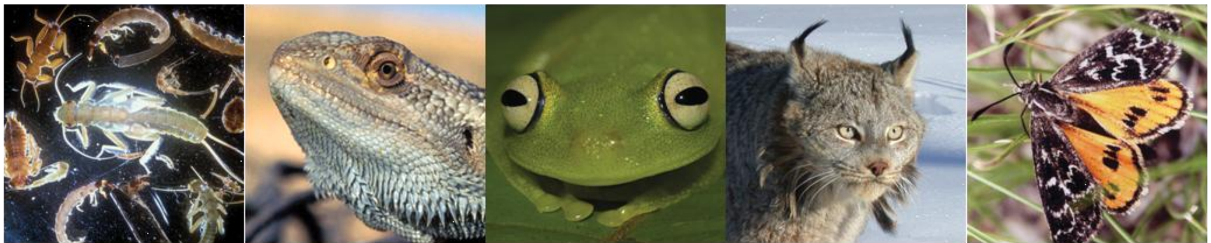

Biological response to flows downstream of Corin, Bendora, Cotter and Googong Dams

Autumn 2011

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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 at sites below dams on the Cotter and Queanbeyan Rivers, to evaluate the rivers' response to environmental flow releases and to meet the requirements of Licence No. WU67 – Licence to take water. Sites on the unregulated Goodradigbee River and Queanbeyan River upstream of Googong Dam are also studied to compare ecological change and responses in unregulated systems.

- This study addresses the needs of ACTEW's License to Abstract Water (WU67) in assessing 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 macroinvertebrates, algae and water quality data.

- Flooding events during the spring and summer months of 2010/11 coincided with changes to algal communities. 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. At below dams sites results were within the ACT environmental flow ecological objectives of <20% cover.

- In autumn 2011, two sites (CM2 and QM2: 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 (Corin Dam), CM3 (Cotter Dam) and QM3 (2km downstream of Googong Dam) remained significantly impaired (band B). Eight 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 autumn 2011.

- Macroinvertebrate communities have remained similar to autumn 2010 below each of the dams on the Cotter and Queanbeyan Rivers with low abundances of sensitive taxa (compared to pre-flood samples from reference sites) (i.e. those with SIGNAL 2 grades ≥7). An absence of improvements in macroinvertebrate taxa richness and the relative abundance of sensitive taxa downstream of dams on the Cotter and Queanbeyan Rivers, may be limited by the lower flow conditions that effected macroinvertebrate communities before flooding. The macroinvertebrate community that developed under the antecedent low-flow conditions may have restricted capacity for an immediate positive response following the large flow event. If further macroinvertebrate community recovery does occur it is likely to take place when community recruitment occurs in spring.

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 (each autumn). 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, water extraction and the effectiveness of environmental flows. This information allows for adaptive management of water supply catchments.

Flooding in spring/summer 2010/11 may have resulted in ecological changes to macroinvertebrate and algal communities. A literature review conducted on the potential effect of the floods on the Cotter and Queanbeyan Rivers concluded that following the floods there will be initial decrease in macroinvertebrate abundance and taxa richness, a change in macroinvertebrate assemblage structure and decreased periphyton/algal biomass. Then with further time macroinvertebrate taxa richness will recover on a trajectory towards reference conditions similar to sites on unregulated rivers (Harrison et al. 2011). Comparison between condition of "Below Dams Assessment Program" study sites before and after flooding presents a unique opportunity to assess flood disturbance effects on the biological condition of the Cotter and Queanbeyan River. Of most interest is how flooding influenced macroinvertebrate assemblages and periphyton/algae 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 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 10/5/2011-10/6/2011 (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).

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, autumn 2011.

Site Code	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500 m 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

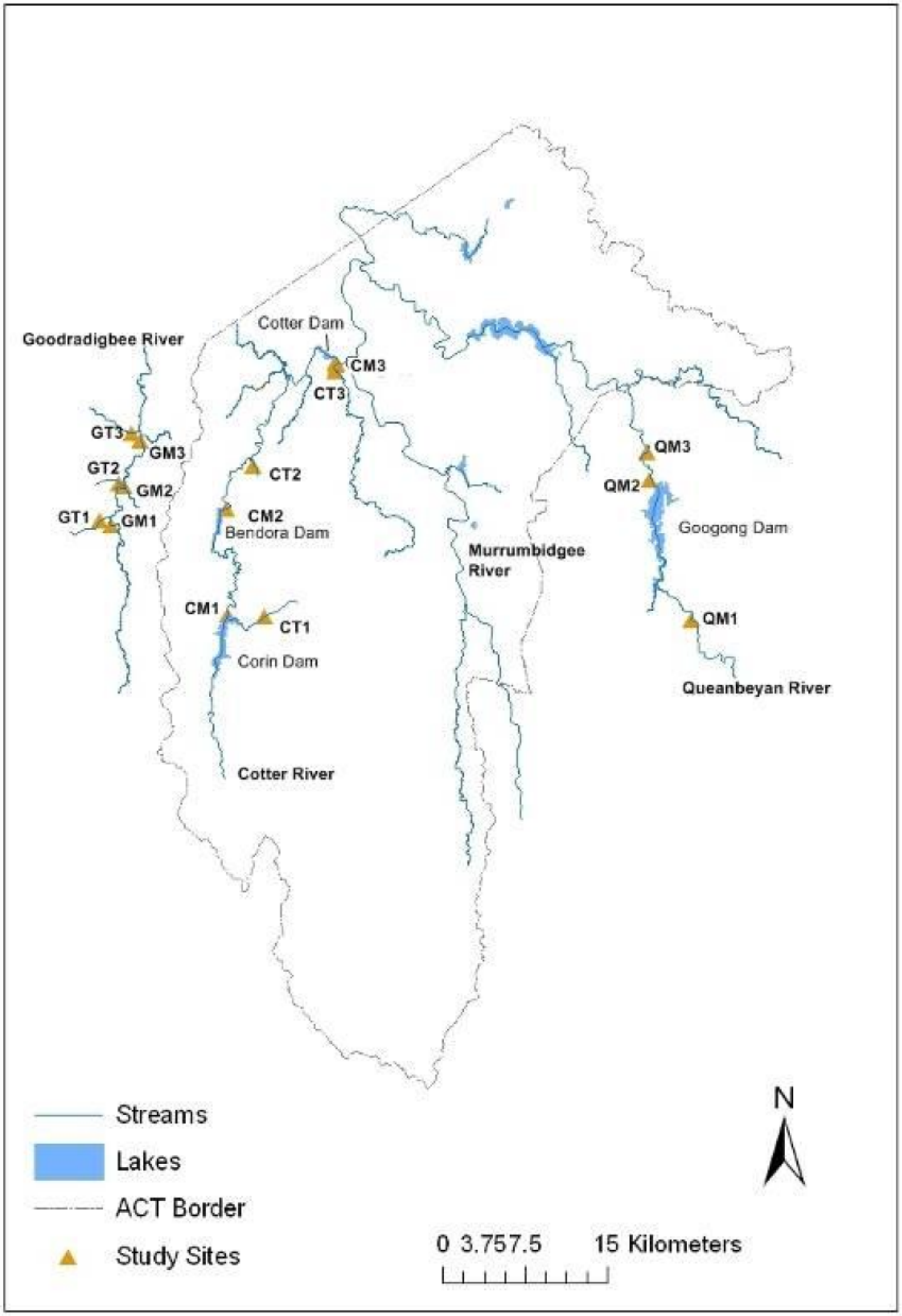

Figure 1: The location of sites usually sampled on the Cotter, Goodradigbee and Queanbeyan River's and tributaries for the Below Dams Assessment Program.

Table 2: Sampling dates and times for each site in May and June 2011.

Site	SAMPLING DATE	SAMPLING TIME
CM1	10/6/2011	11:00
CM2	11/5/2011	12:00
CM3	10/5/2011	13:00
CT1	10/5/2011	10:30
CT2	11/5/2011	10:30
CT3	10/5/2011	15:00
GM1	31/5/2011	14:15
GM2	31/5/2011	11:45
GM3	31/5/2011	09:30
GT1	31/5/2011	15:00
GT2	31/5/2011	12:45
GT3	31/5/2011	10:45
QM1	3/6/2011	10:00
QM2	3/6/2011	11:30
QM3	3/6/2011	13:00

Hydrometric data

To determine changes in river flow and rainfall for the months preceding sampling and when sampling occurred mean daily flow data and rainfall data was obtained for each below dam site and the Goodradigbee River. Mean daily flow data was 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 1992).

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. 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 of chlorophyll-a content of the periphyton/algae. Chlorophyll-a was extracted using 90% ethanol, and measured in a spectrophotometer (A.P.H.A. 1992)

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 (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 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.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 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.canberra.edu.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.

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

Band	Band description	Band width	O/E Taxa interpretations
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	**≥1.13**	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	SIMILAR TO REFERENCE	**0.88-1.12**	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**	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**	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**	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 sampling period (autumn 2011 vs autumn 2010) 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. To determine if there were significant differences between periphyton AFDM and chlorophyll-a at sites in autumn 2011 a single factor ANOVA (SAS 9.1) was used followed by Tukey-Kramer multiple comparisons. Also to determine if there were significant differences in periphyton AFDM and chlorophyll-a between autumn 2011 and summer 2011 (January) at site QM2, a Student's t-test (SAS 9.1) was used. A $\log_{10}(x+1)$ transformation was applied to both the AFDM and 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 autumn 2010 and autumn 2011 were assessed using cluster analysis applied to the fourth root transformed macroinvertebrate relative abundance and presence/absence data (PRIMER v6; Clark and Warwick 2001). Similarity between sites was 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

Large rainfall events occurred frequently throughout spring/summer 2010/11 including one that resulted in severe flooding of the Queanbeyan River after the high rainfall event of 87 mm on 3 December 2010 (Fig. 2). The flow peaks observed in Cotter and Queanbeyan Rivers were substantially greater than the environmental flows released from Corin, Bendora Cotter and Googong Dams in autumn 2010 (Fig. 2, Table 7). Flow in the Cotter, Queanbeyan and Goodradigbee Rivers in autumn 2011 has decreased following the flooding in spring/summer 2010/11 (Fig. 2). However, flows downstream of Corin (73-180ML d^{-1}), Cotter (50-493 ML d^{-1}) and Googong Dams (12-114ML d^{-1}) in autumn 2011 were greater than the environmental flows released when autumn 2010 sampling occurred (Fig. 2, Table 7). Downstream of Cotter Dam in autumn 2011, flows between 50-493 ML d^{-1} were released from the dam to prevent water in the dam spilling over into the Enlarged Cotter Dam construction site and for the drawdown of the dam for construction work (Fig. 2). With the exception of a release 250-257 ML d^{-1} occurring from the 20/04/11-22/04/11, flows downstream of Bendora Dam in autumn 2011 were equivalent to environmental flows released autumn 2010 sampling occurred (Fig. 2, Table 7). Flow in autumn 2011 in the Goodradigbee River was generally greater than the flow downstream of each of the dams on the Cotter and Queanbeyan Rivers and greater than flow in the Goodradigbee River in when autumn 2010 sampling occurred (Fig. 2).

Table 7: Environmental flow regimes downstream of Corin, Bendora, Cotter and Googong Dams in autumn 2010. Data source: ACTEWAGL.

Dam	Environmental flow regime
Corin	base flow average 20 MLd^{-1} and 150 MLd^{-1} for three days every two months
Bendora	base flow average 20 MLd^{-1} and 150 MLd^{-1} for three days every two months
Cotter	flows of approximately 50-200 MLd^{-1}
Googong	base flow average 10 MLd^{-1}

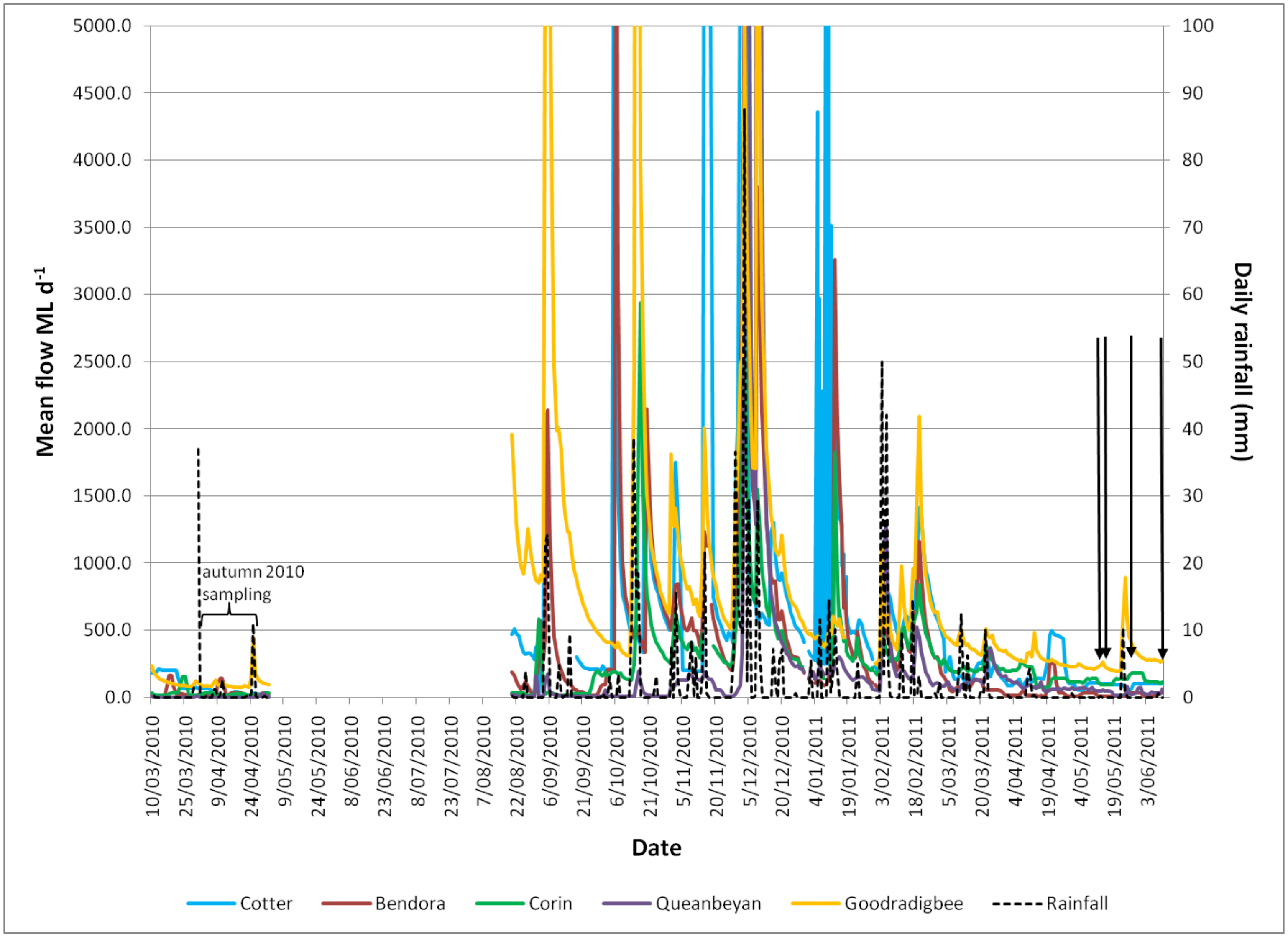

Figure 2: Daily river flow on the Cotter, Goodradigbee and Queanbeyan Rivers: below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams and Goodradigbee River (GM2); and daily rainfall data for Canberra airport from 10/03/2010 to 10/06/2011. NB. Flow peaks >5000 ML d $^{-1}$ are not shown on the graph and there is a gap in the flow data from the 3/05/2010-19/08/2010. **Flow data from the 10/03/2010-2/05/2010 corresponds to when autumn 2010 sampling occurred.** Arrows correspond to autumn 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

Electrical conductivity

Conductivity at all sites in autumn 2011 was below the upper ANZECC trigger value of 350 µS cm^{-1}, which is the same result as autumn 2010 (Table 8).

pH

At all sites pH levels were within the recommended ANZECC trigger value range (6.5 – 8.0) at the time of sampling (Table 8). Previously in summer 2011 all sites sampled also fell within the ANZECC trigger value range (Table 8). In autumn 2010 the pH values (8.19 and 8.01 respectively) at reference sites GM1 and GM2 (Goodradigbee River) were slightly greater than the recommended ANZECC trigger value range (Table 8).

Dissolved oxygen

Dissolved oxygen measurements were not below the ANZECC trigger value (of <6 mg L^{-1}) at all sites (Table 7), which was the same for all sites sampled in summer 2011 and autumn 2010 (Table 7).

Turbidity

Turbidity at sites QM2 and QM3 on the Queanbeyan River was above the Environment Protections Regulations trigger value of 10 NTU, while all other sites were below the trigger value (Table 8). Previously in summer 2011 turbidity at sites QM2 and QM3 was also above the trigger value of 10 NTU (Table 8).

Ammonia

Ammonia concentrations were all below the ANZECC trigger value of 0.9 mg L^{-1}, which is the same result as summer 2011 and autumn 2010 (Table 9).

Nitrogen oxide

Oxidised nitrogen concentrations at sites QM2 and QM3 on the Queanbeyan River were above the ANZECC trigger value of 0.015 mg L^{-1}, while all other sites were below the trigger value (Table 9). Previously in summer 2011 sites QM2 and QM3 also had oxidised nitrogen concentrations above the ANZECC trigger value. In autumn 2010 sites QM2 and CM3 had oxidised nitrogen levels above the ANZECC trigger value (Table 9).

Total Phosphorus

Total phosphorus concentrations at sites CM3, CT1, GM1, QM2 and QM3 were equal to or higher than the ANZECC trigger value of 0.02 mg L^{-1} (Table 9). Previously in summer 2011 sites QM2 and QM3 had total phosphorus concentrations higher than the trigger value, whilst in autumn 2010 all sites had levels lower than the trigger value (Table 9).

Total Nitrogen

Total nitrogen concentrations at sites CM3, CT1, QM2 and QM3 were above the ANZECC trigger value of 0.25 mg L^{-1} (Table 9). Previously in summer 2011 sites QM2 and QM3 had total nitrogen concentrations above the ANZECC trigger value (Table 9). In autumn 2010 sites CM3, CT3 (Paddys River), QM2 and QM3 all had total nitrogen concentrations above the ANZECC trigger value (Table 9).

Periphyton and algae: Ash-Free Dry Mass (AFDM), Chlorophyll-a and visual observations

Mean periphyton AFDM differed significantly between sampling periods (autumn 2011 and autumn 2010) with a lower mean AFDM in autumn 2011 (Fig. 3 and Table 10). However, because of high within site variability AFDM didn't vary significantly by site and there wasn't a significant site-period interaction (Table 10). In autumn 2011 only AFDM at below dam site CM2, was significantly greater than the Goodradigbee River reference site GM2. AFDM was also significantly lower at Goodradigbee reference site GM2 compared to GM3 (F= 3.29; DF= 6,32; P= 0.01). There was no significant difference in AFDM measured at site QM2 below Googong Dam in summer 2011 and autumn 2011. (T= 0.75; DF= 10; P= 0.4728).

Mean periphyton chlorophyll-a differed significantly between sites and sampling period (autumn 2011 and autumn 2010), and the site-period interaction was significant (Fig. 3 and Table 10). Chlorophyll-a concentration was significantly higher at sites CM1 (Corin Dam) and CM2 (Bendora Dam) in autumn 2011 compared to autumn 2010. In autumn 2011 periphyton chlorophyll-a was significantly lower at Goodradigbee River reference sites GM1 and GM2 compared to below dams sites CM1, CM2 and QM2 (F= 10.67; DF= 6,34; P<0.0001). At site QM2 below Googong Dam chlorophyll-a was significantly higher is autumn 2011 when compared to summer (T= 6.28; DF= 10; P<0.0001).

In autumn 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 below dam sites CM1, CM2, CM3 and QM2 (Table 11). Periphyton percentage cover in the riffle at site QM2 below Googong Dam decreased from 10-35% cover in summer 2011 and periphyton percentage cover in the sampling reach at site CM3 decreased from 10-35% cover in autumn 2010 to <10% (Table 11). Filamentous algae cover has remained at <10% for all Goodradigbee reference sites and below dam sites CM1, CM2, CM3 and QM2 (Table 11).

Table 8: Water quality characteristics of sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), the Goodradigbee reference sites (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) and main channel sites on the Queanbeyan River (QM1, QM2 and QM3), autumn 2011 and previously in summer 2011 and autumn 2010. *Shading indicates those sites with measurements not within water quality trigger values from the Environment Protection Regulations SL2005-38* and ANZECC and ARMCANZ (2000)**.* N/A = trigger value not available. n.d. = no data because of high flows.

Site	Alkalinity (mg L^{-1})			Water Temp (^{0}C)			Conductivity (µS cm^{-1})			pH			Diss. Oxygen (mg L^{-1})			Turbidity (NTU)		
	Trigger value																	
	N/A			N/A			350**			6.5 – 8**			<6**			10*		
	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11
CM1	10.0	18.0	10.0	16.2	20.3	8.3	30.2	21.4	24.8	7.0	7.1	7.3	9.0	9.2	10.8	1.0	3.6	1.0
CM2	22.0	n.d.	12.0	15.7	n.d.	11.4	28.9	n.d.	25.5	7.2	n.d.	6.9	9.1	n.d.	10.0	0.0	n.d.	2.9
CM3	22.0	n.d.	26.0	18.9	n.d.	12.4	58.4	n.d.	77.4	7.1	n.d.	7.4	7.9	n.d.	10.4	9.2	n.d.	8.2
CT1	30.0	18.0	16.0	9.6	16.2	5.5	54.4	33.8	40.0	7.2	7.1	7.0	10.1	9.5	11.3	1.0	4.3	1.0
CT2	20.0	n.d.	15.0	12.1	n.d.	7.1	34.0	n.d.	33.4	6.9	n.d.	6.8	9.8	n.d.	11.1	1.6	n.d.	0.7
CT3	24.0	n.d.	30.0	17.0	n.d.	9.5	137.5	n.d.	76.8	7.9	n.d.	7.8	7.9	n.d.	10.9	7.7	n.d.	2.7
GM1	71.0	n.d.	36.0	15.7	n.d.	8.9	96.4	n.d.	82.3	8.2	n.d.	7.8	10.0	n.d.	10.8	0.0	n.d.	3.8
GM2	60.0	n.d.	34.0	15.5	n.d.	8.4	93.3	n.d.	78.4	8.0	n.d.	7.8	9.9	n.d.	11.1	0.0	n.d.	2.3
GM3	78.0	n.d.	34.0	15.4	n.d.	7.6	105.7	n.d.	75.0	7.9	n.d.	7.6	9.8	n.d.	11.4	0.2	n.d.	0.5
GT1	38.0	n.d.	22.0	15.7	n.d.	8.7	63.1	n.d.	50.7	7.8	n.d.	7.5	9.6	n.d.	10.9	3.6	n.d.	2.6
GT2	52.0	n.d.	22.0	15.4	n.d.	8.3	66.9	n.d.	50.4	7.8	n.d.	7.5	9.6	n.d.	11.1	7.1	n.d.	4.7
GT3	42.0	n.d.	20.0	15.4	n.d.	7.9	58.8	n.d.	44.1	7.8	n.d.	7.5	9.9	n.d.	11.2	0.8	n.d.	4.8
QM1	41.0	n.d.	30.0	12.0	n.d.	8.3	85.7	n.d.	74.9	7.1	n.d.	7.4	9.6	n.d.	10.7	0.6	n.d.	4.0
QM2	62.0	45.0	39.0	16.3	21.8	12.7	135.6	88.0	92.9	7.7	7.7	7.7	9.1	8.7	10.6	1.0	15.1	16.9
QM3	78.0	39.0	41.0	14.1	22.3	11.6	221.0	94.8	105.6	7.6	7.6	7.7	8.5	8.1	10.2	1.0	11.3	14.4

Table 9: Ammonia (NH_3), nitrogen oxide, total phosphorus (TP) and total nitrogen (TN) concentrations at sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), the Goodradigbee reference sites (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) and main channel sites on the Queanbeyan River (QM1, QM2 and QM3) autumn 2011 and previously in summer 2011 and autumn 2010. *Shading indicates those sites with measurements not within water quality trigger values from ANZECC and ARMCANZ (2000).* n.d. = no data because of high flows.

Site	NH_3 (mg L^{-1})			NOx (mg L^{-1})			TP (mg L^{-1})			TN (mg L^{-1})		
	Trigger value											
	0.9			0.015			0.02			0.25		
	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11	Aut-10	Sum-11	Aut-11
CM1	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.17	0.2	0.14
CM2	<0.01	n.d.	0.05	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	0.23	n.d.	0.16
CM3	0.02	n.d.	0.09	0.05	n.d.	<0.01	0.01	n.d.	0.02	0.3	n.d.	0.41
CT1	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.04	0.03	0.2	0.54
CT2	<0.01	n.d.	0.03	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	0.02	n.d.	0.09
CT3	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	0.02	n.d.	0.01	0.43	n.d.	0.23
GM1	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	n.d.	0.02	0.03	n.d.	0.24
GM2	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	0.06	n.d.	<0.01
GM3	0.01	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	n.d.	0.01
GT1	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	0.01	n.d.	<0.01	0.12	n.d.	0.13
GT2	<0.01	n.d.	0.02	<0.01	n.d.	<0.01	0.01	n.d.	<0.01	0.18	n.d.	0.08
GT3	<0.01	n.d.	0.05	<0.01	n.d.	<0.01	0.01	n.d.	0.01	0.21	n.d.	0.17
QM1	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	n.d.	<0.01	0.24	n.d.	0.12
QM2	<0.01	0.04	0.02	0.02	0.06	0.04	<0.01	0.04	0.04	0.42	1.21	1.4
QM3	<0.01	0.06	0.03	<0.01	0.08	0.11	<0.01	0.04	0.03	0.38	1.16	1.09

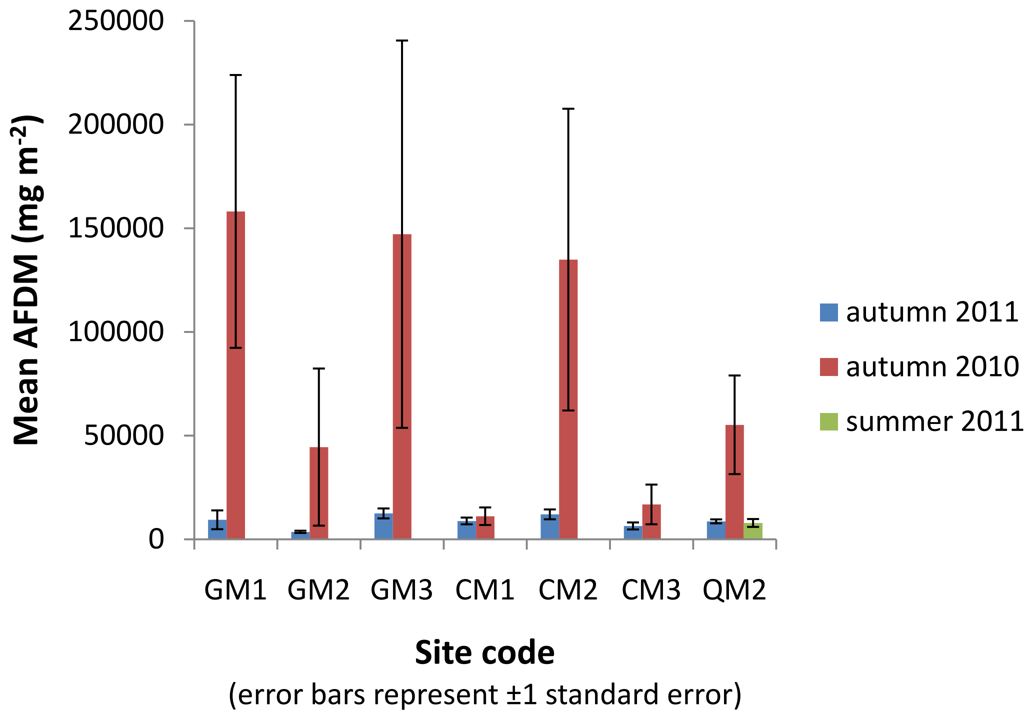

Figure 3: Mean AFDM (mg m^{-2}) at reference sites GM1, GM2 and GM3 (Goodradigbee River), and below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong), autumn 2011 and previously in summer 2011 and autumn 2010.

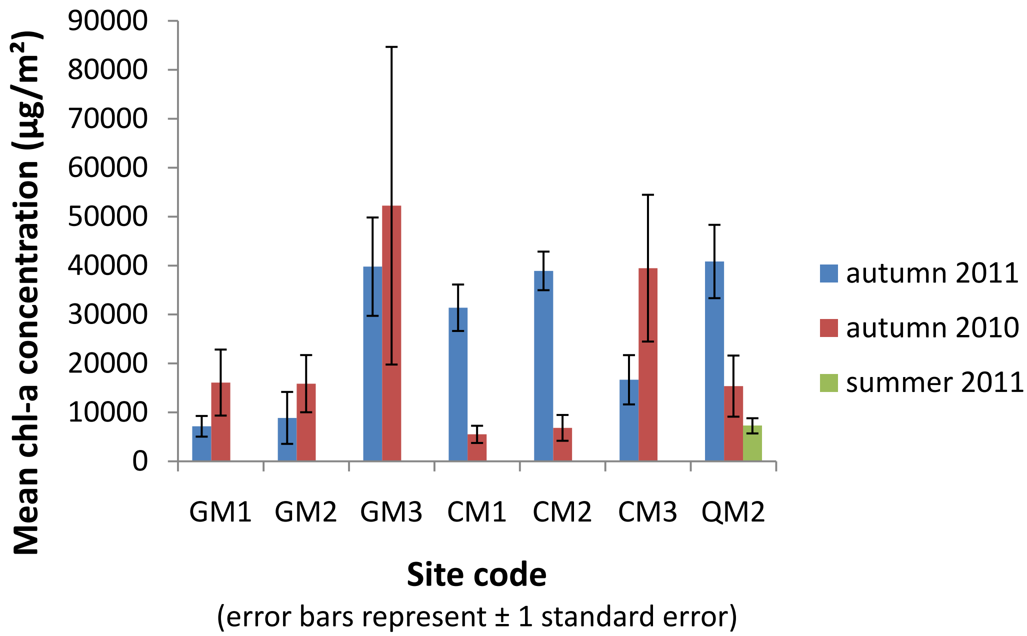

Figure 4: Mean chlorophyll-a (µg m^{-2}) at reference sites GM1, GM2 and GM3 (Goodradigbee River), and below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong), autumn 2011 and previously in summer 2011 and autumn 2010.

Table 10: Effects of site and sampling period on AFDM and chlorophyll-a tested using two-way analysis of variance (ANOVA).

Source of variation:	Site			Period			Site*Period		
Variable	DF	F	P	DF	F	P	DF	F	P
AFDM	6	1.85	0.1032	1	11.10	0.0014	6	0.67	0.6749
Chlorophyll-a	6	3.27	0.0069	1	8.44	0.0049	6	4.81	0.0004

Table 11: Percent cover categories of periphyton and filamentous algae in the riffle and reach at reference sites GM1, GM2 and GM3 (Goodradigbee River), and below dams sites CM1 (Corin), CM2 (Bendora), CM3 (Cotter) and QM2 (Googong), autumn 2011 and previously in summer 2011 and autumn 2010. n.d. = no data because of high flows.

Site	% cover of riffle						% cover of reach					
	Periphyton			Filamentous Algae			Periphyton			Filamentous Algae		
	Aut-11	Sum-11	Aut-10	Aut-11	Sum-11	Aut-10	Aut-11	Sum-11	Aut-10	Aut-11	Sum-11	Aut-10
GM1	<10	n.d	<10	<10	n.d	<10	<10	n.d	<10	<10	n.d	<10
GM2	<10	n.d.	<10	<10	n.d.	<10	<10	n.d.	<10	<10	n.d.	<10
GM3	<10	n.d	<10	<10	n.d	<10	<10	n.d	<10	<10	n.d	<10
CM1	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
CM2	<10	n.d	<10	<10	n.d	<10	<10	n.d	<10	<10	n.d	<10
CM3	<10	n.d.	10-35	<10	n.d.	<10	<10	n.d.	10-35	<10	n.d.	<10
QM2	<10	10-35	<10	<10	<10	<10	<10	10-35	<10	<10	<10	<10

Benthic macroinvertebrates

Relative abundance

The relative abundance of Oligochaeta, Diptera excluding Chiromonidae and Chironomidae was greatest at sites CM1, CM3, QM2 and QM3 (Fig. 5). Generally, the relative abundance of Ephemeroptera in samples was greater at the reference sites, compared with below dam sites (Fig. 5). Similarly, Plecoptera were more abundant in samples from reference sites, although sites CM1 and CM2 were more similar to reference sites than the other below dam sites (Fig. 5). The abundance relative of Trichoptera in samples was more similar between below dam and reference sites than Ephemeroptera and Plecoptera CM2 and QM2 having the greatest Plecoptera relative abundance (Fig. 5). Below dams sites CM2 and QM2 had the greatest Trichoptera (relative abundance dominated by Hydropsychidae)(Fig. 5., Table 12)

Taxonomic richness and whole sample abundance

Generally, more macroinvertebrate taxa were collected from Goodradigbee River reference sites compared with sites below dams, except site GM2 where only 12 taxa were collected (Table 12). Taxonomic richness was lowest at sites CM1 (Corin Dam) and CT3 (Paddys River), followed by CM3 (Cotter Dam)(Table 12). The estimated whole sample abundance was lowest at site QM2 (downstream of Googong Dam), however, several sensitive taxa (SIGNAL 2 grade ≥7) were collected in the subsample (Table 12). The estimated number of macroinvertebrates per sample from site CM2 (Bendora Dam) on the Cotter River was greater than for other Cotter River sites (CM1 and CM2) (Table 11). On the Queanbeyan River site QM1 (upstream of Googong Dam) had a higher whole sample abundance than sites QM2 and QM3 downstream of Googong Dam (Table 12). Downstream of Googong Dam the whole sample abundance was higher at site QM3 2km downstream of the dam compared to site QM2 directly downstream of the dam (Table 12).

AUSRIVAS

Site CM2 (Bendora Dam) and site QM2 (Googong Dam) were assessed as being similar to reference (band A) (Table 12). While, sites CM1 (Corin Dam), CM3 (Cotter Dam) and QM3 (2km downstream of Googong Dam) were assessed significantly impaired (band B) (Table 13). Only reference sites GM3, QM1, CT3, GT1, GT2 and GT3 were assessed as being similar to reference condition (band A) (Table 13). Reference site GM2 was assessed as severely impaired (band C) and sites GM1 and CT1 were assessed as having more taxa present than expected (band X) (Table 13). Six of the missing taxa that were expected to occur were present in the sample scans for six sites (Hydrobiosidae-CM1; Hydropsychidae-GT1; Gomphidae- QM3; Leptophlebiidae-CM2 ,QM3; Tanypodinae-CM2, GT3 ; Tipulidae-CT2) (Tables 14 and 15). The AUSRIVAS results for autumn 2011 were similar to autumn 2010 for all below dam sites on the Cotter and Queanbeyan Rivers. However, reference site GM2 has degraded in condition from band A to C. While reference sites CT1, CT3 and GT3 have improved in condition from bands C (CT3) and B (CT1 and GT3) to bands A (CT3 and GT3) and X (CT1)(Table 13).

Macroinvertebrate community similarity

Three groups of sites from autumn 2010 and autumn 2011 were evident from the cluster analysis of relative abundance data, which were moderately to well separated from one another (Fig 6, Table 16). Group 2 contained only reference sites, while below dam sites were in groups 1 and 3 (Fig. 6). Sites in group 2 were characterised by a greater taxonomic richness and had greater abundances of sensitive macroinvertebrate taxa (SIGNAL 2 grades ≥7) compared to sites in groups 1 and 2 (Tables 17 and 18). Many of the macroinvertebrate taxa collected in higher numbers at Goodradigbee River reference sites in autumn 2010 (group 2) were also algae scraping and grazing taxa (e.g. Griopopterygidae, Leptophebiidae, Elmidae, Glossomatidae) (Tables 17 and 18). Following the floods in spring and early summer 2010 reference sites GM1, GM2 and QM1 changed to groups 3 (GM1 and GM2) and 1 (QM1) because, the relative abundance of sensitive macroinvertebrate taxa (SIGNAL 2 grades ≥7) that discriminated between groups decreased in autumn 2011 compared to autumn 2010 (Fig. 6 and Table 18). Compared to group 2 sites, group 1 and 3 sites were characterised by higher abundances of early colonizing Simulidae, deposition feeding taxa (Orthocladiinae and Chironominae) and disturbance tolerant taxa (Oligochaeta, Baetidae)(Table 17).

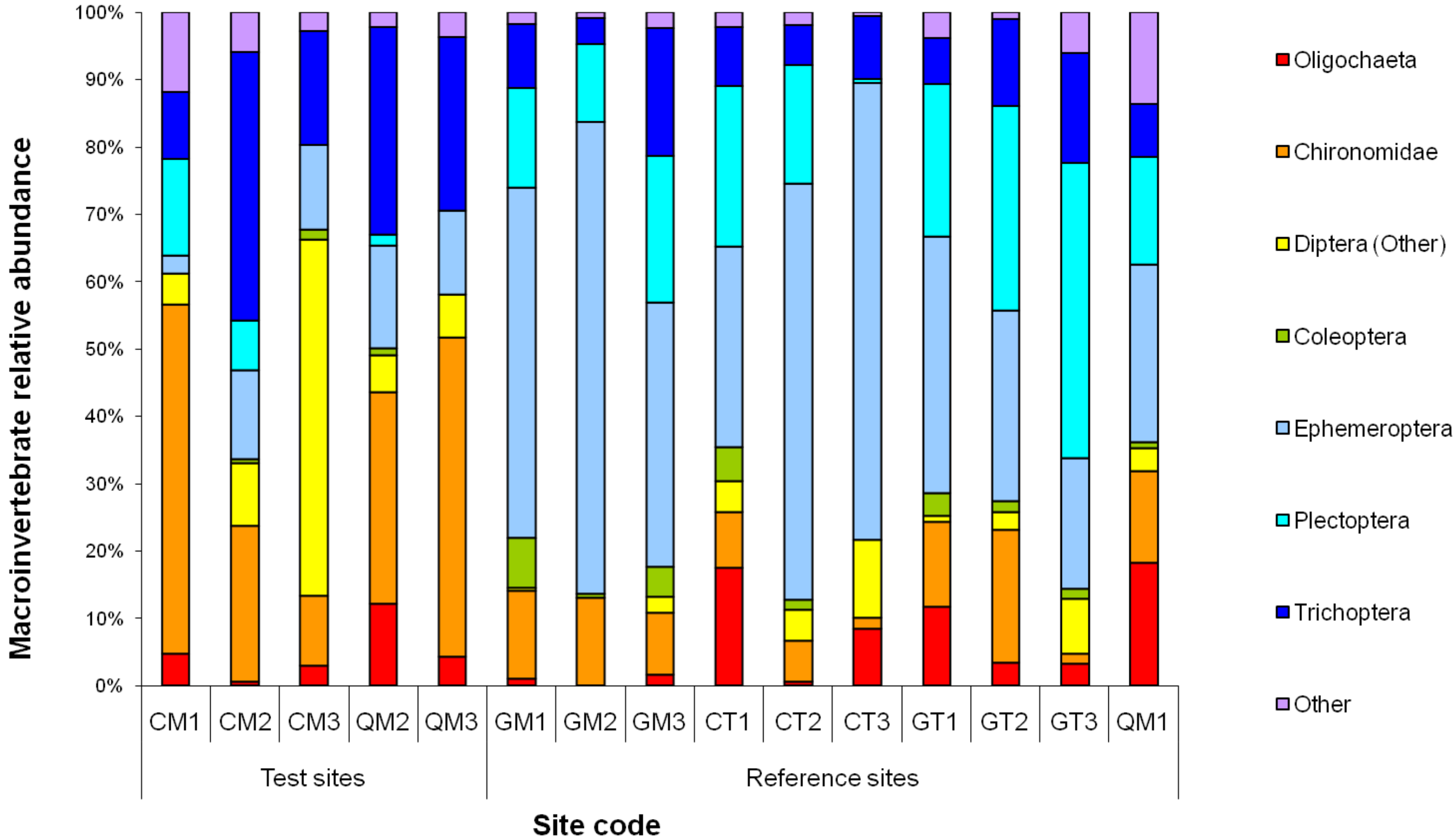

Figure 5: Relative abundance of macroinvertebrates taxa groups (indicated by different colours in the legend) at each sample site on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), autumn 2011.

Table 12: Macroinvertebrate taxa and their sensitivity grade (SIGNAL 2) (Chessman, 2003) collected from sub-samples during autumn 2011 for 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) *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

CLASS **Order** Family *Subfamily*	**SIGNAL 2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT3**	**GT2**	**QM1**	**QM2**	**QM3**
ACARINA	6	15	11	6	4	2	5	5	4	2	5	12	2	27	4	8
OLIGOCHAETA	2	9	1	6	2		3	38	1	26	24	6	6	37	22	9
TURBELLARIA																
Tricladida																
Dugesiidae	2	8														
MOLLUSCA																
Bivalvia																
Sphaeriidae	5		1													
INSECTA																
Hemiptera																
Corixidae	2													1		
Megaloptera																
Corydalidae	7										1					
Plecoptera																
Gripopterygidae	8	28	15		34	24	45	52	38	2	47	86	57	33	3	
Odonata																
Gomphidae	5										2					
Ephemeroptera																
Baetidae	5	2	1	23	11		3	27	44	133	1	4	4	12	15	19
Caenidae	4		26	1	5		4	10		2	2		3	37	12	8
Coloburiscidae	8				6	9	8	1			1	2				
Leptophlebiidae	8	3		3	98	137	66	27	89	77	75	32	46	5	1	
Coleoptera																
Elmidae (Adult)	7				1			1			1			1		
Elmidae (Larvae)	7		1	3	9		8	6	2		2	1	2	1		
Hydraenidae	3												1			
Psephenidae	6				6	1	1	1			4	1				
Scirtidae	6				1			3	1			1			2	
Diptera																
Chironomidae																

Table 11 cont.

CLASS **Order** Family *Subfamily*	SIGNAL 2 grade	CM1	CM2	CM3	GM1	GM2	GM3	CT1	CT2	CT3	GT1	GT3	GT2	QM1	QM2	QM3
Aphroteniinae	8											1				
Chironominae	3		7	5	21	23	9	10	8	2	17	1	24	11	19	38
Orthocladiinae	4	100	40	17	4	1	4	6	3	2	2	1	7	16	38	65
Podonominae	6				1			1	1	1	1					
Tanypodinae	4				4	3	6	1	1		6		6	1	1	
Empididae	5	8	9	4			2	8	10		1	4	4	5	7	3
Simuliidae	5	1	7	108			2	2		36		2		1	2	
Tipulidae	5		3	1	1		1				1	10	1	1	1	11
Trichoptera																
Calamoceratidae	7											1				
Calocidae	9						1						1			1
Conoesucidae	7	11	2		3	2	19	3	8		3	16	6		1	
Ecnomidae	4			2				3						1	11	4
Glossosomatidae	9				1	2	14	2								
Helicopsychidae	8				1											
Hydrobiosidae	8		1	6	1	1	1	9	2	22	4	1	4	2	6	5
Hydropsychidae	6	4	74	3	5		4	1		6		3		8	30	29
Hydroptilidae	4	2	4	4	1						1	2		5	4	15
Leptoceridae	6	2		2	8	3		1	3	1	5	9	12		4	2
Philopotamidae	8			19							1		1		1	
Philorheithridae	8				2											
No. individuals		193	203	213	230	208	206	218	215	312	207	196	187	205	184	217
No. of taxa		13	16	17	23	12	20	21	15	13	22	21	18	18	19	14
% of sub-sample		6	2	3	3	1	4	5	3	2	3	5	4	5	11	7
Whole sample estimate		3217	10150	7100	7667	20800	5150	4360	7167	15600	6900	3920	4675	4100	1673	3100

Table 13: 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 autumn 2011. *Note band X = more biologically diverse than reference, > 1.13; band A = similar to reference condition, 0.87-1.13 (spring), 0.88-1.12 (autumn); band B = significantly impaired, 0.61-0.86 (spring), 0.64-0.87 (autumn); band C = severely impaired 0.35-0.60 (spring), 0.40-0.63 (autumn); band D = extremely impaired 0-0.34 (spring), 0-0.39 (autumn), observed and O/E score values are those for taxa with a greater than 50% probability of occurrence.*

	2009		**2010**	**2011**
Site	**Autumn**	**Spring**	**Autumn**	**Autumn**
CM1	0.86 (B)	0.92 (A)	0.74 (B)	0.73 (B)
CM2	0.84 (B)	0.82 (B)	1.04 (A)	0.89 (A)
CM3	0.84 (B)	0.66 (B)	0.83 (B)	0.82 (B)
QM2	0.77 (B)	0.92 (A)	0.97 (A)	0.96 (A)
QM3	0.67 (B)	0.72 (B)	0.83 (B)	0.67 (B)
GM1	1.1 (A)	1.14 (X)	1.16 (X)	1.16 (X)
GM2	1.12 (A)	1.13 (A)	1.03 (A)	0.57 (C)
GM3	0.88 (A)	1.08 (A)	0.92 (A)	1.05 (A)
QM1	0.54 (C)	1.16 (X)	0.96 (A)	0.96 (A)
CT1	0.93 (A)	0.84 (B)	0.81 (B)	1.17 (X)
CT2	DRY	0.77 (B)	0.77 (B)	0.81 (B)
CT3	DRY	0.61 (B)	0.58 (C)	0.89 (A)
GT1	1.22 (X)	1.08 (A)	1.01 (A)	1.04 (A)
GT2	0.74 (B)	1.22 (X)	1.22 (X)	0.93 (A)
GT3	0.41 (C)	0.69 (B)	0.82 (B)	0.95 (A)

Table 14: 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 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) in autumn 2011 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														
Macroinvertebrate	**SIGNAL 2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Hydrobiidae	4														X	X
Ancylidae	4														X	X
Oligochaeta	2					X										
Amphipoda	3	X			X							X				
Scirtidae	6	X									X	X				
Elmidae	7	X				X				X					X	X
Psephenidae	6		X	X					X	X				X		
Tipulidae	5								X							
Simuliidae	5				X	X			X		X	X				X
Podonominae	6	X	X	X		X	X					X	X	X	X	X
Tanypodinae	4	X	X	X						X			X			X
Chironominae	3	X														
Baetidae	5					X										
Coloburiscidae	8								X							
Leptophlebiidae	8		X													X
Caenidae	4					X			X				X			
Gomphidae	5		X	X			X			X				X	X	X
Gripopterygidae	8			X												
Hydrobiosidae	8	X														
Glossosomatidae	9			X					X				X			
Hydroptilidae	4					X	X	X		X		X				
Philopotamidae	8												X			
Hydropsychidae	6					X			X		X	X				
Conoesucidae	7			X										X		
No. of missing taxa		**7**	**5**	**7**	**2**	**8**	**3**	**1**	**7**	**5**	**3**	**6**	**5**	**4**	**5**	**8**

Table 15: Additional macroinvertebrate families and their sensitivity grade (SIGNAL 2) (Chessman, 2002) 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 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) in autumn 2011. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

		Site														
Macroinvertebrate	**SIGNAL 2 grade**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Dugesiidae															X	X
Atyidae	2													X		
Veliidae	3														X	
Corydalidae	3		X				X						X	X		
Gomphidae	7												X			X
Telephlebiidae	5							X	X							
Leptophlebiidae	9		X													X
Dytiscidae	8													X		
Scirtidae	2										X					
Chironomidae *Aphroteniinae*	6								X							
Chironomidae *Tanypodinae*	8		X										X			
Empididae	4				X											
Simuliidae	5								X							
Tanyderidae	5								X							
Tipulidae	6							X	X							
Calamoceratidae	5		X		X						X					
Ecnomidae	7		X							X						
Hydrobiosidae	4	X														
Hydropsychidae	8										X					
Leptoceridae	6													X		
Philopotamidae	6					X		X		X				X		
Polycentropodidae	8								X							
Tasimiidae	7							X								
No. New Taxa	8	**1**	**5**	**0**	**2**	**1**	**1**	**4**	**6**	**2**	**3**	**0**	**3**	**5**	**2**	**3**

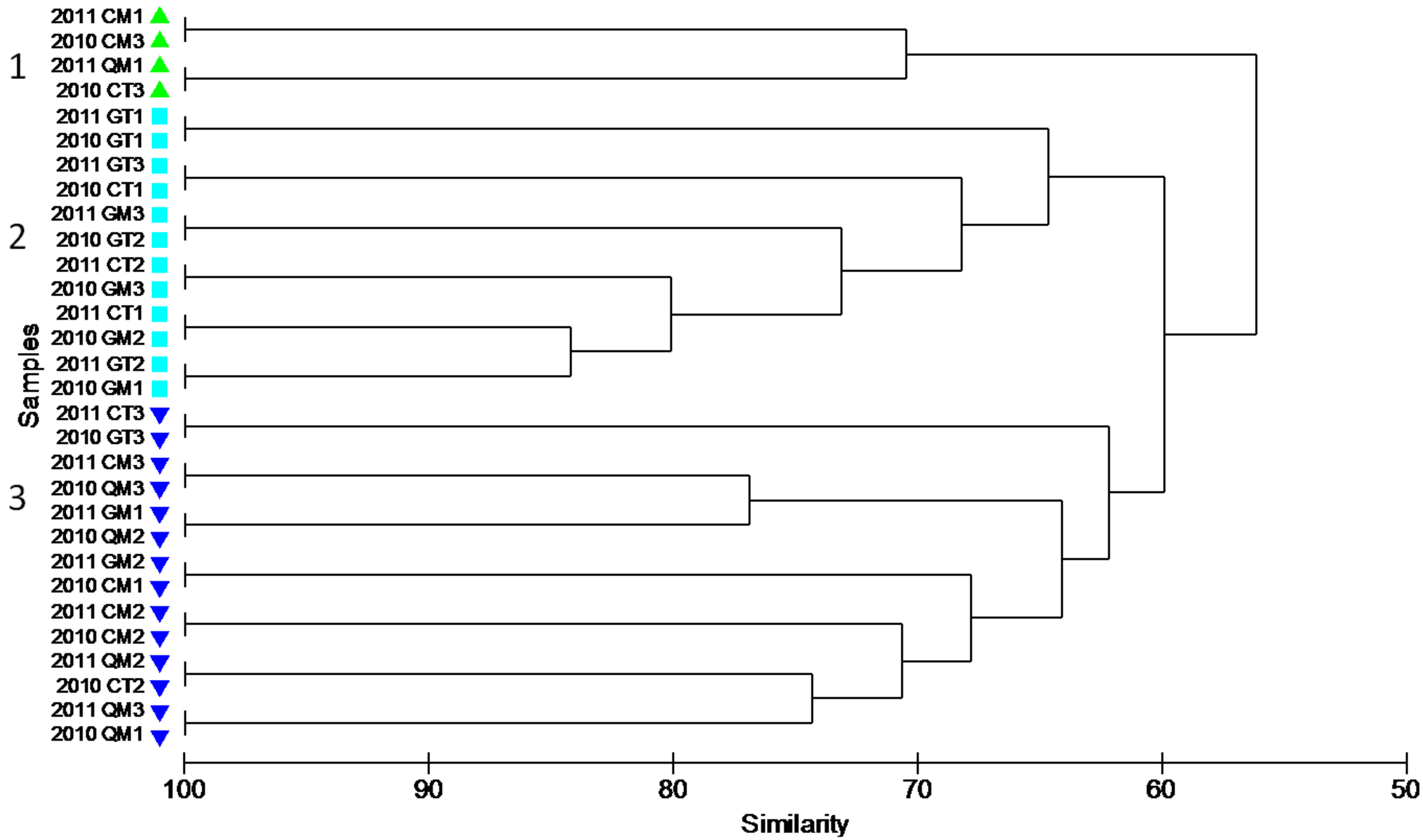

Figure 6: Similarity between macroinvertebrate samples collected in autumn 2010 and 2011 for the below dams assessment program. Similarity based on macroinvertebrate relative abundance data.

Table 16: Results of ANOSIM tests based on macroinvertebrate community structure groups defined in the cluster analysis based on abundance data. (R = ANOSIM test statistic).

Groups	R	P-value
1 and 2	0.96	0.001
1 and 3	0.60	0.001
2 and 3	0.67	0.001

Table 17: 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	Contribution percentage	Cumulative percentage
Group 1	Simuliidae	5	2.66	18.04	18.04
	Orthocladiinae	4	1.93	12.74	30.78
	Chironominae	3	1.89	12.04	42.82
	Baetidae	5	1.65	9.34	52.16
	Caenidae	4	1.17	7.5	59.66
	Hydropsychidae	6	1.21	7.28	66.94
	Hydroptilidae	4	0.96	6	72.94
Group 2	Gripopterygidae	8	1.84	7.42	7.42
	Chironominae	3	1.69	6.95	14.38
	Leptophlebiidae	8	1.87	6.91	21.28
	Caenidae	4	1.5	5.83	27.11
	Elmidae	7	1.43	5.66	32.77
	Hydropsychidae	6	1.48	5.63	38.4
	Acarina	6	1.28	5.53	43.93
	Conoesucidae	7	1.33	5.44	49.36
	Orthocladiinae	4	1.25	4.99	54.35
	Psephenidae	6	0.99	4.14	58.49
	Oligochaeta	2	1.2	4.08	62.57
	Tipulidae	5	0.96	3.9	66.47
	Baetidae	5	1.28	3.81	70.28
Group 3	Chironominae	3	1.94	11.19	11.19
	Orthocladiinae	4	1.65	9.05	20.25
	Acarina	6	1.5	8.39	28.64
	Hydropsychidae	6	1.52	7.92	36.56
	Oligochaeta	2	*1.5*	6.77	43.33
	Gripopterygidae	8	1.47	6.02	49.35
	Baetidae	5	1.2	5.92	55.27
	Caenidae	4	1.34	5.48	60.74
	Leptophlebiidae	8	1.12	4.57	65.31
	Empididae	5	1.03	4.43	69.74

Table 18: 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*	
Gripopterygidae	8	0	1.84	5.69
Simuliidae	5	2.66	1.19	2.29
Conoesucidae	7	0	1.33	4.99
Leptophlebiidae	8	0.69	1.87	1.56
Elmidae	7	0.42	1.43	1.97
Psephenidae	6	0	0.99	7.08
Leptoceridae	6	0	0.93	1.9
Aphroteniinae	8	0	0.91	2.08
Ecnomidae	4	0.87	0	18.85
Glossosomatidae	9	0	0.82	1.84
Orthocladiinae	4	1.93	1.25	2.86
Tanypodinae	4	0.38	0.88	1.45
Hydroptilidae	4	0.96	0.78	1.43
Hydropsychidae	6	1.21	1.48	1.58
Acarina	6	0.87	1.28	4.61
		Group 1	*Group 3*	
Simuliidae	5	2.66	1.1	1.89
Gripopterygidae	8	0	1.47	1.83
Oligochaeta	2	0.67	1.5	1.4
Ecnomidae	4	0.87	0.93	6.28
Philopotamidae	8	0.92	0.37	2.67
Empididae	5	0.38	1.03	1.59
Tanypodinae	4	0.38	0.96	1.45
Acarina	6	0.87	1.5	3.91
Caenidae	4	1.17	1.34	1.72
Baetidae	5	1.65	1.2	1.49
		Group 3	*Group 2*	
Psephenidae	6	0	0.99	7.07
Tipulidae	5	0	0.96	5.8
Conoesucidae	7	0.8	1.33	1.87
Aphroteniinae	8	0.12	0.91	1.8
Empididae	5	1.03	0.3	1.57
Glossosomatidae	9	0	0.82	1.86
Baetidae	5	1.2	1.28	1.42
Orthocladiinae	4	1.65	1.25	1.64

Discussion

Physical and chemical water quality characteristics

The increased stream flow in the Cotter, Queanbeyan and Goodradigbee River catchments from above average rainfall and flooding in spring/summer 2010/11 has resulted in changes in dissolved oxygen, turbidity levels and nutrient concentrations (Fig. 2, Tables 8 and 9). Dissolved oxygen concentrations have increased at all sites since autumn 2010 and dissolved oxygen concentrations at below dam sites are now equivalent to reference sites (Table 8). Elevated nutrient concentrations below Cotter and Googong Dams are the likely result of water carrying increased sediment load from runoff in the surrounding catchment (Table 9). High turbidity levels downstream of Cotter Dam (just below the 10 NTU trigger value) and Googong dam (>10 NTU trigger value) are further evidence of increased sediment loads at both sites.

Periphyton and algae

Filamentous algae cover below dams on the Cotter and Queanbeyan River has remained within the ACT guidelines' ecological objective of <20% cover and similar to reference sites on the Goodradigbee River following the recent flooding. A recent desk-top analysis (Eco Evidence analysis) on the effect of the floods on the condition of the Cotter and Queanbeyan Rivers concluded that algal (periphyton and filamentous) biomass is likely to decrease at below dams sites and be similar to reference sites following the flooding (Harrison et al. 2011). This predicted decrease in biomass has occurred at the Cotter and Queanbeyan River below dam sites following the flood, with a significant decrease in AFDM occurring from autumn 2010 to 2011 and the majority of AFDM measurements are now similar to those from the Goodradigbee River reference sites (Table 10, Fig. 3). Following the flooding and the decrease in biomass, the periphyton in the Cotter and Queanbeyan Rivers is now actively growing and most likely being replaced with fresh diatom assemblages (indicated by the presence of very little filamentous algae and a significant increase in Chlorophyll-a concentrations relative to decreased biomass, and also compared with autumn 2010). Periphyton dominated by diatoms represents a more favourable macroinvertebrate food source than filamentous algae (Table 11, Fig. 4).

Benthic macroinvertebrates

In autumn 2011 all macroinvertebrate communities at sites below dams remained within the same AUSRIVAS O/E score bands as autumn 2010 (Table 13). Only macroinvertebrate communities below Bendora and Googong Dams were within the ecological objective of an AUSRIVAS band A O/E score (Table 13). However, the O/E score for the site below Bendora Dam, moved further from reference compared to autumn 2010, which may be a consequence of the flooding events in spring/summer 2010/11 (Table 13, Fig. 2). Site QM3 (2km downstream of Googong Dam) was significantly impaired (as on previous occasions) and had even less of the expected taxa than it did in autumn 2010 (Table 12). The decreased O/E score at site QM3 is likely the result of the recent flooding (Fig. 2) and elevated sediment deposition/turbidity observed at the site when sampling occurred (Table 8). However, it should be noted that two of taxa that were expected to occur, but missing, were collected in the sample scan for QM3 (Gomphidae and Leptophlebiidae) (Tables 11 and 12), indicating that these taxa are present but in lower numbers that reduce their likelihood of being detected in a random subsample. Their presence indicates the site's potential to reach reference condition under favourable conditions.

In addition to lower than expected O/E scores, sites below dams in autumn 2011, were characterised by low relative abundances of sensitive macroinvertebrate taxa (SIGNAL 2 grades ≥7) high relative abundances of disturbance tolerant and early colonising taxa (Tables 12, 17 and 18). For example, site CM1 downstream of Corin Dam had a high relative abundance of Simulidae (which attaches to clean rocks in flowing water), because flows at the site prior to sampling were still equivalent to small floods (150-200 ML d^{-1}), which keep the rocks free of sediment accumulation (Fig. 2, Tables 12, 17 and 18). Other disturbance tolerant taxa in high abundance at below dam sites included Oligochaeta, Caenidae, Baetidae, Orthocladiinae and Chironominae (Tables 12, 17 and 18). Often, the early colonizing assemblage that establishes after flooding includes a high proportion of suspension feeders (e.g. Simuliidae) and deposition feeders (e.g. Chironomidae subfamilies: Chironominae and Orthocladiinae) (Lepori and Malmqvist, 2007). Taxa such as Oligochaeta and Baetidae are also considered to be tolerant to the effects of flood disturbances (Rader et al., 2008). Therefore, the high abundance of early colonizing taxa and taxa tolerant of flood disturbance downstream of the dams on the Cotter and Queanbeyan Rivers in autumn 2011 is likely the result of high velocity flows that occurred prior to sampling.

The biological condition of some of the Goodradigbee River/tributary reference sites and Cotter tributary reference sites has changed in autumn 2011 after flooding of the sites in spring/summer 2010/11 (Table 13). The O/E score for all three Cotter tributary sites increased since autumn, indicating that the recent above average rainfall and increased stream flows has had a positive effect on the instream habitat and macroinvertebrate communities in these tributaries (Table 13). However, on the Goodradigbee River site GM2 the O/E score decreased in condition from autumn 2010 (Table 13). Also, in autumn 2011 sites GM1 and GM2 were more similar to below dam sites with greater relative abundance of deposition feeding taxa and flood tolerant taxa (Figure 6, Tables 17 and 18)(e.g. Oligochaeta, Baetidae, Orthocladiinae and Chironominae; for other examples see Lepori and Malmqvist, 2007; Rader et al., 2008). This may indicate that the macroinvertebrate communities at some reference sites were affected by the recent flood disturbance and had not yet recovered to the usual reference condition.

Antecedent conditions can play a strong role in structuring macroinvertebrate communities (Finn et al., 2009). In perennial streams, such as the Cotter and Queanbeyan Rivers, floods are generally considered to play the greatest abiotic role in structuring macroinvertebrate communities because drying is rare or absent in natural conditions (Finn et al., 2009). Artificial low flows (under the drought environmental flow releases in the years previous to flooding) may have imposed a strong control in structuring assemblages. Therefore, possibly explaining why the predicted changes (as described in Harrison et al. 2011) in macroinvertebrate community structure following the initial effects of flooding were not observed at all the autumn 2011 sites (e.g. the O/E scores at all sites below dams have not increased compared with autumn 2010: Table 13).

The absence of some taxa expected to occur at below dams sites (Table 14) may also be explained by seasonal nature of invertebrate recruitment (Marchant et al. 1984; Marchant, 1988). For example, as macroinvertebrate communities recover following a flood disturbance, the algal feeders are generally one of the taxonomic groups expected to colonise and displace the suspension or deposition feeders (Leopori and Malmqvist, 2007). Several algal scraping and grazing taxa were expected but not collected at below dam sites (Table 14, e.g. Griopopterygidae: CM3; Leptophebiidae: CM2, QM3; Elmidae: CM1, QM2, QM3; Glossomatidae: CM3). Given that periphyton in the Cotter and Queanbeyan Rivers is now actively growing and most likely being replaced with fresh diatom assemblages (Fig. 4) (a more favourable food source), algae scraping and grazing taxa expected but missing in autumn 2011 are more likely to be collected when population recruitment occurs in spring (Leopori and Malmqvist, 2007).

Conclusion

As a result of high flows during spring/summer 2010/11 in the Cotter and Queanbeyan Rivers periphyton biomass was similar to reference conditions and within the ecological objectives of <20% cover. The macroinvertebrate communities directly below Bendora and Googong Dams were also similar to reference condition (AUSRIVAS band A). However, macroinvertebrate communities at sites downstream of Corin Dam, Cotter Dam and 2km downstream of Googong Dam were significantly impaired (AUSRIVAS band B). Also, in terms of relative abundance the structure of these macroinvertebrate communities has remained similar to autumn 2010 below each of the dams on the Cotter and Queanbeyan Rivers, indicating low abundances (compared to pre-flood samples from reference sites) of sensitive taxa (i.e. those with SIGNAL 2 grades ≥7). The recovery of macroinvertebrates in terms of taxa richness (and thus the O/E score) and the relative abundance of sensitive taxa downstream of dams on the Cotter and Queanbeyan Rivers may be influenced by the low drought flow conditions that occurred before the flooding event (meaning the communities may take longer to recover if already in a degraded condition). Following flooding, flows in the Cotter and Queanbeyan Rivers have been greater than the release requirements under the environmental flow guidelines, which is providing the rivers downstream with good flows (~100-500 MLd^{-1}). Therefore, further macroinvertebrate community recovery is likely following macroinvertebrate recruitment in spring.

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