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Annual riffle sediment survey below Bendora, Cotter and Googong Dams

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A**nnual riffle sediment survey –**

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Front Photograph: Riffle sediment sampling below Cotter Dam (Site CM3), May 2010 (Photo: Evan Harrison)

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Executive summary

1. Flows of the Cotter and Queanbeyan Rivers are regulated by Corin, Bendora and Cotter, and Googong Dams respectively. Regulated flows can create an armoured substrate because of reduced flushing flows combined with fine sediment loads downstream of dams. Currently riffle flushing flows (riffle maintenance flows) below Bendora Dam on the Cotter River are designed only to remove fine sediment from riffle habitats, while downstream of Cotter Dam and Googong Dam, riffle maintenance flows are not released. These flows are unlikely to be sufficient to prevent or break up an armoured substrate. An annual riffle sediment survey is undertaken to assess substrate armouring and sediment composition within the riffle habitat below Bendora Dam (sites CM2 and CM4), Cotter Dam (site CM3) and Googong Dam (site QM2).

2. All sites on both the Cotter and Queanbeyan Rivers were armoured, with an armouring index greater than 1. The armouring index was not significantly different among sites. This indicates that, as expected, regulated flow regimes were inadequate (even where riffle maintenance flows are released) for the prevention of substrate armouring below Bendora, Cotter and Googong Dams.

3. The surface substrate samples from the streambed at all sites were dominated by coarse cobble sized material (64-256 mm), while sub-surface samples (to 20 cm deep) had a greater proportion of smaller material (gravel and sand < 64 mm). A coarse surface layer with fines having infilled the subsurface layer is typical of armoured substrates. There was minimal difference in particle size distributions between all sites for both surface and subsurface samples.

4. The ecological implications of armoured substrate at sites below dams on the Cotter and Queanbeyan Rivers is limited habitat availability and variety for macroinvertebrates, which in turn could restrict taxa diversity. Armouring may also affect fish populations, by reducing habitat suitability for spawning.

5. Sites below Bendora and Googong Dams may require flow volumes in the order of > 3,000 MLd^{-1} to mobilise the substrate and break up the coarse surface layer. Such flows are not likely to be released from reservoirs, therefore, an alternative such as mechanical disturbance of riffles could be considered for improving riffle habitat.

1 Introduction

Armouring of the river substrate describes the formation of a coarse surface layer overlying a finer subsurface that is immobile unless the armour layer is disturbed (Gordon *et al*. 1992). The armouring process commonly occurs on regulated rivers. Dams act as sediment traps, and release clear, 'sediment hungry' water that erodes the river bed (Poff *et al*. 1997). This removes fine sediment and results in a coarsening of the substrate. Furthermore, the flow velocity of the regulated regime is often insufficient to disturb the coarse surface layer (Vericat *et al*. 2005). Substrate armouring reduces habitat availability and complexity (Poff *et al*. 1997), which in turn affects aquatic biota downstream of dams. For example, armouring has consequences for the macroinvertebrate community by reducing the complexity of habitat thus resulting in a reduction in macroinvertebrate diversity (e.g. Beisel *et al*. 1998; Beisel *et al*. 2000). Fish are also susceptible to a loss of complex habitats because of flow regulation and altered sediment processes (Lintermans 2002). Consequently, substrate armouring would also likely affect fish abundance and diversity. Therefore, preventing substrate armouring downstream of dams is important for maintaining complex habitats and aquatic diversity.

The Cotter and Queanbeyan Rivers primarily supply potable water for the Australian Capital Territory (ACT). Consequently, flows are regulated by three dams on the Cotter River and one dam on the Queanbeyan River. Regulation of the Cotter and Queanbeyan Rivers has likely resulted in the armouring of the substrate, with reduced sediment bed loads downstream of dams. Previous work has already recognised that sites on the Cotter River show evidence of armouring and high bed stability (e.g. Nichols *et al*. 2006). Furthermore, it has been determined that a flow of approximately 3360 MLd^{-1} would be required on the Cotter River to initiate movement of the substrate (Nichols *et al*. 2006). Currently flushing flows to both the Cotter and Queanbeyan Rivers are much smaller than those required to prevent substrate armouring. For example, riffle maintenance flows, which are designed to flush fine sediment from riffles (to maintain habitat for fish and macroinvertebrates) consist of only 150 MLd^{-1} released for three consecutive days every two months (ACT Government 2006). Therefore, it is expected that the substrate at sites downstream of Bendora, Cotter and Googong Dams would be armoured, having reduced flows and fine sediment loads, which encourage armouring. This would consequently reduce habitat available for both macroinvertebrates and fish on the Cotter and Queanbeyan Rivers.

Annual sampling is conducted at sites on the Cotter and Queanbeyan Rivers to assess the level of armouring and sediment size class distributions below dams. It also identifies potential changes in armouring at each site over time. Sampling is conducted at least one month following the release of a riffle maintenance flow. This assessment program forms part of ACTEW's licensing requirements (Licence No. WU67 – Licence to take water under the *Water Resources ACT 2007*) and contributes to the effective management of the Cotter and Queanbeyan Rivers as water supply sources.

2 Materials and methods

2.1 Study area

The study area includes the Cotter and Queanbeyan Rivers, which are situated along the western border of the ACT, and to the west of the ACT border in NSW, respectively (Fig. 1). The Cotter River is a fourth order stream downstream of Bendora Dam and a fifth order stream downstream of Cotter Dam, while the Queanbeyan River is a fifth order stream downstream of Googong Dam. The primary management goal for both rivers is providing a secure water supply to Canberra, with conservation being a secondary goal (ACT Government 2006). The Cotter River is regulated by three dams, Cotter Dam, Bendora Dam and Corin Dam, while the Queanbeyan River is regulated by Googong Dam.

Bendora Dam supplies water to the city of Canberra via a gravity main, with minimal releases to the Cotter River downstream of the dam, except for designated environmental flow purposes. Riffle maintenance flows of 150 MLd^{-1} are generally released below Bendora Dam (CM2) every two months for three consecutive days.

The capacity of the Cotter Dam is currently being increased and during construction and subsequent filling of the Enlarged Cotter Dam there will be minimal capacity to release water from the reservoir to the lower Cotter River. The Murrumbidgee to Cotter pumping augmentation (M2C) project has been implemented to provide an environmental flow transfer capability for the Cotter River reach below Cotter Dam by pumping water from Murrumbidgee River. It is proposed that flow from the M2C will be 20-40 MLd^{-1} but the volume may depend on the flow level in the Murrumbidgee River. Pumping sediment-rich water from the Murrumbidgee River to the Cotter River is expected to have an effect on the armouring and sediment composition of the river downstream of the dam, possibly reducing armouring and increasing fine sediment.

The flows in the Queanbeyan River downstream of Googong Dam (QM2) are generally lower and less variable than those released from Bendora Dam. Currently under stage 2 water restrictions or above a 100 MLd^{-1} flushing flow is released once a year for one day. At other times the flow is maintained at approximately 4 MLd^{-1} with releases of approximately 30 MLd^{-1} every 2 months for 1-2 days.

2.2 Site selection

Four sites were sampled as part of the riffle sediment survey (Fig. 1, Table 1). Three sites were on the Cotter River, one downstream of Bendora Dam (CM2), one downstream of Cotter Dam (CM3) and one upstream of Cotter Dam at Vanity's Crossing (CM4). The third site was downstream of Googong Dam on the Queanbeyan River (QM2). Site CM3 downstream of Cotter Dam had been excluded from previous years sampling because it was receiving a drought flow regime that doesn't include a riffle maintenance flow. The site has now been included again with the introduction of environmental flows downstream of Cotter Dam via M2C.

Table 1: Cotter and Queanbeyan River sampling sites for the annual riffle sediment survey, autumn 2010.

Site Code	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM2	Cotter	d/s Bendora Dam	700	51	4
CM3	Cotter	d/s Cotter Dam 100 m upstream Paddy's River confluence	500	75	5
CM4	Cotter	u/s Vanity's Crossing	580	66	4
QM2	Queanbeyan	d/s of road crossing below Googong Dam	590	91.6	5

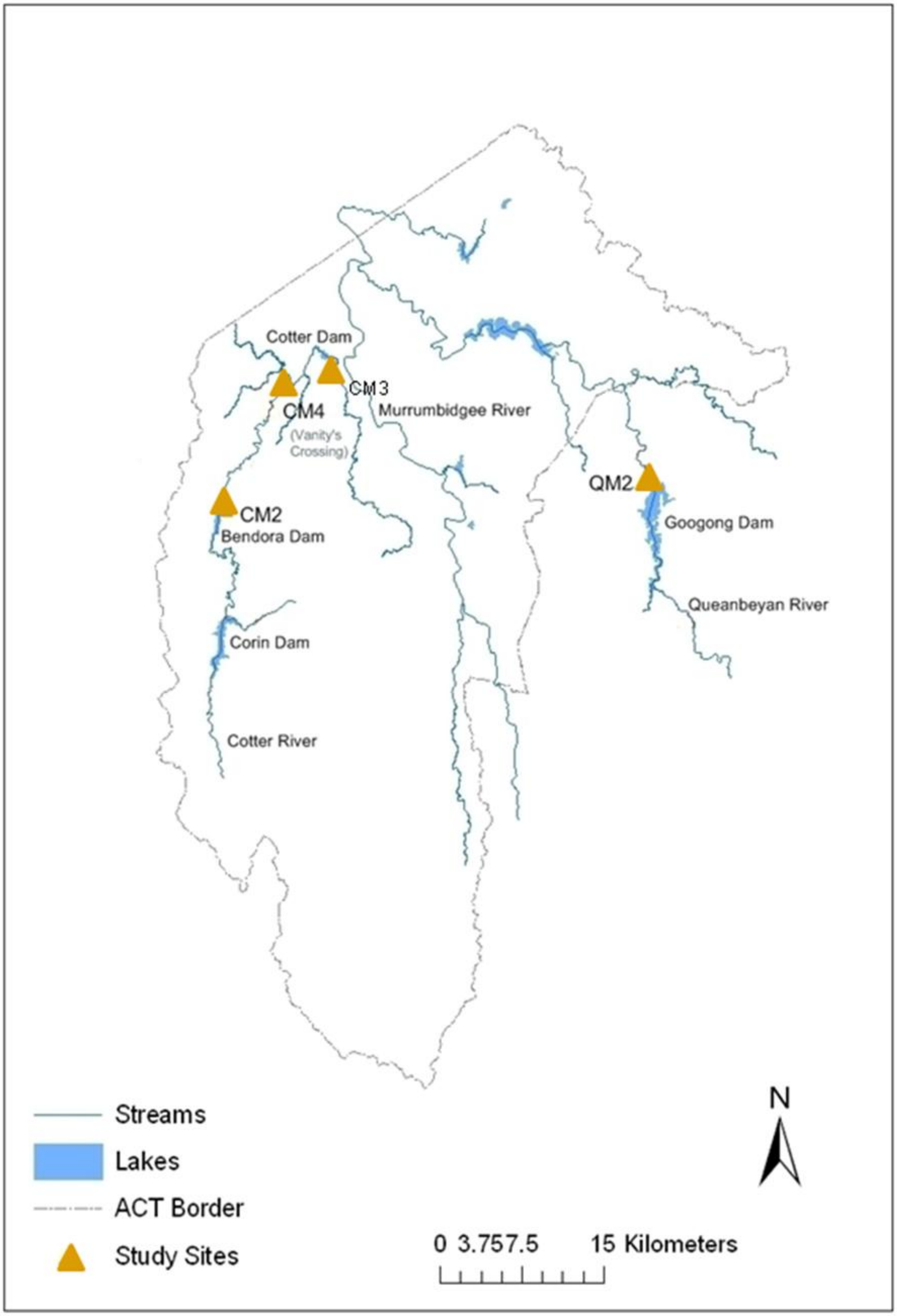

Figure 1: The location of the Cotter (CM2, CM3 and CM4) and Queanbeyan (QM2) River sampling sites for the riffle sediment survey, autumn 2010.

2.3 Sampling period

As per the licence conditions, sampling was undertaken during the autumn period, and at least one month following the release of a riffle maintenance flow. Sampling was conducted between the 7th May 2010 and the 17th June 2010 (Table 2).

Table 2: Dates of riffle maintenance flow release and sampling for each site, autumn 2010.

SITE	RIFFLE MAINTENANCE FLOW RELEASE	SAMPLING DATE
CM2	10-11th April 2010	7/5/2010
CM3	No flow released	14/5/2010
CM4	11-12th May 2010	17/6/2010
QM2	No flow released	10/6/2010

2.4 Hydrometric data

Mean daily flow data were obtained for Bendora Dam, Cotter Dam and Vanity's Crossing on the Cotter River, and Googong Dam on the Queanbeyan River from ActewAGL. Flow data covered the sampling period for the riffle sediment survey, ranging from the 1st April 2010 to the 20th June 2010.

2.5 Riffle sediment survey

At each of the four sampling sites, five replicate sediment samples were obtained from the riffle habitat to determine the level of substrate armouring and sediment size class distributions. Each sample was taken from an area approximately 30 cm^2 and 20 cm deep, with separate surface and subsurface samples. Each sample was sieved separately through a series of different sized sieves, sorting the sediment in size classes ranging from 128-256 mm to <2 mm (fines). To simplify the sampling process, the largest sediment particles (<46 mm) were rinsed and sieved in the field. Also, the mass of the remaining water is considered insignificant compared to the mass of these larger particles (Gordon *et al.* 1992). The remaining sediment was stored in heavy duty plastic bags. In the laboratory the samples were dried at 60 ^{0}C, sieved through a series of Wentworth sieves and then weighed.

2.6 Data entry and analysis

Sediment data were entered into a Microsoft Excel spreadsheet, which were then checked for transcription errors. The sediment D50 (median particle size) was calculated, which is required to determine the armouring index. The armouring index was then calculated for each site in Excel as the ratio of the median surface particle size over the median sub-surface particle size (Gordon *et al*. 1999). An armouring index > 1 indicates that the substrate is armoured. Surface and subsurface sediment data was also arranged according to the Wentworth scale (Wentworth 1922) and graphed in Excel according to size class.

Differences in the armouring index between sites and over time (for sites CM2, CM4 and QM2) (using data from 2008 and 2009) were tested using a two-way Analysis of Variance

(ANOVA, SAS 9.1). A $Log_{10}(x+1)$ transformation before undertaking an ANOVA, was applied to ensure data met the assumption of normality.

3 Results

3.1 Hydrometric data

The hydrographs downstream of Bendora Dam on the Cotter River (CM2 and CM4) and Googong Dam on the Queanbeyan River (QM2) illustrate the release regimes from each reservoir (Fig. 2). The flow at Vanity's Crossing (CM4) generally reflects the flows released from Bendora Dam, in combination with rainfall events and inputs from tributaries. Flows below Bendora Dam peaked in early May at approximately 149 MLd^{-1} at sites CM2 and 166 MLd^{-1} CM4, with the release of a riffle maintenance flow. The flow below Cotter Dam reached a maximum of only approximately 70 MLd^{-1} during the study period and varied between approximately 2-40 MLd^{-1} during the study period. While, the flow below Googong Dam reached a maximum of only 30 MLd^{-1} during the study period, and remained between approximately 2.5-3.5 MLd^{-1} most of the time.

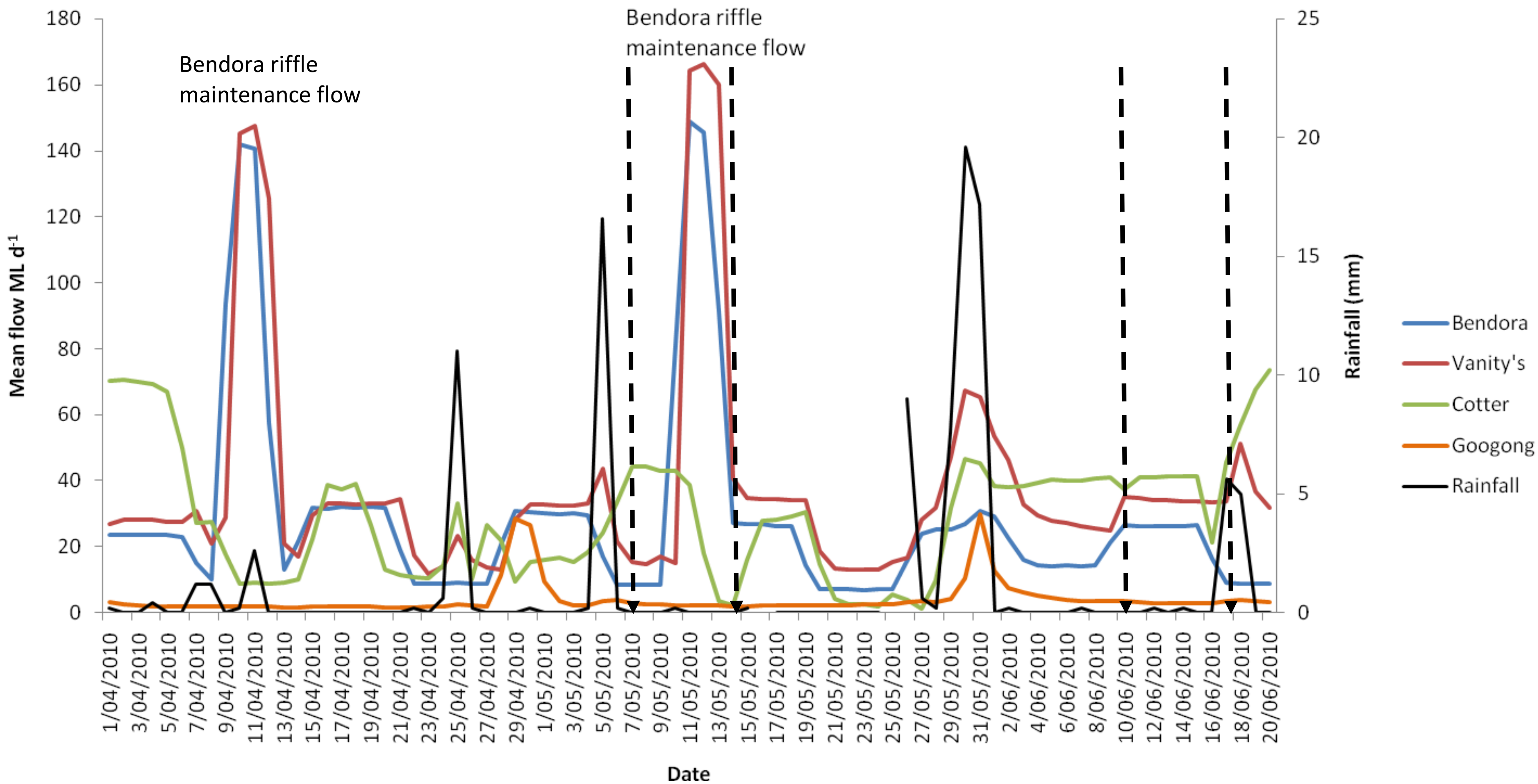

Figure 2: Hydrograph of the Cotter and Queanbeyan Rivers: below Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams, and at Vanity's Crossing (CM4) from 1st April 2010 to 20th June 2010. (Arrows indicate sampling dates.)

3.2 Armouring Index

In Autumn 2010 all four sites below dams had an armoured substrate, with each having an armouring index >1 and there were no significant differences between sites (Fig. 3). Between autumn 2008 and autumn 2010 at sites CM2, CM4 and QM2 the substrate has always been armoured (armouring index >1) (Fig 4). At all three sites the index increased between 2008 and 2009 while in 2010 the index decreased slightly (Fig. 4). However, despite this trend there was no significant decrease/increase in armouring over time at sites or significant differences between sites in each year.

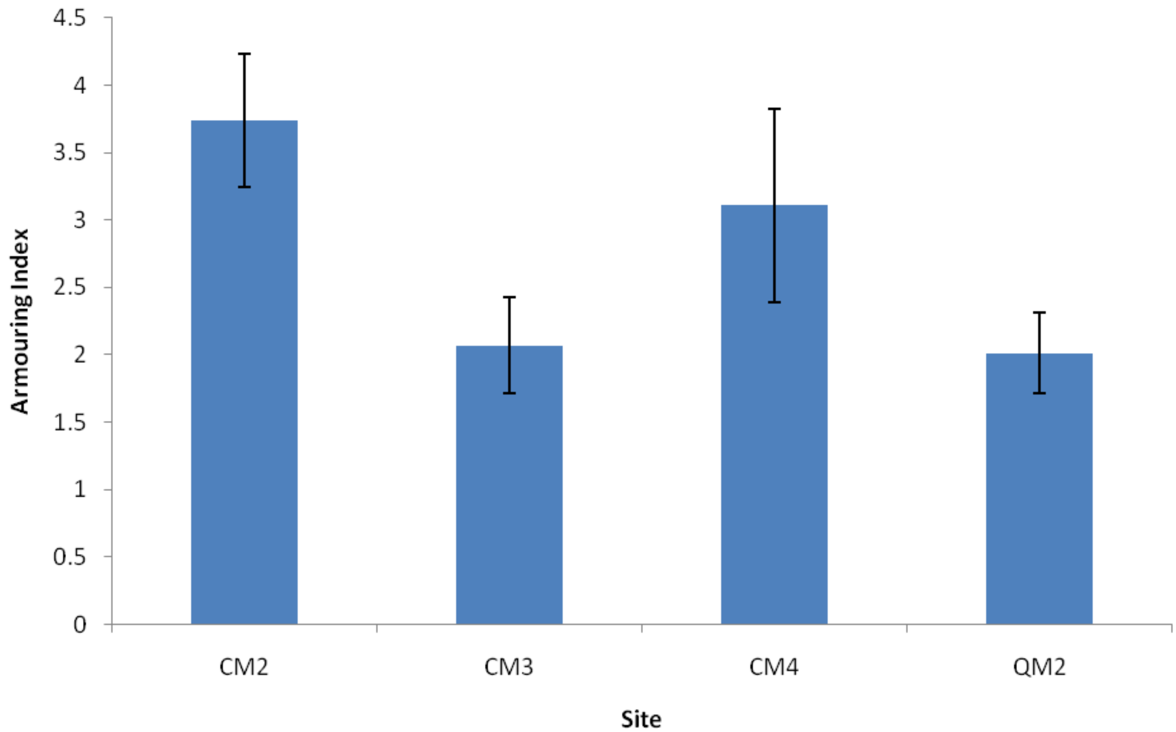

Figure 3: The armouring index below Bendora Dam (CM2), below Cotter Dam (CM3), at Vanity's Crossing (CM4) and below Googong Dam (QM2), autumn 2010. (Note: error bars represent +/- 1 standard error).

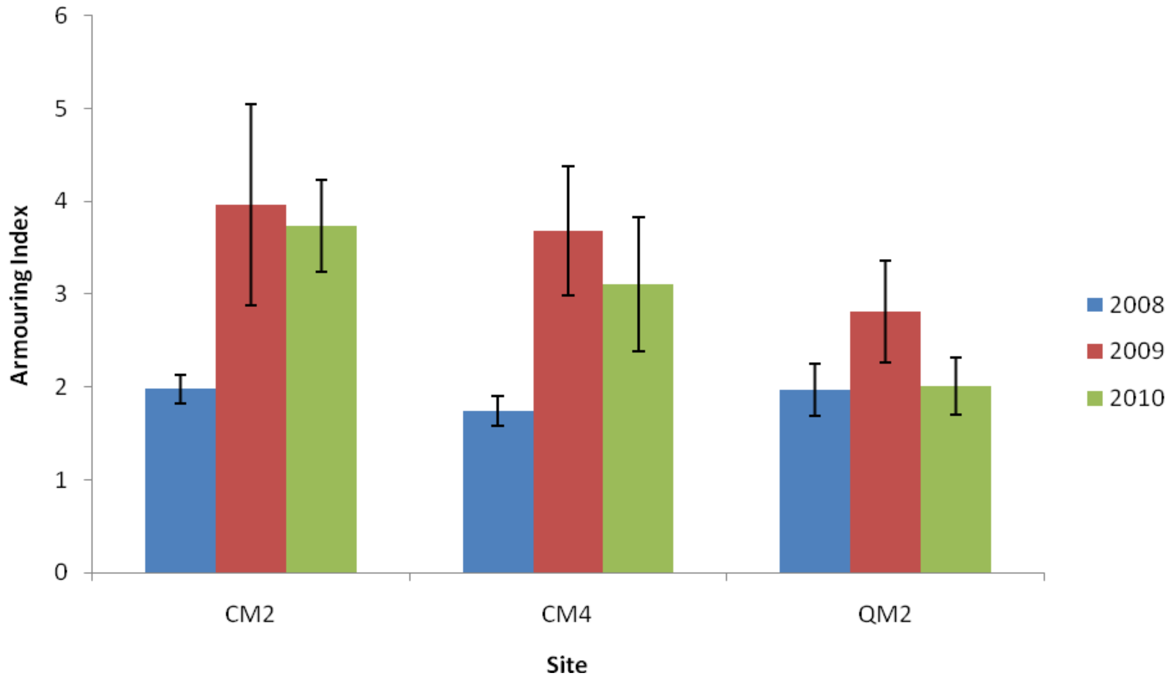

Figure 4: The armouring index below Bendora Dam (CM2), at Vanity's Crossing (CM4) and below Googong Dam (QM2) in autumn 2008, 2009 and 2010. (Note: error bars represent +/- 1 standard error and site CM3 not included on this graph because long term monitoring has not been conducted at this site).

3.3 Sediment size distributions

Sediment at the riffle surface largely consisted of cobbles (64-256 mm) at all four sites, with little material smaller than coarse gravel (<16 mm) (Fig. 5). Relatively more fine gravel (4-8 mm), very fine gravel (2-4 mm) and sand and silt (<2 mm), in particular, was found in the sub-surface samples which has resulted in an armoured substrate at all sites (Figs. 3 and 5). There was little difference in the relative distribution of the sediment size classes between sites (Fig. 5), although sites CM2 and CM4 on the Cotter River were flushed regularly with a riffle maintenance flow.

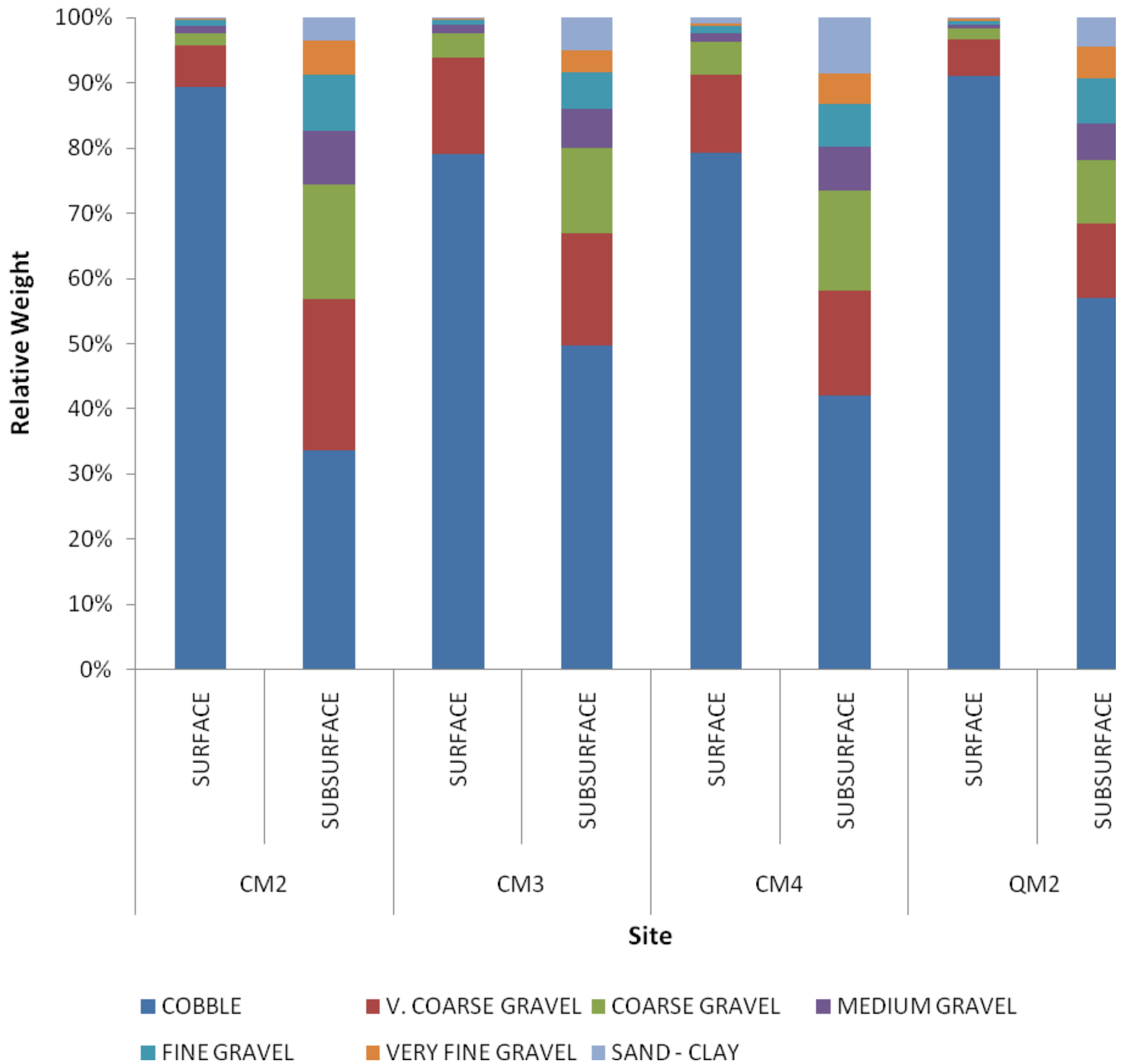

Figure 5: Relative weights of each sediment size class (based on the Wentworth scale: Wentworth 1922) in the riffle surface and sub-surface samples at sites on the Cotter (CM2, CM3 and CM4) and Queanbeyan (QM2) Rivers, autumn 2010.

4 Discussion and Conclusion

Sites below both Bendora, Cotter and Googong Dams and at Vanity's Crossing upstream of Cotter Dam, were all found to have an armoured substrate in autumn 2010 (Fig. 3). All three sites had a coarse surface layer dominated by cobbles, with a sub-surface consisting of relatively more fine material (Fig. 5), which is consistent with river substrate armouring (Gordon *et al*. 1992). Flow regulation has resulted in the armoured substrate at sites on both the Cotter and Queanbeyan Rivers, with reduced flow velocities incapable of turning the substrate, and also low fine sediment bed loads, which have resulted in a coarsened substrate.

The armouring indices were not significantly different among sites in autumn 2010, or in 2008 or 2009 (Fig. 4). This is despite differences in the flow regime, particularly between the Cotter River sites compared to the Queanbeyan River site (Fig. 2). For example, sites downstream of Bendora Dam receive riffle maintenance flows, while downstream of Googong Dam generally has lower and less variable flows, with a 100 MLd^{-1} released once a year. However, this is not surprising if flows >3000 MLd^{-1} (see Nichols *et al*. 2006) are required to roll the substrate and break up the coarse armoured layer. The release of riffle maintenance flows may actually exacerbate the armouring process, further scouring fine sediment and coarsening the substrate downstream of Bendora Dam. Therefore, the current flow regimes downstream of Bendora, Cotter and Googong Dams are insufficient to either prevent or break up the armoured layer. Although armouring does occur in unregulated systems, the substrates of naturally flowing streams are more regularly broken up by flooding events (Haschenburger and Wilcock 2003). Furthermore, site CM3 below Cotter Dam hasn't been included in previous sampling rounds because a drought flows regime has been released at this site that doesn't include a riffle maintenance flow. Ongoing assessment of substrate armouring below Cotter Dam is required to determine the effects of the proposed flow of 20-40 MLd^{-1} via the M2C transfer on substrate condition. To reduce substrate armouring on both the Cotter and Queanbeyan Rivers, flushing flows would need to be increased considerably to better mimic naturally occurring flushing events, however, such flows are unrealistic in a regulated water supply system. Alternatively, mechanical disturbance of the riffle substrate could be considered to break up riffle armouring.

The effects of river regulation are known to decrease with distance from a dam (e.g. Ward and Stanford 1983; Stanford and Ward 2001). For example, site CM4 at Vanity's Crossing theoretically should be less armoured than directly downstream of Bendora Dam (CM2), having greater inputs of fine sediment and flow from tributaries. However, the armouring index at Vanity's Crossing (CM4) was not significantly different to below Bendora Dam (Figs. 3 and 4), despite being a considerable distance further downstream. This is likely because contributions from tributaries have been reduced during dry conditions. For example, Burkes Creek has ceased flowing since spring 2008, which would reduce fine sediment inputs to downstream sites, particularly if a number of tributaries have dried out. This may also have contributed to the increase in the mean armouring index at Vanity's Crossing between 2008 and 2009 (Fig. 4). While, with increasing rainfall and tributary inflows in 2010 the armouring index at Vanity's Crossing has now decreased slightly (Fig. 4). However, the flow regime at site CM4 strongly reflects that of CM2, indicating that flows are insufficient for preventing armouring of the riffle habitat.

Habitat availability and complexity are reduced by substrate armouring (Poff *et al*. 1997; Poff and Hart 2002), consequently reducing macroinvertebrate richness (Beisel *et al*. 1998; Beisel *et al*. 2000). Therefore, the macroinvertebrate communities below Bendora, Cotter and Googong Dams are likely being impaired by substrate armouring. Since at least 2007, AUSRIVAS assessments for below Bendora, Cotter and Googong Dams demonstrated that the macroinvertebrate community at sites CM2, CM3 and QM2 had a different community composition to reference sites with less taxa sensitive to habitat disturbance and/or were assessed as severely or significantly impaired by the Australian River Assessment System model (Harrison *et al.* 2010; Tingle and Norris 2007; White and Norris 2007; White and Norris 2008; White *et al*. 2008; White *et al*. 2009). Substrate armouring has likely contributed to the impaired macroinvertebrate community at CM2, CM3 and QM2, creating habitat conditions that are particularly unfavourable for sensitive taxa. Increased flow volumes that would reduce the coarse surface layer at sites CM2, CM3, CM4 and QM2 would have benefits for the condition of the macroinvertebrate community. Reduced habitat complexity as a result of armouring of riffles may also be detrimental to fish on the Cotter and Queanbeyan Rivers. For example, Macquarie Perch (*Macquaria australasica*) and Two-spined Blackfish (*Gadopsis bispinosus*) (listed in the ACT as endangered and vulnerable respectively: Lintermans 2002) are known to live and breed in the reach between Bendora and Cotter Dams on the Cotter River (Lintermans 2002). Both types of fish use the interstitial spaces between cobbles and gravel in riffles for spawning (Lintermans 2002; Lintermans 2007). Hence, armouring of the riffle substrate would reduce the availability and complexity of habitats utilised by fish in the Cotter and Queanbeyan Rivers, which could result in further declines in abundance. Armouring at sites below dams on the Cotter and Queanbeyan Rivers, therefore is likely contributing to the impairment of biotic condition at these sites, with reduced macroinvertebrate and fish diversity.

Sites below dams on the Cotter and Queanbeyan Rivers are armoured, as a result of river regulation. Without sufficient flows to break up the coarse surface layer it is expected that these sites will remain armoured in the future. However, releasing flows of a sufficient magnitude is not likely given that the primary management objective of dams on the Cotter and Queanbeyan Rivers is to secure potable water supply for Canberra and Queanbeyan. Another alternative to increasing flushing flows below dams would be to mimic a small flood by mechanically disturb the riffle habitat to break up the armoured substrate (e.g. Doeg 1989; Peat 2006); However, this would not likely be a long term solution with the continuation of regulated flows.The reference sites would help to provide a better overall picture of the extent and affects of armouring on the Cotter and Queanbeyan Rivers.

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