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The grain size characteristics of overbank deposits on the flood plains of British lowland rivers

D. E. WALLING, D. FANG, A. P. NICHOLAS & R. J. SWEET
Department of Geography, University of Exeter, Exeter EX4 4RJ, UK
d.e.walling@exeter.ac.uk

Abstract River flood plains are attracting increasing attention because of their wide-ranging environmental significance. In the UK, little is currently known regarding the grain size composition of the fine-grained overbank deposits that dominate most lowland river flood plains. This paper reports the findings of a study aimed at investigating the grain size composition of the overbank flood plain deposits associated with the flood plains of six rivers in southern Britain, embracing a range of catchment characteristics and hydrological conditions. More than 900 cores were collected from representative reaches along the flood plains of the six rivers and their grain size composition was determined. Analysis of the results obtained focuses on contrasts between the rivers, on within-reach and longitudinal variability in grain size composition and on the relationship between grain size composition and sedimentation rate.

Key words fine sediment; flood plain; grain size; overbank deposits; sediment cores; sedimentation rate; southern Britain

INTRODUCTION

River flood plains have long attracted the interest of geomorphologists, both in terms of their contemporary development as readily identifiable fluvial landforms and the potential of their sediments to provide information on past catchment response to environmental change (Hudson, 2003). However, in recent years there has also been a growing recognition of their wider environmental significance. This significance relates particularly to the flood plains of lowland rivers, where overbank deposition, rather than channel migration, represents the key mode of flood plain development. Such flood plains represent an important interface between the river channel and the surrounding catchment and a key component of the river corridor, with its distinctive habitats (Dyer *et al.*, 2002). In addition, these flood plains frequently serve as natural flood control reservoirs. Furthermore, when viewed in a wider catchment context, the overbank deposition that constitutes the primary mechanism for their development also represents an important sink in the transfer of both sediment and sediment-associated nutrients and contaminants from a catchment to its outlet (Walling *et al.*, 1999; Walling & Owens, 2003). Although relatively stable at present, future changes in river response associated with climate change could result in remobilization of the large stores of sediment that have accumulated in these river flood plains.

Against this background, there is a need to develop an improved understanding of the physical properties of the fine overbank deposits that are a key feature of lowland river flood plains. Although, such deposits are known to result primarily from deposition of suspended sediment transported by the river during overbank flood events, and are therefore necessarily fine-grained, relatively little detailed information is currently available in the UK regarding their grain size composition, and the spatial variation of this composition, both within the flood plain of a particular river and between rivers. This contribution reports information on the grain size composition of overbank flood plain deposits obtained from a recent investigation of sediment deposition on the flood plains of six rivers in southern Britain.

THE STUDY RIVERS AND THEIR FLOOD PLAINS

The six rivers were selected to be representative of a range of conditions within southern Britain, including both the underlying geology and terrain characteristics of their catchments and their hydrological response. The location of the rivers selected is shown in Fig. 1 and further details of their catchment and hydrological characteristics are provided in Table 1. Key contrasts include those between the Rivers Exe and Usk, which rise in the wetter upland areas of Exmoor and the Brecon Beacons, respectively, and the Rivers Culm and Stour, whose catchments are more lowland in character and receive substantially less rainfall. The Rivers Torridge and Axe can be seen as intermediate between these two extremes, draining areas of moderate relief. Equally, the underlying geology ranges from the indurated Devonian and Carboniferous slates and sandstones occupying much of the catchments of the Exe, Usk and Torridge, to the softer and more permeable Permian, Triassic, Jurassic and Cretaceous sandstones, marls, shales and clays and the chalk found in the catchments of the Culm, Axe and Stour. These contrasts in topography, underlying geology and annual precipitation give rise to further contrasts in soils and land use. Information on the suspended sediment yields of the study catchments is limited, but estimates of the specific suspended sediment yields are also provided in Table 1. These values must be seen as relatively low by world standards. Similarly, only limited information is available on the grain size composition of the suspended sediment loads of the study rivers, but available data indicate that the sediment loads are relatively fine. Median grain size or d_{50} values for the absolute size distributions are likely to be within the range 5–15 μm and the percent sand content is typically about 10% (Walling & Woodward, 2000).

The flood plains of the study rivers are characterized by subdued microtopography, with the local relief rarely exceeding 1 m amplitude. Flood plain widths along the main channel systems of the study rivers range from a minimum of about 160 m to a maximum of 1150 m, with mean values for the individual rivers ranging from ~300 m (River Torridge) to 630 m

Table 1 Some characteristics of the study rivers and their catchments.

River	Catchment area[a] (km^2)	Mean altitude (m)	Mean slope ($m\ km^{-2}$)	Dominant lithology	Mean annual precipitation (mm)	Specific sediment yield[c] ($t\ km^{-2}\ year^{-1}$)
Axe	303	134	90	sandstone, marl, shale	991	ca 50
Culm	276	140	71	sandstone, marl	952	ca 25
Exe[b]	908	208	116	sandstone, slate, marl	1148	ca 30
Stour	1067	85	51	clay, chalk	861	ca 30
Torridge	723	156	83	slate, sandstone	1176	ca 75
Usk	1124	273	149	sandstone	1304	ca 50

[a] The catchment area listed represents the catchment area above the lowest flood plain reach investigated.
[b] The data for the River Exe are based on the combined catchments of the Rivers Exe and Culm.
[c] The values of specific suspended sediment yield listed are estimates based on available data.

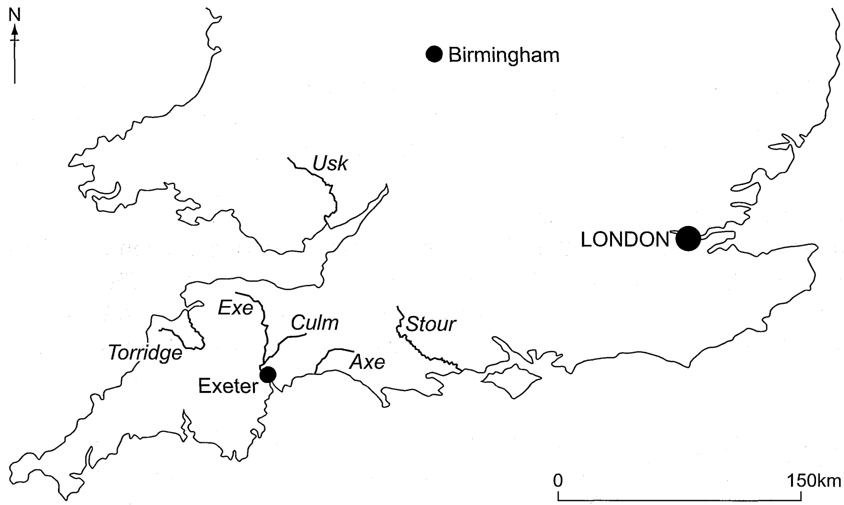

Fig. 1 The six study rivers and their location in southern Britain.

(River Stour). Distinct natural levees are generally absent from the flood plains, probably as a result of the low sand content of the suspended sediment loads transported by the rivers. The flood plains of the study rivers are regularly inundated on several occasions each year, typically during the winter months, although the depth of inundation does not generally exceed 1 m.

DATA COLLECTION

Attention focused on the flood plains bordering the main channels of the six study rivers. In each case, the main channel was subdivided into a number of segments (six for the Exe and eight for the other rivers), and representative reaches of flood plain (~600 m in length) were identified for each of these segments. Within these reaches, 20 bulk sediment cores were collected to a depth of ~0.6 m using a motorized percussion corer equipped with a 6.9 cm diameter core tube. The cores were collected from a representative range of locations, aimed at embracing likely contrasts in sedimentation rate and sediment properties associated with both distance from the channel and different morphological features. Visual inspection of the cores confirmed that, in all cases, they were composed entirely of fine overbank deposits and that there was no clear evidence of major downcore changes in texture.

After drying, disaggregation and sieving (2 mm) to remove coarse organic debris, the grain size composition of a representative subsample of sediment from each core was determined. Grain size analysis was undertaken on chemically dispersed samples, from which organic matter had been removed by treatment with hydrogen peroxide, using a Coulter LS 200 laser granulometer. Estimates of the specific surface area of the samples (m^2 g^{-1}) were derived numerically from the grain size distributions, assuming spherical particles. As part of wider investigations, the cores were also assayed for their Cs-137 inventories by gamma spectrometry, in order to derive estimates of medium-term sedimentation rates at the sampling points (Walling & He, 1997; Walling *et al.*, 1999).

RESULTS

Information regarding the mean values for selected measures of grain size composition obtained for the cores collected from the individual study rivers are presented in Table 2. These measures comprise specific surface area ($m^2\ g^{-1}$), median diameter or d_{50} (μm), percent clay, and percent sand. The results presented in Table 2 emphasize the fine-grained nature of the overbank deposits associated with the study rivers. The mean sand content ranges from 20 to 36%, and in all cases, therefore, the overbank deposits are dominated by clay- and silt-sized material, with the mean clay content ranging from 7.5 to 14.0%. Comparisons with the limited information on the grain size composition of the suspended sediment loads of the study rivers referred to above, suggest that the overbank deposits are characterized by both a greater d_{50} and an increased sand content, relative to the suspended sediment load, and are thus appreciably coarser. This is likely to reflect preferential deposition of the coarser fractions, although it must also be recognized that the grain size composition of the transported sediment may be coarser during high magnitude overbank flood events that inundate the flood plains, than during more normal storm-period events. The presence of significant proportions of clay in the overbank deposits (i.e. ~10%) could appear inconsistent with the preferential deposition of the coarser fractions of the suspended load, but can be readily accounted for in terms of the importance of flocculation and the associated occurrence of larger composite particles with increased settling velocities (Walling & Woodward, 2000). Preferential deposition of the larger composite particles will result in the deposition of smaller clay- and fine-silt-sized particles contained within the composite particles.

Table 2 A comparison of the mean, standard deviation and coefficient of variation of selected measures of grain size composition obtained for the sediment samples collected from the flood plains of the study rivers

River	Specific surface area ($m^2\ g^{-1}$)			d_{50} (μm)			Percent clay			Percent sand		
	$\bar{x}$	sd	CV	$\bar{x}$	sd	CV	$\bar{x}$	sd	CV	$\bar{x}$	sd	CV
Axe	0.32	0.09	0.28	32	22	0.70	7.8	2.5	0.32	29	14	0.47
Culm	0.33	0.08	0.24	35	33	0.93	8.0	2.2	0.28	36	13	0.38
Exe	0.37	0.06	0.17	20	18	0.89	7.8	1.7	0.22	25	11	0.46
Stour	0.51	0.11	0.22	16	15	0.99	14.0	3.6	0.26	20	11	0.53
Torridge	0.37	0.08	0.22	29	25	0.86	9.2	2.1	0.23	30	13	0.44
Usk	0.31	0.08	0.25	39	27	0.68	7.5	2.3	0.31	34	14	0.42

Despite the clear contrasts between the study rivers in terms of relief, lithology, catchment area and mean annual precipitation (see Table 1), with the exception of the River Stour, there is relatively little difference between the rivers in the grain size composition of their overbank flood plain deposits. The flood plain sediments from the River Stour flood plain stand out as being significantly finer, and therefore as having a significantly higher specific surface area than those from the other five rivers. This reflects the clay lithology of the upper part of the Stour catchment. Differences between the rivers have been further explored using a simple *t*-test to compare the mean values for the four measures of grain size composition obtained for the six study rivers. This analysis shows that both the Exe and Stour have values of d_{50} and percent sand that are significantly different from those found in all the other five rivers, with the Stour and Torridge exhibiting similar contrasts for percent clay and the Stour for specific surface area. There is therefore some evidence that the flood plain deposits of the River Exe are also finer than those of the Rivers Axe, Culm, Torridge and Usk, and that the River Torridge has a relatively high clay content when compared with the Rivers Axe, Culm, Exe and Usk. The increased clay content of the overbank sediments collected from the flood plain of the River Torridge may again reflect a lithological control, in that the Carboniferous Culm Measures, which underlie most of this catchment, weather to produce soils with a high clay content. The somewhat finer sediment found on the flood plains of the River Exe may also reflect the outcrop of Carboniferous Culm Measures within the central part of this catchment. Overall, however, the important differences in lithology between the six study catchments are not reflected by major differences in the grain size composition of the overbank flood plain deposits. Rather, they seem likely to account for more minor and subtle differences between the catchments.

Table 2 also lists standard deviation and coefficient of variation values for the four measures of grain size composition obtained for the flood plain sediments collected from each of the six study rivers. The relatively high standard deviation values, which are commensurate with coefficients of variation in the range 17 to 99%, indicate that there is appreciable spatial variability in the grain size composition of the flood plain sediments. This variability could reflect variability both within the individual reaches and longitudinally. Maximum values of the coefficient of variation are associated with the median diameter (d_{50}) and minimum values with specific surface area, whilst the values for percent sand are consistently greater than those for percent clay. This pattern suggests that the magnitude and composition of the coarser fractions, as reflected by the percent sand and d_{50}, evidence greater spatial variability than for the finer fractions, as reflected by the percent clay and specific surface area. Overall, the River Stour appears to show the greatest variability in the grain size composition of its flood plain sediments. This may reflect the considerable range of rock types outcropping within the catchment, which includes both clays and chalk.

In an attempt to distinguish the within-reach and longitudinal components of the spatial variability in the grain size composition of overbank flood plain sediments evidenced by the six study rivers, Table 3 provides a comparison of the mean coefficient of variation (CV) associated with the individual sampled reaches along a particular river with the coefficient of variation representing all the samples collected from the flood plain of that river. The values listed show a substantial degree of uniformity in the CV values for both the reaches and the entire flood plain and comparison of the two values indicates that most of the variability associated with the grain size composition of the flood plain sediments reflects within-reach variability, rather than longitudinal variability. In the case of within-reach variability, this is likely to reflect a general fining of the deposited sediment with increasing distance from the river (Marriott, 1992), spatial contrasts in the relative importance of diffusive and convective

Table 3 A comparison of the mean coefficient of variation for the individual study reaches with the value for all samples collected from the study river.

River	(a) Mean CV for study reaches	(b) CV for all samples	(a)/(b)
Axe	0.22	0.28	0.77
Culm	0.19	0.24	0.81
Exe	0.15	0.17	0.88
Stour	0.17	0.22	0.80
Torridge	0.17	0.22	0.77
Usk	0.20	0.25	0.81

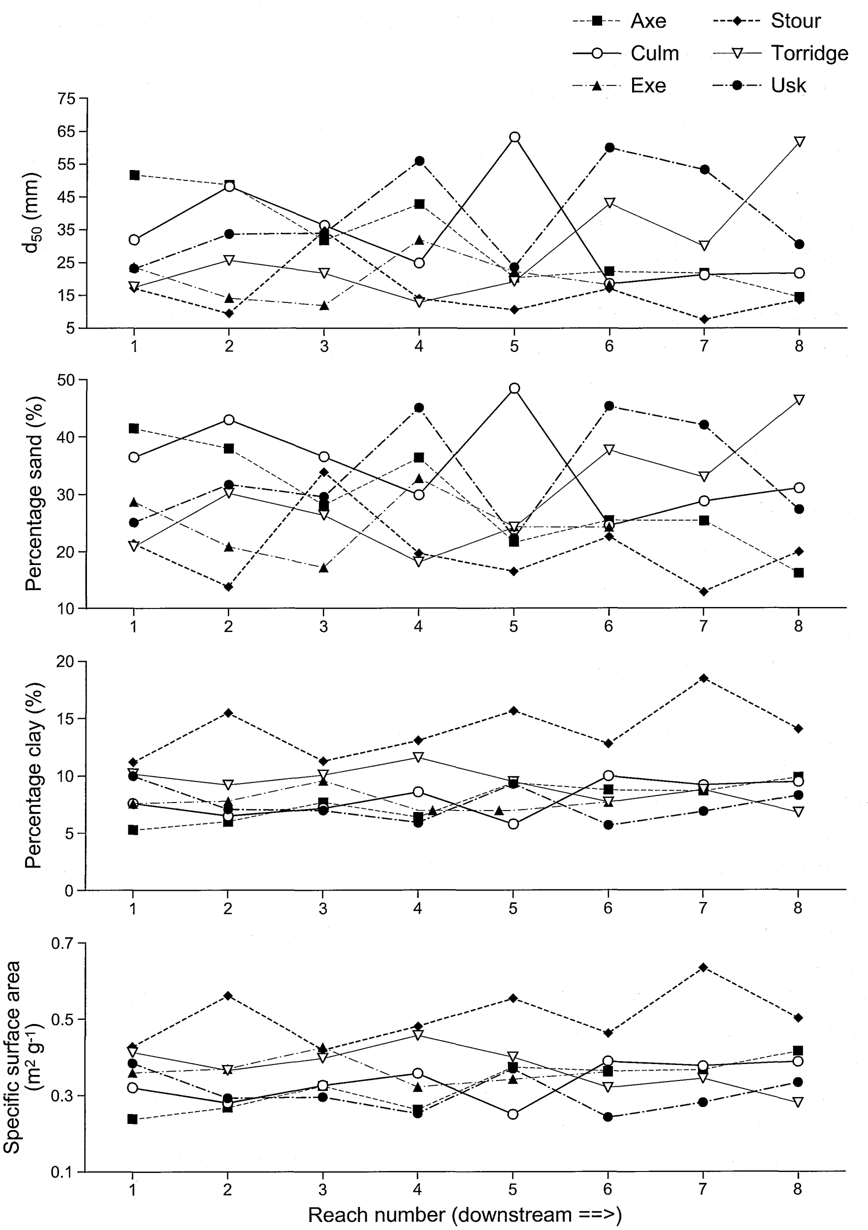

Fig. 2 Downstream changes in the mean values of the four grain size parameters for individual flood plain reaches.

transfer of sediment from the river onto the flood plain (James, 1985; Pizzuto, 1987) and the influence of local morphology on water depth and flow velocity across the flood plain (Walling *et al.*, 1996).

In order to investigate further the downstream or longitudinal variation in the grain size composition of the overbank flood plain deposits, Fig. 2 presents plots of the mean values of

Table 4 Statistically significant relationships between the selected measures of grain size composition for the flood plain sediments and distance downstream.

River	d_{50}	Specific surface area	Percent clay	Percent sand
Axe	–	+	+	–
Culm	0	0	0	0
Exe	0	0	0	0
Stour	0	0	0	0
Torridge	+	–	–	+
Usk	0	0	0	0

\+ Significant positive relationship at the 0.05 level
– Significant negative relationship at the 0.05 level
0 No statistically significant relationship

the four measures of grain size composition obtained for individual reaches *vs* reach number. Although there is no clear consistent pattern evident for all rivers, there is some evidence of a trend for specific surface area and percent clay to increase, and for percent sand to decrease, downstream. Such trends could be accounted for in terms of a progressive downstream fining of the transported sediment, as the coarser sediment is deposited, and thus a downstream fining of the deposited sediment. The existence of statistically significant longitudinal trends was explored by testing the significance of the relationship between the mean values of the four measures of grain size composition obtained for the individual reaches along a river and distance downstream. The results of this analysis presented in Table 4, indicate that only the Rivers Axe and Torridge provide evidence of a statistically significant downstream trend. Interestingly, the trends shown by the Rivers Axe and Usk are opposite. Thus, whereas the River Usk provides evidence of statistically significant downstream decreases in the median diameter (d_{50}) and percent sand content of the flood plain sediment, and increases in the percent clay and specific surface area, which are all consistent with downstream fining, the Torridge provides evidence of downstream coarsening, with the d_{50} and percent sand increasing downstream and the specific surface area and percent clay decreasing. It is difficult to account for the trend evidenced by the River Torridge in terms of hydraulic controls and it is suggested that the downstream coarsening probably reflects local controls associated with inputs of coarser sediment from the River Okement, a southern tributary of the River Torridge, which rises on Dartmoor, an area underlain by granite.

Since estimates of medium-term (i.e. *c.* 40 year) sedimentation rate (g cm^{-2} $year^{-1}$) were available for each of the cores collected from the flood plains of the six study rivers, based on their Cs-137 inventories, the influence of sedimentation rate on the variability of the grain size composition of the overbank sediment deposits associated with the individual rivers was also explored. Low levels of explanation were associated with simple linear relationships between the four measures of grain size composition and sedimentation rate, with r^2 values ranging between 0.001 and 0.11. Only 14 out of the 24 relationships were statistically significant at the 0.05 level. The highest r^2 values and the greatest number of statistically significant relationships (five out of six rivers) were associated with the measures primarily reflecting the finer fractions, namely percent clay and specific surface area. Both these measures showed the expected inverse relationships with sedimentation rate. Figure 3 presents plots of the relationships between specific surface area and sedimentation rate for the six study rivers. In this case a simple exponential function has been fitted to the

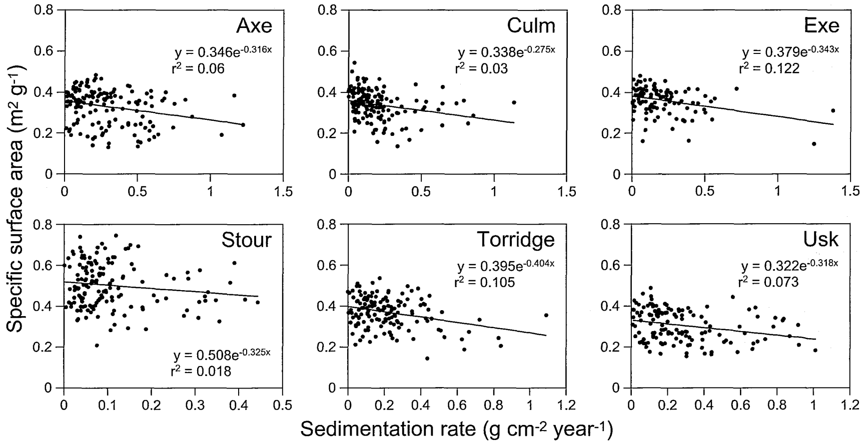

Fig. 3 The relationship between the specific surface area of samples collected from the flood plains of the six study rivers and the sedimentation rate at the sampling points estimated from Cs-137 measurements.

relationship. The lack of a well-defined relationship and the considerable scatter around the fitted lines reflects, at least in part, the influence of composite particles in masking any clear relationship between the two variables. Nevertheless, it also further emphasises that sedimentation rate is not a key control on the spatial variability of the grain size composition of the deposited sediment. Further work is required to identify the key controls on this variability.

PERSPECTIVE

The results presented above provide representative information regarding the grain size composition of overbank deposits on the flood plains of six rivers in southern Britain. Despite appreciable difference between their catchments, in terms of both underlying geology and other terrain characteristics, there is relatively little variation in the grain size composition of flood plain sediments between the six rivers. However, the sediments from the flood plain of the River Stour are shown to be significantly finer than those from the flood plains of the other five rivers. Other relatively minor differences between the rivers can be linked to the influence of catchment lithology. Considering all the samples collected from the flood plains of the individual rivers, there is evidence of appreciable spatial variability in the grain size composition of the overbank flood plain sediments, which reflects both within-reach and longitudinal variability. The former is shown to be the dominant source of variability and the study rivers show only limited evidence of significant downstream trends in the grain size composition of their overbank deposits. Only two out of the six rivers evidence statistically significant downstream trends, but the trends associated with these two rivers are opposite. The Axe shows downstream fining, whereas the Torridge shows evidence of downstream coarsening, which appears to reflect local controls associated with tributary inputs. Examination of the relationships between the measures of grain size composition and sedimentation rate, estimated for the individual sediment cores using Cs-137 measurements, provided only limited evidence of statistically significant relationships. The strongest relationships were associated with the measures primarily reflecting the magnitude of the fine fraction (i.e. percent clay and specific surface area). Overall, however, sedimentation rate was shown not to be a key control of the spatial variability in the grain size composition of the flood plain sediments. Further work is required to identify the key controls on the documented variability.

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