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Establishing fine-grained sediment budgets for the Pang and Lambourn LOCAR catchments, UK

D.E. Walling [a,*], A.L. Collins [a,1], P.A. Jones [a], G.J.L. Leeks [b], G. Old [b]

[a] *Department of Geography, University of Exeter, Amory Building, Rennes Drive, Exeter, Devon EX4 4RJ, UK*
[b] *Centre of Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK*

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Summary An integrated approach to data collection, combining the use of ^{137}Cs measurements, sediment source fingerprinting, bed sediment surveys and conventional river monitoring, has been successfully employed to establish the fine-grained sediment budgets of two lowland groundwater-fed catchments in the UK. Gross surface erosion is higher on cultivated land (Pang: 55263 t yr^{-1} or 507 t km^{-2} yr^{-1}; Lambourn: 79997 t yr^{-1} or 437 t km^{-2} yr^{-1}) than on pasture (Pang: 1960 t yr^{-1} or 140 t km^{-2} yr^{-1}; Lambourn: 1425 t yr^{-1} or 95 t km^{-2} yr^{-1}) in both study areas and a substantial proportion of the mobilized sediment is sequestered within the fields (Pang: 28058 t yr^{-1} or 228 t km^{-2} yr^{-1}; Lambourn: 55575 t yr^{-1} or 281 t km^{-2} yr^{-1}) and between the individual fields and the river channel network (Pang: 28672 t yr^{-1} or 233 t km^{-2} yr^{-1}; Lambourn: 24782 t yr^{-1} or 125 t km^{-2} yr^{-1}). The sediment contribution from banks and subsurface sources is relatively low and typically ca. 5 t yr^{-1} in the Pang and ca. 11 t yr^{-1} in the Lambourn, representing only about 1% of the suspended sediment output from each study catchment. The mean level of fine-grained sediment storage in the main channel system is equivalent to 38% (Pang) and 21% (Lambourn) of the respective mean annual suspended sediment yields of the two catchments. The estimated sediment delivery ratio for both study catchments is ca. 1%.

The context

The Chalk streams of southern and eastern England are characterized by essentially unique hydrological regimes and aquatic habitats. Flow and thermal regimes evidence high stability, due to the dominance of groundwater inputs. High mineral concentrations and the high light penetration associated with the low turbidities encourage extensive macrophyte growth (e.g. *Ranunculus pencillatus var.*), whilst the abundance of plants and detritus supports a diverse community of benthic invertebrates, including mayfly nymphs, caddis larvae, oligochaete worms, stoneflies and white-clawed crayfish (Westlake et al., 1972; Berrie, 1992). Many aspects of the hydrological and ecological func-

* Corresponding author. Tel.: +44 1392 263345; fax: +44 1392 263342.
E-mail address: d.e.walling@exeter.ac.uk (D.E. Walling).
[1] Present address: Environment Systems, ADAS, Woodthorne, Wergs Road, Wolverhampton WV6 8TQ, UK.

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tioning of lowland permeable catchments draining areas of Chalk are, however, relatively poorly understood.

The unique characteristics of Chalk streams make them particularly susceptible to anthropogenic impacts associated with water abstraction, urban and infrastructure development, agricultural activities, land drainage, effluent discharges and flood alleviation schemes. Consequently, an Environment Agency survey undertaken in 2000 (UK Biodiversity Action Plan Steering Group for Chalk Rivers, 2004) showed that only 37% of Chalk streams in England could be classed as 'very good' in terms of chemical and biological quality. Increased suspended sediment concentrations, which result in increased turbidities and reduced light penetration as well as the siltation of salmonid spawning gravels, the accumulation of sediment within channel and channel-margin habitats, and the presence of increased sediment-associated nutrient and contaminant loadings, have frequently been cited as important contributors to the degradation of Chalk stream ecosystems and the associated 'Chalk stream malaise' (UK Biodiversity Action Plan Steering Group for Chalk Rivers, 2004). Whilst point inputs of suspended solids from watercress beds and sewage treatment works contribute to these 'sediment problems', changing agricultural land use and, more particularly, the increase in arable cultivation and the associated expansion of the area of autumn-sown cereals and fodder maize, which in turn result in increased rates of soil erosion and sediment mobilization and sediment transfer to the streams, are frequently cited as a key cause. Sedimentation problems are often exacerbated by groundwater extraction, which reduces flows and the natural flushing action of higher discharges, compounding their negative impacts on macrophyte communities (Clarke and Wharton, 2001), invertebrate biodiversity (Scullion, 1983) and fish populations (Acornley and Sear, 1999). Developing an improved understanding of the fine sediment dynamics of UK Chalk stream catchments, including, sediment sources, sediment mobilization, transfer and storage, and sediment yields, must be seen as a key requirement to inform the development and implementation of improved sediment control strategies and catchment management policies.

In response to the need to develop an improved understanding of the hydrology and ecology of lowland permeable catchments in the UK and for reliable information to assist the management of these fragile hydroecological systems, the UK Natural Environment Research Council established the LOCAR (Lowland Catchment Research) thematic programme. LOCAR targeted its investigations and field-based monitoring in three main study areas, namely, the Frome/Piddle in Dorset, the upper Tern in Shropshire and the Pang/Lambourn in Berkshire. A project aimed at undertaking a detailed investigation of the fine sediment budgets of the study catchments was included within the LOCAR research programme and this contribution reports some of the findings of the investigations undertaken with the Pang and Lambourn catchments. Whilst focusing on these two catchments, the results are likely to be of relevance to Chalk catchments in the UK, more generally, and they also afford a useful and timely contribution to ongoing international research on catchment sediment budgets. The important need for field-based studies of catchment sediment budgets has, for example, been explicitly emphasized by Trimble and Crosson (2000).

The study areas

The Pang ($\sim$166 km^2) and Lambourn ($\sim$234 km^2) catchments are both underlain by the Chalk aquifer of the West Berkshire Downs. The mean annual precipitation (1961–1990) over the Pang catchment lies in the range 647–706 mm, whilst that for the Lambourn catchment is slightly higher and in the range (698–793 mm). Intensive arable agriculture has become increasingly widespread in the Pang catchment over the past few decades and there has also been an expansion of Christmas tree cultivation and free range pig rearing. Recent years have also seen a substantial increase in groundwater abstraction for public supply, and the reduced flows, coupled with the increased risk of soil erosion within the catchment associated with land use change, have resulted in increased concern for 'sediment problems' and their impact on the local EC-designated salmonid fishery. The Lambourn catchment is less intensively farmed and is characterized by a more natural stream system, supporting good populations of trout and grayling and considerable invertebrate diversity. It is one of 27 rivers in the UK designated as a Site of Special Scientific Interest (SSSI). Routine water quality monitoring stations were installed in association with the LOCAR programme at Frilsham, Bucklebury and Tidmarsh Mill in the Pang catchment, and at East Shefford and Shaw in the Lambourn catchment (see Fig. 1).

Methodology

The sediment budget approach

The sediment budget concept provides a valuable framework for assembling the information necessary for understanding and interpreting fine sediment mobilization, delivery, storage and output at the catchment scale (Dietrich and Dunne, 1978; Swanson et al., 1982; Golosov et al., 1992; Nelson and Booth, 2002). Establishing a sediment budget provides a means of clarifying the link between upstream erosion and downstream sediment yield and the role of sediment storage (Walling, 1983, 1999; Dunne, 1994; Trimble, 1995; Trimble and Crosson, 2000; Slaymaker, 2003). Storage frequently equals or exceeds sediment output (Phillips, 1991; Walling et al., 1998).

Despite the obvious utility of the sediment budget concept, it remains difficult to assemble the necessary information for anything other than a small (e.g. <10 km^2) drainage basin. Traditional techniques available for investigating sediment mobilization by erosion and sediment storage, within a catchment, are hampered by significant spatial and temporal sampling constraints (Peart and Walling, 1988; Loughran, 1989; Phillips, 1991; Collins and Walling, 2004), numerous operational problems and the costs incurred in assembling representative datasets (Slaymaker, 2003).

Although there is no commonly accepted and generally applicable methodology for establishing a catchment sediment budget, recent work at the University of Exeter has successfully developed and tested an integrated approach