UNIVERSITY OF CANBERRA

INSTITUTE FOR APPLIED ECOLOGY

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

Spring 2015

Report to Icon Water

APPLIEDECOLOGY.EDU.AU

Prepared for: Icon Water

Produced by:

Institute for Applied Ecology

appliedecology.edu.au

University of Canberra, ACT 2601

Telephone: (02) 6201 2795

Facsimile: (02) 6201 5651

Authors:

Dr Evan Harrison and Ben Broadhurst

Inquiries regarding this document should be addressed to:

Dr Evan Harrison

Institute for Applied Ecology

University of Canberra

Canberra 2601

Telephone: (02) 6201 2080

Facsimile: (02) 6201 5651

Email: Evan.Harrison@canberra.edu.au

Document history and status				
Version	**Date Issued**	**Reviewed by**	**Approved by**	**Revision Type**
Draft	26/11/15	B. Broadhurst	E.Harrison	Internal
Draft	2/12/15	J.Hyam (Icon Water)	E.Harrison	External
Final	14/12/15	J.Hyam (Icon Water)	E.Harrison	External

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

BACKGROUND AND STUDY OBJECTIVE

- The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (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 Icon Water's License to Take Water (WU67) to assess the effects of dam operation, water abstraction, and environmental flows, and to provide information for the adaptive management of the Cotter and Googong water supply catchments. This study specifically focuses on assessing the ecological status of river habitats by investigating water quality and biotic characteristics.

SPRING 2015 RESULTS AND CONCLUSIONS

- Water quality parameters were generally within the recommended water quality guideline levels at below dam test sites and reference sites. Exceptions were pH at below Corin and Bendora Dams which were both slightly lower than the guideline range; turbidity at reference site CT3; ammonia at all below dam sites and reference sites CT2 and GT1; nitrogen oxide below Corin and Cotter dams; and total nitrogen at the Goodradigbee tributary sites. Above guideline ammonia and nitrogen oxide concentrations at below dam sites are likely to be the result of wider catchment influences and not dam operation. Click here for more information
- All test and reference sites met the environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats. Site CM1 below Corin Dam was on the cusp of not meeting the filamentous algae cover objective. Click here for more information
- Sites CM2 downstream of Bendora Dam and QM3 downstream of Googong Dam were the only sites which met the environmental flow ecological objective of AUSRIVAS band A; however, all sites had relatively high proportions of environmentally sensitive taxa. Click here for more information
- Sites QM2 and QM3 in the Queanbeyan River downstream of Googong Dam improved in condition from autumn 2015. This outcome reflects improvements in condition as a result of increased river flows from Googong Dam spilling. Click here for more information

Site	Within environmental flow ecological objective Riffle filamentous algae cover (%)	Outside environmental flow ecological objective AUSRIVAS band (O/E score)
CM1 (Corin Dam)	20	B
CM2 (Bendora Dam)	< 10	A
CM3 (Cotter Dam)	15	B
QM2 (Googong Dam)	10	B
QM3 (Googong Dam)	< 10	A

PROJECT RECOMMENDATIONS

- Future reports will need to account for the effects of the higher flow releases/spills from Cotter and Googong Dams when assessing biological condition in autumn 2016. It is likely that these flows may result in improved conditions and macroinvertebrate communities downstream of Cotter and Googong Dams.
- Future assessments should include the collection of periphyton samples upstream of Googong Dam at reference site QM1 to allow for a comparison with samples collected at site QM2 directly downstream of Googong Dam.

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 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 these rivers is being caused by catchment or river regulation effects. For example, if Cotter River tributaries are assessed in poorer biological condition than reference tributaries on the Goodradigbee River, then catchment condition may be driving instream biological condition at Cotter river test sites regardless of river regulation effects. However, if Cotter and Goodradigbee River tributaries are in similar biological condition, then differences biological condition between Goodradigbee and Cotter River sites may be attributed to river regulation effects.

This sampling and reporting program satisfies Icon Water's Licence to Take Water (WU67) and the requirement to provide an assessment of the effects of dam operation and the effectiveness of environmental flows. The information from the assessment 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 2015, 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 2015 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^{-1}) 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 on the 23/9/15 (Cotter sites CM2 and CT2), 24/9/15(Goodraidgbee sites), 25/9/15 (Cotter sites CM1 and CT1), 8/10/15 (Cotter sites CM3 and CT3) and 14/10/15 (Queanbeyan River sites) (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.

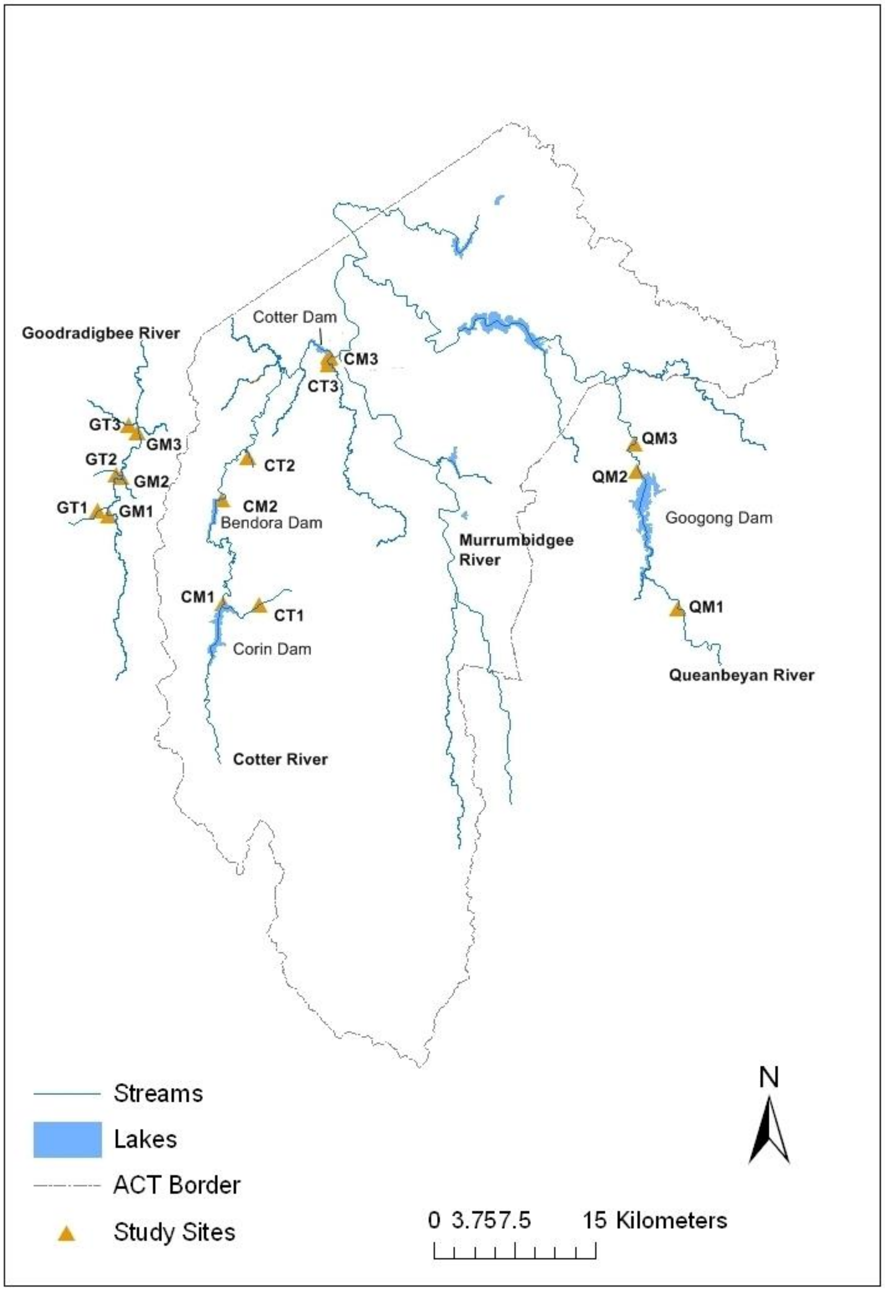


Figure 1. The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program.

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the below dams assessment program, spring 2015.

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

HYDROMETRIC DATA

Mean daily flow data for each of the below dam test sites (provided by Icon 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 concentrations below the minimum guideline level are unlikely to impact on the ecological condition of streams.

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

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

PERIPHYTON AND FILAMENTOUS ALGAE

VISUAL OBSERVATIONS

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

ASH-FREE DRY MASS AND CHLOROPHYLL-A

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

MACROINVERTEBRATE SAMPLE COLLECTION AND PROCESSING

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

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

AUSRIVAS (AUSTRALIAN RIVER ASSESSMENT SYSTEM)

AUSRIVAS predicts the macroinvertebrate fauna expected to occur at a site with specific environmental characteristics, in the absence of environmental stress. The fauna observed (O) at a site can then be compared to fauna expected (E), with the deviation between the two providing an indication of biological condition (Coysh *et al*. 2000; http://ausrivas.ewater.org.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.org.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.org.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 2015, 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 In PRIMER 6 (Clark and Warwick 2001). 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.

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 2015 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). There were changes to flow regimes below Bendora and Cotter Dams to manage river levels for Macquarie Perch spawning requirements, with higher than normal discharges below both dams.

Total discharge below Corin Dam and on the Goodradigbee River between June 2015 and the spring 2015 sampling was generally similar to that preceding the spring 2014 assessment (Figure 2; Levings & Harrison 2014). However, there was a reduced total discharge below Bendora Dam and increased discharges below Cotter and Googong Dams. This is primarily because of changes in flows for Macquarie Perch spawning requirements (below Bendora and Cotter Dams) and dam spillages (Googong Dam). The greatest daily mean discharge (1629 ML d^{-1}) also occurred downstream of Googong Dam on the 3rd August 2015, 2 months before sampling when the dam spilled.

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

Dam	Flow regime
Corin	Base Flows: 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. Pool Maintenance Flow: Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Bendora	Base Flows; 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. Pool Maintenance Flow: Maintain a flow of >550 ML d^{-1} for 2 consecutive days between mid-July and mid-October.
Cotter	Base Flows: Maintain an average flow of 15 ML /day Riffle Maintenance Flow: Maintain a flow of 100 ML d^{-1} for 1 day every 2 months. Pool Maintenance Flow: Not required
Googong	Base Flows: Maintain base flow average of 10 ML d-1 or natural inflow, whichever is less. Riffle Maintenance Flow: Maintain a flow of 100 ML d^{-1} for 1 day every 2 months. Pool Maintenance Flow: Not required

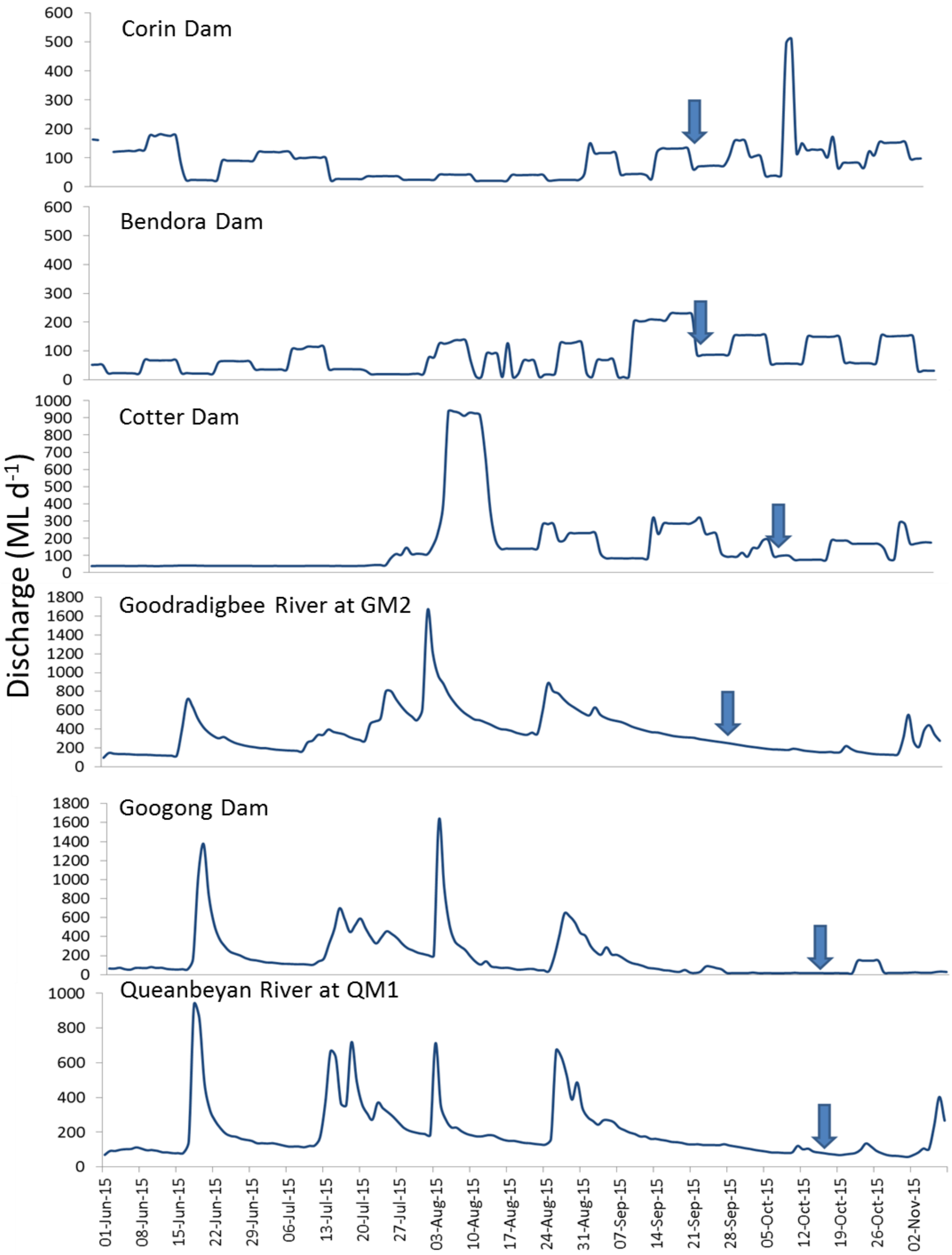


Figure 2. Mean daily discharge below Corin (CM1, station 410752), Bendora (CM2, station 410747), and Cotter (CM3, station 410700) Dams and in the Goodradigbee River (station 410088) and Googong Dam (QM3, station 410760) and the Queanbeyan River upstream of Googong Reservoir (QM1, station 410781) from 1st July 2015 to 11th November 2015. Arrows correspond to spring 2015 sampling dates.

WATER QUALITY

Water quality parameters were generally within guideline levels at test and reference sites in spring 2015. Exceptions were pH at sites CM1 and CM2; turbidity at CT3; ammonia at all below dam sites and reference sites CT2 and GT1; nitrogen oxides at test sites CM1 and CM3 and reference sites GT2 and GT3; and total nitrogen at reference sites GT1, GT2 and GT3 (Table 5). pH, turbidity and electrical conductivity measurements where not collected at the Goodradigbee catchment sites because of a probe malfunction. It is likely these variables would be within guideline limits given the minimal disturbance within the catchment.

Table 5. Water quality parameters measured at each of the test and reference sites in spring 2015. Values outside guideline levels are shaded orange. * indicates probe malfunction.

		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	NA	350	6.5-8	>6	<10	NA	<0.013	<0.015	<0.25	<0.02
Below dam test sites	CM1	9.5	23	5.9	10.6	2	12	0.018	0.019	0.12	0.008
	CM2	8.1	18	6	12	1.6	9	0.017	0.007	0.09	0.006
	CM3	10.3	40	7.2	11.6	6.7	20	0.014	0.016	0.13	0.014
	QM2	16.4	60	7.7	10.8	0	30	0.018	<0.002	0.06	0.012
	QM3	19.7	110	7.8	9.4	3.2	34	0.014	<0.002	0.08	0.004
Reference sites	CT1	6.9	39	6.7	10.9	0	20	0.01	<0.002	0.22	0.015
	CT2	10.9	25	6.9	10.5	0.1	9	0.015	0.002	<0.05	0.006
	CT3	14.8	84	7.1	10	11.5	40	0.004	0.005	0.05	0.006
	QM1	18.1	65	7.9	8.9	0	31	<0.002	0.005	0.1	0.006
	GM1	6.8	*	*	11.8	*	35	0.004	<0.002	0.06	0.009
	GM2	8.4	*	*	11.6	*	35	0.01	<0.002	<0.05	0.009
	GM3	9.3	*	*	11.8	*	32	0.008	<0.002	<0.05	0.01
	GT1	6.3	*	*	11.8	*	27	0.015	0.003	0.48	0.014
	GT2	7.4	*	*	11.5	*	25	0.007	0.06	0.71	0.014
	GT3	7.6	*	*	11.4	*	20	0.01	0.025	0.48	0.016

FILAMENTOUS ALGAE AND PERIPHYTON

The environmental flow ecological objective of <20% cover of filamentous algae in riffle habitats was achieved at all below dams test sites in spring 2015. Filamentous algae cover at site CM1 below Corin Dam was 20% (on the cusp of exceeding the objective). Field observations of periphyton cover of riffle habitats below dams in spring 2015 ranged between <10% below Bendora and Googong Dams to 25% cover periphyton below Cotter Dam. Periphyton and filamentous algae cover at reference sites was 10% and lower except for GM3 where cover was 40% for both periphyton and filamentous algae (Table 6; Figure 3).

Mean ash free dry mass (AFDM) was significantly greater at Goodradigbee reference site GM3 than reference site GM1 and below Bendora Dam (CM2). AFDM was also significantly greater below Googong Dam (QM2) than at the site below Bendora Dam (QM2)($F=5.32$; 6,35; $P<0.0005$). Differences in AFDM between all other sites were not statistically significant because of within site variability (Figure 4).

Mean chlorophyll-a concentrations were also significantly greater below Cotter Dam (CM3), Corin Dam (CM1), Googong Dam and at reference site GM3 than below Bendora Dam (CM2), and reference sites GM1 and GM2 ($F=17.11$; 6,35; $P<0.0001$). Differences in chlorophyll-a concentration between all other sites were not statistically significant, because of within site variability (Figure 5).

Table 6: Periphyton and filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from autumn 2013 to spring 2015. Filamentous algae observations greater than the environmental flow ecological objective of <20% cover are shaded orange.

% cover of riffle habitat												
	Periphyton						Filamentous algae					
	Aut-13	Spr-13	Aut-14	Spr-14	Aut-15	Spr-15	Aut-13	Spr-13	Aut-14	Spr-14	Aut-15	Spr-15
CM1	25	10	<10	10	20	20	<10	80	<10	25	10	20
CM2	75	20	<10	<10	<10	<10	<10	20	<10	10	<10	<10
CM3	<10	50	<10	75	20	25	<10	<10	<10	10	<10	15
QM2	<10	20	10	10	<10	10	<10	<10	<10	10	<10	10
QM3	<10	20	10	10	<10	<10	<10	<10	<10	10	<10	<10
GM1	15	<10	<10	<10	<10	<10	15	<10	<10	<10	0	<10
GM2	<10	<10	<10	<10	<10	10	<10	<10	<10	<10	<10	10
GM3	<10	10	<10	<10	10	40	<10	15	<10	<10	10	40
QM1	10	<10	<10	10	10	<10	<10	<10	<10	10	10	<10

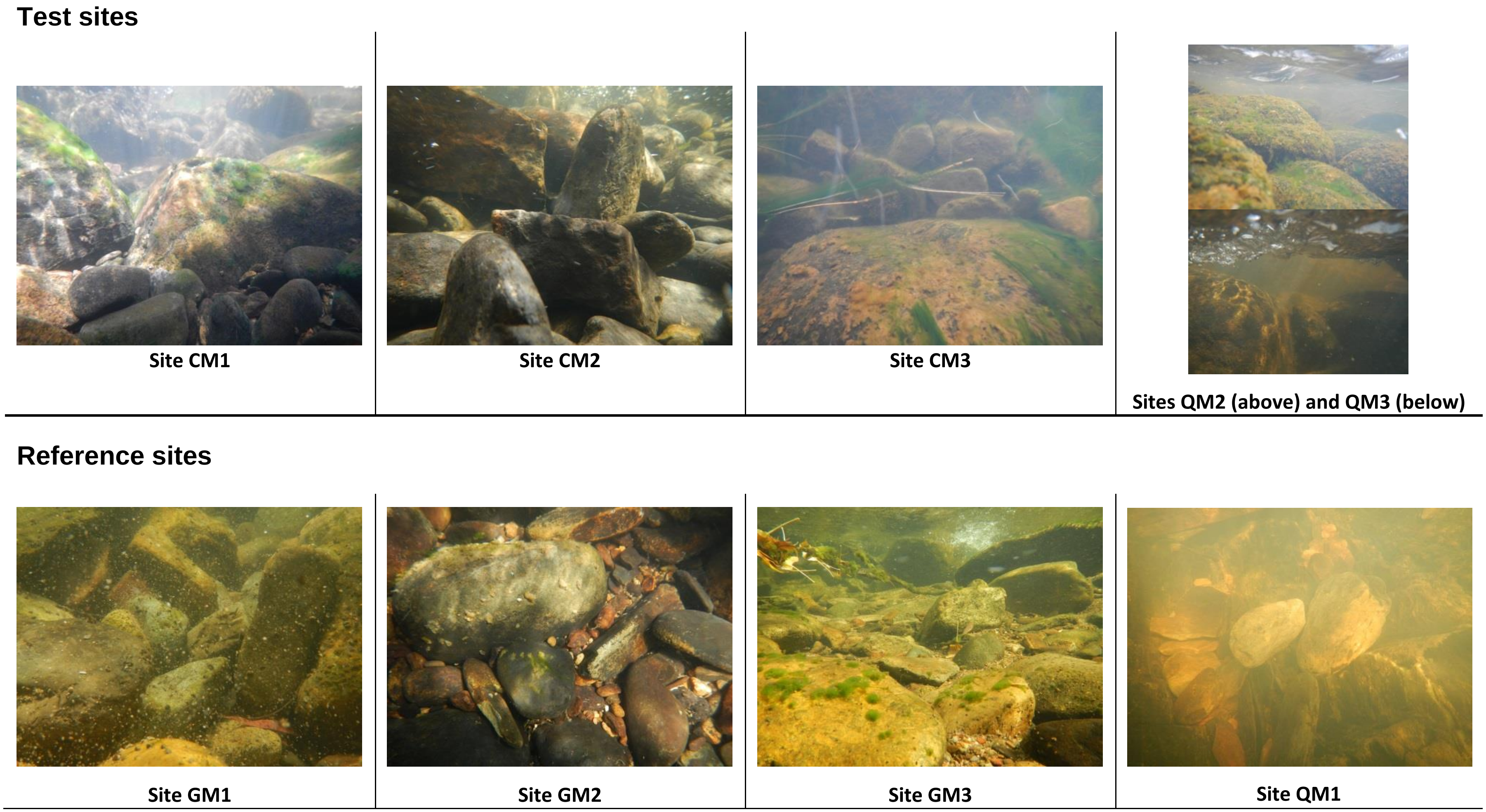


Figure 3. Filamentous algae cover of riffle bed sediments at below dam test sites and corresponding reference sites on the Goodradigbee and Queanbeyan Rivers in spring 2015.

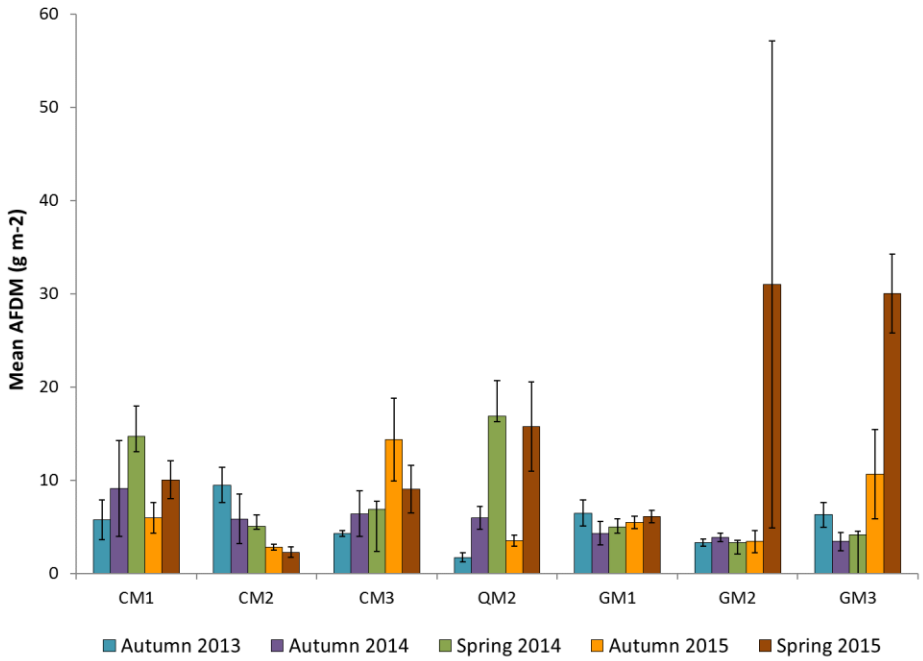


Figure 4: Mean AFDM (g m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2013 to spring 2015. Error bars represent +/- 1 standard error.

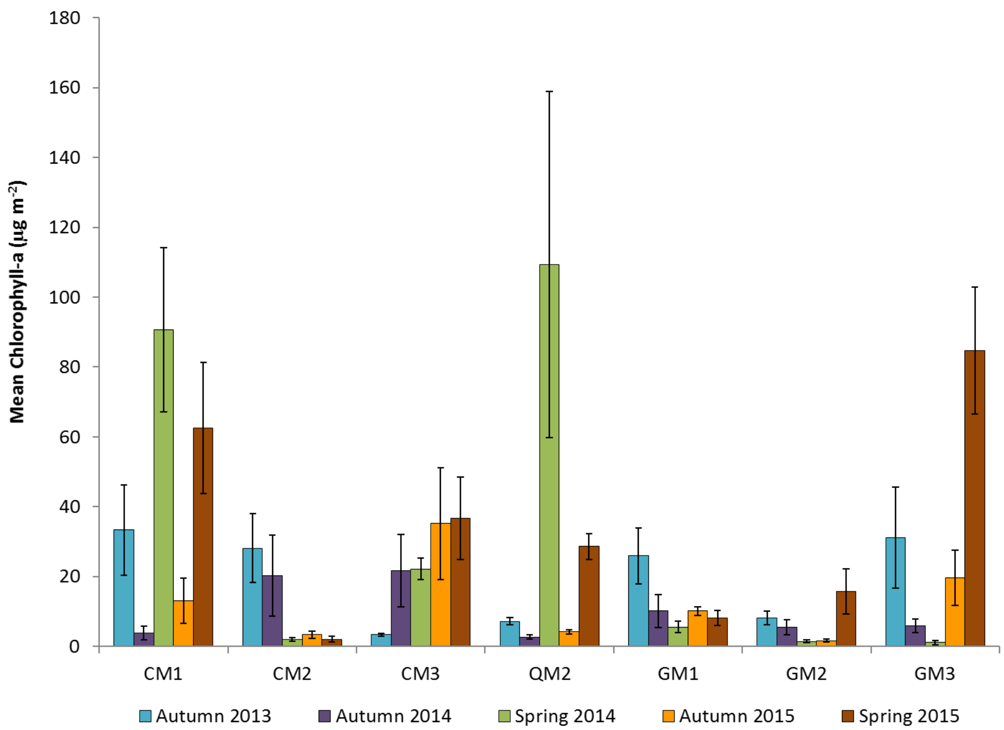


Figure 5: Mean chlorophyll-a (µg m^{-2}) at below dam test sites and reference sites on the Goodradigbee River from autumn 2013 to spring 2015. Error bars represent +/- 1 standard error.

BENTHIC MACROINVERTEBRATES

AUSRIVAS ASSESSMENT

Below dam test sites were assessed as both similar to reference condition (band A) and significantly impaired (band B) in spring 2015 (Table 7).

Cotter River test sites CM1 and CM3 were assessed as significantly impaired (band B), and test site CM2 was similar to reference condition (band A) in spring 2015. This is the same outcome for these sites as the previous assessment in autumn 2014, and is consistent with previous outcomes from both spring and autumn assessments (Table 7).

All of the Goodradigbee River reference sites were assessed as either similar to reference condition (band A) or more biological diverse than reference (band X) (Table 7). Two of the three Cotter River tributary sites (CT1 and CT3) were assessed as similar to reference condition (band A), and CT2 was assessed as more biological diverse than reference (band X). Goodradigbee River tributary site GT1 was assessed as more diverse than reference (band X), and sites GT2 and GT3 were assessed as similar to reference condition (Table 7).

Queanbeyan River test sites QM2 and QM3 downstream of Googong Dam both improved in condition from the previous assessment in autumn 2015. Site QM2 increased from band C (severely impaired) to band B (significantly impaired) and QM3 increased from band C (severely impaired) to band A (similar to reference condition) in spring 2015. The upstream reference site QM1 was assessed as band A (similar to reference condition) (Table 7). This Queanbeyan River reference site has not been assessed as biologically impaired since autumn 2009 (White et al 2009).

Taxa expected with a ≥50% chance of occurrence by the AUSRIVAS model, but missing from sub-samples are presented in Table 8. Missing taxa ranged in SIGNAL 2 grade from 2 (Oligochaeta) to 9 (Glossosomatidae). Cotter River and tributary sites CM1, CM2, and CT3; Queanbeyan River site QM1, had taxa identified in whole of sample scans that were missing from respective sub-samples. This indicates these taxa (Tipulidae – site CM2; Tanypodinae – sites CM1 and QM1; Hydropsychidae – sites CT3 and QM1; and Conoesucidae – site CM1) were present, but in low abundance (Table 8).

Table 7: AUSRIVAS band and Observed/Expected taxa score for each site from autumn 2013 to spring 2015.

	Below dams sites					Reference sites									
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Spring 2015	B (0.69)	A (0.89)	B (0.66)	B (0.80)	A (1.07)	A (0.96)	X (1.15)	A (0.96)	A (1.1)	X (1.27)	A (1.04)	X (1.19)	X (0.91)	A (0.98)	A (1.21)
Autumn 2015	B (0.85)	A (0.94)	B (0.67)	C (0.49)	C (0.63)	A (0.93)	B (0.77)	B (0.70)	A (0.97)	B (0.81)	A (1.05)	A (1.12)	X (1.16)	A (1.05)	A (1.05)
Spring 2014	B (0.77)	A (0.97)	B (0.66)	A (0.88)	B (0.84)	A (1.03)	A (1.07)	A (0.96)	A (0.92)	A (1.12)	A (1.11)	A (1.12)	A (1.13)	A (0.98)	A (1.05)
Autumn 2014	A (0.91)	B (0.86)	B (0.66)	B (0.70)	B (0.83)	A (0.96)	A (0.90)	B (0.84)	A (0.97)	A (0.88)	A (1.04)	A (0.97)	X (1.19)	A (1.12)	A (1.05)
Spring 2013	B (0.69)	A (0.89)	A (0.88)	A (0.88)	A (0.92)	X (1.16)	A (1.00)	B (0.74)	A (1.10)	X (1.19)	A (1.11)	X (1.19)	A (1.13)	A (0.98)	A (1.13)
Autumn 2013	C (0.59)	A (1.12)	C (0.60)	B (0.77)	B (0.77)	A (1.08)	Not sampled	B (0.70)	A (0.97)	A (0.89)	A (0.89)	B (0.81)	A (1.01)	B (0.86)	A (1.05)

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 2015 and their SIGNAL 2 grade (Chessman 2003). Orange shading indicates missing taxa that were identified in the whole of sample scan.

	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Oligochaeta	2													X	X	
Acarina	6				X											
Elmidae	7		X	X	X											
Psephenidae	6	X		X	X	X		X	X							
Tipulidae	5		X				X					X				
Simuliidae	5	X														
Tanypodinae	4	X		X			X			X		X	X			
Chironominae	3	X														
Baetidae	5	X	X	X			X									
Leptophlebiidae	8			X												
Caenidae	4	X		X				X								
Gripopterygidae	8								X							
Notonemouridae	6						X									
Hydrobiosidae	8	X	X		X									X		X
Glossosomatidae	9		X	X	X	X								X	X	
Hydropsychidae	6				X				X	X		X		X	X	
Conoesucidae	7	X		X	X	X			X					X	X	
Leptoceridae	6						X									
Total		**6**	**5**	**8**	**11**	**9**	**4**	**7**	**8**	**4**	**7**	**3**	**2**	**2**	**3**	**3**

TAXONOMIC RELATIVE ABUNDANCE

The ratio of environmentally tolerant Oligochaeta and Chironomidae (OC) taxa to more sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was variable across all sites (Figure 6). Tolerant OC taxa were more prevalent than EPT taxa at below dam test sites CM3 (Cotter Dam), QM2 and QM3 (Googong Dam) compared to sites CM1 (Corin Dam) and CM2 (Bendora Dam) where EPT taxa were dominant (primarily the Plecoptera family Gripopterygidae)(Figure 6 and Appendix 2). At reference sites EPT taxa were generally dominant over OC taxa, with the exceptions being sites CT2 and QM1 where there was dominance by OC taxa. Filter feeding Simuliidae (Diptera (other) category) and disturbance tolerant Chironomidae taxa were the dominant taxa in subsamples from Cotter River test site CM3 and Queanbeyan River test sites QM2 and QM3 (Figure 7 and Appendix 2).

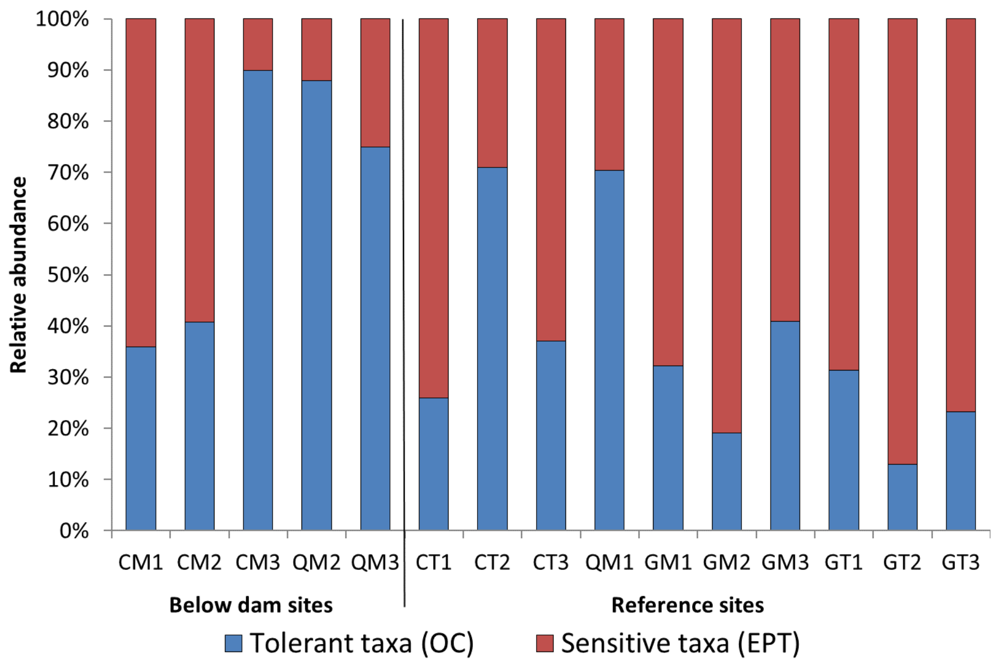


Figure 6. Relative abundance of environmentally tolerant (OC) taxa compared with environmentally sensitive (EPT) taxa from samples collected in spring 2015.

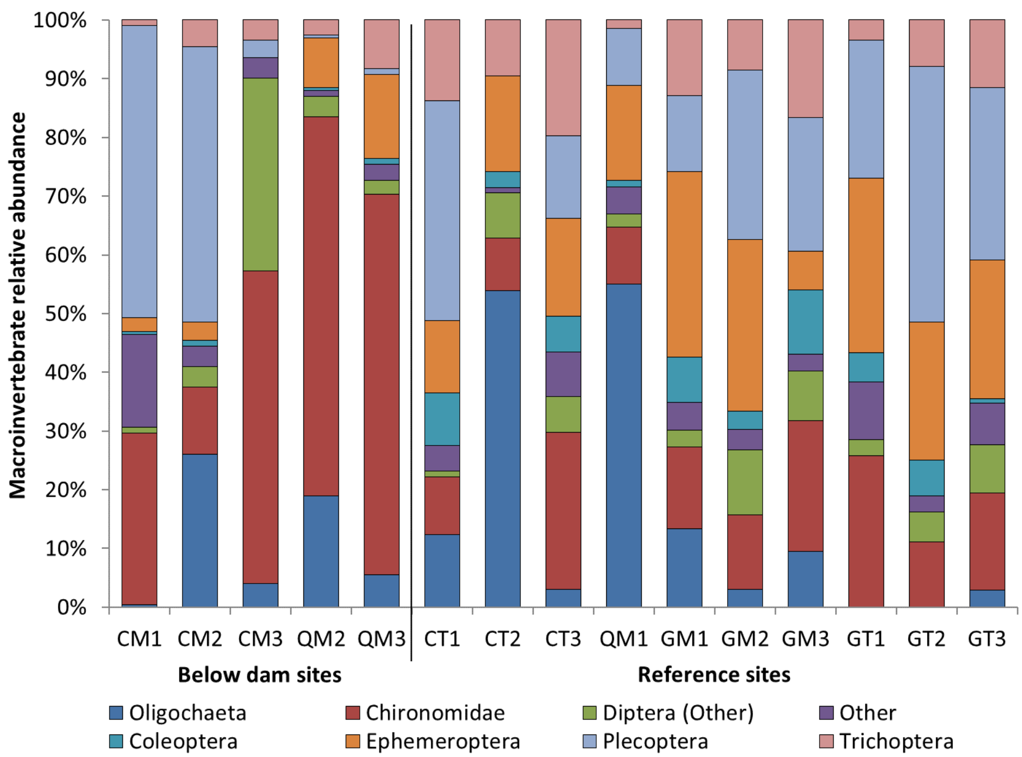


Figure 7: Relative abundance of macroinvertebrate taxonomic groups from samples collected in spring 2015.

MACROINVERTEBRATE ASSEMBLAGE SIMILARITY

Cluster analysis based on the relative abundance of macroinvertebrate taxa identified two groups of sites at 60% similarity (Figure 8). Cotter River test sites CM1 (Corin Dam) and CM3 (Cotter Dam) had macroinvertebrate assemblages dissimilar to all other sites. The macroinvertebrate assemblage at test site CM2 below Bendora Dam grouped with each of the Goodradigbee River reference sites and Cotter River tributary site CT1 and CT2 (Figure 8).

Queanbeyan River test sites QM2 and QM3, grouped with the upstream Queanbeyan River reference site QM1 and Cotter River tributary site CT3. These siteshad macroinvertebrate assemblages that were dissimilar to all other sites. This was primarily because of the higher relative abundance of Simuliidae, Chironominae, Tanypodinae and Orthocladinae taxa at these sites compared to other Goodradigbee and Cotter (except CM3) sites (which had greater relative abundances of taxa including Gripopterygidae, Coloburiscidae, and Elmidae (taxa shown in Figure 8 below with Pearson correlation greater than 0.5; Appendix 2).

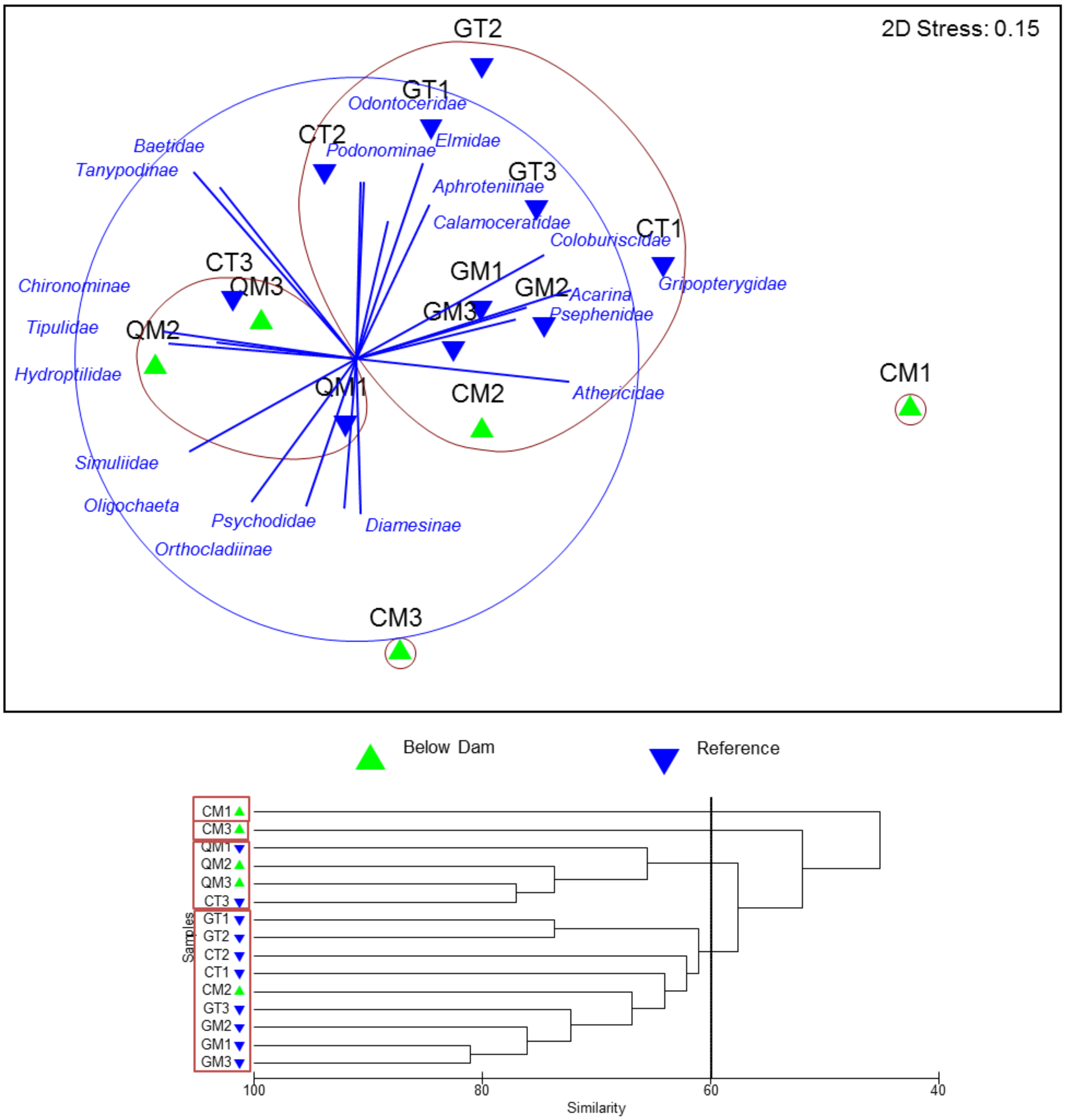


Figure 8. MDS ordination (top) of 60% similarity determined by a cluster analysis (shown below MDS plot with defined groups outlined) between macroinvertebrate samples collected in spring 2015 for the below dams assessment program (red oval lines in the MDS plot). Similarity based on macroinvertebrate relative abundance. Macroinvertebrate taxa contributing to the differences between sites are shown on the plot. These taxa have Pearson correlations greater than 0.5.

DISCUSSION AND CONCLUSIONS

WATER QUALITY

Water quality at below dam test sites and unregulated reference sites was generally within guideline levels in spring 2015 (Table 5). Parameters outside of guideline levels were pH, turbidity, ammonium (NH_4^+), nitrogen oxides (NO_x) and total nitrogen (TN), (Table 5).

Turbidity was within guideline level of 10 NTU at all below dam test sites, and only exceeded the guideline level in Paddys River at site CT3 (Table 5). Turbidity at this site is commonly above guideline levels as a result of instream sedimentation caused by catchment land-use (primarily forestry, rural and large density of unsealed roads).

Guideline exceedances of ammonium (all below dam sites and references site CT2 and GT1), nitrogen oxide (downstream of Corin and Cotter Dams – sites CM1 and CM3) and total nitrogen (Goodradigbee tributary sites) are likely to be the result of wider catchment influences and not dam operations in the case of below dam sites. This is because elevated concentrations have occurred at both below dam test sites and reference sites.

FILAMENTOUS ALGAE AND PERIPHYTON

Filamentous algae cover in riffle habitats was below the environmental flow ecological objective of <20% cover at all below dam sites in spring 2015 (Table 6). These results and the periphyton/algae biomass assessments at below dam sites are consistent with recent spring assessments, and indicate the current environmental flow release strategy is effective in achieving the environmental flow ecological objective to control filamentous algae accumulation downstream of dams on the Cotter and Queanbeyan Rivers during winter and spring.

BENTHIC MACROINVERTEBRATES

AUSRIVAS assessment identified biological impairment at three of the five below dam test sites in spring 2015, which is a net increase in condition at below dam test sites since the previous assessment in autumn 2015, but is consistent with spring assessments over recent years (Table 7).

Cotter River test sites below Corin and Cotter Dams (CM1 and CM3) have remained biologically impaired since the previous assessment and therefore failed to meet the environmental flow ecological objective of AUSRIVAS band A. Site CM1 downstream of Corin Dam was assessed as significantly impaired. Over the last two years this site has regularly been assessed as band B. Therefore, the current assessment is within the biological condition experienced over the last two years.

Biological impairment downstream of Cotter Dam has previously been attributed to the influence of Murrumbidgee River water transferred through the M2C water recirculation pipe (Harrison & Levings 2014). However, the M2C water recirculation was not in operation at the time of the current assessment and the site has remained biologically impaired. It may therefore be high flow volumes (equivalent to small floods) preceding sampling are driving the ongoing biological impairment at this site through scouring of macroinvertebrate taxa and when sampling occurred the macroinvertebrate community had not recovered from the disturbance.

Site CM2 downstream of Bendora Dam achieved the environmental flow ecological objective of AUSRIVAS band A in spring 2015 (Table 7). This site has been assessed as band A since spring 2014 and macroinvertebrate assemblage at this site was similar to that of the three reference sites on the Goodradigbee River (Figure 8). Therefore, the river flows downstream of Bendora Dam have been effective at maintaining a macroinvertebrate community similar to reference condition.

All of the Googradigbee reference sites and the Cotter River tributary sites were assessed as similar to reference condition (band A) or more biologically diverse than reference (band X) (Table 7). Therefore, at the time of sampling both the reference Goodradigbee catchment and unregulated streams in the Cotter River catchment were in good condition. This indicates that Cotter River biological condition in spring 2015 is more likely to be influenced by the effects of river regulation than catchment-scale influences.

Queanbeyan River test sites QM2 and QM3 below Googong Dam were assessed as significantly impaired (band B) and similar to reference condition (band A), respectively, in spring 2015 (Table 7), and the upstream reference site was similar to reference condition (band A). Both QM2 and QM3 have improved in condition since autumn 2015 when they were both assessed as severely impaired (Band C). It is likely that increased flows downstream of Googong Dam from the dam spilling have resulted in the increased biological condition at both site QM2 and QM3. Both sites also have taxa which are indicative of higher flows and early colonizers after a flood - Simuliidae (Diptera (other) category) and disturbance tolerant Chironomidae taxa (Figure 7 and Appendix 2). Prior to the autumn 2015 sampling there were also increased flows from the dam spilling which decreased biological condition (Levings and Harrison, 2015), but in spring 2015 the macroinvertebrate community has had a longer time to recover from the high flow event compared to autumn 2015 . Therefore, in spring 2015 the biological condition of the Queanbeyan River downstream of Googong Dam has been strongly influenced by higher river flows caused by increased rainfall and the dam spilling.

REFERENCES

ACT Government (2013). *2013 Environmental Flow Guidelines*.

ANZECC and ARMCANZ (2000). National water quality management strategy: Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand.

A.P.H.A. (2005). Standard methods for the examination of water and wastewater. 21st edition. American Public Health Association: Washington.

Arthington, A. H., and Pusey, B. J. (2003). Flow Restoration and Protection in Australian Rivers. *River Research and Applications* 19: 377-395.

Chessman, B. C. (2003). New sensitivity grades for Australian river macroinvertebrates. Marine and Freshwater Research 54:95-103.

Chester, H. and Norris, R. (2006). Dams and flow in the Cotter River, Australia: effects on instream trophic structure and benthic metabolism. *Hydrobiologia*, 572: 275–286

Clarke, K. R. and Warwick, R. M. (2001). Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition. Plymouth Marine Laboratory, Plymouth.

Coysh, J. L., Nichols, S. J., Simpson, J. C., Norris, R. H., Barmuta, L. A., Chessman, B. C. and Blackman, P. (2000). AUStralian RIVer Assessment System (AUSRIVAS) National River Health Program Predictive Model Manual. Cooperative Research Centre for Freshwater Ecology, Building 15, University of Canberra, ACT, 2601

Environment Protection Regulations SL2005-38. *Environment Protection regulation 2005 made under the Environment Protection ACT 1997*. Australian Capital Territory Government.

Hawking, J. (2000). *Key to keys, 2nd edition. Identification guide No. 2*. Cooperative Research Centre for Freshwater Ecology, Canberra, Australia.

Levings, C. and Harrison, E. (2015). Biological response to flows downstream of Corin, Bendora, Cotter and Googong Dams. Autumn 2015. Report produced for Icon Water.

Loeb, S. L. (1981). An in situ method for measuring the primary productivity and standing crop of the epilithic periphyton community in lentic systems. *Limnology and Oceanography*, 26: 394-400.

Marchant, R. (1989). A sub-sampler for samples of benthic invertebrates. *Bulletin of the Australian Society of Limnology* 12: 49-52.

Nichols, S.J., Coysh, J.L., Sloane, P. I. W., Williams, C. C., and Norris, R. H. (2000). *Australian Capital Territory (ACT), AUStralian RIVer Assessment System (AUSRIVAS), Sampling and Processing Manual.* Cooperative Research Centre for Freshwater Ecology, Building 15, University of Canberra, ACT, 2601.

Nichols, S., Norris, R., Maher, W., and Thoms, M., (2006). Ecological Effects of serial impoundment on the Cotter River, Australia. *Hydrobiologia,* 572: 255-273.

Parsons, M. and Norris, R. H. (1996). The effect of habitat-specific sampling on biological assessment of water quality using a predictive model. *Freshwater Biology* 36: 419-434.

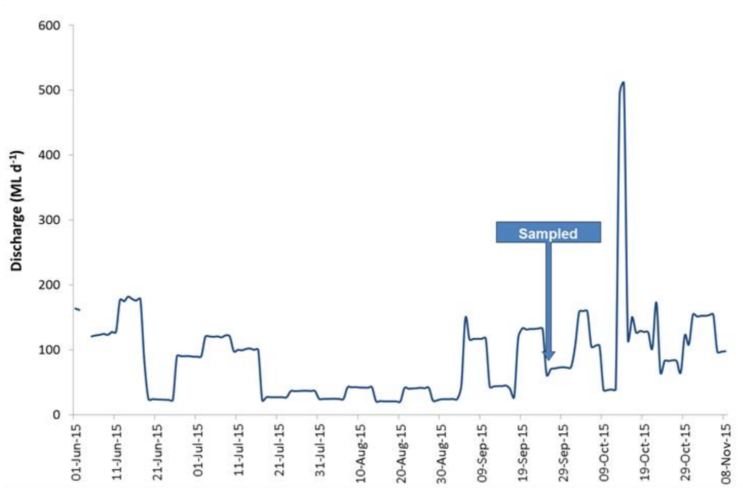
White, H., Deschasequx, E. and Norris, R. (2009). Biological response to environmental flows below Corin, Bendora and Googong Dams ad low flows below the Cotter Dam. Autumn 2009. Report to ACTEW Water.

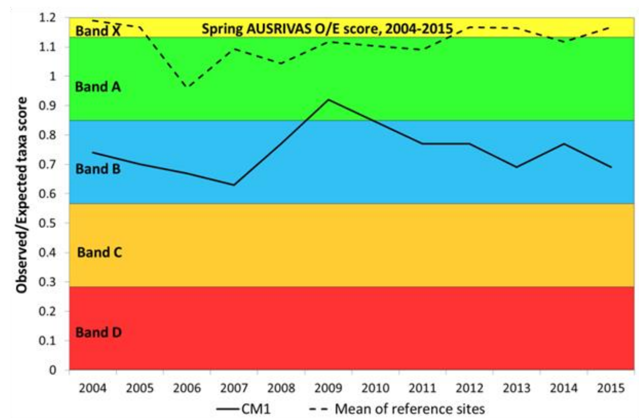
APPENDIX 1: BELOW DAM SITE SUMMARY SHEETS

CM1 – Spring 2015

Downstream of Corin Dam

Environmental flow ecological objective	Autumn 2015	Spring 2015	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	10%	**20%**	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_4^+(mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
9.5	23.0	5.9	10.6	2.0	12	0.018	0.019	0.12	0.008

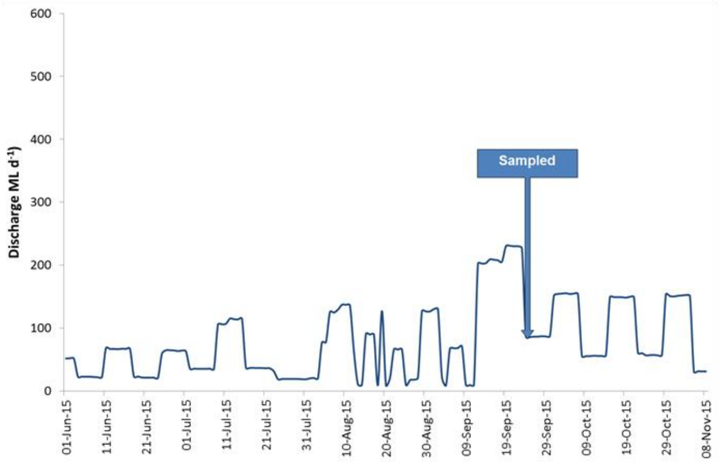
UNIVERSITY OF CANBERRA | INSTITUTE FOR APPLIED ECOLOGY

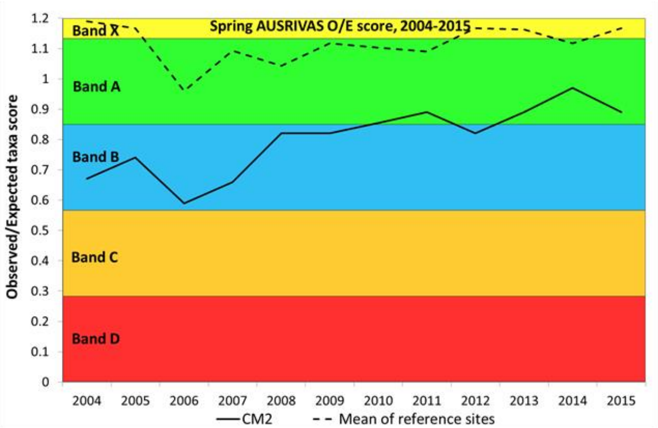
icon WATER

CM2 – Spring 2015

Downstream of Bendora Dam

Environmental flow ecological objective	Autumn 2015	Spring 2015	Objective met?
AUSRIVAS band A	Band A	**Band A**	Yes
<20% filamentous algae cover in riffle habitat	<10%	**<10%**	Yes





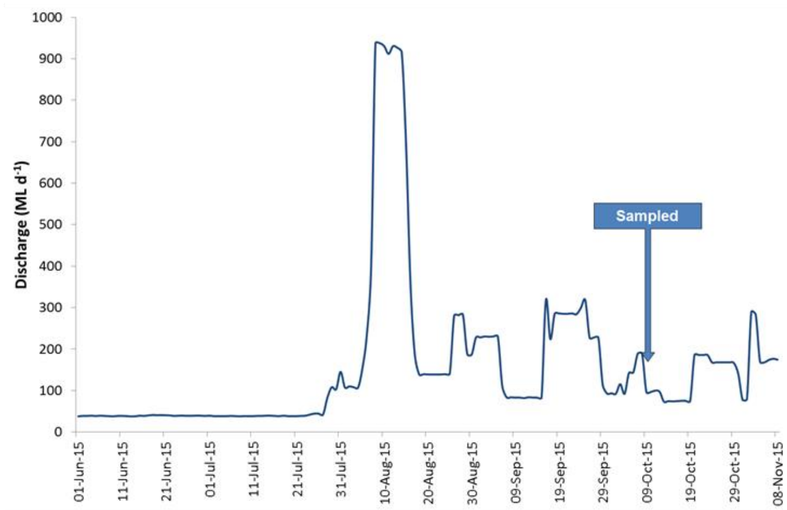
* Denotes values outside guideline levels

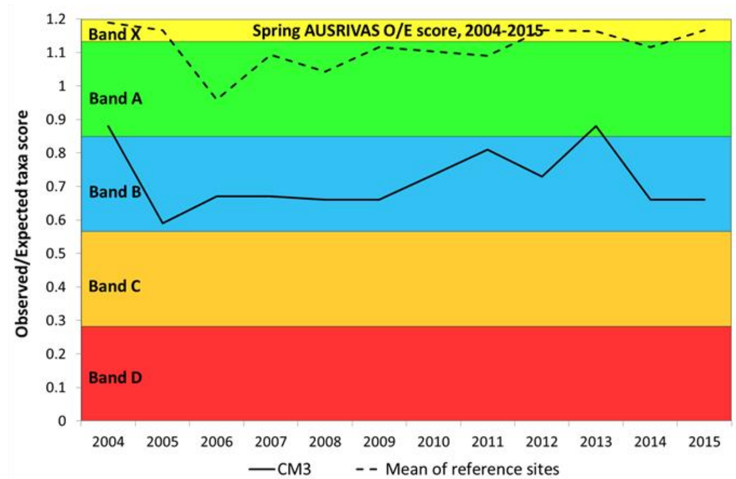
Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_4^+ (mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
8.1	18.0	6.0	12.0	1.6	9	0.017	0.007	0.09	0.006

CM3 – Spring 2015

Downstream of Cotter Dam

Environmental flow ecological objective	Autumn 2015	Spring 2015	Objective met?
AUSRIVAS band A	Band B	**Band B**	No
<20% filamentous algae cover in riffle habitat	<10%	**15%**	Yes





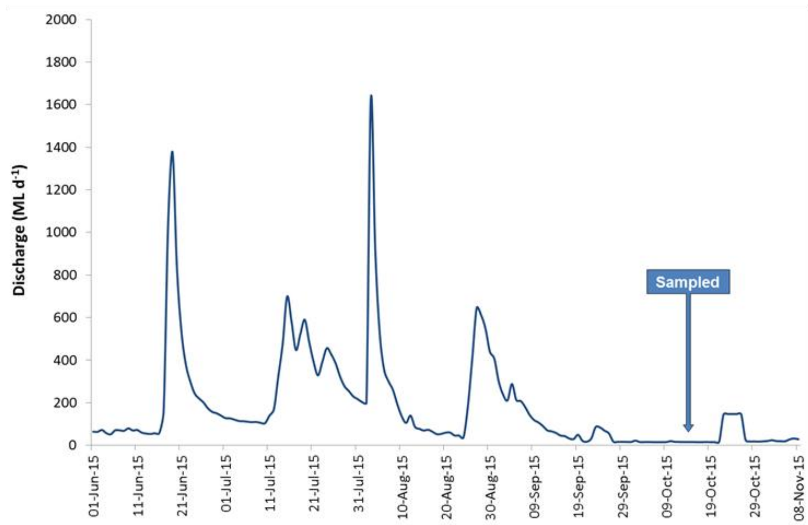
* Denotes values outside guideline levels

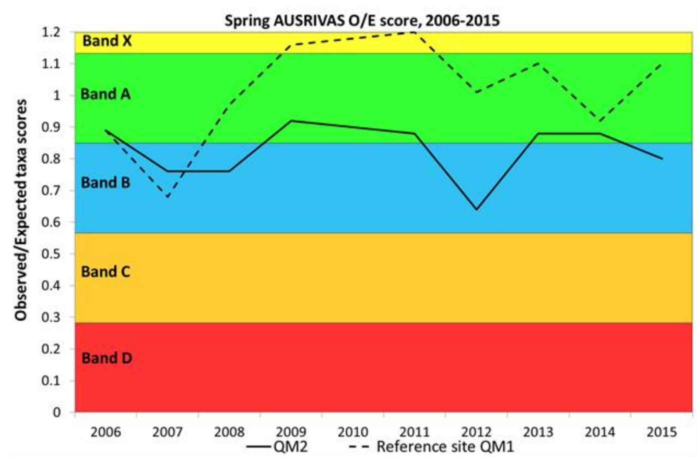
Temp. (°C)	EC (µs cm^{-1})	pH	D.O. (mg l^{-1})	Turbidity (NTU)	Alkalinity (mg L^{-1})	NH_4^+(mg L^{-1})	NOx (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})
10.3	40.0	7.2	11.6	6.7	20	0.014	0.016	0.13	0.014

QM2 – Spring 2015

Downstream of Googong Dam

Environmental flow ecological objective	Autumn 2015	Spring 2015	Objective met?
AUSRIVAS band A	Band C	Band B	No
<20% filamentous algae cover in riffle habitat	10%	10%	Yes





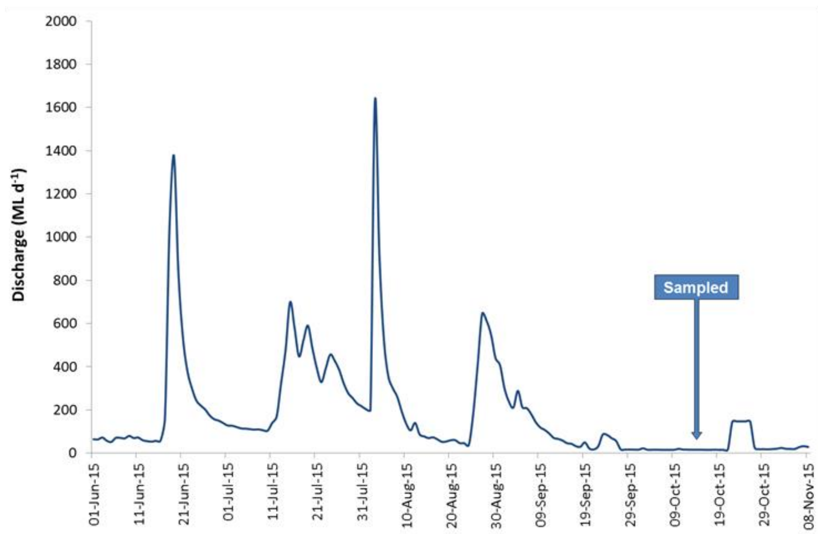
* Denotes values outside guideline levels

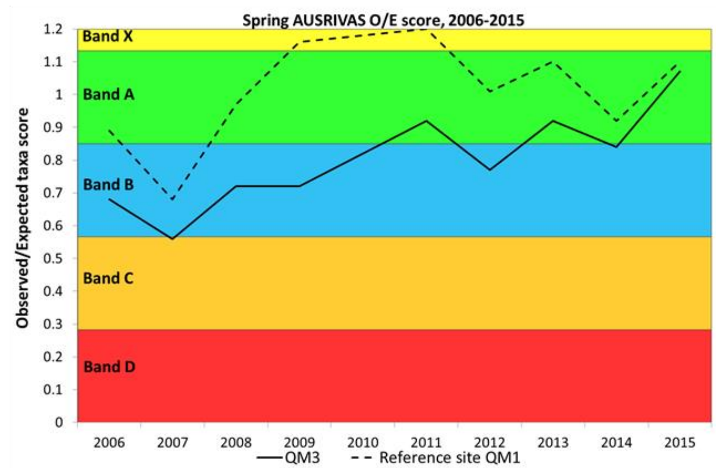
Temp. (°C)	EC (µs cm-1)	pH	D.O. (mg l-1)	Turbidity (NTU)	Alkalinity (mg L-1)	NH_4^+(mg L^{-1})	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
16.4	60.0	7.7	10.8	0.0	30	0.018	<0.002	0.06	0.012

QM3 – Spring 2015

2km Downstream of Googong Dam

Environmental flow ecological objective	Autumn 2015	Spring 2015	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_4^+(mg L-1)	NOx (mg L-1)	TN (mg L-1)	TP (mg L-1)
19.7	110.0	7.8	9.4	3.2	34	0.014	<0.002	0.08	0.004

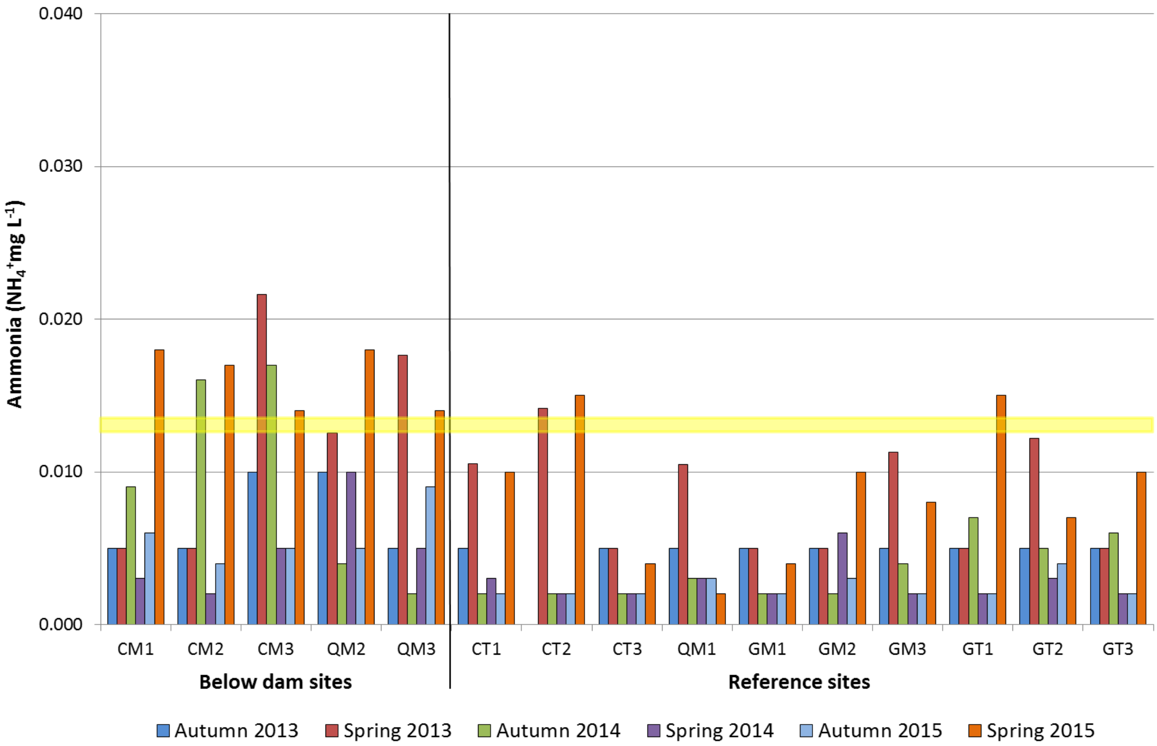
APPENDIX 2: MACROINVERTEBRATE TAXA SPRING 2015

Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples in spring 2015 at each of the study sites.

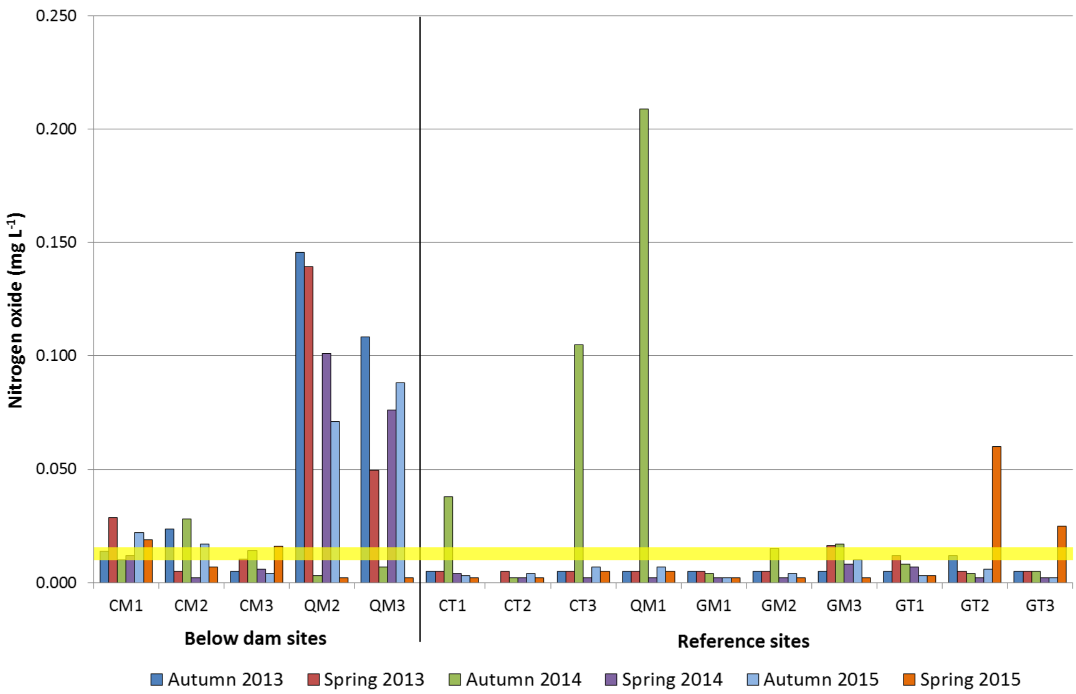
CLASS **Order** Family *Subfamily*	SIGNAL 2 grade	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
GASTROPODA																
Ancylidae	4						4	1								
OLIGOCHAETA	2	1	52	8	38	12	25	6	119	153	28	6	20			7
ACARINA	6	32	6	5	2	6	5	14	2	13	5	5	5	24	6	15
Coleoptera																
Scirtidae	6				1			3								
Elmidae	7	1				2	17	9	6		7	5	19	12	12	1
Psephenidae	6	1	2				1			3	9	1	4	1	1	1
Diptera																
Tipulidae	5			10	1	1		1	1	1	1		1	5	1	12
Simuliidae	5		5	51	6	4	1	11	16	2	3	16	13	1	3	2
Athericidae	8	2					1					1				
Empididae	5		2	4						1	2	5	3	1	7	5
Aphroteniinae	8		2				1				1			10	5	19
Podonominae	6						3	30						1	4	
Psychodidae	3			1									1			
Tanypodinae	4		1		1	10		7	2		1			6	5	2
Orthocladiinae	4	61	16	91	110	41	1	13	9	7	16	15	28	40	4	10
Chironominae	3		4	5	18	89	15	3	9	19	9	4	14	11	6	9
Diamesinae	6			11						1	2	6	5			
Ceratopogonidae	4									2						1
Ephemeroptera																
Baetidae	5				5	3		13	9	2	1	1	6	8	11	7
Coloburiscidae	8	5					12				9	5	1		32	4
Leptophlebiidae	8		1		2	1	12	20	8	25	4	45	5	62		37
Caenidae	4	1	5		10	27	1		19	18	52	7	2	8	8	9
Megaloptera	0															
Corydalidae	7			2								2				2
Odonata																
Gomphidae	5		1		1						5		1		2	
Telephlebiidae	9				1											
Plecoptera																
Gripopterygidae	8	104	94	6	1	2	75	28		27	27	57	48	62	94	70
Notonemouridae	6															1
Austroperlidae							1									
Trichoptera																
Hydrobiosidae	8			1		1	1	5	3		1	1	1		4	

Glossosomatidae	9	1					5	18	3	3	15	3	9			6
Hydroptilidae	4		1	1	5	13	1	2	15	1		2	8	2	3	
Philopotamidae	8											1			1	1
Hydropsychidae	6	1	1	3		4	1	3			1		1			1
Polycentropodidae	7													1		1
Ecnomidae	4		6	1							2	5	2	1		3
Conoesucidae	8		1				19	9			5	4	14			11
Calocidae	9						1									
Calamoceratidae	7							1			2	1			1	2
Leptoceridae	6			1				1			1			3	5	3
Odontoceridae	7													2	3	
No. of individuals		210	200	201	202	216	203	198	221	278	209	198	211	261	218	242
No. of taxa		11	17	16	15	15	22	21	14	16	25	23	23	20	22	27
% of sub-sample		5	7	10	1	2	3	7	3	1	6	3	8	4	3	4
Whole sample estimate		**4200**	**2857**	**2010**	**20200**	**10800**	**6767**	**2829**	**7367**	**27800**	**3483**	**6600**	**2638**	**6525**	**7267**	**6050**

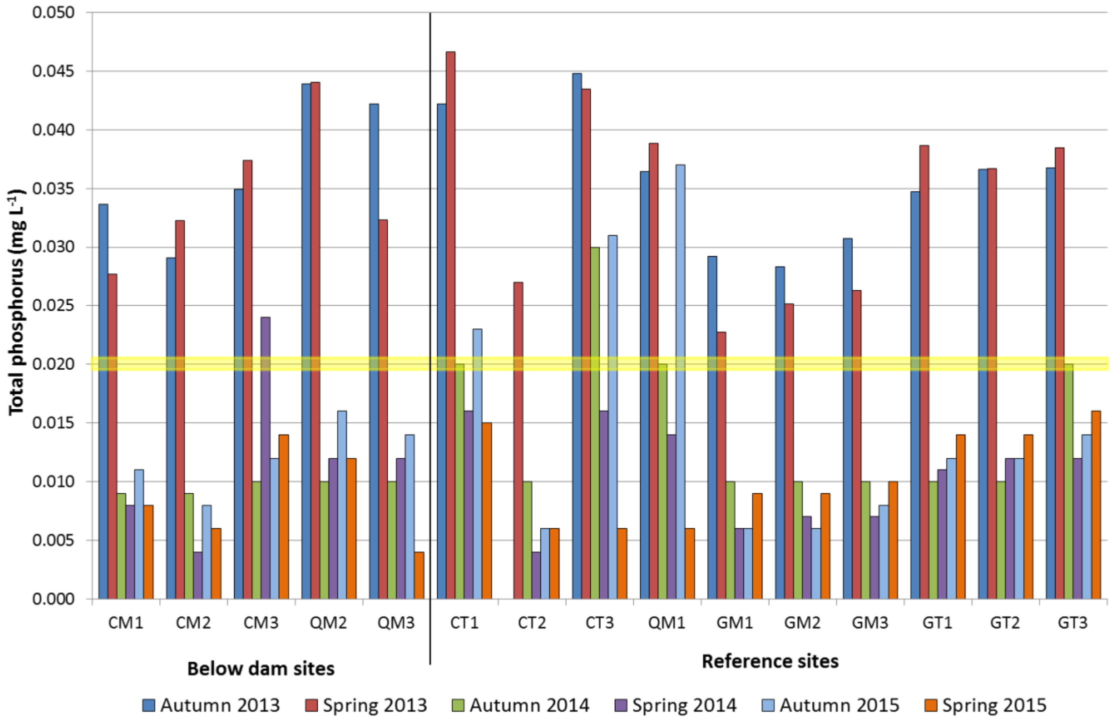
APPENDIX 3: WATER QUALITY FIGURES



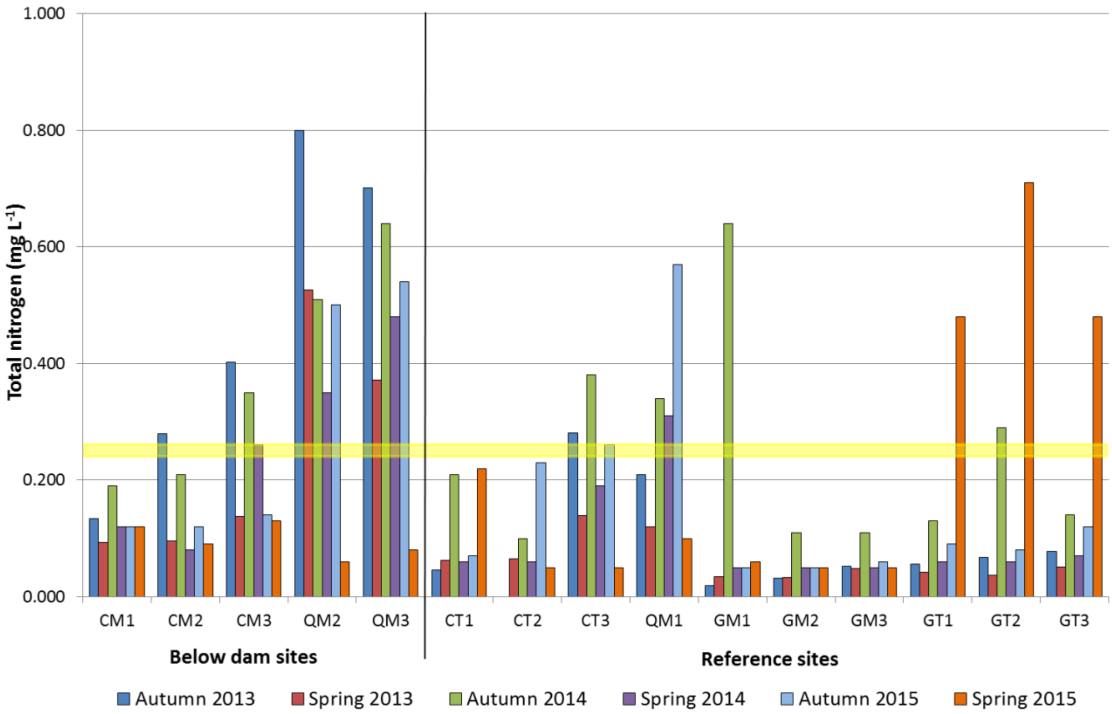
Ammonium (NH_4^+) concentration at all sites from autumn 2013 to spring 2015. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for ammonium (NH_4^+) is shaded yellow.



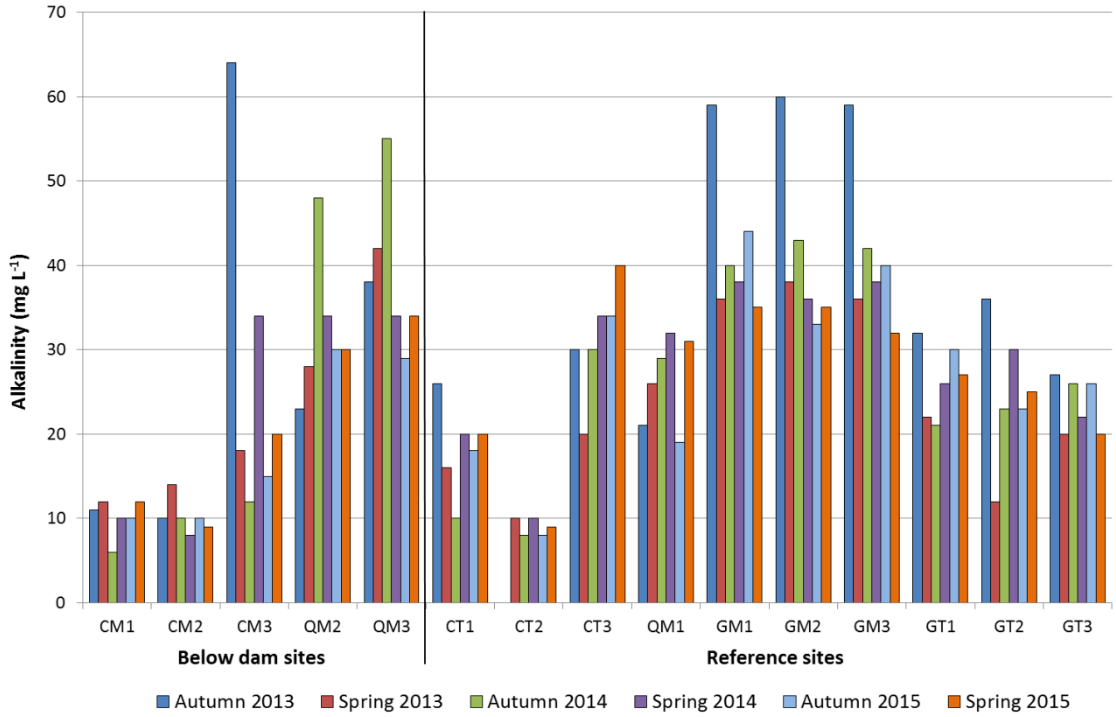
Nitrogen oxide concentrations at all sites from autumn 2013 to spring 2015. Values below the minimum detectable limit of 0.002 mg L^{-1} are shown at 0.001 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for nitrogen oxide is shaded yellow.



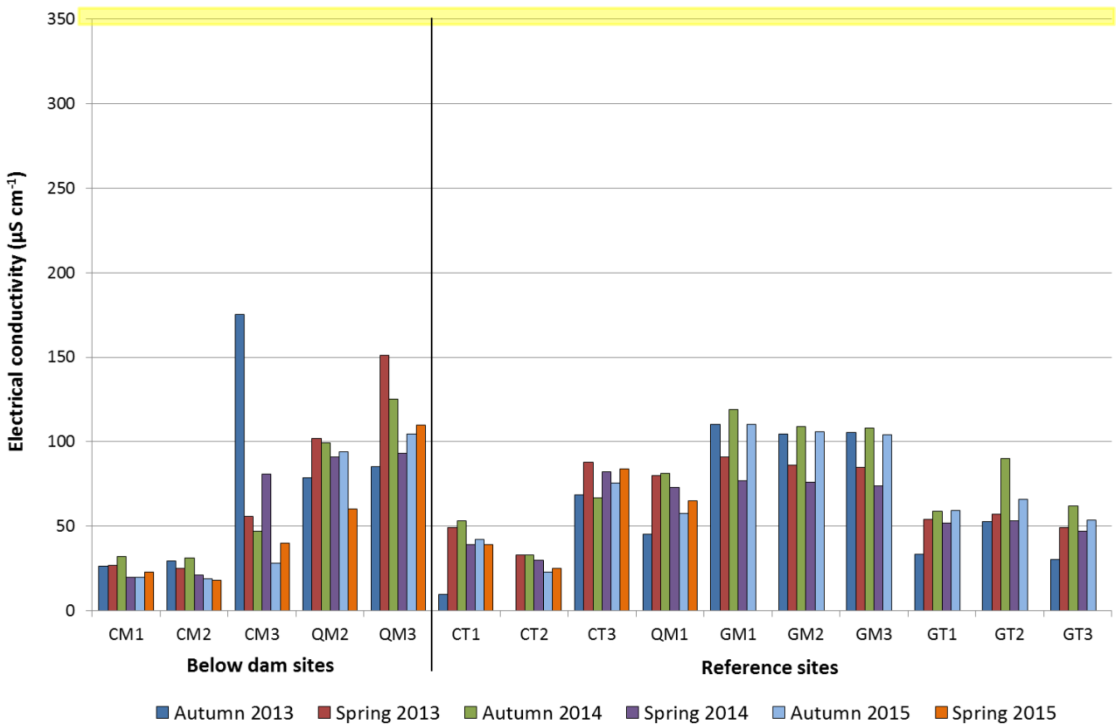
Total phosphorus concentrations at all sites from autumn 2013 to spring 2015. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total phosphorus is shaded yellow.



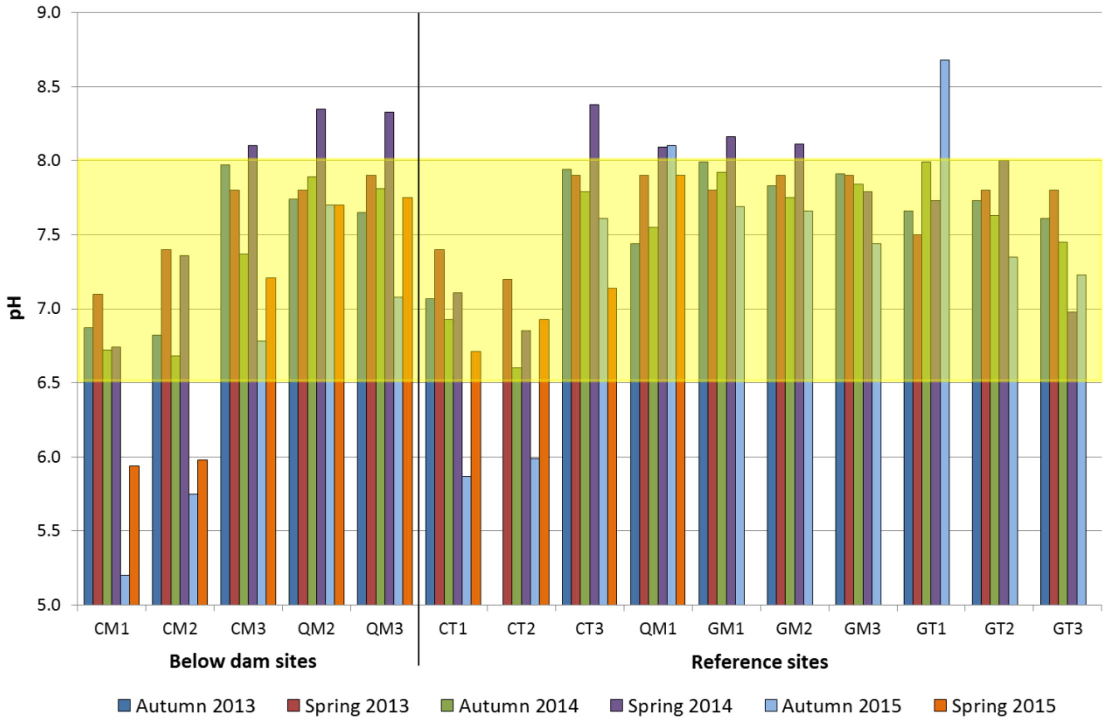
Total nitrogen concentrations at all sites from autumn 2013 to spring 2015. Values below the minimum detectable limit of 0.01 mg L^{-1} are shown at 0.005 mg L^{-1}. The ANZECC/ARMCANZ (2000) guideline concentration for total nitrogen is shaded yellow.



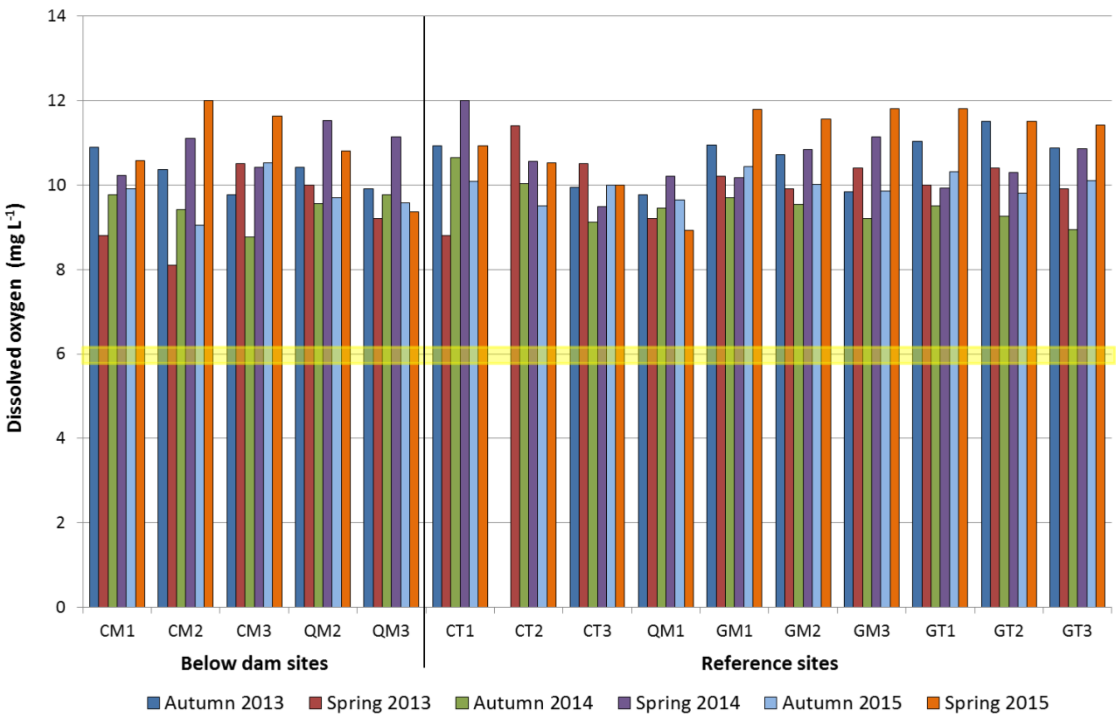
Alkalinity at all sites from autumn 2013 to spring 2015.



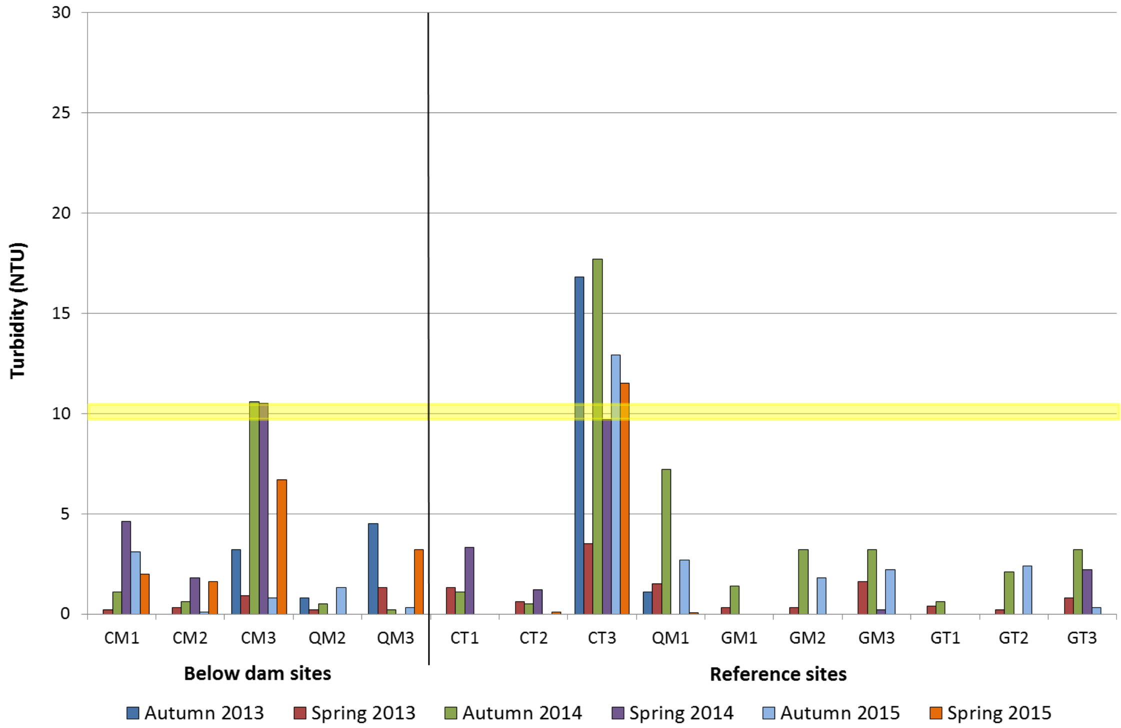
Electrical conductivity at all sites from autumn 2013 to spring 2015. The ANZECC/ARMCANZ (2000) guideline for electrical conductivity is shaded yellow.



pH at all sites from autumn 2013 to spring 2015. The ANZECC/ARMCANZ (2000) guideline for pH is shaded yellow.



Dissolved oxygen concentration at all sites from autumn 2013 to spring 2015. The minimum guideline for dissolved oxygen is shaded yellow (Environment Protection Regulation SL2005-38).



Turbidity at all sites from autumn 2013 to spring 2015. The guideline for turbidity is shaded yellow (Environment Protection Regulation SL2005-38).