Second Australian Stream Management Conference
8-11 February 1999, Adelaide, South Australia

Sediment Storage Capacity of Grass Buffer Strips

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SUMMARY: Performance of grass buffer strips alongside streams is generally considered in relation to sediment transport capacity. Grass strips have a low sediment transport capacity because of the hydraulic roughness of the grass stems, but as deposition progresses and the grass is buried, hydraulic roughness decreases and sediment transport capacity increases until no more sediment is deposited. As an alternative to the sediment transport approach, we use the storage capacity of buffer strips as a measure of their effectiveness. Backwater storage, just upslope of the grass buffer strip, is important in this respect, especially at lower slopes. We investigated the effect of slope on backwater and in-grass storage capacity. Results showed that on a 6 % slope, the backwater can trap 41 kg/m length of buffer, while on a 27 % slope only 5 kg can be trapped in this way. Trap efficiency in a dense 1 m wide buffer strip on a 6 % slope only falls below 60 % in events with >100 year recurrence interval in southern Australia, demonstrating that buffers can provide efficient sediment control.

THE MAIN POINTS OF THIS PAPER:

- Buffer strips have a limited storage capacity which can be used as an indicator of their effectiveness.
- The backwater before a grass buffer stores 41 to 5 kg of sediment per meter length for gradients ranging from 6 % to 27 % respectively on a planar hillslope (equivalent to 4.1 to 0.5 t/100 m length).
- These buffers, on 6 % slopes, provide > 60% sediment trapping for the duration of events of 100 year recurrence interval typical in southern Australia. A greater trap efficiency would be achieved by wider buffer strips.

1. INTRODUCTION

Grass buffer strips alongside streams can be used to filter sediment and nutrients from intensive land use sources, where shallow evenly distributed overland flow occurs (Dillaha, 1989). Their use should be regarded as an addition to good on-farm management not as alternative to it. Generally, buffer strip performance has been considered in relation to sediment transport capacity (Barfield et al., 1979). Overland flow is slowed upon reaching dense grass, because of its high hydraulic roughness, thus reducing the capacity of the flow to transport sediment. This results in sediment deposition and explains the high sediment trapping ability of grass buffers (MacKenzie and Hairsine, 1996). However, as deposition in a grass buffer strip progresses, the grass stems and rhizomes that provide hydraulic roughness are progressively buried, which increases the capacity of flow to transport sediment through the buffer. Eventually a steady-state is reached where the grass is buried to sufficient extent that the flow can transport all the sediment it is carrying through the buffer. By this time the buffer has reached its full storage capacity and no longer traps sediment.

The reduction in flow velocity within a grass buffer increases its flow depth. This effect is transmitted back through the flow before it reaches the buffer, producing an area of deep, slow flowing water, known as a backwater (Figure 1; Dabney et al., 1995; Meyer et al., 1995; Tollner et al., 1976). The backwater traps sediment in the same way as the buffer itself, producing a sediment fan, but it too eventually fills and ceases to trap further sediment. Thus the effectiveness of grass buffers can be measured in terms of the total amount of sediment that can be stored within the backwater and within the buffer itself.

This study measured the sediment storage capacity of grass buffer strips and associated backwaters and how this is affected by slope. It can be expected that sediment storage capacity will decrease with increasing gradient for the higher gradient will reduce the width of the backwater and increase the energy and hence the sediment transport capacity of the flow.

2. METHODS

We used a 7 m long by 1 m wide flume with variable water and sediment inflow rates (Table 1) and a gradient varying between 6 and 27 %.

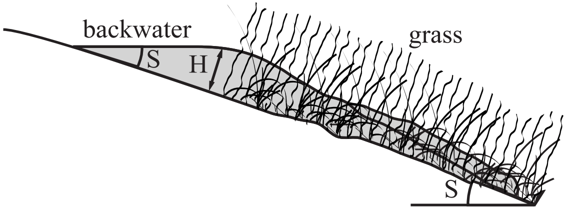

Figure 1: Schematic diagram of backwater with a sediment deposit.

Table 1: Flow and sediment inputs to the flume

Energy	Flow rate (l/s)	Sediment conc. (g/l)
High	1.58	13.6
Medium	0.96	12.0
Low	0.51	9.2

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Sediment was derived from Krasnozem soils used for intensive cropping. The sediment was composed of water-stable aggregates, with relatively uniform nutrient concentrations with aggregate size (Table 2). Consequently, for these materials, nutrient trapping efficiency is similar to sediment trapping efficiency. Grass blocks of 1 x 1 m were used, consisting of 15 cm tall Kikuyu grass (*Pennisetum clandestinum*). For each experiment a fresh block of grass was used. Overland flow was applied to the 100 cm wide flume from a 30 cm wide opening 1.8 m upslope of the grass. The input of flow thus simulates a weak convergence of flow, such as occurs in a plough furrow, compared to that of purely planar flow. The flow spread out to form a fan at the upper edge of the grass. Experiments were generally run until sediment storage capacity was reached. This took from 30 minutes to 5 hours. Both the decline in trap efficiency with time, and the resulting sediment storage volume were measured.

Table 2: Characteristics of sediment used.

Aggregate size class (mm)	Proportion of total sample	TP per size class (%)	TN per size class (%)
>2	18.5	0.18	0.25
1-2	16.6	0.16	0.23
0.5-1	19.8	0.16	0.17
0.25-0.5	17.2	0.16	0.15
0.125-0.250	12.7	0.17	0.18
0.063-0.125	5.7	0.18	0.20
<0.063	8.8	0.16	0.18

TP = total phosphorus content
TN = total nitrogen content

3. RESULTS

3.1. How much sediment can be stored ?

The storage capacity of the backwater clearly decreased with increasing slope (Figure 2). The upslope length of the sediment fan in the backwater varied from 20 cm for a 27 % slope to 150 cm for a 6 % slope. This is equal to an average total storage of 5 kg/m length for 27 % slopes and 41 kg/m length for 6 % slopes, showing considerable backwater storage at low slopes (Figure 2). The surface of the sediment fan had a small slope of between 0.8 and 2.7 % for slopes under 18 % where backwater storage is most relevant. If we approximate the fan surface as level then we can calculate an approximate storage capacity as a triangular wedge, given the slope of the land (S) and the height to which water backs up behind the grass (H; Figure 1). For our experiments, H was approximately 6 cm (standard deviation 1.5). More accurate estimates can be gained from use of predicted fan surface gradients and H as a function of vegetation density, gradient and flow intensity. Variability in density between grass blocks help explain the irregularities in the trend in Figure 2. Backwater storage is largely unaffected by the width of the bufferstrip.

Within the grass, an average sediment depth of approximately 2.9 cm (standard deviation 0.9) was found, equivalent to 26 kg/m length for a 1 m wide strip. The depth of the sediment deposit is generally greatest at the upper edge of the buffer strip and least at the lower edge, where flow accelerates out from the grass (Figure 3). This edge-effect causes increased sediment transport capacity at the downslope end, and lowers total storage volume (Tollner et al., 1976). As buffer width increases, the proportion of the bufferstrip that experiences edge-effects decreases. Consequently we predict that the mass of sediment stored in the flume would be a minimum estimate of sediment storage per metre width in wider buffers.

Sediment storage in the grass declined with increasing gradient; with an average stored mass of 18 kg/m^2 at a 27 % slope compared to 32 kg/m^2 at a 6 % slope (Figure 2). This results from the greater sediment transport capacity of flow over high gradients, for a given discharge. Flow over steep gradients requires less deposition before the surface is sufficiently smooth to allow the flow to transport all of the supplied sediment.

The total storage capacity of a 1 m wide grass buffer strip is the sum of the in-grass and backwater stores, which ranges from 23 kg/m length of buffer at 27% slope to 73 kg/m length of buffer for a 6 % slope. Total storage capacity can be increased by constructing wider grass buffers, as explained above.

3.2. Dynamics of sediment trapping

The backwater store is filled with sediment early in the trapping process. This initial phase is associated with high trap efficiency. Sediment trap efficiency is defined as the amount of sediment being trapped by the whole system, which is equal to the difference between sediment input at the top of the flume and sediment output at the bottom of the flume. As the event continues, the trapping process shifts to within the grass. Deposition is relatively even in the backwater (Figure 3) and the fan builds gradually back up the slope. Within the grass, sediment is deposited as a convoluted bar with a steep forward edge over which saltating sediment falls and then deposits. The grass does not bend with these shallow flows. The deposit grows forward fairly haphazardly, with faster flowing rivulets within the overland flow bringing sediment to different parts of the grass in a seemingly random pattern. Deposition of sediment changes the patterns of fast flow and the fan front changes direction, akin to sediment deposition in deltas. The result is a deposit of quite variable thickness (Figure 3) representing the history of deposition and variations in grass density.

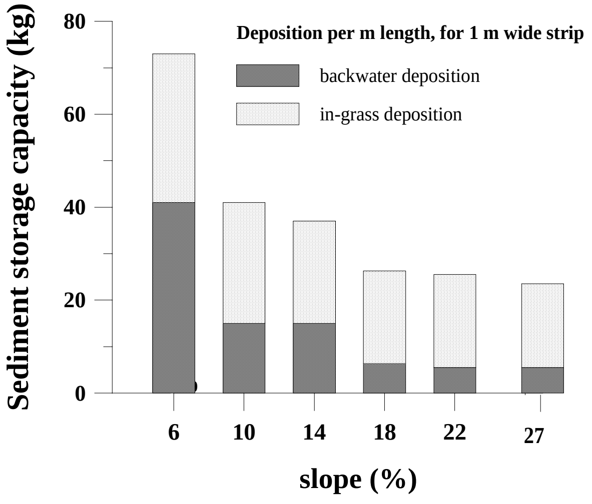

Figure 2: Trapped sediment mass varying with slope.

Trap efficiency decreases with time during each experiment as the backwater store is filled and the in-grass store approaches the downslope edge of the buffer (Figure 4). As an arbitrary cut-off, we take the time at which trap efficiency falls below 60 % to represent the end of effective buffering. The mean trap efficiency of the buffer to this point of time is approximately 80 %.

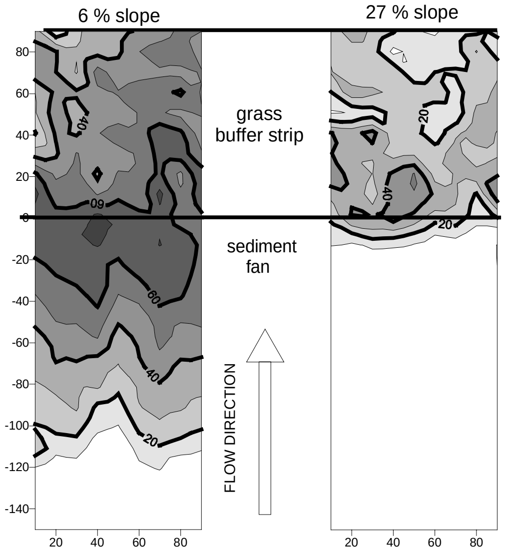

Figure 3: Distribution of sediment depth (mm) for a 6 % and a 27 % slope.

Figure 4 shows that a 1 m wide grass buffer on a 6 % slope has a trap efficiency of > 60 % for up to three times longer than buffers on slopes of 10 % or more. The main reason for this is the larger backwater storage capacity at lower slope. The total mass of sediment stored up to the point of 60 % trap efficiency, for a 1 m wide strip varies from 10 kg/m length at a 27 % gradient to 61 kg/m length at a 6 % gradient. The backwater store is approximately 85 % full by the time trap efficiency falls below 60 %. The effect of slope is the most important in explaining the results, however the variability in grass density between blocks explains some of the variability in trap efficiency between experiments. We observed that the approach of the (uneven) sediment front to the downslope edge of the grass coincided with an obvious decrease in trap efficiency, because the deposit formed a smoothed pathway through the buffer. This suggests that increasing the width of a dense grass buffer increases the mass of sediment that can be stored within the grass before trap efficiency falls below 60 %, and thereby increases the total time over which the buffer is "effective".

3.3. Sediment trapping for multiple events

We have observed in the field and the laboratory that grass grows quickly through, or germinates in, fresh buffer deposits, including in the backwater. Dense grass can grow over the deposit within three to six months, renewing storage capacity over this time. Thus sediment storage capacity should be viewed as the buffer potential for individual or closely spaced series of extreme events, not as the storage capacity for the buffer's total life (Wilson, 1967; Meyer et al., 1995).

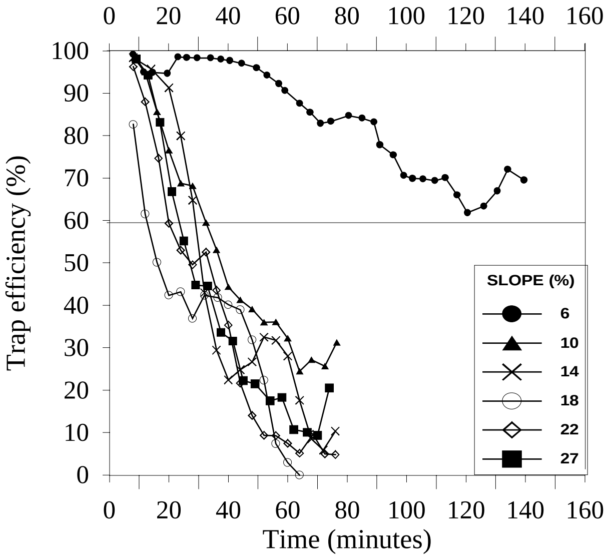

Figure 4: Trap efficiency with time for a medium flow rate (three point running average).

To simulate an example of the size of event that would reduce trap efficiency to < 60 %, we take the medium flow rate, 1.0 l/s, and calculate the rainfall that would be required to generate that flow from a 100 m long paddock. To be conservative we assume all rainfall is converted to runoff. This results in a required rainfall intensity of 36 mm/hr. For a 6 % slope this intensity can be maintained for 2 hours before trap efficiency is < 60 % and for a 27 % slope it can be maintained for 25 minutes. For the Gippsland area, typical of southern Australia, this rainfall intensity and these durations have recurrence intervals of >100 year and 2-5 year respectively (Canterford, 1987; Pilgrim, 1993). Such time intervals are more than sufficient for grass to recover. We used fairly high sediment concentrations, to again be conservative, but our sediment is better aggregated than many, so more substantial grass buffers would be needed in situations where sediment was less well aggregated (e.g. Hairsine, 1997). Hairsine (1997) found grass buffer strip at slopes as steep as 23 % to be effective in field experiments, which is confirmed by our work. However, Dillaha (1989) argues that grass buffer strips should not be used on steeper hill slopes that promote strong flow convergence or channelisation. Fieldwork will be required to establish the gradient at which shallow flow conducive to sediment trapping gives way to concentrated flow.

4. CONSEQUENCES FOR MANAGEMENT

An increased understanding of the dynamics of sediment trapping in grass buffer strips allows better planning in management. To assist in understanding the flume results, we have assumed that similar trapping to that in the flume occurs over a 100 m long strip on a planar hillslope. Topographic convergence of flow, caused by hillslope hollows, contour banks, or stock tracks would decrease the trapping capacity across a paddock compared to a planar hillslope, while topographic divergence would increase the trapping capacity. On a planar hillslope, the sediment volumes across 1 m width of slope (the flume width) multiplied by 100, represent sediment storage along 100 m of grass buffer. If we consider this 100 m long buffer to be at the foot of a 1 ha (100 x 100 m) paddock then the volume of stored sediment expressed in tonnes can be related directly to a soil loss rate expressed in tonnes per hectare. In this way 6 tonnes of deposition is equivalent to trapping 6 t/ha of soil loss from a 1 ha paddock using a 100 m long buffer. Adjustments to the calculations can be made to incorporate convergence of flow for the purpose of designing wider buffer strips in those locations.

Our work indicates that for shallow, evenly distributed overland flow, a 1 metre wide, 100 metre long buffer strip on a 6 % slope can trap 4.1 tonnes of sediment in the backwater while on a 27 % slope around 0.5 tonnes can be trapped in this way during high intensity runoff. Field-observations can be used to estimate the height water backs up to behind the grass. This information, coupled with knowledge of the slope of the land, can give an approximation of the amount of backwater sediment storage. For instance an average backwater height of 5 cm on a 30 % slope means the backwater will be able to store 0.4 t/100 m, while on a 4 % slope it will store 2.8 t/100 m. Within the grass itself, sediment was trapped to an average of around 3 cm depth. The storage capacity of backwater and grass combined, amounts to 7 t/100 m for a 6 % slope.

Wider buffer strips are expected to pay off especially in situations where sediment yields and thus the required storage capacity are high. Where overland flow concentrations are high due to converging slopes, conditions are less favorable for sediment trapping and wider buffer strips will be required. For slopes of 18 %, wider buffer strips are also necessary, as total storage capacity is half that at a 6 % slope, mainly because the backwater storage is relatively minor compared to storage in the grass.

Even the extremely narrow case of a 1 m wide grass buffer strip on a 27 % slope can have >70 % trap efficiency for the first 20 minutes. Because the majority of sediment gets transported during short extreme events, this means that the initial flush of sediment coming from upslope fields will be almost entirely trapped.

5. CONCLUSION

We have confirmed earlier findings that grass buffer strips can have high trap efficiencies (Wilson, 1967; Dillaha et al., 1989; Hairsine, 1997). For shallow, evenly distributed overland flow, our study showed that even relatively narrow grass buffer strips can have a considerable storage potential, especially on slopes <18 %. This is because the grass effectively acts as a permeable weir. The water backing up behind the grass provides a deposition area, as does the grass itself. Backwater storage tends to result in upslope extension of buffer strips, after grass has grown over the sediment deposit. Sediment trapping can be repeated because grass seeds in deposits germinate and grass grows through earlier deposits. Under ideal conditions of weak flow convergence, backwater and narrow dense grass buffers can provide efficient sediment control for events of 2 to 100 y recurrence interval for gradients of 27 to 6 % respectively. Thus grass buffers strips provide a simple and effective measure to trap sediment and prevent stream pollution, even on steep slopes.

6. ACKNOWLEDGEMENTS

This work was funded by the Land and Water Resources Research and Development Corporation. We thank Peter Richardson, Nigel O'Shea, Rodney Dekker, Susie Richmond, Jim Brophy and Jamie Margules from CSIRO Land and Water and the Cooperative Research Centre for Catchment Hydrology for their valuable assistance with the experiments and sample analysis. Peter Hairsine and Bruce Abernethy provided valuable comments on the manuscript.

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