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Preliminary results on the effectiveness of riparian buffers in Far North Queensland.

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SUMMARY: Riparian lands have the potential to buffer streams from hillslope sediment and nutrient transport. Most research on buffer strips has been conducted under laboratory or manipulated experimental conditions; little quantitative data exists on buffer strip performance under field conditions. This study reports on riparian hydrology and sediment trapping ability of buffer strips in Far North Queensland. Hillslopes cropped with bananas are being monitored to measure soil loss and evaluate the effectiveness of riparian buffers on planar and convergent slopes under field hydrological conditions. Highly variable hillslope soil losses of <1 t/ha to >70 t/ha were recorded. High rates of soil loss were from areas of steep gradient with little ground cover experiencing high rainfall intensity. On planar slopes, even with high soil loss, grass buffer strips were able to trap more than 80% of the incoming sediment. In contrast, a densely grassed riparian buffer within a steep hillslope hollow scoured and acted as a sediment source rather than a sediment trap. This creates a high erosion hazard if the riparian land is cropped, which is a common practice in many areas. The study demonstrates both a need for buffer strips and constraints on their potential effectiveness.

THE MAIN POINTS OF THIS PAPER:

- High hillslope soil losses are associated with steep cultivated land with little groundcover.
- Grass riparian buffer strips can trap more than 80% of incoming bedload on planar slopes, even under heavy tropical rainfall.
- Buffer strips are most needed on steep land under intensive cropping to trap sediment and reduce erosion potential.

1. INTRODUCTION

The control of non-point source pollution is one of the major issues facing agricultural communities. Since European settlement near-stream or riparian lands have been degraded throughout Australia and many riparian areas are now used for intensive agriculture. Riparian lands can potentially separate agriculture from streams by promoting infiltration, reducing surface flow velocities and physically filtering sediment (Muscutt et al., 1993), nutrients and other pollutants from runoff. In the context of such water quality improvements riparian lands *buffer* streams from sediment and nutrients. In this paper the term *riparian buffer* refers to the management of riparian land for water quality improvement.

Water transports pollutants through riparian lands so an understanding of riparian hydrology is fundamental to any evaluation of riparian buffering potential. In some environments riparian lands can absorb runoff (Herron and Wilson, 1999) which can immediately reduce the delivery of pollutants to streams. In other cases, riparian lands are areas where soil saturation occurs and sub-surface flow emerges. (e.g. Bosch et al., 1994). This increases the hazard of erosion if the land is cropped, for the positive pore water pressures make it easier to erode the soil. In the most extreme cases this leads to mass soil failure and rill and gully erosion (Huang and Laften, 1996; Bryan et al., 1998). Erosion of riparian land is particularly significant because there is little possibility for intermediate storage and sediment is delivered straight into the stream. Consequently, there is a need to identify where vegetation management is needed to protect streams from hillslope sediment sources.

Riparian buffers are most needed for sediment control where there is high soil loss and a high probability that the eroded soil will be delivered to the stream. Soil loss within a catchment varies with ground cover, land management and topography. So it is useful to identify the conditions within a catchment that lead to the greatest sediment delivery hazard and focus management on these areas.

This study reports preliminary data on patterns of hillslope soil loss, sediment trapping ability and riparian zone hydrology under natural rainfall conditions in the Johnstone River catchment of Far North Queensland. Hillslopes are the predominant source of sediment in this catchment, and the sediment is having significant impact on tributary streams and the main river (Prosser, 1999). The area has extreme conditions for testing the effectiveness of riparian buffers – steep, intensely cropped land with very high intensity rainfall. The only mitigating factor is the well-structured soil, which has a high infiltration capacity and water-stable, coarse aggregates.

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The key questions addressed in this paper are:

- What are the conditions that lead to high sediment delivery from hillslopes?
- Under what conditions are riparian buffers effective in reducing sediment delivery to streams?
- Are grass buffers more effective at trapping sediment than remnant rainforest?
- How does near stream hydrology influence buffer effectiveness?

Table 1. Monthly total rainfall at Dunne's for 1996-98, compared with long-term average monthly rainfall at Innisfail.

		Monthly rainfall (mm)											
Station	**Year**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Dunne's	1996	-	-	-	-	-	-	164	51	11	338	43	398
	1997	413	352	721	408	131	0	95	157	49	38	73	746
	1998	1166	486	361	355	174	-	-	-	-	-	-	-
Innisfail	Mean	509	600	665	465	306	188	133	115	86	81	149	256

Table 2. Characteristics of monitored hillslopes.

Hillslope	Slope (%)	Area (ha)	Topography	Hillslope condition	Riparian condition
Gallagher's Grass	7	0.2	Planar	• ploughed 1996 • bananas planted 1997 • little ground cover	signal grass *(Brachiaria decumbens)*
Gallagher's Tree	7	0.2	Planar		remnant rainforest
Dunne's Moderate	3	0.3	Moderately convergent	• ploughed 1996 • bananas planted 1997 • good grass cover	signal grass *(Brachiaria decumbens)* in hollow
Dunne's Extreme	13	5.0	Highly convergent	• bananas planted 1994 • good grass cover from 1997	steep hollow of signal grass *(Brachiaria decumbens)* with 4 vetiver grass *(Vetiveria zizanioides l.)* hedges

2. STUDY AREA

The study hillslopes are in the banana and sugar cane producing area of wet tropical Far North Queensland. They are part of the North Johnstone River catchment, which meets the coast at Innisfail. Bananas are planted on steeper land in this region, while sugar cane is generally grown on the flatter land. Soils are well aggregated Krasnozems underlain by deeply weathered basalt or sandstones and shales.

The long term average rainfall at Innisfail is 3553 mm. Most of the annual total rainfall occurs in the wet season, December to April (Table 1), and is characterised by long duration and high intensity storms. The winter months are dry by comparison and little runoff occurs on hillslopes at this time.

Riparian buffers at four sites, across two properties, were monitored for this study (Table 2).

2.1 Gallagher's Grass and Gallagher's Tree

Two adjacent hillslopes (both with a catchment area of 0.2 ha) are instrumented on Gallagher's property (Table 2). One has a 15 m wide grassed riparian buffer and the other a 15-20 m wide buffer of remnant rainforest. Both hillslopes drain a 7 % gradient, 200 m long planar slope planted with bananas. Gallagher's Grass is planted with signal grass (*Brachiaria decumbens*), a low-growing perennial, which forms a dense soil cover. The remnant rainforest, Gallagher's Tree, has no understorey, typical of rainforest with a closed canopy. The hillslopes drain into Coventry Creek.

2.2 Dunne's Moderate and Dunne's Extreme

Two hillslope hollows, both draining into Berners Creek, are instrumented on Dunne's property (Table 2). Dunne's Moderate drains 0.3 ha with an average gradient of 3% and has dense signal grass (*Brachiaria decumbens*) cover along 60 m of gently sloping hollow. Dunne's Extreme drains 5.0 ha with an average gradient of 13% and the steeper foot of the hollow is grassed with signal grass *(Brachiaria decumbens*) and four Vetiver grass (V*etiveria zizanioides* L.) hedges. The names of these instrumented hillslopes reflect the degree of topographic convergence of flow. The hollow at Dunne's Extreme drains a 5 ha area and cropping continues across the upper part of the hollow. This results in the runoff travelling as confined overland flow before the buffer is reached. The buffer at Dunne's Moderate covers the full extent of the hollow but flow is not able to disperse within the buffer, in contrast to Gallagher's Grass.

3. METHODOLOGY

Riparian zone hydrology is being investigated using small flumes and piezometer nests. Runoff entering and leaving the riparian zone on each hillslope (Upper and Lower sites, respectively) is monitored using identical flumes, fitted with water level recorders and automatic water samplers (Figure 1).

To measure bedload transport, each flume is fitted with a trap that diverts a known proportion of sediment into a storage drum, which is emptied periodically. The remaining sediment is able to continue moving through the riparian zone. Similar installations are present at Dunne's Moderate and Dunne's Extreme.

Water samples collected by the automatic samplers have been sent to the laboratory for analysis of suspended sediment and nutrient concentrations but results are not yet available.

The sediment trap efficiency of the riparian zone is calculated as the difference between the sediment loads recorded at the upper and lower flumes. Similarly, the hydrology of the riparian zone is inferred from differences between runoff in the upper and lower flumes, and from piezometer nests.

Piezometer nests are installed at the Gallagher's sites only, as shown in Figure 1. Piezometric head is recorded hourly with pressure transducers. Each nest contains at least one piezometer sitting on the bedrock, at a depth of between 1 m and 4.7 m below the ground surface (Figure 1).

Rainfall is measured with tipping bucket rain gauges at both Dunne's and Gallagher's sites.

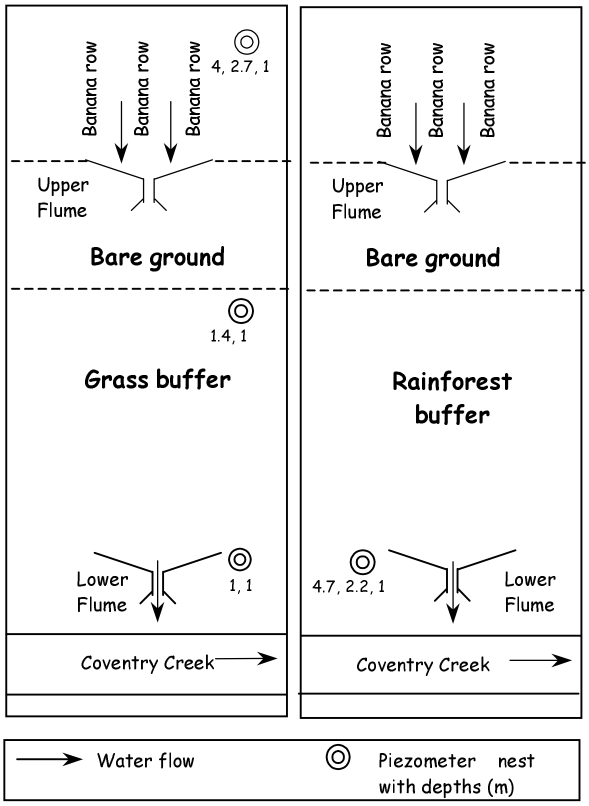

Figure 1 . Schematic of Gallagher's Grass and Gallagher's Tree instrumentation.

4. RESULTS AND DISCUSSION

4.1 Bedload Loss from Hillslopes

At the four sites bedload is made up of water stable soil aggregates of clay and silt, predominantly 2-4 mm in diameter. On the basis of previous work in the catchment (Prove et al., 1997) and visual observation, the proportion of total load that is transported as bedload increases with the total load of the event. That is, high sediment loads contain >50% and often >75% bedload. In events with low bedload transport (<5000 kg) the suspended sediment load dominates, but the total load is always <20 t/ha.

Table 3 shows high spatial and temporal variability in sediment delivery of bedload from hillslopes over the 96/97 and 97/98 wet seasons. Wet season bedload soil loss at our four sites varied from <1 t/ha to 70 t/ha. It is not possible to unravel the precise causes of variation in sediment yield because more than one factor tends to vary between sites. Nevertheless some patterns do emerge.

There is a stark contrast between the 96/97 wet season and that of 97/98. The 96/97 wet season was drier than average with only 2290 mm of rainfall, 35 % less than the average for Innisfail. The 97/98 wet season was wetter than average and 3415 mm of rainfall was recorded at Dunne's. In January alone, 1166 mm fell, following 599 mm in the last 3 days of December. This extreme rainfall accounted for the high total bedload yield for the season. Extreme events are known to dominate sediment yield in the region (Walton and Hunter, 1997).

Ploughing of three of the hillslopes in 1996 (Table 1) may also have contributed to the low bedload sediment yield, contrary to expectation. The soils were deep ripped across the contour, greatly increasing the depth of ponding required to generate overland flow. This, combined with the high infiltration rates of the soil, the lower than average rainfall intensity, and the stability of the aggregates (even under significant ponding), meant that <15% of the 1997/98 wet season runoff occurred on these sites during the 1996/97 wet season.

In contrast bedload sediment yield at Dunne's Extreme was higher in 96/97 than 97/98, although rates were low in both years. This reflects observations of earlier work (Prove et. al., 1997) that bedload transport, and total sediment yield declines with plantation age due to a depletion of readily erodible soil. For example, a 20 x 30 cm rill had eroded along the hollow axis at Dunne's Extreme prior to 1996 but the bed and banks of this rill are composed of cohesive clay and the high intensity runoff of 97/98 was unable to further erode the rill. In contrast, there was extensive rill erosion in an adjacent freshly planted paddock in 97/98.

High sediment delivery only occurred on steeper slopes with little inter-row grass cover (both Gallagher's sites in 97/98 and Dunne's Extreme in 96/97). The low gradient, well grassed site of Dunne's Moderate failed to yield significant bedload in either season. Grass cover may also have contributed to the low bedload yield from Dunne's Extreme in 97/98.

Table 3. Bedload data from Gallagher’s and Dunne’s.

Site	Area (ha)	1996/97 WET SEASON (rainfall 2290 mm) Bedload trapped (kg)				Total load (kg)	Soil loss (t/ha)	1997/98 WET SEASON (3415 mm) Bedload trapped (kg)			Total load (kg)	Soil loss (t/ha)
		21/1/97	14/2/97	27/3/97	14/5/97			6/1/98	7/1/98	12/1/98		
Dunne’s Extreme Upper	4.66		7128	1061		8189	1.76		90		90	0.02
Dunne’s Extreme Lower	4.96		9216	594		9810	1.98		90		90	0.02
Dunne’s Mod. Upper	0.303	0			5	5	0.02				0	0.00
Dunne’s Mod. Middle		0			3	3					0	
Dunne’s Mod. Lower		0			4	4					0	
Gallagher’s Grass Upper	0.191				145	145	0.76	>4161		3663	>7824	40.96
Gallagher’s Grass Lower					24	24		4		no data	>162	
Gallagher’s Tree Upper	0.191				18	18	0.10	>6821		>6474	>13295	69.61
Gallagher’s Tree Lower					37	37		177		no data	>5971	

Very high bedload yields of 40 and 70 t/ha occurred at Gallagher’s sites during the 1997/98 wet season. These figures are still significantly lower than those quoted in the literature for soil loss from sugar cane in this region, even considering that suspended load has not been included in the analysis to date. Prove et al. (1995) reported soil losses from plot studies on conventionally cultivated ratoon cane lands in the Johnstone River catchment of between 47 and 505 t/ha/y. The average loss was 148 t/ha/yr and no-tillage practices reduced this figure to less than 15 t/ha/yr. Matthews and Makepeace (1981) reported a soil loss of 382 t/ha/yr for conventionally cultivated sugar cane on a 16% slope. This soil loss was measured during a wet season that included a record 2742 mm of rain in a single month. Conventional cane practices and banana land use practices have much in common. They both involve intensive cultivation and there is considerable bare ground between the crop, particularly early in the crop rotation. Thus we might expect similar sediment yields between the two land uses, a result found by Walton and Hunter (1997) based upon in-stream sediment loads.

Caesium-137 measurements made at Dunne’s Extreme and Gallagher’s Grass sites suggest a long term average soil loss of between 14 and 25 t/ha/y (Wallbrink, pers. comm.), consistent with this preliminary monitoring. The sediment budget calculations of Prosser (1999) also point to such soil loss rates for the sediment budget to balance. Thus, these results suggest that the published figures of >100 t/ha are too high to be used as hillslope averages over longer time periods. The earlier results tended to include higher than average rainfall intensities, steeper than average slopes and measurement at less than hillslope scale, all of which would over-estimate sediment delivery potential to streams.

4.2 Bedload trapping in riparian lands

The riparian buffers have significant bedload trapping ability but not under all conditions (Table 3). Gallagher’s Grass performs consistently, trapping > 80% of bedload up to 6/1/98. The storage drums at both lower sites at Gallagher’s were forced out of the ground on January 9 1998 preventing calculation of trapping ability. Gallagher's Tree was a source of sediment during the low intensity runoff of 96/97. Significant reworking of deposition in early January 1998 was also observed in later storms. In contrast, deposits at the grassed site were quickly colonised by couch grass and were not reworked. The focus of deposition was at the upper edge of the buffers, consistent with deposition in a backwater (Karssies and Prosser, 1999). Riparian forest may act as a temporary store of sediment but the sediment is easily available for future transport to the stream. Rapid grass growth can ensure longer residence time of sediment in a grassed riparian zone.

The lower flume at Dunne's Extreme also recorded generally higher bedload yields than the upper flume, as a result of scour within the axis of the hollow (Table 3). At this site the riparian land is so steep that runoff is confined to a 1 m wide channel which scours even with a dense grass cover. Here the buffer needs to be placed higher up the hollow, where gradient and discharge are less, for it to have any chance of success.

4.3 Hydrology

All sites are hillslopes so runoff only occurs during high intensity rainfall. Both of the Gallagher’s sites and Dunne’s Moderate have similar hydrology. Runoff at the lower flumes is often greater than at the upper flumes; for example, the event in late December at Gallagher’s Grass shown in Figures 2 and 3. Early in this event more runoff was passing through the upper flume than the lower flume. This suggests that runoff was infiltrating into the soil between the two flumes. The soil between the flumes was not saturated at this time and so runoff was generated as infiltration excess overland flow. Infiltration excess overland flow is typical from croplands under high intensity rainfall.

Later in the event, after the hourly rainfall totals exceed 38 mm, the lower riparian zone at Gallagher’s Grass became saturated and the water table intersected the surface. At the lower piezometer nest (Figure 3 (b)) the water table rose sharply within a period of 2 hours from 90 cm below the surface to within 10 cm of the surface and remained within 10 cm of the surface for 30 hours fluctuating with each rainfall addition.

The water table upslope of the upper flume (the piezometer is located 30 m above the upper flume) also responded quickly to the initial rainfall (Figure 3(c)) and later rose to the surface. The water table was at the surface for the 4 hours after 2300 hrs on 29 December 1997. Once the rainfall had passed its peak hourly total of 55 mm the water table receded, and fluctuated with each new rainfall input.

After the water table intersected the surface and the hillslope was saturated runoff rates and volumes at both flumes were substantial. During the event a total runoff volume of 29.5 m^3 was measured at the lower flume, while 25 m^3 was recorded at the upper flume, so an additional 4.5 m^3 of runoff passed through the lower flume.

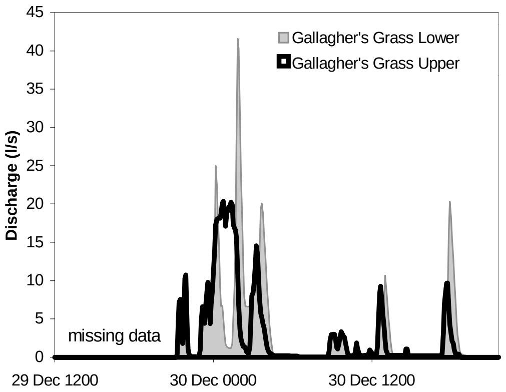

Figure 2: Runoff at Gallagher’s Grass Upper and Lower flumes for a 540 mm event in late December 1997 (see Figure 3 (a) for the storm rainfall).

These results are consistent with the variable source area concept, where the saturated area or wedge expands in response to rainfall. The response at Gallagher’s Grass is swift and more extensive than in less extreme environments. The 7% planar slope becomes saturated more than 35 m upslope a few hours following the start of rain.

Considerable seepage was observed at three of our four sites. Seepage emerging in the riparian zone prevents runoff from being absorbed and reduces soil strength (Huang and Laften, 1996). Thus, a potential erosion hazard exists if the riparian land is cropped rather than protected. Seepage is likely to occur when the riparian and gradient decreases and near-stream soils are shallow and permeable.

The fourth site, Dunne’s Extreme, behaves differently; a large proportion of runoff passing through the upper flume infiltrates within 15 m of the upper flume and does not pass through the lower flume. The proportion infiltrating varies between and within events. Figure 4 shows the runoff associated with a 550 mm rainfall event in late December 1997. In this event 45% (4,440 m^3) of the runoff flowing through the upper flume did not flow through the lower flume. By comparing the peak flow rates we can get an estimate of the maximum seepage rate. For this event the difference in peak flow rates is between 50 and 70 l/s. Around 20% (2,260 m^3) of the flow infiltrated between 7 and 10 January 1998 under the moister antecedent conditions. Maximum seepage rates for this event were between 10 and 30 l/s.

Dunne’s Extreme behaves in this manner as the hollow has a deep soil fill, at least 3 m deep. Runoff can be absorbed by the thick soil layer, slowing it’s delivery to the stream. Such big losses cannot be stored in the soil so the water must make its way to the stream via rapid sub-surface flowpaths.

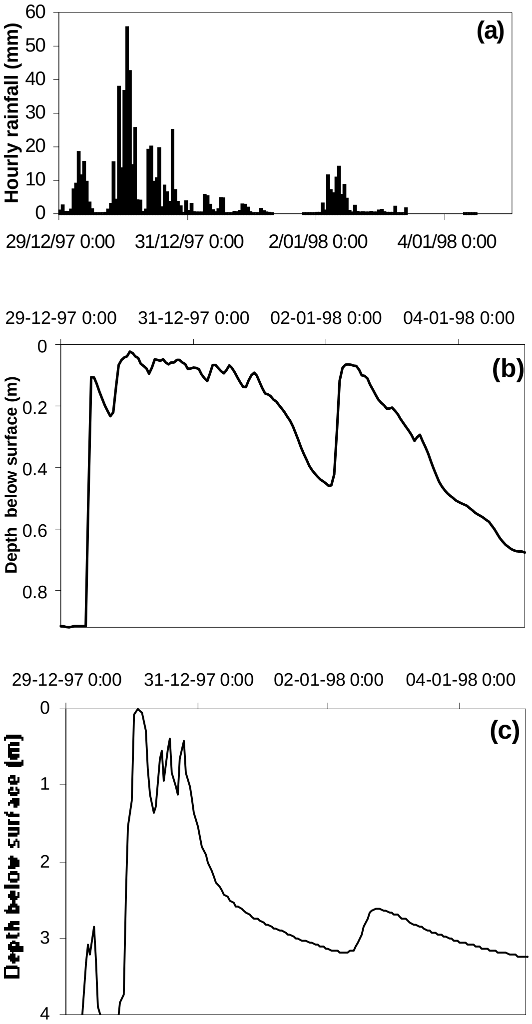

Figure 3: (a) Hourly rainfall totals, (b) piezometric head at Gallagher’s Grass Lower (1 m deep) and (c) piezometric head at Gallagher’s Grass Upper (4 m deep) for the 8 days starting 29 December 1997.

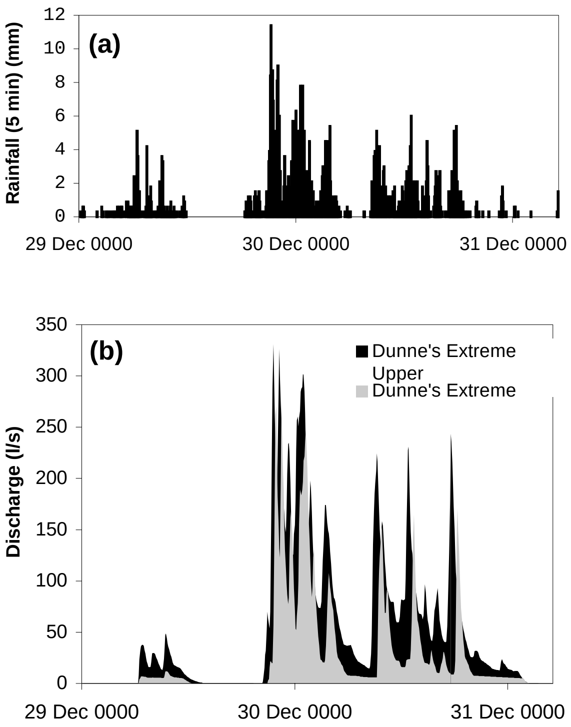

Figure 4: (a) 5 minute rainfall totals at Dunne's and (b) Dunne's Extreme Upper and Lower hydrographs for the 550 mm event in late December 1997.

5. CONCLUSIONS

This study has been conducted under extreme conditions – steep, intensely cropped land subject to high rainfall intensities. High hillslope soil losses were measured on steep slopes with little inter-row grass cover. Low gradients and good inter-row grass cover present little erosion hazard. Slopes are most at risk of erosion in the first wet season of a crop. The results show that riparian buffers are effective at trapping sediment under these extreme conditions. Dense grass cover was able to trap more than 80% of incoming sediment on planar slopes. The riparian rainforest trapped sediment but observations suggest that it was only a temporary sediment store. Rainforest buffers should therefore consist of two zones, a grass buffer upslope of a rainforest buffer.

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