UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

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

Spring 2014

Prepared for ACTEW Water

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ACTEW Water - Water Quality Monitoring Program

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Executive summary

Background and study objective

- The Cotter and Queanbeyan Rivers are regulated to supply water to the ACT. Ecological assessment is undertaken in spring and autumn each year to evaluate river response to environmental flow releases to the Cotter and Queanbeyan Rivers, and to meet the requirements of Licence No. WU67 – Licence to Take Water. 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 ACTEW'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.

Spring 2014 results and conclusions

- In spring 2014 water quality parameters were generally within the recommended water quality guideline levels at below dam test sites and reference sites. Nitrogen oxide and total nitrogen were above guideline concentrations at sites on the Queanbeyan River. Above guideline nitrogen oxide and total nitrogen concentrations downstream of Googong Dam are likely to be the result of water spilling from the dam and nitrogen concentrations in the catchment upstream of Googong Dam (e.g. site QM1). Total phosphorus concentrations and turbidity were within the guideline concentration at all sites except site CM3 (below Cotter Dam). The higher total phosphorus and turbidity at site CM3 compared to other sites is unlikely to be elevated as a direct consequence of the presence or operation of Cotter Dam and possibly a result of higher turbidity Murrumbidgee River water transferred via M2C. Click here for more information

- Only site CM1, below Corin Dam, did not met the environmental flow ecological objective of <20% filamentous algae cover of riffle habitats. The current Corin Dam flow release strategy has proven effective in limiting filamentous algae cover in downstream riffle habitats during previous assessments. This result is likely a consequence of the phase of the flow release cycle in which spring 2014 sampling was conducted, and may not provide an accurate representation of conditions throughout the whole of spring 2014. For example, the increased filamentous algae growth downstream of Corin Dam is likely because of lower discharges before spring 2014 sampling (approx. 100-150 ML d^{-1}) than autumn 2014 sampling (200-550 ML d^{-1}), which have facilitated increased filamentous algae growth. However, compared with spring 2013 the percent cover is much lower (80% in spring 2013) where flow releases were < 100 ML d^{-1} for ~1 month before sampling). Click here for more information

Site	Within environmental flow ecological objective Riffle filamentous algae cover (%)	Outside environmental flow ecological objective AUSRIVAS band (O/E score)
CM1 (Corin Dam)	25	B
CM2 (Bendora Dam)	< 10	A
CM3 (Cotter Dam)	< 10	B
QM2 (Googong Dam)	< 10	A
QM3 (Googong Dam)	< 10	B

- Sites CM2 and QM2 below Bendora and Googong Dams were the only test sites to meet the environmental flow ecological objective of AUSRIVAS band A assessment in spring 2014. Click here for more information

- Test sites below Corin, Cotter, and Googong (QM3) Dams were all assessed as AUSRIVAS band B (*significantly impaired*). These assessments were within the range of biological condition variability that is characteristic of these below dam test sites. Click here for more information.

- Reference sites on the Goodradigbee River and upstream of Googong Reservoir on the Queanbeyan River were all in reference condition (AUSRIVAS Band A) in spring 2014.Assessments of tributaries within the Cotter and Goodradigbee River catchments indicated that these catchments were also in reference condition. Click here for more information.

- Results of the spring 2014 assessment indicate that the ecological effects of dams on the Cotter and Queanbeyan Rivers persist under the current environmental flow regime; however, the degree of biological impairment downstream of the dams remains stable and relatively minor.

Project recommendations

- Higher than normal and variable flows downstream of Bendora and Googong Dams before spring 2014 sampling coincided with the sites CM2 and QM2 meeting the environmental flow ecological objective of AUSRIVAS band A. As was the case in the autumn 2014 assessment for site CM1 downstream Corin Dam, these results provide further evidence that increasing the volume and variability of environmental flow releases from dams on the Cotter and Queanbeyan Rivers will assist in achieving environmental flow ecological objectives.

- Based on the results of this spring assessment and the 2013 spring assessment, it is evident that filamentous algae cover begins to increase below Corin dam when flows are <150 ML d^{-1} .Brief releases of this magnitude may be an effective management tool for controlling accumulated filamentous algae between scheduled releases, if and when required).

- The Murrumbidgee River water released via the M2C transfer pipeline is continuing to possibly influence macroinvertebrate community composition downstream of Cotter Dam (e.g. higher concentrations of fine particulate matter in Murrumbidgee River water resulting in large abundance of filter feeding Simuliidae). Site CM3 is regularly being assessed as biologically impaired and further investigation into the cause of this impairment may be required to ensure the ecological and amenity objectives of this river reach can be adequately maintained under the M2C environmental flow release strategy.

Introduction

Water diversions and modified flow regimes can result in deterioration of both the ecological function and water quality of Australian streams (Arthington and Pusey 2003). Many of the aquatic ecosystems in the Australian Capital Territory (ACT) are subject to flow regulation. Environmental flow guidelines were introduced in 1999 as part of the Water Resources Act 1998 and redefined in 2006 and 2013 (ACT Government 2006, 2013). 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 2013). 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 2013). 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 resources are protected.

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 (autumn and spring) of macroinvertebrate assemblages, algae (periphyton and filamentous algae) and water quality. Sampling is conducted during autumn and spring of each year to evaluate the condition of river habitat downstream of dams on both the Cotter and Queanbeyan Rivers. A comparison is made with the condition of reference sites on the unregulated Goodradigbee River and the Queanbeyan River upstream of Googong Dam.

Tributaries of the Cotter and Goodradigbee Rivers are also sampled to determine whether impacts on biological condition in the Cotter River are 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, and Cotter river test sites will be in poorer biological condition than reference sites on the Goodradigbee River, regardless of river regulation effects. However, if Cotter and Goodradigbee River tributaries are in similar biological condition, then differences biological condition between Goodradigbee and Cotter River sites may be attributed to river regulation effects.

This sampling and reporting program satisfies ACTEW's License 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 links into the adaptive management framework applied in the water supply catchments.

This report provides an assessment of sites downstream of the dams on the Cotter and Queanbeyan Rivers in spring 2014, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments. Site summary sheets outlining the outcomes of the spring 2014 assessment 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 2006). Conservation of ecological values of the river is an important consideration in the ongoing management of the Cotter River. The river is regulated by three dams, the Cotter Dam, Bendora Dam and Corin Dam.

The Cotter River catchment is largely free of pollutants and human disturbance aside from regulation, which provides the opportunity to study the effects of flow releases from the dams with minimal confounding from other factors often present in environmental investigations (Chester and Norris 2006; Nichols *et al.* 2006). The Murrumbidgee to Cotter pumping augmentation (M2C) project has been implemented to provide an environmental flow transfer capability (up to 40ML/d) for the Cotter River reach below Cotter Dam by pumping water from Murrumbidgee River.

The Queanbeyan River is a fifth order stream (at all sampling sites), and is regulated by Googong Dam approximately 90 km from its source to secure the water supply for the ACT and Queanbeyan. Compared to the Cotter River catchment, the Googong catchment is less protected and is therefore subject to disturbance in addition to flow regulation.

The Goodradigbee River is also a fifth order stream (at all sampling sites) and remains largely unregulated until it reaches Burrinjuck Dam (approximately 50 km downstream of the study area). This river constitutes an appropriate reference site for the study because it has similar environmental characteristics (substrate and chemistry) but is largely unregulated (Norris and Nichols 2011).

Fifteen sites were sampled for biological, physical and chemical variables between the 1st and 3rd October 2014 (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.

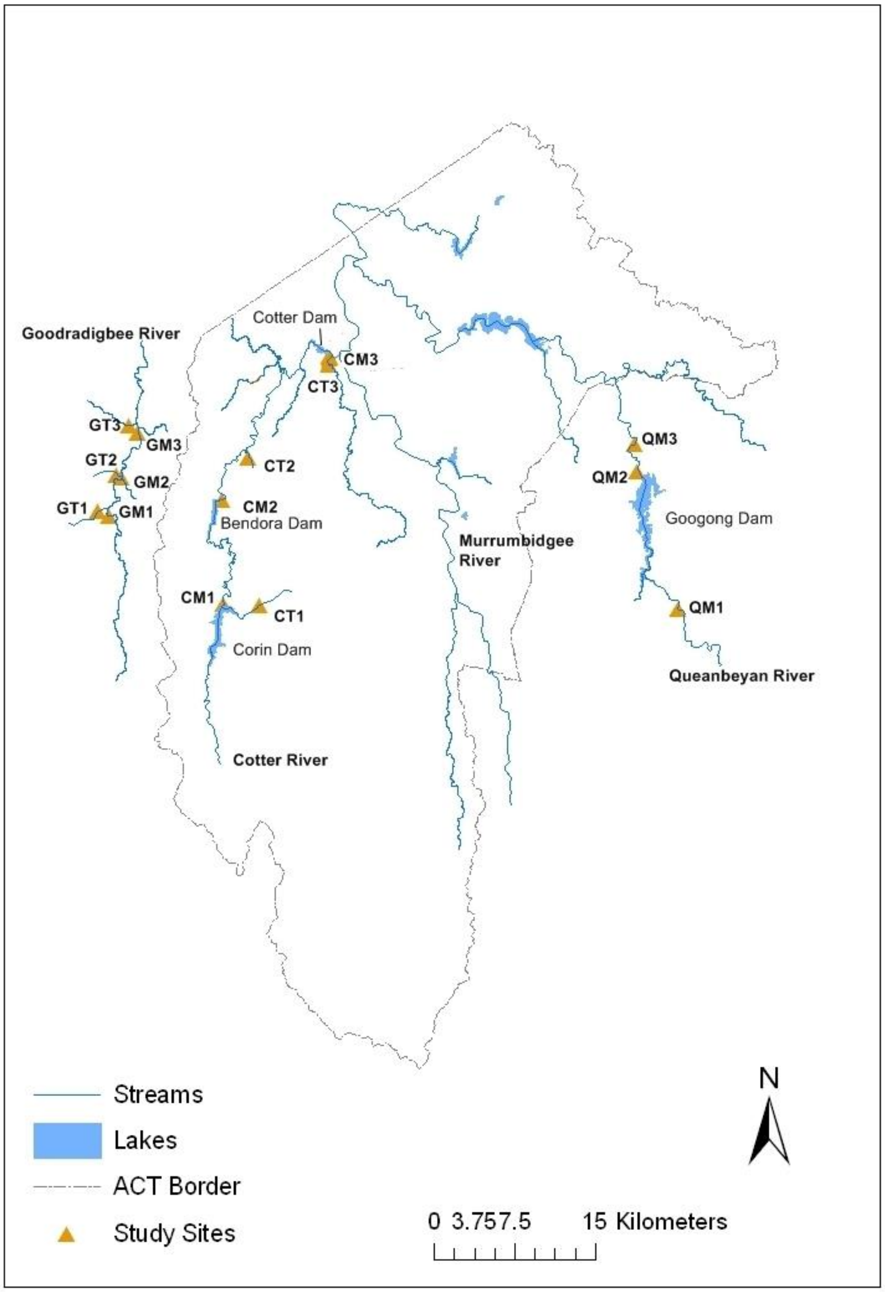

Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the Below Dams Assessment Program, spring 2014.

Site	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500m downstream of Corin Dam	900	31	4
CM2	Cotter	500 m downstream of Bendora Dam	700	51	4
CM3	Cotter	100m upstream Paddy's River confluence	500	75	5
CT1	Kangaroo Ck	50m downstream Corin Road crossing	900	7.3	3
CT2	Burkes Ck	50 m upstream of confluence with Cotter River	680	4.5	3
CT3	Paddys	500 m upstream of confluence with Cotter River	500	48	4
GM1	Goodradigbee	20 m upstream of confluence with Cooleman Ck	680	38	5
GM2	Goodradigbee	20 m upstream of confluence with Bull Flat Ck	650	42	5
GM3	Goodradigbee	100 m upstream of Brindabella Bridge	620	48	5
GT1	Cooleman Ck	50 m upstream of Long Plain Road crossing	680	17.9	4
GT2	Bull Flat Ck	Immediately upstream of Crace Lane crossing	650	15.6	4
GT3	Bramina Ck	30 m upstream of Brindabella Road crossing	630	18	5
QM1	Queanbeyan	12 km upstream of Googong Dam near 'Hayshed Pool'	720	72	5
QM2	Queanbeyan	1 km downstream of Googong Dam	590	91.6	5
QM3	Queanbeyan	2 km downstream of Googong Dam at Wickerslack Lane	600	92.6	5

Hydrometric data

Mean daily flow data for each of the below dam test sites (provided by ACTEW Water) and Goodradigbee River reference sites (obtained from the NSW Department of Primary Industries Office of Water, gauging station 410088) was used to determine changes in river flow for the months preceding sampling. Daily rainfall data for Canberra was obtained from the Bureau of Meteorology.

Physical and chemical water quality assessment

Water temperature, dissolved oxygen, pH, electrical conductivity and turbidity were measured at all sites using a calibrated Horiba U-52 water quality meter. Total alkalinity was calculated by field titration to an end point of pH 4.5 (A.P.H.A. 2005). Two 50ml water samples were collected from each site to measure ammonium, nitrogen oxide, total nitrogen and total phosphorus concentrations. Samples were analysed following methods from the Standard Methods for the Examination of Water and Wastewater (A.P.H.A 2005).

Water quality guideline values for the Cotter, Googong and Goodradigbee catchments were based on the most conservative values from the Environment Protection Regulations SL2005-38 (which cover a variety of water uses and environmental values for each river reach in the ACT), and the ANZECC and ARMCANZ (2000) water quality guidelines for aquatic ecosystem protection in south-east Australian upland rivers. While comparisons with water quality guidelines are not required as part of the environmental flow guidelines, and are used only as a guide, they provide a useful tool for the protection of ecosystems (which is a primary objective of environmental flows). Only the upper guideline value for conductivity was used because ion concentrations below the minimum guideline level are unlikely to impact on the ecological condition of streams.

Table 2: Water quality guideline values from the Environment Protection Regulations SL2005-38* and ANZECC and ARMCANZ (2000)**. N/A *= guideline value not available.*

Measure	Units	Guideline value
Alkalinity	mg L^{-1}	N/A
Temperature	ºC	N/A
Conductivity**	µS cm^{-1}	<350
pH**	N/A	6.5-8
Dissolved oxygen *	mg L^{-1}	>6
Turbidity*	NTU	<10
Ammonium (NH_4^+)**	mg L^{-1}	<0.13
Nitrogen oxides**	mg L^{-1}	<0.015
Total phosphorus**	mg L^{-1}	<0.02
Total nitrogen**	mg L^{-1}	<0.25

Periphyton and filamentous algae

Visual observations

Periphyton and filamentous algae visual observations within riffle habitats were recorded following methods outlined in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000, http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

Ash-free dry mass and chlorophyll-a

Twelve replicate periphyton samples were collected at each of the Cotter and Goodradigbee River sites and site QM2 on the Queanbeyan River using a syringe sampler based on a design similar to that described by Loeb (1981). Samples from each site were measured for Ash-free dry mass (AFDM) and chlorophyll-a content in accordance with methods described in A.P.H.A (2005).

Macroinvertebrate sample collection and processing

Benthic macroinvertebrates were sampled from the riffle habitat following National River Health Program protocols presented in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000; http://ausrivas.ewater.com.au/ausrivas/index.php/manuals-a-datasheets?id=54).

In the laboratory, preserved samples were placed in a sub-sampling box comprising of 100 cells (Marchant 1989) and agitated until evenly distributed. Contents of each cell were removed until approximately 200 animals from each sample were identified (Parsons and Norris 1996). Macroinvertebrates were identified to the family taxonomic level using keys listed by Hawking (2000), except Chironomidae, which were identified to sub-family, aquatic worms (Oligochaeta) and mites (Acarina), which were identified to class. After the ~200 macroinvertebrates were sub-sampled, the remaining unsorted sample was visually scanned to identify taxa which were not found in the ~200 animal sub-sample (Nichols *et al*. 2000). QA/QC procedures were implemented for macroinvertebrate sample processing following those outlined in Nichols *et al*. (2000).

AUSRIVAS (AUStralian RIVer Assessment System)

AUSRIVAS predicts the macroinvertebrate fauna expected to occur at a site with specific environmental characteristics, in the absence of environmental stress. The fauna observed (O) at a site can then be compared to fauna expected (E), with the deviation between the two providing an indication of biological condition (Coysh *et al*. 2000; http://ausrivas.ewater.com.au). A site displaying no biological impairment should have an O/E ratio close to one. The O/E ratio will decrease as the macroinvertebrate assemblage and richness are adversely affected.

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT autumn riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT autumn riffle model uses a set of 6 habitat variables to predict the macroinvertebrate fauna expected to occur at each site in the absence of disturbance.

AUSRIVAS allocates test site O/E taxa scores to category bands that represent a range in biological conditions to aid interpretation. AUSRIVAS uses five bands, designated X, A, B, C, and D (Table 3). The derivation of model bandwidths is based on the distribution of O/E scores of the reference sites used to create each AUSRIVAS model (Coysh *et al.* 2000*,* http://ausrivas.ewater.com.au).

SIGNAL 2 grades

Habitat disturbance and pollution sensitivity grades (SIGNAL 2) range from 1 to 10, with sensitive taxa receiving higher grades than tolerant taxa. The sensitivity grades are based on taxa tolerance to common pollution types (Chessman 2003).

Data entry and storage

Water quality, habitat, and macroinvertebrate data were entered into an Open Office database. The layout of the database matches the field data sheets to minimise transcription errors. All data were checked for transcription errors using standard two person checking procedures. A backup of files was carried out daily.

Data analysis

To determine if there were significant differences in periphyton AFDM and chlorophyll-a between sites in spring 2014, single factor Analysis of Variance (ANOVA) (SAS 9.3) was used followed by Tukey-Kramer multiple comparisons. A $\log_{10}(x+1)$ transformation was applied to AFDM and chlorophyll-a data, before undertaking the ANOVAs, to ensure the data met the ANOVA assumptions.

Similarity in macroinvertebrate community structure between sites in terms of relative abundance data was assessed using the Bray-Curtis similarity measure and group average cluster analysis. Groups in the cluster analysis were defined at 60% similarity. All data was fourth root transformed before the analysis to down weight the influence of highly abundant taxa. The taxa contributing (up to approximately 70% contribution) to each of the defined groups in the cluster analysis and taxa discriminating between defined groups were determined by a Similarity Percentages (SIMPER) analysis (Clark and Warwick 2001). Discriminating taxa were defined as those having a consistency ratio ≥ 1.4.

Table 3: ACT autumn and spring riffle AUSRIVAS model band descriptions, band width and interpretation.

Band	Band description	Band width	Interpretation
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	**>1.12** (autumn) **>1.14** (spring)	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	SIMILAR TO REFERENCE	**0.88-1.12** (autumn) **0.86-1.14** (spring)	Water quality and/or habitat condition roughly equivalent to reference sites.
B	SIGNIFICANTLY IMPAIRED	**0.64-0.87** (autumn) **0.57-0.85** (spring)	Potential impact either on water quality or habitat quality or both, resulting in loss of taxa.
C	SEVERELY IMPAIRED	**0.40-0.63** (autumn) **0.28-0.56** (spring)	Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	EXTREMELY IMPAIRED	**0-0.39** (autumn) **0-0.27** (spring)	Extremely poor water and/or habitat quality. Highly degraded.

Results

Hydrometric data

Stream discharge in the months leading up to spring 2014 sampling at below dam sites on the Cotter and Queanbeyan Rivers was largely determined by operational requirements and environmental flow guidelines (ACT Government 2013) (Table 4, Figure 2).

From the start of May 2014 to when sampling occurred on the 1st-3rd of October the greatest mean daily discharge of 1718 ML d^{-1} occurred on the Goodradigbee River following a 6 day rainfall event totalling 105mm (BOM; station number 071073)(Figure 2). The greatest mean discharge at a regulated site occurred downstream of Googong Dam at site QM2 (1688 ML d^{-1}) on the 28th of August following 15 mm of rainfall over three days, which resulted in Googong Dam spilling (BOM; station number 070072)(Figure 2).

Water quality

Water quality parameters were generally within ANZECC/ARMCANZ (2000) guidelines at test and reference sites in spring 2014. Exceptions were turbidity at site CM3 below Cotter Dam which was slightly above the guideline turbidity level of 10 NTU; and also pH at site CM3, CT3, QM1, QM2 and QM3 which was slightly above the upper guideline level of 8; nitrogen oxides at sites QM2 and QM3; total nitrogen at sites CM3, QM1, QM2 and QM3; and total phosphorus at site CM3 (Table 5; Appendix 3).

Table 4: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams (ACT Government 2013).

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.

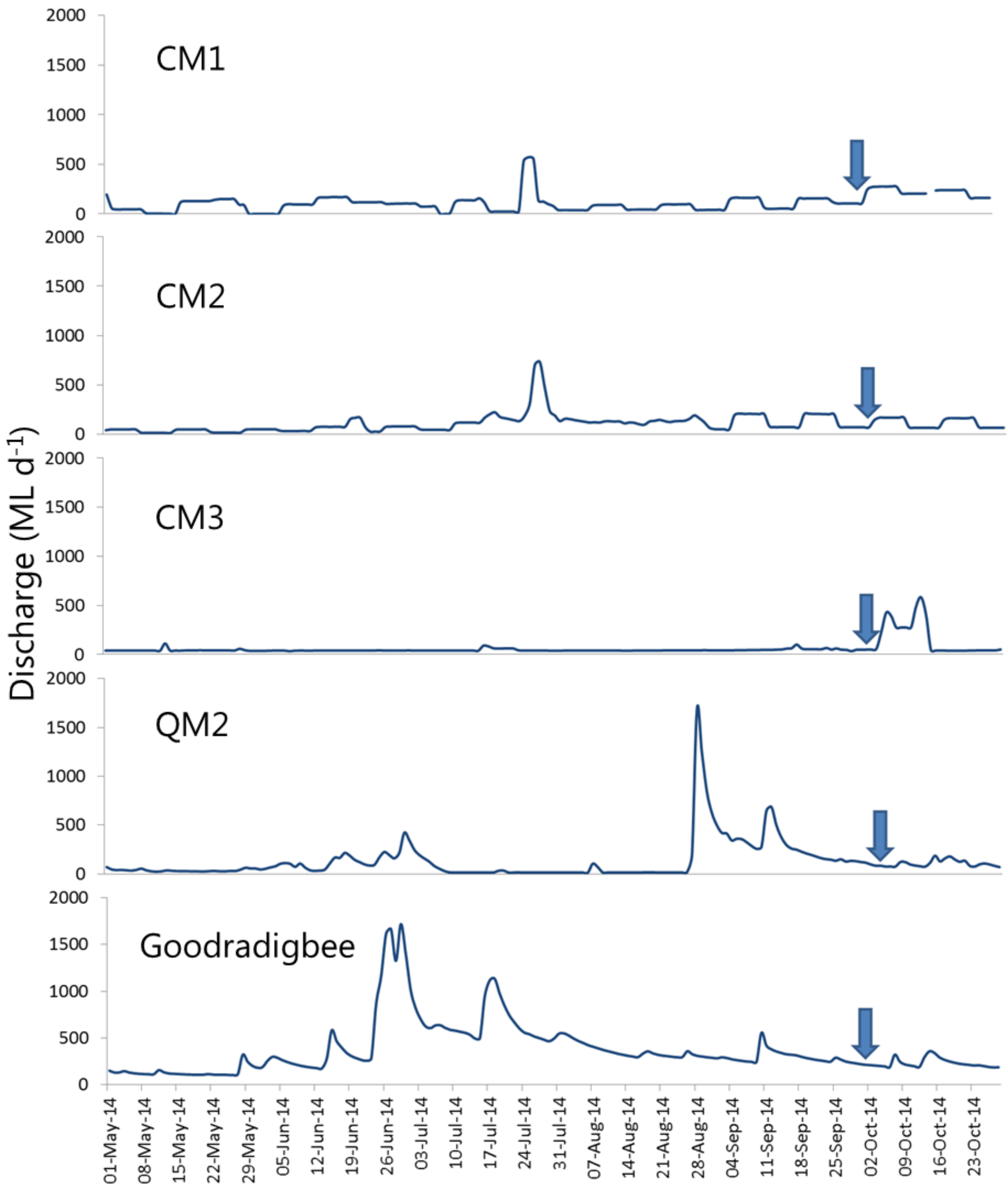

Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), Cotter (CM3, station 410700) and Googong (QM2, station 410760) Dams and in the Goodradigbee River (station 410088) from 1st May 2014 to 31st October 2014. Arrows correspond to spring 2014 sampling dates.

Table 5. Water quality parameters measured at each of the test and reference sites in spring 2014. Values outside guideline levels are shaded orange.

		Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
	Guideline level	NA	350	6.5-8	>6	<10	NA	<0.13	0.015	<0.25	<0.02
Below dam test sites	CM1	10.29	20	6.74	10.23	4.6	10	0.003	0.012	0.12	0.008
	CM2	9.89	21	7.36	11.11	1.8	8	<0.002	<0.002	0.08	0.004
	CM3	16.86	81	8.10	10.42	10.5	34	0.005	0.006	0.26	0.024
	QM2	14.19	91	8.35	11.52	1.0	34	0.010	0.101	0.35	0.012
	QM3	15.26	93	8.33	11.14	1.0	34	0.005	0.076	0.48	0.012
Reference sites	CT1	7.63	39	7.11	11.99	3.3	20	0.003	0.004	0.06	0.016
	CT2	12	30	6.85	10.55	1.2	10	<0.002	<0.002	0.06	0.004
	CT3	18.68	82	8.38	9.49	9.7	34	0.002	<0.002	0.19	0.016
	QM1	14.67	73	8.09	10.2	1.0	32	0.003	<0.002	0.31	0.014
	GM1	13.21	77	8.16	10.17	1.0	38	<0.002	<0.002	<0.05	0.006
	GM2	11.01	76	8.11	10.84	1.0	36	0.006	0.002	0.05	0.007
	GM3	10.91	74	7.79	11.14	0.2	38	<0.002	0.008	0.05	0.007
	GT1	12.35	52	7.73	9.92	1.0	26	0.002	0.007	0.06	0.011
	GT2	10.85	53	8.00	10.29	1.0	30	0.003	<0.002	0.06	0.012
	GT3	8.8	47	6.98	10.85	2.2	22	<0.002	<0.002	0.07	0.012

Periphyton and algae

Field observations of periphyton and filamentous algae cover of riffle habitats were <10% cover at all sites in spring 2014, except site CM1 below Corin Dam which increased from <10% cover in autumn 2014 to 25% cover in spring 2014 (Table 6; Figure 3). However, filamentous algae cover in spring 2014 below Corin Dam was much lower than in spring 2013 (80% Cover; Table 6)The environmental flow objective of <20% cover of riffle habitats was therefore only achieved below Cotter, Bendora and Googong Dams.

Mean ash free dry mass (AFDM) was significantly greater below Corin and Googong Dams compared the Goodradigbee reference sites and below Bendora Dam (F=9.33; DF=6,35; P <.0.0001) (Figure 4). AFDM at below Googong Dam was also significantly greater than below Cotter Dam (Figure 4)

Mean chlorophyll-a concentrations were significantly greater below Corin, Cotter and Googong Dams compared the Goodradigbee reference sites and below Bendora Dam (F=9.33; DF=6,35; P <.0.0001) (Figure 5). Chlorophyll-a concentrations were also significantly greater below Corin and Googong Dams compared to below Cotter Dam (Figure 5).

Table 6: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and Goodradigbee River reference sites, from spring 2011 to spring 2014.

% cover of riffle habitat													
	Periphyton							Filamentous algae					
	Aut-12	Spr-12	Aut-13	Spr-13	Aut-14	Spr-14		Aut-12	Spr-12	Aut-13	Spr-13	Aut-14	Spr-14
CM1	<10	<10	25	10	<10	10		<10	10-35	<10	80	<10	25
CM2	<10	10-35	75	20	<10	5		<10	>90	<10	20	<10	10
CM3	<10	10-35	<10	50	<10	75		<10	<10	<10	<10	<10	10
QM2	<10	<10	<10	20	10	10		<10	<10	<10	<10	<10	10
GM1	<10	<10	15	<10	<10	5		<10	<10	15	<10	<10	<10
GM2	<10	<10	<10	<10	<10	5		<10	<10	<10	<10	<10	<10
GM3	10-35	10-35	<10	10	<10	5		<10	<10	<10	15	<10	<10

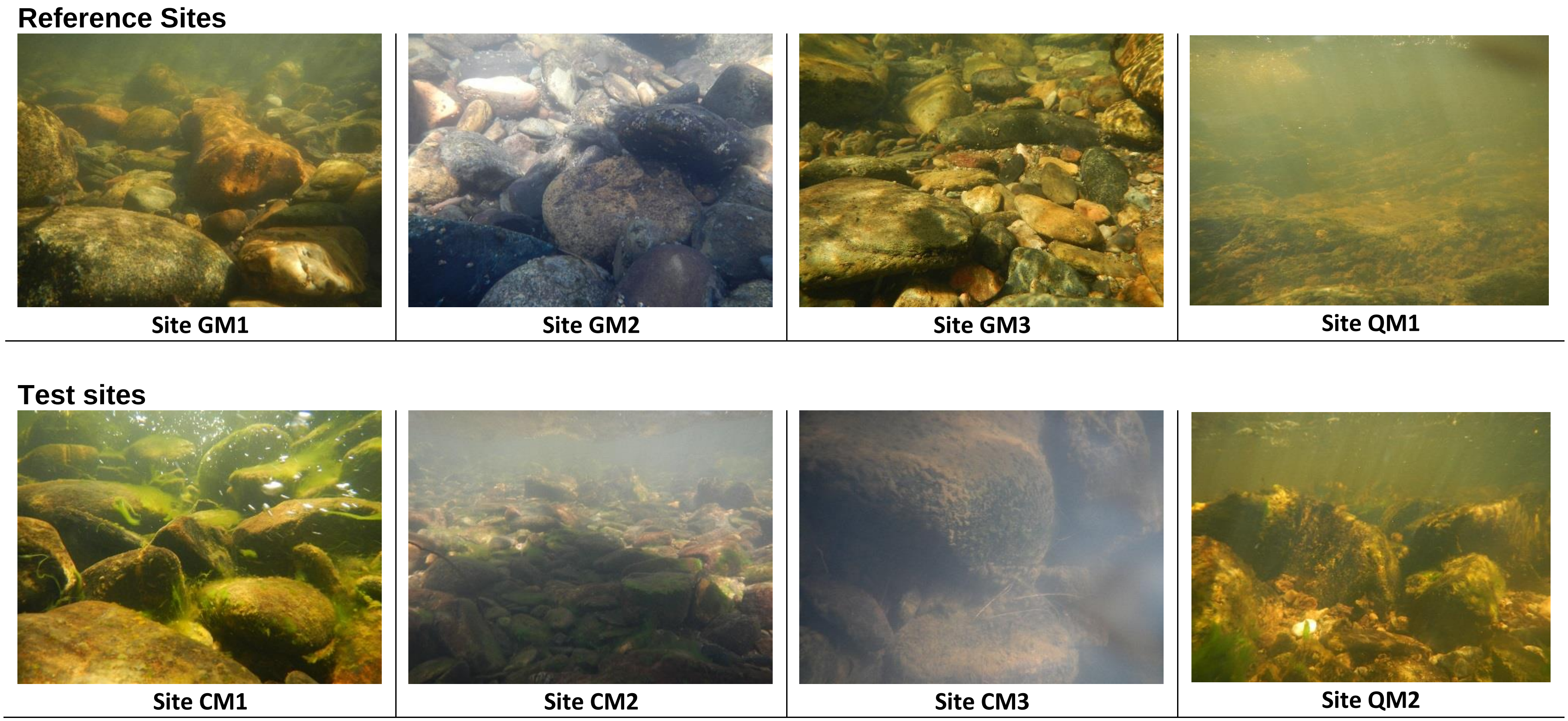

Figure 3. Filamentous algae cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in spring 2014.

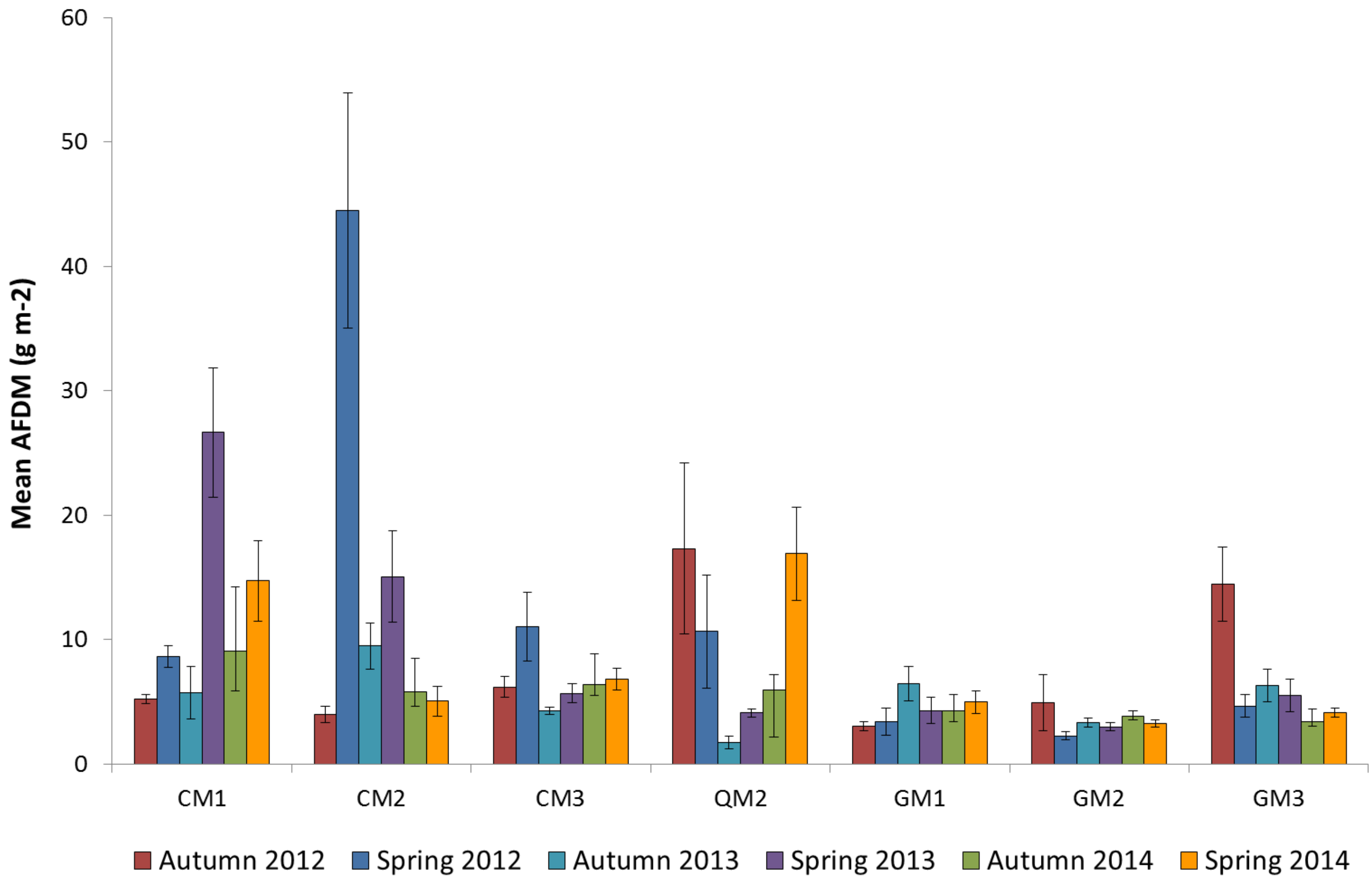

Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2012 to spring 2014. Error bars represent +/- 1 standard error.

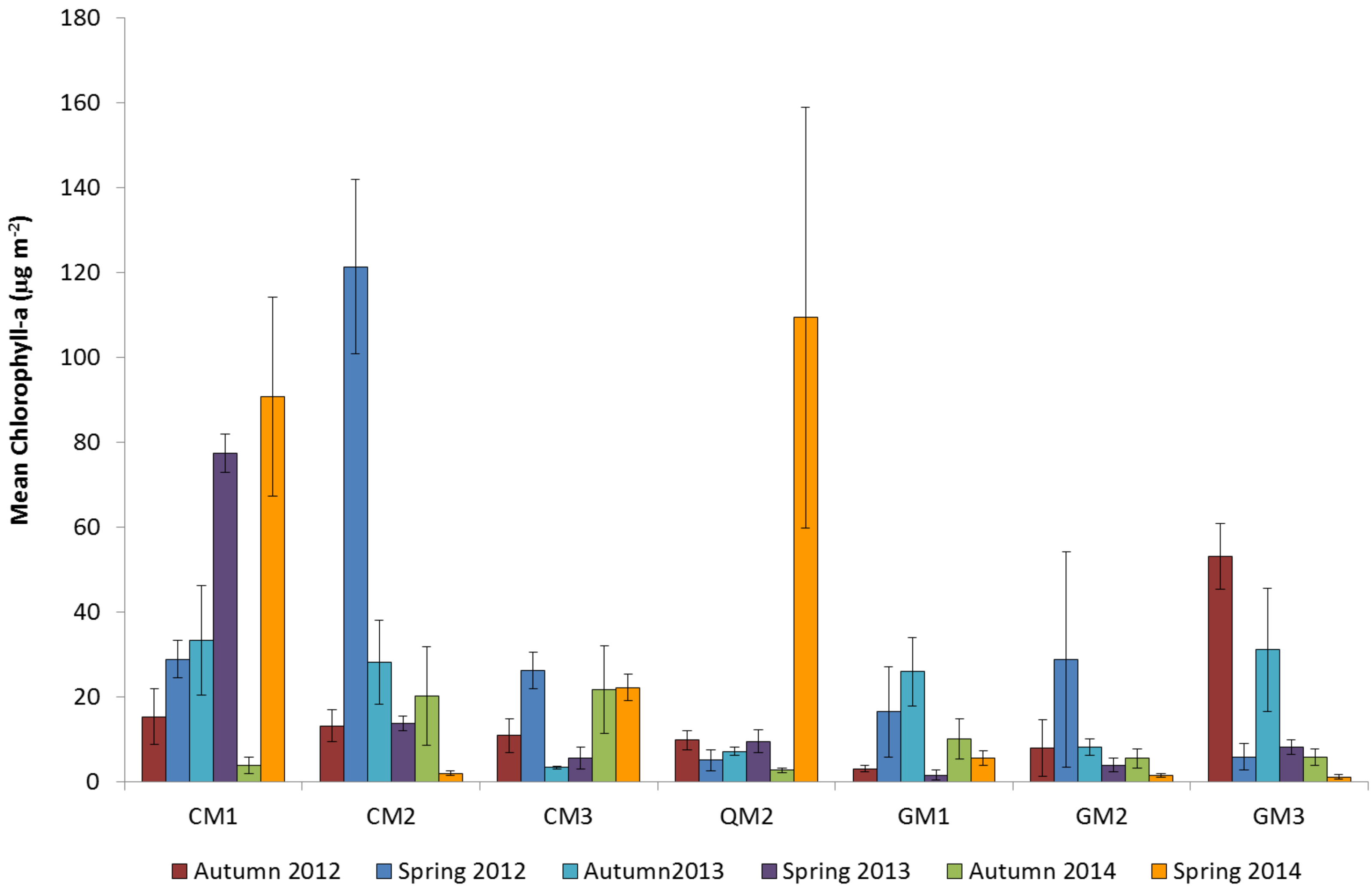

Figure 5: Mean chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2012 to spring 2014. Error bars represent +/- 1 standard error.

Benthic macroinvertebrates

AUSRIVAS assessment

Below dam test sites were generally in poorer biological condition than reference sites based on AUSRIVAS assessment in spring 2014 (Table 7).

Cotter River test site CM2 below Bendora Dam improved in biological condition from band B (*significantly impaired*) in autumn 2014 to band A (*similar to reference condition*) in spring 2014 (Table 7). Test site CM1 below Corin Dam declined in AUSRIVAS assessment from band A to band B from the autumn 2014 to the spring 2014 assessment (Table 7). Test site CM3 below Cotter remained in band B in spring 2014 (Table 7).

Goodradigbee River reference sites GM1, GM2, and GM3 were all assessed as band A in spring 2014 (Table 7).

Cotter River tributary sites CT1 (Kangaroo Creek), CT2 (Burkes Creek), CT3 were assessed as AUSRIVAS band A in spring 2014. Site CT3 improved in condition from a band B assessment in autumn 2014 and has regularly been assessed as biologically impaired (Table 7). Goodradigbee River tributary sites GT1, GT2 and GT3 were assessed as band A in autumn 2014 (Table 7).

The Queanbeyan River test site QM2 improved in biological condition from band B in autumn 2014 to band A in spring 2014 (Table 7). While the Queanbeyan River test site QM3 remained in band B in spring 2014 (Table 7). The upstream Queanbeyan River reference site QM1 was assessed as band A in autumn 2014 (Table 7).

Taxa that were expected with a ≥50% chance of occurrence by the AUSRIVAS model but were missing from sub-samples are presented in Table 8. Missing taxa ranged in SIGNAL 2 grade from 2 (Oligochaeta) to 9 (Glossosomatidae and Calocidae). Cotter River site CM3, Queanbeyan River site QM3, Goodradigbee River sites GM1 and GM3, and Goodradigbee tributary site GT2 and GT3 had taxa identified in whole of sample scans that were missing from respective sub-samples. This indicates that these taxa (Hydrobiosidae - sites CM3, QM2 and GT3, Psephenidae – site QM3, Tipulidae – site GM1, Conoesucidae – site GM3 and Hydropsychidae – site GT2), were present but in low abundance (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2012 to spring 2014.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Spring 2014	B (0.77)	A (0.97)	B (0.66)	A (0.88)	B (0.84)	A (1.03)	A (1.07)	A (0.96)	A (0.92)	A (1.12)	A (1.11)	A (1.12)	A (1.13)	A (0.98)	A (1.05)
Autumn 2014	A (0.91)	B (0.86)	B (0.66)	B (0.70)	B (0.83)	A (0.96)	A (0.90)	B (0.84)	A (0.97)	A (0.88)	A (1.04)	A (0.97)	X (1.19)	A (1.12)	A (1.05)
Spring 2013	B (0.69)	A (0.89)	A (0.88)	A (0.88)	A (0.92)	X (1.16)	A (1.00)	B (0.74)	A (1.10)	X (1.19)	A (1.11)	X (1.19)	A (1.13)	A (0.98)	A (1.13)
Autumn 2013	C (0.59)	A (1.12)	C (0.60)	B (0.77)	B (0.77)	A (1.08)	Not sampled	B (0.70)	A (0.97)	A (0.89)	A (0.89)	B (0.81)	A (1.01)	B (0.86)	A (1.05)
Spring 2012	B (0.77)	B (0.82)	B (0.73)	B (0.64)	B (0.77)	X (1.26)	A (1.12)	B (0.68)	A (1.01)	A (1.12)	X (1.26)	A (1.12)	B (0.83)	B (0.75)	B (0.68)
Autumn 2012	B (0.72)	B (0.79)	D (0.37)	C (0.63)	B (0.70)	A (0.93)	B (0.83)	C (0.56)	A (0.97)	C (0.56)	B (0.67)	B (0.82)	A (0.98)	A (1.06)	A (0.90)

Table 8. Macroinvertebrate taxa that were expected with a ≥ 50% chance of occurrence by the AUSRIVAS ACT spring riffle model but were missing from sub-samples for each of the study sites in spring 2014 and their SIGNAL 2 grade (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan.

Taxa	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Oligochaeta	2	X												X		
Elmidae	7	X	X	X		X	X	**X**		X	X	X	X		X	X
Psephenidae	6	X	X	X	X	X		**X**	X							
Tipulidae	5	X	X	X							X					
Tanypodinae	4			X	X		X			X						
Baetidae	5			X												
Caenidae	4	X														
Gripopterygidae	8				X	X										
Notonemouridae	6						X									
Hydrobiosidae	8			X	X	X	X					X				X
Glossosomatidae	9	X	X	X	X	X			X	X				X	X	
Hydropsychidae	6	X						X	X						X	X
Conoesucidae	7			X	X	X			X				X		X	
Calocidae	9						X									
Total		**7**	**4**	**8**	**6**	**6**	**5**	**3**	**4**	**3**	**2**	**2**	**2**	**2**	**4**	**3**

Taxonomic relative abundance

Oligochaeta and Chironomidae (OC) taxa were not notably more dominant at below dam test sites than at reference sites (Figure 6). With the exception of site CM1 below Corin Dam which had the highest relative abundance of Plecoptera out of all sites in spring 2014, the relative abundance of disturbance sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was greater at Goodradigbee River reference sites than at Cotter River test sites (Figure 6).

Reference site QM1 upstream of Googong Dam had a greater relative abundance of sensitive EPT taxa and relatively fewer tolerant OC taxa compared to test sites QM2 and QM3 downstream of Googong Reservoir on the Queanbeyan River (Figure 6).

Filter feeding Simuliidae comprised 61% of the sub-sample at Queanbeyan River test site QM2 and 27% at QM3, and 56% of the sub-sample from Cotter River test site CM3 (Diptera (other) category in Figure 6 and Appendix 2). The sub-sample from Cotter River tributary site CT3 was also numerically dominated by Simuliidae (52% of the sub-sample; Diptera (other) category in Figure 6 and Appendix 2).

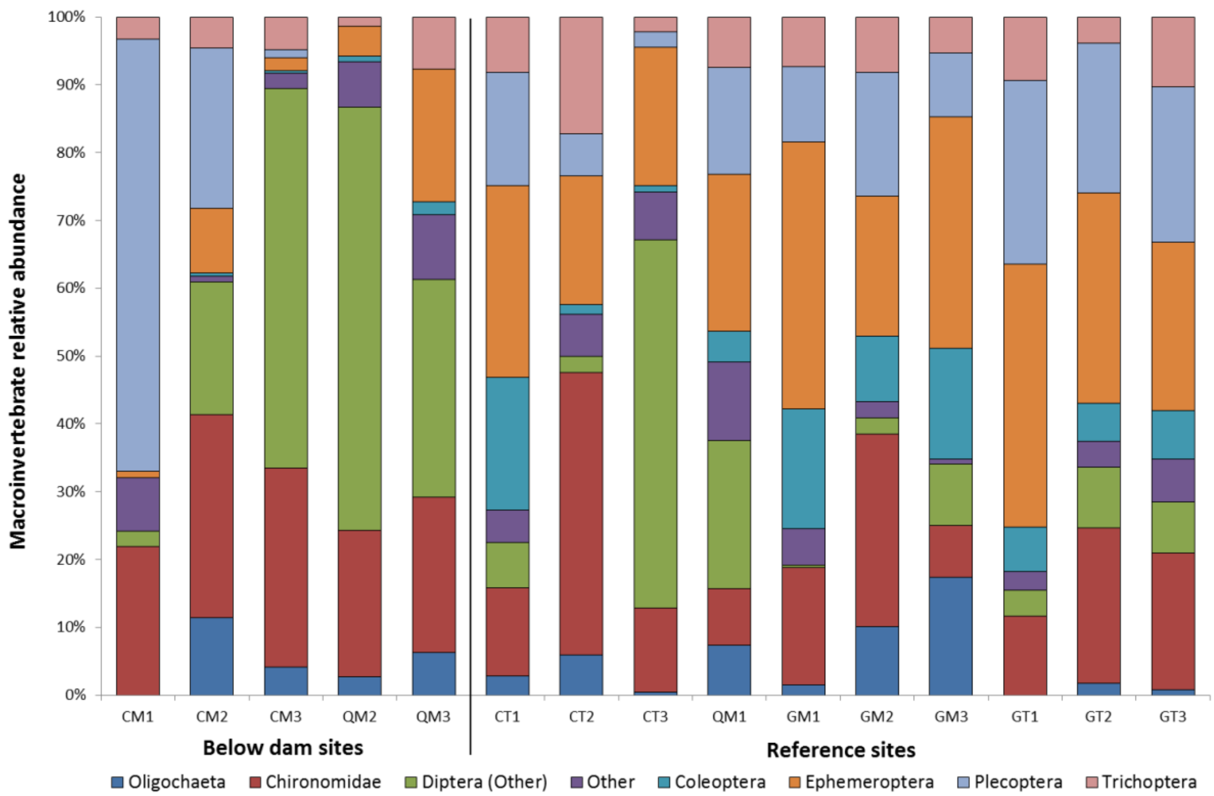

Figure 6: Relative abundance of macroinvertebrate taxonomic groups from samples collected in spring 2014.

Macroinvertebrate assemblage similarity

Cluster analysis based on the relative abundance of macroinvertebrate taxa identified three groups of sites at 60% similarity (Figure 7). Site CM1 was not similar to any of the other sites and grouped separately as Group A. Group B comprised below dam test sites (CM3, QM2, and QM3), Cotter River Tributary site CT3 and the Queanbeyan River reference site QM1 (Figure 7). Compared to other groups, group B was defined by higher abundances of Simuliidae and other disturbance tolerant taxa such as Oligochaeta and Orthocladiinae (Chironomidae sub-family) (Appendix 2). Group C contained Cotter River below dam test site CM2, all of the Goodradigbee River reference sites, and all of the Cotter and Goodradigbee River tributary sites, except for site CT3. Sites in this group were characterised by relatively high abundances of disturbance-sensitive and flow-favouring taxa such as Leptophlebiidae, Philopotamidae and Glossosomatidae compared to groups A and B (Appendix 2).

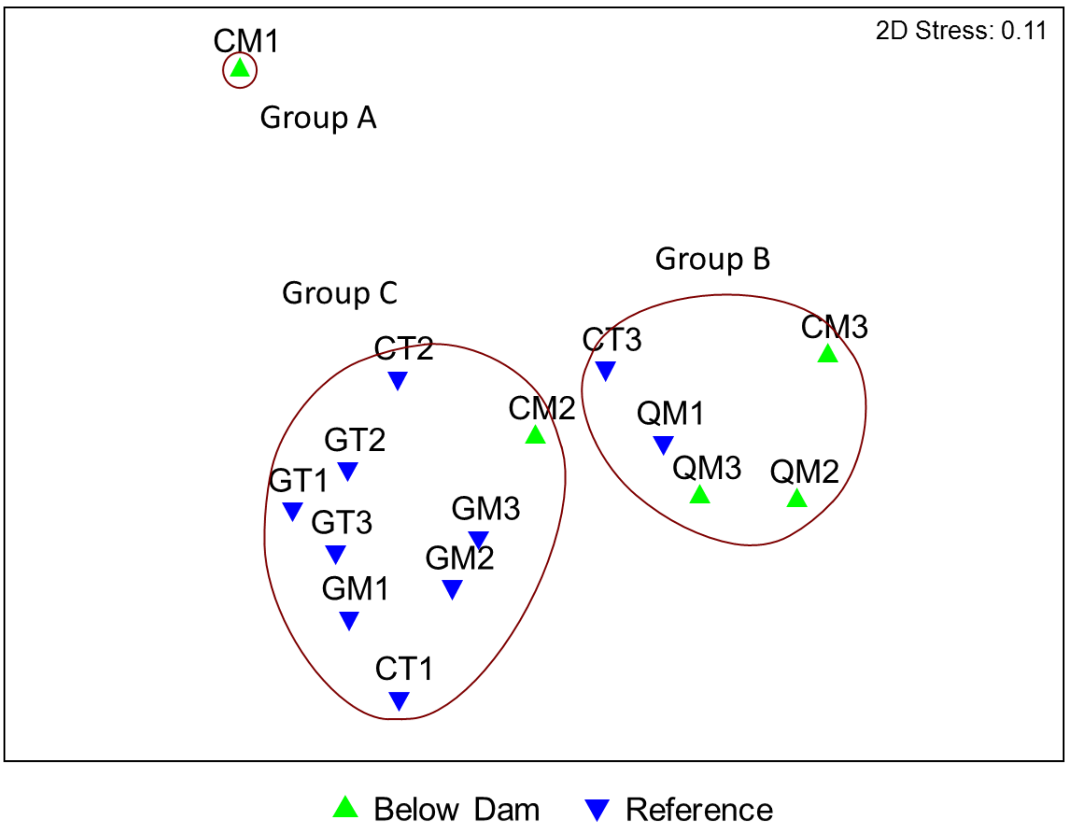

Figure 7. MDS ordination of 60% similarity between macroinvertebrate samples collected in spring 2014 for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance.

Discussion

Water quality

Water quality at below dam test sites and unregulated reference sites was generally within guideline levels in spring 2014 (Table 5). Parameters that were outside of guideline levels were pH, turbidity, total nitrogen (TN), nitrogen oxides (NO_x), and total phosphorus (TP). (Table 5).

pH levels were slightly above the upper guideline level at some below dam (CM3, QM2 and QM3) and reference sites (CT3, QM1, GM1 and GM2) (Table 5). There was no apparent bias towards test or reference sites in high pH measurements. Therefore, it is unlikely that high pH at below dam test sites was a result of dam operation. pH at these sites is regularly assessed as slightly alkaline (see Appendix 3) and likely to be a characteristic of geology in the surrounding catchments,

Turbidity was only slightly above the ANZECC/ARMCANZ (2000) guideline level (10 NTU) at site CM3 (Table 5) and is unlikely to be elevated as a direct consequence of the presence or operation of Cotter Dam. Operation of the M2C transfer is more likely to have contributed to the elevated turbidity at this site; however turbidity at this level is unlikely to have an adverse effect on the ecology of the Cotter River in the study reach.

Total nitrogen (TN) and nitrogen oxides (NOx) exceeded guideline concentrations downstream of Googong Dam (site QM2 and QM3) in spring 2014 (Table 5). Only TN exceeded the guideline concentration at reference site QM1 upstream of Googong Dam (Table 5). Above guideline NOx and TN concentrations downstream of Googong Dam are likely to be the result of water quality conditions in Googong Dam and inflows from the upstream catchment (e.g. above guideline TN concentrations at site QM1 – Table 5) . Historically, NOx and TN concentrations have been above guideline levels downstream of Googong Dam, because of increased concentrations from inflow into Googong Dam during the 2010 and 2012 floods.

Periphyton and algae

Filamentous algae cover in riffle habitats was well below the environmental flow ecological objective of <20% cover at all sites in spring 2014, except CM1 which had 25% cover (Table 6; Figure 3). The increased filamentous algae growth downstream of Corin Dam is likely because of lower discharge rates before spring 2014 sampling (approx. 100-150 ML d^{-1}) than autumn 2014 sampling (200-550 ML d^{-1}). Flows associated with discharged rates >150ML $d^{-1}$are likely to scour excess filamentous algae from riffle habitats (ACT Government 2013). Similarly in spring 2013, lower discharge rates before sampling resulted increased filamentous algae cover below Corin Dam (Table 6; Levings and Harrison 2013). However, compared with spring 2013 (80% cover) the percent cover is much lower, because flow releases were < 100 ML d^{-1} for ~1 month before sampling (Levings and Harrison 2013). Discharge rates downstream of Bendora, Cotter and Googong dams before the spring 2014 sampling have been effective keeping riffle filamentous algae cover below 20%.

Benthic macroinvertebrates

AUSRIVAS assessment identified biological impairment at three of the five below dam test sites in spring 2014. This represents a net improvement in biological condition at below dam test sites since the autumn assessment when one of the five below dam test sites were assessed as being in reference condition by the AUSRIVAS model. None of the Goodradigbee River reference sites were assessed as biologically impaired in spring 2014 (Table 7).

Test sites CM1 below Corin Dam and CM3 below Cotter Dam were both assessed as biologically impaired in spring 2014 (Table 7) and therefore failed to meet the environmental flow ecological objective of AUSRIVAS band A. The greater algae cover and biomass at site CM1 compared to reference sites has likely influenced macroinvertebrate community composition, because it is not a palatable food source for many taxa (Tonkin et al. 2014). Nevertheless the good water quality at site CM1 has resulted in high abundances of water quality sensitive taxa (e.g. Gripopterygidae (Plecoptera) which require well oxygenated flowing water) (Appendix 2). The macroinvertebrate assemblage at site CM3 differed from those of reference sites primarily because of a higher abundance of filter-feeding Simuliidae (Black Fly). A potential driver of the high abundance of Simuliidae below Cotter Dam is the M2C water recirculation transfer pipe which was in operation in the weeks before sampling. High concentrations of fine particulates in water transferred from the Murrumbidgee River create food resources for these taxa, and may be contributing to the accumulation of Simuliidae in riffle habitats downstream of the M2C discharge point.

The Cotter River test site CM2 below Corin Dam was the only Cotter River site with an improved biological condition since autumn 2014 (Table 7). A period of relatively high flow volume and variability in the months preceding spring 2014 sampling have likely contributed to the improved biological condition at this site and created more favourable habitat and resource conditions for a variety of macroinvertebrates.

The Cotter River tributary sites were in a similar biological condition to Goodradigbee River tributary sites in autumn 2014. Site CT3 on Paddys River was assessed as similar to reference condition for the first time since spring 2011 (Table 7). Increased rainfall and river flows in the weeks preceding sampling have likely influenced the improved biological condition at site CT3 and reduced the effect of agricultural land-use pressures within the catchment. Given that there was no detectable difference in catchment condition between the Cotter and Goodradigbee River catchments in spring 2014, instream differences between Cotter River test sites and Goodradigbee River reference sites can be attributed to instream factors such as impoundments and flow regulation.

In spring 2014, the Queanbeyan River test site QM2 improved from biologically impaired (AUSRIVAS band B) in autumn 2014 to similar to reference condition (AUSRIVAS band A) and site QM3 remained biologically impaired (AUSRIVAS band B) just below the band A threshold (Table 7). The upstream reference site QM1 remained in reference condition (Table 7). A minor flood event (1688 ML d^{-1})

occurred in the Queanbeyan River on the 28th August when Googong Dam spilled (Figure 2). It is likely that this disturbance would have influenced instream macroinvertebrate communities in the Queanbeyan River downstream of Googong Dam. The large proportions of filter feeding Simuliidae collected in the macroinvertebrate samples at site QM2 and QM3 are also indicative of high flow conditions and high concentrations of fine organic particulate matter being transported by high flow velocities (Figure 6). Filter feeding Simuliidae are also 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 (Ward and Stanford 1983). If higher than normal flows continue to occur downstream of Googong Dam because of spilling it is likely that sites QM2 and QM3 will remain similar to reference condition or continue on a trajectory towards reference condition.

Conclusion

Water quality parameters were generally within guideline values, except for nitrogen oxides and total nitrogen, which were variable across test and reference sites. All below dam test sites except site CM1 below Corin Dam achieved the environmental flow ecological objective for filamentous algae cover of riffle habitats, which is likely to have resulted from high velocity flow releases from Bendora, Cotter and Googong Dams. AUSRIVAS assessment identified an improved or stable biological condition downstream of Googong and Bendora Dams, because the volume and variability of flow releases or spills (Googong) are likely to have provided favourable conditions for instream ecological processes at these sites. However, biological condition decreased downstream of Corin Dam, because filamentous algae cover in the riffle habitat may have been unfavourable for some macroinvertebrate taxa. This assessment is consistent with previous assessments at the site and it is probable that higher flows which occurred after sampling will scour some of the filamentous algae and lead to improved biological condition downstream of Corin Dam.

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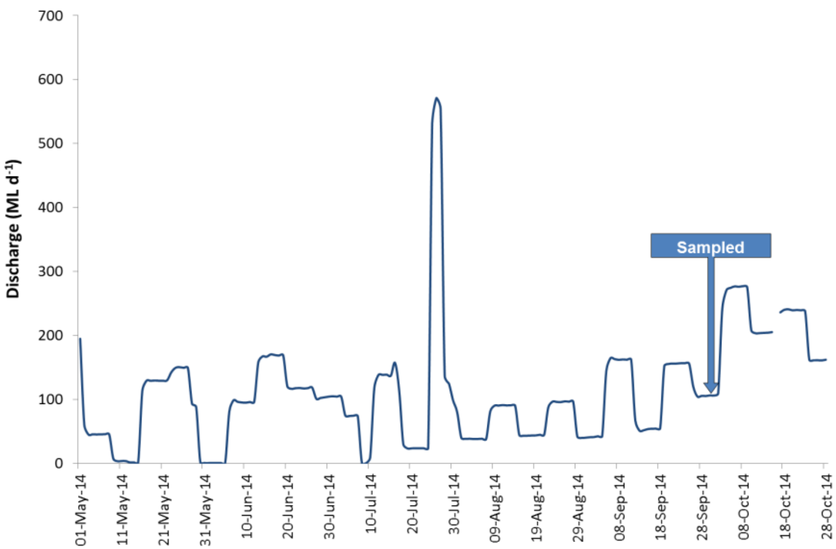
Appendix 1.

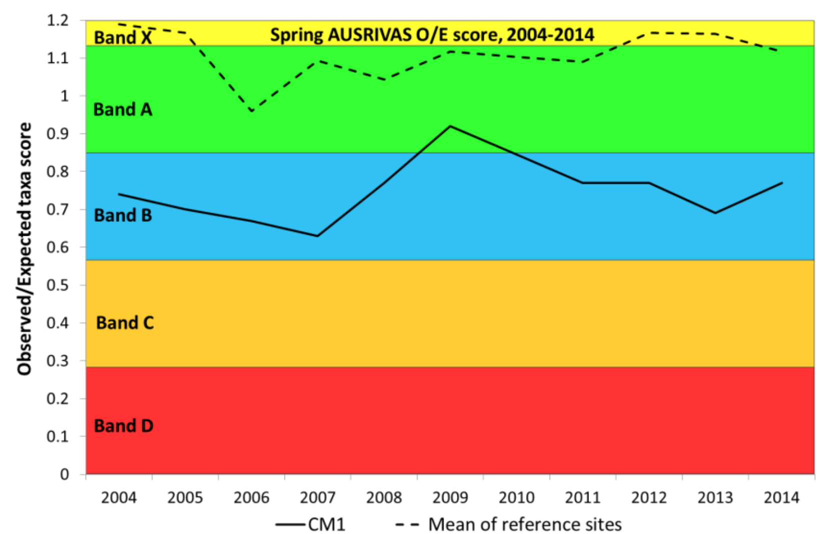
Below dam site summary sheets

CM1 – Spring 2014

Downstream of Corin Dam

Environmental flow ecological objective	Autumn 2014	Spring 2014	Objective met?
AUSRIVAS band A	Band A	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**25%**	No





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_3-N (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
10.29	20	6.74	10.23	4.6	10	0.003	0.012	0.12	0.008

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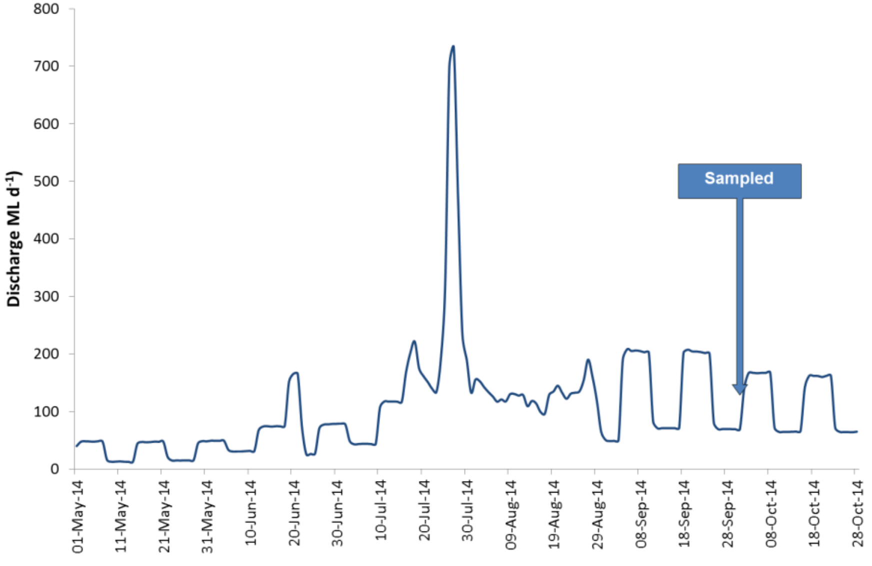
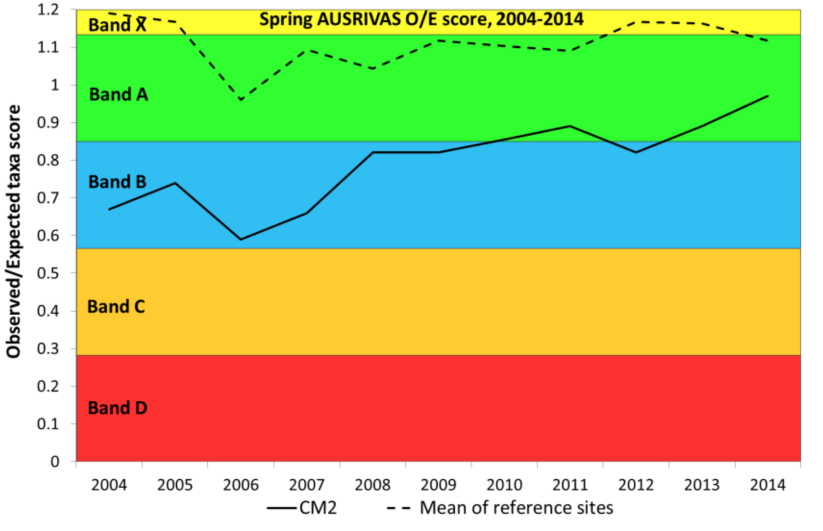
CM2 – Spring 2014

Downstream of Bendora Dam

Environmental flow ecological objective	Autumn 2014	Spring 2014	Objective met?
AUSRIVAS band A	Band B	**Band A**	Yes
<20% filamentous algae cover in riffle habitat	<10%	**10%**	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_3-N (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
9.89	20	6.74	11.11	1.8	8	<0.002	<0.002	0.08	0.004

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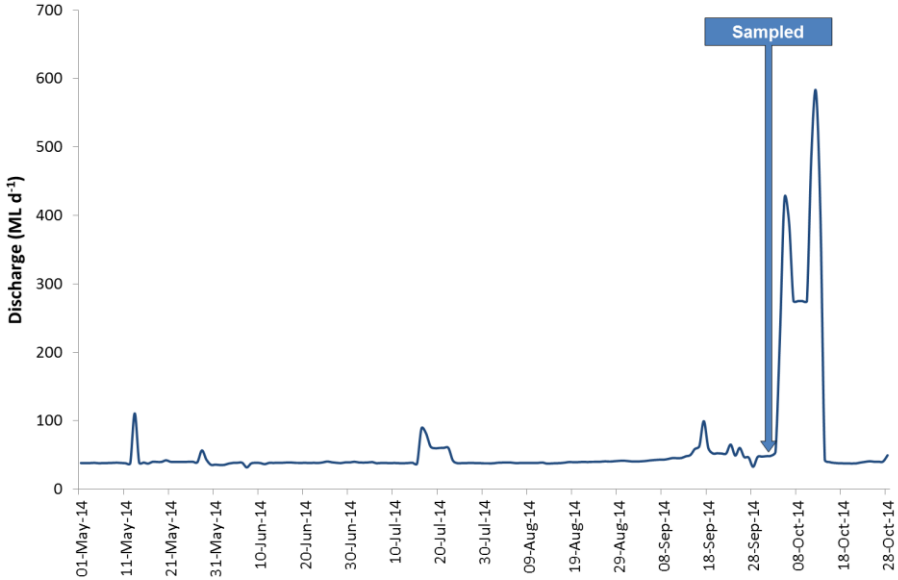
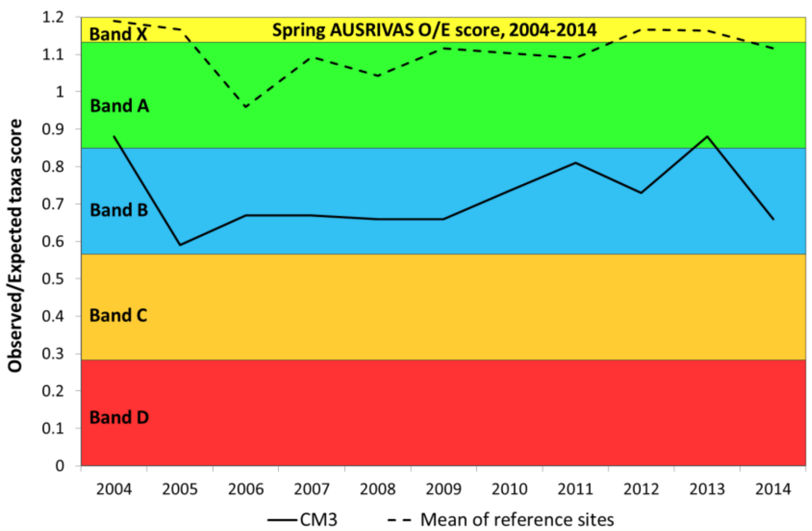
CM3 – Spring 2014

Downstream of Cotter Dam

Environmental flow ecological objective	Autumn 2014	Spring 2014	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**10%**	Yes





* Denotes values outside guideline levels

Temp. (ºC)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_3-N (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
16.86	81	8.10	10.42	10.5	34	0.005	0.006	0.26	0.024

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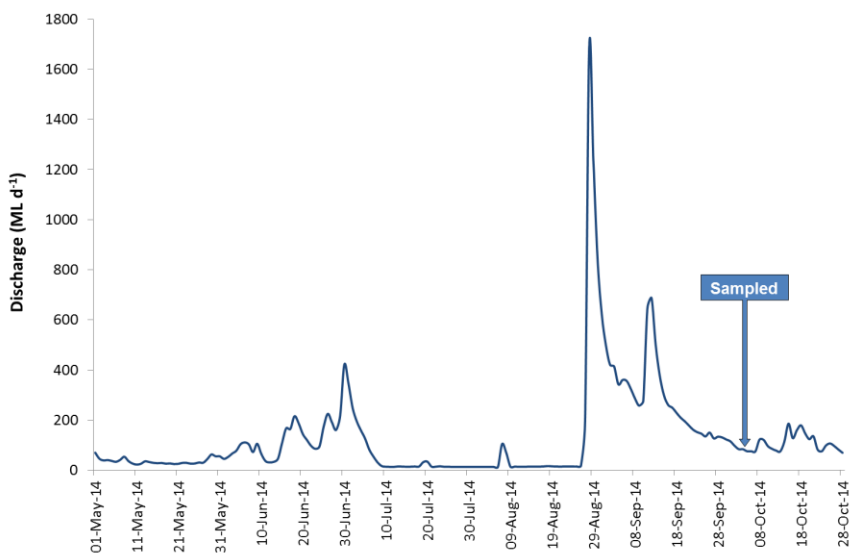
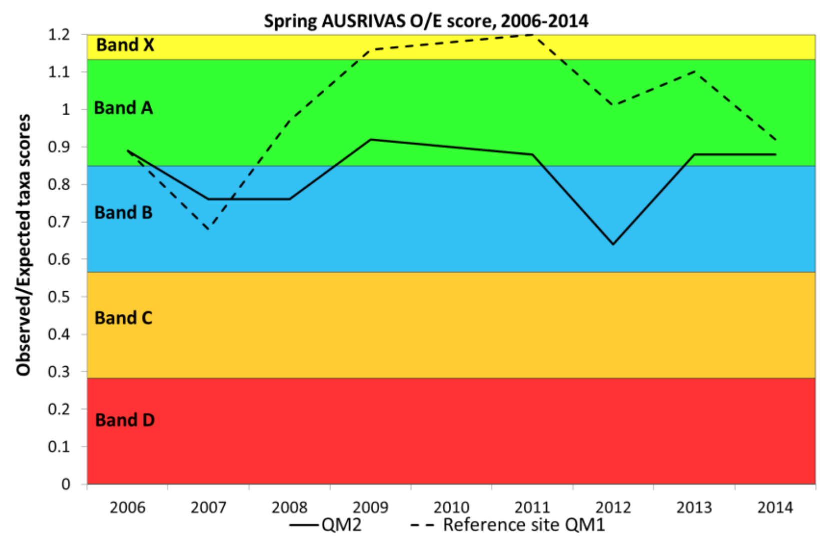
QM2 – Spring 2014

Downstream of Googong Dam

Environmental flow ecological objective	Autumn 2014	Spring 2014	Objective met?
AUSRIVAS band A	Band B	**Band A**	Yes
<20% filamentous algae cover in riffle habitat	<10%	**10%**	Yes





*** Denotes values outside guideline levels**

Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_3-N (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
14.19	91	8.35	11.52	1.0	34	0.010	0.101	0.35	0.012

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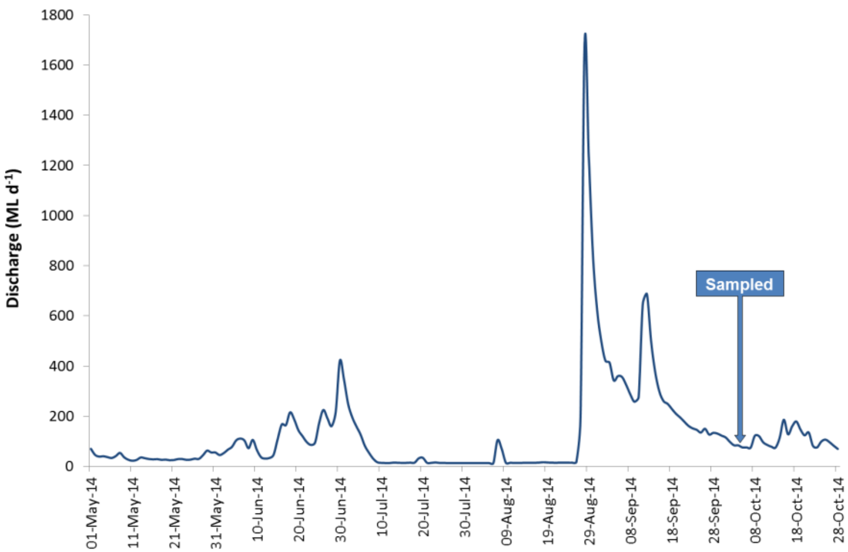
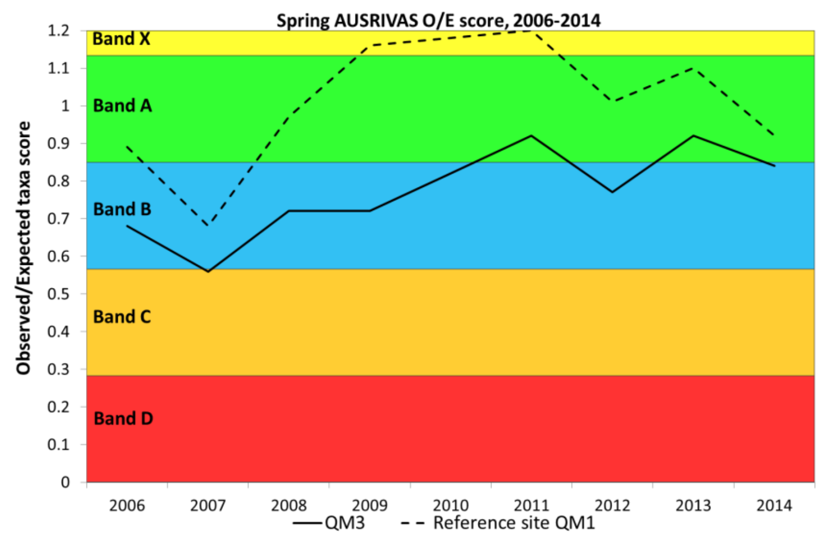
QM3 – Spring 2014

2 km Downstream of Googong Dam

Environmental flow ecological objective	Autumn 2014	Spring 2014	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**<10%**	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3-N (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
15.26	93	8.33	11.14	1.0	34	0.005	0.076	0.48	0.012

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Appendix 2.

Macroinvertebrate taxa

collected in spring 2014

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in spring 2014 at each of the study sites.

CLASS **Order** Family *Subfamily*	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Tricladida																
Dugesiidae	2			1												
Gastropoda																
Ancylidae	4			1			8	1								
Sphaeriidae	5					7									1	
OLIGOCHAETA	2		25	11	6	13	6	17	1	16	4	21	46		4	2
ACARINA	6	17	1	4	10	13	2	17	16	24	6	3	2	5	8	12
Coleoptera																
Hydrophilidae	2															1
Scirtidae	6				1		1				1					
Elmidae	7		1	1	1	4	39	4	2	10	26	10	39	13	12	16
Psephenidae	6										19	10	4	1	1	1
Ptilodactylidae	10															
Diptera																
Tipulidae	5				2	10	2	1	1	3		1	2	2	14	14
Dixidae	7													2		
Ceratopogonidae	4		1				1	1	1							1
Simuliidae	5	5	41	149	137	56	3	4	118	41	1	3	18	3	5	4
Athericidae	8						8						1			
Empididae	5		1		2	1		1	2	3		1	3	1	2	
Aphroteniinae	8						6				12		2	5	16	22
Podonominae	6	4									1	15	3			1
Tanypodinae	4	1					2	17			3			1	10	1
Diamesinae	6	2	12			1		21	1		6	1	1	2	7	2
Orthocladiinae	4	39	24	59	47	36	8	10	24	14	13	15	6	11	4	11
Chironominae	3	1	30	19	2	11	11	73	3	4	10	28	8	6	17	14
Ephemeroptera																
Baetidae	5	1	3		5	9	15	24	18	3	27	10	48	48	23	12
Coloburiscidae	8		1				6				7	4				
Leptophlebiidae	8	1	8	1	1	2	35	29	11	4	33	21	40	24	45	41
Caenidae	4		9	4	4	30	3	2	17	43	36	8	2	11	5	10
Megaloptera																
Corydalidae	7				3							1		1		4
Odonata																
Gomphidae	5		1		2						8	1				
Telephlebiidae	9									1						
Plecoptera																
Eustheniidae	10	1												1		
Gripopterygidae	8	135	52	3			35	18	5	34	29	38	25	57	52	58
Notonemouridae	6	1														
Trichoptera																
Hydrobiosidae	8	3	1					9	1		2		1	1	3	
Glossosomatidae	9						3	8			6	7	6			5
Hydroptilidae	4		1	2			2		3	9			2			
Philopotamidae	8		1					2				2	1	2		3
Hydropsychidae	6		1	11	2	15	3			7	4	6	3	1		
Polycentropodidae	7		1										1		1	
Ecnomidae	4		2		1			1	1							
Tasimiidae	8														1	
Conoesucidae	8	4	1				4	30			3	1		2		12
Helicopsychidae	8						2				1			1		
Odontoceridae	7													10		
Calamoceratidae	7														1	
Leptoceridae	6		2			1	3				3	1		3	3	6
No. of individuals		**215**	**220**	**266**	**226**	**209**	**208**	**290**	**225**	**216**	**261**	**208**	**264**	**214**	**235**	**253**
No. of taxa		**14**	**23**	**13**	**16**	**15**	**24**	**21**	**17**	**15**	**24**	**23**	**23**	**25**	**22**	**23**
% of sub-sample		**5**	**3**	**2**	**3**	**7**	**4**	**9**	**2**	**5**	**4**	**4**	**4**	**4**	**2**	**4**
Whole sample estimate		**4300**	**7333**	**13300**	**7533**	**2986**	**5200**	**3222**	**11250**	**4320**	**6525**	**5200**	**6600**	**5350**	**11750**	**6325**

Macroinvertebrate taxa and their SIGNAL 2 grades (Chessman 2003) defined from SIMPER analysis on relative abundance data that contribute to each cluster analysis group. *Average abundance values are fourth root transformed and the top ~70% of contributing taxa are shown). Group A consists of single site and is therefore not shown below.*

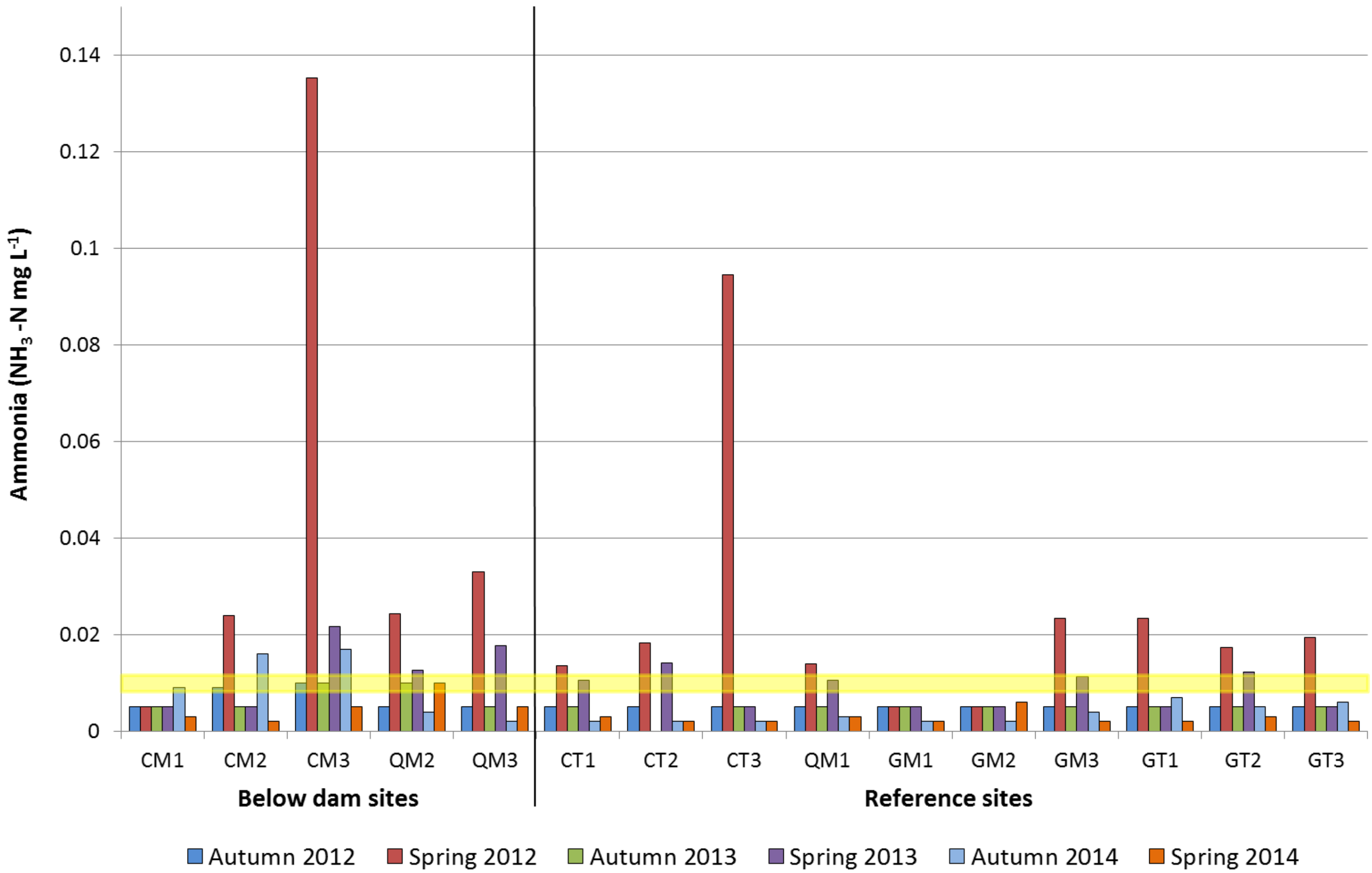
Group	Taxa	SIGNAL 2 grade	Average abundance	Consistency ratio	Contribution %	Cumulative %
Group B	Simuliidae	5	2.52	5.97	16.72	16.72
	Orthocladiinae	4	1.95	6.05	12.93	29.64
	Acarina	6	1.52	9.11	9.61	39.26
	Caenidae	4	1.6	5.44	9.3	48.55
	Oligochaeta	2	1.35	3.63	8.26	56.81
	Chironominae	3	1.27	5.68	7.83	64.64
	Leptophlebiidae	8	1.05	9.65	6.19	70.84
Group C	Gripopterygidae	8	2.01	8.83	9.45	9.45
	Leptophlebiidae	8	1.86	9.12	8.81	18.26
	Baetidae	5	1.69	5.94	7.54	25.8
	Chironominae	3	1.64	7	7.37	33.16
	Orthocladiinae	4	1.45	9.94	6.71	39.87
	Elmidae	7	1.54	4.19	6.58	46.45
	Caenidae	4	1.31	5.63	5.69	52.14
	Simuliidae	5	1.24	5.55	5.31	57.45
	Acarina	6	1.19	5.74	5.24	62.69
	Oligochaeta	2	1.3	1.64	4.84	67.53
	Tanypodinae	4	1.03	1.67	3.84	71.37

Macroinvertebrate taxa and their SIGNAL 2 grades (Chessman 2003) defined from SIMPER analysis on relative abundance data that discriminate between cluster analysis groups. *Average abundance values are fourth root transformed and discriminating taxa are defined as having a consistency ratio of ≥1.4.*

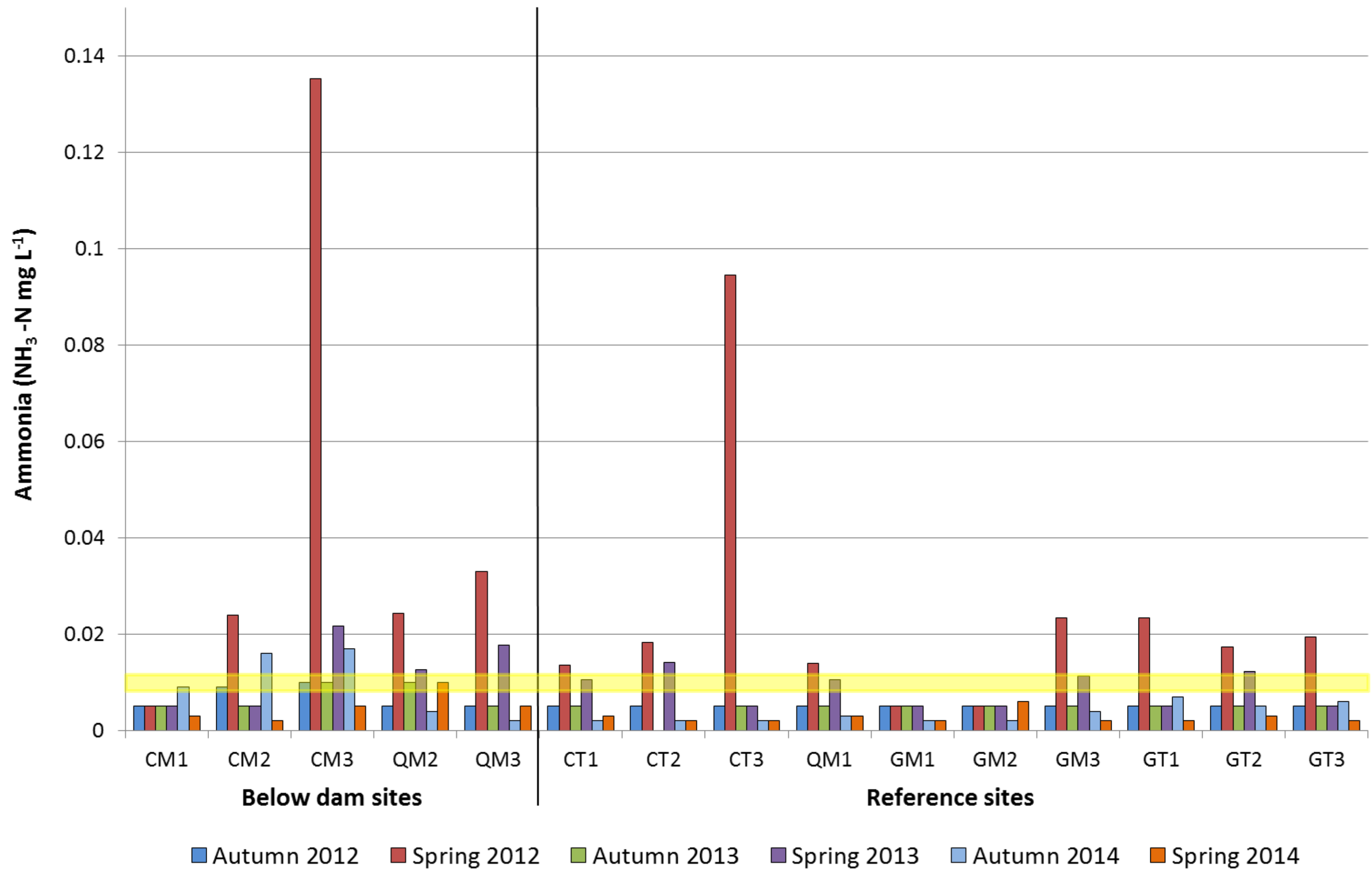
Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group B	***Group A***	
Tipulidae	5	0.87	0	1.61
Hydropsychidae	6	1.07	0	1.66
Gripopterygidae	8	0.85	2.81	2.3
Hydrobiosidae	8	0.16	1.09	2.46
Simuliidae	5	2.52	1.23	3.5
Oligochaeta	2	1.35	0	4.09
Caenidae	4	1.6	0	4.2
Elmidae	7	1.04	0	4.41
Diamesinae	6	0	1.17	16.44
Conoesucidae	8	0	1.17	16.44
Podonominae	6	0	0.83	16.44
Eustheniidae	10	0	0.83	16.44
Notonemouridae	6	0	0.83	16.44
		Group B	***Group C***	
Glossosomatidae	9	0	0.82	1.38
Philopotamidae	8	0	0.61	1.38
Tanypodinae	4	0.33	1.03	1.45
Caenidae	4	1.6	1.31	1.5
Conoesucidae	8	0	0.9	1.55
Leptoceridae	6	0.17	0.81	1.55
Elmidae	7	1.04	1.54	1.56
Gripopterygidae	8	0.85	2.01	1.61
Orthocladiinae	4	1.95	1.45	1.81
Leptophlebiidae	8	1.05	1.86	2.45
Simuliidae	5	2.52	1.24	2.71
		Group C	***Group A***	
Tipulidae	5	0.84	0	1.52
Leptoceridae	6	0.81	0	1.72
Diamesinae	6	0.47	1.17	1.77
Oligochaeta	2	1.3	0	2.06
Chironominae	3	1.64	0.83	2.4
Baetidae	5	1.69	0.83	2.62
Eustheniidae	10	0.09	0.83	2.66
Orthocladiinae	4	1.45	2.06	2.95
Gripopterygidae	8	2.01	2.81	3.24
Elmidae	7	1.54	0	4.18
Caenidae	4	1.31	0	4.41
Leptophlebiidae	8	1.86	0.83	5.08
Notonemouridae	6	0	0.83	29.85

Appendix 3.

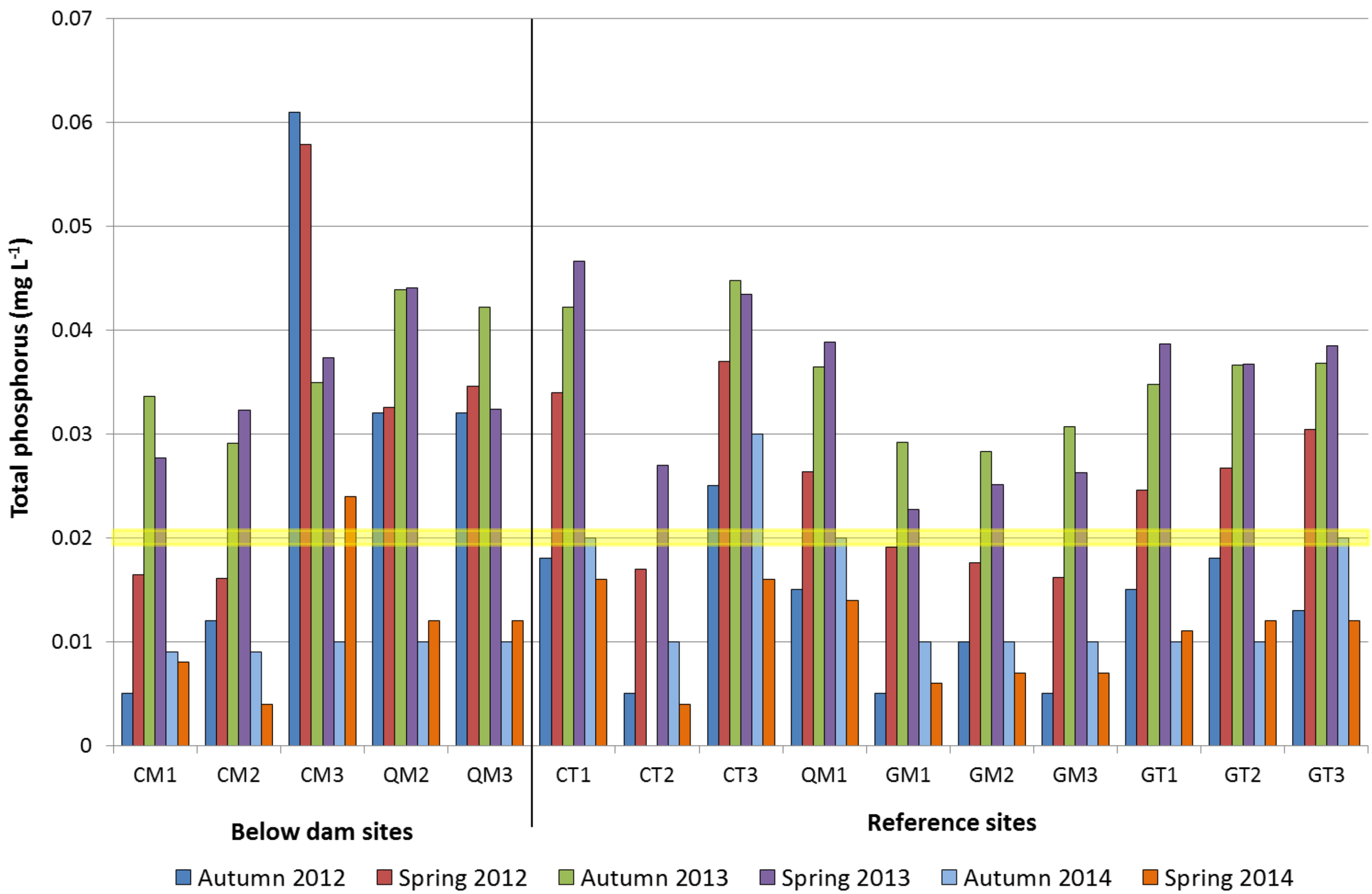
Water quality figures



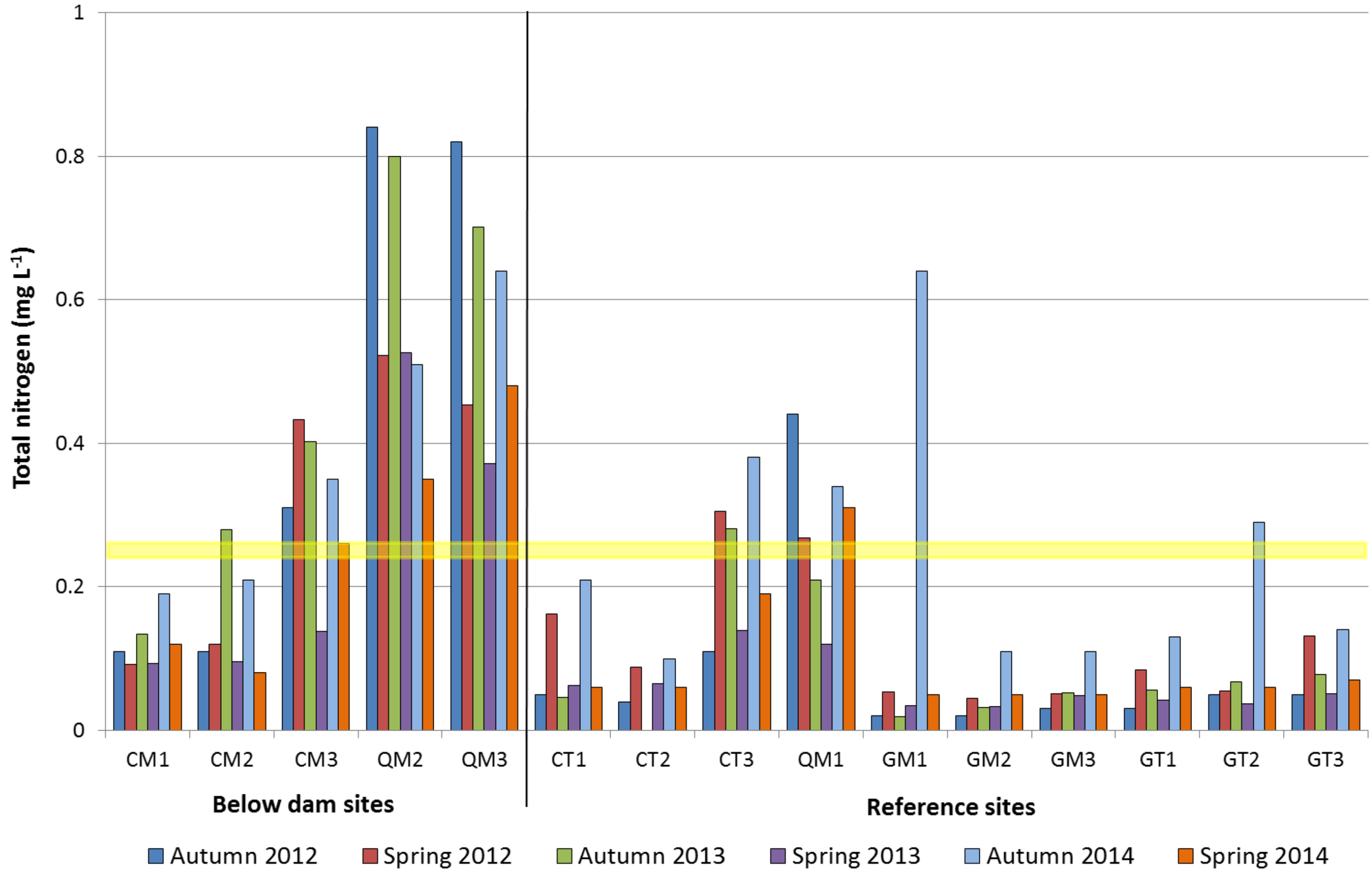
Ammonium (NH_4^+) concentration at all sites from autumn 2012 to spring 2014. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



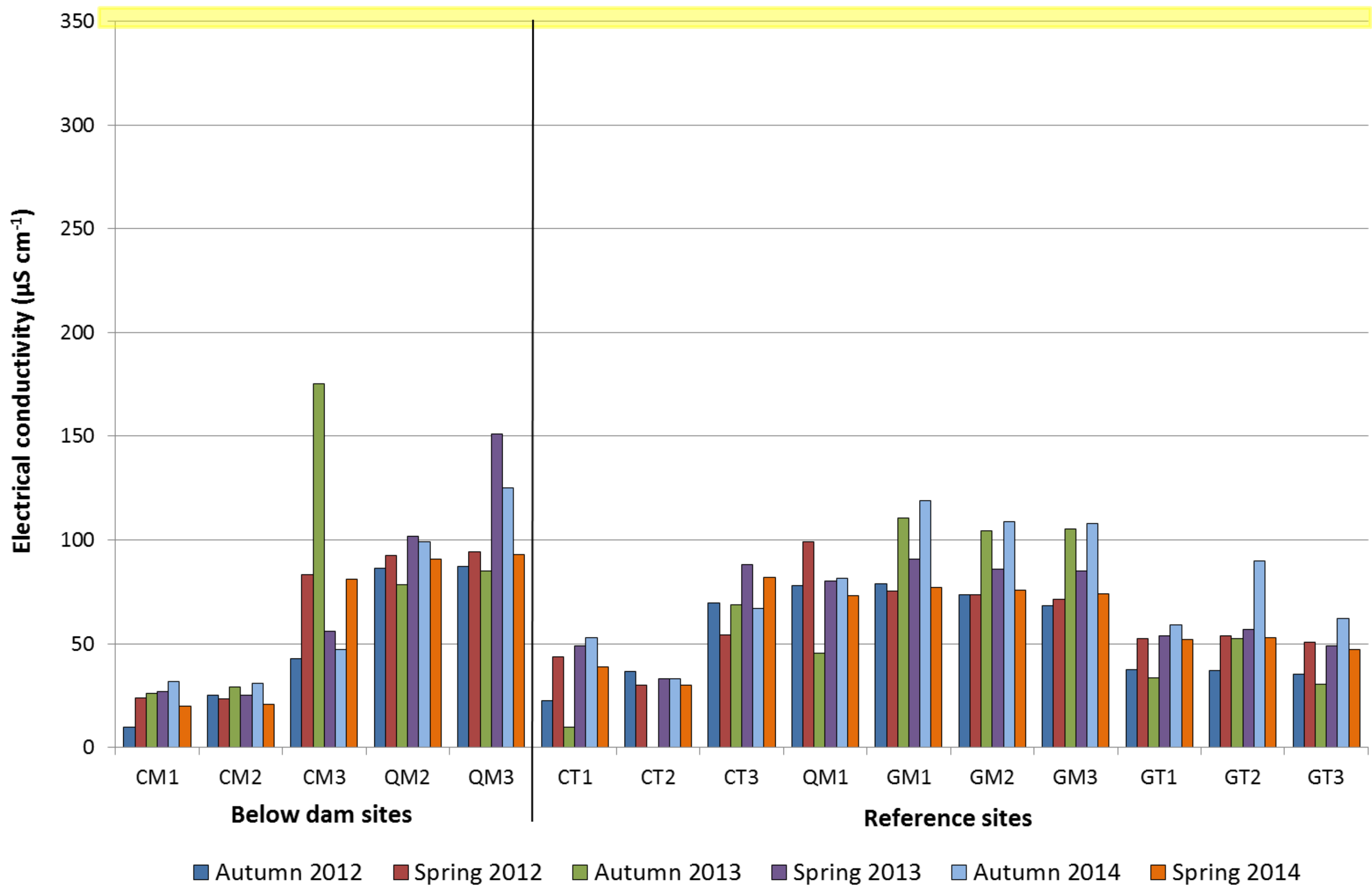
Nitrogen oxide concentrations at all sites from autumn 2012 to spring 2014. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



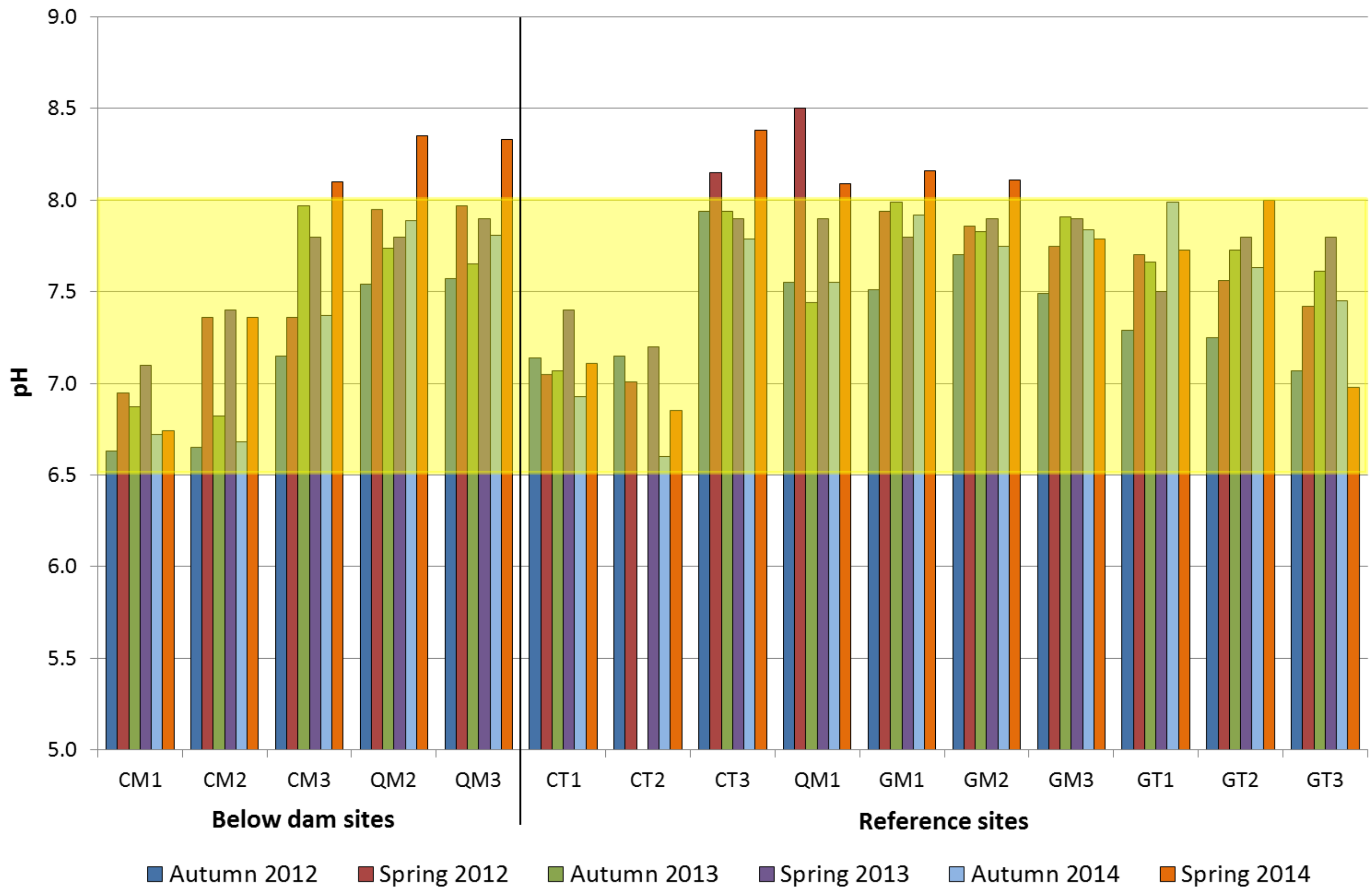
Total phosphorus concentrations at all sites from autumn 2012 to spring 2014. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



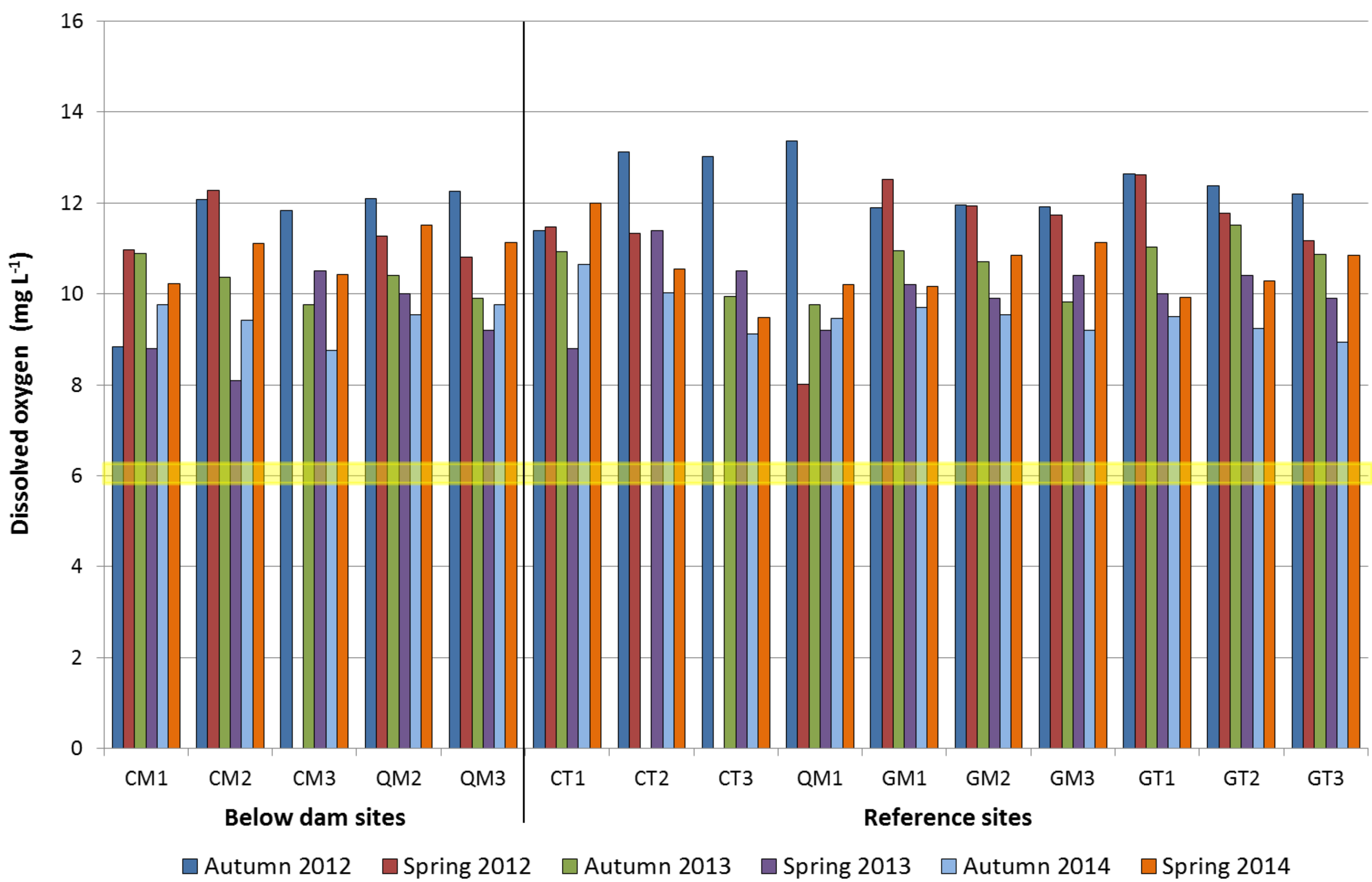
Total nitrogen concentrations at all sites from autumn 2012 to spring 2014. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



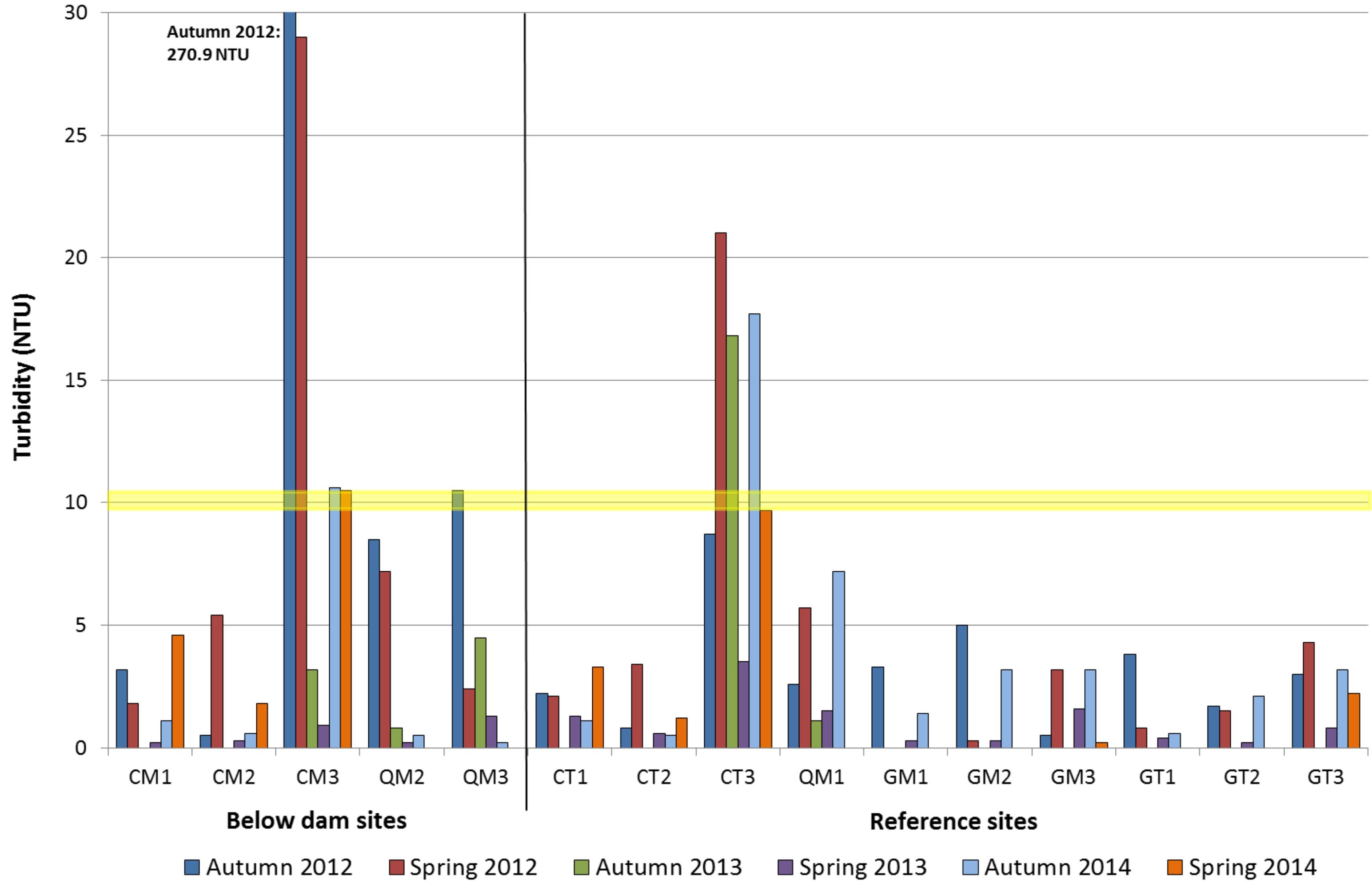
Electrical conductivity at all sites from autumn 2012 to spring 2014. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from autumn 2012 to spring 2014. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from autumn 2012 to spring 2014. The minimum guideline for electrical conductivity is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from autumn 2012 to spring 2014. The guideline for turbidity is shaded yellow (Environment Protection Regulation SL2005-38).