Buffer-Strip Induced Flow Retardation and Sediment Deposition

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Abstract: Experiments were carried out in a 6m long tilting flume to study the effect of buffer strips on flow hydrology and sediment generation, transportation and deposition. The results show that buffer strips behave like porous barriers against the flow, creating zones with increased flow depth or backwater whose length varies with slope angle and buffer strip density. Flow velocity within this backwater is significantly lower than that of the unaffected regions further upslope. This velocity reduction caused the deposition rate to exceed the erosion rate, so resulting in net deposition. Since larger soil particles settle more rapidly than the finer particles, a spatial distribution in sediment size takes place within the backwater. Sediment passing though the strips is significantly finer than that initially dislodged by the flow. As a result of the settlement of mostly large particles in the backwater, finer particles were preferentially transported in the runoff that flowed through the grass strips. As these fine particles are richer in sorbed chemicals, such preferential transport of fine particles will lead to a reduction in sediment flow, but commonly with an enrichment of sorbed nutrients, agricultural chemicals and organic matter in the sediment which passes through the buffer strip. Such transmitted fine particles together with their chemical load either get deposited downslope of the strips as fans or stay in suspension until entering receiving waters. Except for soils of high clay content grass strips are therefore less effective in reducing overland transport of solutes or solids-associated chemical pollutants than they are in reducing sediment load.

Keywords: grass strip, buffer strip, porous barrier, barrier strips, sediment entrapment, flow hydrology

1 Introduction

Grass buffer strips are a well recognized and long-practiced soil conservation measure, mostly used on low to moderately sloped agricultural lands and in riparian zones. Buffer strips appear to force surface runoff to off-load most of its sediment load resulting in a significant reduction in the amount of sediment leaving the field (Hurni, 1986; Dillaha *et al*., 1989; Meyer *et al*., 1995; Magette *et al*., 1989; Raffaelle *et al*., 1997). Therefore buffer strips appear to serve the dual purpose of reducing soil erosion and lessening the downstream impact of intensive land use (Landry and Thurow, 1997). It is widely believed, with some support from field studies, that grass strips filter out the suspended sediment as runoff passes through them with emerging runoff significantly cleaner in terms of sediment, nutrients and soil-sorbed contaminants. However the mechanics of such action has not been clear. In recent years there has been a renewed interest in understanding the mechanics of flow through grass strips and the effectiveness of such strips in reducing sediment and pollutants transport down slopes and into the surface water resources (Hairsine, 1996; Magette *et al*., 1989; Dabney *et al*; Ghadiri *et al*., 2000; Ghadiri *et al*., 2001; Rose *et al*., 2002a).

Experiments such as those described in the above references have demonstrated the effectiveness of even quite narrow continuous vegetated strips in leading to net deposition of sediment. There is experimental evidence in the literature suggesting little or no deposition within the buffer strips themselves, deposition mostly occurring upslope of the strips (Ligdi and Morgan,1995; Ghadiri *et al*., 2001), as well as significant deposition (Karssies and Prosser, 1999) . The occurrence of erosion rather than sedimentation inside the grass strips has been observed under some specific conditions (Loch *et al*.,1999; Ghadiri *et al*., 2001).

It is recognised that a flow-resistive element such as a cross-slope strip of vegetation modifies the hydrology of overland flow, and that this modification has implications for transport and deposition of sediment and associated nutrients (Barfield *et al.*, 1979; Flanagan *et al.*, 1989; Dabney *et al.*, 1995; Ghadiri *et al.*, 2000; Ghadiri *et al.*, 2001, Rose *et al.*, 2002a). It is the hydraulic consequences for overland flow when it meets and flows through a resistive element which needs to be fully understood in order to accertain the effectiveness or otherwise of grass strips in reducing erosion, enhancing deposition and reducing transportation of pollutants into surface water bodies. Rose *et al.* (2002b) interprets flume experiments carried out to investigate: (a) the influence of simulated buffer strips on flow hydrology and on sediment deposition in regions around the strips and (b) to measure the spatial and size distribution of sediment deposited in the back water and that which passed through the strips.

2 Materials and methods

The experiments were carried out in a 1m × 6m tilting flume of Griffith University's rainfall simulation facilities (GUTSR). The flume has an adjustable slope capability and is instrumented with accurate inflow and outflow measuring equipment. The experiments covered both artificial (nail) and natural (grass) buffer strips at three densities of low, medium, and high and two strip widths of 20 cm and 40 cm. Modest slopes of 1% to 8 % were used for all experiments. A constant head device constructed at the top end of the flume supplied water at a constant flow rate of 2.27×10^{-3} $m^3 \cdot m^{-1} \cdot s^{-1}$. Two surface conditions of bare flume floor and a soil bed of 10 cm thickness in the flume were used in the first set of experiments. A second set of experiments was carried out on the bare flume floor during which saturated soil aggregates in sufficient quantities were introduced to the flow path to investigate spatial and size distribution of deposited sediment in and around the buffer strips.

PVC boards of 2 mm thick with tapered edge and stained with potassium permanganate powder were inserted into the strips every time a flow height recording was needed. The recorded watermarks were photocopied and digitized using a specially developed computer program. The recording started at some distance prior to the point where flow began to be affected by the presence of the buffer strips, and ended where water height stabilized after emerging from the strips. Fig 1 shows the experimental set up and the section of the flume where the effects of buffer strips on flow configuration and sediment deposition were observed, recorded and measured.

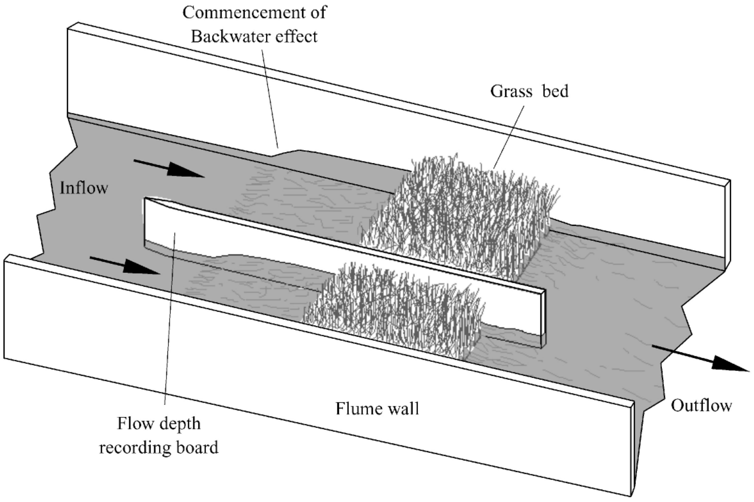

Fig.1 An illustration of flume, grass strip and flow recording device

3 Results and discussion

Experiments with water flow over a bare flume floor prior to entering into a buffer strip were designed to investigate the hydraulic effect of buffer strips (Rose *et al.*, 2002a). A model porous resistive element consisting of beds of nails of various densities were used to ensure reproducible results of the hydraulic resistance offered by such a strip. Four flume slopes (S) up to 8.8%, and three nail densities (N) were investigated. Because of the smooth surface of the flume flow was supercritical, and a region of hydraulic adjustment upslope of the nail bed commenced with the formation of a hydraulic shock (Fig 1). The length of the zone of hydraulic adjustment was found to be approximately proportional to N/S, so decreasing with slope, but increasing with nail density.

The increase in flow depth (D) prior to and upslope of the nail or grass bed (Fig. 1) indicates a corresponding decrease in flow velocity (V), since the product of these two variables is the volumetric flow rate (q), which remained constant at $q = DV$ in these experiments. The spatial variation in flow depth D, both prior to and within the nail bed could be predicted from the theory of momentum conservation (Rose *et al*., 2002a).

For flow over soil the character of flow is generally subcritical rather than supercritical as the experiments of Rose *et al*. (2002a). However a region upslope of the vegetative strip with reduced flow velocity still develops, and is referred to as a backwater. The effect on downslope sediment flow over a bare soil bed of a backwater produced by a grass strip was investigated by Ghadiri *et al*. (2000, and 2001). Slopes investigated were over the modest range of 1.5% to 5.2%.

The length of the backwater was again found to be inversely related to slope. The hydraulic effect of nail and grass buffer strips were found to be very similar, whether or not there was a soil bed in the flume. The main difference observed was that with soil the length of the backwater formed increased gradually with time. This increase in backwater length could be partly caused by the formation of a deposited layer as shown in Fig. 3. However the presence of root material in the soil moved with the water as floating debris, and when this accumulated at the upstream edge of the grass strip it effectively increased the hydraulic resistance of the grass strip, thus also tending to increase backwater length (Fig. 2).

In all these experiments the majority of sediment was deposited in the backwater region, and not within the resistive strip itself. Similar results are reported by Dillaha *et al*. (1989), Jordon *et al*. (1993), and Smith *et al*. (1992). However, with higher slopes, and with higher and probably denser grass than in our experiments, Karssies and Prosser (1999) observed significant deposition not only in the backwater, but also in the grass buffer strip.

Sediment passing though the strips is significantly finer than those initially dislodged by the flow. Mean Weight Diameter (MWD) of sediment that passed through the strip was 0.8 mm while that of the suspended sediment in unaffected flow, prior to sensing the strip, was 2.1 mm for the experiment whose results are given in Table 2. Ghadiri and Rose (1991) showed that the concentrations of organic matter, sorbed nutrients and agricultural chemicals can be significantly higher on the finer particles. Whilst this is not the case for soils of high clay content, for other soils the preferential deposit of larger aggregates and particles leaves that sediment which emerges from the buffer strip relatively enriched in soil sorbed chemicals. Thus, although vegetative buffer strips can be effective in substantially reducing the amount of sediment transmitted beyond them, such sediment as does penetrate the buffer strip will often be richer in sorbed nutrients and other chemicals than the original eroding soil upslope of the strip.

The second set of experiments were designed to investigate the spatial and size distribution of sediment deposited upslope of a resistive buffer strip. The hydraulic effect of a grass strip was again simulated by beds of nails. Prewetted soil was formed into a slurry and introduced at an approximately uniform rate into a steady flow of water over the bare boards of the flume. The resulting continuous sediment flow at the transport limit formed a net deposit upslope of the nail bed which, at the end of the experiment, was sampled by location for mass and size distribution of the sediment.

As sediment deposited, the position of the hydraulic jump indicating the commencement of the region of hydraulic adjustment moved upslope. This movement was due to the low barrier provided by the deposited sediment itself (Fig. 3). Analysis of these results by Rose *et al*. (2002b) showed that the spatial and size distribution characteristics of the deposited sediment could be generally understood in terms of soil erosion theory.

Table 1 shows the distribution of sediment between that which deposited in the backwater of length B, inside the buffer strip, and as fans downstream of the strip. For the soil type and experimental conditions employed, the percentage of sediment deposited inside and downstream of the strip was small relative to that deposited in the backwater, but this percentage increased as slope increased (Table 1). Ghadiri *et al*. (2001) explain that the small amount of sediment stored within the strip may only be temporary, caused by the abrupt end to the flow in the flume. If sediment-free flow had continued all sediment could be removed from within strips. The size distribution of sediment deposited within the backwater was coarser than that inside the strip and on the lower flume segment. The size distribution of sediment which left the flume was finer again than the sediment deposited within the nail bed or lower flume segment.

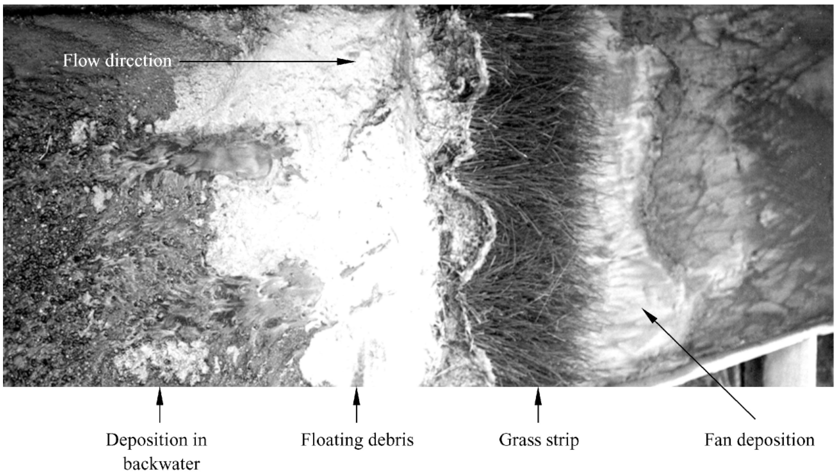

Fig.2 Blockage of strip front rows by floating debris

Table 1 Distribution of deposited sediment in and around the strip in an experiment where soil was introduced to the flowing water in the flume

Flume slope (%)	Deposited sediment (% of total)		
	In backwater	Inside strip	Downstream side of strip
1.6	92	3	5
3.4	84	7	9
5.1	63	15	22

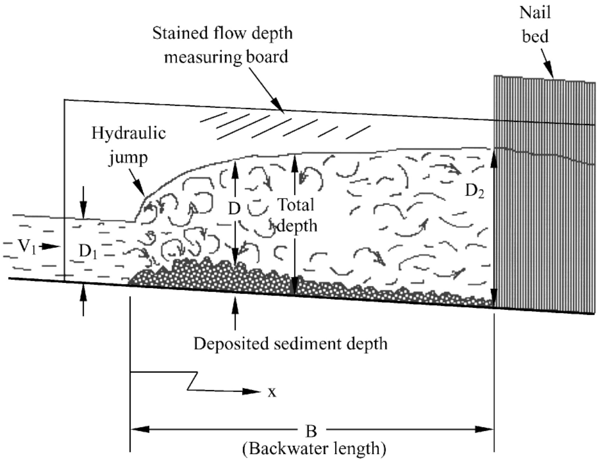

Fig.3 An illustration of flow and deposition in the backwater region

4 Conclusion

In general terms the hydraulic resistance provided by buffer strips slows down the flow even before it reaches the strip. The reduction in velocity in this upstream backwater region implies a reduction in erosion rate, so that the deposition process wins and net deposition of sediment occurs. Because larger sediment or aggregates settle more quickly than smaller or finer sediment, the layer of deposited sediment formed just up slope of the buffer strip tends to be richer than the eroding sediment in larger particles. Indeed some of the fine sediment may not deposit upstream of the buffer strip, nor be trapped by it, and so move through and beyond the buffer strip with the onflowing water. Thus sediment size distribution appears to be the dominant factor governing the efficiency of the buffer strip in trapping sediment. The increase in flow depth, and corresponding reduction in velocity in the backwater region reduces the rate of erosion, allowing net deposition of sediment to occur.

Buffer strips behave like porous barriers against the flow, creating backwater regions with raised flow depth whose length vary with slope and strip density. Backwater length also increases with time when sediment is available for continuous transport by flow. This can be the result of increased blockage of the front rows of the strips by floating debris or the formation of secondary barriers by the deposited coarse sediment in the backwater. Sediment deposition takes place mainly in the backwater region, with the coarser fractions depositing earlier than finer aggregates. Some deposition also takes place on the downstream side of the strips but very little deposition occurred inside the strips. In these experiments the width of the strips in the direction of flow had no great effect on either flow hydrology or sediment deposition in and around the strips. Soil sorbed nutrients, organic matter and other agricultural chemicals are mainly attached to finer soil particles, which pass through the strips largely unchanged. Grass buffer strips are capable of reducing the overall load of these chemicals in runoff, a load which increases with slope. Unless soils are high in clay content, the sediment which emerges from a buffer strip can be enriched in soil-sorbed chemicals relative to chemical content of the eroding soil.

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