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

Annual report July 2021

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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 2020 and autumn 2021.

SPRING 2020 & AUTUMN 2021 RESULTS AND CONCLUSIONS

- Stream discharge at test sites was dominated by natural/flood events flow conditions as all reservoirs were full and spilling in autumn 2021. Total discharge in the six months prior to sampling in spring 2020 were lower than discharge in the six months prior to sampling in autumn 2021 at all the test and reference sites. Total rainfall six months prior to sampling was greater than historical average rainfall across the entire study area in both spring 2020 and autumn 2021.
- Water quality parameters at below dam test sites were largely within guideline levels in spring 2020 and autumn 2021, with the exception of nitrogen oxides (NO_x) in both spring 2020 and autumn 2021, total nitrogen (TN) which were above guideline levels at a number of test sites and total phosphorus (TP) especially in autumn 2021. Click here for more information.
- All test and reference sites met the environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats, except for the test sites downstream of Bendora Dam (CM2) in spring 2020 and Googong Dam (GM2) in autumn 2021. Click here for more information.
- Among the test sites, downstream of Googong Dam (QM2) was the only test site which met the biological condition of AUSRIVAS band A in spring 2020 and downstream of Bendora Dam (CM2) in autumn 2021. A number of reference sites were also impacted and reduced in biological condition in autumn 2021, especially site CT3 (Paddy's River) which has decreased its biological condition of AUSRIVAS band B in spring 2020 to band C in autumn 2021. Click here for more information
- A decrease in macroinvertebrate community condition at some of the test and reference sites in autumn 2021 is likely to be related to high discharge disturbance events in the months leading up to sampling. 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 2020**	**Autumn 2021**	**Spring 2020**	**Autumn 2021**
CM1 (Corin Dam)	<10	<10	B	B
CM2 (Bendora Dam)	40	<10	B	A
CM3 (Cotter Dam)	<10	<10	B	B
QM2 (Googong Dam)	<10	30	A	B
QM3 (Googong Dam)	<10	<10	B	C

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 2020 and autumn 2021 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 2020 and autumn 2021 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 14th - 16th September 2020 and in autumn between 26 – 28th April and 4th May 2021 (Table 1). Site characteristics including latitude, longitude, altitude, stream order, catchment area, and distance from source were obtained from 1:100 000 topographic maps. Latitude and longitude were confirmed in the field using a Global Positioning System.

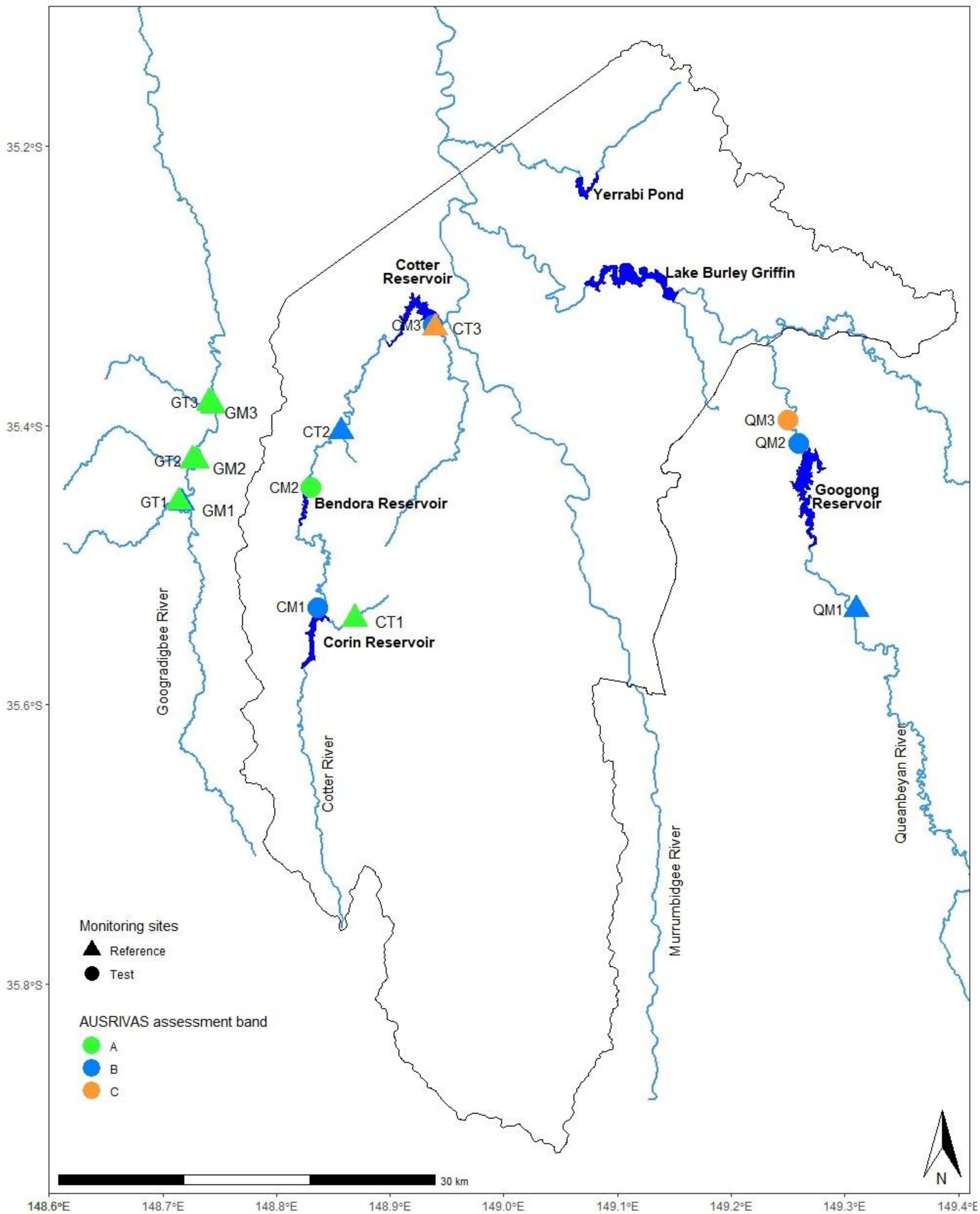

Figure 1: The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program (Circles indicate test sites, triangles indicate reference tributaries. Colours indicate AUSRIVAS assessment Band for Autumn 2021).

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 was obtained from ALS environmental monitoring sites 570965 (Queanbeyan Catchment) and 570958 (Bendora Dam).

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 sampling in spring 2020 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). In contrast, the period leading up to autumn 2021 sampling followed on from wet spring and summer, with below dams sites largely operating as unregulated as reservoirs were predominantly at full supply level during this time. All below dam sites met base flow regulations. There was a reduction in the variability of operational releases from Bendora Dam in October – November 2020, with weekly variations reduced from 50% to 25% to prevent loss of Macquarie perch eggs and larvae.

Goodradigbee River recorded highest total discharge (165597 ML) and Cotter River (Downstream Corin Dam) recorded least total discharge (46712 ML) from 14th March 2020 to 26th May 2021 (407 days). Differences in total discharges for the six months prior to sampling varied between spring 2020 and autumn 2021 sampling depending on site, with increases in total discharge for site QM2 (1835%), CM1 (419%), CM2 (249%), CM3 (1139%) and QM1 (52%) and decrease in total discharge for Goodradigbee River (-27.55%) (Figure 2). The large increase in discharge volume at site QM2 was largely attributable to several large flow events after spring 2020 and before autumn 2021 sampling. The greatest mean discharge at a regulated site, six months prior to sampling occurred downstream of Googong Dam at site QM2 in both spring 2020 and autumn 2021 assessments (339 ML d^{-1} and 14238 ML d^{-1}, respectively) and the least at downstream of Cotter Dam at site CM3 (106 ML d^{-1}) in spring 2020 and downstream of Corin Dam CM1 (872 ML d^{-1}) autumn 2021 assessments.

A total of 571 mm rainfall was recorded in the Cotter River catchment in the six months prior to sampling in spring 2020 which is higher (62nd percentile) than historical mean rainfall of 519.2 mm over the same period from 1957 to 2021. The total of 583.8 mm rainfall that fell prior to the autumn 2021 assessment was much higher (85th percentile) than historical mean rainfall of 452.3 mm for the same period from 1957 to 2021 (ALS Environmental, Site 570958 – Bendora Dam).

A total of 301.8 mm rainfall was recorded in the Queanbeyan River Catchment in the six months prior to sampling in spring 2020, which is greater (67th percentile) than the mean historical rainfall of 260.2 mm over the same period from 1966 - 2021. A total of 414.2 mm of rainfall was recorded in the six months prior to sampling in autumn 2021, which is greater (77th percentile) than the historical rainfall of 366.2 mm over the same period from 1966 - 2021 (ALS Environmental, Site 570965 – QBN at Tinderry).

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.

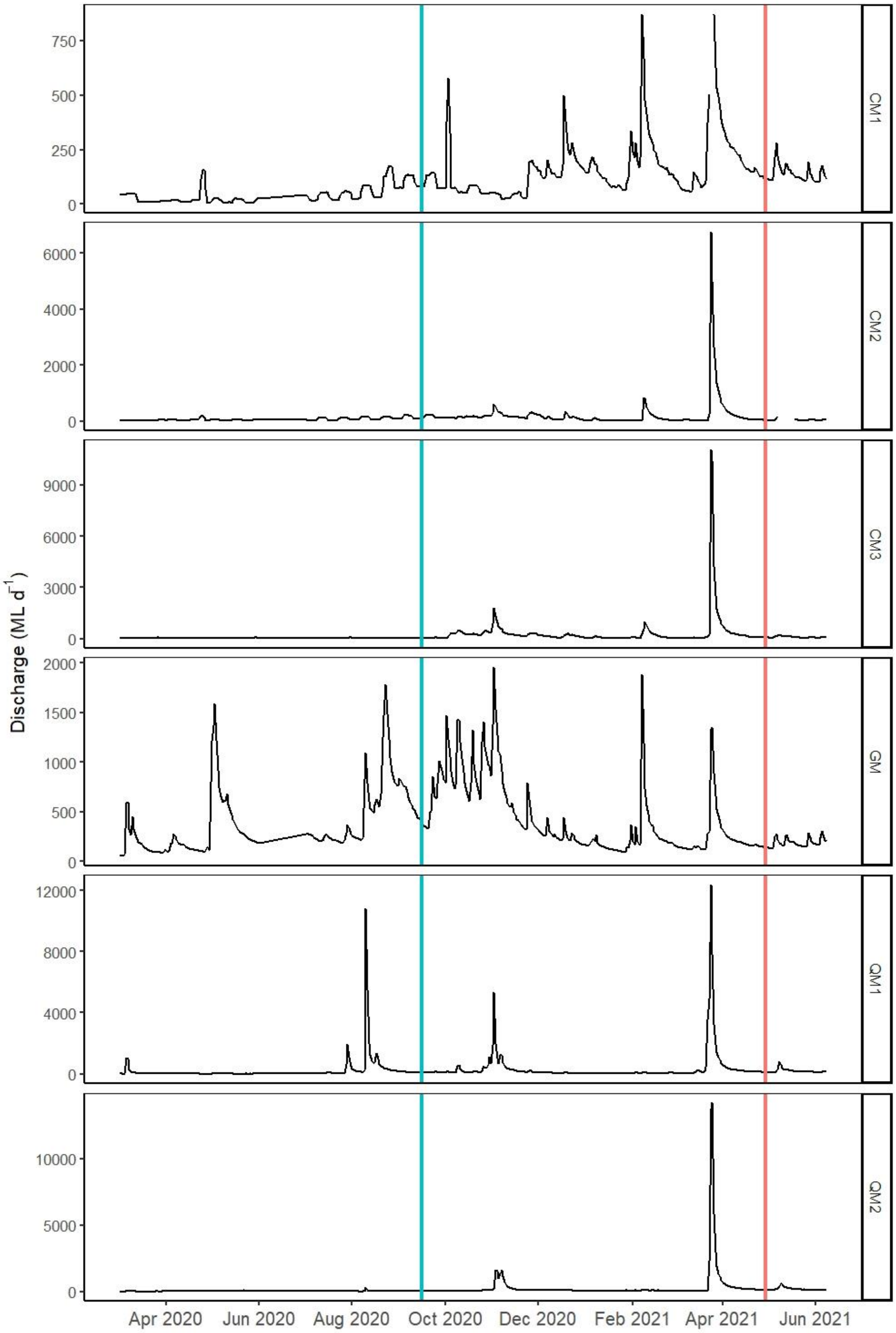

Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781)

from 2nd July 2020 to 8th June 2021. Green bar corresponds to spring 2020 sampling and orange bar corresponds to autumn 2021 sampling.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in spring 2020 and autumn 2021. Notable exceptions were NO_x in all test sites in spring 2020 and all the test sites and reference site GM3 in autumn 2021; Total Nitrogen in reference site QM1and CT3 and test sites CM1, QM2 and QM3 in spring 2020 and QM2 and QM3 in autumn 2021; Total Phosphorus in test sites QM2 and QM3 in autumn 2021 and Turbidity was three-times the guideline levels at CT3 in autumn 2021 (Table 6). The concentration of NO_x was up to 10 times the guideline levels in spring 2020 and greater than two times the guideline levels in autumn 2021. (Table 5 and Table 6).

Table 5: Water quality parameters measured at each of the test and reference sites in spring 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	7.43	1	7.29	11.32	0.0	18	0.008	0.185	0.31	0.011
	CM2	8.06	0	7.27	11.5	0.3	13	0.004	0.141	0.22	0.005
	CM3	11.88	14	6.94	10.84	4.1	19	0.025	0.037	0.17	0.007
	QM2	11.56	76	8.00	11.49	2.6	72	0.032	0.154	0.63	0.013
	QM3	14.01	120	7.89	10.62	5.0	100	0.012	0.079	0.63	0.013
Reference sites	CT1	11.25	9	6.73	9.7	0.0	25	0.004	0.009	0.07	0.019
	CT2	11.67	0	6.77	10.15	0	10	<0.002	<0.002	<0.05	0.002
	CT3	14.17	58	7.90	10.87	6.1	34	0.02	0.007	0.26	0.011
	QM1	13.82	39	7.74	9.8	0.4	40	0.007	0.006	0.25	0.011
	GM1	10.99	35	7.89	10.81	0.9	45	0.008	0.004	<0.05	0.006
	GM2	9.75	31	8.11	11.44	1.5	30	0.007	0.008	0.05	0.006
	GM3	8.7	25	7.21	11.72	0.9	50	0.006	0.005	0.06	0.006
	GT1	9.83	7	7.81	10.66	0.3	25	0.02	0.006	0.08	0.008
	GT2	9.16	5	7.59	10.81	0.0	30	0.008	<0.002	0.06	0.008
	GT3	7.69	0	7.99	11.14	4.8	21	0.009	0.007	0.09	0.011

Table 6: Water quality parameters measured at each of the test and reference sites in autumn 2021. Values outside guideline levels are shaded orange.

		Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
	Guideline level	NA	<350	6.5-8	>6	<10	NA	<0.13	<0.015	<0.25	<0.02
Below dam test sites	CM1	13.62	27	6.96	9.39	1.9	14	0.008	0.029	0.14	0.007
	CM2	12.65	26	6.98	9.8	3.5	12	0.004	0.026	0.14	0.006
	CM3	14.45	34	7.61	10.49	5.9	15	0.016	0.041	0.19	0.008
	QM2	15.41	77	7.66	10.45	4.5	90	0.013	0.023	0.65	0.022
	QM3	15.1	83	7.66	9.97	4.8	34	0.009	0.032	0.64	0.021
Reference sites	CT1	10.54	35	6.87	9.91	3.1	20	<0.002	<0.002	0.06	0.012
	CT2	11.39	28	6.88	10.2	1.8	12	0.003	<0.002	0.025	0.002
	CT3	13.74	62	7.85	10.59	29.4	26	0.029	0.01	0.18	0.015
	QM1	10.57	64	7.58	10.69	5.2	24	<0.002	0.004	0.16	0.01
	GM1	10.07	94	7.96	11.05	3.2	42	<0.002	0.004	0.025	0.004
	GM2	9.81	90	7.70	10.57	4.4	40	<0.002	<0.002	0.025	0.004
	GM3	9.74	81	7.41	10.59	3.7	40	0.003	0.015	0.025	0.004
	GT1	8.18	59	7.70	11.44	3.0	28	<0.002	<0.002	0.05	0.004
	GT2	7.54	59	7.71	11.2	3.8	34	<0.002	0.011	0.05	0.004
	GT3	7.16	49	7.48	10.81	4.5	28	<0.002	0.003	0.07	0.007

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 CM2 and in spring 2020 and QM2 in autumn 2021. Field observations of periphyton cover of riffle habitats were <20% in most of the sites, except for sites GM3, QM2 and CM2 in spring 2020 (Table 7; Figure 3 and Figure 4).

Mean ash free dry mass (AFDM) concentrations were significantly different between sites for spring 2020 assessment ($F_{6,35} = 5.613$, $p < 0.001$), but were not significantly different from one another in the autumn 2021 assessment ($F_{6,35} = 0.491$, $p = 0.811$). Differences in concentrations of AFDM between sites in spring 2020 was mixed across reference and test sites, with the largest difference being driven by very low AFDM concentrations at references sites GM1 and GM2 (Figure 5).

Mean Chlorophyll-a concentrations differed between sites in both the spring 2020 assessment ($F_{6,35} = 5.037$, $p < 0.001$) and the autumn 2021 assessment ($F_{6,35} = 2.785$, $p < 0.026$). Differences in concentrations of Chlorophyll-a between sites in spring 2020 were driven by very low concentrations at sites GM1 and GM2 and very high concentration in CM1 (Figure 6). In autumn 2021 differences in mean Chlorophyll-a concentrations between sites was driven by very high concentrations at test site QM2 and very low concentrations at sites CM1, GM1 and GM2 (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 2018 to autumn 2021. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat													
	Periphyton							Filamentous algae					
	Spr-18	Aut-19	Spr-19	Aut-20	Spr-20	Aut-21		Spr-18	Aut-19	Spr-19	Aut-20	Spr-20	Aut-21
CM1	<20	<10	30	<10	<20	<10		<20	<10	30	<10	<10	<10
CM2	<20	<10	<10	<10	30	30		<10	<10	<10	<10	40	<10
CM3	<20	<10	<10	<10	<10	<10		<20	<10	<10	<10	<10	<10
QM2	40	<10	<10	30	<10	20		40	<10	<10	40	<10	30
QM3	40	<10	<10	20	<20	<10		<10	<10	<10	20	<10	<10
GM1	<20	<10	NA	<10	<10	<10		<20	<10	NA	<10	<10	<10
GM2	<20	<10	<10	<10	<20	<10		<10	<10	<10	<10	<10	<10
GM3	40	<10	30	<10	30	35		<10	<10	<20	<10	<10	<10
QM1	40	<20	<10	<20	<20	<10		<20	<20	<10	<20	<10	<10

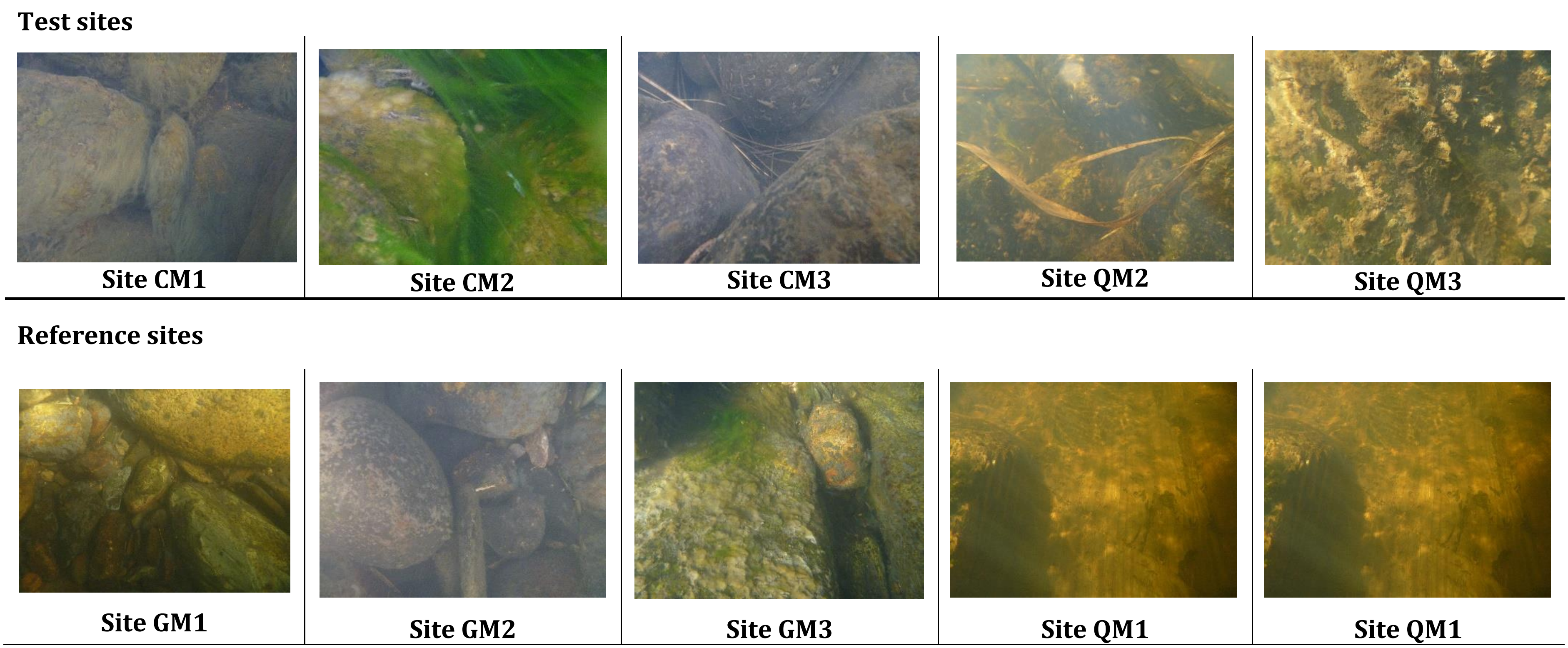

Figure 3. Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in spring 2020.

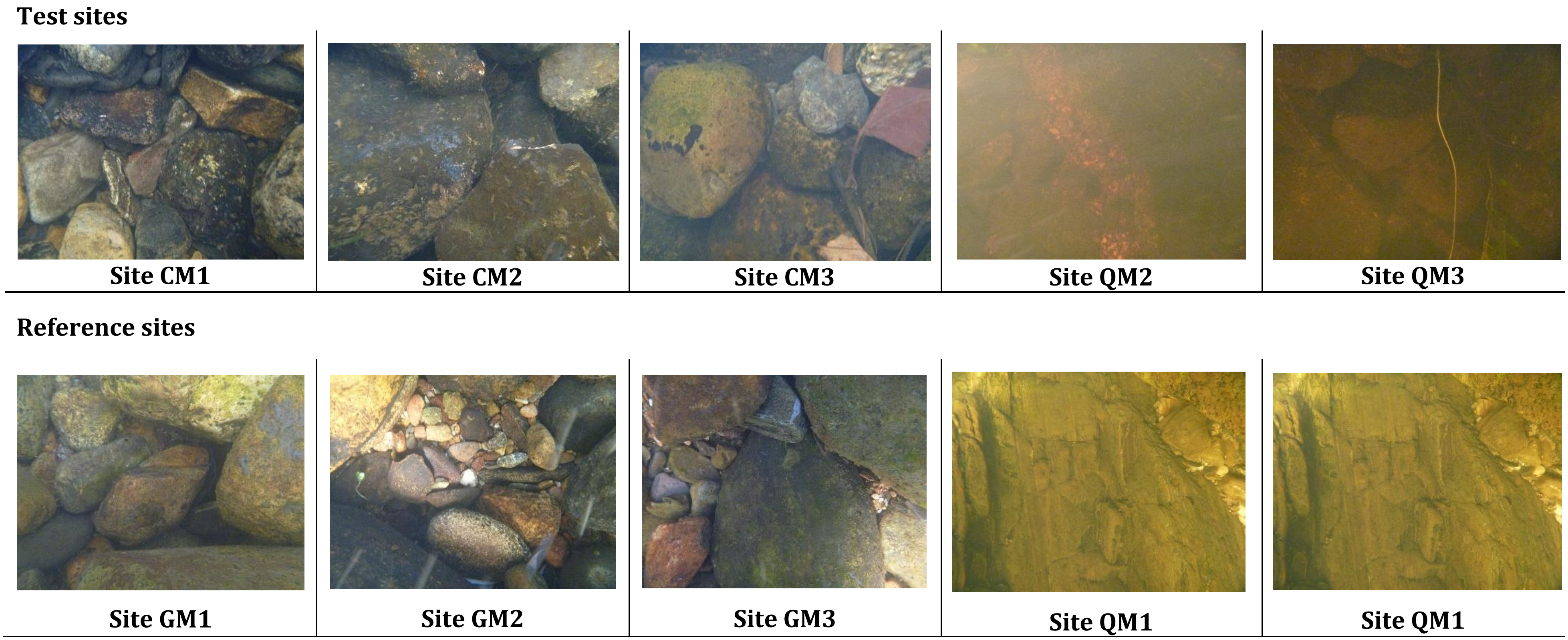

Figure 4: Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in autumn 2021.

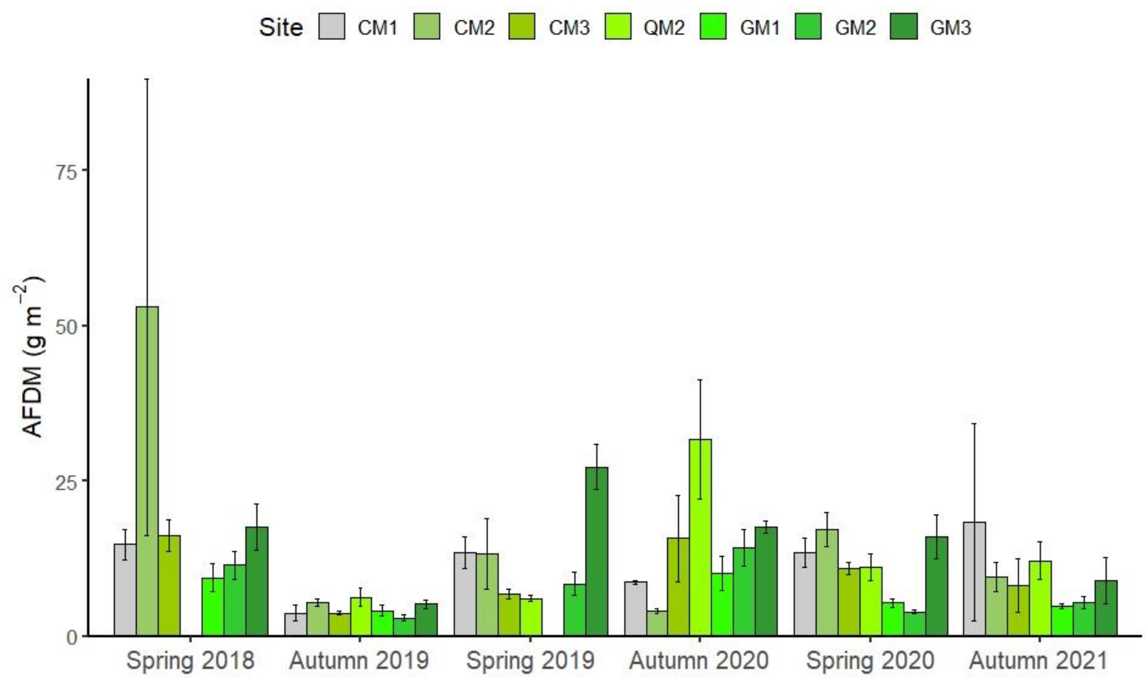

Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2018 to autumn 2021. Error bars represent +/- 1 standard error.

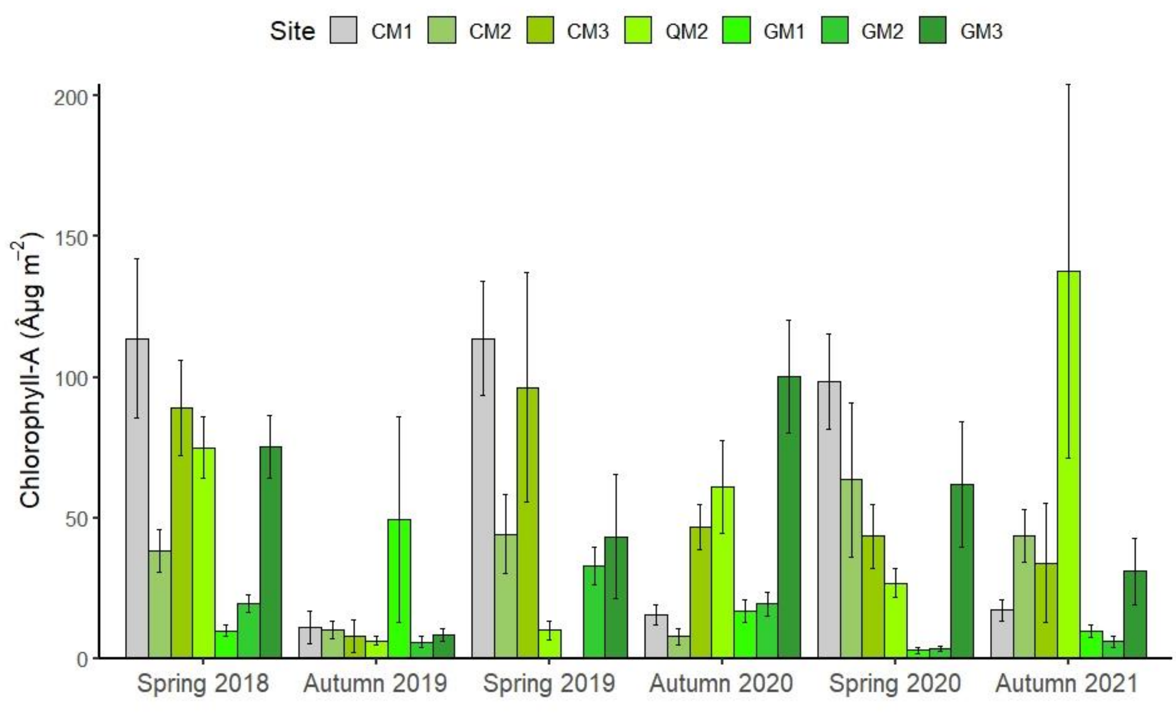

Figure 6: Mean Chlorophyll-a (μg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2018 to autumn 2021. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in spring 2020 and again in autumn 2021 (Table 8), though this difference was less evident in autumn 2021.

Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in spring 2020 and autumn 2021 (Table 8). Test site CM1 remained in band B for the past seven assessments and has had a relatively stable O/E score of around 0.75 – 0.85 since autumn 2018 (Table 8). The dominant taxa at this site for both spring 2020 and autumn 2021 was the environmentally tolerant Orthocladiinae (Appendix 2). In spring 2020 three taxa (Elimidae, Glossosamatidae and Hydropshychidae) 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 spring 2020.

Condition of the Cotter River below Bendora Dam (CM2) increased in biological condition from significantly impaired (band B) to similar to reference (band A) in autumn 2021 for the first time since spring 2016 (Table 8). Between spring 2016 and autumn 2021, this site had remained in band B biological condition (Table 8). The macroinvertebrate community at CM2 in spring 2020 was characterised by a high abundance of Simuliidae and more so in autumn 2021 (Appendix 2).

The condition of the Cotter River below Cotter Dam (CM3) was assessed as significantly impaired (band B) for both spring 2020 and autumn 2021 assessments, a decline from the previous two assessments where it was similar to reference condition (band A) (Table 8). Simuliidae and Orthocladiinae were the dominant taxa in spring 2020, though changed to environmentally tolerant Oligochaeta in autumn 2021 (Appendix 2).

The below Googong Dam test site (QM2) was assessed as similar to reference (band A) in spring 2020 and significantly impaired (band B) in autumn 2021 (Table 8). This continues a seasonal fluctuation that has occurred since spring 2018 (Table 8). The below Googong Dam test site (QM3) was assessed as significantly impaired (band B) in spring 2020 and decreased in biological condition to severely impaired (band C) in autumn 2021 (Table 8). The reduction in the O/E score in autumn 2021 was driven by very low taxa diversity, with only 10 taxa identified in the sub-sample processing (the next lowest was 13 – QM1).

Biological condition of reference sites varied both within and across seasons for spring 2020 and autumn 2021, though one clear pattern was evident, that reference sites in the Goodradigbee River catchment were generally in better biological condition compared to those in the Cotter River catchment and the Queanbeyan River catchment (Table 8). The main anomaly from the reference sites was CT3 (Paddys River) which was assessed as severely impaired in autumn 2021 (Table 8). The macroinvertebrate community at this site was characterized by low density (2.5 times lower abundance than the next lowest site, and seven times lower abundance than the average for all sites in autumn 2021) (Appendix 2). The macroinvertebrate community at CT3 was dominated by environmentally tolerant Oligochaeta in autumn 2021 (Appendix 2).

Table 8: AUSRIVAS band and Observed/Expected taxa score for each site from spring 2018 to autumn 2021.

	Below dams sites					Reference sites									
	CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**QM1**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Autumn 2021	**B** (0.72)	**A** (0.98)	**B** (0.67)	**B** (0.83)	**C** (0.56)	**A** (1.00)	**B** (0.77)	**C** (0.62)	**B** (0.82)	**B** (0.81)	**A** (0.90)	**A** (0.97)	**A** (1.09)	**A** (1.06)	**A** (1.05)
Spring 2020	**B** (0.77)	**B** (0.67)	**B** (0.73)	**A** (0.88)	**B** (0.84)	**B** (0.82)	**A** (1.00)	**B** (0.66)	**B** (0.83)	**A** (1.04)	**A** (0.97)	**A** (0.89)	**X** (1.21)	**A** (1.13)	**A** (0.98)
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)

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 2020 and autumn 2021 (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 2020																
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				
Acarina	6						X		X							X
Scirtidae	6						X									
Elmidae	7	X	X		X				X	X	X	X				X
Psephenidae	6	X	X	X	X	X		X	X							
Tipulidae	5	X			X			X	X							
Ceratopogonidae	4															X
Tanypodinae	4			X							X					
Chironominae	3										X					
Baetidae	5	X	X	X		X										
Leptophlebiidae	8		X	X		X			X	X						
Caenidae	4	X	X					X								
Gripopterygidae	8					X										
Notonemouridae	6						X									
Hydrobiosidae	8			X	X		X					X			X	
Glossosomatidae	9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hydropsychidae	6	X	X				X		X			X		X	X	X
Conoesucidae	7		X	X	X	X	X		X						X	
Calocidae	9						X									
Total		**7**	**8**	**7**	**6**	**6**	**7**	**4**	**8**	**3**	**4**	**5**	**1**	**2**	**4**	**5**

Missing taxa in Autumn 2021																
Taxon Name	Signal Score	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
Hydrobiidae	4				X	X			X	X						
Ancylidae	4				X	X			X	X						
Oligochaeta	2					X		X					X	X	X	
Acarina	6					X			X		X					X
Scirtidae	6	X												X		
Elmidae	7		X	X		X			X		X					
Psephenidae	6	X		X				X								X
Tipulidae	5	X						X								
Podonominae	6		X	X	X	X	X					X	X			X
Tanypodinae	4	X		X	X	X				X	X	X				X
Chironominae	3								X							
Coloburiscidae	8	X						X						X		
Leptophlebiidae	8		X	X		X										
Caenidae	4	X						X								
Gomphidae	5			X		X			X	X	X	X			X	X
Hydrobiosidae	8			X	X		X			X						
Hydroptilidae	4		X	X					X	X	X	X	X		X	X
Hydropsychidae	6							X								
Leptoceridae	6	X	X		X	X		X	X							
Total taxa		**7**	**5**	**8**	**6**	**10**	**2**	**7**	**8**	**6**	**5**	**4**	**3**	**3**	**3**	**6**

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 2020 and autumn 2021 assessments. In spring 2020, tolerant OC taxa were extremely dominant (> 70%) at all below dam test sites, as well as reference sites CT1, CT2 and QM1 (Figure 7), driven largely by high abundances of tolerant Chironomidae (Figure 8). Autumn 2021 saw some improvement in the ratio of EPT to OC, though all test sites, except for QM3, comprised > 50% tolerant taxa (Figure 7).

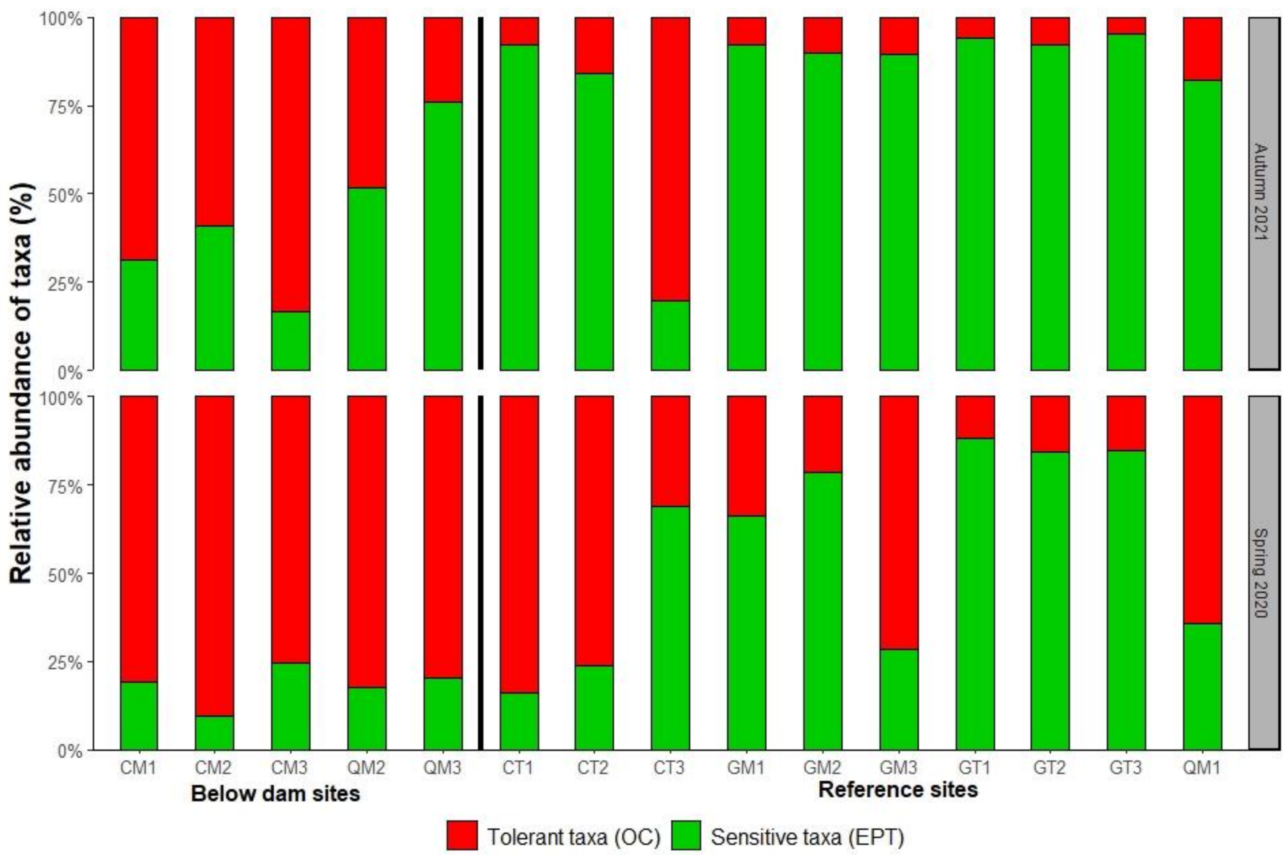

Figure 7. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in spring 2020 and autumn 2021.

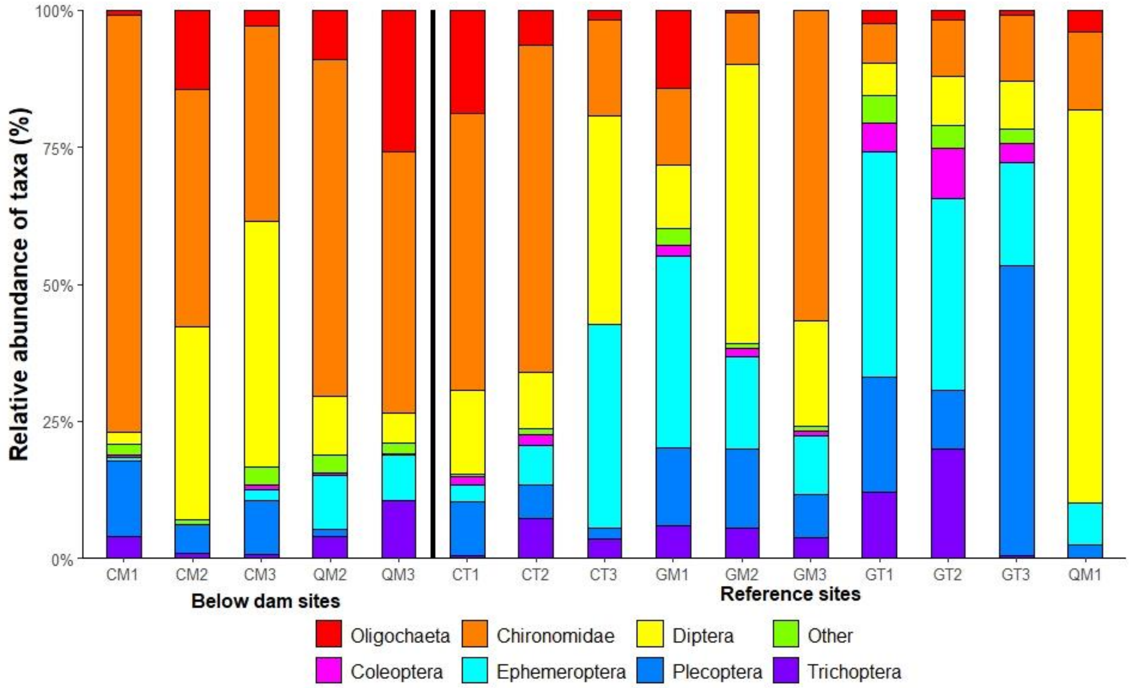

Figure 8: Relative abundance of macroinvertebrate taxonomic groups from samples collected in spring 2020.

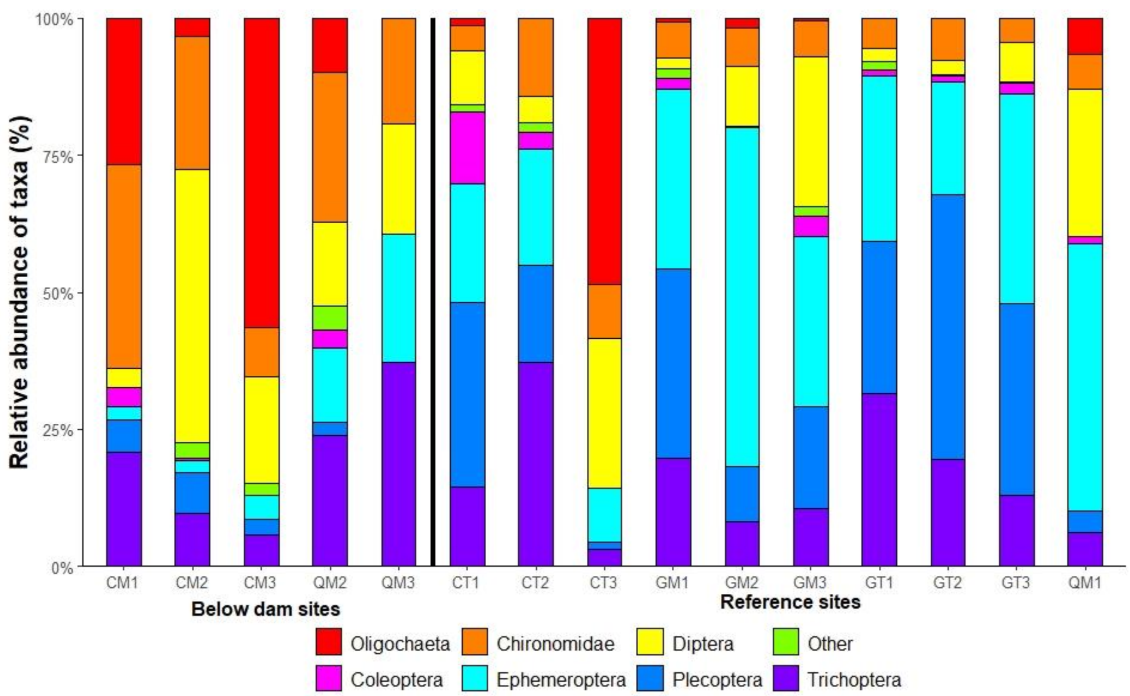

Figure 9: Relative abundance of macroinvertebrate taxonomic groups from samples collected in autumn 2021.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Macroinvertebrate assemblages were not clearly different between the test site and reference site groups, though there was some clumping of similar site groups (Goodradigbee tributary sites grouped together, and Cotter Tributary sites grouped together) in spring 2020 (Figure 10Figure 11). The macroinvertebrate assemblage at test sites CM2 and CM3 in the Cotter River catchment and test sites QM2 and QM3 in the Queanbeyan River catchment were similar, which is mostly driven by relative abundance of environmentally tolerant taxa Orthocladiinae. The macroinvertebrate assemblage at test site CM1 (Below Corin Dam) grouped with all the reference sites of Cotter River catchment because of higher relative abundance of Athericidae. The reference site GM3 on the Goodradigbee River had similar macroinvertebrate assemblage to reference sites in the Cotter and Queanbeyan River catchments (Figure 10).

A clearer divergence of macroinvertebrate communities between test and reference sites was evident in autumn 2021 (Figure 11), with reference sites having higher abundances of environmentally sensitive taxa Scirtidae, Aphroteniinae, Philopotamidae, Conoesucidae, Gripopterygidae, and Leptophlebiidae and test site having higher environmentally tolerant taxa Hydropsychidae, Orthocladiinae and Hydroptilidae. Queanbeyan River Test site QM3 (Below Googong Dam) had macroinvertebrate assemblages dissimilar to all other sites (Figure 11).

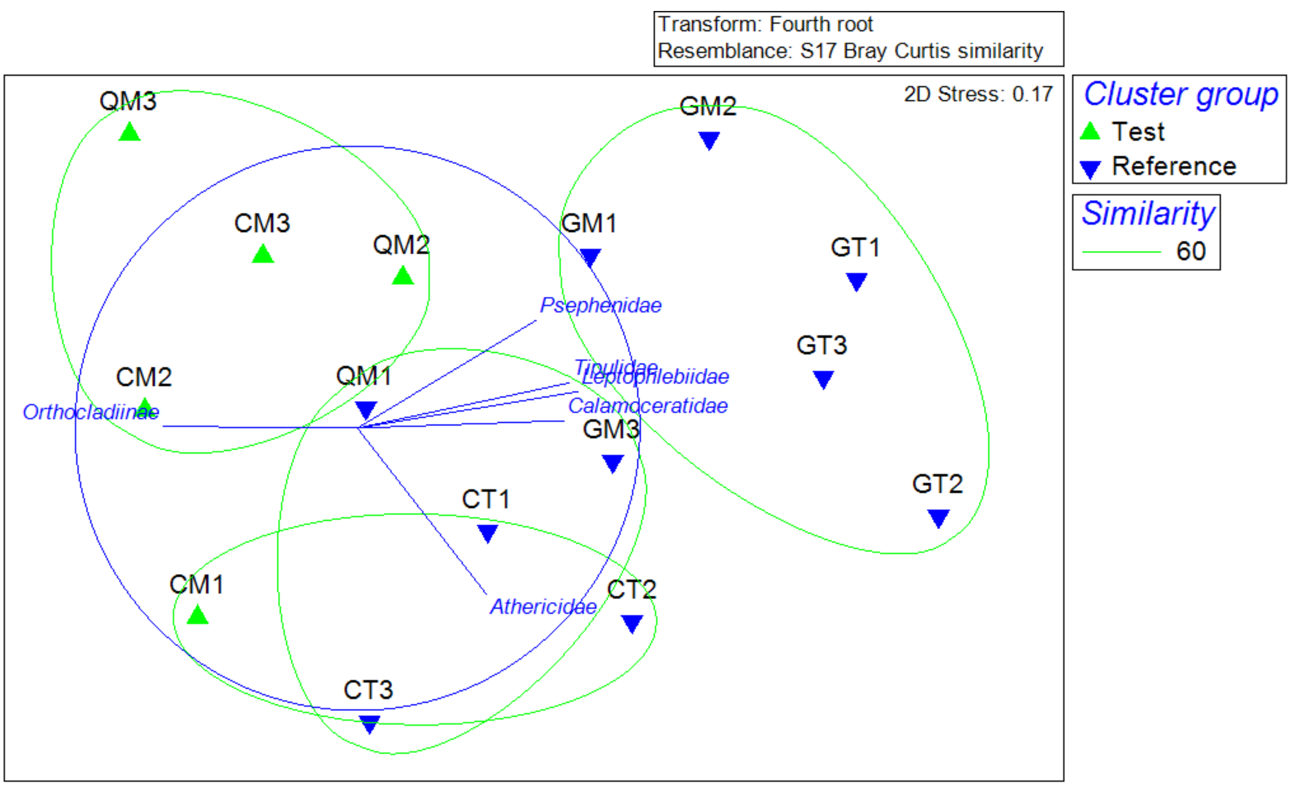

Figure 10. MDS ordination of 60% similarity between macroinvertebrate samples collected in spring 2020 for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative

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.

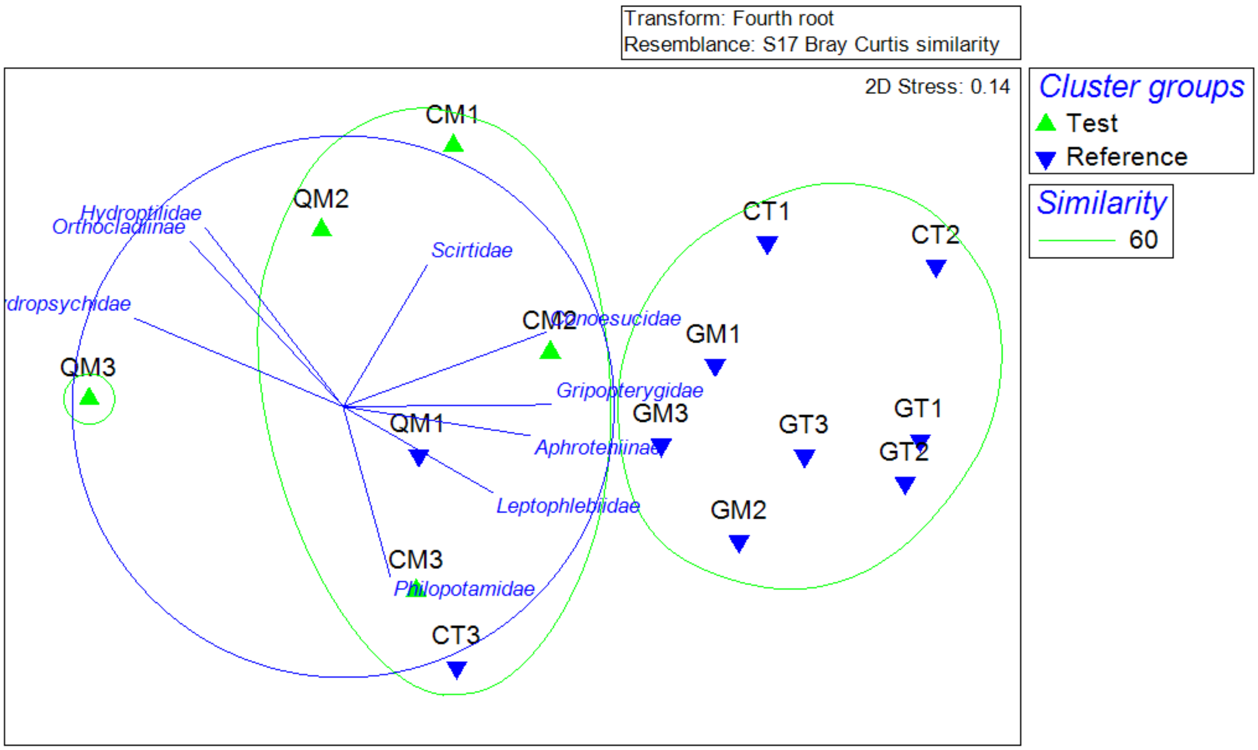

Figure 11. MDS ordination of 60% similarity between macroinvertebrate samples collected in autumn 2021 for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa that 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 were generally within guideline levels in both spring 2020 and autumn 2021. Parameters outside of guideline levels were Turbidity, Nitrogen Oxides (NOx), Total Nitrogen (TN) and Total Phosphorus (Table 5 and Table 6).

Turbidity at reference site CT3 (Paddy's River above Cotter River Junction) exceeded the guideline level of <10 NTU in autumn 2021 assessment. The higher level of turbidity is because of instream sedimentation caused by catchment land use (predominantly forestry, rural and large density of unsealed roads) and huge flood event which occurred prior to sampling in autumn 2021.

Nitrogen oxides (NO_x) had exceeded guideline level at all test sites in spring 2020 and all the test sites and reference site GM3 in autumn 2021. 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 2021 are not likely related to the environmental flow regime (Saunders and Kalff 2001). High level of NOx at GM3 may be attributed to land use , which is predominantly livestock grazing on the river valley (see Burnett and Dodds 2005).

Test sites CM1, QM2 and QM3 and reference sites QM1 and CT3 in spring 2020 and test sites QM2 and QM3 in autumn 2021 had high level of Total Nitrogen (TN) and exceeded guideline levels. This high level of nutrients may have been triggered as a result from runoff due to higher rainfall and big flow events that occurred prior to sampling in spring 2020 and autumn 2021 (Figure 2).

Total Phosphorus concentration at test sites QM2 and QM3 (below Googong Dam) were marginally higher than guideline level (0.02 mgL-1 and 0.01 mgL-1 respectively)in autumn 2021. This increase in TP concentrations cannot be attributed by the dam operations but it is likely due to the result of water carrying increased sediment load from runoff in the surrounding catchment (Harrison *et al.* 2010).

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 Bendora dam in spring 2020 and below Googong Dam (QM2) in autumn 2021. 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.

Ash free dry mass (AFDM) differed between sites in spring 2020, mostly because of extremely low concentrations at two reference sites (GM1 and GM2) compared to all other sites. There was no difference in AFDM concentration between test and reference sites in the following assessment in autumn 2021. There were a number of significant differences chlorophyll-a concentrations between sites for both the spring 2020 and autumn 2021 assessments, though there was no clear trend based on whether sites were test or reference. Despite some significantly difference in ash free dry mass and chlorophyll-a concentrations between sites in both spring 2020 and autumn 2021, concentrations across all sites was within the range of those measured in recent sampling (dating back to spring 2018).

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at four of five below dam test sites in both spring 2020 and autumn 2021. 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 2021 when four of the 10 reference sites were biologically impaired. In addition, one test site and one reference site has been assessed as severely impaired in autumn 2021 (Table 8).

The Cotter River test site below Corin Dam (CM1) remained significantly impaired in both spring 2020 and autumn 2021 assessment and has been for the past three years (and has had an O/E score very close to band A from autumn 2018 to autumn 2020). Short-term disturbance events (such as the high flow events prior to autumn 2021 sampling) led to a macroinvertebrate community dominated by the establishment of early colonizing taxa. Although this site had a reasonable taxonomic richness (Appendix 2), it had a high percentage of environmentally tolerant taxa in both spring 2020 and autumn 2021 (Figure 7).

The Cotter River test site below Bendora Dam (CM2) remained significantly impaired in spring 2020 and it has been assessed as similar to reference in autumn 2021 (Table 8). Despite relative low macroinvertebrate taxa richness, and a high percentage of environmentally tolerant taxa being present, Cotter River test site downstream of Bendora Dam (CM2) was the only test site to achieve the environmental flow ecological objective of AUSRIVAS band A in autumn 2021, despite high discharge prior to sampling, indicating some level of resistance in the community at this site (Table 8 and Figure 2).

The Cotter River test site downstream of Cotter Dam (CM3) was assessed as significantly impaired in both spring 2020 and autumn 2021 (from being assessed as band A in spring 2019 and autumn 2020). There has been decreased in O/E score (0.73) in spring 2020 to (0.67) in autumn 2021. The macroinvertebrate community at CM3 in both the assessments were characterised by low taxonomic richness and an extremely high percentage composition of tolerant taxa (Figure 7). The simplified and environmentally tolerant macroinvertebrate community present at CM3 was unlikely to be a result of the operation of Cotter Dam flows but a relatively high disturbance frequency in the months leading up to sampling. High discharge disturbance events have been shown to reduce macroinvertebrate density, biomass and diversity (Robinson et al. 2003; Death 2008). At the time of sampling the macroinvertebrate community may have been in a state of recovery following several large flooding events in the preceding months. This is supported by the prevalence of Simuliidae and Orthocladiinae which are early colonisers following disturbance events (Robinson et al. 2003). The lower abundance of case building Tricopterans at CM3 further supports evidence of flood related disturbance, as cases of these taxa can be destroyed by high and turbulent velocities and shifting sediments and high mortalities can be experienced (Robinson et al. 2003).

Macroinvertebrate communities at the site immediately downstream of Googong Dam (QM2) decreased in biological condition from being assessed as band A in spring 2020 to band B in autumn 2021. Similarly, biological condition at test site QM3 approximately 3.5 km downstream of Googong Dam was assessed as severely impaired in autumn 2021 (Table 8). The ratio of environmentally sensitive taxa (Ephemeroptera, Tricoptera and Plecoptera) in autumn 2021 was greater than environmentally tolerant taxa (Oligochaeta and Chironomidae) in spring 2020 (Figure 7). It is likely that the macroinvertebrate communities at both sites are recovering following disturbances caused by high discharge prior to sampling.

The most upstream site of the Goodradigbee River (GM1) has decreased in biological condition in autumn 2021 and assessed as band B. This is the first time since spring 2017 that this site had been assessed as band B. it is likely that disturbance events associated weith high discharge have contributed to this decrease in biological condition. We expect that this site should return to band A in the coming assessments. Four of the Goodradigbee River catchment reference sites did not change their biological condition between spring 2020 and autumn 2021 assessment. Cooleman Creek (GT1), the tributary of Googdradibee River was assessed band A in autumn 2021 but decreased its biological condition from being assessed as band X in spring 2020. Goodradigbee River catchment encountered several large discharge events leading up to sampling, though their macroinvertebrate communities were able to recover more rapidly. There are a number of factors that are likely to have contributed to the difference in the recovery between the Goodradigbee reference sites. Recolonisation by drift from riverine macroinvertebrate communities upstream (found to be one of the main mechanisms of recolonization (Death 2008)) is not limited in the Goodradigbee River when compared to the other catchments whose macroinvertebrate communities are fragmented by the presence of reservoirs.

The reference site at Kangaroo Creek undertook a significant recovery of macroinvertebrate community assemblage between spring 2020 and autumn 2021. The macroinvertebrate assemblage at this site in spring 2020 was dominated by environmentally tolerant taxa (Oligochaeta and Chironomidae). However, the macroinvertebrate assemblage at this site in autumn 2021 was dominated by environmentally sensitive taxa (e.g. Ephemeroptera, Tricoptera and Plecoptera). Despite the impacts of the bushfire and resultant sedimentation from erosion in early 2020, the site is gradually improving (Figure 12).

Figure 12. Condition of Kangaroo Creek site (CT1) following January 2020 Bushfires (Photo: Ben Broadhurst; Ugyen Lhendup).

The reference site CT3 (Paddy's River) upstream of Cotter River Junction has significantly changed it condition in autumn 2021. The biological condition at this site was assessed as severely impaired (band C) from being assessed as significantly impaired (band B) in spring

2020. The site has been characterised by low abundance of macroinvertebrates and dominated by environmentally tolerant taxa (Oligochaeta and Chironomidae) (Table 8). It is likely the large flood event prior to sampling and higher turbidity (3-fold higher than guideline level) have driven the numerical dominance of tolerant taxa, and subsequently influenced the outcome of the AUSRIVAS assessment in autumn 2021 (Table 6; Figure 7; Figure 13).

Figure 13. Condition of Paddy's River site (CT3) following flood event prior the sampling in autumn 2021 (Photo: Ugyen Lhendup; Rhian Clear).

CONCLUSION

Water quality parameters at below dam test sites were largely within guideline levels in spring 2020 and autumn 2021, with the exception of nitrogen oxides (NOx) in all the test sites in both assessment seasons and total nitrogen (TN), total phosphorus (TP) and turbidity in a few sites. Despite some increased nutrient availability, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites, except for CM2 spring 2020 and at QM2 in autumn 2021. Among five test sites, one of the sites has increased its biological condition, two sites did not change their biological condition and two sites decreased their biological condition in autumn 2021. There was no significant change in biological condition in the reference site between spring 2020 and autumn 2021, except for the site CT3 (Paddy's River) which is severely impaired due to a hydrological disturbance prior to autumn 2021 sampling. Higher number of missing bugs predicted by AUSRIVAS model, particularly in the test sites and none of the taxa detected in sub-sample scan indicated very low number of relative abundance in autumn 2021. As a result of high flows prior to autumn 2021 sampling in the Cotter and Queanbeyan River catchments, periphyton biomass was similar to reference conditions and within the ecological objectives of <20% cover. High rainfall and flooding in the Cotter and

Googong catchments has provided rivers downstream with good flows, which can cause disturbance to macroinvertebrate communities. The macroinvertebrate community condition will likely increase as these sites are recolonized.

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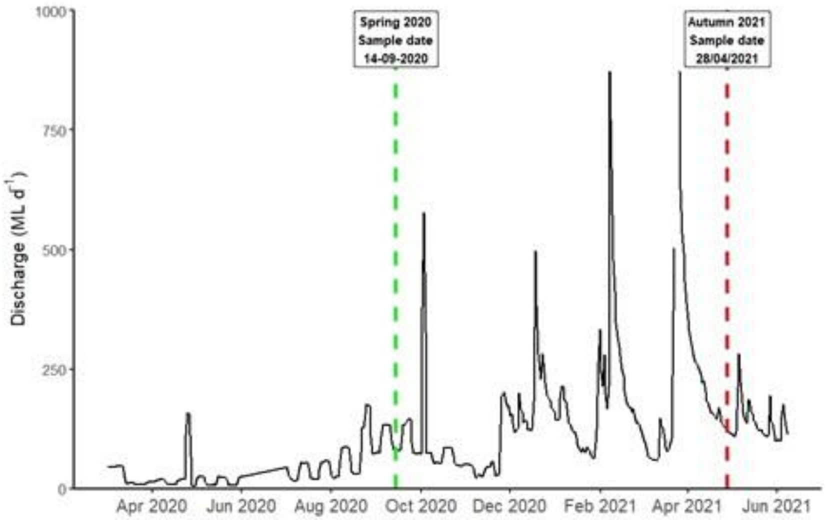
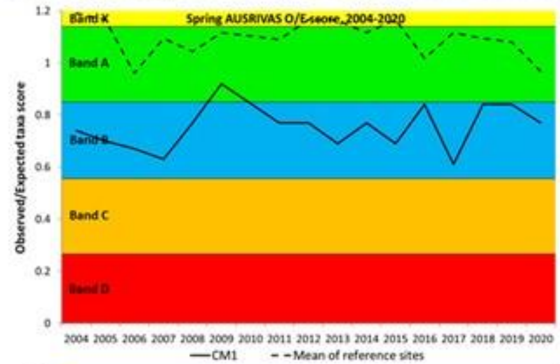
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

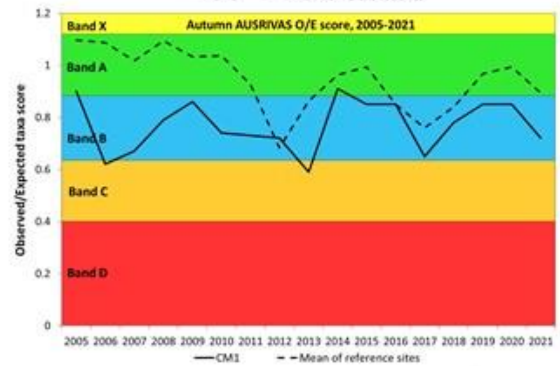
CM1 - Spring 2020 - Autumn 2021

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2020	Autumn 2021	Objective met?
AUSRIVAS band A	Band B	Band B	No in both seasons
<20% filamentous algae cover in riffle habitat	<30%	<10%	No - spring 2020 Yes – Autumn 2021







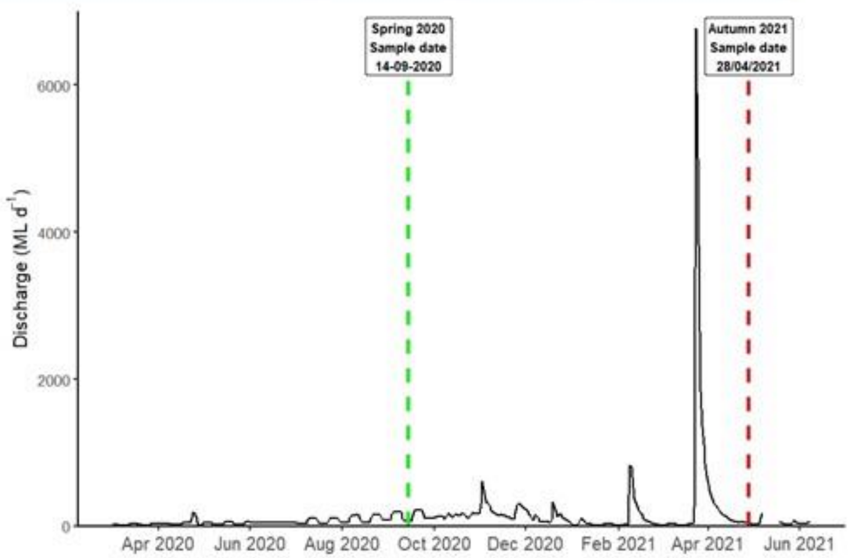
* Denotes values outside guideline levels

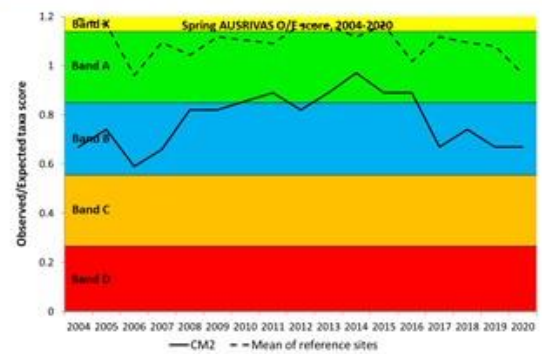
Sampling season	Temp. (^{o}C)	EC ($\mu s\ cm^{-1}$)	pH	D.O. ($mg\ l^{-1}$)	Turbidity (NTU)	Alkalinity ($mg\ L^{-1}$)	NH_4^+ ($mg\ L^{-1}$)	NOx ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
Spring 2020	7.43	1	7.29	11.32	0.0	18	0.008	0.185	0.31	0.011
Autumn 2021	13.62	27	6.96	9.39	1.9	14	0.14	0.008	0.029	0.007

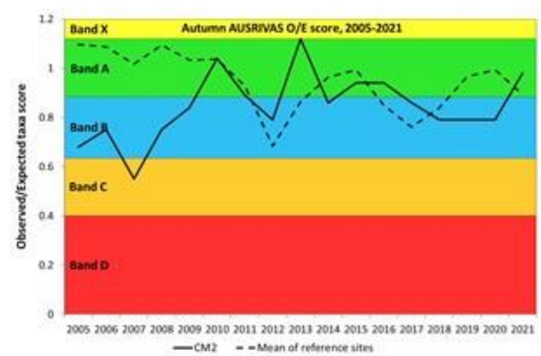
CM2 - Spring 2020 - Autumn 2021

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2020	Autumn 2021	Objective met?
AUSRIVAS band A	Band B	Band A	No – Spr. 2020 Yes – Aut. 2021
<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 2020	8.06	0	7.27	11.5	0.3	13	0.004	0.141	0.22	0.005
Autumn 2021	12.65	26	6.98	9.8	3.5	12	0.14	0.004	0.026	0.006

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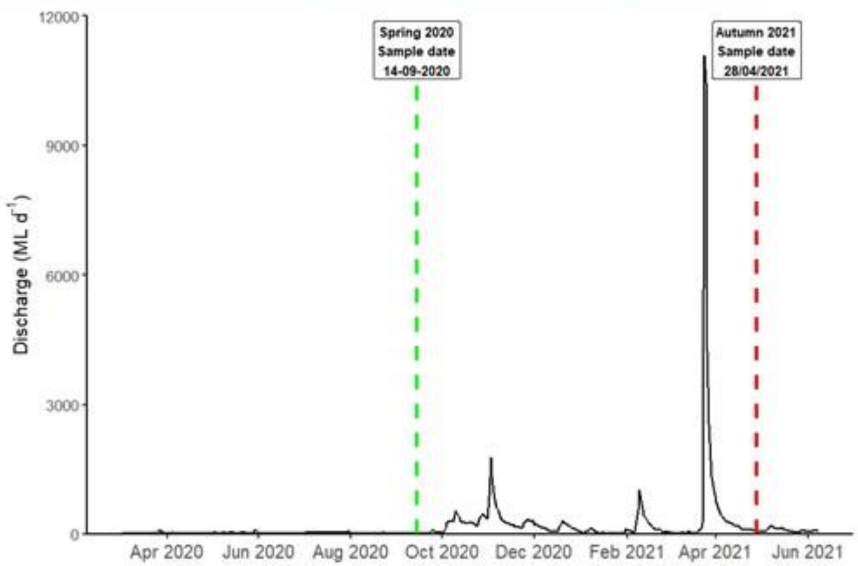
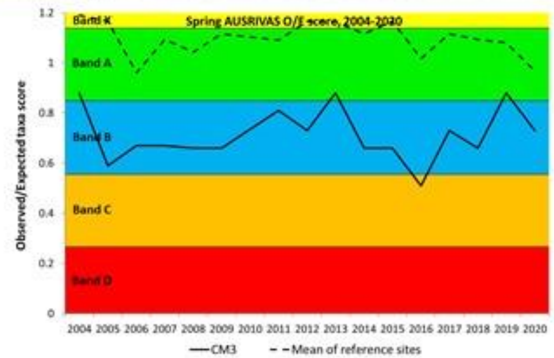
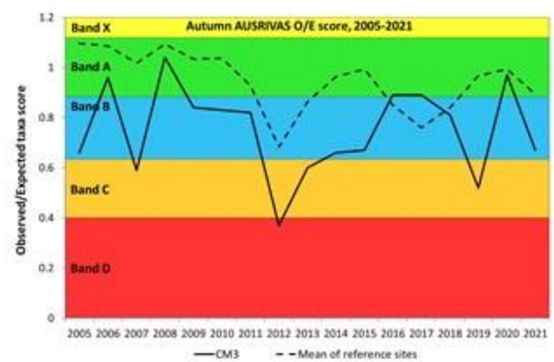
CM3 - Spring 2020 - Autumn 2021

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2020	Autumn 2021	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 2020	11.88	14	6.94	10.84	4.1	19	0.025	0.037	0.17	0.007
Autumn 2021	14.45	34	7.61	10.49	5.9	15	0.19	0.016	0.041	0.008

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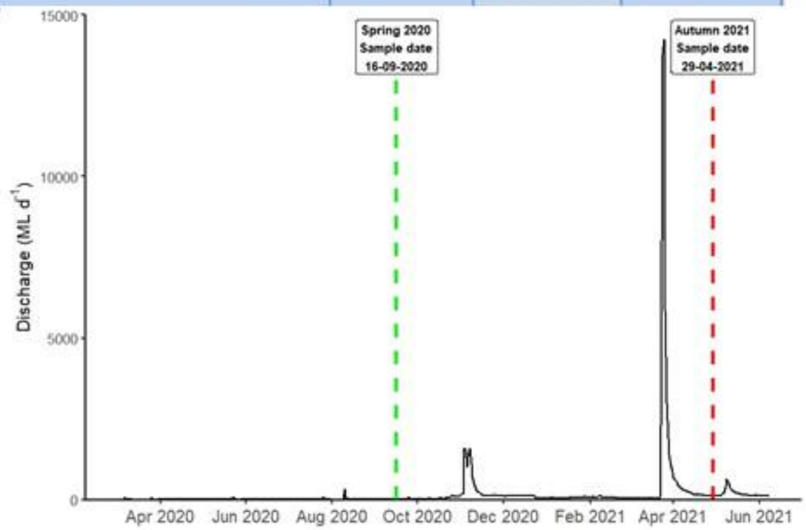
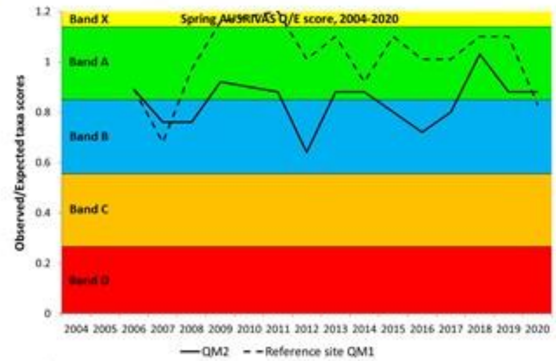
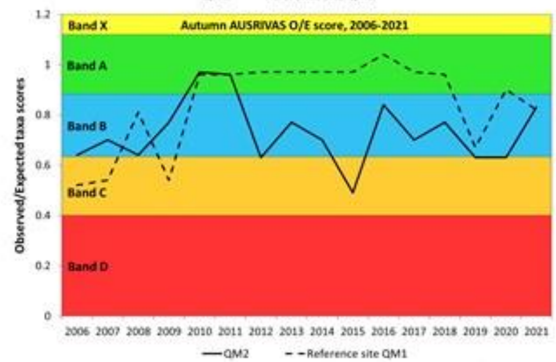
QM2 - Spring 2020 - Autumn 2021

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2020	Autumn 2021	Objective met?
AUSRIVAS band A	Band A	Band B	Yes - Spring 2020 No - Autumn 2021
<20% filamentous algae cover in riffle habitat	<10%	30%	Yes – Spr. 2020 No – Aut.. 2021







* Denotes values outside guideline levels

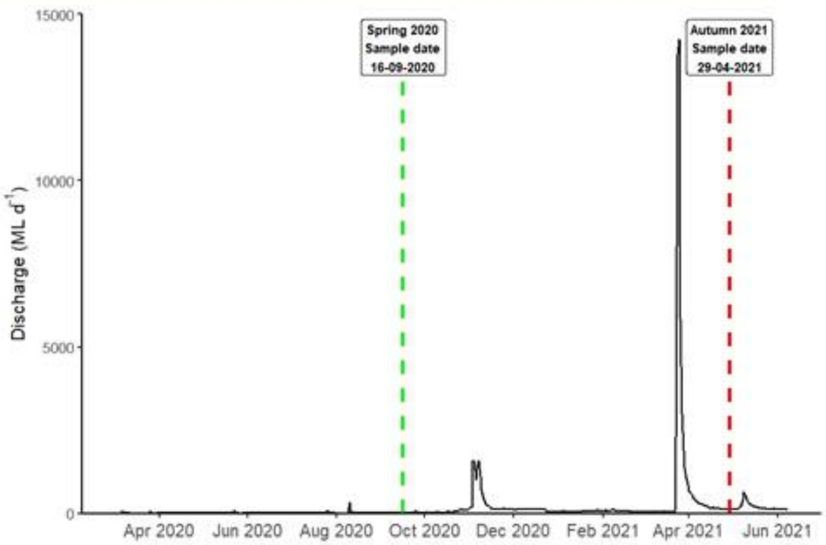
Sampling season	Temp. (^oC)	EC ($\mu s\ cm^{-1}$)	pH	D.O. ($mg\ l^{-1}$)	Turbidity (NTU)	Alkalinity ($mg\ L^{-1}$)	NH_4^+ ($mg\ L^{-1}$)	NOx ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
Spring 2020	11.56	76	8.00	11.49	2.6	72	0.032	0.154	0.63	0.013
Autumn 2021	15.41	77	7.66	10.45	4.5	90	0.65	0.013	0.023	0.022

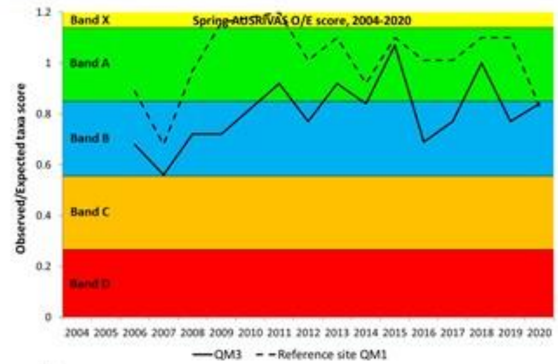
QM3 - Spring 2020 - Autumn 2021

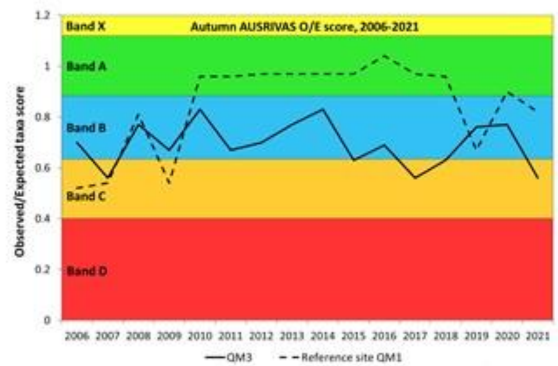
2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2020	Autumn 2021	Objective met?
AUSRIVAS band A	Band B	Band C	No in both seasons
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons

Autumn 2020
Photo N/A







* 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 2020	14.01	120	7.89	10.62	5.0	100	0.012	0.079	0.63	0.013
Autumn 2021	15.1	83	7.66	9.97	4.8	34	0.64	0.009	0.032	0.021

APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2020 AND AUTUMN 2021

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

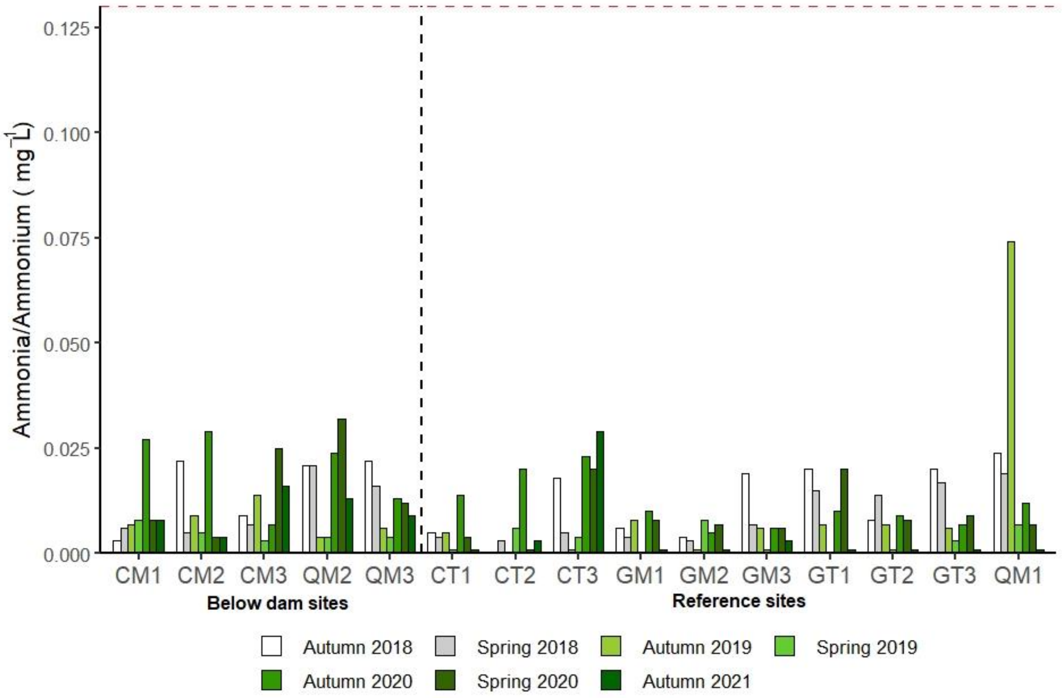
CLASS **Order** Family *Sub-family*	**Signal 2 Grade**	**Test sites** **CM1**	**CM2**	**CM3**	**QM2**	**QM3**	**Reference sites** **CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
GASTROPODA																
Lymnaeidae	1				1											
Planorbidae	4		1							1						
Physidae	1															
Sphaeriidae	5	1			1	1										
OLOGOCHAETA	2	2	31	7	20	81	38	13	4	28	1		5	4	2	8
ACARINA	6	3	1	8	5	2		2		4	2	1	10	8	3	
Coleoptera																
Elmidae (Adult)	7						1						2	1		
Elmidae (Larvae)	7			2		1	2	3					7	14	3	
Scirtidae		1			1			1						3	3	
Psephenidae	6									4	3	2	2	2	1	
Diptera																
Tipulidae	5		2	1		1	1			1	3	2	9	9	6	1
Ceratopogonidae	4						1		1			1	2	3		
Simuliidae	5	2	69	105	24	16	29	18	78	21	99	37	1	2	11	141
Athericidae	8							3	3	1		1		4	1	
Empididae	5	2	4	1					1					1		
Aphroteniinae	8						6	2				2		5		
Podonominae	6							7					4	1	5	
Tanypodinae	4	12	1		3	4	7	14	3	1		4	2	2	2	5
Orthocladiinae	4	134	78	83	128	144	83	67	33	22	19	115	5	10	13	21
Chironominae	3	3	13	2	6	2	6	31	2	5		1	4	4	4	2
Ephemeroptera																
Baetidae	5				12		2	10	80	16	11	18	8	3	2	8
Coloburiscidae	8									6	4		1		4	
Leptophlebiidae	8	1			2		2	5			13	1	48	31	31	1
Caenidae	4			5	8	26	2		1	47	6	4	27	41	1	6
Megaloptera																
Corydalidae	7													1	2	
Neuroptera																
Osmylidae	7					3										
Odonata																
Gomphidae	5									1		1				
Telephlebiidae	9						1									
Plecoptera																
Gripopterygidae	8	27	11	23	3		20	12	4	28	29	17	43	23	107	5
Trichoptera																
Hydrobiosidae	8	6	1			2		7	6	1	2		1	3		
Calamoceratidae	7												1	1	1	
Hydroptilidae	8										1		3			
Philopotamidae	8							2	2					1		
Philorheithridae	8				1									8		
Hydropsychidae	6			1	8	26		3		2	3		4			
Ecnomidae	4		1	1		5						2				
Conoesucidae	8	2						2		9	5	5	13	6		
Helicopsychidae	8													17		
Leptoceridae	6						1	1				1	3	7		
No. of individuals		196	213	239	223	314	202	203	218	198	201	215	205	215	202	198
No. of taxa		13	12	12	15	14	16	19	13	18	15	18	23	28	19	10
% of sub-sample		3	4	6	2	2	6	7	3	9	2	4	5	3	4	1
Whole sample estimate		**6533**	**5325**	**3983**	**11150**	**15700**	**3367**	**2900**	**7267**	**2200**	**10050**	**5375**	**4100**	**7167**	**5050**	**19800**

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2021 at each of the study sites.

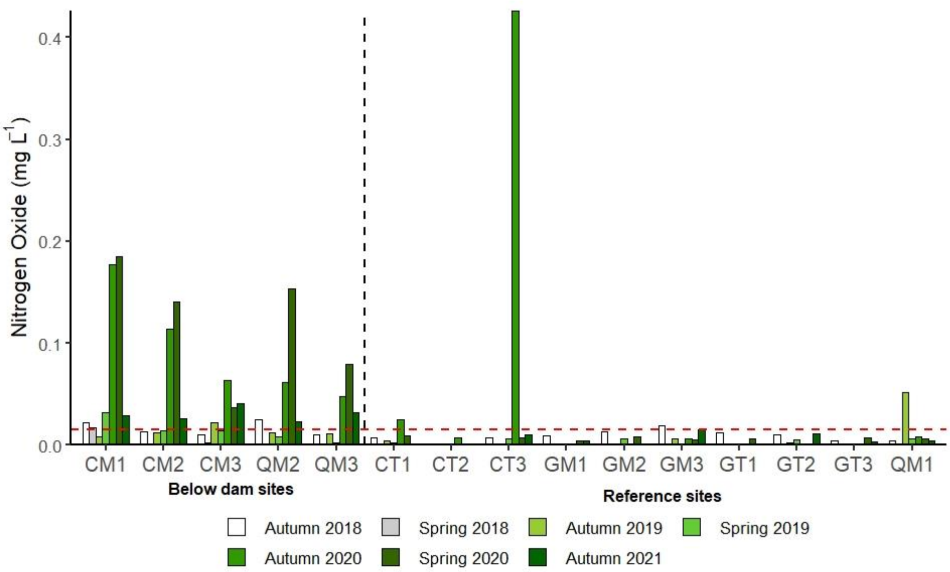
CLASS **Order** Family *Sub-family*	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
GASTROPODA																
Lymnaeidae	1		1		1											
Planorbidae	4		3		1											
Physidae	1				4											
Pelecypoda																
Sphaeriidae	5		1	1						1						
OLIGOCHAETA	2	54	8	126	21		3		109	2	5	1				14
ACARINA	6		2	4	1			4		4		4	1		1	
Coleoptera																
Staphylinidae	3											1				
Scirtidae	6				2		3	4							1	
Elmidae (Adult)	7	1					3	1							1	
Elmidae (Larvae)	7	6			5		22	2		2		4	1	2	2	3
Psephenidae	6		1				1			3	1	3	2	1	1	
Ptilodactylidae	10						2									
Diptera																
Tipulidae	5		3	1	17	37	1		1			10	5	2	9	1
Ceratopogonidae	4															
Simuliidae	5	3	115	42	12	11	12	11	60	5	28	49	1	4	11	55
Athericidae	8	4	1		4		10				1		1	2		
Aphroteniinae	8		1				1	1			2		1	2	1	
Podonominae	6							1	5	1	1				1	
Tanypodinae	4		2					1					1	8	1	
Orthocladiinae	4	73	53	19	52	44	9	29	17	12	7	13	6	7	7	11
Chironominae	3	2	2	1	6	2	1	1		4	9	1	7	6	2	2
Ephemeroptera																
Baetidae	5	2	4	5	13	53	12	35	15	29	31	11	26	11	33	98
Coloburiscidae	8						17			24	7	9	1		2	
Leptophlebiidae	8	3			1		20	14	5	10	126	41	51	49	69	2
Caenidae	4		1	5	15	3	2		2	23	3	6	5	2	2	2
Megaloptera																
Corydalidae	7						1						2	1		
Odonata																
Austropetaliidae	N/A												1			
Gomphidae	5				2											
Telephlebiidae	9						2									
Plecoptera																
Gripopterygidae	8	12	18	6	5		79	41	3	91	27	40	76	146	97	8
Trichoptera																
Hydrobiosidae	8	15	4			7		9	1		1	1	11	1	3	3
Glossosomatidae	9		1	1			2	1	1			4	1	1		
Hydroptilidae	8	1			1	1	1									
Philopotamidae	8			5			2		2		2	1	3	2	1	1
Hydropsychidae	6	22	12	4	40	71	4		1	10	2	9	3	1	1	9
Ecnomidae	4	1	1	2	10	10	1	1	2	11	7	1	1	6	6	
Conoesucidae	8	3	5	1			24	74		31	7	7	30	26	20	
Helicopsychidae	8							1					1	2		
Calamoceratidae	7												1	1		
Leptoceridae	6										3		36	19	5	
No. of individuals		202	239	223	213	239	235	231	224	263	270	216	275	302	277	209
No. of taxa		15	21	15	20	10	25	18	14	17	19	20	26	23	23	13
% of sub-sample		3	3	4	3	3	5	7	16	2	2	3	2	1	2	5
Whole sample estimate		**6733**	**7967**	**5575**	**7100**	**7967**	**4700**	**3300**	**1400**	**13150**	**13500**	**7200**	**13750**	**30200**	**13850**	**4180**

APPENDIX 3: WATER QUALITY FIGURES

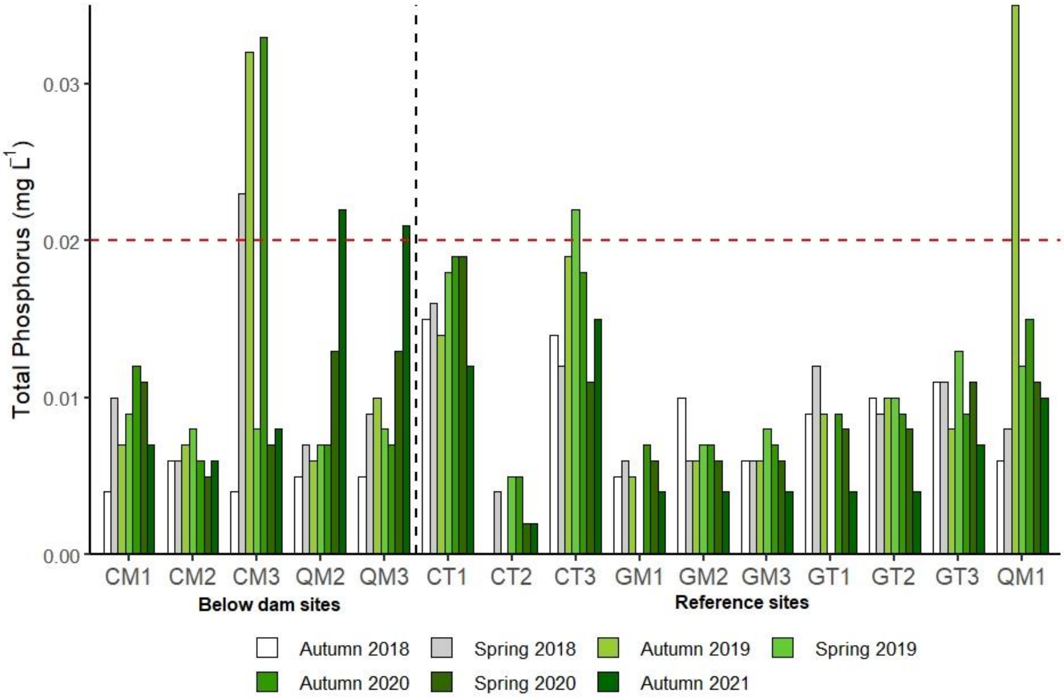
(Note: There was no flow during sampling and water samples could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).



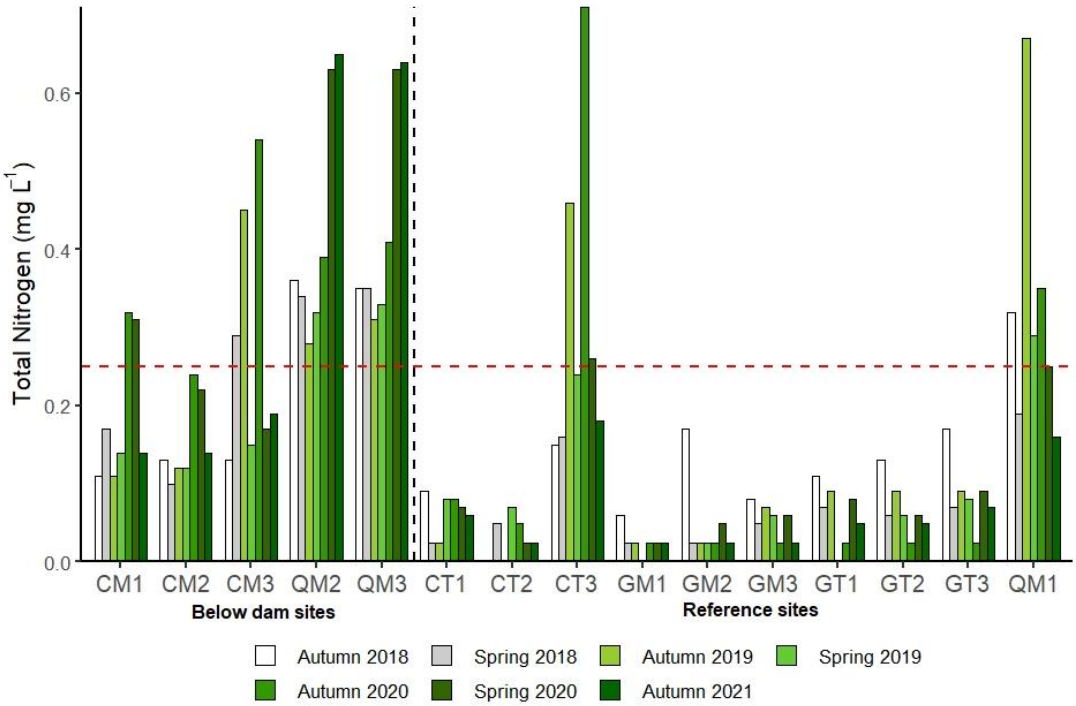
Ammonium (NH_4^+) concentration at all sites from spring 2018 to autumn 2021. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is shaded yellow.



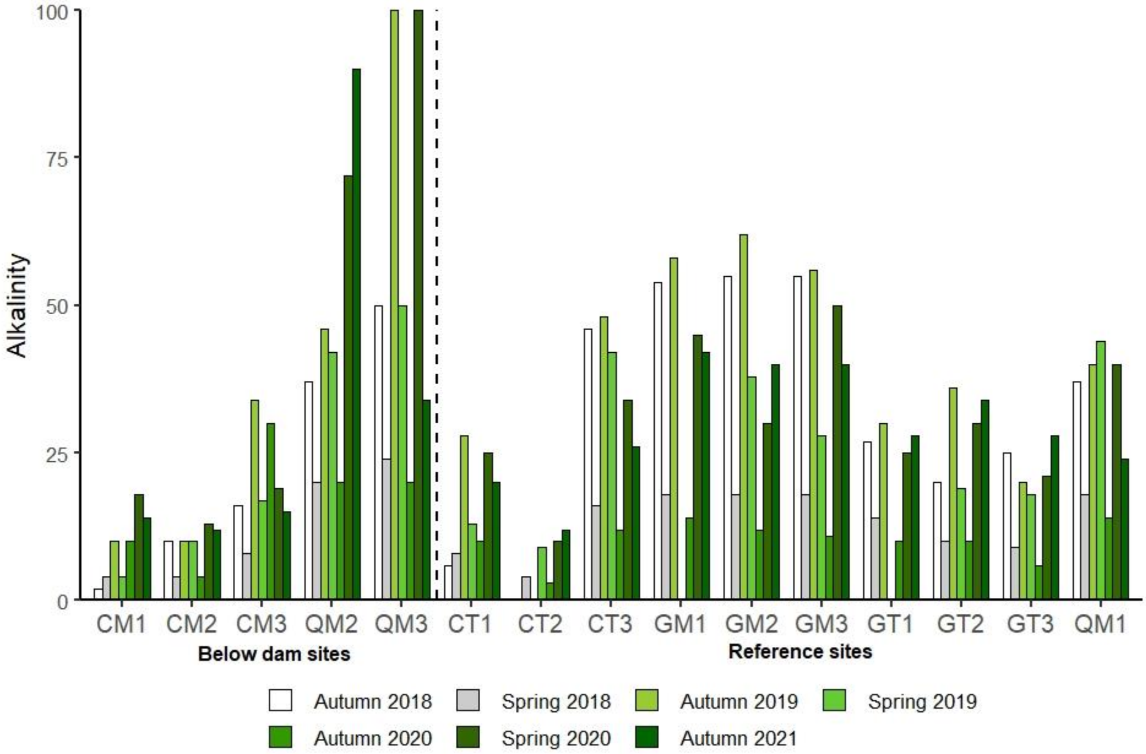
Nitrogen oxide concentrations at all sites from spring 2018 to autumn 2021. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is shaded yellow.



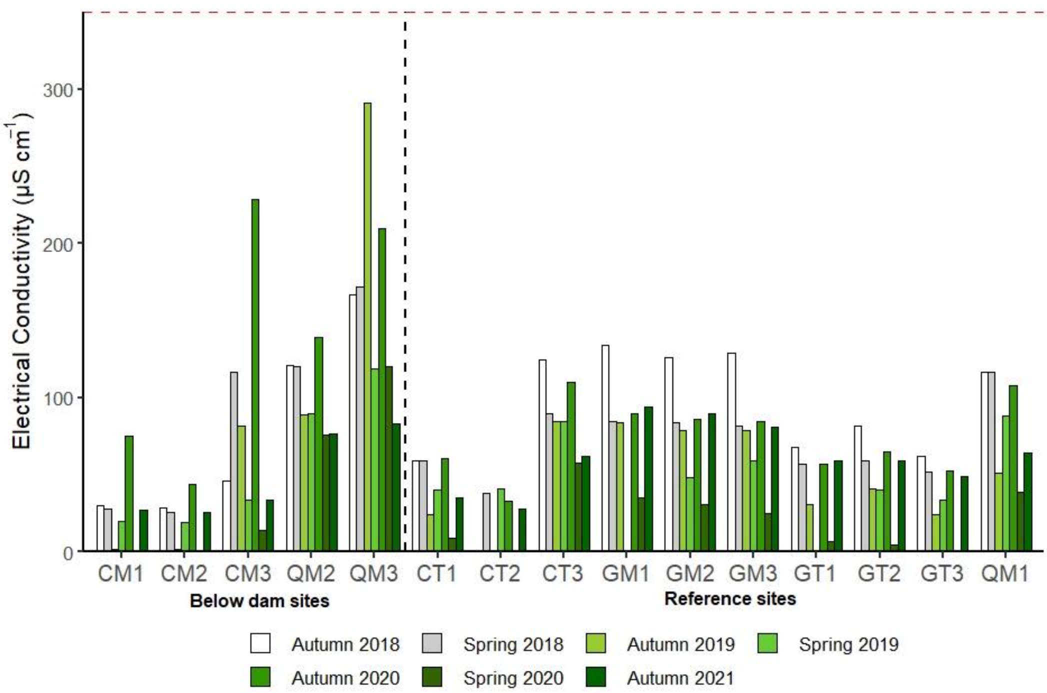
Total phosphorus concentrations at all sites from spring 2018 to autumn 2021. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is shaded yellow.



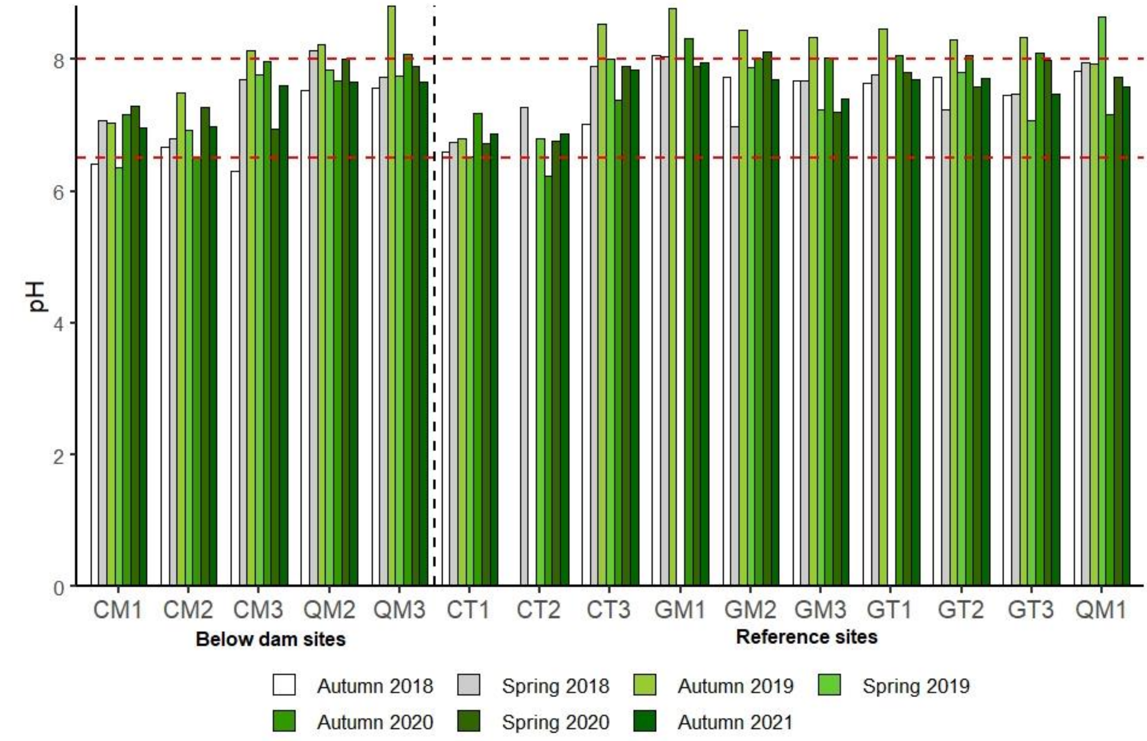
Total nitrogen concentrations at all sites from spring 2018 to autumn 2021. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is shaded yellow.



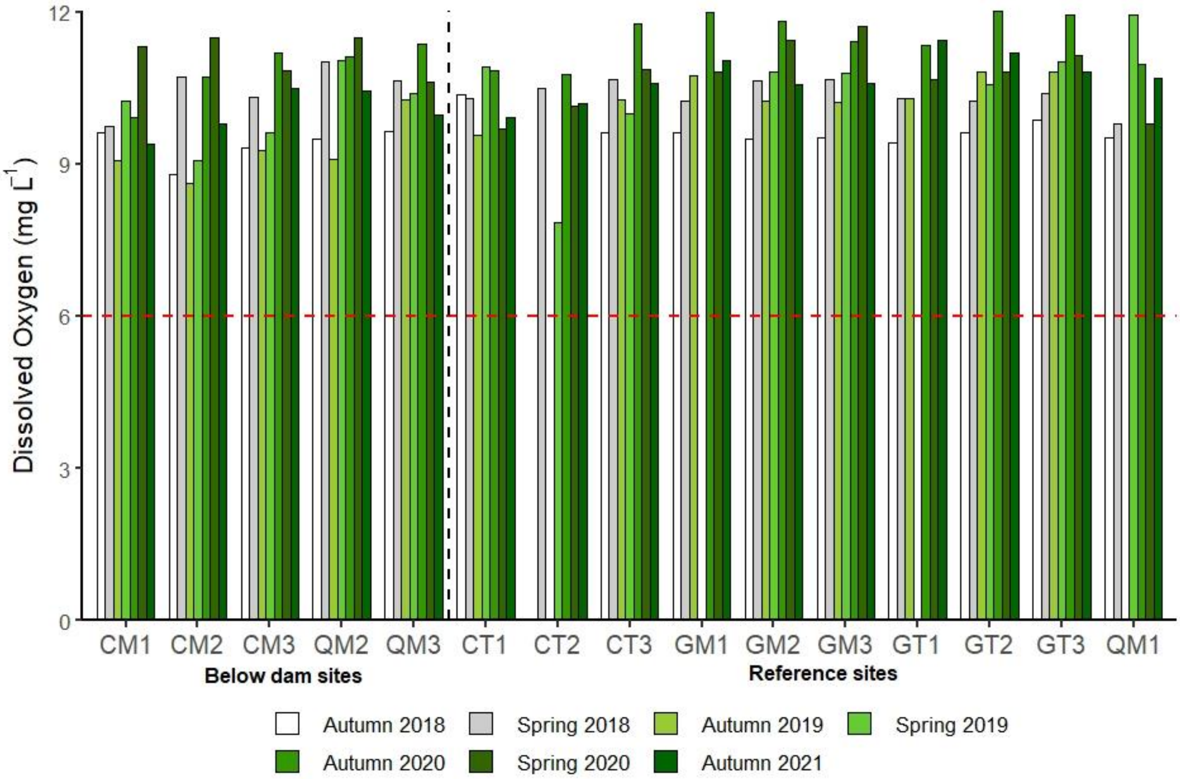
Alkalinity at all sites from spring 2018 to autumn 2021.



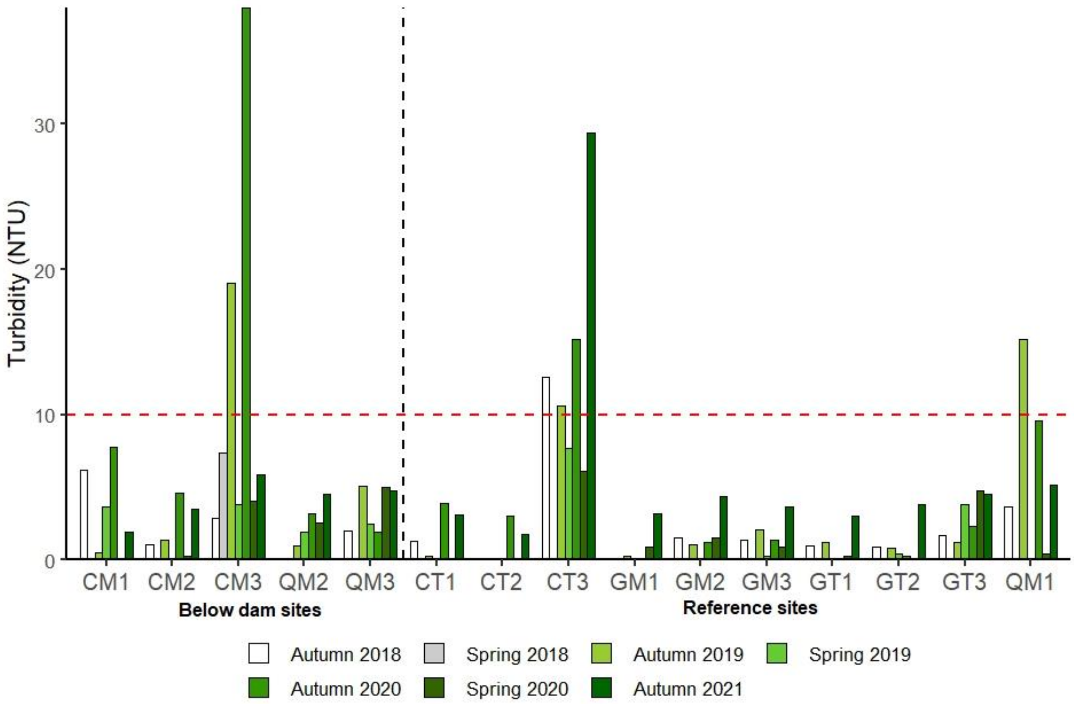
Electrical conductivity at all sites from spring 2018 to autumn 2021. The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is shaded yellow.



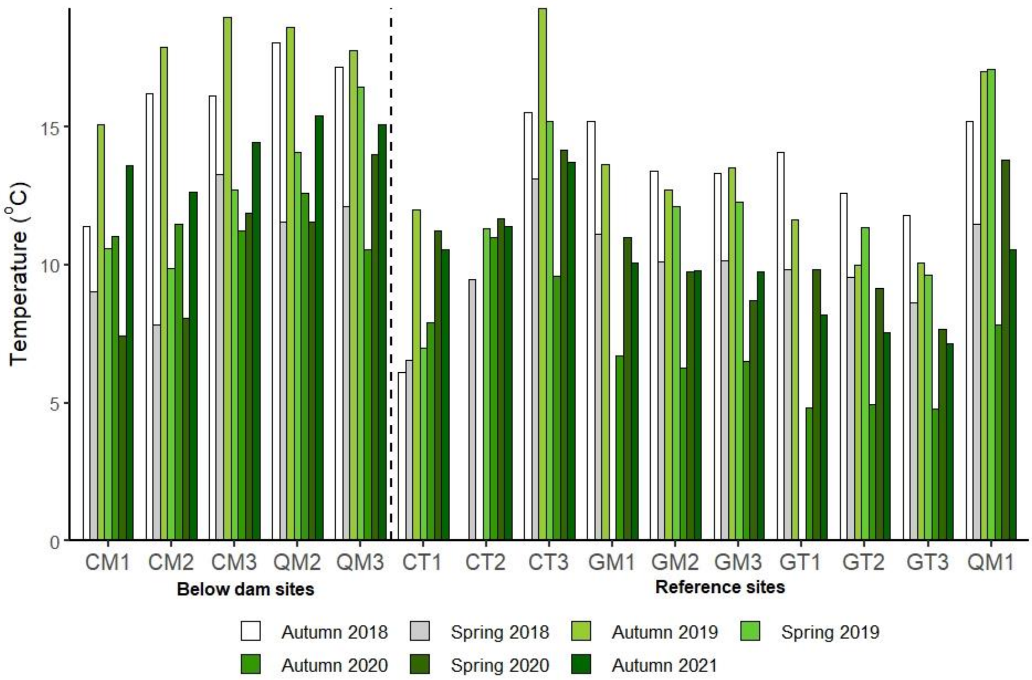
pH at all sites from spring 2018 to autumn 2021. The ANZECC/ARMCANZ (2000) guideline range for pH is shaded yellow.



Dissolved oxygen concentration at all sites from spring 2018 to autumn 2021. The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from spring 2018 to autumn 2021. The guideline for maximum turbidity is shaded yellow (Environment Protection Regulation SL2005-38).



Water temperature at all sites from spring 2018 to autumn 2021.