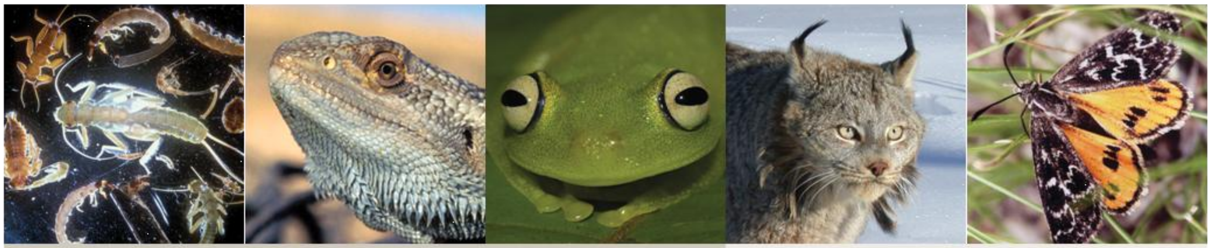

Biological response to floods downstream of Corin, Bendora, Cotter and Googong Dams

Spring 2010

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Front Photograph: Googong Dam spilling, December 2010 (S. Nichols)

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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.

- In spring/summer 2010/11 major flooding prevented field sampling at the majority of the assessment sites usually sampled in spring and autumn. The effects of flooding on aquatic biota below Corin, Bendora, Cotter, and Googong Dams is largely unknown given few major floods have affected these river sections since their regulation. This report presents the results from four sites that were sampled in January 2011 (CM1, CT1, QM2, QM3). The report also uses Eco Evidence analysis (Nichols et al. 2011) to review the scientific literature to provide more confidence in establishing effects of flooding in the Cotter and Queanbeyan River systems. This includes the effects on the macroinvertebrate and algal communities (periphyton and filamentous) and whether higher flow events initiate an improvement of habitat closer to the reference conditions in the nearby unregulated Goodradigbee River.

- Compared to autumn 2010 sampling there was an increase in nutrient levels at the four sampled sites. This is associated with major runoff in these catchments and it is likely that the associated effects have not been observed as a biological response in this sampling event. A decrease in periphyton growth downstream of Googong Dam and a decrease in macroinvertebrate abundance and taxa richness at all four sites compared to autumn 2010 sampling results confirms that these effects have not yet been observed.

- Effects of high flows were observed at sites below Googong Dam. Decreased concentrations of periphyton, AFDM and chlorophyll-a were observed at site QM2. This is likely associated with the disturbance of stream bed and detachment of periphyton during high flows. Simulidae (an early colonizer) dominated the macroinvertebrate community at the two sites sampled downstream of Googong Dam suggesting that the community is undergoing recovery following the disturbance.

- Eco Evidence analysis suggested that the floods affecting the catchments will result in an initial decrease in macroinvertebrate abundance and taxa richness, a change in macroinvertebrate assemblage structure, and decreased algal biomass. These changes should also be observed in reference sites. Following these high flows, the analysis suggested that there will be a period of recovery of macroinvertebrate taxa richness or a trajectory towards reference sites at regulated sites. These responses at reference sites and some regulated sites could not be confirmed by field sampling because the sites could not be sampled.

- Given the findings of the scientific literature reviewed and results of the Eco Evidence analysis the recent flooding in the Cotter and Queanbeyan River systems is likely to have a positive effect on macroinvertebrate and algal communities and potentially make these communities more similar to reference conditions of the nearby unregulated Goodradigbee River. Furthermore, the effects of recent floods may contribute to ecological resilience in the Cotter and Queanbeyan River systems to better cope with the effects of regulated flows in the short term by increasing available habitat space and available food sources for macroinvertebrates such as diatoms.

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 score (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.

In spring/summer 2010/11 major flooding and high water levels in the rivers prevented field sampling at the majority of the regular sampling sites. Flooding disturbances are drivers of productivity, and biotic diversity and composition patterns in river ecosystems (Cardinale *et al.,* 2005). Floods may be more significant for altered aquatic communities of regulated rivers, which may have adjusted to accommodate a stable, and reduced flow regime compared to natural conditions (Poff and Allan, 1995, Armitage, 1976). Effects of flooding on aquatic biota downstream of Corin, Bendora, Cotter, and Googong Dams is largely unknown given that few major floods have affected these river sections in recent years. Of most interest is how flooding will result in changes in macroinvertebrate assemblages and periphyton downstream of each of the dams because these are the selected indicators of river health in the environmental flow objectives. This report presents the results from four sites that were accessible and sampled in January 2011. Eco Evidence analysis (see page 16) was used to systematically review the scientific literature to provide more confidence regarding the inferences about the effects of flooding in the Cotter and Queanbeyan River systems. This included the expected effects on the macroinvertebrate and algal communities (periphyton and filamentous) and if the subsequent effects of flooding is likely to bring the habitats closer to the reference conditions in the nearby unregulated Goodradigbee River. The Eco Evidence analysis will assist with the interpretations of the limited field data collected during the floods and period of high flows of the Cotter and Queanbeyan Rivers.

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, 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 a number of variables including reservoir levels, 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 relied on for supply. A gravity main supplies water from Bendora Dam to Stromlo Water Treatment Plant, where water is treated prior to distribution to the cities of Canberra and Queanbeyan. Overall, minimal releases occur to the river except for designated environmental flow purposes. 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 without many of the confounding 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.

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 stream order river constitutes an appropriate reference site for the Cotter River because it is has similar environmental characteristics (cobble substrate and chemistry) but is largely unregulated (Norris and Nichols 2011).

Site selection and sampling period

Fifteen sites are usually sampled for macroinvertebrates and physicochemical water quality variables, but flooding resulted in access to only four sites in January 2011 (the earliest possible time these sites could be accessed (Fig. 1; Table 1; Table 2). Only one of the three sites on the Cotter River (CM1, CM2, CM3), and one of the three Cotter River tributary sites (CT1, CT2, CT3) were sampled. No sites on the unregulated Goodradigbee River (GM1, GM2, GM3) and three of its tributaries (GT1, GT2, GT3) were sampled. The two sites downstream of Googong

Dam on the Queanbeyan River (QM2, QM3) were sampled but not the one upstream of Googong Dam (QM1). The inclusion of the unregulated main channel and tributary sites were used to enable 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).

Table 1: Cotter, Goodradigbee and Queanbeyan River sites sampled for the below dams assessment program, January 2011.

Site Code	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500 m downstream of Corin Dam	900	31	4
CT1	Kangaroo Ck	50 m downstream Corin Road crossing	900	7.3	3
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	96	5

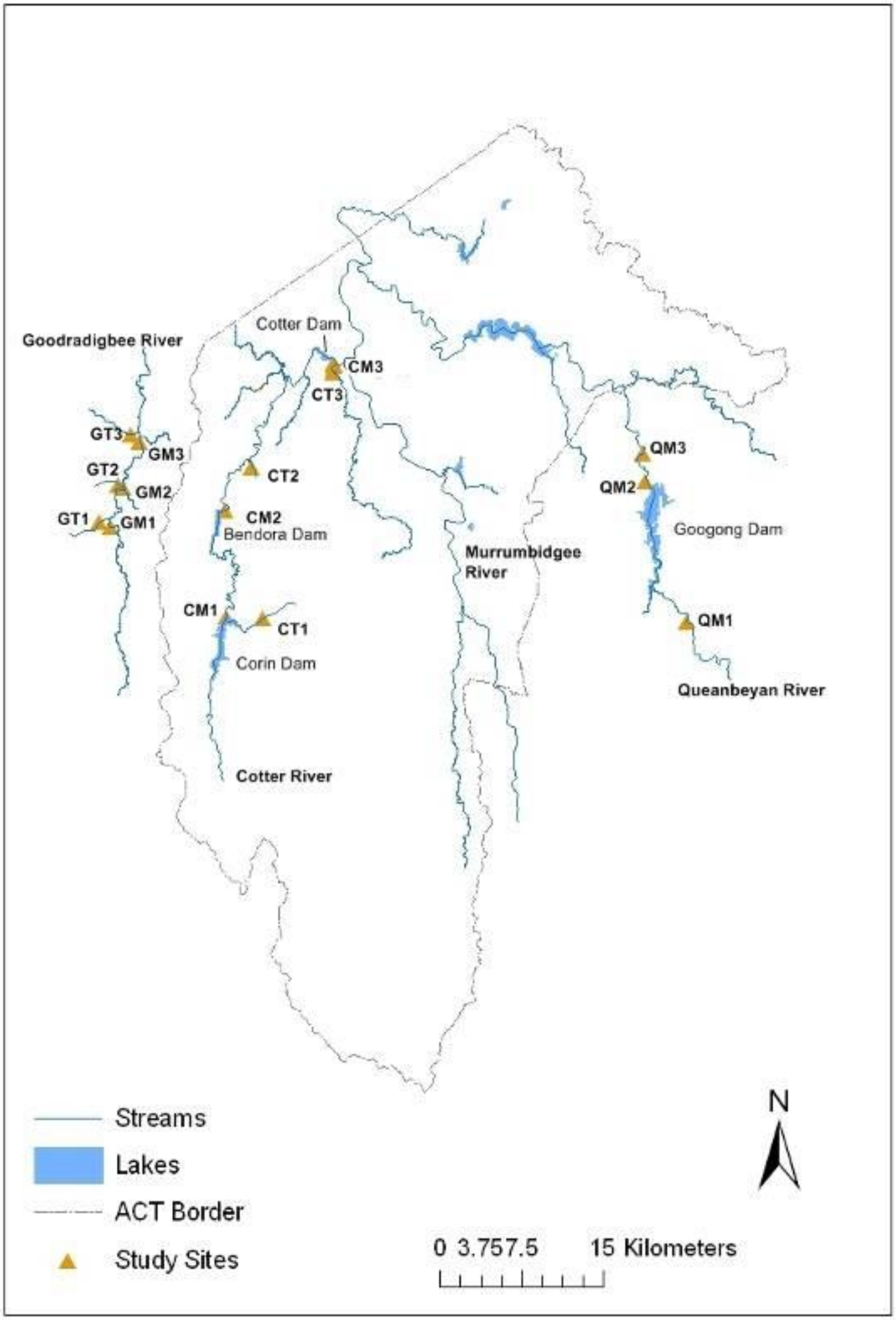

Figure 1: The location of sites usually sampled on the Cotter, Goodradigbee and Queanbeyan River's and tributaries for the 'Below Dams Assessment Program'.

Table 2: Sampling dates and times for each site sampled in January 2011.

Site	Sampling date	Sampling time
CM1	11/1/2011	11:30
CT1	11/1/2011	12:30
QM2	11/1/2011	14:00
QM3	11/1/2011	15:00

Hydrometric data

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/). Both rainfall and flow data covered the sampling period, ranging from the 20th August 2010 to the 30th January 2011.

Sampling sites

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.

Physical and chemical water quality assessment and guidelines

Water temperature (^{o}C), dissolved oxygen (as %DO and mg L^{-1}), pH, conductivity (EC, µS cm^{-1}) and turbidity (NTU) 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 total nitrogen (TN), total phosphorus (TP) concentrations, ammonia (NH_3) and nitrate/nitrite (NO_X) 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 from the ANZECC and ARMCANZ (2000) guidelines were used for comparison of water quality conditions compared to a baseline reference. Specifically, the guidelines used were those for an upland river system in south-east Australia, which includes the ACT (Table 3). While comparisons with the guidelines are not required as part of the environmental flow guidelines, and should be used only as a guide, the guidelines are a useful tool for the protection of ecosystems, which is a primary objective of environmental flows.

Table 3: Water quality trigger values for aquatics ecosystems in upland rivers in south-east Australia (from 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}	30 - 350
pH	N/A	6.5-8
Dissolved Oxygen	mg L^{-1}	<6
Turbidity	NTU	2.0 - 25
Ammonia	mg L^{-1}	N/A* detection limit of assay = 0.01
Nitrate/Nitrite	mg L^{-1}	<0.015
Total Phosphorus	mg L^{-1}	<0.02
Total Nitrogen	mg L^{-1}	<0.25

Ash-free dry mass and chlorophyll-a

One (QM2) out of the four below dam sites (CM1, CM2, CM3 and QM2) was sampled because of the high flows. At this site, twelve individual rocks, selected at random, were scrubbed for periphyton. These samples were obtained using a syringe sampler based on two 60 ml syringes and the scrubbing surface of nylon bristles that brushed an area of 637 mm^2, similar to that described by Loeb (1981). The twelve samples were separated into two groups of six. One set of six was used to obtain a measure of Ash Free Dry Mass (AFDM), being dried in an oven at 45 ^{o}C for 2 hours, weighed, then ashed in a furnace at 500 ^{o}C for one hour and reweighed. The other samples were used to obtain a measure of chlorophyll-a using 90% ethanol, and measured in a spectrophotometer (Franson 1985).

Macroinvertebrates

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.

Benthic macroinvertebrates were sampled from the riffle habitat using a 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/AUSRIVAS).

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. 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.

SIGNAL grades

To aid the interpretation of results, habitat disturbance and pollution sensitivity (SIGNAL) grades for macroinvertebrate taxa commonly predicted with ≥50% chance of occurrence are provided (Table 4). Grades range from 1 to 10, with sensitive taxa receiving high scores and tolerant taxa low scores. The sensitivity grades are based on taxa tolerance to common pollution types (Chessman 1995). Several changes have been made to the original SIGNAL grade numbers to better reflect the pollution sensitivities of different families. These new grade numbers are referred to as the SIGNAL two, grade numbers.

Macroinvertebrate Predictive models - AUSRIVAS (AUStralian RIVer Assessment System)

The AUSRIVAS predictive model could not be used to analyse the macroinvertebrate data collected in the January 2011, because models are only available for data collected during autumn and spring.

Table 4: Habitat disturbance and pollution sensitivity (SIGNAL) 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 in periphyton AFDM and chlorophyll-a at site QM2 between autumn 2010 sampling and January 2011 sampling were tested using a Students T-test (SAS 9.1). A log10(x+1) transformation was applied to both the AFDM and chlorophyll-a data, before undertaking the test, to ensure data met the assumption of normality.

Literature review methods

Eco Evidence analysis

Evidence for cause-effect relationships from various sources can collectively build a strong case to infer cause-effect associations by using a 'causal criteria' method commonly applied in epidemiology (Beyers, 1998, Weed and Gorelic, 1996, Hill, 1965). Causal criteria such as 'Consistency of association', 'Temporality' and others were used to assemble evidence in a 1964 report to the US Surgeon General on the health effects of smoking and used to establish the causal link between smoking and lung cancer (USDHEW, 1964). The causal criteria approach was developed and applied in epidemiology because experimental data was often limited, weakening the ability to draw inferences about causality (Haynes *et al.,* 2006, Susser, 1991, Hill, 1965). Ecology experiences similar difficulties where investigations are often carried out in situations where it is difficult to draw strong causal inferences because of the limited opportunity for manipulations, replication and randomization of treatments (Norris *et al.,* 2005). The Eco Evidence analysis method employs causal criteria specifically adapted for environmental science (Norris *et al.,* Submitted; Norris *et al.,* 2005; Nichols et al. 2011) (Table 5). Eco Evidence is used to systematically review the scientific literature to provide a transparent assessment of the level of support for specific causal hypotheses (Nichols et al, 2011; Norris *et al.,* Submitted). The application of causal criteria analysis in ecology is not widely applied (see Downes *et al.,* 2002, Beyers, 1998, Norris *et al.,* 2005) most likely because it has previously lacked a standardised method for its application, which is now offered by Eco Evidence . The Eco Evidence method is supported by a freely-available software package, which assists and guides the application of the method (eWater CRC, 2010).

Eco-Evidence analysis is an 8-step process to guide the extraction, weighting, synthesis and analysis of the causal evidence (Fig. 2). The results of the analysis specify the level of support for or against specific causal hypotheses, and also identifies knowledge gaps where there is insufficient evidence to reach a confident conclusion.

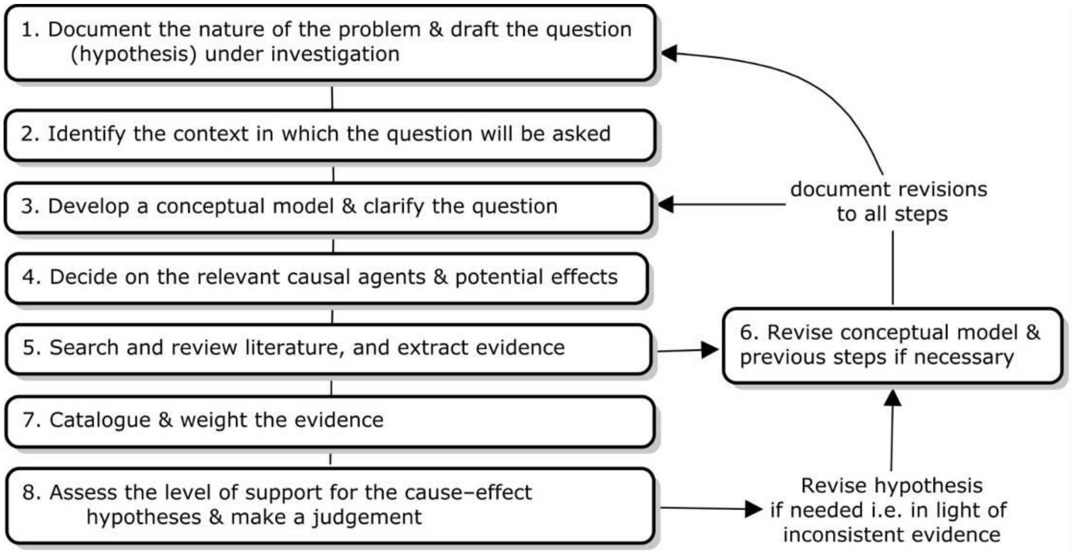

Figure 2: Steps involved in Eco-Evidence Analysis (Nichols *et al,* 2011).

Table 5: Causal criteria included in the eight-step Eco Evidence framework for application in environmental sciences (adapted from Norris *et al.,* Submitted, and Nichols *et al.,* 2011).

Causal Criterion	Definition	Description
Plausibility	A plausible mechanism (e.g. biochemical reaction) that could explain the relationship between the causal agent and the potential effect.	This is addressed by the conceptual model. A plausible conceptual model is a necessary step for any further analysis, because it sets the bounds of the literature review, clearly displaying the causal relationships considered.
Evidence of Response	The study reports an association between the causal agent and potential effect.	This includes the various study designs used in environmental science, to which we have assigned different weights (see Table 6). Studies are most easily classified as contributing to this criterion when there is a statistically significant difference among treatment levels.
Dose–Response*	The association between causal agent and potential effect is in the form of a dose–response curve.	This would normally be a monotonic relationship.
Consistency of Association	The potential effect occurs in the presence of the causal agent in all or almost all of the studies.	Because of the frequent confounding and low statistical power often found with environmental studies, the presence of small numbers of non-significant or even contrary results does not necessarily indicate a lack of consistency (which is why the method incorporates criterion thresholds and does not require that the effect is *always* seen in the presence of the cause).
Evidence of Stressor in Biota	This would include evidence of a chemical residue within an organism of interest.	Within the Eco Evidence framework this evidence should be reported but is not used in the weighting process. If present, this evidence may provide further support and strengthen confidence in the conclusion. Not considered relevant to this study as the focus was on the physical and habitat-removal effects of fine-sediment addition.
Agreement Among Hypotheses	When the results for the individual cause–effect hypotheses are considered collectively, do they support or refute the high-level question developed at Step 1?	This is a 'meta-criterion'. The final conclusion is always a matter of judgment by the user. It requires collective consideration of all the evidence for each hypothesized cause–effect relationship.

* Dose–Response is a subset of Evidence of Response. In summing study weights to assess support for a hypothesis, the study weight for a Dose–Response evidence item will also contribute to the summed study weight for Evidence of Response.

Steps 1-4

The first 4 steps in the analysis considered and documented the nature of the problem under investigation, identified the context in which the question was asked (see Introduction section of this report) and developed a conceptual model to identify the quantifiable cause/s and quantifiable effect/s for investigation.

The overall aim of this Eco Evidence review was to determine if an increase in stream flow downstream of Cotter and Queanbeyan River dams (as a result of the dams spilling) over several months would result in changes to indicators of river health. The indicators of river health were defined as algae (periphyton and filamentous algae) and macroinvertebrates.

The quantifiable cause in this case was ‘over bankfull flooding’ (see the conceptual model Fig. 3).

The hypothesized quantifiable effects were separated into four categories:

- macroinvertebrate abundance,
- macroinvertebrate taxa richness,
- macroinvertebrate assemblage, and
- algae (periphyton and filamentous).

The increased volume of water (compared to low flow) during a flood event is hypothesized to result in stream bed substrate movement, and in changes to algal biomass and macroinvertebrate community composition (Fig. 3).

The specific questions addressed by this literature review in relation to flooding downstream of the dams are:

- Is there an initial decrease in macroinvertebrate abundance?
- Is there an initial decrease in macroinvertebrate taxa richness?
- Is there a change in macroinvertebrate assemblage structure?
- Will algal biomass decrease to similar to reference condition after the flood (periphyton and filamentous)?
- Will macroinvertebrate taxa richness be similar to reference condition or show a trajectory towards reference condition after the flood?
- Are there benefits to the aquatic ecosystems from periodic flooding events and high flows?

A ‘high flow event’ is defined as an over-bankfull flood;
‘An initial’ period defined as a period of < 3 weeks after a high flow event; and
‘Reference condition’ is defined as the nearby unregulated Goodradigbee River.

Steps 5 and 6: Search and review the literature, and extract evidence

ISI Web of Knowledge and SCOPUS databases were searched for relevant literature using the keywords “flow”, “invertebrate” or “macroinvertebrate”, “periphyton”, “algae” and then “flood”, “high flow”, and “dam” (“filamentous” was used for algae advanced searches). The reference lists of relevant literature were also searched. Only literature assessing flood or high flow effects on macroinvertebrate or periphyton assemblages in freshwater rivers were used in the analysis. The previous unpublished studies conducted on the Cotter and Queanbeyan River when dams spilled (January 2011 sampling in this report; Deschaseaux and Norris, 2009; White and Norris, 2008) were also included in the Eco Evidence analysis.

Evidence was extracted from relevant studies to fulfil a set of ‘causal criteria’ that included ‘Evidence of response’, ‘Dose-response’ and ‘Consistency of association’. The extracted information from each study constitutes an ‘evidence item’ and includes information on study design and replication, which is then used to weight the evidence at Step 7. Each evidence item is constructed by answering and recorded the following checklist of questions:

	Checklist question	Answer / action
a.	Is the study relevant to the cause-effect hypotheses posed in Step 1?	Yes or No If ‘Yes’, the justification for why it was relevant was documented. If ‘No’, then the reasons were recorded and that study was excluded from the analysis.
b.	What type of study-design was used?	A study-design type was selected from a predefined list and weighted accordingly (see weights in Table 6).
c.	How many independent reference/control and treatment locations were used in the study?	This information was then assigned to one of three categories and weighted accordingly (Table 6).
d.	Was the reported response consistent with the Eco Evidence hypothesis?	Yes, No, the response is inconsistent, or No, there was no response. When the answer was ‘No’ for a relevant study, the information was used to build a case for lack of consistency.
e.	Is there a dose–response relationship? This question could be answered when a response was indicated.	Yes, No, or Not applicable. (The ‘Not-applicable’ option is for studies that have not investigated a dose–response.)
f.	Is there evidence of the causal agent in the organism of interest (such as a body burden of heavy metals)?	Obviously not applicable to all studies (and not used in this review) but if present and applicable this criterion can provide added confidence.
g.	Was a p-value reported?	Yes or No If ‘No’, were the results obvious (like a mass extinction)? If no data analysis was performed (and the results were not explained as obvious) then the study was not included in the Eco Evidence analysis. Likewise, only the results of primary research literature were included in the analysis.

Step 7: Cataloguing and weight the evidence

The Eco Evidence analysis method uses 3 study-design features to weight the evidence from a study and to provide an overall study weight for each piece of evidence. They are:

1) The type of study design;
2) The number of independent sampling-units used as controls/reference locations; and
3) the number of independent sampling-units (i.e. impact locations) used to investigate the effects of fine-sediment addition.

The overall study-weight was obtained by adding the weighting values from each of the three study features (Norris *et al.,* Submitted, Nichols *et al.,* 2011) (Table 6).

In weighting the studies, the method adopts the philosophy that studies which account better for environmental variability or error (e.g. BACI designs), should carry more weight in the overall analysis than those with less robust designs (Norris, *et al.,* 2005; Nichols *et al.,* 2011). The inclusion of independent control or reference locations improves inferential power, as does the provision of data from before the hypothesized disturbance, or a gradient-based study design to quantify relationships between hypothesized cause and effect (see Downes *et al.,* 2002). Studies with several replicate locations add more weight by providing an estimate of variability around 'normal' conditions. This means that any difference detected between treatment and control is more likely to have been caused by the treatment (Downes *et al.,* 2002).

For the 'Evidence of response' criterion, the study-weights of all evidence items in favour of the hypothesis are summed. Similarly, for 'Dose response', the study-weights of all evidence items that show a dose-response relationship are summed. For Consistency of association, the study-weights of all evidence items that do not support the hypothesis (i.e. no evidence of a response even though the flooding was present or a response in the opposite direction to that hypothesized) are summed and contribute to build a case for lack of consistency. Dose-response is a subset of the Evidence-of-response criterion. In summing study-weights to assess support for a hypothesis, the study-weight for a Dose-response evidence item will contribute to the summed study-weight for Evidence of response. Dose-response is identified (although not counted as a separate criterion) because of the added confidence a dose-response could imply.

Step 8: Make a judgement (accept or reject the hypothesis)

A high level of support from evidence for either, or both, the 'Response' and the 'Dose-response' causal criteria demonstrate an association between a cause and effect when the summed value of all weighted studies reached ≥ 20 and the expected response was consistently observed in the presence of the particular causal agent of interest (i.e. the 'Consistency of association' criterion value < 20 for the sum of all weighted studies). We applied the 20-point thresholds suggested by the method, which developers adopted during the expert consultation process conducted during method development (Norris *et al.,* Submitted). The 20-point threshold means that as few as three very high-quality studies are sufficient to provide strong support for the presence (or absence) of a causal relationship. Conversely, seven or more low quality studies might be needed to reach the same conclusion.If three high-quality studies show the evidence is inconsistent then the hypothesized relationship is not supported (Norris *et al.,* 2005, Nichols *et al.,* 2011, Norris *et al.,* Submitted).The 20-point threshold is analogous to the convention of 0.05 as a 'significant' p-value, but like significance levels it should not be applied unthinkingly.

The final criterion of ‘Agreement among hypotheses’ is then applied. The individual cause–effect hypotheses are considered collectively, to assess whether they support or refute the initial question developed at Step 1.

Table 6: Weights applied to study design type, number of independent control locations, number of independent impact locations and number of locations for gradient based designs to calculate an overall weight for each study used in the Eco Evidence analysis (Nichols *et al.,* 2011).

Study design type	**Weight**
After impact only	1
Reference/Control vs impact no before	2
Before vs after no reference/control	2
Gradient response model	3
BACI or BARI MBACI or Beyond MBACI	4

Number of independent control locations	**Weight**
0	0
1	2
≥ 2	3

3. Number of independent impact locations	**Weight**
1	0
2	2
> 2	3

4. Number of locations for gradient-based designs	**Weight**
3	0
4	2
5	4
6	6

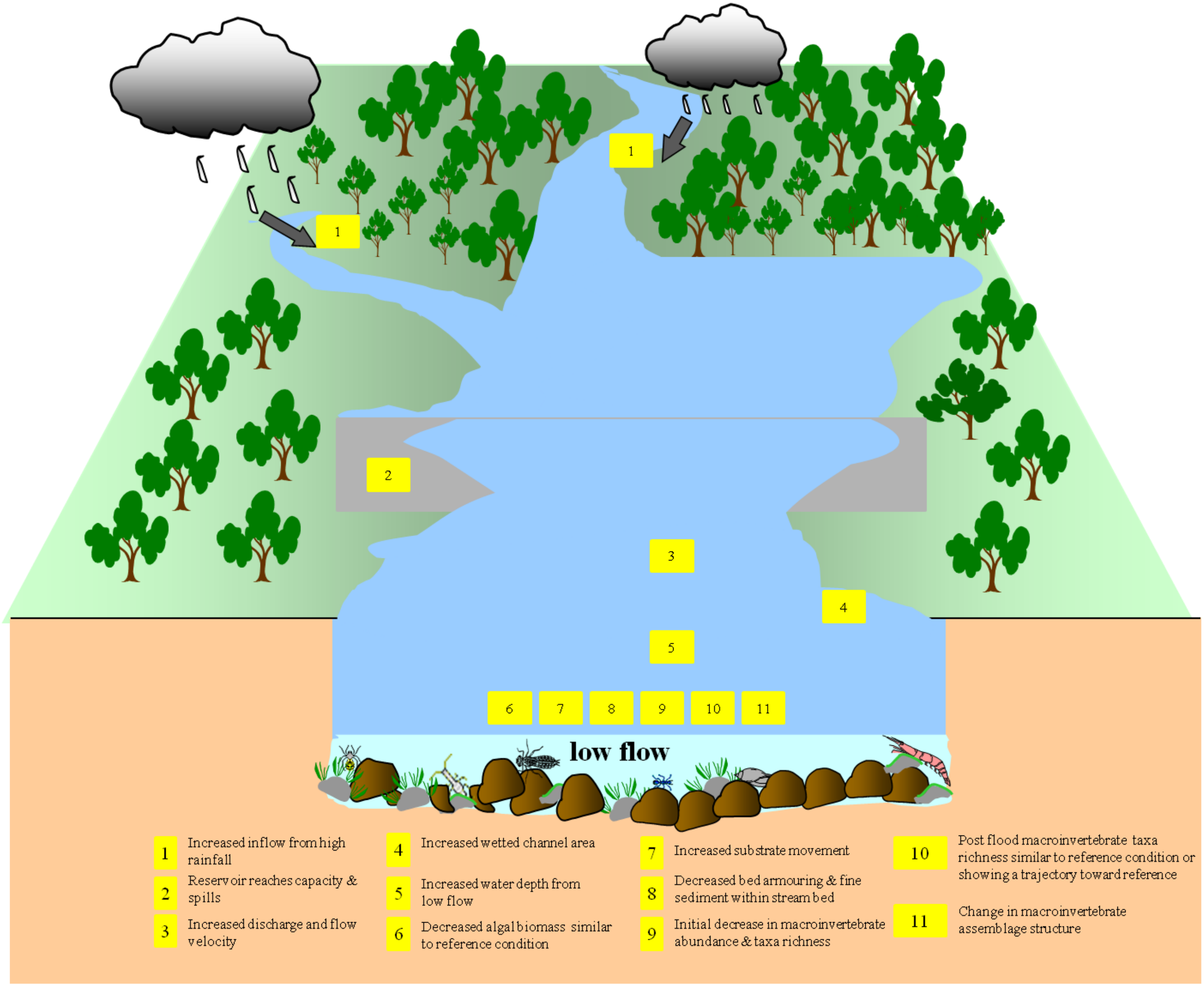

Figure 3: Conceptual model of flooding effects on indicators of river health (algae and macroinvertebrates) downstream of dams on the Cotter and Queanbeyan Rivers.

Field and Laboratory Results

Hydrometric data

Large rainfall events occurred frequently throughout spring and early summer 2010 including one that resulted in severe flooding of the Queanbeyan River after the high rainfall event of 87 mm on 3 December 2010 (Fig. 4). Between August and December 2010 total monthly rainfall was above the long-term monthly averages (1939 – 2010) at Canberra Airport (Table 7).This increased rainfall resulted in all reservoirs reaching capacity and spilling volumes of water equivalent to over bankfull flows in November and December which resembled flow peaks in the unregulated Goodradigbee River (Fig. 4). The flow peaks observed in Cotter and Queanbeyan Rivers were greater than the environmental flows released from Corin, Bendora Cotter and Googong Dams in autumn 2010 (Table 8). Flow peaks in the Goodradigbee River in spring and early summer 2010 (Fig. 4) were also greater than the Goodradigbee River average flow of 122 MLd-^{1} in autumn 2010 (data source: NSW Department of Water and Energy).

Table 7: Canberra long-term averages (1939-2010) and total rainfall and for August-December 2010. ***Data source: Bureau of Meteorology*****.**

Month	Long-term average (mm)	2010 total rainfall (mm)
August	48.2	66.2
September	52	63.8
October	65.4	102.8
November	64.4	119.4
December	53.8	198.4

‘

Table 8: 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}

Physical and chemical water quality characteristics

Electrical conductivity

Electrical conductivity of water at site CM1 was slightly outside the recommended ANZECC and ARMCANZ 2000 trigger value range for conductivity (30 - 350 µS cm^{-1}). However, it should be noted that conductivity readings below the lower trigger values will not have an effect on macroinvertebrate communities. All other sites sampled were within the recommended range (Table 9). Compared to autumn 2010 there was a decrease in conductivity at all sites sampled, and this is likely a result of the high flows (Table 9).

pH

The pH levels for water at all sites was within the recommended trigger values (6.5 – 8.0) at the time of sampling and similar to autumn 2010 (Table 9).

Dissolved oxygen

Dissolved oxygen content of the water was above recommended trigger value level of 6 mg L^{-1} at all sites and similar to autumn 2010 (Table 9).

Turbidity

All sites were within the trigger value range of 2 and 25 NTU at the time of sampling (Table 9. At sites QM2 and QM3 turbidity increased by more than 10 NTU since autumn 2010, and is associated with higher stream flows (Table 9).

Ammonia

Ammonia concentrations were below the method detection limit (<0.01 mg L^{-1}) for CM1 (decrease from autumn 2010) and CT1, but not QM2 and QM3 sites where concentrations increased to be above the detection limit (Table 10).

Nitrates/Nitrites

Site QM2 and QM3 were above the ANZECC trigger value for NO_x and concentrations increased from autumn 2010 (Table 10). While other sampled sites were below the trigger value (Table 10).

Total Phosphorus

Total phosphorus was above the ANZECC trigger value for QM2 and QM3 sites and concentrations were greater than autumn 2010 (Table 10).

Total Nitrogen

Total nitrogen was above the ANZECC trigger value at QM2 and QM3 sites but not other sampled sites (Table 10). At all sites total nitrogen concentrations were greater than autumn 2010 (Table 10).

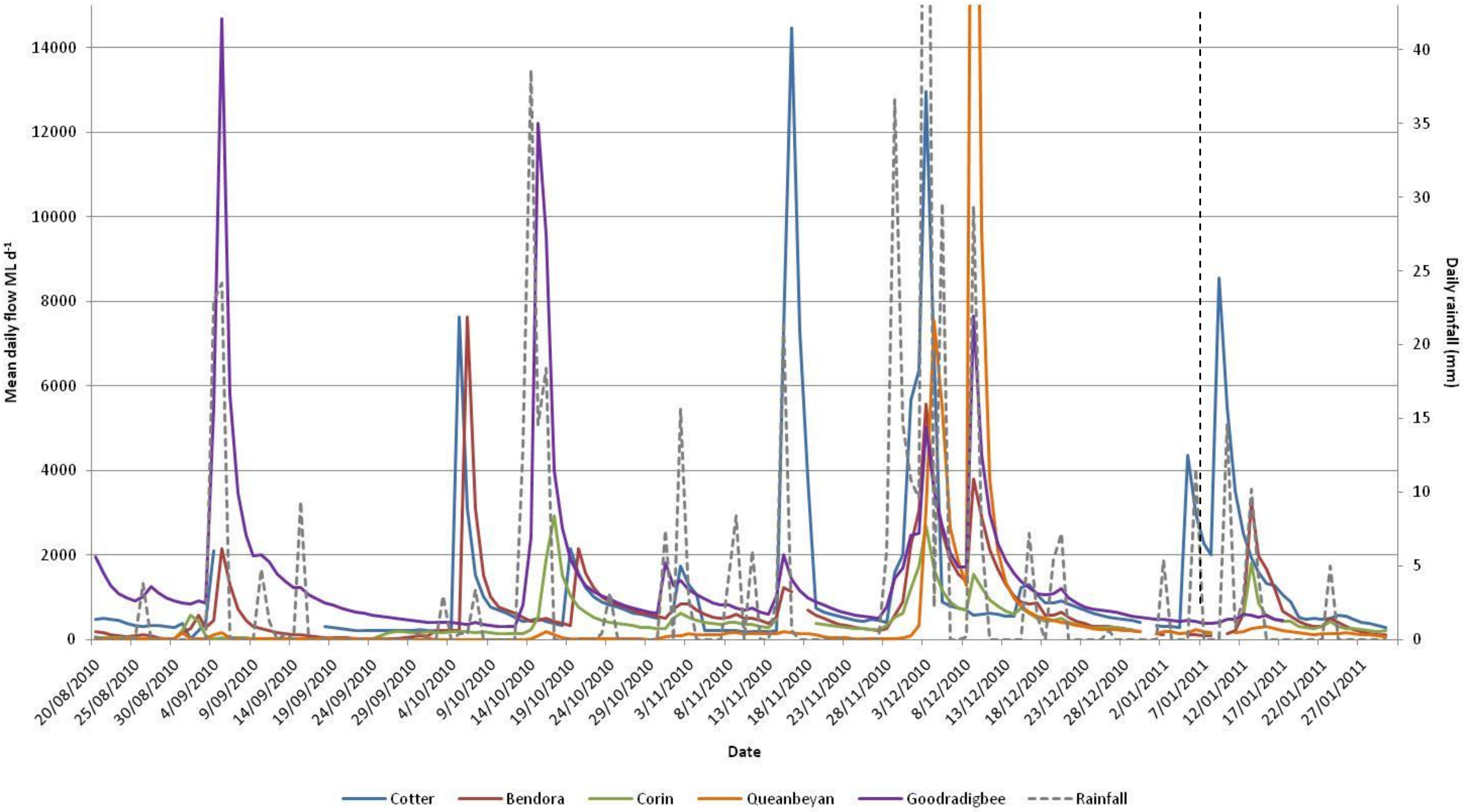

Figure 4: Mean daily flow of the Cotter, Goodradigbee and Queanbeyan Rivers: below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams, and Goodradigbee River (GM2); and daily rainfall data for Canberra between 20/8/2010 to 30/1/2011. ***(Note: Dotted arrows indicate sampling dates and a gap in the rainfall data is a result of missing data. The rainfall event of 87.6 mm on 3 December 2010 and resultant flow of 30648 ML d^{-1} in the Queanbeyan River on 9 December 2010 are not shown on scales chosen for this figure). Data source: ACTEWAGL and NSW Department of Water and Energy; Bureau of Meteorology.***

Table 9: Water quality characteristics of sampled sites in January 2011 and previously in autumn 2010. Shading indicates those sites with values not within the trigger value range for aquatic ecosystems in upland rivers in south eastern Australia (ANZECC/ARMCANZ 2000). N/A = trigger value not available.

Site	Alkalinity (mg L^{-1})		Water Temp (^{0}C)		Conductivity (µS cm^{-1})		pH		Dissolved Oxygen (mg L^{-1})		Turbidity (NTU)	
Trigger value	**N/A**		**N/A**		**30 – 350**		**6.5 - 8**		**<6**		**2.0 - 25**	
	January 2011	Autumn 2010	January 2011	Autumn 2010	January 2011	Autumn 2010	January 2011	Autumn 2010	January 2011	Autumn 2010	January 2011	Autumn 2010
CM1	18	10	20.34	16.20	21.4	30.2	7.1	7.02	9.19	8.97	3.6	1.0
CT1	18	30	16.23	9.61	33.8	54.4	7.13	7.18	9.47	10.12	4.3	9.2
QM2	45	62	21.82	16.28	88	135.6	7.72	7.69	8.74	9.13	15.1	1.0
QM3	39	78	22.26	14.08	94.8	221.0	7.64	7.63	8.1	8.45	11.3	1.0

Table 10: Total Phosphorus, Total Nitrogen, NH_3 and NO_X concentrations, January 2011 and previously in autumn 2010. Shading indicates those sites with values above the trigger value for aquatic ecosystems in upland rivers in south eastern Australia (ANZECC/ARMCANZ 2000) or above the detection limit of the assay for Ammonia. ** Indicates the detection limit for ammonia.* ***Trigger values for south eastern Australian upland aquatic ecosystems (ANZECC/ARMCANZ 2000).***

Site	**NH_3 (mg L^{-1})**		**NOx (mg L^{-1})**		**TP (mg L^{-1})**		**TN (mg L^{-1})**	
	Detection value		**Trigger value**					
	0.01**		**0.015***		**0.02***		**0.25***	
	January 2011	Autumn 2010	January 2011	Autumn 2010	January 2011	Autumn 2010	January 2011	Autumn 2010
CM1	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.20	0.17
CT1	<0.01	0.01	<0.01	<0.01	0.01	0.01	0.20	0.03
QM2	0.04	<0.01	0.06	<0.01	0.04	<0.01	1.21	0.42
QM3	0.06	<0.01	0.08	<0.01	0.04	<0.01	1.16	0.38

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

Mean AFDM and chlorophyll-a content of periphyton was measured at one site, QM2 below Googong Dam (Table 11). The AFDM and chlorophyll-a concentration of periphyton was less than autumn 2010, but not significantly less (Students T-Test $p > 0.05$) (Table 11). Visual observations of the percent cover of periphyton in both the riffle and reach habitats were greatest at site QM2, below Googong Dam compared to sites CM1 and QM3 (Table 12), which both had less than 10% periphyton cover of both the riffle and reach (Table 12). Filamentous algae cover was less than 10% at all sites (Table 12). The visual observations of periphyton and filamentous algae were similar to the results reported in autumn 2010 (see Harrison *et al.,* 2010).

Table 11: AFDM (mg m^{-2}) and chlorophyll-a (µg m^{-2}) at site QM2 (Googong) below dam site in January 2011 and autumn 2010. (Note: values represent mean ± standard error).

Site	Biomass (mg m^{-2})	Chl-A (µg m^{-2})
QM2 (January 2011)	7897.2 ± 1903.1	7254.9 ± 1552.6
QM2 (Autumn 2010)	55233.4 ± 23783.72	15368.6 ± 6245.9

Table 12: Percent cover categories of periphyton and filamentous algae observed in the riffle and reach at sampled sites, January 2011.

	% Cover of Riffle		% Cover of Reach	
SITE	**Periphyton**	**Filamentous Algae**	**Periphyton**	**Filamentous Algae**
CM1	<10	<10	<10	<10
QM2	10-35	<10	10-35	<10
QM3	<10	<10	<10	<10

Benthic macroinvertebrates

The relative abundance of Oligochaeta (SIGNAL score 2), Chironomidae (SIGNAL score 3) and other Diptera was greatest at sites QM2 and QM3 on the Queanbeyan River compared to CM1 (Cotter River) and CT1 (Kangaroo Creek) (Fig. 5). At sites QM2 and QM3 the high relative abundance of Diptera was predominantly Simuliidae (Table 13). The relative abundance of Ephemeroptera, Plecoptera and Trichoptera taxa (EPT) was greater at site CM1 on the Cotter River compared to the two sites on the Queanbeyan River (Fig. 5). More macroinvertebrate taxa were collected from CT1 and CM1 sites compared to QM2 and QM3 sites (Table 13), with the highest number of taxa collected at site CT1 (Table 13). Only three families (Gripopterygidae, Notonemouridae and Philoptamidae) with SIGNAL scores >6 were collected at site CT1 (Table 13). The estimated whole sample abundance was lowest at site

CT1, with sites QM2 and QM3 having a greater whole sample abundance than site CM1 (Table 13).

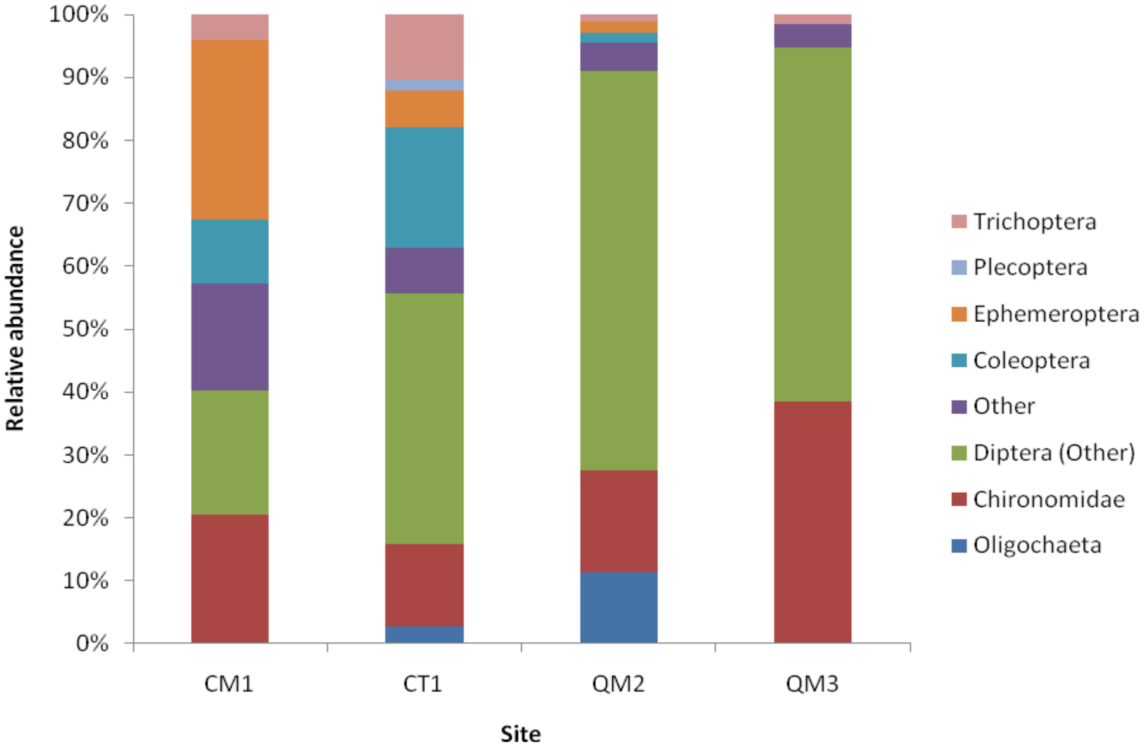

Figure 5: Relative abundance of macroinvertebrates taxa groups (indicated by different colours in the legend) at each sampled site; Cotter River (CM1), tributary of the Cotter River (CT1), and the Queanbeyan River below Googong Dam (QM2 and QM3), January 2011.

Table 13: Macroinvertebrate taxa and their sensitivity score (SIGNAL) (Chessman, 2002) collected for taxa identified to family from sub-samples for sites in January 2011.

CLASS			**Site**			
Order						
Family		**SIGNAL**	**CM1**	**CT1**	**QM2**	**QM3**
Subfamily		**Score**	**290**	**441**	**286**	**109**
OLIGOCHAETA		2		5	20	
ACARINA		6	41	13	8	7
INSECTA						
Coleoptera						
Gyrinidae		4				
Curculionidae		2				
Elmidae (Adult)		7		15		
Elmidae (Larvae)		7	24	20	1	
Hydrophilidae		2	1			
Psephenidae		6				
Scirtidae		6			2	
Diptera						
Athericidae		8	1			
Ceratopogonidae		4		1	1	
Empididae		5	8	6	1	3
Simuliidae		5	14	66	111	105
Tipulidae		5	25			
	Chironominae	3	4	11	11	30
	Orthocladiinae	4	37	10	18	42
	Podonominae	6		3		
	Tanypodinae	4	9			2
Ephemeroptera						
Baetidae		5	3	2		

Table 13 cont.

CLASS		**Site**			
Order					
Family	**SIGNAL**	**CM1**	**CT1**	**QM2**	**QM3**
Subfamily	**Score**	**290**	**441**	**286**	**109**
Gripopterygidae	8		2		
Notonemouridae	6		1		
Trichoptera					
Conoesucidae					1
Ecnomidae					2
Hydrobiosidae	8	5		1	1
Hydropsychidae	6	3	11	1	1
Hydroptilidae					1
Leptoceridae	6	2	1		
Philopotamidae	8		7		
No. individuals		243	183	178	195
No. of taxa		15	18	12	11
% of sub-sample		15	52	3	9
whole sample estimate		1620	352	5933	2166

Eco Evidence analysis results

A total of 21 of the 53 studies returned from the initial search of scientific literature were deemed relevant to the cause and effect linkages defined for this Eco Evidence investigation (Table 14). These studies provided a high level of support for an initial response of decreased macroinvertebrate abundance and taxa ricnhess, and subsequent recovery resulting in algal biomass similar to those found in reference conditions and a recovery of macroinvertebrate taxa richness to similar to reference or showing a trajectory towards reference (Tables 14 and 15). There was also a high level of support from the literature for a response regarding changes in macroinvertebrate assemblages after flood events (Tables 14 and 15).

Table 14: Effects and detailed effects reported in the literature of increased flow from flooding on macroinvertebrates and algae used in the Eco-Evidence Analysis.

Effect	Detailed effect	Citations
Initial decrease in macroinvertebrate abundance	Initial decrease	Angradi (1997); Jakob et al.(2003); Maier (2001); Mannes et al. (2008); Quinn and Hickey (1990); Rader et al. (2008); Robinson et al. (2004); Robinson and Uehlinger (2008); Robinson et al. (2003); Scrimgeour et al. (1988); Scrimgeour and Winterbourn (1989); Suren and Jowett (2006); January 2011 sampling
Initial decrease in macroinvertebrate taxa richness	Initial decrease	Angradi (1997); Jakob et al. (2003); Mannes et al. (2008); Palmer et al. (1992); Quinn and Hickey (1990); Rader et al. (2008); Robinson et al. (2003); Robinson and Uehlinger (2008); Scrimgeour et al. (1988); January 2011 sampling
	No initial decrease	Suren and Jowett (2006)
Macroinvertebrate taxa richness similar to reference condition or showing a trajectory towards reference condition	Recovery to reference condition levels	Angradi (1997); Deschaseaux and Norris (2009); Robinson et al. (2003); Scrimgeour et al. (1988) White and Norris (2008)
	No recovery to reference condition levels	Mannes et al. (2008)
Change in macroinvertebrate assemblage	Change in assemblage	Angradi (1997); Fuller et al. (2010) Jakob et al. (2003); Lepori and Malmqvist (2007); Maier (2001); Mannes et al. (2008); Rader et al. (2008); Robinson et al. (2004); Robinson and Uehlinger (2008); Robinson et al. (2003); Suren and Jowett (2006); Scrimgeour and Winterbourn (1989); Quinn and Hickey (1990); January 2011 sampling
Algal biomass (periphyton and filamentous) similar to reference condition after the flood.	Algae (periphyton and filamentous) scoured from substrate after a flood	Biggs (1995); Biggs and Close (1989); Franscoeur and Biggs (2006); Jakob et al. (2003); Jowett and Biggs (1997); Lohman et al. (1992); Mannes et al. (2008); Robinson et al. (2003); Robinson and Uehlinger (2008); Scrimgeour and Winterbourn (1989); Uehlinger et al. (2003); January 2011 sampling

Table 15: Summed study weights for the response, dose response and consistency of association causal criteria for each effect of increased flow from flooding on macroinvertebrates and algae. Response and dose causal criteria (if summed study weight < 20 level of support = low; if ≥ 20 level of support = high); consistency of association causal criteria (if summed study weight < 20 level of support = high; if ≥ level of support = low). [a] A = support for hypothesis.

Effect	Response	Dose response	Consistency of association	Conclusion [a]
Initial decrease in macroinvertebrate abundance	38	0	0	A
Initial decrease in macroinvertebrate taxa richness	33	3	2	A
Macroinvertebrate taxa richness similar to reference condition or showing a trajectory towards reference condition	27	0	2	A
Change in macroinvertebrate assemblage	32	2	0	A
Algal biomass (periphyton and filamentous) similar to reference condition after the flood	48	5	0	A

Discussion

In spring and early summer 2010 large rainfall events resulted in flooding in the Cotter and Queanbeyan Rivers downstream of each the reservoirs when they reach capacity and large volumes of water overtopped the spillways (Fig. 4) This has potentially lead to changes in indicators of river health such as macroinvertebrate communities and algae (periphyton and filamentous algae) (Fig. 3). As a result of the flooding, sampling was possible at 4 sites only (Table 1) and no sites could be sampled on the nearby unregulated Goodradigbee River, which should have provided a reference condition to compare data collected from the Cotter River. Therefore, a literature review using Eco Evidence analysis was conducted to support the results from limited field data collected and to make inferences about the effects of the flooding on the indicators river health in the Cotter and Queanbeyan Rivers.

Water quality data collected at Kangaroo Creek (CT1) downstream of Corin (CM1) and Googong Dams (QM2 and QM3) are indicative of the likely effects of increased runoff and flooding when the results are compared to the autumn 2010 samples collected before the dams were spilling (Harrison *et al.,* 2010). For example, downstream of Googong Dam the concentration of ammonia, nitrites/nitrates, TN and TP has increased since the autumn 2010 sampling (Harrison *et al.,* 2010) (Table 10). This increase in nutrient concentration is likely the result of water carrying increased sediment load from runoff in the surrounding catchment.

There was sufficient evidence collected from the literature to support a cause-effect relationship between flooding and a decrease in algae (periphyton and filamentous algae) to biomass levels similar to reference condition (Tables 14 and 15). This reduction in algal biomass occurs because of the increased stream velocity during the flood that removes the algae from the stream bed (see references in Table 14). This is evident in the periphyton data collected at the site directly downstream of Googong Dam (Table 11) where periphyton AFDM and Chlorophyll-a concentrations decreased compared to the autumn sampling, before the floods (Table 11). Therefore, given this result and the supporting evidence from the literature it is probable that flooding downstream of the dams on the Cotter and Queanbeyan Rivers will result in decreased amounts of algae (periphyton and filamentous algae). The decrease in algal biomass will have a positive effect on the ecosystem because the higher flows will scour filamentous algae (an undesirable macroinvertebrate food source) allowing fresh diatom assemblages to grow, which are a preferred macroinvertebrate food source (see Chester and Norris, 2006).

There was sufficient evidence from the literature review to conclude that flooding flows in river systems similar to the Cotter and Queanbeyan Rivers can result in initial decreases in macroinvertebrate abundance and taxa richness and a change in assemblage structure (Tables 14 and 15). These initial decreases can occur because of increased macroinvertebrate drift as a result of increased flow velocity dislodging and entraining macroinvertebrates into the flow (Robinson *et al.,* 2003). In comparison to the autumn 2010 sampling (Harrison *et al.,* 2010) total macroinvertebrate abundance was less at the four sites sampled in January 2011 (Fig. 5, Table 13). Furthermore, there were fewer taxa at sites on Kangaroo Creek and the Queanbeyan River in January 2011 (Table 13) compared to sampling in autumn 2010 (Harrison *et al.,* 2010).

The result of the literature review and the field data collected downstream of Corin and Googong Dams supports the hypothesis that flooding can result in initial decreases in macroinvertebrate abundance and change in the assemblage structure. For example, the literature evidence indicates that a general change in the macroinvertebrate assemblage following flooding was an initial increase in the relative abundance of taxa like Chironomidae, Simuliidae and Baetidae (Maier, 2001, Robinson *et al.,* 2004a, Robinson and Uehlinger, 2008, Jakob *et al.,* 2003, Suren and Jowett, 2006 see other references in Table 14). The literature evidence is supported by the result from January 2011 sampling showing that macroinvertebrate assemblage at the 2 sites downstream of Googong Dam were numerically dominated by Simuliidae following the flood. In comparison, the abundance of Simuliidae was not as great in autumn 2010 before the flood (Harrison *et al.,* 2010). Often, the early colonizing assemblage that establishes after flooding includes a high proportion of suspension feeders (e.g. Simuliidae and Hydropsychidae) and deposition feeders (e.g. Chironomidae subfamilies: Chironominae and Orthocladiinae) (Lepori and Malmqvist, 2007). This is followed by the establishment of algae feeders and then predators when the food sources re-establish (e.g. fresh diatoms growing on cobbles) (Lepori and Malmqvist, 2007). Although there will be initial reductions in macroinvertebrate abundance and taxa richness, the increased flows downstream of the dams in the Cotter and Queanbeyan Rivers are likely to lead to a more diverse assemblage because the high flows will mobilise the sediments, open interstitial spaces (i.e. more habitat niches) for invertebrates to colonise and establish new food resources such as diatoms (see conceptual model Figure 2 and Biggs and Close, 1989; Larned, 2010; Norris and Nichols, 2011). Sampling in autumn and spring 2011 will provide information on the longer-term effects on macroinvertebrate community structure and their recovery from the floods.

Previously, on the Cotter River when dams have spilled or when the release of a pool maintenance flow mimicked a flood, the macroinvertebrate community has improved, as indicated by a condition similar to reference condition (see Deschaseaux and Norris, 2009; White and Norris, 2008). When such evidence was combined with the evidence from the literature there was sufficient evidence to support macroinvertebrate taxa richness being similar to reference or showing a trajectory towards reference condition following flooding (Tables 14 and 15). However, any macroinvertebrate community recovery and resilience is dependent upon the frequency of floods in a river system (see Clausen and Biggs, 1997; Biggs *et al.,* 1999) and the conditions that follow. In a regulated river, increasing the frequency of floods to a more natural regime is likely to lead to longer-term benefits and a greater resilience in macroinvertebrate community structure and algal biomass (Clausen and Biggs, 1997; Biggs *et al.,* 1999; Robinson *et al.,* 2003). Therefore, if flood frequency returns to the previous regulated regime in the Cotter or Queanbeyan River systems the benefits of the recent flooding may only be short-term.

Conclusion

Overall, the recent flooding in the Cotter and Queanbeyan River systems is likely to have a positive effect on macroinvertebrate and algal communities and potentially bring these communities to a condition more similar to reference conditions of the nearby unregulated Goodradigbee River. As a result of the floods there should be increased space and habitat niches available within the stream bed following the removal of fine sediment supporting macroinvertebrate colonisation. The associated increase in diatom food sources because of floods will also allow for the succession of diatom feeding macroinvertebrates. Furthermore, the effects of recent floods and continuation of higher river flows may result in increased stability of macroinvertebrate populations. As this sampling event was not able to utilise the AUSRIVAS protocols given the time sampling was undertaken was not during spring or autumn, the next sampling undertaken in autumn 2011 will allow confirmation of these improved conditions and allow assessment against the ecological objectives of environmental flows.

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