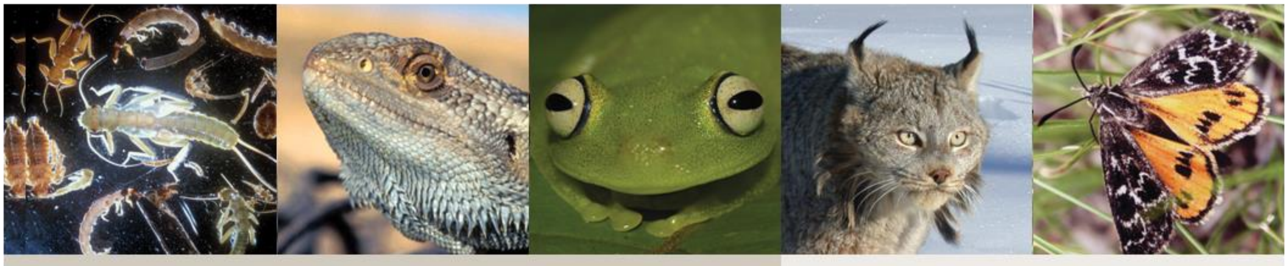

ACTEW WATER

Riffle sediment survey below Bendora, Cotter, and Googong Dams - 2012

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Front Photograph: Coarse riffle sediments downstream of Bendora Dam (site CM2).

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Executive summary

1. Riffle maintenance flows, which are designed to maintain habitat (including removal of fine sediment from the bed surface) for fish and macroinvertebrates, consist of 150 MLd^{-1} released for three consecutive days every two months downstream of Bendora and Corin Dams and 100 MLd^{-1} for 1 day every two months downstream of Cotter and Googong Dams (ACT Government 2006). This study assesses the level of riffle substrate armouring and riffle surface sediment size class distributions downstream of dams on the Cotter (Bendora and Cotter Dams) and Queanbeyan Rivers (Googong Dam) in relation to river flows. Click here for more information

2. A flood event in March 2012 delivered peak discharges well above those previously described as required to break up armoured substrates in the Cotter and Queanbeyan Rivers. Substrate armouring decreased at all sites directly downstream of dams as a result of the flood event. However, all sites on both the Cotter and Queanbeyan Rivers remained armoured. Click here for more information

3. Since the March 2012 floods, the proportion of fine sediment (sand-clay: <2mm) on riffle surfaces downstream on Cotter (site CM3) and Googong (site QM2) Dams has increased to levels greater than other sampling occasions since 2008. This increase is likely the result of fine sediment laden water delivered from upstream catchments during the floods and is unlikely to be a result of dam operations. Click here for more information

4. Flooding increased fine sediment on riffle surfaces downstream of Cotter and Googong Dams. Prior to floods in late 2010 and March 2012, riffle surface fine sediment across all sites had been ≤1% of riffle surface substrate composition. This indicates that dam flow releases before the floods have been adequate at maintaining very low levels of fine sediment on riffle surfaces. Click here for more information

5. Future assessment of riffle maintenance flow releases on the Cotter and Queanbeyan rivers should focus on the effectiveness of the flow releases at removing fine sediment from riffle surfaces. A revised research program should include the following; before and after flow sampling, placing sites upstream and downstream of tributary inputs and inclusion of samples from unregulated reference sites to increase the potential to disentangle management influences from background variability. Click here for more information

Introduction

Armouring of the river substrate refers to 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 where dams act as sediment traps and then release clear, 'sediment hungry' water that erode the downstream river bed (Poff et al. 1997). This removes fine sediment and results in a coarsening of the substrate. The velocity of regulated flow releases is often insufficient to disturb this coarse surface layer (Vericat et al. 2006). Substrate armouring reduces habitat availability and complexity (Poff et al. 1997), which can impact on the abundance and diversity of aquatic biota (e.g. Beisel et al. 1998; Beisel et al. 2000; Lintermans 2002; Poff *et al.* 1997). Therefore, assessment of the effects river flows on the degree of substrate armouring downstream of impoundments can aid in the management of river health in regulated systems.

River bed armouring has previously been identified on the Cotter River (e.g. Nichols et al. 2006). It has been determined that a flow of approximately 3360 MLd^{-1} would be required to initiate movement of the Cotter River substrate (Nichols *et al*. 2006). Such flows cannot be physically released from dams on the Cotter and Queanbeyan Rivers and only occur with natural flood events. Current riffle maintenance flows in both the Cotter and Queanbeyan Rivers are less than those required to prevent and reverse substrate armouring. Riffle maintenance flows, which are designed to maintain habitat (including removal of fine sediment from the bed surface) for fish and macroinvertebrates, consist of 150 MLd^{-1} released for three consecutive days every two months downstream of Bendora and Corin Dams and 100 MLd^{-1} for 1 day every two months downstream of Cotter and Googong Dams (ACT Government 2006).

A reduction in stream flow downstream of a dam can also allow sediment to accumulate on the riverbed downstream of sediment inputs (Kondolf 1997; Milhous 1998). This accumulation can result in the infiltration of fine particles into coarse substrate, particularly below tributary sources (Petts 1988; Brookes 1992). If flows are incapable of flushing fine sediment, the interstitial spaces within the coarse substrate fill with fine sediment and reduce habitat quality for aquatic biota (Waters 1995).

This study assesses the level of armouring and surface sediment size class distributions downstream of dams on the Cotter (Bendora and Cotter Dams) and Queanbeyan Rivers (Googong Dam) in relation to river flows.

Materials and methods

Study area

The study area is the Cotter and Queanbeyan Rivers, which are situated along the western border of the ACT, and to the east of the ACT in NSW (Fig. 1). The Cotter River is regulated by three dams, Cotter Dam, Bendora Dam and Corin Dam, and the Queanbeyan River is regulated by Googong Dam. 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.

Four sites were sampled as part of the riffle sediment survey (Fig. 1, Table 1). Three sites were on the Cotter River, two downstream of Bendora Dam (CM2 – Bendora Dam and CM4 – Vanitys Crossing) and one downstream of Cotter Dam (CM3). The fourth site was downstream of Googong Dam on the Queanbeyan River (QM2). Sampling was undertaken at sites CM2 and CM3 in February 2012 (sites CM4 and QM2 were not sampled because of high stream flow) and at all four sites in December 2012 (Table 1).

Table 1: Cotter and Queanbeyan River sampling sites, 2012.

Site code	River	Location	Altitude (m)	Distance from source (km)	Stream order	Sampling date(s)
CM2	Cotter	300 m downstream of Bendora Dam	700	51	4	23/2/2012 18/12/12
CM3	Cotter	1.3 km downstream of Cotter Dam	500	75	5	22/2/2012 18/12/12
CM4	Cotter	180 m upstream of Vanitys Crossing	580	66	4	19/12/2012
QM2	Queanbeyan	700 m downstream of below Googong Dam	590	92	5	17/12/2012

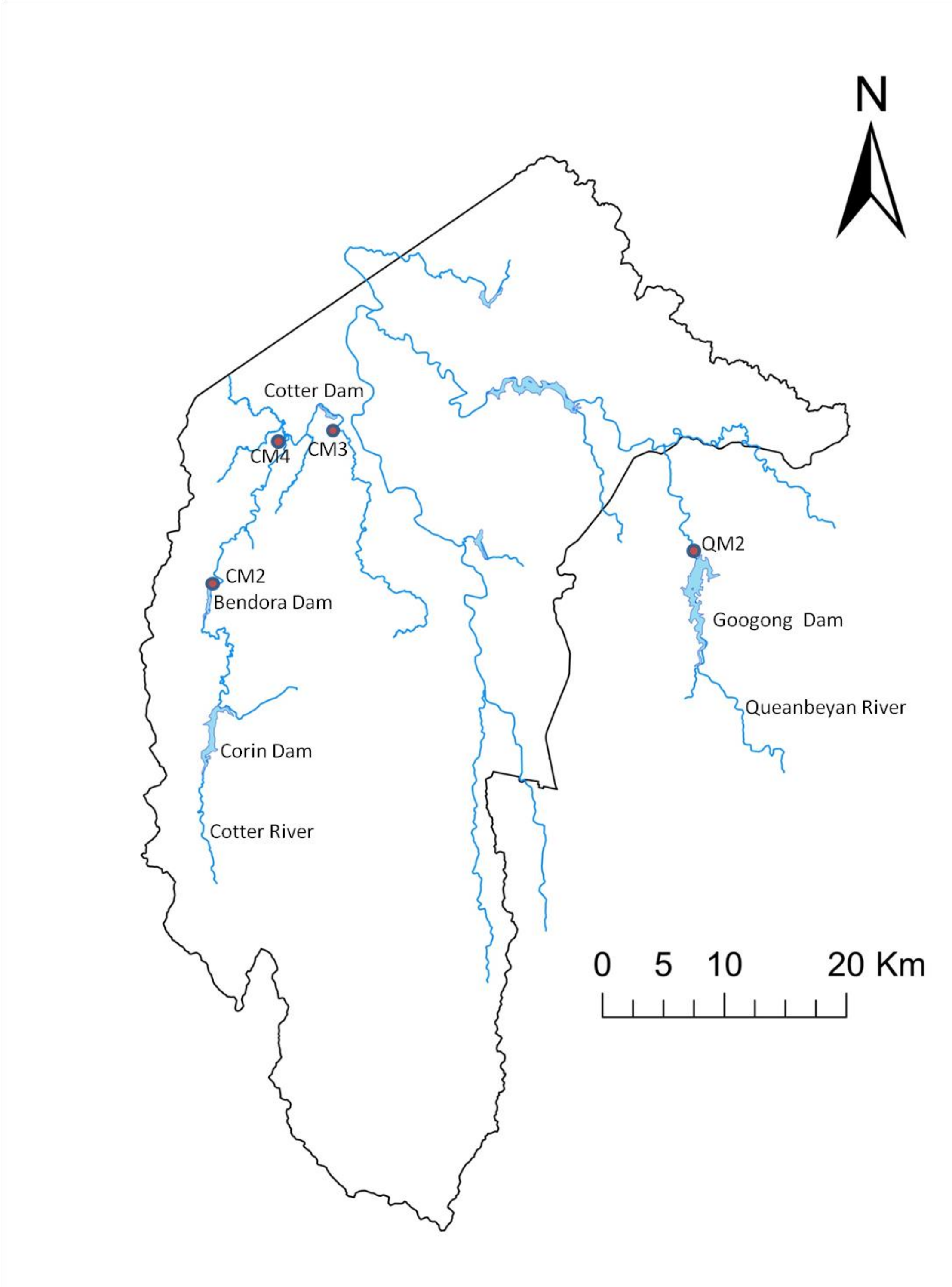

Figure 1: The location of the Cotter (CM2, CM3 and CM4) and Queanbeyan (QM2) River sampling sites, 2012.

Hydrometric data

Mean daily flow data were obtained for Bendora Dam, Cotter Dam and Vanitys Crossing on the Cotter River, and Googong Dam on the Queanbeyan River from ACTEW Water. Flow data covered the sampling period for the riffle sediment survey, from the 1st January 2012 to the 1st January 2013.

Riffle sediment survey

Five replicate sediment samples were collected from the riffle habitat at each of the four survey sites. Each sample was collected from an area approximately 800 cm^2. Surface sediments were first removed, and then the subsurface sediment was collected to a depth of approximately 30 cm. Each surface and subsurface sample was sieved separately through a series of Wentworth sieves, sorting the sediment into 14 size classes ranging from >256mm mm to <2 mm diameter (see Appendix 1). To simplify the sampling process, the largest sediment particles (>46 mm) were sieved and weighed in the field. The remaining sediment was stored in heavy duty plastic bags, then dried in the laboratory and sieved through a series of Wentworth sieves and weighed. Surface and subsurface samples were analysed separately.

Data analysis

The sediment median particle size (D50) was calculated, which is required to determine the armouring index. The armouring index was then calculated for each site as the ratio of the median surface particle size over the median sub-surface particle size (Gordon *et al*. 1992). An armouring index > 1 indicates that the substrate is armoured. Surface and subsurface sediment data was then arranged according to the Wentworth scale (Wentworth 1922) and graphed according to size class.

Differences in the armouring index between the current and previous assessments were tested using a one-way Analysis of Variance test (ANOVA, SAS 9.3) for each site. A $Log_{10}(x+1)$ transformation was applied before undertaking an ANOVA to ensure data met the assumptions of the test.

Results and conclusions

A major flood event occurred in the Cotter and Queanbeyan River in early March 2012. This resulted in discharge peaks of 9432 ML day^{-1} at site CM2, 27252 ML day^{-1} at site CM3, 30375 ML day^{-1} at site CM4, and 15344 ML day^{-1} at site QM2 (Fig. 2). Flow velocities during this flood event would have been well above those required to mobilise the armoured substrate at each of the study sites (see Nichols *et al.* 2006). It can therefore be expected that the armouring index would reduce after this flood event.

Riffle sediments were armoured at all survey sites in February and December 2012 (Fig. 3). At each of the below dam sites (CM2, CM3, and QM2) the mean armouring index was less than all previous assessments (Fig. 3). Downstream of Bendora Dam (CM2) was the only site that had a significantly lower armouring index in December 2012 compared to previous assessments (d.f.=4,20; F=5.25; p=0.0047). It is likely that the lower armouring index downstream of Bendora, Cotter and Googong Dams in December 2012 is the result of river bed disturbance in the Cotter and Queanbeyan Rivers during the March 2012 flood (Fig. 2).

Site CM4 at Vanitys Crossing, which is downstream of tributary sediment inputs downstream of Bendora Dam, had a higher mean armouring index in December 2012 compared to previous sampling occasions (Fig. 3). However, the mean armouring index in December 2012 was not significantly different from previous assessments (d.f.=3,16; F=1.90; p=0.1702) because of high within site variability (Fig. 3). This result shows that even with tributary inputs downstream of Bendora Dam, the Cotter River stream bed remains armoured at Vanitys Crossing following the March 2012 flood event and similar to previous sampling occasions since 2008 (Fig. 3). Therefore, given the stream bed armouring results downstream of dams on the Cotter and Queanbeyan Rivers following the floods, it is likely that multiple flood flows of this magnitude would have to occur to further decrease stream bed armouring.

Riffle surface sediment all Cotter River sites in 2012 were dominated by cobbles (64-256mm), with little material smaller than coarse gravel (<16 mm) (Fig. 4). While, riffle surface sediment in Queanbeyan River downstream of Googong Dam in 2012 was dominated by cobbles (64-256mm) and very coarse gravel (32-64mm) (Fig. 4). Since the March 2012 floods, the proportion of fine sediment (sand-clay: <2mm) on riffle surfaces downstream on Cotter (site CM3) and Googong (site QM2) Dams has increased to levels greater than other sampling occasions since 2008 (2.5 % and 3.1% respectively - Fig. 4). This increase is likely the result of fine sediment laden water from upstream catchments with areas of stream bank erosion sources spilling over Cotter and Googong Dams during the March 2012 floods. Similar increases were not observed at sites CM2 (Bendora Dam) and CM4 (Vanitys Crossing), most likely because the amount of stream bank erosion upstream of these sites is much lower compared to site CM3 and QM2. Prior to floods in late 2010 and March 2012, riffle surface fine sediment across all sites has been ≤1% of riffle surface substrate composition (Fig 4.). This indicates that dam flow releases before the floods have been adequate at maintaining very low levels of fine sediment on riffle surfaces.

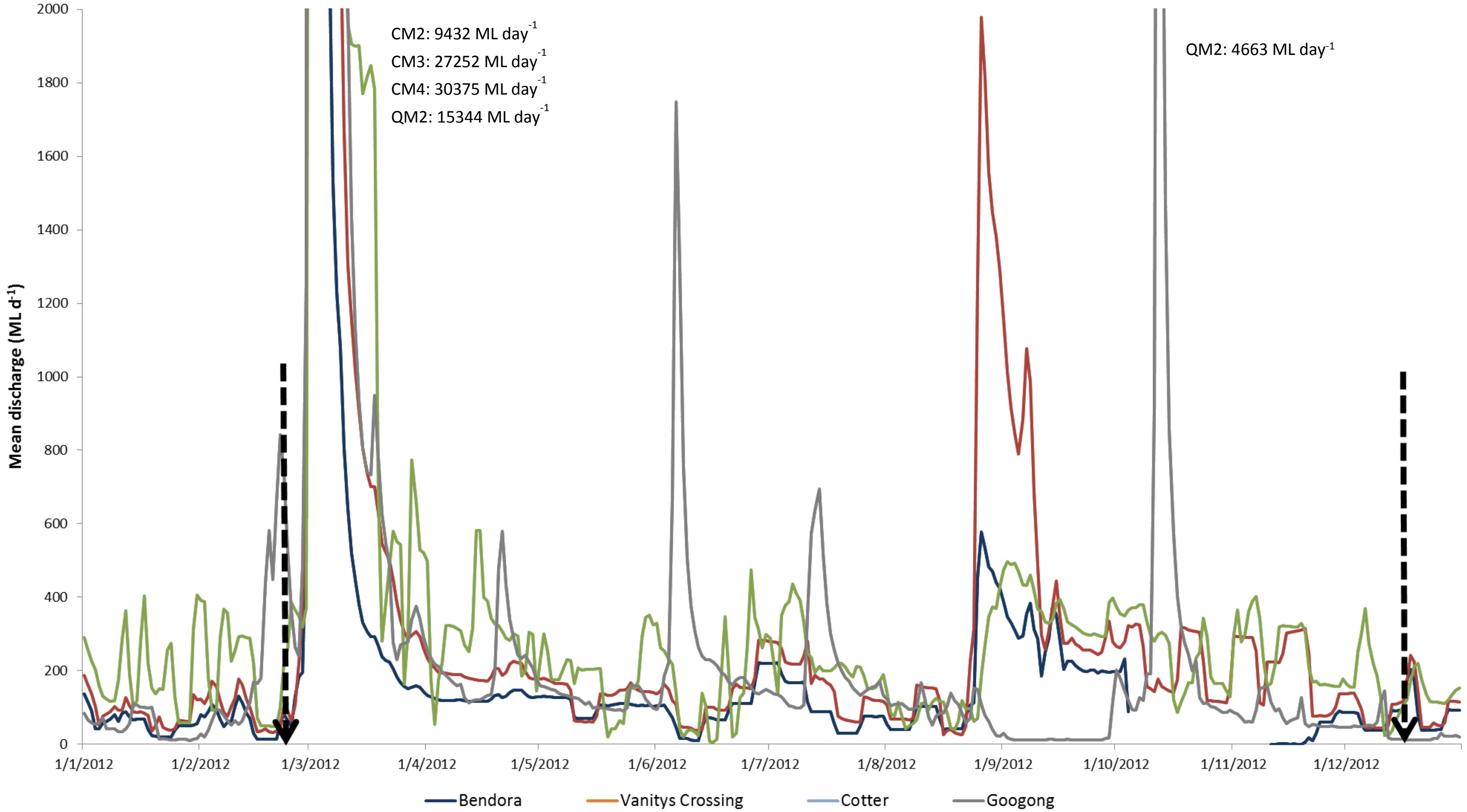

Figure 2. Mean daily discharge at sites CM2, CM3, CM4, and QM2 from 1/1/12 to 1/1/13. Note: Flow peaks >2000 ML d $^{-1}$ are not shown. Arrows correspond to sampling dates.

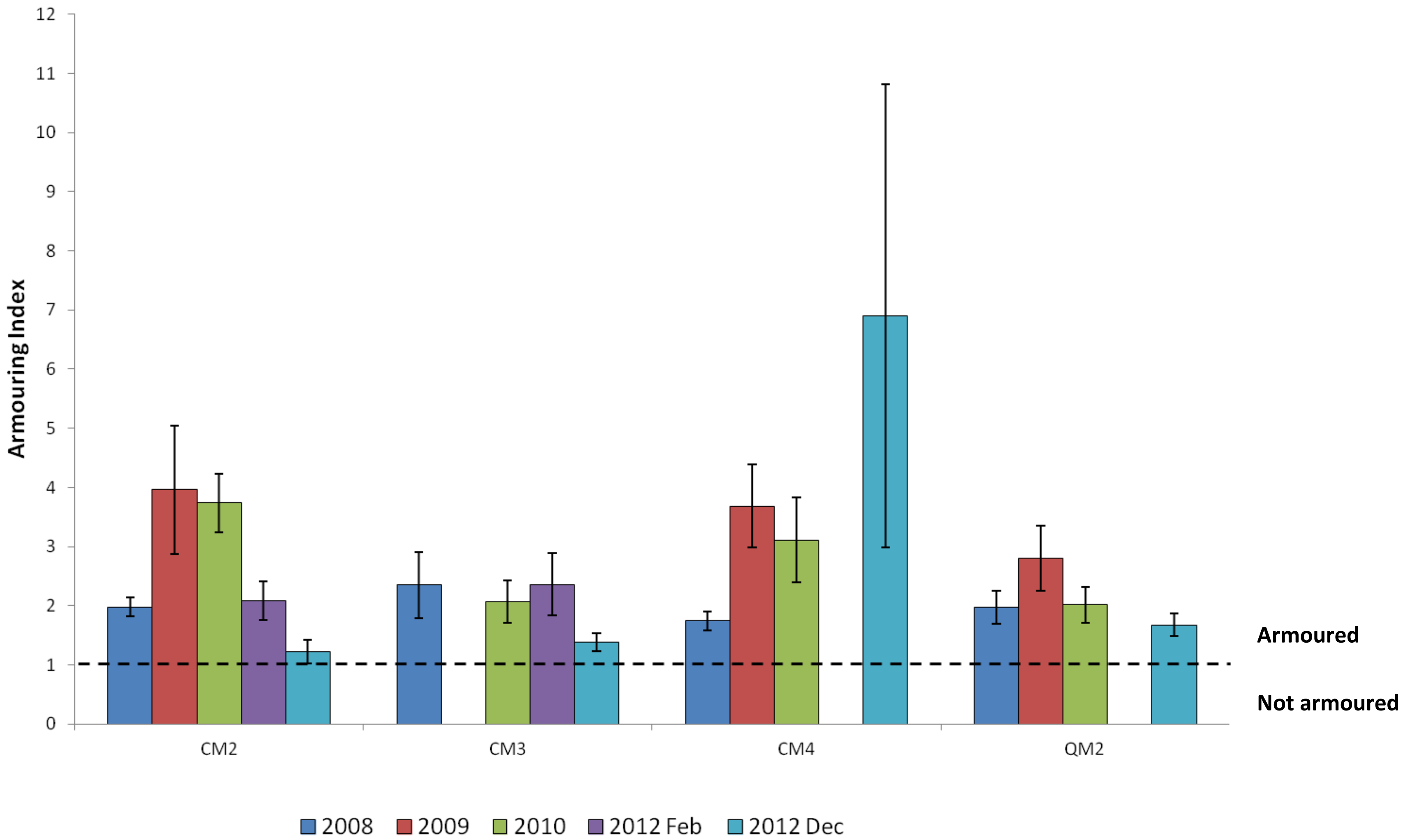

Figure 3: The armouring index below Bendora Dam (CM2), below Cotter Dam (CM3), at Vanitys Crossing (CM4) and below Googong Dam (QM2) in autumn 2008, 2009 and 2010. Error bars represent +/- 1 standard error. Note- site CM3 was not sampled in 2009.

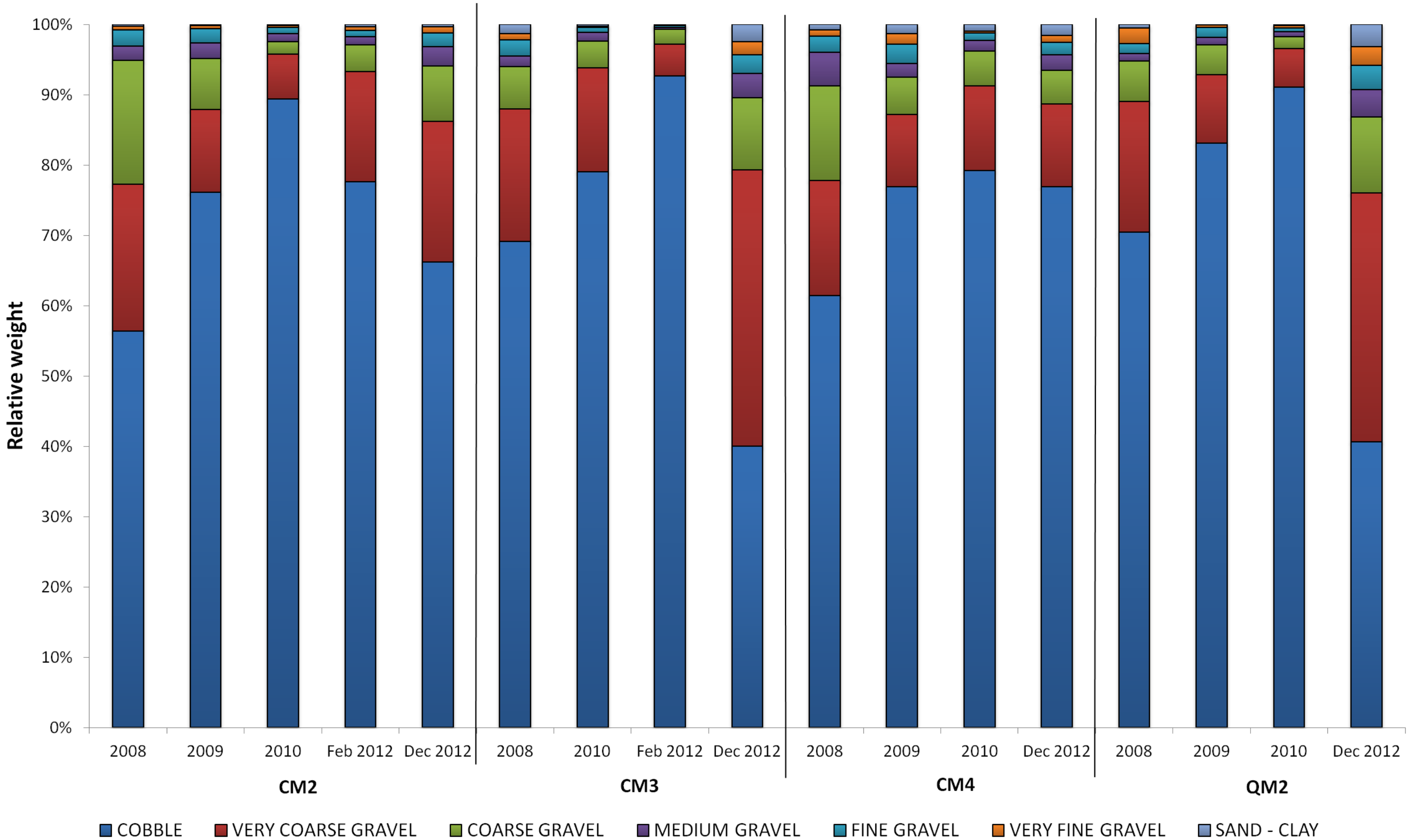

Figure 4. Relative weights of sediment size classes (based on the Wentworth scale; Wentworth 1922) in surface samples from sites on the Cotter River (CM2, CM3, CM4) and Queanbeyan River (QM2), from 2008 to 2012. Cobble (64-256mm); Very coarse gravel (32-64mm); coarse gravel (16-32mm); medium gravel (8-16mm); fine gravel (4-8mm); very fine gravel (2-4mm); sand-clay (<2mm). Note- site CM3 was not sampled in 2009.

Project recommendations

Based on these data it is evident that dam flow releases before the floods have been adequate at maintaining very low levels of fine sediment on riffle surfaces. Large natural flow events appear to be the dominant factor in determining substrate composition downstream of dams in the Cotter and Queanbeyan Rivers. However there is potential for dam operations to alter composition of surface sediment, through mobilising fine particles. We recommend that a revised monitoring program could better address the research objectives of the current program.

Future assessment of riffle maintenance flow releases on the Cotter and Queanbeyan Rivers need to focus more on the assessment of surface sediment composition, given that one of the objectives of riffle maintenance flows is to remove fine sediment from the surface of riffles. Before and after flow release sampling and placement of sites upstream and downstream of tributary inputs will also allow greater assessment of the effectiveness of riffle maintenance flow releases on removing fine sediment from riffle surfaces. The inclusion of unregulated reference sites into the study design will also allow for greater inferential power regarding the effect of riffle maintenance flows on riffle surface sediment composition.

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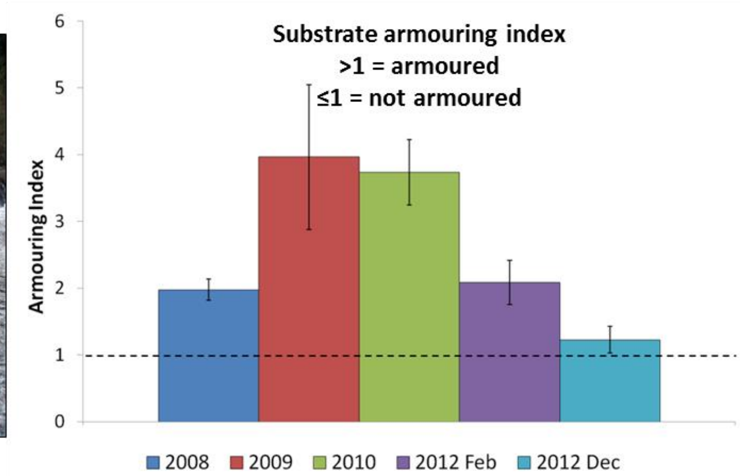
Appendix 1. Riffle sediment survey size classes

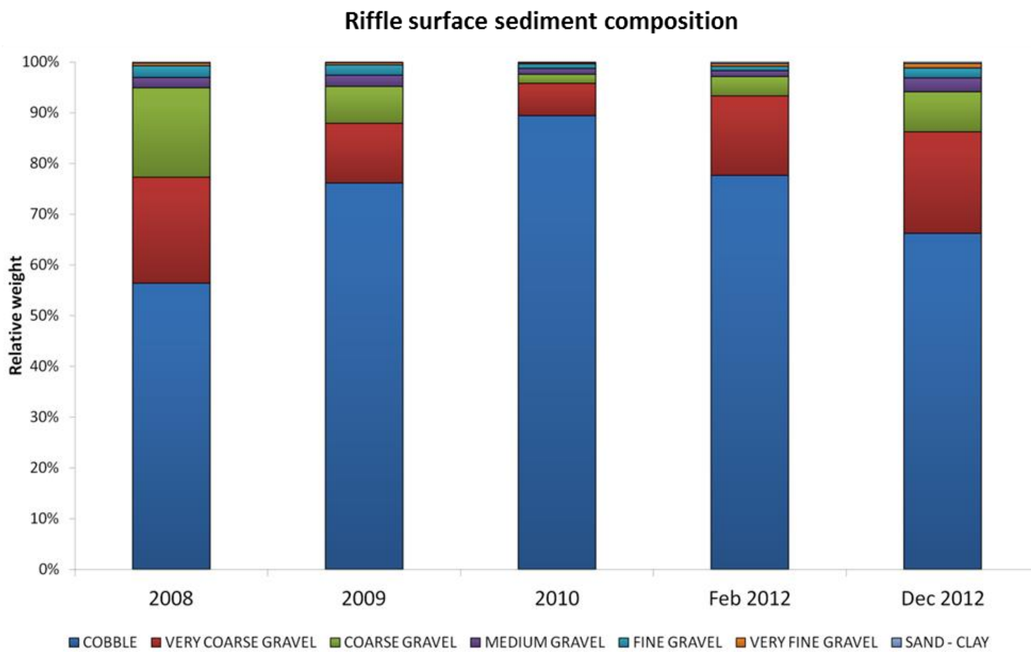
128-256mm
96-128mm
64-96mm
46-64mm
32-46mm
24-32mm
16-24mm
13.2-16mm
8-13.2mm
6.7-8mm
4-6.7mm
2.8-4mm
2-2.8mm
<2mm

Appendix 2. Site summaries

Riffle sediment survey below Bendora, Cotter and Googong Dams – 2012

Downstream of Bendora Dam (CM2) result summary





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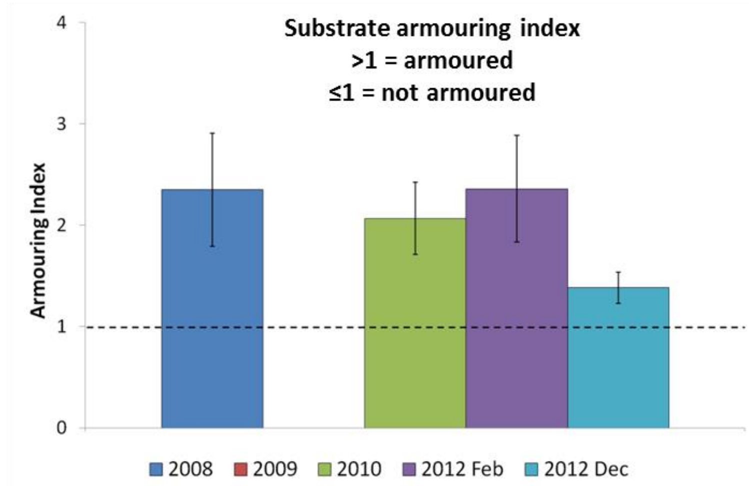
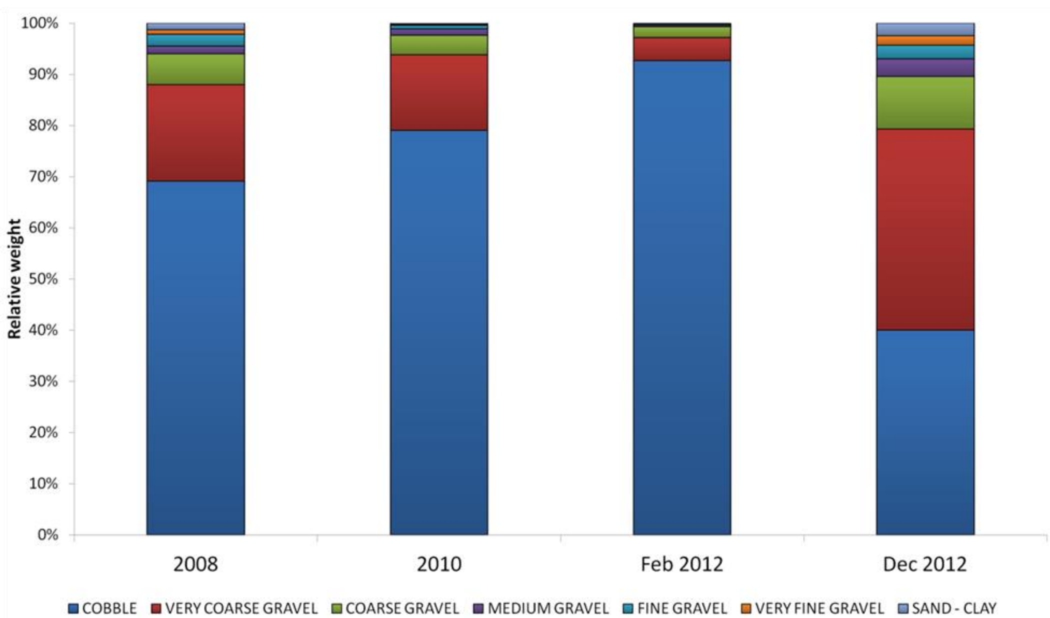
Riffle sediment survey below Bendora, Cotter and Googong Dams – 2012

Downstream of Cotter Dam (CM3) result summary



Riffle surface sediment composition



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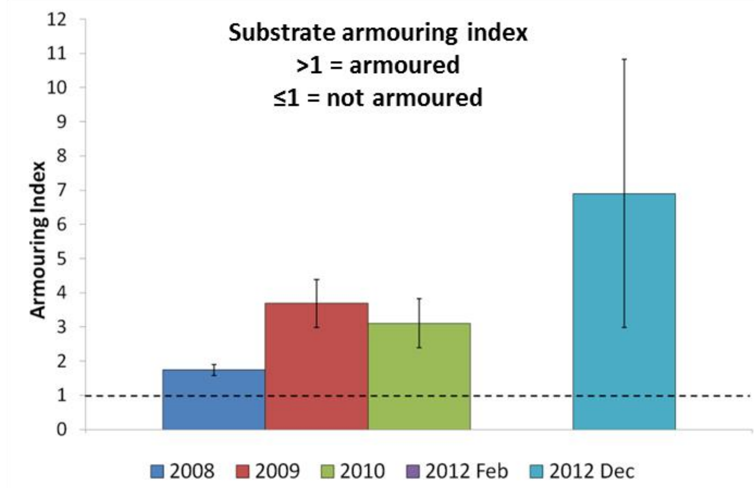
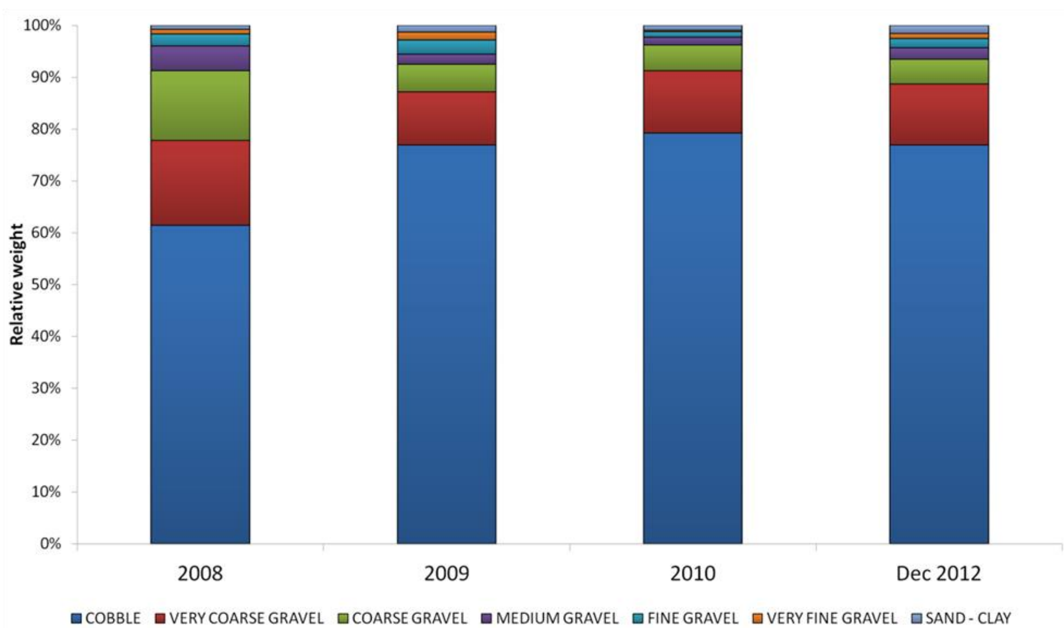
Riffle sediment survey below Bendora, Cotter and Googong Dams – 2012

Downstream of Bendora Dam - Vanitys Crossing (CM4) result summary

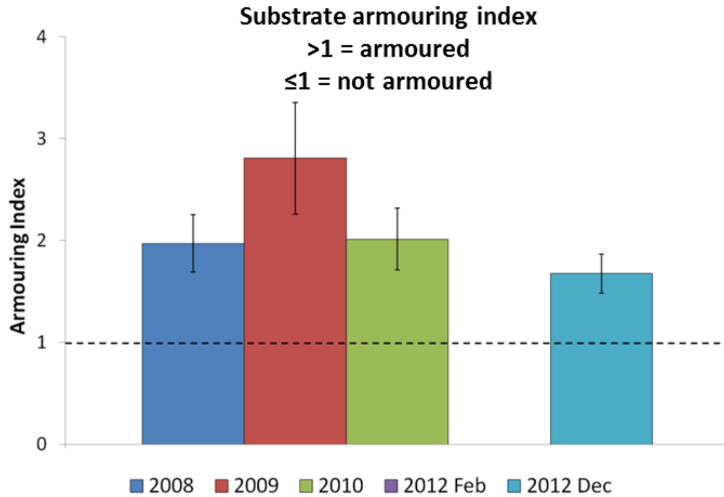


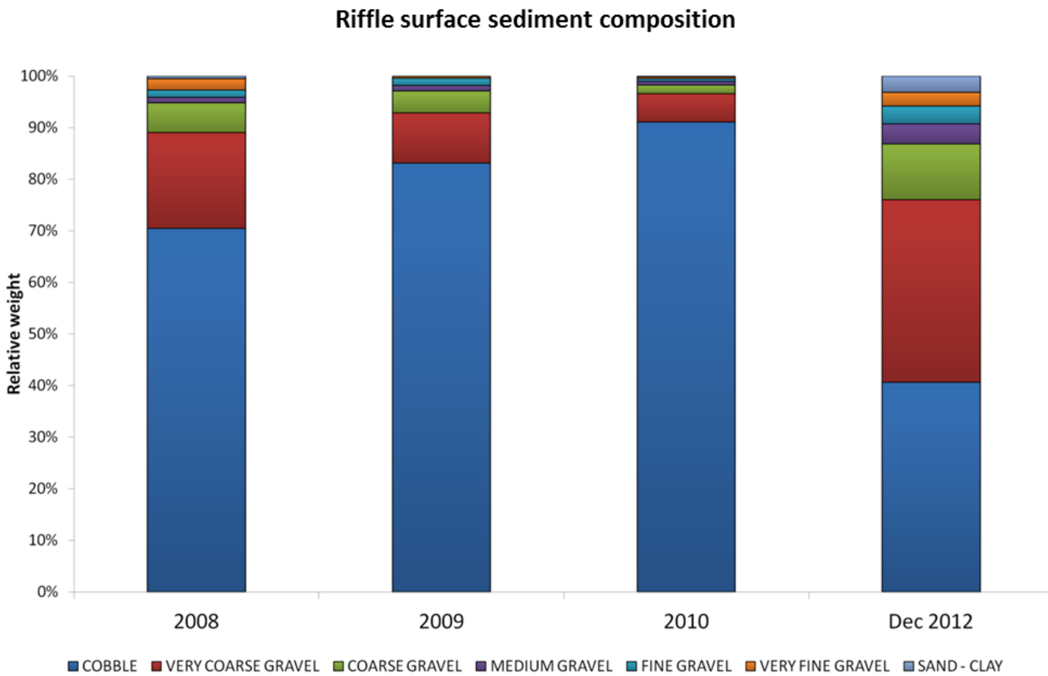
Riffle surface sediment composition



Riffle sediment survey below Bendora, Cotter and Googong Dams – 2012

Downstream of Googong Dam (QM2) result summary





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