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The use of buffer features for sediment and phosphorus retention in the landscape: implications for sediment delivery and water quality in river basins

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Abstract There is a variety of buffering features within the landscape that can be used to trap sediment and associated contaminants such as phosphorus (P), thereby helping to reduce sediment and P delivery to watercourses. Astroturf mats were placed within contrasting buffer features at nine sites within the River Parrett basin in England. Mats collected sediment at only four of the sites during the sampling period due to limited erosion and/or sediment by-passing the mats at most sites. For those sites where mats collected sediment, which tended to be either grass strips and/or hedges at mid- or bottom-field locations, there was a considerable range in sedimentation with average values for the sites ranging from 0.07 to 9.1 g cm^{-2} (average for all mats = 1.7 g cm^{-2}). Most of the sediment was sand-sized material (average for all mats: %sand = 82%, d_{50} = 123 μm). The site-average total-P content of the <63-μm fraction of the deposited sediment ranged between 559 and 1185 mg kg^{-1}. Comparison between mats located at the front and back of one of the sites shows that more sediment was trapped at the front than at the back, although the particle size and total-P content were similar at both locations. The results suggest that different types of buffers are more effective than others in reducing sediment and P delivery to watercourses, and that the strategic location and careful design of buffer features is a key factor in their effectiveness.

Key words buffer features; particle size; phosphorus; sediment; water quality

INTRODUCTION

The pollution of surface and ground waters represents one of the main environmental problems presently facing society, and has resulted in a variety of relevant legislation and policy measures to protect the quality of waters. In many river basins, diffuse pollution from agriculture is the main contributor that affects the chemical quality and ecological status of river systems, and such sources are often difficult to control due to their widespread occurrence (i.e. throughout a basin) and temporal characteristics (i.e. associated with rainfall events). There is a variety of pollutants from diffuse sources of which two of particular concern, especially in the USA and EU, are phosphorus (Correll, 1998) and sediment (Owens *et al*., 2005). In agricultural areas, the control of phosphorus (P) and sediment delivery to surface waters are often considered together because a large proportion of P is transported in association with fine-grained sediment

(Owens & Walling, 2002), and thus measures to control the mobilization and delivery of sediment should also help to control P transfers.

Buffer features such as filter strips and grassed waterways have often been used to intercept sediment and pollutants such as P (e.g. Kronvang *et al*., 2000). Traditionally, such features are 5–10 m wide and have been placed in riparian locations. There are, however, a variety of additional features—such as farm ponds, within-field wetlands, hedges and other field boundaries—that could be utilized to control sediment and P transfers both within fields and from fields to rivers. Such features offer many advantages over more "end-of-pipe" features such as riparian grass strips in that they offer the potential to reduce transfers closer to the source. This paper describes some preliminary results of the field testing of some existing in-field buffer features. This work forms part of a much larger project (BUFFERS) funded by the UK government, which is concerned with the strategic design and placement of buffer features within the landscape to control diffuse pollution from agriculture.

STUDY AREA AND METHODS

The River Parrett basin is located in southwest England (Fig. 1). The basin occupies an area of 1665 km^2 and drains in a northwest direction into the Bristol Channel. It was selected for study because it has been identified as a basin with high sediment production on hillslopes and high sediment delivery to watercourses, and because there are concerns over the P content of river water (McHugh *et al*., 2002; Murdoch & Culling, 2003). In addition, it has a long history of flooding. Land use in the Parrett basin is predominantly grassland, followed by cereals and other arable crops and woodland (Godwin & Dresser, 2003). Rainfall is greatest in December and January with the driest months being April–July. The average rainfall total for the region is 800–1000 mm with as little as 700 mm in low-lying parts of the basin. July and August are the warmest months with mean daily maxima ranging from 19°C on the coast to 21°C inland. January is the coldest month with mean minimum temperatures between 1 and 2°C (Met Office, 2005). The geology of the Parrett catchment is predominantly Oxford Clay with a small band of Upper Greensand and Gault in the headwaters. There are also areas of Old Red Sandstone, Jurassic limestone and marls, and Lower Lias clays in the southern and western sections of the catchment (NERC, 2005).

Nine contrasting field sites were instrumented in autumn/winter 2004 (additional sites have been subsequently instrumented in 2005) in order to evaluate the design and placement of buffering features in the landscape, as part of the larger BUFFERS project. These sites, together with six others (Fig. 1) were also qualitatively assessed over this time period using a buffer zone inventory and evaluation form (BZIEF) modified from Ducros & Joyce (2003). The nine instrumented sites include a variety of land uses (maize, wheat, barley, potatoes, intensive grassland and outdoor pig farms) and soil types (sandy loams, silty clay loams and sandy clay loams) identified as being of concern for soil erosion and/or the delivery of sediment and P within the basin. In addition, a variety of buffering features at different spatial locations within the hillslope–channel system were selected, including mid-field hedges, end-of-field grass strips, channel wetlands and flood plains.

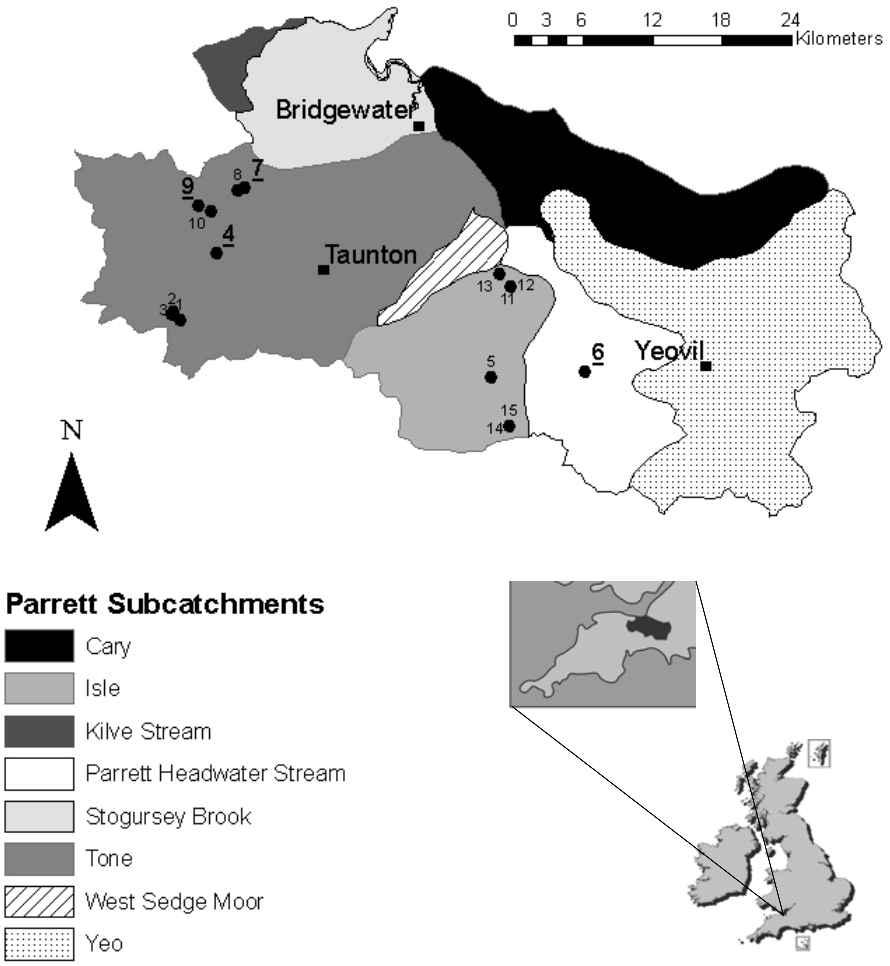

Fig. 1 Location of the study catchment and the instrumented and BZIEF sites, including those sites where sediment was collected on mats (underlined).

At each site, astroturf mats were installed within the buffer in order to "sample" the trapping effect of the buffer, and thereby estimate the retention of sediment and sediment-associated P. At the sites with hedges and/or grass strips, mats were placed at the upslope leading edge, mid-buffer and downslope edge of the buffer, and where possible downslope of the buffer feature, usually at two contrasting locations within each field (i.e. mats were positioned along two transects). For the wetland/flood plain sites, mats were placed at strategic locations on the wetland/flood plain surface in order to document spatial patterns of sediment and P accumulation. Mats were installed in December 2004 and checked in February, May and July 2005. Although it is recognized that there may be problems with the use of the mats, such as the potential for wash-off of previously trapped sediment due to the long periods that the traps remain in the fields, such effects are believed to be minimal and the use of astroturf mats is now a reasonably established method to collected sediment due to overland flow on hillslopes and overbank flows on flood plains.

Mats that contained sediment that could be clearly identified as derived from soil erosion and overland flow were removed and transferred in plastic bags to the laboratory, where the sediment was air-dried at room temperature for a minimum of

48 hours. The sediment was then carefully removed and the dry weight obtained. The particle size distribution (2 μm–1 mm) was determined by mechanical sieving down to 63 μm and then by sedigraph analysis. The cumulative particle size distribution was determined, from which the median grain size (D_{50}), the percentages of sand (>63 μm), silt (2–63 μm) and clay (<2 μm) were determined. Total-P content was determined on the <63-μm fraction of the air-dried sediment samples using the sodium hydroxide fusion method described by Smith & Bain (1982) and the Murphy & Riley (1962) method was used to determine the Mo-reactive P in the extract.

RESULTS

Of the nine sites instrumented, sediment was deposited on mats at only four of these: sites 4, 6, 7 and 9 (Table 1). Furthermore, samples were only collected in May (representing the period from February to May 2005) and July (representing the period May–July 2005). Table 2 shows the average amount of sediment deposited at each of these sites and also the average for all of the 28 mats collected. It is clear from Table 2 that there is considerable variation in the amount of sediment deposited between the four sites, with average values ranging from 0.07 g cm^{-2} (Site 6) to 9.1 g cm^{-2} (Site 9). Generally, average values of sediment deposition at each site are similar for May and July (no significant differences at $\alpha = 0.05$, Student's *t* test), although no samples were collected at Site 9 in May. The average value for all 28 mats that collected sediment is 1.7 g cm^{-2}; however, this value (and also the average for July) is heavily influenced by the high value for the three mats collected from Site 9.

Table 2 also has average values of the particle size composition (D_{50} and %sand) and the total-P content of the deposited sediment. For total-P, this represents the value for the <63-μm fraction of the deposited sediment, as P is primarily associated with this size fraction (Owens & Walling, 2002). Generally, most of the sediment trapped by the mats, which in turn represents the efficiency of the buffers in trapping sediment, is sand-sized material with the average sand content for all 28 mats being 82% Again, average values are similar for the two time periods (no significant differences at $\alpha = 0.05$), and also are generally similar between sites, with Site 6 being the main exception with only approx. 50% of the trapped material being sand-sized, this being significantly different (at $\alpha = 0.05$) than the values for the other sites. Average values

Table 1 Characteristics of the four sites where samples were collected.

Site	Buffer feature	Soil type	Slope	Land use	Evidence of erosion
4	Bottom of field: 7.5-m wide grass strip, then 1-m high bank.	Sandy loam	Moderate to steep	Wheat	Rill network
6	Mid-field: 3-m wide grass strip, then 1-m wide hedge, then 3-m wide grass strip.	Silty clay loam	Gentle	Barley-wheat	Some minor rills
7	Bottom of field: 9-m wide grass strip then trees.	Sandy clay loam	Moderate	Wheat	Major rill and gully network
9	Bottom of field: 6-m wide grass strip, then hedge.	Sandy clay loam	Moderate to steep	Maize	Rill network

Table 2 Amount of sediment deposited on the astroturf mats in the buffer features at each of the four sites and the particle size and total-P content of the sediment.

Site	Date in 2005	*N*	Sediment deposition (g cm^{-2})	Sand (%)	D_{50} (μm)	Total-P * (mg kg^{-1})
4	May	2	1.5	94	130	–
	July	4	1.5	96	127	941
	Both	6	1.5	95	128	941
6	May	2	0.07	52	70	1250
	July	2	0.07	52	21	1054
	Both	4	0.07	52	53	1185
7	May	4	0.90	88	118	532
	July	11	0.54	82	129	568
	Both	15	0.64	84	125	559
9	July	3	9.1	91	287	893
All	May	8	0.84	80	109	771
	July	20	2.0	83	134	652
	Both	28	1.7	82	123	707

* Represents the <63-μm fraction only. Also, only 20 out of 28 mat samples were analysed for Total-P.
N is sample number, and values only relate to those mats that collected sediment.

Table 3 Amount, particle size composition and total-P content of the sediment deposited on the front and back mats at site 7 collected in July 2005.

Location	*N*	Sediment deposition (g cm^{-2})	Sand (%)	D_{50} (μm)	Total-P * (mg kg^{-1})
Front	5	0.66	85	142	639
Back	4	0.30	79	162†	554

* Represents the <63-μm fraction only.
† Influenced by a single sample.
N is sample number, and values only relate to those mats that collected sediment.

of the d_{50} are more variable between the sites and range between 53 μm (Site 6) and 287 μm (Site 9), with the average for all 28 mats being 123 μm.

Values of total-P for the <63-μm fraction range from 559 mg kg^{-1} (Site 7) to 1185 mg kg^{-1} (Site 6), and the average for all 28 mats is 707 mg kg^{-1}. There are no significant differences between time periods.

At sites 4, 6 and 9, only a limited number of samples were collected—*n* ranges between 3 (Site 9) and 6 (Site 4)—and it is therefore not appropriate to compare sediment amounts and composition between mats located at different parts of the buffer features. However, at Site 7, there were enough samples collected in July for an assessment of the differences in the sediment collected by mats located at the front and back of the buffer feature (Table 3). Differences between front and back mats are as expected, with greater amounts of sediment deposited at the front of the buffer. However, there were no statistically significantly differences in the particle size and total-P content of the sediment from the two locations, although there is a trend of coarser and P-enriched sediment deposited at the front of the buffer.

DISCUSSION

Only four of the nine buffer features instrumented collected sediment during the sample period (December 2004–October 2005). This suggests that, for those sites where no sediment samples were collected, either: (a) erosion at these sites was minimal; (b) the mats were located inappropriately; or (c) the buffer features were ineffective in trapping sediment, which instead passed straight through them. It is likely that there are site-specific scenarios to explain the lack of sediment. For example, for sites under grassland there was no visible evidence of soil erosion, or sediment transport and deposition. Equally, for other sites (including some of the four sites where samples were collected) it was evident that soil erosion had occurred, but that sediment transport had been focused in particular flow paths which had by-passed some of the mats, and in some cases breached the buffer features at specific "break-points". This highlights the problems associated with placing a limited number of mats to trap sediment in features such as buffer strips, where water and sediment flow paths are concentrated in relatively narrow areas. It also underlines the fact that linear buffer features such as grass strips and hedges are only likely to be effective in trapping sediment and sediment-associated contaminants such as P at limited locations, defined by topography, hydrological pathways, and the management and maintenance of the buffer features. This suggests that the targeted location and careful maintenance of buffer features at key locations where flow converges may be more effective than more widespread distribution of buffers.

For those sites where sediment samples were collected from buffer features (i.e. sites 4, 6, 7 and 9), most samples (i.e. 17 out of 28) were collected from the front of the buffers. For Site 7, where enough samples were collected to enable some preliminary comparison, the mats located at the front of the buffer collected significantly more sediment than those at the back. Furthermore, none of the mats placed downslope of the buffer features (i.e. beyond them) collected sediment. These findings suggest that, where buffer features intercept water and sediment pathways, they are effective in trapping sediment, and that the width of the buffer will influence their effectiveness, although research has indicated that there will likely be some point at which a further increase in width becomes less effective.

The results suggest that there is a considerable variation in the amount of sediment trapped by the buffers, and the particle size and total-P content of that sediment. Sediment deposition ranged between 0.07 and 9.1 g cm^{-2} over the approx. 2–3 month period that the mats were installed for each period, with values at each site being similar for the periods February–May and May–July. Some sites are less effective at trapping sediment due to inherent variations in limiting factors such as soil type, slope and buffer maintenance. Although only a limited number of samples have been collected to date, the greatest sediment deposition in a buffer was at Site 9, which has sandy-clay loam soils, moderate to steep slopes and maize crops. On the other hand, the smallest sedimentation was at Site 6 which has silty-clay loam soils, gentle slopes and barley-wheat crops. Observations made upon visits and the use of the BZIEF suggest that sedimentation in the buffer features is associated with either individual or a small number of erosion events within each time period at each site. Observations also suggest that specific land management operations may also influence buffer effectiveness. For example, Fig. 2 shows sediment deposition at the interface between

Fig. 2 Sediment deposition at the interface between the buffer and the field at Site 4 due to a “step” between the two created by tillage. The arrows mark the start of the buffer.

the buffer and the field at Site 4 due to a “step” between the two created by tillage. It is only when this difference in height is in-filled by sedimentation that the actual buffer feature (i.e. the grass) is required to perform its designed function and trap sediment.

Initial results suggest that the buffer features primarily trap sand-sized material. The silt- and clay-sized material (i.e. <63-μm fraction) that is trapped has relatively low total-P concentrations compared to either UK soils (Owens & Deeks, 2004) or the fine sediment delivered to and transported by UK rivers (Owens & Walling, 2002). Further work is presently underway to compare the particle size and total-P content of the sediment trapped in the buffers with values for the soils in the contributing fields.

CONCLUSION AND IMPLICATIONS

Preliminary results for the first year’s fieldwork suggest that certain types of buffer features in certain spatial locations are more effective than others in trapping sediment, and thereby reducing sediment and associated P delivery to watercourses. Therefore, if buffer features are to help control the delivery of sediment and associated nutrients/contaminants to watercourses, and to assist with improving water quality to meet legislative targets, such as those set by the EU Water Framework Directive, their strategic location and careful design is important in order for them to be effective.

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