Sources of fine grained sediment in incised and un-incised channels, Jugiong Creek, NSW, Australia

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Abstract In southeastern Australia land-use changes due to European settlement (~180 years ago) triggered widespread channel incision, and erosion from these features delivered massive volumes of sediment to rivers. It is proposed that the channels remain a major source of sediment. We use measurements of ^{137}Cs concentrations in soils and sediments to examine sources of fine sediment in incised and un-incised channels. In un-incised channels the ^{137}Cs concentrations decreased to around 40–60% of surface hillslope values by stream order 3, whereas the ^{137}Cs concentrations in incised channels decreased to 10–15% of surface hillslope values in the 1st order streams. In both cases we attribute the decreases in ^{137}Cs concentrations to input of sediment from the channel walls; the input is four times greater in the incised channels. It is concluded that erosion from the walls of incised channels remains a significant source of sediment to rivers in southeastern Australia.

Key words catchment management; channel bank erosion; Cs-137; deposited sediments; gully erosion; land-use change

INTRODUCTION

Subsoil derived from stream incision has been identified as the major contributor to the suspended sediment loads in many large Australian rivers (Prosser *et al.*, 2001a). The rates of release of this material are believed to be much higher than naturally occurred prior to European settlement 180 years ago (Olley & Wasson, 2003). This sediment is recognized as a significant river contaminant causing decreases in stream water quality and alterations to physical habitats (Baldwin *et al.*, 2002). Catchment managers are now required to plan river rehabilitation strategies that achieve greatest benefits in sediment reduction for the least cost. This task is best undertaken by identifying the most active erosion sources. While subsoil sources have been clearly shown to be a significant contributor of sediment to rivers in southeastern Australia (Olley *et al.*, 1993; Wallbrink *et al.*, 1998), the question remains as to whether this material is derived from recent erosion of channel banks or from reworking of sediment stored in the river network. In this paper we use measurements of ^{137}Cs on soils and sediments to compare the sources of sediment in incised and un-incised channels, and determine the contribution of channel bank erosion in these two systems. We focus our attention on material <10 μm, and make the assumption that this represents recent erosional activity given the short residence time of fine sediment in these systems (Wallbrink *et al.*, 1998).

Caesium-137 is a product of atmospheric nuclear weapons testing and is concentrated in surface soil (Walling & He, 1997). It has a half life of 30 years and deposition from testing effectively ceased in Australia by 1970 (Longmore *et al.*, 1983). Sediments derived from hillslope erosion have high concentrations of this radionuclide, while those eroded from gullies or channels have little or none (Wallbrink & Murray, 1993). In this study we compare concentrations of ^{137}Cs on hillslope soils to those on sediments collected from along both un-incised and incised streams of increasing stream order.

STUDY AREA

The Jugiong catchment (34050′S 148040′E) is 2170 km^2 in area and located on the south-western slopes of New South Wales (NSW), Australia (Fig. 1). It was previously identified as the major contributor of fine grained sediment to the Murrumbidgee River, one of Australia's largest rivers (Olive *et al.*, 1996). Agriculture for cereal crops (wheat and canola) occurs on ~20% of the area. Cropping is rotated with pasture for sheep and cattle grazing which occupies the majority of the catchment area. The catchment is dominated by undulating terrain in the northern areas on Silurian granodiorite and is steeper in the south on Silurian dacite, where the density of channel incision is higher (Zierholz *et al.*, 2001).

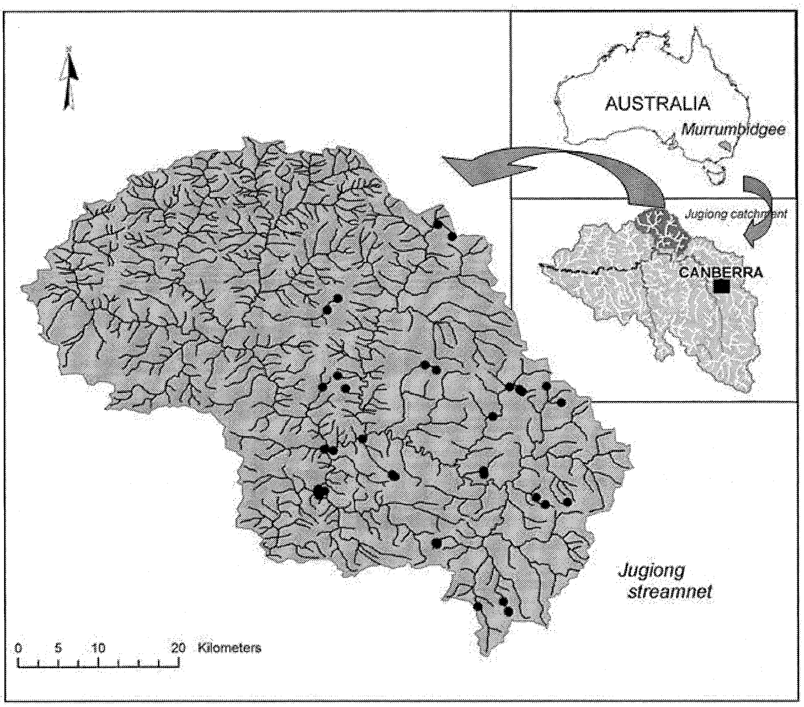

Fig. 1 Site location diagram, Jugiong Creek, NSW, Australia.

SAMPLE COLLECTION AND TREATMENT

The incised and un-incised channel networks in the catchment have been mapped and incorporated into a GIS database by Zierholz *et al.* (2001). We use this database in our study to identify stream sections from order 1 to 6, according to Strahler (1969), in both un-incised and incised sections of the network. A summary of the number of replicates of each order

Table 1 Number of locations for which ^{137}Cs concentrations have been analysed on the <10 µm fraction of a representative mixed sediment sample.

Channel type	Hillslope positions	Stream order (according to Strahler, 1969)					
		1st	2nd	3rd	4th	5th	6th
Un-incised	8	16	5	2	1	1	0
Incised		6	4	0	1	1	3

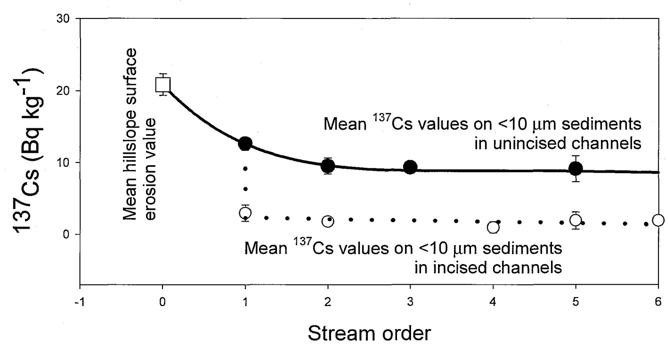

Fig. 2 Concentrations of ^{137}Cs (Bq kg^{-1}) on <10 µm fraction of soils (open squares) and sediments in un-incised (closed circles) and incised (open circles) channels, Jugiong Creek, NSW, Australia.

stream for each channel type is given in Table 1. As many reaches of the same stream order were sampled as practicably possible; though the number of high order streams that were un-incised in their lower order tributaries was limited, thus constraining the number of sites available. The locations of the reaches are given as circles in Fig. 2. In each of the selected reaches 20–40 grab samples of recently deposited sediment was collected. These samples were then combined to give one sample from each reach. Each of these reach samples was then analysed for its ^{137}Cs concentration (see below).

To characterize the ^{137}Cs concentration on sediments derived from hillslope erosion a series of samples were taken from uncultivated slopes around the Jugiong catchment incorporating a range of different slope positions and slope angles. At each location a number of surface scrapes (20–30) to 10 mm depth were then taken over a hillslope surface area of ~400 m^{-2}. This material was then mixed together to provide a single "averaged" ^{137}Cs concentration value for that hillslope position and location. The mixing procedure was used to average out the variability in soil ^{137}Cs concentrations that arise from initial fallout (Wallbrink *et al.*, 1994). The number of hillslope sampling locations is also summarized in Table 1.

Measurements were made on samples fractionated by a combination of wet-sieving and settling to recover the <10µm fraction (clay and fine silt). This is the fraction that corresponds best to sediment transported in the suspended form. Furthermore, most of the nutrients and contaminants associated with sediment are in this fraction. All discussion hereafter pertains to our analyses of this fine sediment fraction. The ^{137}Cs concentrations were determined by routine high resolution gamma spectrometry, using the methods described by Murray *et al.* (1987). The detectors used in this study are n-type closed ended co-axials. Detection limits were about ±0.3 Bq kg^{-1} for ^{137}Cs. Count times were typically one day. The data was time corrected to June 2000.

RESULTS

The ^{137}Cs concentrations (Bq kg^{-1}) on the <10 μm fraction from the Jugiong catchment hill-slopes were in the range 15–24 Bq kg^{-1} with a weighted mean of 20.6 ± 1.5 Bq kg^{-1} (uncertainties given as standard errors: Fig. 2). These values are consistent with those from surface soils in the general region (see Wallbrink & Murray, 1993; Wallbrink *et al.*, 1998). The mean ^{137}Cs concentrations on deposited sediments in the un-incised channels are also given in Fig. 2 (closed circles). The mean concentrations decreased from ~12.6 ± 1.0 Bq kg^{-1} in the first-order streams to 9.1 ± 1.8, and 9.3 ± 1.8 Bq kg^{-1} respectively in the 3rd and 5th order streams. Given the uncertainties, this indicates a varying hillslope contribution to these stream orders of between 60–40%, assuming a two component mix between surface soils and channel wall material (Wallbrink *et al.*, 1996).

The ^{137}Cs concentrations from the incised channels are given as the open circles in Fig. 2 and are much lower (by a factor of 4) than those in the un-incised channels. The mean concentration in the first order streams of 3.0 ± 1.1 Bq kg^{-1} indicates a hillslope contribution of only ~15%. The mean value is 1.8 ± 0.5 Bq kg^{-1}in 2nd order streams and then remains low and constant in higher order streams thereafter. Using the procedure above, these data indicate a varying hillslope contribution of only 10–15% for incised stream orders 1–6, and that the major contribution from channel walls has probably already occurred by 3rd order streams. These ^{137}Cs sediment concentrations are also similar to those observed in the main channel of the Murrumbidgee River (reported by Wallbrink *et al.*, 1998) and are a marked contrast to those in the un-incised channels.

DISCUSSION

A USLE based erosion map of Lu *et al.* (2001) shows that erosion is in the range 0–10 t ha year^{-1} for hillslopes of both incised and un-incised streams in the Jugiong catchment. Thus, if we assume that the hillslope contribution to the un-incised and the incised streams are similar, then the ^{137}Cs data indicate that channel erosion in incised streams contributes ~4 times more sediment than that in un-incised channels. It is unlikely that these differences are due to lithology as the incised and un-incised channels were selected across the two major rock types in the catchment. The largest decrease in ^{137}Cs concentrations occurs in the first order streams, with concentrations in the un-incised stream being half those of the hillslope sediments, and those in the incised stream being 1/7th of values from hillslope sediments. A similar large decrease in ^{137}Cs concentrations was shown to arise from sediment input from 1st order channel walls in rainfall simulator experiments in the Goulburn region, NSW. In these experiments the ^{137}Cs concentrations on material eroding directly from gully walls was extremely low and sediment production from them substantially diluted the high concentrations on the material eroded from the surrounding surface areas (Wallbrink & Murray, 1993).

The ^{137}Cs concentrations in the 3rd to 6th order incised channels 1.9 ± 0.6 Bq kg^{-1} are also similar to those observed in the main channel of the downstream Murrumbidgee River 2.1 ± 0.3 Bq kg^{-1} (time corrected from data in Wallbrink *et al.*, 1998). This result is consistent with sediment in the main channel being primarily derived from erosion of channel walls in 1st to 3rd order incised streams, and that the relative proportions of hillslope and channel erosion remain approximately constant thereafter.

CONCLUSIONS

We have used the reduction in ^{137}Cs concentrations on deposited stream sediments relative to the initially high concentrations of hillslope eroding material, to infer that channel walls dominate sediment supply in incised channels. This work indicates that management action to reduce sediment delivery to the main channel of the Murrumbidgee River needs to focus on channel erosion, particularly in the 1st to 3rd order incised streams. The management effort should concentrate on improving and protecting riparian vegetation along channels. It should be noted that most sediment will be delivered during infrequent floods (Olive *et al.*, 1996) so management strategies must be robust enough to cope with erosion and sediment delivery occurring during these events.

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