2019	17.77	291	8.81	10.27	5.1	100	0.006	0.011	0.31	0.01

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APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2018 AND AUTUMN 2019

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

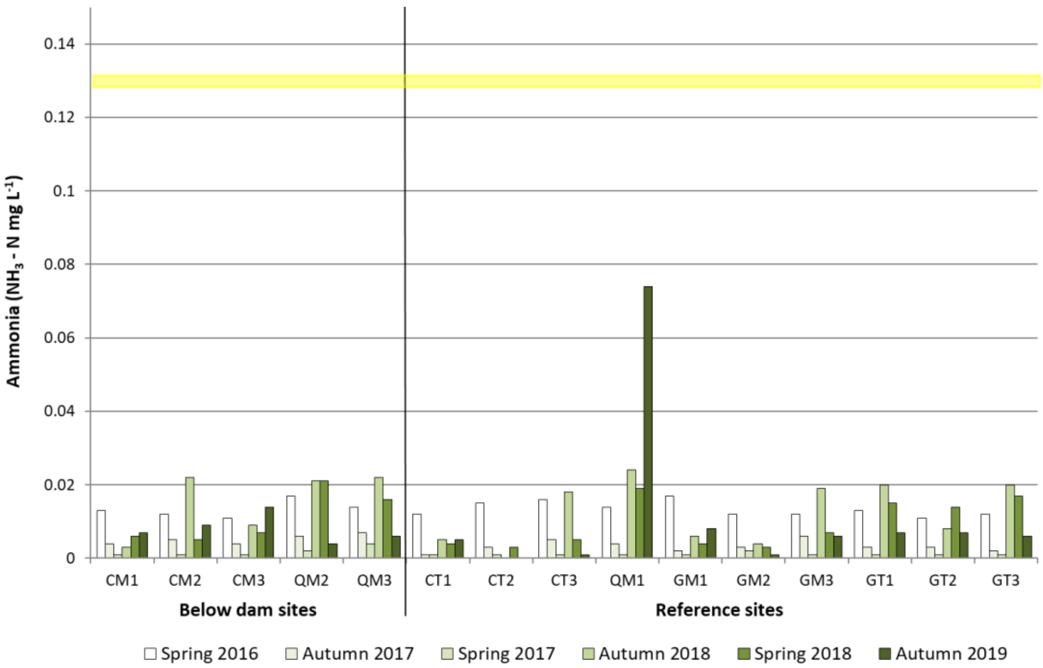
CLASS Order Family *Sub-family*	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
GASTROPODA								Very low flow during sampling on 17/09/2018								
Lymnaeidae	1	1														
Planorbidae	4	9		2			7									
Physidae	1									1						
PELECYPODA																
Sphaeriidae	5					2			1							2
OLIGOCHAETA	2	9	12	57	30	20	4		18	18	1	7				54
ACARINA	6	82	1	9	1	3	1		6	2	2	4	6	1	9	6
Coleoptera																
Carabidae	3												1			
Dytiscidae	2												3			
Hydrophilidae	2													1		
Hydrophilidae (Larva)	2									1						
Hydraenidae	3													1		
Scirtidae	6					1			2				2			
Elmidae (Adult)	7				1		5		1	1	1		2	2		2
Elmidae (Larvae)	7	5				6	11		14	1		5		6	2	10
Psephenidae	6		1							38	2	2		2	2	
Ptilodactylidae	10						2									
Chrysomelidae	2			1												
Diptera																
Tipulidae	5	2	3	1	7	16	2		3	5	2	5	9	18	2	1
Blephariceridae	10												1			
Chaoboridae	2		3													
Ceratopogonidae	4			1								1			1	1
Simuliidae	5	1	59	36	10	27			74	4	33	27	6	1	6	26
Athericidae	8				1		6		4						2	
Empididae	5	13												1		2
Ephydridae	2									1						
Muscidae	1	2														1
Aphroteniinae	8		1		4		4				1		3	1	6	
Podonominae	6		5			5						1				
Tanypodinae	4						1			2	2			3	2	4
Orthocladiinae	4	17	11	64	64	34	4		34	28	91	52	30	57	8	23
Chironominae	3	2	5	7	12	6	1		3	13	12	16		14	9	8
Ephemeroptera																
Baetidae	5				11	15	18		2	10		2	8	3	6	1
Coloburiscidae	8						15			13		4	1		7	
Leptophlebiidae	8				1	3	28		9	50	105	15	53	38	88	
Caenidae	4	2	3	1	49	42	1		24	8		6	5	5	1	20
Megaloptera																
Corydalidae	7	4		4												
Odonata																
Gomphidae	5		1	1			1		1	30	2					1
Telephlebiidae	9					1	1			1			1			
Plecoptera																
Gripopterygidae	8	78	110	47	10	1	73		26	109	47	37	107	38	48	43
Notonemouridae	6						14		5				4		1	
Trichoptera																
Hydrobiosidae	8	1			1	1			1		4		1	1	1	
Glossosomatidae	9						1		1	1		3	1	1	3	
Hydroptilidae	4		1	5	2	4					1	2			2	4
Philopotamidae	8					2	6		1	1	1	1	1	1	1	
Hydropsychidae	6		1	1		19	2		5	2		2	1			26
Polycentropodidae	7		1													
Ecnomidae	4			1					2	1	1	2			3	
Conoesucidae	8	1			1		7		1	44	6	11	10	6	6	4
Helicopsychidae	8									2			1			
Calocidae	9						2							1		1
Calamoceratidae	7						1			1			1	3		
Leptoceridae	6								1		3	7	15	13	2	
No. of individuals		229	218	238	205	208	218	NA	239	388	317	212	273	218	218	240
No. of taxa		16	16	16	16	19	26	NA	24	27	19	22	25	24	24	21
% of sub-sample		4	6	3	3	7	3	NA	3	3	1	5	2	2	4	3
Whole sample estimate		**5725**	**3633**	**7933**	**6833**	**2971**	**7267**	**NA**	**7967**	**12933**	**31700**	**4240**	**13650**	**10900**	**5450**	**8000**

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in **autumn 2019** at each of the study sites. **Note:** Burkes Creek was completely dry during sampling and macroinvertebrate could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).

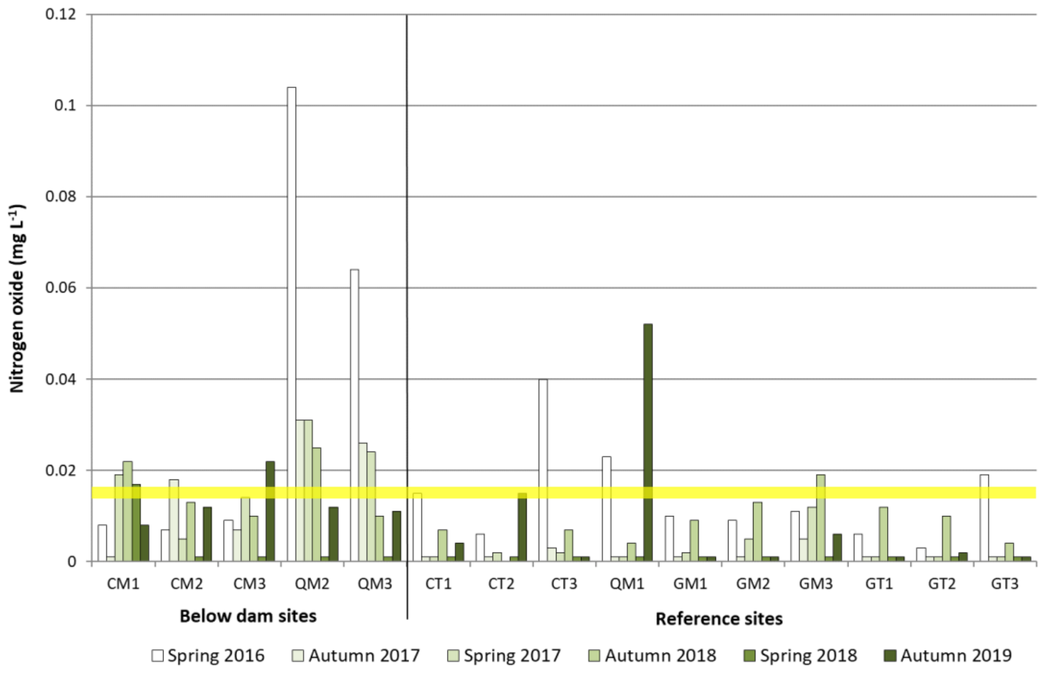
CLASS **Order** Family *Sub-family*	**Signal 2 Grade**	**Test sites**					**Reference sites**									
		CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
GASTROPODA								**No flow during sampling on 12/04/2019**								
Lymnaeidae	**1**	1														
Planorbidae	**4**	3	3		2		38					1			1	
Physidae	**1**	6														1
PELECYPODA																
Sphaeriidae	**5**			1		26			7							1
OLIGOCHAETA	**2**	11	6		13	3	1		22	6	9	3	6	26	8	2
ACARINA	**6**	6	2	5		1	1		2	2	8	2	9	12	2	1
Coleoptera																
Hydrophilidae	**2**									1			2		2	
Scirtidae Sp.	**6**						1						2			
Elmidae (Adult)	**7**					3	5		5	2		1	1	6	1	2
Elmidae (Larvae)	**7**	4				24	45		3	4	5	2	2	18	5	7
Psephenidae	**6**	1	1				8		1	6		2	4	5	2	
Ptilodactylidae	**10**						2									
Diptera																
Tipulidae	**5**		1	1	3	1	2			3		5	2	1	3	1
Ceratopogonidae	**4**								1		1					1
Simuliidae	**5**	26	146	133	1	112	6		138	9	51	31	6	29	17	277
Athericidae	**8**	3	1			1	8					1	1			
Empididae	**5**	1	3	1						1	1		1	2		
Aphroteniinae	**8**			2			2			3			2		2	
Podonominae	**6**									3	1				1	
Tanypodinae	**4**	1					1			3	3		2	6	1	
Orthocladiinae	**4**	3	15	25	26	13	4		4	23	5	24	18	20	8	19
Chironominae	**3**	4	4	17	4	1	1		1	22	15	13	11	10	4	7
Ephemeroptera																
Baetidae	**5**	19	21	9	62	57	13		1	45	28	55	5	3	19	5
Coloburiscidae	**8**						6					3	1		2	
Leptophlebiidae	**8**	14		1	1	2	23		2	33	107	7	62	53	58	3
Caenidae	**4**	17	5	42	61	8	4		15	23	5	12	16	14	4	8
Hemiptera																
Veliidae	**3**													2		
Lepidoptera	**2**					1										
Megaloptera																
Corydalidae	**7**	2		1	4	1			1						2	1
Odonata																
Aeshnidae	**4**						1								1	
Gomphidae	**5**								1	15				2	1	
Telephlebiidae	**9**					1	2							1		
Lindeniidae	**3**									1						
Plecoptera																
Gripopterygidae	**8**	21	5				19		4	46	10	4	14	31	21	1
Trichoptera																
Hydrobiosidae	**8**		27							1	5	3	2		1	
Glossosomatidae	**9**						2									
Hydroptilidae	**4**	4	1				2		1	3	2		8	3	2	
Philopotamidae	**8**			3		3	6			5	3	8	6	3	9	
Hydropsychidae	**6**	21		16	17	74	24			94	6	41	9	2	22	
Ecnomidae	**4**	4	13	1	4	2	5		1	19	3	25	3	8	4	
Psychomyiidae	**NA**				1											
Conoesucidae	**8**	43			4	5	10			12	11	2	7		5	
Helicopsychidae	**8**													1		
Helicophidae	**10**													8		
Philorheithridae	**8**						2				1	1		3	1	
Calamoceratidae	**7**						3			1				9	4	
Leptoceridae	**6**				1	1	6				1		4			
No. of individuals		215	254	258	204	340	253	NA	210	386	281	246	206	278	213	337
No. of taxa		22	16	15	15	21	31	NA	18	27	22	22	27	26	30	16
% of sub-sample		2	2	1	2	1	2	NA	3	1	1	2	1	2	1	1
Whole sample estimate		10750	12700	25800	10200	34000	12650	NA	7000	38600	28100	12300	20600	13900	21300	33700

APPENDIX 3: WATER QUALITY FIGURES

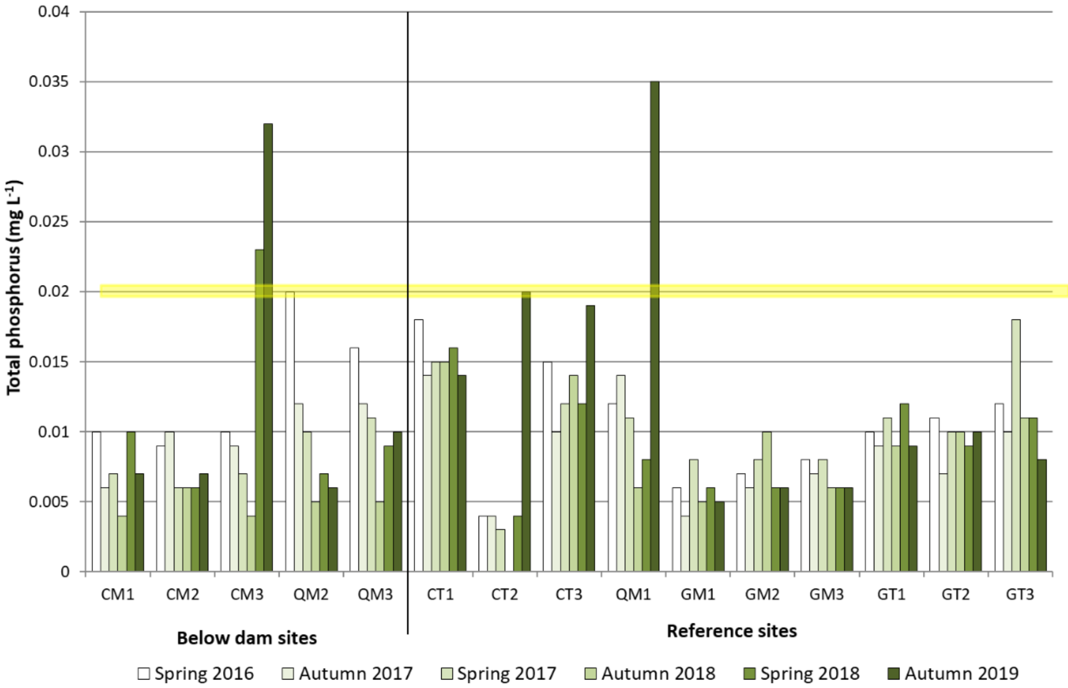
(Note: There was no flow during sampling and water samples could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).



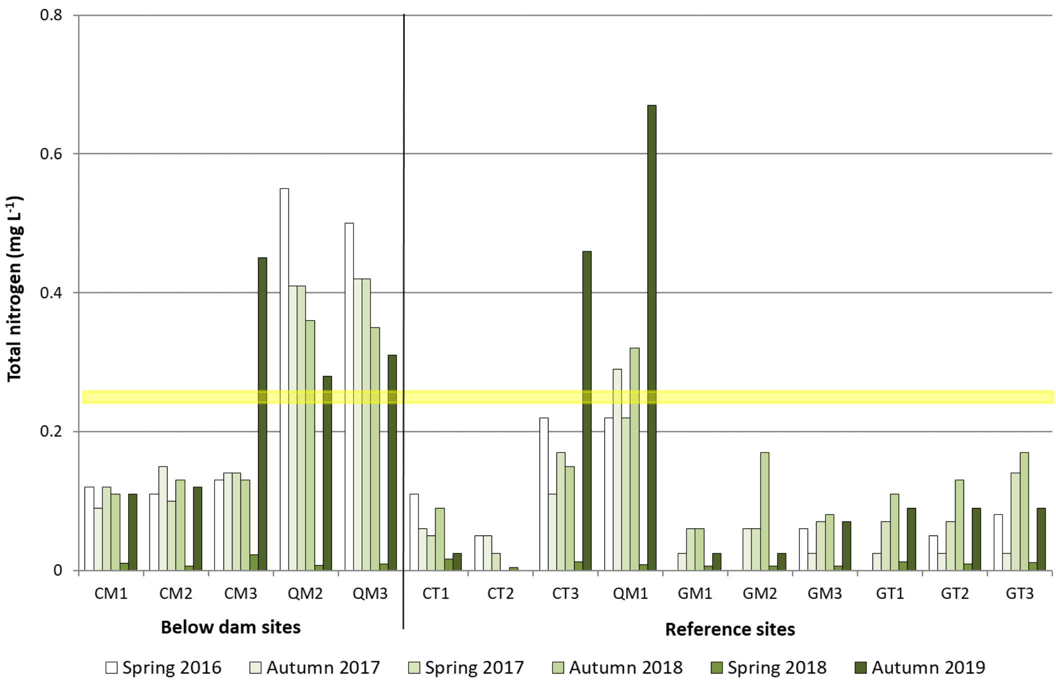
Ammonium (NH_4^+) concentration at all sites from **spring 2015 to autumn 2019**. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is shaded yellow.



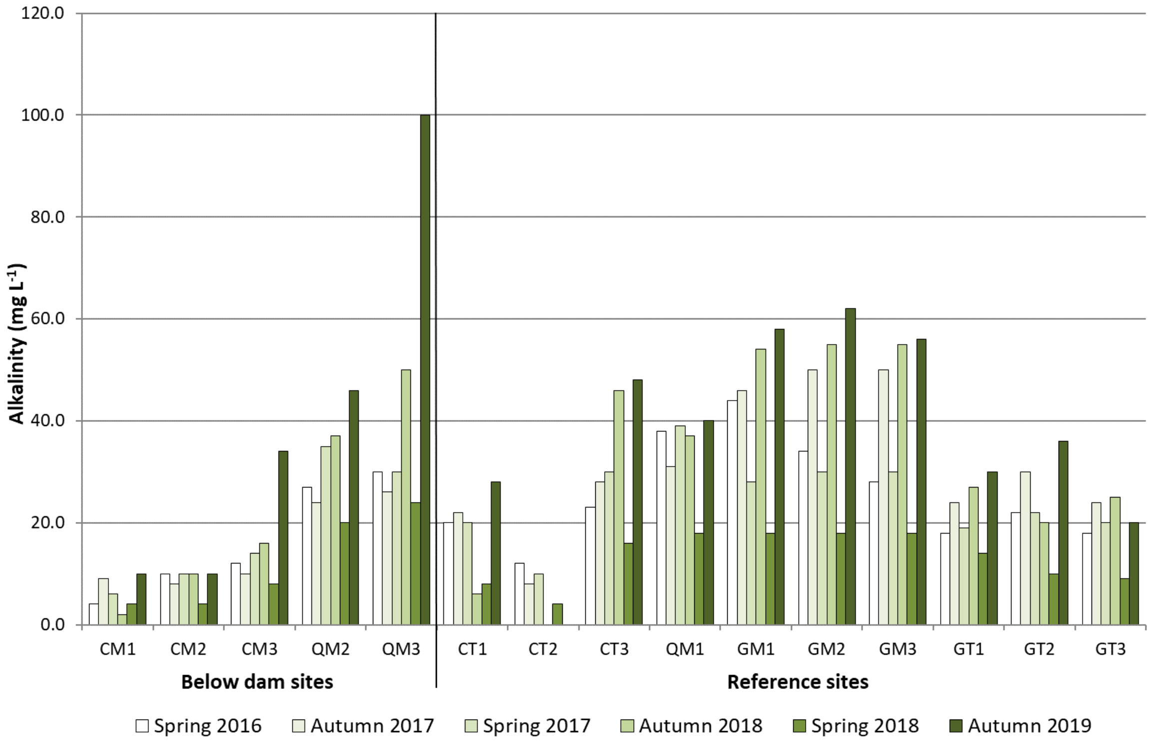
Nitrogen oxide concentrations at all sites from **spring 2016 to autumn 2019**. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is shaded yellow.



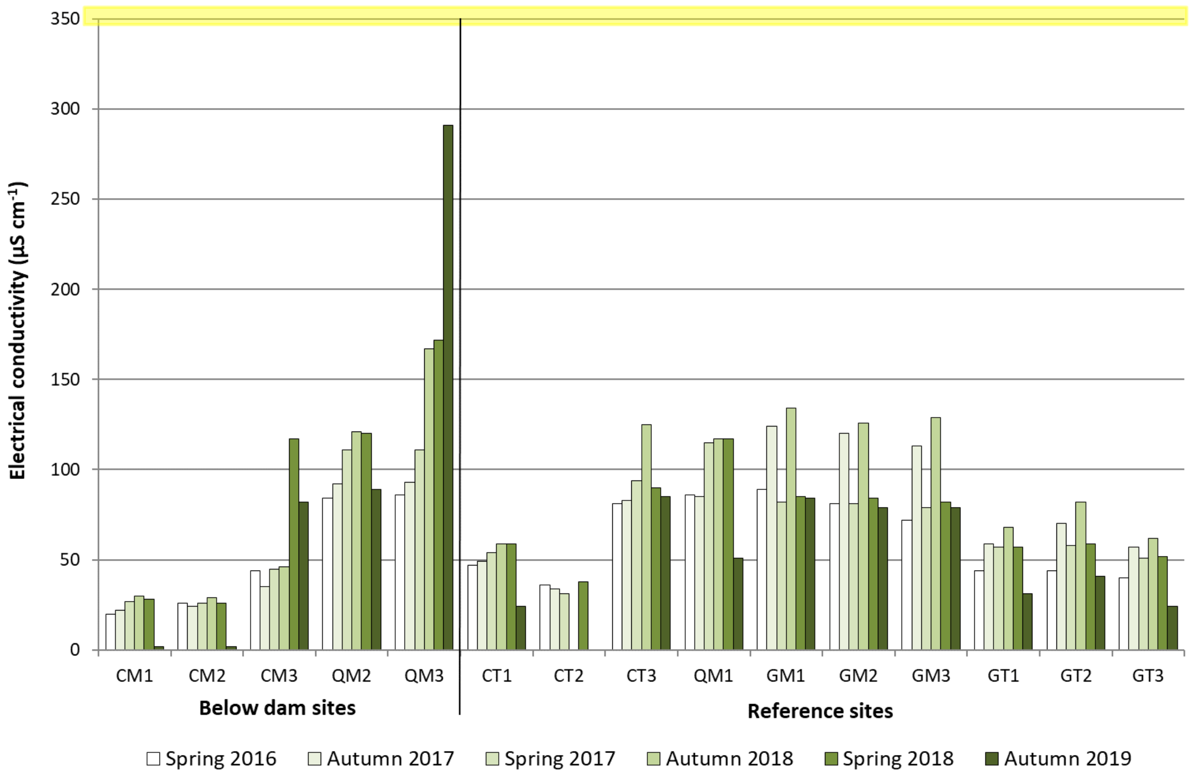
Total phosphorus concentrations at all sites from **spring 2016 to autumn 2019**. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is shaded yellow.



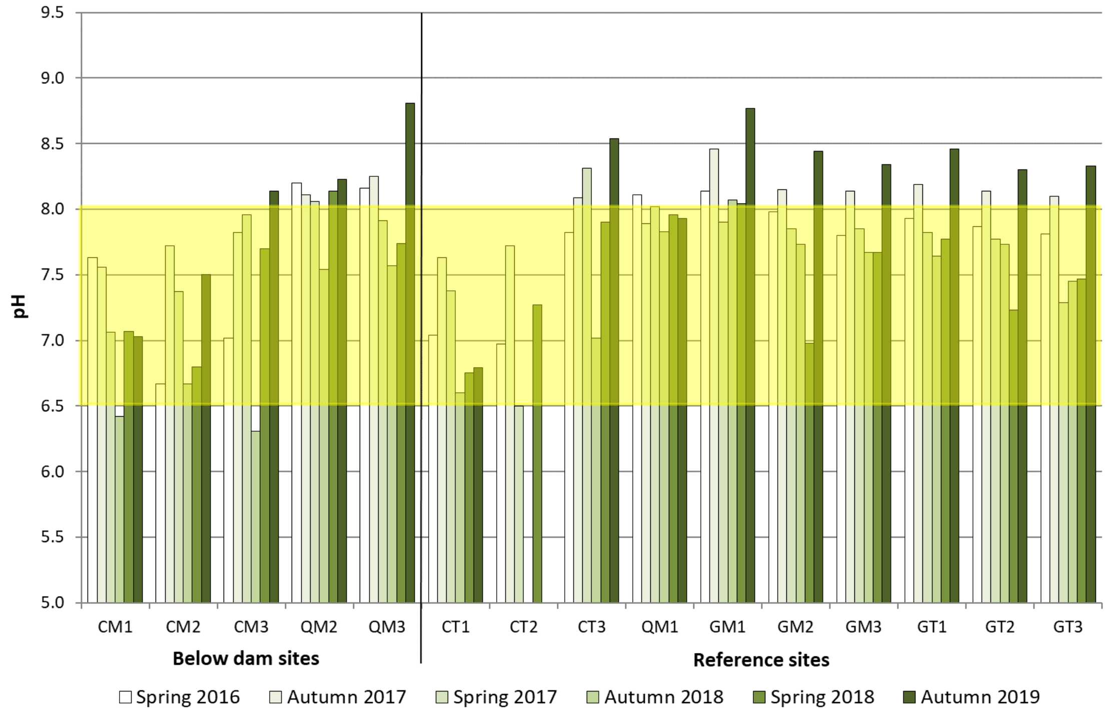
Total nitrogen concentrations at all sites from **spring 2016 to autumn 2019**. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is shaded yellow.



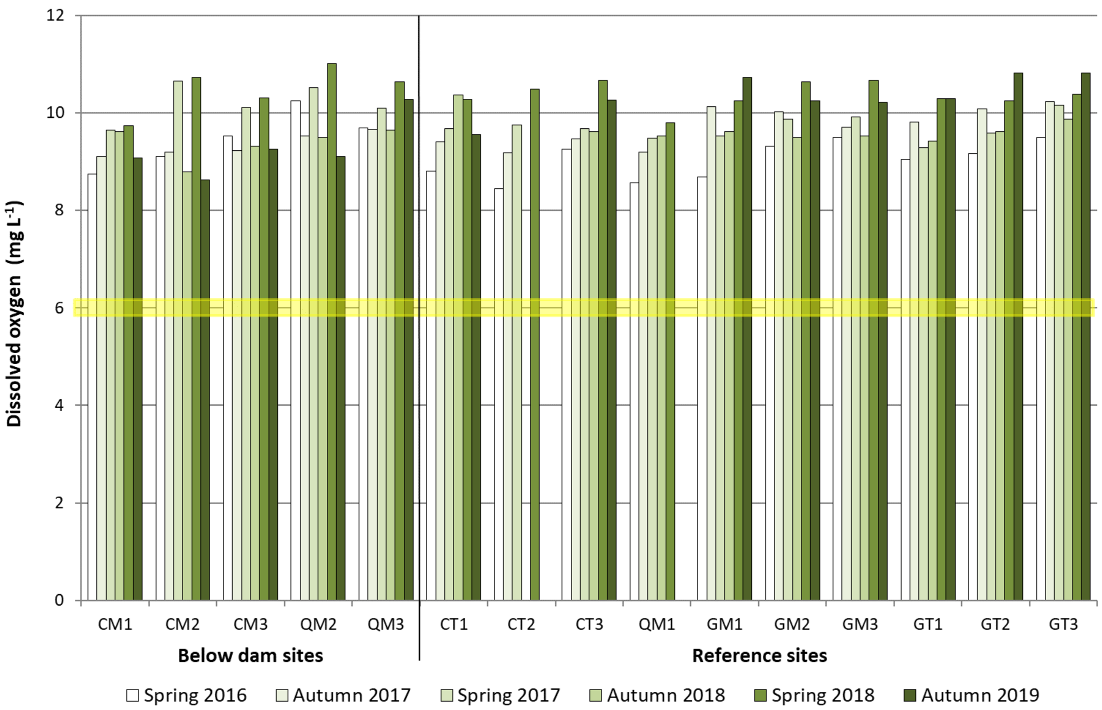
Alkalinity at all sites from **spring 2016 to autumn 2019**.



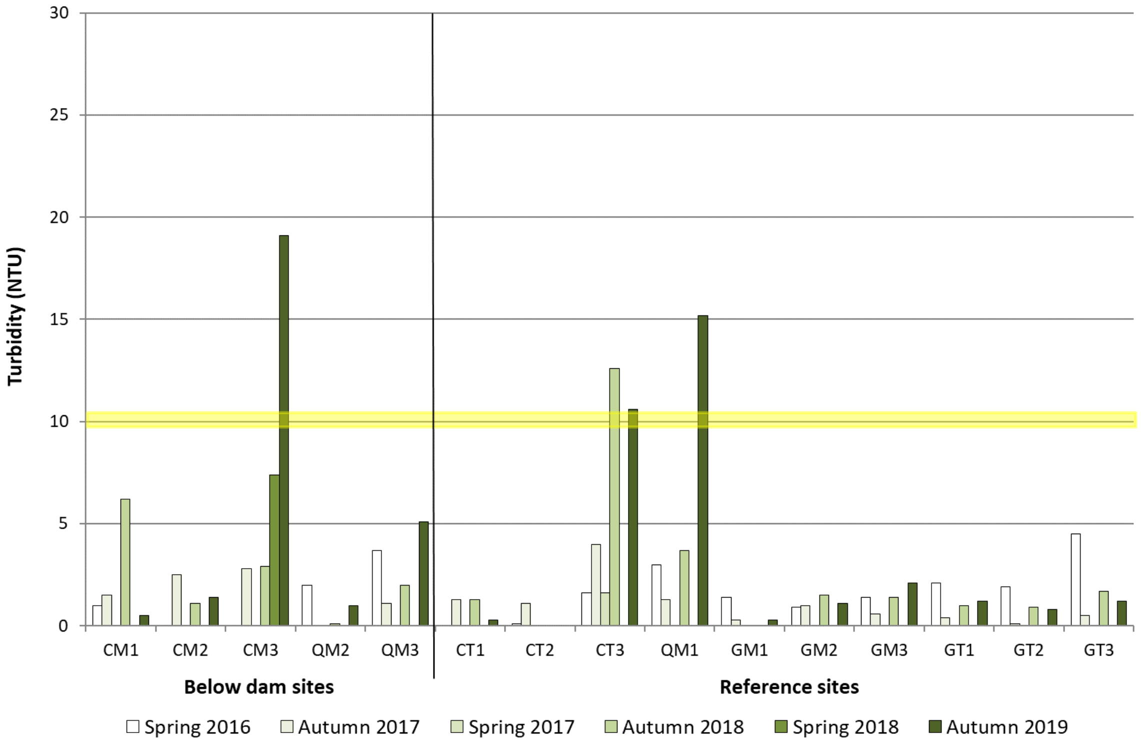
Electrical conductivity at all sites from **spring 2016 to autumn 2019.** The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is shaded yellow.



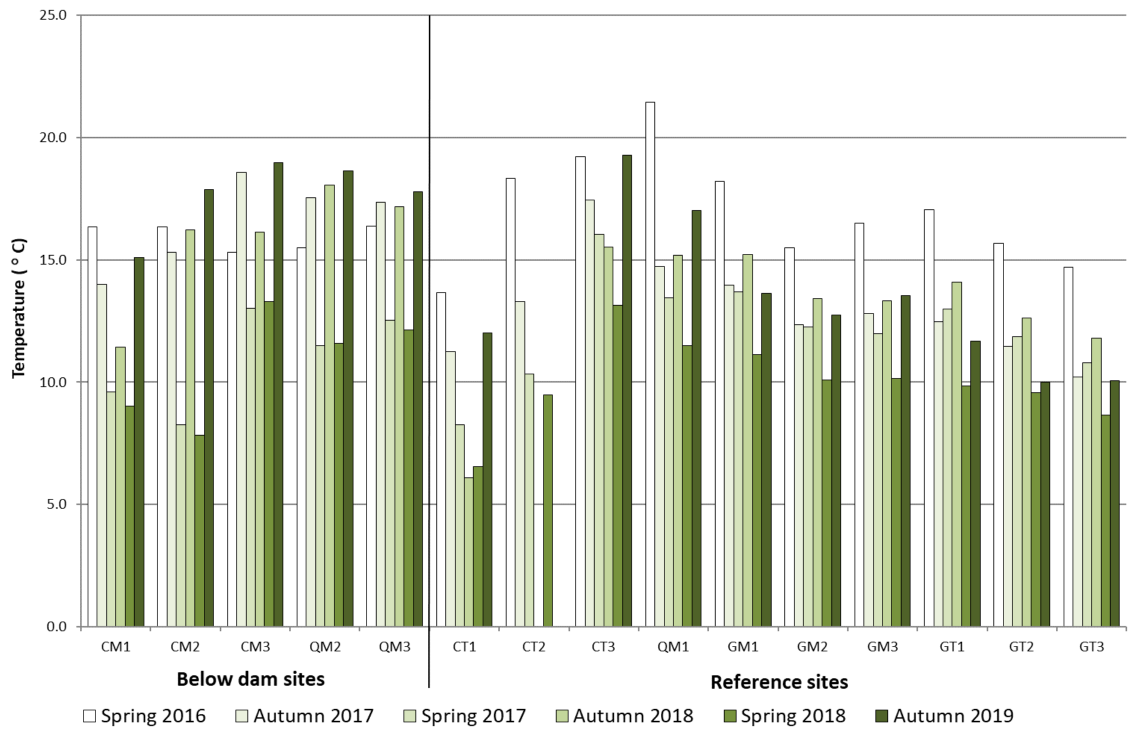
pH at all sites from **spring 2016 to autumn 2019.** The ANZECC/ARMCANZ (2000) guideline range for pH is shaded yellow.



Dissolved oxygen concentration at all sites from **spring 2016 to autumn 2019.** The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from **spring 2016 to autumn 2019**. The guideline for maximum turbidity is shaded yellow (Environment Protection Regulation SL2005-38).



Water temperature at all sites from **spring 2016 to autumn 2019**.