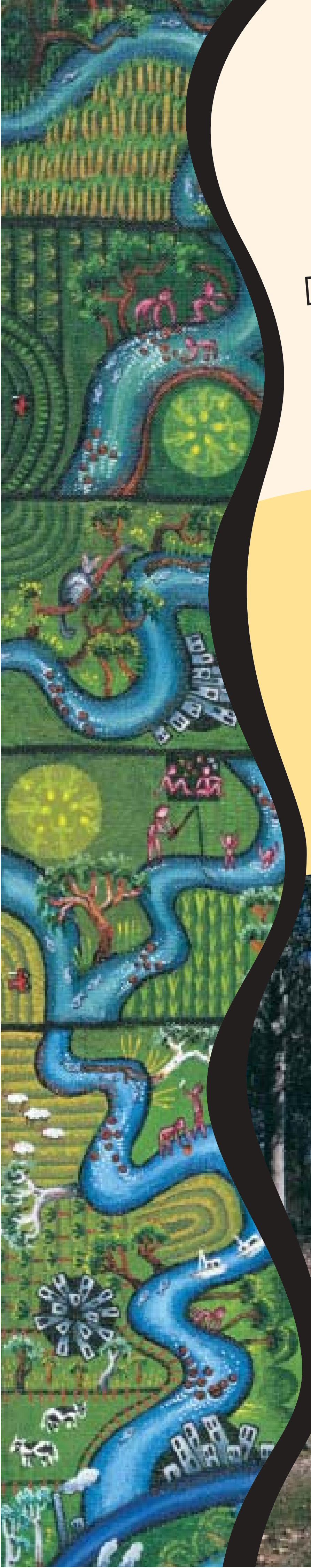

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# Designing filter strips to trap sediment and attached nutrient

*Ian Prosser and Linda Karssies, CSIRO Land & Water*

## Summary


- Riparian filter strips are needed to protect streams and riparian lands from high sediment and attached nutrient loss from hillslopes.
- Riparian filter strips are needed in areas of intensive land use on sloping ground.
- Under good land management practices, relatively narrow filter strips of dense grass can protect streams effectively.
- Riparian filter strips should be placed at the foot of the paddock.
- This update outlines design criteria for filter strip width to trap sediment and attached nutrients, and to accommodate typical soil losses from hill slopes.


## 1 Background

In Volume 1, Chapter 5 of the *Riparian Land Management Technical Guidelines* we outlined the principles of where riparian filter strips are needed to protect streams from high sediment and attached nutrient loss from hillslopes. In Volume 2, Section D of the *Riparian Land Management Technical Guidelines* we gave generic principles for the design of such filter strips. In this *Technical Guideline Update* we outline design criteria for filter strip width to trap sediment and attached nutrients. The design criteria are based on a recent set of sediment trapping experiments conducted as part of Land & Water Australia's National Riparian Lands R&D Program.

In essence, the information provided in Volumes 1 and 2 of the *Riparian Land Management Technical Guidelines* explained that riparian filter strips are needed in areas of intensive land use on sloping ground. We argued that the filter strip should be a dense ground vegetation cover of spreading grasses. The strip should be of variable width designed for the incoming discharges and sediment loads. We are now able to give more prescriptive advice on required filter strip widths to accommodate typical soil losses.

## 2 Sediment storage capacity

Sediment is trapped by riparian vegetation because when the flow enters a vegetated strip the velocity is reduced by the increased surface roughness, or flow resistance of the vegetation. The decrease in velocity results in a decrease in the capacity of flow to transport sediment. Sediment is deposited if the resultant transport capacity is less than the incoming sediment load. The reduction in flow velocity within a filter is transmitted back through the flow to the area upslope. This gives rise to an area of deep, slow flowing water, known as a backwater (Figure 1).

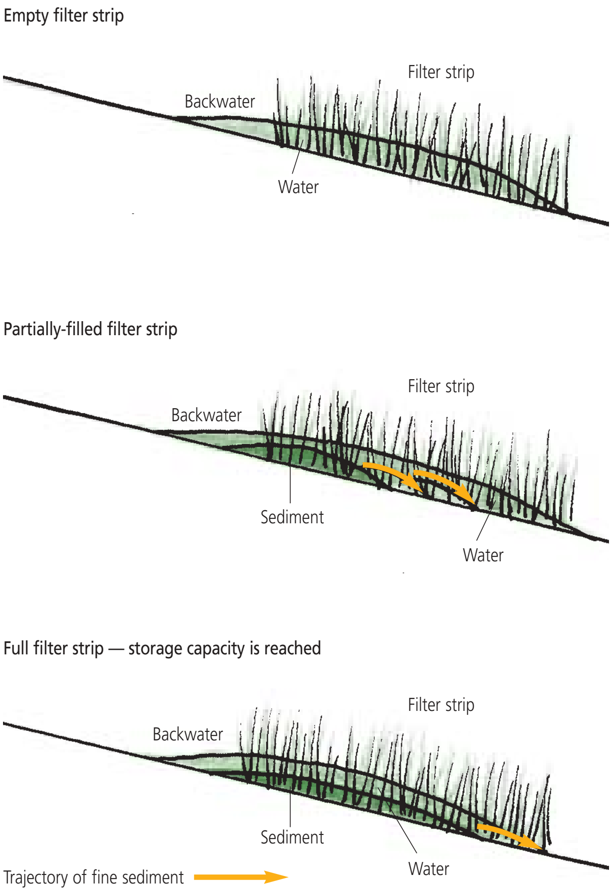
Deposition occurs initially in the backwater, and progresses into the grass strip. During deposition, the grass stems and stolons that provide hydraulic roughness are progressively buried, which increases the capacity of flow to transport sediment through the filter.

**Units**

| | | | |
|---|---|---|---|
| cm | centimetre | t/ha | tonne/hectare |
| l/s | litre/second | t/ha/y | tonne/hectare/year |
| m | metre | t/m$^3$ | tonne/cubic metre |
| mm | millimetre | t/m | tonne/metre |

**Figure 1**

Conceptual diagram of sediment storage in a backwater and a growing wedge of deposition in a grass filter strip.




Deposition on a grass riparian buffer downslope of a ploughed paddock. Photo by Ian Prosser.

Eventually, a steady-state is reached where the grass is buried to a sufficient extent that the flow can transport all the sediment it is carrying through the buried grass, and the wedge of deposition moves forward through the vegetation. The wedge may continue through the full length of the strip. By this time, the filter strip has reached its full storage capacity and no longer traps any sediment. Fine suspended sediment may be transported well beyond the front of the sediment wedge because of its slow settling velocity. As a result, the sediment trapping efficiency of a filter may fall below 50% well before the main depositional front reaches the end of the filter.

The storage capacity of a filter is constantly renewed by vegetation germination and growth on, and through, the trapped sediment. This renews the strip filtering capacity for future events. In warm climates, we have observed dense grass cover to re-establish within three months of burial.

This concept of a wedge of deposition in the backwater and within the vegetation, means that a filter has a limited sediment storage capacity beyond which it is no longer effective. We use this concept of a sediment storage limit in the strip to formulate design rules for strip widths.

## 3 Experiments on sediment storage capacity of grass filters

The design guidelines that we give below use sediment storage capacity of backwaters and grass strips measured in a set of flume experiments conducted recently at CSIRO Land & Water. The experiments were led by Linda Karssies and, to our knowledge, they are the only filter strip results aimed at measuring storage capacities. As a result, they provide the best data for the designs. They are of course limited by the range of experimental conditions that were applied.

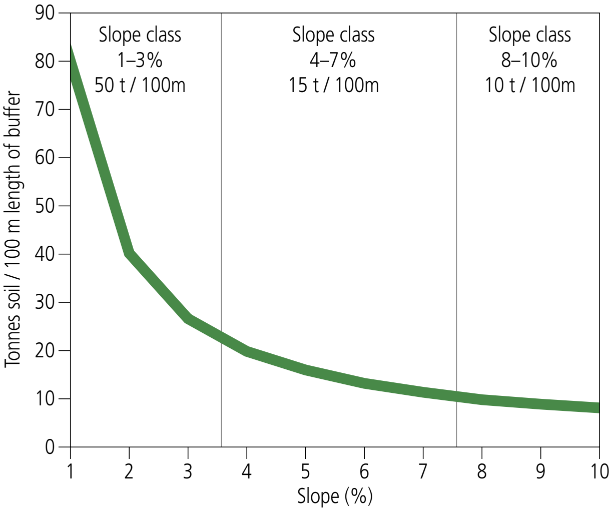
The experiments used dense grass strips of *Kikuyu* grass with a grass height of 15 to 30 cm. Flow resistance through the grass was similar to that obtained in other published grass strip experiments. The sediment applied was from a *kraznozem* soil used for potato cultivation. The soil was well aggregated with 10% of material finer than 0.063 mm in diameter. Discharge was applied to the grass at a rate of 1.0 l/s across a 1 m wide flume. The results obtained are probably applicable to intensively cropped land in humid environments where dense grass cover can be achieved.

Linda Karssies and Susie Richmond measuring flow depth during a sediment trapping experiment. Photo by Ian Prosser.

Sediment in the backwater formed a triangular wedge with a horizontal surface. Thus, backwater sediment storage increases with decreasing gradient at the leading edge of the filter (Figure 2) varying from 0.035 t/m length for 18% slopes and 0.160 t/m length for 6% slopes. The average height of the wedge at the grass front was 13 cm, and the sediment deposit had a bulk density of 0.9 t/m³.

**Figure 2**

Backwater storage changes with slope of the grass filter.




Sugar cane crop soon after planting. It is conditions like these that require grass filter strips. Johnstone River, Queensland. Photo by Ian Prosser.

The sediment accumulated to an average depth of 9 cm in the grass, with a bulk density of 0.7 t/m$^3$. The sediment storage capacity of the grass was not influenced noticeably by incoming discharge or slope of the plot. We found that particles smaller than 0.063 mm diameter were trapped effectively over a period of 2 hours in a 2 m wide filter. This finding leads us to suggest that fine particles settle out within 2 m of reaching a grass strip.

## 4 Design criteria

A well designed filter strip will trap sediment supplied during intense storms. We use average annual soil loss as an indicator of the intensity of a typical large erosion event, as soil loss in any season is focussed in a few events at most. Such filters will be effective sediment traps over most conditions, but will not be effective for extreme events such as 1 in 100 year recurrence interval events. Much wider filter strips are required for such purposes, as soil losses from extreme events can be many times the mean annual soil loss and can reach high levels of the order of 300 to 700 t/ha (Edwards 1993). Gradual recovery of grass filters between erosion events guarantees a long-term effectiveness and incorporation of sediment in the filter will not raise its height significantly within a generational time-span.

A 100% grass cover will trap sediment better than scarce grass because if grass is patchy the runoff can bypass the areas with a high roughness (Magette et al. 1989). Stock tracks are infamous in this respect because they provide fast flow paths for runoff, usually straight down the hill towards the stream. Other important characteristics for grass filter species are that they should be perennial, resistant to flooding and drought, and able to keep growing after partial inundation.

The height of the vegetation is also important, since this affects the surface roughness. Heights of 10–15 cm have been recommended (Dillaha et al. 1986). Longer grass should not pose a problem as long as the stem density near ground level is still high and does not suffer from lack of light. Obviously, grasses that are highly invasive or are significant weed problems should be avoided.

The average annual soil loss can be estimated from local erosion studies or the Universal Soil Loss Equation (USLE) (Wischmeier 1978) and its local derivatives such as SOILOSS (Rosewell 1993 – NSW DLWC) or PERFECT (Qld DNR).

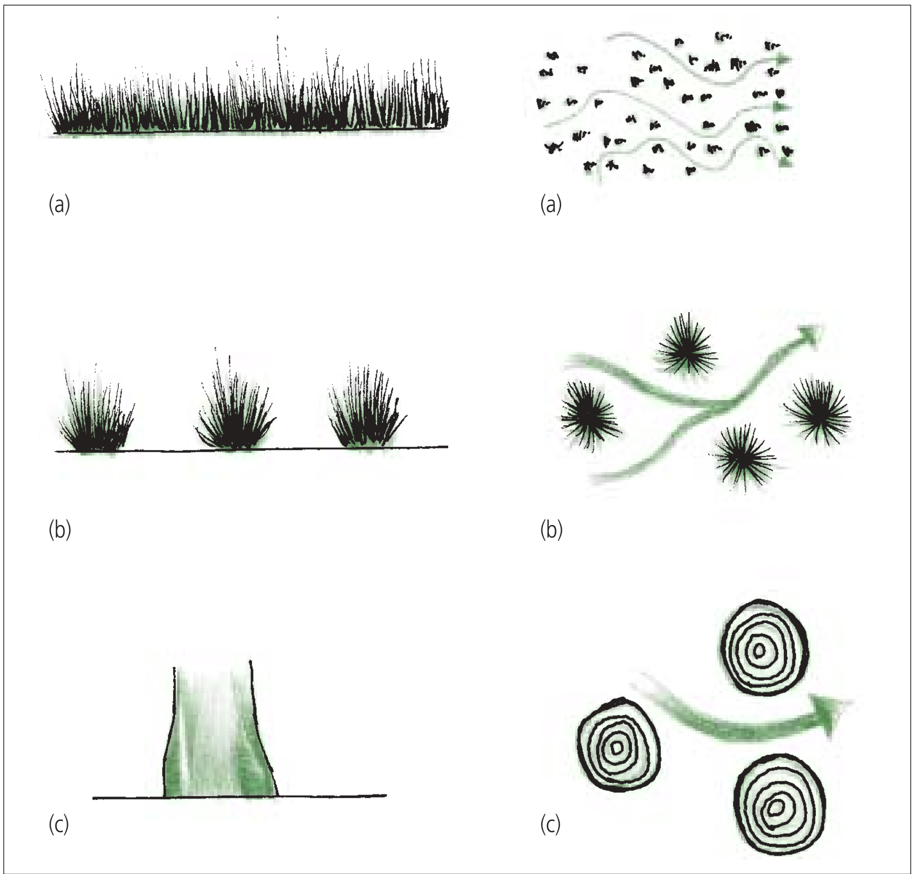



**Figure 3**

Flow paths through different density vegetation. Left column: side view, right column: plan view.

(a) Dense, spreading grass encourages many small, low velocity flow paths.

(b) Tussock grass has larger and faster flow paths, bypassing the dense tussocks.

(c) Trees accentuate this pattern further, with little interaction between the foliage and overland flow.

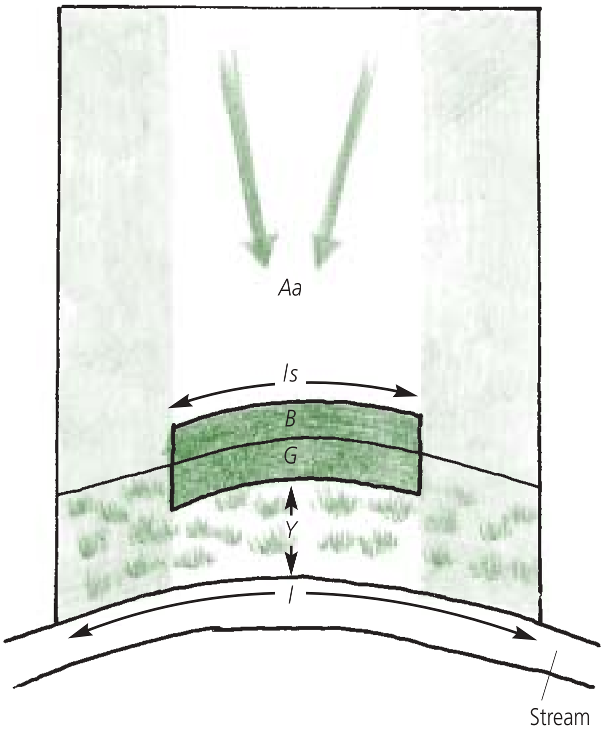
To design a filter strip to trap the annual soil loss requires consideration of three factors.

1. The amount of sediment that gets stored in the backwater before the grass strip.
2. The width of grass required to store the remaining sediment.
3. An additional width of un-impacted grass to trap as much of the fine suspended sediment as possible.

The width of riparian filter strip required for a paddock will depend upon the area of the paddock ($a$, ha), its annual soil loss ($A$, t/ha) derived from the USLE or other methods, and the length of riparian land into which the sediment is deposited ($l_s$, m). The total amount of sediment delivered to the riparian land is $Aa$ (Figure 4).

**Figure 4**

Definition of riparian filter strip at the bottom of a paddock of area $a$, with annual soil loss $A$. $B$ = backwater sediment mass; $G$ = grass sediment mass; $w$ = filter width; $l$ = filter length; $l_s$ = length of deposit and $Y$ = additional width required for settling sediment. The shaded area is the extent of a sediment deposit.




Sediment stored in the backwater forms a triangular wedge with an approximately horizontal surface. Consequently, the storage volume increases with decreasing gradient at the filter edge ($\theta$, measured in degrees). The mass of sediment stored in the backwater ($B$, t) is the volume of the wedge multiplied by the average bulk density of the deposit ($\rho_b$, t/m$^3$). This can be expressed as

$$B = \frac{l_s \rho_b H_b^2}{2\tan\theta} \quad (1)$$

where $H_b$ (m) is the sediment depth at the front of the grass.

Sediment encroaches into the grass as a depositional wedge. It buries the grass until a stage is reached when all sediment is transported over the deposit to the front of the wedge. Consequently, the wedge grows forward over time as the sediment storage capacity of each metre of grass is reached. It should be noted that the sediment density of deposits in grass ($\rho_g$) is lower than that for most sediment deposits because of space filled by grass and entrapped air. The storage capacity within a grass filter ($G$, t) is

$$G = \rho_g H_g l_s w \quad (2)$$

where $w$ is the width of the filter.

The total storage capacity of the backwater and grass must at least balance that of the supplied annual mass of sediment:

$$Aa = B + G \quad (3)$$

Substituting equations (1) and (2) into (3) gives

$$Aa = \frac{l_s \rho_b H_b^2}{2\tan\theta} + \rho_g H_g l_s w \quad (4)$$

Equation (4) can be rearranged to calculate the required width of filter strip. To this we add an additional width ($Y$, m) for trapping of fine suspended sediment beyond the sediment wedge. We used a value for $Y$ of 2 m on low and moderately erodible soils, and 5 m for highly erodible soils with a high clay content. Rearranging equation (4) and adding $Y$ gives

$$w = Y + \frac{1}{\rho_g H_g}\left[\left(\frac{Aa}{l_s}\right) - \left(\frac{\rho_b H_b^2}{2\tan\theta}\right)\right] \quad (5)$$

The length of riparian land over which sediment is deposited is often much less than the total length of riparian land ($l$, m) along a paddock edge because of convergence of flow. This may result from topography or concentration of flow in plough furrows, stock tracks or other features. Thus we can express a convergence ratio ($c$) defined as

$$c = \frac{l}{l_s} \quad (6)$$

Canola crop, Harden NSW. A filter strip is required to protect streams from soil loss during crop establishment. Photo Ian Prosser.

Substituting equation (6) into (5) gives the complete equation needed to design filter strip widths:

$$w = Y + \frac{1}{\rho_g H_g}\left[\left(\frac{cAa}{l}\right) - \left(\frac{\rho_b H_b^2}{2\tan\theta}\right)\right] \qquad \textbf{(7)}$$

In our experiments we found $H_b$ = 0.13 m, $\rho_b$ = 0.9 t/m$^3$, $H_g$ = 0.09 m and $\rho_g$ = 0.7 t/m$^3$. For the purposes of designing indicative filter strip widths we assumed a typical situation to be a 2 ha paddock draining into a 100 m long riparian filter at the bottom of the paddock and a convergence ratio of 2. Using these values and $Y$ = 2 m, equation (7) reduces to

$$w = 2 + 0.636A - \frac{0.12}{\tan\theta} \qquad \textbf{(8)}$$

This expresses the design width purely in terms of the predicted or measured annual soil loss and the gradient at the foot of the paddock. Values of filter width predicted by equation (8) are given for a range of typical soil losses and gradients in Table 1 (see over page). Equation (7) can be used for other paddock configurations if these are known locally. Equations (7) and (8) will give values less than $Y$, and in some cases negative values, where annual soil loss is less than the storage capacity of the backwater. For these cases $w$ should be set equal to $Y$, the distance required to settle suspended particles.

For the conditions simulated, Table 1 shows that filter strips alone are not effective techniques alone to manage high soil losses (> 40 t/ha/y), requiring an unreasonably wide strip. If soil loss is reduced below 10 t/ha/y, however, design widths are not onerous impositions on agricultural land and aid in effective sediment management. Soil losses beyond 40 t/ha are common using traditional farming practices but can be reduced to < 10 t/ha with modern practices of soil conservation an minimum tillage. This illustrates that riparian management is not a substitute for good on farm management but can be an effective last line of defence when used with other farm management practices. Grass filter strips should be installed at the foot of the paddock, which should be set back from the stream. Native riparian vegetation should be planted between the paddock and stream to perform ecological riparian functions/habitat not provided by the grass filter strip. Details about riparian zone functions are given in the *Riparian Land Management Technical Guidelines*, Volumes 1 and 2.

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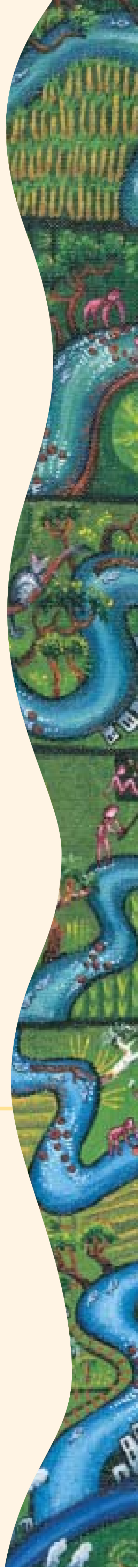
**Table 1**

Recommended grass filter strip widths (m) for typical values of annual soil loss and filter gradient under conditions of dispersed overland flow.

| soil loss (t/ha/y) | filter strip slope (%) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m |
| 2 | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m | 2 m |
| 5 | 2 m | 2 m | 2 m | 2 m | 3 m | 3 m | 3 m | 4 m | 4 m | 4 m |
| 10 | 2 m | 2 m | 4 m | 5 m | 6 m | 6 m | 7 m | 7 m | 7 m | 7 m |
| 20 | 3 m | 9 m | 11 m | 12 m | 12 m | 13 m | 13 m | 13 m | 13 m | 14 m |
| 30 | 9 m | 15 m | 17 m | 18 m | 19 m | 19 m | 19 m | 20 m | 20 m | 20 m |
| 40 | 15 m | 21 m | 23 m | 24 m | 25 m | 25 m | 26 m | 26 m | 26 m | 26 m |
| 50 | 22 m | 28 m | 30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m |
| 60 | 28 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m |
| 70 | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m | >30 m |

- Grass filter strips can effectively protect streams and riparian lands from sediment and attached nutrients.
- The filter strip needs to be wide enough to trap the annual soil loss and allow sufficient width for settling of fine sediment.
- Sediment is trapped first in a backwater, behind the strip. More sediment is trapped in low gradient backwaters so filter width can be narrower on gentle slopes.
- The greater the annual soil loss, the wider the strip needs to be to trap the eroded soil.
- Filter strips are only effective for low to moderate soil loss.
- Table 1 shows design widths for *kraznozem* soil loss trapped in dense *kikuyu* grass.



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