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

Spring 2013

Report produced for ACTEW Water




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ACTEW Water - Water Quality Monitoring Program

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Front Photograph: Bendora Dam (15/10/13).

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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 2013 results and conclusions

- In spring 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 and nitrates above trigger concentrations downstream of Googong Dam. High nutrient concentrations in reservoirs resulting from the March 2012 flood event continue to decrease, but are expected to remain elevated in the medium-term. Click here for more information

- Sites CM1 and CM2 below Corin and Bendora Dams did not meet the environmental flow ecological objective of <20% filamentous algae cover in the riffle habitat (ACT Government 2013). At site CM1 the high accumulation of filamentous algae may be a result of sampling at the end of the low-flow phase of the environmental flow cycle, and it is likely that the flow release following spring 2013 sampling would have scoured the majority of algal biomass from the river reach. Click here for more information

	Within environmental flow ecological objective	Outside environmental flow ecological objective
Site	**Riffle filamentous algae cover (%)**	**AUSRIVAS band (O/E score)**
CM1 (Corin Dam)	80	B (0.69)
CM2 (Bendora Dam)	20	A (0.89)
CM3 (Cotter Dam)	< 10	A (0.88)
QM2 (Googong Dam)	< 10	A (0.88)
QM3 (Googong Dam)	< 10	A (0.92)

- Site CM1 was the only site that did not meet the environmental flow ecological objective of AUSRIVAS band A assessment in spring 2013; however, the biological condition of this site has improved since the autumn 2013 assessment. Click here for more information

- Test site CM3 below Cotter Dam was assessed as AUSRIVAS band A for the first time since autumn 2008. The biological condition of this river reach has been highly variable over recent assessments. Flows in excess of 100 ML d^{-1} were released from Cotter Reservoir in the month preceding spring 2013 sampling are likely to have had a positive effect on biological condition at this site. Click here for more information

- A flood event on the Queanbeyan River approximately one month before sampling is likely to have contributed to the improved biological condition at test sites QM2 and QM3 in spring 2013. Click here for more information

Project recommendations

- Analysis of the long-term data set from the Below Dams Assessment Program may assist in interpreting the effects of environmental flow releases on downstream waterway condition on the Cotter and Queanbeyan Rivers. This would enable the identification of spatial and temporal trends, and increase the power of statistical inference. Such an assessment would provide a valuable knowledge base that would increase the relevance of subsequent assessments.

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 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 spring 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 15^{th} and 17^{th} October 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.

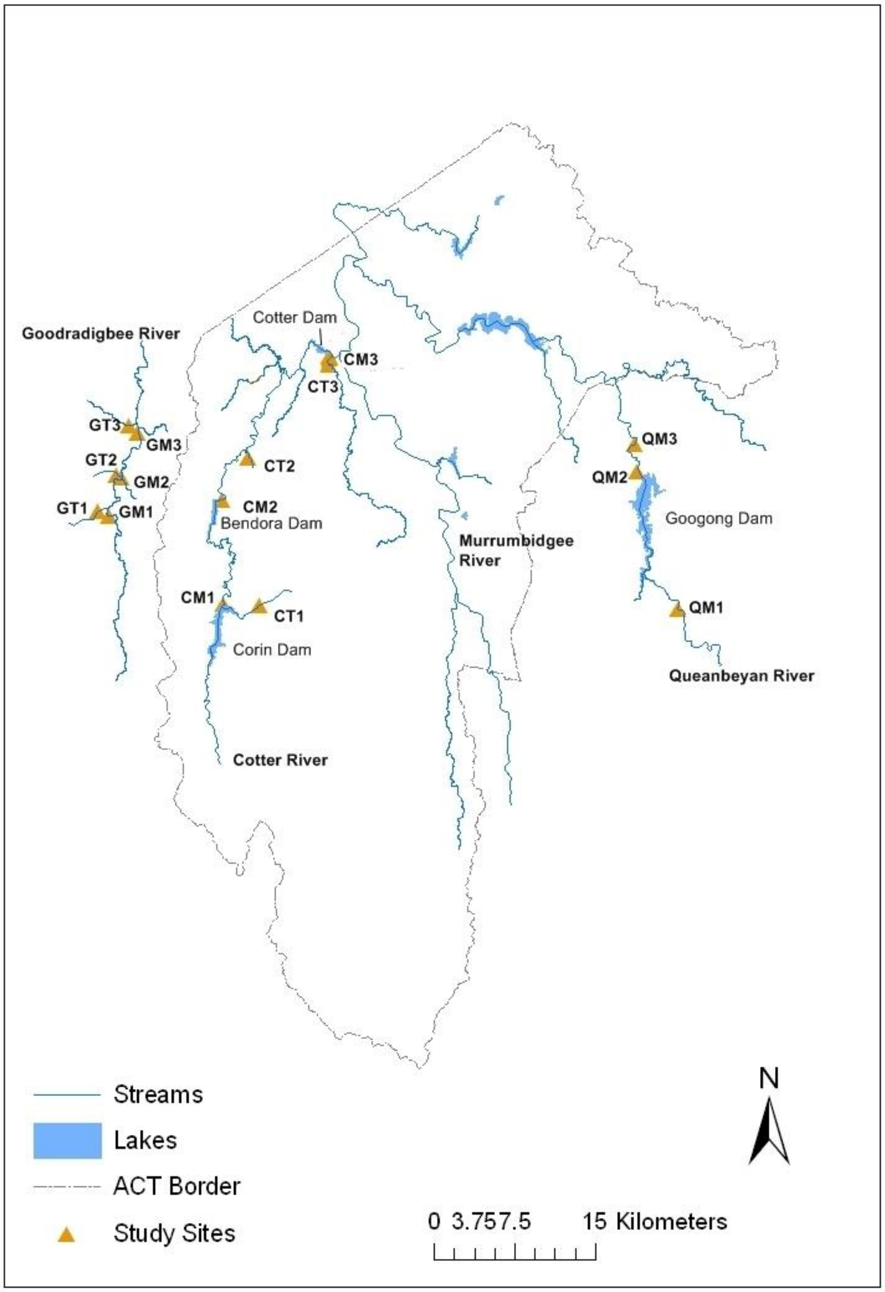


Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

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

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

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/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, 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 spring riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT spring 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 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 groups 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 spring 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). Flow releases and a 58 mm rainfall event on 17th September resulted in a high degree of flow variability at below dam test sites in the month preceding sampling (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 spring 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. 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.

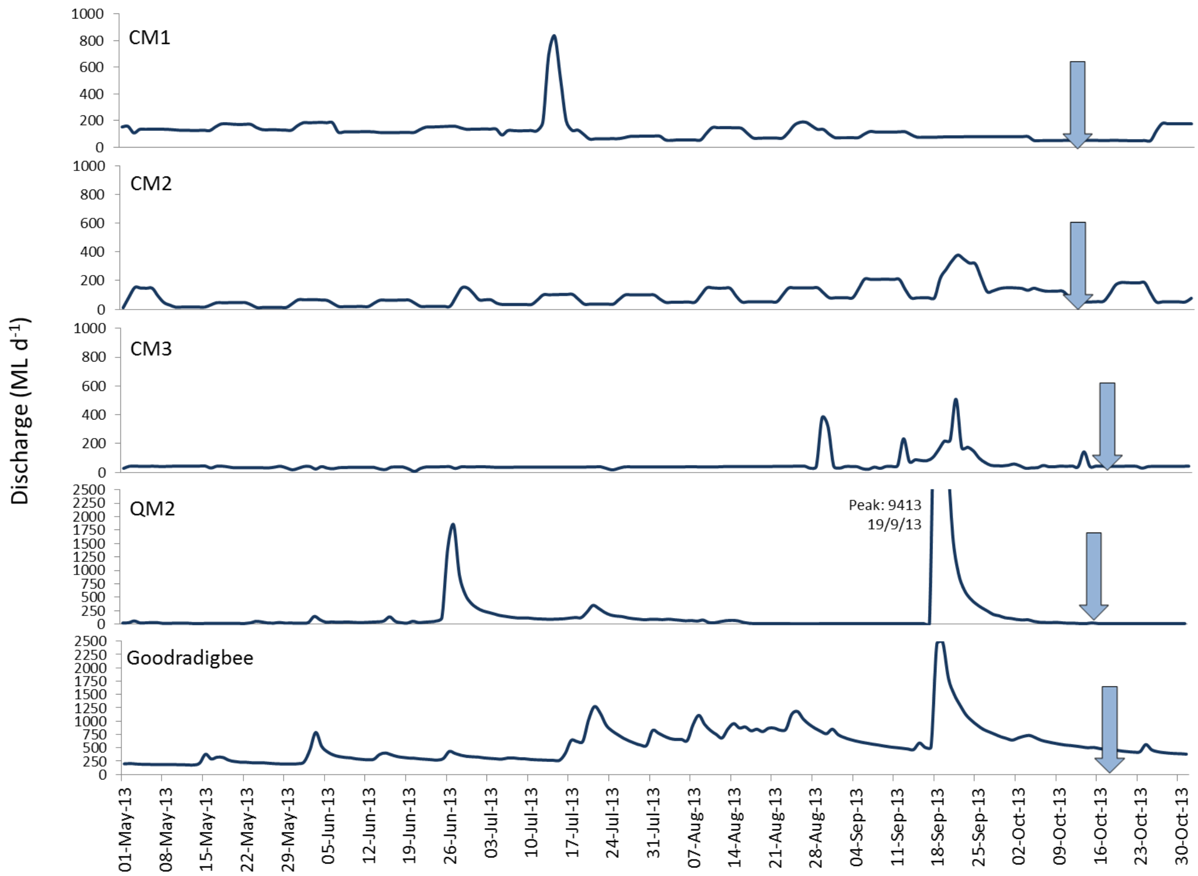


Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), Cotter (CM3, station 410700) and Googong (QM2, station 410760) Dams and in the Goodradigbee River (station 410088) from 1st May to 31st October 2013. Arrows correspond to spring 2013 sampling dates.

Water quality

Water quality parameters were generally within ANZECC/ARMCANZ (2000) guidelines except for total nitrogen (TN), nitrate, and total phosphorus (TP) concentrations (Table 5; Appendix 3). Total nitrogen was only above guideline concentrations (0.25 mg L^{-1}) at sites QM2 and QM3 below Googong Dam (Table 5). Nitrogen oxide concentrations were above guideline levels (0.015 mg L^{-1}) at sites QM2 and QM3, and also at test site CM1 below Corin Dam and reference site GM3 on the Goodradigbee River (Table 5). Total phosphorus concentrations (TP) exceeded guideline levels at all sites in spring 2013 (Table 5; Appendix 3).

Table 5. Water quality parameters measured at each of the test and reference sites in spring 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	8.0	27	7.1	8.8	0.2	12	<0.01	0.03	0.09	0.03
	CM2	14.3	25	7.4	8.1	0.3	14	<0.01	<0.01	0.10	0.03
	CM3	13.6	56	7.8	10.5	0.9	18	0.01	0.01	0.14	0.04
	QM2	13.2	102	7.8	10.0	0.2	28	0.01	0.14	0.53	0.04
	QM3	15.5	151	7.9	9.2	1.3	42	0.02	0.05	0.37	0.03
Reference sites	CT1	8.3	49	7.4	8.8	1.3	16	0.01	<0.01	0.06	0.05
	CT2	11.8	33	7.2	11.4	0.6	10	0.01	<0.01	0.07	0.04
	CT3	16.3	88	7.9	10.5	3.5	20	<0.01	<0.01	0.14	0.03
	QM1	14.0	80	7.9	8.4	1.5	26	0.01	<0.01	0.12	0.04
	GM1	10.3	91	7.8	10.2	0.3	36	<0.01	<0.01	0.03	0.02
	GM2	11.1	86	7.9	9.9	0.3	38	<0.01	<0.01	0.03	0.03
	GM3	12.6	85	7.9	10.4	1.6	36	0.01	0.02	0.05	0.03
	GT1	9.6	54	7.5	10.0	0.4	22	<0.01	0.01	0.04	0.04
	GT2	9.9	57	7.8	10.4	0.2	12	0.01	<0.01	0.04	0.04
	GT3	11.3	49	7.8	9.9	0.8	20	<0.01	<0.01	0.05	0.04

Periphyton and algae

Periphyton cover in riffle habitats ranged from <10 to 50% across all sites, and was slightly greater at below dam test sites than at reference sites on the Goodradigbee River during spring 2013 sampling (Table 6). Filamentous algae cover in riffle habitats met the environmental flow ecological objective of <20% at below dam test sites CM3 (below Cotter Dam) and QM2 (below Googong Dam), while filamentous algae cover at site CM2 (below Bendora Dam) was equal to the objective (20% cover) and well above the objective at site CM1 (below Corin Dam – 80% cover) (Figure 3; Table 6).

Periphyton ash free dry mass (AFDM) at test sites CM1 (below Corin Dam) and CM2 (below Bendora Dam) was significantly greater than at each of the other sites (F=15.14; DF=6,35; P=<0.0001); however, differences in AFDM between these two sites were not statistically significant (Figure 4).

Estimations of periphyton/algae standing crop based on chlorophyll-a concentration analysis reflect field observations of filamentous algae cover, with the highest chlorophyll-a concentrations found below Corin Dam (CM1) (Table 6; Figure 3; Figure 5). Chlorophyll-a concentrations were significantly higher below Corin Dam than at each of the other sites (F=11.39; DF=6,35; P=<0.0001); however, unlike AFDM, chlorophyll-a concentrations at site CM2 (below Bendora Dam) were not significantly higher than other sites (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 autumn 2010 to spring 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	Spr-13	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12	Aut-13	Spr-13
CM1	<10	<10	35-65	<10	<10	25	10	<10	<10	10-35	<10	10-35	<10	80
CM2	<10	<10	10-35	<10	10-35	75	20	<10	<10	10-35	<10	>90	<10	20
CM3	10-35	<10	<10	<10	10-35	<10	50	<10	<10	<10	<10	<10	<10	<10
QM2	<10	<10	35-65	<10	<10	<10	20	<10	<10	10-35	<10	<10	<10	<10
GM1	<10	<10	<10	<10	<10	15	<10	<10	<10	<10	<10	<10	15	<10
GM2	<10	<10	<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	<10	15

Reference Sites


Site GM1

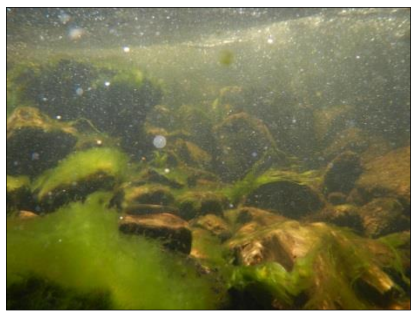

Site GM2

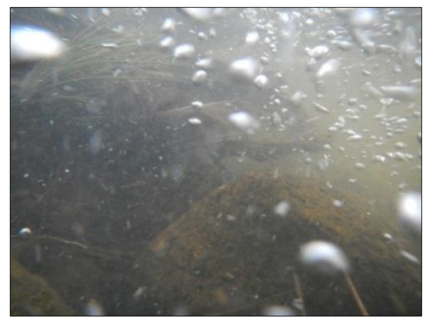

Site GM3


Site QM1

Test sites


Site CM1


Site CM2


Site CM3


Site QM2

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 2013.

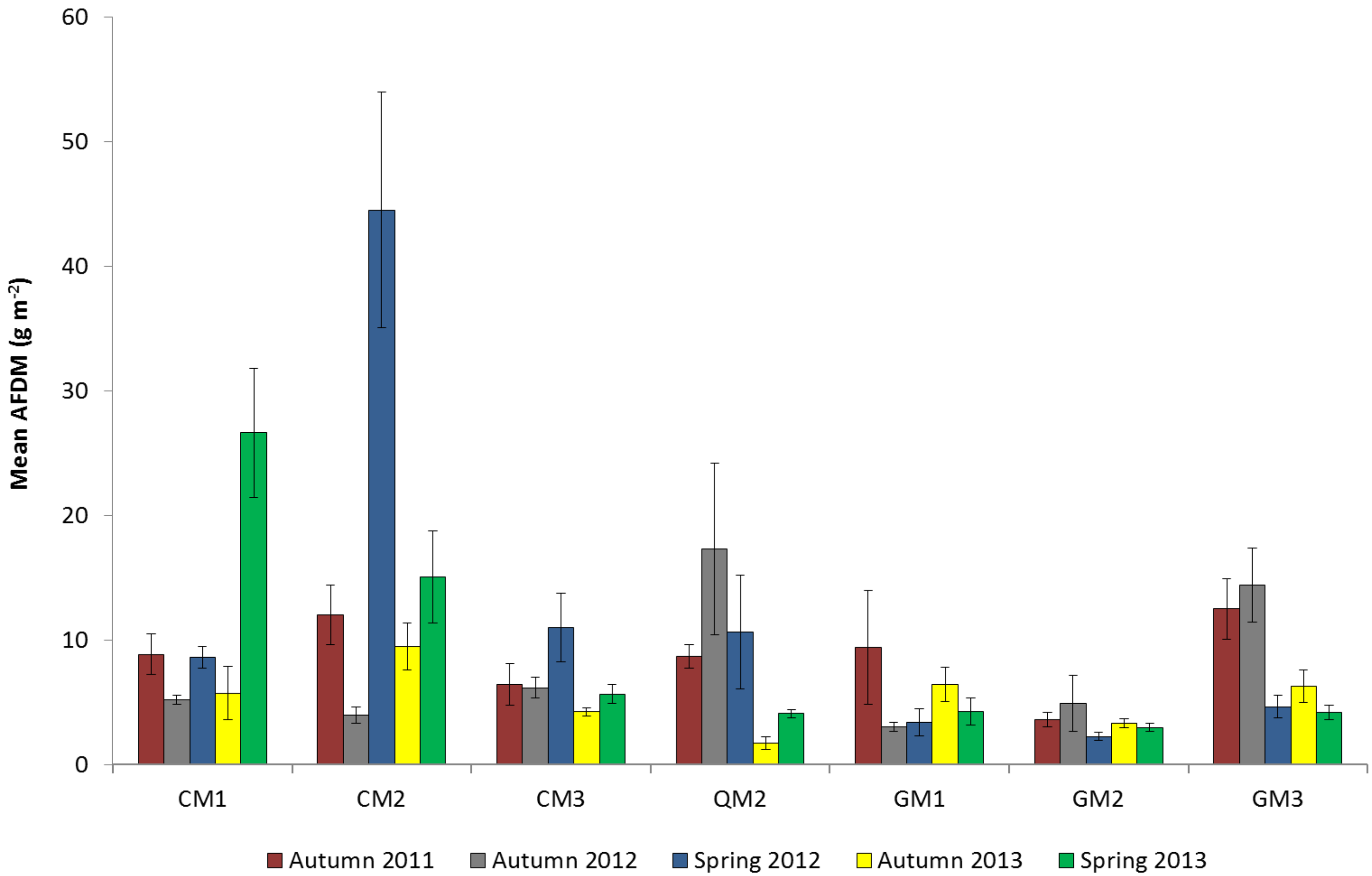


Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2011 to spring 2013. Error bars represent +/- 1 standard error.

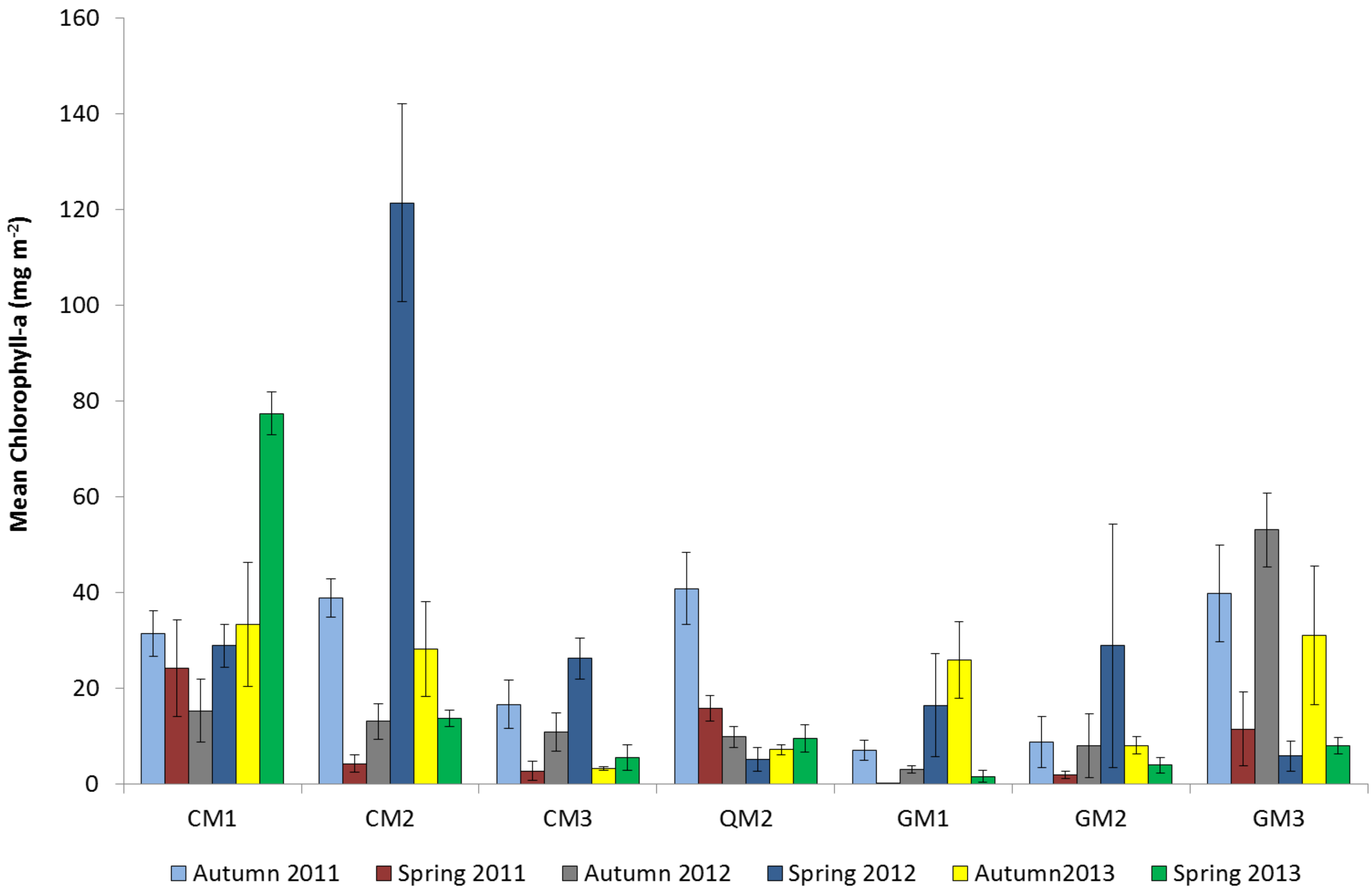


Figure 5: Mean chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2011 to spring 2013. Error bars represent +/- 1 standard error.

Benthic macroinvertebrates

AUSRIVAS assessment

There was an overall improvement in biological condition since autumn 2013 based on AUSRIVAS assessment (Table 7). Five sites improved in AUSRIVAS assessment and six sites maintained the same assessment since autumn 2013 (Table 7).

Cotter River test sites CM1 (below Corin Dam) and CM3 (below Cotter Dam) both improved from band C assessments (*severely impaired*) in autumn 2013 to band B (*significantly impaired*) and band A (*similar to reference condition*) respectively (Table 7). The other Cotter River test site below Bendora Dam (CM2) maintained an AUSRIVAS band A assessment since autumn 2013 (Table 7).

Goodradigbee River reference sites GM1 and GM3 were both assessed as AUSRIVAS band X (*more diverse than reference condition*) and reference site GM2 maintained band A assessment in spring 2013 (Table 7).

Cotter River tributary sites CT1, CT2, and CT3 were assessed as band X, band A, and band B respectively, similar to recent assessments at these sites. Goodradigbee River tributaries GT1, GT2, and GT3 were all assessed as AUSRIVAS band A in spring 2013 (Table 7).

Both test sites QM2 and QM3 downstream of Googong Dam were improved in biological condition to be assessed as band A in the spring 2013 assessment for the first time since spring 2011 (Table 11). The upstream reference site on the Queanbeyan River has remained in band A (or band X) condition since autumn 2009 (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). All sites, except for sites CT1, CT2, GM2, 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 Glossosomatidae (QM2 and GT2), Leptophlebiidae (CM3), Gripopterygidae (CT3 and QM3), Hydrobiosidae (CT3, GM1, and GT1), Psephenidae (GT2), Hydropsychidae (CM1 and QM2), Tipulidae (CM3), Baetidae (CM2 and QM1), and Oligochaeta (GT2) (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2011 to spring 2013.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
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)
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)

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 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	CT2	CT3	QM1	QM2	QM3	GM1	GM2	GM3	GT1	GT2	GT3
Glossosomatidae	9	X	X				X	X	X	X					X	
Calocidae	9				X											
Leptophlebiidae	8			X												
Gripopterygidae	8						X			X						
Hydrobiosidae	8				X		X		X		X	X		X		
Elmidae	7		X													
Conoesucidae	7			X			X		X	X						
Psephenidae	6	X	X	X		X	X		X	X					X	
Notonemouridae	6				X											
Hydropsychidae	6	X							X						X	
Tipulidae	5	X	X	X		X	X									
Simuliidae	5												X			X
Baetidae	5	X	X					X								
Tanypodinae	4	X		X					X	X						
Orthocladiinae	4															X
Caenidae	4	X				X										
Chironominae	3	X					X									
Oligochaeta	2					X						X		X	X	
Total		**8**	**5**	**5**	**3**	**4**	**7**	**2**	**6**	**5**	**1**	**2**	**1**	**2**	**4**	**2**

Taxonomic relative abundance

There were proportionally more of the disturbance tolerant Oligochaeta and Chironomidae (OC) taxa compared to sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa in spring 2013 than there were in autumn 2013 across test and reference sites (Figure 6) (Levings and Harrison 2013).Macroinvertebrate samples from below Cotter Dam (CM3), below Googong Dam (QM2 and QM3) and Paddys River (CT3) were numerically dominated by Simuliidae compared to other sites (53%, 59%, 69%, and 74% of the sub-sample respectively) (Figure 6).

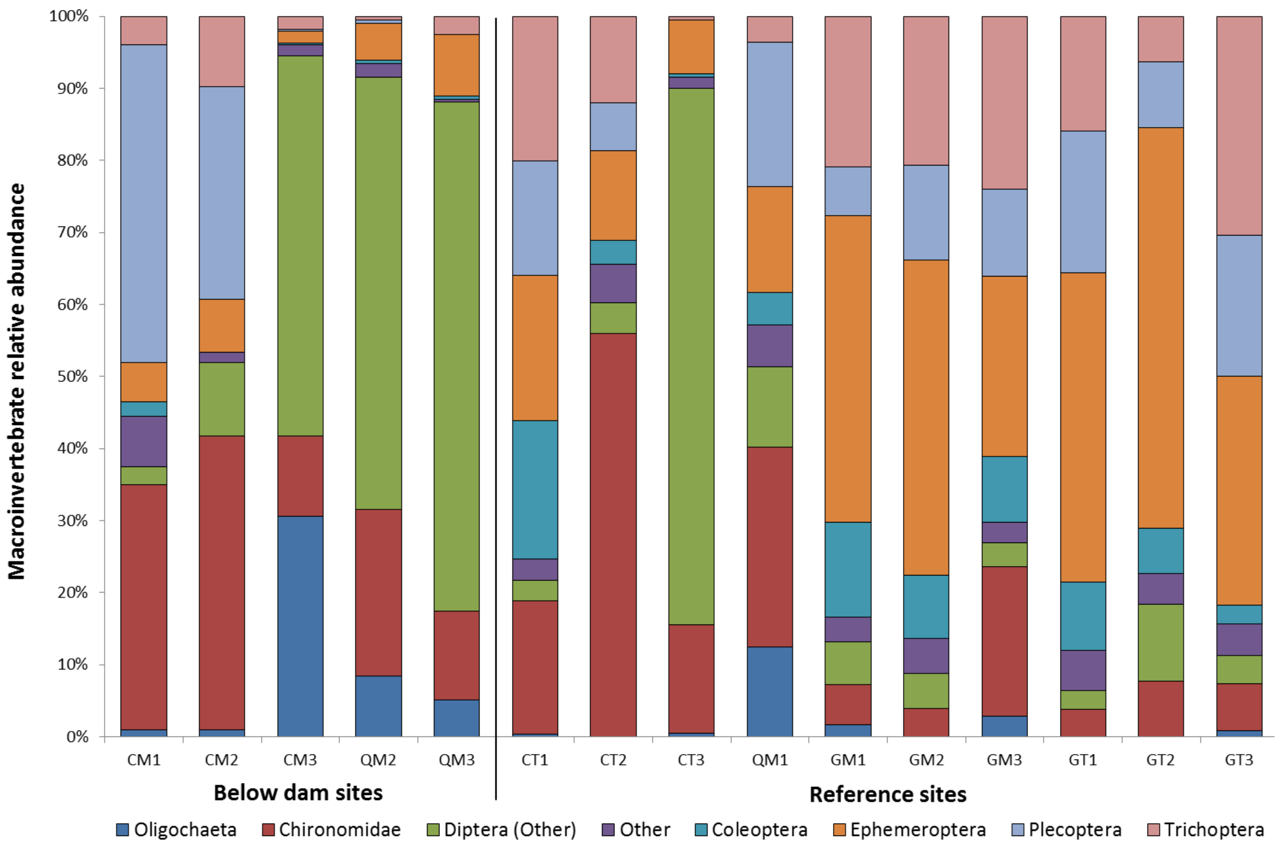


Figure 6: Relative abundance of macroinvertebrates taxonomic groups from samples collected in spring 2013.

Macroinvertebrate assemblage similarity

Cluster analysis based on the relative abundance of macroinvertebrate taxa identified three groups of sites at 60% similarity, which were significantly well separated (ANOSIM $p<0.05$; $R>0.93$) (Figure 7). Group A consisted of test sites QM2 and QM3 below Googong Dam and CM3 below Cotter Dam, and reference site CT3 on Paddys River. Sites in this group were characterised by higher abundances of Simuliidae, Oligochaeta and Chironomidae compared to groups B and C (Appendix 2). Group B consisted of the Goodradigbee River and tributary sites, and reference site CT1 on Kangaroo Creek. This group was defined by high abundances disturbance-sensitive and flow-favouring taxa compared to groups A and C (Appendix 2). Group C consisted of test sites CM1 below Corin Dam and CM2 below Bendora Dam, and reference sites CT2 on Burkes Creek and QM1 upstream of Googong Reservoir on the Queanbeyan River. Sites in group C had a lower relative abundance of Simuliidae and Orthocladinae taxa compared to group B sites, and had a lower relative abundance of Gripopterygidae compared to group A sites (Figure 7; Appendix 2).

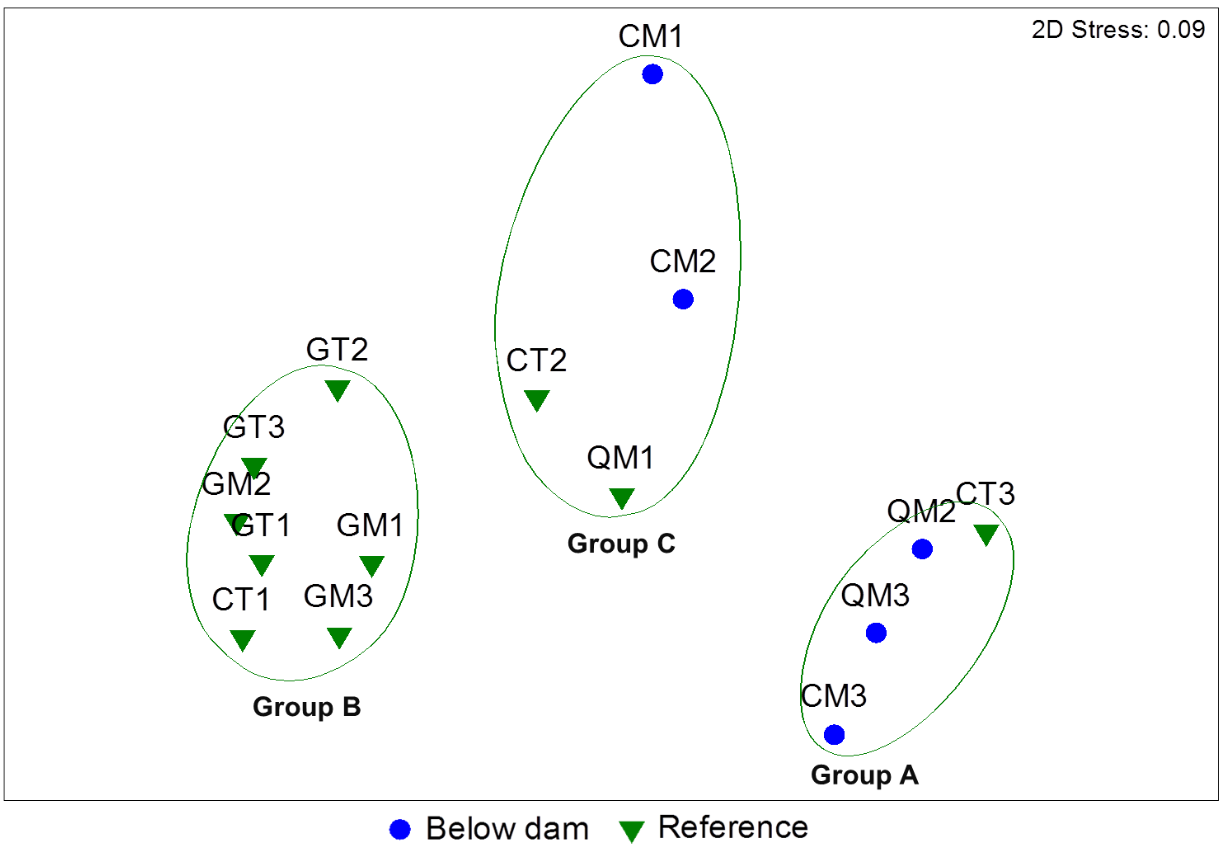


Figure 7. MDS ordination of similarity between macroinvertebrate samples collected in spring 2013 for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance.

Discussion and Conclusions

Water quality

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

Total phosphorus was above guideline concentrations at all sites during both the autumn and spring assessment periods in 2013 (Appendix 3). The cause of these elevated concentrations is unclear; however, the similarity in TP concentrations between test and reference sites indicates that the presence and operation of dams on the Cotter and Queanbeyan Rivers is having a negligible effect on TP concentrations in downstream river reaches.

Total nitrogen concentrations were generally greater at below dam test sites on the Cotter River than at reference sites on the Goodradigbee River in spring 2013 (Table 5). However, all concentrations were within the guideline level and were likely higher in the Cotter catchment because of catchment differences in TN given that TN concentrations at the Cotter tributary sites were similar to the below dam sites. Sites downstream of Googong Dam (QM2 and QM3) were the only sites with TN above guideline concentrations and had NOx concentrations above guideline levels. TN and NOx concentrations at these sites reflects high concentrations within the reservoir following flooding (Levings and Harrison 2013), which despite decreasing since autumn 2013 are likely to take a number of years to reduce to within guideline levels.

Periphyton and algae

Filamentous algae cover in riffle habitats was variable between sites (Table 6). Site CM1 below Corin Dam had a dense cover and biomass of actively growing filamentous algae, and was the only site to not meet the environmental flow ecological objective of <20% cover in the riffle habitat in spring 2013.

There are a number of environmental variables that determine the growth rate of filamentous algae within a river reach; however, the abundance of filamentous algae present at a given location is largely controlled by the growth rate/nutrient inputs and flow velocity (King 2012). Environmental flow releases of 150 ML d^{-1} are likely to create flow velocities capable of scouring excess filamentous algae from riffle habitats (ACT Government 2013). Site CM1 was sampled toward the end of the low-flow phase of the environmental flow cycle below Corin Dam, with an environmental flow release equivalent to a small flood occurring 49 days prior to sampling, compared to 15 days and 21 days at CM2 and CM3 respectively (Figure 2). This extended period of relatively low flows may therefore be the cause of filamentous algae accumulation below Corin Dam. It should be noted that a landslide blocked access to Corin Dam which prevented environmental flow increases from Corin Dam in the months before sampling and an exemption on environmental flow increases was granted from the Environment Protection Authority.

Benthic macroinvertebrates

The biological condition of test and reference sites was relatively higher in spring 2013 compared to previous assessments (Table 7). The Goodradigbee River reference sites were in good biological condition at the time of spring 2013 sampling. The three Goodradigbee river sites were assessed as AUSRIVAS band A (GM2) and band X (GM1 and GM3), and had similar macroinvertebrate communities to adjacent tributary sites GT1, GT2, and GT3 (Figure 7). The band X assessments at these sites are likely to have resulted from natural variation around the reference condition given that these sites have varied between bands A and X for the majority of previous assessments (Table 7).

Cotter River tributary sites were generally in a similar biological condition to Goodradigbee River tributary sites in spring 2013 (Table 7). The exception was site CT3 on Paddys River, which has been assessed as biologically impaired since spring 2011. This sub-catchment is exposed to a range of agricultural land-use pressures that are not present throughout the rest of the Cotter River catchment. Test site CM3 below Cotter Dam is upstream of the Paddys River confluence, and is unaffected by the Paddys River catchment condition (Figure 1). Therefore, differences in biological condition between test sites CM1, CM2, and CM3 and reference sites GM1, GM2, and GM3 are likely to be because of the instream effects relating to river regulation rather than differences in catchment condition.

Cotter River test site CM1 below Corin Dam was the only test site that did not meet the environmental flow ecological objective of AUSRIVAS band A in spring 2013, despite improving in biological condition since autumn 2013 (Table 7). It is likely that the macroinvertebrate assemblage at this site was being impacted upon by the dense filamentous algae cover (approximately 80% cover in the riffle habitat) observed below Corin Dam during sampling, because it an unpalatable food sources for many taxa (Chester & Norris, 2006). Orthocladiinae midges which reside, feed and possibly avoid predation within large filamentous chlorophytes were also abundant downstream of Corin Dam (Chester & Norris, 2006)(Appendix 2).

Test sites CM2 and CM3 on the Cotter River and sites QM2 and QM3 on the Queanbeyan River all met the ecological objective of AUSRIVAS band A assessment in spring 2013 (Table 7). The AUSRIVAS observed/expected taxa score at site CM2 below Bendora Dam had decreased from the top of band A in autumn to the bottom of the band in spring 2013 (Table 7). The current assessment is more consistent with previous assessment outcomes and highlights an ongoing minor biological impairment downstream of Bendora Dam, which may be the result of filamentous algae cover on the stream bed (similar to downstream of Corin Dam). Also similar to downstream of Corin Dam, Orthocladiinae midges were abundant (Appendix 2), which is most likely because of the quantity of filamentous algae on the stream bed.

Cotter River test site CM3 downstream of Cotter Dam was assessed as AUSRIVAS band A in spring 2013 for the first time since autumn 2008. The biological condition of this river reach has been highly variable over recent assessments (Table 7), which may be related to a change in the primary water source for environmental flows coming from the Murrumbidgee River via the M2C transfer pipeline. Flushing flow releases from Cotter Dam prior to spring 2013 sampling may have contributed to the improved biological condition of the downstream river reach. Filter feeding Simuliidae continue to numerically dominate the macroinvertebrate assemblage at this site, indicating a high concentration of fine particulate organic material in the water column.

Queanbeyan River test sites QM1 and QM2 downstream of Googong Dam were both assessed as AUSRIVAS band A for the first time since spring 2011 (Table 7). These sites were also numerically dominated by Simuliidae (Figure 6; Appendix 2) in spring 2013, despite this taxa being absent from these sites in autumn 2013 (Levings & Harrison 2013). These taxa are indicative of either high flow, which provide abundant particulate food supply, or a prior flood event which activate desiccation resistant eggs in dry sections of the river bed (Adler & Crosskey 2008). It is likely that the flood event in the Queanbeyan River from the 18th to 20th September 2013 has caused the numerical dominance of Simuliidae at these sites, and contributed to the improved biological condition at these sites by scouring and flushing accumulations of sediments and organic material from the river channel.

Overall since autumn 2013, all sites in the below dams assessment program have either improved or maintained biological condition. Improvements in biological condition downstream of dams have primarily been the result of increased river flows from environmental flow releases or minor flooding before spring sampling occurred.

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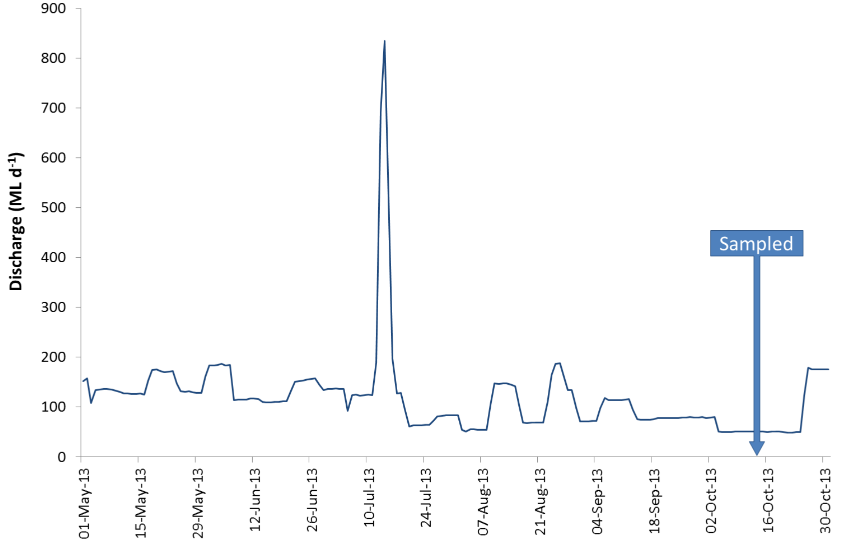
Appendix 1.

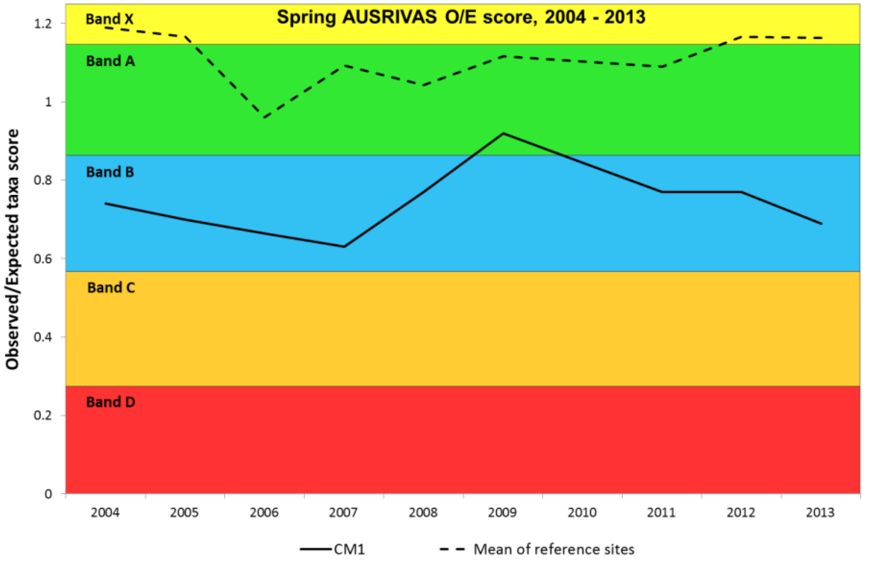
Site summary sheets

CM1 – Spring 2013

Downstream of Corin Dam

Environmental flow ecological objective	Autumn 2013	Spring 2013	Objective met?
AUSRIVAS band A	Band C	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**80%**	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)
8.0	27	7.1	8.8	0.2	12	<0.01	0.03*	0.09	0.03*

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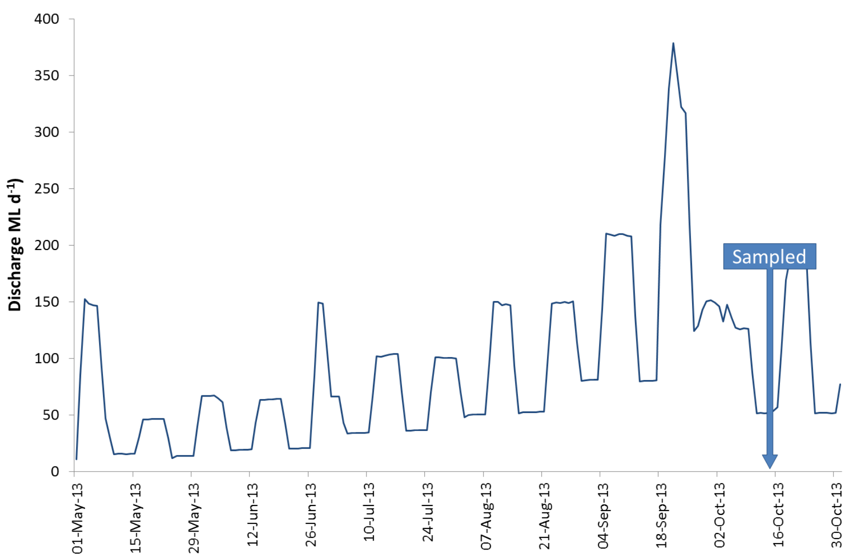
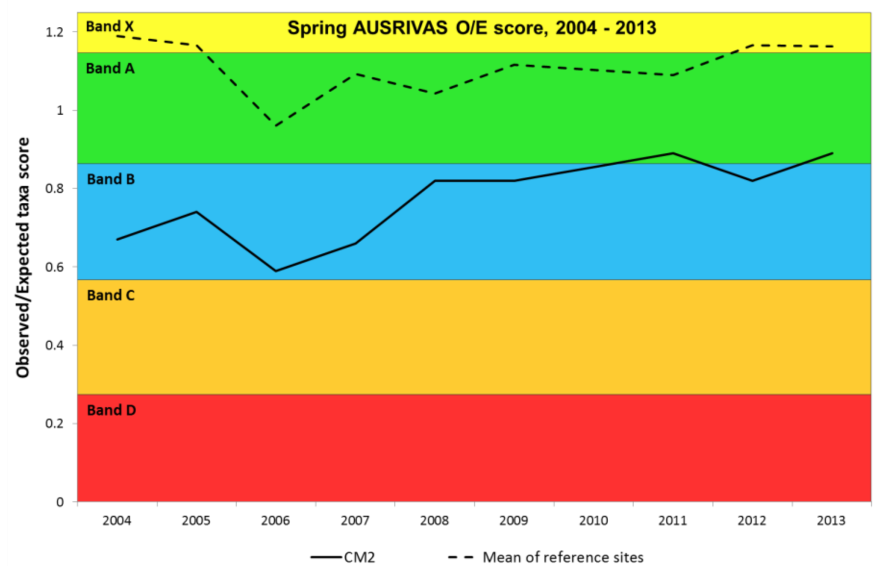
CM2 – Spring 2013

Downstream of Bendora Dam

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





* 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)
14.3	25	7.4	8.1	0.3	14	<0.01	<0.01	0.10	0.03*

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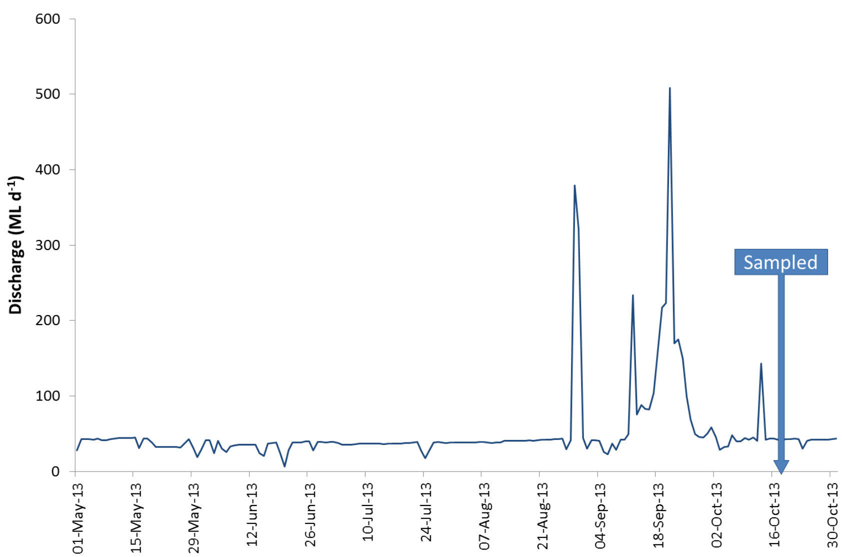
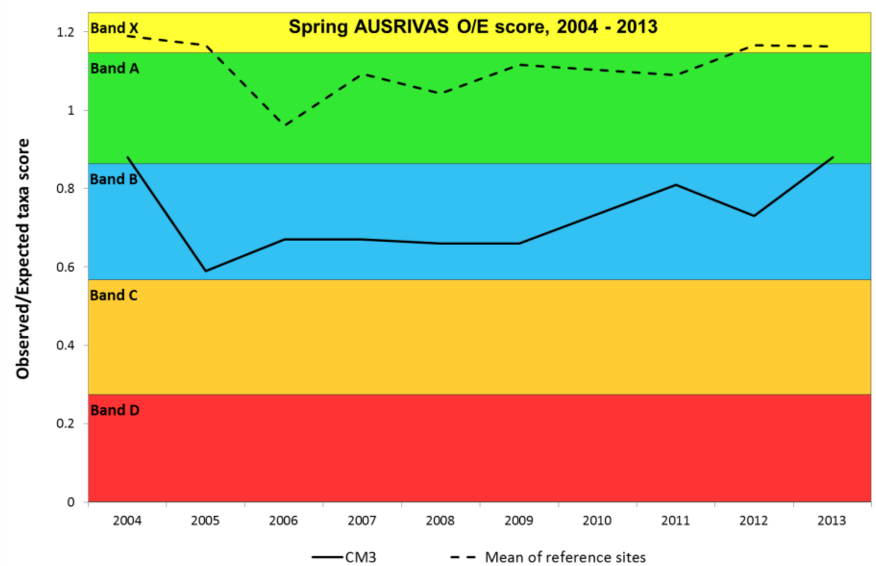
CM3 – Spring 2013

Downstream of Cotter Dam

Environmental flow ecological objective	Autumn 2013	Spring 2013	Objective met?
AUSRIVAS band A	Band C	**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)
13.6	56	7.8	10.5	0.9	18	0.01	0.01	0.14	0.04*

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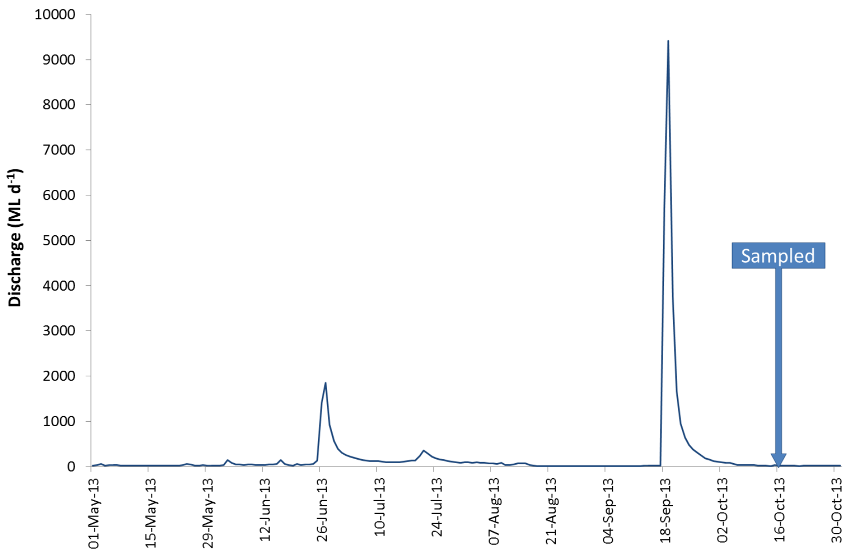
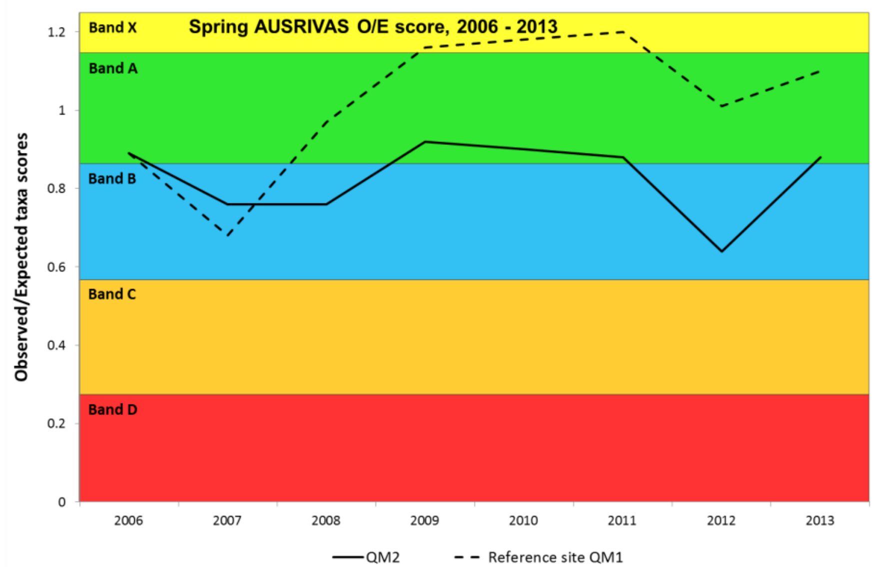
QM2 – Spring 2013

Downstream of Googong Dam

Environmental flow ecological objective	Autumn 2013	Spring 2013	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)
13.2	102	7.9	10.0	0.2	28	0.01	0.14*	0.53*	0.04*

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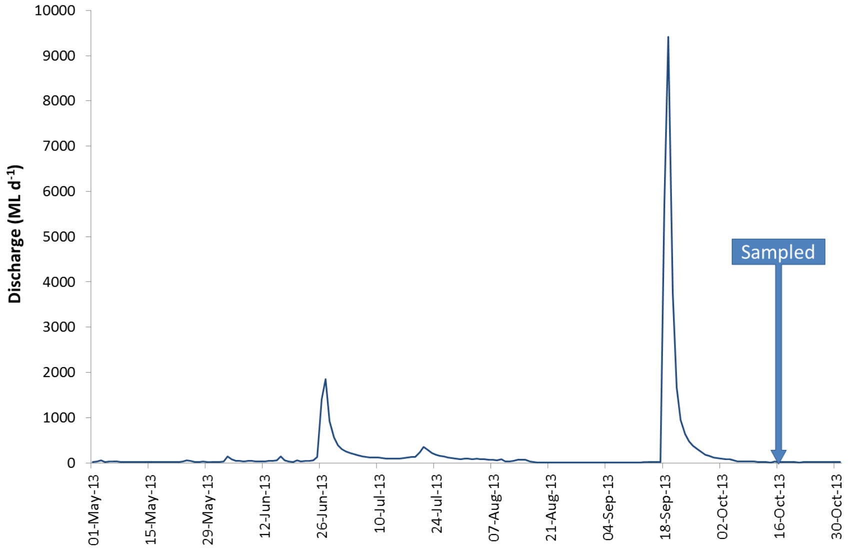
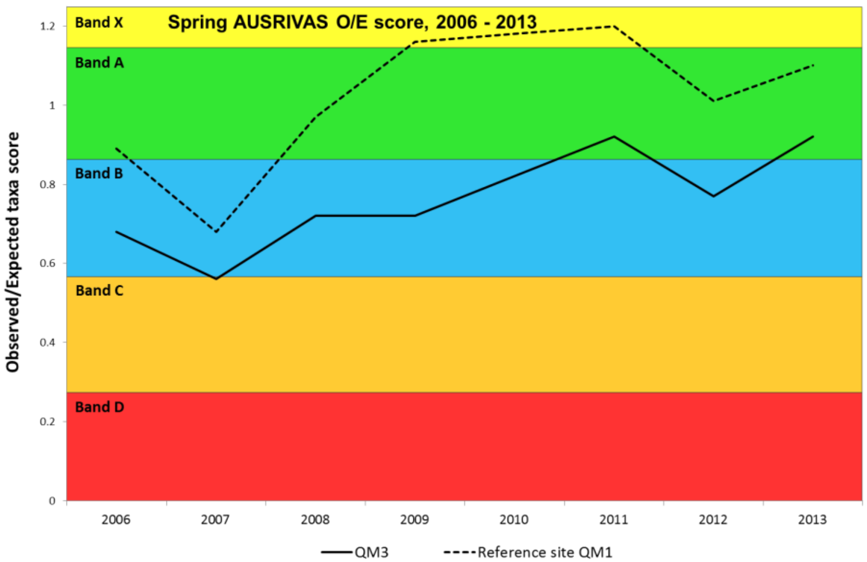
QM3 – Spring 2013

2 km Downstream of Googong Dam

Environmental flow ecological objective	Autumn 2013	Spring 2013	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)
15.2	151	8.2	9.2	1.3	42	0.02	0.05*	0.37*	0.03*

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Appendix 2.

Macroinvertebrate taxa

collected in spring 2013

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

CLASS **Order** Family *Subfamily*	**SIGNAL 2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
TURBELLARIA																
Tricladida	**2**						1									
Gastropoda																
Lymnaeidae	**1**			1												
Ancylidae	**4**							2								
OLIGOCHAETA	**2**	2	2	116	4		6	1		1			2	28	18	12
ACARINA	**6**	10	3	5	7	5	5	5	11	3	9	8	10	13	4	1
Coleoptera																
Scirtidae	**6**					1	1	2	1		2	8				
Elmidae	**7**	4		1	26	10	13	43	6	1	13	5	5	10	1	1
Psephenidae	**6**				5	9	5	1			7		1			
Diptera																
Tipulidae					10	8	5	3			4	18	7	1	1	2
Ceratopogonidae	**4**				1		2			1				1		1
Simuliidae	**5**	2	16	199	3	1		1	9	148	1	1		23	126	163
Psychodidae	**3**			1												
Athericidae	**8**							3			1					
Empididae	**5**	3	5			2						3	2			
Aphroteniinae	**8**			1	5		1	1			1	2	1			
Diamesinae	**6**	12					10									
Podonominae	**6**							2	8				2			
Tanypodinae	**4**		4		2	3	3	1	10	1	2	3	3	8		
Orthocladiinae	**4**	56	75	33	4	1	22	8	71	29	2	2		31	43	24
Chironominae	**3**		5	8	2	5	7	32	28		4	9	9	23	6	5
Ephemeroptera																
Baetidae	**5**			5	5	3	5	3	13	3	27	12	3		4	17
Coloburiscidae	**8**				5	15	3	3					3	1		
Leptophlebiidae	**8**	11	8		75	70	40	39	13	6	71	101	62	14	2	1
Caenidae	**4**		7	1	15	12	4	3		6	2	2	5	18	5	2
Megaloptera																

Appendix 2 continued over page.

Appendix 2 continued

CLASS **Order** Family *Subfamily*	**SIGNAL 2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Corydalidae	**7**	4				3					1	1				
Odonata																
Gomphidae	**5**				1	3					2					
Telephlebiidae	**9**										1					
Plecoptera																
Eustheniidae	**10**							1								
Austroperlidae	**10**							4								
Gripopterygidae	**8**	88	61	1	16	30	25	33	14		46	19	45	45	1	
Trichoptera																
Hydrobiosidae	**8**	1	1	1			1		4			2	1	1		2
Glossosomatidae	**9**			1	2	9	3	3	2		3		26			
Hydroptilidae	**4**	2	2	1	1	3		5			1	1		4		
Philopotamidae	**8**					1		2				2	2			
Hydropsychidae	**6**		3	4	1	2	2	4	2	1	6		1	1		3
Ecnomidae	**4**		1												1	
Conoesucidae	**7**	5	13		19	12	29	29	16		9	3	21	1		
Helicopsychidae	**8**							1								
Philorheithridae	**8**						2				4					
Calamoceratidae	**7**						1		1			1				
Leptoceridae	**6**				26	20	12	4			14	4	19	1		1
No. of individuals		**200**	**206**	**379**	**235**	**228**	**208**	**239**	**209**	**200**	**233**	**207**	**230**	**224**	**212**	**235**
No. of taxa		**13**	**15**	**16**	**22**	**23**	**25**	**28**	**16**	**11**	**24**	**21**	**21**	**18**	**12**	**14**
% of sub-sample		**13**	**7**	**3**	**3**	**9**	**8**	**5**	**8**	**2**	**5**	**3**	**5**	**6**	**4**	**2**
Whole sample estimate		**1538**	**2943**	**12633**	**7833**	**2533**	**2600**	**4780**	**2613**	**10000**	**4660**	**6900**	**4600**	**3733**	**5300**	**11750**

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.*

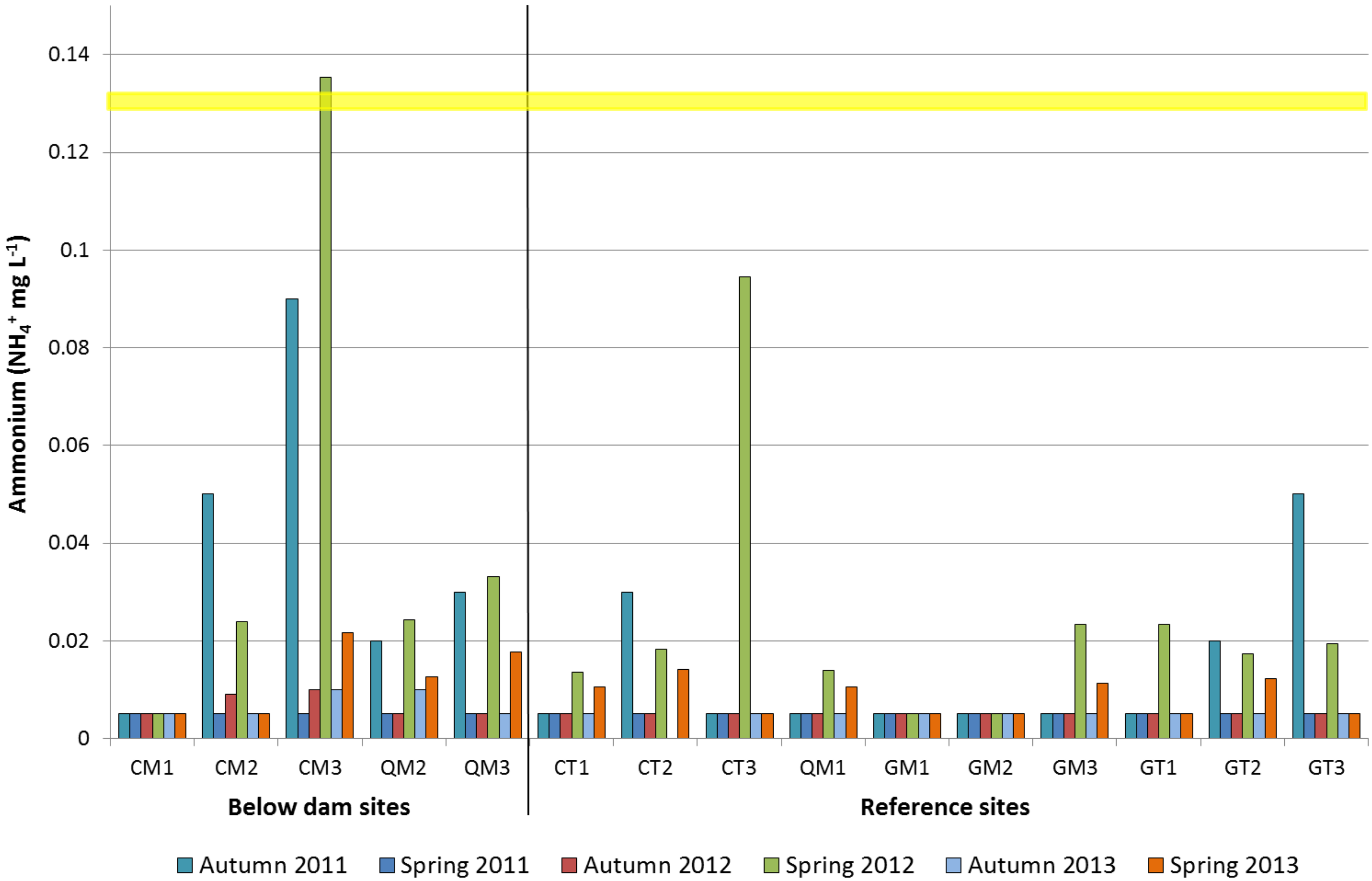
Group	Taxa	SIGNAL 2 grade	Average abundance	Consistency ratio	Contribution %	Cumulative %
Group A	Simuliidae	5	18.23	10.59	23.9	23.9
	Orthocladiinae	4	12.28	6.64	15.61	39.51
	OLIGOCHAETA	2	10.05	3.46	11.48	50.99
	Baetidae	5	8.02	7.19	9.97	60.96
	ACARINA	6	6.73	5.32	8.36	69.32
Group B	Leptophlebiidae	8	8.44	7.11	10.58	10.58
	Gripopterygidae	8	6.89	13.37	8.94	19.52
	Conoesucidae	7	5.79	8.17	7.4	26.92
	Elmidae	7	5.61	13.81	7.24	34.17
	Leptoceridae	6	5.57	5.05	6.82	40.99
	ACARINA	6	4.83	7.91	6.1	47.09
	Chironominae	3	4.88	6.39	6.02	53.11
	Baetidae	5	4.73	5.83	5.6	58.71
	Caenidae	4	4.43	6.53	5.35	64.06
	Tanypodinae	4	3.69	6.18	4.65	68.72
	Glossosomatidae	10	3.82	1.51	3.65	72.37
Group C	Orthocladiinae	4	10.94	5.98	15	15
	Gripopterygidae	8	10.49	4.81	13.12	28.12
	Leptophlebiidae	8	7.29	110.19	10.61	38.73
	Simuliidae	5	6.95	7.24	9.53	48.26
	ACARINA	6	6.76	8.66	9.33	57.59
	Conoesucidae	7	6.4	2.71	8.19	65.78
	Hydrobiosidae	8	4.37	8.37	6.03	71.81

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.*

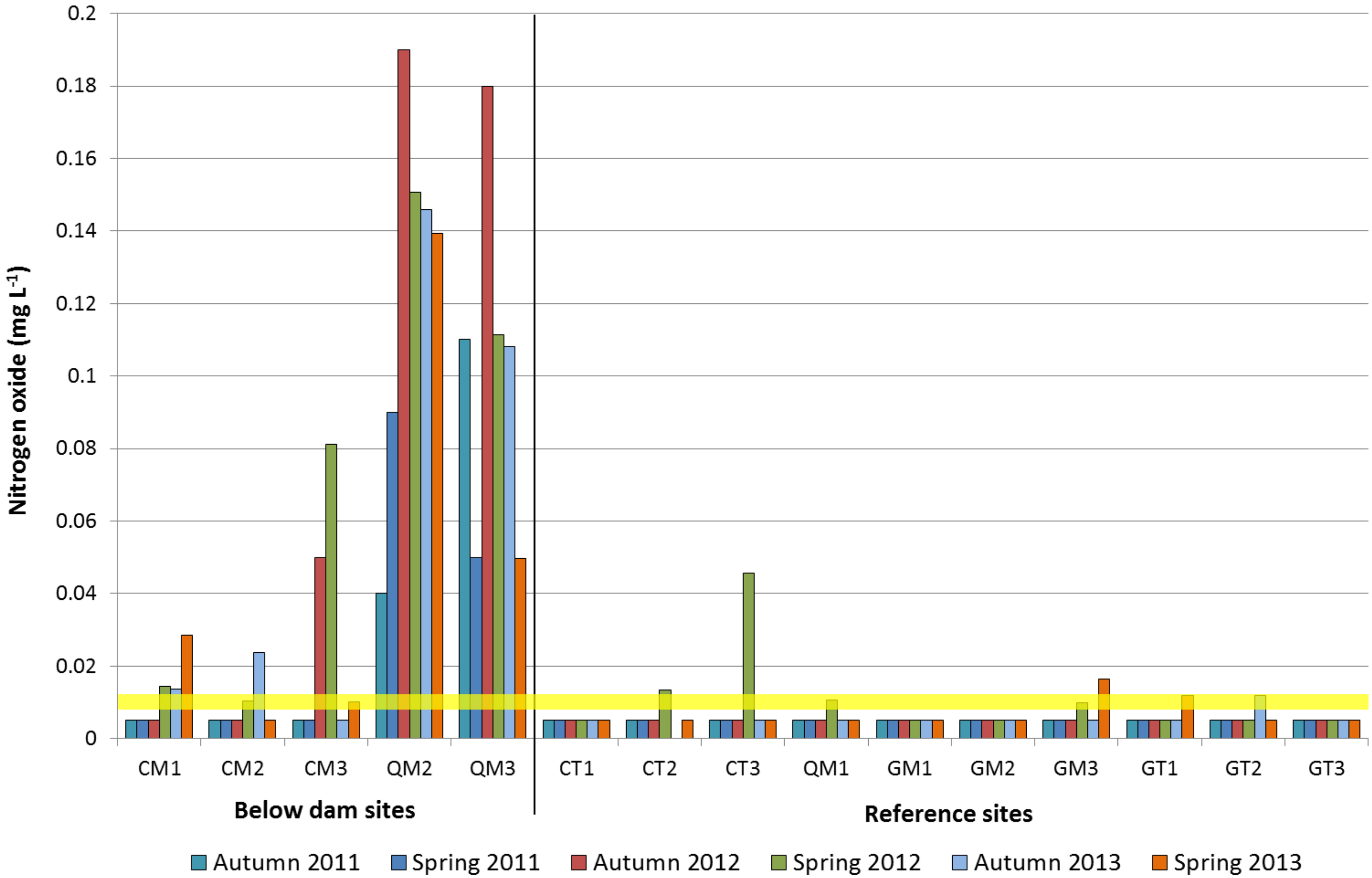
Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group C	***Group A***	
Conoesucidae	7	1	0	10.84
Baetidae	5	0.25	1	1.65
		Group C	***Group B***	
Aphroteniinae	6	0	0.86	2.36
Psephenidae	6	0	0.86	2.36
Leptoceridae	6	0.25	1	1.68
Baetidae	5	0.25	1	1.68
Glossosomatidae	9	0.25	0.86	1.42
		Group A	***Group B***	
Conoesucidae	7	0	1	11.52
Psephenidae	6	0	0.86	2.35
Leptoceridae	6	0.25	1	1.67
Tanypodinae	4	0.25	1	1.68
Coloburiscidae	8	0	0.71	1.53
Scirtidae	6	0	0.71	1.53
Aphroteniinae	6	0.25	0.86	1.41
Glossosomatidae	9	0.25	0.86	1.42

Appendix 3.

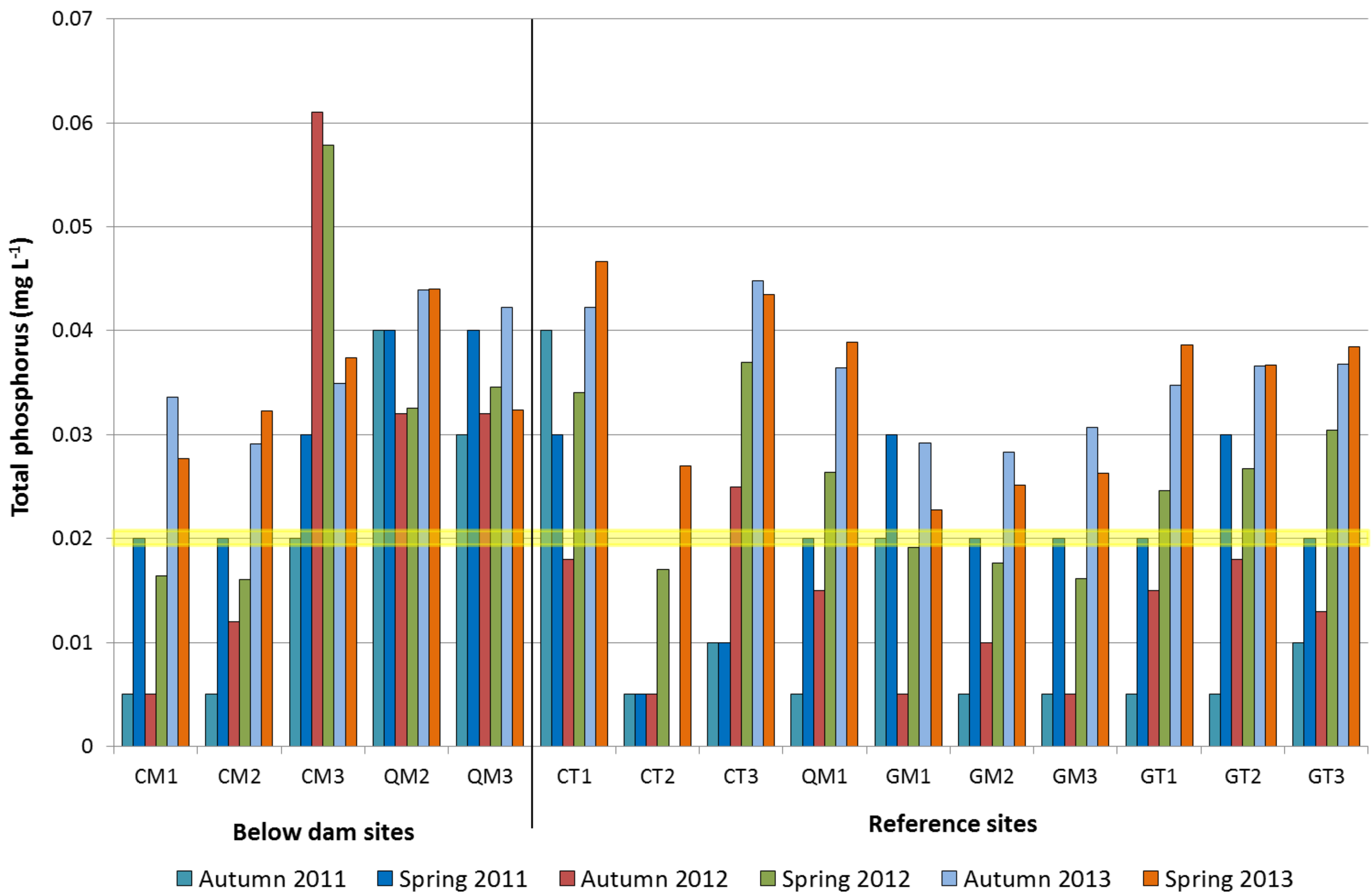
Water quality figures



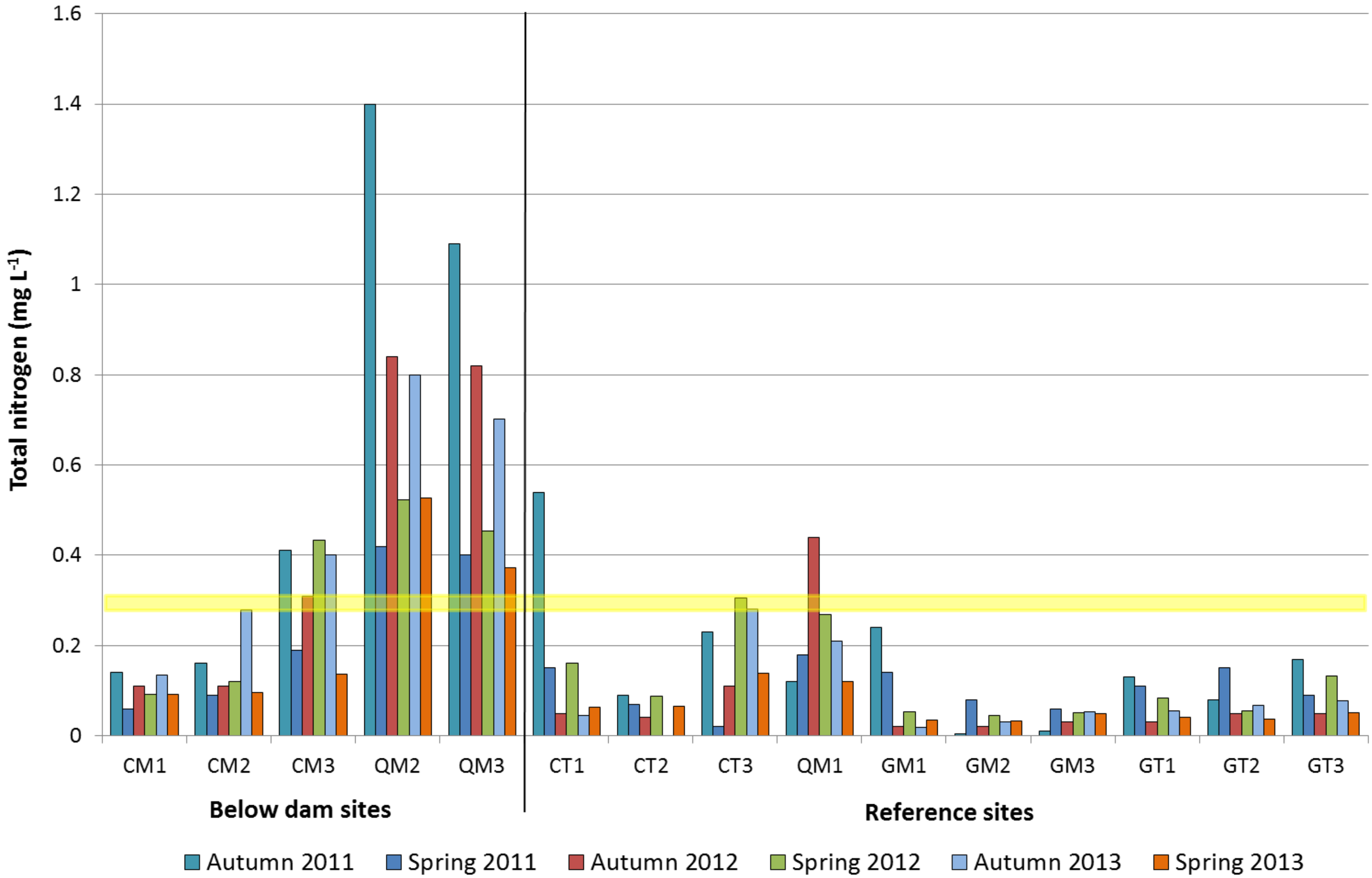
Ammonium (NH_4^+) concentration at all sites from autumn 2011 to spring 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



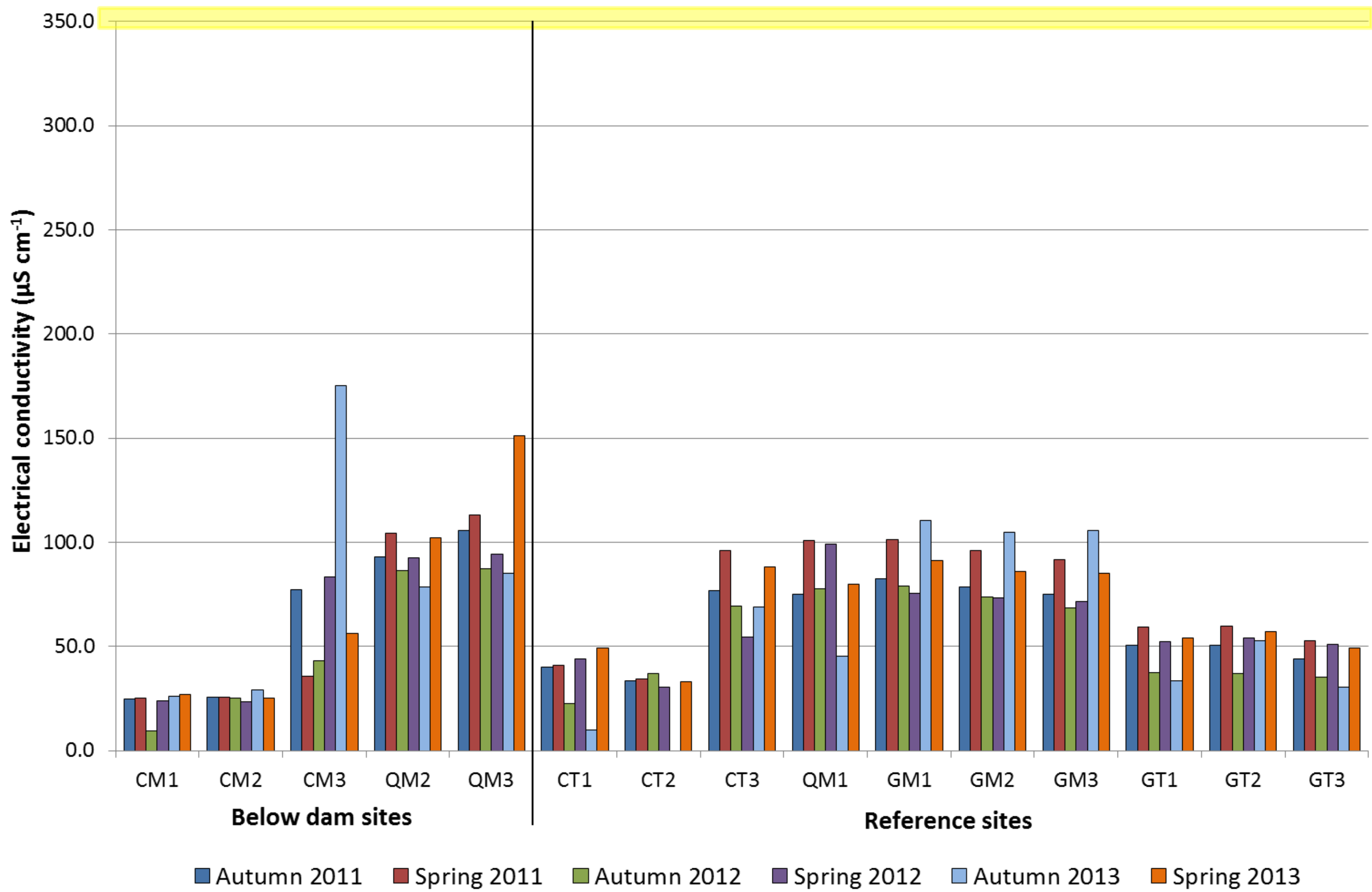
Nitrogen oxide concentrations at all sites from autumn 2011 to spring 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



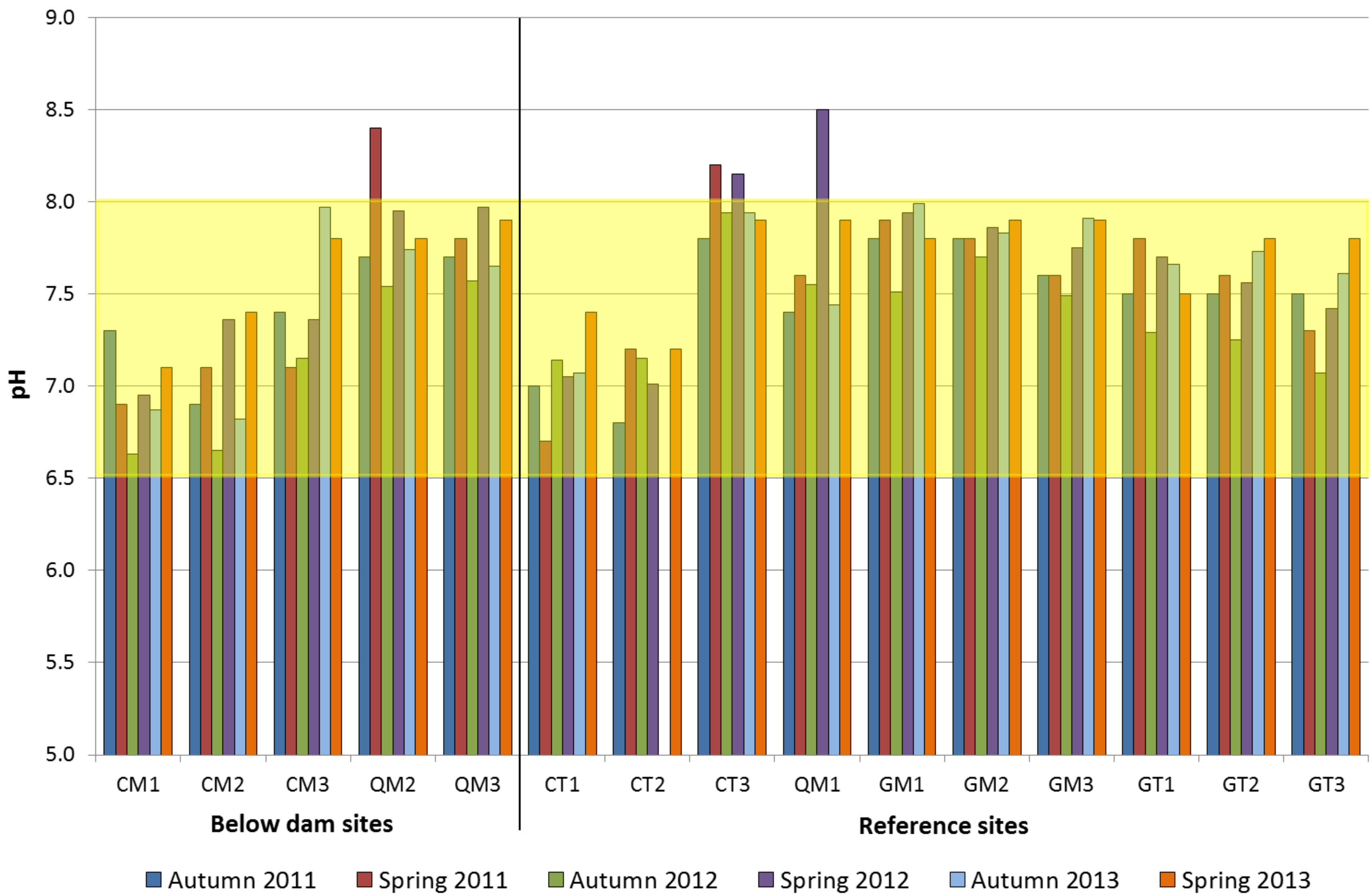
Total phosphorus concentrations at all sites from autumn 2011 to spring 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



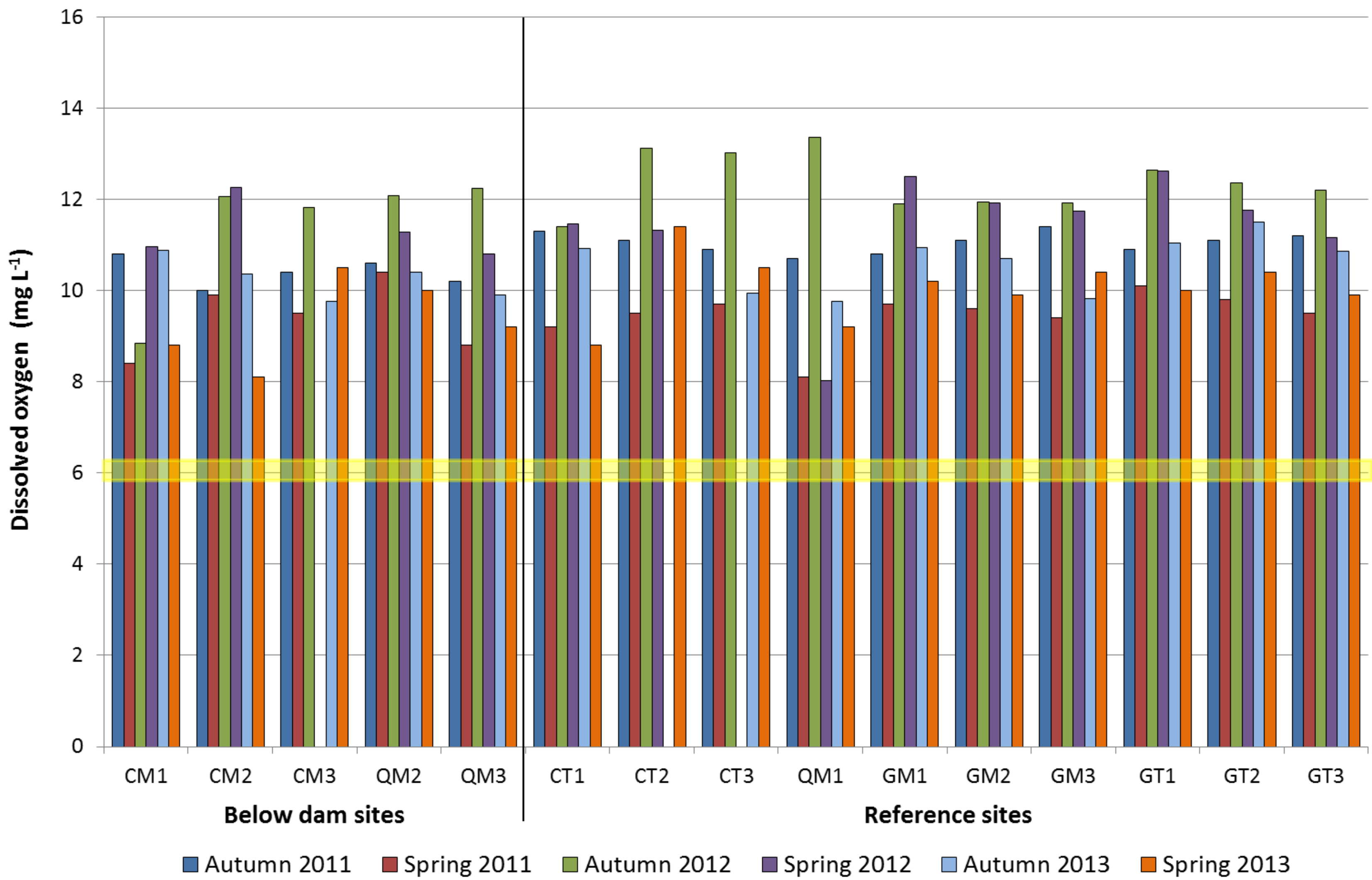
Total nitrogen concentrations at all sites from autumn 2011 to spring 2013. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



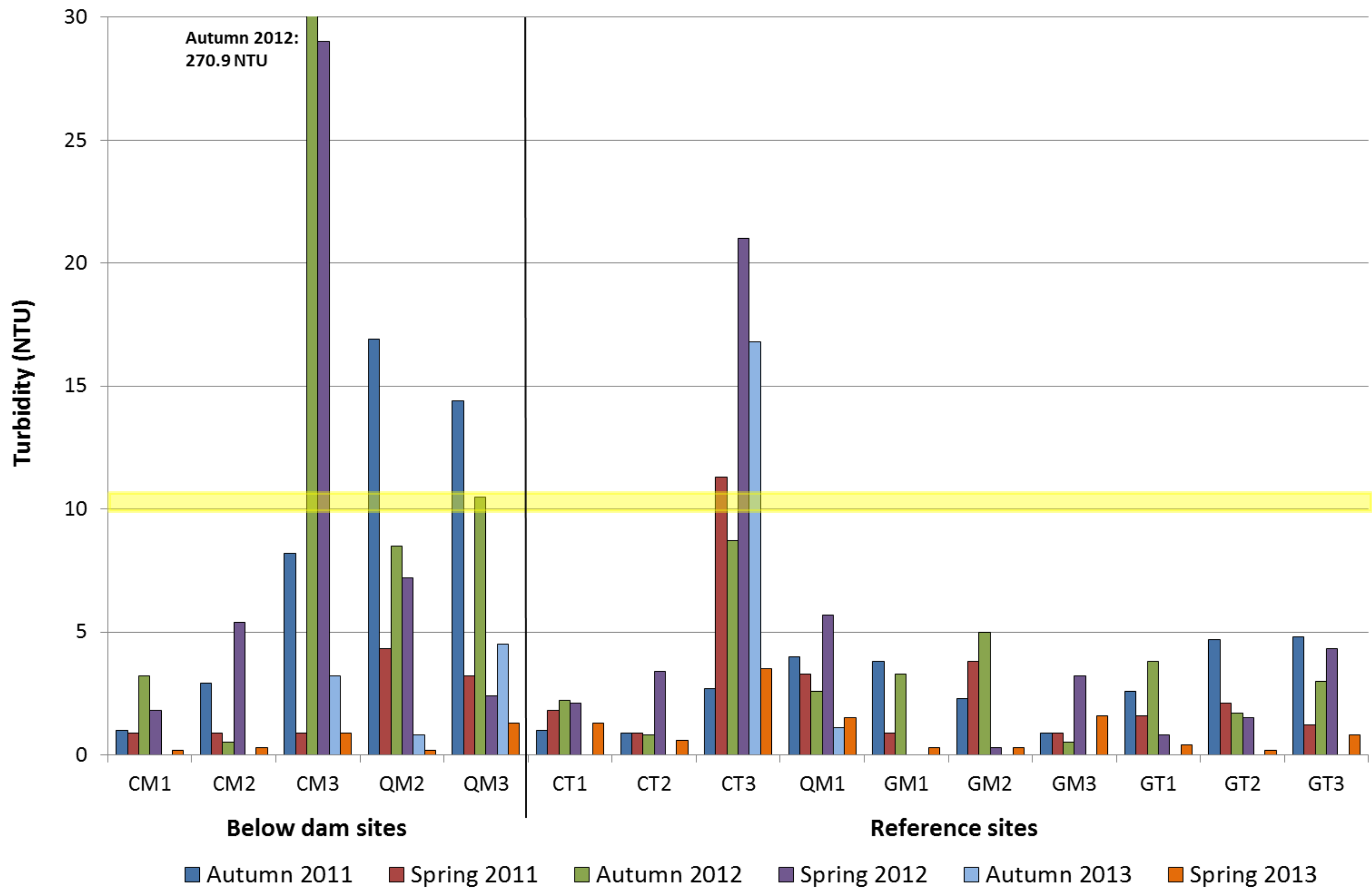
Electrical conductivity at all sites from autumn 2011 to spring 2013. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from autumn 2011 to spring 2013. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from autumn 2011 to spring 2013. The minimum guideline for electrical conductivity is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from autumn 2011 to spring 2013. The guideline for turbidity is shaded yellow (Environment Protection Regulation SL2005-38).