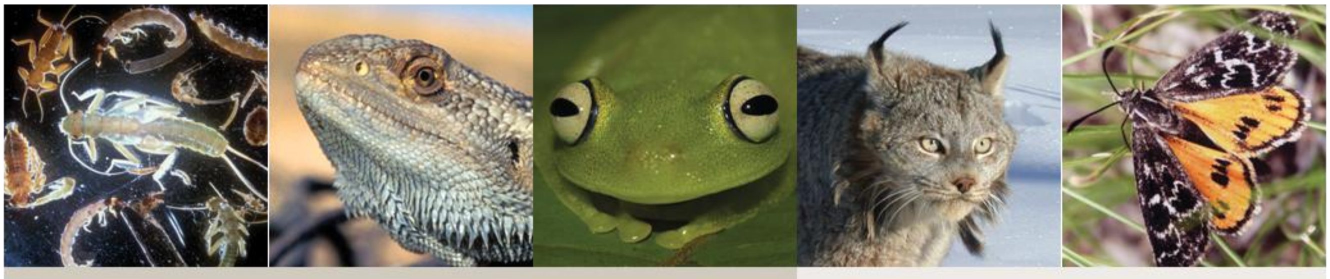

Biological response to flows downstream of Corin, Bendora, Cotter and Googong Dams

Autumn 2012

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Front Photograph: Photo taken by Chris Levings of site CM2 below Bendora Dam.

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Executive summary

Background and study objective

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

- This study addresses the needs of ACTEW's License to Abstract Water (WU67) to assess the effects of dam operation, water abstraction, 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

- Water quality parameters were generally within water quality trigger levels (ANZECC and ARMCANZ 2000) at all sites at the time of sampling. Notable exceptions included turbidity downstream of the Cotter Dam (270.9 NTU) on the Cotter River and nutrient concentrations downstream of Googong Dam on the Queanbeyan River, which were above trigger levels.

- In autumn 2012 riffle filamentous algae cover at all below dams sites met the specified environmental flow ecological objective of <20% cover (ACT Government 2006).However, below dam sites did not meet the specified environmental-flow ecological objective of AUSRIVAS band A for maintaining healthy aquatic ecosystems.

Legend	Within environmental flow ecological objective	Outside environmental flow ecological objective
Site	**Riffle filamentous algae cover**	**AUSRIVAS band**
CM1 (Corin Dam)	<10%	B
CM2 (Bendora Dam)	<10%	B
CM3 (Cotter Dam)	<10%	D
QM2 (Googong Dam)	<10%	C

- Macroinvertebrate communities at unregulated Goodradigbee River reference sites were also biologically impaired (AUSRIVAS bands B and C). This result implies that has likely cause the biological impairment at below dam and reference sites was the ~1:40 annual return interval (ARI) flood disturbance of early autumn 2012 given that the below dam and reference sites both experienced similar flood disturbances.

- The very high turbidity (270.9 NTU) that was measured on the day of sampling downstream of Cotter Dam may have also influenced the decline in biological condition at this site, through increased macroinvertebrate drift during the high turbidity event.

- Macroinvertebrate communities at below dam sites had relatively low abundances of sensitive taxa (i.e. those with SIGNAL 2 grades ≥7) compared to reference sites. It is likely that the recovery and recruitment of macroinvertebrate communities at below dam sites post flooding may be delayed by the barrier effects of the dams. Also macroinvertebrate communities at below dam sites may not be as adapted to high flow disturbances as those in the unregulated Goodradigbee River, which regularly experiences high flow disturbances.

Project recommendations

- A long-term assessment of Below Dams Assessment Program water quality, physical habitat, periphyton and macroinvertebrate data. The Below Dams Assessment Program has been in place for over 10 years. Therefore, it is an opportune time to make a long-term assessment of changes in and relationships between water quality, physical habitat periphyton and macroinvertebrates across a variety of flow conditions and assess any seasonal differences

- An assessment of periphyton/algae taxa present below dams compared to the Goodradigbee River. This would enable an assessment of periphyton/alage community responses to river regulation in the Cotter and Queanbeyan Rivers which could be related to differences in macroinvertebrate community structure between below dam and reference sites.

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. This information allows for adaptive management of the water supply catchments.

In early autumn 2012 a major flood event ~1:40 annual return interval (ARI) in the ACT region affected the physical and biological condition of waterways in this assessment. This report provides an assessment of sites downstream of the dams on the Cotter and Queanbeyan Rivers in autumn 2012, and focuses on comparisons of these sites with unregulated reference sites and the results of previous assessments within the context of post-flood recovery.

Field and laboratory methods

Study area

The study area includes the Cotter and Goodradigbee Rivers, which are situated along the western border of the ACT and east of the border in NSW, respectively. 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 study area also includes the Queanbeyan River, which is located to the east of the ACT border in NSW. 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 located to the west of the ACT border within NSW. The Goodradigbee River is a fifth order stream (at all sampling sites), which remains largely unregulated until it reaches Burrinjuck Dam (near Yass). 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 15/05/2012-23/05/2012 (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

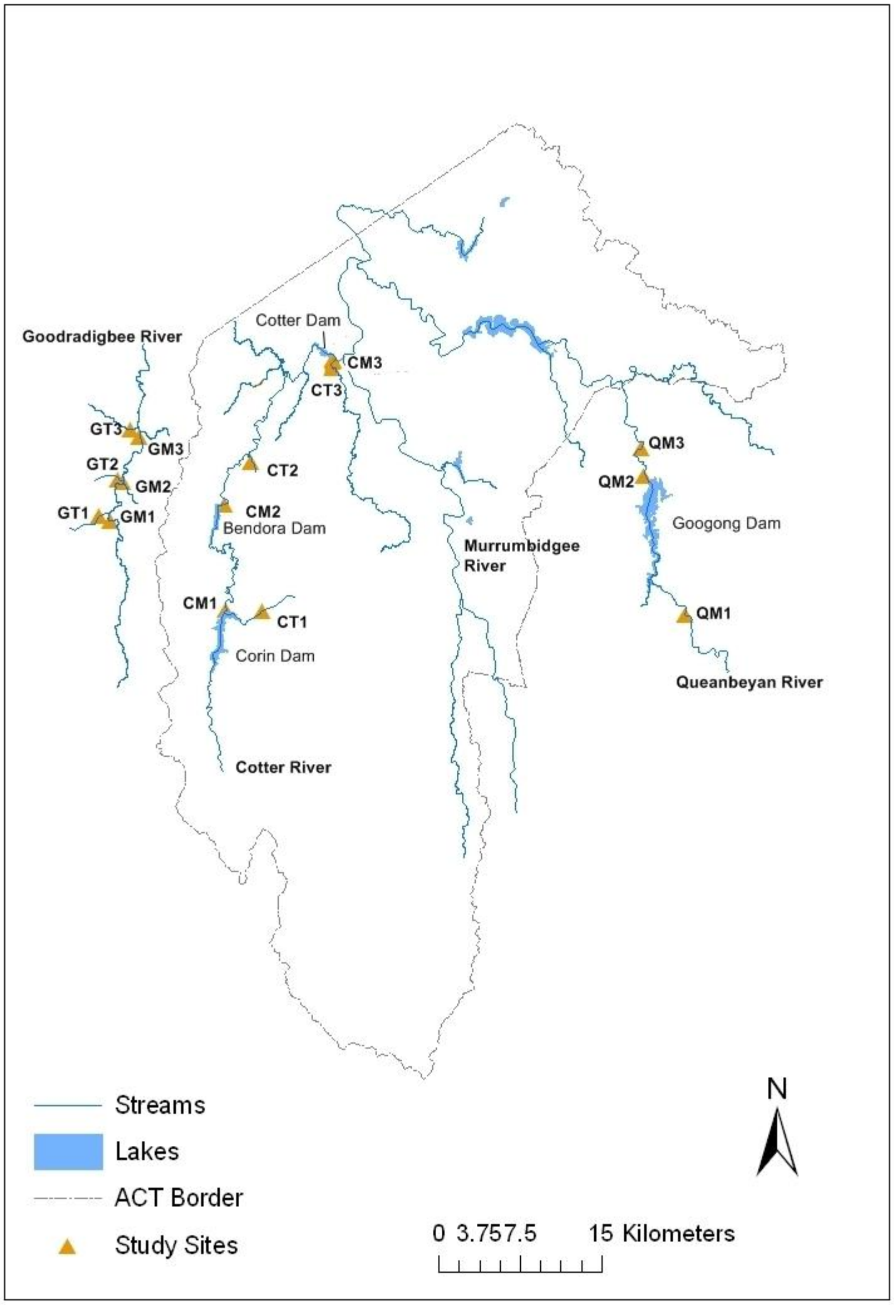

Figure 1: The location of sites sampled on the Cotter, Goodradigbee and Queanbeyan River's and tributaries for the Below Dams Assessment Program.

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

Site	Sampling date	Sampling time
CM1	17/05/2012	11:30
CM2	22/05/2012	11.30
CM3	22/05/2012	15:00
CT1	17/05/2012	10:15
CT2	22/05/2012	10:00
CT3	22/05/2012	13:00
GM1	18/05/2012	11:30
GM2	15/05/2012	13:00
GM3	18/05/2012	15:00
GT1	18/05/2012	10:00
GT2	15/05/2012	12:30
GT3	18/05/2012	15:00
QM1	23/05/2012	10:30
QM2	23/05/2012	12:30
QM3	23/05/2012	14:00

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: 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 the 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).

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. The following internal QA/QC procedures were implemented for macroinvertebrate sample processing.

- All samples were separated into Orders and placed in separate vials to eliminate any high level discrepancies. This was also required for future curatorial preservation and storage.

- When an identification problem was encountered a decision tree for identifications (Hawking and O'Conner 1997) was followed. The decision tree has been reproduced in the ACT AUSRIVAS sampling and processing manual (Nichols *et al*. 2000). Very small, damaged, immature animals or pupae that were unable to be identified with confidence were noted as such and were not included in the taxa list for that sample. The counts for unidentified animals were not included in the 200-organism sub-sample.

- Damaged animals were identified if possible, recorded and placed in the appropriate vials. If a specimen could not be identified it was noted as such (e.g. Ephemeroptera damaged) and placed in the appropriate vial.

- A quality control staff member checked the first five samples identified by each person.

- A miss-identification error of < 5 % of the total number of animals was deemed acceptable at family level. If the error was ≥ 5 %, the miss-identifications were corrected under the guidance of quality control staff. All miss-identifications were shown to the person and suitable instruction given to rectify the miss-identification. Other samples containing the same miss-identified taxa were checked by the original identifier for miss-identification errors and corrected if necessary.

- Following the initial checking of five samples, a random selection of two samples in the following 10, were checked.

- Persons checking samples were those who have passed the AUSRIVAS QAQC procedure outlined in Nichols *et al.* (2000) and accredited in macroinvertebrate identification.

Macroinvertebrate community 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 autumn riffle model

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT autumn riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT autumn riffle model uses a set of 12 habitat variables to predict the macroinvertebrate fauna expected at each site (Table 4).

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

Variable	Description
ALTITUDE	Height above sea level (m)
CATCHAREA	Catchment area upstream of site (km^2)
DFS	Distance from source (km)
LONGITUDE	Longitude (Degrees/Minutes e.g. 14857)
PEBBLE	Percent cover in edge of pebble (16-64 mm)
STORDER	Stream order calculated from 1:100,000 map
GFS	Percent cover of riparian zone by grasses, ferns and sedges. (%)
ALKALINITY	Total carbonates. (mg L^{-1})
BOULDER	Percent boulder [>256mm] in habitat. (%)
COBBLE	Percent cobble [64-256mm] in habitat. (%)
RIPWIDTH	Width of the riparian zone; mean from both banks. (m)
SHRUBVINE	Percent cover of riparian zone by shrubs and vines. (%)

Biological condition bands for the AUSRIVAS autumn 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 autumn riffle model, test site grades that fall between 0.88-1.12 (Band A) are considered similar to reference condition). A significantly impaired site will have an O/E score between 0.64 and 0.87 (Band B); a severely impaired site (Band C) will have an O/E score between 0.40 - 0.63; and the extremely impaired sites will have an O/E score of 0 - 0.39 (Band D) . Sites that have O/E scores ≥1.13 (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 (autumn 2010, autumn 2011, spring 2011** and autumn 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. To determine if there were significant differences in periphyton AFDM and chlorophyll-a between sites in autumn 2012, a 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 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 autumn 2012 was characterised by a period of elevated discharge between the 3rd and 6th of March, 2012 (Fig. 2). This event occurred in response to 153 mm of rainfall over the preceding four day period (Fig.2). Discharge downstream of each of the dams increased substantially during this high rainfall event. Maximum discharge rates of 7641.9 ML day^{-1} (Corin), 27128.6 ML day^{-1} (Cotter), and 15344.4 ML day^{-1} (Googong) were recorded. No data is available for the maximum discharge at Bendora Dam during this event because the gauge was damaged during the flood; however, flows at Corin and Cotter provide an indication of the volume of water overtopping Bendora dam. All of the dams in this study overflowed during the flood event. The highest maximum daily discharge recorded during the study period was 40613.4 ML day^{-1} on the unregulated Goodradigbee River (Fig 2).

With the exception of the flood event, stream discharge downstream of dams for the majority of autumn 2012 was regulated and determined by operational requirements and environmental flow guidelines (ACT Government 2006). Discharge in the Goodradigbee River was greater than discharge below each of the dams on the Cotter and Queanbeyan Rivers for the majority autumn 2012 (Fig. 2).

Table 7: Flow regime targets and releases downstream of Corin, Bendora, Cotter and Googong Dams preceding the autumn 2012 Below Dams Assessment Program (excluding unscheduled releases during flooding) (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.

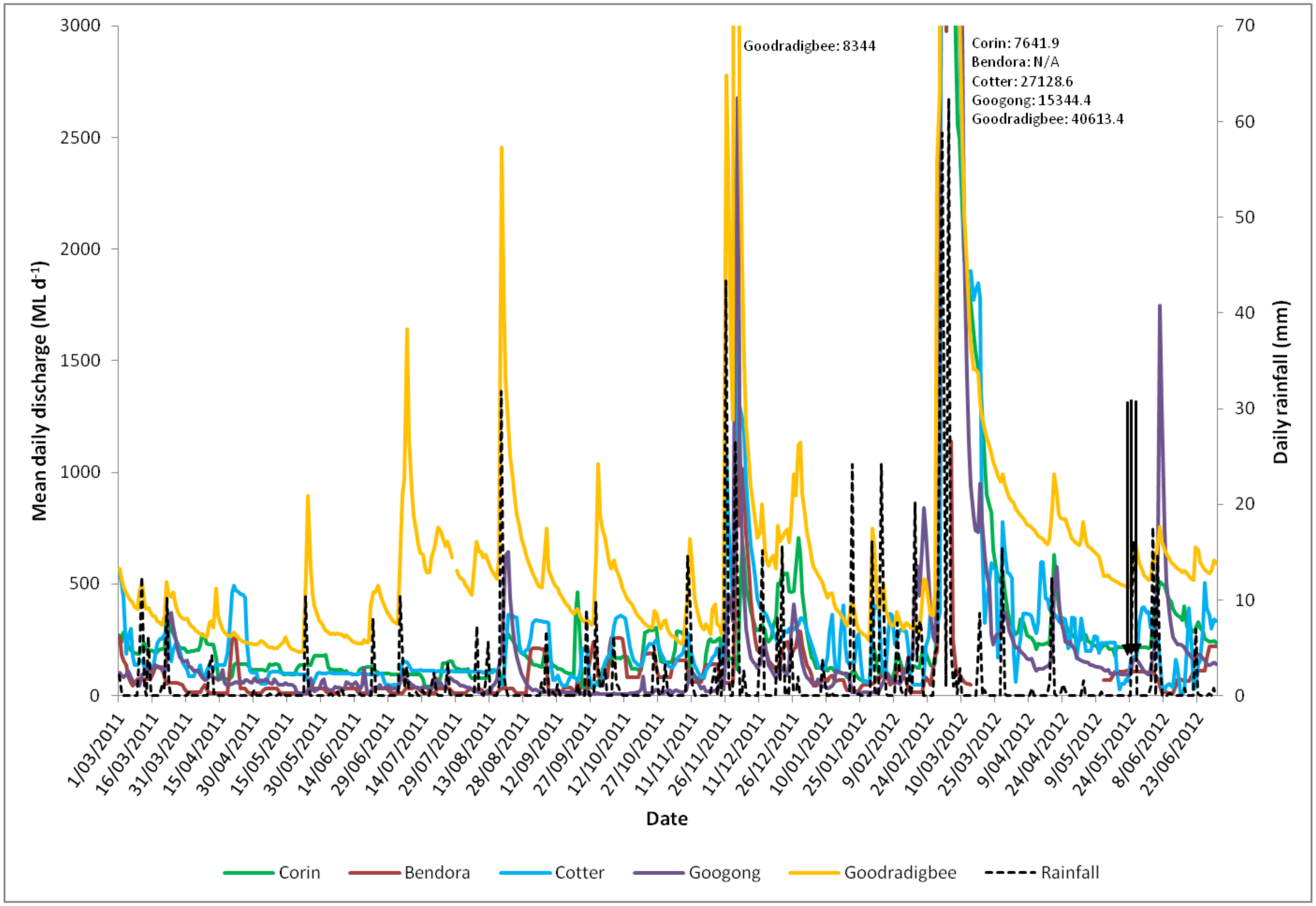

Figure 2: Mean daily discharge in the Cotter, Goodradigbee and Queanbeyan Rivers: below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams and Goodradigbee River (GM2); and daily rainfall data for Canberra airport (station: 070351) from 1/3/2011 to 1/7/2012. NB. Flow peaks >5000 ML d $^{-1}$ are not shown on the graph. Arrows correspond to autumn 2012 sampling dates (see Table 2). Data source: ACTEW Water and NSW Department of Water and Energy; Bureau of Meteorology.

Physical and chemical water quality characteristics

Alkalinity

Alkalinity was within the range of concentrations measured over the past three sampling runs (autumn 2010, autumn 2011, and spring 2011) (Fig. 3). Alkalinity concentrations at sites below Corin (CM1), Bendora (CM2) and Googong (QM2, QM3) Dams, upstream of Googong Dam (QM1), Cotter tributaries CT2 and CT3, and Goodradigbee site GM3 declined since sampling in spring 2011(Fig. 3).

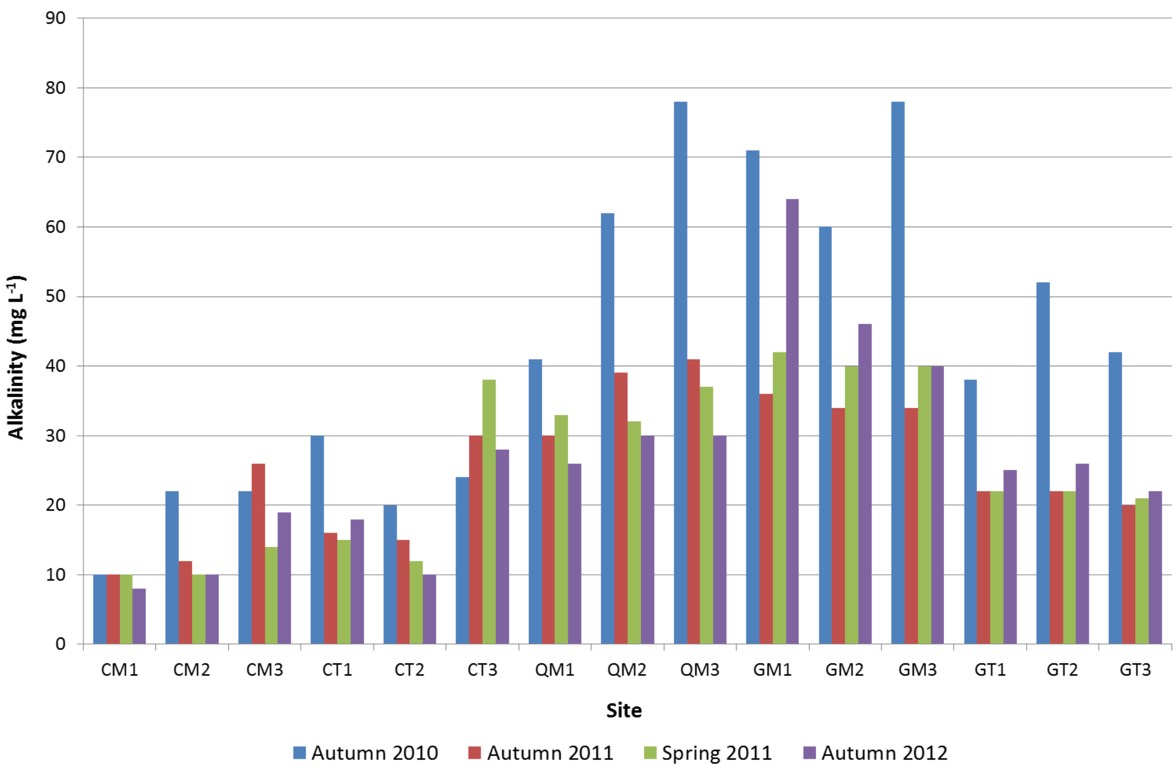

Figure 3: Alkalinity at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 2011, autumn 2011 and autumn 2010.

Water temperature

Water temperatures at all sites (excluding CM1) in autumn 2012 were cooler than in the previous three sampling runs (Fig. 4). It should be noted that water temperature is dependent upon seasonal variability and the time of sampling.

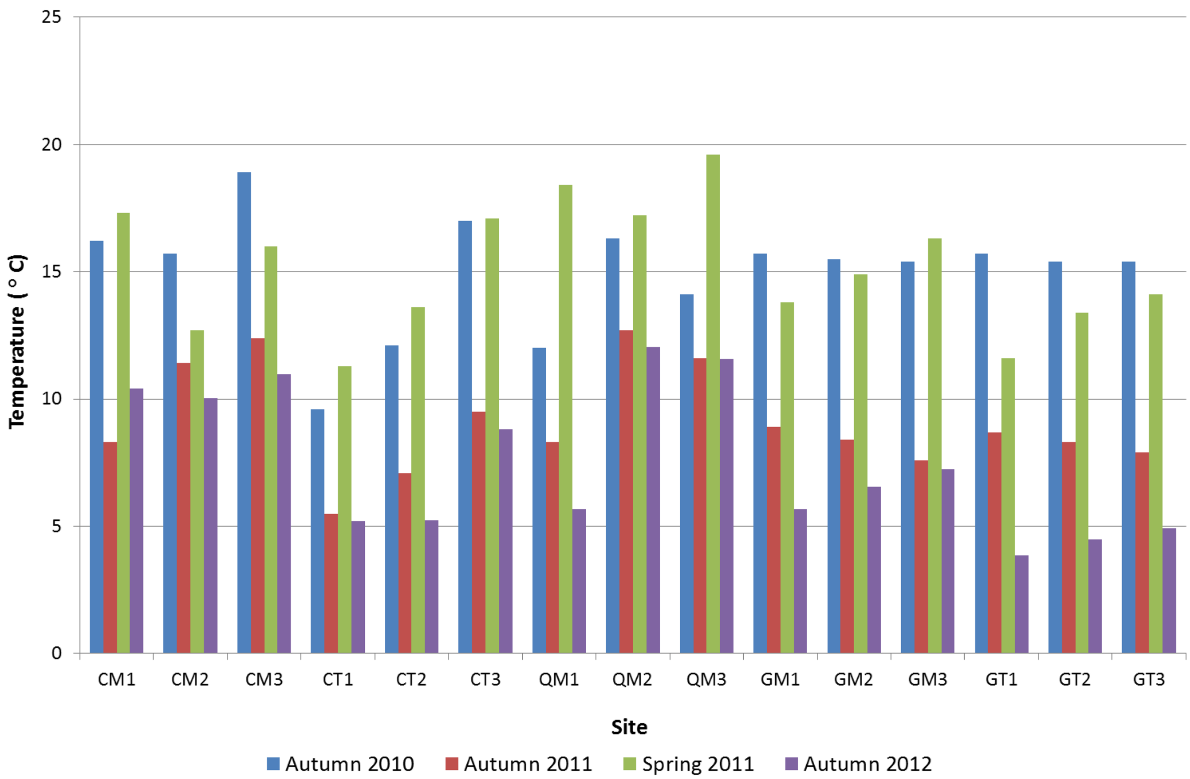

Figure 4: Water temperature at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 2011, autumn 2011 and autumn 2010.

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 three sampling runs (Fig. 5). It should be noted that electrical conductivity is dependent upon factors such as catchment geology and rainfall, so may vary between sites.

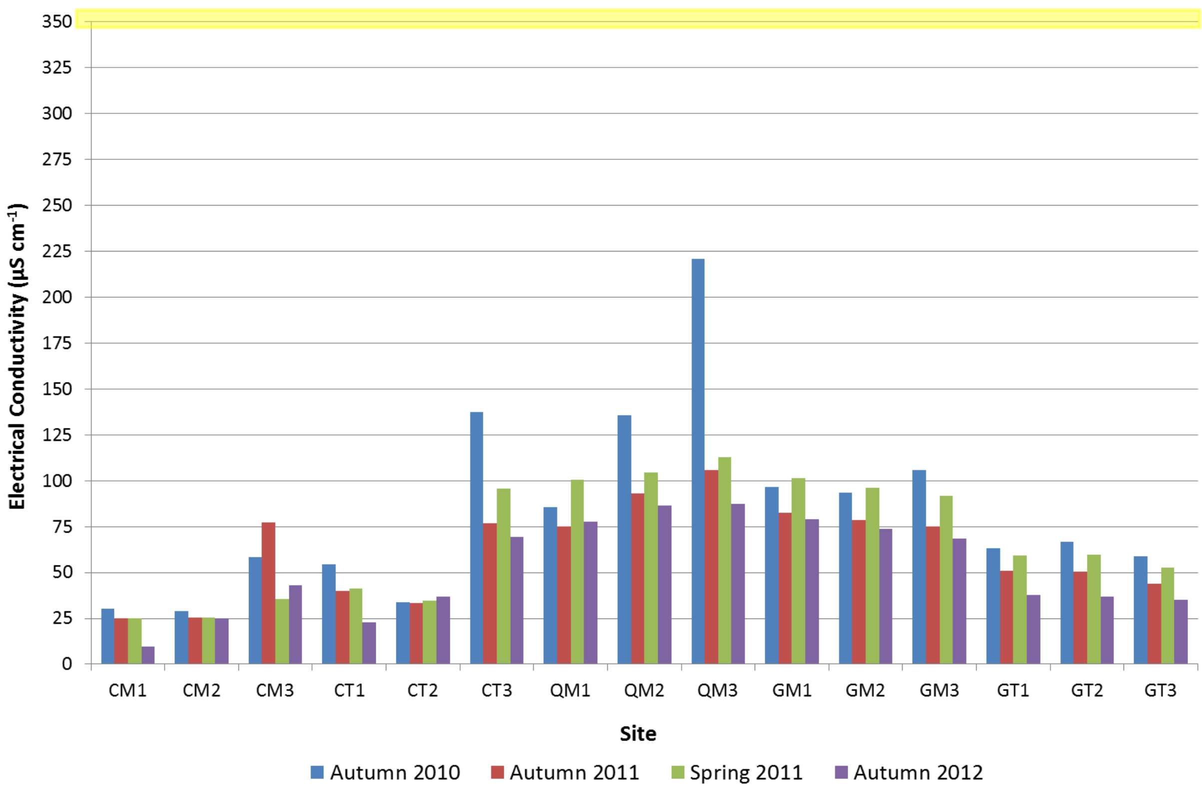

Figure 5: Electrical conductivity at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 2011, 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 (Fig. 6). pH levels in autumn 2012 were lower at all sites than in autumn 2011, except for all Cotter tributary sites (CT1, CT2, CT3) and the Queanbeyan River upstream of Googong Dam (QM1), which were slightly higher (Fig. 6).

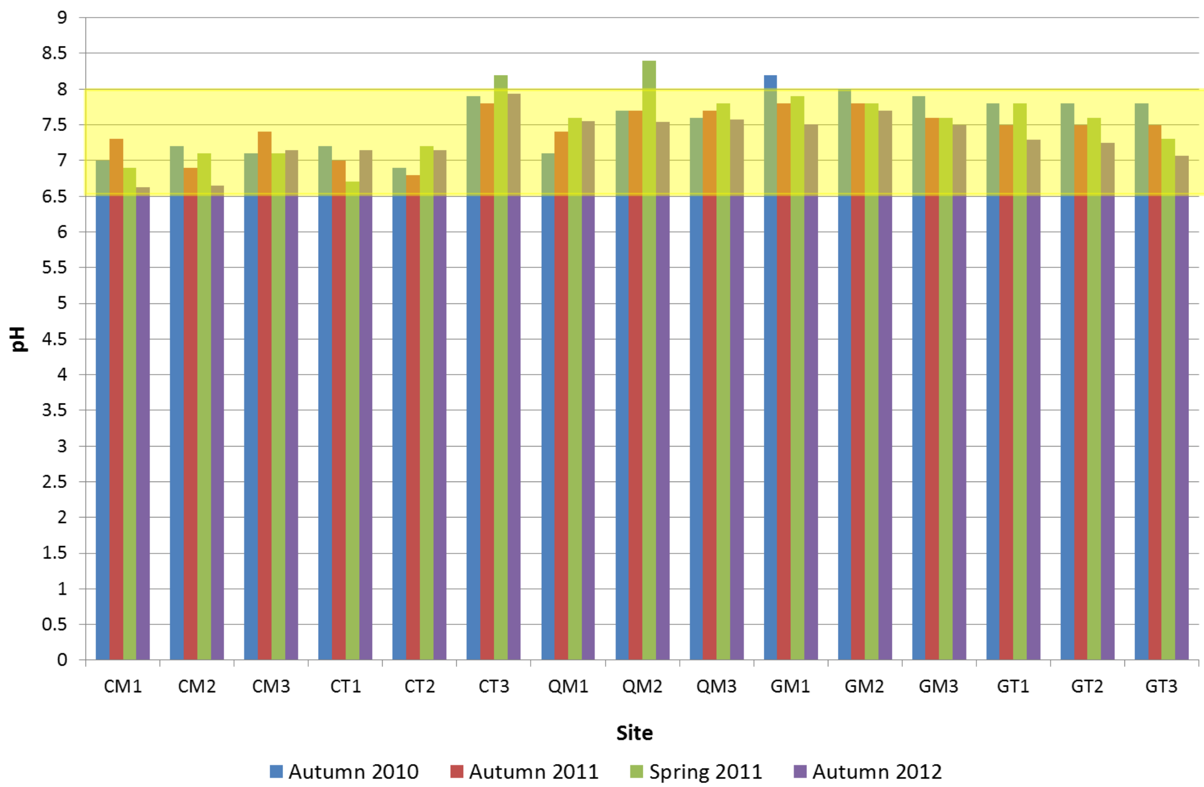

Figure 6: pH at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 2011, autumn 2011 and autumn 2010. *The ANZECC and ARMCANZ (2000) trigger value range for pH is shaded in yellow.*

Dissolved oxygen

Dissolved oxygen concentrations across all sites were well above the trigger value of 6 mg L^{-1} (Fig. 7). With the exception of site CM1, dissolved oxygen concentrations in autumn 2012 were higher than the past three sampling runs, likely because of cooler water temperatures and increased river flows (Figs.2, 4 and 7).

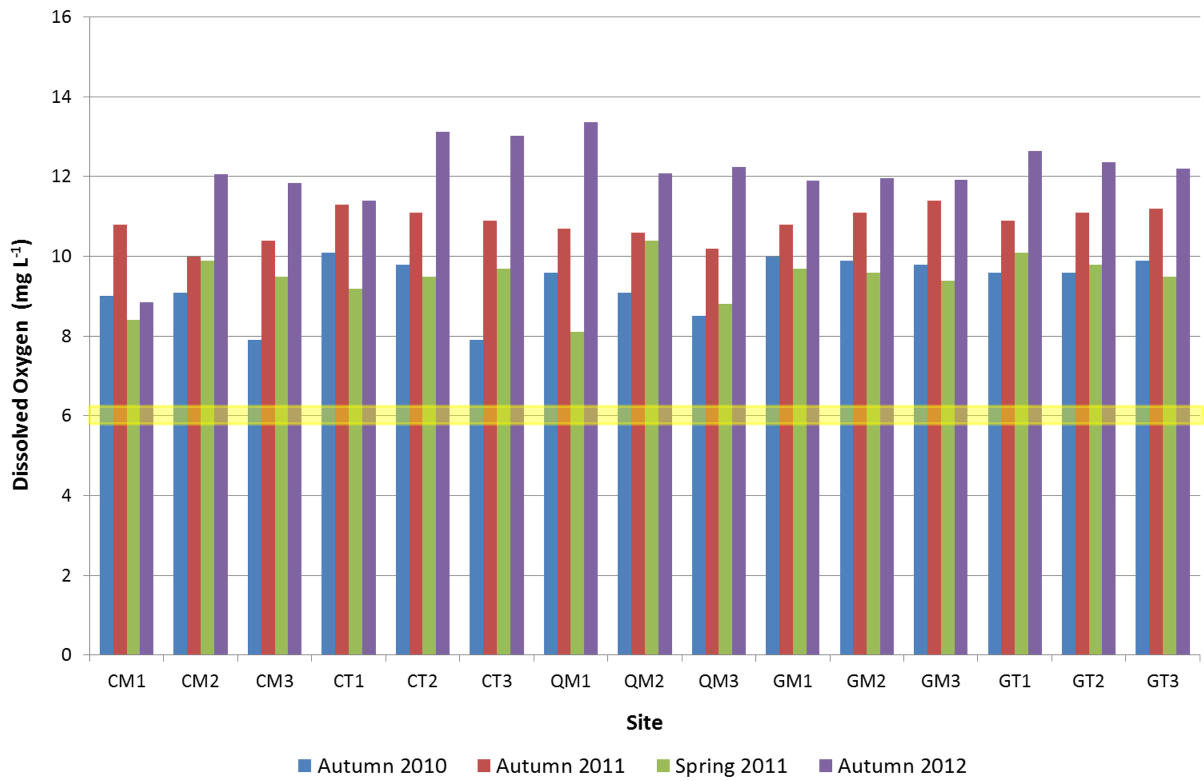

Figure 7: Dissolved oxygen concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3),), autumn 2012, and previously in spring 2011, autumn 2011 and autumn 2010. *The Environment Protection Regulations SL2005-38 trigger value for dissolved oxygen is shaded in yellow.*

Turbidity

Turbidity at site CM3 on Cotter River was well above the recommended trigger value of 10 NTU and was higher than the previous three sampling runs (Fig. 8). Turbidity below Googong Dam (QM3) was also above the recommended trigger value and higher than spring 2011 (Fig. 8). All other sites were below the recommended turbidity trigger value (Fig. 8).

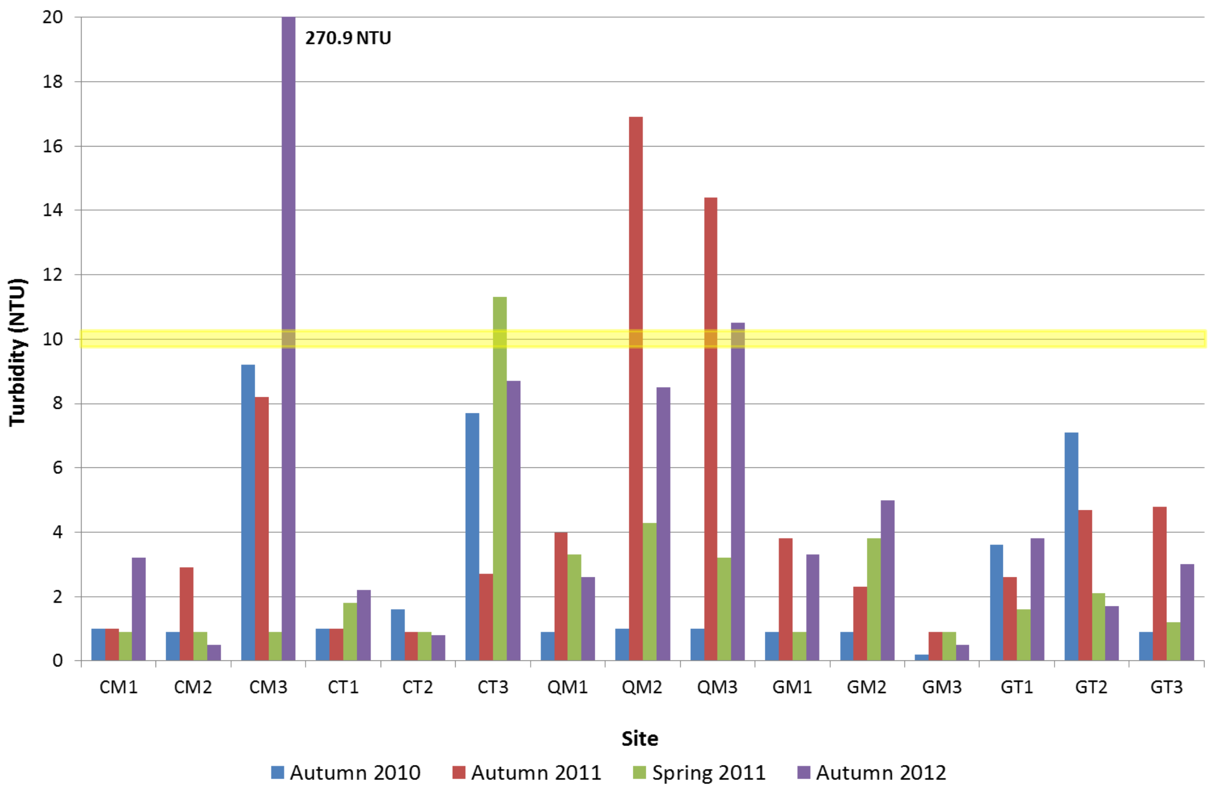

Figure 8: Turbidity at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 2011, autumn 2011 and autumn 2010. *The Environment Protection Regulations SL2005-38 trigger value for turbidity is shaded in yellow.*

Ammonia

Ammonia concentrations in autumn 2012 were all below the trigger value of 0.09 mg L^{-1}, which is similar to sampling in spring 2011 (Fig. 9).

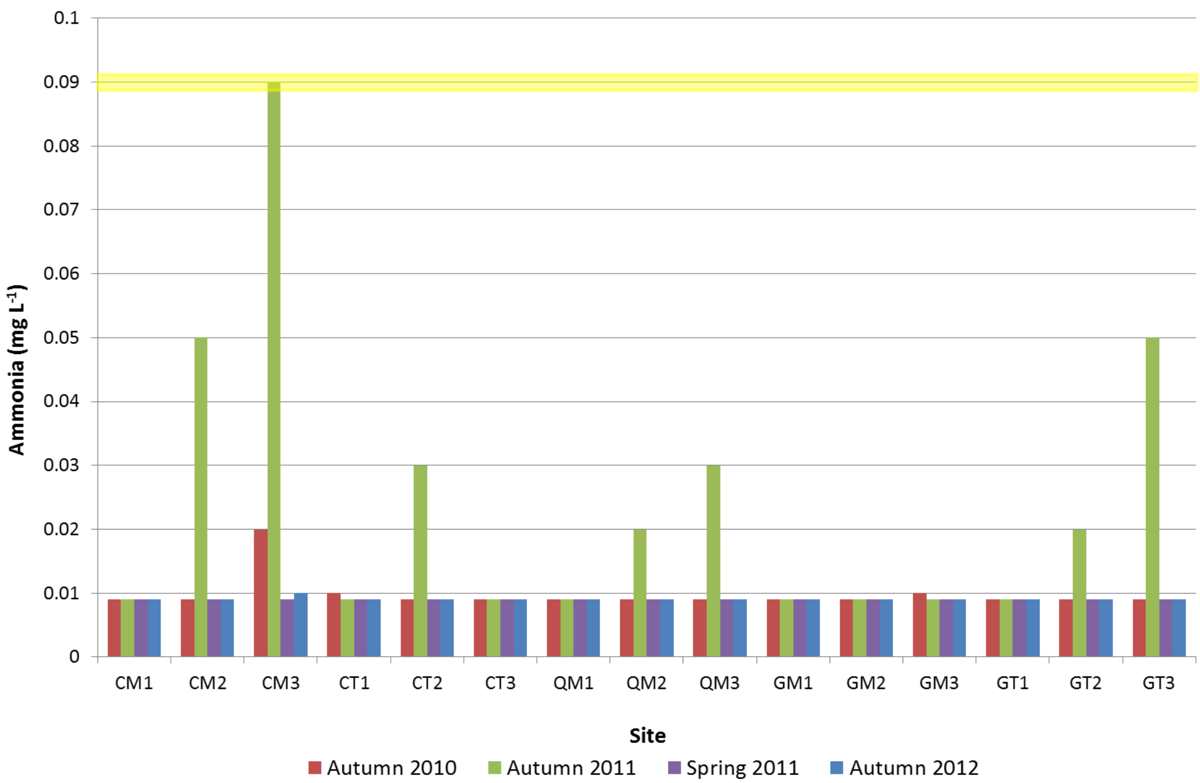

Figure 9: Ammonia (NH_3) concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 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 oxide

Oxidised nitrogen concentrations in autumn 2012 at both sites downstream of Googong Dam (QM2 and QM3) were above the trigger value of 0.015 mg L^{-1}. All other sites were below the trigger value and similar to the past three sampling runs (Fig. 10).

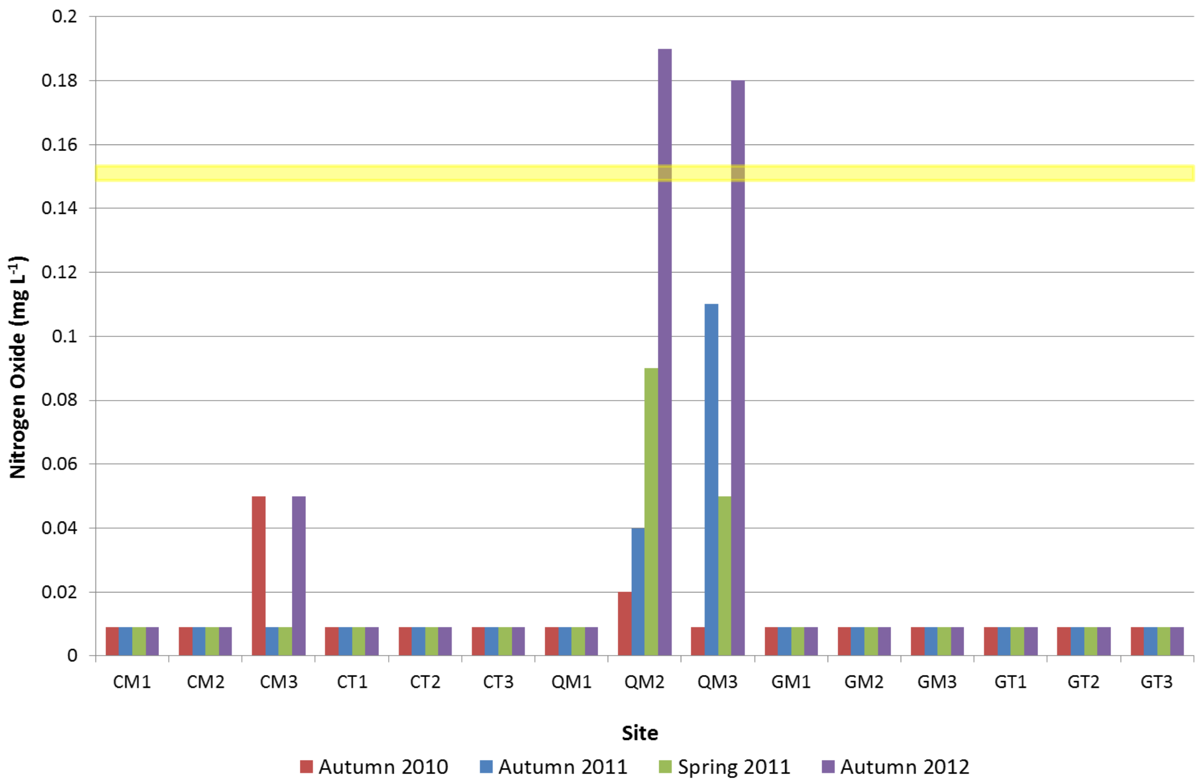

Figure 10: Nitrogen oxide concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 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 concentrations below Cotter Dam (CM3) and in Paddys River (CT3) were above the trigger value of 0.02 mg L^{-1}, and had increased since spring 2011 (Fig. 11). Total phosphorus concentrations at both sites below Googong Dam (QM2 and QM3) were also above the trigger value, however, total phosphorus concentrations were lower than spring 2011 (Fig. 11). Total phosphorus at all other sites was below the trigger value of 0.02 mg L^{-1} and lower than spring 2011 (Fig. 11).

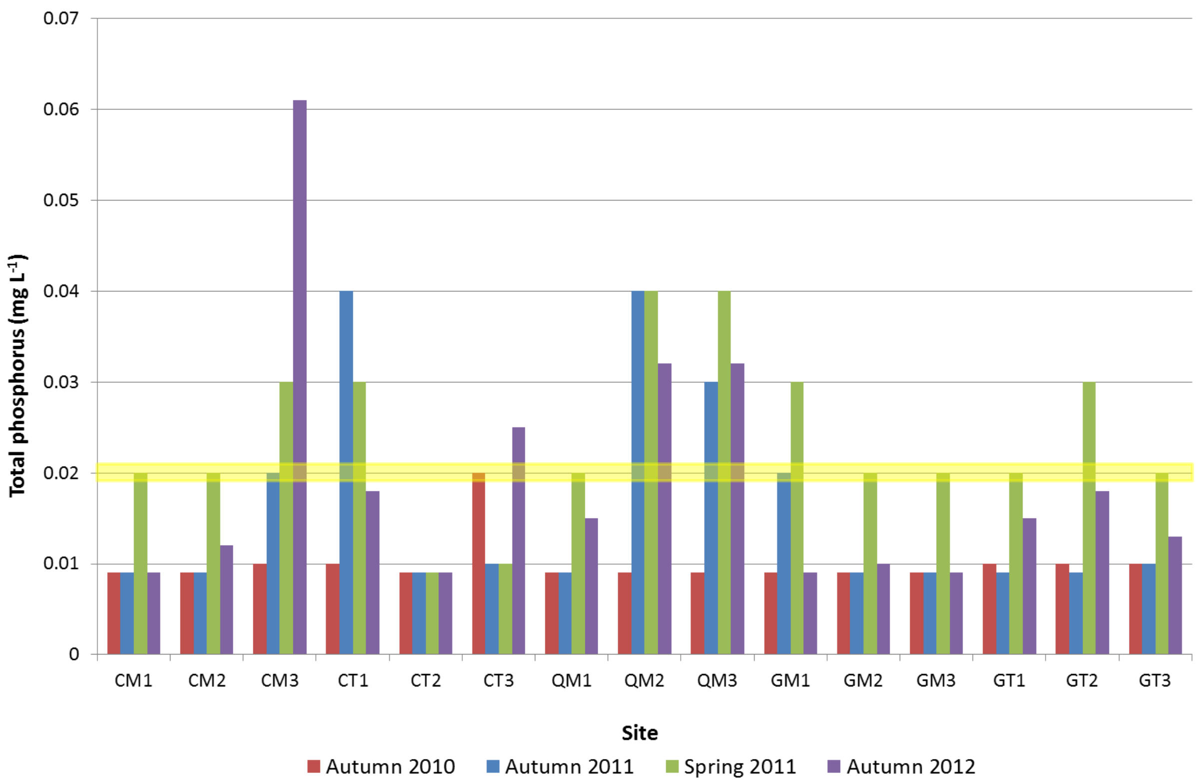

Figure 11: Total phosphorus concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 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 concentrations in autumn 2012 at all sites on the Queanbeyan River, both upstream and downstream of Googong Dam, were above the trigger value of 0.25 mg L^{-1} (Fig. 12). Both sites downstream of Googong Dam (QM2 and QM3) had higher total nitrogen concentrations than upstream of Googong Dam (QM1) (Fig. 12). The total nitrogen concentration below Cotter Dam (CM3) was also above the trigger value (Fig. 12). Total nitrogen concentrations at all other sites were below the trigger value (Fig. 12).

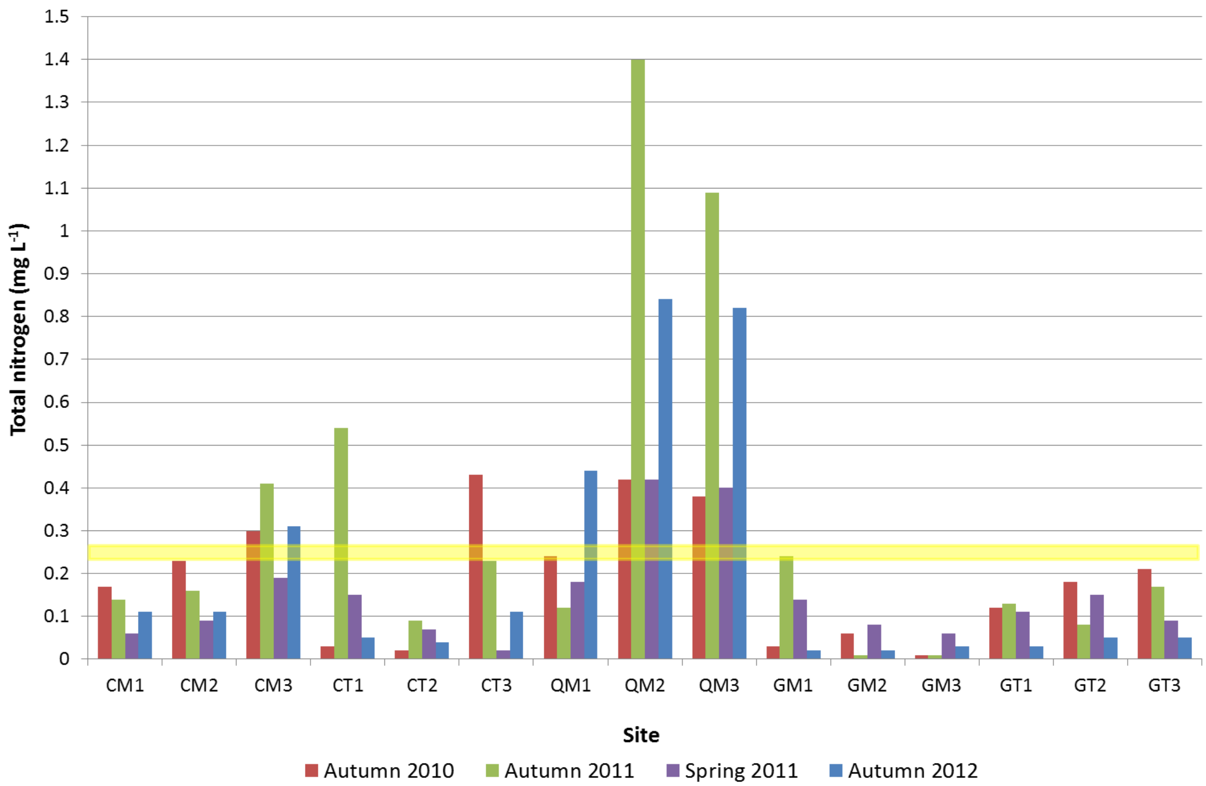

Figure 12: Total nitrogen concentration at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), autumn 2012, and previously in spring 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, AFDM (biomass), and chlorophyll-a

In autumn 2012, periphyton cover within the riffle and reach decreased below Corin, Bendora and Googong Dams compared to spring 2011 (Table 8). The periphyton in the riffle habitat was < 10 % in autumn 2012 for all below dam sites (CM1, CM2, CM3 and QM2) and Goodradigbee reference sites GM1 and GM2 (Table 8). Within the reach at site QM2 downstream of Googong Dam periphyton cover was 10-35% in autumn 2012 and greater than other below dam sites which had periphyton cover <10% within the reach (Table 8). Site GM3 on the Goodradigbee River was the only site to increase from < 10 % periphyton percentage cover within both the riffle and reach in spring 2011 to 10-35 % in autumn 2012 (Table 8). Visual observations of filamentous algae cover were <10 % within both the riffle and reach at all sites in autumn 2012, and decreased since spring 2011 at sites below Corin, Bendora and Googong Dams (CM1, CM2, QM2) from 10-35 % (Table 8).

AFDM was significantly higher across all sites in autumn 2010 compared to autumn 2011 and 2012 (Table 9, Fig. 13). Also across autumn 2010, 2011 and 2012, AFDM at Goodradigbee reference site GM3 was significantly higher than Goodradigbee reference site GM2 (Table 9, Fig. 13). However, there was not a significant interaction between site and season (Table 9). In autumn 2012, AFDM was significantly higher below Googong Dam (QM2) compared to below Bendora Dam (CM2) and on the Goodradigbee River (GM1, GM2) (Fig. 13) ($F=5.44$; $df = 6,34$; $p = 0.0005$).

There was a significant interaction between sampling site and season in terms of Chlorophyll-a concentration (Table 8, Fig. 14). In autumn 2012, Chlorophyll-a was significantly higher below Cotter Dam (CM3) and at Goodradigbee reference site GM1 compared to spring 2011 (Fig. 14). In autumn 2012, Chlorophyll-a was significantly higher below Corin (CM1) and Bendora (CM2) Dams compared to Goodradigbee reference site GM2 ($F=7.26$; $df = 6,35$; $p <0.0001$)(Fig. 14). Goodradigbee reference site GM3 also had significantly higher Chlorophyll-a in autumn 2012 compared to the other two Goodradigbee reference sites (GM1, GM2) ($F=7.26$; $df = 6,35$; $p <0.0001$)(Fig. 14).

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), autumn 2012 and previously in spring 2011, autumn 2011 and autumn 2010.

Site	% cover of riffle								% cover of reach							
	Periphyton				Filamentous Algae				Periphyton				Filamentous Algae			
	Aut-12	Spr-11	Aut-11	Aut-10	Aut-12	Spr-11	Aut-11	Aut-10	Aut-12	Spr-11	Aut-11	Aut-10	Aut-12	Spr-11	Aut-11	Aut-10
CM1	<10	35-65	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10
CM2	<10	10-35	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10
CM3	<10	<10	<10	10-35	<10	<10	<10	<10	<10	<10	<10	10-35	<10	<10	<10	<10
QM2	<10	35-65	<10	<10	<10	10-35	<10	<10	10-35	35-65	<10	<10	<10	10-35	<10	<10
GM1	<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
GM3	10-35	<10	<10	<10	<10	<10	<10	<10	10-35	<10	<10	<10	<10	<10	<10	<10

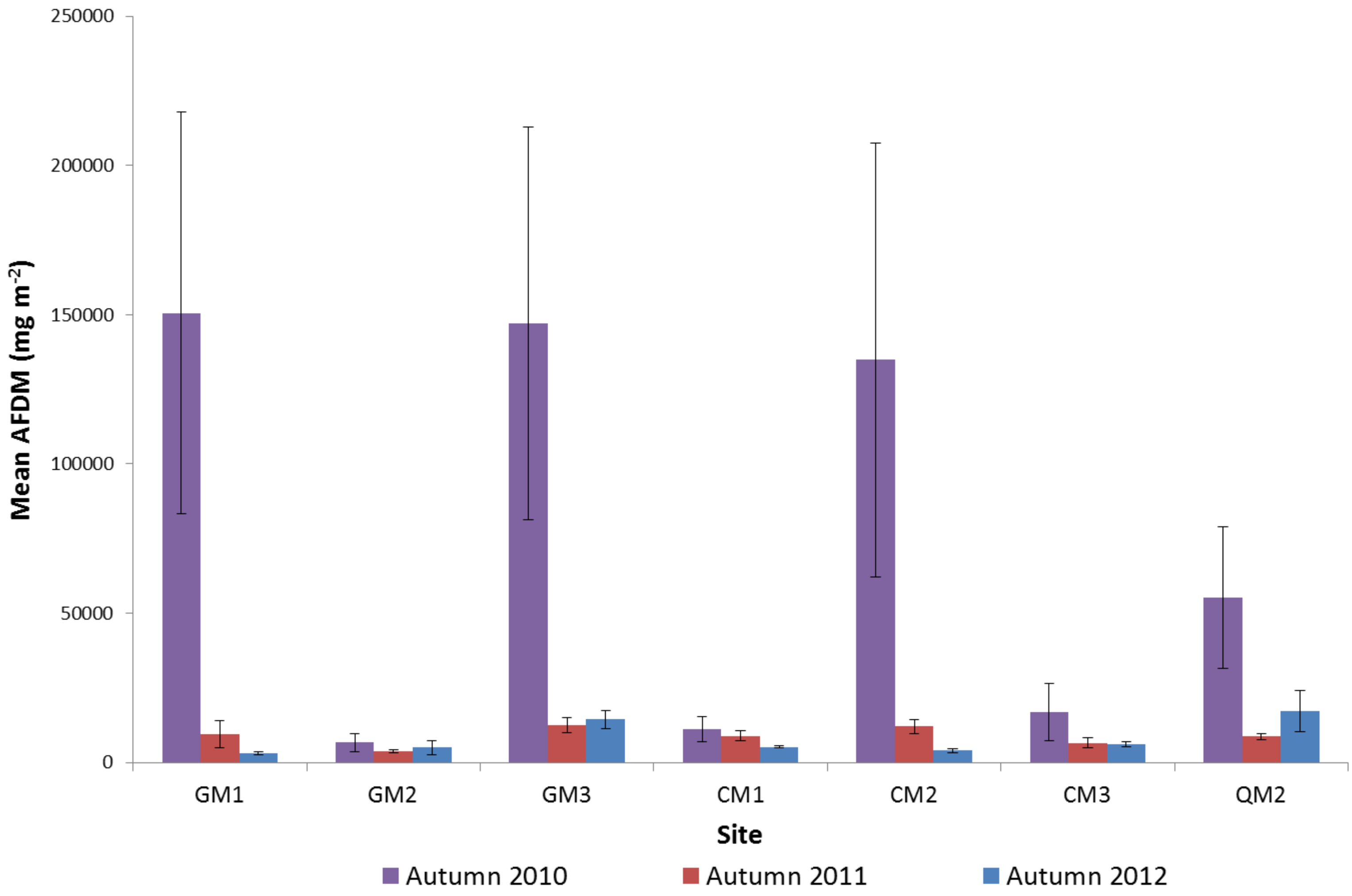

Figure 13: Mean AFDM (µg m^{-2}) at below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong) and reference sites GM1, GM2 and GM3 (Goodradigbee River), autumn 2010, autumn 2011 and autumn 2012. Error bars represent +/- 1 standard error.

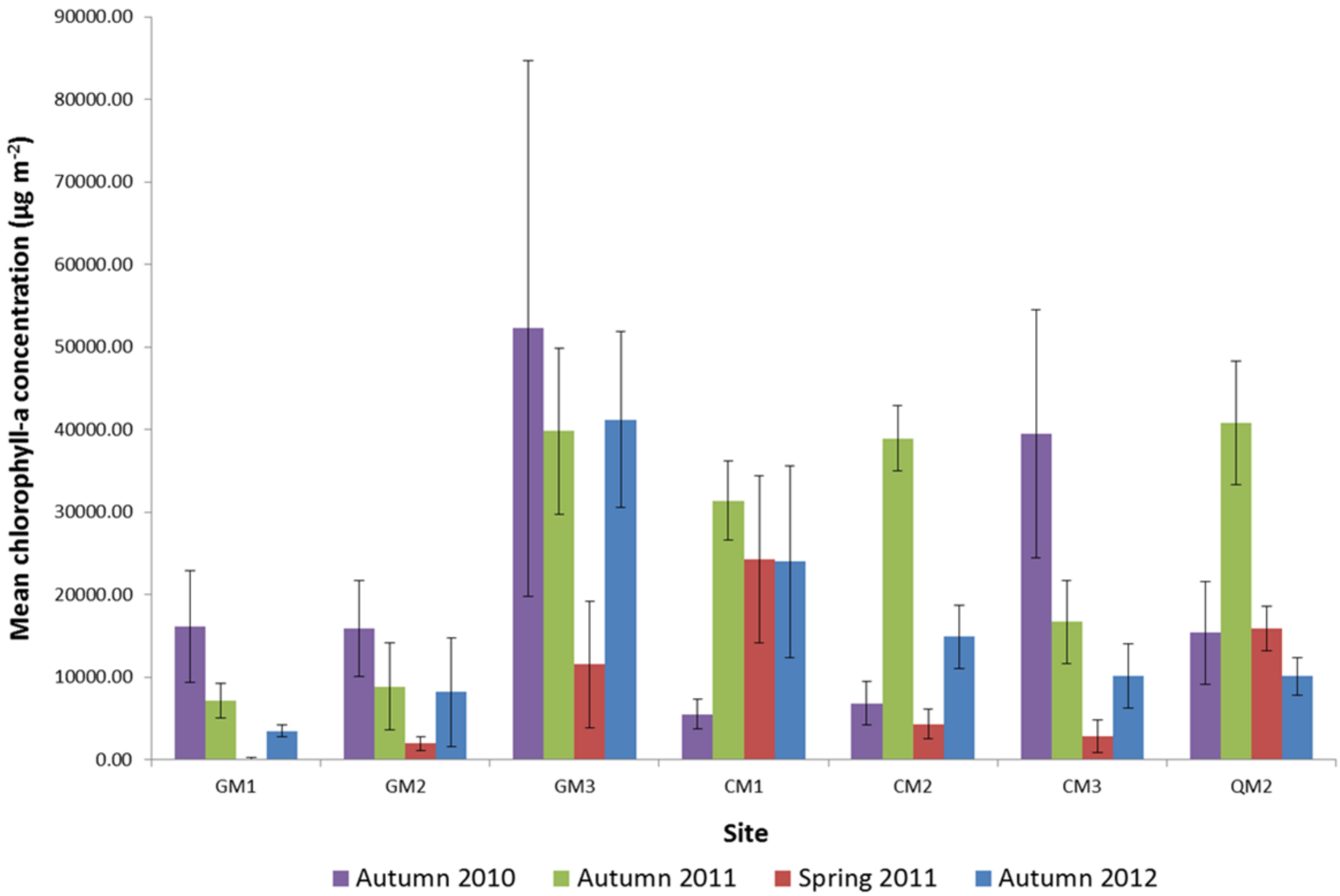

Figure 14: Mean chlorophyll-a (µg m^{-2}) at below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong) and reference sites GM1, GM2 and GM3 (Goodradigbee River) from autumn 2010 to autumn 2012. Error bars represent +/- 1 standard error.

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	5.44	0.0005	3	204.15	<0.0001	18	19.31	<0.0001
Chlorophyll-a	6	7.26	<0.0001	4	85.93	<0.0001	24	4.15	<0.0001

Benthic macroinvertebrates

Relative abundance

The relative abundance of pollution tolerant taxa Diptera (other families) was greatest below Cotter Dam (CM3), 2km downstream of Googong Dam (QM3) and at cotter tributary site (Fig. 15). The relative abundance of Diptera (Chironomidae family only) and Oligochaeta was greatest at below Corin and Bendora Dams (CM1 and CM2), and also at Cotter tributary site CT3 (Paddys River) (Fig. 15). Pollution sensitive taxa Ephemeroptera, Plecoptera and Trichoptera were most abundant at Goodradigbee River reference sites (GM1, GM2, GM3) and adjoining tributaries (GT1, GT2, GT3), compared to below dam sites on the Cotter and Queanbeyan Rivers (Fig. 15).

Taxonomic richness and whole sample abundance

Taxonomic richness was generally higher at reference sites than at below dam sites, with sites GT2, GT3 (Goodradigbee tributaries), GM1 (Goodradigbee River) and CT1 (Kangaroo Creek) having the highest taxonomic richness (Table 10). Taxonomic was lowest at test site CM3 (below Cotter Dam), followed by test site CM1 (below Corin Dam) and QM2 (below Googong Dam) (Table 10). The estimated whole sample abundance was lowest at Cotter tributary site CT2 (Burkes Creek) and greatest at sites Goodradigbee tributary site GT2 (Bull Flat Creek), below Bendora Dam (CM2) and Cotter Tributary site CT3 (Paddys River) (Table 10).

AUSRIVAS

The AUSRIVAS results for autumn 2012 indicated that all sites on the Goodradigbee River (GM1, GM2 and GM3) had declined in condition, the most notable decline being at site GM1 where condition decreased from similar to reference in spring 2011(band A) to severely impaired in autumn 2012 (band C) (Table 11). Site GM2 declined from being similar in reference condition (band A) to being significantly impaired (band B) in autumn 2012. Goodradigbee tributaries (GT1, GT2 and GT3) were the only sites to remain in band A since spring 2011 (Table 11).

Sites on the Queanbeyan River below Googong Dam (QM2 and QM3) also declined in biological condition since spring 2011. Site QM2 declined from band A to a band C and site QM3 declined from band A to a band B (Table 11). While reference site QM1 was biologically similar to reference condition (band A) (Table 11).

Sites on the Cotter River below Bendora and Cotter Dams (CM2 and CM3) declined in condition since spring 2011, with CM2 declining from band A to band B and CM3 declining from band B to band D (Table 11). The site below Corin Dam remained in Band B in autumn 2012, with a slight decrease in the O/E score compared to spring 2011 (Table 11). The decline in biological condition was also observed at Cotter tributary sites CT2 (Burkes Creek) and CT3 (Paddys River) (Table 11), with site CT2 declining from band A to a band B and CT3 declining from band A to a band C (Table 11). The Cotter tributary site CT1 on Kangaroo Creek was the only site to improve in biological condition in autumn 2012, from band B in spring 2011 to band A in autumn 2012 (Table 11).

Seven of the expected but missing taxa were present in the sample scans for eight sites (Gomphidae- GM1; Coloburiscidae- GT1; Gripopterygidae-CM3; Elmidae- GM2; Scirtidae-QM3; Psephenidae- GM2 and Hydrobiosidae- CM3, GM1, GM2, GM3, GT1, GT3 and QM3). Missing taxa had SIGNAL 2 grades ranging from 3 to 10 and reference sites GM2 and GM1 had the highest number of missing taxa found in the sample scans (Table 12). Taxa found in scans were not abundant enough to be collected in the sub-sample and the presence of these taxa indicates the site's potential to increase in condition under favourable conditions (Tables 12 and 13).

Macroinvertebrate community similarity

Based on relative abundance data two groups of sites were identified in the cluster analysis (SIMPROF test $p < 0.05$) (Fig. 16). Group one contained all sites below dams on the Cotter River (CM1, CM2 and CM3) and sites from Queanbeyan River upstream and downstream of Googong Dam (QM1, QM2 and QM3), in addition to Cotter tributary site CT3 (Paddys River) (Fig. 16). Group two contained Cotter tributary site CT1 and CT2, reference sites from the Goodradigbee River (GM1, GM2 and GM3) and Goodradigbee tributary sites GT1, GT2 and GT3 (Fig. 16). Compared to sites in group 1, group 2 sites were characterised by a greater taxonomic richness and abundance of pollution sensitive taxa (Leptophlebiidae - SIGNAL2 grade 8, Gripopterygidae - SIGNAL2 grade 8, Baetidae - SIGNAL2 grade 5) (Tables 10, 14 and 15).

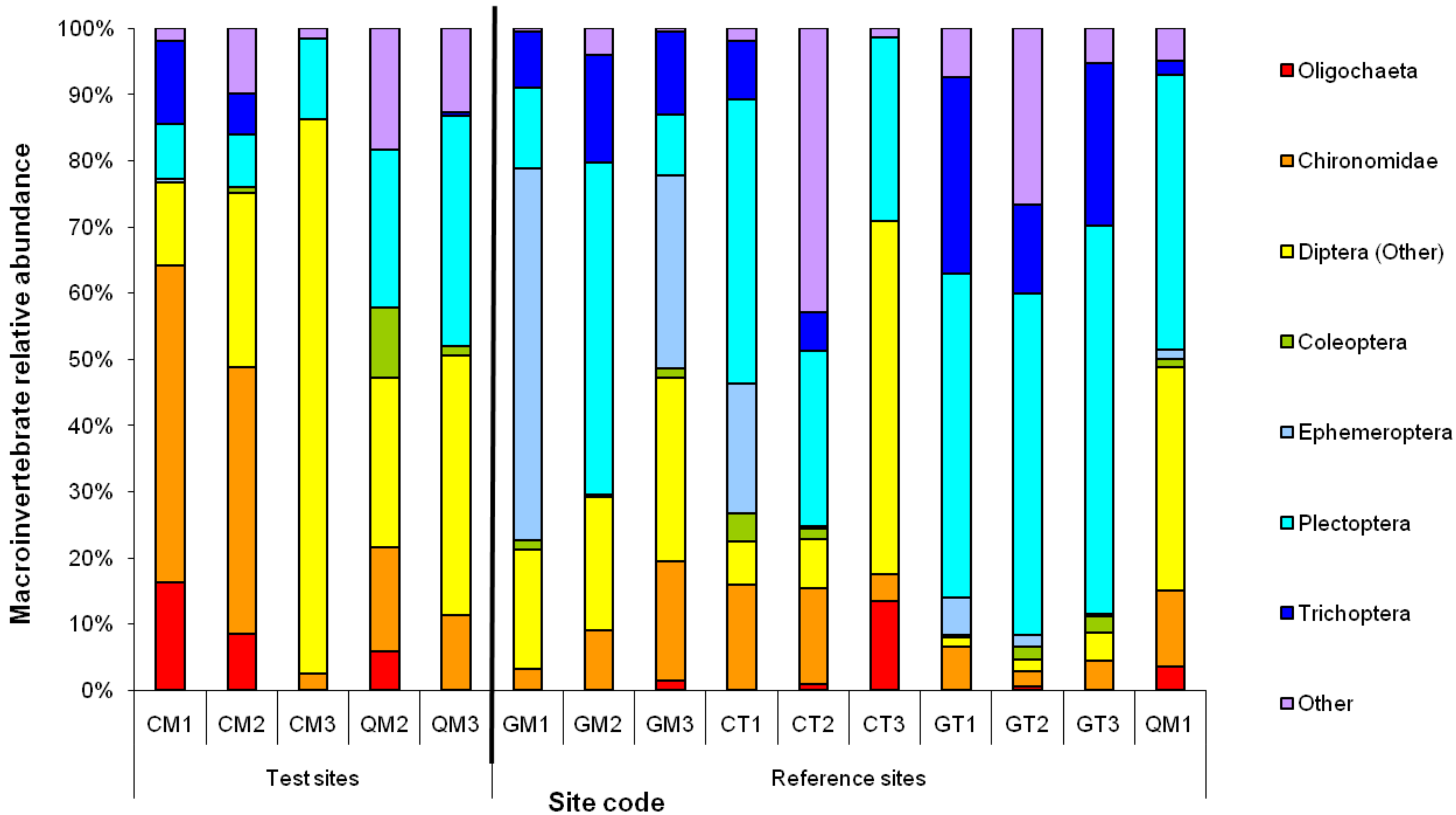

Figure 15: Relative abundance of macroinvertebrates taxa groups (indicated by different colours in the legend) at each sample site on the Cotter River (CM1a, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), autumn 2012.

Table 10: Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples during autumn 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**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
									Site							
ACARINA	**6**		1			1	1	4	4		1	4	4	3	2	3
OLIGOCHAETA	**6**	35	19				3		2	38		1		8	13	
TURBELLARIA																
Tricladida																
Dugesiidae	**2**		1												22	
Megaloptera																
Corydalidae	**7**				1											
Plecoptera																
Eustheniidae	**10**				1											
Gripopterygidae	**8**	27	14		26	40	19	92	14		64	29	51	5		1
Odonata																
Telephlebiidae	**9**												1			
Ephemeroptera																
Baetidae	**5**	4	13	24	31	13	13	7	35	55	11	7	13	68	39	70
Caenidae	**4**					1		5				1	1	2	14	3
Coloburiscidae	**8**				3	15	6				7		3			
Leptophlebiidae	**8**	14	5	22	91	95	41	30	29	23	88	104	105	24		1
Coleoptera																
Elmidae (Adult)	**7**							1	1			1	1			
Elmidae (Larvae)	**7**	1					1	8			3	1		3		

Table 10 cont.

CLASS **Order** Family *Subfamily*	**SIGNAL2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Dytiscidae	**2**						1									
Hydraenidae	**3**				1											
Psephenidae	**6**										1					
Scirtidae	**6**				2		1				8	2				
Diptera																
Chironomidae																
Diamesinae	**6**						1									
Chironominae	**3**	1	62				1	21	27	4	1	3	3	16	25	3
Orthocladiinae	**4**	100	28	9	5	21	32	12	3	4	8	2	3	9	10	20
Podonominae	**6**				1		3	1	5	3	3		1	1		
Tanypodinae	***4***	2			1	1					2		2			1
Empididae	**5**	4	12			1		2	7	2		1			2	1
Simuliidae	**5**	22	47	317	24	48	49	2	11	148		1	2	76	54	81
Tipulidae	**5**	1			16	1	8			1	3	2	7		1	1
Athericidae	**8**							10								
Trichoptera																
Calamoceratidae	**7**		9													
Calocidae	**9**				1											
Conoesucidae	**7**		1		5	4	18	4	56		4	10	1			
Ecnomidae	**4**														15	
Glossosomatidae	**9**				9	1	4	3	42		3	9	1			
Hydrobiosidae	**8**	4	8						2	4		1		5	3	
Hydropsychidae	**6**		3	6	1			10	1		4	6	2	5	23	22
Hydroptilidae	**4**					1		1				1				2

Table 10 cont.

CLASS																
Order									**Site**							
Family	**SIGNAL2**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Subfamily	**grade**															
Leptoceridae	**6**		1		3	4	4	1	2		5	29	7			
Odontoceridae	**7**											1				
Philopotamidae	**8**								1			1		1		3
No. individuals		**215**	**224**	**378**	**222**	**247**	**206**	**214**	**242**	**282**	**216**	**217**	**208**	**226**	**223**	**212**
No. of taxa		**12**	**15**	**5**	**18**	**15**	**17**	**18**	**17**	**10**	**17**	**21**	**18**	**14**	**13**	**14**
% of sub-sample		**5**	**3**	**2**	**8**	**2**	**6**	**2**	**9**	**2**	**8**	**1**	**3**	**2**	**5**	**2**
Whole sample estimate		**4300**	**7467**	**18900**	**2775**	**12350**	**3433**	**10700**	**2689**	**14100**	**2700**	**21700**	**6933**	**11300**	**4460**	**10600**

Table 11: AUSRIVAS O/E score and band 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 autumn 2012.

	Site														
	CM1	CM2	CM3	CT1	CT2	CT3	QM1	QM2	QM3	GM1	GM2	GM3	GT1	GT2	GT3
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)

Table 12: Macroinvertebrate taxa missing from the 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 autumn 2012 that were predicted with a ≥ 50% chance of occurrence by the AUSRIVAS ACT autumn riffle model 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														
Taxa	**SIGNAL2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Acarina	**6**				**X**					**X**						
Oligochaeta	**2**			**X**	**X**	**X**		**X**			**X**		**X**			**X**
Gastropoda																
Ancylidae	**4**				**X**					**X**					**X**	**X**
Diptera																
Chironominae	**3**			**X**	**X**	**X**										
Podonominae	**6**		**X**	**X**		**X**									**X**	**X**
Tanypodinae	**4**		**X**	**X**			**X**	**X**	**X**	**X**		**X**		**X**	**X**	
Simuliidae	**5**										**X**					
Tipulidae	**5**		**X**						**X**							
Coleoptera																
Elmidae	**7**		**X**	**X**	**X**	**X**				**X**					**X**	**X**
Hydrobiidae	**4**				**X**					**X**					**X**	**X**
Scirtidae	**6**	**X**							**X**							
Psephenidae	**6**	**X**	**X**	**X**		**X**	**X**	**X**	**X**			**X**	**X**	**X**		
Ephemeroptera																
Leptophlebidae	**8**														**X**	
Caenidae	**2**	**X**	**X**	**X**	**X**				**X**	**X**	**X**					
Coloburiscidae	**8**	**X**							**X**			**X**				
Odonata																
Gomphidae	**5**			**X**	**X**	**X**	**X**			**X**			**X**	**X**	**X**	**X**
Plecoptera																
Gripopterygidae	**8**			**X**												

Table 12 cont.

		Site														
Taxa	**SIGNAL2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Trichoptera																
Glossosomatidae	**9**	**X**														
Conoesucidae	**7**	**X**		**X**												
Hydrobiosidae	**8**			**X**	**X**	**X**	**X**	**X**			**X**		**X**			**X**
Hydropsychidae	**6**	**X**				**X**	**X**			**X**						
Hydroptilidae	**4**		**X**	**X**	**X**		**X**			**X**	**X**		**X**	**X**	**X**	
Leptoceridae	**6**	**X**								**X**					**X**	
No. of missing taxa		**8**	**7**	**12**	**10**	**8**	**6**	**4**	**6**	**10**	**5**	**3**	**5**	**4**	**9**	**8**

Table 13: Additional macroinvertebrate families and their sensitivity grade (SIGNAL 2) (Chessman, 2003) observed in the visual scan of entire 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 autumn 2012. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

CLASS **Order** Family *Subfamily*	**SIGNAL2 grade**	**Site** **CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Decapoda																
Palaemonidae	**4**			**X**												
INSECTA																
Hemiptera																
Velidae	**3**									**X**						
Megaloptera																
Corydalidae	**7**						**X**			**X**	**X**	**X**	**X**		**X**	
Odonata																
Gomphidae	**5**					**X**					**X**			**X**		
Telephlebiidae	**9**							**X**				**X**				
Ephemeroptera																
Coloburiscidae	**8**		**X**	**X**				**X**		**X**		**X**				
Plecoptera																
Eusthenidae	**10**					**X**			**X**							
Gripopterygidae	**8**			**X**												
Coleoptera																
Elmidae (Larvae)	**7**					**X**							**X**			
Scirtidae	**6**					**X**		**X**								**X**

Table 13 cont.

CLASS **Order** Family *Subfamily*	**SIGNAL2 grade**	**Site** **CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Psephenidae	**6**					**X**										
Ptilodactylidae	**10**							**X**								
Diptera																
Chironomidae																
Podonominae	***6***	**X**														
Tipulidae	**5**													**X**		
Trichoptera																
Calocidae	**9**							**X**	**X**							
Ecnomidae	**4**			**X**												
Hydrobiosidae	**8**			**X**	**X**	**X**	**X**	**X**			**X**		**X**			**X**
Philopotamidae	**8**		**X**					**X**					**X**			
No. New Taxa		**1**	**2**	**5**	**1**	**6**	**2**	**7**	**2**	**3**	**3**	**3**	**4**	**2**	**1**	**2**

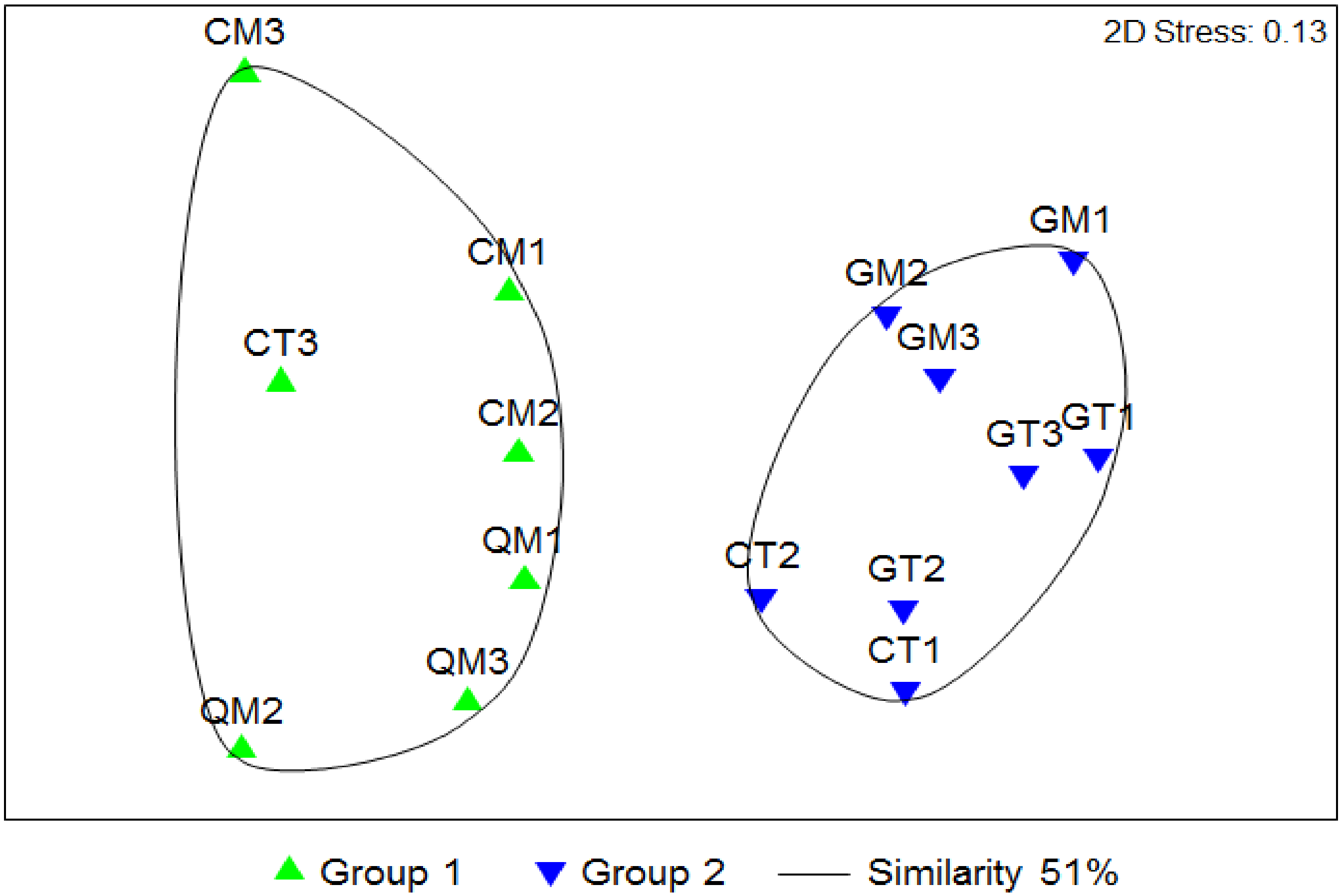

Figure 16: MDS ordination of similarity between macroinvertebrate samples collected in autumn 2012 for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance data and groups are defined from a cluster analysis and SIMPROF test.

Table 14: 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 %
1	Simuliidae	5	2.39	3.8	22.04	22.04
1	Baetidae	5	1.88	3.94	16.26	38.3
1	Orthocladiinae	4	1.64	6.41	13.42	51.73
1	Leptophlebiidae	8	1.24	1.28	9.41	61.14
1	Chironominae	3	1.25	1.42	7.3	68.44
1	Oligochaeta	2	1.22	0.9	6.8	75.24
1	Hydropsychidae	6	1	0.9	5.57	80.81
1	Hydrobiosidae	8	0.85	0.93	4.87	85.68
1	Empididae	5	0.77	0.92	4.07	89.75
1	Gripopterygidae	8	0.79	0.59	2.75	92.5
2	Leptophlebiidae	8	2.34	6.55	14.27	14.27
2	Gripopterygidae	8	2.02	7.09	12.05	26.32
2	Baetidae	5	1.59	8.97	9.65	35.97
2	Orthocladiinae	4	1.37	5.09	7.69	43.66
2	Conoesucidae	7	1.36	5.81	7.39	51.05
2	Leptoceridae	6	1.21	6.42	6.79	57.83
2	Glossosomatidae	9	1.23	5.75	6.6	64.43
2	Simuliidae	5	1.3	1.39	5.66	70.09
2	Acarina	6	0.89	1.63	4.51	74.6
2	Tipulidae	5	0.91	1.02	3.61	78.2
2	Chironominae	3	0.93	0.99	3.38	81.59
2	Hydropsychidae	6	0.82	1.02	3.22	84.81
2	Podonominae	6	0.73	1.04	3.08	87.89
2	Elmidae	7	0.75	1.04	2.97	90.86

Table 15: 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).

Taxa	SIGNAL2 grade	Average abundance		Contribution %	Consistency ratio
		Group 1	Group 2		
Gripopterygidae	8	0.79	2.02	6.73	1.46
Conoesucidae	7	0.12	1.36	6.46	2.43
Glossosomatidae	9	0	1.23	6.33	3.2
Simuliidae	5	2.39	1.3	5.96	1.38
Leptoceridae	6	0.12	1.21	5.68	2.5
Leptophlebiidae	8	1.24	2.34	5.58	1.75
Oligochaeta	2	1.22	0.36	5.42	1.51
Coloburiscidae	8	0	0.8	4.21	1.21
Chironominae	3	1.25	0.93	4.08	1.25
Hydrobiosidae	8	0.85	0.22	3.77	1.43
Hydropsychidae	6	1	0.82	3.63	1.32
Tipulidae	5	0.46	0.91	3.52	1.33
Elmidae	7	0.27	0.75	3.31	1.3
Podonominae	6	0.26	0.73	3.21	1.33
Empididae	5	0.77	0.49	3.15	1.25
Caenidae	2	0.52	0.46	3.06	1.17
Acarina	6	0.56	0.89	2.91	1.13
Orthocladiinae	4	1.64	1.37	2.47	1.2
Tanypodinae	4	0.26	0.45	2.42	1.02
Baetidae	5	1.88	1.59	2.36	1.56

Discussion and conclusions

Physical and chemical water quality characteristics

In autumn 2012 water quality at below dams sites and at unregulated reference sites was generally good and has improved in some cases since spring 2011. For example, turbidity at site CT3 was below the turbidity trigger level of 10 NTU and a reduction in total phosphorus and nitrogen concentrations occurred across the majority of sites (Figs. 8, 11 and 12) There were; however, four exceptions; (1) Turbidity was well above trigger level below Cotter Dam (CM3)(Figs.8 and 18); (2) Nitrogen oxide was above the trigger value at sites downstream of Googong Dam (Fig 10); (3) total phosphorus levels were above the trigger value below Cotter Dam and in Paddys River (CT3) (Fig. 11) and; (4) total nitrogen concentrations were above concentrations the trigger value upstream and downstream of Googong dam and Cotter Dam (Fig. 12).

The increased turbidity at site CM3 is likely to have been caused by a temporary instream disturbance associated with in stream construction activities up stream of the site. In the days following sampling it was confirmed there had been an excavator upstream in the river (Pers Comm- Marco Bottari ACTEW Water). Downstream of Googong Dam (site QM2 and QM3) nitrogen oxide concentrations were also above the trigger value in spring 2011 (Fig. 10). The continuation of above trigger level nitrogen oxide concentration at site QM2 and QM3 may be the result of continued high nitrogen oxide concentrations in Googong Reservoir following increased inflows during flooding in early autumn 2012. In terms of total phosphorus and nitrogen concentrations, above trigger level concentrations in the Queanbeyan river, downstream of Cotter Dam and in Paddys River are likely the result of increased catchment erosion and runoff during high rainfall in early autumn 2012 (Boulton and Brock 1999)(Figs. 2, 11 and 12). The high nutrient concentrations below Cotter Dam are also possibly the result of increased suspended sediment levels from upstream construction activities, increased turbidity at times of high rainfall when Cotter Dam spills with water from the lower Cotter Catchment (an ex-forestry estate with erosion sources) or from Murrumbidgee River water pumped via M2C (Fig. 17).

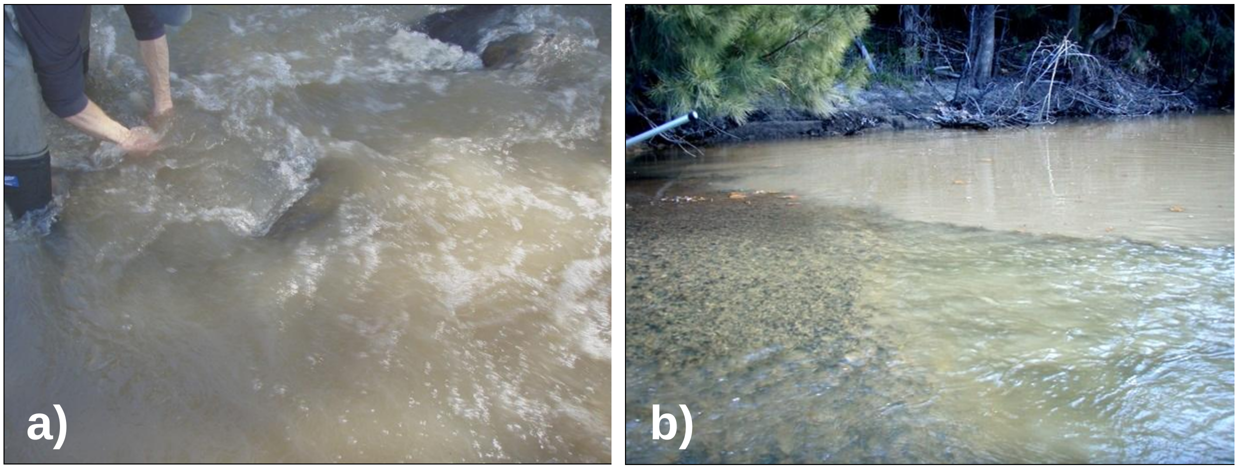

Figure 17: a) High turbidity below Cotter Dam (CM3) during sampling on 22/5/12; and b) turbid water of the Cotter River at the confluence with Paddys River.

Periphyton and algae

One of the ecological objectives of environmental flows releases in the Cotter and Queanbeyan Rivers is to maintain filamentous algae cover at <20% for 95% of time (ACT Government, 2006). In autumn 2012 filamentous algae cover returned to <10% covering the riffle habitat below Corin, Bendora and Googong Dams compared to 10-35% in spring 2011 (Table 9). It should be noted that the decrease in filamentous algae at site CM1 may be related to the changed site location in spring 2011 (i.e. closer to Corin Dam- see Harrison and Nichols 2011). In autumn 2012, samples were collected from the original site location and filamentous algae cover was the same as autumn 2011 and 2010 at this location (<10% - Table 8).

In autumn 2012, Periphyton/algae AFDM was also similar between all below dam sites on the Cotter River and two out of three of the Goodradigbee River reference sites (GM1, GM2). The decrease in filamentous algae cover and similar periphyton/algae AFDM between the Cotter and Goodradigbee Rivers is likely the result of algae being scoured during high flow velocities in floods in early autumn. However, on the Queanbeyan River downstream of Googong Dam, AFDM was significantly higher compared to Goodradigbee reference sites (GM1, GM2) in autumn 2012 and may be indicative continued elevated phosphorus concentrations increasing periphyton growth downstream of Googong Dam (Allan 1995)(Figs. 11 and 13).

Between autumn 2010 and autumn 2012 periphyton/algae active growth indicated by Chlorophyll-a concentration has changed in response to floods and possible changes in taxonomic composition (Chester and Norris 2006; Harrison et al. 2011; Harrison and Nichols 2011; White et al. 2012). As a result of the flooding events there was a significant interaction between site and season in chlorophyll-a concentration and between 2010-2012 sampling periods and there have been significant changes in chlorophyll-a below dams and at reference sites (Table 8; Fig 14). In autumn 2012, the minimal significant differences in Chlorophyll-a concentration between below dam sites and Goodradigbee river reference sites are likely because of the increased stream discharge experienced in both rivers which increased velocity and scoured periphyton/algae (Fig. 14). However, the exception to this was below Corin and Bendora dams, where periphyton/algae was growing more actively than Goodradigbee reference site (GM2) (indicated by significantly higher Chlorophyll-a concentrations - Fig. 14). This difference in active periphyton/algae growth could be result of different periphyton/alage taxa below Corin and Bendora Dams compared to the Goodradigbee River (see Chester and Norris 2006).

Benthic macroinvertebrates

In autumn 2012 there was an overall decline in the biological condition of sites below Bendora, Cotter and Googong Dams (CM2, CM3, QM2 and QM3) (Table 11). The exception was site CM1 (below Corin Dam), which has been assessed as significantly impaired (band B) for 9 of the last 10 sampling occasions (Harrison and Nichols 2011; Deschaseaux and Norris 2009). However, declines in biological condition also occurred at unregulated reference sites on the Goodradigbee River (GM1, GM2, GM3) (Table 11). The decline in biological condition of sites on the Cotter, Queanbeyan, and Goodradigbee Rivers in autumn 2012 indicates that flood conditions in early autumn 2012 (caused by the 153 mm of rainfall in March 2012) have had a negative effect on in stream habitat and macroinvertebrate communities are still recovering from this disturbance (Fig. 2). Therefore, the decline in the biological condition of the Goodradigbee River as a result of the flood disturbance (indicated by a decline in AUSRIVAS O/E score bands) means that the biological impairment of below dam sites on the Cotter and Queanbeyan Rivers cannot be attributed directly to the effects of the dams.

After flooding in autumn 2012 differences in macroinvertebrate community composition (based on relative abundance data) were observed between below dam and reference sites. Below dam sites on the Cotter and Queanbeyan Rivers had a lower taxonomic richness and had a high abundance of pollution/disturbance sensitive taxa compared to reference sites on the Goodradigbee River (Tables 10, 14 and 15, Fig. 15). It is likely that the recovery and recruitment of macroinvertebrate communities at below dam sites post flooding may take longer as a result of barrier effects associated with the dams (i.e. reducing macroinvertebrate community recruitment via drift from upstream - Marchant and Hehir 2002). Also macroinvertebrate communities at below dam sites are may not be as adapted to high flow disturbances as the unregulated Goodradigbee River, which regularly experiences high flow disturbances.

Site CM3 downstream of Cotter Dam was the most biologically impaired site in Autumn 2012 (Table 11), and declined from band B in spring 2011 to band D in autumn 2012 (Table 11). The very high turbidity that was measured on the day of sampling (Fig. 8) was an isolated event, and therefore unlikely to have caused the full extent of biological impairment observed at this site. The decline in biological condition is more likely to have been caused by the effects of the preceding flood disturbance, and may have been increased by macroinvertebrate drift during this high turbidity event (Jones et al. 2011; Waters 1995).

Changes in channel morphology and the removal of riparian vegetation were observed on the Goodradigbee River as a result of the high flows before sampling (40613 ML day^{-1}) (Fig. 2) (Fig. 18). The removal of refugia (both instream and trailing riparian vegetation), alterations to flow hydraulics, event-based variations in water quality (e.g. increased turbidity during flooding), and entrainment/deposition of bed material as a result of these physical habitat changes may have resulted in many of the missing predicted taxa and declines in the AUSRIVAS O/E scores at reference sites on the Goodradigbee River (Tables 11 and 12). Recovery from flood disturbance is usually rapid and only takes a few weeks (Bolton *et al.* 1988; Lake *et al.*1989). However, longer recovery times have been observed following disturbances that have resulted in alterations to physical conditions, such as those evident in the Goodradigbee, and can take up to 3 months to recover (Gore 1982).

In contrast to sites on the larger Cotter, Queanbeyan and Goodradigbee Rivers, four out of six tributary sites were less affected by the flood disturbance (Table 11). For example, no change in biological condition was evident at Goodradigbee tributary sites GT1, GT2 and GT3, which has remained similar to reference condition (band A) since autumn 2011 (Table 11). Furthermore, Cotter tributary site CT1 on Kangaroo Creek was the only site to improve in biological condition from being significantly impaired in spring 2011 (band B) to being similar to reference condition (band A) in autumn 2012. Therefore, given that the macroinvertebrate communities in several of the tributary sites appear to have recovered from the flood disturbance, it is likely that there will be recovery of macroinvertebrate communities in the larger Cotter, Queanbeyan and Goodradigbee Rivers in the coming months if more floods do not occur.

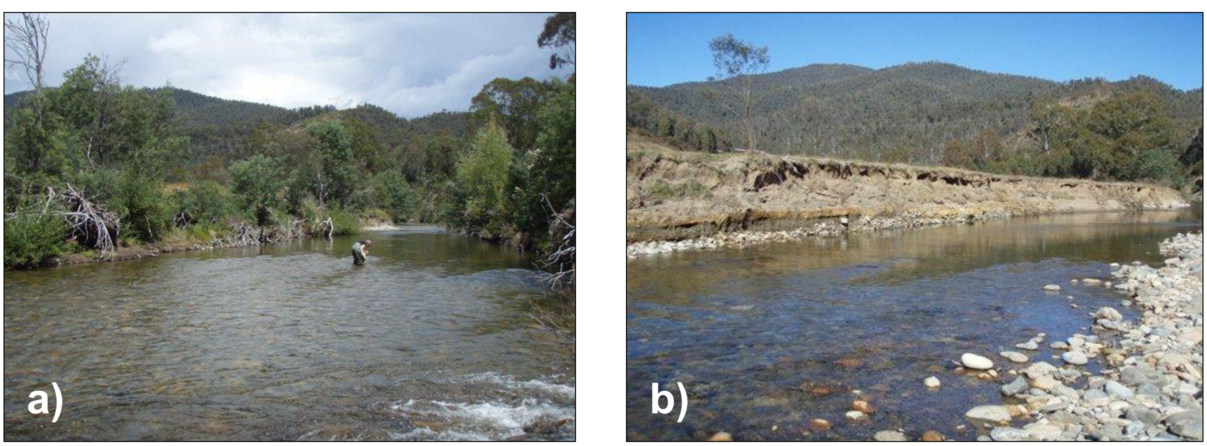

Figure 18: Site GM1 on the Goodradigbee River in a) spring 2011, and b) autumn 2012.

Project recommendations

Based on the results and conclusions of this report future project recommendations for the Below Dams Assessment Program include:

- A long-term assessment of Below Dams Assessment Program water quality, physical habitat, periphyton and macroinvertebrate data. The Below Dams Assessment Program has been in place for over 10 years and during this time Cotter, Queanbeyan and Goodradigbee Rivers have experienced a variety of low and high flow conditions. Therefore, it is an opportune time to make a long-term assessment of changes in and relationships between water quality, physical habitat, periphyton and macroinvertebrates across a variety of flow conditions. Such an assessment would allow for a better understanding of seasonal changes in river condition and responses to changing flows downstream of dams in the Cotter and Queanbeyan Rivers.

- An assessment of periphyton/alage taxa present below dams compared to the Goodradigbee River. It has been discussed (in this report and previous reports) that differences in periphyton biomass and chlorophyll-a between below dams and reference sites may be because of different periphyton/alage taxa being present. Collection and identification of periphyton/algae present in riffles should take place under a variety of river flow conditions at below dam and reference sites. This would enable an assessment of periphyton/alage community responses to river regulation in the Cotter and Queanbeyan Rivers which could be related to differences in macroinvertebrate community structure between below dam and reference sites.

Acknowledgements

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