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

Spring 2011

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ActewAGL Water Quality Monitoring Program –

Report prepared for: ActewAGL Distribution

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Front Photograph: Cotter River at site CM3 downstream of Cotter Dam (E. Harrison).

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Executive summary

- 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 Queanbeyan River water supply catchments. This study specifically focuses on assessing the ecological status of river habitats using water quality data, algae and macroinvertebrates.

- The riffle normally sampled 500m downstream of Corin Dam could not be accessed for sampling because of high river flow. Therefore, a riffle 50m downstream of Corin Dam (CM1a), which could be accessed, was sampled.

- In spring 2011 water quality at below dam sites on Cotter and Queanbeyan Rivers and at unregulated references was in good condition. Downstream of Corin, Bendora and Googong Dams there was an increase in periphtyon and filamentous algae cover, this may be the result of an increased water temperature prior to sampling or an increased concentration of phosphorus compared to nitrogen.

- In the response to previously higher river flows, the periphyton communities downstream of Bendora Dam, Cotter Dam and on the unregulated Goodradigbee River now possibly have an increased abundance of taxa with less Chlorophyll-a.

- Three sites (CM2, QM2 and QM3: below Bendora and Googong Dams) were assessed as AUSRIVAS band A (similar to reference condition), and therefore met the specified environmental-flow ecological objective for maintaining healthy aquatic ecosystems in terms of biota. Sites CM1 (represented by CM1a) (Corin Dam) and CM3 (Cotter Dam) remained significantly impaired (band B). Nine of the ten reference sites on the Goodradigbee, Cotter and Queanbeyan Rivers and tributaries (Cotter and Goodradigbee) were assessed as similar to reference condition or more diverse than reference condition (bands A and X) in spring 2011.

- Macroinvertebrate communities at below dam sites have remained similar to spring 2009 (the last spring sample before the floods) with low abundances (compared to reference sites) of sensitive taxa (i.e. those with SIGNAL 2 grades ≥7). Therefore, following the flooding in spring/summer 2010, the instream habitat at below dam sites on the Cotter and Queanbeyan Rivers has not yet improved from pre-flood conditions to the point where it can support macroinvertebrate communities with similar taxa abundances to unregulated reference sites on the Goodradigbee River.

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 and 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 of 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.

Assessment, based on the ecological objectives of environmental flow regimes in the ACT, has been ongoing at fixed sampling sites since 2001 and is based on 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 water supply catchments.

In autumn 2011 (following flooding events in the spring and summer months of 2010/11) algal ash free dry mass at below dams sites on the Cotter and Queanbeyan Rivers (periphyton and filamentous) was similar to the ash free dry mass recovered from reference sites on the Goodradigbee River (Harrison et al. 2011). However, there was an absence of improvements in macroinvertebrate taxa richness and the relative abundance of sensitive taxa downstream of dams on the Cotter and Queanbeyan Rivers. This may be because the macroinvertebrate community that developed under the antecedent low-flow conditions prior to flooding may have restricted capacity for an immediate positive response following the large flow event (Harrison et al. 2011). Further macroinvertebrate community recovery was predicted to occur below dams following macroinvertebrate recruitment in spring 2011 (Harrison et al. 2011), because of good flows on the Cotter and Queanbeyan Rivers which have been greater than the release requirements under the environmental flow guidelines (~100-500 MLd^{-1}). This report assesses the condition of "Below Dams Assessment Program" study sites in spring before and after flooding. Of most interest is how macroinvertebrate assemblages and periphyton/algae have responded to flows downstream of each of the dams because these are the selected indicators of river health in the environmental flow objectives.

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 $ML.d^{-1}$ could 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) regulated by Googong Dam approximately 90 km from its source. Similar to the Cotter River, the primary goal for the Queanbeyan River above Googong Dam is to secure the water supply for the ACT and Queanbeyan. Compared to the Cotter River catchment, the Queanbeyan River 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 Cotter River because of its 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 28/10/2011-14/12/2011 (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). These sites were then replicated on the unregulated Goodradigbee River (GM1, GM2, GM3) and three of its tributaries (GT1, GT2, GT3). Three sites were also sampled on the Queanbeyan River, one upstream of Googong Dam (QM1) and two downstream of the dam (QM2, QM3).

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 CM1 (downstream of Corin Dam) was sampled at a later date than the other Cotter River sites because of high flows (Table 2). The riffle normally sampled 500m downstream of Corin Dam could not be accessed on the 14/12/2011 because of high river flow. Therefore, a riffle 50m downstream of Corin Dam (CM1a) which could be accessed was sampled. The nearby tributary reference site CT1 (Kangaroo Ck) was also sampled on the 14/12/2011 (Table 2).

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.

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the Below Dams Assessment Program, spring 2011.

Site Code	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1a	Cotter	50 m downstream of Corin Dam (*note usual site location CM1 is 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

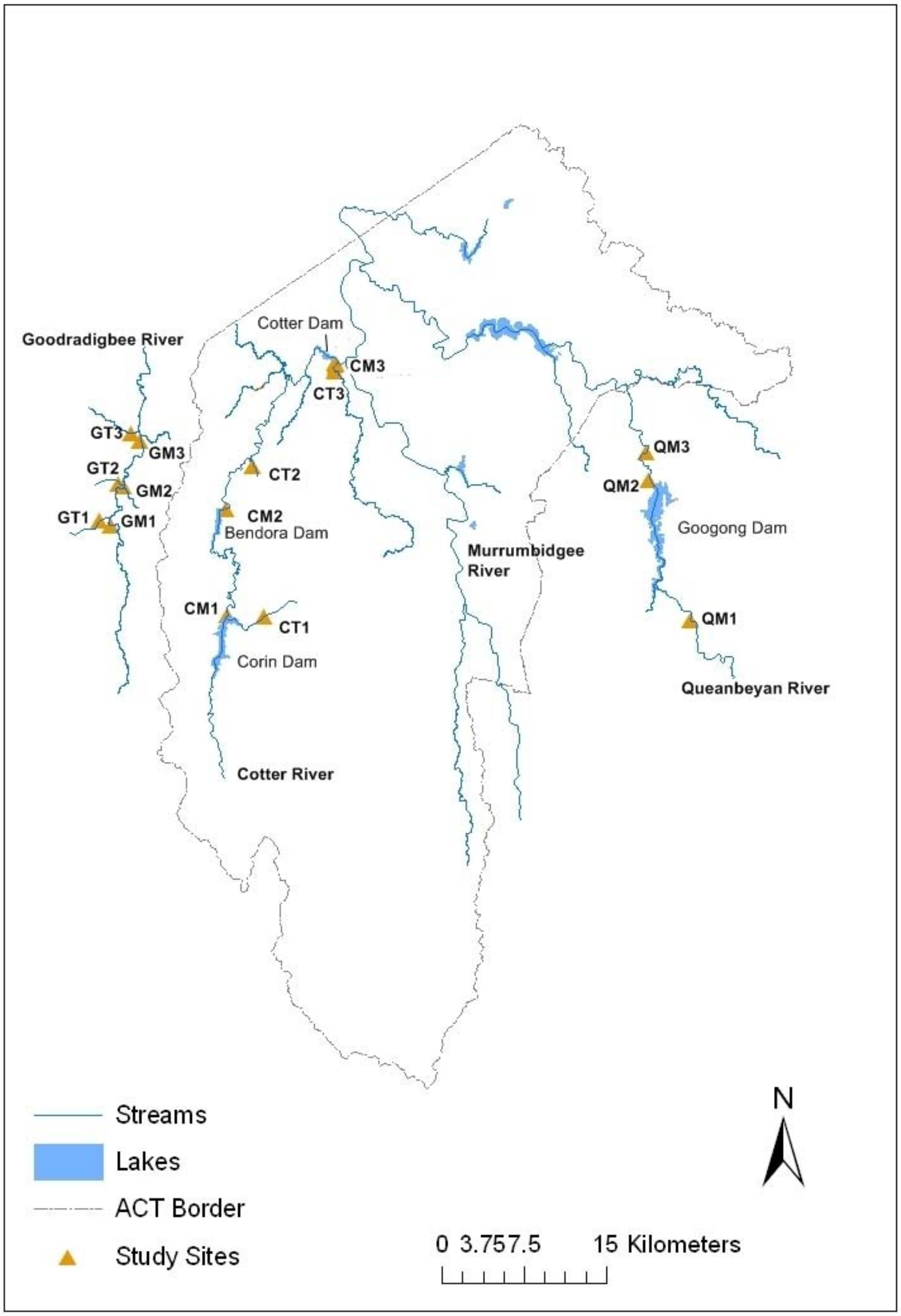

Figure 1: The location of sites usually sampled on the Cotter, Goodradigbee and Queanbeyan River's and tributaries for the Below Dams Assessment Program. *Note in spring 2011 site CM1 is referred to as site CM1a (see Table 1).*

Table 2: Sampling dates and times for each site October-December 2011.

Site	SAMPLING DATE	SAMPLING TIME
CM1a	14/12/2011	12:00
CM2	28/10/2011	14:00
CM3	28/10/2011	09:40
CT1	14/12/11	10:00
CT2	28/10/11	13:00
CT3	28/10/11	11:30
GM1	3/11/11	11:00
GM2	3/11/11	12:50
GM3	3/11/11	15:30
GT1	3/11/11	09:45
GT2	3/11/11	11:30
GT3	3/11/11	14:00
QM1	2/11/11	10:30
QM2	2/11/11	12:00
QM3	2/11/11	14:00

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 ActewAGL. 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). Water velocity was measured with a calibrated Hydrological Services CMC20 flow meter. One 60ml 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, Queanbeyan and Goodradgibee 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 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 45 ^oC to a constant weight, then ashed in a furnace at 500 ^oC 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)

***AFDM samples from spring 2011 were not analysed further and included in this report, because measurements were well outside previously biomass from the Cotter, Queanbeyan and Goodradigbee Rivers. Visual observations of samples did not correspond with AFDM results and in reviewing these results laboratory processing error in the analysis could not be ruled out. Furthermore, with increased periphyton AFDM it would also be expected that an increase in Chlorophyll-a would occur, but this was not the case. Therefore, we could not confidently interpret the data. In this report Chlorophyll-a measurements and field visual observations of periphyton cover are used as surrogate measures of periphyton biomass.*

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.canberra.edu.au).

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 invertebrate 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.canberra.edu.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.canberra.edu.au.* Also provided in the manual is a comprehensive explanation of how the AUSRIVAS predictive models are constructed, the statistical workings of the models, details on interpretation of the outputs, and how to gain a password to run AUSRIVAS. 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.canberra.edu.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.

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

Band	Band description	Band width	O/E Taxa interpretations
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	>1.14	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	SIMILAR TO REFERENCE	0.86-1.14	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	0.57-0.85	Fewer families than expected. Potential impact either on water quality or habitat quality or both resulting in loss of taxa.
C	SEVERELY IMPAIRED	0.28-0.56	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	EXTREMELY IMPAIRED	0-0.27	Few of the expected families remain. Extremely poor water and/or habitat quality. Highly degraded.

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 2 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 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 2011, autumn 2011, autumn 2010, spring 2009) in periphyton AFDM and chlorophyll-a were tested using a two-way analysis of variance (ANOVA) (SAS 9.1), followed by a Tukey-Kramer pairwise comparisons to indentify significant differences. Spring 2009 data was used in the data analysis because it was the last time all sites were sampled before flooding occurred. No sites were sampled in spring 2010 because of flooding. To determine if there were significant differences between periphyton chlorophyll-a at sites in spring 2011 a single factor ANOVA (SAS 9.1) was used followed by Tukey-Kramer multiple comparisons. A $\log_{10}(x+1)$ transformation was applied to chlorophyll-a data, before undertaking the ANOVAs and t-test, to ensure the data met the assumption of normality.

Differences in the macroinvertebrate community structure between sites in spring 2009 and spring 2011 were assessed using Multi-Dimensional Scaling (MDS) ordination applied to fourth root transformed macroinvertebrate relative abundance data (PRIMER v6; Clark and Warwick 2001). Groups in the ordination were defined by cluster analysis (PRIMER v6; Clark and Warwick 2001). Only spring 2009 and 2011 data was used in the cluster analysis to eliminate the effect of season on macroinvertebrate community structure to assess the pre and post effects of flooding on macroinvertebrate communities calculated using the Bray-Curtis similarity index and an analysis of similarity (ANOSIM) applied to the relative abundance to test the separation of the groups defined in the cluster analysis. The taxa contributing (up to approximately 70% contribution) to each of the defined groups in the cluster analysis and taxa discriminating between cluster analysis groups were determined by a Similarity Percentages (SIMPER) analysis (Clark and Warwick 2001). In SIMPER analysis a consistency ratio ≥1.4 is viewed as a reliable means of assigning discriminating taxa between groups (Clark and Warwick 2001).

Results

Hydrometric data

Flow in the Cotter, Queanbeyan and Goodradigbee Rivers during spring 2011 was less than flow during spring/summer 2010/11 (Fig. 2). Preceding spring 2011 sampling (taken from July 2011) flows, downstream of each dam, ranged between 36-685ML d^{-1} at Corin, 9.5-260ML d^{-1}, at Bendora, 44-362 ML d^{-1} at Cotter and 7.3-644.1ML d^{-1} at Googong Dams (Fig. 2, Table 7). Flows generally resulted from the environmental flow releases (ACT Government 2006), with exceptions occurring when special releases (higher flows) were released for Enlarged Cotter Dam (ECD) construction purposes or when dams spilled following rainfall (Table 7). Downstream of Cotter Dam in spring 2011, flows were released from the dam to prevent water spilling over the dam into the ECD construction site and for the drawdown of the reservoir for construction work (Table 7, Fig. 2). Flow during spring 2011 in the Goodradigbee River was generally greater than the flow downstream of 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 (from 1st July 2011) spring 2011 Below Dams Assessment program. Data source: ACTEWAGL.

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
	*Note: other flow releases to fill Cotter Reservoir following drawdown for dam construction and dam spilled in late November prior to sampling
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
	*Note: other flow releases to fill Cotter Reservoir following drawdown for dam construction
Cotter	flows of approximately 44-2189 MLd-^{1} during Enlarged Cotter Dam construction to prevent flooding of construction site
Googong	base flow average 10 MLd-^{1}
	riffle maintenance flow 100 MLd-^{1} for 1 day every 2 months
	*Note: dam spilled in late August

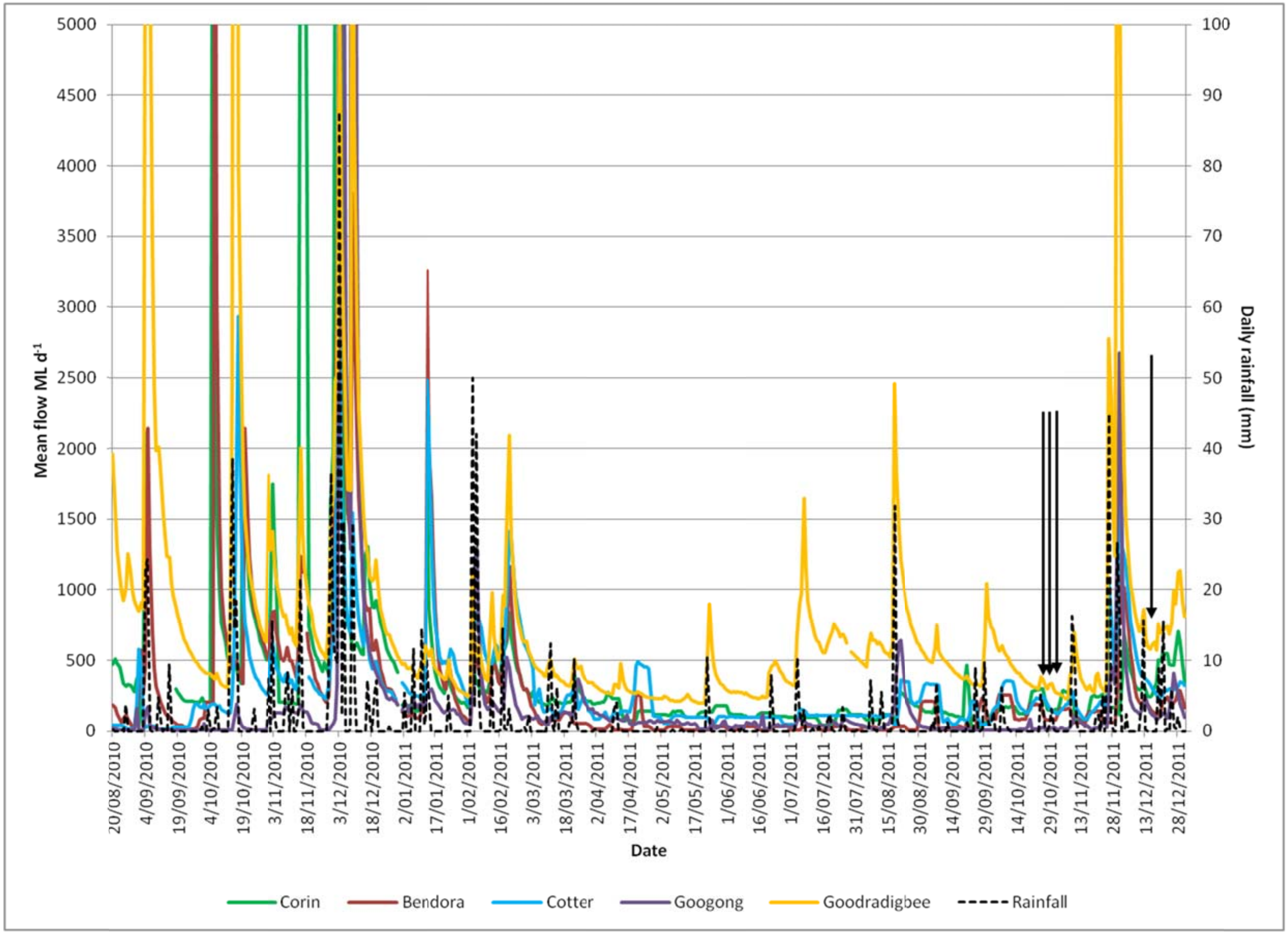

Figure 2: Daily river flow in the Cotter, Goodradigbee and Queanbeyan Rivers: below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams and Goodradigbee River (GM2); and daily rainfall data for Canberra airport from 20/08/2010 to 31/2/2011. NB. Flow peaks >5000 ML d $^{-1}$ are not shown on the graph. Arrows correspond to spring 2011 sampling dates (see Table 2). Data source: ACTEWAGL and NSW Department of Water and Energy; Bureau of Meteorology.

Physical and chemical water quality characteristics

Alkalinity

Alkalinity at all sites in spring 2011 (except Cotter tributary site CT3-higher than the past three alkalinity measurements) was within the range of concentrations measured in the past three full sampling runs (spring 2009, autumn 2010, autumn 2011) (Fig. 3).

Water temperature

Water temperature at all sites in spring 2011 was similar to temperatures measured in the past three full sampling runs (Fig. 4). It should be noted that water temperature is dependent upon the time of sampling in autumn or spring.

Electrical conductivity

Electrical conductivity of stream water at all sites in spring 2011 was below the upper trigger value of 350 µs cm^{-1}, which was the same result as the past three full sampling runs (Fig. 5). In spring 2011 and the past three full sampling runs electrical conductivity at sites upstream and downstream of Googong Dam has been consistently higher than other below dam and reference sites. It should be noted that electrical conductivity is dependent upon factors such as catchment geology and rainfall.

pH

Most sites in spring 2011 pH values were within the recommended ANZECC trigger value range of pH 6.5-8 (Fig. 6). The exceptions were at site QM3 (downstream of Googong Dam) and Cotter tributary site CT3 (Paddys River) where pH values were slightly greater than the recommended trigger value range (Fig. 6). Previously in autumn 2011 all sites were within the recommended trigger value range (Table 8). The last time sites QM3 and CT3 were above the pH trigger value range was in spring 2009 (Fig. 6).

Dissolved oxygen

Dissolved oxygen concentrations were lower at all sites in spring 2011 compared to autumn 2011, but were not below the trigger value of 6 mg L^{-1} at any of the sites (Fig. 7), which is the same result as the past three full sampling runs (Fig. 7).

Turbidity

Turbidity at the Cotter River tributary site CT3 (Paddys River) was above the trigger value of 10 NTU, while all other sites were below the trigger value in spring 2011 (Fig. 8). Compared to autumn 2011, turbidity at both sites downstream of Googong Dam (QM2 and QM3) decreased to be below the trigger value of 10NTU (Fig. 8).

Ammonia

Ammonia concentrations in spring 2011 were all below the trigger value of 0.9 mg L^{-1}, which is the same result as the past three full sampling runs (Fig. 9).

Nitrogen oxide

Oxidised nitrogen concentrations in spring 2011 at both sites downstream of Googong Dam (QM2 and QM3) were above the trigger value of 0.015 mg L^{-1} , while all other sites were below the trigger value (Fig. 10). Previously in autumn 2011 sites QM2 and QM3 also had oxidised nitrogen concentrations above the trigger value (Fig. 10).

Total Phosphorus

Total phosphorus concentrations in spring 2011 at all below dam sites and reference/tributary sites (except CT2 and CT3) were equal to or higher than the trigger value of 0.02 mg L^{-1} (Fig. 11). Compared to autumn 2011, spring 2011 total phosphorus concentrations have increased or remained the same at below dam sites on the Cotter and Queanbeyan Rivers (Fig. 11). Total phosphorus concentrations at reference/tributary sites (except CT2 and CT3) also increased since autumn 2011 (Fig. 11).

Total Nitrogen

Total nitrogen concentrations in spring 2011 at both sites downstream of Googong Dam (QM2 and QM3) were above the trigger value of 0.25 mg L^{-1} (Fig. 12). TN concentrations at sites QM2 and QM3 have decreased since autumn 2011 to be similar to concentrations from autumn 2010 (Fig. 12). Also in spring 2011 total nitrogen at the below Cotter Dam site (CM3) and Cotter tributary site CT1 (Kangaroo Creek) decreased from autumn 2011 to be below ANZECC trigger value (Fig. 12).

Periphyton and algae: Chlorophyll-a and visual observations

Within the spring 2011 sampling period periphyton chlorophyll-a was significantly lower at Goodradigbee River reference site GM1 compared to the Goodradigbee River site GM3 and below dam sites QM2 (Googong Dam) and CM1 (Corin Dam) ($F= 5.94$; $DF= 6,35$; $P=0.0002$)(Fig. 13).

From spring 2009 to spring 2011 mean periphyton chlorophyll-a concentration differed significantly by site and season (spring 2009, autumn 2010, autumn 2011 and spring 2011), and the site-season interaction was significant (Fig. 13 and Table 8). At below dam sites CM2 (Bendora Dam), CM3 (Cotter Dam) and Goodradigbee reference sites GM1, GM2 and GM3 periphyton chlorophyll-a was significantly lower (based on Tukey-Kramer mutilpe comparisons) in spring 2011 compared to spring 2009 (sites GM1, GM2), autumn 2010 (sites CM3, GM1, GM2) and autumn 2011 (sites CM2, CM3, GM1) (Fig. 13).

In spring 2011 visual observations of periphyton percentage cover in both the riffle habitat and reach was less than 10 % for all Goodradigbee River reference sites and site CM3 below

Cotter Dam (Table 9). Periphyton percentage cover at sites CM1, CM2 and QM2 increased from <10% in autumn 2011 to 10-35% (CM2: Bendora Dam) and 35-65% (CM1, QM2) in the riffle habitat and increased from <10% in autumn 2011 to 10-35% (CM1, CM2) and 35-65% (QM2) cover in within the reach (Table 9). Filamentous algae cover has remained at <10% for all Goodradigbee reference sites and below dam site CM3 (Cotter Dam) (Table 9). Within the riffle habitat and reach at below dam sites CM1, CM2 and QM2 filamentous algae has increased from <10% to 10-35% cover (Table 9). For example at site CM2 downstream of Bendora Dam there were large masses of filamentous algae present (Fig. 14).

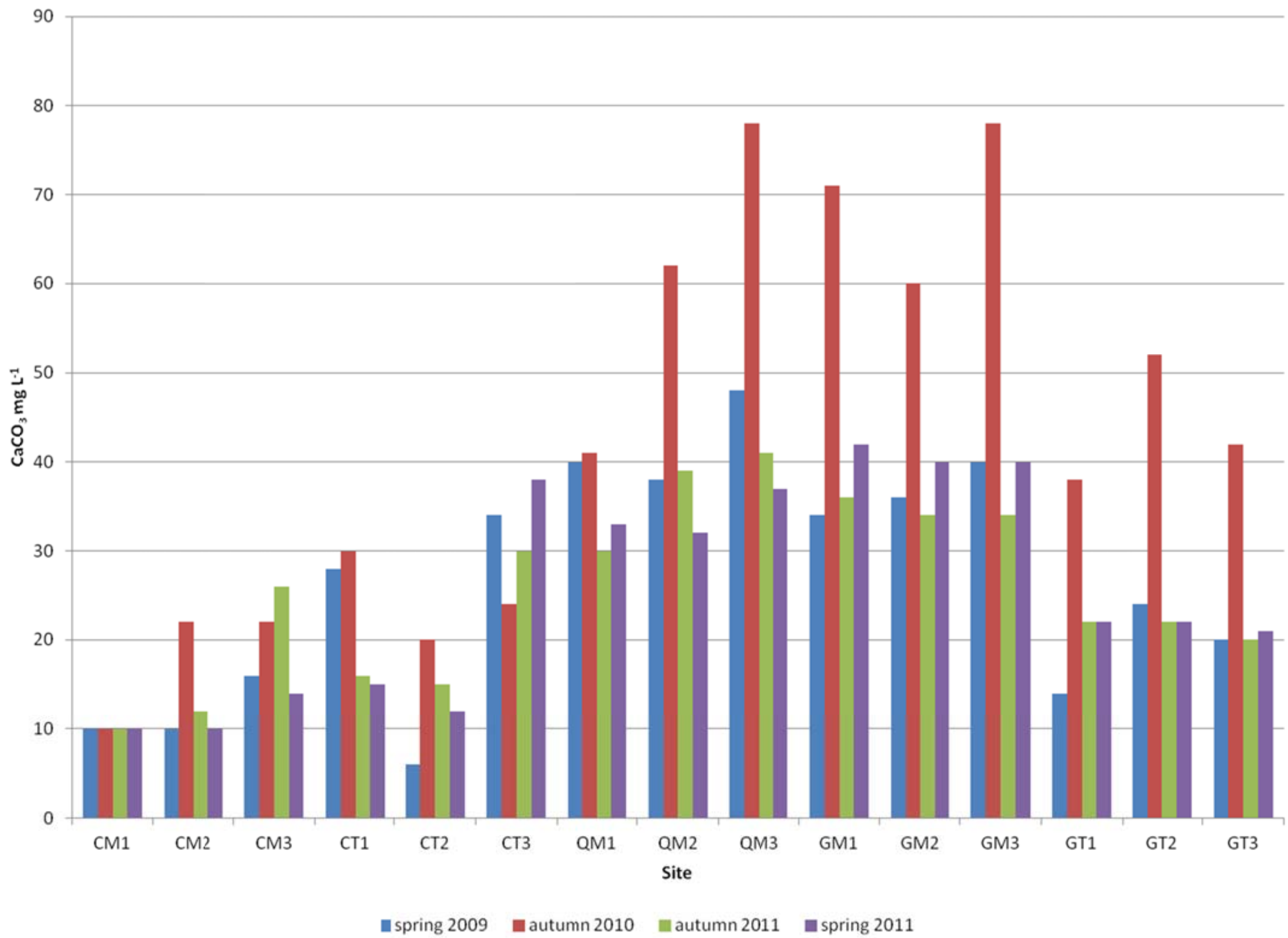

Figure 3: Alkalinity at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).*

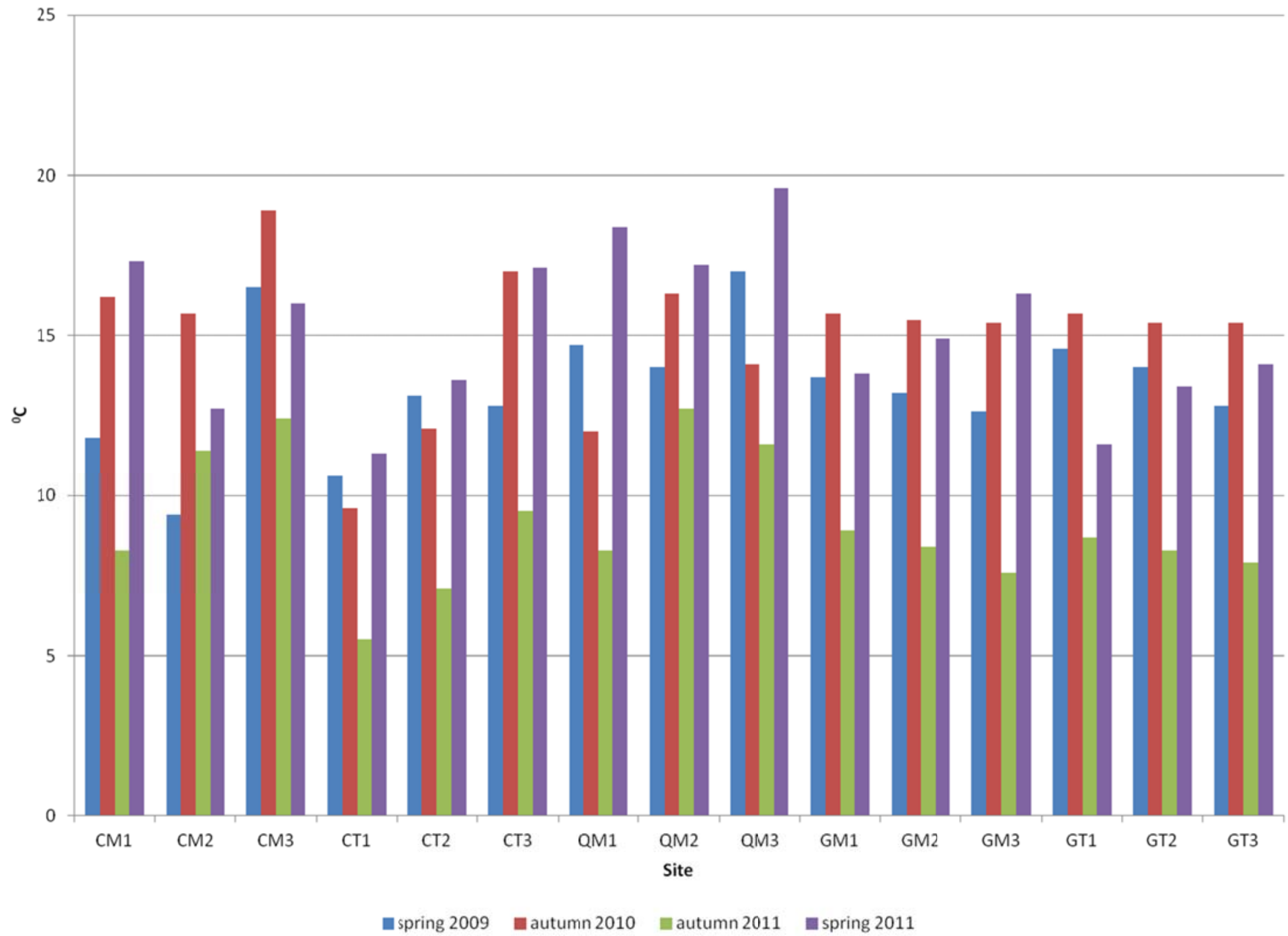

Figure 4: Water temperature at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1.*

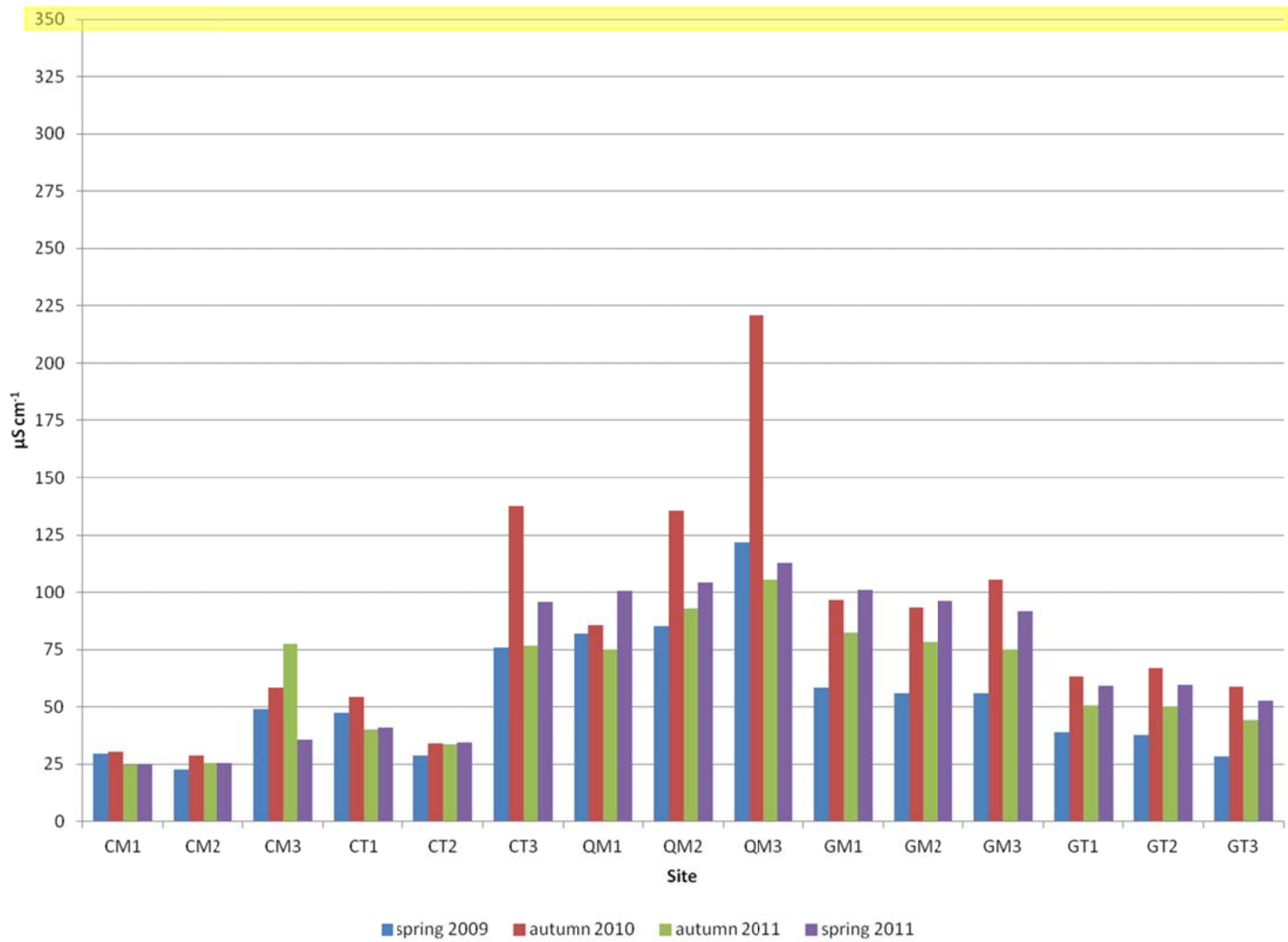

Figure 5: Electrical conductivity at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. *The ANZECC and ARMCANZ (2000) trigger value for electrical conductivity is shaded in yellow. *Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).*

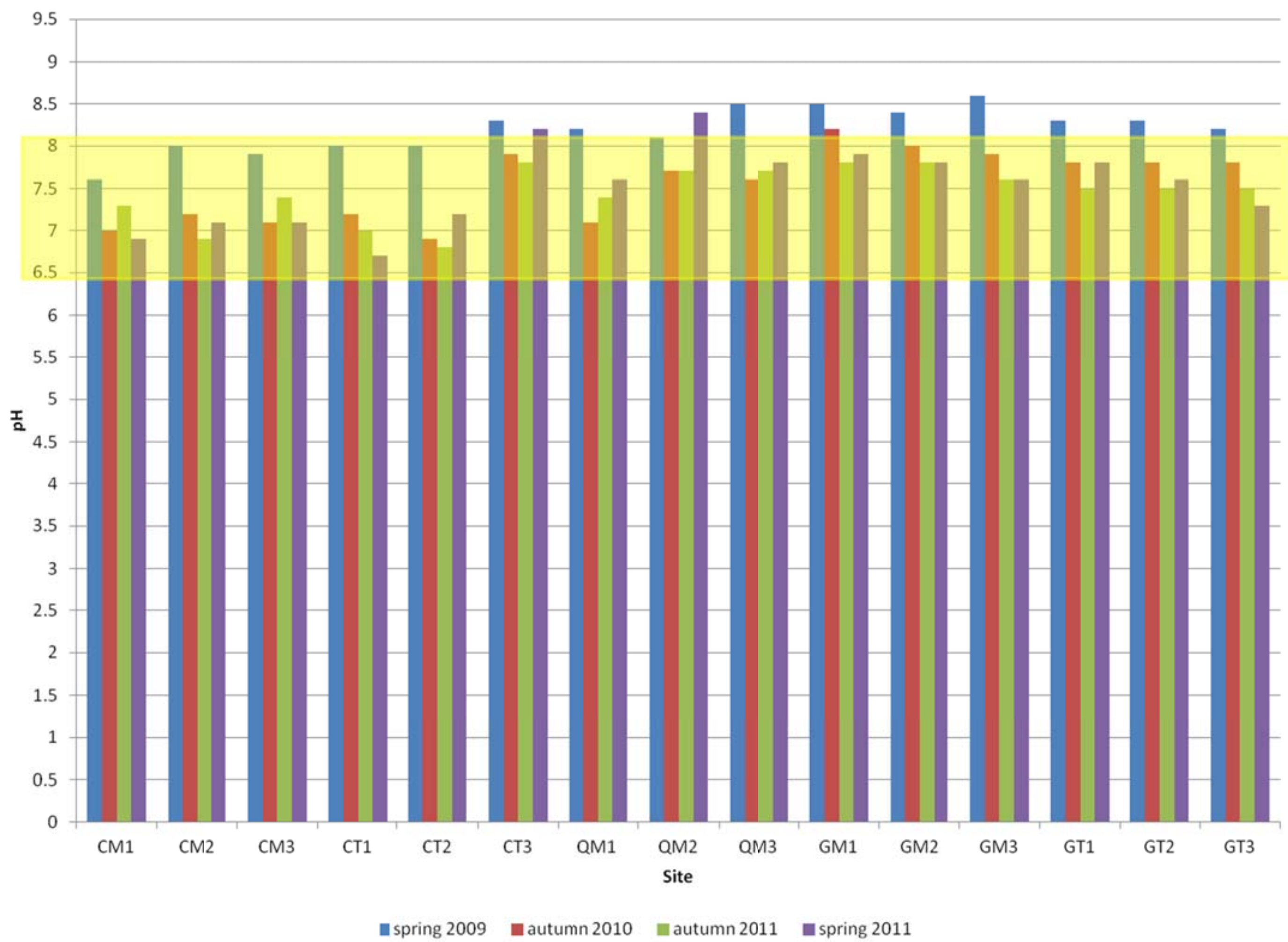

Figure 6: pH at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).The ANZECC and ARMCANZ (2000) trigger value range for pH is shaded in yellow.*

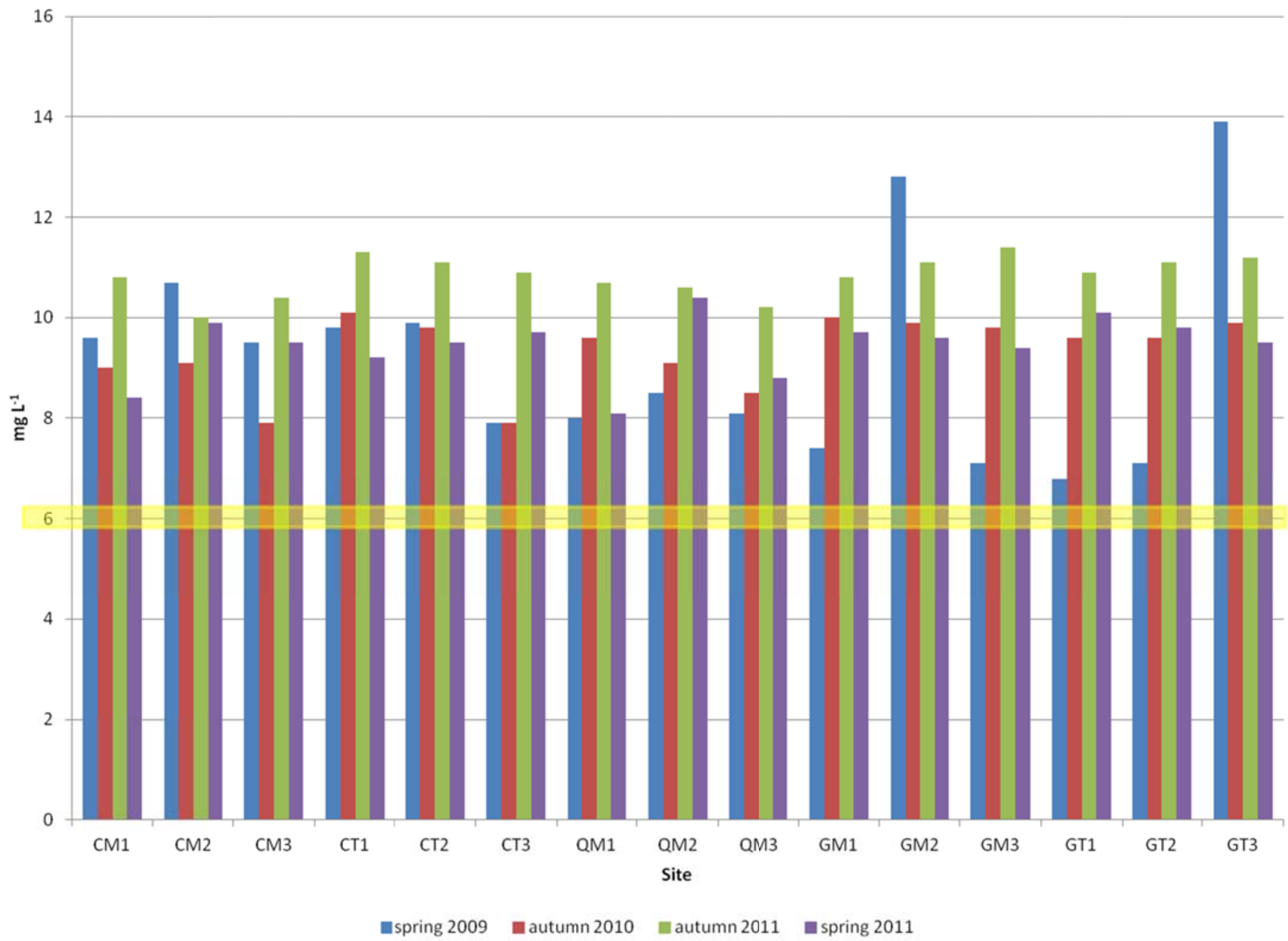

Figure 7: Dissolved oxygen concentration at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).The Environment Protection Regulations SL2005-38 trigger value for dissolved oxygen is shaded in yellow.*

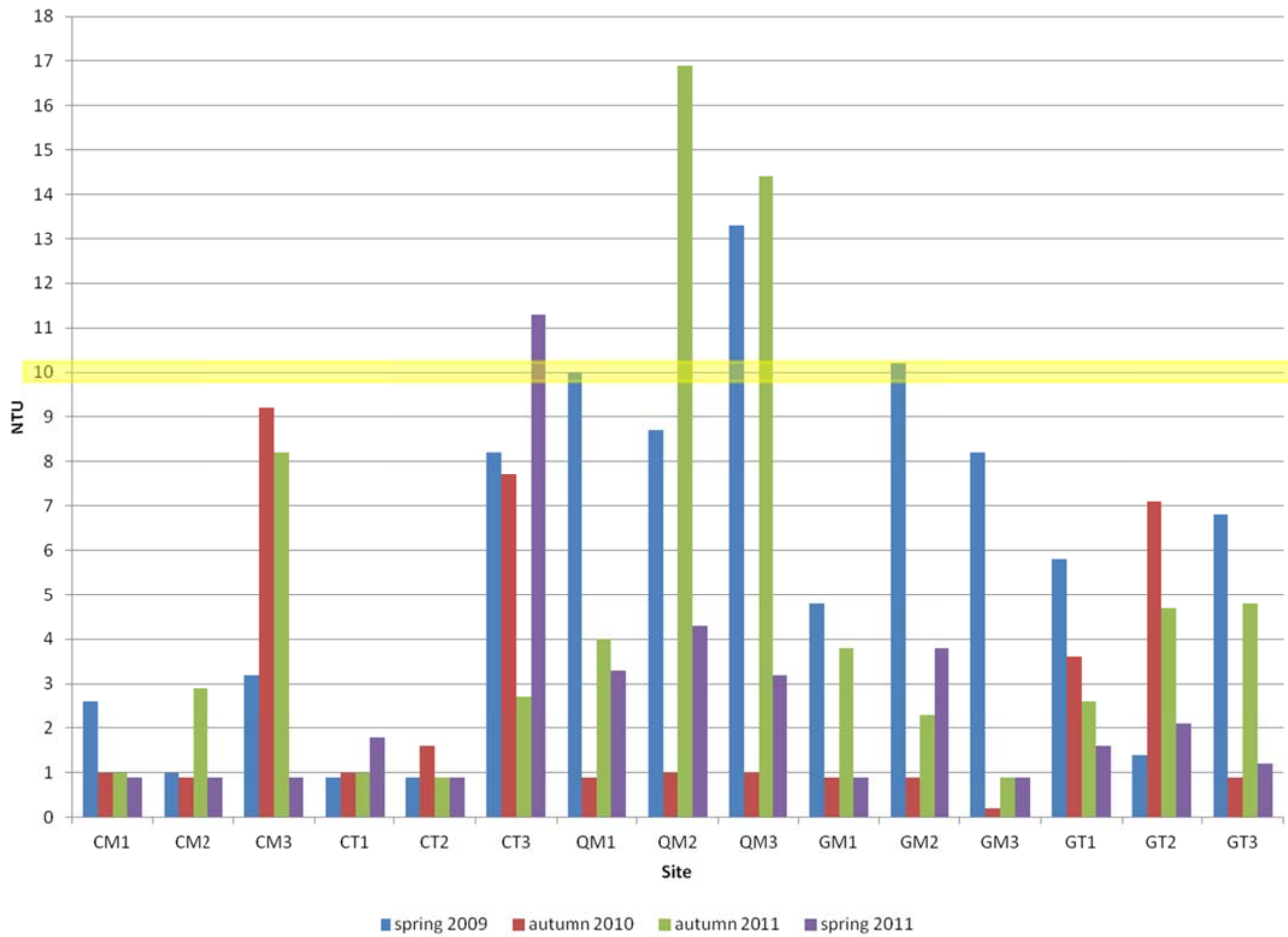

Figure 8: Turbidity at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).The Environment Protection Regulations SL2005-38 trigger value for turbidity is shaded in yellow.*

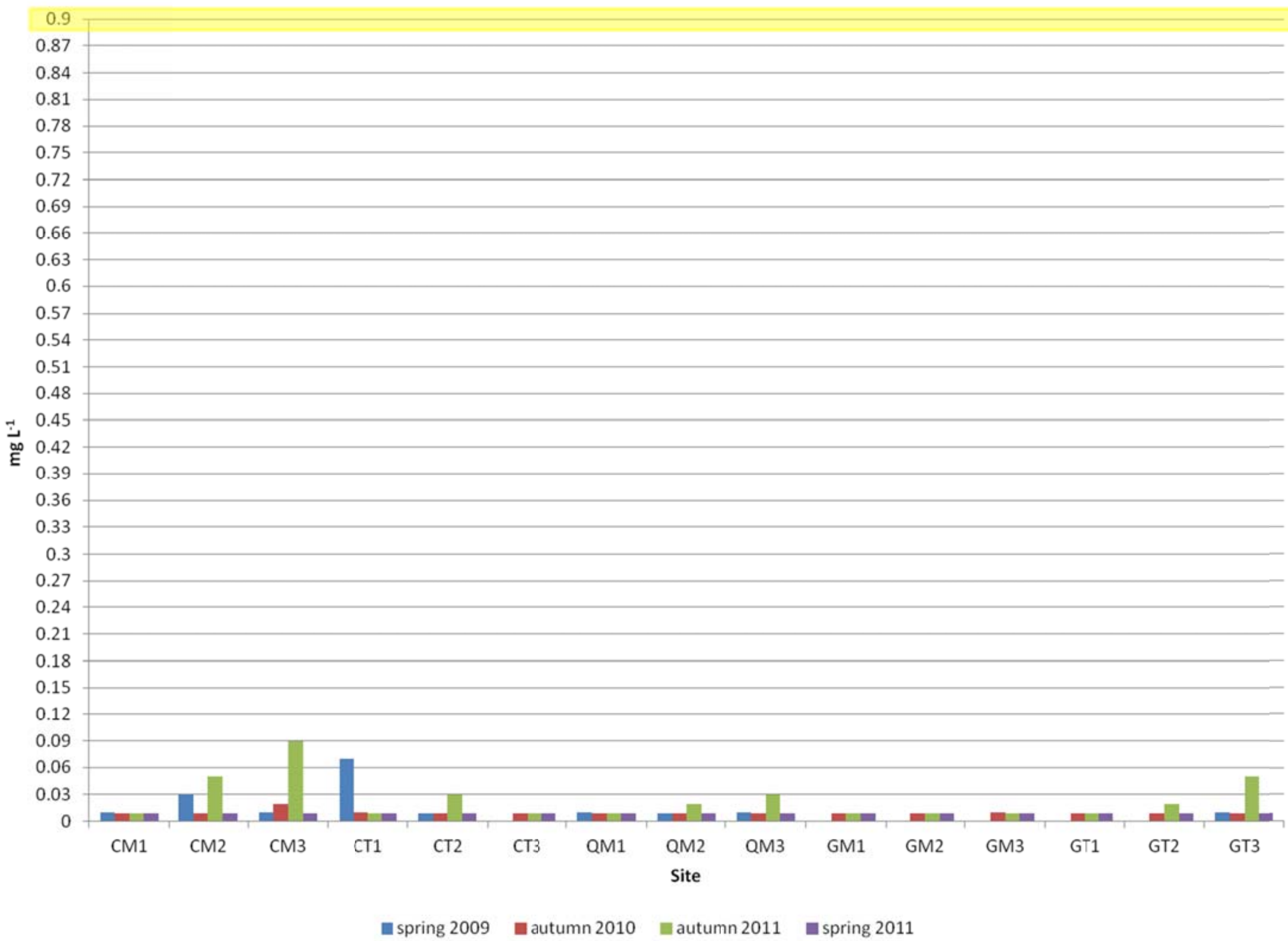

Figure 9: Ammonia (NH_3) concentration at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. * *Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).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.*

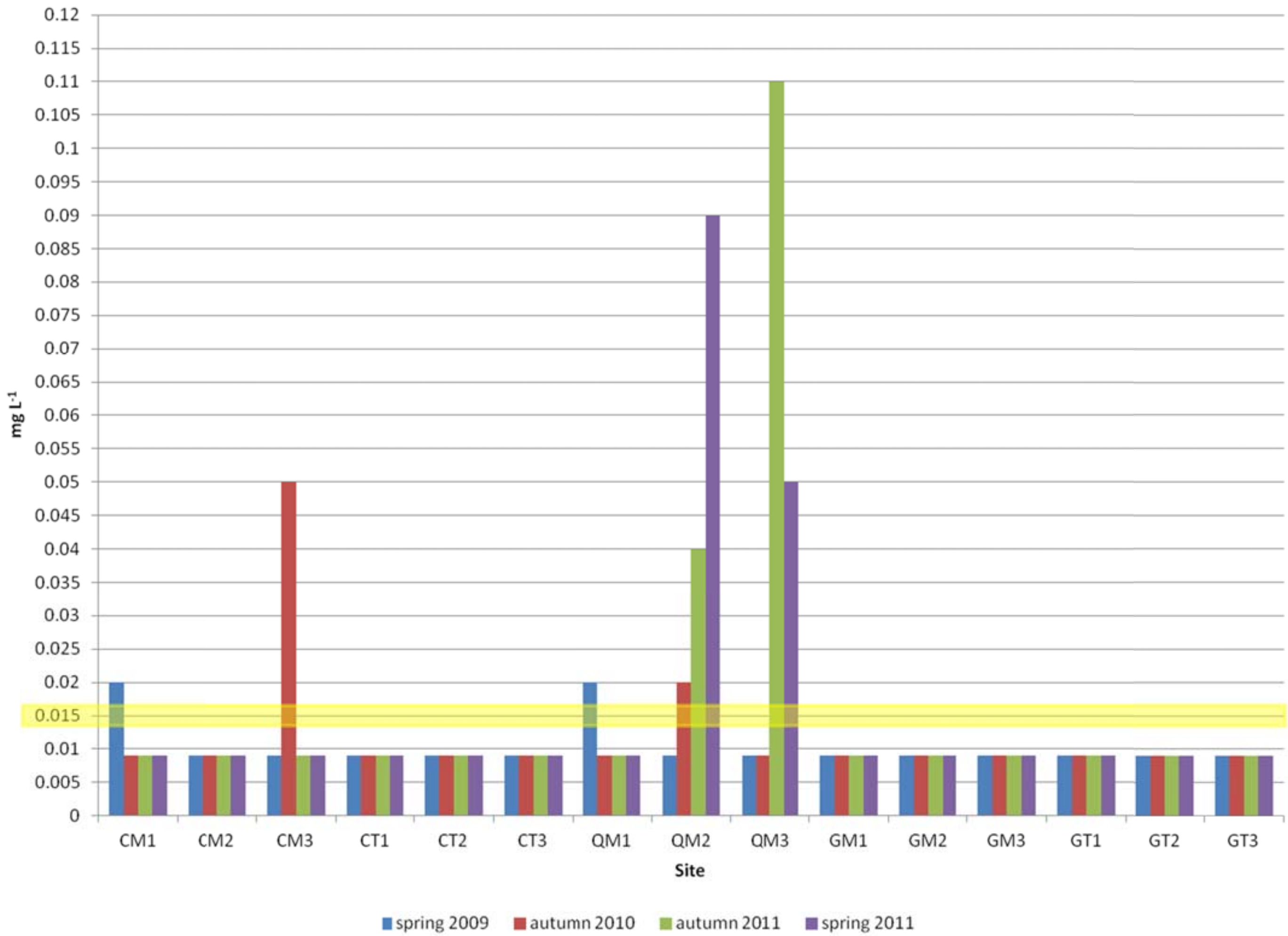

Figure 10: Nitrogen oxide concentration at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).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.*

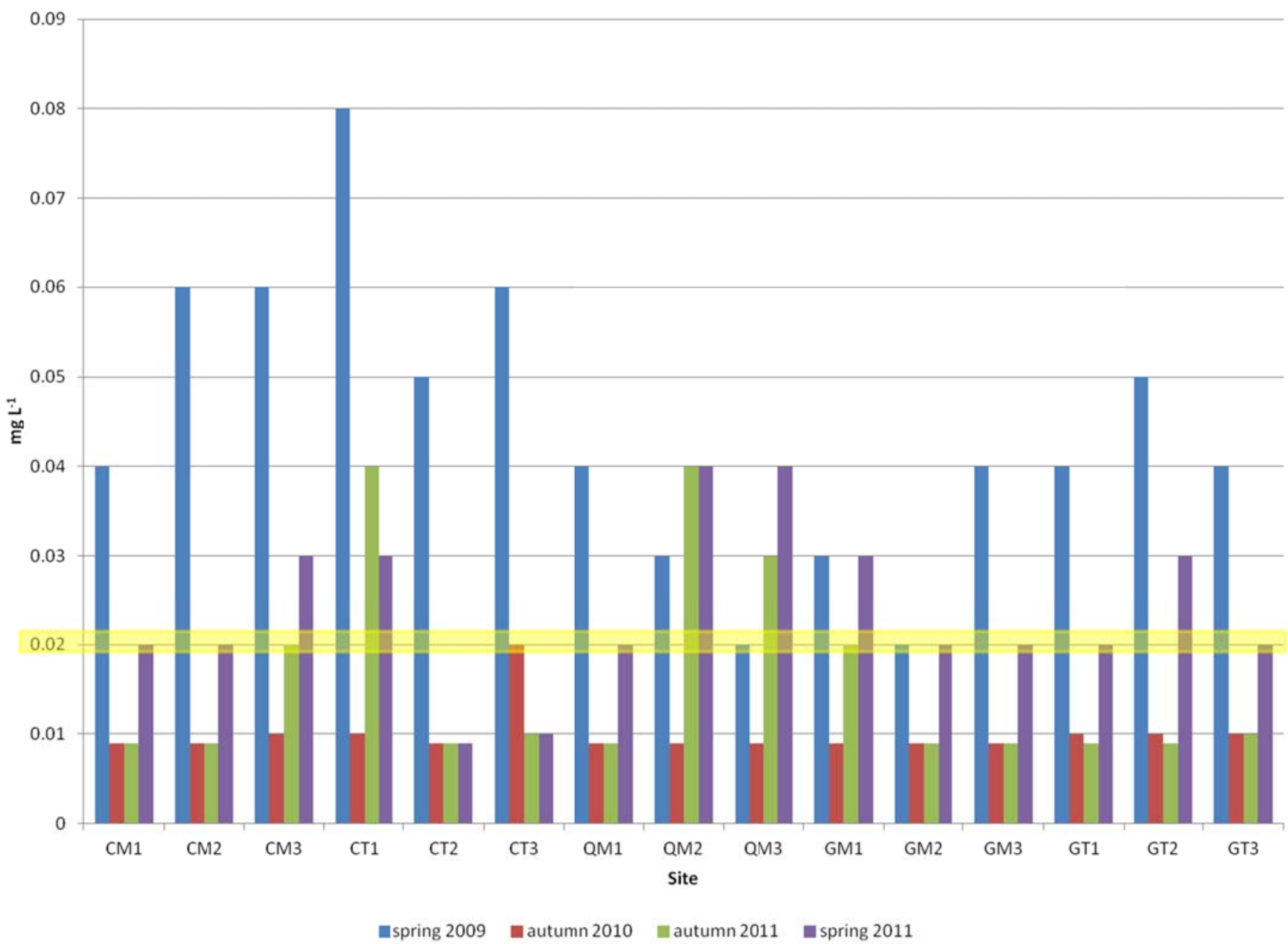

Figure 11: Total phosphorus concentration at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).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 to set to 0.009 mg L^{-1} on the graph.*

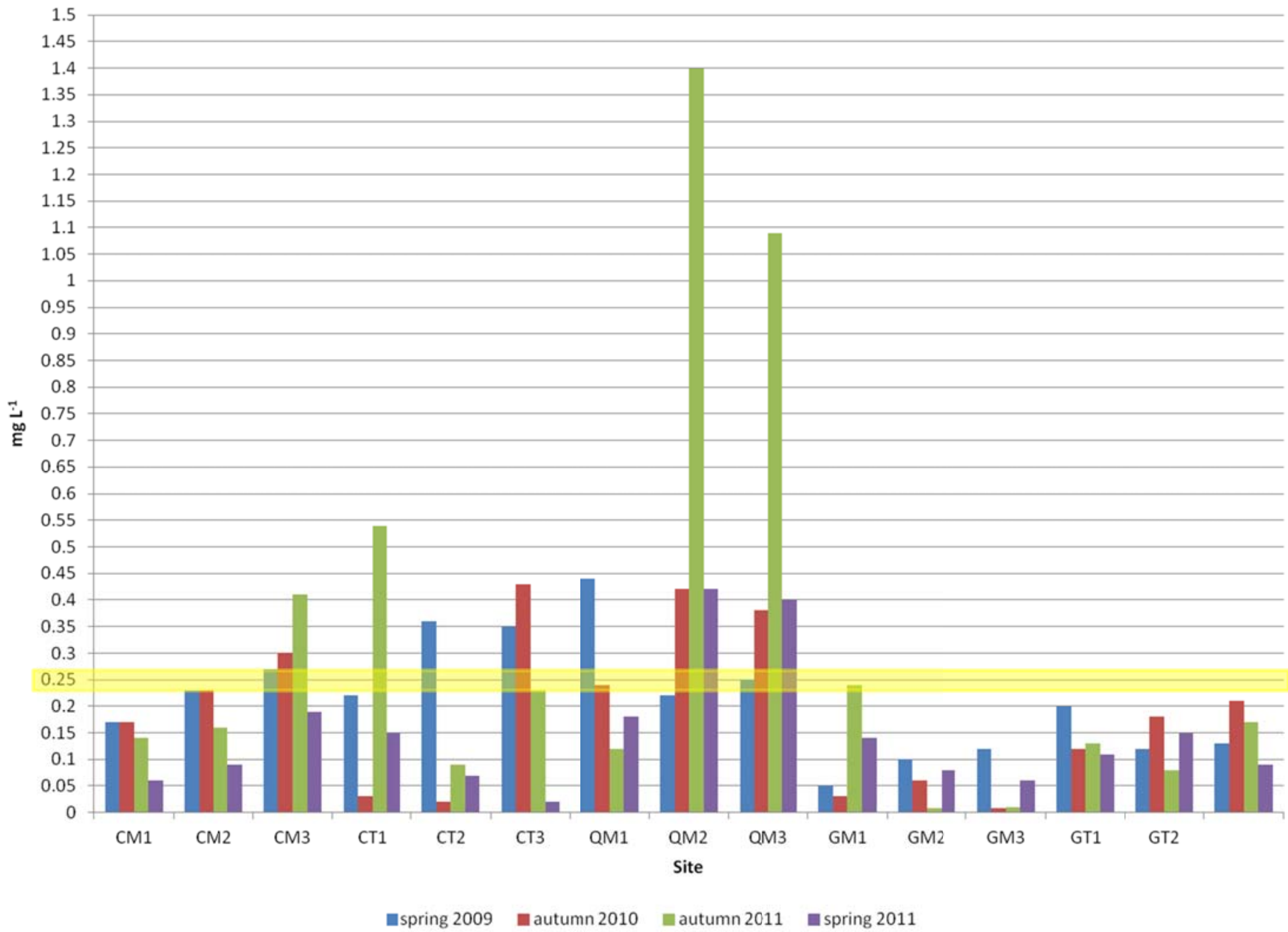

Figure 12: Total nitrogen concentration at sites downstream of the dams along the Cotter River (CM1*, CM2, CM3), tributaries of the Cotter River (CT1), main channel sites on the Queanbeyan River (QM1, QM2 and QM3) and the Goodradigbee reference sites (GM1, GM2, GM3), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1). 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.*

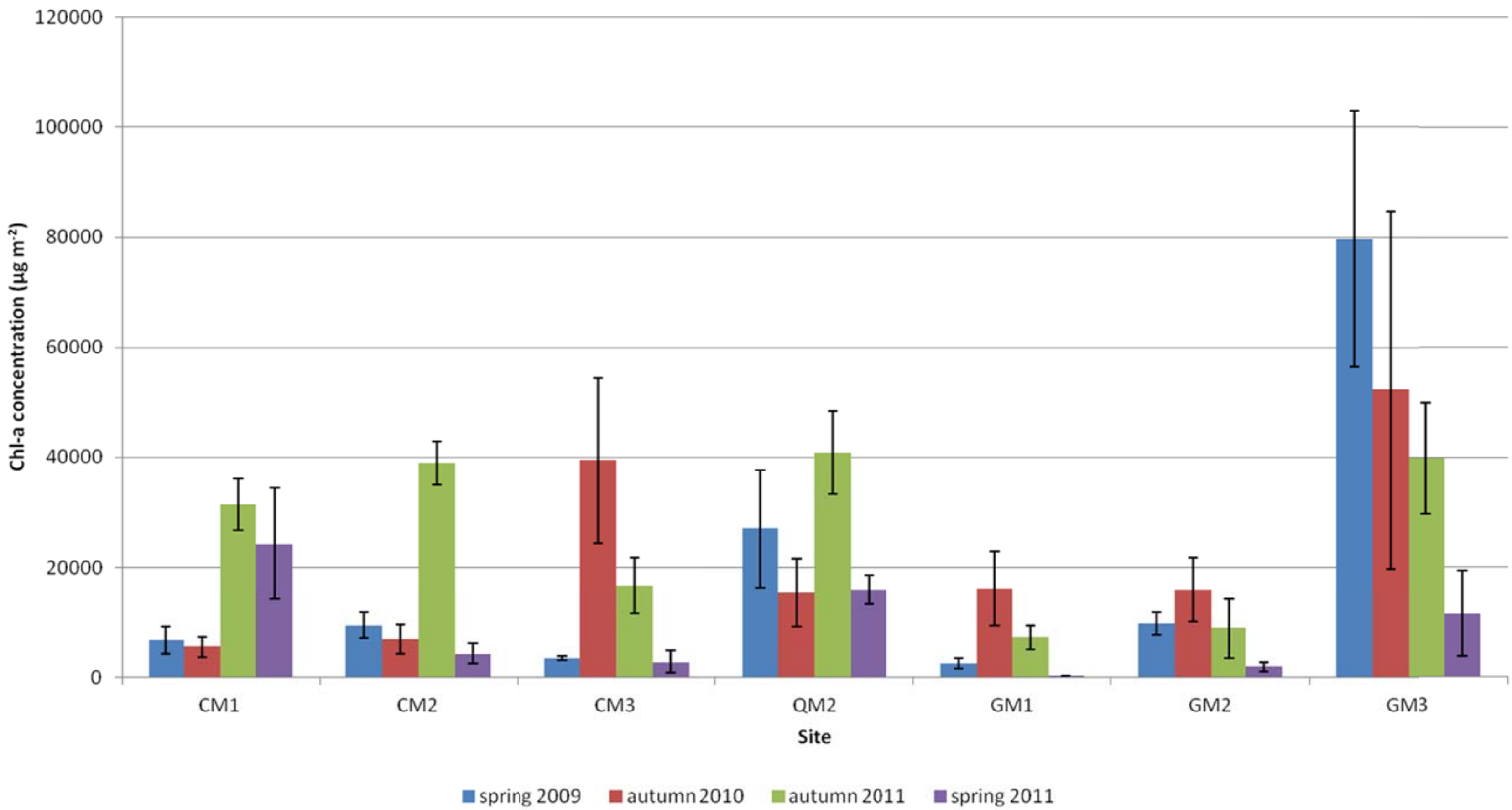

Figure 13: Mean chlorophyll-a (µg m^{-2}) at below dams sites CM1* (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong) and reference sites GM1, GM2 and GM3 (Goodradigbee River), spring 2011 and previously in autumn 2011, autumn 2010 and spring 2009. Error bars are +/- 1 standard error. **Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).*

Table 8: Effects of site and season on chlorophyll-a tested using two-way analysis of variance (ANOVA).

Source of variation:	Site			Season			Site*Season		
Variable	DF	F	P	DF	F	P	DF	F	P
Chlorophyll-a	6	10.58	<0.0001	3	32.85	<0.0001	18	4.46	<0.0001

Table 9: 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 2011 and previously in autumn 2011, autumn 2010 and spring 2009. *****_Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1)._

Site	% cover of riffle								% cover of reach							
	Periphyton				Filamentous Algae				Periphyton				Filamentous Algae			
	Spr-11	Aut-11	Aut-10	Spr-09	Spr-11	Aut-11	Aut-10	Spr-09	Spr-11	Aut-11	Aut-10	Spr-09	Spr-11	Aut-11	Aut-10	Spr-09
CM1*	35-65	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10	<10
CM2	10-35	<10	<10	<10	10-35	<10	<10	<10	10-35	<10	<10	10-35	10-35	<10	<10	<10
CM3	<10	<10	10-35	10-35	<10	<10	<10	<10	<10	<10	10-35	65-90	<10	<10	<10	<10
QM2	35-65	<10	<10	10-35	10-35	<10	<10	<10	35-65	<10	<10	35-65	10-35	<10	<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	<10	<10	10-35	<10	<10	<10	10-35	<10	<10	<10	35-65	<10	<10	<10	35-65

Figure 14: Filamentous algae on the stream bed at site CM2 (downstream of Bendora Dam).

Benthic macroinvertebrates

Relative abundance

The relative abundance of Oligochaeta, Diptera (excluding Chironomidae) and Chironomidae was greatest at below dam sites and reference site QM1 upstream of Googong Dam (Fig. 15). Generally, the relative abundance of Ephemeroptera in samples was greater at the reference sites, compared with below dam sites (Fig. 15). Similarly, Plecoptera were more abundant in samples from reference sites, although site CM2 was more similar to reference sites than the other below dam sites (Fig. 15). The relative abundance of Trichoptera in samples was more similar between below dam and reference sites than Ephemeroptera and Plecoptera (especially sites CM2 and QM3)(Fig. 15).

Taxonomic richness and whole sample abundance

Generally, more macroinvertebrate taxa were collected from Goodradigbee River reference sites compared with sites below dams (Table 10). Taxonomic richness was lowest at sites CM1a (Corin Dam) followed by QM2 (Googong Dam) and CM3 (Cotter Dam) (Table 10). The estimated whole sample abundance was lowest at site CM3 (downstream of Cotter Dam) (Table 10). The estimated number of macroinvertebrates per sample from site CM1a (Corin Dam) on the Cotter River was slightly greater than for other Cotter River sites (CM2 and CM3) (Table 10). The estimated macroinvertebrate abundance in the sample from Queanbeyan River site QM1 (upstream of Googong Dam) was higher compared to sites QM2 and QM3 downstream of Googong Dam (Table 10). Downstream of Googong Dam the estimated abundance was greater at site QM2 directly downstream compared to site QM3 2km downstream (Table 10).

AUSRIVAS

Site CM2 (Bendora Dam), site QM2 (Googong Dam) and site QM3 (2km downstream of Googong Dam) were assessed as being similar to reference (band A) (Table 11). While, sites CM1a (Corin Dam) and CM3 (Cotter Dam) were assessed as significantly impaired (band B) (Table 11). Reference sites GM1, GM2, CT2, CT3, GT1, GT2 and GT3 were assessed as being similar to reference condition (band A) (Table 11). Reference site CT1 was assessed as significantly impaired (band B) and sites GM3 and QM1 were assessed as having more taxa present than expected (band X) (Table 11). Eight of the expected but missing taxa were actually present in the sample scans for eight sites (Calocidae- CT1; Gripopterygidae- CM3; Hydropsychidae-CT2, CT3, GT1; Tipulidae-CM2, QM2) but not abundant enough to be collected in the sub-sample (Tables 12 and 13).The presence of these indicates the site's potential to increase in condition under favourable conditions.

The AUSRIVAS results for spring 2011 were similar to autumn 2010 for all below dam sites CM1, CM2 and QM2 on the Cotter and Queanbeyan Rivers in terms of AUSRIVAS banding (Table 11). Sites downstream of Bendora (CM2) and Googong Dams (QM2 and QM3) were within the ecological objective of band A AUSRIVAS O/E score (Table 11). Site QM3 (2km downstream of Googong Dam) improved in condition to band A (Table 11). Reference sites GM2, CT2 and QM1 improved in condition from bands C (GM2), B (CT2) and A (QM1) to bands A (GM2 and CT2) and X (QM1) (Table 11). While reference site CT1 declined from band X to band B (Table 11).The O/E score for all remaining reference sites (CT3, GT1, GT2, GT3) increased, but were still within band A (Table 11)

Macroinvertebrate community similarity

Two groups of sites from spring 2009 and spring 2011 were evident from the cluster analysis of relative abundance data, which were well separated from one another in an MDS ordination (Fig. 16, Table 14). Site QM3 downstream of Googong Dam (sampled in spring 2009) and Cotter tributary site CT1 (sampled in spring 2011) were both outliers and did not group with other sites. With the exception of site CM1 09, Group 2 contained only reference sites, while below dam sites were in group 1 or were an outlier (site QM3 09) (Fig. 16). Sites sampled in spring 2009 and spring 2011 were generally within the same group (Fig. 16) indicating that macroinvertebrate communities downstream of dams and at reference sites have returned to a community composition similar to before flooding occurred in spring/summer 2010/11. Site QM3 09 was well separated from other below dams sites because of a lower taxonomic richness and lower abundance of several taxa (including sensitive taxa with- SIGNAL 2 grades ≥7: Hydrobiosidae and Gripopterygidae) (Table 16). Sites in group 1 were characterised by a lower taxonomic richness and had lower abundances of sensitive macroinvertebrate taxa (SIGNAL 2 grades ≥7) compared to sites in group 2 and site CT1 11 (Tables 15 and 16)(e.g. Griopopterygidae, Leptophebiidae, Elmidae, Glossomatidae, Tasimiidae, Conoesucidae).

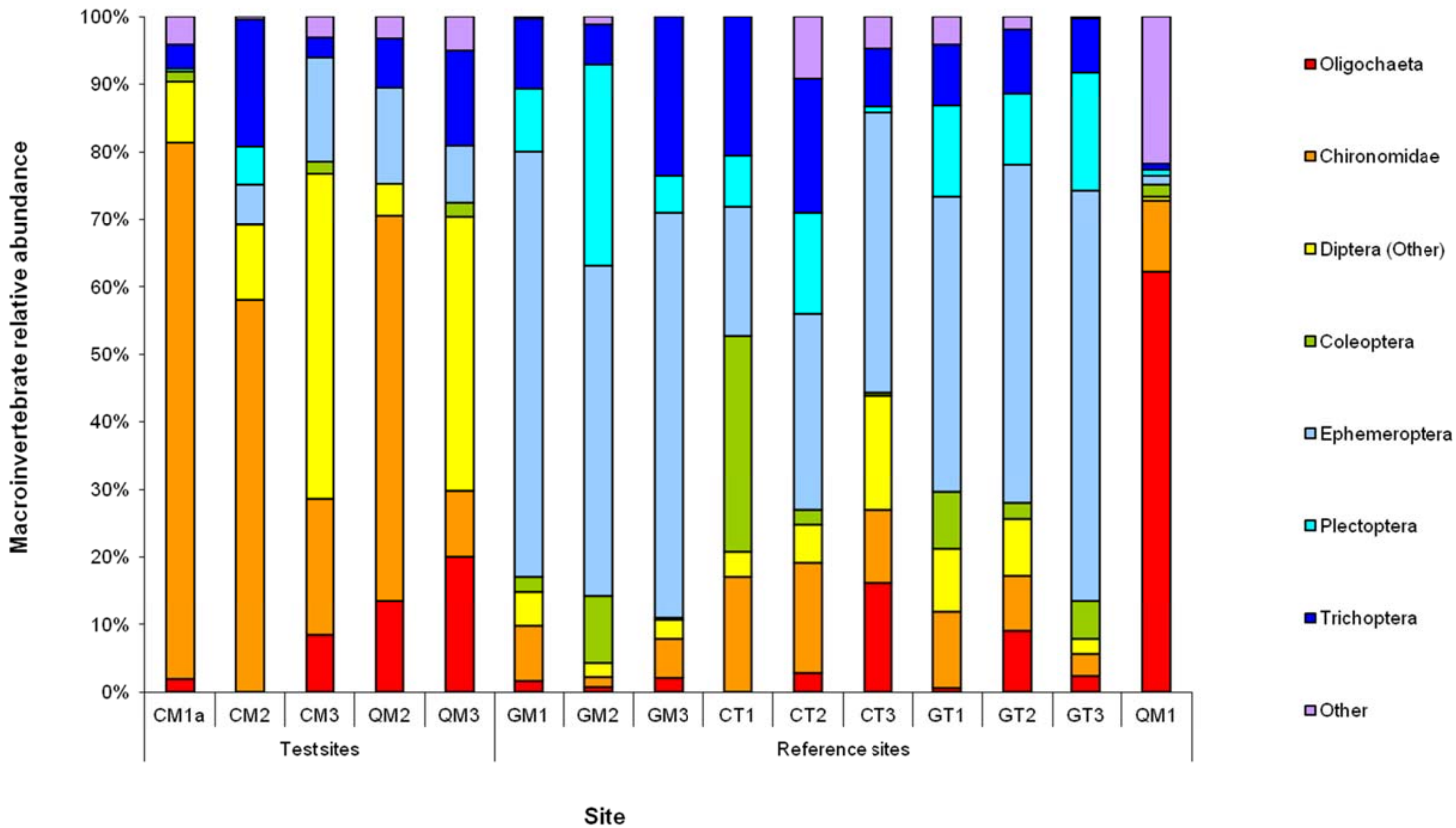

Figure 15: Relative abundance of macroinvertebrates taxa groups (indicated by different colours in the legend) at each sample site on the Cotter River (CM1a, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), spring 2011.

Table 10: Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples during spring 2011 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*	**SIGNAL 2 grade**	**CM1a**	**CM2**	**CM3**	**CT1**	**CT2**	**CT3**	**QM1**	**QM2**	**QM3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
ACARINA	**6**	4	1	6		21	11	100	14	22		1	3	7	6	
OLIGOCHAETA	**2**	4		19		6	37	285	56	94	4	2	5	1	27	7
TURBELLARIA																
Tricladida																
Dugesiidae	2													1		
GASTROPODA																
Lymnaeidae	1									2						
Ancylidae	4			1												
Physidae	1	5														
INSECTA																
Megaloptera																
Corydalidae	7										1	1		1		
Plecoptera																
Gripopterygidae	8	1	12		14	34	2	4			26	100	14	29	32	55
Odonata																
Gomphidae	5											2				
Telephlebiidae	9															1
Ephemeroptera																
Baetidae	5		1	35	13	9	31	2	52	34	2	1	3	4	6	5
Caenidae	4		9				2	1	6	6	1	4	14	6	2	4
Coloburiscidae	8										2	28	7	3		1
Leptophlebiidae	8		3		22	57	63	3	2		171	131	131	80	145	180
Coleoptera																
Elmidae	7	3	0	4	28	2	1	8	0	6	6	21	0	7	2	7
Psephenidae	6											9	1	3		5
Scirtidae	6				31	3				4		3		8	5	6
Diptera																
Chironomidae																
Aphroteniinae	*8*										11			3		2
Chironominae	*3*	5	4	6	21	13	6	3	40	38	6		3	4	8	
Orthocladiinae	*4*	169	121	37	8	16	18	44	196	162	5	5	10	10	10	8
Podonominae	*6*					3										
Tanypodinae	*4*		1	3	2	5	1	1	4	8	1		2	7	7	

Table 10 cont.

CLASS **Order** Family *Subfamily*	**SIGNAL 2 grade**	**CM1a**	**CM2**	**CM3**	**CT1**	**CT2**	**CT3**	**QM1**	**QM2**	**QM3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Athericidae	8				2							1				
Ceratopogonidae	4						5	1								
Empididae	5	13	7	2	2	10	1			10		1	2	2	9	1
Simuliidae	5	7	17	105	1	3	32	1	20	14	14		1	2		3
Tipulidae	5			3	2		1	1		6		5	4	16	17	3
Trichoptera																
Calamoceratidae	7					1						2				1
Calocidae	9													1		
Conoesucidae	7	1	13	0		23					1	7	37	4	5	11
Ecnomidae	4			2			2									
Glossosomatidae	9					3	2				14	6	9			
Hydrobiosidae	8	3	2	1	9	4	10	2	4	4	2	1	1	2	7	3
Hydropsychidae	6	4	18	1	5			1	14	14	1	3	2		1	2
Hydroptilidae	4		8	2			6	1	10	32					2	1
Leptoceridae	6			1		11			2	4	11	1	12	12	11	6
Philopotamidae	8				4					12					3	1
Tasimiidae	8				20	3										
No. individuals		219	217	228	184	227	231	458	420	472	279	335	261	213	305	313
No. of taxa		12	15	17	16	19	18	16	14	18	18	22	20	23	19	22
% of sub-sample		5	5	7	2	4	5	1	2	6	2	2	3	2	3	1
Whole sample estimate		4380	4340	3257	9200	5675	4620	45800	21000	7867	13950	16750	8700	10650	10167	31300

Table 11: AUSRIVAS O/E score and band each sample 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 2009 and spring 2011. ***Note in spring 2011 site CM1 was located closer to Corin Dam (site CM1a- see Table 1).band X = more biologically diverse than reference, > 1.12 (autumn), >1.14 (spring); band A = similar to reference condition, 0.88-1.12 (autumn), 0.86-1.14 (spring); band B = significantly impaired, 0.64-0.87 (autumn), 0.57-0.85 (spring); band C = severely impaired, 0.40-0.63 (autumn), 0.28-0.56 (spring); band D = extremely impaired, 0-0.39 (autumn), 0-0.27 (spring) observed and O/E score values are those for taxa with a greater than 50% probability of occurrence.*

Site	2009 Spring	2010 Autumn	2011 Autumn	2011 Spring
CM1*	0.92 (A)	0.74 (B)	0.73 (B)	0.77 (B)
CM2	0.82 (B)	1.04 (A)	0.89 (A)	0.89 (A)
CM3	0.66 (B)	0.83 (B)	0.82 (B)	0.81 (B)
QM2	0.92 (A)	0.97 (A)	0.96 (A)	0.88 (A)
QM3	0.72 (B)	0.83 (B)	0.67 (B)	0.92 (A)
GM1	1.14 (X)	1.16 (X)	1.16 (X)	1.04 (A)
GM2	1.13 (A)	1.03 (A)	0.57 (C)	1.04 (A)
GM3	1.08 (A)	0.92 (A)	1.05 (A)	1.19 (X)
QM1	1.16 (X)	0.96 (A)	0.96 (A)	1.20 (X)
CT1	0.84 (B)	0.81 (B)	1.17 (X)	0.82 (B)
CT2	0.77 (B)	0.77 (B)	0.81 (B)	1.00 (A)
CT3	0.61 (B)	0.58 (C)	0.89 (A)	1.03 (A)
GT1	1.08 (A)	1.01 (A)	1.04 (A)	1.13 (A)
GT2	1.22 (X)	1.22 (X)	0.93 (A)	1.05 (A)
GT3	0.69 (B)	0.82 (B)	0.95 (A)	0.98 (A)

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 2011 that were predicted with a ≥ 50% chance of occurrence by the AUSRIVAS ACT spring 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														
Macroinvertebrate	**SIGNAL2 grade**	**CM1a**	**CM2**	**CM3**	**CT1**	**CT2**	**CT3**	**QM1**	**QM2**	**QM3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Oligochaeta	**2**		X		X											
Acarina	**6**				X						X					X
Elmidae	**7**		X						X				X			
Psephenidae	**6**	X	X	X		X	X		X	X	X				X	
Tipulidae	**5**	X	X			X			X		X					
Simuliidae	**5**											X			X	
Tanypodinae	**4**	X										X				X
Chironominae	**3**											X				X
Baetidae	**5**	X														
Leptophlebiidae	**8**	X		X						X						
Caenidae	**4**	X		X	X	X										
Gripopterygidae	**8**			X					X	X						
Notonemouridae	**6**				X											
Glossosomatidae	**9**	X	X	X	X			X	X	X				X	X	X
Hydropsychidae	**6**					X	X							X		
Conoesucidae	**7**			X	X		X		X	X						
Calocidae	**9**				X											
Leptoceridae	**6**				X											
No. of missing taxa		**7**	**5**	**6**	**8**	**4**	**3**	**1**	**6**	**5**	**3**	**3**	**1**	**2**	**3**	**4**

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 spring 2011. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

		Site														
Macroinvertebrate	**SIGNAL2 Grade**	**CM1a**	**CM2**	**CM3**	**CT1**	**CT2**	**CT3**	**QM1**	**QM2**	**QM3**	**GM1**	**GM2**	**GM3**	**GT1**	**GT2**	**GT3**
Sphaeriidae	**5**									X						
Corydalidae	**7**	X	X										X			X
Gomphidae	**5**													X	X	
Telephlebiidae	**9**	X	X		X									X	X	
Baetidae	**5**															
Coloburiscidae	**8**			X	X										X	
Dytiscidae	**2**															
Scirtidae	**6**								X							
Tipulidae	**5**		X						X							
Eustheidae	**10**												X			
Gripopterygidae	**8**			X												
Calamoceratidae	**7**														X	
Calocidae	**9**				X											
Ecnomidae	**4**		X													
Glossomatidae	**9**														X	
Hydropsychidae	**6**					X	X							X		
Philopotamidae	**8**											X				
No. New Taxa		**2**	**4**	**2**	**3**	**1**	**1**	**0**	**2**	**1**	**0**	**1**	**2**	**3**	**5**	**1**

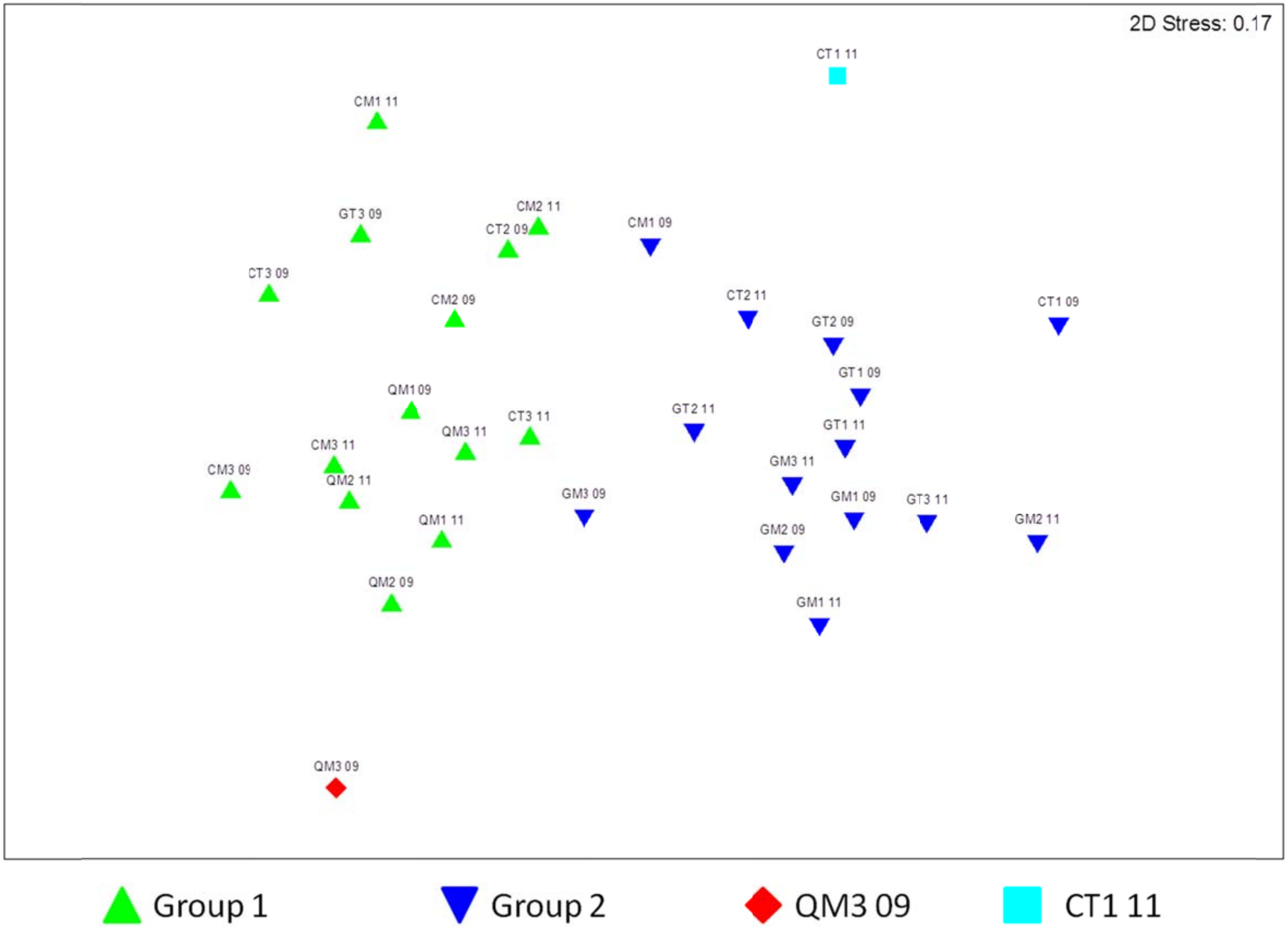

Figure 16: MDS ordination of similarity between macroinvertebrate samples collected in spring 2009 (09 following site code) and 2011 (11 following site code) for the Below Dams Assessment Program. Similarity based on macroinvertebrate relative abundance data and groups based on cluster analysis results. *Note site CM1 11 is located closer to Corin Dam (site CM1a – see Table 1).*

Table 14: Results of ANOSIM tests based on macroinvertebrate community structure groups defined in the cluster analysis based on relative abundance data. (R = ANOSIM test statistic) (Note –A pairwise ANOSIM cannot be conducted for sites CT1 11 and QM3 09 both sites group separately and in ANOSIM at least one group must have a sample size larger than 1).

Groups	R
1 and 2	0.75
1 and CT1 11	0.93
2 and CT1 11	0.79
1 and QM3 09	0.76
2 and QM3 09	0.96

Table 15: 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; Sites CT1 11 and QM3 09 are not included because both sites group separately and cannot be included in the SIMPER analysis).

Group	Taxa	SIGNAL 2 grade	Average abundance	Consistency ratio	Contribution percentage	Cumulative percentage
Group 1	Orthocladiinae	4	2.31	5.45	17.19	17.19
	Oligochaeta	2	1.99	2.09	13.07	30.26
	Chironominae	3	1.44	4.59	10.18	40.45
	Simuliidae	5	1.53	3.64	9.88	50.33
	Acarina	6	1.34	4.99	9.27	59.6
	Hydrobiosidae	8	0.93	2.29	6.28	65.87
	Hydroptilidae	4	0.95	1.12	4.55	70.42
Group 2	Leptophlebiidae	8	2.12	2.9	10.64	10.64
	Gripopterygidae	8	1.88	6.92	10.18	20.82
	Orthocladiinae	4	1.46	7.53	7.93	28.75
	Conoesucidae	7	1.43	5.01	7.31	36.06
	Elmidae	7	1.29	2.21	5.9	41.96
	Oligochaeta	2	1.37	1.98	5.83	47.79
	Chironominae	3	1.14	1.57	5.15	52.94
	Baetidae	5	0.96	1.56	4.57	57.51
	Caenidae	4	0.99	1.53	4.25	61.76
	Empididae	5	0.96	1.51	3.97	65.73
	Acarina	6	1.02	1.17	3.94	69.67
	Leptoceridae	6	0.95	1.11	3.83	73.5

Table 16: 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	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group 1	*Group 2*	
Leptophlebiidae	8	0.7	2.12	1.81
Conoesucidae	7	0.34	1.43	2.07
Gripopterygidae	8	0.81	1.88	1.59
Oligochaeta	2	1.99	1.37	1.52
Orthocladiinae	4	2.31	1.46	1.98
Hydroptilidae	4	0.95	0.18	1.38
Glossosomatidae	9	0.07	0.87	1.42
Leptoceridae	6	0.33	0.95	1.4
Baetidae	5	0.82	0.96	1.62
		Group 1	*Site CT1 11*	
Oligochaeta	2	1.99	0	2.67
Scirtidae	6	0.21	2.03	3.74
Tasimiidae	8	0	1.82	14.94
Acarina	6	1.34	0	3.65
Elmidae	7	0.7	1.98	2.11
Leptophlebiidae	8	0.7	1.86	2.16
Philopotamidae	8	0.21	1.21	2.36
Athericidae	8	0	1.02	14.94
Baetidae	5	0.82	1.63	1.4
Hydroptilidae	4	0.95	0	1.43
Gripopterygidae	8	0.81	1.66	1.41
Orthocladiinae	4	2.31	1.44	2.22
Hydropsychidae	6	0.61	1.28	1.43
Tipulidae	5	0.32	1.02	1.65
Simuliidae	5	*1.53*	*0.86*	1.4
Hydrobiosidae	8	0.93	1.49	1.64
Chironominae	3	1.44	1.84	1.74
		Group 2	*Site CT1 11*	
Tasimiidae	8	0.08	1.82	5.58
Conoesucidae	7	1.43	0	3.83
Scirtidae	6	0.68	2.03	1.99
Oligochaeta	2	1.37	0	1.91
Philopotamidae	8	0.18	1.21	2.77
Acarina	6	1.02	0	1.7
Caenidae	4	0.99	0	2.03

Table 16 Cont.

Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group 2	*Site CT1 11*	
Leptoceridae	6	0.95	0	1.59
Athericidae	8	0.05	1.02	4.68
Glossosomatidae	9	0.87	0	1.43
Hydrobiosidae	8	0.72	1.49	1.65
Elmidae	7	1.29	1.98	1.5
Hydropsychidae	6	0.54	1.28	1.81
Baetidae	5	0.96	1.63	1.68
Leptophlebiidae	8	2.12	1.86	2.06
		Group 1	*Site QM3 09*	
Scirtidae	6	0.21	1.69	3.13
Hydroptilidae	4	0.95	0	1.42
Hydrobiosidae	8	0.93	0	2.89
Leptoceridae	6	0.33	1.18	1.89
Physidae	1	0.14	0.94	3.27
Gelastocoridae	5	0	0.79	12.96
Empididae	5	0.79	0	1.58
Orthocladiinae	4	2.31	1.56	1.93
Hydropsychidae	6	0.61	1.24	1.43
Tanypodinae	4	0.74	0	1.77
Simuliidae	5	1.53	2.06	1.71
Chironominae	3	1.44	0.79	1.75
Ecnomidae	4	0.26	0.79	1.85
Gripopterygidae	8	0.81	0.79	1.65
Caenidae	4	0.69	0.79	1.4
		Group 2	*Site QM3 09*	
Conoesucidae	7	1.43	0	3.79
Oligochaeta	2	1.37	2.75	1.89
Leptophlebiidae	8	2.12	0.79	2.06
Elmidae	7	1.29	0	2.64
Simuliidae	5	0.93	2.06	1.91
Gripopterygidae	8	1.88	0.79	3.44
Scirtidae	6	0.68	1.69	1.54
Baetidae	5	0.96	0	2.22
Physidae	1	0	0.94	13.64
Empididae	5	0.96	0	1.96
Glossosomatidae	9	0.87	0	1.42
Tanypodinae	4	0.83	0	1.69
Tipulidae	5	0.84	0	1.4

Table 16 Cont.

Taxa	SIGNAL 2 grade	Average abundance		Consistency ratio
		Group 2	*Site QM3 09*	
Gelastocoridae	5	0	0.79	13.64
Ecnomidae	4	0	0.79	13.64
Hydrobiosidae	8	0.72	0	1.47
Hydropsychidae	6	0.54	1.24	1.7
Chironominae	3	1.14	0.79	2.66
Caenidae	4	0.99	0.79	1.42

Discussion and conclusions

Physical and chemical water quality characteristics

In spring 2011 water quality at below dams sites and at unregulated reference sites was generally good and in some cases has improved since autumn 2011. Improvements at sites downstream of Googong dam (e.g. turbidity at sites QM2 and QM3: Fig. 8) coincides with a marked improvement in the water quality within the reservoir. There were; however, four exceptions; (1)Turbidity increased to above the trigger value at Cotter tributary site CT3 (Paddys River) (Fig.8); (2) Nitrogen oxide was above the trigger value at sites downstream of Googong Dam (Fig 10); (3) pH was above the upper trigger value at site QM3 (downstream of Googong Dam) and Cotter tributary site CT3 (Paddys River)(Fig. 6) and; (4) total phosphorus concentrations were above or equal to the trigger value at all sites (except CT2 and CT3) (Fig. 11).

Increased turbidity at site CT3 is more than likely the result of rainfall events that occurred in the weeks before sampling (Fig. 2), which have lead to increased fine sediment loads being added to Paddys River from the surrounding catchment. Downstream of Googong Dam (site QM2 and QM3) nitrogen oxide concentrations were also above the trigger value in autumn 2011 (higher than autumn 2010 and spring 2009) (Fig. 10). The higher nitrogen oxide concentration at site QM2 and QM3 may be the result of increased nitrogen oxide concentrations in Googong Reservoir following increased inflows in 2010/11. In the last spring sampling run in 2009 pH levels were also marginally above the upper trigger at sites QM3 and CT3 (Fig. 6). Hence, the pH measurements in spring 2011 are not dissimilar to previously measured values at these sites. In terms of total phosphorus concentrations, any increase in phosphorus compared to previous sampling occasions cannot be attributed to dam operation because concentrations were similar at the below dam sites and reference sites (Fig. 11).

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 spring 2011 it is the first time since autumn 2009 (below Corin and Bendora Dams) and spring 2007 (below Googong Dam) (White and Norris, 2007; White el. 2009) that filamentous algae cover has risen from <10% to 10-35% cover (Table 9, Fig. 14). If filamentous algae levels increase through 2012 to 35-65% cover, further investigation will be needed to determine the cause of the change in filamentous algae cover and whether the flow releases downstream of Corin, Bendora and Googong Dams can maintain filamentous algae cover at <20% for 95% of the time. In spring 2011, the increase in periphyton and filamentous algae cover downstream of Corin, Bendora and Googong Dams may have occurred because of favourable water temperature prior to sampling or a change in the proportion of phosphorus to nitrogen concentrations (e.g. increased phosphorus and decreased nitrogen concentration: Figs 11 and 12) (Allan 1995, Blum 1956). However, at site CM1 the observed increase in filamentous algae compared to the previous sampling occasion and significantly higher chlorophyll-a compared to Goodradigbee River site GM1 in spring 2011 may also be related to the change in site location (i.e. closer to Corin Dam).

Significantly lower chlorophyll-a concentrations below Bendora Dam, Cotter Dam and on the Goodradigbee River in spring 2011 compared to samples from the past three full sampling runs may be indicative of an increase in algal taxa that contain less chlorophyll-a (Fig. 13). Previously in the Cotter River decreases in chlorophyll-a concentrations have been associated with a change in taxonomic composition which contains less chlorophyll-a (e.g. diatoms and detritus, with the detritus containing unicellular green algae, protists, bacteria and fungi: Chester and Norris 2006). The change in periphyton community composition below Bendora Dam, Cotter Dam and on the Goodradigbee River is likely the result of higher flow velocity (see Chester and Norris 2006; White et al. In Press) that has occurred since spring 2010 (Fig. 2). Periphyton community taxonomic information is not collected as a part of the below dams assessment program, but there is a clear need to collect such information to fully understand how the periphyton community in the Cotter, Queanbeyan and Goodradigbee Rivers changes in response to river flows.

Benthic macroinvertebrates

In spring 2011 macroinvertebrate communities at sites below dams, with the exception of site QM3 downstream of Googong Dam, remained within the same AUSRIVAS O/E score bands as autumn 2011 (Table 11). Despite the increased flow conditions downstream of Cotter Dam, site CM3 remained within band B and not similar to reference (Table 11). Other potential stressors downstream of Cotter Dam include: barrier effects of the dam (i.e. no drift from upstream to help macroinvertebrate recolonisation- Marchant and Hehir 2002), altered riparian vegetation (removing habitat for adult insects which may aerially recolonise-Marchant and Hehir 2002) and 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) and potentially from Murrumbidgee River water pumped via M2C. Site QM3 (2km downstream of Googong Dam) improved from a band B O/E score to a band A score (Table 11). The increased O/E score at site QM3 is the result of more favourable instream conditions that allow macroinvertebrate community recruitment (such as the decreased turbidity observed at the site when sampling occurred compared to autumn 2011) (Fig. 8).

In spring 2011 previously impaired Cotter tributary site CT2 and Goodradigbee reference sites GM2 improved in condition. The increased O/E score for Cotter tributary site CT2 to band A, since autumn, indicates that the increased stream flows in spring/summer 2011 have had a positive effect on the instream habitat and the macroinvertebrate community (Table 11). Reference site GM2 on the Goodradigbee River also appears to have recovered from the flood disturbance and has increased from band C to be similar to other Goodradigbee reference/tributary sites, which were in reference condition or more biologically diverse than reference (Table 11). However, the opposite occurred at Cotter tributary site CT1, where the O/E score decreased to band B to be below the band A threshold (Table 11). The O/E score at site CT1 in spring 2011 is similar to autumn 2010 and spring 2009 (Table 11), which indicates that the decrease in condition compared to autumn 2011 possibly the result of natural variability around reference condition. The increase in O/E scores to band X at reference sites QM1 (Queanbeyan River upstream of Googong Dam) and GM3 (Goodradigbee River) may also be variability around the reference condition or possibly be the result of increased phosphorus levels which may have increased instream production at both of these sites. However, the same increase in O/E score to band X did not occur at other sites with similar phosphorus concentrations (Table 11, Fig. 11). If both sites QM1 and GM1 remain at band X in future sampling runs, further investigation will be required to determine the possible causes of macroinvertebrate taxonomic richness being greater than reference condition.

Following flooding in the Cotter and Queanbeyan Rivers it was predicted that macroinvertebrate communities would become more similar to those in the unregulated Goodradigbee River (Harrison et al. 2011). However, in terms of relative abundances of macroinvertebrate taxa this does not appear to have occurred because, the macroinvertebrate collected were similar in spring 2011 to those collected in last pre-flood spring sample in 2009 (Fig. 16). In spring 2011 and 2009 below dam sites were characterised by a low relative abundances of sensitive macroinvertebrates compared to reference sites (SIGNAL 2 grades ≥7) (Fig. 16, Tables 10, 15 and 16). Furthermore, it was also predicted that in spring 2011 there would be an increase in algal grazing and scraping macroinvertebrate taxa (Harrison et al. 2011). However, several algae scraping and grazing taxa were expected to occur but not collected at below dam sites (Table 12: Leptophebiidae, Elmidae, Glossomatidae). Rather, at sites downstream of Corin, Bendora and Googong Dams there was a high relative abundance of algae feeding Orthocladiinae, which would prefer the habitat provided by the increased cover of filamentous algae (Tables 9 and 10). Therefore, at below dam sites in spring 2011, population recruitment, the periphyton assemblages or substrate conditions present may not be favourable for high abundances of sensitive macroinvertebrate taxa (including algae scraping grazing taxa) that are highly abundant at reference sites on the unregulated Goodradigbee River.

The change in macroinvertebrate community results for the site downstream of Corin Dam compared to previous sampling may be influenced by the changed location of the site to a riffle closer to the Corin Dam wall. The site sampled for spring 2011 was located closer to the dam wall than other below dams sites and appeared to be heavily armoured and have a more extensive cover of periphyton and filamentous algae compared to previous sampling occasions at the site further downstream of Corin Dam (Table 9). The armoured stream bed and higher cover of algae will have influenced the macroinvertebrate community, which was dominated by a high proportion of algae feeding Orthocladiinae (Table 10).

Acknowledgements

This assessment program and report review has been funded by ActewAGL and ACTEW Corporation. Flow data for the Cotter and Queanbeyan Rivers was provided by ActewAGL and the Department of Water and Energy supplied flow data for the Goodradigbee River.

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