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

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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.

Autumn 2014 results and conclusions

- In autumn 2014 water quality parameters were generally within the recommended water quality guideline levels at below dam test sites and reference sites. Nitrogen oxide and total nitrogen were above guideline concentrations at test and reference sites. However, total phosphorus concentrations had declined since the spring 2013 assessment to within guideline concentrations at all sites except Cotter River tributary site CT3 on Paddys River. Turbidity was within guidelines for all sites except CM3 (below Cotter Dam) and at tributary site CT3 on Paddys River. The elevated turbidity at CM3 is unlikely to be elevated as a direct consequence of the presence or operation of Cotter Dam and possibly a result of higher turbidity Murrumbidgee River water transferred via M2C. Nutrient concentrations are commonly outside guideline levels at CT3 and are attributed to upstream land-use effects. Click here for more information

- All below dam test sites met the environmental flow ecological objective of <20% filamentous algae cover of riffle habitats. This is likely a result of high flow velocities below Corin and Googong Dams prior to sampling scouring excess algae from the streambed, and low phosphorus concentrations across all test sites limiting algae growth. 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)	< 10	A (0.91)
CM2 (Bendora Dam)	< 10	B (0.86)
CM3 (Cotter Dam)	< 10	B (0.66)
QM2 (Googong Dam)	< 10	B (0.70)
QM3 (Googong Dam)	< 10	B (0.83)

- Site CM1 below Corin Dam was the only test site to meet the environmental flow ecological objective of AUSRIVAS band A assessment in autumn 2014. Click here for more information

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

- Reference sites on the Goodradigbee River and upstream of Googong Reservoir on the Queanbeyan River were all in reference condition in autumn 2014, and assessments of tributaries within the Cotter and Goodradigbee River catchments indicated that these catchments were in comparable condition. Click here for more information.

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

Project recommendations

- Flow releases from Corin Dam were more variable and of greater volume in the lead up to autumn 2014 sampling compared with previous assessments. This has coincided with the site meeting the environmental flow ecological objective of AUSRIVAS band A for the first time at site CM1 since spring 2009. Therefore, it is likely that increasing the volume and variability of environmental flow releases from dams on the Cotter and Queanbeyan Rivers will assist in achieving environmental flow ecological objectives.

- The current Below Dams Assessment Program study design with reference and test sites has been effective at detecting the effects of river regulation and catchment disturbances (e.g. fire, drought and floods) on the Cotter and Queanbeyan Rivers. Now that a large data set has been assembled it is timely that a long-term assessment of the data collected is undertaken to inform future management decisions by ACTEW Water. A long-term analysis of the data set will also assist in setting water quality guidelines specific to the Cotter and Queanbeyan Rivers.

- Macroinvertebrate identification for AUSRIVAS assessment is required to family taxonomic level only. This is the most appropriate level for Rapid Biological Assessment because it is cost effective and relatively rapid at detecting the effects of river regulation on stream ecological condition. However, the degree of analysis permitted by this level of identification is limited because of variability in within family responses to habitat change and disturbance. Introducing species analysis may increase the capacity to understand changes in macroinvertebrate community composition below dams. This would greatly enhance ACTEW Waters' capacity to detect and respond to longer-term changes to instream biological condition, such as those associated with climate change (e.g. taxa sensitive to changes in temperature and stream flow). Increased project costs could potentially be offset with efficiencies generated from compromises to lower priority project components following a review of the project objectives and data set.

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 autumn 2014, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments. Site summary sheets outlining the outcomes of the autumn

2014 assessment for each of the test sites CM1 (Corin Dam), CM2 (Bendora Dam), CM3 (Cotter Dam), QM2 (Googong Dam), and QM3 (downstream of QM2) are included as Appendix 1.

Field and laboratory methods

Study area

The study area includes the Cotter and Goodradigbee Rivers, which are situated to the east and west of the western border of the ACT, respectively, and the Queanbeyan River to the east of the ACT (Figure 1). The Cotter River is a fifth order stream (below Cotter Dam) with a catchment area of approximately 480 km^2. The Cotter River is a major source of drinking water for Canberra and Queanbeyan, with the principal management outcome to ensure a secure water supply (ACT Government 2006). Conservation of ecological values of the river is an important consideration in the ongoing management of the Cotter River. The river is regulated by three dams, the Cotter Dam, Bendora Dam and Corin Dam.

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

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

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

Fifteen sites were sampled for biological, physical and chemical variables between the 15th and 17th 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.

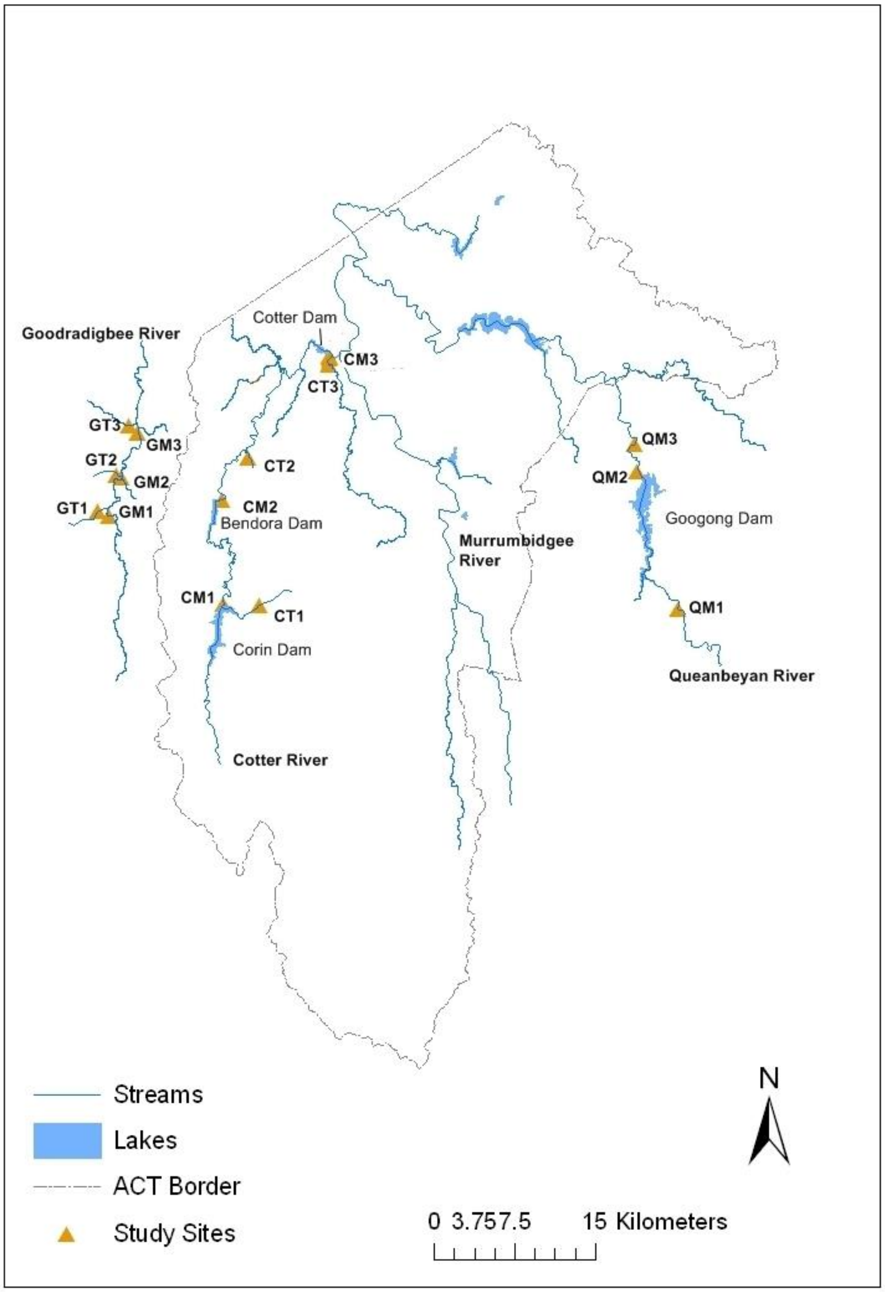

Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

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

Site	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500m downstream of Corin Dam	900	31	4
CM2	Cotter	500 m downstream of Bendora Dam	700	51	4
CM3	Cotter	100m upstream Paddy's River confluence	500	75	5
CT1	Kangaroo Ck	50m downstream Corin Road crossing	900	7.3	3
CT2	Burkes 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 autumn riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT autumn riffle model uses a set of 6 habitat variables to predict the macroinvertebrate fauna expected to occur at each site in the absence of disturbance.

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

SIGNAL 2 grades

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

Data entry and storage

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

Data analysis

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

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

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

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

Results

Hydrometric data

Stream discharge in the months leading up to autumn 2014 sampling at below dam sites on the Cotter and Queanbeyan Rivers was largely determined by operational requirements and environmental flow guidelines (ACT Government 2013) (Table 4). An extended period of staged flow releases exceeding 400 ML d^{-1} from Corin Dam between 29th November 2013 and 17th February 2014 resulted in greater total flow volume at site CM1 than at all other test sites on the Cotter and Queanbeyan Rivers and at reference sites on the Goodradigbee River (Figure 2).

The greatest mean daily discharge of 877 ML d^{-1} occurred on the Queanbeyan River downstream of Googong Dam at site QM2 (Figure 2) following a three day rainfall event totalling 38 mm, which resulted in Googong Dam spilling (BOM; station number 070072).

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

Dam	Flow regime
Corin	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 ML d^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML d-1 for 2 consecutive days between mid-July and mid-October.
Bendora	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 ML d^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Cotter	From Murrumbidgee to Cotter (M2C) transfer: If Murrumbidgee River flow at Mt MacDonald gauging station is greater than 80 MLd^{-1}, then M2C discharges 40 MLd^{-1}. Each month, M2C discharge flow is reduced temporarily to 20 ML d^{-1} for a 36 to 46 hour period. Cotter Dam releases bimonthly flows peaking at 100 MLd^{-1} and a flow peaking at 150 ML d^{-1} between mid-July and mid-October.
Googong	Maintain base flow average of 10 ML d^{-1} or natural inflow, whichever is less. Riffle maintenance flow of 100 ML d^{-1} for 1 day every 2 months.

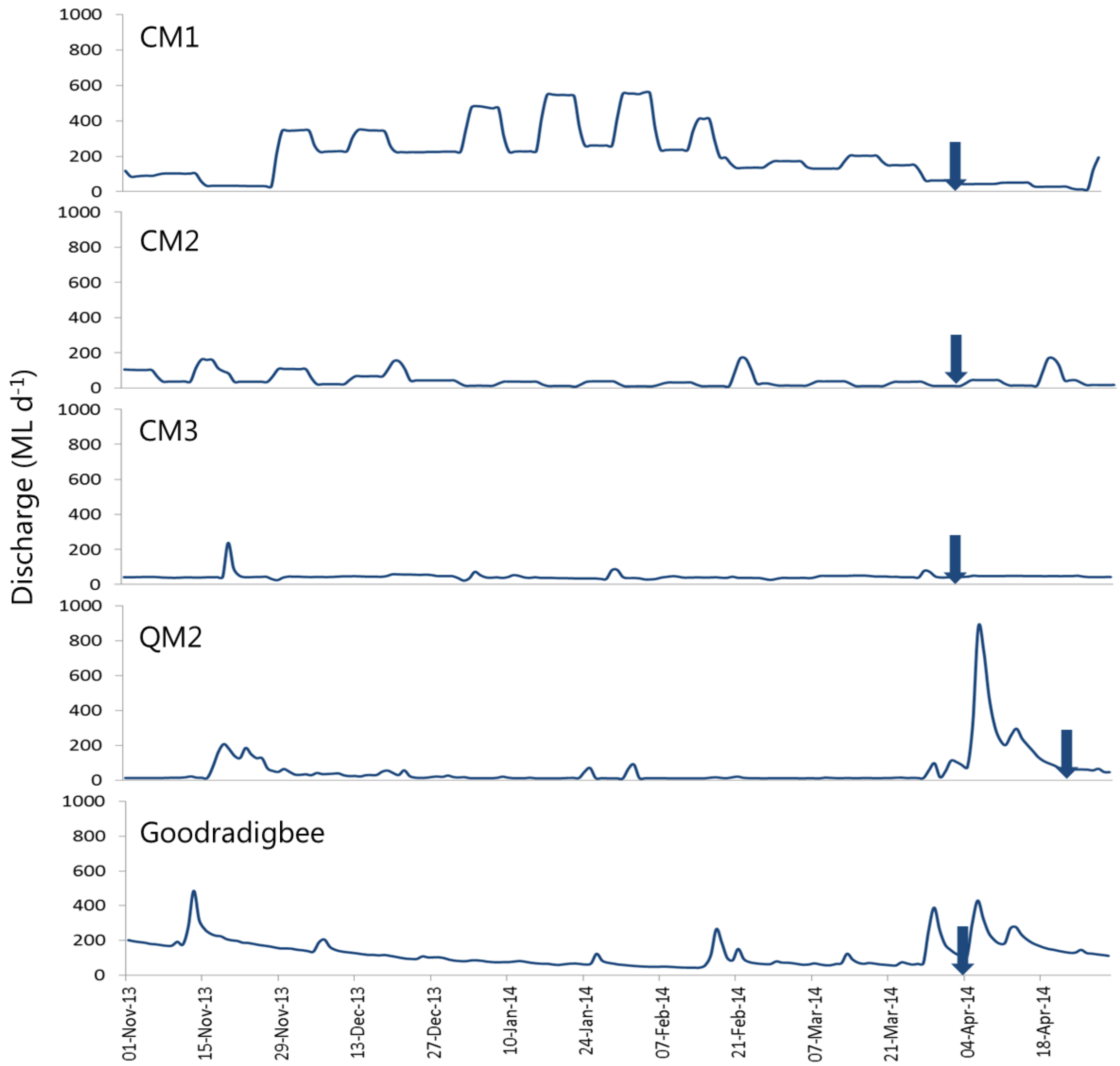

Figure 2: Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), Cotter (CM3, station 410700) and Googong (QM2, station 410760) Dams and in the Goodradigbee River (station 410088) from 1st November 2013 to 30th April 2014. Arrows correspond to autumn 2014 sampling dates.

Water quality

Water quality parameters were generally within ANZECC/ARMCANZ (2000) guidelines at test and reference sites in autumn 2014. Exceptions were turbidity at sites CM3 below Cotter Dam and CT3 on Paddys River which were slightly above the guideline turbidity level of 10 NTU; and also nitrogen oxides and total nitrogen which exceeded guideline concentrations at sites CM2, CT1, CT3, QM1, GM3, and sites CM3, QM2, QM3, CT3, QM1, GM1, and GT2 respectively, and total phosphorus which was within guideline concentrations (0.02 mg L^{-1}) at all sites except for site CT3 on Paddys River (Table 5; Appendix 3).

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

		Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg L^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3 N (mg L^{-1})	NO_x (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total phosphorus (mg L^{-1})
		Guideline level									
		NA	<350	6.5-8	>6	<10	NA	<0.13	<0.015	<0.25	<0.02
Below dam test sites	CM1	16.33	32	6.72	9.77	1.1	6	0.009	0.010	0.19	0.01
	CM2	18.53	31	6.68	9.42	0.6	10	0.016	0.028	0.21	0.01
	CM3	16.08	47	7.37	8.76	10.6	12	0.017	0.014	0.35	0.01
	QM2	16.48	99.3	7.89	9.55	0.5	48	0.004	0.003	0.51	0.01
	QM3	15.95	125.3	7.81	9.76	0.2	55	0.002	0.007	0.64	0.01
Reference sites	CT1	14.82	53	6.93	10.64	1.1	10	0.002	0.038	0.21	0.02
	CT2	14.84	33	6.6	10.03	0.5	8	0.002	0.002	0.10	0.01
	CT3	16.51	67	7.79	9.11	17.7	30	0.002	0.105	0.38	0.03
	QM1	12.82	81.4	7.55	9.46	7.2	29	0.003	0.209	0.34	0.02
	GM1	14.9	119	7.92	9.7	1.4	40	0.002	0.004	0.64	0.01
	GM2	15.35	109	7.75	9.54	3.2	43	0.002	0.015	0.11	0.01
	GM3	17.05	108	7.84	9.2	3.2	42	0.004	0.017	0.11	0.01
	GT1	14.55	59	7.99	9.51	0.6	21	0.007	0.008	0.13	0.01
	GT2	14.93	90	7.63	9.25	2.1	23	0.005	0.004	0.29	0.01
	GT3	14.7	62	7.45	8.94	3.2	26	0.006	0.005	0.14	0.02

Periphyton and algae

Field observations of periphyton and filamentous algae cover of riffle habitats were <10% cover at all sites in autumn 2014, which was a notable decrease in filamentous algae cover at site CM1 below Corin Dam and CM2 below Bendora Dam since spring 2013 (Table 6; Figure 3). The environmental flow objective of <20% cover of riffle habitats was therefore achieved at each of the below dam test sites.

Mean ash free dry mass (AFDM) and chlorophyll-a concentrations were similar between test and reference sites (Figure 4 and Figure 5). Differences in AFDM and chlorophyll-a between sites were not statistically significant (F=4.26; DF=6,35; P=0.86).

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 2011 to autumn 2014.

% cover of riffle habitat														
	Periphyton								Filamentous algae						
	Aut 2011	Spr 2011	Aut 2012	Spr 2012	Aut 2013	Spr 2013	Aut 2014		Aut 2011	Spr 2011	Aut 2012	Spr 2012	Aut 2013	Spr 2013	Aut 2014
CM1	<10	35-65	<10	<10	25	10	<10		<10	10-35	<10	10-35	<10	80	<10
CM2	<10	10-35	<10	10-35	75	20	<10		<10	10-35	<10	>90	<10	20	<10
CM3	<10	<10	<10	10-35	<10	50	<10		<10	<10	<10	<10	<10	<10	<10
QM2	<10	35-65	<10	<10	<10	20	10		<10	10-35	<10	<10	<10	<10	<10
GM1	<10	<10	<10	<10	15	<10	<10		<10	<10	<10	<10	15	<10	<10
GM2	<10	<10	<10	<10	<10	<10	<10		<10	<10	<10	<10	<10	<10	<10
GM3	<10	<10	10-35	10-35	<10	10	<10		<10	<10	<10	<10	<10	15	<10

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 autumn 2014.

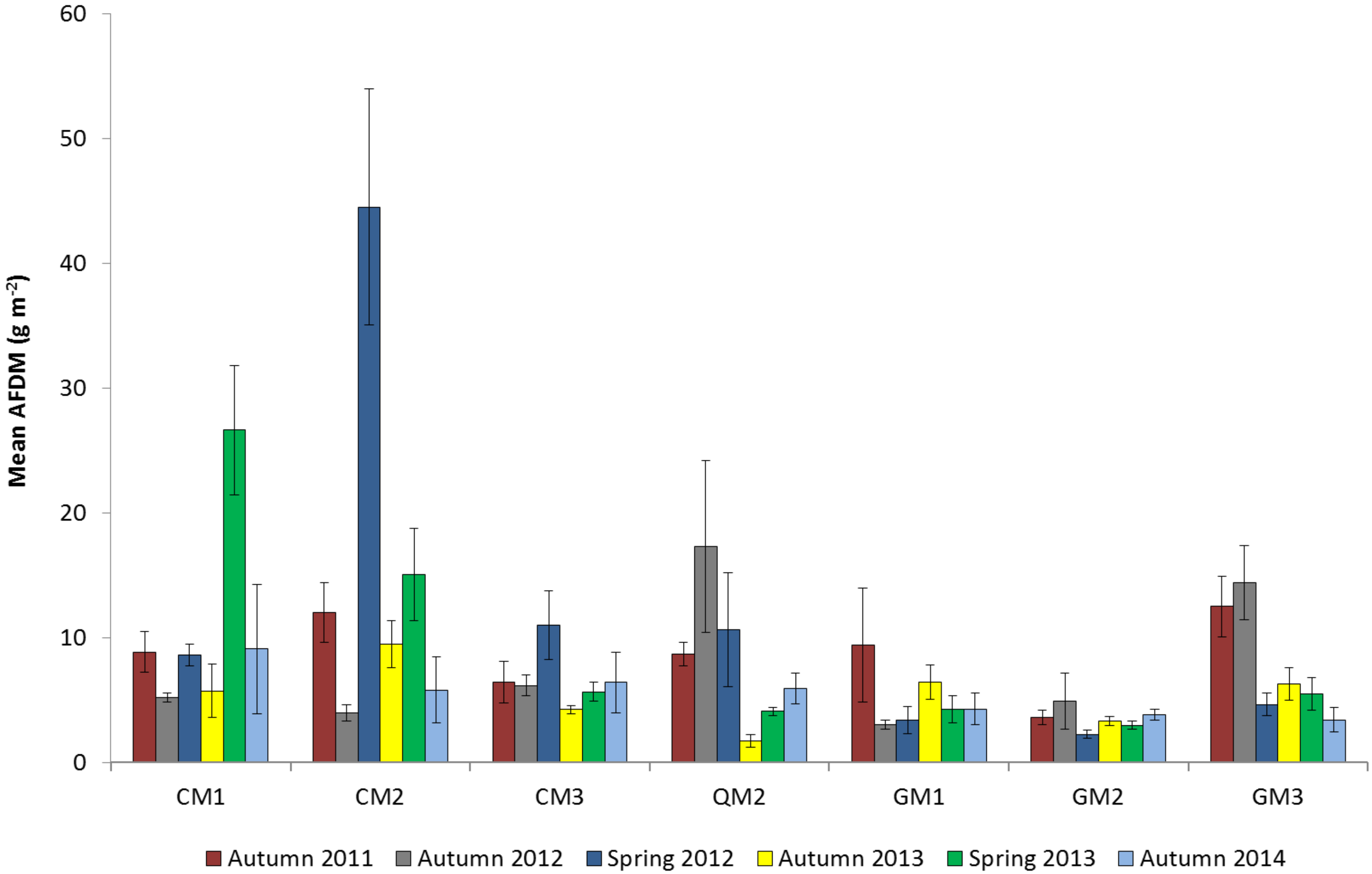

Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2011 to autumn 2014. Error bars represent +/- 1 standard error.

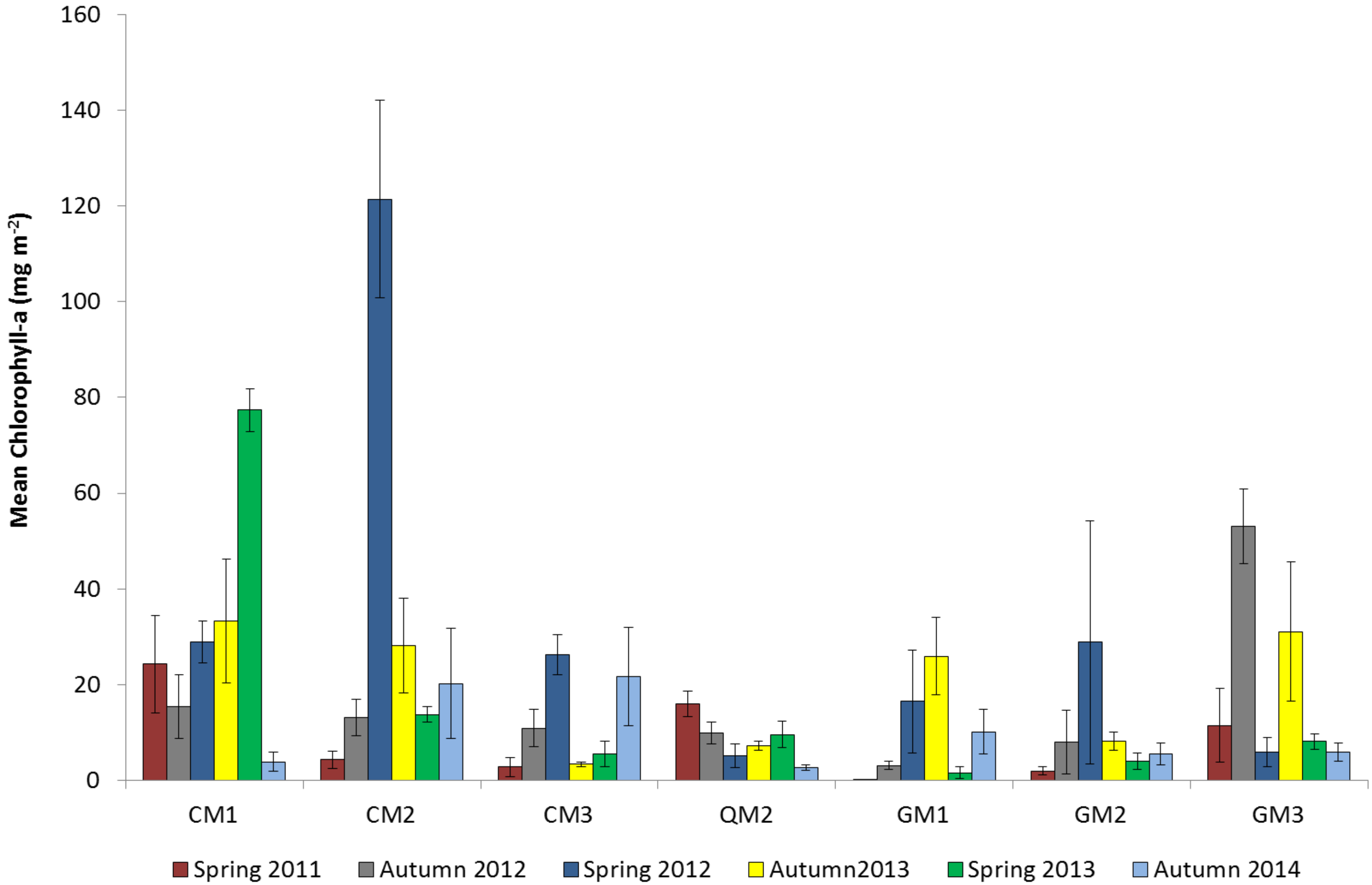

Figure 5: Mean chlorophyll-a (μg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from spring 2011 to autumn 2014. Error bars represent +/- 1 standard error.

Benthic macroinvertebrates

AUSRIVAS assessment

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

Cotter River test site CM1 below Corin Dam improved in AUSRIVAS assessment from band B (*significantly impaired*) in spring 2013 to band A (*similar to reference condition*) in autumn 2014 (Table 7). The other Cotter River test sites CM2 below Bendora Dam and CM3 below Cotter Dam declined in AUSRIVAS assessment from band A to band B from the spring 2013 to the autumn 2014 assessment (Table 7).

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

Cotter River tributary sites CT1 (Kangaroo Creek) and CT2 (Burkes Creek) were assessed as AUSRIVAS band A, and site CT3 (Paddys River) was assessed as band B in autumn 2014. Site CT3 has been assessed as biologically impaired since autumn 2012 (Table 7). Goodradigbee River tributary site GT1 was assessed as AUSRIVAS band X (*more biologically diverse than reference*), and sites GT2 and GT3 were assessed as band A in autumn 2014 (Table 7).

Queanbeyan River test sites QM2 and QM3 both returned to band B in autumn 2014 after being assessed as band A in spring 2013. The upstream Queanbeyan River reference site QM1 was assessed as band A in autumn 2014 (Table 7).

Taxa that were expected with a ≥50% chance of occurrence by the AUSRIVAS model but were missing from sub-samples are presented in Table 8. Missing taxa ranged in SIGNAL 2 grade from 2 (Oligochaeta) to 9 (Glossosomatidae). Cotter River tributary site CT3, Queanbeyan River sites QM1, QM2, and QM3, and Goodradigbee River site GM1 and tributary site GT1 had taxa identified in whole of sample scans that were missing from respective sub-samples. This indicates that these taxa (Hydrobiosidae - sites QM1, QM2, GM1, and GT1, and Gomphidae - sites CT3 and QM3) were present at these sites, but in low abundance (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2011 to autumn 2014.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Autumn 2014	A (0.91)	B (0.86)	B (0.66)	B (0.70)	B (0.83)	A (0.96)	A (0.90)	B (0.84)	A (0.97)	A (0.88)	A (1.04)	A (0.97)	X (1.19)	A (1.12)	A (1.05)
Spring 2013	B (0.69)	A (0.89)	A (0.88)	A (0.88)	A (0.92)	X (1.16)	A (1.00)	B (0.74)	A (1.10)	X (1.19)	A (1.11)	X (1.19)	A (1.13)	A (0.98)	A (1.13)
Autumn 2013	C (0.59)	A (1.12)	C (0.60)	B (0.77)	B (0.77)	A (1.08)	Not sampled	B (0.70)	A (0.97)	A (0.89)	A (0.89)	B (0.81)	A (1.01)	B (0.86)	A (1.05)
Spring 2012	B (0.77)	B (0.82)	B (0.73)	B (0.64)	B (0.77)	X (1.26)	A (1.12)	B (0.68)	A (1.01)	A (1.12)	X (1.26)	A (1.12)	B (0.83)	B (0.75)	B (0.68)
Autumn 2012	B (0.72)	B (0.79)	D (0.37)	C (0.63)	B (0.70)	A (0.93)	B (0.83)	C (0.56)	A (0.97)	C (0.56)	B (0.67)	B (0.82)	A (0.98)	A (1.06)	A (0.90)
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 autumn riffle model but were missing from sub-samples for each of the study sites in autumn 2014 and their SIGNAL 2 grade (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan.

Taxa	Signal 2 grade	CM1	CM2	CM3	CT1	CT2	CT3	QM1	QM2	QM3	GM1	GM2	GM3	GT1	GT2	GT3
Glossosomatidae	9	X				X									X	
Coloburiscidae	8	X				X									X	
Leptophlebiidae	8			X					X							
Gripopterygidae	8			X												
Hydrobiosidae	8		X	X	X	X	X	X	X		X		X	X		
Elmidae	7		X													
Conoesucidae	7			X												
Psephenidae	6			X		X										
Podonominae	6		X	X			X	X	X	X	X	X	X	X		X
Leptoceridae	6	X	X				X		X	X						
Tipulidae	5		X		X											
Simuliidae	5	X														
Gomphidae	5			X			X	X		X		X	X			X
Hydrobiidae	4						X		X	X	X					
Ancylidae	4						X		X	X	X					
Tanypodinae	4				X			X	X	X	X		X			
Caenidae	4	X				X										
Hydroptilidae	4		X		X				X			X				X
Oligochaeta	2			X												
Total		**5**	**6**	**8**	**4**	**5**	**6**	**4**	**8**	**6**	**5**	**3**	**4**	**2**	**2**	**3**

Taxonomic relative abundance

The relative abundance of disturbance tolerant Oligochaeta and Chironomidae (OC) taxa was greater at Cotter River test sites than at Goodradigbee River reference sites (Figure 6). The sum of disturbance sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa relative abundance was greater at Goodradigbee River reference sites than at Cotter River test sites (Figure 6).

Differences in relative abundance of OC and EPT taxa between reference site QM1 and below dam test sites QM2 and QM3 on the Queanbeyan River were negligible.

OC taxa were generally in greater relative abundance in Cotter River tributaries than in Goodradigbee River tributaries. This was because of high abundances of Chironomidae at CT2 (51%) and Simuliidae (presented as 'Diptera (other)' in Figure 6) at CT3 (47%). Simuliidae comprised 56% of the sub-sample at Queanbeyan River test site QM2 and 41% at QM3, and 27% of the sub-sample from Cotter River test site CM3.

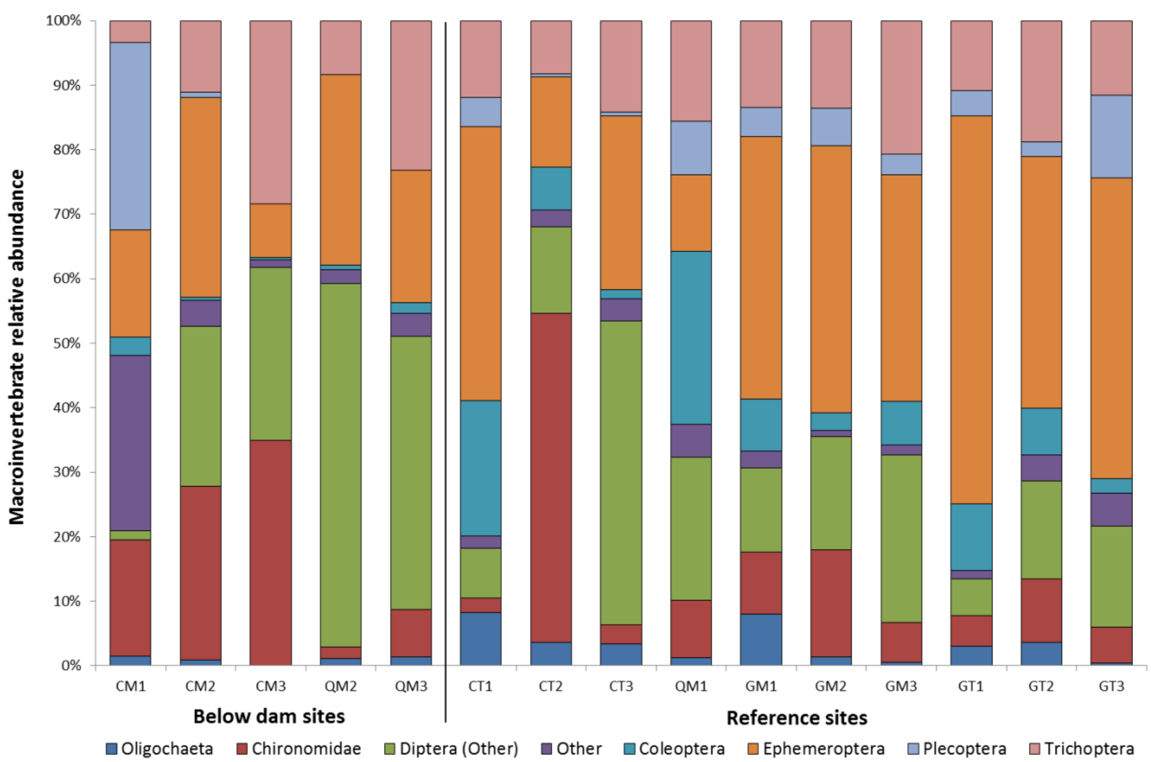

Figure 6: Relative abundance of macroinvertebrate taxonomic groups from samples collected in autumn 2014.

Macroinvertebrate assemblage similarity

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

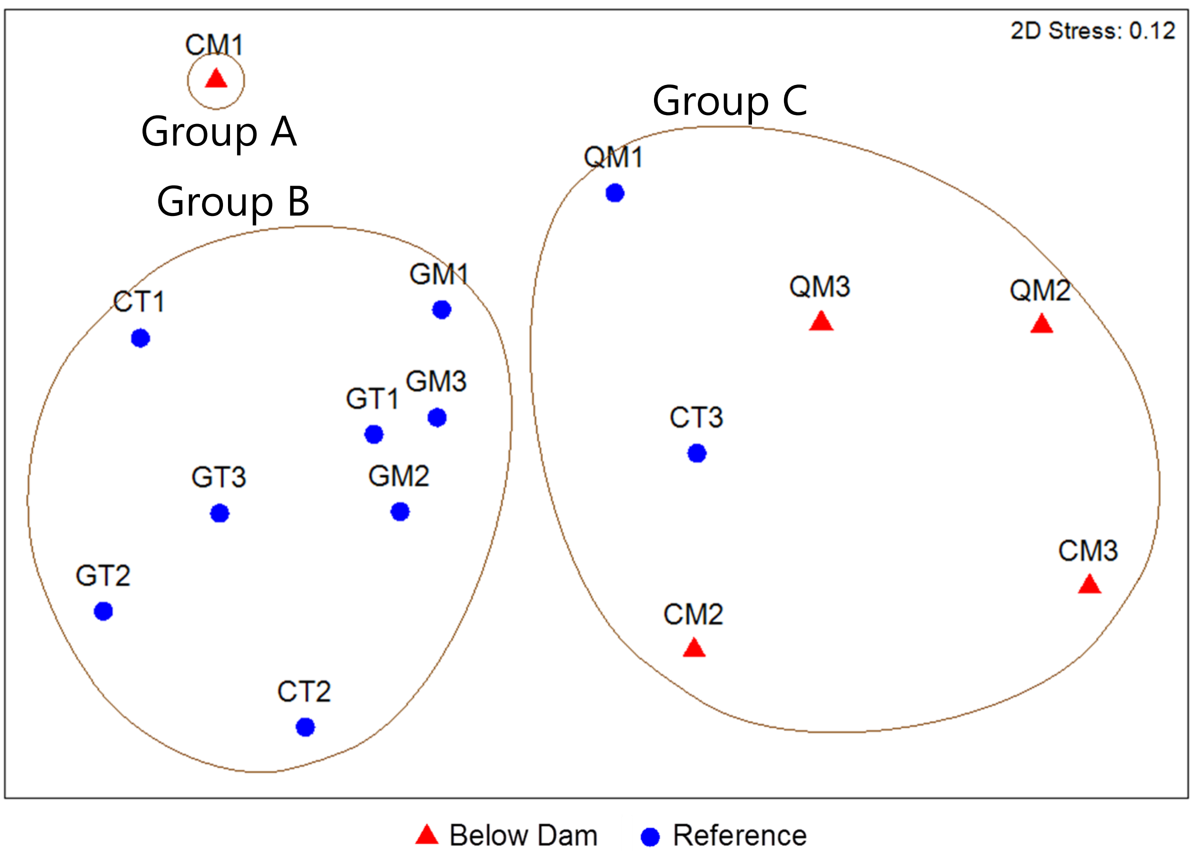

Figure 7. MDS ordination of 60% similarity between macroinvertebrate samples collected in autumn 2014 for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance.

Discussion

Water quality

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

Turbidity was only slightly above the ANZECC/ARMCANZ (2000) guideline level (10 NTU) at site CM3 (Table 5) and is unlikely to be elevated as a direct consequence of the presence or operation of Cotter Dam. Operation of the M2C transfer is more likely to have contributed to the elevated turbidity at this site; however turbidity at this level is unlikely to have an adverse effect on the ecology of the Cotter River in the study reach. Turbidity at tributary site CT3 on Paddys River was also above the guideline level at the time of sampling (Table 5). Turbidity and nutrient concentrations are commonly outside guideline levels at this site and have been attributed to upstream land-use effects (see Levings and Harrison 2013).

Total nitrogen (TN) and nitrogen oxide (NOx) concentrations exceeded guideline concentrations at several below dams test sites and reference sites in autumn 2014 (Table 5). There was no apparent bias toward test or reference sites in the distribution of these results, which suggests that the presence or operation of dams on the Cotter and Queanbeyan Rivers did not appear to be causing elevated nutrient concentrations in downstream river reaches in autumn 2014. The above guideline concentrations may be because of increased run-off during rainfall before sampling.

Periphyton and algae

Filamentous algae cover in riffle habitats was well below the environmental flow ecological objective of <20% cover at all sites in autumn 2014 (Table 6; Figure 3). Discharge rates in excess of 150 ML d^{-1} were recorded prior to sampling below Corin and Googong Dams (sites CM1 and QM2) and in the Goodradigbee River (Sites GM1, GM2, and GM3). Flow velocities associated with these rates of discharge are likely to scour excess filamentous algae from riffle habitats (ACT Government 2013), and may have scoured any build-up of filamentous algae and prevented accumulation of algal biomass.

A decline in instream phosphorus concentrations is also likely to have contributed to the relatively low levels of algal biomass in august 2014. Instream phosphorus concentrations in autumn 2014 were less than 50% of those during the spring 2013 assessment across test and reference sites (Table 5; Levings and Harrison 2013). The cause of the decline in phosphorus concentrations is unclear; however, phosphorus is often a limiting nutrient on freshwater productivity, particularly that of filamentous algae (Stevenson *et al* 2012) and may have limited the potential for algal growth in autumn 2014.

Benthic macroinvertebrates

AUSRIVAS assessment identified biological impairment at four of the five below dam test sites in autumn 2014. This represents a net decline in biological condition at below dam test sites since the spring 2013 assessment when four of the five below dam test sites were assessed as being in reference condition by the AUSRIVAS model. None of the Goodradigbee River reference sites were assessed as biologically impaired in autumn 2014 (Table 7).

Cotter River test site CM1 below Corin Dam was the only site with an improved biological condition in autumn 2014, and was assessed as similar to reference condition for the first time since the spring 2009 assessment (Table 7; Harrison et al 2011). An extended period of relatively high flow volume and variability in the months preceding autumn 2014 sampling is likely to have contributed to the improved biological condition at this site by reducing algal biomass and more favourable habitat and resource conditions for a variety of macroinvertebrates.

Test sites CM2 below Bendora Dam and CM3 below Cotter Dam were both assessed as biologically impaired in autumn 2014 (Table 7) and therefore failed to meet the environmental flow ecological objective of AUSRIVAS band A. The macroinvertebrate assemblages at these sites differed from those of reference sites primarily because of a higher abundance of filter-feeding Simuliidae (Black Fly) and Hydropsychidae (Caddis Fly) larvae at the below dam sites. Such filter-feeding taxa are commonly found in greater abundance downstream of impoundments where fine particulate food sources are abundant and the downstream transport of coarser organic material has been interrupted (Ward and Stanford 1983).

Cotter River tributary sites were generally in a similar biological condition to Goodradigbee River tributary sites in autumn 2014. The exception was site CT3 on Paddys River, which has been assessed as biologically impaired since autumn 2012 (Table 7). As discussed in previous reports, the Paddys River sub-catchment is exposed to a range of agricultural land-use pressures that do not extend beyond the sub-catchment, and are therefore not representative of the greater Cotter River catchment condition. Therefore, there was no detectable difference in catchment condition between the Cotter and Goodradigbee River catchments in autumn 2014, and instream differences between Cotter River test sites and Goodradigbee River reference sites can be attributed to instream factors such as impoundments and flow regulation.

Queanbeyan River test sites QM2 and QM3 had declined from reference condition (AUSRIVAS band A) in spring 2013 to biologically impaired (AUSRIVAS band B) in autumn 2014, while the upstream reference site QM1 remained in reference condition (Table 7). A minor flood event (877 ML d^{-1}) occurred in the Queanbeyan River on the 6^{th} and 7^{th} of April, 16 days before autumn 2014 sampling (Figure 2). It is likely that this disturbance would have influenced instream macroinvertebrate communities in the Queanbeyan River, and while reference site QM1 is likely to have recovered relatively quickly because the community is more resistant/adapted to flood disturbances, recovery at test sites QM2 and QM3 may be delayed because the communities are not as resistant/adapted to flood disturbances. Differences in the intensity of the flood peak between test and reference sites on the Queanbeyan River based on their position in the catchment may have also contributed to the degree of instream disturbance. However, the band B assessment is consistent with previous assessments at sites QM2 and QM3, and indicates that the Queanbeyan River downstream of Googong Dam had a degree of biological impairment in autumn 2014 that was consistent with previous assessments.

Conclusion

Water quality parameters were generally within guideline values, except for nitrogen oxides and total nitrogen, which were variable across test and reference sites. All below dam test sites achieved the environmental flow ecological objective for filamentous algae cover of riffle habitats, which is likely to have resulted from high velocity flow releases from Corin Dam and a decrease in phosphorus availability since the previous assessment. AUSRIVAS assessment identified an overall decline in the biological condition of river reaches downstream of dams on the Cotter and Queanbeyan Rivers in autumn 2014 since the previous assessment in spring 2013; however, the biological impairment at these test sites was of a level consistent with previous assessments. The exception was downstream of Corin Dam which was assessed as being in reference condition. The volume and variability of flow releases are likely to have provided favourable conditions for instream ecological processes at this site.

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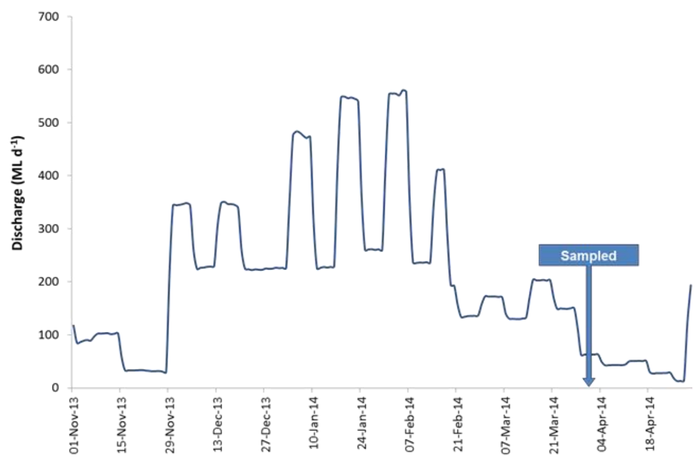
Appendix 1.

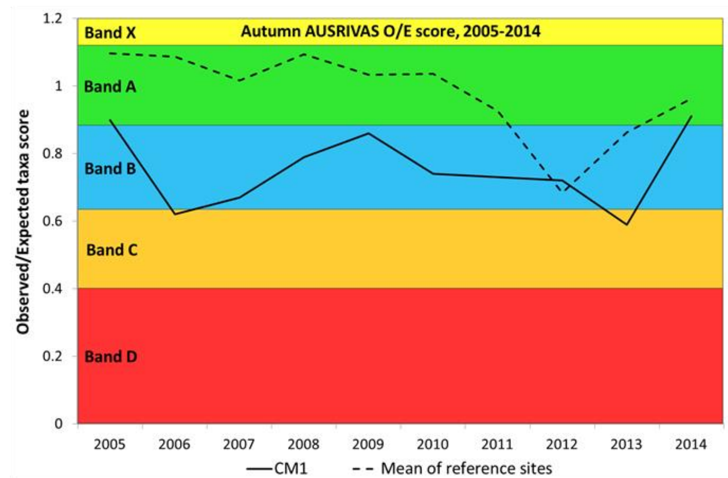
Below dam site summary sheets

CM1 – Autumn 2014

Downstream of Corin Dam

Environmental flow ecological objective	Spring 2013	Autumn 2014	Objective met?
AUSRIVAS band A	Band B	**Band A**	Yes
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm⁻¹)	pH	D.O. (mg l⁻¹)	Turbidity (NTU)	Alkalinity (mg L⁻¹)	NH_3-N (mg L⁻¹)	NOx (mg L⁻¹)	TN (mg L⁻¹)	TP (mg L⁻¹)
16.3	32	6.7	9.8	1.1	6	0.009	0.01	0.19	0.009

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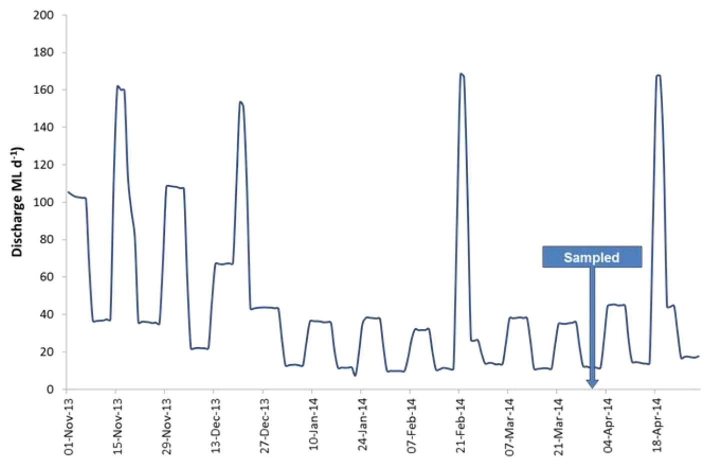
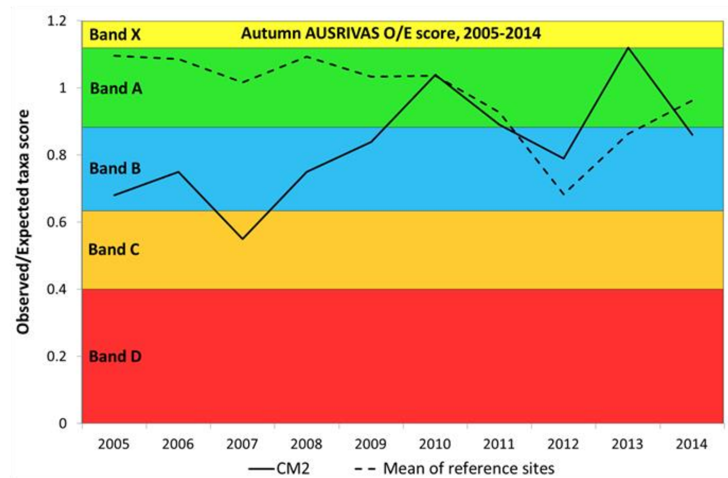
CM2 – Autumn 2014

Downstream of Bendora Dam

Environmental flow ecological objective	Spring 2013	Autumn 2014	Objective met?
AUSRIVAS band A	Band A	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





* Denotes values outside guideline levels

Temp. (^oC)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3-N (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
18.5	31	6.7	9.42	0.6	10	0.016	0.028*	0.21	0.009

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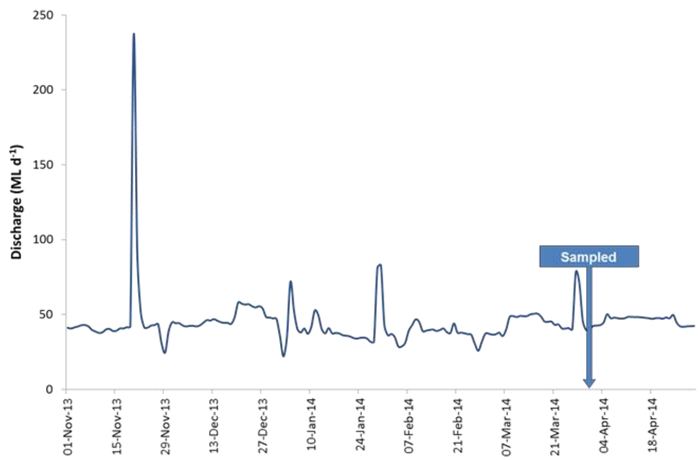
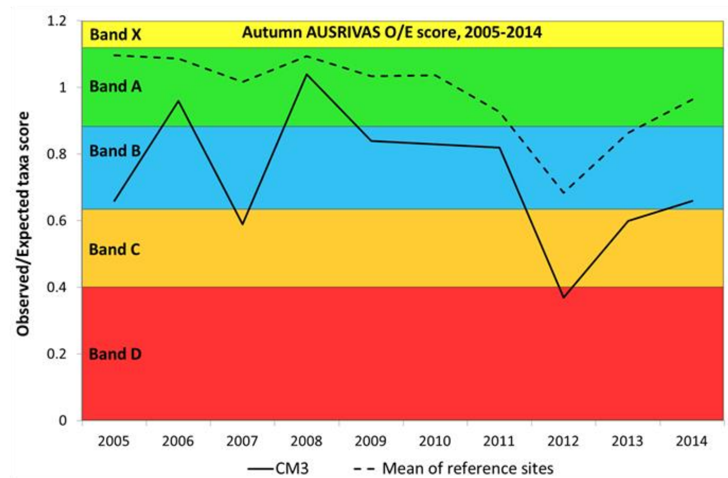
CM3 – Autumn 2014

Downstream of Cotter Dam

Environmental flow ecological objective	Spring 2013	Autumn 2014	Objective met?
AUSRIVAS band A	Band A	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





* Denotes values outside guideline levels

Temp. (^oC)	EC ($\mu s\ cm^{-1}$)	pH	D.O. ($mg\ l^{-1}$)	Turbidity (NTU)	Alkalinity ($mg\ L^{-1}$)	NH_3-N ($mg\ L^{-1}$)	NOx ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
16.1	47	7.4	8.76	10.6	12	0.017	0.014	0.035*	0.01

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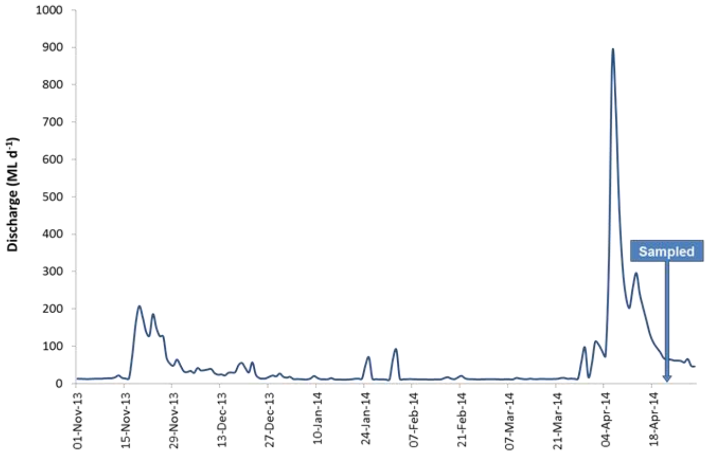
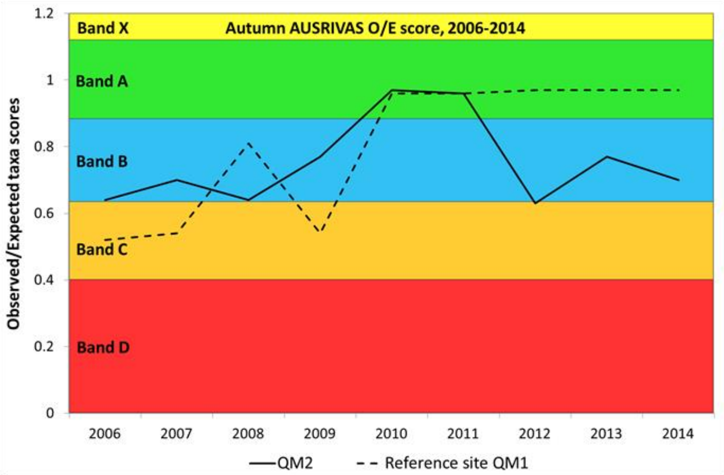
QM2 – Autumn 2014

Downstream of Googong Dam

Environmental flow ecological objective	Spring 2013	Autumn 2014	Objective met?
AUSRIVAS band A	Band A	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





* Denotes values outside guideline levels

Temp. (^oC)	EC ($\mu s\ cm^{-1}$)	pH	D.O. ($mg\ l^{-1}$)	Turbidity (NTU)	Alkalinity ($mg\ L^{-1}$)	NH_3-N ($mg\ L^{-1}$)	NOx ($mg\ L^{-1}$)	TN ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
16.5	99.3	7.9	9.6	0.5	48	0.004	0.003	0.51*	0.01

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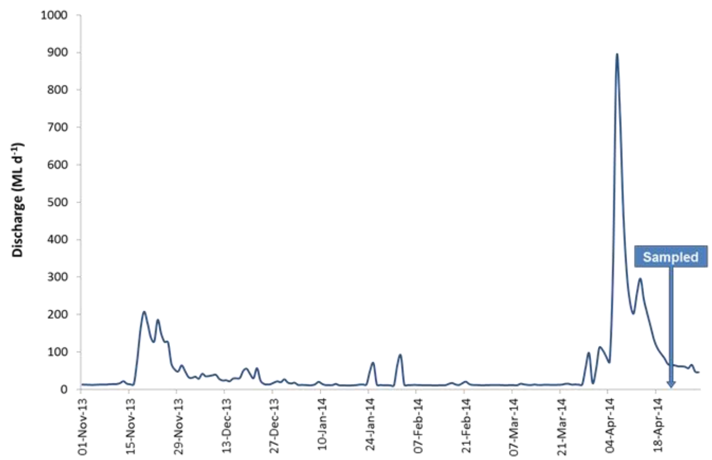
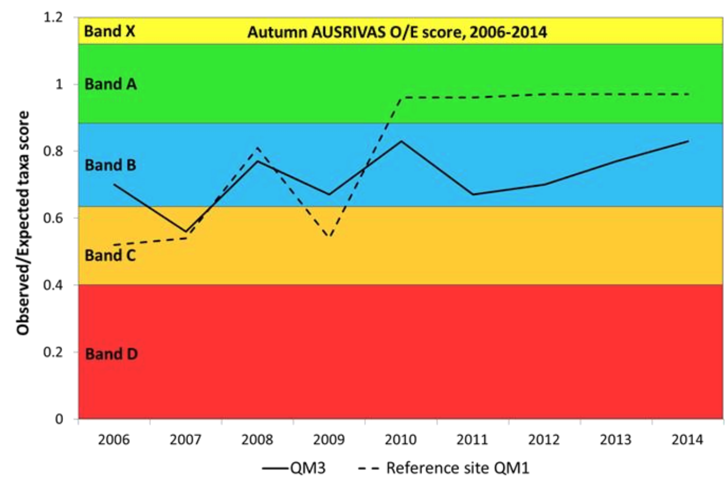
QM3 – Autumn 2014

2 km Downstream of Googong Dam

Environmental flow ecological objective	Spring 2013	Autumn 2014	Objective met?
AUSRIVAS band A	Band A	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	<10%	Yes





* Denotes values outside guideline levels

Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_3-N (mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
16.0	125.3	7.8	9.76	0.2	55	0.002	0.007	0.64*	0.01

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Appendix 2.

Macroinvertebrate taxa

collected in autumn 2014

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in autumn 2014 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**
Tricladida																
Dugesiidae	2														1	
Gastropoda																
Lymnaeidae	1	3														
Ancylidae	4		5										2			
Sphaeriidae	5															2
OLIGOCHAETA	2	3	2		21	3	1	18	7	7	7	8	1	3	3	3
ACARINA	6	54	3	2	1	2	2	3	5	7	3	6	5	12	2	6
Coleoptera																
Hydrophilidae	2								2			1				
Scirtidae	6	1			1	2	2	1	1		2	2	1			
Elmidae	7	4		1	17	3	8	42	10	3	18	9	3	63	2	3
Psephenidae	6	1	1		3	1	3	1			4	4	1	1		1
Ptilodactylidae	10							2								
Diptera																
Tipulidae	5	1					1		1		1	4	2	3	2	4
Dixidae	7											2				
Ceratopogonidae	4				1				1					2		
Simuliidae	5		52	90	32	39	49	3	24	96	12	27	31	47	154	93
Athericidae	8							9								
Empididae	5	2	4		1			5				1	1	1		
Aphroteniinae	8				2			1	2			2	2			
Podonominae	6							1	26							
Tanypodinae	4	1	4	1		1			5	1	2	1	3			
Orthocladiinae	4	36	15	17	13	16	8	2	28	1	5	5	1	19	4	16
Chironominae	3	1	42	99	10	20	4	1	38	4	4	14	6	2	1	1
Ephemeroptera																
Baetidae	5	6	19	10	65	25	35	17	19	17	100	45	49	11	73	26
Coloburiscidae	8				3		2	12					2			
Leptophlebiidae	8	29	3		24	66	29	48	8	7	36	39	45	2		1
Caenidae	4		48	18	14	1	2	16		31	3	3	5	15	9	20
Megaloptera																
Corydalidae	7			2								1	3		2	
Odonata																
Gomphidae	5		1		6							1			1	
Telephlebiidae	9						1	1				1	1			
Plecoptera																
Gripopterygidae	8	61	2		12	13	6	10	1	1	9	5	28	20		
Trichoptera																
Hydrobiosidae	8	1				1						1	2			4
Hydroptilidae	4			1	2		1			2	1	2		8		1
Philopotamidae	8					8	8	2	6	3	1	9	4			
Hydropsychidae	8	2	6	94	31	19	30	19	1	24	6	1	4	8	21	48
Ecnomidae	4		15										1	21	2	
Conoesucidae	7	4	4		1	1		3	8		4	1	13			
Helicopsychidae	8				1											
Calocidae	9											4				
Odontoceridae	7											1				
Calamoceratidae	7											1				
Leptoceridae	6					1	1	2	1		13	22	1			
No. of individuals		**210**	**226**	**335**	**261**	**222**	**193**	**219**	**194**	**204**	**231**	**223**	**217**	**238**	**277**	**229**
No. of taxa		**17**	**17**	**11**	**21**	**18**	**19**	**23**	**20**	**14**	**19**	**30**	**26**	**17**	**14**	**15**
% of sub-sample		**5**	**4**	**1**	**2**	**1**	**2**	**3**	**18**	**2**	**2**	**4**	**3**	**4**	**1**	**2**
Whole sample estimate		**4200**	**5650**	**33500**	**13050**	**22200**	**9650**	**7300**	**1078**	**10200**	**11550**	**5575**	**7233**	**5950**	**27700**	**11450**

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.*

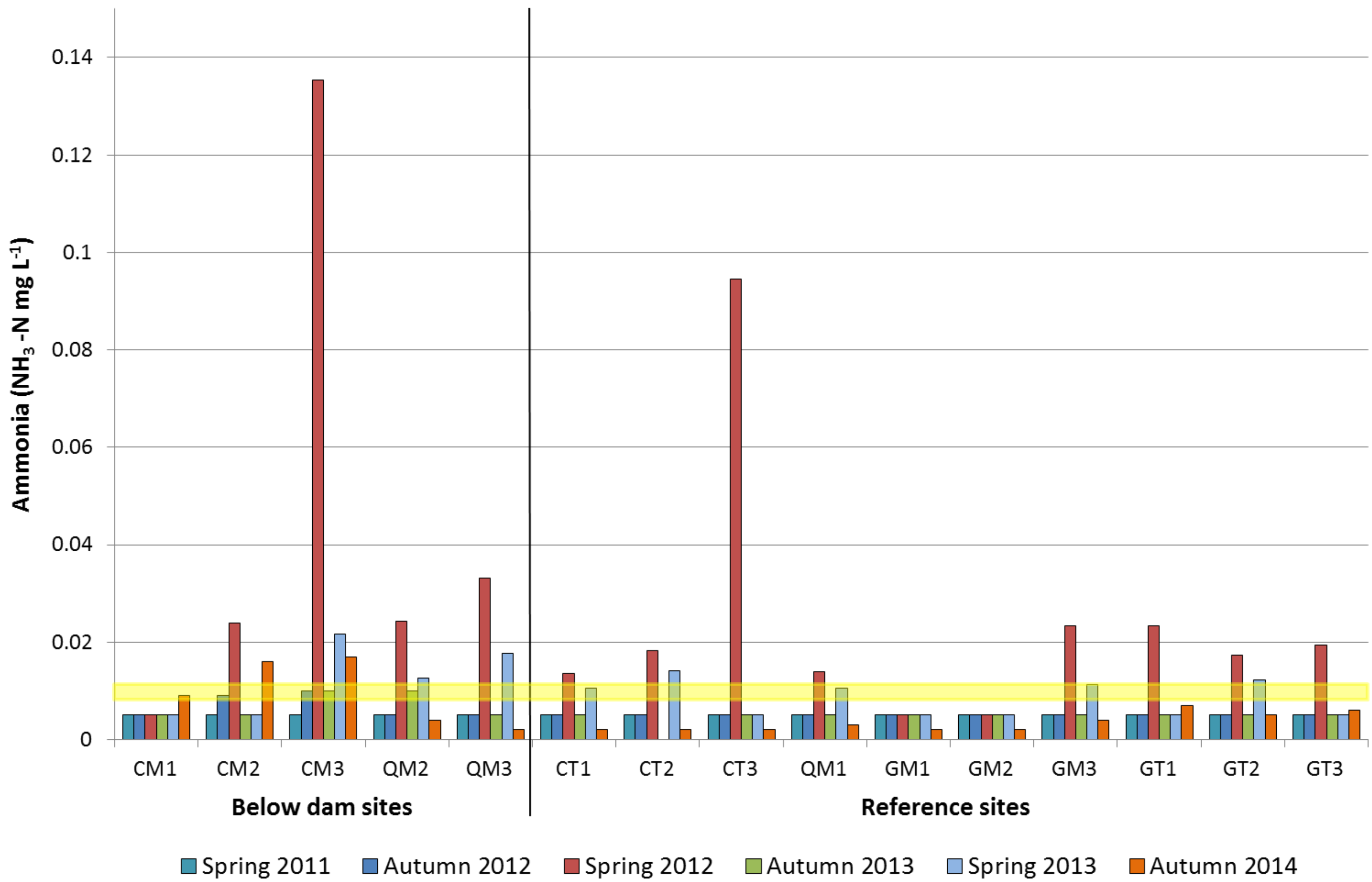
Group	Taxa	SIGNAL 2 grade	Average abundance	Consistency ratio	Contribution %	Cumulative %
Group C	Simuliidae	5	12.67	4.97	16.61	16.61
	Caenidae	4	8.84	7.4	12.18	28.79
	Baetidae	5	8.96	6.66	11.55	40.35
	Hydropsychidae	8	9.45	3.4	11.18	51.53
	Orthocladiinae	4	7.18	4.59	9.24	60.77
	Acarina	6	5.97	8.15	8.27	69.03
Group A	**Less than two samples in group**					
Group B	Baetidae	5	7.62	7.61	9.53	9.53
	Leptophlebiidae	8	7.32	7.13	9.14	18.66
	Simuliidae	5	6.72	4.24	8.05	26.71
	Elmidae	7	5.49	4.66	6.67	33.38
	Gripopterygidae	8	5.17	4.15	6.32	39.7
	Chironominae	3	5.24	4.18	6.05	45.75
	Hydropsychidae	8	5.37	2.57	5.81	51.56
	Orthocladiinae	4	5.06	3.2	5.68	57.24
	Oligochaeta	2	4.7	3.93	5.59	62.83
	Acarina	6	3.99	7.81	5.2	68.04

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.*

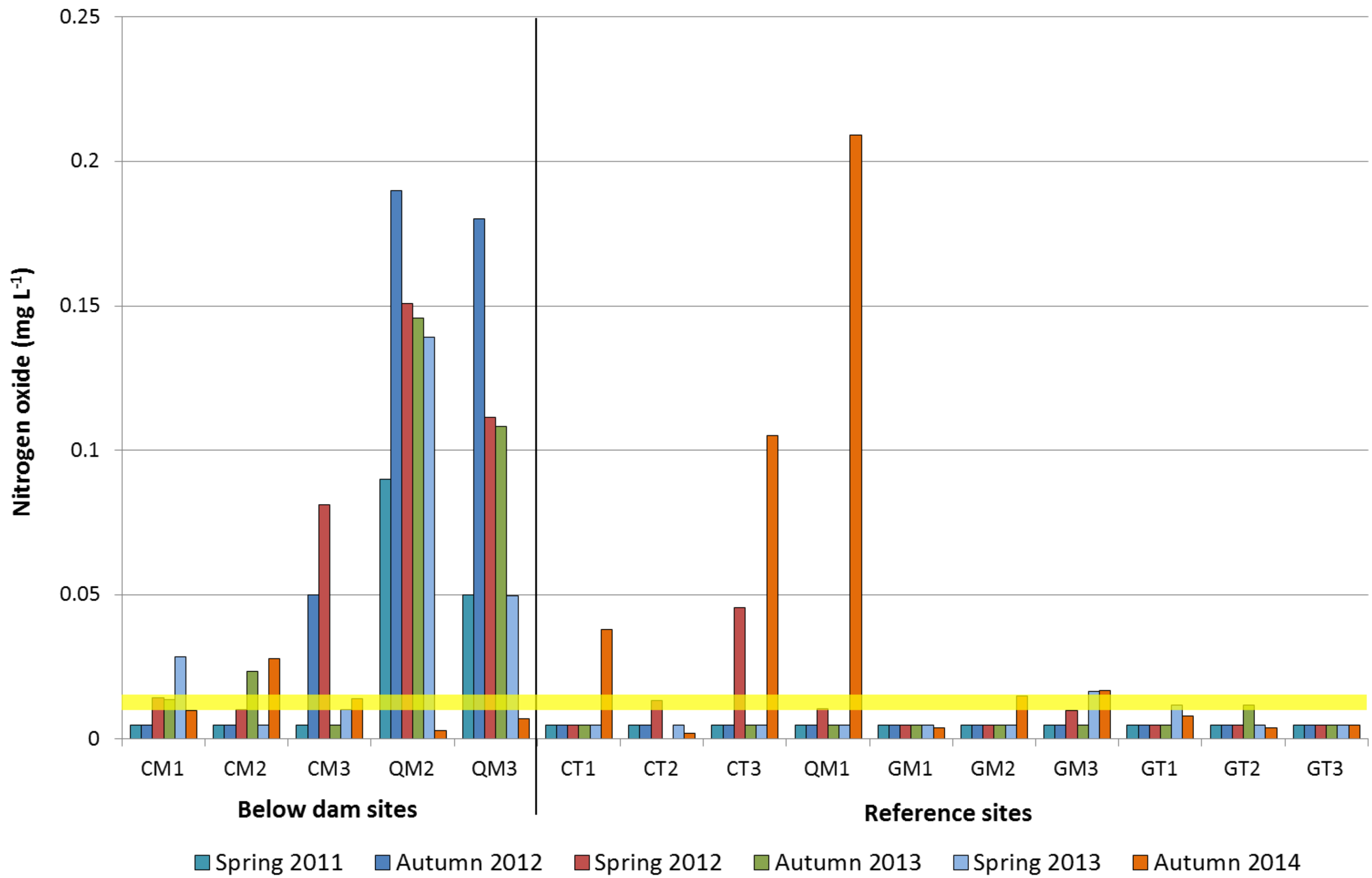
Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group A	***Group C***	
Corydalidae	7	0	1.86	0.64
Chironominae	3	3.89	7.22	0.76
Ecnomidae	4	0	3.29	0.9
Psephenidae	6	3.89	1.85	1.08
Baetidae	5	6.09	8.96	1.2
Hydroptilidae	4	0	3.33	1.26
Hydropsychidae	8	4.63	9.45	1.36
		Group A	***Group B***	
Podonominae	6	0	1.27	0.48
Psephenidae	6	3.89	3.19	0.89
Coloburiscidae	8	0	2.07	0.9
Telephlebiidae	9	0	1.42	0.92
Hydroptilidae	4	0	1.64	0.93
Tipulidae	5	3.89	2.07	1.06
Tanypodinae	4	3.89	2.27	1.07
Baetidae	5	6.09	7.62	1.11
Chironominae	3	3.89	5.24	1.13
Conoesucidae	7	5.51	3.48	1.15
Aphroteniinae	8	0	2.02	1.19
Oligochaeta	2	5.12	4.7	1.31
		Group C	***Group A***	
Podonominae	6	0	1.27	0.51
Hydrobiosidae	8	0.97	1.14	0.86
Gomphidae	5	1.35	0.87	0.87
Corydalidae	7	1.86	0.74	0.89
Chironominae	3	7.22	5.24	0.95
Coloburiscidae	8	0	2.07	0.96
Telephlebiidae	9	0	1.42	0.97
Ecnomidae	4	3.29	0.34	1.04
Empididae	5	1.41	1.53	1.12
Elmidae	7	5.19	5.49	1.15
Baetidae	5	8.96	7.62	1.18
Oligochaeta	2	4.54	4.7	1.19
Aphroteniinae	8	0	2.02	1.25
Tanypodinae	4	2.37	2.27	1.27

Appendix 3.

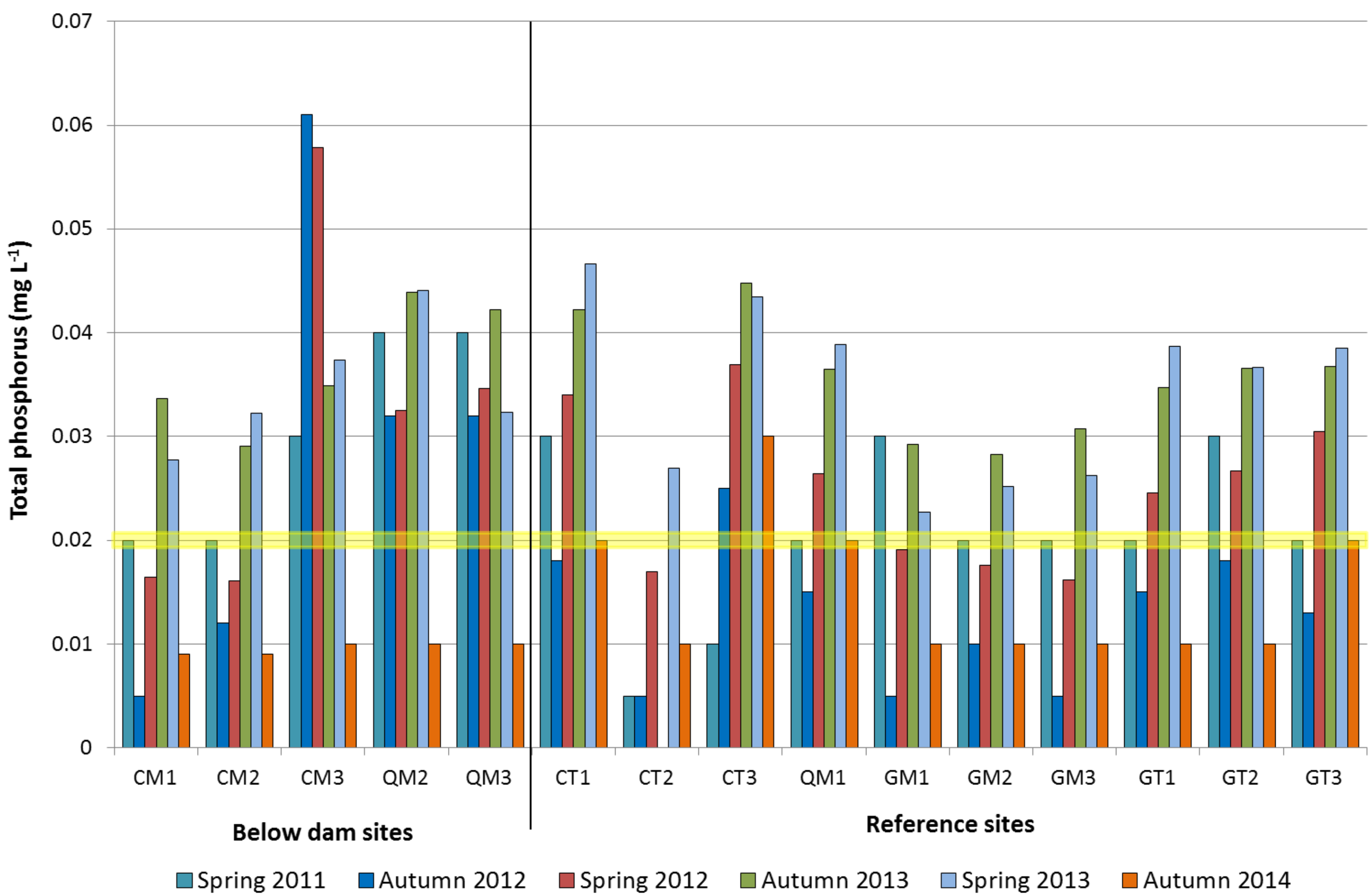
Water quality figures



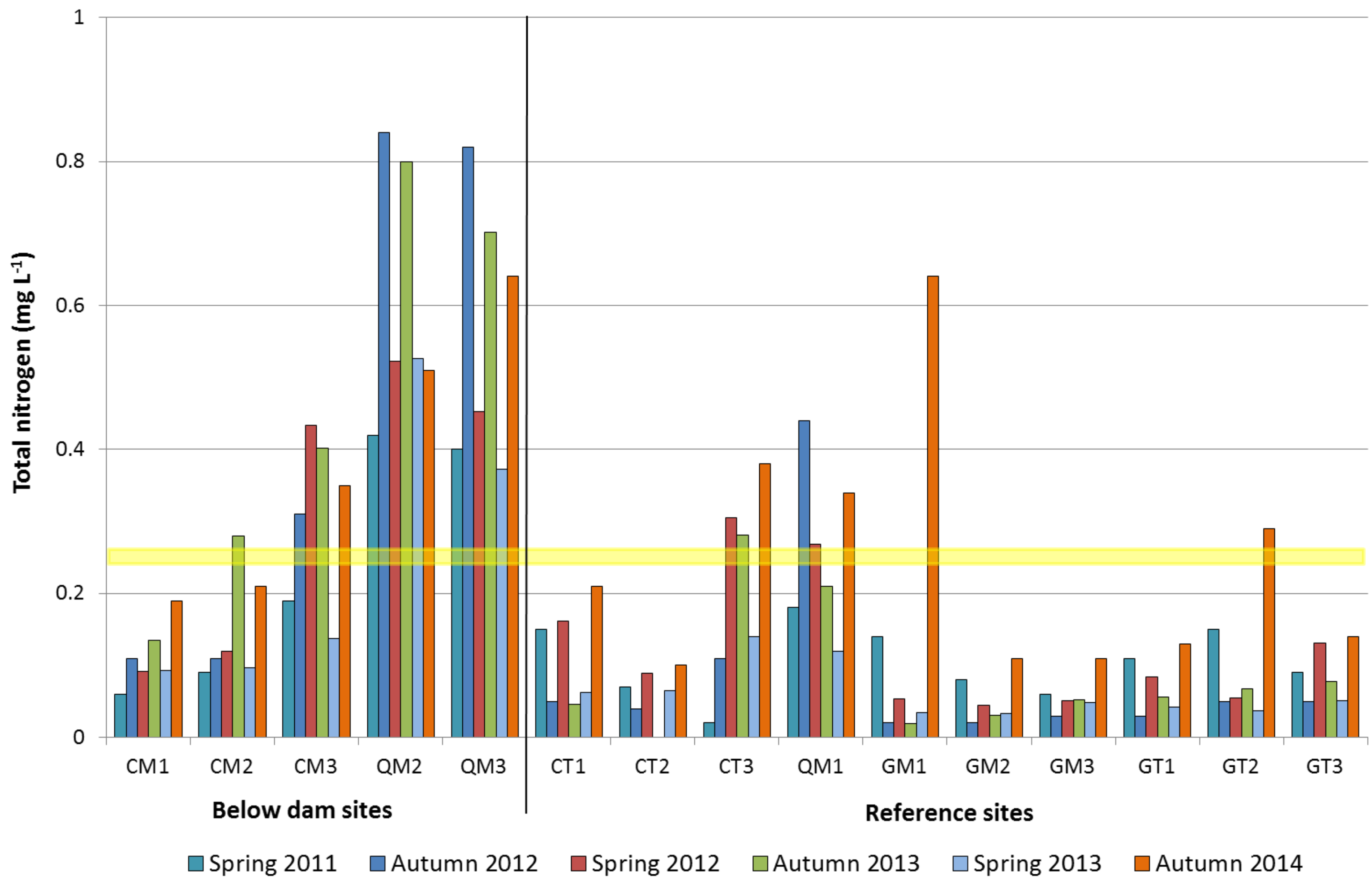
Ammonium (NH_4^+) concentration at all sites from spring 2011 to autumn 2014. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



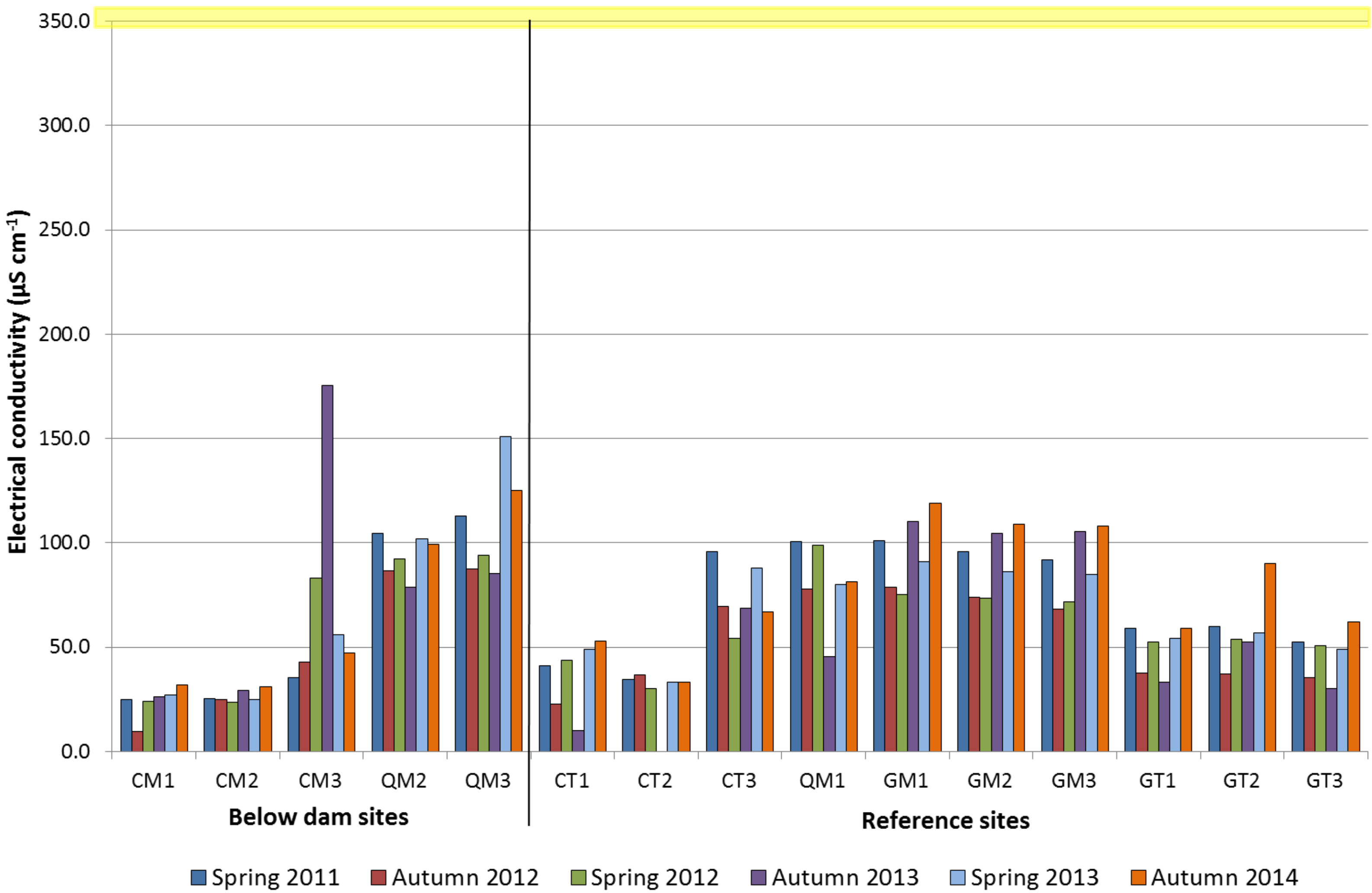
Nitrogen oxide concentrations at all sites from spring 2011 to autumn 2014. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



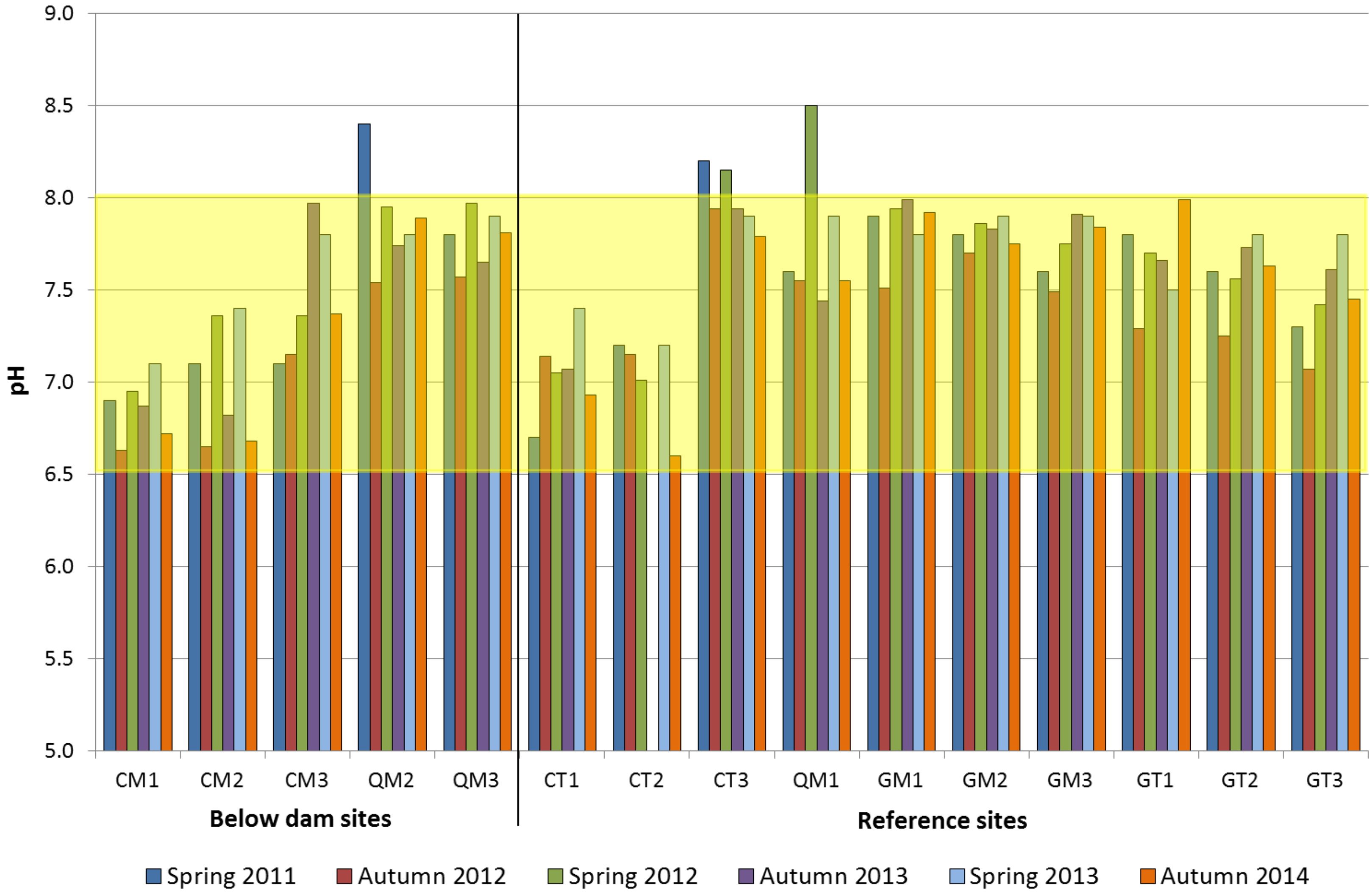
Total phosphorus concentrations at all sites from spring 2011 to autumn 2014. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



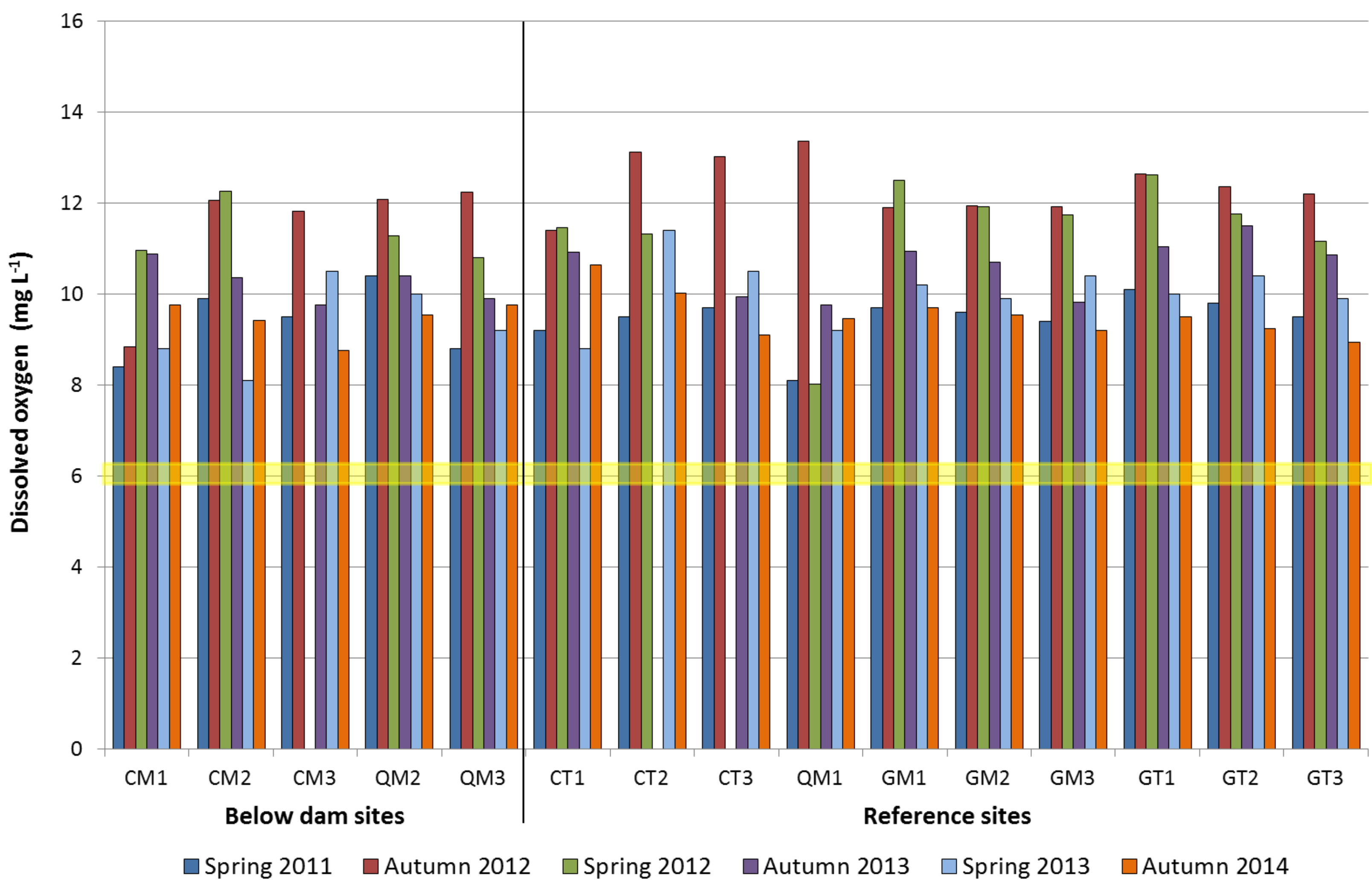
Total nitrogen concentrations at all sites from spring 2011 to autumn 2014. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



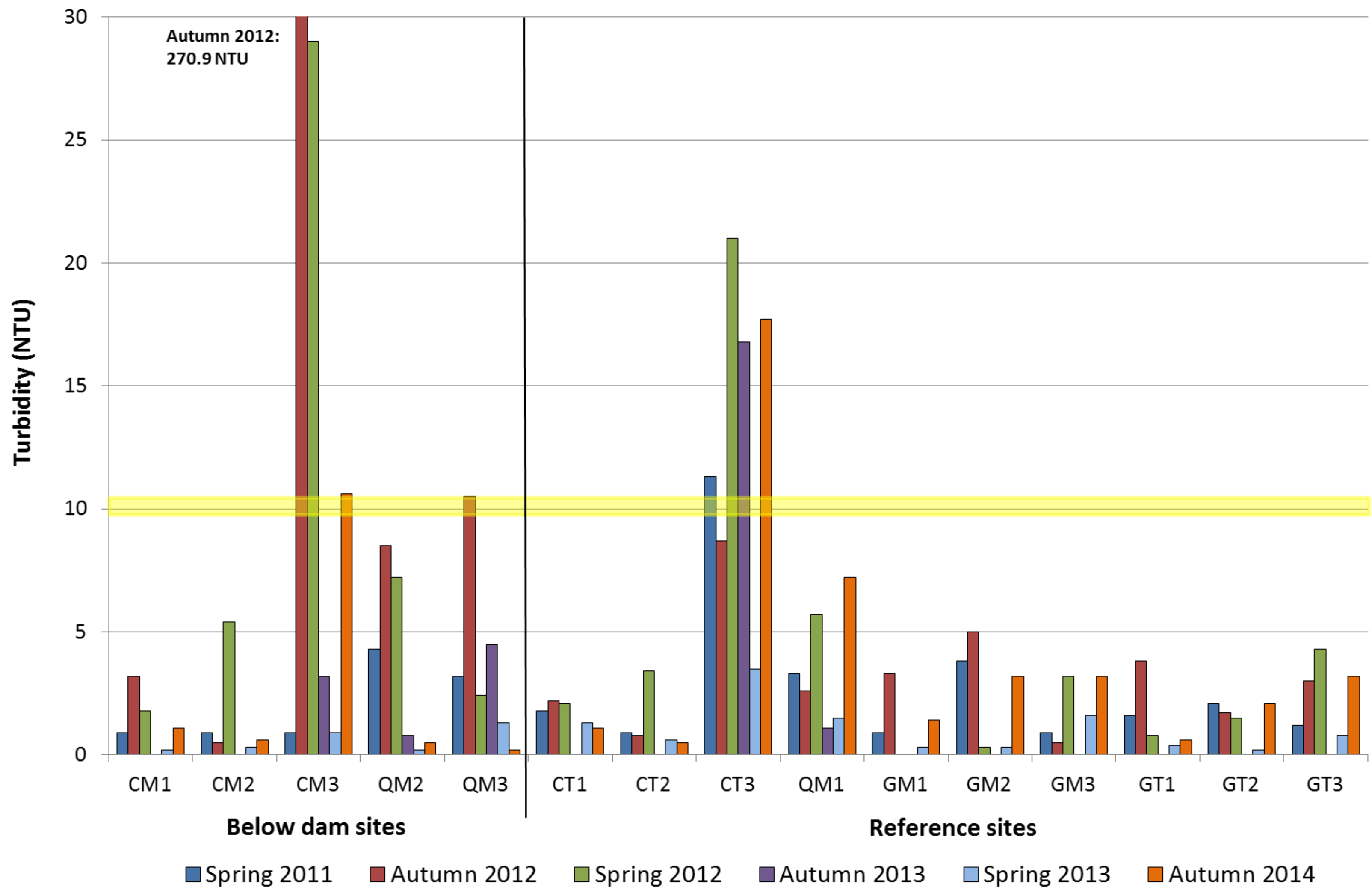
Electrical conductivity at all sites from spring 2011 to autumn 2014. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from spring 2011 to autumn 2014. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from spring 2011 to autumn 2014. The minimum guideline for electrical conductivity is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from spring 2011 to autumn 2014. The guideline for turbidity is shaded yellow (Environment Protection Regulation SL2005-38).