



Biological response to flows downstream of Corin, Bendora, Cotter and Googong Dams

ACTEW WATER

Autumn 2013

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Front Photograph: Site QM2 downstream of Googong Dam.

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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 the rivers' 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 also 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 Abstract 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.

Autumn 2013 results and conclusions

- Site summary sheets for each of the below dam sites are included as Appendix 1. Click here for more information

- In autumn 2013 water quality parameters were generally within the recommended water quality trigger levels at below dam test sites and reference sites. Notable exceptions were nutrient concentrations with total phosphorus above trigger concentrations at all sites, and total nitrogen above trigger concentrations at below dam test sites. High nutrient concentrations in reservoir outflows are likely a result of a lag in flushing the high nutrient influx to reservoirs during the March 2012 flood event. Click here for more information

- All below dam test sites met the environmental flow ecological objective of < 20% filamentous algae cover in the riffle habitat (ACT Government 2013); however, prolific filamentous algae in a low flow backwater and algal grazing taxa in the riffle habitat below Corin Dam indicate that filamentous algae may have been more abundant at this site prior to sampling in autumn 2013. Click here for more information

- The macroinvertebrate assemblage of the riffle habitat below Bendora Dam was the only site to meet the specified environmental flow ecological objective of AUSRIVAS band A assessment (ACT Government 2013). Click here for more information

Site	Within environmental flow ecological objective	On the cusp of the environmental flow ecological objective	Outside environmental flow ecological objective
	Riffle filamentous algae cover	AUSRIVAS band (O/E score)	
CM1 (Corin Dam)	< 10 %	C (0.59)	
CM2 (Bendora Dam)	< 10 %	A (1.12)	
CM3 (Cotter Dam)	< 10 %	C (0.60)	
QM2 (Googong Dam)	< 10 %	B (0.77)	
QM3 (Googong Dam)	< 10 %	B (0.77)	

- Riffle habitats below Corin and Cotter Dams declined in biological condition to AUSRIVAS band C in autumn 2013. This is possibly because of abundant filamentous algae prior to sampling below Corin Dam, and reduced habitat availability arising from numerical dominance of Black Fly (Simuliidae) larvae below Cotter Dam. Click here for more information
- Macroinvertebrate assemblages below dams had a greater abundance of taxa with 'filterer' and 'gatherer' feeding strategies possibly as a result of high concentrations of fine organic particulates that are typical of reservoir outflows. Click here for more information

Project recommendations

- The frequency component of the current environmental flow objective for < 20% filamentous algae cover in riffle habitats **for 95% of the time** is difficult to assess under a standard sampling regime. Removing the reference to frequency from this objective will make assessment of whether or not the objective has been met more achievable, and thus increase the value of the objective as a management tool for ACTEW Water.
- Recent assessments have identified a shift in the macroinvertebrate assemblage at site CM3 below Cotter Dam. Murrumbidgee River water released via the M2C transfer pipeline is possibly contributing to this shift by altering the physicochemical properties of the river reach (e.g. higher concentrations of fine particulate matter in Murrumbidgee River water). If the biological condition at site CM3 remains severely impaired, further investigation into the cause of this decline may be required to ensure the ecological and amenity values 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) have <20% filamentous algal cover in riffles for 95% of the time (ACT Government 2006). 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 and 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, Cotter and Goodradigbee River tributaries, and the Queanbeyan River upstream of Googong Dam. The 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 autumn 2013, 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 autumn 2013 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 9th and 11th April 2013 (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.

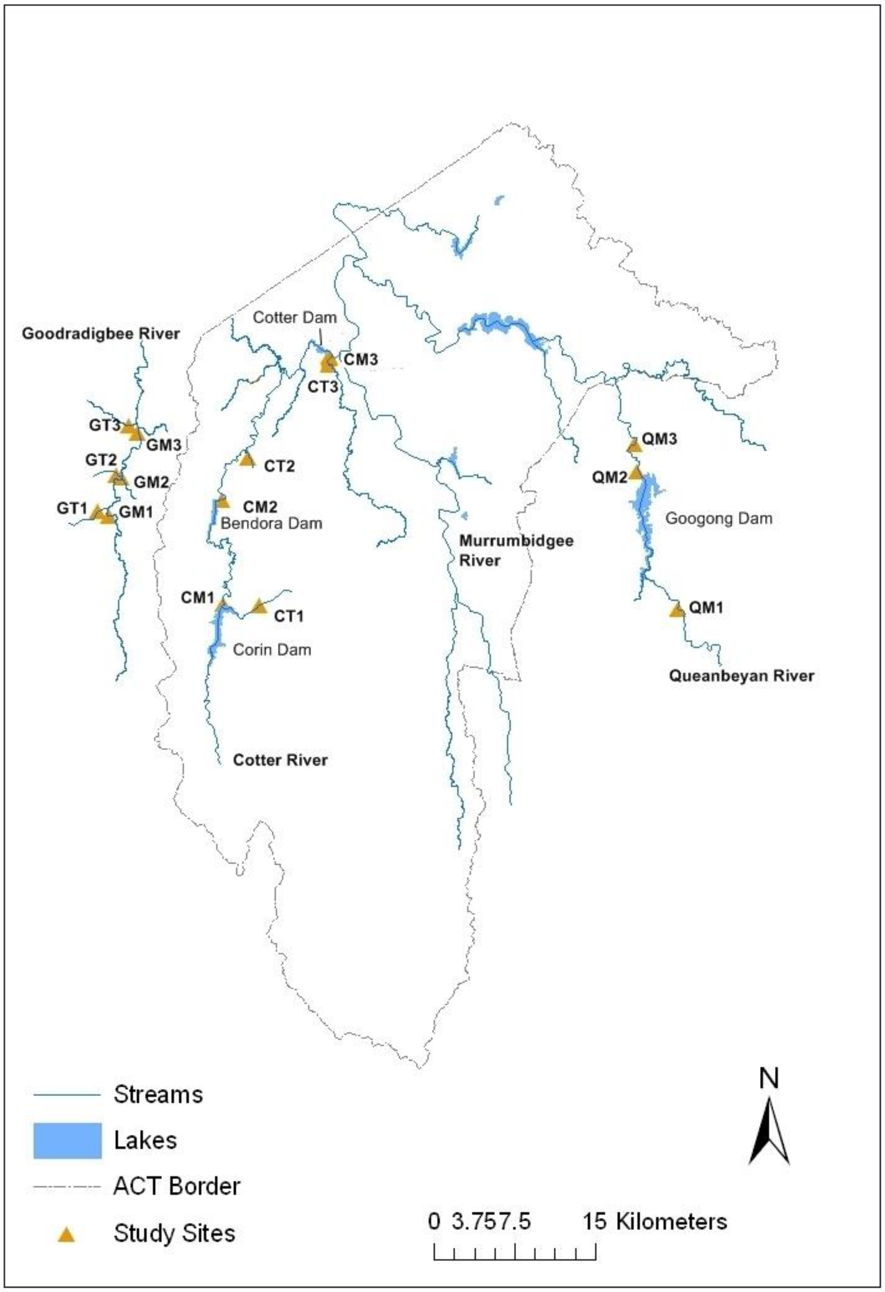

Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the Below Dams Assessment Program, autumn 2013.

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 Creek	50 m upstream of confluence with Cotter River	680	4.5	3
CT3	Paddy's	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 River	12 km upstream of Googong Dam near 'Hayshed Pool'	720	72	5
QM2	Queanbeyan River	1 km downstream of Googong Dam	590	91.6	5
QM3	Queanbeyan River	2 km downstream of Googong Dam at Wickerslack Lane	600	92.6	5

Hydrometric data

To determine changes in river flow and rainfall for the months preceding sampling, mean daily flow data were obtained for each below dam sites and the Goodradigbee River. Mean daily flow data were obtained for Corin, Bendora, Cotter and Googong Dams on the Cotter and Queanbeyan Rivers from ACTEW Water. Mean daily flow data was also obtained for the Goodradigbee River at site GM2 (gauging station 410088) from the NSW Department of Primary Industries Office of Water. 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 Hydrolab DS5 Multiprobe. 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 ammonia, 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 guidelines 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). For conductivity, the upper value of the ANZECC and ARMCANZ (2000) trigger value range is used as a trigger value, because the lower trigger values are not likely to have an effect on stream ecological condition (see the autumn 2010 report: Harrison et al. 2010) .

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/index.php/manuals-a-datasheets).

Ash-free dry mass and chlorophyll-a

Twelve periphyton samples were collected from 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/index.php/manuals-a-datasheets).

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, and 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 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 grades 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 autumn 2013, 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 and separation of defined was tested using an Analysis of Similarities (ANOSIM). 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 autumn 2013 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) . A sustained period of low flows (< 100 ML d^{-1}) preceded sampling below Bendora Dam (CM2), Cotter Dam (CM3), and Googong Dam (QM2), compared to flows below Corin Dam (CM3) which were variable between 75 and 170 ML d^{-1} over the same period (Figure 2). Stream discharge in the unregulated Goodradigbee River was generally higher and more variable than that of the below dam test sites on the Cotter and Queanbeyan Rivers (Figure 2).

Table 4: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams preceding the autumn 2013 Below Dams Assessment Program (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.
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	Maintain an average flow of 15 ML d^{-1}. Riffle maintenance flow of 100 ML d^{-1} for 1 day every 2 months.
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.

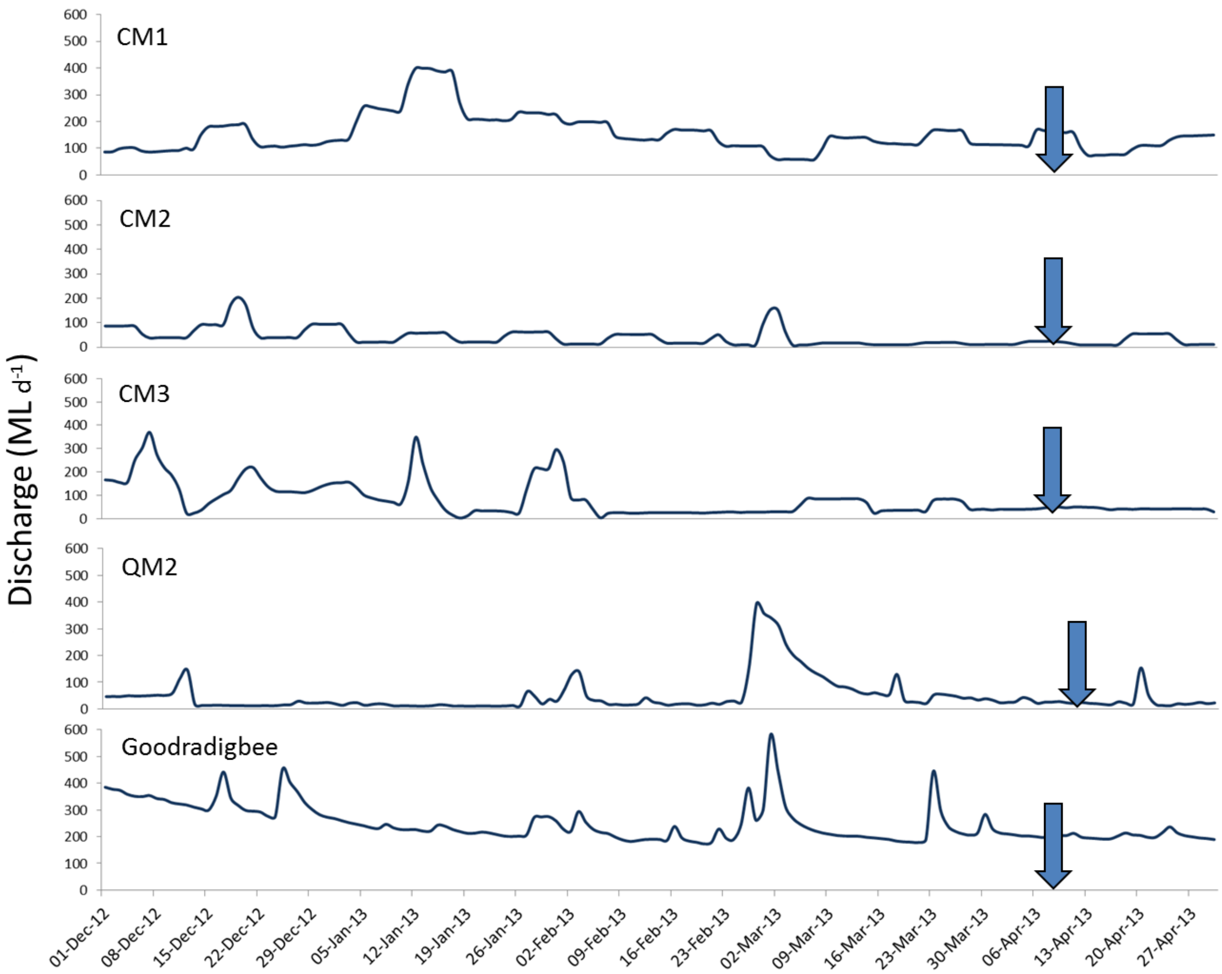

Figure 2: Mean daily discharge below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams and in the Goodradigbee River from 1st December 2012 to 31st April 2013. Arrows correspond to autumn 2013 sampling dates.

Water quality

Water quality parameters were generally within ANZECC/ARMCANZ (2000) guidelines except for nutrient concentrations (Table 5). Water quality data are presented in context with previous assessments (autumn 2010 to autumn 2013) in Appendix 3.

Total nitrogen concentrations (TN) exceeded guideline concentrations at all below dam test sites except for below Corin Dam (CM1), but was within guideline concentrations at all reference sites except Paddys River (CT3) (Table 5).

Total phosphorus concentrations (TP) exceeded guideline levels at all sites, and exceeded concentrations measured in spring and autumn 2012 at all sites except below Cotter Dam (CM3) (Table 5, Appendix 3).

Table 5. Water quality parameters measured at each of the test and reference sites in autumn 2013. 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_4^+ (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
		Guideline level									
			350	6.5-8	>6	<10		0.13	0.015	0.25	0.02
Below dam test sites	CM1	15.1	26.2	6.87	10.89	<1	11	<0.01	0.01	0.13	0.03
	CM2	17.5	29.3	6.82	10.37	<1	10	<0.01	0.02	0.28	0.03
	CM3	20.44	175.3	7.97	9.77	3.2	64	0.01	<0.01	0.40	0.03
	QM2	18.00	78.6	7.74	10.41	0.8	23	0.01	0.15	0.80	0.04
	QM3	18.13	85.2	7.65	9.91	4.5	38	<0.01	0.11	0.70	0.04
Reference sites	CT1	9.74	9.9	7.07	10.93	<1	26	<0.01	<0.01	0.05	0.04
	CT3	20.74	68.7	7.95	9.94	16.8	30	<0.01	<0.01	0.28	0.04
	QM1	15.14	45.4	7.44	9.77	1.1	21	<0.01	<0.01	0.21	0.04
	GM1	12.54	110.4	7.99	10.95	<1	59	<0.01	<0.01	0.02	0.03
	GM2	13.98	104.6	7.83	10.71	<1	60	<0.01	<0.01	0.03	0.03
	GM3	17.03	105.4	7.91	9.83	<1	59	<0.01	<0.01	0.05	0.03
	GT1	11.61	33.4	7.66	11.04	<1	32	<0.01	<0.01	0.06	0.03
	GT2	12.56	52.6	7.73	11.51	<1	36	<0.01	0.01	0.07	0.04
	GT3	12.96	30.3	7.61	10.87	<1	27	<0.01	<0.01	0.08	0.04

Periphyton and algae

Periphyton cover in riffle habitats ranged from <10 to 25% across all sites in autumn 2013 (Table 6). Observed periphyton cover was slightly higher at below dam test sites than at reference sites on the Goodradigbee River during sampling. Filamentous algae cover in riffle habitats was <10% at all below dam test sites; however, a dense coverage of filamentous algae was observed in a low-flow backwater below Corin Dam (CM1) (Figure 3).

Periphyton biomass (AFDM gm m^{-2}) was relatively low across all sites in autumn 2013 compared to previous assessments and was at similar densities across test and reference sites (Figure 4). Periphyton biomass was significantly lower below Googong Dam (QM2) than below Bendora Dam (CM2) and sites GM1 and GM3 on the Goodradigbee River (F=5.13; DF=6; P=0.0012).

Estimations of periphyton standing crop based on chlorophyll-a concentration analysis reflect field observations of periphyton cover, with the highest chlorophyll-a concentrations found below Corin Dam (CM1), Bendora Dam (CM2), and at site GM3 on the Goodradigbee River (Table 6; Figure 5). However, differences in chlorophyll-a concentrations between site were not significant (F=2.40; DF=6; P=0.0536).

Table 6: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and Goodradigbee River reference sites, from autumn 2010 to autumn 2013.

Met objective	On the cusp of objective	Did not meet objective

	% cover of riffle habitat											
	Periphyton						Filamentous algae					
	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12	Aut-13	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12	Aut-13
CM1	<10	<10	35-65	<10	<10	25	<10	<10	10-35	<10	10-35	<10
CM2	<10	<10	10-35	<10	10-35	25	<10	<10	10-35	<10	>90	<10
CM3	10-35	<10	<10	<10	10-35	<10	<10	<10	<10	<10	<10	<10
QM2	<10	<10	35-65	<10	<10	<10	<10	<10	10-35	<10	<10	<10
GM1	<10	<10	<10	<10	<10	15	<10	<10	<10	<10	<10	10
GM2	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
GM3	<10	<10	<10	10-35	10-35	<10	<10	<10	<10	<10	<10	<10

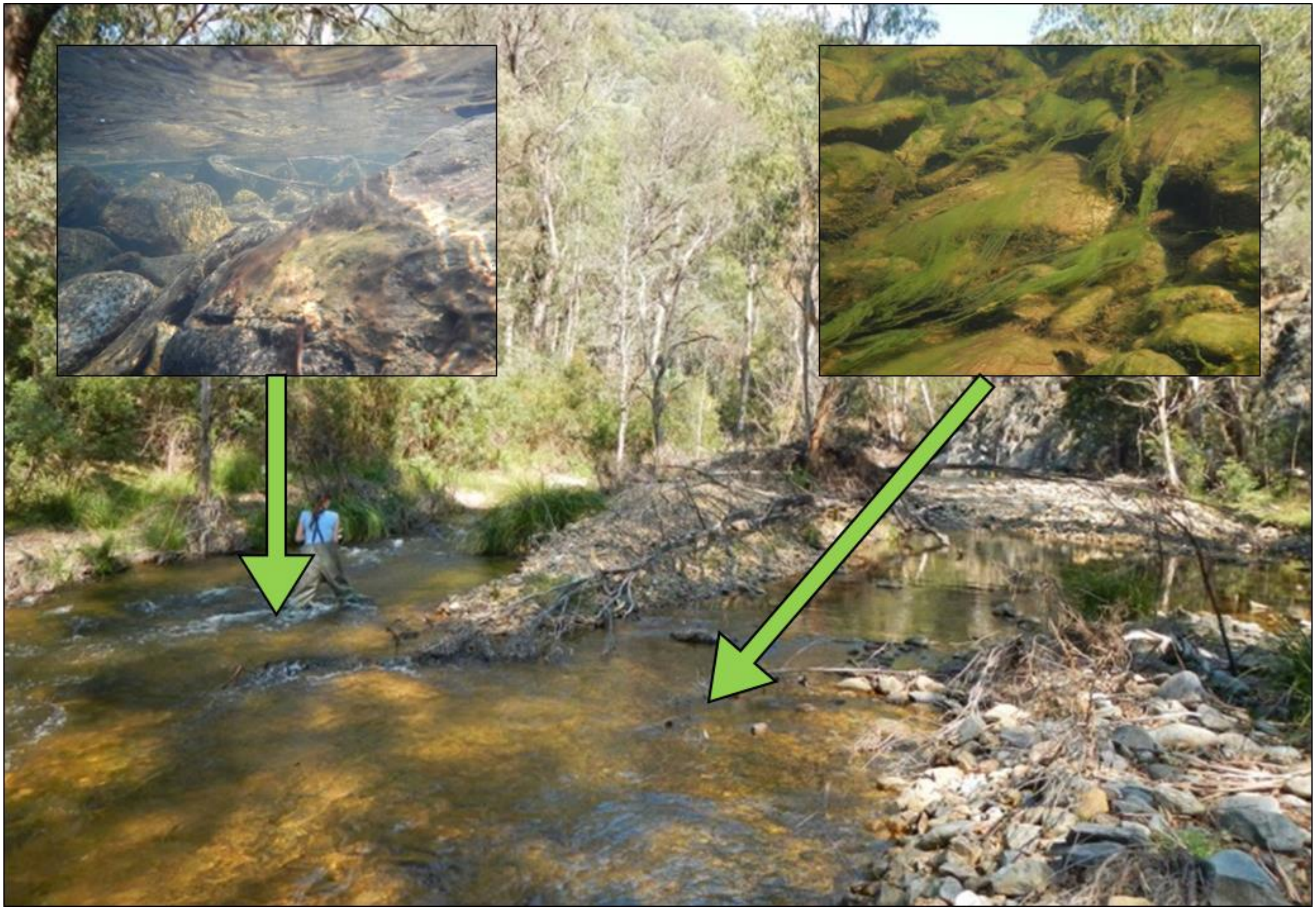

Figure 3. Minimal algae cover on the streambed in the main channel below Corin Dam (left), and dense algae cover in an adjacent low-flow backwater (right). (10/4/2013).

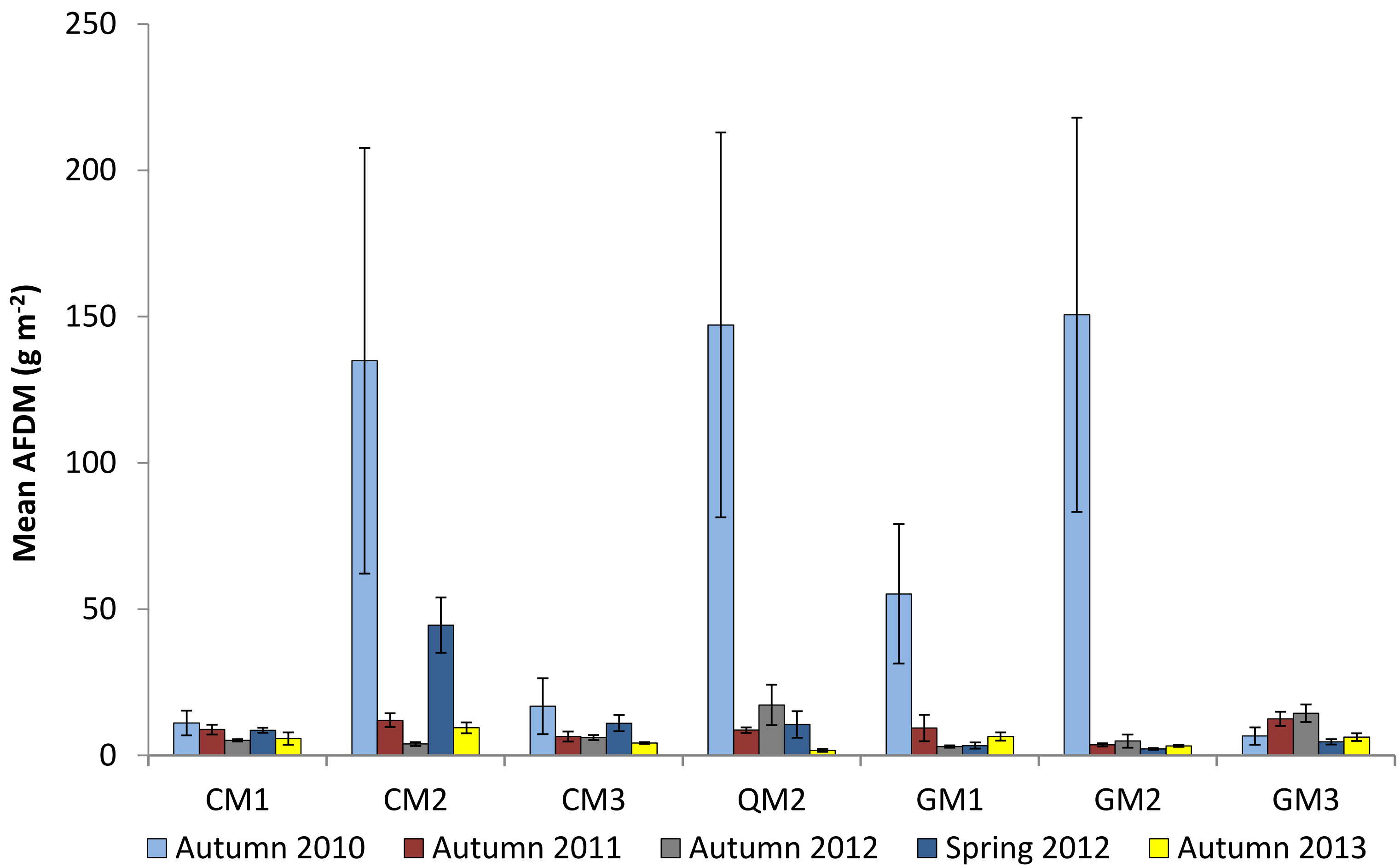

Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2010 to autumn 2013. Error bars represent +/- 1 standard error.

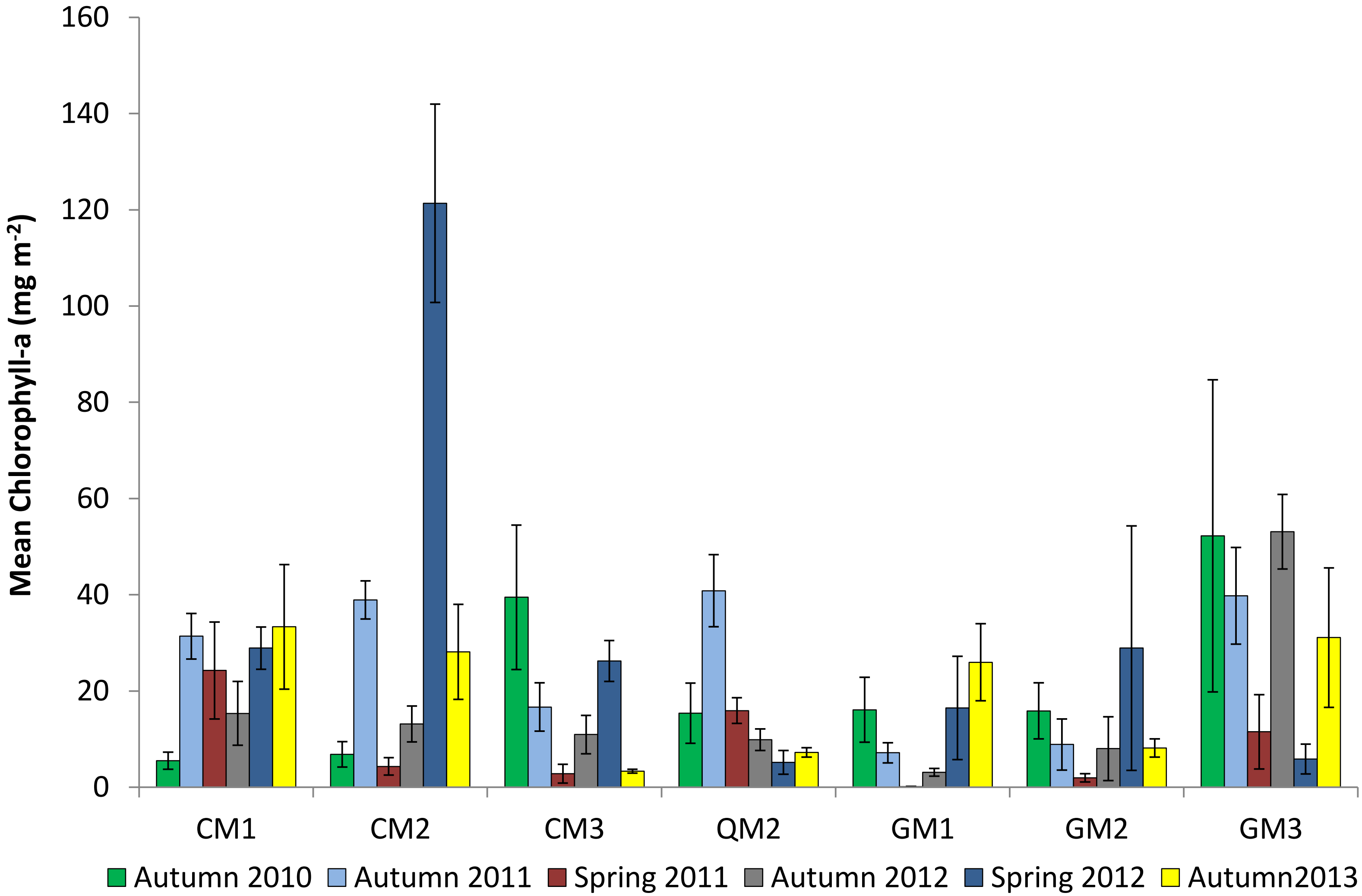

Figure 5: Mean chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2010 to autumn 2013. Error bars represent +/- 1 standard error.

Benthic macroinvertebrates

AUSRIVAS assessment

Test sites CM1 below Corin Dam and CM3 below Cotter Dam both declined in biological condition since spring 2012 from AUSRIVAS band B (significantly impaired) to band C (severely impaired) in autumn 2013 (Table 7). The other Cotter River test site below Bendora Dam (CM2) improved in biological condition from significantly impaired (band B) in spring 2012 to similar to reference condition (band A) in autumn 2013 (Table 7).

Reference sites GM1 and GM2 on the Goodradigbee River maintained similar to reference condition (band A) assessments in autumn 2013 (Table 7); however, reference site GM3 declined from similar to reference (band A) in spring 2012 to significantly impaired in autumn 2013. The O/E taxa score for this site was similar to the assessment of autumn 2012 following the March 2012 flood disturbance (Table 7).

Tributary sites on the Cotter and Goodradigbee Rivers (CT1, CT3, GT1, GT2, and GT3) remained in similar biological condition to the spring 2012 assessment. The exceptions being Burkes Creek which had no surface flow and was therefore not sampled, and Cooleman Creek (GT1) and Bramina Creek (GT3) which returned to reference condition (band A) after declining to significantly impaired (band B) in spring 2012 (Table 7).

Test sites QM2 and QM3 downstream of Googong Dam have remained significantly impaired (band B) since spring 2012 (Table 7). The upstream reference site on the Queanbeyan River QM1 has remained similar to reference condition (band A) in autumn 2013.

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) (Table 8). All sites, except for sites CT1, GM3, and GT3, had taxa identified in whole of sample scans that were missing from site sub-samples. These taxa, in order of highest to lowest SIGNAL 2 grade, include Leptophlebiidae (CM3), Hydrobiosidae (QM3, GM1, GT1, and GT2), Scirtidae (CM1), Psephenidae (CM2, QM1, and GT2), Gomphidae (CM3, CT3, and GM2), and Hydroptilidae (QM2) (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2010 to autumn 2013.

	Below dam test sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
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)
Spring 2011	B (0.77)	A (0.89)	B (0.81)	A (0.88)	A (0.92)	B (0.82)	A (1.00)	A (1.03)	X (1.20)	A (1.04)	A (1.04)	X (1.19)	A (1.13)	A (1.05)	A (0.98)
Autumn 2011	B (0.73)	A (0.89)	B (0.82)	A (0.96)	B (0.67)	X (1.17)	B (0.81)	A (0.89)	A (0.96)	X (1.16)	C (0.57)	A (1.05)	A (1.04)	A (0.93)	A (0.95)
Autumn 2010	B (0.74)	A (1.04)	B (0.83)	A (0.97)	B (0.83)	B (0.81)	B (0.77)	C (0.58)	A (0.96)	X (1.16)	A (1.03)	A (0.92)	A (1.01)	X (1.22)	B (0.82)

Table 8. 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 2013 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	CT1	CT3	QM1	QM2	QM3	GM1	GM2	GM3	GT1	GT2	GT3
Glossosomatidae	9	X												X	
Coloburiscidae	8	X												X	
Leptophlebiidae	8			X											
Gripopterygidae	8			X											
Hydrobiosidae	8								X	X			X	X	
Acarina	6			X											
Scirtidae	6	X													
Psephenidae	6		X	X	X		X							X	
Podonominae	6		X	X		X	X	X	X	X	X	X	X		X
Leptoceridae	6	X				X									
Tipulidae	5	X													
Simuliidae	5	X			X				X				X		
Baetidae	5	X													
Gomphidae	5			X		X		X		X	X	X			X
Hydrobiidae	4					X		X	X	X	X	X			
Ancylidae	4					X		X	X	X	X	X			
Tanypodinae	4		X	X		X	X	X	X			X			
Caenidae	4	X												X	
Hydroptilidae	4			X		X		X				X			
Chironominae	3	X													
Oligochaeta	2			X			X				X		X	X	X
Total		9	3	9	2	7	4	6	6	5	5	6	4	6	3

Relative abundance

In autumn 2013 the proportions of tolerant taxa (mean below dam sites – 8%; mean reference sites - 9%) , and sensitive taxa (mean below dam sites – 64%; mean reference sites - 82%) were more similar between below dam and reference sites (Figure 6, Figure 7) compared to spring 2012 (see Florance and Levings 2012). In spring 2012 below dam sites were numerically dominated by tolerant taxa (mean below dam sites – 44%; mean reference sites - 14%), and sensitive taxa comprised the majority of reference site samples (mean below dam sites – 8%; mean reference sites - 66%) (see Florance and Levings 2012).

The macroinvertebrate sample from below Cotter Dam (CM3) was dominated by Simuliidae (61% of the sub-sample – Diptera Other), and Plecoptera were absent from samples collected below Cotter and Googong Dams (CM3, QM2, and QM3) (Figure 6, Figure 8).

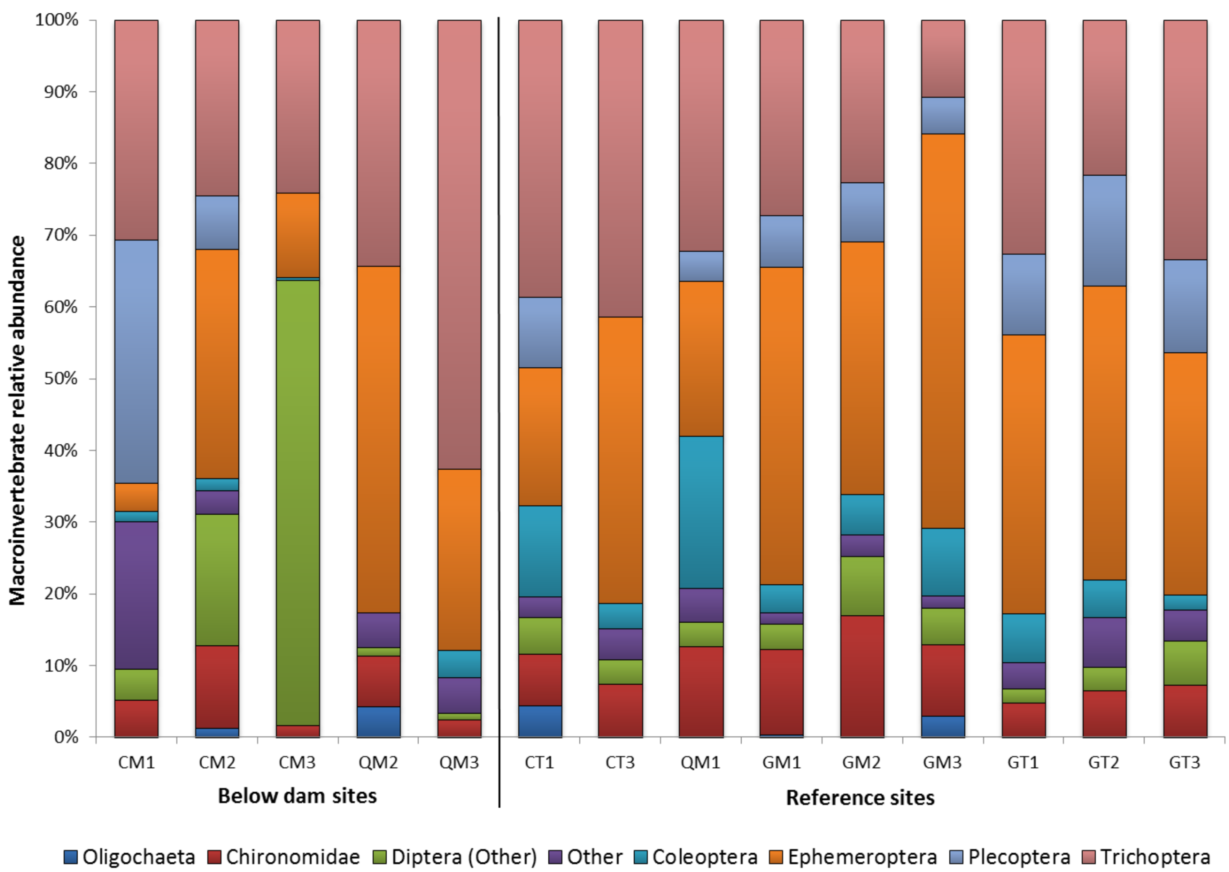

Figure 6: Relative abundance of macroinvertebrates taxa groups from samples collected in autumn 2013.

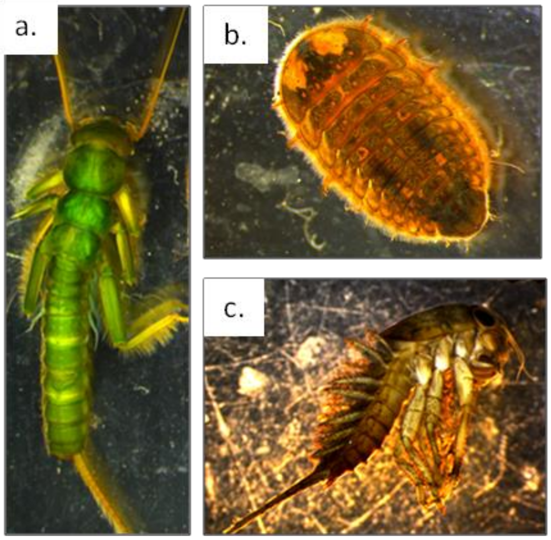

Figure 7. Examples of macroinvertebrate taxa sensitive to habitat disturbance collected from Goodradigbee River reference sites in autumn 2013. (a) Eustheniidae (Plecoptera), (b) Psephenidae (Coleoptera), (c) Coloburiscidae (Ephemeroptera). ***Photos A. Florance.***

Figure 8. Macroinvertebrate taxa typical of below dam riffle habitats. (a) Hydropsychidae (Trichoptera), (b) Philopotamidae (Trichoptera), (c and e) Hydrobiosidae (Trichoptera), (d) Simuliidae (Diptera), (f) Gripopterygidae (Plecoptera). ***Photos A Florance.***

Differences in macroinvertebrate community composition between below dam test sites and reference sites was evident when macroinvertebrate taxa were categorised into Functional Feeding Groups (see www.mdfrc.org.au/bugguide) (Figure 9). Collector (filterer and gatherer) taxa were numerically dominant at each of the below dam test sites (except for below Corin Dam, site CM1), whereas scraper taxa were numerically dominant at each of the reference sites (Figure 9).

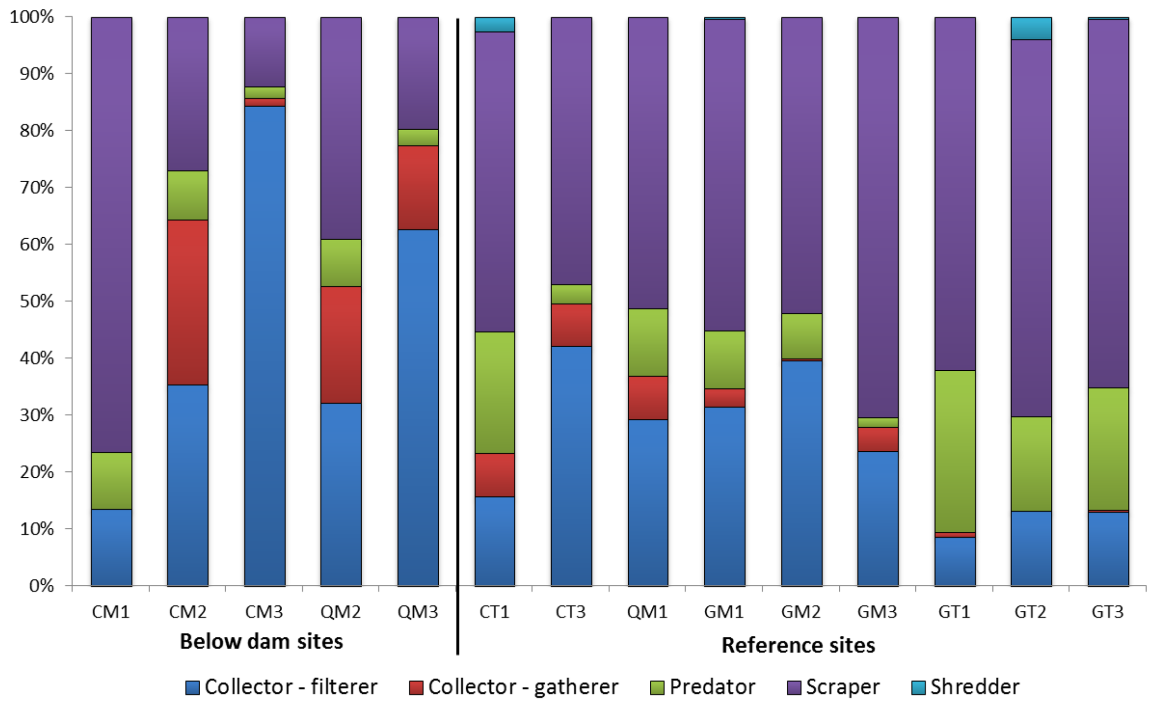

Figure 9. Functional feeding groups of macroinvertebrate taxa from samples collected in autumn 2013.

Macroinvertebrate assemblage similarity

Cluster analysis based on the relative abundance of macroinvertebrate taxa identified four groups of sites at 60% similarity, which were well separated (ANOSIM R >0.85) (Figure 10). Sites below Corin Dam (CM1) and Cotter Dam (CM3) had distinct macroinvertebrate assemblages. The macroinvertebrate assemblage below Corin Dam (CM1) was primarily defined by the presence of Lymnaeidae and the absence Baetidae and Leptoceridae (Appendix 2); and site CM3 below Cotter Dam was defined by a greater abundance of Simuliidae, Hydropsychidae, and Baetidae compared to other sites (Appendix 2). Sites QM1, QM2, and QM3 on the Queanbeyan River were grouped together with site CM3 on Paddys River (Figure 10). These sites were defined by a greater abundance of Hydropsychidae and Caenidae compared to other sites (Appendix 2). Reference sites on the Goodradigbee River and tributaries were grouped with reference site CT1 (Kangaroo Creek) and test site CM2 below Bendora Dam and had greater abundances of sensitive macroinvertebrates taxa (SIGNAL 2 grades > 7) (Figure 10, Appendix 2).

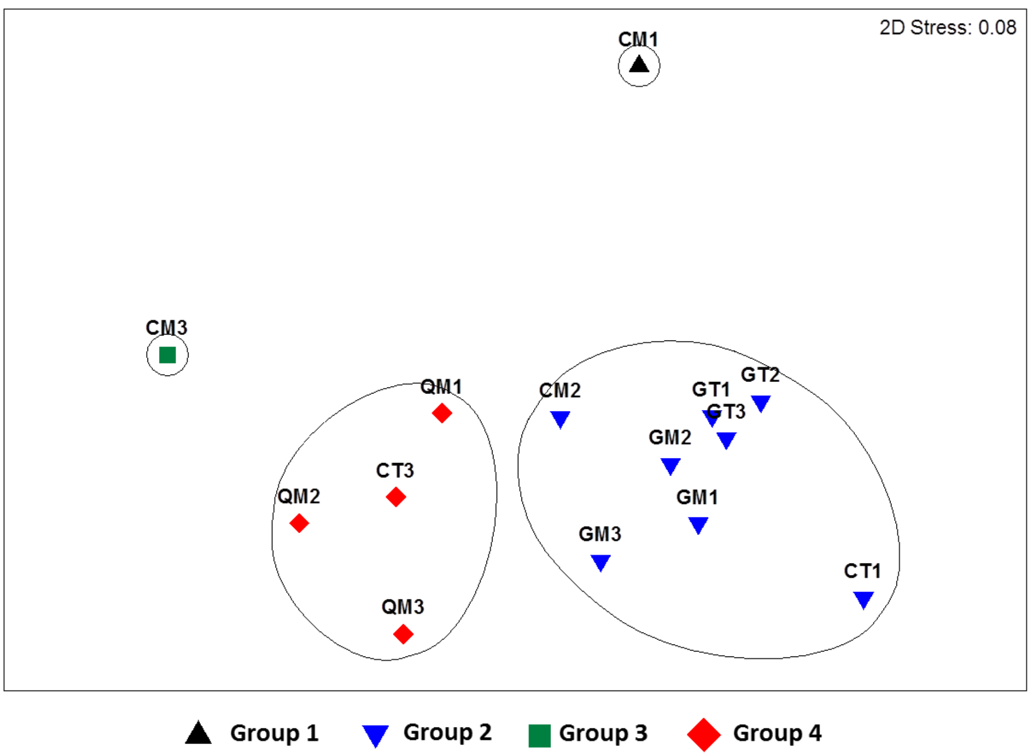

Figure 10. MDS ordination of similarity between macroinvertebrate samples collected in autumn 2013 for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance and site groups are defined from a cluster analysis.

Discussion and Conclusions

Water quality

Water quality at below dam test sites and unregulated reference sites was generally within guideline levels in autumn 2013 (Table 5). Parameters that were outside of guideline levels in autumn 2013 were total phosphorus (TP), total nitrogen (TN), and nitrogen oxide (NO_x) concentrations (Table 5).

It is unclear exactly what has caused the elevated TP concentrations across all sites in autumn 2013. It may be that coarse organic matter and sediment that entered these streams during floods in March 2012 is breaking down and releasing phosphorus into the system. Phosphorus concentrations were similar at below dam test sites and reference sites in autumn 2013, which precludes the presence or operation of dams on the Cotter and Queanbeyan Rivers as a cause of increased TP concentrations.

Total nitrogen and nitrogen oxide concentrations were higher below dams than at reference sites (Table 5). This has been identified in previous assessments (see Florance et al. 2012), particularly below Googong Dam, and is likely to be caused by an influx of organic material to reservoirs during recent flood events. Nitrogen concentrations downstream of dams on the Cotter and Queanbeyan Rivers is a consequence of organic matter breakdown in the storages post flooding and is not a result of reservoir management.

Periphyton and algae

Although observations of periphyton cover of riffle habitats during sampling indicated greater coverage below Corin and Bendora Dams, AFDM and chlorophyll-a analysis showed that periphyton cover at these sites was not significantly higher than at reference sites on the Goodradigbee River (Table 6; Figure 4; Figure 5). Periphyton has been shown to reach 'nuisance' levels where it can smother the stream bed and have a negative effect on many types of macroinvertebrate taxa at 100 to 150 mg chlorophyll-a m^{-2} (Rosen 1995). Periphyton cover was well below this level at all sites in autumn 2013 and is therefore unlikely to be having a negative effect on overall river health.

Filamentous algae cover met the environmental flow ecological objective of <20% cover of riffle habitats at all test sites in autumn 2013 (Table 6). A dense cover of filamentous algae was observed in a low-flow backwater below Corin Dam (CM1) in autumn 2013, indicating a potential for prolific algal growth under low-flow conditions. In the main channel, however, flow releases have been adequate to prevent the establishment of dense algal cover at this site (Figure 3).

Benthic macroinvertebrates

The biological condition of test and reference sites in the autumn 2013 assessment remained relatively stable since the spring 2012 assessment compared to the shifts in biological condition observed in these streams in autumn and spring 2012 (Table 7). Reference sites on the Goodradigbee River and tributaries were generally in AUSRIVAS band A condition in autumn 2013, except for sites GM3 and GT2 which had O/E scores in the upper region of band B (Table 7).

Site CM2 below Bendora Dam met the environmental flow ecological objective of AUSRIVAS band A assessment, and had a similar macroinvertebrate assemblage to Goodradigbee River reference sites (Figure 10). This is the first time a band A O/E score has been achieved at a below dam site since spring 2011 before the March 2012 flood disturbance (Table 7). It is likely that the biological impairment observed below Bendora Dam in 2012 assessments resulted from the initial flood disturbance and a lag in recovery because of the upstream barrier to re-colonisation (see Florance et al. 2012). Therefore, in the absence of further disturbance, the Cotter River reach downstream of Bendora Dam is likely to be able to maintain a biological condition similar to reference condition under current management.

Sites CM1 (below Corin Dam) and CM3 (below Cotter Dam) on the Cotter River both declined from band B to band C in autumn 2013 (Table 7). These two sites had macroinvertebrate assemblages that were distinct from all other sites (Figure 10). The presence of the gastropod Lymnaeidae was the primary contributor to the taxonomic distinction below Corin Dam (this taxa was not present at any of the other sites)(Appendix 2). Lymnaeidae comprised part of a numerical dominance of algae grazing ‘scraper’ taxa that were identified in the sub-sample from this site in autumn 2013 (Figure 9), which may be related to a low-flow backwater adjacent to the riffle habitat at site CM1.

This backwater is a remnant of a side channel that was scoured into the streambed below Corin Dam during the March 2012 flood event. Under post-flood flow conditions this area provides shallow, low-flow habitat which enhances algal production and favours algae grazing taxa such as Lymnaeidae. The presence of low-flow algae grazing taxa in the CM1 macroinvertebrate sample may be because Lymnaeidae have drifted into the riffle habitat from the adjacent low flow habitat.

The macroinvertebrate assemblages downstream of dams on the Cotter and Queanbeyan Rivers are characteristic of findings from previous research which has described macroinvertebrate functional feeding groups downstream of impoundments. Impoundments can results in higher proportions of ‘filterer’ and ‘gatherer’ taxa that feed on fine organic particulates in water being released from the dam (Stanford and Ward 1983; Casas et al. 2000). Higher proportions of ‘filterer’ and ‘gatherer’ taxa were observed at below dam sites on the Cotter and Queanbeyan Rivers in autumn 2013, with the exception of site CM1 below Corin Dam that was numerically dominated by algal grazers (see previous paragraph, Figure 9).

The macroinvertebrate assemblage below Cotter Dam (CM3) was characterised by numerical dominance of Simuliidae (Black Fly larvae) taxa (Figure 6, Appendix 2). This filter feeding taxa is suited to fast-flowing rock bed streams below impoundments where they attach to the substrate and filter fine organic particulates from the water column (Gooderham and Tsyrlin 2003; Ward and Stanford 1983). These taxa have been found in very high abundance below Cotter Dam during the past three assessments, and may be outcompeting less suited taxa for habitat availability. The presence of two taxa (Leptophlebiidae and Gomphidae) in the sample scan, that were expected to occur by the AUSRIVAS model but missing from sub-sample for site CM3 (Table 8) suggests they were present in low abundance which supports a hypothesis of competition for habitat availability at this site.

A potential driver of the high abundance of Simuliidae taxa below Cotter Dam is the M2C water recirculation transfer pipe. 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 taxa in riffle habitats downstream of the M2C discharge point.

Sites QM2 and QM3 below Googong Dam have remained significantly impaired since the flood disturbance in March 2012 (Table 7). Inflows from this flood event increased concentrations of dissolved organics and nutrients in the reservoir. This shift in water quality released from Googong Dam may be limiting the capacity for these sites to return to pre-flood disturbance biological condition. The macroinvertebrate assemblages at Queanbeyan River sites (QM1, QM2, and QM3) were similar to reference site CT3 on Paddys River (Figure 10), which had high nutrient concentrations compared to other reference sites in autumn 2013 (Table 5). This provides further evidence that water quality may be influencing macroinvertebrate assemblages at these sites.

Reference sites on Cotter River tributaries sampled in the autumn 2013 (CT1 and CT3), remained in a similar condition to spring 2012 (CT1 – similar to reference condition, CT3 – significantly impaired) (Table 7). The change of O/E score at site CT1 in autumn 2013 from a Band X O/E score (more biologically diverse than reference) to a Band A O/E score (similar to reference) is likely the result of natural variability around the reference condition for the site. The results for the Cotter tributary sites sampled in autumn 2013 exclude a catchment-scale effect as a driver behind the declines in condition observed at the Cotter River main-channel sites below Corin and Cotter Dams.

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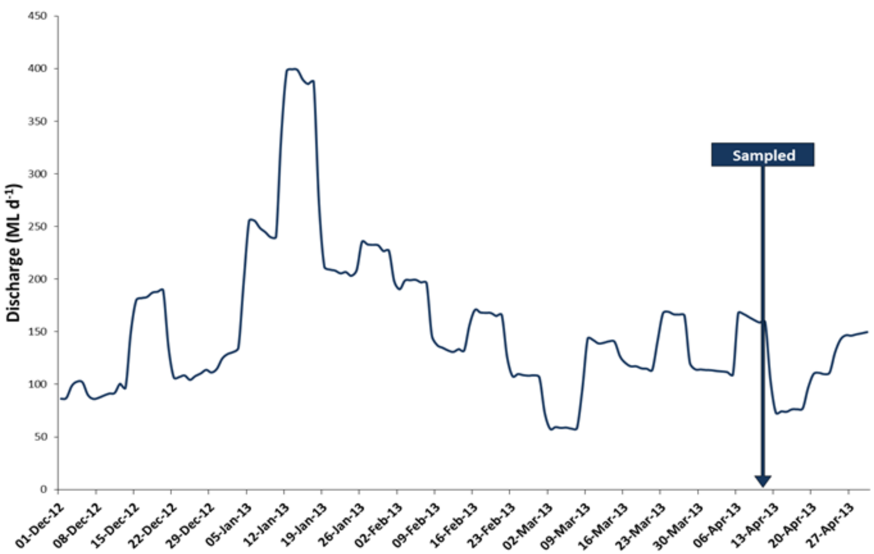
Appendix 1.

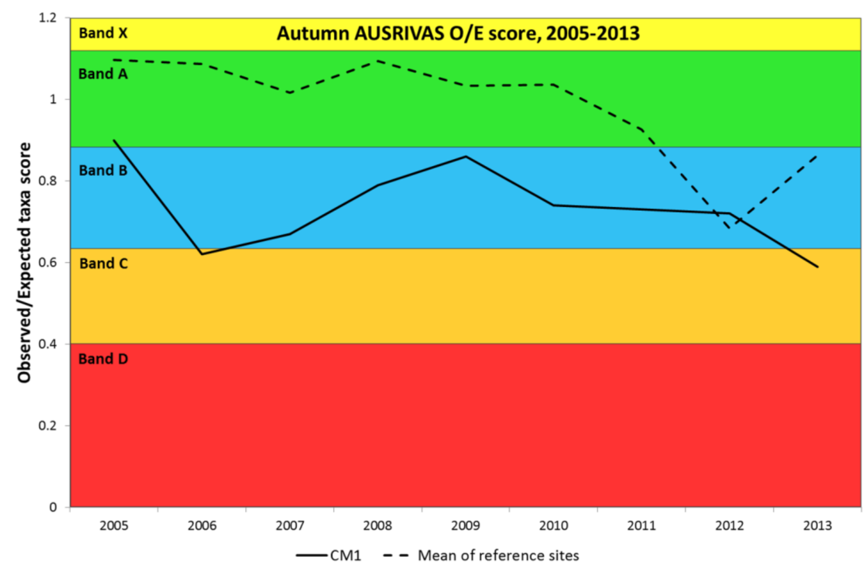
Site summary sheets

CM1 – Autumn 2013

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2012	Autumn 2013	Objective met?
AUSRIVAS band A	Band B	Band C	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





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* Denotes values outside ANZECC/ARMCANZ (2000) guideline levels

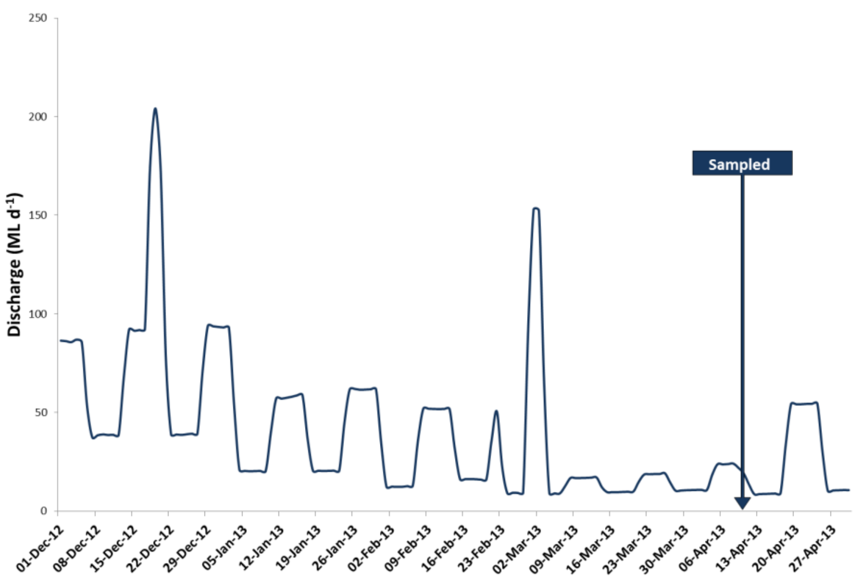
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	D.O. (% sat.)	Turbidity (NTU)	Alkalinity (mg L^{-1})	Ammonia (NH_3 mg L^{-1})	Nox (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
13.0	30.3	7.6	10.87	108.8	0	27	<0.01	0.01	0.13	0.03*

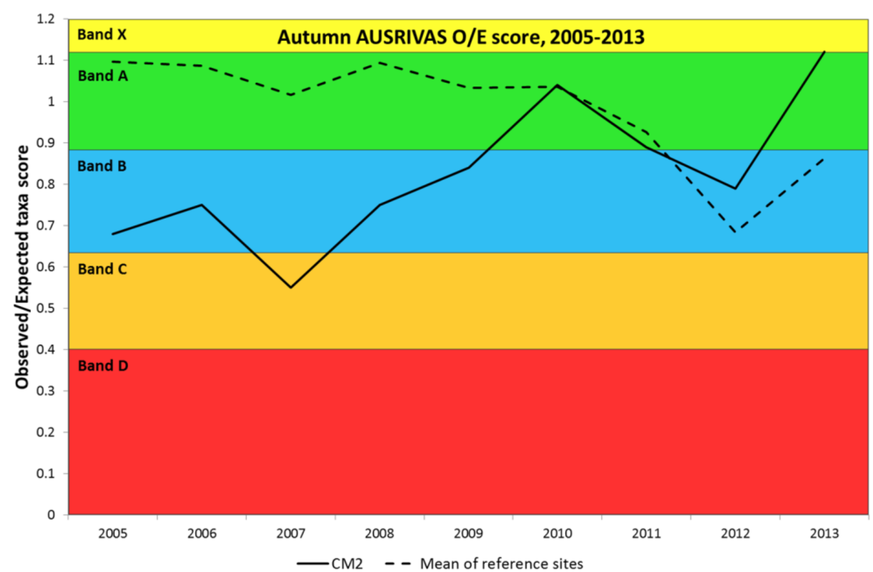
ACTEW WATER

CM2 – Autumn 2013

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2012	Autumn 2013	Objective met?
AUSRIVAS band A	Band B	Band A	Yes
<20% filamentous algae cover in riffle habitat	>90%	<10%	Yes





Institute for Applied Ecology

* Denotes values outside ANZECC/ARMCANZ (2000) guideline levels

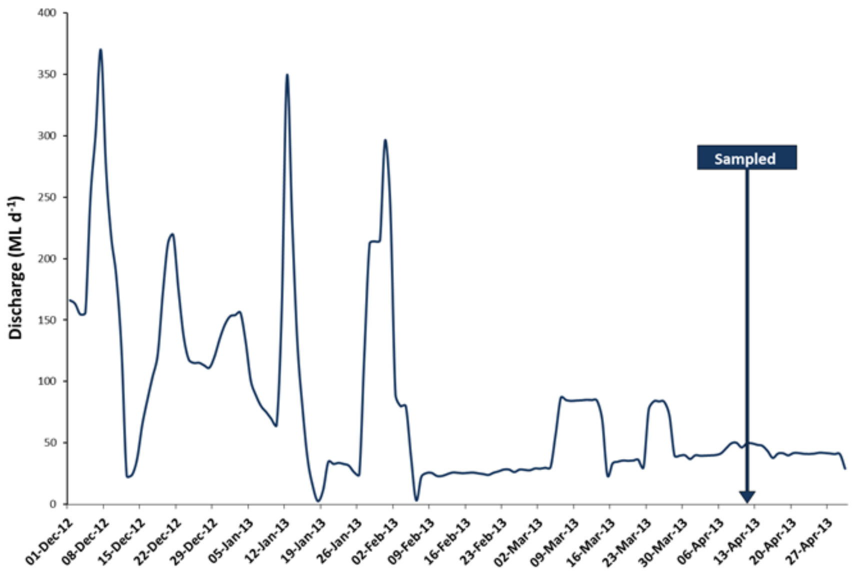
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	D.O. (% sat.)	Turbidity (NTU)	Alkalinity (mg L^{-1})	Ammonia (NH_3 mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
17.5	29.3	6.8	10.4	112.1	0	10	<0.01	0.02*	0.28*	0.03*

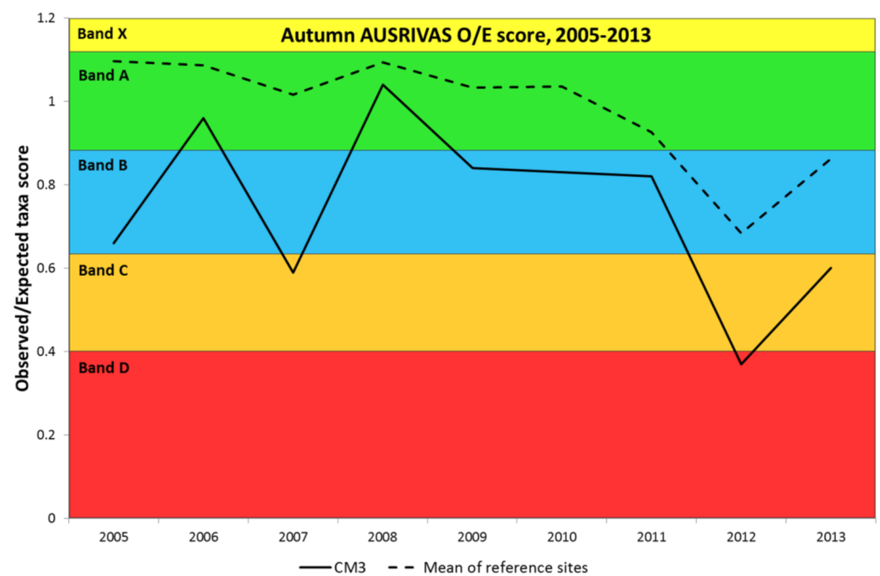
ACTEW WATER

CM3 – Autumn 2013

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2012	Autumn 2013	Objective met?
AUSRIVAS band A	Band B	Band C	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





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* Denotes values outside ANZECC/ARMCANZ (2000) guideline levels

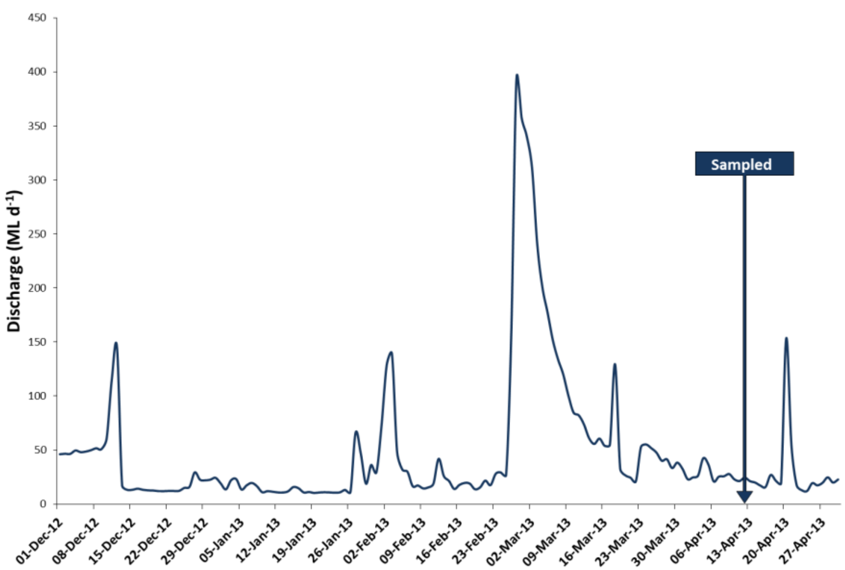
Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	D.O. (% sat.)	Turbidity (NTU)	Alkalinity (mg L-1)	Ammonia (NH_3 mg L-1)	Nox (mg L-1)	TN (mg L-1)	TP (mg L-1)
20.44	175.3	7.9	9.77	114.9	3.2	64	0.01	<0.01	0.40*	0.03*

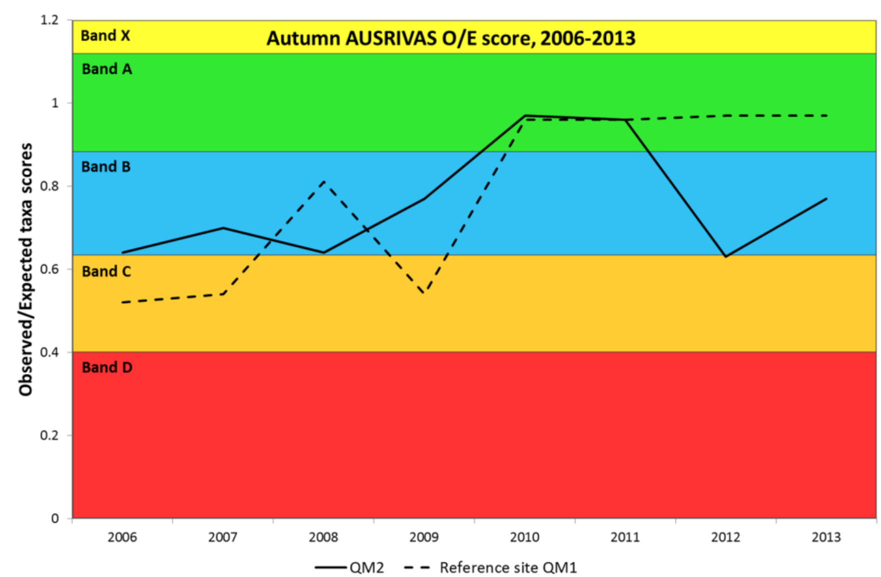
ACTEW WATER

QM2 – Autumn 2013

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2012	Autumn 2013	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





Institute for Applied Ecology

* Denotes values outside ANZECC/ARMCANZ (2000) guideline levels

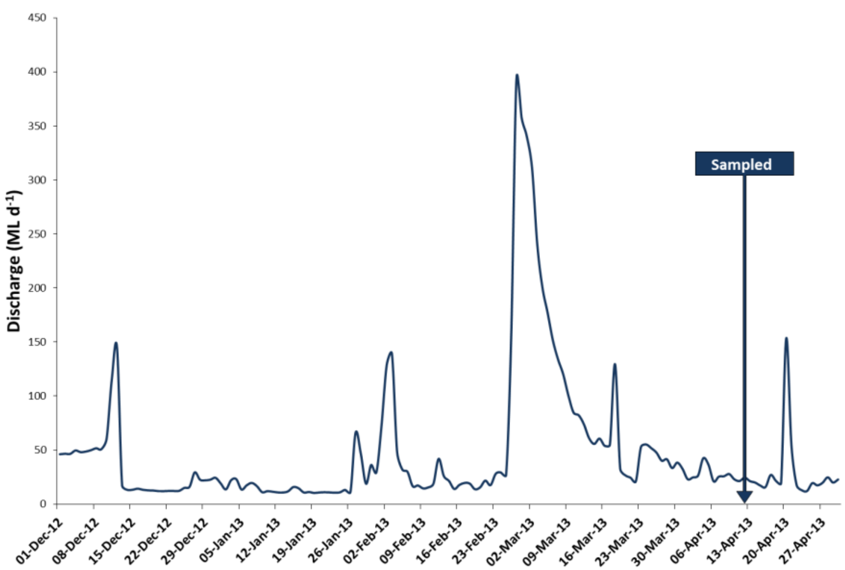
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	D.O. (% sat.)	Turbidity (NTU)	Alkalinity (mg L^{-1})	Ammonia (NH_3 mg L^{-1})	Nox (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
18.0	78.6	7.7	10.41	118.0	0.8	23	0.01	0.15*	0.80*	0.04*

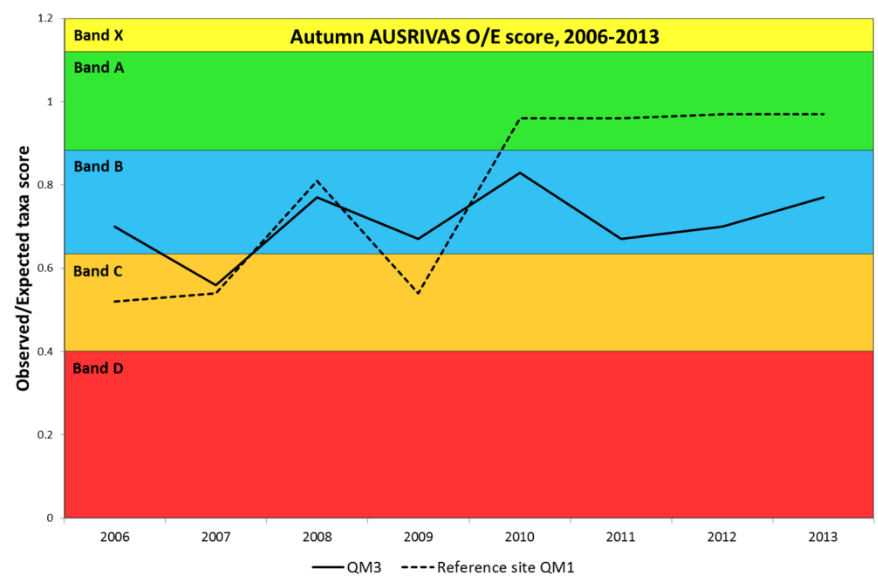
ACTEW WATER

QM3 – Autumn 2013

2 km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2012	Autumn 2013	Objective met?
AUSRIVAS band A	Band B	Band B	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





Institute for Applied Ecology

* Denotes values outside ANZECC/ARMCANZ (2000) guideline levels

Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	D.O. (% sat.)	Turbidity (NTU)	Alkalinity (mg L^{-1})	Ammonia (NH_3 mg L^{-1})	Nox (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
18.3	85.2	7.6	9.91	112.8	4.5	38	<0.01	0.11*	0.70*	0.04*

ACTEW WATER

Appendix 2.

Macroinvertebrate taxa

collected in autumn 2013

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples during autumn 2013 at each of the study sites.

CLASS **Order** Family *Subfamily*	**SIGNAL2 Grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
ACARINA	**6**	28	8		4	6	4			8	8	18	7	8	5	9
OLIGOCHAETA	**6**		3		1		7	12							8	
TURBELLARIA																
Tricladida																
Dugesiidae	**2**							1				3	1	1	3	
Megaloptera																
Corydalidae	**7**	6				1		1			2			1		
Plecoptera																
Eustheniidae	**10**				1											
Gripopterygidae	**8**	71	18		18	19	12	27			30	47	30	10		
Odonata																
Gomphidae	**5**													1		2
Telephlebiidae	**9**							1		2						1
Ephemeroptera																
Baetidae	**5**		2	25	28	22	42	4		64	47	38	28	27	58	23
Caenidae	**4**		67	3	7	1	3	8		17	2		1	18	30	35
Coloburiscidae	**8**				8	4	3	7								
Leptophlebiidae	**8**	8	8		69	54	80	34		11	55	87	49	6	1	2
Coleoptera																
Elmidae	**7**	1	4	1	5	9	8	30		8	12	3	2	50		8
Ptilodactylidae	**10**							2								
Psephenidae	**6**	2			1		2				2		1			
Scirtidae	**6**				4	4	12	3			4	13	2			1
Diptera																
Ceratopogonidae	**4**						1			1						1
Chironomidae																
Aphroteniinae	***6***				1			3								
Chironominae	***3***		14	1	16	35	13	9		1	9	11	13	10	6	1
Orthocladiinae	***4***	8	14	3	4	2	10	5		16	2	3	2	20	7	5
Podonominae	***6***							1								
Tanypodinae	***4***	3			9	2		2			2	6	2			
Empididae	**5**	9	3	3		1		1			2	5	2			

Appendix 2 ***continued over page.***

Appendix 2 ***continued***

CLASS **Order** Family *Subfamily*	**SIGNAL2 Grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Simuliidae	**5**		40	144	3	16	9			6		3	9	6	1	
Tipulidae	**5**		1		5	1	1	1		1	3	2	3	2	1	1
Athericidae	**8**				1	1	1	12								
Gastropoda																
Ancylidae	**4**							5					2			
Lymnaeidae	**1**	9														
Physidae	**1**														1	
Trichoptera																
Calamoceratidae	**7**											1	1			
Calocidae	**9**							2				11				
Conoesucidae	**7**	32	10		10	8	6	22		1	10	6	27			
Ecnomidae	**4**		6	1						3	4				9	
Glossosomatidae	**9**							16					2			
Helicopsychidae	**8**							1								
Hydrobiosidae	**8**	2	4	1		2	1	1		1			1	4	1	
Hydropsychidae	**6**	28	13	55	48	30	18	20		88	8	4	6	53	52	147
Hydroptilidae	**4**	1	4		1	2		2			2	2	2	19		1
Leptoceridae	**6**		3		9	8		37			36	29	39		1	1
Philorheithridae	**8**										25	4				
Philopotamidae	**8**		18		1	2		4		2	2	9				
Tasimiidae	**8**	1	1					1								
No. individuals		**209**	**241**	**237**	**254**	**230**	**233**	**275**		**230**	**267**	**305**	**232**	**236**	**184**	**238**
No. of taxa		**15**	**21**	**10**	**22**	**22**	**19**	**32**		**16**	**21**	**21**	**232**	**10**	**15**	**15**
% of sub-sample		**3**	**2**	**1**	**2**	**1**	**5**	**2**		**3**	**2**	**2**	**2**	**3**	**2**	**3**
Whole sample estimate		**6967**	**12050**	**23700**	**12700**	**23000**	**4660**	**13750**		**7667**	**13350**	**15250**	**11600**	**7867**	**9200**	**7933**

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). Groups 1 and 2 each consist of single sites and are therefore not shown below.*

Group	Taxa	SIGNAL 2 grade	Average abundance	Consistency ratio	Contribution %	Cumulative %
Group 3	Leptophlebiidae	8	7.16	4.62	9.08	9.08
	Gripopterygidae	8	6.24	8.81	8.21	17.29
	Leptoceridae	6	5.67	5.6	7	24.29
	Chironominae	3	5.39	6.42	6.83	31.12
	Baetidae	5	5.77	2.9	6.83	37.95
	Conoesucidae	7	5.12	15.7	6.74	44.68
	Hydropsychidae	6	5.38	6.44	6.58	51.26
	Elmidae	7	4.42	7.27	5.65	56.91
	Orthocladiinae	4	3.85	18.43	4.86	61.77
	Acarina	6	4.12	1.52	4.53	66.3
	Hydroptilidae	4	3.31	7.74	4.27	70.57
Group 4	Hydropsychidae	6	11.11	4.05	14.07	14.07
	Baetidae	5	9.85	8.42	13.63	27.7
	Caenidae	2	8.12	3.11	10.1	37.8
	Orthocladiinae	4	6.99	9.78	10	47.8
	Acarina	6	6.29	6.27	8.65	56.46
	Leptophlebiidae	8	6.42	5.67	7.97	64.43
	Chironominae	3	5.54	4.67	7.4	71.83

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 were groups contained two or more sites.*

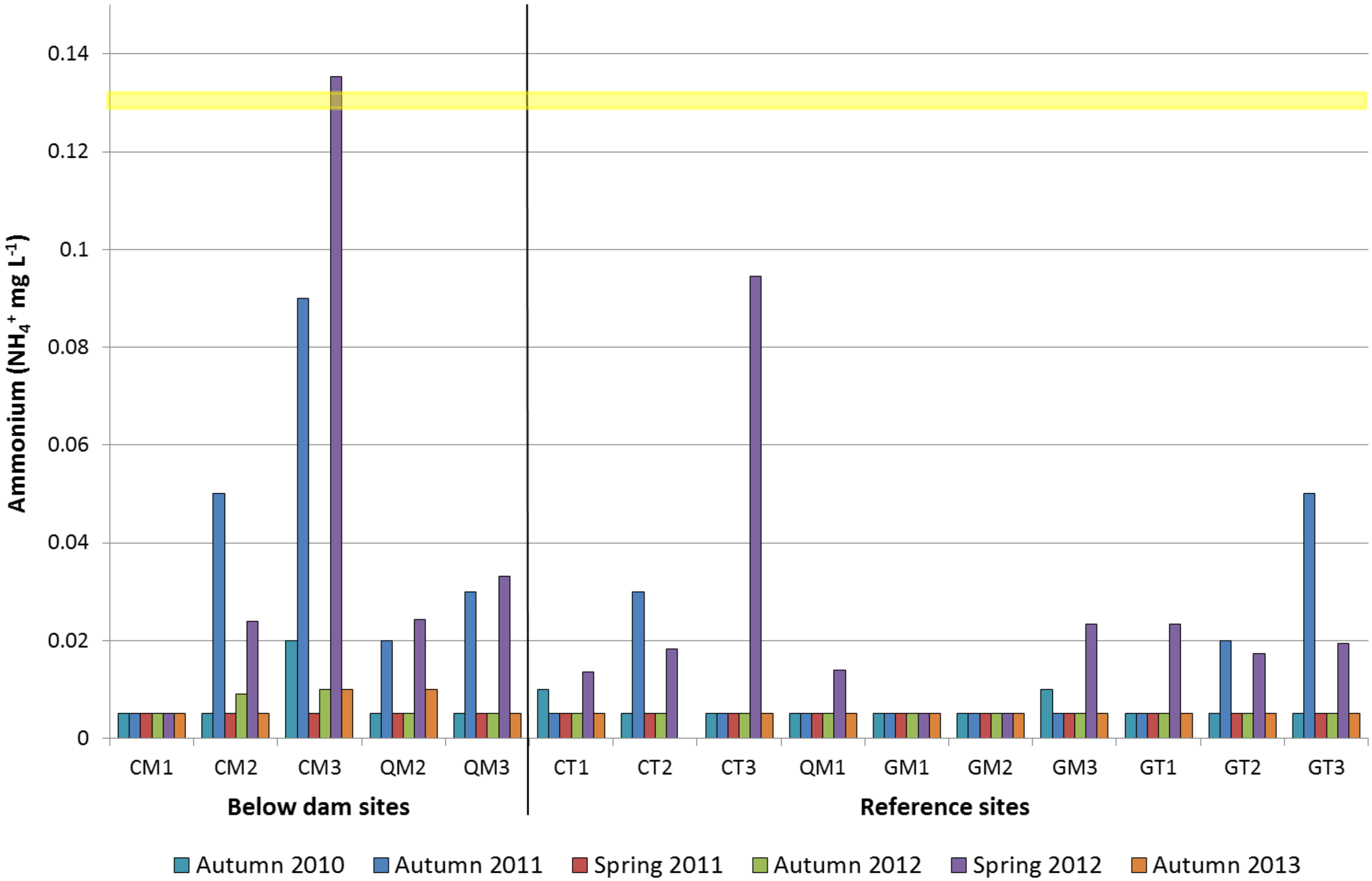
Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group 1	***Group 2***	
Simuliidae	5	0	21.16	
Baetidae	5	0	13.66	
Gripopterygidae	8	11.63	0	
Conoesucidae	7	9.53	0	
Acarina	6	9.21	0	
Caenidae	4	0	8.04	
Hydropsychidae	6	9.21	16.63	
Lymnaeidae	1	6.94	0	
Leptophlebiidae	8	6.74	0	
Corydalidae	7	6.27	0	
Chironominae	3	0	6.11	
Ecnomidae	4	0	6.11	
Tanypodinae	4	5.27	0	
Psephenidae	6	4.76	0	
Hydroptilidae	4	4	0	
		Group 1	***Group 3***	
Lymnaeidae	1	6.94	0	
Gripopterygidae	8	11.63	6.24	6.82
Conoesucidae	7	9.53	5.12	6.2
Chironominae	3	0	5.39	5.26
Tipulidae	5	0	3.3	4.84
Leptoceridae	6	0	5.67	4.56
Leptophlebiidae	8	6.74	7.16	4.12
Baetidae	5	0	5.77	3.31
Corydalidae	7	6.27	1.21	3.25
Orthocladiinae	4	6.74	3.85	3.24
Hydropsychidae	6	9.21	5.38	2.99
Empididae	5	6.94	2.86	2.86
Acarina	6	9.21	4.12	2.69
Tasimiidae	8	4	0.73	2.56
Psephenidae	6	4.76	1.3	2.13
Scirtidae	6	0	3.38	2.02
Philopotamidae	8	0	3.39	1.78
Hydrobiosidae	8	4.76	1.82	1.62
Caenidae	2	0	3.7	1.44
		Group 2	***Group 3***	
Hydropsychidae	6	16.63	5.38	8.77
Gripopterygidae	8	0	6.24	7.89
Conoesucidae	7	0	5.12	7.22
Simuliidae	5	21.16	3.67	6.16
Hydroptilidae	4	0	3.31	6.07
Leptophlebiidae	8	0	7.16	5.01
Tipulidae	5	0	3.3	4.84
Orthocladiinae	4	8.04	3.85	4.7
Leptoceridae	6	0	5.67	4.56
Baetidae	5	13.66	5.77	4.52
Empididae	5	8.04	2.86	3.63
Hydrobiosidae	8	6.11	1.82	2.36
Elmidae	7	6.11	4.42	2.28
Ecnomidae	4	6.11	1.25	2.26
Acarina	6	0	4.12	2.17
Scirtidae	6	0	3.38	2.02

Continued from previous page.

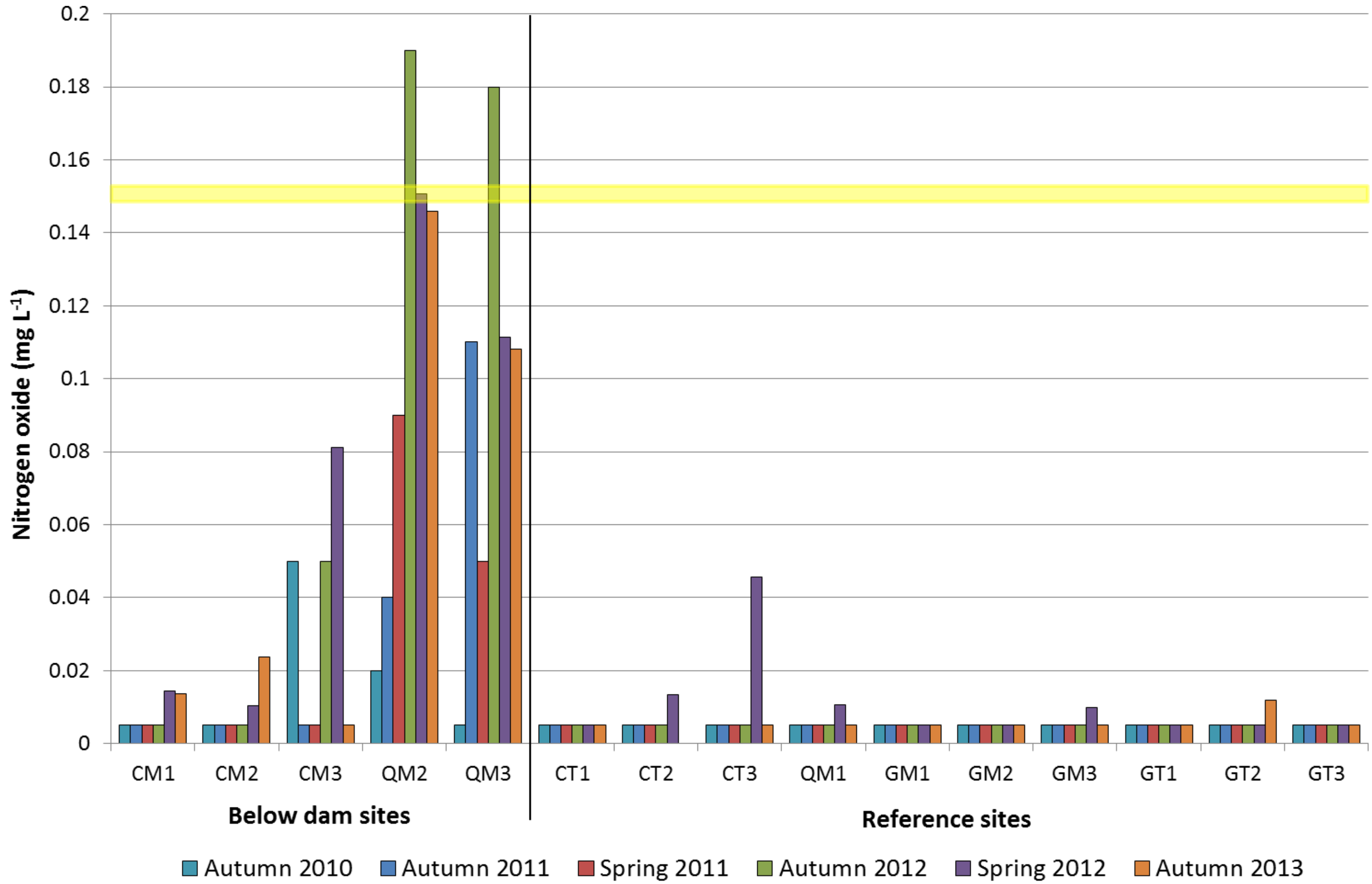
Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
Caenidae	4	8.04	3.7	2.01
Tanypodinae	4	0	3.15	2.01
		Group 1	***Group 4***	
Empididae	5	6.94	0	
Lymnaeidae	1	6.94	0	
Tanypodinae	4	5.27	0	
Tasimiidae	8	4	0	
Tipulidae	5	0	4.05	8.3
Baetidae	5	0	9.85	5.89
Chironominae	3	0	5.54	4.43
Corydalidae	7	6.27	0.72	3.46
Caenidae	4	0	8.12	3.14
Conoesucidae	7	9.53	1.8	3.09
Gripopterygidae	8	11.63	2.48	2.69
Acarina	6	9.21	6.29	2.57
Psephenidae	6	4.76	0.77	2.31
Elmidae	7	4	5.83	2.24
Hydroptilidae	4	4	2.39	2.07
Simuliidae	5	0	4.34	1.72
		Group 2	***Group 4***	
Empididae	5	8.04	0	
Tipulidae	5	0	4.05	8.3
Simuliidae	5	21.16	4.34	6.67
Acarina	6	0	6.29	5.51
Leptophlebiidae	8	0	6.42	3.06
Baetidae	5	13.66	9.85	2.27
Hydropsychidae	6	16.63	11.11	1.69
Ecnomidae	4	6.11	2.53	1.51
Hydrobiosidae	8	6.11	3.31	1.42

Appendix 3.

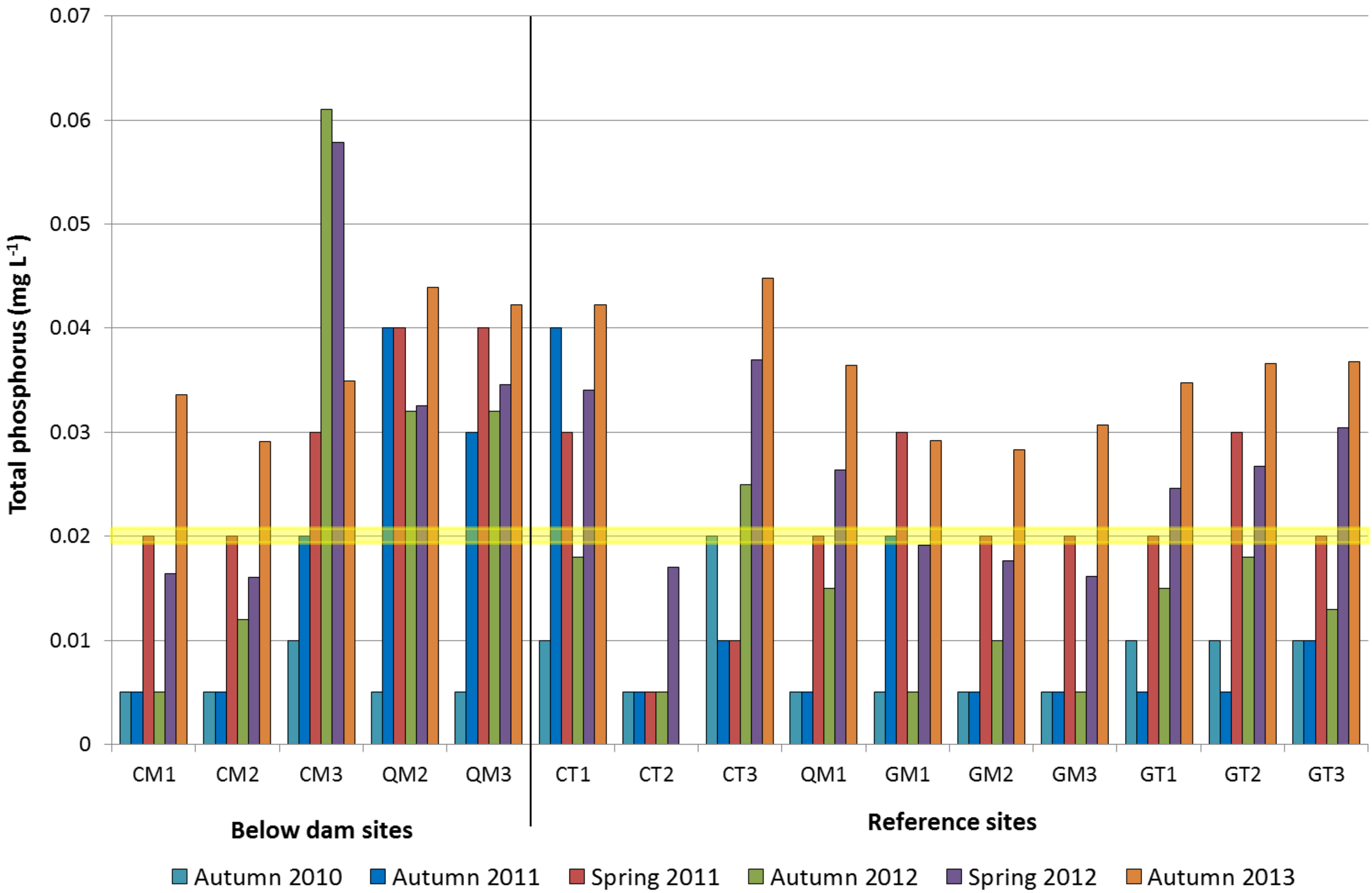
Water quality figures



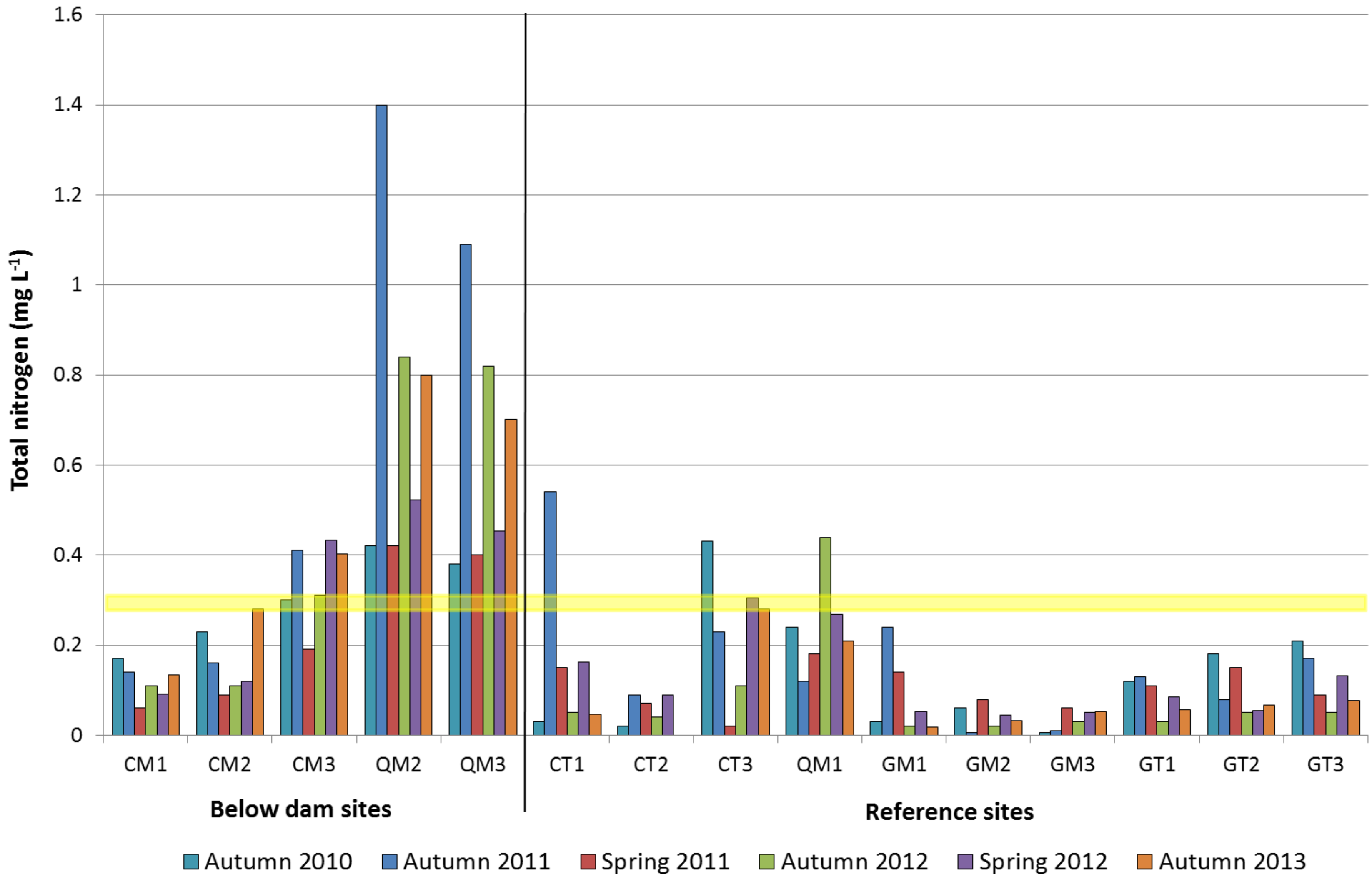
Ammonium (NH_4^+) concentration at all sites from autumn 2010 to autumn 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



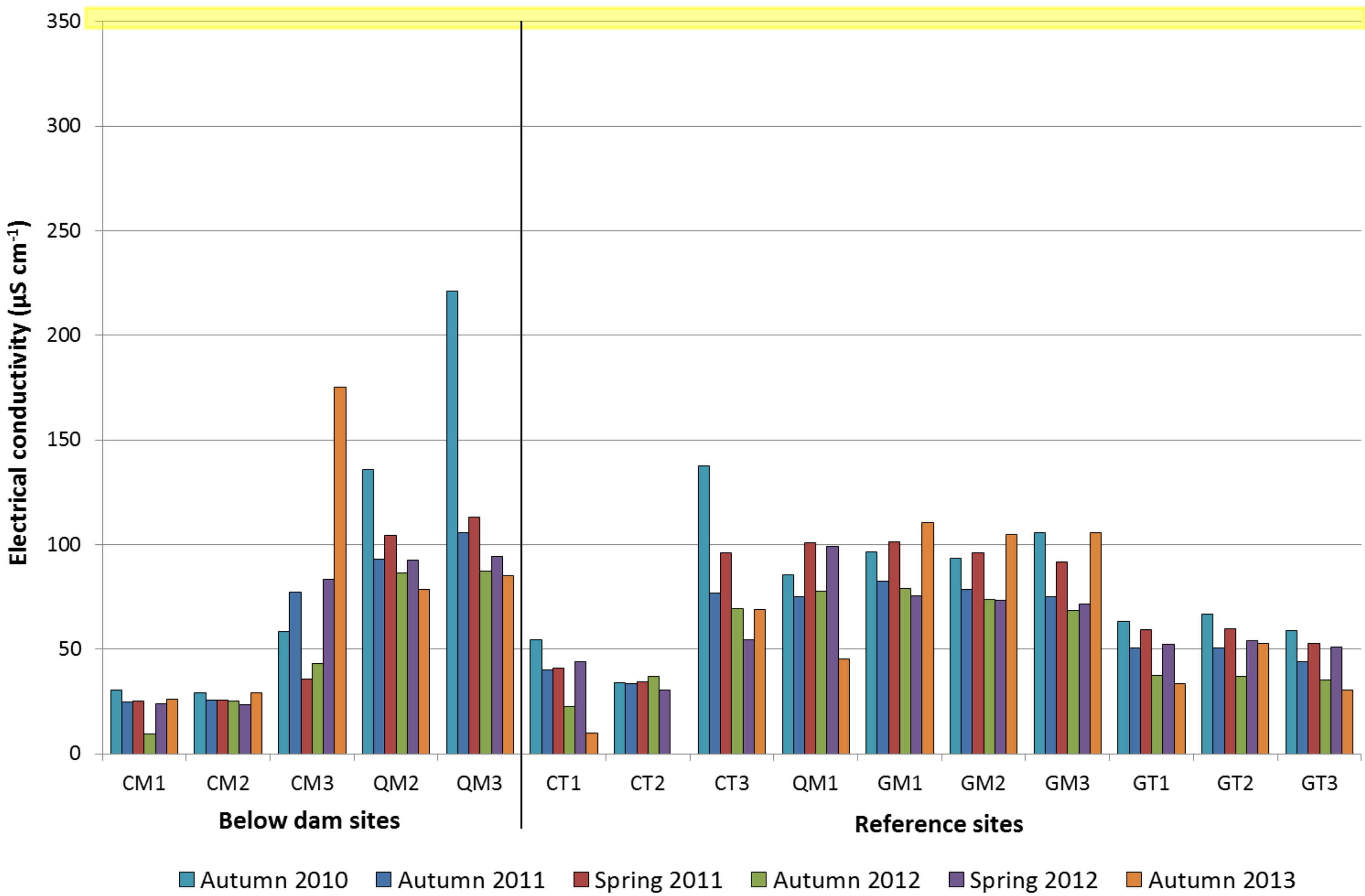
Nitrogen oxide concentrations at all sites from autumn 2010 to autumn 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



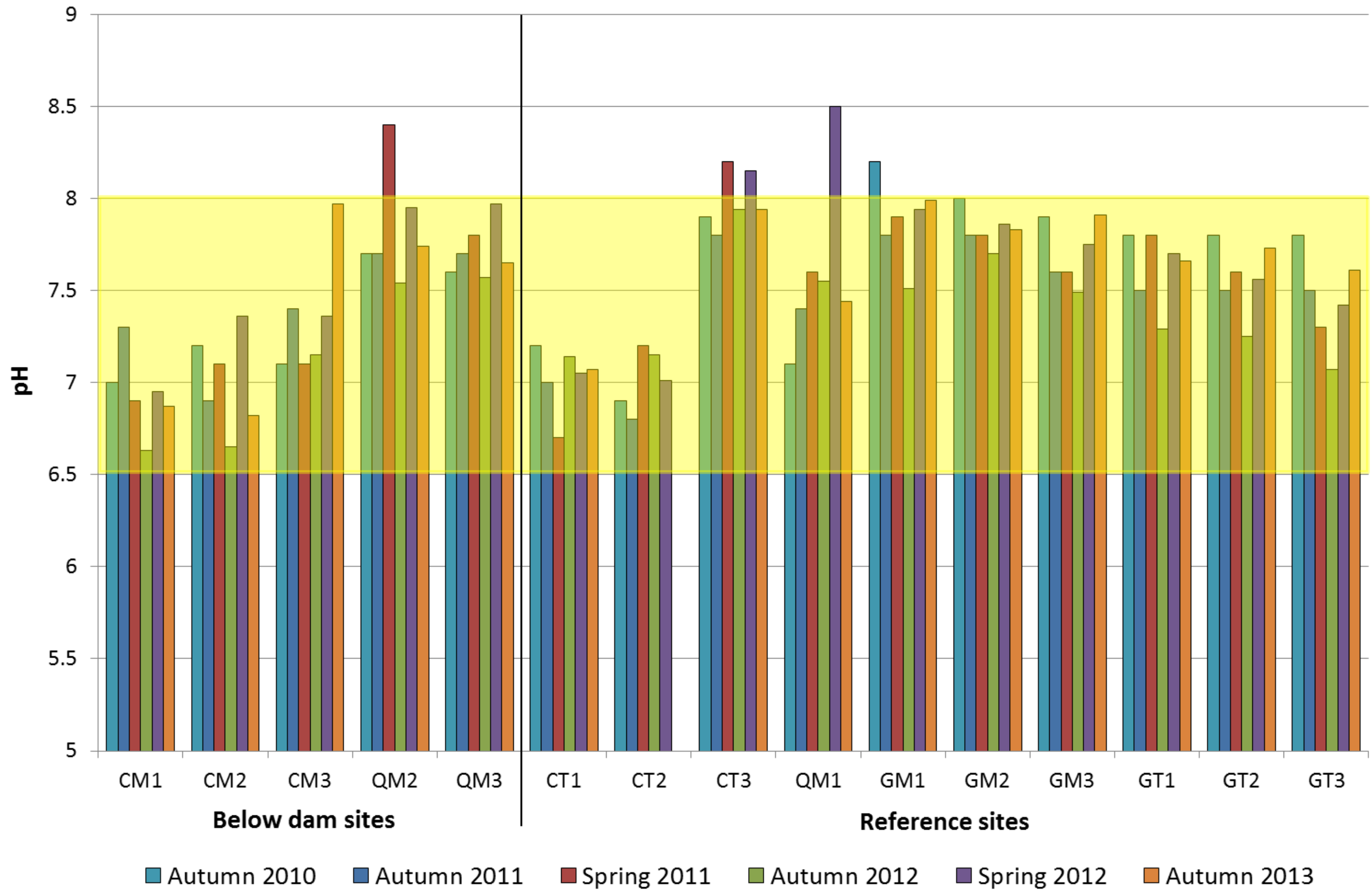
Total phosphorus concentrations at all sites from autumn 2010 to autumn 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



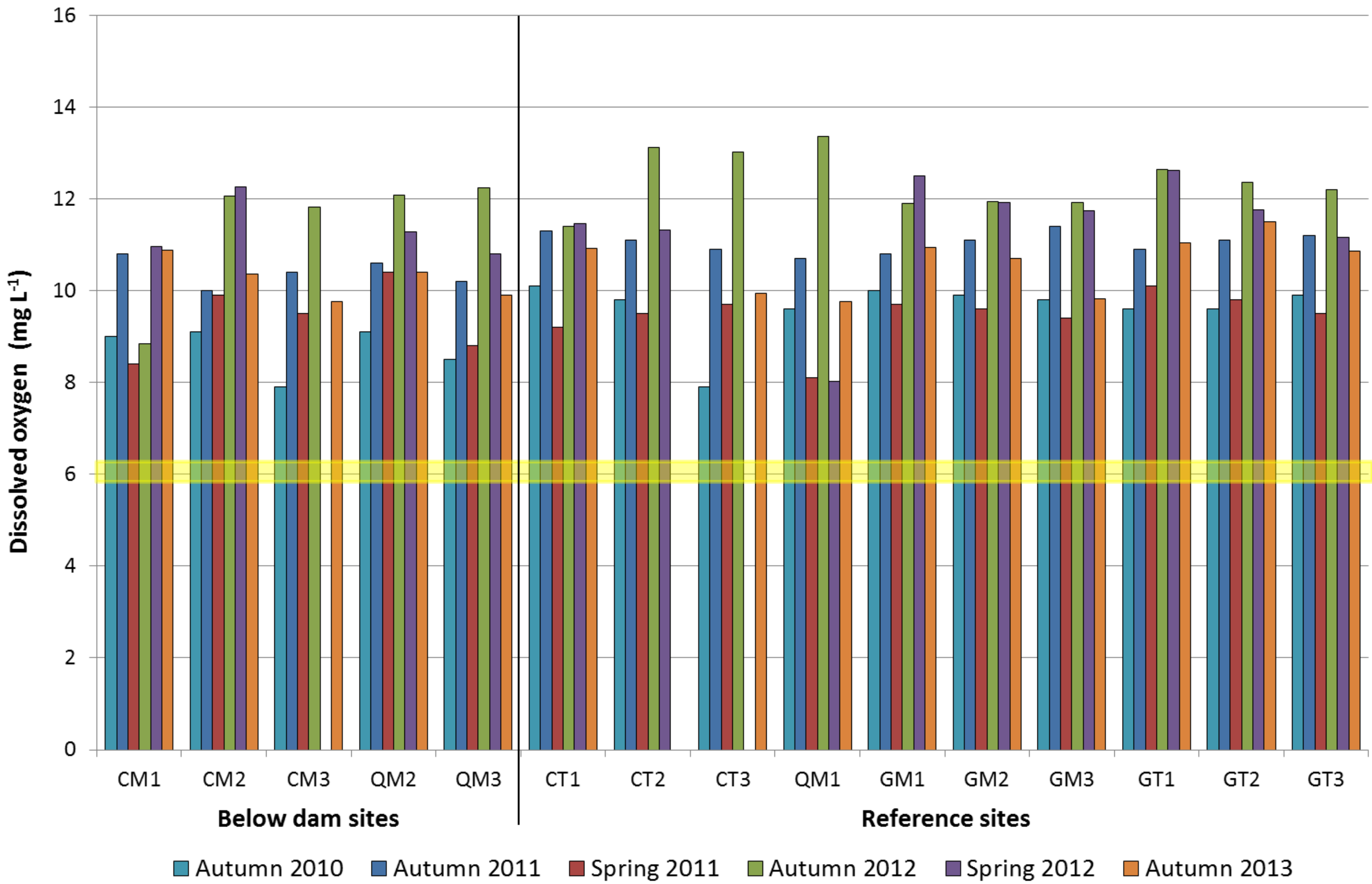
Total nitrogen concentrations at all sites from autumn 2010 to autumn 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



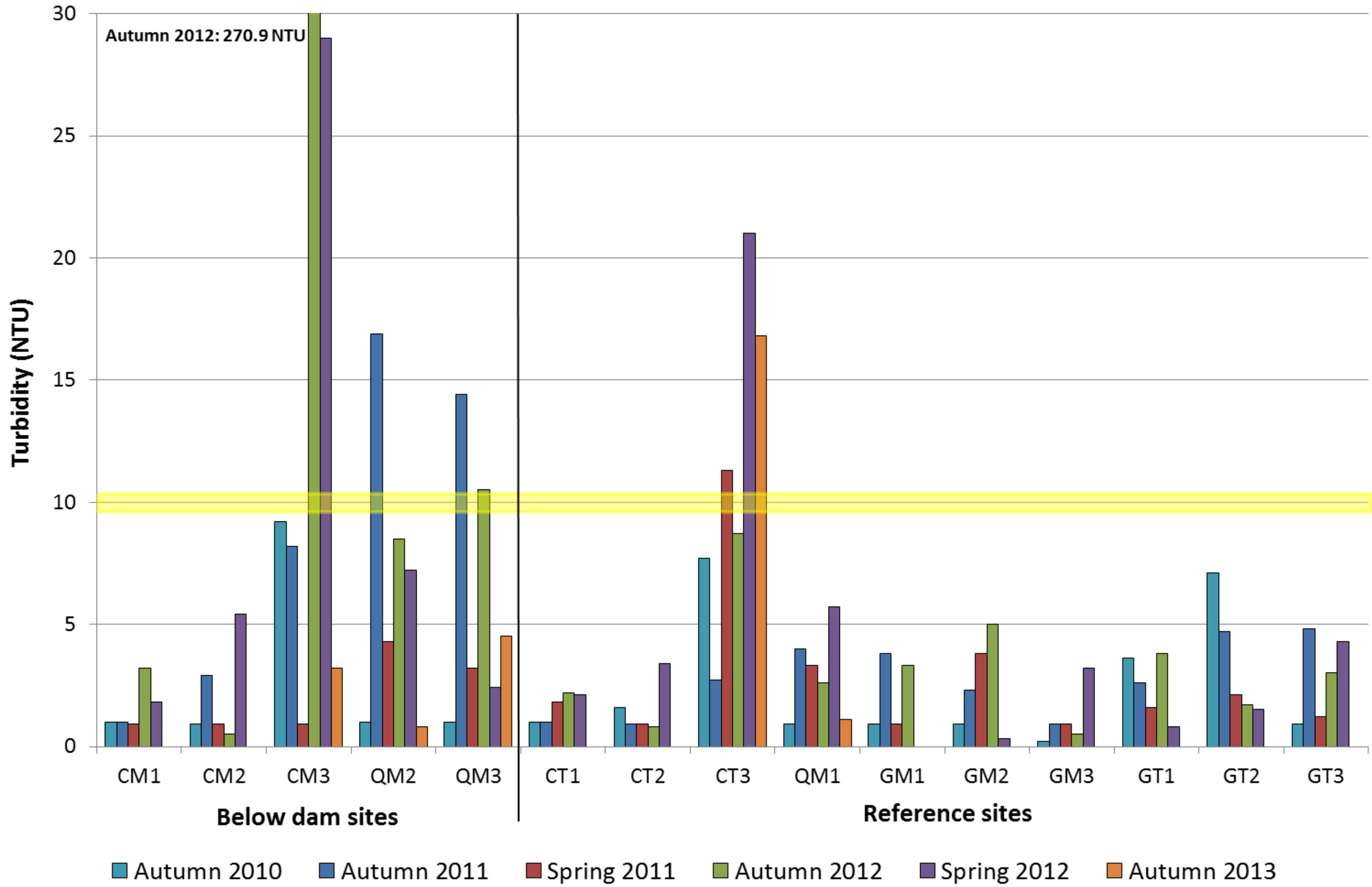
Electrical conductivity at all sites from autumn 2010 to autumn 2013. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from autumn 2010 to autumn 2013. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from autumn 2010 to autumn 2013. The Environment Protection Regulation SL2005-38 guideline for electrical conductivity is shaded yellow.



Turbidity at all sites from autumn 2010 to autumn 2013. The Environment Protection Regulation SL2005-38 guideline for turbidity is shaded yellow.