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

Spring 2012

ACTEW WATER

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Executive summary

Background and study objective

- The Cotter and Queanbeyan Rivers are regulated to supply water to the ACT. Ecological assessment is undertaken in spring and autumn each year to evaluate the rivers' response to environmental flow releases to the Cotter and Queanbeyan Rivers, and to meet the requirements of Licence No. WU67 – Licence to take water. Sites below dams are assessed and also compared with sites on the unregulated Goodradigbee River and Queanbeyan River upstream of Googong Dam to evaluate ecological change and responses attributed to the flow regulation.

- This study addresses the needs of ACTEW's License to Abstract Water (WU67) to assess the effects of dam operation, water abstraction, and environmental flows, and to provide information for the adaptive management of the Cotter and Googong water supply catchments. This study specifically focuses on assessing the ecological status of river habitats using water quality data, algae and macroinvertebrates.

Results and conclusions

- In spring 2012 water quality parameters were generally within the recommended water quality trigger levels at below dam test sites and reference sites. The most notable exceptions included turbidity downstream of Cotter Dam (CM3) and Paddy's River (CT3) and nutrient concentrations downstream of Cotter (CM3) and Googong (QM2, QM3) Dams, which were above trigger levels. The continued above trigger level turbidity level downstream of Cotter Dam is possibly the result of instream storages of sediment from flooding earlier in 2012 or Murrumbidgee River water pumped via M2C which had a turbidity of 44 NTU from a high flow event one day before sampling occurred on the 16/10/13.

- In spring 2012 riffle filamentous algae cover below Bendora (CM2) Dams did not meet the specific environmental flow ecological objective of <20 % cover (ACT Government 2006). All sites below dams did not meet the specified environmental flow ecological objective of AUSRIVAS band A for maintaining healthy aquatic ecosystems.

Legend	Within environmental flow ecological objective	On the cusp of being outside the ecological objective
	Outside environmental flow ecological objective	
Site	**Riffle filamentous algae cover**	**AUSRIVAS band (O/E score)**
CM1 (Corin Dam)	10-35 %	B (0.77)
CM2 (Bendora Dam)	> 90 %	B (0.82)
CM3 (Cotter Dam)	< 10 %	B (0.73)
QM2 (Googong Dam)	< 10 %	B (0.64)
QM3 (Googong Dam)	< 10 %	B (0.77)

- Below dam test sites on the Cotter River (CM1, CM2, and CM3) were all assessed as Band B (significantly impaired) in spring 2012. These results are consistent with pre-flood biological condition in spring 2011 at sites CM1 (Corin Dam) and CM3, indicating macroinvertebrate assemblages at these sites have recovered from the flood disturbance earlier in 2012.

- Site CM2 did not return to a pre flood disturbance Band A assessment that occurred in spring 2011. It is likely that the ongoing biological impairment at this site has resulted from prolific filamentous algae coverage in the riffle habitat.

- Sites QM2 improved from Band C after the flood disturbance to Band B in spring 2012, but had not returned to the Band A condition frequently achieved in previous assessments. It is unclear if this result is from a lag in post-flood recovery, or from instream disturbance during a smaller flood event in the Queanbeyan River on the 12th of October, approximately three weeks prior to sampling. Water quality conditions within Googong Dam from the recent flooding (e.g. high levels of dissolved organics, nutrients and metals) may also be having an influence on the biological condition of sites QM2 and QM3 (below reference condition) downstream of Googong Dam. It is likely that the biological condition of these sites will continue to improve in the absence of further disturbance.

- Pollution tolerant Simuliidae have been the dominant taxa at downstream of Cotter Dam (site CM3) over the past two sampling periods. High flow conditions downstream of Cotter Dam have provided ideal habitat conditions for early colonising/filter feeding Simuliidae.

Project recommendations based on spring 2012 results

- It is likely that the increased filamentous algae cover downstream of Bendora Dam influenced macroinvertebrate composition downstream of the dam, with a high relative abundance of tolerant Chironomidae and a Band B AUSRIVAS score. Filamentous algae is not a favoured food source for many macroinvertebrate taxa including sensitive Ephemeroptera, Plecoptera and Trichoptera (EPT). The increased algal growth is possibly the result of increased concentrations of biologically available nitrogen following increased catchment runoff and flooding earlier in 2012. If filamentous algal cover continues to be above 20% cover below Bendora Dam, management actions such as a high flow release would be advisable to scour the algae from the stream bed, because of the negative effect it is having on the macroinvertebrate community.

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 (ACT Government 2006). 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 2006). The ecological objectives for environmental flows are 1) for the Cotter and Queanbeyan Rivers to reach an Australian River Assessment System (AUSRIVAS) observed/expected band A grade (similar to reference condition) and 2) have <20% filamentous algal cover in riffles for 95% of the time (ACT Government 2006). Ecological assessment evaluates the effectiveness of the flow regime for meeting the ecological objectives and provides the scientific basis to inform decisions about refinements to future environmental flow releases to ensure that these resources are protected.

This assessment is based on the ecological objectives of environmental flow regimes in the ACT and has been ongoing at fixed sampling sites since 2001 and is based on measurements of macroinvertebrate assemblages, algae (periphyton and filamentous algae), water quality and an annual riffle sediment survey. Sampling is conducted during autumn and spring of each year to evaluate the condition of river habitat downstream of each dam on both the Cotter and Queanbeyan Rivers. Comparison is made to the condition of reference sites on the unregulated Goodradigbee River, Cotter and Goodradigbee River tributaries, and the Queanbeyan River upstream of Googong Dam. The sampling and reporting program satisfies ACTEW's License to Take Water (WU67) and the requirement to provide an assessment of the effects of dam operation and the effectiveness of environmental flows. The information from the assessment links into the adaptive management framework applied in the water supply catchments.

This report provides an assessment of sites downstream of the dams on the Cotter and Queanbeyan Rivers in spring 2012, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments. A major flood event in early March 2012 had a short-term negative effect on the biological condition of the Cotter, Goodradigbee, and Queanbeyan Rivers by increased flow velocity, riverbed disturbance, and channelization (Levings *et al.* 2012). The effect of this disturbance on biological condition at test and reference sites was reflected in the autumn 2012 assessment, where AUSRIVAS results revealed a decline in biological condition at all main-channel sites on both test (Cotter and Queanbeyan) and reference (Goodradigbee) rivers (Table 11). The current assessment provides an insight into the capacity for each of the Cotter, Goodradigbee, and Queanbeyan Rivers to recover from this disturbance; and whether impoundments on the Cotter and

Queanbeyan Rivers are affecting macroinvertebrate re-colonisation rates over seasonal timescales (*see* Marchant and Heir 2002).

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. 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 operational requirements of each dam on the Cotter River differ according to reservoir levels, urban demand, and water quality. Corin Dam releases water to the river channel to maintain water levels in Bendora Reservoir, which is often the primary reservoir for urban supply. A gravity main supplies water from Bendora Dam to Stromlo Water Treatment Plant, where water is treated before distribution to Canberra and Queanbeyan. Overall, minimal releases occur to the river downstream of Bendora except for designated environmental flow purposes or when the water overtops the spillway. During construction of the Enlarged Cotter Dam flow releases of up to 500 $ML.d^{-1}$ have occurred (via a cone valve) to lower the water level in the reservoir (e.g. for construction purposes). 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 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 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 includes human disturbances such as agriculture.

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

Site selection and sampling period

Fifteen sites were sampled for biological, physical and chemical variables between the 17/10/2012-23/11/2012 (Fig. 1; Tables 1 and 2). Three sites were on the Cotter River (CM1, CM2, CM3), one below each dam, each with a nearby tributary site (CT1, CT2, CT3) (Fig. 1; Table 1). These sites were then replicated on the unregulated Goodradigbee River (GM1, GM2, GM3) and three of its tributaries (GT1, GT2, GT3) (Fig. 1; Table 1). Three sites were also sampled on the Queanbeyan River, one upstream of Googong Dam (QM1) and two downstream of the dam (QM2, QM3) (Fig. 1; Table 1). The inclusion of the unregulated main channel and tributary sites enables a better understanding of the effects of different environmental flows and changes resulting from natural events relative to the condition of naturally flowing rivers (Peat and Norris 2007).

Site characteristics

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.

Hydrometric data

To determine changes in river flow and rainfall for the months preceding sampling, and when sampling occurred, the mean daily flow and rainfall data were obtained for each below dam site and the Goodradigbee River. Mean daily flow data were obtained for Corin, Bendora, Cotter and Googong Dams on the Cotter and Queanbeyan Rivers from ACTEW Water. Mean daily flow data was also obtained for the Goodradigbee River at site GM2 (gauging station 410088) from the Department of Water and Energy in NSW. Daily rainfall data for Canberra was obtained from the Bureau of Meteorology (http://www.bom.gov.au/climate/dwo/).

Physical and chemical water quality assessment and guidelines

Water temperature, dissolved oxygen, pH, conductivity and turbidity were measured at all sites using a calibrated Hydrolab DS5 Multiprobe. Total alkalinity was calculated by field titration to an end point of pH 4.5 (APHA 1992). One 50ml water sample was collected from each site to measure ammonia, nitrogen oxide, total nitrogen and total phosphorus concentrations. Samples were analysed following methods from the Standard Methods for the Examination of Water and Wastewater (A.P.H.A 2005).

Water quality trigger 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 Australia upland rivers. While comparisons with water quality guidelines are not required as part of the environmental flow guidelines, and are used only as a guide, they provide a useful tool for the protection of ecosystems (which is a primary objective of environmental flows). For conductivity, the upper value of the ANZECC and ARMCANZ (2000) trigger value range is used as a trigger value, because the lower trigger values are not likely to have an effect on stream ecological condition (see the autumn 2010 report: Harrison et al. 2010) .

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the Below Dams Assessment Program, autumn 2012.

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

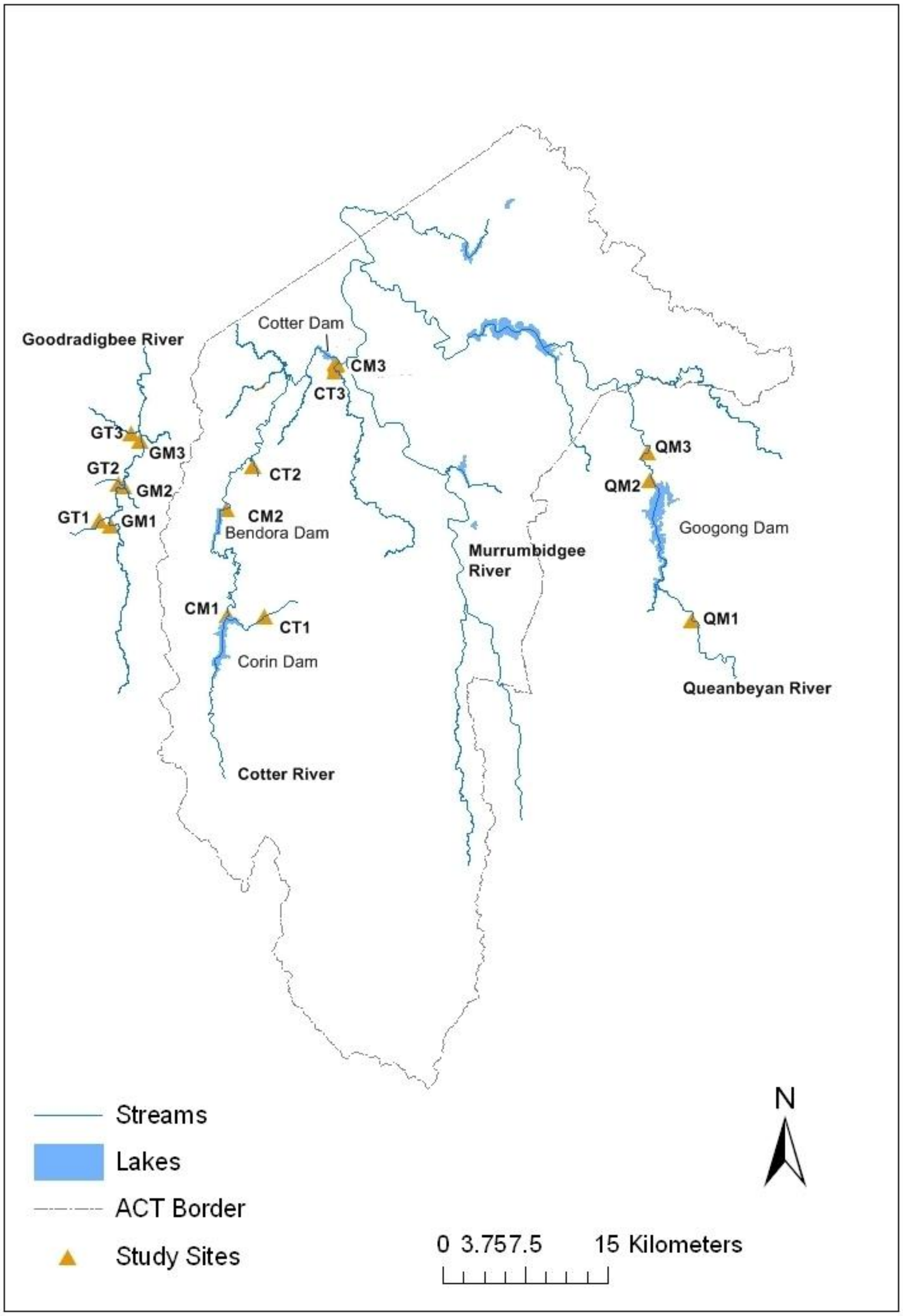

Figure 1: The location of sites sampled on the Cotter, Goodradigbee and Queanbeyan River's and tributaries for the Below Dams Assessment Program.

Table 2: Sampling dates and times for each site October and November 2012.

Site	Sampling date	Sampling time
CM1	31/10/2012	11:55
CM2	29/10/2012	10.40
CM3	17/10/2012	10:20
CT1	31/10/2012	11:00
CT2	29/10/2012	11:43
CT3	17/10/2012	11:40
GM1	18/10/2012	11:15
GM2	18/10/2012	01:15
GM3	18/10/2012	14:50
GT1	18/10/2012	10:30
GT2	18/10/2012	12:30
GT3	18/10/2012	14:18
QM1	23/11/2012	10:25
QM2	01/11/2012	10:30
QM3	01/11/2012	12:00

Table 3: Water quality trigger values from the Environment Protection Regulations SL2005-38* and ANZECC and ARMCANZ (2000). N/A = *trigger value not available*.**

Measure	Units	Trigger 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
Ammonia**	mg L^{-1}	0.9
Nitrogen oxides**	mg L^{-1}	0.015
Total phosphorus**	mg L^{-1}	0.02
Total nitrogen**	mg L^{-1}	0.25

Biological measurements

Biological measurements are particularly useful for assessing river health. Studying river ecology shows the temporal changes occurring in watercourses because biota populations change over time, depending on the aquatic conditions. Biological measurements can detect the effects of events that may pass unnoticed by periodic physical and chemical sampling, because these instantaneous measurements only give an indication of the river condition at the time of sampling.

Periphyton/algae (ash free dry mass) is an important ecological indicator because it will respond to changes in water quality and flow regime. The determination of periphyton/algae chlorophyll-a content can also provide an indication of how actively the periphyton/algae is growing and can be a surrogate measure of periphyton biomass. Changes to macroinvertebrate communities and other biota, arise as a consequence of changes in water quality, flow regime and periphyton/algae.

Periphyton/algae

Visual observations

Periphyton/algae visual observations within the sampling reach and riffle habitat were collected 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

At four sites below dams (CM1, CM2, CM3 and QM2) twelve individual rocks, selected at random, were scrubbed to collect periphyton using a syringe sampler based on a design similar to that described by Loeb (1981). The sampling device consists of two 60 ml syringes and a scrubbing surface of nylon bristles that brushed an area of 637 mm^2. The twelve samples were separated into two groups of six. One set of six was used to measure Ash Free Dry Mass (AFDM). Samples were dried in an oven at 103 ˚C to a constant weight, then ashed in a furnace at 500 ˚C for one hour and reweighed. The other set of six samples were used to measure chlorophyll-a content of the periphyton/algae. Chlorophyll-a was extracted using 90% ethanol, and measured in a spectrophotometer (A.P.H.A. 2005).

Note- in spring 2012 only 3 samples each were used to calculate AFDM and chlorophyll-a because of unexpected overheating in a furnace which caused the disintegration of six biomass samples.

Macroinvertebrate sample collection and processing

Benthic macroinvertebrates were sampled from the riffle habitat using a D-framed net 350 mm across the bottom with a mesh size of 250 µm. Collection of macroinvertebrates, recording and measurement of water quality and physical habitat variables followed National

River Health Program protocols presented in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000, http://ausrivas.ewater.com.au/index.php/manuals-a-datasheets).

In the laboratory, preserved samples were placed in a sub-sampling box comprising of 100 cells (Marchant 1989) and agitated until evenly distributed. Contents of each cell were removed until approximately 200 animals from each sample were identified (Parsons and Norris 1996). Macroinvertebrates were identified to the family taxonomic level using keys listed by Hawking (2000), except Chironomidae, which were identified to sub-family, and worms (Oligochaeta) and mites (Acarina), which were identified to class. After the ~200 macroinvertebrates were sub-sampled, the remaining unsorted sample was placed into a large white tray with water to evenly distribute the sample. This sample was then visually scanned with a large magnifying lamp for 15 minutes and any taxa, which were not found in the ~200 animal sub-sample, were collected for identification (Nichols *et al*. 2000). By conducting a visual scan, a more complete taxa list can be obtained, incorporating large and rare taxa that may not have been collected in the ~200 organism sub-sample. This method of scan sampling was not used in the construction of the AUSRIVAS model and therefore the macroinvertebrates collected in the scan cannot validly be used when making site assessments using the Australian River Assessment System (AUSRIVAS) predictive models (Coysh *et al.* 2000; Simpson and Norris 2000). The results from the visual scan are thus recorded separately from the ~200 organism sub-sample records and should be regarded as a separate data set.

Macroinvertebrate quality control/quality assurance procedures

Quality control/quality assurance procedures are designed to establish an acceptable taxonomic standard of macroinvertebrate sorting and identifications. The quality control (QC) component controls error and variation in the macroinvertebrate data, and quality assurance (QA) provides assurance that the accuracy of results is within controlled and acceptable limits. QA/QC procedures were implemented for macroinvertebrate sample processing following those outlined in Nichols *et al*. (2000).

Macroinvertebrate assemblage structure

Benthic macroinvertebrate richness and relative numbers can provide valuable information about a river's condition. Taxa such as Oligochaeta (worms), Gastropoda (freshwater snails), Diptera (true flies), and particularly Chironomidae (midge larvae) are either tolerant or thrive in nutrient rich environments. These organisms are found in all river systems, but large numbers of these taxa relative to more sensitive taxa can indicate a disturbed or unhealthy river environment. Alternatively, most Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddis flies), and some Coleoptera (beetles) are sensitive to reduced water quality and habitat alterations. Thus, high relative numbers of these organisms, in an aquatic ecosystem, indicates a healthy river system. AUSRIVAS outputs were also used to further analyse the macroinvertebrate community structure and provide an assessment of stream condition (Simpson and Norris, 2000).

Macroinvertebrate predictive models - 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.

AUSRIVAS spring riffle model

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT spring riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT spring riffle model uses a set of 6 habitat variables to predict the macroinvertebrate fauna expected at each site (Table 4).

Table 4: Habitat variables used by the ACT spring riffle AUSRIVAS model to predict the macroinvertebrate fauna expected at a site.

Variable	Description
ALTITUDE	Height above sea level (m)
HABAREA	Habitat area of riffle in reach (%)
CATCHAREA	Catchment area upstream of site (km^2)
DFS	Distance from source (km)
LONGITUDE	Longitude (Degrees/Minutes eg. 14857)
STORDER	Stream order calculated from 1:100,000 map

Biological condition bands for the AUSRIVAS spring riffle model

To simplify interpretation and aid management decisions, AUSRIVAS allocates test site O/E taxa grades to category bands that represent a range in biological conditions. AUSRIVAS uses five bands, designated X, A, B, C, and D (Table 5). 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). When using the spring riffle model, test site grades that fall between 0.86 - 1.14 (Band A) are considered similar to reference condition). A significantly impaired site will have an O/E score between 0.57 - 0.85 (Band B); a severely impaired site (Band C) will have an O/E score between 0.28 - 0.56; and the extremely impaired sites will have an O/E score of 0 - 0.27 (Band D). Sites that have O/E scores ≥ 1.14 (Band X) are considered to be more biologically diverse than reference. Allocation to Band X should result in further assessment to determine whether the site is richer than reference because of naturally high diversity or an impact such as mild nutrient enrichment.

SIGNAL 2 grades

To aid the interpretation of results, habitat disturbance and pollution sensitivity (SIGNAL 2) grades for macroinvertebrate taxa commonly predicted with ≥50% chance of occurrence are provided (Table 6). Grades range from 1 to 10, with sensitive taxa receiving high grades and tolerant taxa low grades. The sensitivity grades are based on taxa tolerance to common pollution types (Chessman 2003). Several changes have been made to the original SIGNAL grade numbers to better reflect the pollution sensitivities of different families. These new grade numbers are referred to as SIGNAL 2 grade numbers (Chessman 2003), which are now incorporated into the AUSRIVAS platform.

Table 5: ACT autumn and spring riffle AUSRIVAS model band descriptions, band width and interpretation.

Band	Band description	Band width	O/E taxa score interpretations
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	**0.88-0.12** (autumn) **0.86-1.14** (spring)	Most/all of the expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity.
B	SIGNIFICANTLY IMPAIRED	**0.64-0.87** (autumn) **0.57-0.85** (spring)	Fewer families than expected. 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)	Many fewer families than expected. 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)	Few of the expected families remain. Extremely poor water and/or habitat quality. Highly degraded.

Table 6: Habitat disturbance and pollution sensitivity (SIGNAL 2) grades for macroinvertebrate taxa commonly predicted with a ≥50% chance of occurring.

Taxa	Grade	Taxa	Grade
Acarina	6	Helicophidae	10
Aeshnidae	4	Helicopsychidae	8
Amphipoda	3	Hydrobiidae	4
Ancylidae	4	Hydrobiosidae	8
Aphroteniinae	8	Hydrophilidae	2
Athericidae	8	Hydropsychidae	6
Atriplectididae	7	Hydroptilidae	4
Atyidae	3	Leptoceridae	6
Austroperlidae	10	Leptophlebiidae	8
Baetidae	5	Lymnaeidae	1
Caenidae	4	Notonectidae	1
Calamoceratidae	7	Notonemouridae	6
Calocidae	9	Odontoceridae	7
Ceratopogonidae	4	Oligochaeta	2
Chironominae	3	Orthocladiinae	4
Coenagrionidae	2	Philopotamidae	8
Coloburiscidae	8	Physidae	1
Conoesucidae	7	Planorbidae	2
Corbiculidae	4	Podonominae	6
Corduliidae	5	Polycentropodidae	7
Corixidae	2	Psephenidae	6
Corydalidae	7	Pyralidae	3
Dixidae	7	Scirtidae	6
Dytiscidae	2	Simuliidae	5
Ecnomidae	4	Sphaeriidae	5
Elmidae	7	Stratiomyidae	2
Empididae	5	Synlestidae	7
Glossosomatidae	9	Tanypodinae	4
Gomphidae	5	Tipulidae	5
Gripopterygidae	8	Turbellaria	2

Data entry and storage

The water characteristics, habitat data from field data sheets, and macroinvertebrate data with national taxa codes 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

Differences between site and season (spring 2009, autumn 2010, autumn 2011, spring 2011**, autumn 2012 and spring 2012) in periphyton ash free dry mass (AFDM) and chlorophyll-a were tested using a two-way analysis of variance (ANOVA) (SAS 9.3), followed by a Tukey-Kramer pairwise comparisons to identify significant differences. Note that periphyton samples were not collected from the Goodradigbee River before autumn 2010 as a part of the project and are not included in the analysis.

To determine if there were significant differences in periphyton AFDM and chlorophyll-a between sites in spring 2012, single factor ANOVAs (SAS 9.3) were 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 assumption.

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 using a Similarity Profile (SIMPROF) test applied a 0.05 significance level and displayed in a Multi-Dimensional Scaling (MDS) ordination (PRIMER v6; Clark and Warwick 2001). 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.

** Spring 2011 AFDM was not used in the two-way ANOVA because of concerns with confidence in the data analysed (see Harrison and Nichols, 2011).

Results

Hydrometric data

Discharge in the Cotter, Queanbeyan, and Goodradigbee Rivers during spring 2012 was similar to discharge in spring 2011 (Fig. 2). Moderate rainfall events occurred in spring 2012, which led to increased discharge downstream of dams from spilling and flow releases for Enlarged Cotter Dam construction site flood mitigation (Fig 2). The most noticeable rainfall event occurred within the Googong catchment, which caused a peak in discharge downstream of Googong Dam in early October (4662.6 ML day^{-1}) (Fig 2). Preceding spring 2012 sampling (taken from 1st June 2012) flows downstream of each of the dams ranged between 141 – 547 ML day^{-1} at Corin , 10 – 534 ML day^{-1} at Bendora, 6 – 497 ML day^{-1} at Cotter and 12 – 4662.6 ML day^{-1} at Googong. During spring 2012, stream discharge downstream of dams was regulated and determined mainly by operational requirements and environmental flow guidelines (ACT Government 2006). During the spring sampling period discharge in the Goodradigbee River was greater than discharge below each of the dams on the Cotter and Queanbeyan Rivers (Fig 2).

Table 7: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams preceding the spring 2012 Below Dams Assessment Program (excluding unscheduled releases during flooding and releases for Enlarged Cotter Dam construction site flood mitigation) (ACT Government 2006).

Dam	Flow regime
Corin	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 MLd^{-1} for 3 consecutive days every 2 months.
Bendora	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less. Riffle maintenance flow 150 MLd^{-1} for 3 consecutive days every 2 months. Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid- October.
Cotter	Maintain an average flow of 15 ML day^{-1}. Riffle maintenance flow of 100 ML day^{-1} for 1 day every 2 months.
Googong	Maintain base flow average of 10 MLd^{-1} or natural inflow, whichever is less. Riffle maintenance flow of 100 MLd^{-1} for 1 day every 2 months.

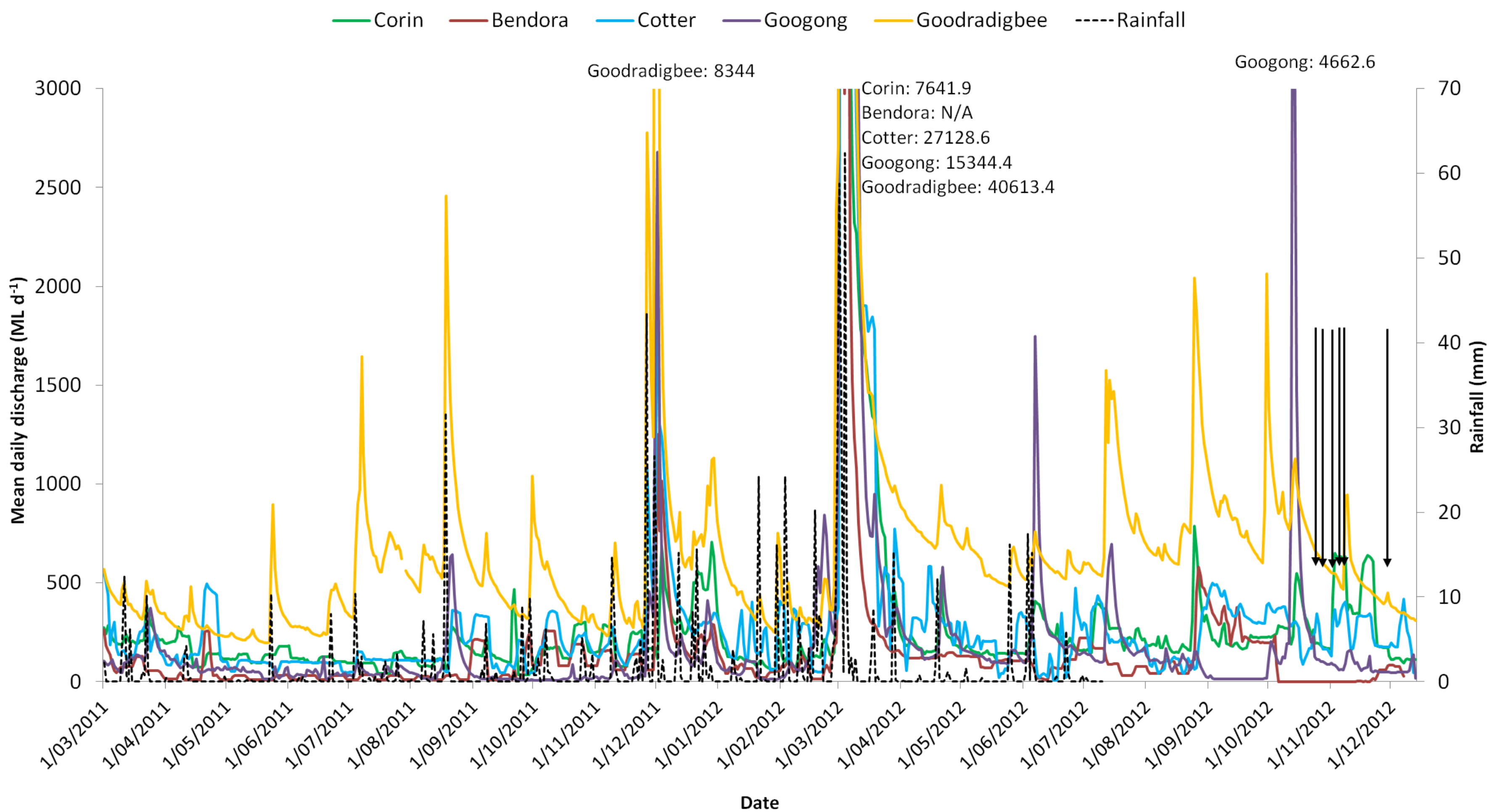

Figure 2: Mean daily discharge in the Cotter, Goodradigbee and Queanbeyan Rivers: below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams and Goodradigbee River (GM2); and daily rainfall data for Canberra airport (station: 070351) from 1/3/2011 to 12/12/2012. NB. Flow peaks >5000 ML d^{-1} are not shown on the graph. Arrows correspond to spring 2012 sampling dates (see Table 2). Data source: ACTEW Water and NSW Department of Water and Energy; Bureau of Meteorology.

Water quality

Electrical conductivity

Electrical conductivity at all sites was well below the upper trigger value of 350 µs cm^{-1}, which was similar to the past four sampling runs (Fig. 3). It should be noted that electrical conductivity is dependent upon factors such as catchment geology and rainfall, so may vary between sites.

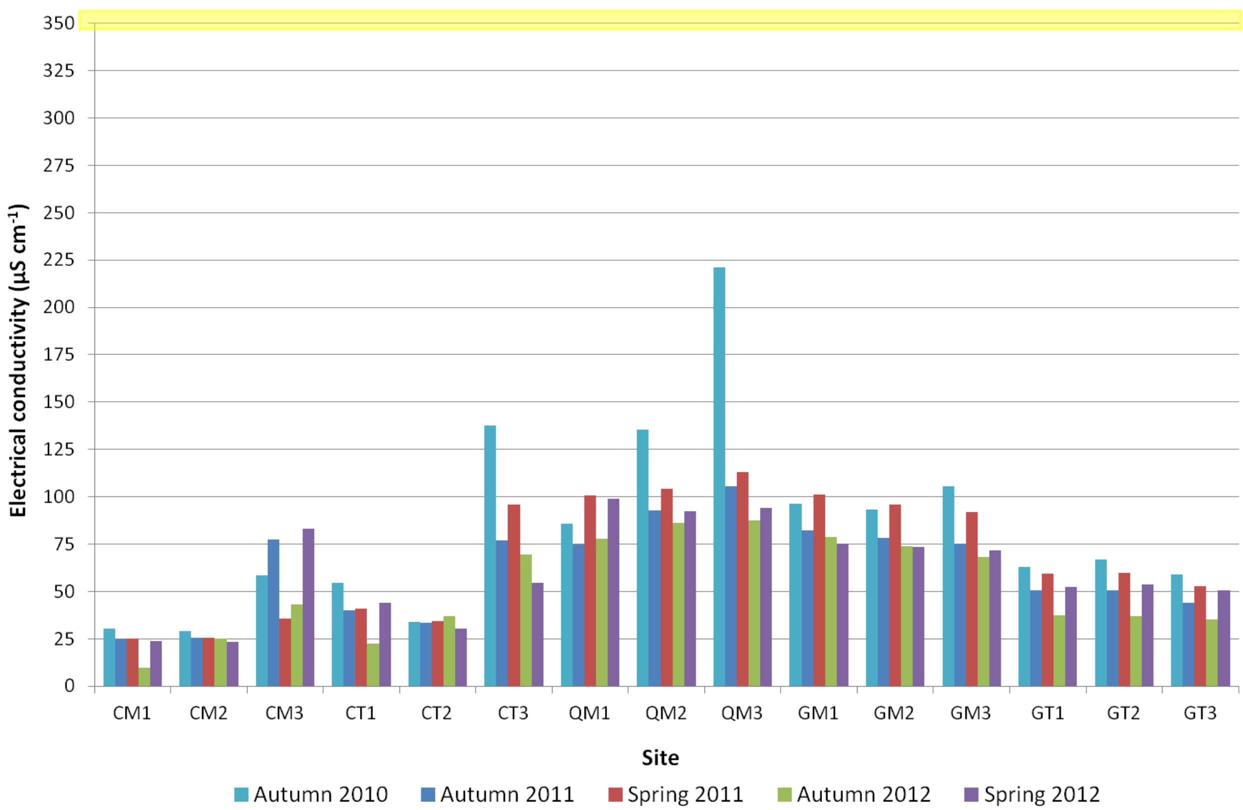

Figure 3: Electrical conductivity at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value for electrical conductivity is shaded in yellow.*

pH

pH levels were within the recommended ANZECC trigger value range of pH 6.5-8, except for sites CT3 (Paddy's River) and QM1 (Queanbeyan River) which were slightly higher than the upper trigger value of pH 8 (Fig. 4). Since autumn 2010 pH at site QM1 has increased from approximately 7 to a pH of 8.5 (Fig. 4).

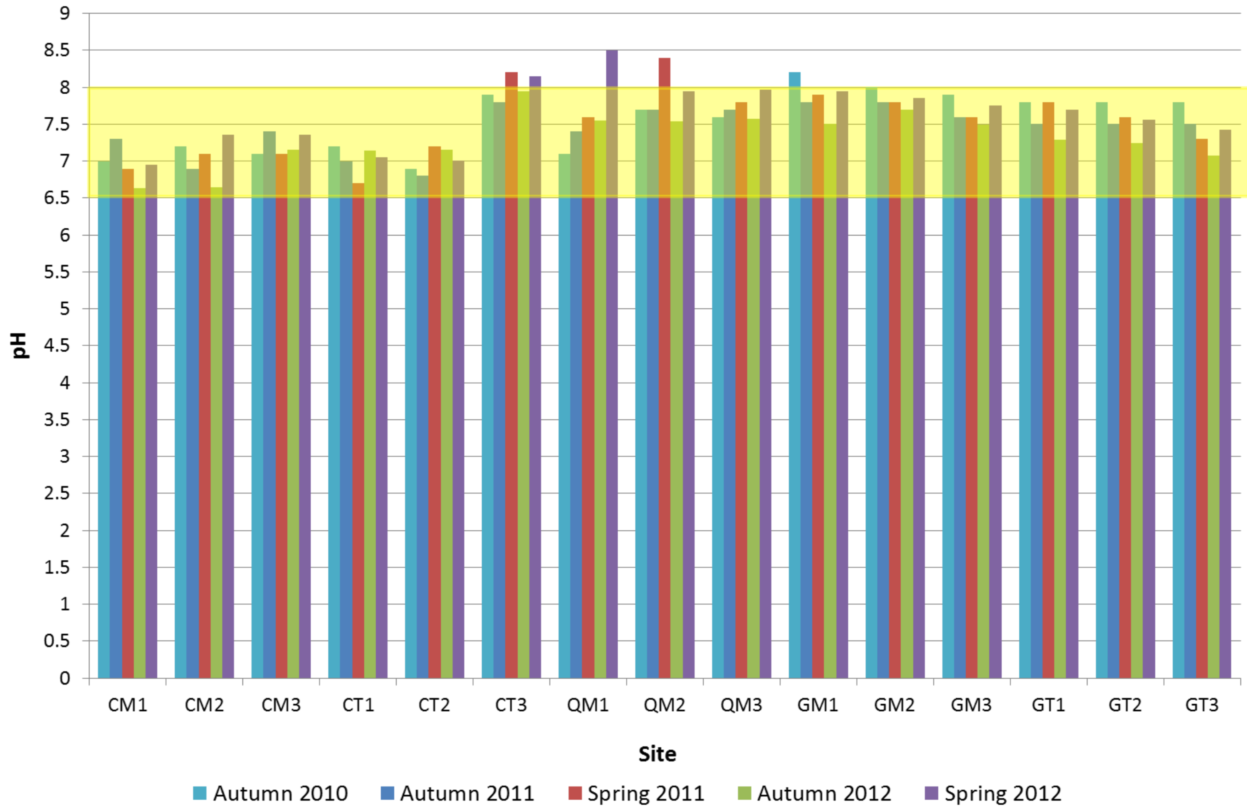

Figure 4: pH at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value range for pH is shaded in yellow.*

Dissolved oxygen

As has been the case for the previous four sampling runs, dissolved oxygen concentrations across all sites were well above the minimum trigger value of 6 mg L^{-1} (Fig. 5). Dissolved oxygen was not measured in spring 2012 at sites CM3 (Cotter Dam) and CT3 (Paddys River) because of equipment failure. However, it is likely the dissolved oxygen concentrations at both of these sites would be above the 6 mg L^{-1} because water was flowing in riffles at both sites (readings collected at site CM3 in December 2012 for a river health workshop were 9 mg L^{-1}). In spring 2012, dissolved oxygen concentrations were higher across all sites compared to spring 2011, excluding CM1 (Fig. 5)

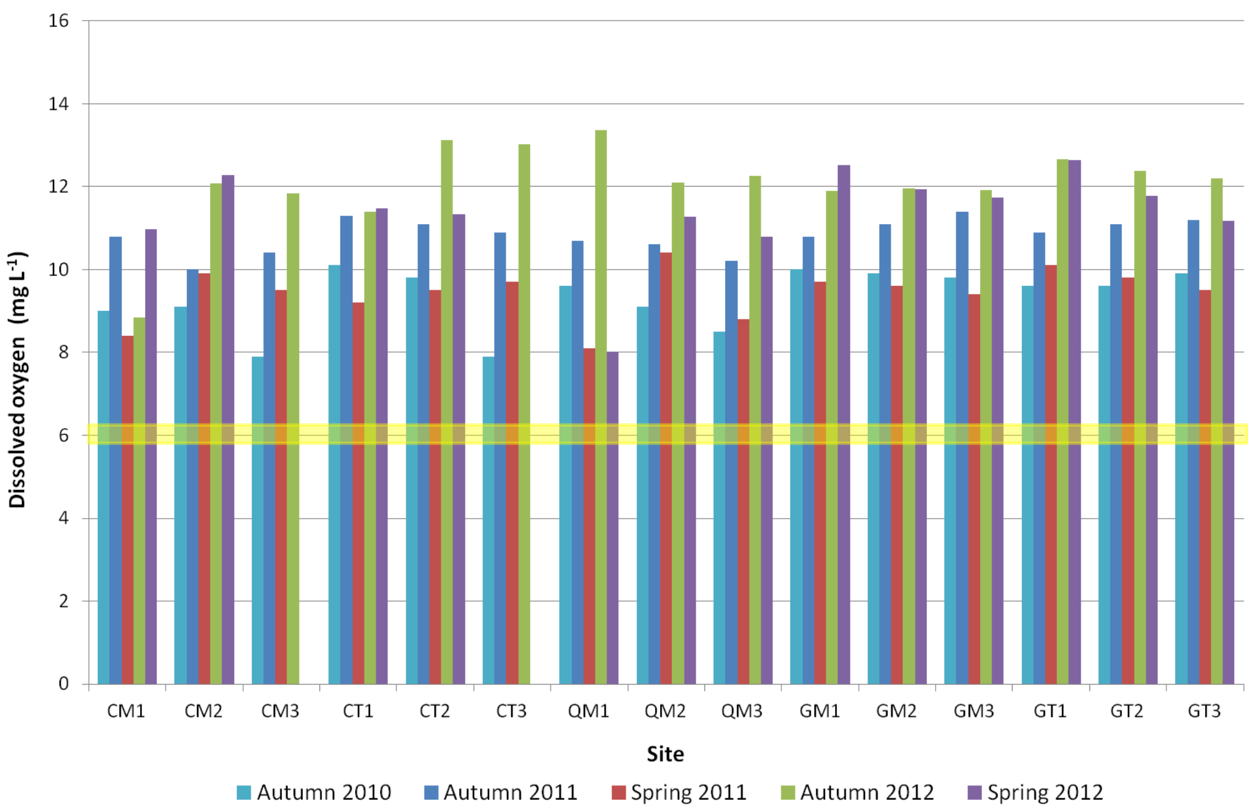

Figure 5: Dissolved oxygen concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The Environment Protection Regulations SL2005-38 trigger value for dissolved oxygen is shaded in yellow.*

Turbidity

Turbidity levels at site CM3 below Cotter Dam and site CT3 on Paddy's River were above the recommended trigger value of 10 NTU (Fig. 6).Turbidity at site CM3 declined substantially from 270.9 NTU in autumn 2012 to 29.0 NTU in spring 2012, while Paddy's River increased from 8.7 NTU in autumn 2012 to 21.0 NTU in spring 2012 (Fig. 6). All other sites were below the recommended turbidity trigger value (Fig. 6).

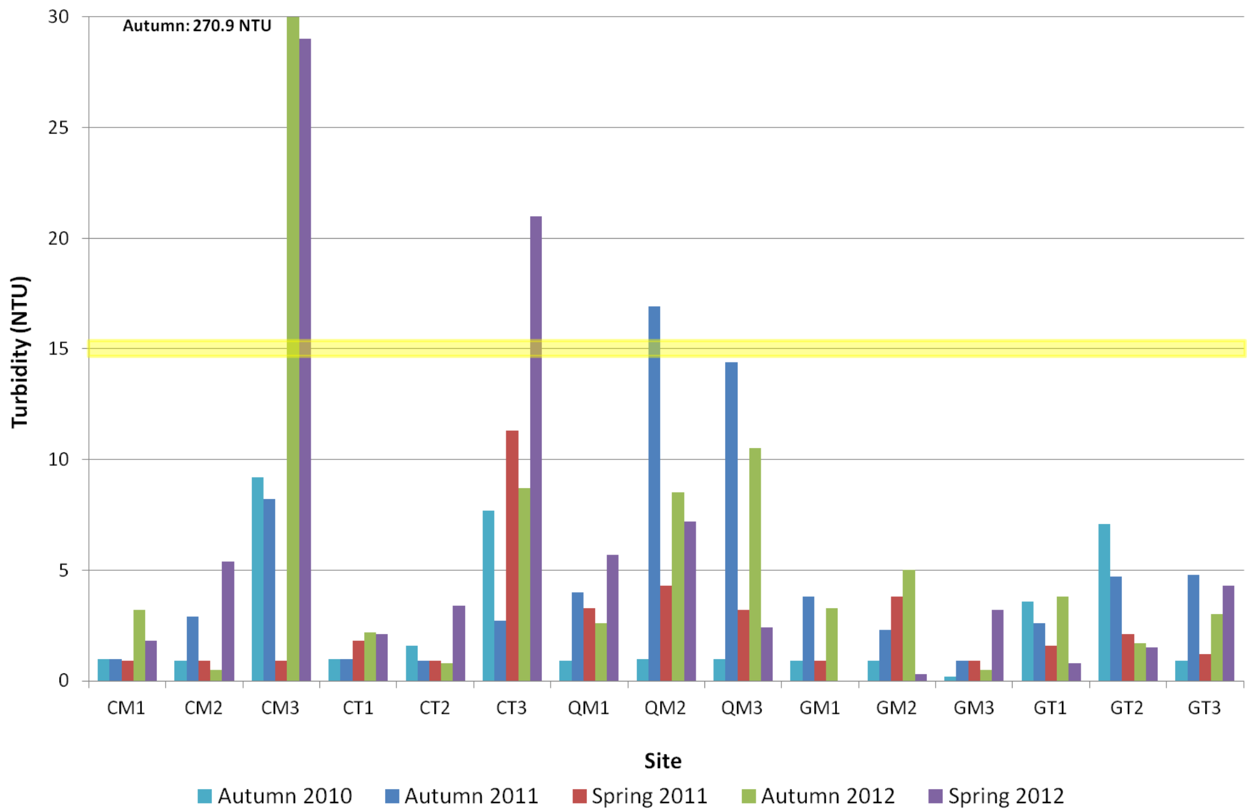

Figure 6: Turbidity at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The Environment Protection Regulations SL2005-38 trigger value for turbidity is shaded in yellow.*

Ammonia

Ammonia concentrations in spring 2012 were all below the trigger value of 0.09 mg L^{-1}, except for sites CM3 on Cotter River and CT3 on Paddy's River, which increased since autumn 2012 (Fig. 7). Ammonia concentrations increased at all sites since autumn 2012, except for site CM1 on Cotter River and Goodradigbee sites GM1 and GM2 (Fig. 7).

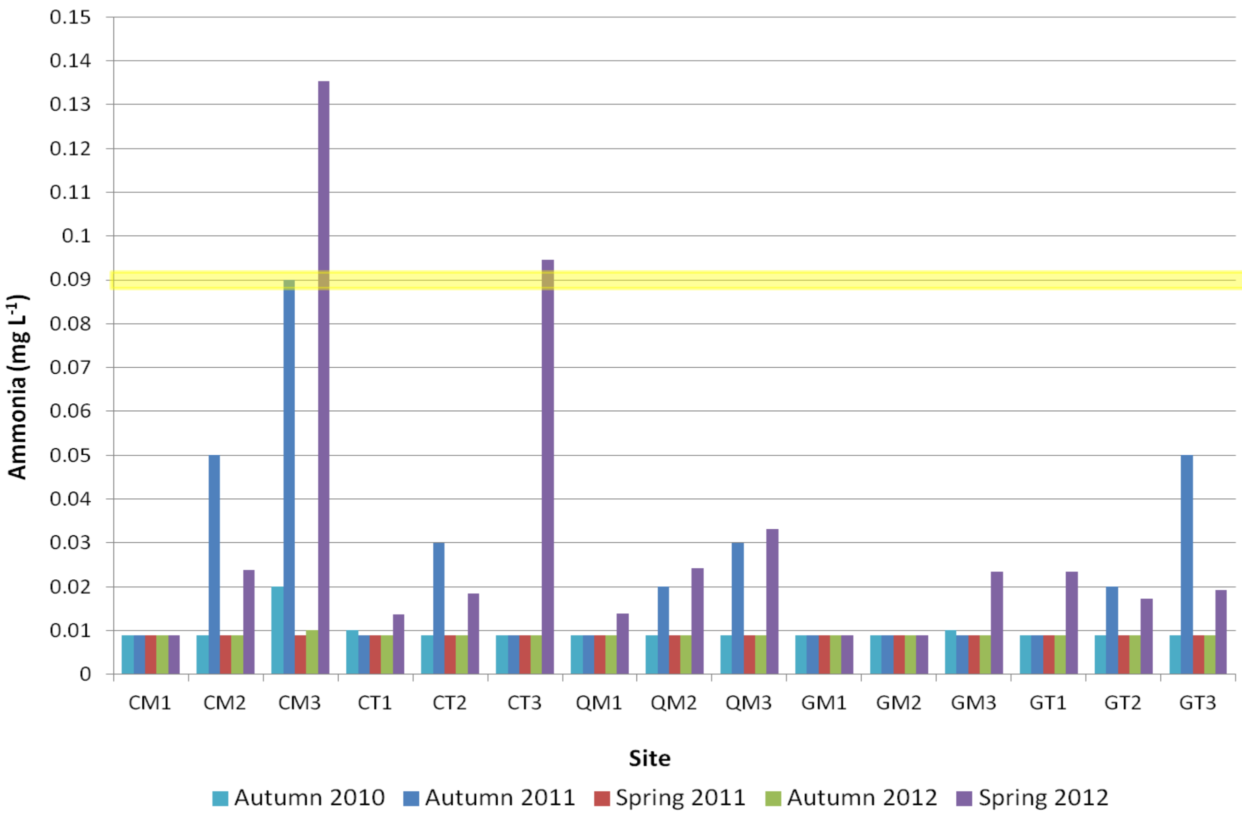

Figure 7: Ammonia (NH_3) concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value for Ammonia is shaded in yellow. The detection limit for the analysis method is 0.01 mg $L^{-1}$and values <0.01 mg L^{-1} have been to set to 0.009 mg L^{-1} on the graph.*

Nitrogen oxides

Oxidised nitrogen concentrations in spring 2012 were all below the trigger value of 0.015 mg L^{-1} (Fig. 8). Nitrogen oxide concentrations declined since autumn 2012 at sites QM2 and QM3 on Queanbeyan River (Fig. 8). With the exception of sites CM3 below Cotter Dam and CT3 on Paddys River where nitrogen oxide concentrations increased from autumn 2012, all other sites were similar to the past four sampling periods (Fig. 8).

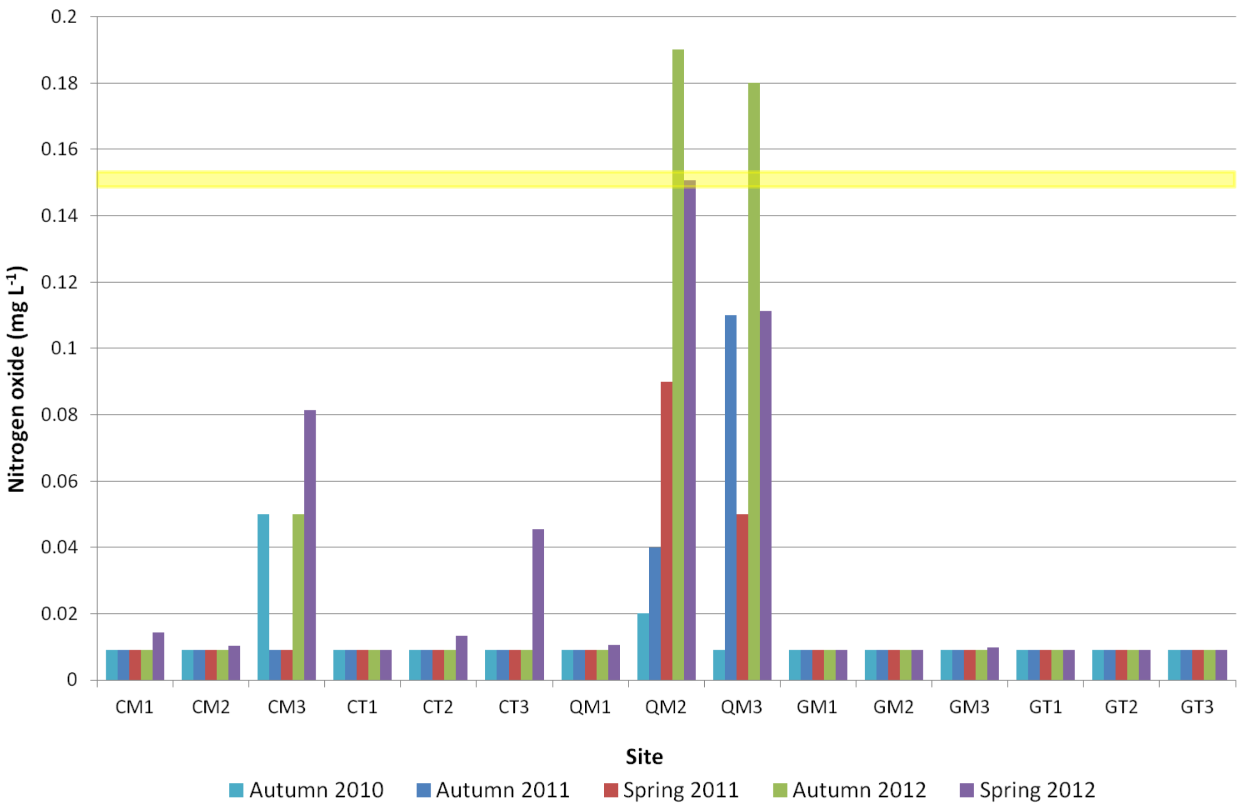

Figure 8: Nitrogen oxide concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value for nitrogen oxide is shaded in yellow. The detection limit for the analysis method is 0.01 mg $L^{-1}$and values <0.01 mg L^{-1} have been to set to 0.009 mg L^{-1} on the graph.*

Total phosphorus

Total phosphorus (TP) concentrations below Cotter Dam (CM3), Paddy's River (CT3), Kangaroo Creek (CT1), Queanbeyan River (QM1, QM2, QM3) and Goodradigbee tributaries (GT1, GT2, GT3) were above the trigger value of 0.02 mg L^{-1} (Fig. 9). With the exception of site CM3, TP concentrations increased at all sites since autumn 2012 (Fig. 9).

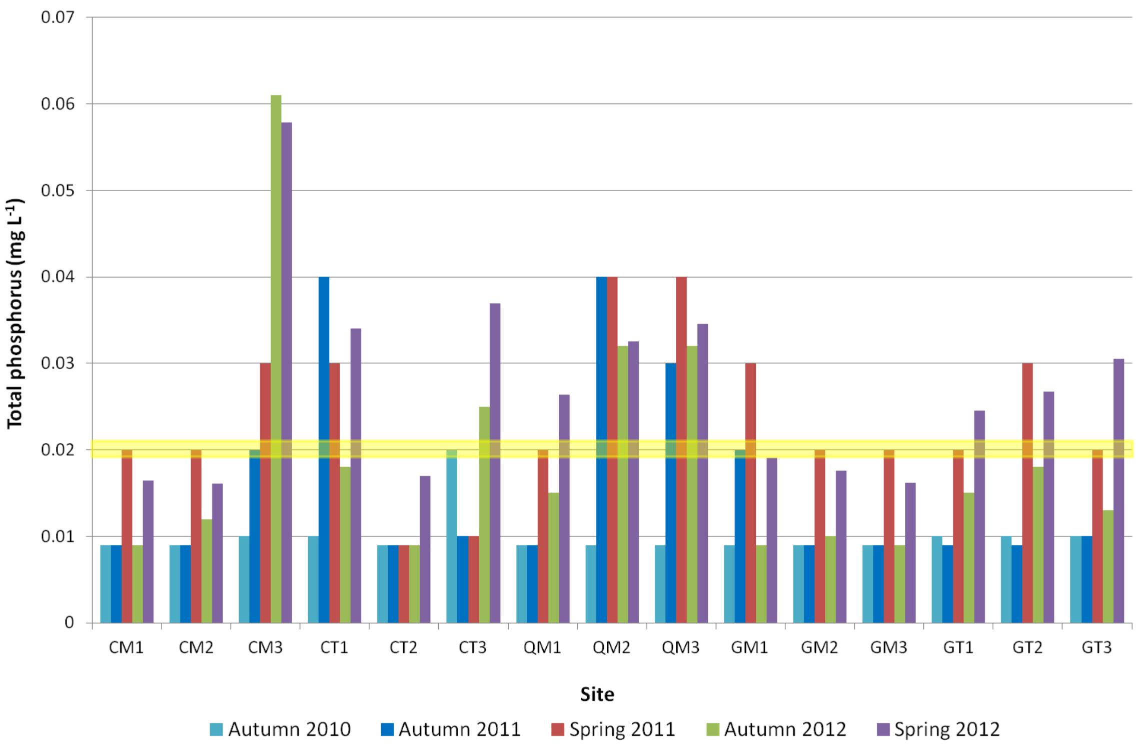

Figure 9: Total phosphorus concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) in spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value for total phosphorus is shaded in yellow. The detection limit for the analysis method is 0.01 mg $L^{-1}$and values <0.01 mg L^{-1} have been set to 0.009 mg L^{-1} on the graph.*

Total nitrogen

Total nitrogen (TN) concentrations in spring 2012 at sites below Cotter Dam (CM3), Googong Dam (QM2 and QM3) and on Paddys River (CT3) were above the trigger value of 0.25 mg L^{-1} (Fig. 10). Site QM1 upstream of Googong Dam had declined since autumn 2012 to being below the trigger value in spring 2012. TN concentrations below Cotter Dam (CM3) and on Paddy's River (CT3) increased since autumn 2012 (Fig. 10). TN concentrations below Googong Dam (QM2, QM3) declined since autumn 2012 (Fig. 10).

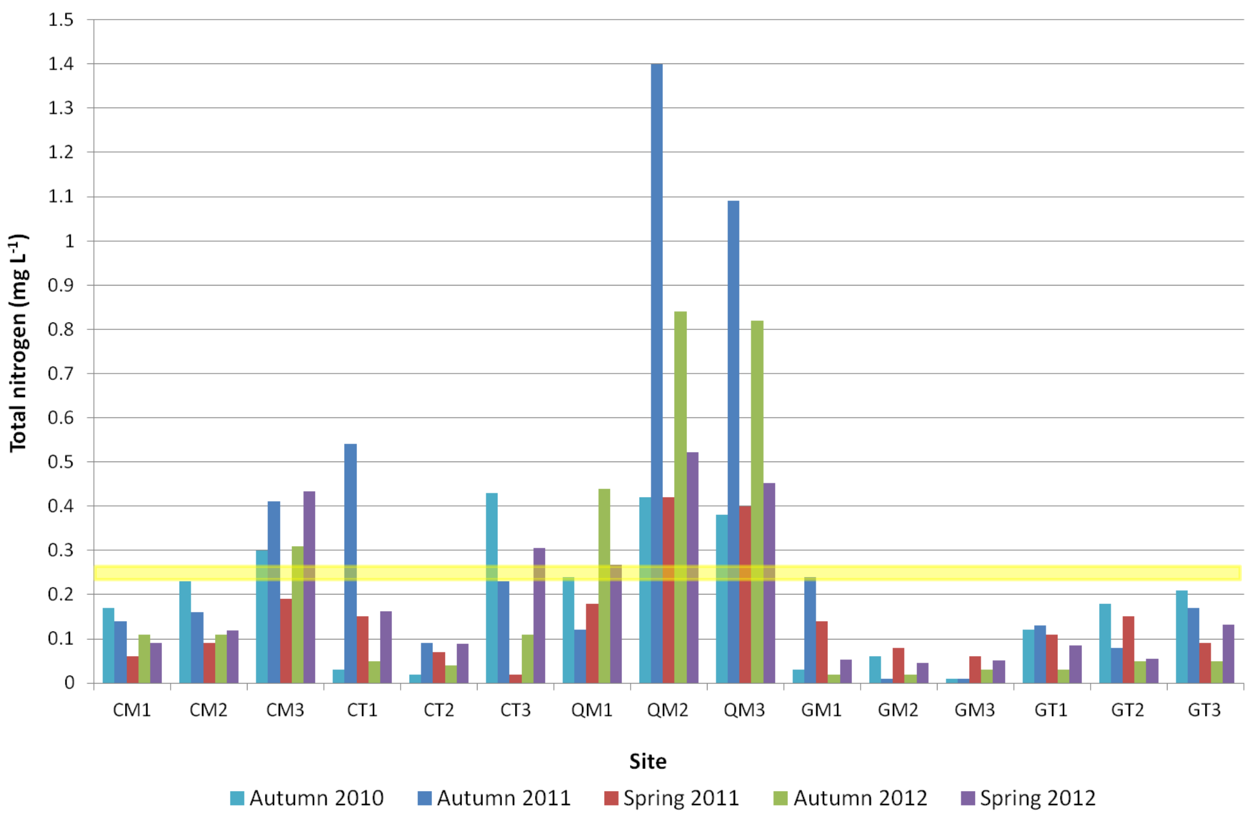

Figure 10: Total nitrogen concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3, GT1, GT2, GT3) spring 2012, and previously in autumn 2012, spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value for total nitrogen is shaded in yellow. The detection limit for the analysis method is 0.01 mg L^{-1} and values <0.01 mg L^{-1} have been to set to 0.009 mg L^{-1} on the graph.*

Periphyton and algae

Visual observations

In spring 2012, periphyton cover within the riffle and reach increased below Bendora (CM2) and Cotter (CM3) Dams from <10 % in autumn 2012 to 10-35 % in spring 2012 (Table 8). Periphyton cover within the riffle and reach at all other sites (CM1, QM2, GM1, GM2 and GM3) remained the same in spring 2012 compared to autumn 2012 (Table 8). The periphyton cover within the riffle and reach was < 10 % in spring 2012 for Goodradigbee sites GM1 and GM2 and below Corin Dam (CM1) (Table 8). Below Googong Dam (QM2) periphyton cover was <10 % in the riffle habitat and 10-35 % within the reach. While, Goodradigbee site GM3 had 10-35 % periphyton cover within the riffle and reach in spring 2012 (Table 8).

Filamentous algae cover within the riffle and reach at all Goodradigbee sites (GM1, GM2 and GM3), below Googong (QM2) and Cotter (CM3) Dams was <10 % and were all similar in spring 2012 when compared to autumn 2012 (Table 8). Filamentous algae cover within the riffle and reach increased from <10 % in autumn 2012 to 10-35 % (on the cusp of being above the ecological objective) in spring 2012 below Corin Dam (CM1) (Table 8). Filamentous algae cover within the riffle and reach increased substantially from <10 % in autumn 2012 to >90 % (above the ecological objective) in spring 2012 at below Bendora Dam (CM2) (Fig. 11 and Table 8).

Table 8: Percent cover categories of periphyton and filamentous algae in the riffle and reach at below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong) and reference sites GM1, GM2 and GM3 (Goodradigbee River), spring 2012, and previously in autumn 2012, spring 2011, autumn 2011, autumn 2010 and spring 2009. *Sites that did not reach the specific environmental flow ecological objective of < 20 % riffle filamentous cover are shaded in red; on the cusp of the of not meeting the objective are shading in yellow and within the objective are shaded in green*. ***Note in spring 2011 site CM1 was located closer to Corin Dam***

Site	% cover of riffle												% cover of reach											
	Periphyton						Filamentous algae						Periphyton						Filamentous algae					
	Spr-09	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12	Spr-09	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12	Spr-09	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12	Spr-09	Aut-10	Aut-11	Spr-11	Aut-12	Spr-12
CM1	<10	<10	<10	35-65	<10	<10	<10	<10	<10	10-35	<10	10-35	<10	<10	<10	10-35	<10	<10	<10	<10	<10	10-35	<10	10-35
CM2	<10	<10	<10	10-35	<10	10-35	<10	<10	<10	10-35	<10	> 90	10-35	<10	<10	10-35	<10	10-35	<10	<10	<10	10-35	<10	> 90
CM3	10-35	10-35	<10	<10	<10	10-35	<10	<10	<10	<10	<10	< 10	65-90	10-35	<10	<10	<10	10-35	<10	<10	<10	<10	<10	< 10
QM2	10-35	<10	<10	35-65	<10	< 10	<10	<10	<10	10-35	<10	< 10	65-90	<10	<10	35-65	10-35	10-35	<10	<10	<10	10-35	<10	< 10
GM1	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10	< 10
GM2	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10	< 10	<10	<10	<10	<10	<10	< 10
GM3	10-35	<10	<10	<10	10-35	10-35	10-35	<10	<10	<10	<10	< 10	35-65	<10	<10	<10	10-35	10-35	35-65	<10	<10	<10	<10	< 10

Figure 11: Filamentous algae in the riffle at site CM2 downstream of Bendora Dam.

AFDM (biomass) and chlorophyll-a

AFDM variability between sites and seasons spring 2009 – spring 2012

For AFDM there was a significant interaction between sampling site and season in (Table 9, Fig. 12). The differences between seasons were focussed on sites below Bendora Dam (CM2), Googong Dam (CM3) the Goodradigbee reference site GM1 and are likely the result of increased river flows from recent flooding, which have likely scoured periphyton/algae and caused a decline in AFDM. These differences included:

- In autumn 2010 AFDM below Bendora Dam was significantly higher than autumn 2012 (Fig. 12).
- In spring 2009 the AFDM below Googong Dam was significantly higher than autumn 2011 (Fig. 12)
- In autumn 2010 AFDM at Goodradigbee reference site GM1 was significantly higher than autumn 2011, autumn 2012 and spring 2012 (Fig. 12).

AFDM differences between sites – spring 2012

In spring 2012, AFDM was significantly higher below Bendora Dam (CM2) compared to all other below dam sites and reference sites on the Goodradigbee River (Fig. 12). AFDM at Goodradigbee reference site GM2 was also significantly lower than AFDM below Cotter and Googong Dams (CM3 and QM2) ($F=14.59$; $df = 6,14$; $p<0.0001$).

Chlorophyll-a variability between sites and seasons spring 2009 – spring 2012

Chlorophyll-a concentrations have been highly variable between sites and seasons (Fig. 13), possibly because of changes in the types of periphyton/algae taxa present which are not measured as a part of this project. There was a significant interaction between sampling site and season in terms of Chlorophyll-a concentration (Table 9, Fig. 13). The differences between seasons were focussed on sites below Bendora Dam (CM2), Cotter Dam (CM3) the Goodradigbee reference sites: These differences included:

- In spring 2009 chlorophyll-a was significantly lower below Corin and Bendora Dams compared to autumn 2011 (Fig. 13).
- In spring 2009 chlorophyll-a was significantly lower below Cotter Dams compared to autumn 2010 (Fig. 13).

- In autumn 2010 and 2011 chlorophyll-a concentrations were significantly greater below Bendora Dam, Cotter Dam and at the Goodradigbee reference sites compared to spring 2011 (Fig. 13).

- In spring 2011 chlorophyll-a was significantly lower below Cotter Dam and at Goodradigbee reference sites GM1 and GM3 compared to autumn 2012 (Fig. 13).

- In spring 2012 chlorophyll-a was significantly greater below Bendora Dam, Cotter Dam and Goodradigbee reference site GM1 compared to spring 2011 (Fig. 13).

Chlorophyll-a differences between sites – spring 2012

In spring 2012, chlorophyll-a concentration was highest downstream of Bendora Dam (Fig. 15). However, because of high within site variability, chlorophyll-a concentration at site CM2 was only significantly higher than site QM2 downstream of Googong Dam ($F=3.04$; $df = 6,14$; $p = 0.0404$)(Fig. 13).

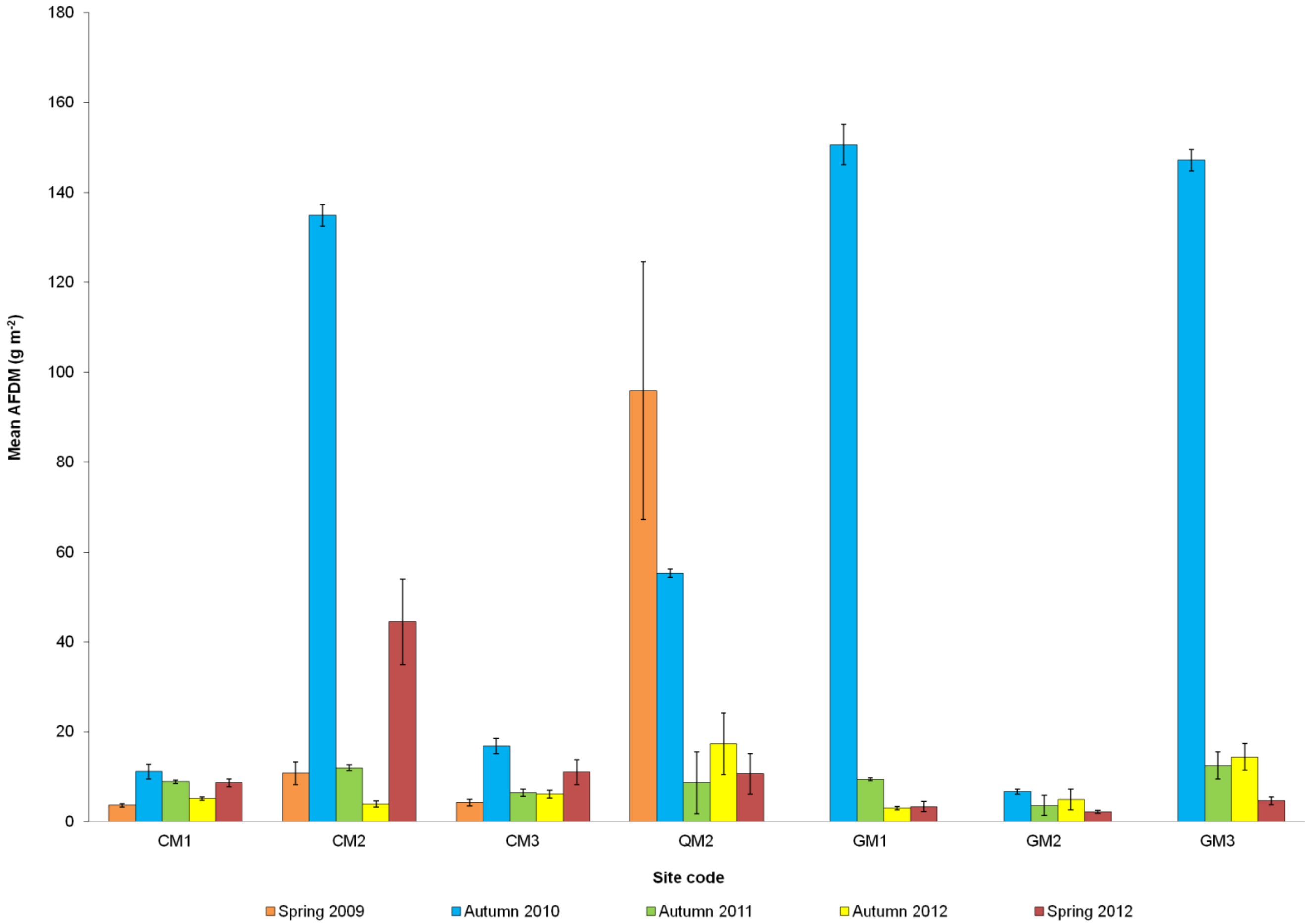

Figure 12: Mean AFDM (g m^{-2}) at below dam sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong) and reference sites GM1, GM2 and GM3 (Goodradigbee River) from spring 2009, autumn 2010, autumn 2011, autumn 2012, and spring 2012. Error bars represent +/- 1 standard error.

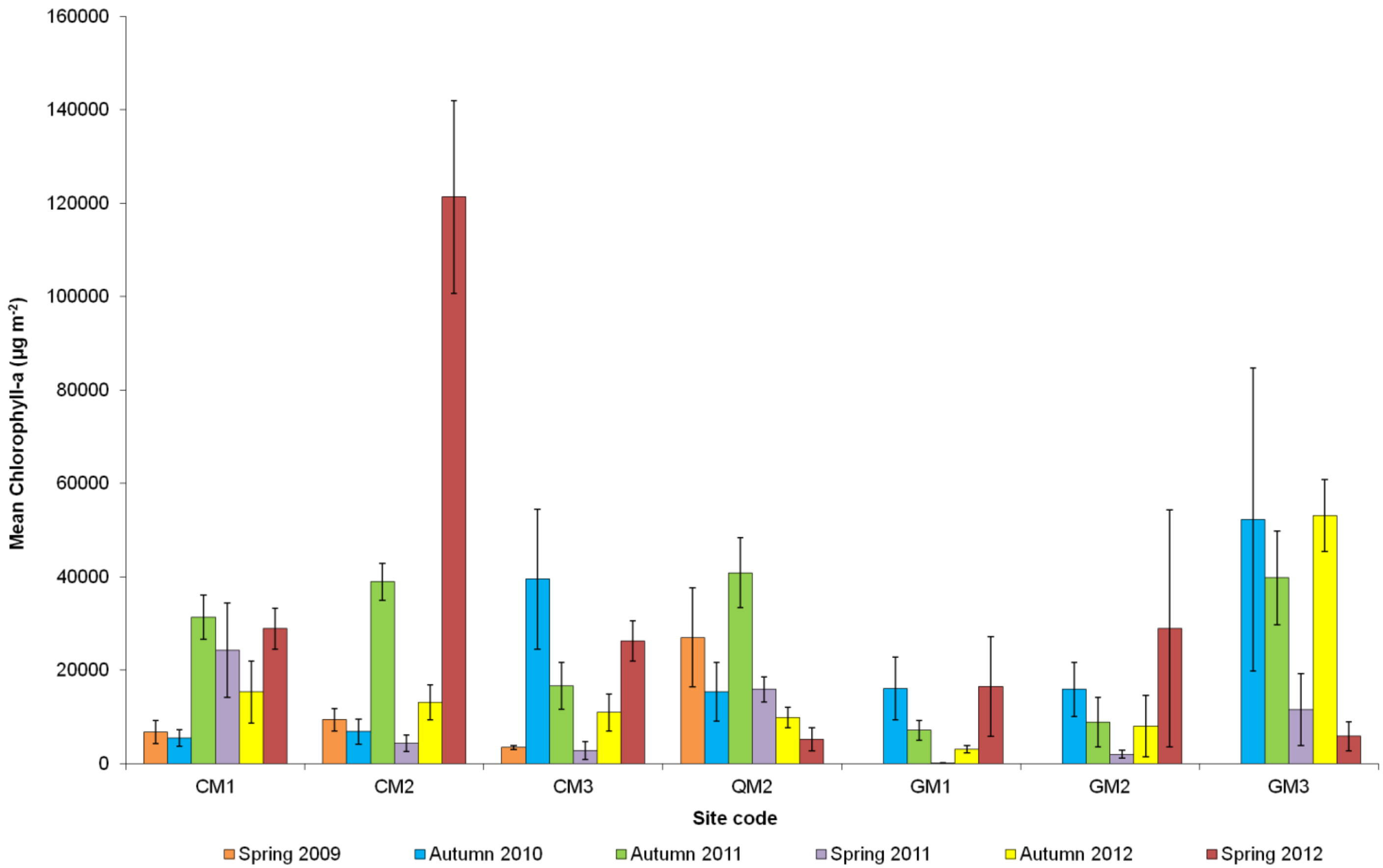

**Figure 13: Mean chlorophyll-a (µg m^{-2}) at below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong) and reference sites GM1, GM2 and GM3 (Goodradigbee River) from spring 2009, autumn 2010 , autumn 2011, spring 2011,autumn 2012 and spring 2012. Error bars represent +/- 1 standard error. ****Note in spring 2011 site CM1 was located closer to Corin Dam.*

Table 9: Effects of site and season on periphyton biomass and chlorophyll-a concentration tested using two-way analysis of variance (ANOVA).

Source of variation	Site			Season			Site*Season		
	DF	F	P	DF	F	P	DF	F	P
Biomass	6	6.08	<0.0001	4	10.49	0.0015	18	2.25	0.0007
Chlorophyll-a	6	8.15	<0.0001	5	68.20	<0.0001	27	3.96	<0.0001

Benthic macroinvertebrates

Relative abundance

The relative abundance of pollution tolerant Chironomidae, Diptera (other families) and Oligochaeta was greatest at below dam sites on the Cotter and Queanbeyan Rivers (CM1, CM2, CM3, QM2 and QM3) and Paddys River (CT3) (Fig. 14). Pollution sensitive Ephemeroptera, Plecoptera and Trichoptera were most abundant at reference sites on the Goodradigbee River (GM1, GM2, GM3), Goodradigbee trbutaries (GT1, GT2, GT3), Cotter tributary sites (CT1, CT2) and upstream of Googong Dam on the Queanbeyan River (QM1) (Fig. 14).

Taxonomic richness and whole sample abundance

Taxonomic richness was generally higher at reference sites than at below dam sites, with reference all sites on the Goodradigbee River (GM1, GM2, GM3) and Cotter Tributary sites (CT1, CT2) having the highest taxonomic richness (Fig. 15). Taxonomic richness was lowest at below dam sites on the Cotter River (CM1, CM3) and Queanbeyan Rivers (QM2) and Paddys River (CT3) (Table 10). The estimated whole sample abundance was greatest below Cotter Dam (CM3), which consisted predominately of pollution tolerant Simuliidae, and at reference sites GM1 and GM2 on the Goodradigbee River (Appendix 1).

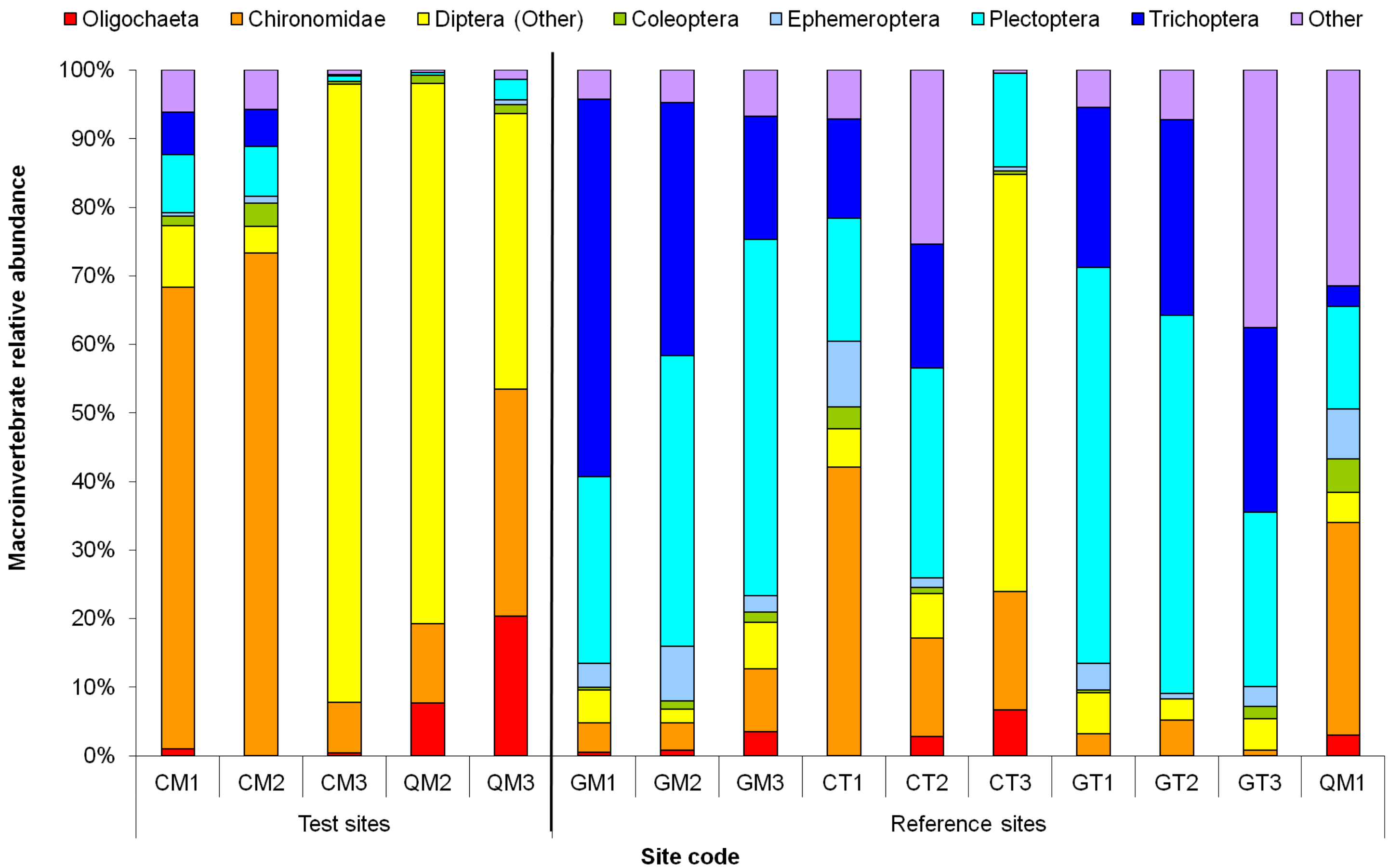

Figure 14: Relative abundance of macroinvertebrates taxa groups at each site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), spring 2012.

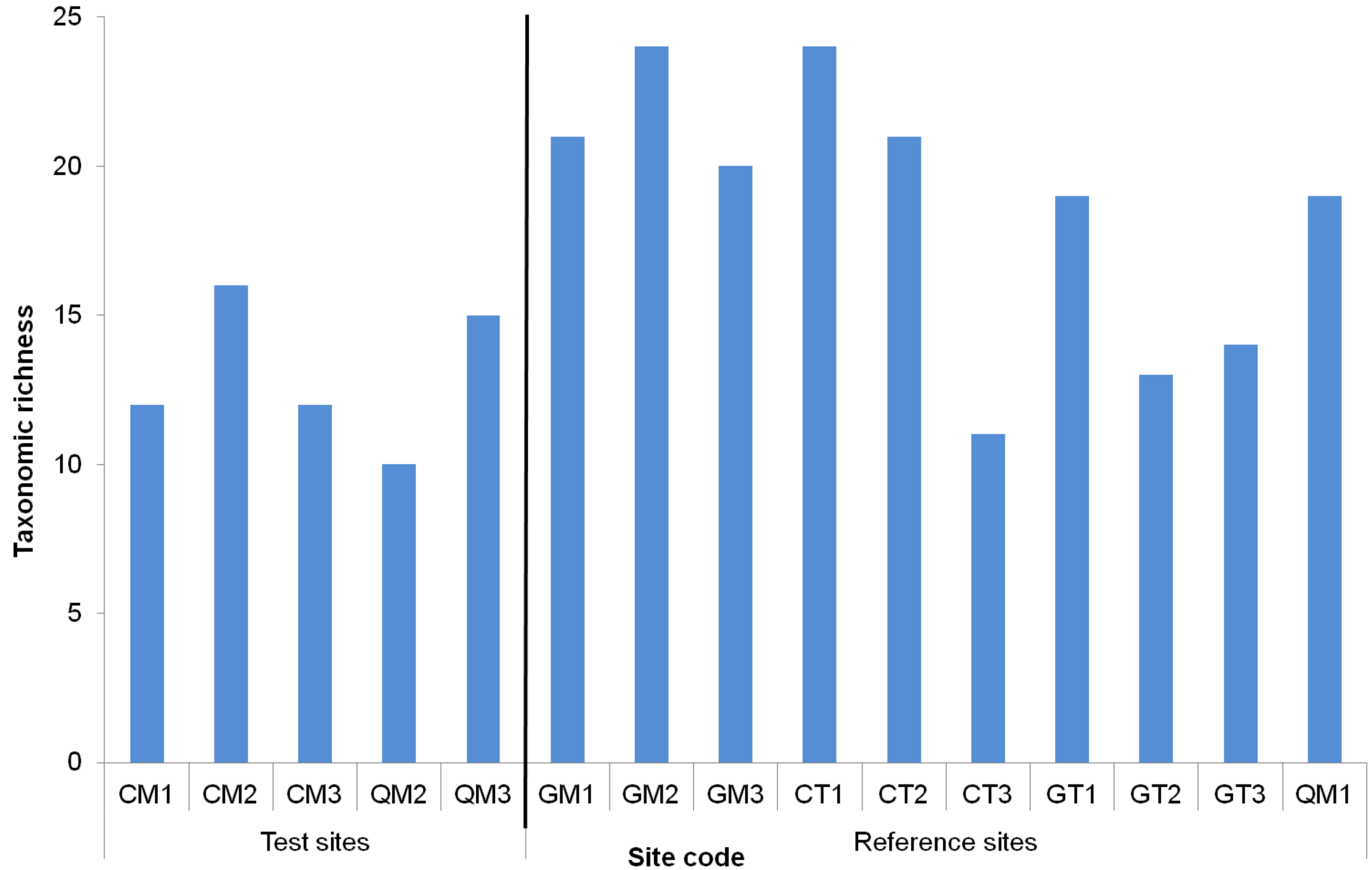

Figure 15: Taxonomic richness at each site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), spring 2012.

AUSRIVAS

The AUSRIVAS results for spring 2012 indicated that all sites on the Goodradigbee tributaries (GT1, GT2 and GT3) had declined in condition from being similar to reference in autumn 2012 (band A) to being significantly impaired in spring 2012 (band B). Reference sites on the Goodradigbee River (GM1 and GM3) improved in condition since autumn 2012 (Table 10). Site GM1 improved from being severely impaired in autumn 2012 (band C) to being similar to reference (band A) in spring 2012. Site GM3 improved from being significantly impaired in autumn 2012 (band B) to being similar to reference condition (band A), while site GM2 went from significantly impaired in spring 2012 (band B) to being more biologically diverse than reference condition (band X).

Sites on Queanbeyan River both upstream (QM1) and downstream (QM3) of Googong Dam remained in stable condition since autumn 2012 sampling, with QM1 remaining similar to reference condition (band A) and QM2 remaining significantly impaired (band B) since autumn 2012 (Table 10). Site QM2 improved from being severely impaired (band C) in autumn 2012 to being significantly impaired (band B) in spring 2012 (Table 10).

Sites on the Cotter River downstream of both Corin and Bendora Dams (CM1 and CM2) remained in the same condition since autumn 2012 (significantly impaired – band B; Table 10). Site CM3 downstream of Cotter Dam improved in condition from being extremely impaired (band D) in autumn 2012 to being significantly impaired (band B) in spring 2012 (Table 10). Cotter tributary sites CT2 and CT3 improved in condition since autumn 2012, from a band B to band A and band C to a band B respectively in spring 2012 (Table 10). Site CT1 went from being similar to reference condition in autumn 2012 to being more biologically diverse than reference condition (band X) in spring 2012 (Table 10).

Taxa that were expected to occur by the AUSRIVAS model but were not identified in the sub-samples had SIGNAL 2 grades ranging from 2 to 9 (Appendix 2). Five of these taxa were present in the sample scans for seven sites (Hydropsychidae – GM1, CT3, GT1, GT2 and QM2; Glossomatidae – CM1; Gripopterygidae – CT3; Leptophlebiidae – QM2; Tipulidae – QM3). Taxa found in scans were not abundant enough to be collected in the sub-sample and the presence of these taxa indicates the sites potential to increase in condition under favourable conditions (Appendices 2 and 3).

**Table 10: AUSRIVAS band and O/E score for each site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), between autumn 2010 and spring 2012. ****Note in spring 2011 site CM1 was located closer to Corin Dam.*

	Site														
	CM1	**CM2**	**CM3**	**CT1**	**CT2**	**CT3**	**QM1**	**QM2**	**QM3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Spring 2012	**B** (0.77)	**B** (0.82)	**B** (0.73)	**X** (1.26)	**A** (1.12)	**B** (0.68)	**A** (1.01)	**B** (0.64)	**B** (0.77)	**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)	**A** (0.93)	**B** (0.83)	**C** (0.56)	**A** (0.97)	**C** (0.63)	**B** (0.70)	**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)	**B** (0.82)	**A** (1.00)	**A** (1.03)	**X** (1.20)	**A** (0.88)	**A** (0.92)	**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)	**X** (1.17)	**B** (0.81)	**A** (0.89)	**A** (0.96)	**A** (0.96)	**B** (0.67)	**X** (1.16)	**C** (0.57)	**A** (1.05)	**A** (1.04)	**A** (0.93)	**A** (0.95)
Autumn 2010	**B** (0.74)	**A** (1.04)	**B** (0.83)	**B** (0.81)	**B** (0.77)	**C** (0.58)	**A** (0.96)	**A** (0.97)	**B** (0.83)	**X** (1.16)	**A** (1.03)	**A** (0.92)	**A** (1.01)	**X** (1.22)	**B** (0.82)

Macroinvertebrate assemblage similarity

Based on relative abundance data three groups of sites were identified in the cluster analysis (SIMPROF test $p < 0.05$) (Fig 16). Group one contained sites below Corin (CM1) and (CM2) Bendora Dams and site QM1 on Queanbeyan River upstream of Googong Dam (Fig 16). Group two contained Queanbeyan River sites downstream of Googong Dam (QM2 and QM3), Cotter tributary site (CT3) and site CM3 below Cotter Dam (Fig 16). Group three contained all Goodradigbee River (GM1, GM2, GM3) and tributary sites (GT1, GT2, GT3), as well as Cotter tributary sites CT1 on Kangaroo Creek and CT2 on Burkes Creek (Fig. 16). Compared to sites in group one and two, group three sites were characterised by greater taxonomic richness and abundance of pollution sensitive taxa with SIGNAL2 grades higher than 6 (Tables 11 and 12). Compared to sites in group one, group two sites were characterised by lower taxonomic richness and abundance of pollution tolerant taxa (Tables 11 and 12).

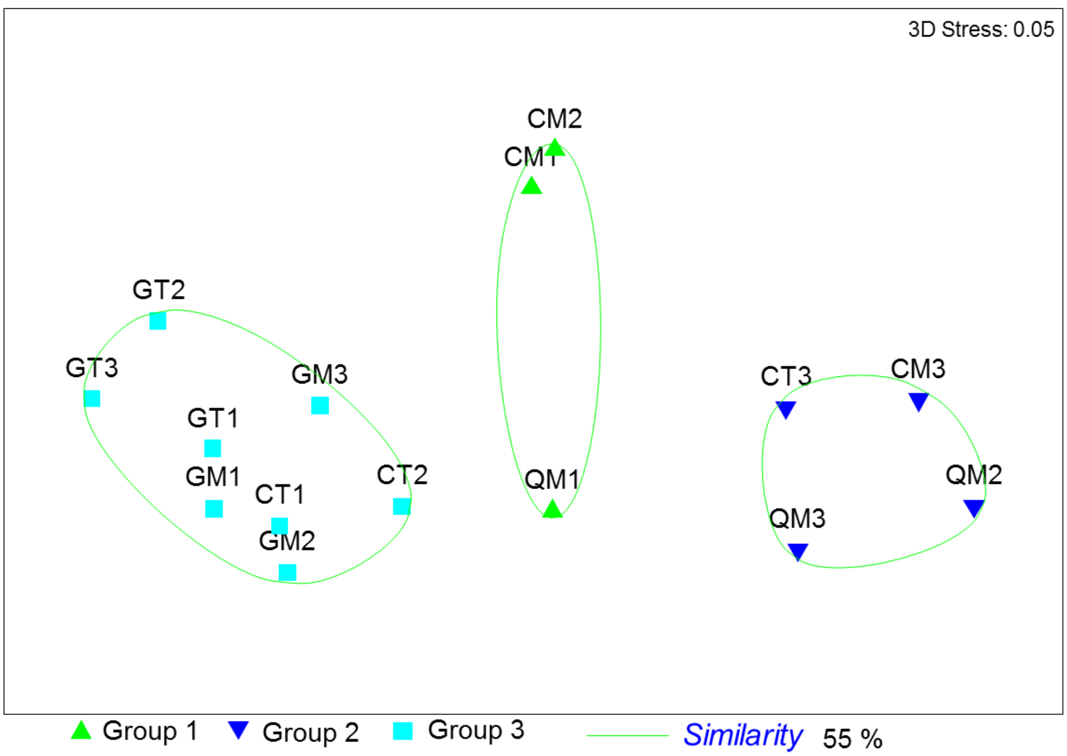

Figure 16: MDS ordination of similarity between macroinvertebrate samples collected in spring 2012 for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance and groups are defined from a cluster analysis and SIMPROF test.

Table 11: Macroinvertebrate taxa and their corresponding SIGNAL 2 grades (Chessman, 2003) defined from SIMPER analysis on relative abundance data that contribute to each cluster analysis group. (Note – Average abundance values are based on fourth root transformed values and the top ~70% of contributing taxa are shown).

Group	Taxa	SIGNAL 2 grade	Average abundance	Consistency ratio	Contribution %	Cumulative %
Group 1						
	Orthocladiinae	4	2.58	2.88	19.32	19.32
	Leptophlebiidae	8	1.75	8.69	13.56	32.88
	Gripopterygidae	8	1.47	4.71	11.57	44.45
	Hydrobiosidae	8	1.31	3.74	10.1	54.55
	Acarina	6	1.23	12.3	9.5	64.05
	Empididae	5	1.3	3.45	9.27	73.32
	Simuliidae	5	1.09	8.6	8.55	81.87
Group 2						
	Simuliidae	5	2.83	5.31	27.02	27.02
	Orthocladiinae	4	1.95	12.79	17.5	44.52
	Oligochaeta	2	1.53	2.8	11.65	56.18
	Baetidae	5	1.1	10.01	8.67	64.85
	Hydrobiosidae	8	0.86	9.96	8.29	73.14
	Chironominae	3	0.93	10.14	8.15	81.3
	Acarina	6	0.78	6.73	6.86	88.16
Group 3						
	Gripopterygidae	8	2.25	6.4	12.52	12.52
	Leptophlebiidae	8	2.17	7.45	12.13	24.65
	Baetidae	5	1.6	3.12	7.87	32.52
	Tipulidae	5	1.27	5.35	6.87	39.39
	Conoesucidae	7	1.37	3.06	6.21	45.59
	Leptoceridae	6	1.14	4.06	6.13	51.72
	Podonominae	6	1.13	4.92	5.79	57.51
	Hydrobiosidae	8	1.03	4.76	5.26	62.77
	Orthocladiinae	4	1.11	1.64	4.79	67.56
	Elmidae	7	0.9	1.67	4.16	71.72

Table 12: Macroinvertebrate taxa and their corresponding SIGNAL 2 grades (Chessman, 2003) defined from SIMPER analysis on relative abundance data that discriminate between cluster analysis groups. (Note – Average abundance values are based on fourth root transformed values and discriminating taxa are defined as having a consistency ratio ≥ 1.4).

Taxa	SIGNAL2 grade	Average abundance		Consistency ratio
		Group 1	***Group 2***	
Simuliidae	5	1.09	2.83	4.05
Gripopterygidae	8	1.47	0.14	3.8
Leptophlebiidae	3	1.75	0.59	1.68
Oligochaeta	2	0.76	1.53	1.52
Orthocladiinae	4	2.58	1.95	1.45
Chironominae	3	1.06	0.93	1.87
Hydrobiosidae	8	1.31	0.86	2.26
Acarina	6	1.23	0.78	2.56
		Group 1	***Group 3***	
Orthocladiinae	4	2.58	1.11	1.88
Leptoceridae	6	0	1.14	3.92
Podonominae	6	0	1.13	3.83
Baetidae	5	0.56	1.6	1.53
Coloburiscidae	8	0	0.96	1.52
Gripopterygidae	8	1.47	2.25	2.99
Caenidae	4	0.28	0.93	1.44
Hydrobiosidae	8	1.31	1.03	1.54
		Group 2	***Group 3***	
Simuliidae	5	2.83	0.7	3.37
Gripopterygidae	8	0.14	2.25	5.01
Leptophlebiidae	3	0.59	2.17	2.11
Conoesucidae	7	0	1.37	2.22
Podonominae	6	0	1.13	3.83
Oligochaeta	2	1.53	0.55	1.61
Tipulidae	5	0.2	1.27	2.63
Leptoceridae	6	0.19	1.14	2.11
Coloburiscidae	8	0	0.96	1.54
Elmidae	7	0	0.9	2.45
Orthocladiinae	4	1.95	1.11	1.43

Discussion and conclusions

Water quality

Water quality at below dam sites and at unregulated reference sites was generally within the recommended guideline trigger values in spring 2012 (Table 3). There were, however, four exceptions, (1) pH was slightly above the trigger level at test site CT3 on Paddy's River and at reference site QM1 above Googong Dam (Fig 4); (2) turbidity and ammonia were above trigger levels below Cotter Dam (CM3) and on Paddys River (CT3) (Figs 6 and 7); (3) total phosphorus was above the trigger level below Cotter Dam (CM3), below Googong Dam (QM2 and QM3) at Cotter tributary sites CT1 and CT3 and at all Goodradigbee tributary sites (GT1, GT2 and GT3) (Fig. 8); and (4) total nitrogen was above the trigger level below Cotter Dam (CM3), Googong Dam (QM2 and QM3), and on Kangaroo Creek (CT3) (Fig. 9). Increased catchment runoff from high rainifall earlier in 2012 is likely to have resulted in the above trigger level nutrient concentrations (ammonia, total nitrogen and total phosphorus).

With the abatement of the short-term instream disturbance from construction activities (see Levings et al. 2012), turbidity levels at site CM3 downstream of Cotter Dam were substantially lower at the time of spring 2012 sampling than during autumn 2012 sampling. However, turbidity levels were still above the 10 NTU trigger level in spring 2012. The continued above trigger level turbidity level downstream of Cotter Dam is possibly the result of Murrumbidgee river water pumped via M2C, which had a turbidity of 44 NTU from a high flow event one day before sampling occurred on the 16/10/13 (data source: ACTEW water) or instream storages of sediment from flooding earlier in 2012. Turbidity in Cotter Reservoir before sampling (5/10/12) had an average of 4.91 NTU and was well below what was measured at site CM3. Therefore the turbidity level in spring 2012 at site CM3 is likely the result of sediment sources downstream of the dam wall.

The decrease in nitrogen oxide concentrations at sites QM2 and QM3 downstream of Googong Dam (Fig. 8) to below the trigger level in spring 2012 compared to autumn 2012 may be the result of decreased inflows into Googong Reservoir. Concentrations of total phosphorus, total nitrogen, and ammonia were above trigger levels in the Queanbeyan river, downstream of Cotter Dam, and at Cotter and Goodradigbee River tributaries and may be the result of increased catchment erosion and runoff during high rainfall earlier in 2012 (Boulton and Brock 1999) (Figs. 7, 9 and 10). The high nutrient concentrations below Cotter Dam may have also resulted from Murrumbidgee River water pumped via M2C that had increased turbidity from the high flow event that occurred on the Murrumbidgee River in the week before sampling (data source: ACTEW Water). Furthermore, in the weeks before sampling nutrient concentrations in Cotter Reservoir were well below the levels measured at site CM3 (Cotter Reservoir 5/10/12 average – Nitrogen oxides – 0.0082 mg L^{-1}; TP - 0.012 mg L^{-1} TN - 0.13 mg L^{-1}; data source: ACTEW Water).

Periphyton and algae

Increased periphyton/algae biomass and growth (especially filamentous algae) (Figs 11-13; Table 8) below Bendora Dam in spring 2012, is possibly the result of higher concentrations of biologically available nitrogen in the form of ammonia after autumn 2012 flooding (Fig. 7) (Allan, 1995). Increases in concentrations of biologically available nitrogen, such as ammonia can result in increased algal growth (Camargo and Alonso, 2006). If filamentous algal cover continues to be high below Bendora Dam, management actions such as a high flow release would be advisable to scour the algae from the stream bed, because it can smother the stream bed and have a negative effect on macroinvertebrate communities (see Chester and Norris 2006).

Benthic macroinvertebrates

Reference sites on the Goodradigbee River (GM1, GM2, and GM3) had all returned to pre-disturbance condition of Band A (similar to reference condition) or Band X (more biologically diverse than reference condition) by spring 2012 (Table 10). This indicates that under natural flow conditions and in the absence of impoundments, post-flood recovery of macroinvertebrate assemblages can be expected within less than six months of disturbance. This is consistent with much of the scientific literature on instream recovery following disturbance (e.g. Gore 1982).

Goodradigbee River tributary sites (GT1, GT2, and GT3) were less affected by the March flood disturbance than the main channel sites (Levings *et al.* 2012). These sites are largely isolated from human disturbance and consistently achieve Band A assessment (similar to reference condition). However, in spring 2012 the biological condition at each of these tributary sites declined to Band B (significantly impaired) (Table 10). Despite the decline in AUSRIVAS band assessment at these sites, the relative abundance of sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa was higher at the Goodradigbee tributary sites than at all test sites and Cotter River tributary sites (Fig. 14). These sites were also grouped with reference sites that were assessed as Band A in an MDS ordination from a cluster analysis of macroinvertebrate relative abundance (Fig. 16). It is therefore likely that these sites will return to Band A condition in future assessments. However, if these sites continue to decline in biological condition an assessment will need to be made as to whether they are still appropriate reference sites for the assessment program.

Below dam test sites on the Cotter River (CM1, CM2, and CM3) were all assessed as Band B (significantly impaired) in spring 2012 (Table 10). These results are consistent with pre-flood biological condition at sites CM1 (Corin Dam) and CM3 (Cotter Dam), indicating macroinvertebrate assemblages at these sites have recovered from the flood disturbance. However, site CM2 (Bendora Dam) had not returned to a Band A in spring 2012 (Table 10). Band A has occurred at this site previously with the current environmental flow regime and no disturbances such as floods (Table 10). It is likely that the ongoing biological impairment at this site has resulted from prolific filamentous algae coverage in the riffle habitat (Table 8; Fig. 11), because filamentous algae is not a favourable food source for many macroinvertebrate taxa , including EPT taxa which had a low relative abundance at site CM2 compared to reference sites on the Goodradigbee River which had significantly lower periphyton/algae AFDM (Figs12 and 14) (Chester and Norris, 2006).

Cotter River tributary sites were assessed as Band X (CT1; more biologically diverse than reference condition), Band A (CT2; similar to reference condition), and Band B (CT3; significantly impaired) in spring 2012 (Table 11). With the exception of site CT3 on Paddys River, which is most likely impaired as a result of sedimentation from upstream landuse, assessment outcomes from these unregulated tributary sites more closely resemble those of the unregulated sites in Goodradigbee River catchment (Table 11). This result shows that differences in biological condition between the Cotter and Goodradigbee Rivers are influenced by the effects of impoundments on the Cotter River rather than natural variability between the two catchments.

Site CM3 downstream of Cotter Dam was extremely biologically impaired (band D) in autumn 2012, possibly as a result of disturbance from high flow releases/spills from Cotter Dam and high turbidity caused by an isolated upstream disturbance (Levings *et al*. 2012). It is likely that site CM3 improved in its biological condition in spring 2012 as a result of these disturbances subsiding, which has allowed macroinvertebrates to recolonise. Pollution tolerant Simuliidae have been the dominant taxa at this site over the past two sampling periods. Simulidae are an early colonising macroinvertebrate, which occur in fast flowing waters and filter feed on particles from the water (Gooderham and Tsyrlin 2002). To prevent the Enlarged Cotter Dam construction sites from flooding, flows downstream of Cotter Dam have been much higher than the recommended environmental flows with higher flow velocities (Fig. 2, Table 7). These flow conditions downstream of Cotter Dam have provided ideal habitat conditions for filter feeding Simuliidae.

The effect of the March 2012 flood disturbance on the Queanbeyan River was less evident at the upstream reference site QM1 than at downstream test sites QM2 and QM3 (Table 10). Site QM1 was assessed as Band A (similar to reference condition) in spring 2012, which is consistent with previous assessments. Test site QM2 improved from Band C after the flood disturbance to Band B in spring 2012, but had not returned to the Band A condition (frequently achieved in previous assessments – Table 10). It is unclear if this outcome has resulted from a lag in post-flood recovery, or from instream disturbance during a smaller flood event in the Queanbeyan River on the 12th of October, approximately three weeks prior to sampling. It is likely that the biological condition of this site will continue to improve in the absence of further disturbance. Water quality conditions within Googong Dam as a result of recent flooding (e.g. high levels of dissolved organics, nutrients and metals – data source ACTEW Water) may also be having an influence on the biological condition of sites QM2 and QM3 (below reference condition) downstream of Googong Dam.

Acknowledgements

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Appendicies

Appendix 1. Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples during spring 2012 for each sample site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), the Goodradigbee River (GM1, GM2, GM3) and tributaries of the Goodradigbee River (GT1, GT2, GT3) *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

CLASS **Order** Family *Subfamily*	**SIGNAL2 Grade**	**CM1 290**	**CM2 005**	**CM3 001**	**GM1 435**	**GM2 133**	**GM3 136**	**CT1 441**	**CT2 666**	**CT3 442**	**GT1 316**	**GT2 315**	**GT3 137**	**QM1 731**	**QM2 286**	**QM3 109**
ACARINA	**6**	3	5	1	1	1	3	8	1	1			5	7	1	2
AMPHIPODA	**3**					1										
OLIGOCHAETA	**6**	2		3	1	2	7		6	13				6	19	60
TURBELLARIA																
Tricladida																
Dugesiidae	**2**		1	3					1		1				2	1
Megaloptera																
Corydalidae	**7**					1								2		
Gastropoda																
Ancylidae	**4**													1		
Lymnaeidae	**1**															1
Bivalvia																
Sphaeriidae	**5**		1													
Plecoptera																
Eustheniidae	**10**				1											

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Appendix 1 continued.

Gripopterygidae	**8**	13	11	1	125	93	37	36	38		59	66	75	6		
Notonmouridae	**6**				1				1							
Ephemeroptera																
Baetidae	**5**		1	5	11	4	33	2	7	13	87	27	20	1	1	5
Caenidae	**4**		1		6	28	5	4		1	3	2				4
Coloburiscidae	**8**				12	29	7	2			2		4			
Leptophlebiidae	**8**	18	13	3	34	46	62	37	59	13	54	99	47	30		
Coleoptera																
Elmidae (Adult)	**7**		1		3	8	3	3			2	2	1	2		
Elmidae (Larvae)	**7**	1			3	3	2	10		1	2		7	13		2
Dytiscidae	**2**															
Hydraenidae	**3**															
Hydrophilidae	**6**		1													
Psephenidae	**6**				1	4										
Ptilodactylidae	**10**							3								
Scirtidae	**6**				1	5		8	3		6					
Diptera																
Athericidae	**8**							5								
Ceratopoginidae	**4**										1			1		
Chironomidae																
Aphroteniinae	**8**							2			2				1	
Diamesinae	**6**		2				2									
Chironominae	**3**		4	3	1	3	4	74	5	3				32	1	4
Orthocladiinae	**4**	141	145	67	6	3	7	23	8	31	2	4		32	27	92
Podonominae	**6**				2	1	5	4	13		3	8	2			
Tanypodinae	**4**	1			1	3	1	2	5		1					2

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Appendix 1 continued.

Empididae	**5**	14	6	1		1	4	1	10	2	2		1	2		3
Simuliidae	**5**	3	2	846		1	1	1	2	118	4	3		4	196	116
Tipulidae	**5**	2			11	3	9	7	2		8	4	12	2	1	
Trichoptera																
Calocidae	**9**							1								
Conoesucidae	**7**	5	3		3	1	4	12	37		1	6	88			
Glossosomatidae	**9**				1	2	3		4			1				
Hydrobiosidae	**8**	8	9	6	1	1	5	1	7	1	8	2	2	3	1	2
Hydropsychidae	**6**			1		1		1	5				3	31		1
Hydroptilidae	**4**							1						8		
Leptoceridae	**6**				5	7	2	2	1		5	8	8			1
Tasimiidae	**8**												4			
Odontoceridae	**7**															
Philopotamidae	**8**								1					23		
No. individuals		211	206	940	231	252	206	250	216	197	253	232	279	206	250	296
No. of taxa		12	16	12	21	24	20	24	21	11	19	13	14	19	10	15
% of sub-sample		10	11	3	1	1	4	2	2	4	4	4	1	2	2	2
Whole sample estimate		2110	1873	31333	23100	25200	5150	12500	10800	4925	6325	5800	27900	10300	12500	14800

Appendix 2: 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 sample site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), the Goodradigbee River (GM1, GM2, GM3) and tributaries of the Goodradigbee River (GT1, GT2, GT3) in spring 2012 and their sensitivity grade (SIGNAL 2) (Chessman, 2003). SIGNAL 2 grades are from 1–10, the greatest sensitivity represented by 10. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

		Site														
Macroinvertebrate	**SIGNAL 2 grade**	**CM1 290**	**CM2 005**	**CM3 001**	**GM1 435**	**GM2 133**	**GM3 136**	**CT1 441**	**CT2 666**	**CT3 442**	**GT1 316**	**GT2 315**	**GT3 137**	**QM1 731**	**QM2 286**	**QM3 109**
Acarina	**6**										**X**	**X**				
Oligochaeta	**2**		**X**					**X**			**X**	**X**	**X**			
Diptera																
Chironominae	**3**	**X**		**X**							**X**	**X**	**X**			
Orthocladiinae	**4**												**X**			
Tanypodinae	**4**		**X**	**X**						**X**		**X**	**X**	**X**	**X**	
Tipulidae	**5**		**X**	**X**						**X**						**X**
Simuliidae	**5**				**X**								**X**			
Coleoptera																
Elmidae	**7**			**X**					**X**			**X**			**X**	
Psephenidae	**6**	**X**	**X**	**X**			**X**		**X**	**X**	**X**	**X**	**X**		**X**	**X**
Ephemeroptera																
Leptophlebidae	**8**														**X**	**X**
Baetidae	**5**	**X**														
Caenidae	**4**	**X**		**X**					**X**				**X**	**X**	**X**	
Plecoptera																
Gripopterygidae	**8**									**X**					**X**	**X**
Notonmouridae	**6**							**X**								

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Trichoptera															
Conoesucidae	7			X						X					X	X
Glossosomatidae	9	X	X	X				X		X	X		X	X	X	X
Hydropsychidae	6	X	X		X		X			X	X	X			X	
No. of missing taxa		6	6	8	2	0	2	3	3	7	6	7	8	3	9	6

Appendix 3: Additional macroinvertebrate families and their sensitivity grade (SIGNAL 2) (Chessman, 2003) observed in the visual scan of entire samples for each site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), the Goodradigbee River (GM1, GM2, GM3) and tributaries of the Goodradigbee River (GT1, GT2, GT3) in autumn 2012. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

CLASS **Order** Family *Subfamily* (signal score)	SIGNAL2 Grade	CM1 290	CM2 005	CM3 001	GM1 435	GM2 133	GM3 136	CT1 441	CT2 666	CT3 442	GT1 316	GT2 315	GT3 137	QM1 731	QM2 286	QM3 109
Decapoda																
Palaemonidae	4													X		
Parastacidae	4													X		
INSECTA																
Hemiptera																
Gelastrocridae	3											X				
Megaloptera																
Corydalidae	7	X		X	X				X		X	X	X			
Odonata																
Gomphidae	5				X	X	X				X		X			

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Appendix 3 continued.

Telephlebiidae	**9**					X		X								
Ephemeroptera																
Leptophlebiidae	**8**														X	
Coloburscidae	**8**			X						X		X		X		
Plecoptera																
Eusthenidae	**10**					X		X			X					
Gripopterygidae	**8**									X						
Coleoptera																
Scirtidae	**6**														X	X
Psephenidae	**6**						X									
Diptera																
Athericidae	**8**				X											
Dolichopodidae	***3***							X								
Tipulidae	**5**															X
Trichoptera																
Calocidae	**9**								X							
Ecnomidae	**4**														X	X
Glossosomatidae	**9**	X														
Hydropsychidae	**6**				X		X			X	X	X			X	
Philoheithridae	**8**				X	X										
Philopotamidae	**8**							X					X			
No. New Taxa		**2**	**0**	**2**	**5**	**4**	**3**	**4**	**2**	**3**	**4**	**4**	**3**	**3**	**4**	**3**