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

Annual report August 2023

Report to Icon Water

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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. This report is the results of assessments undertaken in spring 2022 and autumn 2023.

SPRING 2022 & AUTUMN 2023 RESULTS AND CONCLUSIONS

- Discharge in the six months prior to sampling in spring 2022 was higher than discharge in the six months prior to sampling in autumn 2023. Total rainfall for the six months leading up to spring 2022 was greater than the historical average rainfall for the entire study area. Conversely, rainfall in the preceding six months for autumn 2023 was below the historical average rainfall. As all dams were full, flow in spring 2022 were dominated by 'natural' flow conditions at all test sites. Both Corin and Bendora Reservoirs were below full supply in the months leading into autumn 2023 sampling, meaning flows were dominated below these dams by regulated flow conditions. Cotter Reservoir was at full supply level leading up to autumn 2023 sampling, resulting in largely unregulated flows for the river downstream. Googong Reservoir was largely full leading up to sampling, with the exception of March and two weeks in April, meaning the river was largely operating as unregulated leading into sampling. Instream samples (Macroinvertebrates, chlorophyll-a and ash-free dry mass) were not able to be collected at most sites during the spring 2022 assessment because of high river levels.
- Water quality parameters at below dam test sites were largely within guideline levels in spring 2022 and autumn 2023 with a few exceptions. Nutrients below Googong Reservoir were above guideline levels in spring 2022 and autumn 2023. Sites below dams in the Cotter Catchment all had nitrogen oxide levels that exceeded guidelines in autumn 2023. There were a few minor spot measurements that were outside guideline levels (e.g. turbidity and pH) that was seemingly unrelated to whether a site was test or reference. Click here for more information.
- In both sampling seasons, the ecological objective of maintaining a filamentous algae cover of less than 20% in riffle habitats was achieved at all test and reference sites. However, in spring 2022, the test sites downstream of Googong Dam (QM3) and in autumn 2023, test sites downstream of Corin Dam (CM1), downstream of Bendora Dam (CM2), and downstream of Googong Dam (QM2, and QM3) failed to meet the ecological objective of maintaining the periphyton cover below 20% in riffle habitats. Click here for more information.

- Assessment of whether test sites met the ecological objective of band A macroinvertebrates community assemblages could not be assessed in spring 2022 because of high river levels preventing safe sampling. Test site CM2 (downstream Bendora Reservoir) was the only test site to achieve AUSRIVAS band A and meet the ecological objective. Click here for more information
- All reference sites (except GM1 which only missed band A by 0.02) sampled in autumn 2023 were in band A biological condition (similar to reference). 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 2022	Autumn 2023	Spring 2022	Autumn 2023
CM1 (Corin Dam)	<10	<10		B
CM2 (Bendora Dam)	<10	<10		A
CM3 (Cotter Dam)	<10	<10		B
QM2 (Googong Dam)	<10	<10		C
QM3 (Googong Dam)	<10	<10		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 & 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 spring and autumn 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.

The present report evaluates the sites located downstream of the dams on the Cotter and Queanbeyan Rivers in spring 2022 and autumn 2023. The assessment primarily concentrates on comparing these sites with unregulated reference sites and the findings of previous assessments.

Macroinvertebrate samples were not collected at test sites in spring 2022 due to high flow during the sampling season. In contrast, the river flow during autumn 2023 had subsided, allowing for the collection of macroinvertebrates at the sites. Site summary sheets outlining the outcomes of both the spring 2022 and autumn 2023 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, 2019). 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 & 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 & Nichols, 2011)

Fifteen sites were sampled for biological, physical and chemical variables in spring between 25 to 28 November 2022 and 15 to 19 May 2023 in autumn 2023 (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.

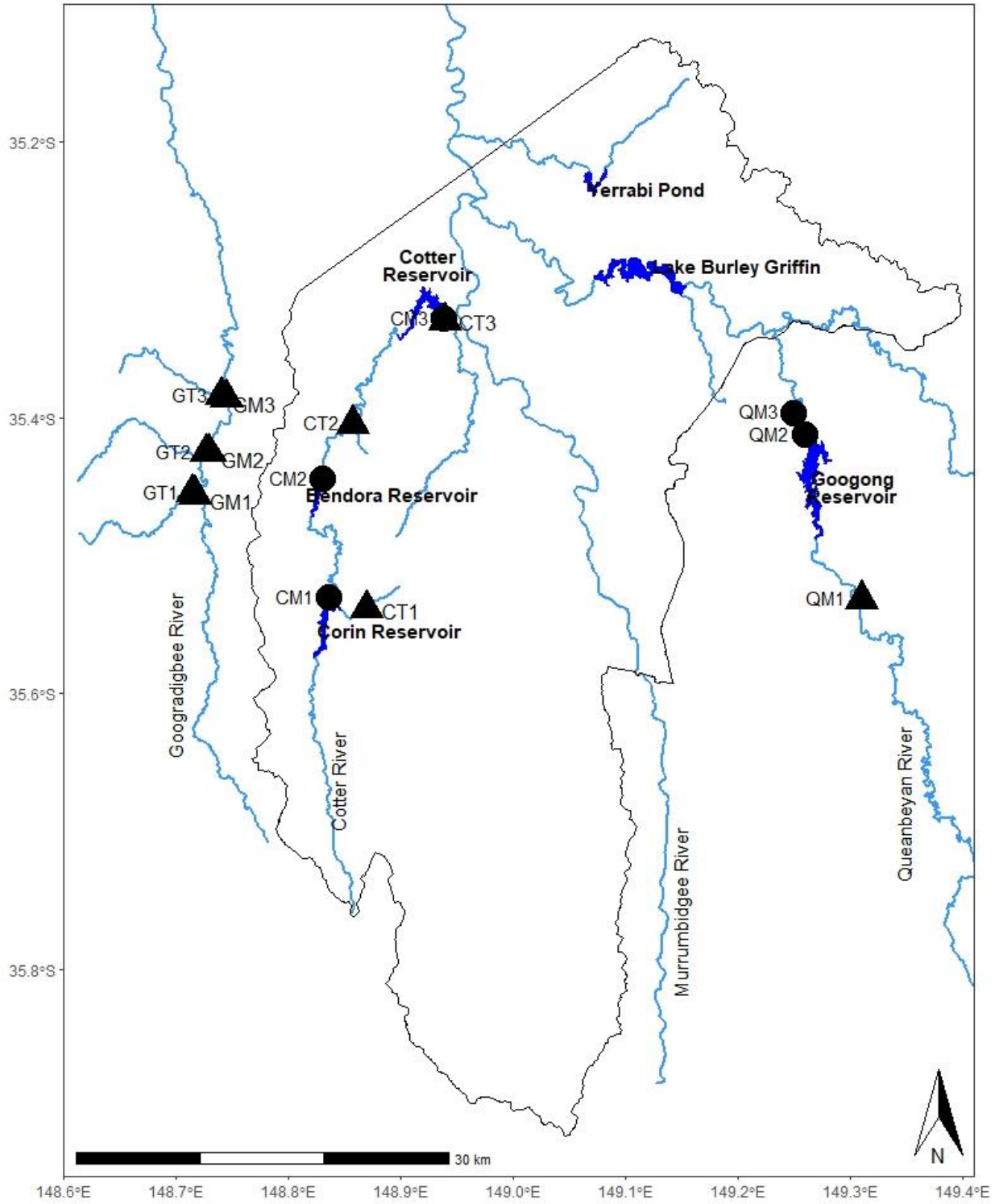


Figure 1: The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program (Circles indicate test sites, triangles indicate reference tributaries).

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

To analyze the variations in river flow leading up to the sampling period, mean daily flow data for each of the below dam test sites (supplied by Icon Water) and the Goodradigbee River reference sites (obtained from the NSW Department of Primary Industries Office of Water, gauging station 410088) were utilised. Daily rainfall data was gathered from various environmental monitoring sites, including ALS site 570965 in the Queanbeyan Catchment, ALS site 570958 at Bendora Dam, ALS site 570825 in Peirces Creek, and Bureau of Meteorology station number 071073 located in Brindabella.

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 (Association & Association, 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 (Association & Association, 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 (ANZECC & ARMCANZ, 2000). 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., 2000a; Nichols et al., 2000b) http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

ASH-FREE DRY MASS AND CHLOROPHYLL-A

Only three replicate periphyton samples were collected from reference site (Goodradigbee River Sites) 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 (Association & Association, 2005). The collection of periphyton samples from test sites was not possible in spring 2022 due to the high flow condition. However, due to low flow in autumn 2023, the periphyton samples were collected from all the test sites.

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., 2000a) http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54). However, because of high flows during spring 2022, only three

reference sites were sampled in spring 2022 and all the sites were sampled in autumn 2023.

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 & 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., 2000a) QA/QC procedures were implemented for macroinvertebrate sample processing following those outlined in (Nichols et al., 2000a).

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 the University of Canberra 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) (R) was used followed by Tukey-Kramer multiple comparisons for autumn 2023 assessment. The similarity in macroinvertebrate community structure between sites was evaluated by utilizing the Bray-Curtis similarity measure and the group average method, focusing on the relative abundance data.

In contrast, due to the absence of AFDM, Chlorophyll-a concentration data, and macroinvertebrate data in the spring 2022 assessments, no formal data analysis was conducted to explore significance differences between sites regarding these metrics.

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

The stream discharge at below dams sites on the Cotter and Queanbeyan Rivers in the months leading up to both spring 2022 sampling was primarily influenced by natural flow conditions, as all reservoirs were at full supply level. This continued to be the case largely at Cotter and Googong Reservoirs for the autumn 2023 sampling, but both Corin and Bendora Reservoirs were below full supply level from ~January/February 2023 and discharge in the rivers below dominated by environmental flow releases for this period. The flow regime targets were exceeded beyond the operational flow requirements as stipulated by the environmental flow guidelines (ACT Government, 2019) (Table 4). The discharge in the six months prior to sampling in spring 2022 was higher compared to the discharge in the six months prior to sampling in autumn 2023 at all test and reference sites.

Goodradigbee River experienced a significant increase in mean discharge during spring 2022, reaching a value of 1410.48 ML/Day, which is double the historical average discharge for the same period where the daily mean discharge was in the 98th percentile. Additionally, in autumn 2023, the river recorded a mean daily discharge of 410.65 ML/Day, which is more than 1.5 times higher than the historical average discharge for that season where the flow was in the 87th percentile.

Among the regulated sites, the highest daily mean discharge was recorded in CM3 (below Cotter Reservoir) with 1135.48 ML/Day and 213.51 ML/Day in both spring 2022 and autumn 2023, respectively, in the six months prior to sampling. Therefore, the daily mean discharge was in the 94th percentile and 78th percentile for spring 2022 and autumn 2023, respectively. Similarly, the daily mean discharge was approximately twice as high as the historical average.

During spring 2022, the site CM1 (below Corin Reservoir), recorded the lowest daily mean discharge at 551.89 ML/Day. However, this discharge level was approximately three times greater than the historical average, placing it around the 98th percentile compared to the flow distribution. Conversely, in the autumn of 2023, the site CM2 (below Bendora Reservoir), recorded the lowest daily mean discharge at 131.78 ML/Day. This value was 1.5 times higher than the historical average, corresponding to approximately the 83rd percentile within the flow distribution (Table 5).

In the Cotter River Catchment, a total of 958 mm of rainfall was recorded at Bendora Reservoir in the six months prior to sampling in spring 2022 which is 1.6 times higher than historical rainfall over the same period, placing it around the 95th percentile compared to the total rainfall distribution. However, autumn 2023, the total rainfall was 498 mm which is similar to historical rainfall over the same period, placing in the 62nd percentile compared to rainfall distribution (ALS Environmental, Site 570958).

A total of 534.4 mm rainfall was recorded in the Queanbeyan River Catchment at site QM1 (Upstream of Googong Reservoir) in the six months prior to sampling in spring 2022 which is approximately 1.7 times higher than the historical average over the same period where the total rainfall was in the 100th percentile. However, in the six months prior to sampling in autumn 2023, the total rainfall was 360.2 mm which was similar (326.14) to historical

average over the same period corresponding to approximately the 70th percentile within the total rainfall distribution (ALS Environmental, Site 570816, Table 6).

In the Goodradigbee Catchment (reference sites), a total of 861.6 mm rainfall was recorded in the six months prior to sampling in spring 2022 which is 1.6 times higher than historical total rainfall corresponding to approximately the 98th percentile within the total rainfall distribution. Whereas, in autumn 2023, a total of 457.2 mm rainfall was recorded in the six months prior to sampling but 1.2 times higher than historical rainfall over the same period with total rainfall corresponding to approximately the 77th percentile within the total rainfall distribution (BOM, station no. 071073, Table 6).

Table 4: Flow regime targets (non-drought) and releases downstream of Corin, Bendora, Cotter and Googong Dams.

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.

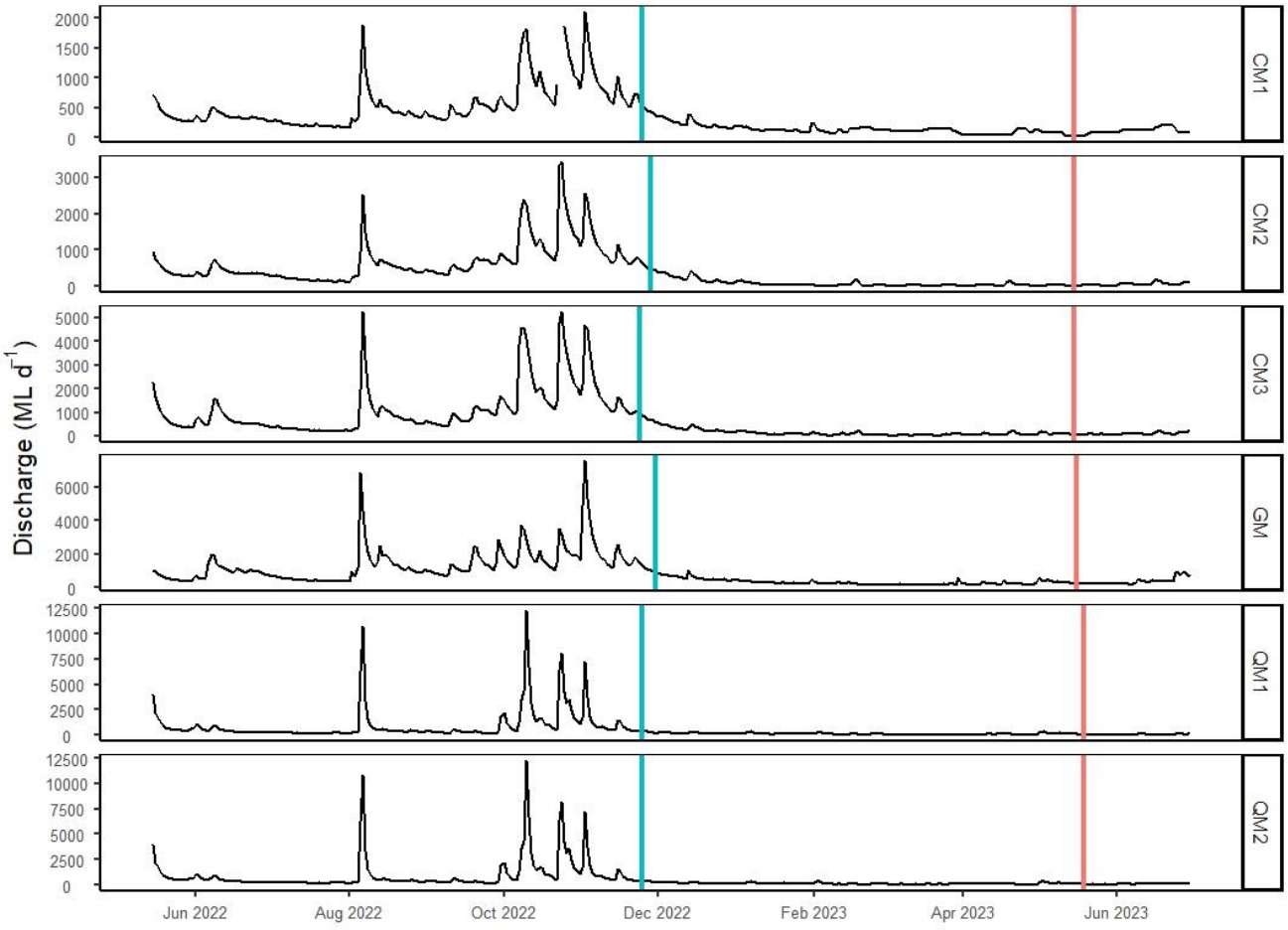


Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from June 2022 to July 2023. NOTE: Blue bar corresponds to spring 2022 sampling and orange bar corresponds to autumn 2023 sampling.

Table 5: Discharge summary for monitoring sites (Data: NSW water and ALS).

Station	Relevant monitoring site/s	Mean flow in six months prior to spring 2022 sampling (ML/Day)	Mean flow in six months prior to autumn 2023 sampling (ML/Day)	Historical mean flow in spring (ML/Day)	Historical mean flow in autumn (ML/Day)	Percentile mean flow in spring 2022 (ML/Day)	Percentile mean flow in autumn 2023 (ML/Day)
Cotter River at D/S Bendorra Dam (Station no. 410747)	CM2, CT2	691.59	131.78	153.28	91.76	100th	83rd
Cotter River at D/S Corin Dam (Station no. 410752)	CM1, CT1	551.89	180.25	174.93	167.76	98th	67th
Cotter River at Kiosk (Station no. 410777)	CM3, CT3	1135.48	213.51	453.44	186.14	94th	78th
Goodradigbee River at Brindabella (Station no. 410729)	GM1, GM2, GM2, GT1, GT2, Gt3	1410.19	410.65	616.72	253.36	98th	87th
Queanbeyan River U/S Googong Dam (Station no. 410781)	QM1	686.44	138.82	168.87	129.97	100th	74th
Queanbeyan River Wickerslack (Station no. 410760)	QM2, QM3	971.06	152.92	254.68	169.38	96th	66th

Table 6: Rainfall summary for monitoring sites (Data: BOM and ALS).

Station	Relevant monitoring site/s	Total rainfall in six months prior to spring 2022 sampling (mm)	Total rainfall in six months prior to autumn 2023 sampling (mm)	Historical total rainfall in spring (mm)	Historical total rainfall in autumn (mm)	Percentile total rainfall in spring 2022 (mm)	Percentile total rainfall in autumn 2023 (mm)
Rainfall at Bendorra Dam (Station no. 570958)	CM1, CM2, CT1, CT2	958	498	581.2	458.4	95th	62nd
Rainfall at Peirces Creek (Station no. 570825)	CM3, CT3	659	400.6	387.82	354.79	100th	68th
Rainfall at Queanbeyan River Wickerslack (Station no. 570983)	QM2, QM3	540	342.6	304.89	305.66	100th	74th
Rainfall at Queanbeyan River U/S Googong Dam (Station no. 570816)	QM1	534.4	360.2	308.99	326.14	100th	70th
Rainfall at Goodradigbee at Brindabella (Station no. 71073)	GM1, GM2, GM3, GT1, GT2, GT3	861.6	457.2	509.98	364.23	98th	77th

WATER QUALITY

The water quality parameters were generally within the guideline levels at the test and reference sites during spring 2022 and autumn 2023, with some exceptions. pH at test site QM3, turbidity at reference site CT3, NOx concentration at test sites QM2 and QM3 and reference site CT3, TN concentration at test sites QM2 and QM3 and TP concentration at test sites QM2 and QM3 were outside guideline levels in spring 2022 (Table 7and Table 8). During spring 2022, the turbidity levels at reference site CT3 were nearly twice as high as the recommended guideline values (Table 7). Similarly, in autumn 2023, the turbidity levels at test site CM1 were approximately four times higher than the guidelines (Table 8). All the test sites, and reference site CT2 had higher concentration of NOx in autumn 2023. TN was above guideline levels in QM2 and QM3 in autumn 2023. In spring 2022, NOx in QM2 and QM3 and TP at QM3 were approximately eight times higher than guideline levels. The pH at the test sites below Googong Dam (QM2 and QM3) was higher than guideline levels in autumn 2023 (Table 7).

Table 7. Water quality parameters measured at each of the test and reference sites in spring 2022. Values outside guideline levels are shaded orange. NOTE: WQ parameters at QM1 and GM1 were not recorded due to sites being inaccessible during sampling.

		Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
		Guideline level									
		NA	<350	6.5-8	>6	<10	NA	<0.13	<0.015	<0.25	<0.02
Below dam test sites	CM1	15.57	22	7.62	8.93	0.5	8.5	<0.002	<0.002	0.1	0.009
	CM2	16.29	22	6.67	9.38	0.6	10	0.004	0.002	0.09	0.008
	CM3	14.78	29	7.20	9.38	3.6	12	<0.002	0.003	0.13	0.01
	QM2	15.29	89	7.20	10.16	2.1	38	0.008	0.128	0.69	0.025
	QM3	15.38	177	8.26	10.57	2.3	67	0.003	0.123	0.62	0.162
Reference sites	CT1	13.8	36	7.07	8.87	0.5	16	0.003	0.002	0.06	0.011
	CT2	15.61	26	6.98	9.13	0	10	<0.002	0.012	0.07	0.005
	CT3	14.61	61	7.23	9.82	19.4	28	0.019	0.033	0.22	0.018
	QM1										
	GM1										
	GM2	14.93	75	7.48	9.57	2.8	40	0.004	0.013	0.06	0.01
	GM3	14	69	7.15	10.03	3.8	36	<0.002	0.005	0.07	0.011
	GT1	15.73	44	7.67	9.27	1.6	20	0.003	<0.002	0.08	0.011
	GT2	12.86	44	7.30	9.86	1.6	20	<0.002	<0.002	0.07	0.012
	GT3	12.89	42	7.33	9.93	8.0	20	0.003	<0.002	0.11	0.016

Table 8: Water quality parameters measured at each of the test and reference sites in autumn 2023. 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	11.34	29	6.99	9.58	39.2	10	0.009	0.023	0.06	0.013
	CM2	10.58	27	7.13	10.28	0.1	13	0.002	0.049	0.08	0.007
	CM3	14.34	34	7.15	9.44	8.1	12	0.004	0.025	0.08	0.006
	QM2	12.98	102	8.48	11.23	4.0	28	0.014	0.08	0.5	0.013
	QM3	10.87	246	8.28	11.05	0.0	86	0.021	0.1	0.38	0.012
Reference sites	CT1	8.89	41	7.12	9.91	5.0	18	0.003	<0.002	<0.05	0.012
	CT2	10.04	29	6.97	10.45	0	9	<0.002	0.051	0.06	0.006
	CT3	11.81	72	7.83	10.75	5.8	29	<0.002	0.009	0.08	0.009
	QM1	6.68	99	7.84	11.56	2.5	37	0.017	0.005	0.23	0.01
	GM1	8.12	90	7.98	11.08	0.8	50	0.008	0.005	<0.05	0.007
	GM2	7.46	87	7.87	11.37	0.1	48	0.003	0.005	<0.05	0.007
	GM3	7.33	83	7.68	11.56	1.5	34	0.002	<0.002	<0.05	0.007
	GT1	6.62	57	7.80	11.39	2.4	28	<0.002	0.005	0.05	0.011
	GT2	6.05	59	7.81	11.4	2.2	32	0.004	<0.002	<0.05	0.007
	GT3	5.79	53	7.84	11.08	6.9	25	<0.002	<0.002	<0.05	0.011

FILAMENTOUS ALGAE AND PERIPHYTON

The environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats was achieved at all below dams test sites in both spring 2022 and autumn 2023 assessments (Table 9). Field observations of periphyton cover of riffle habitats were <20% at all but one site (QM3) in spring 2022. Test sites CM1, CM2, QM2 and QM3 had >20% periphyton cover in autumn 2023 (Table 9).

Ash free dry mass (AFDM) and Chlorophyll-A samples were not collected during spring 2022 due to high river flows in the test sites. Therefore, the sites cannot be evaluated or compared for AFDM concentrations (Figure 5).

In the autumn 2023 assessment, there were differences in the mean ash-free dry mass (AFDM) concentrations observed among the sites ($F_{6,35} = 18.77$, $p = 0.001$). The mean AFDM concentration varied across the sites, with the reference site GM3 exhibiting significantly higher levels compared to the other sites. Specifically, the mean AFDM concentration at GM3 was 7.94 gm/m^2 higher than CM1 ($p < 0.001$), 10.02 gm/m^2 higher than CM2 ($p = 0.0000035$), 14.19 gm/m^2 higher than CM3 ($p < 0.001$), 13.22 gm/m^2 higher than GM1 ($p < 0.001$), 11.50 gm/m^2 higher than GM2 ($p < 0.001$), and 8.18 gm/m^2 higher than QM ($p < 0.001$), (Figure 5).

Furthermore, the test site CM3 exhibited significantly higher AFDM concentration, with levels 6.24 gm/m^2 higher than the test site CM3 ($p < 0.005$) and 5.28 gm/m^2 higher than

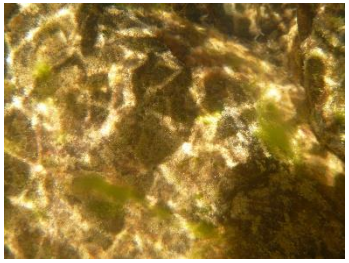
GM1 (p = 0.02). Similarly, the test site QM2 had significantly higher AFDM concentration, with levels 6.01 gm/m^2 higher than CM3 (p = 0.007) and 5.04 gm/m^2 higher than GM1 (p = 0.035). The mean AFDM concentration did not differ between any other sites in autumn 2023 assessment (Figure 5).

There were variations in Mean Chlorophyll-a concentrations across different sites (F6,35 = 8.622, p = 0.001) in autumn 2023 assessment. These variations included a combination of differences observed in both test and reference sites. The test site below Bendora Reservoir (CM2) had significantly higher mean chlorophyll-a concentrations 68.28 µg/m^2 higher than CM3 (p = 0.001), 78.27 µg/m^2 higher than GM1 (p < 0.001) and 74.78 µg/m^2 higher than GM2 (p < 0.001). Similarly, the test site QM2 had significantly higher mean chlorophyll-a concentration, with levels 56.69 µg/m^2 higher than CM3 (p = 0.009), 66.68 µg/m^2 higher than GM1 (p = 0.001) and 63.19 µg/m^2 higher than GM2 (p = 0.002). No significant differences were observed in mean chlorophyll-a concentrations among the other sites (Figure 6).

Table 9: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from spring 2022 to autumn 2023. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange. NA represents sites inaccessible.

% cover of riffle habitat													
	Periphyton							Filamentous algae					
	Aut-20	Spr-20	Aut-21	Spr-21	Spr-22	Aut-23		Aut-20	Spr-20	Aut-21	Spr-21	Spr-22	Aut-23
CM1	<10	<20	<10	NA	<10	40		<10	<10	<10	NA	<10	<10
CM2	<10	<30	30	15	15	40		<10	40	<10	40	<10	<10
CM3	<10	<10	<10	<10	<10	20		<10	<10	<10	<10	<10	<10
QM2	30	<10	20	<10	20	30		40	<10	30	<10	<10	<10
QM3	20	<20	<10	<10	30	40		20	<10	<10	<10	<10	<10
GM1	<10	<10	<10	<10	NA	10		<10	<10	<10	<10	NA	<10
GM2	<10	<20	<10	<10	<10	15		<10	<10	<10	<10	<10	<10
GM3	<10	<30	35	15	<10	20		<10	<10	<10	<10	<10	<10
QM1	<20	<20	<10	<10	NA	10		<20	<10	<10	<10	NA	<10

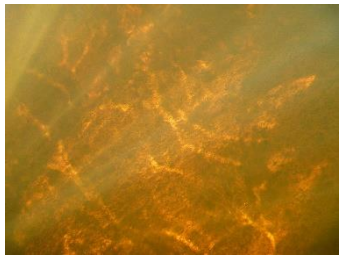
Test sites



Site CM1

Site CM2

Site CM3



Site QM2

Site QM3

Reference sites

SITE INACCESSIBLE DURING SAMPLING

Site GM1

Site GM2

Site GM3

SITE INACCESSIBLE DURING SAMPLING

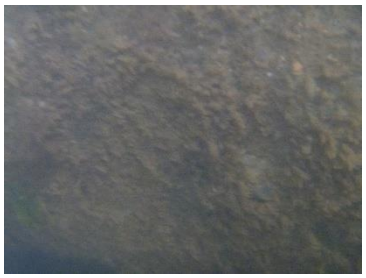
Site QM1

SITE INACCESSIBLE DURING SAMPLING

Site QM1

Figure 3. Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Cotter, Goodradigbee and Queanbeyan Rivers in spring 2022.

Test sites

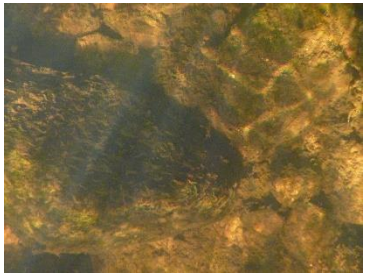


Site CM1

Site CM2

Site CM3

Site QM2



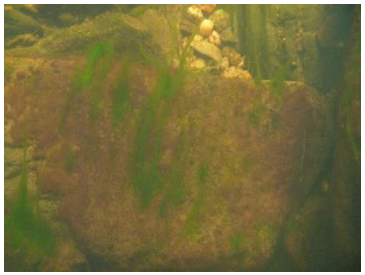
Site QM3

Reference sites

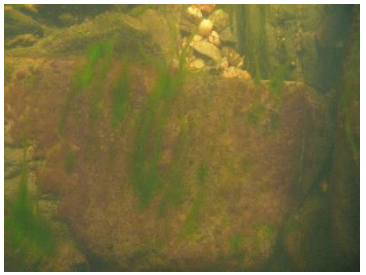
Site GM1

Site GM2

Site GM3



Site QM1



Site QM1

Figure 4: Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Cotter, Goodradigbee and Queanbeyan Rivers in autumn 2023.

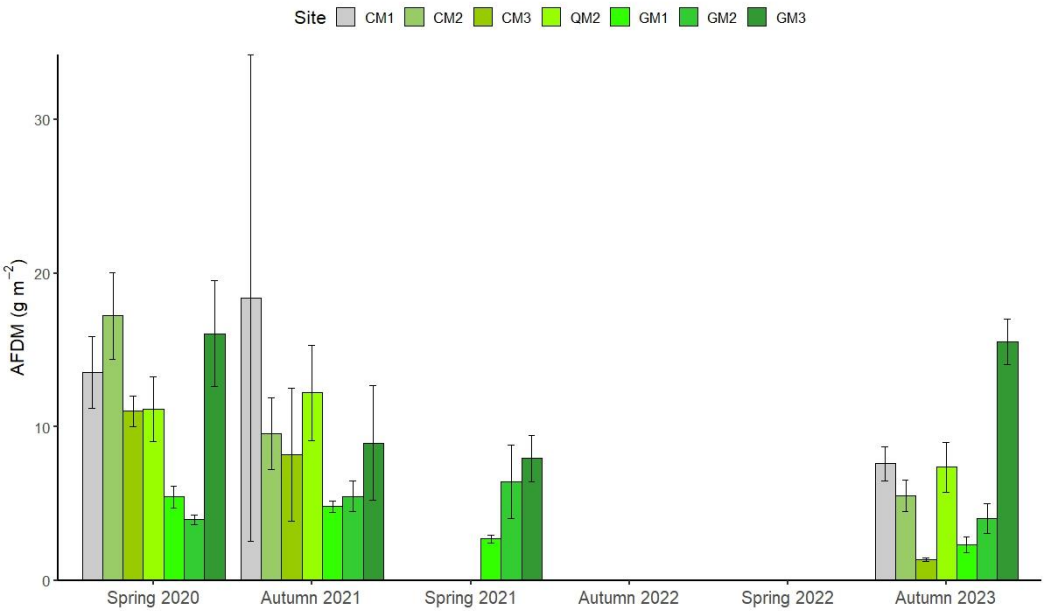


Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2020 to autumn 2023. Error bars represent +/- 1 standard error. **NOTE**: AFDM samples were not collected in autumn 2022 and spring 2022 due to high flow during sampling period.

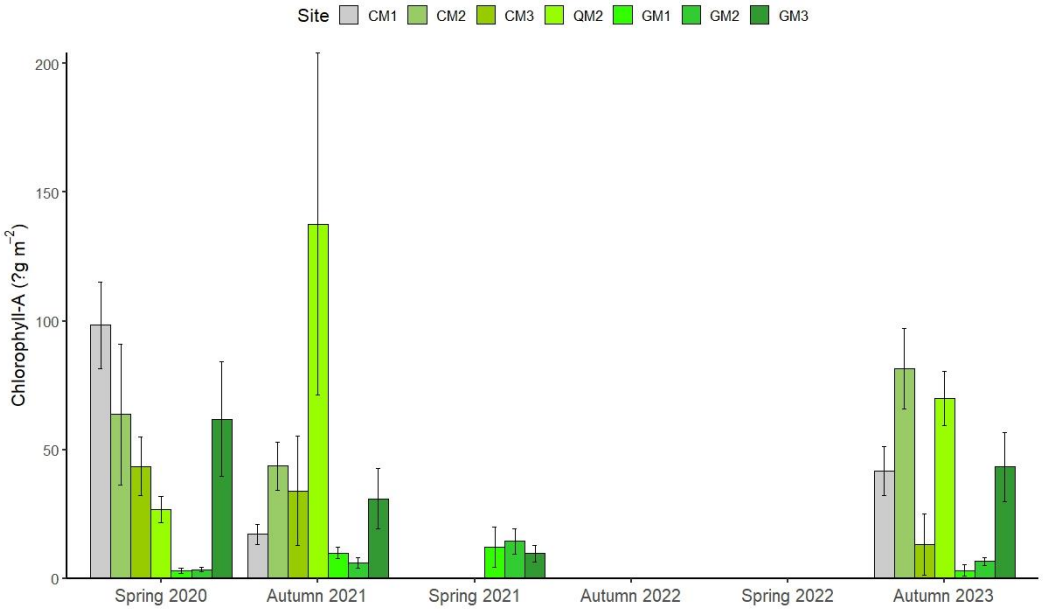


Figure 6: Mean Chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2019 to autumn 2023. Error bars represent +/- 1 standard error. **NOTE:** Chlorophyll-a samples were not collected in autumn 2022 and spring 2022 due to high flow during sampling season.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Macroinvertebrate samples were not collected during autumn 2022 and spring 2022 from both the reference and test sites due to the higher flow observed during the sampling period, which prevented the collection of macroinvertebrate samples (Table 10). Additionally, only a limited number of reference sites were sampled during spring 2021 due to the same reason. As a result, the biological condition of the sites cannot be compared with the autumn 2023 assessment. The absence of macroinvertebrate data from these periods hinders the ability to make meaningful comparisons and draw conclusions regarding the overall trend in biological condition of the sites.

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in autumn 2023. However, the test site below Bendora Reservoir (CM2) was assessed as being similar to reference site with band A.

Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in autumn 2023 (Table 10). Test site CM1 remained in band B for the past five assessments (excluding non-sampled sites) and has had a relatively stable O/E score of between 0.72 – 0.85 since autumn 2019 (Table 10). The dominant taxa at this site for autumn 2023 was Gripopterygidae (Appendix 2). The taxa Simuliidae and Glossosomatidae which were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model were detected in the whole sample scan (Table 11) but not in the subsample that was processed, suggesting those taxa were present, but in relatively low abundances at this site in autumn 2023.

Condition of the Cotter River below Bendora Dam (CM2) was assessed as band A (similar to reference) in the autumn 2023 assessment, as it was for its pervious autumn assessment in 2021(Table 10). This site has improved in condition since receiving a band B in spring 2020 (Table 10). The taxa Gripopterygidae dominated the macroinvertebrate community at CM2 in autumn 2023 (Appendix 2). None of the taxa were detected which were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model in the whole sample scan, suggesting very low abundances at this site in autumn 2023.

The condition of the Cotter River below Cotter Dam (CM3) was assessed as band B (significantly impaired) in the autumn 2023 assessment, an improvement from autumn 2019 (band C) but decreased in biological condition compared to spring 2019 and autumn 2020 from being assessed as band A (similar to reference). The site has generally improved in condition since being assessed as band C in autumn 2019, with O/E scores now ranging between 0.67 – 0.97 since autumn 2019 (Table 10). The site has been dominated by Chironominae in the autumn 2023 assessment (Appendix 2). None of the taxa were detected which were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model in the whole sample scan, suggesting very low abundances at this site in autumn 2023.

The test site QM2 was assessed as severely impaired (band C) in autumn 2023, receiving it's lowest O/E score for some time (Table 10). This continues a trend at this site for autumn assessment to result in band C classification over the past 4 years. The biological condition of the site has decreased from being assessed band A (similar to reference) in spring 2019 and 2020 and band B (significantly impaired) in autumn 2021 (Table 10). The site has been dominated by Simuliidae in the autumn 2023 assessment (Appendix 2). The site has O/E score ranging between 0.49 – 0.88 since autumn 2019 (Table 10). Taxa Hydrobiosidae which was predicted to have a ≥50% chance of occurrence by the AUSRIVAS model were detected in the whole sample scan (Table 11) but not in the subsample that was processed, suggesting those taxa were present, but in relatively low abundances at this site in autumn 2023.

The below Googong Dam test site (QM3) was assessed as band B (significantly impaired) in autumn 2023. The site remained in band B from autumn 2019 except for autumn 2021 which was assessed as band C (severely impaired) and has had a very stable O/E score of between 0.56 – 0.84 since autumn 2019 (Table 10). The site has been dominated by Simuliidae in the autumn 2023 assessment (Appendix 2). None of the taxa were detected which were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model in the whole sample scan, suggesting very low abundances at this site in autumn 2023.

The biological condition of the reference sites was assessed as band A (similar to reference) except for site GM1 (20 m upstream of confluence with Cooleman Creek) which was assessed as band B (significantly impaired) in autumn 2023 (Table 10). In general, the biological conditions of all the reference sites remained consistent, transitioning from being assessed as band X (More biologically diverse than the reference) to band B (significantly impaired), except for site CT3 (Paddys River above Cotter River confluence), which was assessed as band C (severely impaired) in autumn 2021 assessment (Table 10). The macroinvertebrate community at reference sites CT1, CT2, GM3, GM1 and GT3 was dominated by Gripopterygidae. Similarly, at reference sites GM1, GM2, and QM1, the macroinvertebrate community was dominated by Leptophlebiidae and at reference site GT2, Baetidae was the dominant taxa. However, the macroinvertebrate community at reference site CT3 was dominated by Simuliidae which is considered as early coloniser in aquatic ecosystems (Appendix 2). Taxa Psephenidae at site CT2, Gomphidae at site GM1, Elmidae at site GM2, Psephenidae, Tipulidae, Tanypodinae and Coloburiscidae at site GT2, Simuliidae at site GT3 and Hydropsychidae at site QM1 which were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model were detected in the whole sample scan (Table 11) but not in the subsample that was processed, suggesting those taxa were present, but in relatively low abundances at reference sites in autumn 2023.

Table 10: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2019 to autumn 2023. NOTE: N/A represents absence of data due to inaccessible sites.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Autumn 2023	**B** (0.72)	**A** (0.91)	**B** (0.74)	C (0.49)	B (0.69)	**A** (0.93)	**A** (0.96)	A (0.90)	A (0962)	B (0.85)	**A** (0.89)	**A** (1.04)	**A** (1.01)	**A** (0.99)	**A** (1.05)
Spring 2022	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Autumn 2022	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Spring 2021	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**A** (0.96)	**N/A**	**N/A**	**N/A**	**A** (1.12)	**A** (1.11)	**A** (1.12)	**A** (1.13)	**A** (1.13)	**A** (0.90)
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)

Table 11: Macroinvertebrate taxa that were expected with a ≥ 50% chance of occurrence by the AUSRIVAS ACT autumn riffle model but were missing from sub-samples for each of the study sites in autumn 2023 (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 Autumn 2023																		
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								
Ancylidae	4				X													
Oligochaeta	2									X								
Scirtidae	6	X																
Elmidae	7		X		X	X					X							
Psephenidae	6	X	X	X			X	X					X	X				
Tipulidae	5													X				
Simuliidae	5	X					X			X			X		X			
Podonominae	6		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	X												
Caenidae	4							X			X		X					
Gomphidae	5			X	X	X			X	X	X	X			X	X		
Hydrobiosidae	8				X	X												
Glossosomatidae	9	X																
Hydroptilidae	4			X	X		X		X	X		X			X			
Hydropsychidae	6				X			X								X		
Conoesucidae	7			X														
Leptoceridae	6	X	X		X	X			X									
Total taxa		8	6	7	11	7	4	4	5	5	4	3	3	4	3	3		

TAXONOMIC RELATIVE ABUNDANCE

The ratio between environmentally tolerant Oligochaeta and Chironomidae (OC) taxa and sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was variable across all sites (Figure 7, Figure 8, Figure 9) for both spring 2022 and autumn 2023 assessments. However, macroinvertebrate samples were only collected from a few reference sites due to higher river flow during the sampling period. Environmentally sensitive taxa were dominant (> 50%) at all the reference sites that were sampled. In autumn 2023, test sites CM3, QM2 and QM3 and reference site CT3 were dominated by tolerant OC taxa (> 50%). Conversely, test sites CM1 and CM2 and all reference sites (except CT3) were dominated by environmentally sensitive (EPT) taxa (>50%) (Figure 7). In general, reference sites had a higher composition of environmentally sensitive taxa in autumn 2023. However, there was a major shift in the macroinvertebrate community in autumn 2023 where tolerant OC taxa were (~70%) higher than environmentally sensitive taxa (EPT) mainly driven by Oligochaeta and Simuliidae (Figure 7).

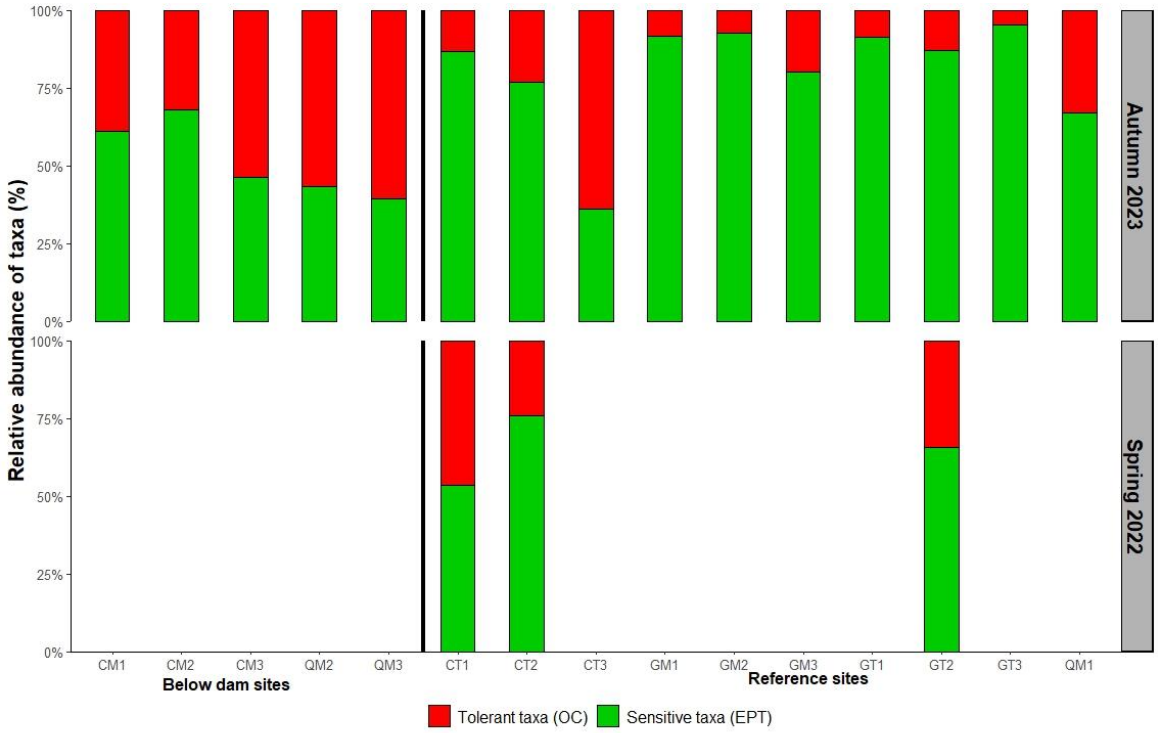


Figure 7. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in spring 2022 and autumn 2023. Note: The sites without a bar graph indicates unavailability of data due to high flow.

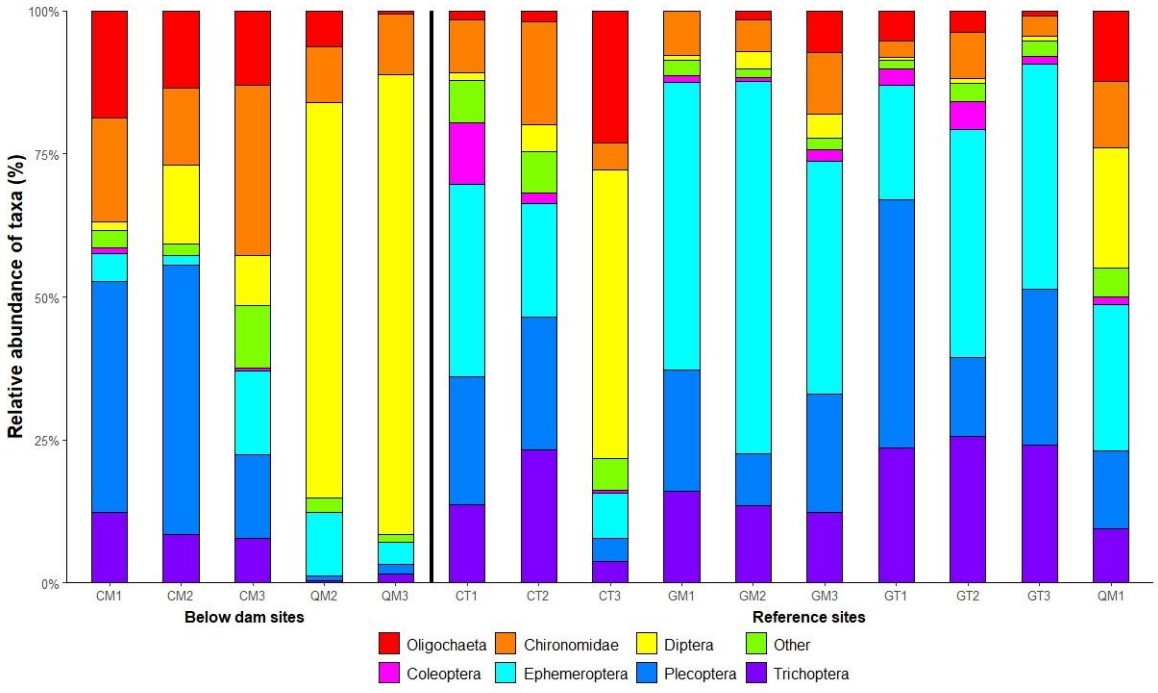


Figure 8: Relative abundance of macroinvertebrate taxonomic groups from samples collected in autumn 2023.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Macroinvertebrate communities of test sites were largely dissimilar to that of reference sites in autumn 2023 (Figure 9). Differences in macroinvertebrate assemblage between test and reference sites were driven by higher abundances of environmentally sensitive Coloburiscidae, Glossosomatidae and Leptoceridae at reference sites and environmentally tolerant Caenidae, Simuliidae, Orthocladiinae and Hydroptilidae in test sites (Figure 9).

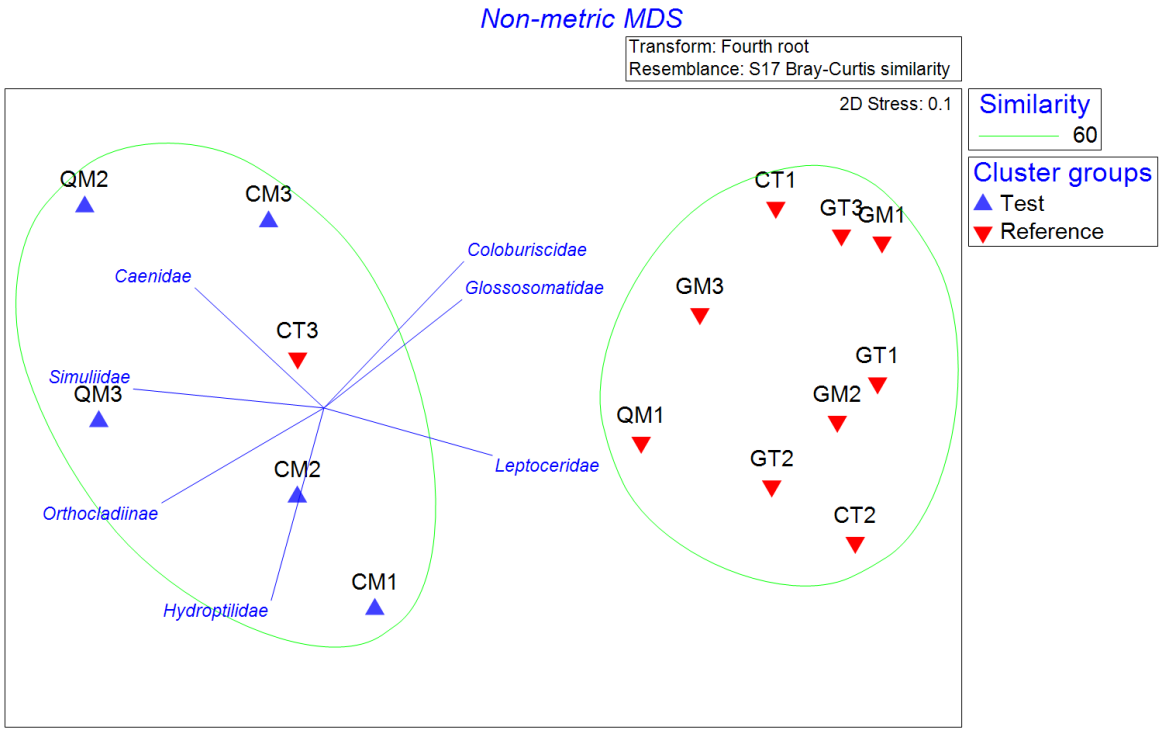


Figure 9. MDS ordination of 60% similarity between macroinvertebrate samples collected in autumn 2023 for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.60 (i.e. taxa that 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

During both spring 2022 and autumn 2023, the water quality parameters at the test and reference sites generally remained within the guideline levels. A notable exception was nutrients parameters, which were above guideline levels at below Googong Reservoir sites in spring 2022 and at all test sites (NOx) in autumn 2023.

The higher levels of Total Nitrogen (TN) and Total Phosphorus (TP) detected may be attributed to elevated rainfall that occurred prior to the sampling event. Heavy rainfall events can contribute to increased runoff, leading to the transport of nutrients from the surrounding landscape into water bodies (Rattan et al., 2017). 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) due to flow events in the months leading to sampling.

The increased nutrient concentrations observed at QM2, QM3, and CT3 during the spring 2022 assessment could potentially be attributed to rainfall runoff entering the stream before sampling. This is especially relevant considering that the Paddys River Catchment primarily consists of forestry and agricultural land, which may have contributed to higher nutrient levels in the water (Weijters et al., 2009).

The turbidity levels observed at test site CM1 for the autumn 2023 were approximately four times higher than the recommended guideline values. Elevated turbidity level can be directly attributed to approved construction activities taking place directly downstream of Corin Dam, resulting in a significant influx of suspended sediment into the river. The increased turbidity levels during autumn 2023 were not related to the operation of Corin Dam.

In autumn 2023, high concentrations of nitrogen oxides (NOx) were detected at four out of five test sites, exceeding the recommended guideline levels. Furthermore, two out of five test sites exhibited total nitrogen levels that surpassed the guidelines. The elevated NOx concentrations observed below reservoirs may be attributed to elevated nitrogen levels and the occurrence of denitrification processes within the reservoirs. Importantly, the high concentrations observed in autumn 2023 are unlikely to be influenced by the environmental flow regime (Saunders & Kalff, 2001).

FILAMENTOUS ALGAE AND PERIPHYTON

The coverage of filamentous algae in riffle habitats was considerably lower than the ecological objective of <20% cover at all sites during both spring 2022 and autumn 2023 (refer to Table 7). The findings confirm previous assessments and suggest that natural flows have effectively controlled the accumulation of filamentous algae downstream of dams.

The autumn 2023 assessment revealed several notable disparities in both ash free dry mass and chlorophyll-a concentrations across different sites. These variations were observed

regardless of whether the sites were independent of site category (test or reference) (Figure 5, Figure 6). This suggests that the differences in ash free dry mass and chlorophyll-a concentrations were not directly associated with the site classification and therefore dam operations. While there were significant differences in ash-free dry mass and chlorophyll-a concentrations between sites in autumn 2023, the concentrations were within the range of those measured in recent sampling. This suggests that the observed variations are part of the natural variability. Further research and monitoring will be necessary to investigate the underlying factors driving these variations and their ecological implications.

Concentration of AFDM at reference site (GM3 at Brindabella Valley above Brindabella Road Crossing) was significantly higher. The high concentration of AFDM suggests the potential for nutrient-rich sediments or biomass accumulation in the area due to natural factors such as decaying of plant materials (leaves and algae) and agricultural practices (grazing) in the Brindabella Valley.

BENTHIC MACROINVERTEBRATES

Macroinvertebrate samples were not collected during spring 2022 from both the reference and test sites due to the higher flow observed during the sampling period. (Table 10). As a result, the biological condition of the sites cannot be compared with the autumn 2023 assessment. The absence of macroinvertebrate data from these periods hinders the ability to make meaningful comparisons and draw conclusions regarding the overall biological condition of the sites.

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in autumn 2023. However, the test site below Bendora Reservoir (CM2) was assessed as being similar to reference with band A. The stable flow experienced at the site in the six months before sampling might have played a significant role in enabling the recolonization of macroinvertebrates after big flow events in the previous year, especially at reference sites. It is hyopthesised that maximum diversity of ecological communities is believed to be achieved through an intermediate disturbance regime. This regime strikes a balance between the ability of species to colonize (early colonizers) and the competitive ability of species that thrive under stable conditions (Lancaster, 1990).

Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in autumn 2023 (Table 10). Test site CM1 remained in band B for the past five assessments (excluding non-sampled sites) and has had a very stable O/E score of between 0.72 – 0.85 since autumn 2019 (Table 10). Both early environmentally sensitive taxa and environmentally tolerant taxa have been observed at the site. This indicates that the ecosystem supports a wide range of organisms with varying levels of sensitivity to environmental conditions. The construction works at the base of the dam in autumn 2023 may have had some effect on the river, potentially leading to impacts on water quality. These impacts, in turn, could have contributed to the impaired biological condition observed (band B) at the site. Further research and investigation are necessary to fully comprehend the extent and significance of these effects and implement appropriate

measures to restore and preserve the ecological health of the river ecosystem (Connell, 1978).

The Cotter River test site below Cotter Reservoir (CM3) remained significantly impaired during autumn 2023 (as it was for the past two assessments). Biological condition at this site has fluctuated over the past 4 years from band C to band A. The two best assessments were consecutive between spring 2019 and autumn 2020, when river levels were relatively stable (no large hydrologic disturbances). Since spring 2020 this site has endured regular hydrological disturbances, likely impacting on the macroinvetebrate community. Apart from a small disturbance event two weeks prior to sampling, stable river levels were dominant, and thus we saw an increase in O/E score, but not enough to elevate this site to band A. It appears as though a lack of longitudinal riverine connectivity upstream and long term reduction in community resilience is hampering recovery of this site when disturbances are more frequency.

Macroinvertebrate communities at the site immediately downstream of Googong Dam (QM2) has been assessed as band C (Severely impaired) in autumn 2023. Autumn is generally dominated by lower discharges and stable water levels following a dry and warm summer period in the region, with any rainfall events being captured by reservoirs operating at below full supply levels. A moderate disturbance event passed through this site approximately two weeks prior to sampling in autumn 2023, which may have impacted on the macroinvertebrate community. In previous years, relatively stable water levels with a moderate disturbance event approximately 4 weeks prior to sampling has yielded the best biological conditions in terms of macroinvertebrate community composition. Additionally, water levels keep too stable at this site (e.g. summer – autumn 2019 and also 2020) resulted in a simplified macroinvertebrate community, where a small number of taxa dominate the community, and a poor biological condition.

The biological condition of the reference sites were assessed as band A (similar to reference) except for site GM1 (20 m upstream of confluence with Cooleman Creek) which was assessed as band B (significantly impaired) in autumn 2023 (Table 10). In general, the biological conditions of all the reference sites remained consistent, transitioning from being assessed as band X (More biologically diverse than the reference) to band B (significantly impaired), except for site CT3 (Paddys River above Cotter River confluence), which was assessed as band C (severely impaired) in autumn 2021 assessment (Table 10).

The general difference in biological condition between the reference sites and test sites in autumn 2023, following a very wet spring 2022, may be attributed to reference site macroinvertebrate communities being more resilient to disturbance (more diverse prior to disturbance, better quality refuge habitat), and also having greater capacity to recover following a disturbance (better quality habitat, longitudinal connectivity to facilitate colonization following disturbance). Generally, test sites are performing best when sites have small to moderate disturbance events relatively frequently (1 – 2 months) and sampling is conducted > 2 weeks following an event.

CONCLUSION

The water quality parameters at the below dam test sites were largely within the guideline levels during the spring of 2022 and autumn of 2023. 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 2022 and autumn 2023. This indicates that efforts to maintain and manage water quality have been effective, ensuring the preservation and sustainability of these vital aquatic ecosystems. In the autumn of 2023 assessment, only one test site (CM2) was assessed as band A. The remaining test sites, CM1, CM3, and QM3, were assessed as band B. The test site QM2, on the other hand, was classified as band C. In contrast, the reference sites were predominantly assessed as band A in autumn 2023. Disturbance regime is likely playing a key role in driving biological condition at the time of sampling, with test sites much more susceptible and taking longer to recover from disturbance events. The decrease in flows at all the test sites in autumn 2023 had provided an opportunity to collect macroinvertebrate samples. The collection and analysis of macroinvertebrate samples provided valuable insights into the recolonizing capabilities of macroinvertebrates after higher flow and flood events.

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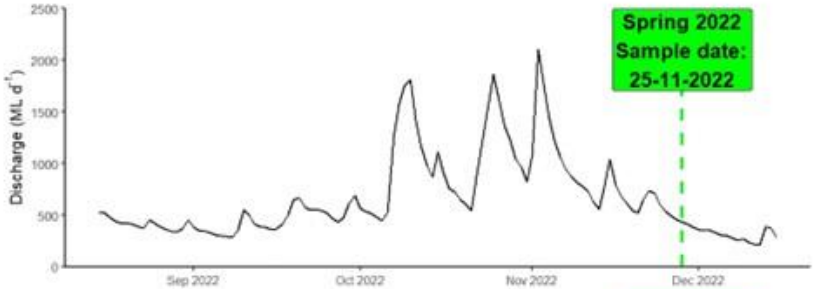
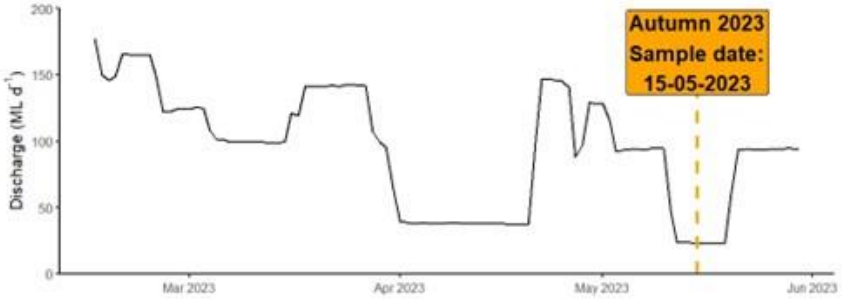
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

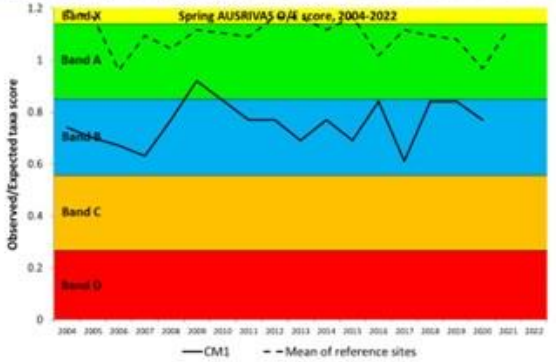
CM1 - Spring 2022 - Autumn 2023

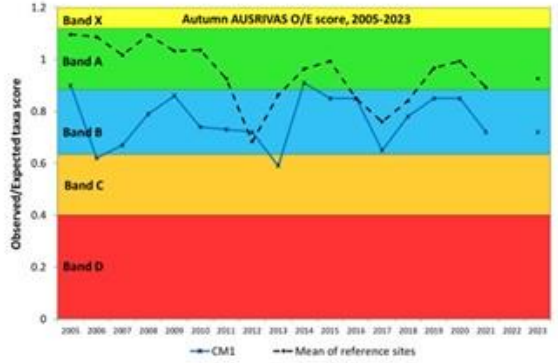
Downstream of Corin Dam

Environmental flow ecological objective	Spring 2022	Autumn 2023	Objective met?
AUSRIVAS band A	Not assessed	Band B	Not in autumn 2023
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons









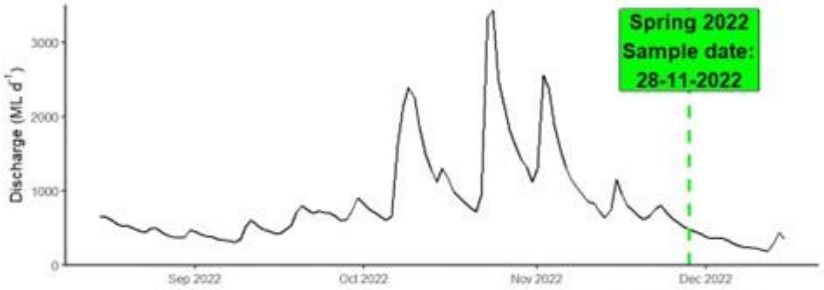
* Denotes values outside guideline levels

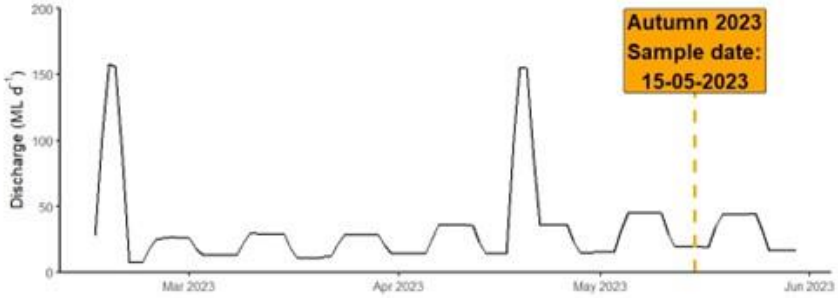
Sampling season	Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_4^+ (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
Spring 2022	15.57	22	7.62	8.93	0.5	8.5	<0.002	<0.002	0.1	0.009
Autumn 2023	11.34	29	6.99	9.58	39.2*	10	0.009	0.023*	0.06	0.013

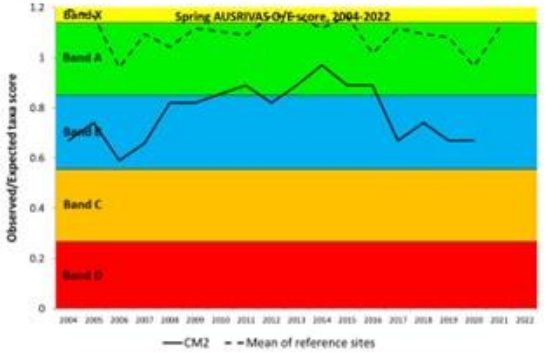
CM2 - Spring 2022 - Autumn 2023

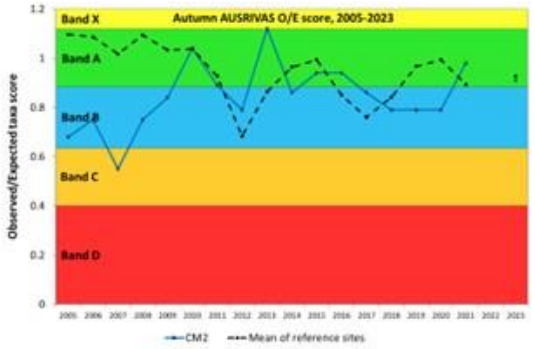
Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2022	Autumn 2023	Objective met?
AUSRIVAS band A	Not assessed	Band A	Yes in autumn 2023
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons









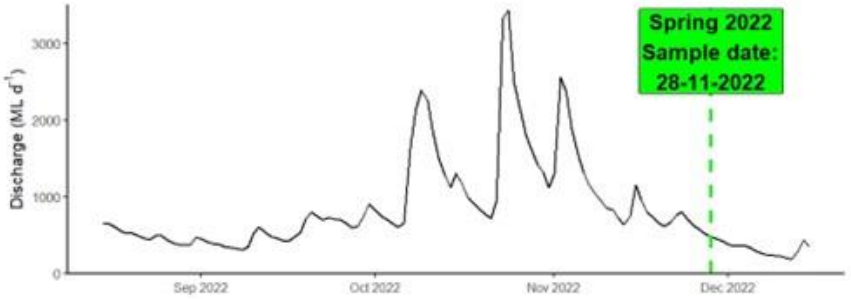
* Denotes values outside guideline levels

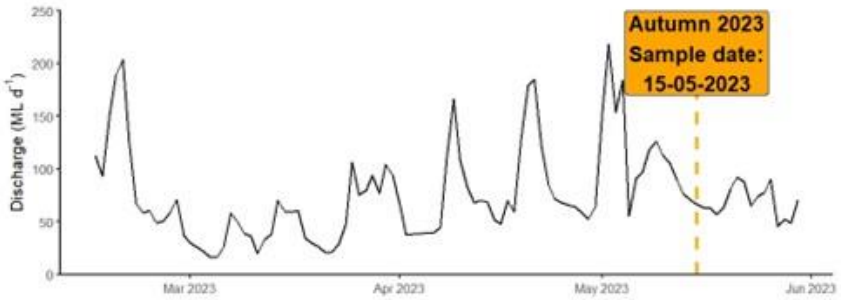
Sampling season	Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_4^+ (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
Spring 2022	16.29	22	6.67	9.38	0.6	10	0.004	0.002	0.09	0.008
Autumn 2023	10.58	27	7.13	10.28	0.1	13	0.002	0.049*	0.08	0.007

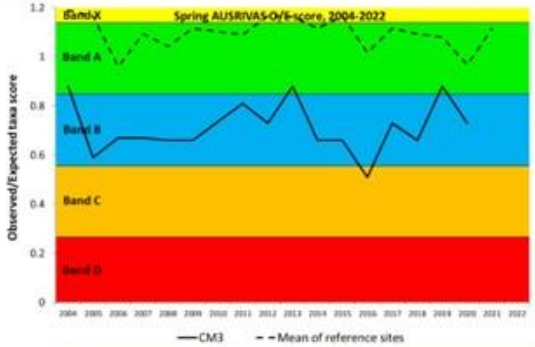
CM3 - Spring 2022 - Autumn 2023

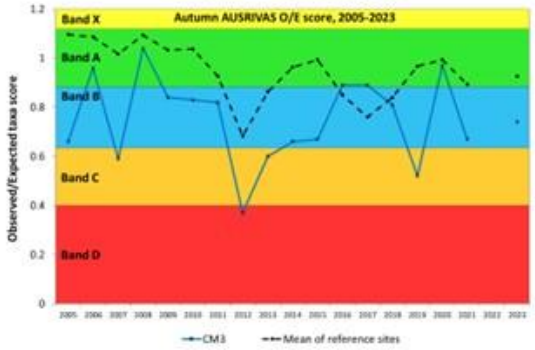
Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2022	Autumn 2023	Objective met?
AUSRIVAS band A	Not assessed	Band B	Not in autumn 2023
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons









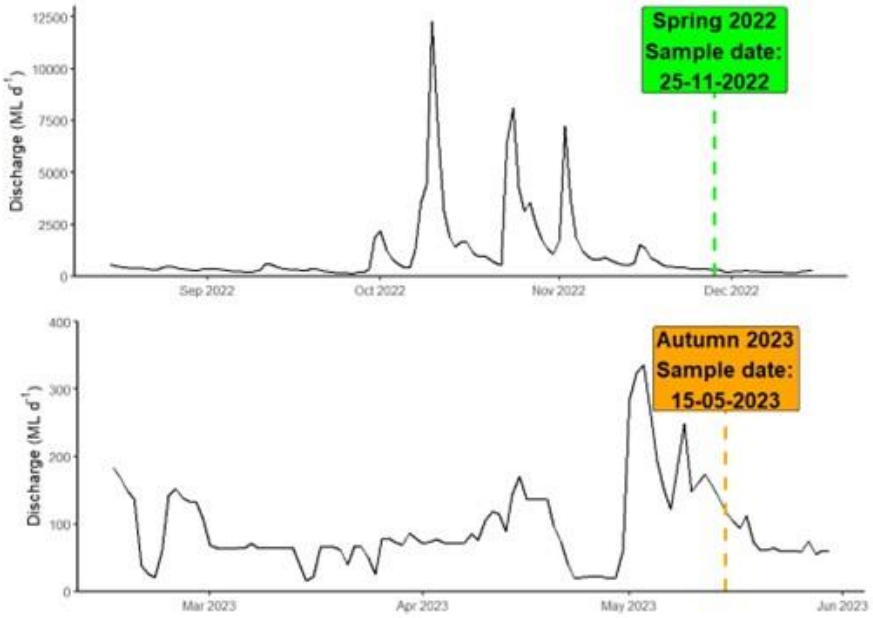
* Denotes values outside guideline levels

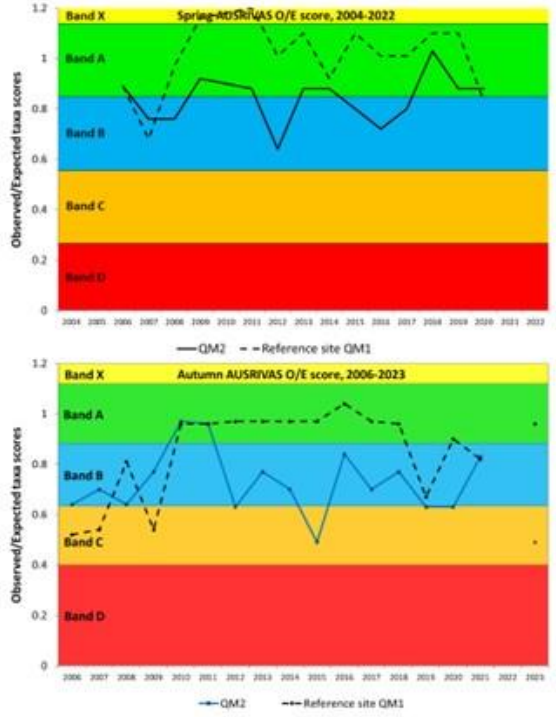
Sampling season	Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+ (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
Spring 2022	14.78	29	7.20	9.38	3.6	12	<0.002	0.003	0.13	0.01
Autumn 2023	14.34	34	7.15	9.44	8.1	12	0.004	0.025*	0.08	0.006

QM2 - Spring 2022 - Autumn 2023

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2022	Autumn 2023	Objective met?
AUSRIVAS band A	Not assessed	Band C	Not in autumn 2023
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes in both seasons





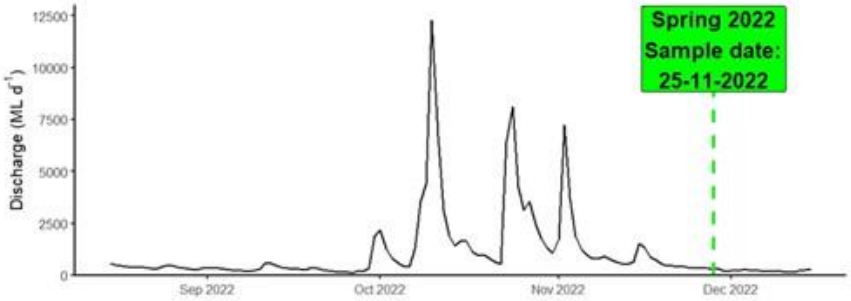
* Denotes values outside guideline levels

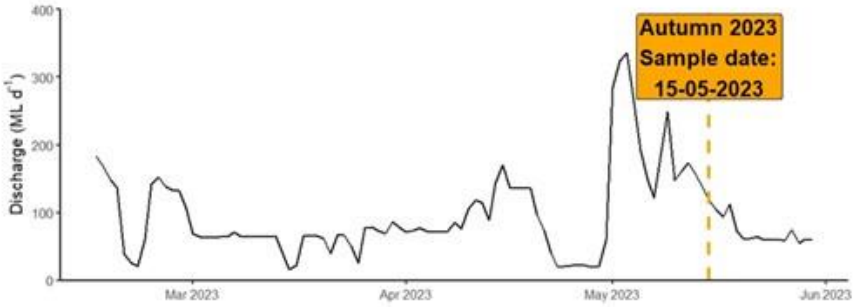
Sampling season	Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+ (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
Spring 2022	15.29	89	7.20	10.16	2.1	38	0.008	0.128*	0.69*	0.025*
Autumn 2023	12.98	102	8.48	11.23	4.0	28	0.014	0.08*	0.5*	0.013

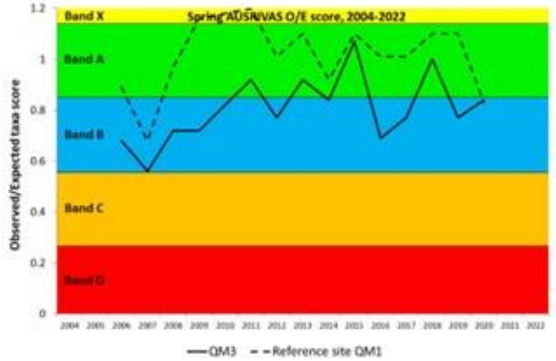
QM3 - Spring 2022 - Autumn 2023

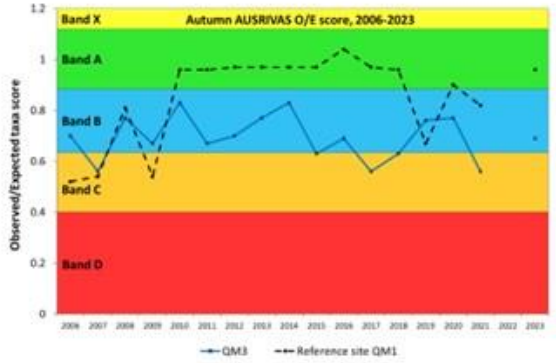
2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2022	Autumn 2023	Objective met?
AUSRIVAS band A	Not assessed	Band B	Not in autumn 2023
<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 2022	15.38	177	8.26*	10.57	2.3	67	0.003	0.123*	0.62*	0.162*
Autumn 2023	10.87	246	8.28	11.05	0.0	86	0.021	0.1	0.38*	0.012

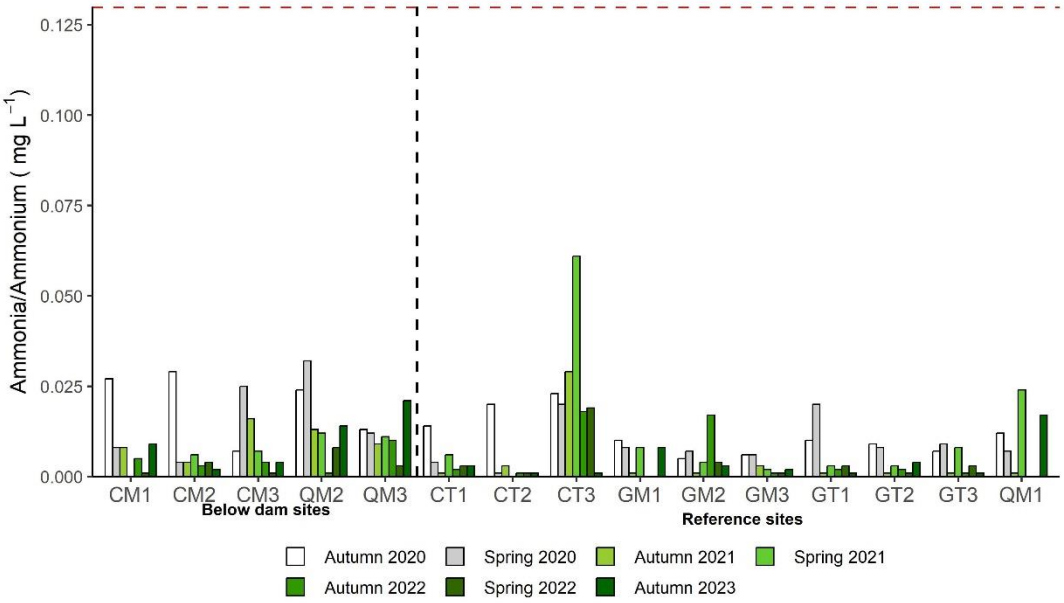
APPENDIX 2: MACROINVERTEBRATE TAXA AUTUMN 2023

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2023 at each of the study sites. **NOTE:** Blue highlight indicates maximum taxa of the site for the sampling season.

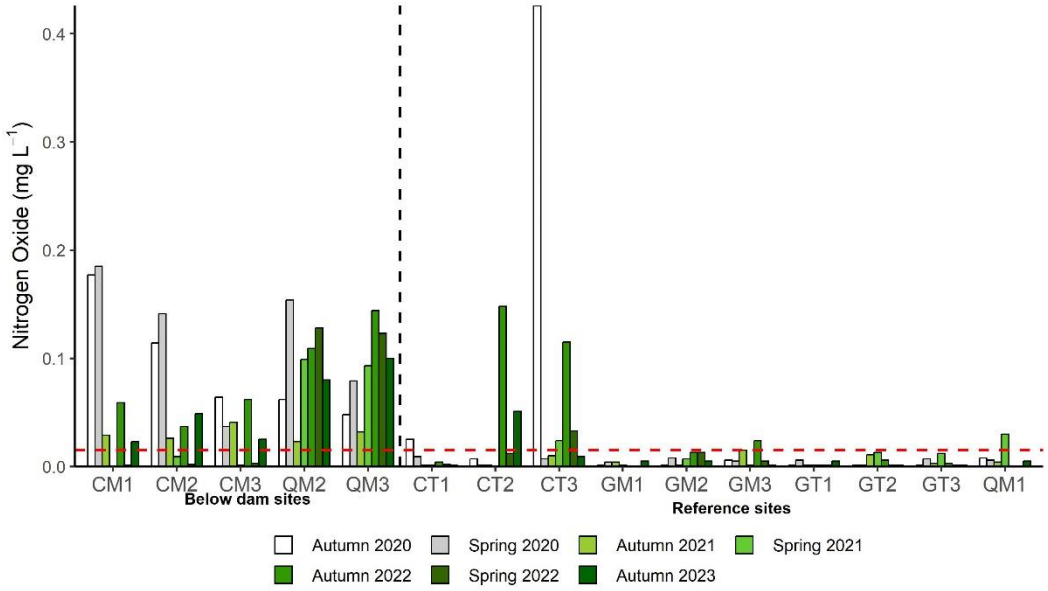
CLASS Order Family *Sub-family*	Signal 2 Grade	Test sites					Reference sites									
		CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	GM1	GM2	GM3	GT1	GT2	GT3	QM1
Gastropoda																
Planorbidae	4						11						1			
Ancylidae	4	1				2		11	8	3						1
Tricladidae																
Dugesiidae	2		2	10				1						1		
OLIGOCHAETA	2	38	40	25	15	2	3	4	50		5	14	13	9	2	29
ACARINA	6	5	4	11	5	2	4	3	4	3	5	4	3	6	5	11
Coleoptera																
Scirtidae Sp.	6						4	2			2		4	9		
Elmidae	7	1		1				2		1			1		1	
Elmidae (Larvae)	7						18		1			3	1	3	1	2
Hydrochidae	4	1											1			
Psephenidae	6									2		1			1	1
Diptera																
Diamesinae	6							6								
Tanyderidae	6														1	
Tipulidae	5	1	4	1	1	3	2	1	1	1			1		1	3
Ceratopogonidae	4															1
Simuliidae	5		34	16	166	264		3	107		10	7		1		45
Athericidae	8									1						
Empididae	5	2	3		1	1	1		1			1		1		
Aphroteniinae	8						2	1		1				1		
Podonominae	6						1	2	1						2	
Tanypodinae	4							1		5	1	2	1		2	2
Orthocladiinae	4	37	11	24	21	34	8	25	7	1	6	10	2	1	1	16
Chironominae	3		29	33	3	1	8	9	2	11	11	9	4	18	3	9
Ephemeroptera																
Baetidae	5	6	2	22	20	4	18	2	7	45	14	24	21	52	21	8
Coloburiscidae	8						12		1	15	5	9	1		9	
Leptophlebiidae	8	1					35	40	1	51	194	37	27	41	53	49
Caenidae	4	3	3	6	7	9	4		8	5		9		5	7	3
Megaloptera																
Corydalidae	7				1										1	
Odonata																
Telephlebiidae	9													1		
Plecoptera																
Gripopterygidae	8	82	140	28	2	6	46	49	9	49	30	40	107	34	62	32
Trichoptera																
Hydrobiosidae	8	1	1	1			1	2	2	1	1	1	2	1	1	4
Glossosomatidae	9						8	1		3	2	9	1	2	5	2
Hydroptilidae	8	13	8			1		2			1		1	4		2
Philopotamidae	8							2			1	1	1	1		6
Hydropsychidae	6	3	8	3		4	3		6	3	2	1	2	8	2	
Ecnomidae	4			11	1											
Calocidae	9						1						1			
Conoesucidae	8	8	6				13	25		12	6	8	9	2	33	6
Calamoceratidae	7		2					1		2						
Tasimiidae	8						1							1		1
Leptoceridae	6						1	16		16	31	4	41	44	14	1
No. of individuals		203	297	192	243	333	205	211	216	231	327	194	246	246	228	234
No. of taxa		16	16	14	12	13	23	24	17	21	18	20	23	23	22	22
% of sub-sample		2	1	5	2	1	2	3	2	2	2	5	2	2	2	3
Whole sample estimate		10150	29700	3840	12150	33300	10250	7033	10800	11550	16350	3880	12300	12300	11400	7800

APPENDIX 3: WATER QUALITY FIGURES

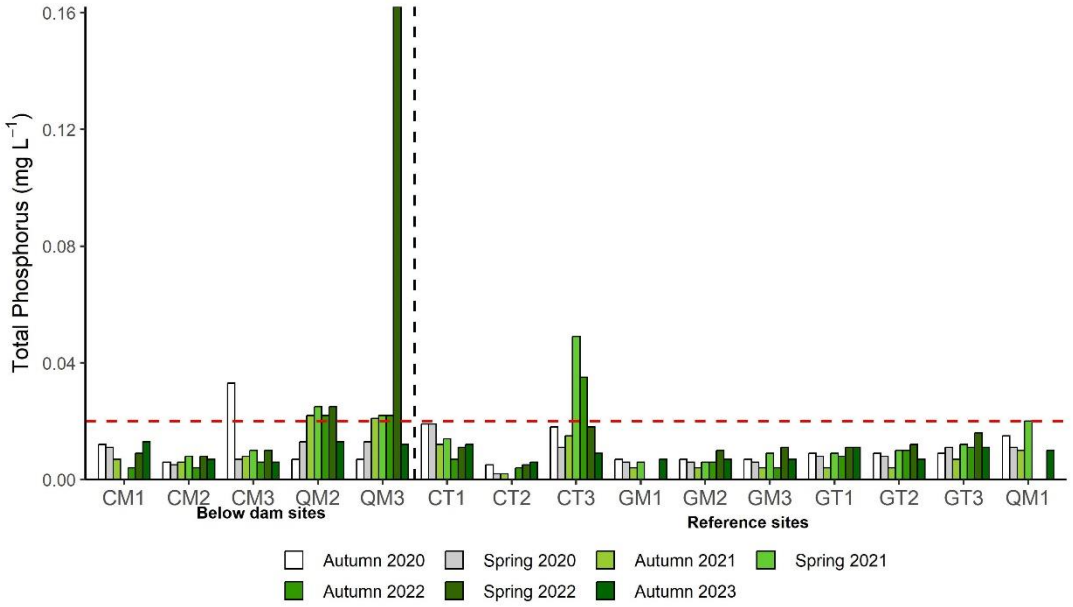
(Note: There was no flow during sampling and water samples could not be collected at site CT2 (Burkes Creek at above Pipeline Crossing).



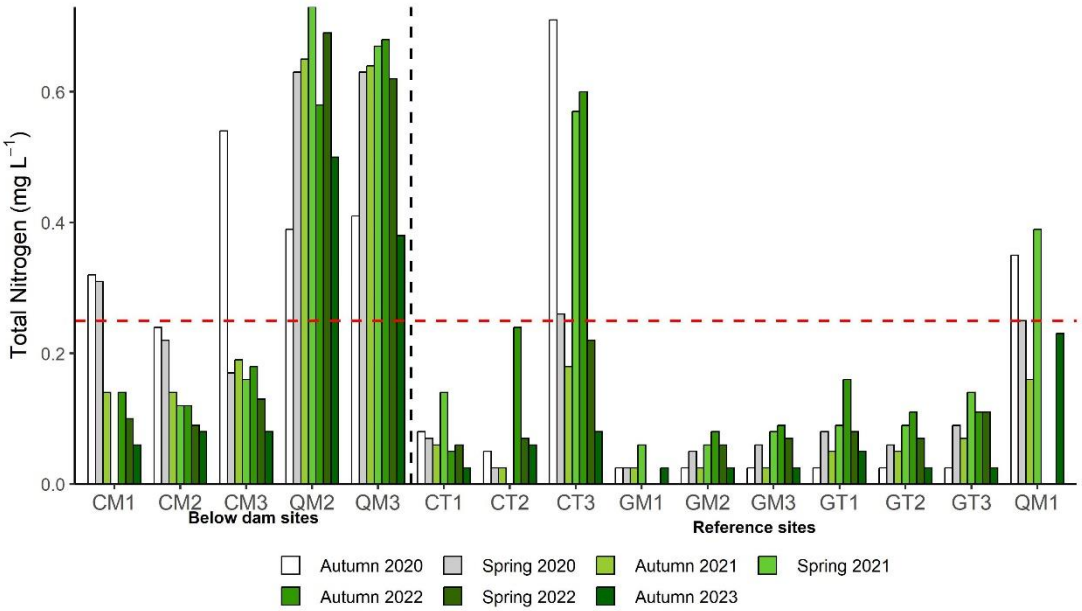
Ammonium (NH_4^+) concentration at all sites from autumn 2020 to autumn 2023. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is dashed line and shaded red.



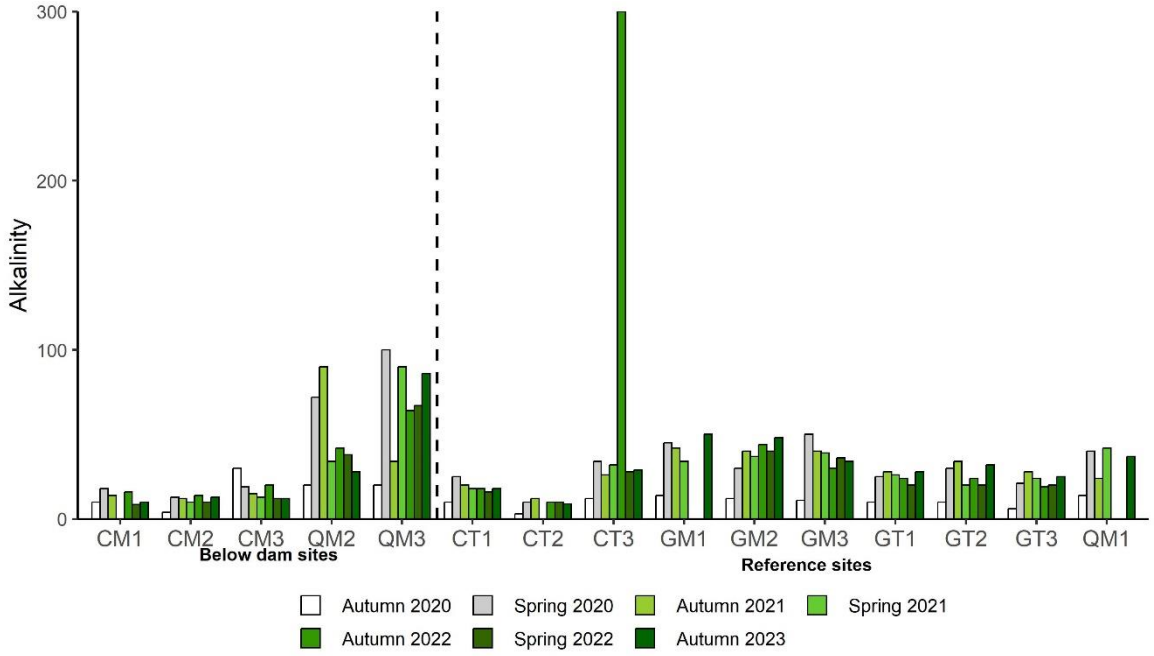
Nitrogen oxide concentrations at all sites from autumn 2020 to autumn 2023. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is dashed line and shaded red.



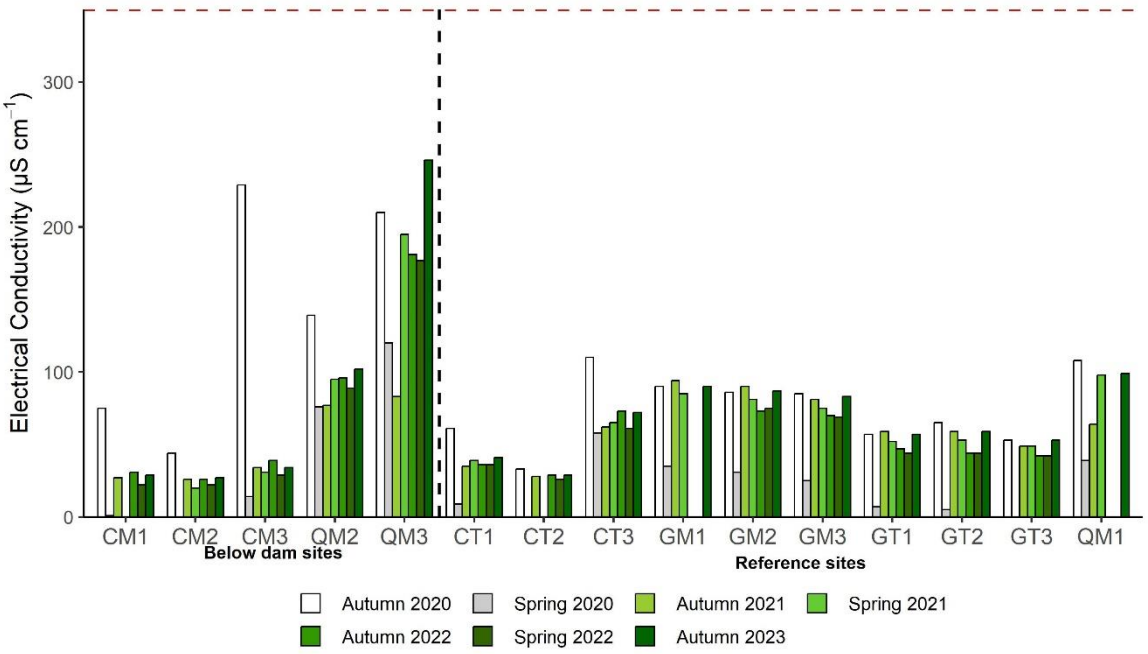
Total phosphorus concentrations at all sites from autumn 2020 to autumn 2023. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is dashed line and shaded red.



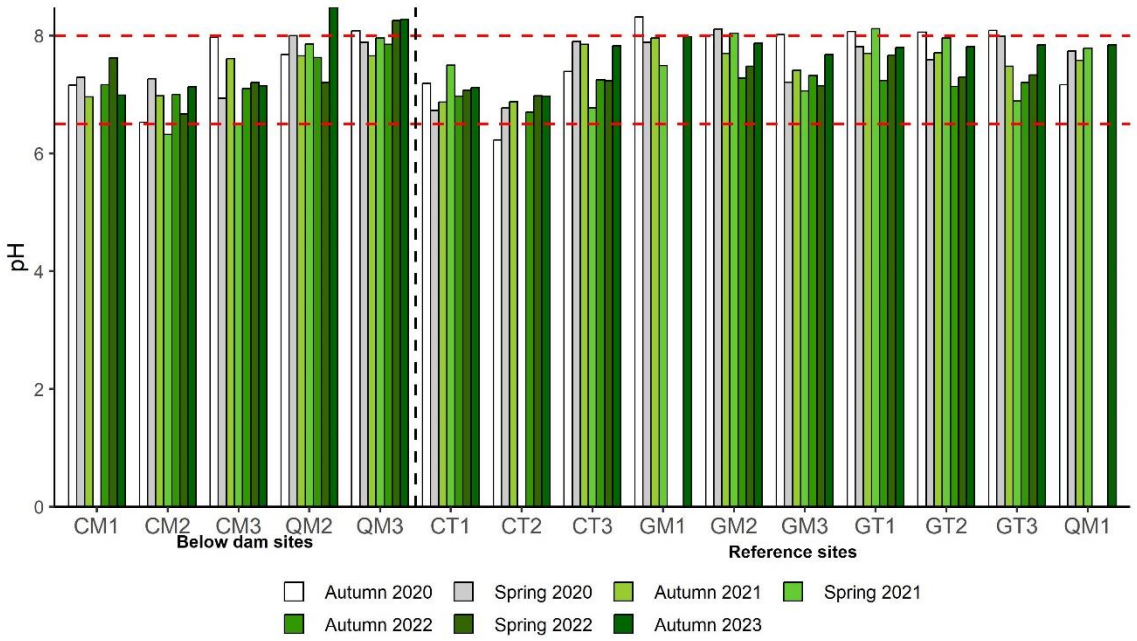
Total nitrogen concentrations at all sites from autumn 2020 to autumn 2023. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is dashed line and shaded red.



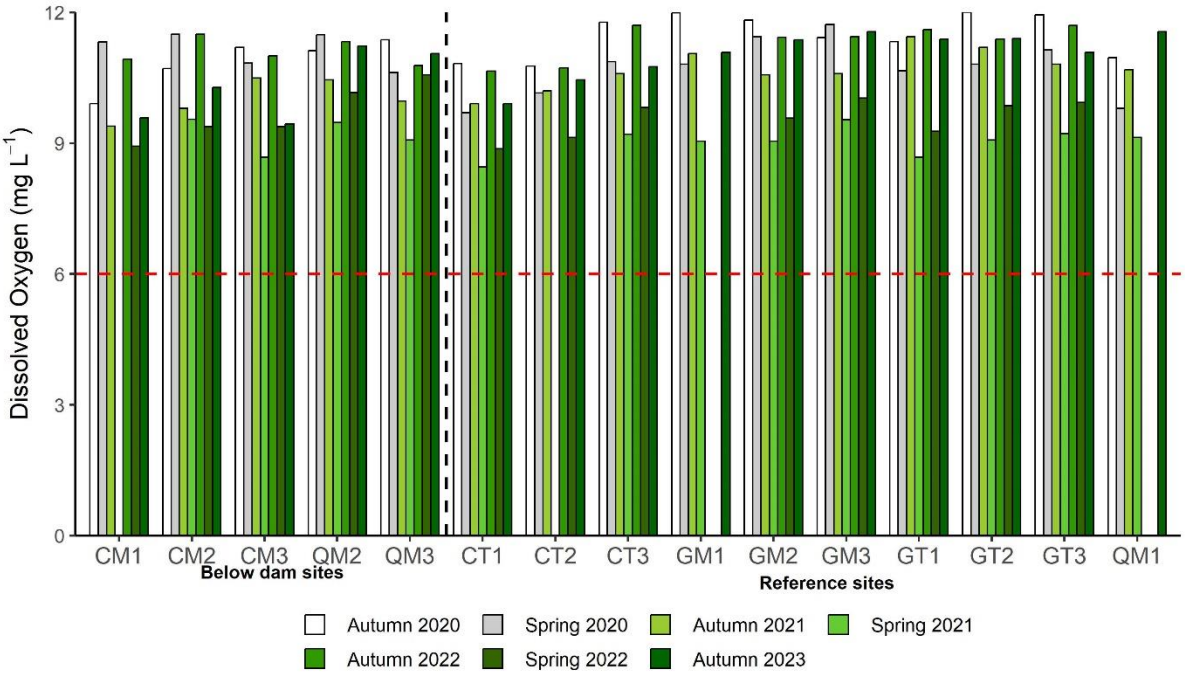
Alkalinity at all sites from autumn 2020 to autumn 2023.



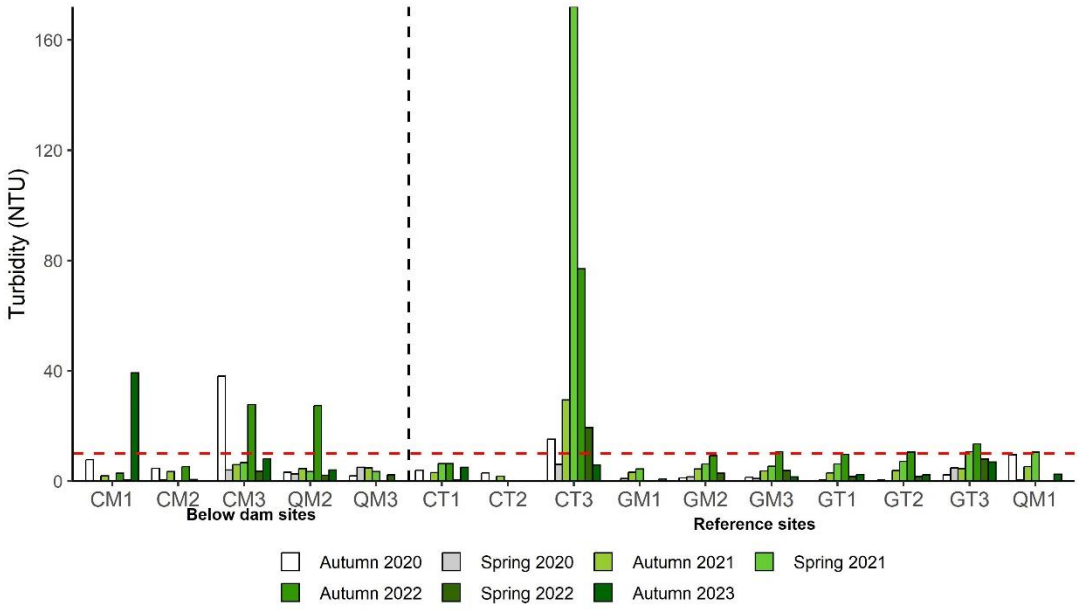
Electrical conductivity at all sites from autumn 2020 to autumn 2023. The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is dashed line and shaded red.



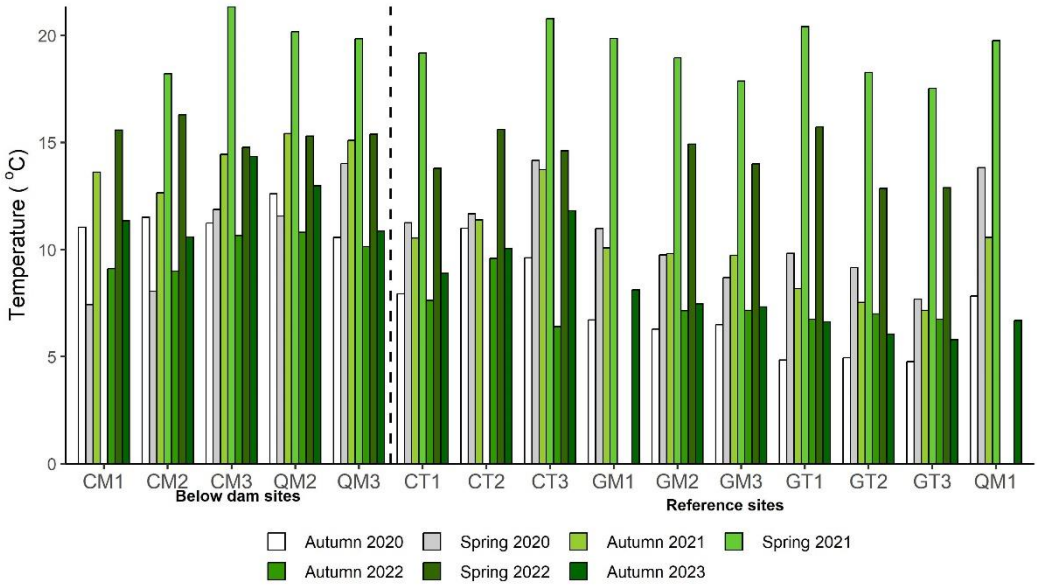
pH at all sites from autumn 2020 to autumn 2023. The ANZECC/ARMCANZ (2000) guideline range for pH are dashed lines and shaded red.



Dissolved oxygen concentration at all sites from autumn 2020 to autumn 2023. The minimum guideline for dissolved oxygen is dashed line and shaded red (Environment Protection Regulation SL2005-38).



Turbidity at all sites from autumn 2020 to autumn 2023. The guideline for maximum turbidity is dashed line and shaded red (Environment Protection Regulation SL2005-38).



Water temperature at all sites from autumn 2020 to autumn 2023.