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

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EXECUTIVE SUMMARY

BACKGROUND AND STUDY OBJECTIVE

- The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (ACT) and Queanbeyan. Ecological assessment is undertaken in spring and autumn each year to evaluate river response to environmental flow releases to the Cotter and Queanbeyan Rivers. Sites below dams are assessed and compared with sites on the unregulated Goodradigbee River and Queanbeyan River (upstream of Googong Dam) to evaluate ecological change and responses attributed to the flow regulation.
- This study addresses the needs of Icon Water's License to Take Water (WU67) to assess the effects of dam operation, water abstraction, and environmental flows, and to provide information for the adaptive management of the Cotter and Googong water supply catchments. This study specifically focuses on assessing the ecological status of river habitats by investigating water quality and biotic characteristics. Here we present the results of assessments undertaken in spring 2019 and autumn 2020.

SPRING 2019 & AUTUMN 2020 RESULTS AND CONCLUSIONS

- Stream discharge at test sites was dominated by regulated flow conditions as all reservoirs were operating below full supply level. Total discharge in the six months prior to sampling in spring 2019 were higher than discharge in the six months prior to sampling in autumn 2020 at sites on the Cotter River and lower on sites on the Queanbeyan and Goodradigbee Rivers. Total rainfall six months prior to sampling was less than historical average rainfall across the entire study area in spring 2019. Rainfall was higher than the long-term average across the study area leading up to sampling in autumn 2020.
- Water quality parameters at below dam test sites were largely within guideline levels in spring 2019 and autumn 2020, with the exception of nitrogen oxides (NO_x) total nitrogen (TN) which were above guideline levels at a number of test sites, especially in autumn 2020. 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 Googong Dam (QM2 and QM3) in autumn 2020. Click here for more information.
- Two out of five test sites met the environmental flow ecological objective of AUSRIVAS band A in spring 2019 and one of the five test sites met the environmental flow ecological objective of AUSRIVAS band A in autumn 2020. A number of reference sites were also impacted and reduced in biological condition in autumn 2020. Click here for more information
- Macroinvertebrate community condition at the test sites downstream of Corin, Bendora and Cotter Dams as well at site QM3 (the most downstream site on the Queanbeyan River) remained in similar condition for both of the assessments (AUSRIVAS band B, B, A and B, respectively). The site immediately below Googong Dam (QM2) decreased in biological condition in autumn 2020 compared to spring 2019 (from AUSRIVAS band A to C). 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 2019**	**Autumn 2020**	**Spring 2019**	**Autumn 2020**
CM1 (Corin Dam)	<30	<10	B	B
CM2 (Bendora Dam)	<10	<10	B	B
CM3 (Cotter Dam)	<10	<10	A	A
QM2 (Googong Dam)	<10	<10	A	C
QM3 (Googong Dam)	<10	<20	B	B

PROJECT RECOMMENDATIONS

No new recommendations based on the result of the current assessment period.

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 2019 and autumn 2020 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 2019 and autumn 2020 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 15^{th} to 17^{th} September 2019 and in autumn between 12^{th} and 13^{th} May and 11th June 2020 (Table 1). Delay in completing autumn 2020 sampling until the 11^{th} June was a result of field travel restriction precautions as a result of the Covid-19 pandemic. 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.

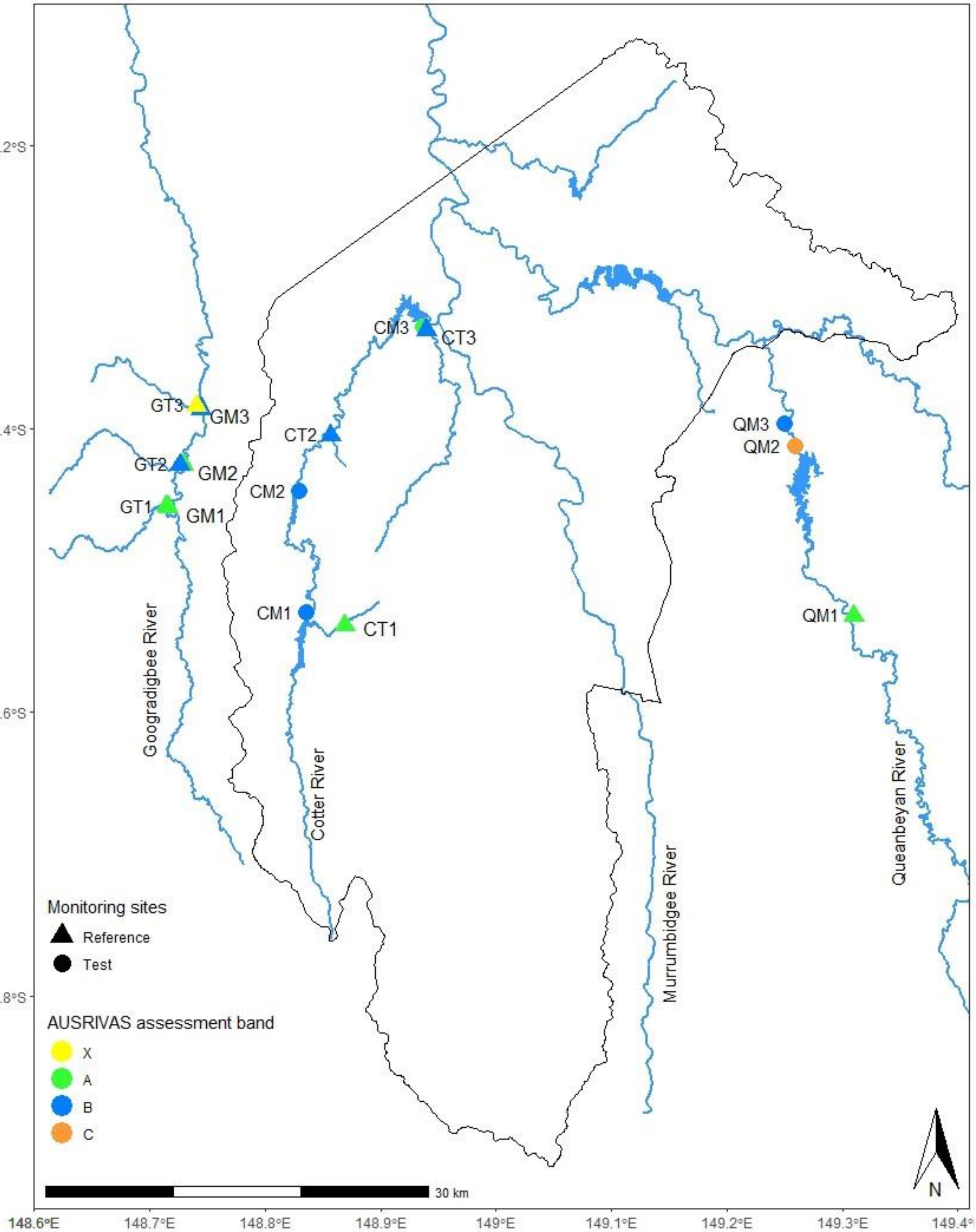

Figure 1: The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program (Circles indicate test sites, triangles indicate reference tributaries. Colours indicate AUSRIVAS assessment Band for Autumn 2020).

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 generally 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 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, 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 2019 and autumn 2020 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 4). All below dam sites met base flow regulations. All dams were below full supply level in the months leading up to sampling in both spring 2019 and autumn 2020. There was a reduction in the variability of operational releases from Bendora Dam in October – November 2019, with weekly variations reduced from 50% to 25% to prevent loss of Macquarie perch eggs and larvae.

Goodradigbee River recorded highest total discharge (76,749 ML) and Queanbeyan River (Downstream Googong Dam) recorded least total discharge (6,121 ML) from 15th March 2019 to 11th June 2020 (455 days). Differences in total discharges for the six months prior to sampling varied between spring 2019 and autumn 2020 sampling depending on site, with increases in total discharge for site QM1 (453%), Goodradigbee River (8.5%) and QM3 (4.7%) and decrease in total discharge for site CM1 (-55%), CM2 (-43%) and QM2 (-40%) (Figure 2). The large increase in discharge volume at site QM1 was largely attributable to two large flow events in mid-February 2020 and early March 2020. The greatest mean discharge at a regulated site, six months prior to sampling occurred downstream of Corin Dam at site CM1 in both spring 2019 and autumn 2020 assessments (214 ML d^{-1} and 163 ML d^{-1}, respectively) and the least at upstream of Googong Dam at site QM1 in spring 2019 and autumn 2020 assessments where the river ceased to flow

A total of 416 mm rainfall was recorded in the Cotter River catchment in the six months prior to sampling in spring 2019 which is less than historical rainfall of 475 mm over the same period. The total of 676.4 mm rainfall that fell prior to the autumn 2020 assessment was higher than historical mean rainfall of 478.4 mm for the same period from 2004 to 2020 (BOM; station number 070349). A total of 185.6 mm rainfall was recorded in the Queanbeyan River Catchment in the six months prior to sampling in spring 2019 which is less than the historical rainfall of 274.5 mm over the same period. A total of 345.2 mm of rainfall was recorded in the six months prior to sampling in autumn 2020 which is less than the historical rainfall of 382 mm from 1966 to 2020 (ALS Environmental, Site 570965).

Table 4: Flow regime targets (non-drought) 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.

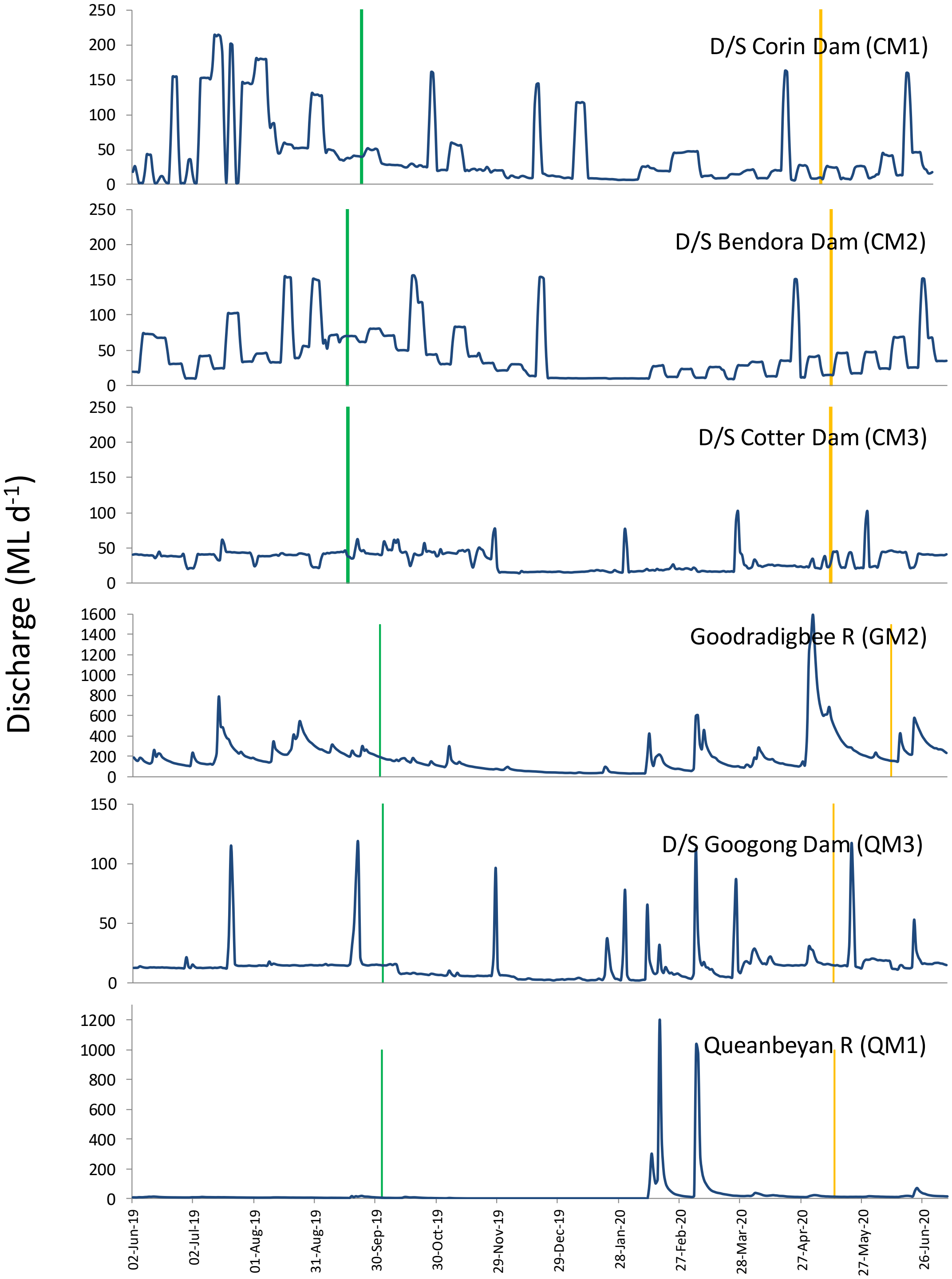

Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 2nd June 2019 to 8th July 2020. Green bar corresponds to spring 2019 sampling and orange bar corresponds to autumn 2020 sampling.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in spring 2019 and autumn 2020. Exceptions were pH at test site CM1 and reference site QM1; nitrogen oxides at test site CM1 and total nitrogen at test sites QM2 and QM3 and reference site QM1 in spring 2019 (Table 5). For the autumn 2020 assessment pH was higher than guideline at all Goodradigbee catchment reference sites and at reference site CT2 (Table 6). Total nitrogen and nitrogen oxides were also above guideline levels at most test sites and a number of reference sites in autumn 2020 (Table 6). Turbidity was above guideline levels at two sites, one test (CM3) and one reference (CT3) in autumn 2020 (Table 6).

Table 5: Water quality parameters measured at each of the test and reference sites in **spring 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	10.61	20	6.36	10.23	3.7	4	0.008	0.032	0.14	0.009
	CM2	9.87	19	6.92	9.08	0.1	10	0.005	0.014	0.12	0.008
	CM3	12.71	34	7.77	9.61	3.8	17	0.003	0.014	0.15	0.008
	QM2	14.09	90	7.84	11.03	1.9	42	0.004	0.008	0.32	0.007
	QM3	16.43	119	7.75	10.39	2.5	50	0.004	0.002	0.33	0.008
Reference sites	CT1	6.99	40	6.52	10.92	0.0	13	<0.002	0.002	0.08	0.018
	CT2	11.31	41	6.80	7.85	0.0	9	0.006	<0.002	0.07	0.005
	CT3	15.2	85	8.01	10	7.7	42	0.004	0.006	0.24	0.022
	QM1	17.09	88	8.64	11.94	0.0	44	0.007	0.006	0.29	0.012
	GM1	No									
	GM2	12.12	48	7.88	10.82	0.0	38	0.008	0.006	<0.05	0.007
	GM3	12.29	59	7.24	10.8	0.3	28	<0.002	<0.002	0.06	0.008
	GT1	No									
	GT2	11.35	40	7.81	10.56	0.4	19	<0.002	0.005	0.06	0.01
	GT3	9.64	34	7.07	11.02	3.8	18	0.003	<0.002	0.08	0.013

Table 6: Water quality parameters measured at each of the test and reference sites in **autumn 2020**. 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**	11.04	75	7.16	9.91	7.8	10	0.027	0.177	0.32	0.012
	CM2	11.5	44	6.53	10.71	4.6	4	0.029	0.114	0.24	0.006
	CM3	11.24	229	7.97	11.2	38.0	30	0.007	0.064	0.54	0.033
	QM2	12.6	139	7.68	11.12	3.2	20	0.024	0.062	0.39	0.007
	QM3	10.56	210	8.08	11.37	1.9	20	0.013	0.048	0.41	0.007
Reference sites	**CT1**	7.93	61	7.19	10.83	3.9	10	0.014	0.025	0.08	0.019
	CT2	11	33	6.23	10.77	3	3	0.02	0.007	0.05	0.005
	CT3	9.61	110	7.39	11.77	15.2	12	0.023	0.426	0.71	0.018
	QM1	7.83	108	7.17	10.96	9.6	14	0.012	0.008	0.35	0.015
	GM1	6.72	90	8.32	11.99	0.0	14	0.01	<0.002	<0.05	0.007
	GM2	6.29	86	8.01	11.82	1.2	12	0.005	<0.002	<0.05	0.007
	GM3	6.5	85	8.02	11.42	1.4	11	0.006	0.006	<0.05	0.007
	GT1	4.84	57	8.07	11.33	0.0	10	0.01	<0.002	<0.05	0.009
	GT2	4.95	65	8.06	12.01	0.3	10	0.009	<0.002	<0.05	0.009
	GT3	4.77	53	8.09	11.94	2.3	6	0.007	<0.002	<0.05	0.009

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 and QM3 in autumn 2020. Field observations of periphyton cover of riffle habitats were <20% in most of the sites, except for sites QM2 and QM3 in autumn 2020 (Table 7; Figure 3 and Figure 4).

Mean ash free dry mass concentrations were significantly different between sites for both the spring 2019 ($F_{5,30}$ = 6.547, $p < 0.001$) and autumn 2020 assessments ($F_{6,35}$ = 3.492, p = 0.008). In spring 2019, reference site GM3 had significantly higher ($p < 0.05$) mean ash free dry mass concentrations than all other sites (Figure 5). In autumn 2020, test site QM2 had significantly higher mean ash free dry mass concentrations than test sites CM1 and CM2 and reference site GM1 (Figure 5).

Mean Chlorophyll-a concentrations differed between sites in both the spring 2019 assessment ($F_{6,35}$ = 7.30, p = 0.001) and the autumn 2020 assessment ($F_{6,35}$ = 9.793, $p <$ 0.001). In spring 2019, the only significant difference between sites was test site CM1 having significantly higher mean Chlorophyll-a concentrations than test site QM2 (p = 0.02; Figure 6). In autumn 2020, reference site GM3 had significantly higher mean Chlorophyll-a concentrations than all other sites, except for QM2 (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 2017 to autumn 2020. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat												
	Periphyton						Filamentous algae					
	Spr-17	Aut-18	Spr-18	Aut-19	Spr-19	Aut-20	Spr-17	Aut-18	Spr-18	Aut-19	Spr-19	Aut-20
CM1	<20	<20	<20	<10	<30	<10	<20	<20	<20	<10	<30	<10
CM2	<10	<10	<20	<10	<10	<10	<20	<10	<10	<10	<10	<10
CM3	40	<10	<20	<10	<10	<10	40	<10	<20	<10	<10	<10
QM2	40	<20	40	<10	<10	30	40	<10	40	<10	<10	40
QM3	<20	<20	40	<10	<10	20	<20	<10	<10	<10	<10	20
GM1	<20	<10	<20	<10	NA	<10	<10	<10	<20	<10	NA	<10
GM2	<20	<10	<20	<10	<10	<10	<10	<10	<10	<10	<10	<10
GM3	40	<10	40	<10	<30	<10	<10	<10	<10	<10	<20	<10
QM1	<20	40	40	<20	<10	<20	<10	40	<20	<20	<10	<20

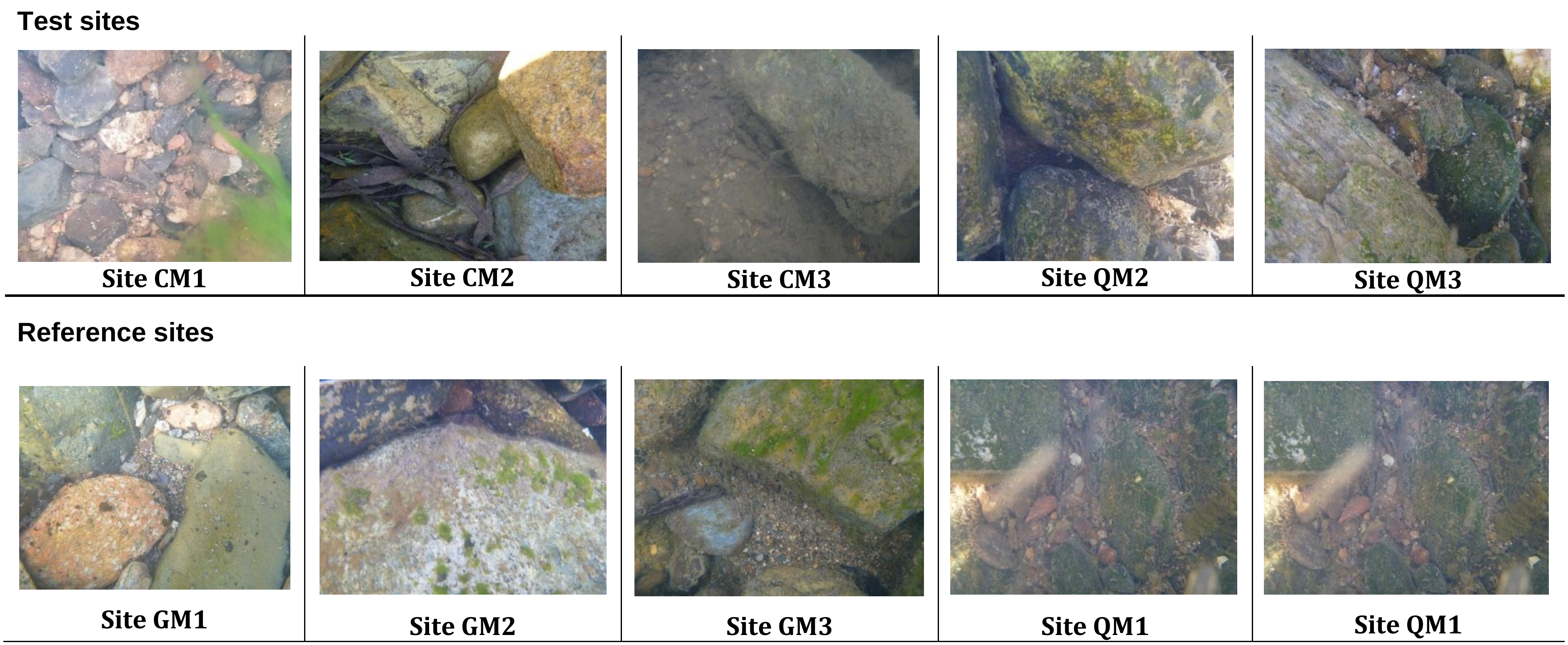

Figure 3. Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in **spring 2019**.

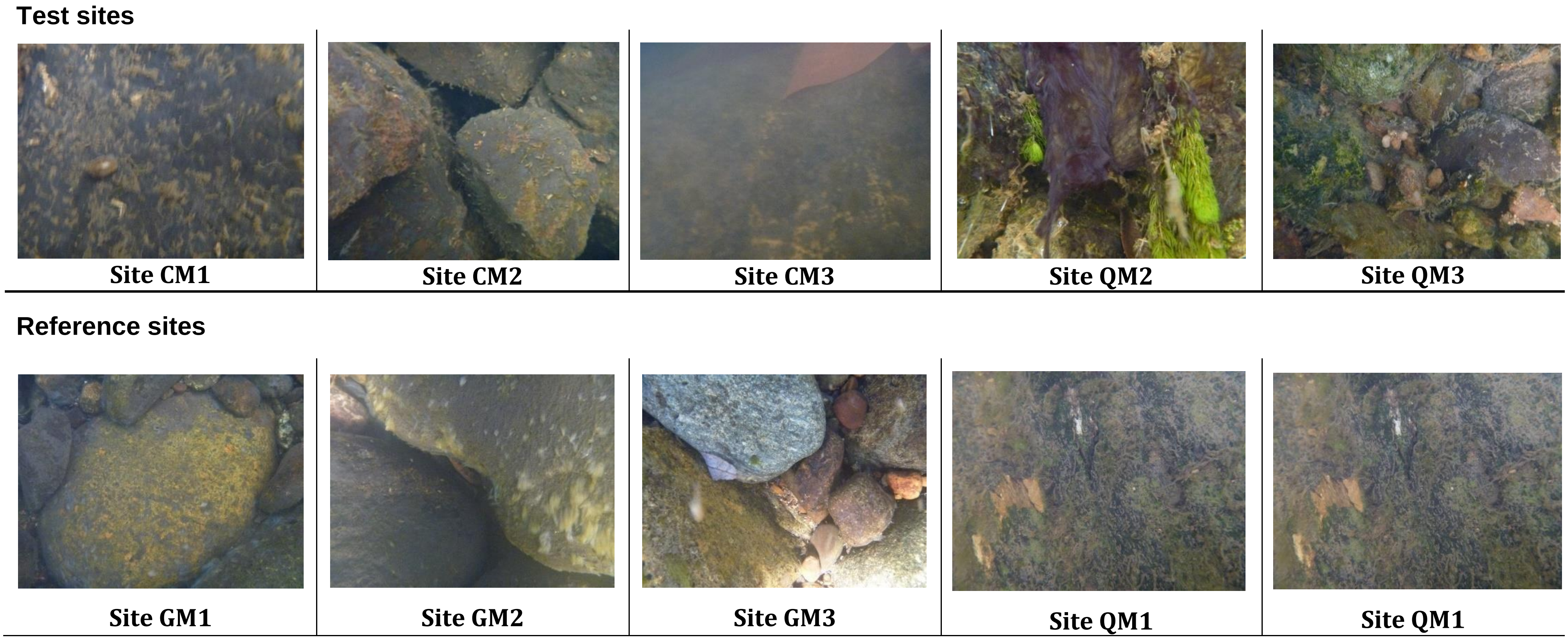

Figure 4: Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in **autumn 2020.**

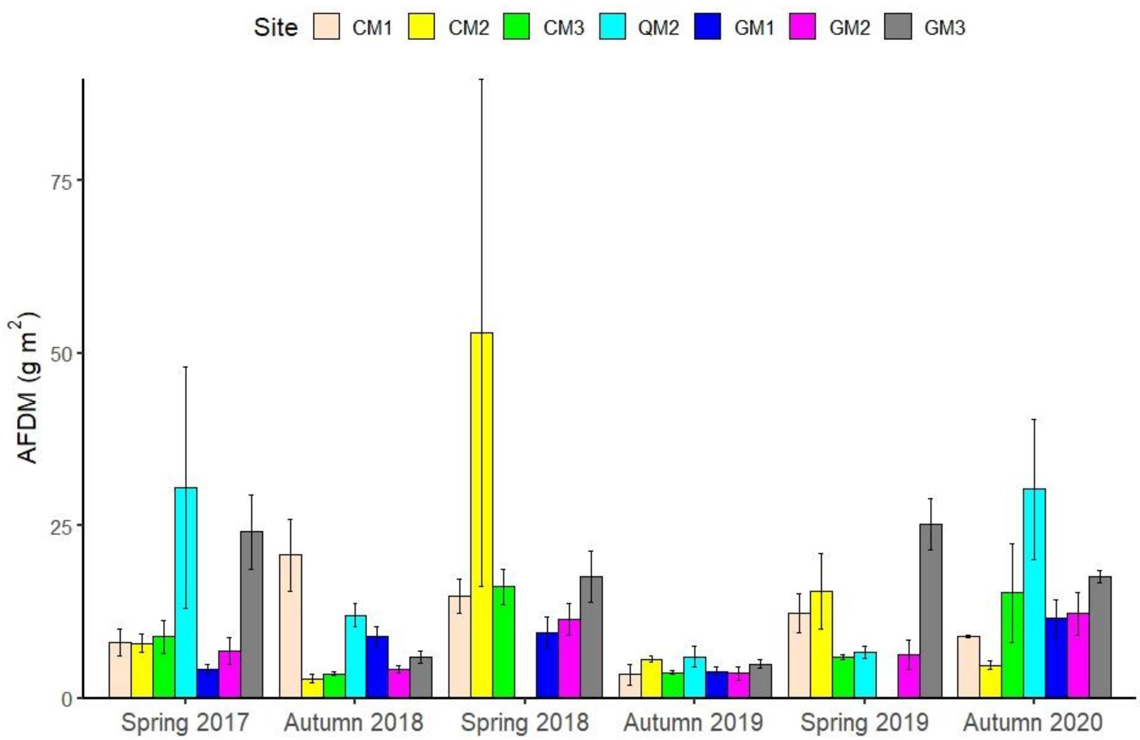

Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2017 to autumn 2020. Error bars represent +/- 1 standard error.

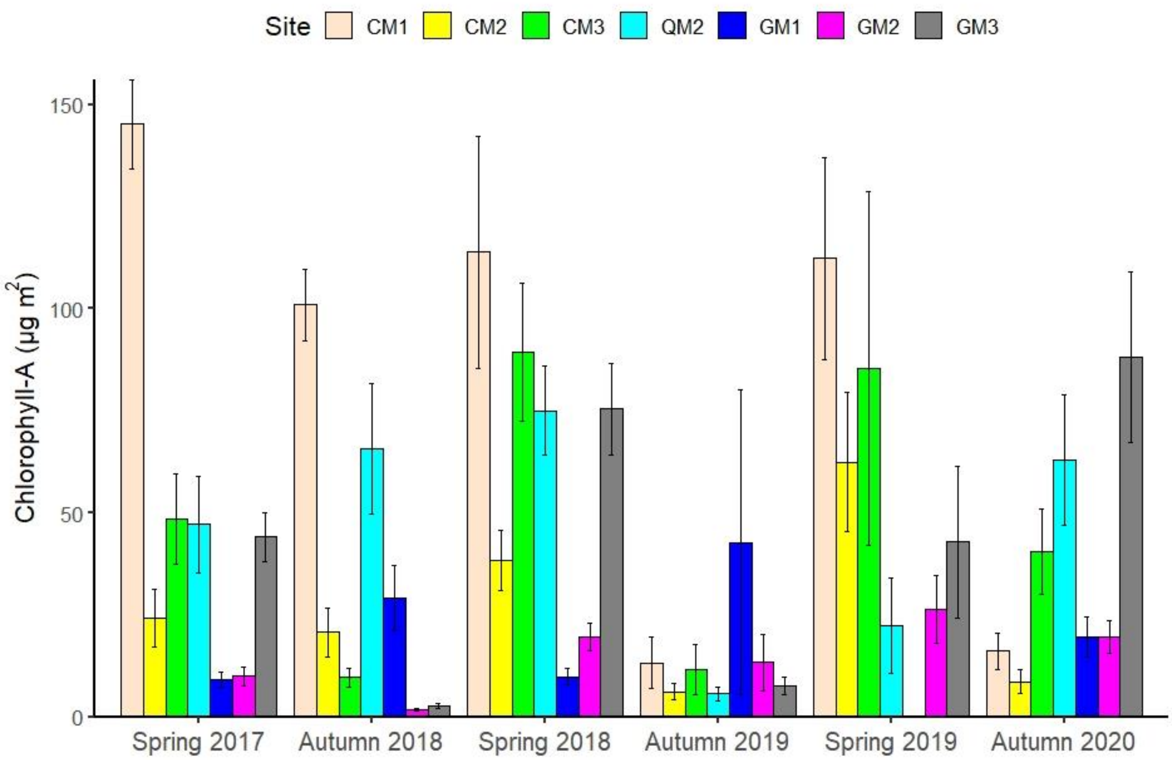

Figure 6: Mean Chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2017 to autumn 2020. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in spring 2019 and again in autumn 2020 (Table 8), though this difference was less evident in autumn 2020.

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 2019 and autumn 2020 (Table 8). Test site CM1 remained in band B for the past eight assessments and has had a very stable O/E score of between 0.84 – 0.85 since spring 2018 (Table 8). The dominant taxa at this site for both spring 2019 and autumn 2020 was Gripopterygidae (Appendix 2). One taxa (Hydrobiosidae) which was predicted to have a ≥50% chance of occurrence by the AUSRIVAS model was detected in the whole sample scan (Table 9) but not in the subsample that was processed, suggesting that this taxon was present, but in low abundances at this site in autumn 2020.

Condition of the Cotter River below Bendora Dam (CM2) was assessed as band B in both spring 2019 and autumn 2020 assessment. This site has remained in similar biological condition since autumn 2017, with some fluctuation in O/E score of between 0.67 – 0.86 (Table 8). The macroinvertebrate community at CM2 in spring 2019 was characterised by an extremely high abundance of Simuliidae and more so in autumn 2020 (Appendix 2).

The condition of the Cotter River below Cotter Dam (CM3) was assessed as similar to reference (band A) in both spring 2019 and autumn 2020 assessments, an improvement from autumn 2019 (band C) and its previous assessments dating back to spring 2017 (band B) (Table 8). Simuliidae and Orthocladiinae were the dominant taxa in both the spring 2019 and autumn 2020, though other taxa such as Gripopterygidae, Oligochaeta and Caenidae were also abundant (Appendix 2).

The below Googong Dam test site (QM2) was assessed as similar to reference (band A) in spring 2019 and severely impaired (band C) in autumn 2020 (Table 8). This continues a seasonal fluctuation that has occurred since spring 2018 (Table 8). The shift in condition between spring 2019 and autumn 2020 was largely driven by reduction in diversity and an increase in dominance of two taxa Baetidae and Orthocladiinae, which accounted for approximately 65% of the total number of individuals identified (Appendix 2). The below Googong Dam test site (QM3) was assessed as band B (significantly impaired) in both spring 2019 and autumn 2020 (and the previous assessment autumn 2019)(Table 8). The O/E score at this site has remained very stable since autumn 2019 (0.76 – 0.77), which followed a period of drastic seasonal fluctuations of between 0.56 – 1.00 between assessments from spring 2016 – spring 2018 (Table 8). Taxa composition was relatively similar between spring 2019 and autumn 2020, though Orthocladiinae were much more dominant in spring 2019 (Appendix 2) The somewhat fluctuating biological condition of the test sites in the Queanbeyan River below Googong Dam contrast with the largely stable biological condition of the reference site (QM1) above Googong Dam, which has largely been assessed as similar to reference since spring 2016 (Table 8)

Biological condition of reference sites varied both within and across seasons for spring 2019 and autumn 2020. Reference sites CT1 and QM1 remained in band A (similar to reference) and site CT2 remained in band B (significantly impaired) between spring 2019 and autumn 2020 (Table 8). Sites GM3 and GT2 have fluctuated between band A in spring and band B in autumn since spring 2018, though prior to this were relatively stable in biological condition either being assessed as band A or band X (more diverse than reference) (Table 8). The change of GM3 from a band A to a band B is largely driven by increased dominance of Simuliidae in autumn 2020, where it comprised 45 % of the total number of individuals identified (Appendix 2). Site GT3 was the only reference site to increase in biological condition, from a band A in spring 2019 to a band X in autumn 2020 (Table 8).

Table 8: AUSRIVAS band and Observed/Expected taxa score for each site from spring 2016 to autumn 2020. **Note:** Reference site CT2 (Burkes Creek) was not able to be sampled for macroinvertebrates in spring 2019 as the creek was too dry for standardised sampling methods. Reference sites GM1 and GT1 were not able to be sampled in spring 2019 due to road closure from a fallen tree.

	Below dams sites					Reference sites									
	CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**QM1**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Autumn 2020	**B** (0.85)	**B** (0.79)	**A** (0.97)	**C** (0.63)	**B** (0.77)	**A** (0.96)	**B** (0.64)	**B** (0.76)	**A** (0.90)	**A** (1.12)	**A** (1.04)	**B** (0.82)	**A** (1.08)	**B** (0.85)	**X** (1.13)
Spring 2019	**B** (0.84)	**B** (0.67)	**A** (0.88)	**A** (0.88)	**B** (0.77)	**A** (0.96)	Not sampled	**B** (0.74)	**A** (1.10)	Not sampled	**X** (1.19)	**A** (0.97)	Not sampled	**A** (1.05)	**A** (1.13)
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)

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 2019 and autumn 2020** (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). **Note:** Reference site CT2 (Burkes Creek) was not able to be sampled as the creek was too dry for standardised sampling methods. Reference sites GM1 and GT1 were not able to be sampled in spring 2019 due to road closure from a fallen tree.

Missing taxa in Spring 2019																
Taxa	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
Oligochaeta	2						X					X		X		
Acarina	6		X	X					X			X				
Scirtidae	6						X									
Elmidae	7			X	X											
Psephenidae	6	X	X		X	X			X							X
Tipulidae	5						X									
Simuliidae	5						X									
Tanypodinae	4	X	X			X			X							
Orthocladiinae	4															
Chironominae	3															
Baetidae	5		X												X	
Leptophlebiidae	8		X	X	X				X							X
Caenidae	4	X	X									X				
Gripopterygidae	8					X										
Hydrobiosidae	8	X			X	X						X				
Glossosomatidae	9	X	X	X	X	X			X					X	X	X
Hydropsychidae	6	X				X			X		X			X		
Conoesucidae	7		X	X	X	X			X							
Total		**6**	**8**	**5**	**6**	**7**	**4**	**0**	**7**	**0**	**1**	**4**	**0**	**3**	**2**	**3**

Missing taxa in Autumn 2020																
Taxa	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
Acarina	6								X							
Scirtidae	6	X						X						X		
Elmidae	7	X	X	X	X	X										
Psephenidae	6	X	X	X				X						X		X
Tipulidae	5						X	X								
Podonominae	6				X				X	X		X				
Tanypodinae	4										X	X	X	X		
Chironominae	3														X	
Coloburiscidae	8	X						X						X		
Leptophlebiidae	8		X	X	X			X								X
Caenidae	4		X					X								
Gomphidae	5				X	X			X							X
Hydrobiosidae	8	X			X	X	X	X		X		X	X	X	X	
Hydroptilidae	4		X		X	X	X		X		X	X				X
Hydropsychidae	6										X	X				X
Conoesucidae	7		X	X			X	X				X				
Leptoceridae	6	X	X		X	X		X	X				X	X		
Total		**6**	**7**	**4**	**7**	**5**	**4**	**9**	**5**	**2**	**3**	**6**	**3**	**6**	**2**	**5**

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, Figure 9) for both spring 2019 and autumn 2020 assessments. In spring 2019, tolerant OC taxa were dominant (> 50%) at below dam test sites below Cotter Dam (CM3) and below Googong Dam (QM2 and QM3) (Figure 7). In contrast, environmentally sensitive taxa (EPT) were dominant (>60%) in below dams test sites below Corin Dam (CM1) and below Bendora Dam (CM2) in spring 2019 (Figure 7). In autumn 2020, the site below Corin Dam (CM1) was again dominated by environmentally sensitive taxa, along with the two Queanbeyan River sites below Googong Dam (QM2 and QM3), whilst the other two sites on the Cotter River (CM2 and CM3) comprised macroinvertebrate communities dominated by tolerant taxa (primarily Diptera and Chironomidae)(Figure 7).

Generally, reference sites had a higher composition of environmentally sensitive taxa in autumn 2020 compared to spring 2019, with the exception of sites CT1 and QM1.The largest change in community was at the reference site on Kangaroo Creek (CT1), which went from being dominated by environmentally sensitive taxa in spring 2019 (~80%) to less than 10% environmentally tolerant taxa in autumn 2020, mainly driven by an increase in Oligochaeta and Chironomidae (Figure 7).

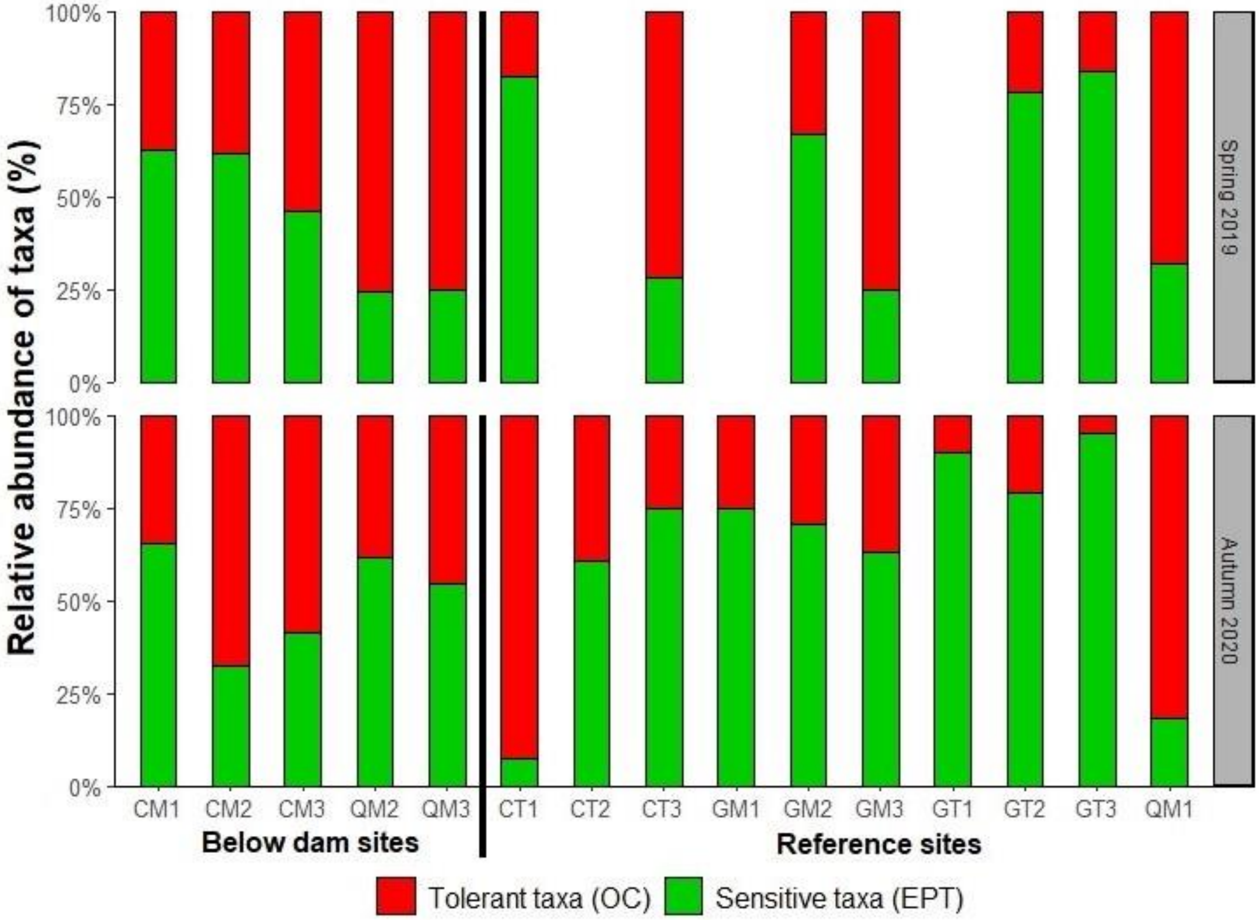

Figure 7. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in **spring 2019 and Autumn 2020**. Note: Reference site CT2 (Burkes Creek) was not able to be sampled for macroinvertebrates in spring 2019 as the creek was too dry for standardised sampling methods. Reference sites GM1 and GT1 were not able to be sampled in spring 2019 due to road closure from a fallen tree.

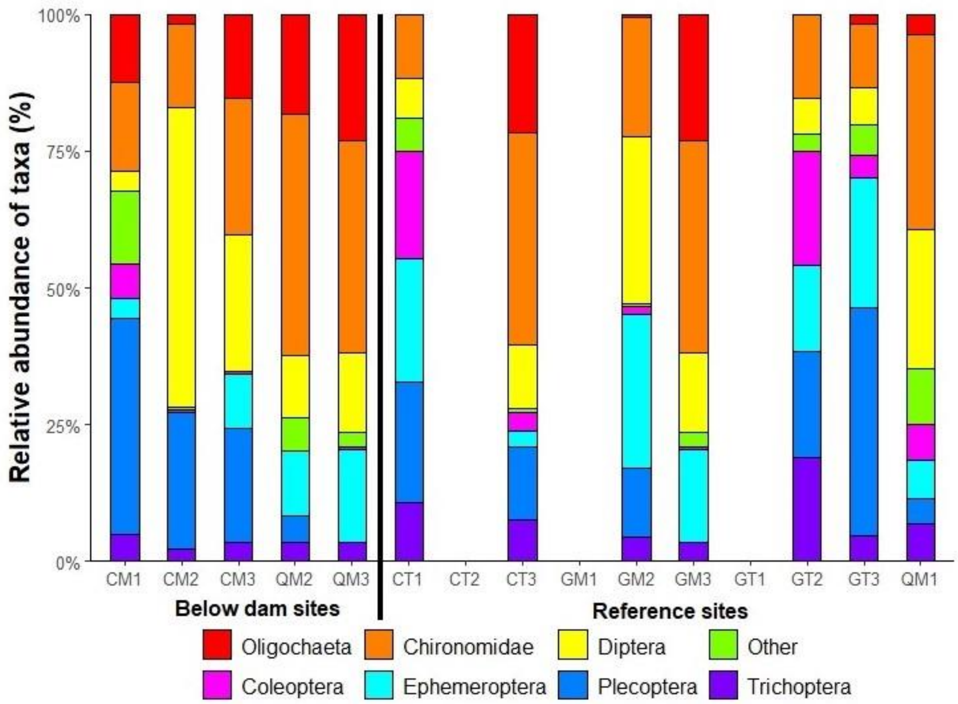

Figure 8: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **spring 2019**. Note Reference site CT2 (Burkes Creek) was not able to be sampled for macroinvertebrates in spring 2019 as the creek was too dry for standardised sampling methods. Reference sites GM1 and GT1 were not able to be sampled in spring 2019 due to road closure from fallen tree.

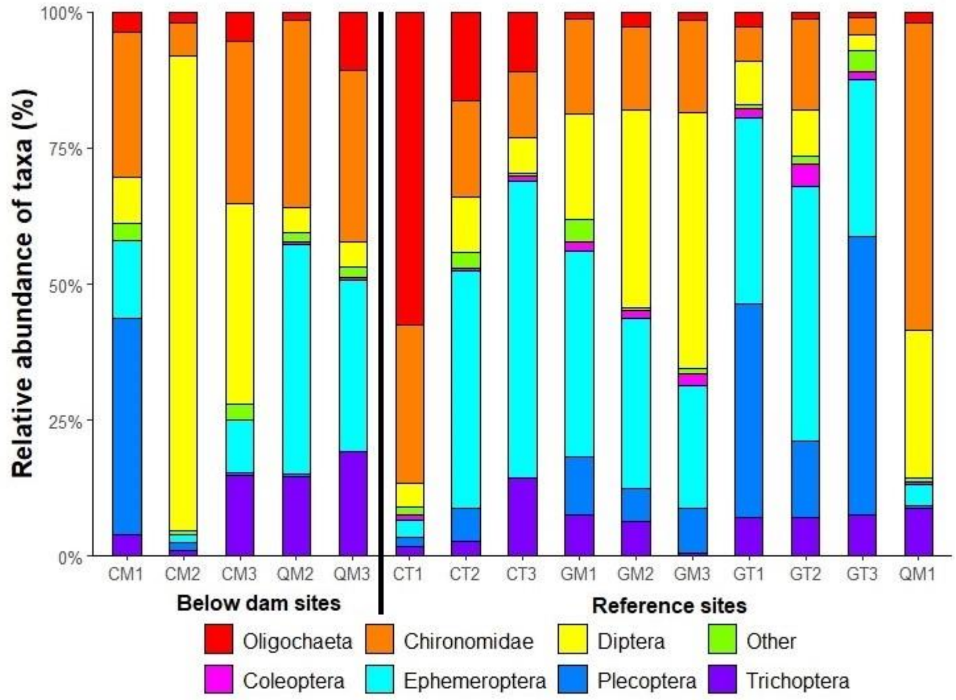

Figure 9: Relative abundance of macroinvertebrate taxonomic groups from samples collected in **autumn 2020**.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

In general macroinvertebrate assemblages at reference sites were similar to other reference sites both spring 2019 and autumn 2020 assessments (Figure 10 and Figure 11). Macroinvertebrate assemblages of test sites were varied for the spring 2019 assessment, however, test site assemblages were more similar to each other in the autumn 2020 assessment (Figure 10 and Figure 11). Differences in macroinvertebrate assemblage between test and reference sites were driven by higher abundances of Elmidae, Tanypodinae, Conoesucidae at reference sites in spring 2019 and higher abundances of Conoesucidae at reference sites in autumn 2020 (Figure 10 and Figure 11).

The macroinvertebrate assemblages of test sites below Corin Dam (CM1), below Bendora Dam (CM2) and downstream of Googong Dam (QM3) were dissimilar to all other sites in spring 2019 (Figure 10), driven by high abundances of Gripopterygidae, Simulidae and Orthocladiinae, respectively (Appendix 2). Reference site CT1 had a macroinvertebrate assemblage dissimilar to all other sites in autumn 2020, largely driven by an extremely high abundance of Oligochaeta (Figure 11 and Appendix 2).

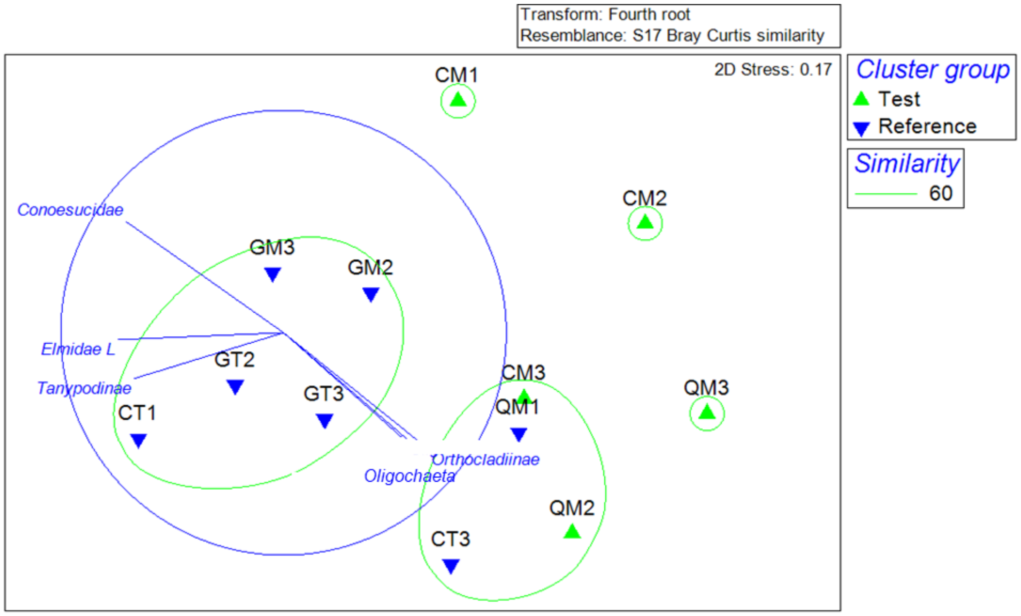

Figure 10. MDS ordination of 60% similarity between macroinvertebrate samples collected in **spring 2019** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa 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.

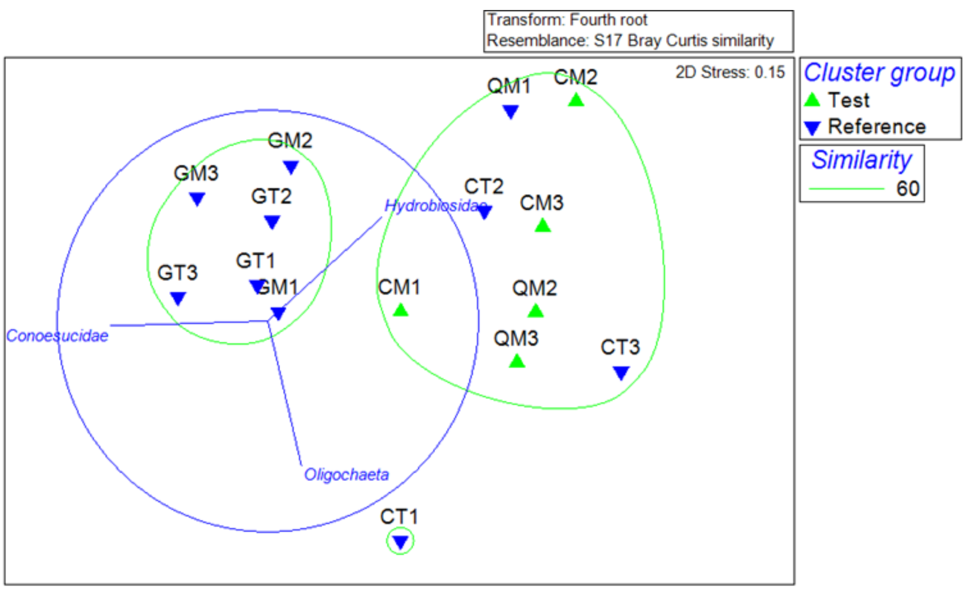

Figure 11. MDS ordination of 60% similarity between macroinvertebrate samples collected in **autumn 2020** for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa 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 2019 and autumn 2020 (Table 5 and Table 6). The higher than guideline pH levels assessed in autumn 2020 may be because of instrument malfunction, as they all occurred on the same day of field data collection. Some attention to the pH at these sites in further assessments will provide further insight. The higher than guideline turbidity detected at site CM3 is likely because of the water in this reach being predominantly part of the Murrumbidgee to Cotter River recirculation, where Murrumbidgee River water (generally quite turbid) is pumped up to the base of Cotter Dam and released to flow back down to the junction with the Murrumbidgee River.

Nitrogen oxides (NO_x) had exceeded guideline concentrations at all test sites and total nitrogen was above guideline levels at four of five test sites in autumn 2020. High Nitrogen levels and denitrification within the reservoir could be the cause of elevated NOx concentrations at sites directly below reservoirs and the high concentrations experienced in autumn 2020 are not likely related to the environmental flow regime (Saunders and Kalff 2001). Concentrations of both NOx and total nitrogen were extremely high at reference site on Paddy's River (CT3). High concentrations of nutrients at CT3 during the autumn 2020 assessment may have been a result from rainfall runoff entering the stream prior to sampling. The Paddys River Catchment is mainly forestry and agricultural land which may have contributed to both the higher nutrient concentrations (see Burnett and Dodds 2005) as well as the higher turbidity following rainfall. There was rainfall in the catchment (approximately 5 mm) in the weeks leading up to sampling.

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 Googong Dam (QM2 and QM3) in autumn 2020 (Table 7). This is largely consistent with recent assessments, and indicates that the current environmental flow release strategy is mostly effective in achieving the environmental flow ecological objective to control filamentous algae accumulation downstream of dams on the Cotter and mostly on the Queanbeyan Rivers during spring and autumn.

There were a number of significant differences in both ash free dry mass and chlorophyll-a concentrations between sites for both the spring and autumn 2020 assessments, though this appeared to be unrelated to whether sites were test or reference (Figure 5, Figure 6). Despite some significantly difference in ash free dry mass and chlorophyll-a concentrations between sites in both spring 2019 and autumn 2020, concentrations across all sites was within the range of those measured in recent sampling (dating back to spring 2017).

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at three of five and four of five below dam test sites spring 2019 and autumn 2020, 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, particularly in autumn 2020 when four of the 10 reference sites were biologically impaired.

The Cotter River test site below Corin Dam (CM1) remained significantly impaired in both spring 2019 and autumn 2020 assessment and has been for the past three years (and has had an O/E score very close to band A since spring 2018). The increase of the O/E score from 0.65 – 0.78 up to autumn 2018, then >0.84 from spring 2018 onwards may be related to a reduction in monthly volumes of discharge at this site during that time (Figure 12). Because of low Corin reservoir levels less water was discharged to Bendora for water supply purposes. A reduction in discharge, especially short-term disturbance events may have led to a more diverse macroinvertebrate community by allowing establishment of both early and late colonizing taxa. Another contributing factor to the impaired biological condition in autumn 2020 was that bushfires in summer 2020 impacted the catchment upstream. This may have resulted in some impacts on water quality which may have contributed to biological condition at this site.

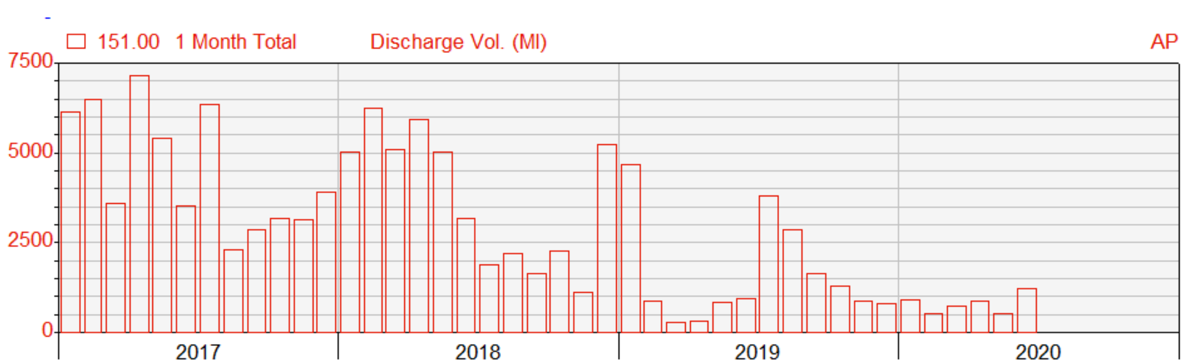

Figure 12. Total monthly discharge of the Cotter River downstream of Corin Dam (Icon Water data from Gauge 410752).

The Cotter River test site below Bendora Dam (CM2) remained significantly impaired in both spring 2019 and autumn 2020 (Table 8). The macroinvertebrate community at this site is stable and 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) was assessed as similar to reference in both spring 2019 and autumn 2020 (for the first time since autumn 2017), despite higher turbidity readings at this site as a result of the Murrumbidgee to Cotter recirculation program. This may be related to a more varied flow regime with some more frequent higher flows (~100 ML Day^{-1}) being released, especially during early 2020. It is hyopthesised that maximum diversity of ecological communities is achieved by an intermediate disturbance regime which finds the balance between species colonizing ability (early colonisers) and species competitive ability (species that can dominated under stable conditions) (Connell 1978). It is likely that the increase disturbances (in terms of hydrologic disturbance) has created a hydrological regime more suitable to support a more varied macroinvertebrate community than that of the previously level variable regime.

Macroinvertebrate communities at the site immediately downstream of Googong Dam (QM2) decreased in biological condition from spring 2019 (band A) to autumn 2020 (band C). The assessment in spring 2019 was undertaken about a month after a flow peak in the river, whereas the assessment in autumn 2020 followed a period of relatively low stable flows. It is likely that simplification of the macroinvertebrate community (i.e. loss of diversity) may be due to low disturbance frequency at QM2 leading up to autumn 2020 sampling. The lack of disturbance was 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.

Five of the six references sites in the Goodradigbee River catchment decreased the O/E scores between spring 2019 and autumn 2020 (and three of these five also decreased in AUSRIVAS assessment bands). Approximately one month prior to the autumn 2020 assessment, a large rainfall even resulted in a large peak in river discharge. It is likely that this peak caused significant disturbance to the macroinvertebrate community in this catchment, resulting in reduced diversity compared to the spring 2019 assessment. Ideally, more time would be allowed to pass following a significant disturbance event before sampling would be undertaken, however, logistically, this was the latest that sampling could be undertaken in 2020.

The reference site at Kangaroo Creek undertook a significant change macroinvertebrate community assemblage between spring 2019 and autumn 2020. The macroinvertebrate assemblage at this site in spring 2019 was dominated by environtmentally sensitive taxa (e.g. Ephemeroptera, Tricoptera and Plecoptera) but changed to a community assemblage dominated by Oligochaeta and Chironomidae. This was likely due to impacts of bushfire and resultant sedimentation from erosion from fires that burnt the catchment in early 2020 (Figure 13). Despite this significant disturbance event, the site remained in band A (similar to reference) in autumn 2020, which highlights the resilience of the macroinvertebrate community at this site.

Figure 13. Sedimentation of Kangaroo Creek site (CT1) following January 2020 Bushfires (Photo: Ben Broadhurst).

CONCLUSION

Water quality parameters at below dam test sites were largely within guideline levels in spring 2019 and autumn 2020. Despite some increased nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites in spring 2019 and at three of five test sites in autumn 2020. Four of five test site remained in similar biological condition between the spring 2019 and autumn 2020 assessments, with the only change being site QM2 declining in condition from similar to reference to severely impaired. Generally, reference sites decreased in biological condition (either within band or across bands) between spring 2019 and autumn 2020, with a hydrological disturbance prior to autumn 2020 sampling the likely cause. The macroinvertebrate assemblage at reference site CT1 was affected by bushfires, although still remained in similar to reference condition biologically.

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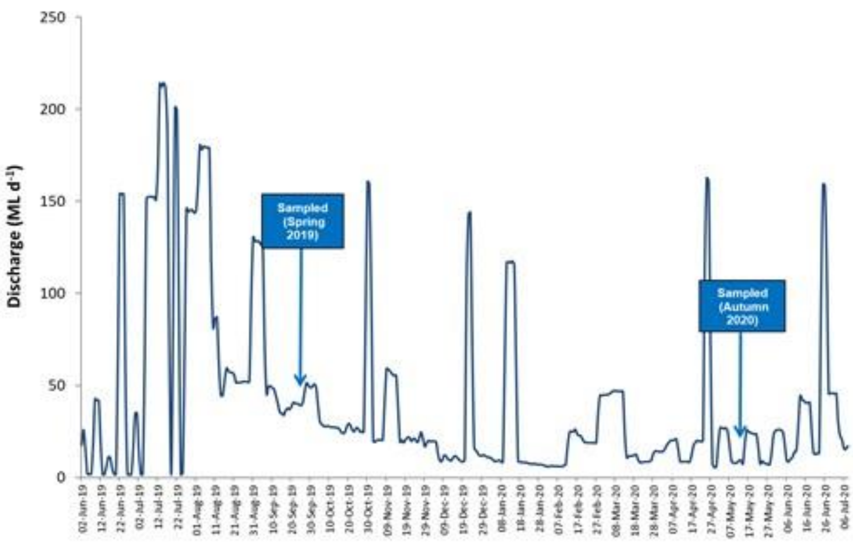
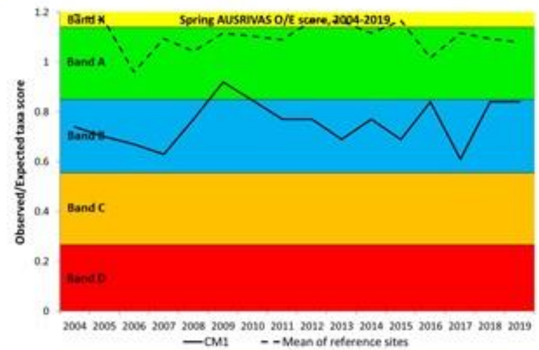
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

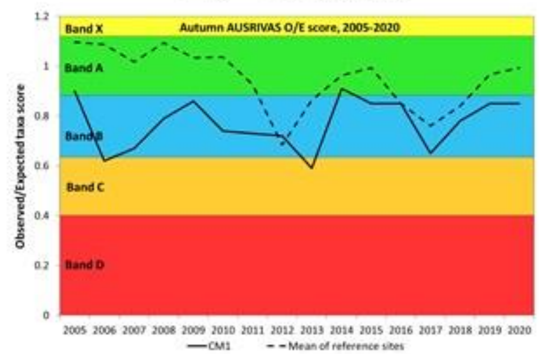
CM1 - Spring 2019 - Autumn 2020

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2019	Autumn 2020	Objective met?
AUSRIVAS band A	Band B	Band B	No in both seasons
<20% filamentous algae cover in riffle habitat	<30%	<10%	No - spring 2019 Yes – Autumn 2020







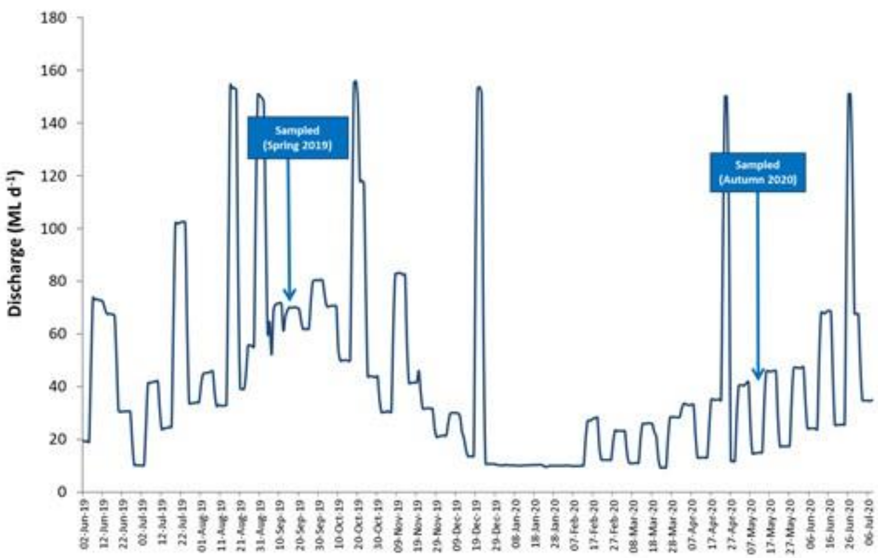
* Denotes values outside guideline levels

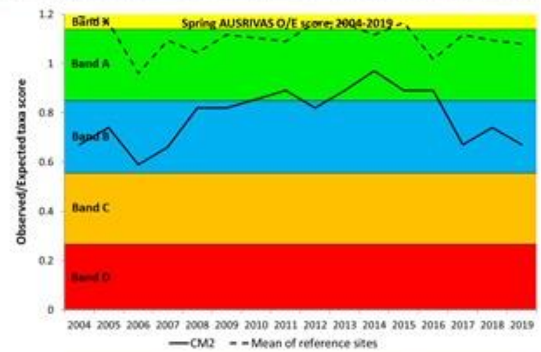
Sampling season	Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+ (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
Spring 2019	10.61	20	6.36	10.23	3.7	4	0.008	0.032	0.14	0.009
Autumn 2020	11.04	75	7.16	9.91	7.8	10	0.027	0.177	0.32	0.012

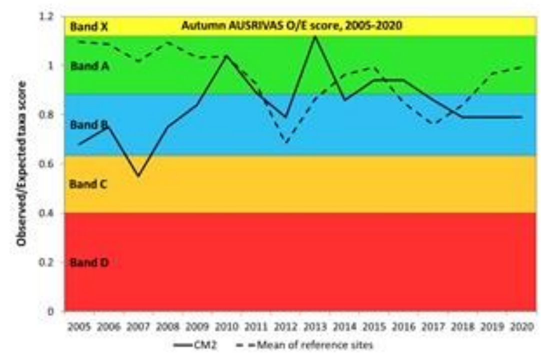
CM2 - Spring 2019 - Autumn 2020

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2019	Autumn 2020	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







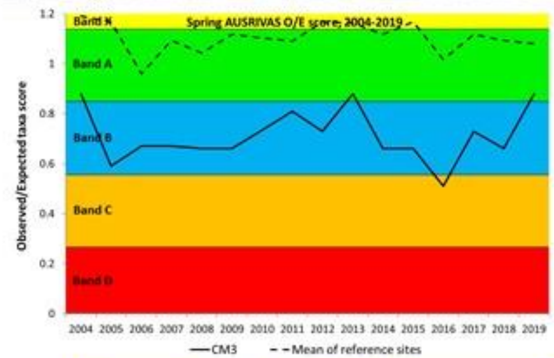
* Denotes values outside guideline levels

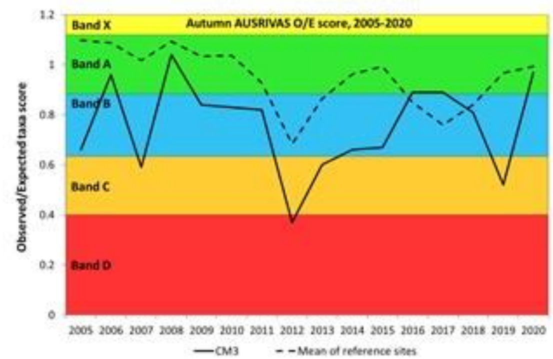
Sampling season	Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_4^+ (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
Spring 2019	9.87	19	6.92	9.08	0.1	10	0.005	0.014	0.12	0.008
Autumn 2020	11.5	44	6.53	10.71	4.6	4	0.029	0.114	0.24	0.006

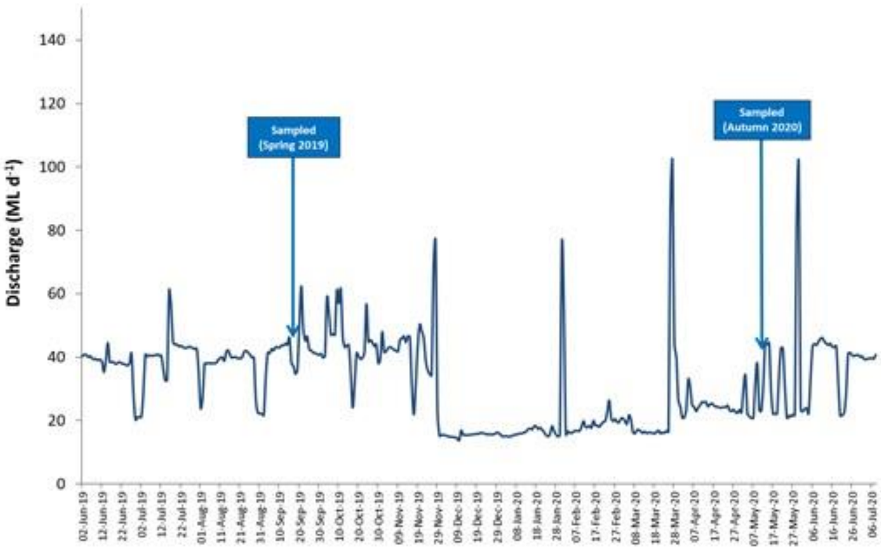
CM3 - Spring 2019 - Autumn 2020

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2019	Autumn 2020	Objective met?
AUSRIVAS band A	Band A	Band A	Yes in both seasons
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons







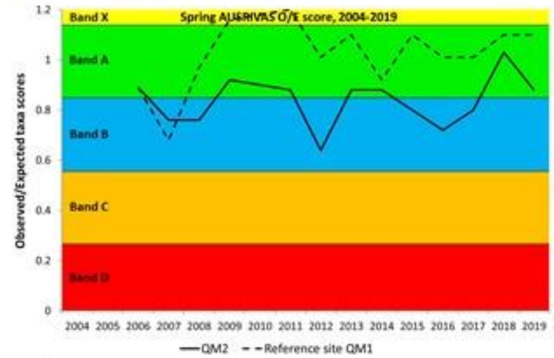
* Denotes values outside guideline levels

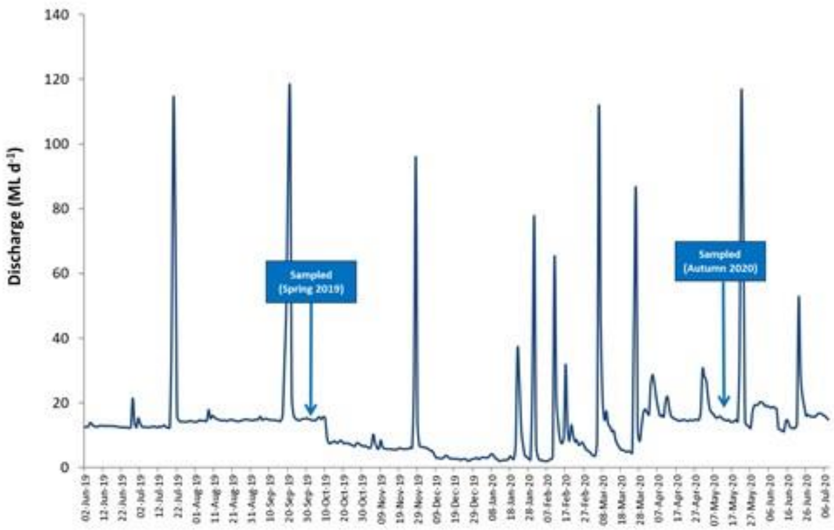
Sampling season	Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_4^+ (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
Spring 2019	12.71	34	7.77	9.61	3.8	17	0.003	0.014	0.15	0.008
Autumn 2020	11.24	229	7.97	11.2	38.0	30	0.007	0.064	0.54	0.033

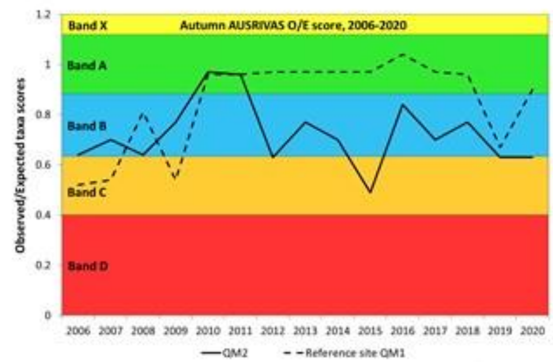
QM2 - Spring 2019 - Autumn 2020

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2019	Autumn 2020	Objective met?
AUSRIVAS band A	Band A	Band C	Yes - Spring 2018 No - Autumn 2019
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both the season







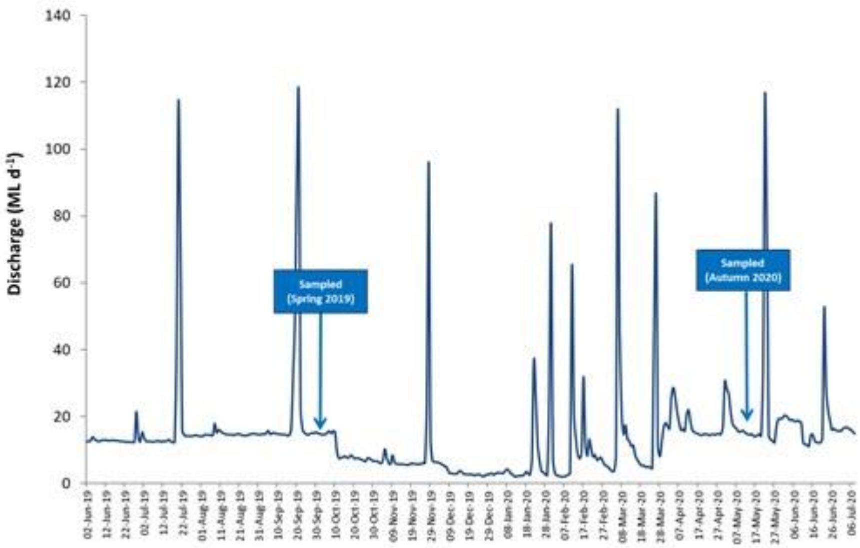
* Denotes values outside guideline levels

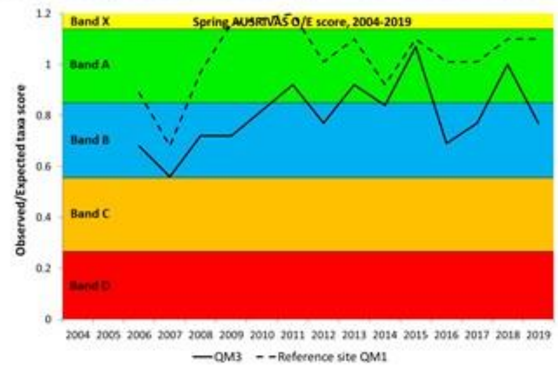
Sampling season	Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
Spring 2019	14.09	90	7.84	11.03	1.9	42	0.004	0.008	0.32	0.007
Autumn 2020	12.6	139	7.68	11.12	3.2	20	0.024	0.062	0.39	0.007

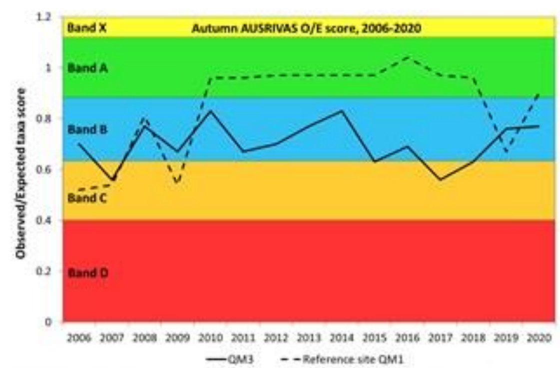
QM3 - Spring 2019 - Autumn 2020

2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2019	Autumn 2020	Objective met?
AUSRIVAS band A	Band B	Band B	No in both the seasons
<20% filamentous algae cover in riffle habitat	<10%	<20%	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 2019	16.43	119	7.75	10.39	2.5	50	0.004	0.002	0.33	0.008
Autumn 2020	10.56	210	8.08	11.37	1.9	20	0.013	0.048	0.41	0.007

APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2019 AND AUTUMN 2020

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in **spring 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).

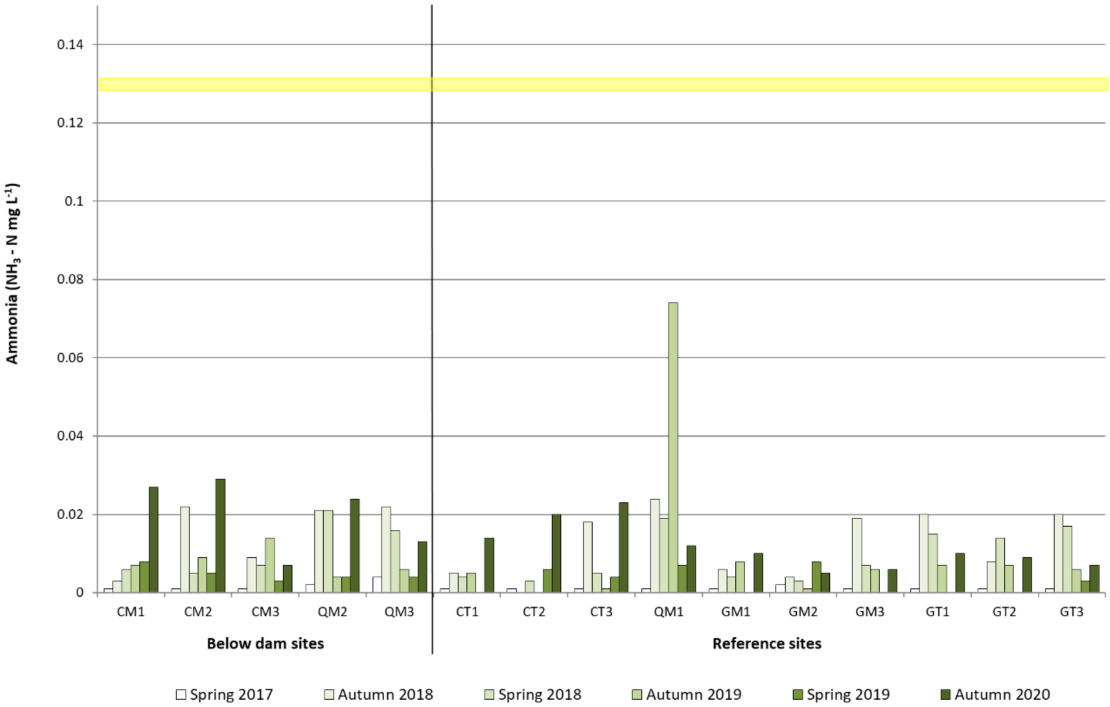
CLASS Order Family *Sub-family*	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
GASTROPODA																
Lymnaeidae	1	2			1			Very low flow for sampling bugs on 16/09/2019		No access to sampling site due to road block on 2/10/2019			No access to sampling site due to road block on 2/10/2019			
Planorbidae	4		1												2	1
Physidae	1															2
Sphaeriidae	5					3	7									2
OLIGOCHAETA	2	25	4	31	43	53			73		1				4	8
ACARINA	6	25			11	2	4				1			5	9	17
Coleoptera																
Staphylinidae	3															1
Elmidae (Adult)	7						9		3					20	1	7
Elmidae (Larvae)	7	13	1			1	36		8		1	6		17	7	6
Psephenidae	6			1							2	6		8	1	
Diptera																
Tipulidae	5	2	2	1	1	3			4		1	21		10	3	1
Ceratopogonidae	4						1		1							1
Simuliidae	5	4	114	47	26	30			33		65	18		4	12	50
Athericidae	8		2	2		1	16				2	6				3
Empididae	5	1														
Muscidae	1								1							
Aphroteniinae	8						16					2		1	7	
Diamesinae	6														1	
Podonominae	6	2									1			1		
Tanypodinae	4			1	2		4				3	1		5	1	2
Orthocladiinae	4	28	32	47	71	85	4		107		38	23		23	10	67
Chironominae	3	3	1	2	32	4	3		25		7	18		3	6	8
Ephemeroptera																
Baetidae	5	1		1	12	2	11		2		4	22		4		2
Coloburiscidae	8				1		14				2				2	
Leptophlebiidae	8	6				1	22				54	2		19	46	
Caenidae	4			19	15	36	5		8		3			11	4	13
Megaloptera																
Corydalidae	7				1				1					1		
Neuroptera																
Osmylidae	7					1										
Odonata																
Gomphidae	5								2					1	1	
Telephlebiidae	9				1		3									
Plecoptera																
Gripopterygidae	8	80	54	42	12		51		45		28	64		42	91	10
Trichoptera																
Hydrobiosidae	8		3	1			1		2		2			3	1	4
Glossosomatidae	9						1				1	3				
Hydroptilidae	4			2		2	2		11			2		2		9
Philopotamidae	8			1			2		2		2			4	1	
Hydropsychidae	6		2	2	6		6					2			3	1
Polycentropodidae	7								1						1	
Ecnomidae	4			1	2		3		9			2		1	2	1
Conoesucidae	8	10					8				4	5		9	2	
Helicopsychidae	8					6	1							19		
Odontoceridae	7								1							
Leptoceridae	6						1				1	1		3		
No. of individuals		202	216	201	237	230	231		339		223	204		216	218	216
No. of taxa		14	11	16	16	15	25		20		21	18		24	24	22
% of sub-sample		8	3	3	2	2	2		2		2	5		2	3	3
Whole sample estimate		2525	7200	6700	11850	11500	11550		16950		11150	4080		10800	7267	7200

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in **autumn 2020** at each of the study sites.

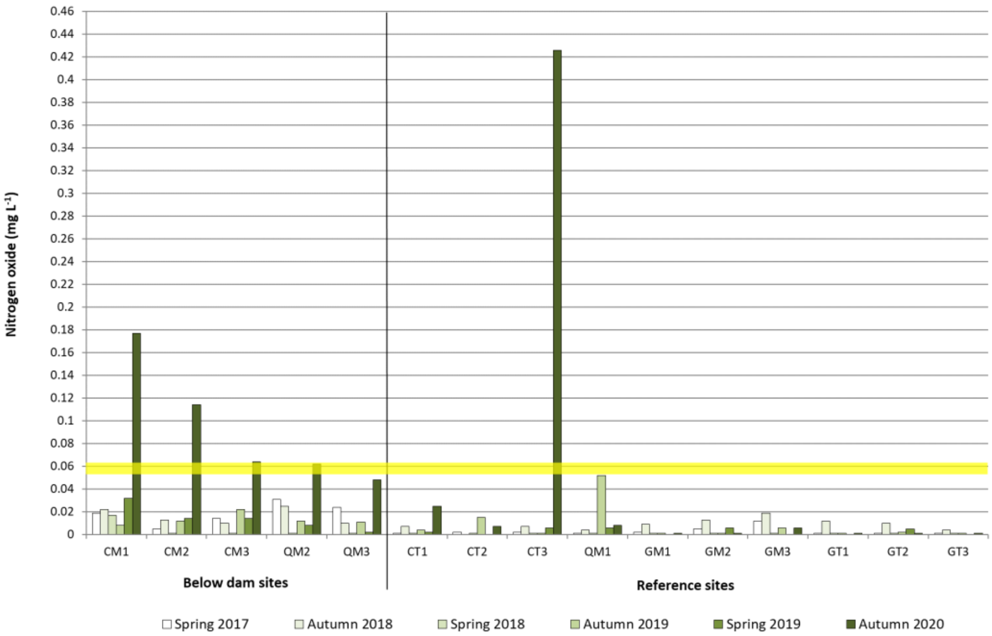
CLASS Order Family *Sub-family*	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
GASTROPODA																
Lymnaeidae	1					1										
Pelecypoda																
Sphaeriidae	5	3		2		2										
OLIGOCHAETA	2	11	8	12	4	23	128	37	23	3	8	3	7	3	2	6
ACARINA	6	6	3	4	4	1		6		4	1	1	2	3	5	2
Coleoptera																
Scirtidae Sp. (Unident.)	6				1							1				
Elmidae (Unident.)	7							1	1		1		1			
Elmidae (Unident.)(Larvae)	7						1		1	2		2	2	10	1	1
Psephenidae (Unident.)	6					1	1			2	3	1	1		2	
Diptera																
Tanyderidae	6													1		
Tipulidae (Unident.)	5	1	1	1	3	2				2	3	4	10	5	1	
Simuliidae (Unident.)	5	20	333	79	8	7	8	21	5	42	103	87	10	15	5	76
Athericidae	8	4		4	1	1		2	9		1					2
Empididae	5		2													
Psychodidae	3						2									
Aphroteniinae	8	1					3									
Podonominae	6	2	2	3		3	2	1			1		3	10	2	14
Tanypodinae	4	6	1	1	1	1	16	6	3	1					1	7
Orthocladiinae	4	57	10	48	72	36	34	27	11	36	42	31	9	20	4	76
Chironominae	3	15	10	16	13	27	10	6	11	2	2	2	4	12		65
Ephemeroptera																
Baetidae	5	11	5	2	91	31	2	99	109	57	15	36	25	31	21	7
Coloburiscidae	8						1			10	23	2	2		1	
Leptophlebiidae	8	2				1	2		1	1	40	1	52	50	33	
Caenidae	4	30		20	15	35	2		4	17	14	5	7	36	6	4
Lepidoptera	2							1								
Megaloptera																
Corydalidae	7	1					1		1							
Odonata																
Gomphidae	5			1						5	1	1		1	3	
Telephlebiidae	9						2									
Plecoptera																
Gripopterygidae	8	120	6	1	1		4	14		24	18	16	99	35	108	2
Trichoptera																
Hydrobiosidae	8		2	2					1		1					1
Glossosomatidae	9	1						1			5	1		3	1	
Hydroptilidae	4	3		7				1		1			2		1	
Philopotamidae	8			2				2	3		2		2	2		1
Hydropsychidae	6	4	1	18	33	32	1	1	22	5			2	1	3	
Ecnomidae	4	1	1	5	4	9	1	1	4	1	4		1	1		11
Calocidae	9						1									
Conoesucidae	8	3								7	4		10	7	10	
Helicopsychidae	8									1	3			2		12
Calamoceratidae	7									1			1	2		
Tasimiidae	8														1	
Leptoceridae	6						1			1						
No. of individuals		302	385	228	251	213	223	227	209	225	295	194	252	250	211	287
No. of taxa		21	14	19	14	17	21	17	16	22	22	16	21	21	20	16
% of sub-sample		1	1	3	2	1	5	5	3	4	4	2	2	2	2	1
Whole sample estimate		**30200**	**38500**	**7600**	**12550**	**21300**	**4460**	**4540**	**6967**	**5625**	**7375**	**9700**	**12600**	**12500**	**10550**	**28700**

APPENDIX 3: WATER QUALITY FIGURES

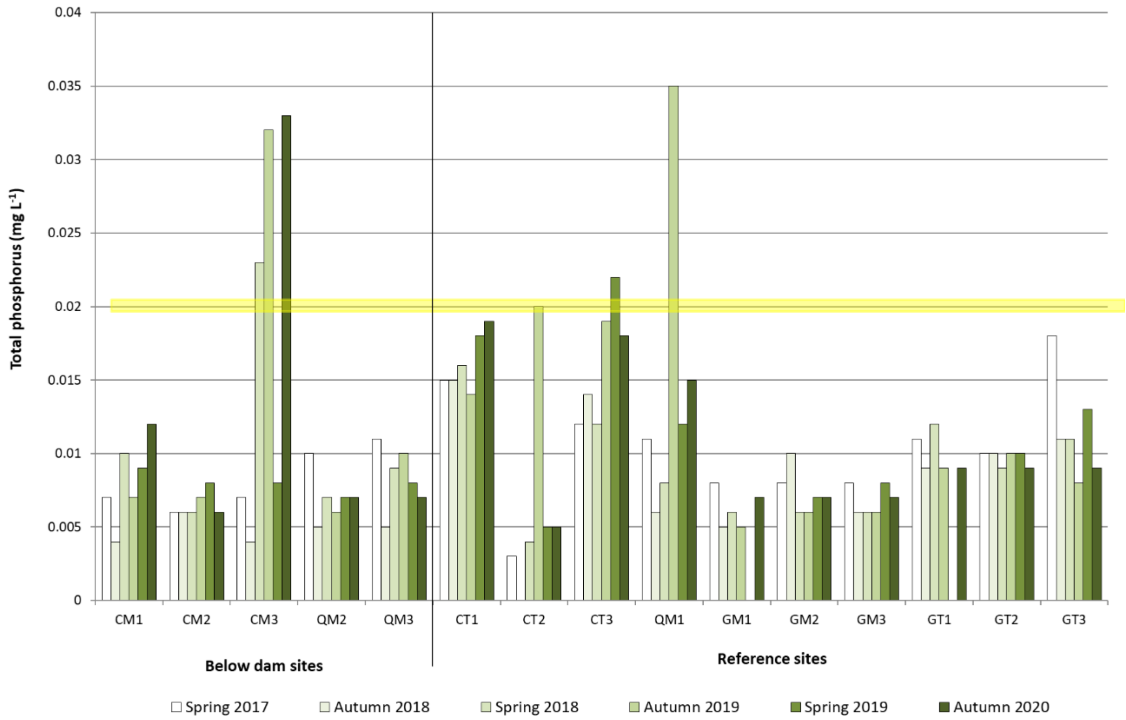
(Note: There was no flow during sampling and water samples could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).



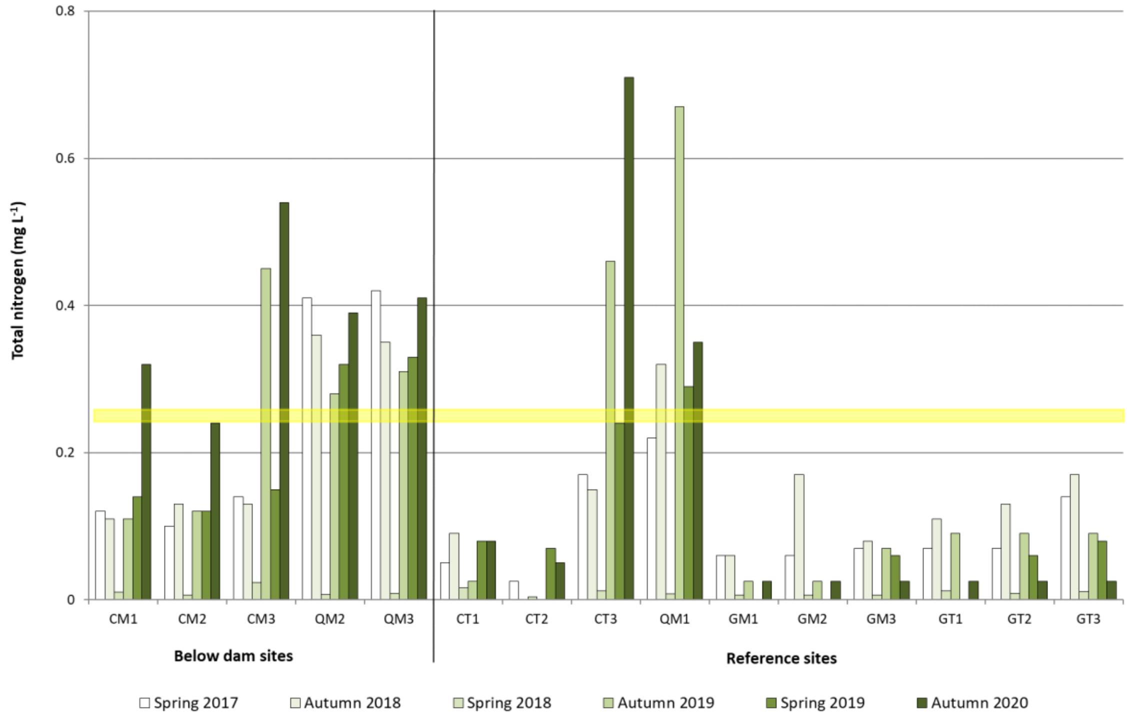
Ammonium (NH_4^+) concentration at all sites from **spring 2017 to autumn 2020**. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is shaded yellow.



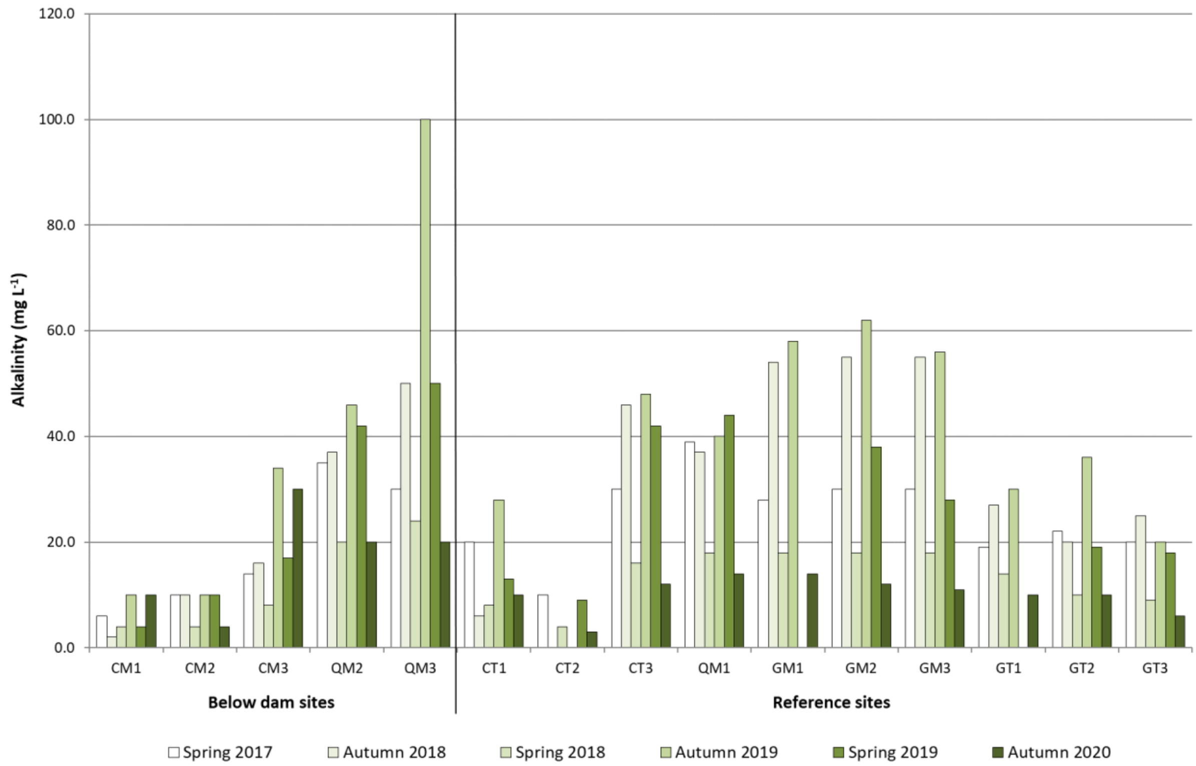
Nitrogen oxide concentrations at all sites from **spring 2017 to autumn 2020**. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is shaded yellow.



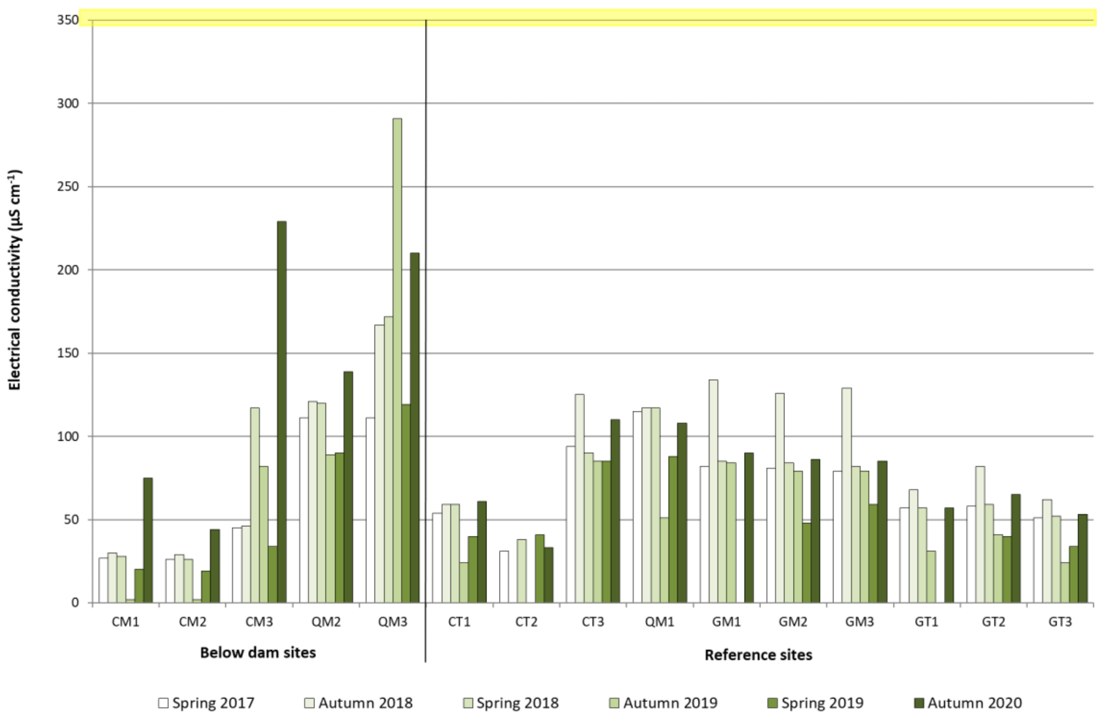
Total phosphorus concentrations at all sites from **spring 2017 to autumn 2020**. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is shaded yellow.



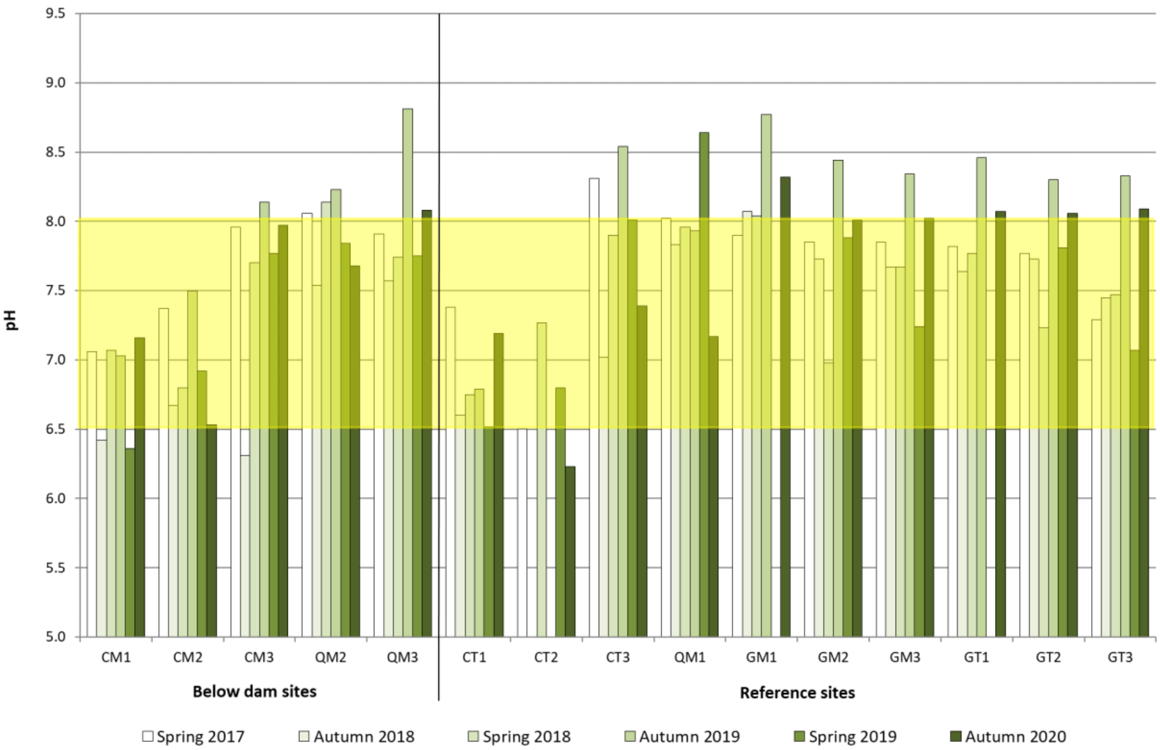
Total nitrogen concentrations at all sites from **spring 2017 to autumn 2020**. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is shaded yellow.



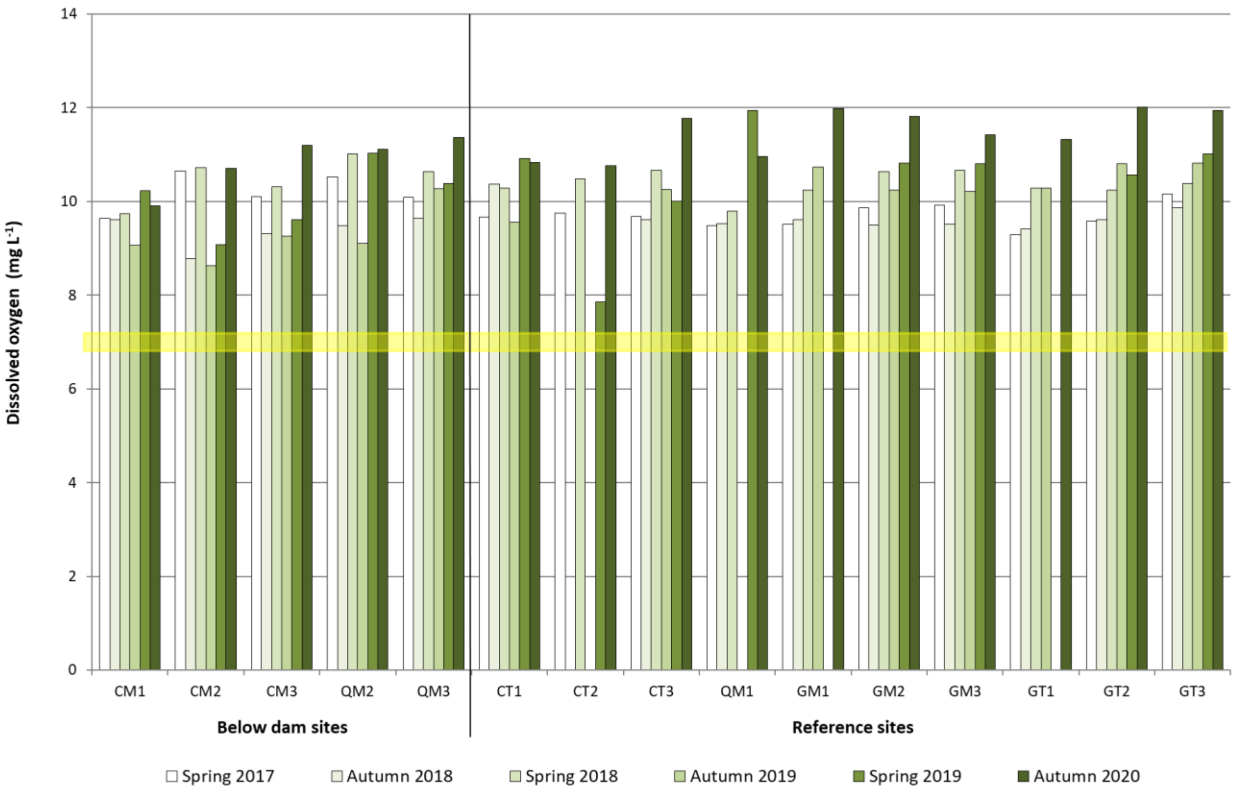
Alkalinity at all sites from **spring 2017 to autumn 2020**.



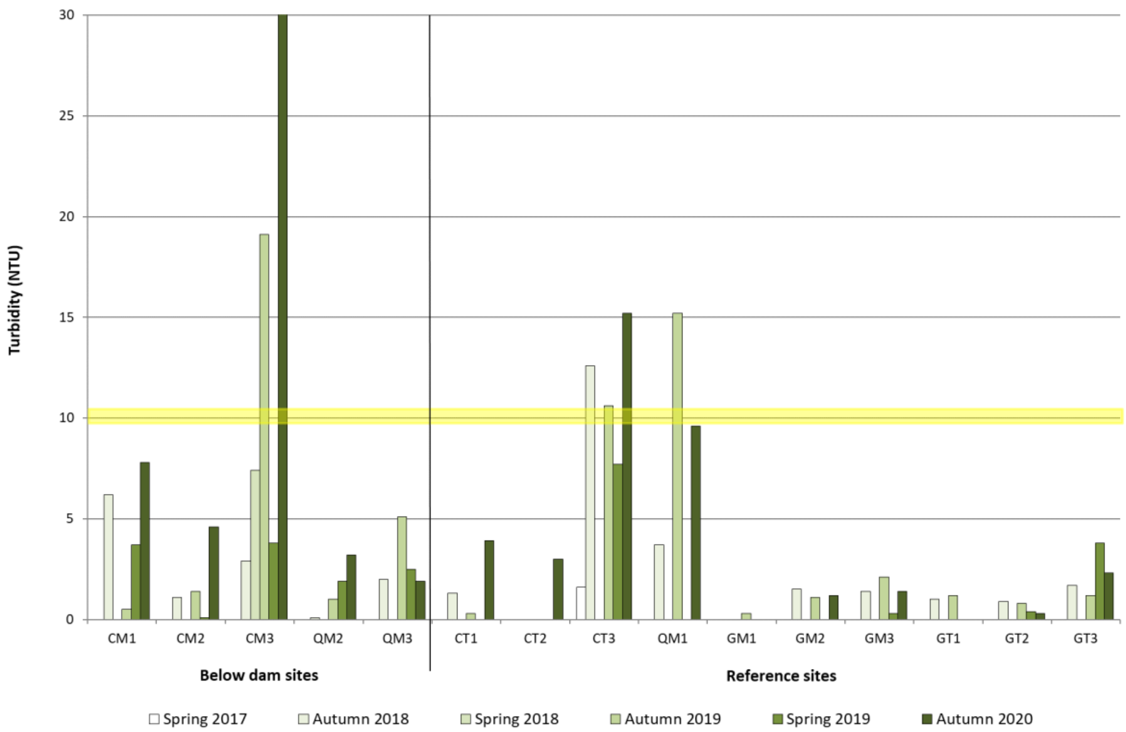
Electrical conductivity at all sites from **spring 2017 to autumn 2020**. The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is shaded yellow.



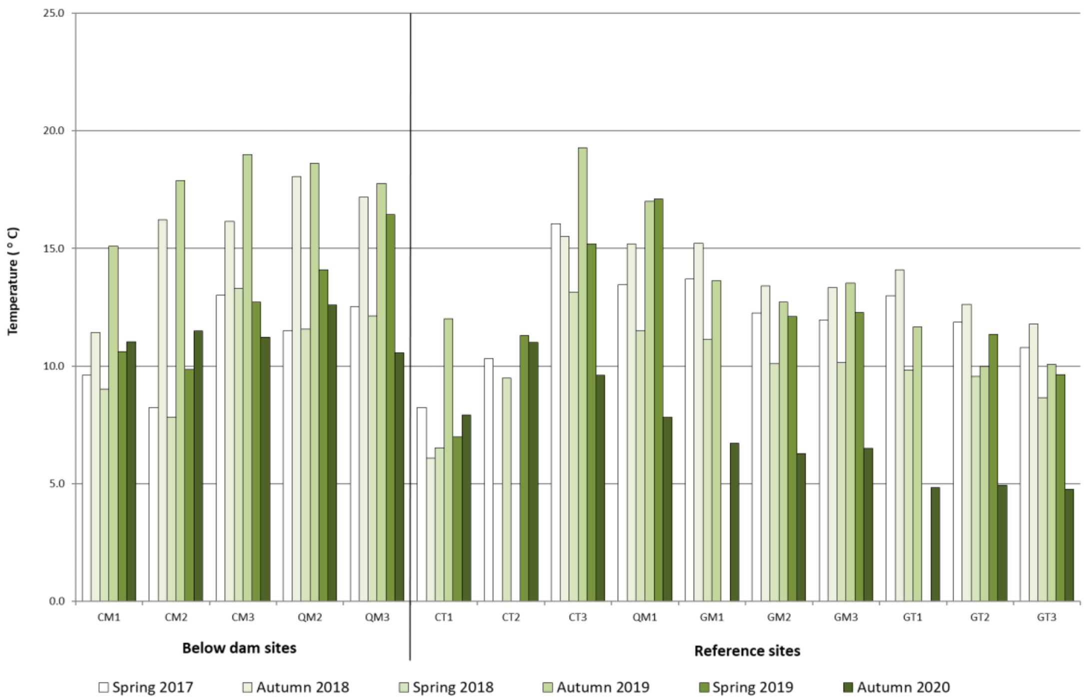
pH at all sites from **spring 2017 to autumn 2020**. The ANZECC/ARMCANZ (2000) guideline range for pH is shaded yellow.



Dissolved oxygen concentration at all sites from **spring 2017 to autumn 2020.** The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from **spring 2017 to autumn 2020**. The guideline for maximum turbidity is shaded yellow (Environment Protection Regulation SL2005-38).



Water temperature at all sites from **spring 2017 to autumn 2020.**