Geoderma 155 (2010) 249–261

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

# Apportioning catchment scale sediment sources using a modified composite fingerprinting technique incorporating property weightings and prior information

A.L. Collins [a,*], D.E. Walling [b], L. Webb [c], P. King [c]

[a] Environment Group, ADAS, Woodthorne, Wergs Road, Wolverhampton WV6 8TQ, UK
[b] School of Geography, Archaeology and Earth Resources, University of Exeter, Rennes Drive, Exeter EX4 4RJ, UK
[c] Environment Agency, Rivers House, East Quay, Bridgwater TA6 4YS, UK

ARTICLE INFO

*Article history:*
Received 15 April 2009
Received in revised form 2 October 2009
Accepted 9 December 2009
Available online 8 January 2010

*Keywords:*
Sediment source fingerprinting
Uncertainty
Monte Carlo
Prior information
Sediment mitigation
Cross sector
England Catchment Sensitive Farming Delivery Initiative

ABSTRACT

Sediment fingerprinting techniques provide a means of assembling valuable reliable information on the principal sources of sediment problems at catchment scale. However, there is a need to refine existing approaches to take account of a variety of sources of uncertainty and to incorporate prior information. To address this need, a modified mass balance model incorporating a Monte Carlo approach for representing the uncertainty surrounding source and sediment sampling, as well as weightings to take account of the within-source variability and discriminatory power of individual tracer properties and prior information on bank erosion, was used to apportion recent sediment sources in sub-catchments of the Somerset Levels, south west UK. Sensitivity tests confirmed that the precision of source apportionment was improved by incorporating the weightings and prior information into the mixing model. Estimates of the overall mean contributions from individual source types, bounded by 95% confidence limits, were assessed to be 42 ± 2% (pasture topsoils), 22 ± 2% (cultivated topsoils), 22 ± 1% (channel banks/subsurface sources), 12 ± 2% (damaged road verges) and 2 ± 1% (STWs). Respective estimates of net sediment delivery to watercourses, provided by integrating the source ascription results with estimated sediment yield ranges and sub-catchment or land use areas, ranged between 33–829 kg $ha^{-1} yr^{-1}$, 30–1995 kg $ha^{-1} yr^{-1}$, 2–315 kg $ha^{-1} yr^{-1}$, 0–217 kg $ha^{-1} yr^{-1}$, and 0–28 kg $ha^{-1} yr^{-1}$. Sediment fingerprinting should always include uncertainty analysis but on the understanding that the latter will be conditional on the assumptions used.


## 1. Introduction

There is growing appreciation of the pivotal role of sediment in catchment diffuse pollution issues. Excessive fine sediment loadings in the water column increase turbidity, restrict light penetration and thereby reduce primary production (Davies-Colley et al., 1992; Wood and Armitage, 1997). Accelerated sedimentation smothers river substrates (Richards and Bacon, 1994), alters channel morphology (Wright and Berrie, 1987) and reduces the availability of high quality habitat for benthic organisms (Wilbur and Clarke, 2001) and aquatic flora (Best et al., 2001). Enhanced ingress of fine sediment into spawning gravels reduces hyporheic exchanges which are important for sustaining incubating progeny (Packman and Mackay, 2003). In addition, fine sediment represents a key vector governing the transfer and fate of nutrients, organic and inorganic contaminants and trace or heavy metals (Sibbesen and Sharpley, 1997; Meharg et al., 1999; Warren et al., 2003; Jamieson et al., 2005; Collins et al., 2005; Sormunen et al., 2008).

Given widespread concerns about diffuse pollution in England, including sediment, the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) identified 40 priority catchments in April 2006 where stakeholders require assistance to improve the protection of aquatic habitats (Collins et al., 2007). Catchment Sensitive Farming Officers (CSFOs) are responsible for appraising pollutant pressures and impacts and for devising support and advice for stakeholders including workshops, seminars and farm demonstrations. The ECSFDI focuses upon the delivery of evidence-based advice and the programme has recently been expanded to a further 10 catchments.

Specification and delivery of appropriate management solutions requires an understanding of the sediment problem at catchment scale and a focus upon the key sources involved. Due to the problems associated with documenting catchment sediment sources using indirect approaches founded upon erosion measurements (Collins and Walling, 2004), the direct approach based on fingerprinting procedures, has attracted increasing attention as an alternative means of assembling the information required (Walling et al., 1993; Walling and Woodward, 1995; Collins et al., 1996; Collins et al., 1997a, 1997b, 1998, 2001; Wallbrink et al., 1998; Walling et al., 1999; Bottrill et al., 2000; Foster and Lees, 2000; Russell et al., 2001; Collins and Walling, 2002; Carter et al., 2003; Wallbrink et al., 2003; Krause et al., 2003; Motha et al., 2004; Walling, 2005; Collins and Walling, 2006, 2007a; Foster et al., 2007; Minella et al., 2008a; Stutter et al., 2009; Wilkinson et al., 2009). Sediment source fingerprinting is founded upon the link

* Corresponding author. Tel.: +44 1902 693404; fax: +44 1902 693400.
*E-mail address:* adrian.collins@adas.co.uk (A.L. Collins).

0016-7061/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2009.12.008

**Table 1**
Potential sources of uncertainty influencing the deployment of the sediment fingerprinting approach.

| Fieldwork | Laboratory analysis | Mass balance modelling |
|---|---|---|
| Identification of all principal sources | Sieving of samples | Particle size and organic matter correction |
| Spatial and temporal representativeness of source material sampling | Fingerprint property extraction error | Spatial and temporal variability of source and sediment tracers |
| Spatial and temporal representativeness of sediment sampling | Fingerprint property analytical error | Source contribution boundary constraints |

between the geochemical properties of suspended sediment and those if its sources. Assuming potential sediment sources can be readily distinguished on the basis of their constituent properties or 'fingerprints', the provenance of the sediment transported by the river can be established using a comparison of its properties with those of the individual potential sources.

There are a number of sources of uncertainty that should be recognised when using the fingerprinting approach to apportion sediment sources (Table 1). Previous work has highlighted both the uncertainty associated with characterising the fingerprint property values of potential sediment sources required as input for sediment mixing models and the associated sampling density (e.g. Rowan et al., 2000; Franks and Rowan, 2000; Small et al., 2002; Krause et al., 2003; Motha et al., 2004; Small et al., 2004; Collins and Walling, 2007a,b; Fox and Papanicolaou, 2008a) and the need to include particle size and organic matter content corrections in mass balance models in recognition of potential changes in fingerprint properties during sediment delivery due to the grain size selectivity of sediment mobilisation, transport and deposition processes (Collins et al., 1997a, Krause et al., 2003; Motha et al., 2004; Small et al., 2004). The sediment mixing model proposed by Collins et al. (1997a) also incorporated the uncertainty associated with fingerprint property analytical error. Recent work by Minella et al. (2008b) has examined the uncertainty associated with source contributions using a likelihood function approach. Less attention has been directed towards examining the potential benefits for reducing uncertainty ranges in source contributions by using weightings to take explicit account of the within-source variability of individual tracer properties and their discriminatory power, as well as manipulating source contribution boundary constraints on the basis of prior information.

On the basis of its existing and successful application, the fingerprinting approach was selected as being the most appropriate means of assembling catchment scale sediment source apportionment data for a project commissioned by the Environment Agency to assemble reliable information on sediment sources in the Somerset Levels ECSFDI priority catchment, south-west UK. The project afforded a convenient opportunity to continue refining an existing sediment source fingerprinting procedure and the specific objectives were;

- to examine the potential benefits of applying weightings to reflect the within-source variability of tracer property values and the discriminatory power of those properties for reducing the uncertainty ranges in sediment source contributions
- to examine the corresponding potential benefits of including prior information on channel bank erosion inputs in addition to the weightings
- to provide the CSFO with reliable sediment source data to help target advice and mitigation planning.

In order to support the CSFO in presenting a balanced evidence base to stakeholders, the sediment sourcing exercise aimed to assemble information on the contributions from different sectors as opposed to just those from agriculture alone (cf. Collins and McGonigle, 2008).

## 2. Study area

The Somerset Levels ECSFDI priority catchment represents one of the UK's largest and most important wetland areas of high conservation importance, but within the context of intensive agriculture. Soils are dominated by heavy clays and clay loams as well as loamy peats. Soil degradation as a result of livestock or crop management is widespread (Palmer, 2003). Land use data are summarised in Table 2. Agricultural land use is dominated by grassland especially in northern areas, with a shift towards more mixed and arable farming enterprises further south. Average annual rainfall (1971–2000) varies between 700 and 1220 mm with the north and south of the catchment being wetter than central areas. Soil erosion, sediment delivery and siltation have been identified as problems during the catchment characterisation phase of ECSFDI.

## 3. Methods

The source fingerprinting approach was used to apportion sediment source types in the catchments of the River Brue above North Drain pumping station, the River Cary above Low Ham Bridge, the Halse Water upstream of Norton Fitzwarren, the River Isle above Midelney Bridge, the River Tone above Knapp Bridge, the upper River Parrett upstream of Kingsbury Episcopi and the River Yeo above Yeovilton (Fig. 1). In addition, the exercise also aimed to provide information on the relative contributions of the three sub-catchments of the River Parrett upstream of Middle Moor (Fig. 1), by treating these sub-catchments as spatial sources.

**Table 2**
Summary information on the study sub-catchments.

| Sub-catchment | Area ($km^2$)[a] | % urban[b] | % freshwater[b] | % grassland[b,c] | % arable[b] | % woodland[b] |
|---|---|---|---|---|---|---|
| Brue | 373.0 | 9.0 | 0.7 | 75.7 | 8.4 | 6.1 |
| Cary | 95.9 | 10.3 | 0.5 | 49.4 | 33.7 | 6.2 |
| Halse Water | 41.4 | 6.0 | 0.9 | 57.7 | 29.8 | 5.6 |
| Isle | 159.3 | 7.1 | 0.8 | 53.0 | 31.8 | 7.2 |
| Tone | 396.7 | 9.6 | 1.1 | 55.2 | 25.8 | 8.3 |
| Upper Parrett | 153.8 | 10.5 | 0.9 | 50.7 | 31.8 | 6.1 |
| Yeo | 314.1 | 11.4 | 0.9 | 55.0 | 26.1 | 6.5 |
| Parrett | 764.9 | 9.7 | 0.9 | 53.6 | 29.6 | 6.2 |

[a] Based on Environment Agency data from the Flood Estimation Handbook.
[b] Based on the MAGPIE database system (Lord and Anthony, 2000).
[c] Rough and improved grassland combined.