The hydraulics of shallow overland flow: a comparison between a grass filter strip and a near-natural riparian forest

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ABSTRACT: *The hydraulic resistance to overland flow presented by buffer strips can reduce flow velocities and hence the ingress of sediments and associated nutrients to streams. The spatial variability of overland flow is a key factor affecting the effectiveness of the buffer. Grass filter strips and near-natural riparian forests are compared in terms of the spatial distribution of flow and flow velocities. Spatial variability of these two quantities was measured for a range of sediment-free inflows in the field. Flow velocities in a near-natural riparian forest were relatively higher and more variable than those in a grassed filter strip. This is consistent with lower sediment and sorbed-nutrient trapping efficiencies of near-natural riparian forests (Hairsine, 1996).*

1. INTRODUCTION

The riparian zone is the strip of land flanking a stream where overland flow from general catchment runoff enters the stream channel. It is subjuect to shallow overland flow from hillslope runoff, hence rills and small gullies may form normal to the contour. It may also be subject to overbank flow and to streambank erosion from channel discharge.

The zone is frequently specially managed to minimise streambank erosion and also to provide a buffer zone to overland flow which may contain sediment and sorbed nutrients from upslope origins (Barling and Moore, 1993; Woodfull, *et al*, 1993). In this paper we concentrate on the role of riparian vegetation in slowing overland flow to induce sediment deposition and thus the removal of a significant proportion of sediment and sorbed nutrients which would otherwise enter the stream.

This paper describes an investigation of the hydraulics of overland flow through two types of buffer zones, a grassed buffer strip and a near-natural riparian forest. It examines the velocity distributions of flow of sediment-free water across these two landscape types and is complementary to another investigation at the same site which measures the generation and entrapment of sediment (Hairsine, 1996). These two studies are linked to a larger project which investigates the role of the riparian zone in the management of Australian waterways (Wilson *et al*, 1995).

Flow through natural vegetation is heterogeneous (Kadlec, 1987; Abrahams *et al*, 1994). However, much of the study of shallow flow has been on artificial surfaces, often with regularly spaced artificial resistance elements introduced. The common descriptors of hydraulic roughness (Manning's n; Darcy-Weisbach's friction factor, f; Chezy's coefficient, C) have been derived from such studies and cater adequately for the uniform conditions of those studies. The difficulty of obtaining some appropriate measure to describe roughness elements (microtopography, stones, vegetation) has invariably led researchers to attempt the application of these same descriptors to variable natural surfaces.

Here we measure rates of shallow flow over differently vegetated surfaces, describe the spatial distribution of the resulting velocities and discuss the implications for sediment transport.

2. SITE DESCRIPTION

The study area is in the 116 km^2 catchment of the Tarago Reservoir (Victoria, Australia), constructed to supply water to the Mornington Peninsula. The reservoir is fed by the Tarago River: approximately 70% of the catchment is forested and drained by the West Branch and the remainder, drained by the East Branch, is given to mixed farming, predominantly dairying and seed potato growing. The reservoir was out of service at the time of the experiments partly because of recurring water quality problems thought to be related to sediment and nutrient accessions, particularly from the agricultural segment of the catchment.

The study site was located on a planar hillslope in the catchment of a small stream which enters the reservoir downstream of where the Tarago River enters the reservoir (lat 37° 59' 45"; long 145° 54' 30"). The soils are sandy loams overlying sandy clay subsoil and are derived from Upper Devonian Granites (Soil Conservation Authority, 1973). The riparian zone of the stream, comprising forest vegetation, was 2-300 m wide on the study side of the stream. A cleared area sown to pasture adjoined it on the upslope side. An experimental site was chosen from each vegetation type.

2.1. Grassed Filter Strip

The Grassed Filter Strip site (GFS) had a mean slope of 16.2% and was on semi-improved pasture, ungrazed for some years, but topped (slashed) intermittently to reduce fire hazard. The pasture was 30-50 cm high and comprised mostly introduced grasses of generally low grazing value which reflected a relatively low soil nutrient level, as did the presence of sundry non-grass

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weed species. There was little or no legume component. Nevertheless, there was a dense mat of dead aboveground roots which apparently had developed in the moist near-ground environment during wetter periods. This layer varied from 0 to about 15 mm thick. A dense network of grass stems arose from this root mat. There was little or no bare soil in the experimental area.

2.2. Forested Riparian Zone

The Forested Riparian Zone site (FRZ) had a mean slope of 20.8%. Although the vegetation may have been disturbed many years previously, it was regarded as being in a near natural state. It was classified as open mid-high mixed *Eucalyptus* forest (Walker and Hopkins, 1990). There was a sparse, mixed species understorey comprising mostly leggy shrubs with stem diameters up to 2.0 cm. Very little vegetation grew at the soil surface which was covered by a litter of dead and decaying leaves up to 5 cm thick. From the surface of the litter down to the soil surface there was a gradation from loose dry leaves to decayed leaves almost completely incorporated into the solum. The surface was strewn with occasional fallen twigs and small wood in varying stages of decay up to 3 cm diameter.

3. METHODOLOGY

At both sites, water was supplied to a 3 m x 10 m flume constructed on the undisturbed field surface (Figure 1). The flume consisted of 3 mm galvanised steel walls driven vertically into soil slots cut normal to the contour. The walls were sealed into the soil with paraffin wax, melted for pouring and allowed to set.

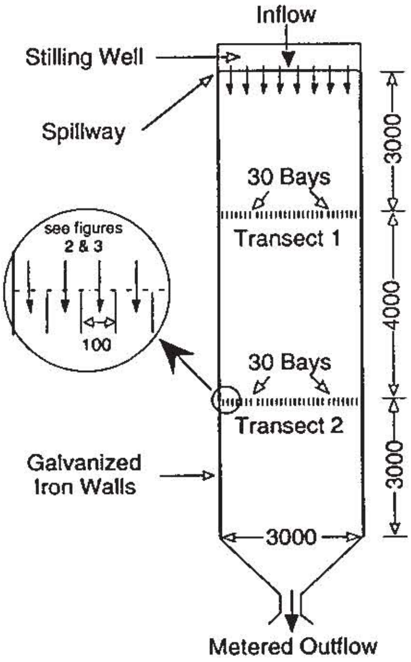

Figure 1. Field layout of experimental flume for shallow overland flow studies. (Dimensions in mm.)

Inflow was metered through a portable 90° V-notch sharp crested (or Thomson) weir (Bos, 1989) into a stilling well and delivered as a constant depth line source over a level spillway. At the lower end of the flume, outflow was metered through a portable long throated (RBC) flume (Bos *et al*, 1991). Outflow stage was sensed with a capacitance water depth probe and logged at 1 minute intervals.

Flow rates for the experiment were calculated to correspond with runoff levels of 5, 10 and 20 mm h^{-1} from a 200 m contributing hillslope length. The corresponding outflow rates were respectively 0.833, 1.667 and 3.333 l s^{-1}, subsequently referred to respectively as the low, medium and high rates.

Two sampling transects normal to the flume walls were located at 3.5 m and 7 m downstream from the inlet spillway (Figure 1). Along each 3 m transect, 29 vertical baffle plates of galvanised steel (22 cm high x 35 cm long and 0.7 mm thick) were inserted into the soil, normal to the contour and to a depth of about 2.5 cm. These created 30 mini-flumes each 10 cm wide (subsequently referred to as bays) (Figure 1). The downstream end of a bay was made into a 3-sided metal sluice box by covering the ground surface between the baffles with a 10 cm square horizontal sill plate (0.7 mm thick) and sealing it to the baffles on either side with silicon rubber (Figure 2). A 25 mm vertical downturn on the upstream edge of the sill plate was driven into the ground to deter flow under the sill.

These devices partitioned the total flow into segments of equal width. They allowed measurements of the depth of undisturbed flow over an undisturbed surface at the upstream end of a bay. At the lower end of a bay water flowed through the sluice box from which it could be extracted for flow rate measurements. The baffles offered minimum resistance to the flow and reduced

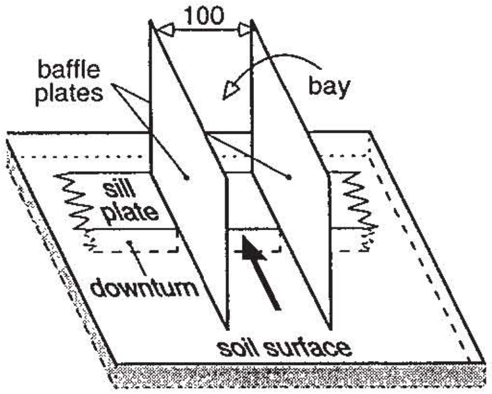

Figure 2. Detail of a bay showing baffle and sill plates forming a three-sided sluice at exit. (Dimensions in mm.)

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the total width of the flume by only 0.68%. The 30 bays effectively provided the opportunity to sample the variability in flow across the flume along a 3 m long transect. This approach is similar to the partial section technique of Abrahams *et al* (1986) and the sampling technique of Parsons and Abrahams (1989) and Parsons *et al* (1990).

Discharge in any one bay was measured by suction sampling. A close fitting suction head attached to a flexible hose was inserted into the metal lined sluice box at the downstream end of a bay. Flow in a bay was intercepted and removed by vacuum (provided by an industrial vacuum cleaner) over a timed interval. The sample was collected in a cyclone, decanted and weighed. Total discharge was calculated for each bay.

A 3 m long level tool bar (constructed from 3 mm aluminium as a box section, 150 x 50 mm) was fastened above the entrance to the bays. Water level was measured at the mid-point of the entrance to each bay using a digital reading depth gauge suspended from the tool bar (Figure 3). Surface profile elevation along the line of the entrances was measured with a recording profilemeter (pin spacing 15 mm) suspended from the tool bar. Profiles were measured at the conclusion of the experimental flows and vegetation was clipped to allow pin contact with the exposed soil surface.

Velocity of flow in a bay (V_{bay}) was calculated using the relationship

$$V_{bay} = q_{bay} . A_{bay} \text{..............................} (1)$$

where q_{bay} is the discharge from a bay and A_{bay} is the area bounded by the baffle plates, the water surface and the soil surface, calculated using the trapezoidal rule.

4. RESULTS AND DISCUSSION

There was no marked difference in data trends between transects at either site. Consequently, we report results from Transect 1 only where local slopes were 15.8% (GFS) and 21.7% (FRZ).

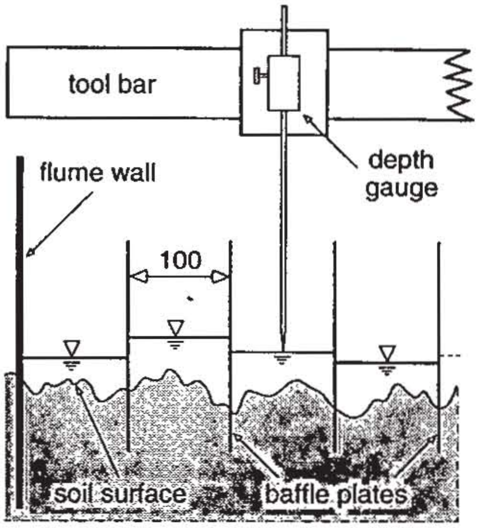

Figure 3. Components of field equipment: level aluminium tool bar and depth gauge suspended above entrance to bays. (Dimensions in mm.)

Soil surface profiles are presented in Figure 4. Total relief was 45 mm (GFS) and 73 mm (FRZ). Apart from this difference, variations in microtopography were markedly greater at the forested site. Localised channelling of overland flow would have resulted at each site, but the potential for this would have been greater at the forested site.

The distribution of discharge from individual bays has been expressed as cumulative percentage of total flow less than a specified value of discharge (Figure 5). These data reflect the effect on discharge of resistance to flow and micro-topography over the distance from the inlet to the transect. Heterogeneity of roughness results in channelling of flow with consequent variations in discharge across the transect. At each site the different distributions reflect the different outflow rates. If the flow had been evenly distributed there would have been mean discharges per bay of 27, 56 and 111 ml s^{-1}. The grassed site maximum discharges were between two and three times the mean discharges per bay. However,

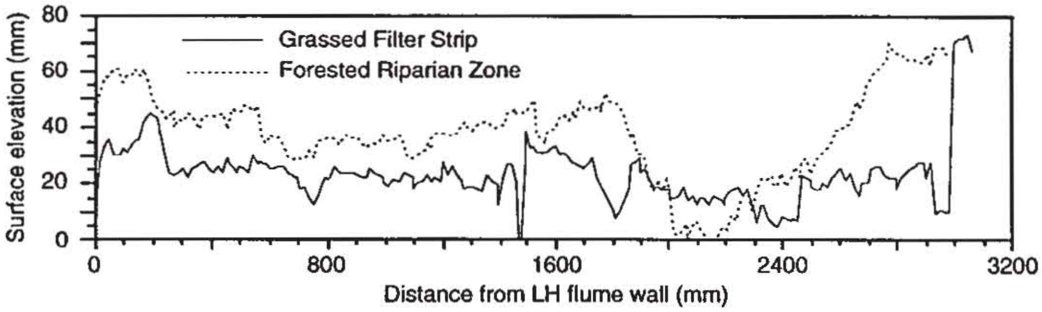

Figure 4. Soil surface elevation (mm) profiles for the Grassed Filter Strip and Forested Riparian Zone sites. **Note:** verical exaggeration x 10.

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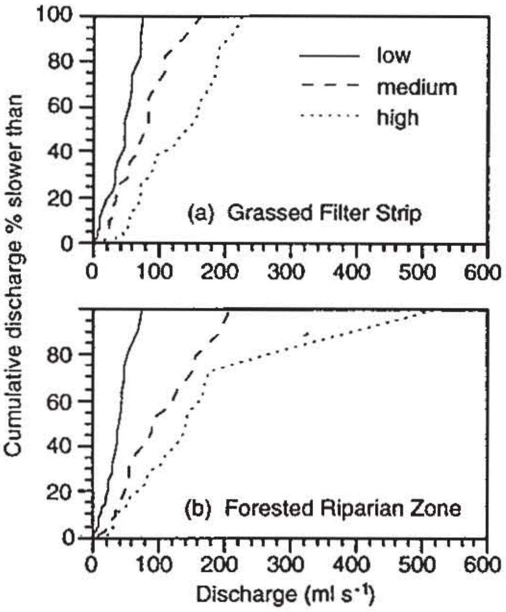

Figure 5. Distribution of discharge (ml s^{-1}) of shallow overland flow through 30 bays along a 3 m wide transect for each of 3 rates of flow. Data expressed as cumulative percentage of total flow less than specified value of discharge. (a) Grassed Filter Strip; (b) Forested Riparian Zone.

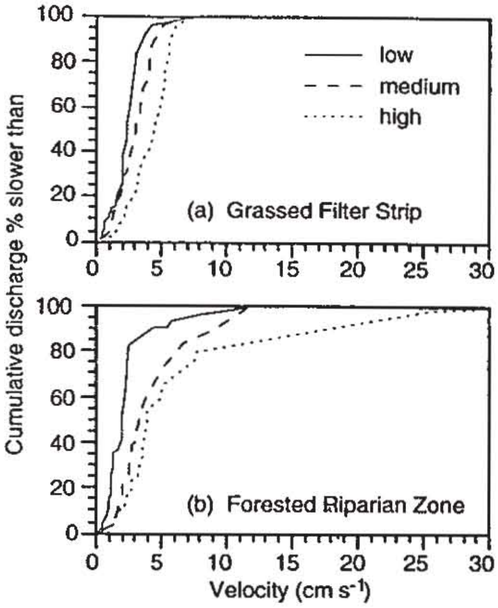

Figure 6. Velocity distribution of discharge (cm s-1) of shallow overland flow through 30 bays (miniflumes) along a 3 m wide transect for each of 3 rates of flow. Data expressed as cumulative percentage of total less than specified value of velocity. (a) Grassed Filter Strip; (b) Forested Riparian Zone.

the forested site maxima were three, four and finally, five times the mean dicharges.

The ranges of discharge levels in the bays differ markedly between sites. Note that at the forested site (Figure 5b), the maximum discharge for the medium flow exceeded the highest discharge of all recorded in the grassed plot (Figure 5a). For the high outflow rate, considerably higher (133%) discharges were recorded at the forested site than at the grassed site. From these data we infer that, over the lengths of the flow paths, there is a greater variability in total roughness of the forested site than of the grassed site.

In Figure 6 we present flow velocities in the bays expressed as cumulative percentage of discharge less than a specified value of velocity. The steeper slopes of the forested sited would have resulted in higher velocities independant of roughness effects. For purposes of comparing velocities between the two vegetation types we have scaled the forested site velocities according to Equation (2), on the assumption that $V \propto S^{1/2}$, where V is velocity and S is slope.

Thus, $V_{frz(corrected)} = V_{frz(measured)} . S_{gfs}^{1/2} . S_{frz}^{-1/2}$ .... (2)

As with the discharge distributions (Figure 5), at each site the different distributions of velocity reflect the different outflow rates. Again there is similarity with the discharge distributions in that the range of maxima is much less at the grassed site than at the forested site. This indicates a relatively higher, more uniform roughness at the grassed site. At the forested site (Figure 6b), the high outflow rate resulted in velocities that exceeded the maximum at the grassed site by nearly threefold. This trend is in accord with the development of channelling observed during the high flow treatment at the forested site. No such phenomenon was observed at the grassed site. However, at the grassed site maximum velocities (Figure 6a), in marked comparison to maximum discharges (Figure 5a), cover a much narrower range: maximum velocities are all similar while the maximum discharge at the high flow rate is nearly twice that of the low flow rate.

The wider distributions of discharge and the higher velocities observed in the forested site are considered the result of larger roughness elements there (calculated mean flow depths ranged from 1-36 mm). The leaf litter appeared to present a reasonably heterogeneous resistance to flow as evidenced by the relatively even distribution of discharge at the lower flow rates. However, the material was sufficiently mobile that during high flow there was some redistribution observed as channelling developed and rills formed. Also, the relatively narrower distributions of discharge and the lower velocities at the grassed site can be attributed to the apparently greater resistance presented to flow by the dense network of above ground roots and stems (mean flow depths ranged from 3-45 mm). At the flow rates imposed there was sufficient energy to remove portions of the organic protective layer on the forest floor but not at the grassed site

For maximum sediment trapping efficiency, discharges ideally should be evenly distributed and velocities should be minimised. These conditions are more readily met in the grassed site than at the forested site, trends which are in accord with the findings reported in this volume by Hairsine (1996). While it is not possible to partition roughness effects between vegetation, microtopography and slope at this stage, the usefulness of the comparison between total roughness at the two sites is evident.

5. CONCLUSIONS

A grass filter strip has been shown to result in slower, more uniform overland flow in comparison with a surface formed under a riparian native forest. The difference between the two vegetation types was found to be greater for increasing total overland flow input. The trend in the results is consistent with lower sediment and sorbed-nutrient trapping efficiencies of near-natural riparian forests (Hairsine, 1996).

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