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

Annual report June 2024

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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. This report is the results of assessments undertaken in spring 2023 and autumn 2024.

SPRING 2023 & AUTUMN 2024 RESULTS AND CONCLUSIONS

- Flows leading up to sampling in both spring 20-23 and autumn 2024 reflected general rainfall patterns across the catchments Spring 2023 saw cumulative flows lower than historical average flow for the three months leading up to sampling. In contrast, the cumulative flow in autumn 2024 was greater than historical autumn average flow.
- Cotter Reservoir was at full supply level leading up to both the spring 2023 and autumn 2024 assessments. Corin, Bendora and Googong reservoirs had mixed of both natural and regulated flow in both spring 2023 and autumn 2024. These reservoirs were mostly in full supply in level in July (before spring 2023 sampling period) and January (autumn 2024 sampling period).
- Water quality parameters at below dam test sites were largely within guideline levels in spring 2023 and autumn 2024 with a few exceptions. Nutrients below Googong Reservoir were above guideline levels in both spring 2023 and autumn 2024. Sites below Bendera and Cotter Reservoir had nitrogen oxide levels that exceeded guidelines in autumn 2024. 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. The reference site CT2 had higher Total Nitrogen (TN) in both spring and autumn 2024.
- The ecological objective of maintaining a filamentous algae cover of less than 20% in riffle habitats was achieved at all test sites in spring 2023 and autumn 2024. Click here for more information.
- As per previous assessments, test sites were generally in poorer condition than reference sites for both spring 2023 and autumn 2024 assessments.
- The test sites downstream of Googong Reservoir (QM2 and QM3), were the only sites to achieve AUSRIVAS band A and meet the ecological objectives in Spring 2023, but declined its biological condition to band C in autumn 2024 (QM2 has been fluctuating between band A and band C for the past few assessments). For the autumn 2024 assessment only

one test site (site below Bendora Reservoir (CM2)) to achieved the ecological objective of AUSRIVAS band A. Click here for more information

- All reference sites (except CT3 and GM2 in spring 2023 and CT3 and QM1 in autumn 2024) were all assessed as 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, red shading indicates environmental flow objective not met).

	Riffle filamentous algae cover (%)		AUSRIVAS band (O/E score)	
Site	**Spring 2023**	**Autumn 2024**	**Spring 2023**	**Autumn 2024**
CM1 (Corin Dam)	<10	<10	B	B
CM2 (Bendora Dam)	<10	<20	B	A
CM3 (Cotter Dam)	<10	<10	C	B
QM2 (Googong Dam)	<20	<10	A	C
QM3 (Googong Dam)	<20	<10	A	C

PROJECT RECOMMENDATIONS

The drivers of the continued differential biological condition between test and reference sites in this program (test sites generally in worse biological condition that reference sites) appear to be site and season specific. It is recommended that a more thorough investigation to determine what is contributing to the long-term lower condition at test sites, and what possible remediation action may be taken to more consistently meet band A should be undertaken.

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 2023 and autumn 2024. The assessment primarily concentrates on comparing these sites with unregulated reference sites and the findings of previous assessments. Site summary sheets outlining the outcomes of both the spring 2023 and autumn 2024 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 20 to 22 September and autumn between 28th March and 3 April 2024 (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.

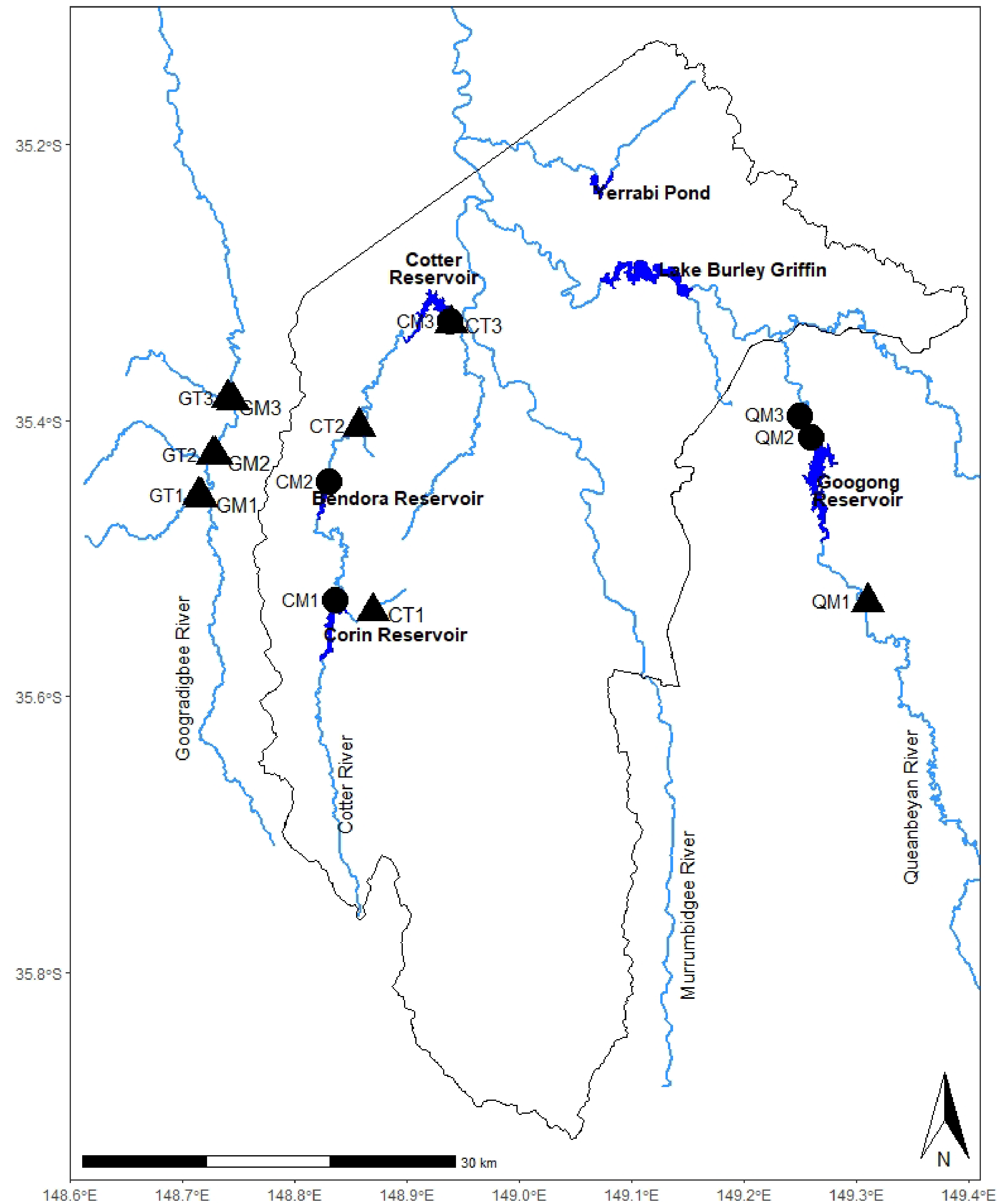

Figure 1: The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program (Circles indicate test sites, triangles indicate reference tributaries).

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 (WaterNSW, 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

Six replicate periphyton samples were collected at each of the Cotter and Goodradigbee River sites (except for GM1 due to lack of access to the site in Autumn 2024) and site QM2 on the Queanbeyan River using a syringe sampler based on a design similar to that described by Loeb (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).

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). Macroinvertebrate samples from the site GM1 (Goodradigbee River) and GT1 (Coolman Creek) could not be collected due to lack of access to the site in autumn 2024.

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 within the sampled sites for each sampling season. 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.

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** (Springer)	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** (Springer)	Water quality and/or habitat condition roughly equivalent to reference sites.
B	SIGNIFICANTLY IMPAIRED	**0.64-0.87** (autumn) **0.57-0.85** (Springer)	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** (Springer)	Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	EXTREMELY IMPAIRED	**0-0.39** (autumn) **0-0.27** (Springer)	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 spring 2023 sampling were generally lower than the historical average for the same period, and were primarily influenced by regulated flow conditions (Figure 2 and Table 5). Similarly, for the Goodrabidgee River, cumulative flow in leading up to sampling in spring 2023 was much lower than the historical average for the same period (Figure 2 and Table 5). These flow patterns were driven by lower-than-average rainfall across the entire study area in the months leading up to spring 2023 sampling (Table 6). In contrast, flow in the months leading up to sampling in autumn 2024 had both natural and regulated flow events at the test sites (Figure 2), with cumulative flows for this period much higher than the historical average for the same period (Table 5). The Goodradigbee River reference stream also had higher than historical average cumulative discharge leading up to autumn 2024 sampling (Table 5). Higher than average flows in autumn were driven by multiple large spikes in discharge from early December 2023 until mid-January 2024 at all sites (Figure 2).

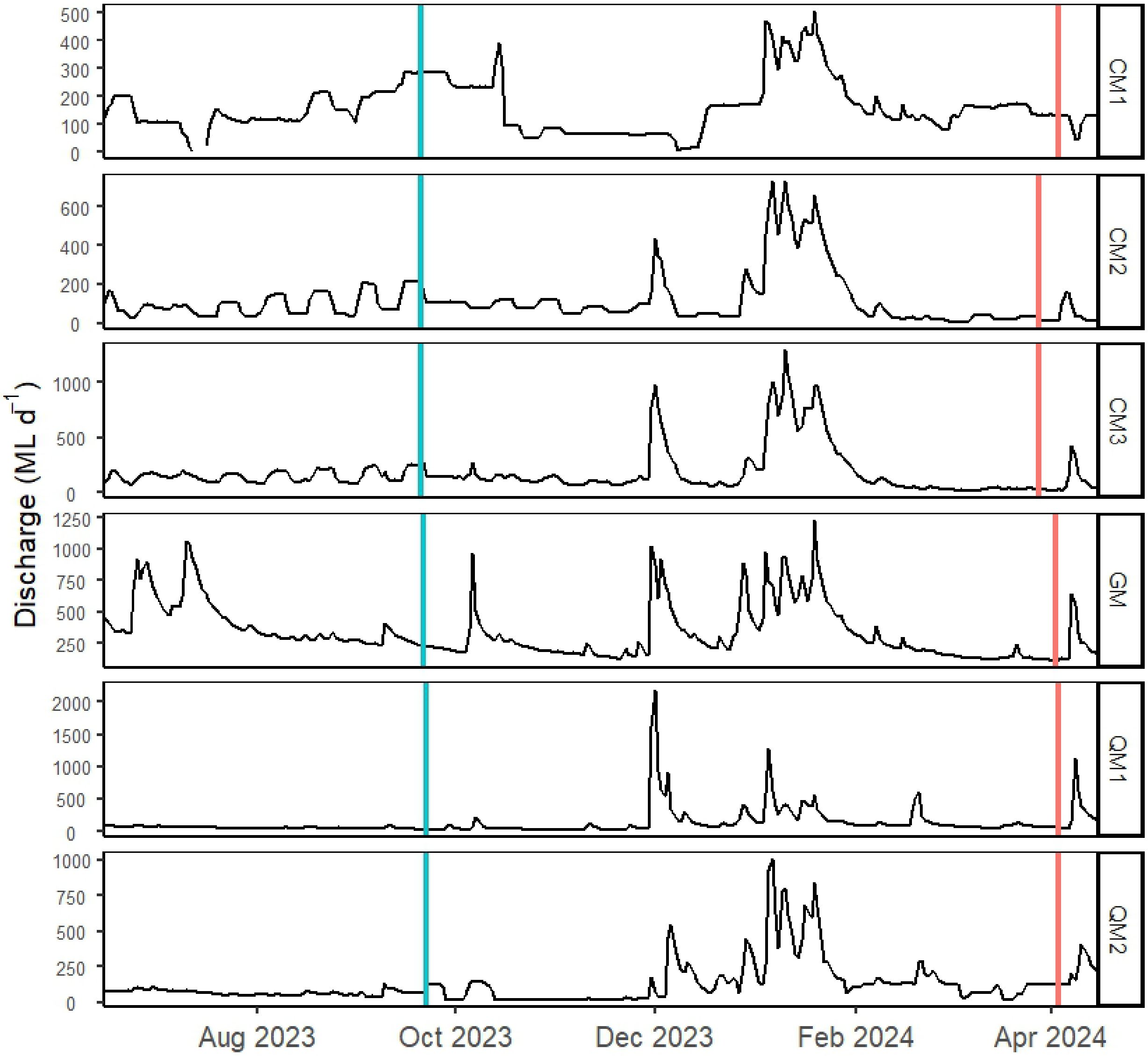

Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (GM2, station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from June 2023 to May 2024. **NOTE:** Blue bar corresponds to spring 2023 sampling and orange bar corresponds to autumn 2024 sampling.

Table 4: Discharge summary for monitoring sites (Data: NSW water and ALS).

Station	Relevant monitoring site/s	Cumulative flow in three months prior to spring 2023 sampling (ML)	Cumulative flow in three months prior to autumn 2024 sampling (ML)	Historical mean flow in spring (ML)	Historical mean flow in autumn (ML)	Percentile mean flow in spring 2023 (ML/Day)	Percentile mean flow in autumn 2024 (ML/Day)
Cotter River at D/S Bendorra Dam (Station no. 410747)	CM2, CT2	8663.89	15245.8	12283.07	5926.39	54th	88th
Cotter River at D/S Corin Dam (Station no. 410752)	CM1, CT1	13043	18356.02	13545	15050.17	66th	72nd
Cotter River at Kiosk (Station no. 410777)	CM3, CT3	13719.32	23043.23	43535.7	12840.42	30th	85th
Goodradigbee River at Brindabella (Station no. 410729)	GM1, GM2, GM2, GT1, GT2, Gt3	38247.38	29636.24	58717.55	17441.18	32nd	89th
Queanbeyan River U/S Googong Dam (Station no. 410781)	QM1	5194.3	15571.03	15522.46	11622.6	38th	80th
Queanbeyan River Wickerslack (Station no. 410760)	QM2, QM3	5853.1	19635.14	22400.82	13781.81	48th	80th

Table 5: Rainfall summary for monitoring sites (Data: BOM and ALS).

Station	Relevant monitoring site/s	Total rainfall in three months prior to spring 2023 sampling (mm)	Total rainfall in three months prior to autumn 2024 sampling (mm)	Historical total rainfall in spring (mm)	Historical total rainfall in autumn (mm)	Percentile total rainfall in spring 2023 (mm)	Percentile total rainfall in autumn 2024 (mm)
Rainfall at Bendorra Dam (Station no. 570958)	CM1, CM2, CT1, CT2	166	273.6	305.67	227.98	15th	70th
Rainfall at Peirces Creek (Station no. 570825)	CM3, CT3	96.2	167.4	179.39	181.75	11th	55th
Rainfall at Queanbeyan River Wickerslack (Station no. 570983)	QM2, QM3	39.45	195.4	133.95	186.47	5th	59th
Rainfall at Queanbeyan River U/S Googong Dam (Station no. 570816)	QM1	55.19	176.8	132.19	173.53	9th	56th
Rainfall at Goodradigbee at Brindabella (Station no. 71073)	GM1, GM2, GM3, GT1, GT2, GT3	131.4	102.4	259.22	171.43	21st	23rd

WATER QUALITY

The water quality parameters were generally within the guideline levels at the test and reference sites during both the spring 2023 and autumn 2024 assessment, with some exceptions. Notable deviations were NOx and total Nitrogen at the Queanbeyan River test sites in both spring 2023 and autumn 2024 assessments and NOx at test sites CM2 and CM3 in the autumn assessment (Table 7 and Table 8).

Table 6. Water quality parameters measured at each of the test and reference sites in spring 2023. Values outside guideline levels are shaded orange.

		Temp. (^{0}C)	EC (µs cm^{-1})	pH	D.O. (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
		Guideline level									
		NA	<350	6.5-8	>6	<10	NA	<0.13	<0.015	<0.25	<0.02
Below dam test sites	CM1	9.17	23	7.06	10.2	1.0	10	0.004	0.004	0.1	0.008
	CM2	9.85	24	7.48	10.33	1.5	10	0.006	0.012	0.06	0.007
	CM3	14.93	37	7.38	9.49	0.6	19	0.007	0.007	0.1	0.007
	QM2	13.2	116	7.85	10.71	0.0	30	0.011	0.004	0.48	0.009
	QM3	13.32	255	8.18	10.76	0.2	56	0.025	0.065	0.44	0.008
Reference sites	CT1	12.69	50	7.12	9.27	2.4	20	0.012	0.01	<0.05	0.013
	CT2	14.29	36	7.27	9.37	1.2	10	0.008	0.031	0.08	0.006
	CT3	18.53	91	8.14	9.65	4.4	42	0.004	0.009	0.15	0.013
	QM1	14.21	146	7.50	9.48	0.0	48	0.002	<0.002	0.23	0.009
	GM1	13.18	115	7.25	10	0.0	44	0.009	0.01	0.05	0.009
	GM2	12.24	108	7.45	10.17	5.2	40	0.003	0.003	0.06	0.009
	GM3	12.9	104	7.58	10.27	4.5	34	<0.002	0.005	0.12	0.008
	GT1	11.98	62	7.51	9.86	7.5	18	0.025	0.004	0.08	0.012
	GT2	10.44	64	7.47	10.06	13.5	26	<0.002	<0.002	0.11	0.013
	GT3	10.61	59	7.45	10.16	13.4	26	0.01	0.004	0.1	0.013

Table 7: Water quality parameters measured at each of the test and reference sites in autumn 2024. Values outside guideline levels are shaded orange. **NOTE:** WQ parameters at GM1 and GT1 were not recorded due to sites being inaccessible during sampling.

		Temp. (^{0}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	17.44	26	6.72	8.84	0.2	10	0.005	<0.002	0.07	0.004
	CM2	18.42	24	6.72	9.21	0.8	10	0.012	0.027	0.12	0.005
	CM3	15.6	44	6.84	9.56	1.9	15	0.008	0.032	0.12	0.006
	QM2	19.8	123	7.42	9.49	1.0	32	0.019	0.049	0.41	0.010
	QM3	18.54	187	7.90	9.58	1.0	60	0.012	0.046	0.38	0.011
Reference sites	CT1	13.51	48	7.19	9.23	1.8	17	0.003	<0.002	<0.05	0.012
	CT2	16.62	36	7.34	8.86	0.6	12	0.014	0.044	0.10	0.004
	CT3	17.8	83	8.63	10.18	5.0	31	<0.002	0.005	0.13	0.013
	QM1	16.56	92	7.38	9.16	39.0	30	0.004	0.002	0.19	0.013
	GM1	Site inaccessible during sampling									
	GM2	15.05	133	7.51	9.44	1.3	46	0.024	0.007	0.06	0.006
	GM3	16.18	129	7.64	9.31	1.5	44	0.011	0.005	0.08	0.009
	GT1	Site inaccessible during sampling									
	GT2	14.46	86	7.40	9.56	4.5	30	0.021	<0.002	0.12	0.012
	GT3	14.26	74	7.44	9.68	8.2	28	0.026	<0.002	0.07	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 dam test sites in both spring 2023 and autumn 2024 assessments (Table 9). Similarly, field observations of periphyton cover of riffle habitats were <20% at all test sites except for the test site QM1 (upstream of Googong Reservoir) in autumn 2024, which had higher percentage of periphyton cover of riffle habitat.

Mean ash free dry mass (AFDM) concentrations were not significantly different between sites in the spring 2023 assessment ($F_{6,35} = 1.222$, $p = 0.318$), but were significantly different between sites in the autumn 2024 assessment ($F_{5,30} = 5.592$, $p < 0.001$). Differences in concentrations of AFDM between sites in autumn 2024 were mixed across reference and test sites, with the largest difference being driven by very high AFDM concentrations at references site GM3, which were significantly higher than sites CM1, CM2, CM3 and GM2 (Figure 5).

Mean Chlorophyll-a concentrations differed between sites in both the spring 2023 ($F_{6,35} = 3.494$, $p < 0.05$) and the autumn 2024 assessments ($F_{5,30} = 4.271$, $p < 0.05$). Differences in concentrations of Chlorophyll-a between sites in spring 2023 were driven by significantly lower concentrations at test site CM3 and reference site GM2 and higher concentrations at the test site CM1 (Figure 6). In autumn 2024 differences in mean Chlorophyll-a concentrations between sites was driven by very high concentrations at test site CM2 and reference site GM3 and very low concentrations at sites CM1, CM3, QM2 and GM2 (Figure 6).

Table 8: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from spring 2023 to autumn 2024. 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					
Site	Aut-21	Spr-21	Spr-22	Aut-23	Spr-23	Aut-24		Aut-21	Spr-21	Spr-22	Aut-23	Spr-23	Aut-24
CM1	<10	NA	<10	40	<10	<10		<10	NA	<10	<10	<10	<10
CM2	30	15	15	40	<10	<10		<10	40	<10	<10	<10	<20
CM3	<10	<10	<10	20	<10	<10		<10	<10	<10	<10	<10	<10
QM2	20	<10	20	30	<20	<10		30	<10	<10	<10	<20	<10
QM3	<10	<10	30	40	<20	<10		<10	<10	<10	<10	<20	<10
GM1	<10	<10	NA	10	<10	NA		<10	<10	NA	<10	<10	NA
GM2	<10	<10	<10	15	<10	<10		<10	<10	<10	<10	<10	<10
GM3	35	15	<10	20	<20	<10		<10	<10	<10	<10	<10	<10
QM1	<10	<10	NA	10	<20	25		<10	<10	NA	<10	<10	<10

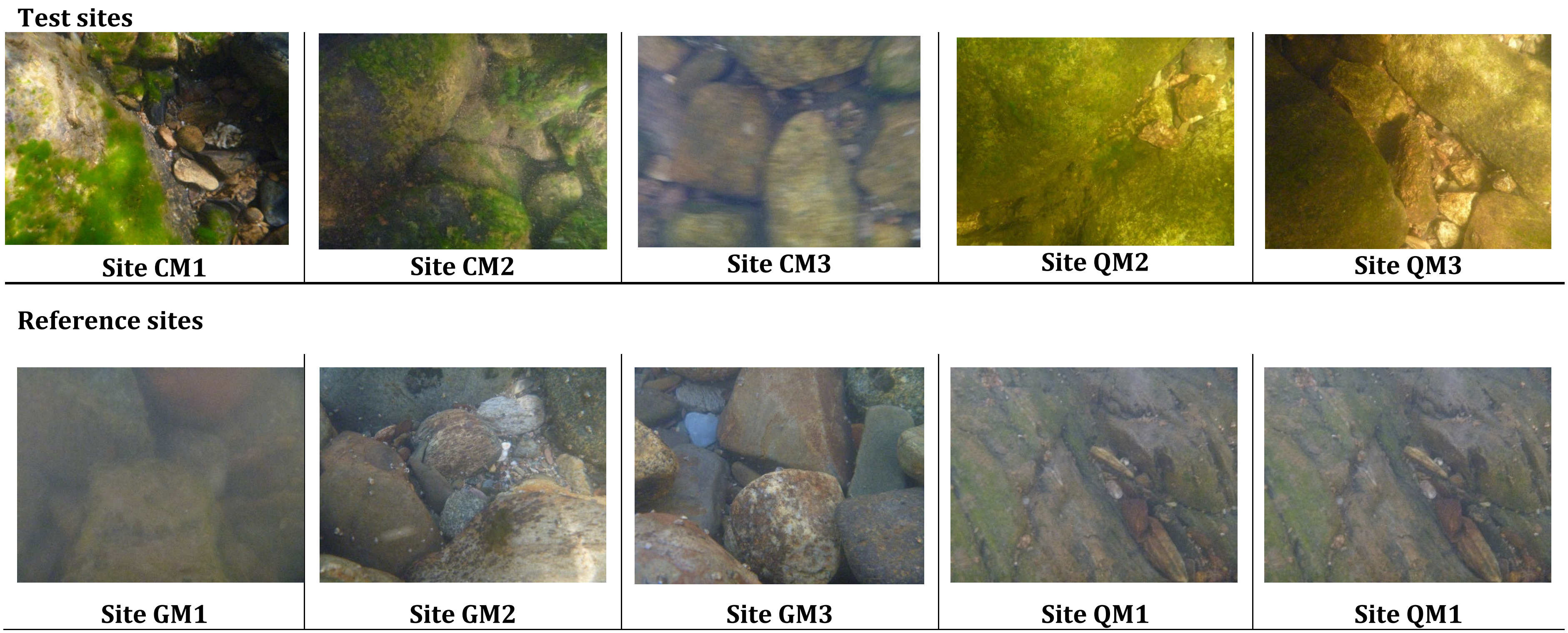

Figure 3. Filamentous algae and periphyton cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Cotter, Goodradigbee and Queanbeyan Rivers in spring 2023.

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 2024.

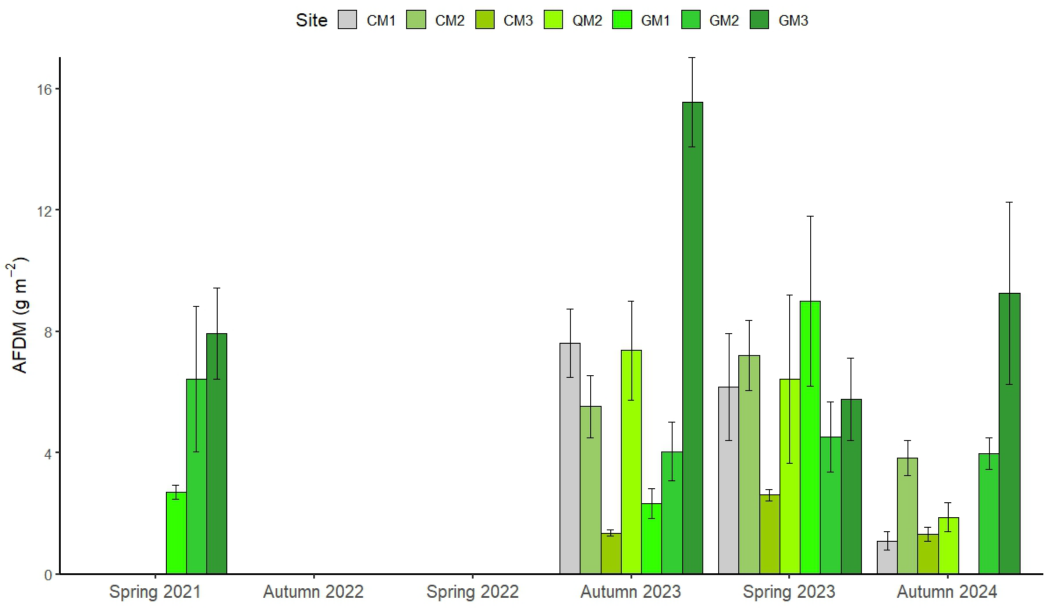

Figure 5: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2021 to autumn 2024. Error bars represent +/- 1 standard error. **NOTE**: AFDM samples were not collected in autumn 2022 and spring 2022 due to high flow during sampling period.

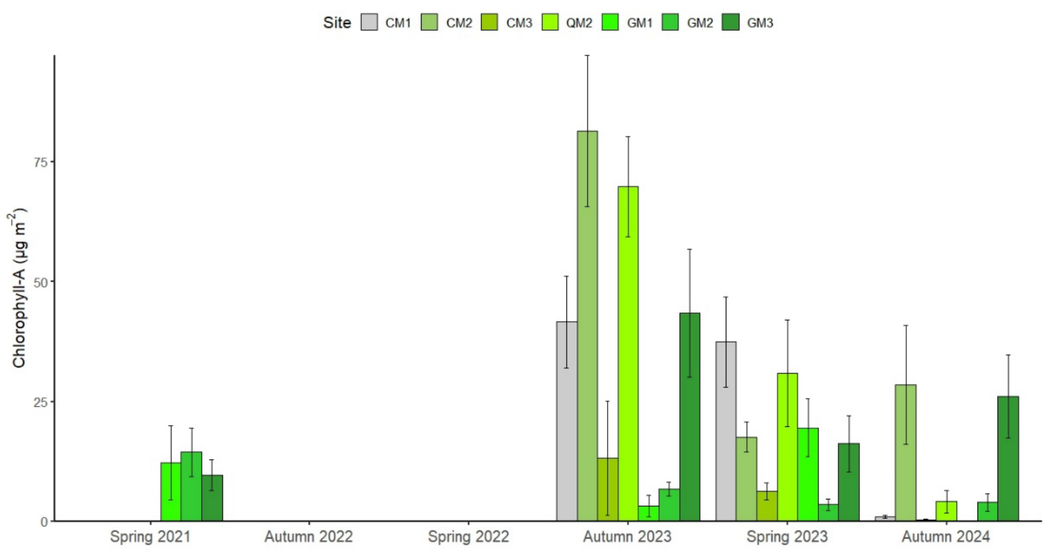

Figure 6: Mean Chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2021 to autumn 2024. Error bars represent +/- 1 standard error. **NOTE:** Chlorophyll-a samples were not collected in autumn 2022 and spring 2022 due to high flow during sampling season.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in both spring 2023 and autumn 2024 assessments (Table 10), following on from a similar trend in autumn 2023.

Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in spring 2023 and autumn 2024 (Table 10). Test site CM1 remained in band B for the past several assessments and has had a relatively stable O/E score of around 0.72 – 0.85 since autumn 2019 (Table 10). The dominant taxa at this site in spring 2023 was environmentally sensitive Gripopterygidae and Hydropsychidae (Appendix 2). The taxa Leptophlebiidae in spring 2023 and Psephenidae in autumn 2024 where the only taxa that were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model was detected in the whole sample scan (Table 11 and Table 12), but not in the subsample that were processed, suggesting that this taxa were present, but in low abundances at this site.

Condition of the Cotter River below Bendora Dam (CM2) increased in biological condition from significantly impaired (band B) in spring 2023 to similar to reference (band A) in autumn 2024 (Table 10). This site had remained in band B, between spring 2016 and autumn 2021 and the biological condition of the site has been alternating between band A and B since spring 2020 (Table 10). The macroinvertebrate community at CM2 was characterised by a high abundance of Gripopterygidae in spring 2023 and Simuliidae in autumn 2024 (Appendix 2). The taxa Tipulidae was the only taxa that was predicted to have a ≥50% chance of occurrence by the AUSRIVAS model was detected in the whole sample scan (Table 11) ,but not in the subsample that was processed, suggesting that this taxon was present, but in low abundances at this site in spring 2023. No taxon had been detected in autumn 2024 whole sample scan for this site.

The condition of the Cotter River below Cotter Dam (CM3) has been assessed as band B (significantly impaired) in Autumn 2024, improving in biological condition from being assessed as band C (severely impaired) in spring 2023 (Table 10). The most dominant taxa in spring 2023 was environmentally tolerant taxa Orthocladiinae and environmentally sensitive taxa baetidae in autumn 2024 (Appendix 2). Taxa Hydropsychidae the only taxa that was predicted to have a ≥50% chance of occurrence by the AUSRIVAS model was detected in the whole sample scan (Table 11), but not in the subsample that was processed, suggesting that this taxon was present, but in low abundances at this site in spring 2023. No taxon had been detected in autumn 2024 whole sample scan at CM3.

The below Googong Dam test sites (QM2 and QM3) were both assessed as band C (Severely impaired) in autumn 2024, decreasing vastly in biological condition from being assessed as band A (similar to reference) in spring 2023 (Table 10). The most abundant taxa in the site QM2 were Orthocladiinae in spring 2023 and baetidae autumn 2024. Meanwhile, the most dominant taxa in QM3 were Oligochaeta in spring 2023 and Simuliidae in autumn 2024. Taxa Gomphidae and Hydrobiosidae were the only taxa that were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model was detected in the whole sample scan (Table 11), but not in the subsample that was processed, suggesting that this taxon was present, but in low abundances at this site in autumn 2024.

The biological condition of reference sites varied within and between the seasons of spring 2023 and autumn 2024. A consistent observation was that the reference sites within the Goodradigbee River catchment typically showed better biological condition in comparison to those within the Cotter River and Queanbeyan River catchments. An exception to this pattern was noted at site GM2 (Goodradigbee River upstream of Bullflat Creek) where it has been assessed as band B in spring 2023 (Table 10). The macroinvertebrate community at all the reference sites were dominated byGripopterygidae, Leptophlebiidae, Simuliidae, Orthocladiinae and Oligochaeta in spring 2023 and Baetidae and Leptophlebiidae in autumn 2024. Taxa Scirtidae and Hydrobiosidae at site CT1, Tipulidae and Simuliidae at site CT2, Baetidae, Leptophlebiidae, Glossosomatidae, Hydropsychidae and Conoesucidae at site CT3, Tanypodinae and Hydropsychidae at GM1, Elmidae, Psephenidae, Hydrobiosidae and Hydropsychidae at site GM2, Psephenidae, Hydrobiosidae and Hydropsychidae at site GM3 and Baetidae 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 spring 2023. Taxa Psephenidae at site CT2, Coloburiscidae at site GT2 and Hydrobiosidae at site GT3 which were predicted to have a ≥50% chance of occurrence by the AUSRIVAS model were detected in the whole sample scan (Table 11, Table 12) but not in the subsample that was processed, suggesting those taxa were present, but in relatively low abundances at reference sites in autumn 2024.

Table 9: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2020 to autumn 2024. 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 2024	**B (0.72)**	**A (1.01)**	**B (0.67)**	**C (0.56)**	**C (0.49)**	**A (0.92)**	**A (1.03)**	**B (0.69)**	**B (0.75)**	**NA**	**A (0.97)**	**A (1.04)**	**NA**	**A (1.06)**	**A (0.97)**
Spring 2023	**B (0.84)**	**B (0.74)**	**C (0.44)**	**A (0.88)**	**A (0.92)**	**A (0.96)**	**A (1.07)**	**B (0.66)**	**A (1.01)**	**A (0.97)**	**B (0.82)**	**A (1.04)**	**X (1.21)**	**X (1.28)**	**A (1.05)**
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)

Table 10: Macroinvertebrate taxa that were expected with a ≥ 50% chance of occurrence by the AUSRIVAS ACT autumn riffle model but were missing from sub-samples for each of the study sites in spring 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 spring 2023																
Taxon Name	**Signal Score**	**Test sites**					**Reference sites**									
		CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
Scirtidae	6						X									
Elmidae	7		X	X	X						X					
Psephenidae	6		X	X	X	X			X	X	X	X	X		X	
Tipulidae	5		X	X				X								
Ceratopogonidae	4															X
Simuliidae	5	X		X			X	X		X					X	
Tanypodinae	4	X	X	X		X	X		X	X	X				X	
Baetidae	5								X							X
Leptophlebiidae	8	X	X	X	X	X			X							
Caenidae	4	X		X				X	X		X					X
Notonemouridae	6						X									
Hydrobiosidae	8	X	X	X			X				X	X				
Glossosomatidae	9	X	X	X	X	X			X							
Hydropsychidae	6			X	X				X	X	X	X				
Conoesucidae	7			X	X	X			X							
Total taxa		**6**	**7**	**11**	**6**	**5**	**5**	**3**	**8**	**4**	**6**	**3**	**1**	**0**	**3**	**3**

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 2024 (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 2024																
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				Site inaccessible			Site inaccessible			
Ancylidae	4				X	X										
Acarina	6					X			X							X
Scirtidae	6	X														
Elmidae	7			X	X											
Psephenidae	6	X	X	X			X	X			X				X	
Tipulidae	5													X		
Podonominae	6		X	X	X	X	X		X		X	X			X	X
Tanypodinae	4	X	X	X	X	X	X		X							X
Chironominae	3	X				X										
Coloburiscidae	8	X						X						X		
Leptophlebiidae	8			X	X	X										
Caenidae	4										X					
Gomphidae	5			X	X	X			X		X	X			X	X
Gripopterygidae	8															X
Hydrobiosidae	8	X			X	X									X	
Glossosomatidae	9	X						X						X		
Hydroptilidae	4			X	X	X	X		X			X				X
Hydropsychidae	6															X
Leptoceridae	6	X	X		X	X			X							
Total taxa		**8**	**4**	**7**	**10**	**11**	**4**	**3**	**6**	**0**	**4**	**3**	**0**	**3**	**4**	**7**

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) for both spring 2023 and autumn 2024 assessments. Environmentally sensitive taxa were dominant (> 50%) at all the sites in spring 2023 and autumn 2024, except for test sites CM3, QM2 and QM3 and reference sites CT2 and CT3 in spring 2023, where environmentally tolerant taxa were dominant (> 50%). In general, reference sites had a higher composition of environmentally sensitive taxa in autumn 2024 than spring 2023 (Figure 7, Figure 8).

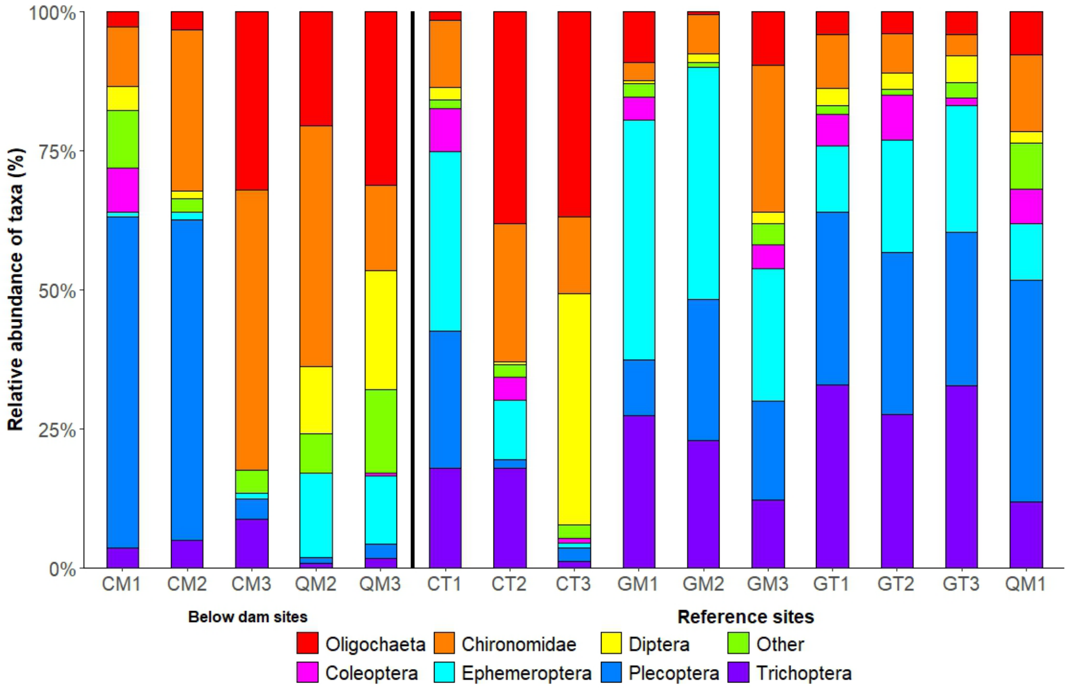

Figure 7: Relative abundance of macroinvertebrate taxonomic groups from samples collected in spring 2023.

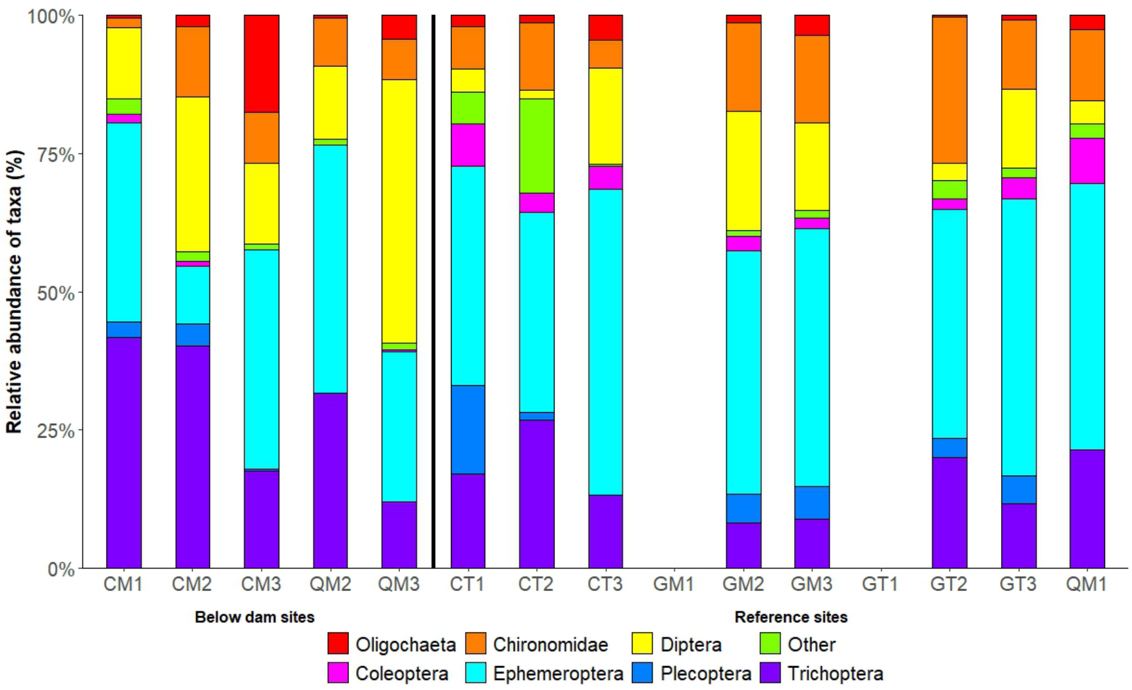

Figure 8: Relative abundance of macroinvertebrate taxonomic groups from samples collected in autumn 2024.
Note: The sites without a bar graph indicates unavailability of data due to site inaccessible.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Macroinvertebrate communities of test sites were largely dissimilar to that of reference sites in both spring 2023 and autumn 2024 (Figure 9, Figure 10). Differences in macroinvertebrate assemblage between test and reference sites were driven by higher abundances of environmentally sensitive Glossosomatidae, Conoesucidae, Gripopterygidae and Leptoceridae at reference sites and environmentally tolerant Orthocladiinae, Ecnomidae and Oligochaeta test sites (Figure 9, Figure 10). The reference site CT3 has grouped with below dams test sites QM2, QM3 and CM3 in both the seasons largely driven by relative abundance of environmentally tolerant taxa. Similarly, test sites CM1 and CM2 have grouped with Goodradigbee River reference sites and Cotter River reference sites (Figure 9, Figure 10) which were largely driven by prevalence of environmentally sensitive taxa.

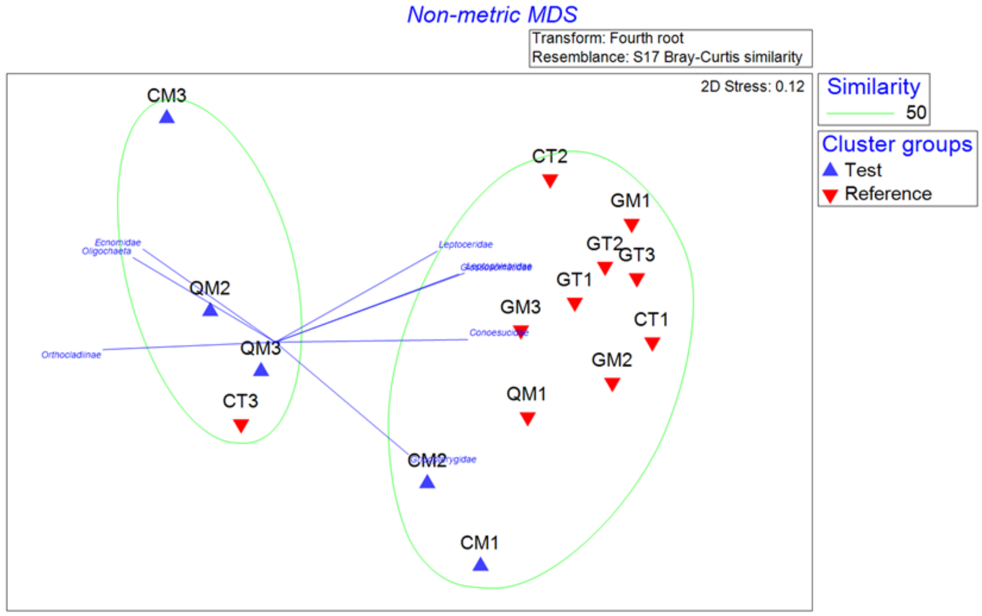

Figure 9. MDS ordination of 50% similarity between macroinvertebrate samples collected in spring 2023 for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.50 (i.e. taxa that 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.

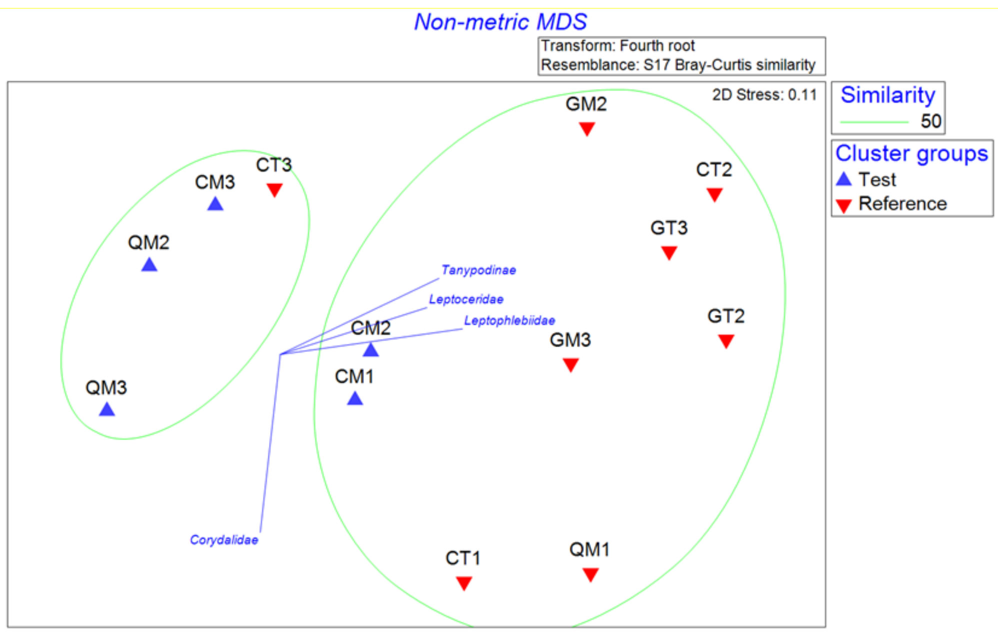

Figure 10. MDS ordination of 50% similarity between macroinvertebrate samples collected in autumn 2024 for the below dams assessment program (green oval lines). Similarity is based on macroinvertebrate relative abundance. Macroinvertebrate taxa with Pearson correlations greater than 0.50 (i.e. taxa that 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 the periods of spring 2023 and autumn 2024 assessments, water quality measurements at both test and reference sites were predominantly within the within the guideline levels. However, there were exceptions for nutrient levels mostly in tests sites. In spring 2023, the nutrient parameters exceeded the guideline levels specifically at downstream of the Googong Reservoir. Similarly, in autumn 2024, elevated levels of nitrogen oxides (NOx) were recorded at all test sites except CM1.

Total nitrogen and nitrogen oxides (NOx) continue to exceed guideline levels at test sites, especially those below Googong Reservoir, though at most test sites in autumn 2024. There are a couple of likely sources of the elevated nitrogen at the test sites. Firstly, denitrification within the reservoir could be the cause of elevated NOx concentrations at sites directly below reservoirs and the high concentrations experienced in autumn 2024 (Saunders & Kalff, 2001). Secondly, heavy rainfall events contribute to increased runoff, which can lead to elevated transport of nutrients from the surrounding landscape into water bodies (Rattan et al., 2017). Two weeks prior to sampling in autumn 2024 35 mm of rain fell in the catchment, and this may have led to the increased nutrient levels measured during the autumn assessment at the test sites (Harrison et al., 2010).

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 2023 and autumn 2024 (refer to Table 9). The findings follow on previous assessments and suggest that 'natural' (i.e. overtopping) and regulated flow are effectively controlling the accumulation of filamentous algae downstream of dams.

Differences between sites in ash free dry mass (AFDM) and chlorophyll-a concentration were independent of whether a site was test or reference, indicating that the differences between sites were not directly associated with dam operations. Likely these patterns likely reflect 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 (Norton et al., 2012).

BENTHIC MACROINVERTEBRATES

Apart from a couple of exceptions, below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in both spring 2023 and autumn 2024 assessments. Below dam test sites continue to be largely significantly impaired, with sites achieving reference condition on only 23% of occasions since autumn 2020 (Our monitoring suggests that water quality parameters are generally similar between test and reference sites indicating that water quality is unlikely to be the driving factor for the difference in biological conditions between test and reference sites. More likely, differences in macroinvertebrate communities above and below dams can be attributed to flow regime and / or physical habitat (that may be influenced by flow regime) (Growns & Growns, 2001; Krajenbrink et al., 2019; Mbaka & Wanjiru Mwaniki, 2015). Impacts of altered flow regimes from regulation can be taxa specific (Growns & Growns, 2001), with some taxa being negatively impacted, while others positively impacted. The main drivers of the hydrology impacted by dams that may be driving macroinvertebrate communities is base flow and daily rate of change (both generally reduced in regulated streams) (Growns & Growns, 2001). The drivers of the continued differential biological condition between test and reference sites in this program appear to be site and season specific. It is recommended that a more thorough investigation to determine what is contributing to the long-term lower condition at test sites, and what possible remediation action may be taken to more consistently meet band A should be undertaken.

SITE SPECIFIC BIOLOGICAL CONDITION

Cotter River below Corin Dam (CM1) was assessed as significantly impaired (band B) in both spring 2023 and autumn 2024 (Table 10). Test site CM1 has remained in band B for since autumn 2014, and has only recorded biological condition similar to reference twice since spring 2008 (just 7% of occasions). Despite this, the site has generally had a very stable O/E scores, some very close to band A, since autumn 2020 (Table 10). The macroinvertebrate assemblages at these sites differed from those of reference sites primarily because of a higher abundance of filter-feeding Simuliidae and Hydropsychidae larvae at the below dam sites, although this site had a reasonable taxonomic richness (Appendix 2).

The Cotter River test site below Bendora Dam (CM2) improved in biological condition in from a band B in spring 2023 to a band A in autumn 2024. Aside from a run of eight consecutive assessments (Autumn 2017 – Spring 2020) where this site was assessed as significantly impaired, this site has generally been assessed as similar to reference (as it has been for each autumn since 2021). For this site officially, an extended period of relatively high flow and variability in the months preceding autumn 2024 looks likely to have resulted in improved biological condition at this site by reducing algal biomass and providing more favourable habitat and resource conditions for environmentally sensitive taxa (Dewson et al., 2007).

The Cotter River test site below Cotter Reservoir (CM3) has improved its biological condition from being assessed as band C (Severely impaired) in spring 2023 to band B (Significantly impaired) in autumn 2024. Biological condition at this site has fluctuated over the past 4 years (excluding non-sampling yeas) from band C to band A. The macroinvertebrate assemblages at these sites differed from those of reference sites primarily because of a higher abundance of filter-feeding Simuliidae and Baetidae larvae at the site. Such filter-feeding taxa are commonly found in greater abundance downstream of impoundments where fine particulate food sources are abundant and the downstream transport of coarser organic material has been interrupted (Stanford & Ward, 1983).

Macroinvertebrate communities at the sites downstream of Googong Dam (QM2 and QM3) both deteriorated in biological condition from band A in spring 2023 to band C in autumn 2024. The pattern of band B or Bend C in autumn and band A in spring assessments has been evident since autumn 2018 at site QM2, indicating the influence of season on the biological condition of this site. The driver of this pattern in biological condition is unclear based on parameters measured in this program, though warmer temperatures in spring compared to the previous autumn assessment may provide a clue (except for autumn 2024, which was much warmer than other autumn assessments).

Overall, the reference sites were in excellent biological condition across both spring 2023 and autumn 2024 assessments. Cotter Tributary sites remained in the same condition between spring 2023 and autumn 2024 assessments (CT1 and CT2 remained band A, CT3 remained band B). Reference sites in the Goodradigbee catchment were largely assessed as similar to reference or more diverse than reference, with the exception of GM2 in spring 2023, which was assessed as significantly impaired. The continued excellent condition of most of the reference sites indicates that conditions in the general area were conducive to good river health, and that biological impairment was unlikely to be related to larger scale climatic conditions.

CONCLUSION

The water quality parameters at the below dam test sites were largely within the guideline levels during the spring of 2023 and autumn of 2024. Despite some increased nutrient availability eat test sites, filamentous algae coverage of riffle habitats remained well within environmental flow ecological objective levels at all test sites in spring 2023 and autumn 2024. This indicates that efforts to maintain and manage water quality have been effective, ensuring the preservation and sustainability of these vital aquatic ecosystems. Aside from some exceptions (Sites QM2 and QM3 in spring 2023 and CM2 in autumn 2024), test sites were biologically impaired and generally in worse condition than reference sites in spring 2023 and autumn 2024. This continues a long trend of test sites being impaired and reference sites being similar to reference. Impairment appears to be somewhat site and at times seasons specific, and further research or review to elucidate the drivers of impairment at test sites would be invaluable in mediation moving forward.

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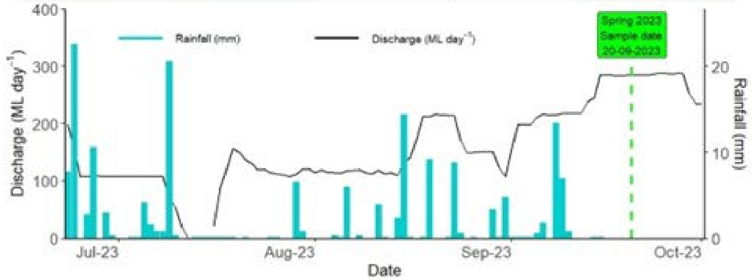
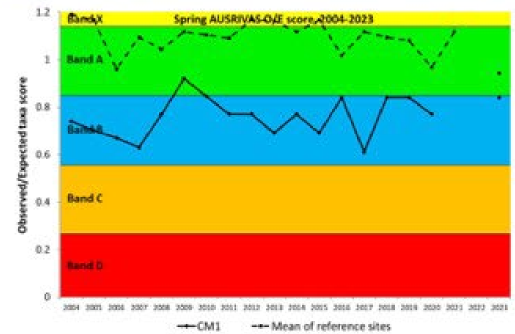
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

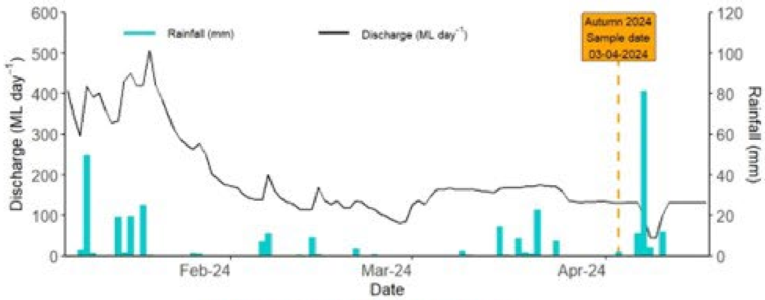
CM1 - Spring 2023 - Autumn 2024

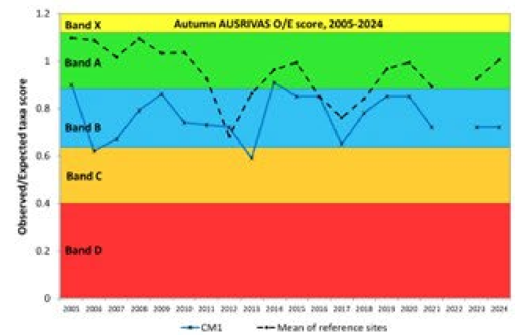
Downstream of Corin Dam

Environmental flow ecological objective	Spring 2023	Autumn 2024	Objective met?
AUSRIVAS band A	Band B	Band B	Not for either assessment
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes, for both assessment









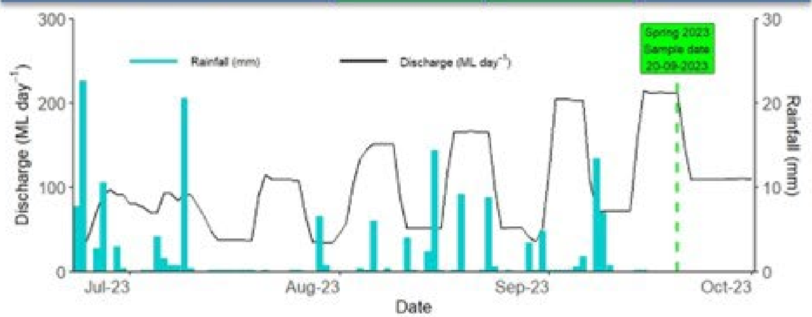
* Denotes values outside guideline levels

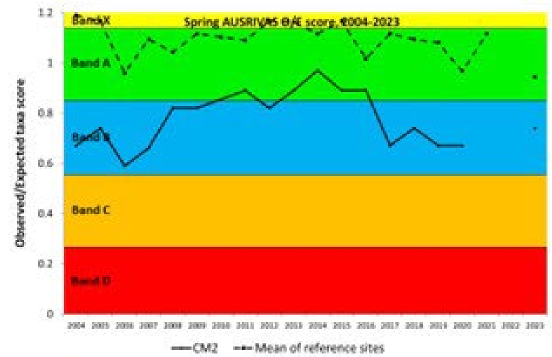
Sampling season	Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_4^+ (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
Spring 2023	9.17	23	7.06	10.2	1.0	10	0.004	0.004	0.1	0.008
Autumn 2024	17.44	26	6.72	8.84	0.2	10	0.005	<0.002	0.07	0.004

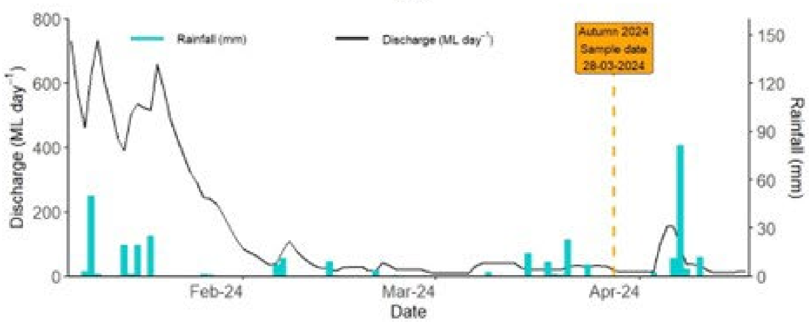
CM2 - Spring 2023 - Autumn 2024

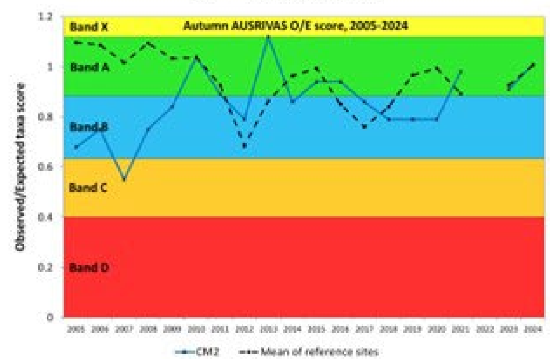
Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2023	Autumn 2024	Objective met?
AUSRIVAS band A	Band B	Band A	Only for autumn 2024
<20% filamentous algae cover in riffle habitat	<10%	<20%	Yes, for both assessment









* 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 2023	9.85	24	7.48	10.33	1.5	10	0.006	0.012	0.06	0.007
Autumn 2024	18.42	24	6.72	9.21	0.8	10	0.012	0.027	0.12	0.005

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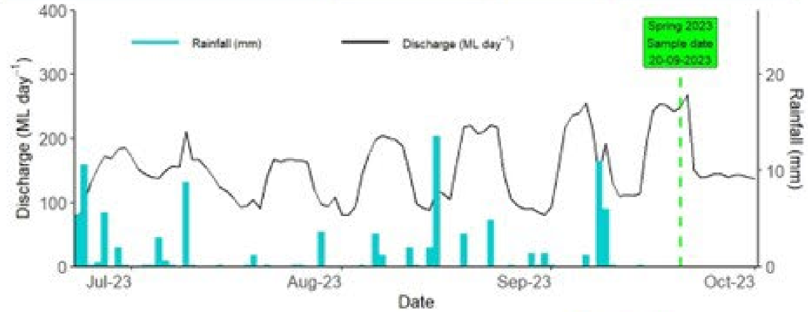
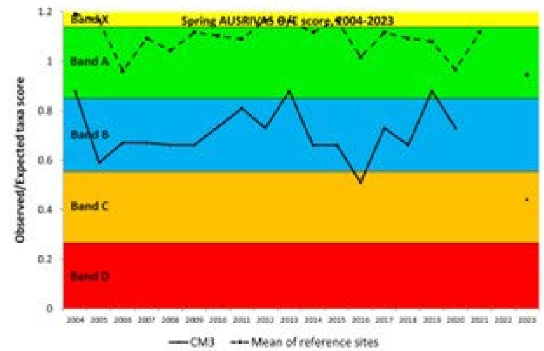
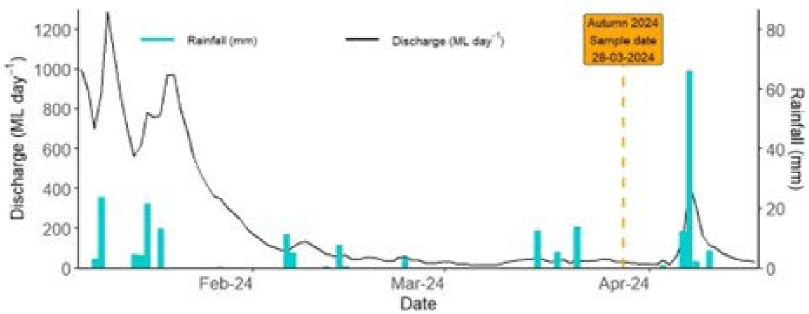
CM3 - Spring 2023 - Autumn 2024

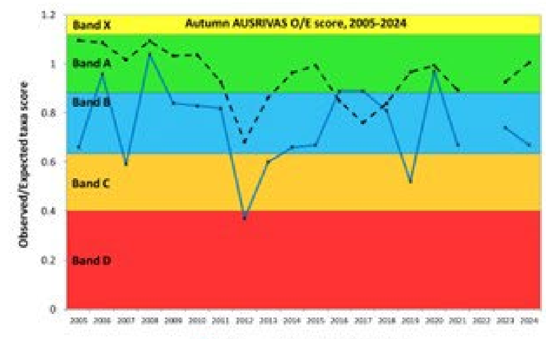
Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2023	Autumn 2024	Objective met?
AUSRIVAS band A	Band C	Band B	Not for either assessment
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes, for both assessment









* Denotes values outside guideline levels

Sampling season	Temp. (^{o}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 2023	14.93	37	7.38	9.49	0.6	19	0.007	0.007	0.1	0.007
Autumn 2024	15.6	44	6.84	9.56	1.9	15	0.008	0.032	0.12	0.006

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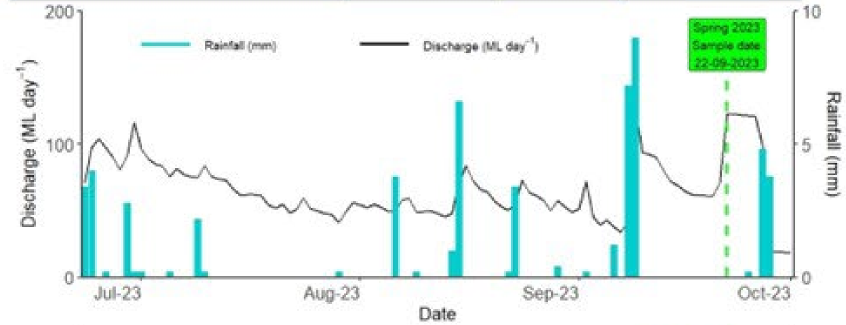
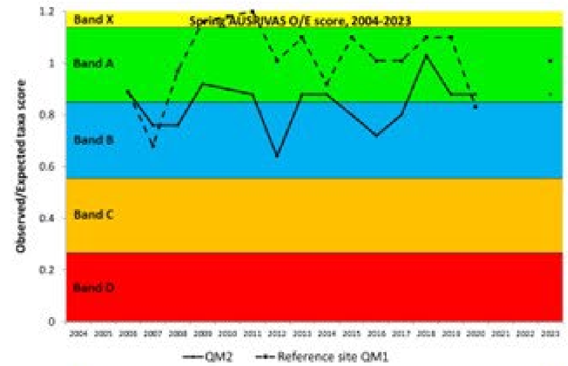
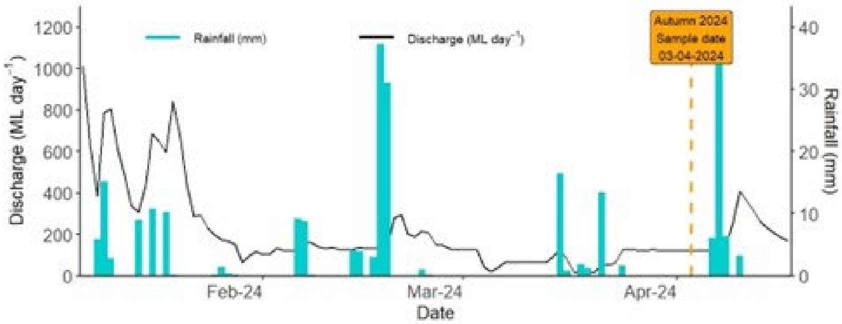
QM2 - Spring 2023 - Autumn 2024

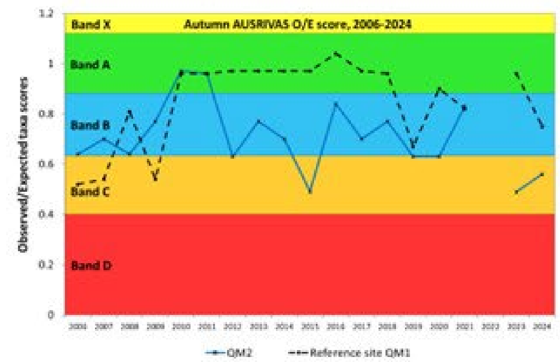
Downstream of Googong Dam

Environmental flow ecological objective	Spring 2023	Autumn 2024	Objective met?
AUSRIVAS band A	Band A	Band C	Only for spring 2023
<20% filamentous algae cover in riffle habitat	<20%	<10%	Yes, for both assessment









* 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 2023	13.2	116	7.85	10.71	0.0	30	0.011	0.004	0.48	0.009
Autumn 2024	19.8	123	7.42	9.49	1.0	32	0.019	0.049	0.41	0.010

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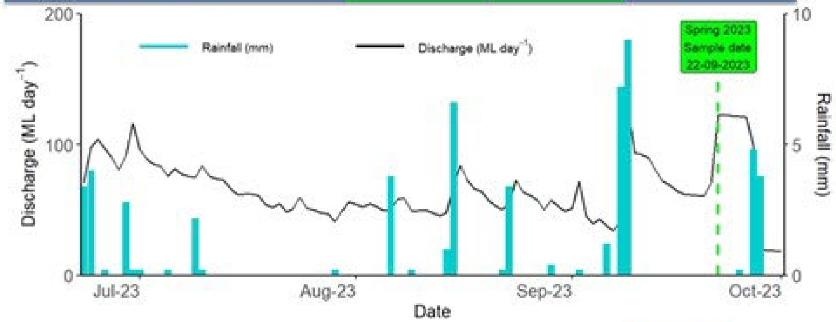
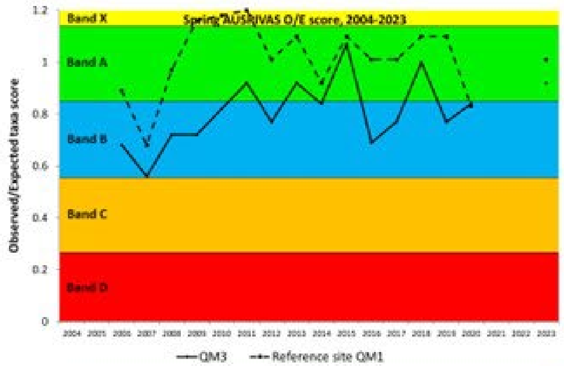
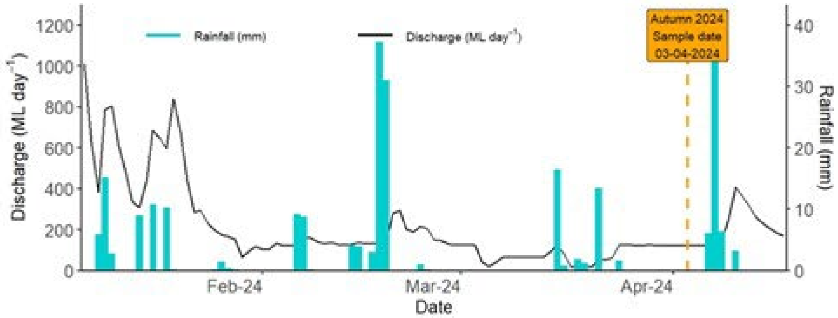
QM3 - Spring 2023 - Autumn 2024

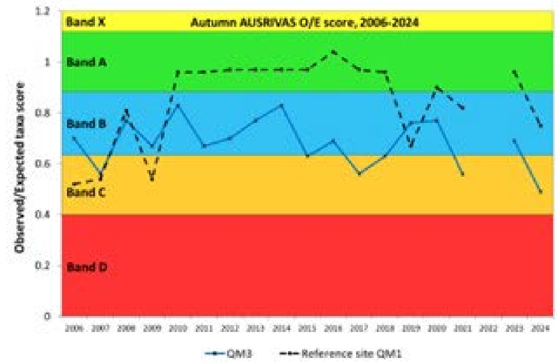
2km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2023	Autumn 2024	Objective met?
AUSRIVAS band A	Band A	Band C	Only for spring 2023
<20% filamentous algae cover in riffle habitat	<20%	<10%	Yes, for both assessment









* 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 2023	13.32	255	8.18	10.76	0.2	56	0.025	0.065	0.44	0.008
Autumn 2024	18.54	187	7.90	9.58	1.0	60	0.012	0.046	0.38	0.011

APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2023

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

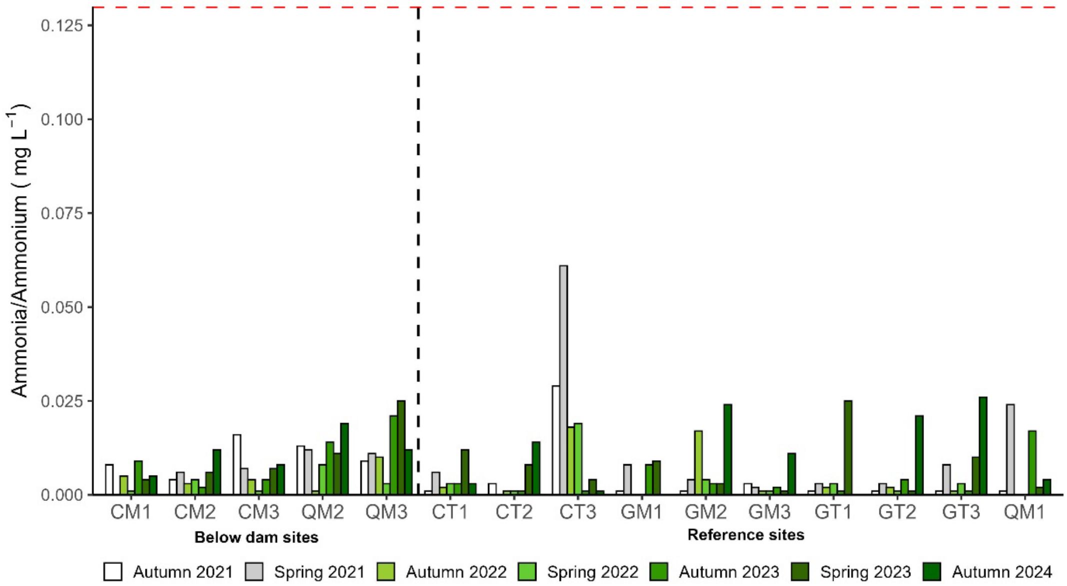
CLASS **Order** Family *Sub-family*	**Signal 2 Grade**	**Test sites**					**Reference sites**									
		CM1	**CM2**	**CM3**	**QM2**	**QM3**	**CT1**	**CT2**	**CT3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**	**QM1**
Lymnaeidae	**1**				6											
Ancylidae	**4**					4	1	4								
Physidae	**1**									1						
Dugesiidae	**2**			3										1		
OLIGOCHAETA	**2**	6	7	62	41	71	3	100	89	22	1	18	11	8	11	19
ACARINA	**6**	14	5	5	8	29	2	2	6	5	2	7	4	1	7	19
Coleoptera																
Scirtidae Sp.	**6**												2	11	1	
Elmidae (Adult)	**7**						2	2	1	4		1	2	1	2	
Elmidae (Larvae)	**7**	15				1	10	8	1	6		7	11	3	1	15
Psephenidae	**6**	2					1	1						1		
Ptilodactylidae	**10**						1									
Diptera																
Tanyderidae	**6**	1														
Tipulidae	**5**	1			1	17	2		1	1	1	2	4	5	11	1
Ceratopogonidae	**4**						1	1								
Simuliidae	**5**		1		23	32			98		2	1	2	1		3
Empididae	**5**	7	2				1		1			1	2		2	1
Diamesinae	**6**	1	2			1		3	1		1	2				
Aphroteniinae	**8**							2		3			3	3	1	
Podonominae	**6**	1					2	4					1	1	3	
Tanypodinae	**4**				1			1				3	5	1		1
Orthocladiinae	**4**	20	41	74	76	32	7	39	30	4	8	36	8	2	2	29
Chironominae	**3**	1	19	23	9	2	13	16	2	1	6	8	8	7	4	3
Ephemeroptera																
Baetidae	**5**	2	1	2	1	3	5	7		18	9	11	15	13	6	
Coloburiscidae	**8**		1				7		2	4	7	12		1	2	
Leptophlebiidae	**8**						45	21		77	71	20	13	23	45	25
Caenidae	**4**		1		29	25	2			4		1	3	3	7	
Megaloptera																
Corydalidae	**7**	8				1										
Odonata																
Telephlebiidae	**9**															1
Plecoptera																
Gripopterygidae	**8**	127	123	7	2	6	45	4	6	24	53	33	81	58	73	96
Trichoptera																
Hydrobiosidae	**8**				1	1		2	3	3			1	1	1	1
Philorheithridae	**8**	1														
Glossosomatidae	**9**						4	1		36	24	6	12	12	22	3
Hydroptilidae	**8**	1	4		1	1	1				4	3	4	1		6
Philopotamidae	**8**						2									1
Hydropsychidae	**6**	2	2			1	2	1					1	2	2	1
Ecnomidae	**4**			17		1										
Conoesucidae	**8**	4	5				23	40		11	13	10	29	1	29	17
Calamoceratidae	**7**														1	
Leptoceridae	**6**						1	3		16	7	4	39	38	32	
No. of individuals		214	214	193	199	228	183	262	241	240	209	186	261	199	265	242
No. of taxa		18	14	8	13	17	24	21	13	18	15	20	23	25	22	18
% of sub-sample		15	4	9	3	4	5	3	1	2	3	2	3	3	3	2
Whole sample estimate		**1427**	**5350**	**2144**	**6633**	**5700**	**3660**	**8733**	**24100**	**12000**	**6967**	**9300**	**8700**	**6633**	**8833**	**12100**

APPENDIX 2: MACROINVERTEBRATE TAXA AUTUMN 2024

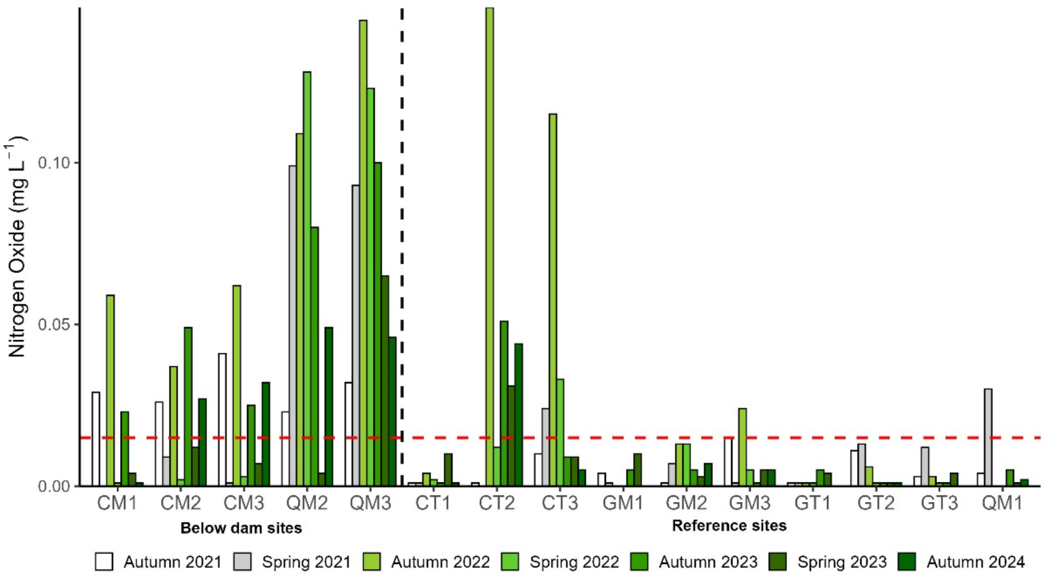
Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2024 at each of the study sites. **NOTE:** Orange highlight indicates maximum taxa of the site for the sampling season.

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										Site inaccessible			Site inaccessible			
Planorbidae	4					1										
Bivalvia																
Sphaeriidae	5	2	2			1	3	26				1		6	1	2
Oligochaeta	2	1	5	48	1	11	4	3	10		4	8		1	2	6
Acarina	6	1		1	1		1	7			3	2			2	
Coleoptera																
Scirtidae Sp.	6							1			6			1	4	
Elmidae (Adult)	7		1				1							1		1
Elmidae (Larvae)	7	3	1			1	13	6	9		1	3		2	5	17
Psephenidae	6											1		1		1
Ptilodactylidae	10						1									
Diptera																
Tanyderidae	6														2	
Tipulidae	5	2	2	1				1	1		4				1	
Ceratopogonidae	4											1				1
Chrysomelidae	2						1									
Simuliidae	5	24	63	39	27	118	2	2	37		57	32		8	30	9
Athericidae	8						2									
Empididae	5	1					3					1				
Aphroteniinae	**8**							2	1							
Tanypodinae	**4**							4			1	1		3	5	
Orthocladiinae	**4**	4	21	24	12	18	14	18	9		12	10		11	6	12
Chironominae	**3**		8	1	6		1	1	1		32	23		52	18	18
Ephemeroptera																
Baetidae	**5**	50	15	106	83	38	33	12	105		38	29		61	51	47
Coloburiscidae	**8**										1	27				
Leptophlebiidae	**8**	19	1				41	60	2		85	38		36	61	43
Caenidae	**4**	7	8	2	9	29	3	2	14			6		6	4	22
Megaloptera																
Corydalidae	**7**	2	2	1	1	1	7									4
Odonata																
Telephlebiidae	**9**	1		1				1	1						1	
Gomphidae	5							1						2		
Plecoptera																
Gripopterygidae	8	6	9	1			31	3			15	13		9	12	
Trichoptera																
Hydrobiosidae	8		2	2			1	2	1		7	2		8		1
Helicopsychidae	8													1	2	25
Hydroptilidae	8		10					2			1				1	
Philopotamidae	8			3	1			1	1		6	1		6	2	19
Polycentropogonidae	7														1	
Hydropsychidae	6	82	57	41	61	27	8	3	26		6	8		2	1	
Ecnomidae	4	4	13	2	3	3	6	1	1		2	2		3	7	3
Conoesucidae	8	2	11				14	11				5		6	3	2
Calamoceratidae	7							20						2	2	
Tasimiidae	8						4							1		
Leptoceridae	6							15			1	1		21	8	
No. of individuals		211	231	273	205	248	194	205	219		282	215		250	232	233
No. of taxa		17	18	15	11	11	22	25	15		19	22		24	25	18
% of sub-sample		4	2	4	3	2	3	4	5		1	3		2	2	2
Whole sample estimate		**5275**	**11550**	**6825**	**6833**	**12400**	**6467**	**5125**	**4380**		**28200**	**7167**		**12500**	**11600**	**11650**

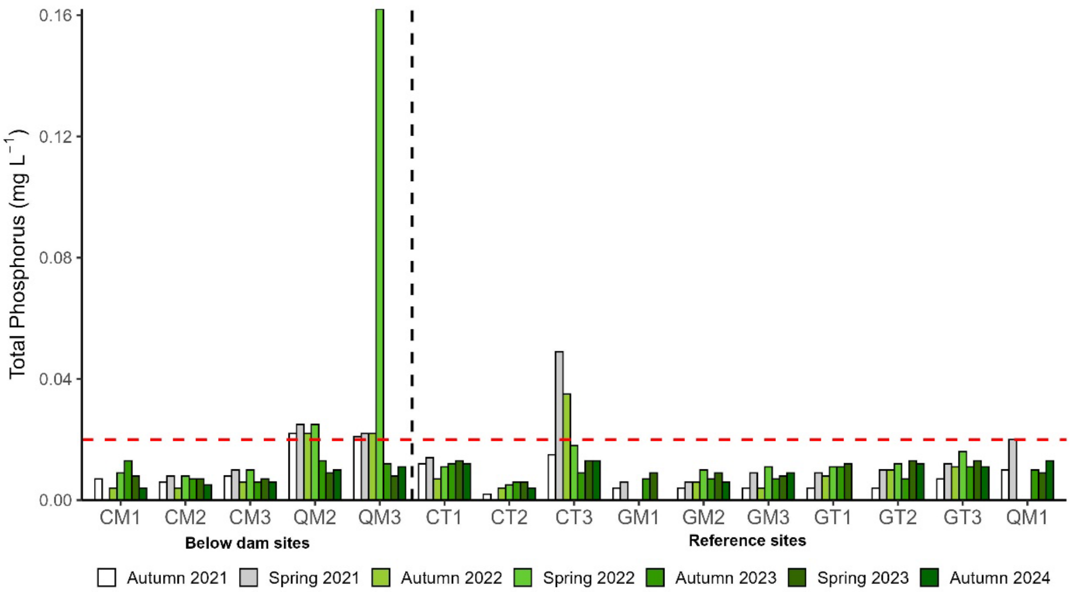
APPENDIX 3: WATER QUALITY FIGURES



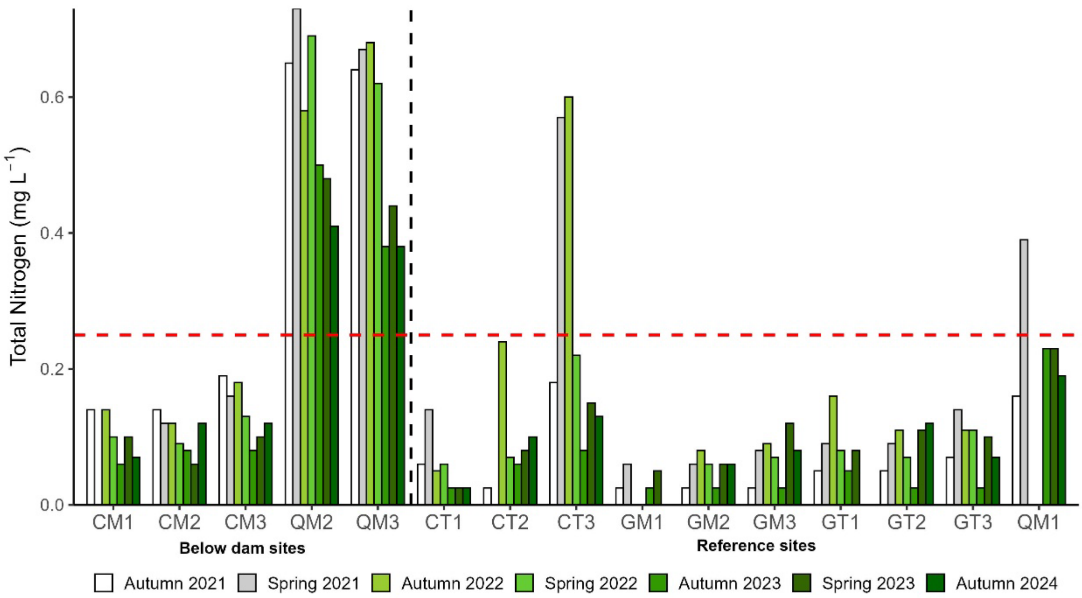
Ammonium (NH_4^+) concentration at all sites from autumn 2021 to autumn 2024. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline maximum concentration for ammonium (NH_4^+) is dashed line and shaded red.



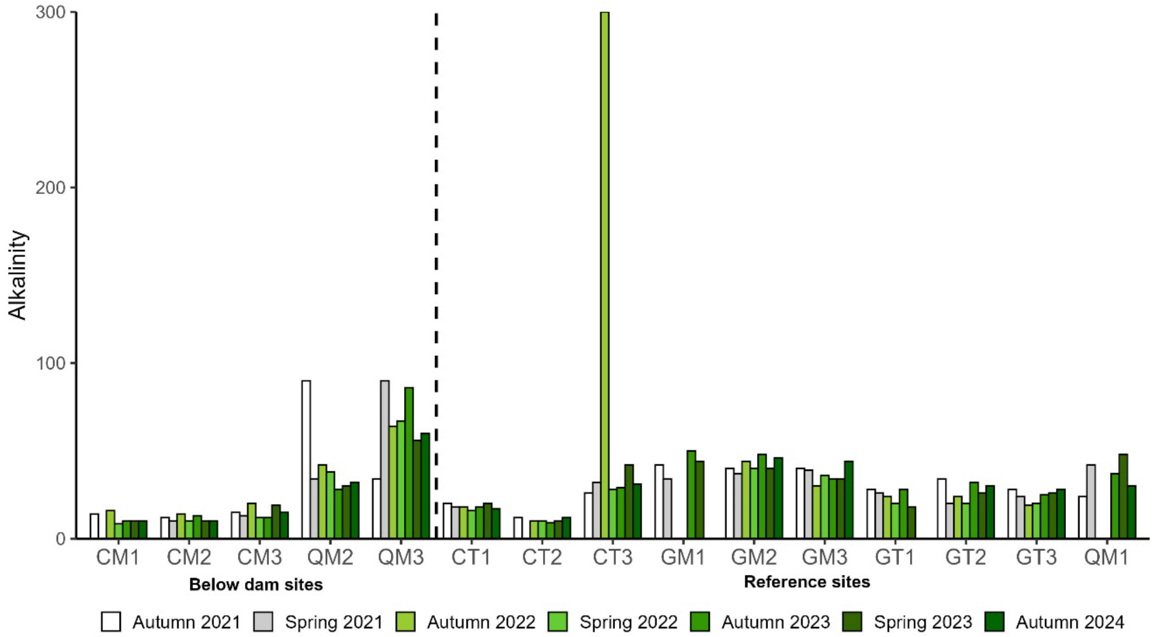
Nitrogen oxide concentrations at all sites from autumn 2021 to autumn 2024. Values below the minimum detectable limit of 0.002 mg L-1 are shown at 0.001 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for nitrogen oxide is dashed line and shaded red.



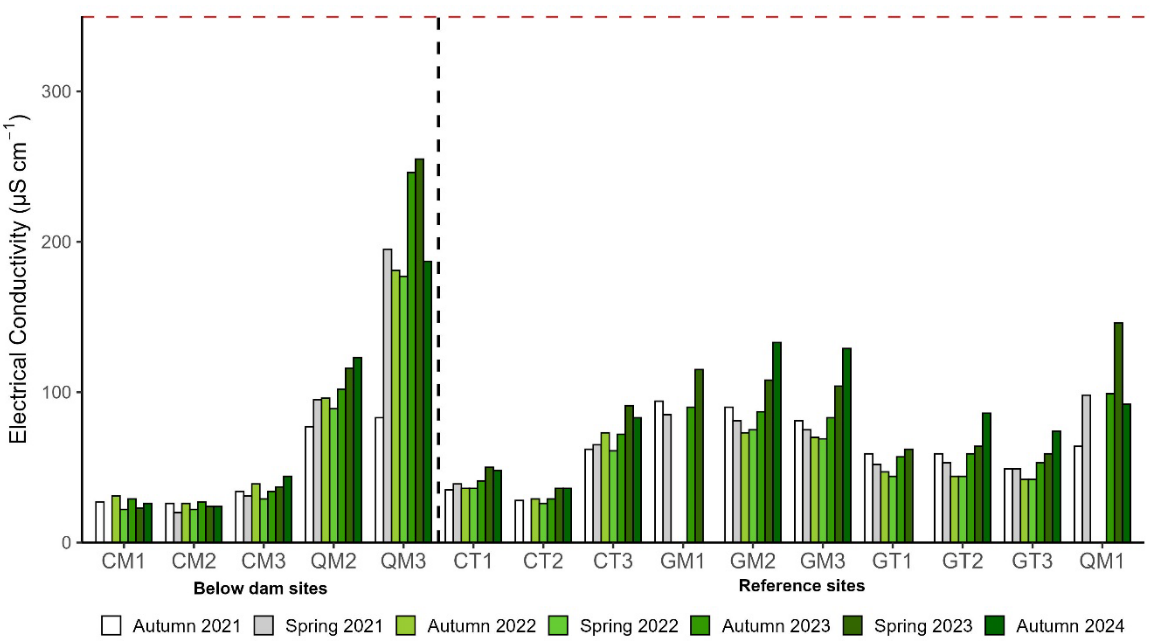
Total phosphorus concentrations at all sites from autumn 2021 to autumn 2024. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total phosphorus is dashed line and shaded red.



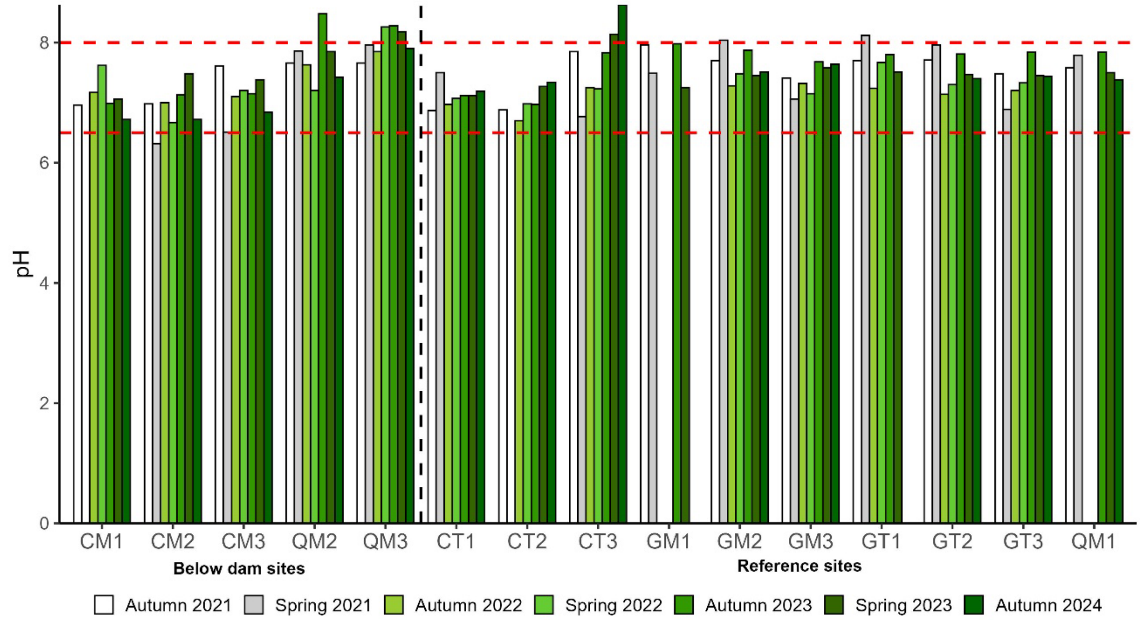
Total nitrogen concentrations at all sites from autumn 2021 to autumn 2024. Values below the minimum detectable limit of 0.01 mg L-1 are shown at 0.005 mg L-1. The ANZECC/ARMCANZ (2000) guideline maximum concentration for total nitrogen is dashed line and shaded red.



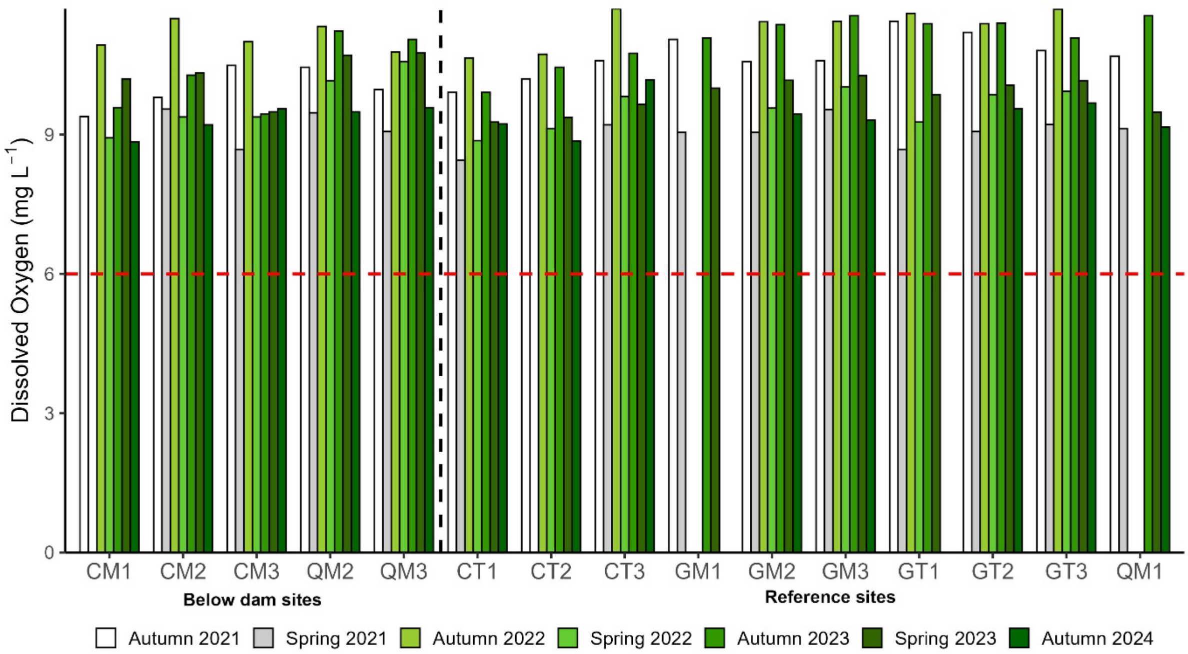
Alkalinity at all sites from autumn 2021 to autumn 2024.



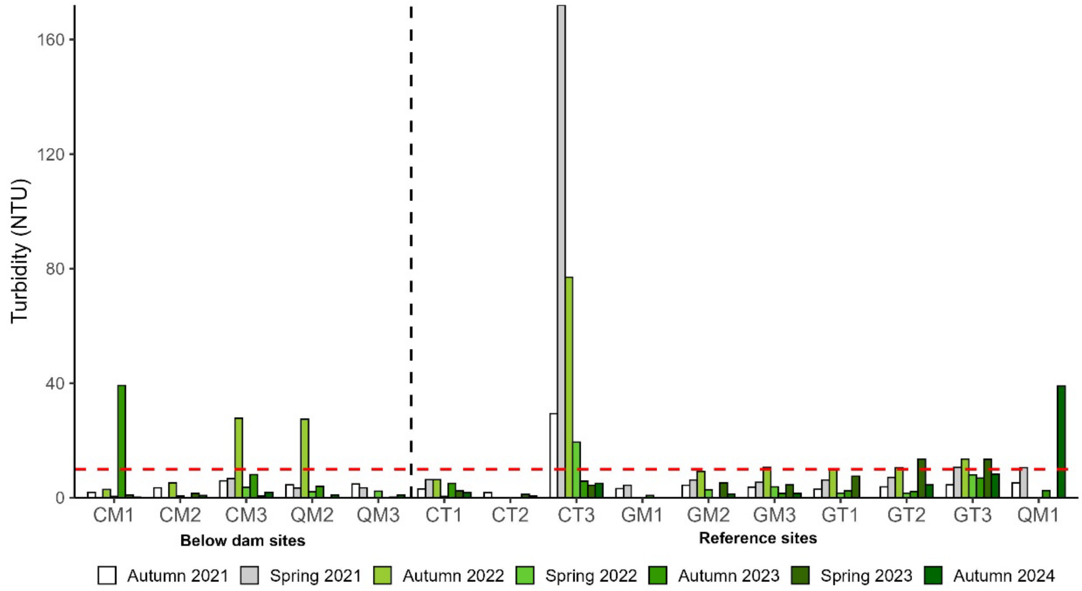
Electrical conductivity at all sites from autumn 2021 to autumn 2024. The ANZECC/ARMCANZ (2000) guideline for maximum electrical conductivity is dashed line and shaded red.



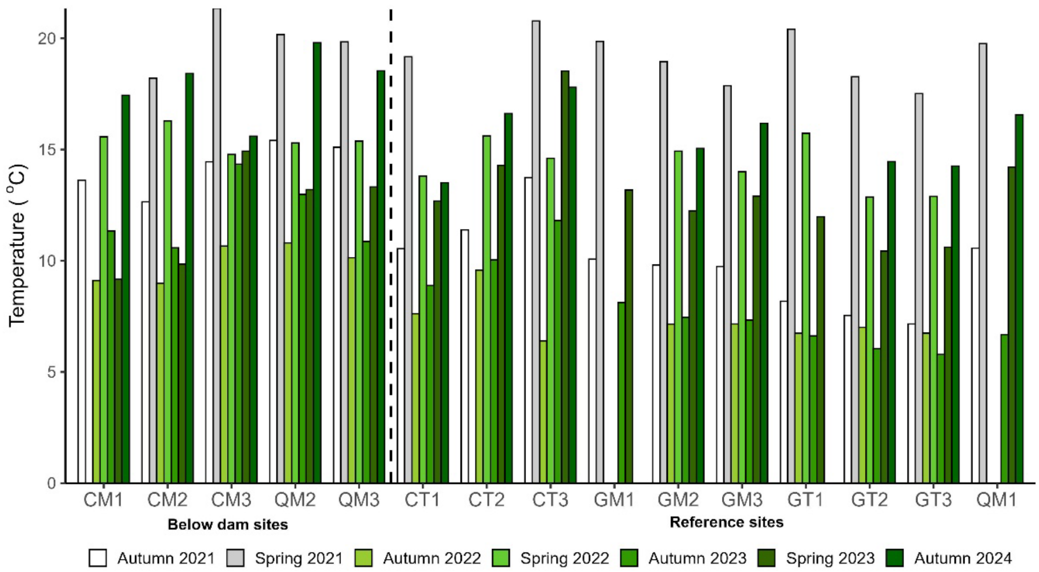
pH at all sites from autumn 2021 to autumn 2024. The ANZECC/ARMCANZ (2000) guideline range for pH are dashed lines and shaded red.



Dissolved oxygen concentration at all sites from autumn 2021 to autumn 2024. The minimum guideline for dissolved oxygen is dashed line and shaded red (Environment Protection Regulation SL2005-38).



Turbidity at all sites from autumn 2021 to autumn 2024. The guideline for maximum turbidity is dashed line and shaded red (Environment Protection Regulation SL2005-38).



Water temperature at all sites from autumn 2021 to autumn 2024.