Layout and Establishment of Grass Hedges for Gully Control

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Abstract

Grass hedges are dense, erect, vegetative barriers made of large-stemmed grass that slow runoff and reduce erosion. Research has shown that well-established hedges can remain erect against flows that pond to depths of 0.4 to 0.5 m. We hypothesized that planting grass hedges every 0.45 m vertically within a gully would allow the entire gully bed to be protected by low-velocity backwater areas during high flows. To test this we established a series of hedges in a number of concentrated flow channels during 2000. Two of the channels were previously eroded spillways cut into in compacted fill; and all flow was diverted from these channels during the hedge establishment period. The other channels were located at the margin of floodplain fields adjacent to an incised stream channel, Little Topashaw Creek, in Chickasaw County, MS, USA. Natural rainfall runoff was allowed to pass through most of the Topashaw channels during hedge establishment, and various techniques were used to keep transplanted hedge grasses from being washed away during their establishment period. We gauged the discharge through some of these channels and monitored resulting damage. We plan to introduce flow into these three channels during February and March, 2002, using synthetic trapezoidal-shaped hydrographs with peak discharge rates of 0.042, 0.085, and 0.170 $m^3 s^{-1}$, flow rates that are similar to those observed flowing through gullies into Little Topashaw Creek. We will monitor pore water potential that contributes to mass failure of soil blocks and record the extent and mode of erosion of the hedge-lined channel during the controlled inflow tests.

Introduction

In tropical areas, planting vetiver grass (*Vetivaria zizainoides* L.) hedges has been used as a soil and water conservation practice for over 50 years (Vélez, 1952). However, it was not until 2001 that the United States Department of Agriculture - Natural Resources Conservation Service (NRCS) officially added the use of grass hedges to their National Handbook of Conservation Practices, with the title "Vegetative Barriers, Code 601." The Vegetative Barrier practice is designed for controlling runoff and reducing soil erosion by water in cropland and for stabilizing steep slopes. However, control of steep gullies in non-cropped areas was not included in this standard.

Where floodplains are farmed adjacent to deeply incised stream channels, streambank failure frequently occurs by mass failure, and gullies form where overbank runoff concentrates. In the United States, such edge-of-field gullies are normally controlled with "drop-pipe" structures comprised of a small earthen dam drained with a metal culvert. Drop-pipes have proved to be quite effective, but require capital investment and eventually deteriorate due to corrosion.

Throughout most of the United States, where winter temperatures drop below -15^{O}C, switchgrass (*Panicum virgatum* L.) forms more robust hedges than vetiver grass. Flume studies have shown that switchgrass hedges can remain erect in flows great enough to produce head losses exceeding 0.4 to 0.5 m across the hedge. These deeper flows reduce flow velocity to levels that do not create soil erosion, but rather promote deposition of suspended sediment upslope of the hedges. For example, Figure 1 illustrates flow depths reported by Temple and Dabney (2001) upslope and downslope of single-row switchgrass hedges in unit channels whose beds were lined with mowed grass. Also shown, for reference, are lines of depth predicted by Manning's equation for a broad channel with a bare soil surface (n = 0.025, S = 5%) and the depth required to keep velocity at 0.6 m s^{-1}, below which bare soil surfaces are not expected to erode. Related flume studies have shown that the depth of backwater upslope of grass hedges is rather insensitive to bed slope (Dabney et al., 1996), so the upslope flow depths illustrated in Fig. 1 may be expected to vary much less with slope steepness than would the other curves, where depth would decrease with $S^{1/2}$.

We concluded from flume studies that intact single-row grass hedges could keep upstream flow velocities below critical limits for specific discharges up to 0.2 $m^2 s^{-1}$ and hypothesized that planting grass hedges every 0.45 m vertically within a gully might allow the entire gully bed to be protected by low-velocity backwater areas during high flows. If successful, this solution would be less capital intensive solution than drop pipes. Rock and brush check dams are long-recognized methods of gully control. Grass hedges offer a

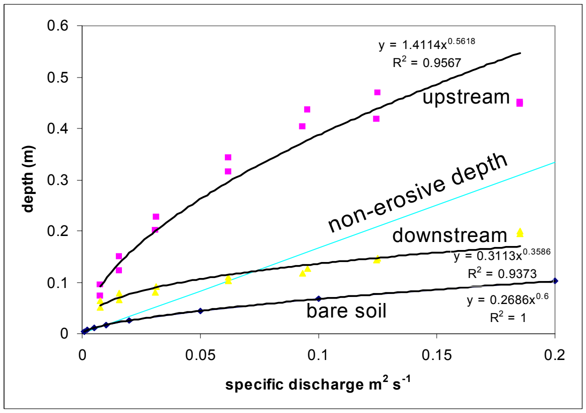

Figure 1. Water depth measured upstream and downstream of a 1-row switchgrass hedge (Temple and Dabney, 2001) compared with flow depth for a wide bare earth channel predicted by Manning's equation (n=0.025), and with the minimum flow depth to keep velocity below 0.6 m s^{-1}. All measurements and calculations made with bed slope of 5%.

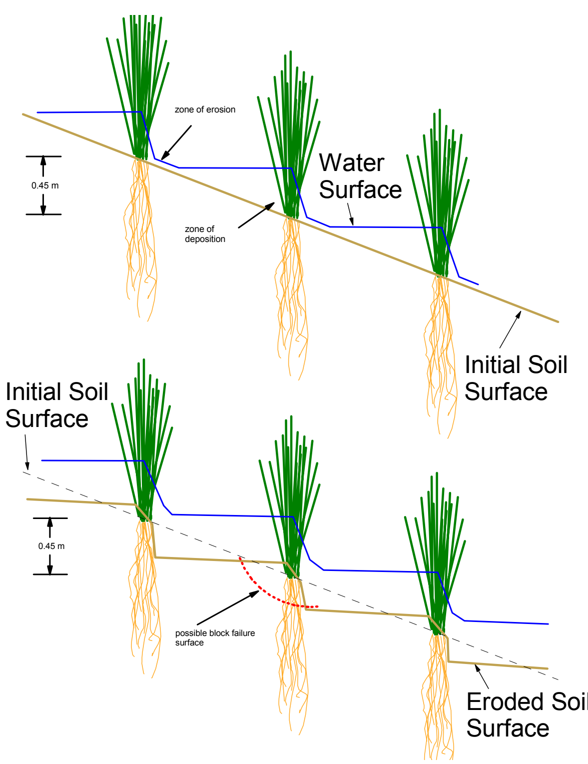

Figure 2. Schematic illustration of concept for stabilizing steep concentrated flow channels with a series of grass hedges spaced with a vertical interval of about 0.45 m.

promising alternative with advantages of root systems and the ability to re-grow when partially buried by sediment. The practice, however, is uncertain because some erosion would be expected to occur between the hedges before the slope stabilized. For example, for a channel containing grass hedges spaced with a vertical interval of 0.45 m and separated by bare earth, an area with erosive flow velocities would develop downslope of the grass hedges for flow rates that did not create backwaters deep enough to submerge the toe of the next upslope hedge (Fig. 2). Trapped sediment might raise the bed level upslope of each hedge, while erosion would lower it downslope each hedge. Over time, flow depths could become non-erosive everywhere. As seen in Fig. 2, in this final stage, grass roots could play an important role in resisting migration of local headcuts and in preventing mass failure of soil blocks .

Methods

The authors termed the practice of using grass hedges to control edge-of-field gullies adjacent to incised channels “Vegetated Side Inlet” and proposed it as an unproven technology worthy of evaluation to the NRCS and the United States Army Corps of Engineers. These agencies agreed to assist in the evaluation of the concept and to provide funds for construction of a number of test sites along a reach of Little Topashaw Creek, Chickasaw County, MS, USA. The 2.3 km sinuous reach drains a watershed of about 37 km^2. The channel cross section is about 35 m wide and about 6 m deep, the bed slope is about 0.002. Adjacent to the study reach, five fields comprising 75 ha are cropped to cotton (*Gossypium hirsutum* L.) and corn (*Zea Mays* L.) (Fig. 3). Surface runoff leaves these fields at about 26 discrete points. We identified 14 of these inlets for potential study. Meetings were held with local conservationists and landowners to discuss the concept and obtain their cooperation.

We obtained topographic surveys of the 14 inlets and designated six for "treatment" with grass hedges, leaving eight as untreated “controls.” Three of the treated gullies were shaped to smooth contours with a track hoe prior to planting grass hedges and three gullies were planted with grass using only hand labor. A source of sod was provided to the contractor who transplanted it during June 2000.

It was recognized that the grass hedges would need protection from being washed away during the establishment period shortly after planting. Two approaches were investigated: (1) diversion of all runoff during the establishment phase and (2) protecting the young grass with check dams placed downslope of each grass hedge. The first option was tested at one location where an alternative stable outlet for runoff was available. Burlap (a coarse, jute fabric) was initially used to construct the check dams for the second option at the other field locations. However, the burlap placed in the field during May and June was too decayed to resist

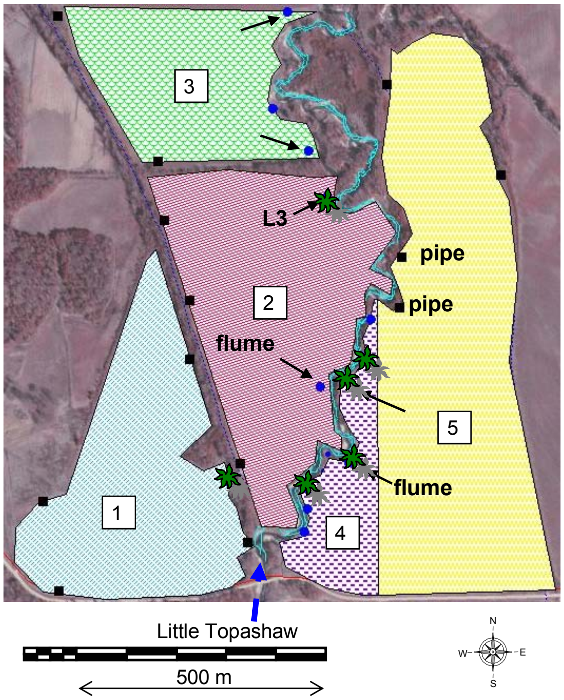

Figure 3. Study reach of Little Topashaw Creek and adjacent fields. Arrows indicate locations of acoustic Doppler flow measurement points, plant symbols indicate location of inlets with grass plantings, circles indicate untreated control inlets, squares indicate other field runoff discharge points; side inlet L3 is where controlled discharge measurements are planned.

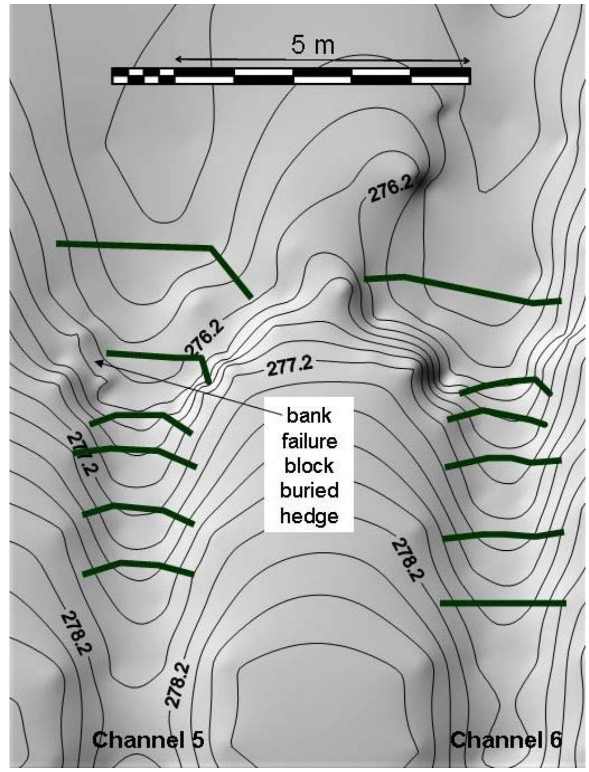

Figure 4. Shaded relief contour map (0.2 m contour interval) of two test channels at Stillwater, OK, showing the extent of grass hedges and pre-existing unshaped headcuts at the toe of each channel.

runoff events in Nov and Dec. During these events, erosion was most severe in "shaped" inlets where soil had been filled. In many cases, erosion removed all fill material. Subsequently, the grass hedges were re-planted in Feb 2001 without further inlet shaping. During re-planting, the burlap was replaced with a longer-lasting, 2.5-cm mesh made of polypropylene that was supported by steel fence posts and 2.4 mm steel cable.

To provide a more controlled environment and a different soil material, we also established a series of six grass hedges in each of two outdoor test channels at the Soil Conservation Research Laboratory at Stillwater, OK, USA (Fig. 4). The channels were initially trapezoidal channels with 0.91 m wide bases and 1:1 side slopes cut into compacted fill (1.78 Mg m^{-3}), lined with bermudagrass (*Conodon dactylon* (L) Pers.), and used for simulating erosion of embankment dams subjected to overtopping (Temple and Hanson, 1998). Each channel was tested in 1997 with a flow rate of 1.1 m^3 s^{-1} for 64 to 75 hours that resulted in the formation of an approximately 1-m deep headcut near the toe of each channel (Fig. 4). These headcuts were left to weather in the eroded condition until the switchgrass hedges were transplanted without shaping in spring 2000 and then for an additional two years while the switchgrass became established and shaded out remnant bermudagrass. Runoff was excluded from both Stillwater test channels during the switchgrass establishment, and supplemental irrigation was applied to ensure adequate grass growth on the droughty southern slope involved. One risk associated with planting grass on unshaped gullies was demonstrated when a local bank failure block buried a section of hedge in channel 5 (Fig. 4) during fall 2001.

At the Mississippi site, precipitation records were obtained using tipping-bucket rain gages that were located at the northern and southern ends of the study area, runoff quantities were measured for one treated and one untreated gully using 0.45-m H flumes, and natural runoff depths and velocities were monitored in a number of treated and untreated inlets using self-contained, incoherent, acoustic Doppler velocity loggers (Fig. 3). These devices computed Doppler shifts resulting from targets (suspended particles) anywhere in the water column intercepted by an ultrasonic beam that was propagated for ~2 sec every 5 min. Up to 200 velocity measurements were accumulated during each 2 sec period, and the median of these values was assumed to be the mean flow velocity. The instrument also logged flow depth, which was measured using a pressure transducer vented to the atmosphere. Channel cross-sectional areas were computed as a function of flow depth using cross-sectional survey data collected with a total station, and the best velocity data were used to compute a discharge rating curve for each channel using the continuity equation. These ratings were then used with the flow depth data collected at 5 min intervals to compute total runoff volumes for events producing depths > 25 mm. Lower flow depths produced unreliable data.

Erosion and sedimentation within treated and un-treated gullies were monitored periodically through topographic surveys to determine the influence of natural runoff on side inlet erosion. Channel topography is also utilized in a geotechnical model, assuming a range of soil strength and permeability parameters, to predict pore water pressures, water surface profiles, and mass failure factors of safety.

We plan to introduce flow into one of the Topashaw channels (L3, Fig. 3) and the two Stillwater channels during February and March, 2002, using synthetic trapezoidal-shaped hydrographs with peak discharge rates of 0.042, 0.085, and 0.17 $m^3 s^{-1}$. As discussed below, these flow rates are similar to those observed in the inlets to Little Topashaw Creek. We will monitor pore water potential, determine site-specific soil mechanical properties, and record the extent and mode of failure of the hedge-lined channel during the controlled inflow tests. The grass root systems will be characterized subsequent to the potentially destructive flow tests, and its influence on the cohesive strength of the bank will be considered in the geotechnical analysis.

Results

Precipitation and runoff through treated and untreated (control) inlets measured over a period of 18 months are summarized in Figures 5 and 6. Records from 85 inlet-events showed runoff volumes and maximum unit discharges spanned several orders of magnitude. The largest precipitation event recorded was 158 mm. Runoff event durations ranged from minutes up to 36 hrs. Maximum flow depths were not well correlated with maximum discharges (Fig. 6), reflecting differences in vegetal cover and slope steepness. More than half the peak runoff rates occurred at velocities that would not cause erosion of bare soil in a smooth channel. However, the acoustic Doppler meters were positioned in relatively uniform segments of sometimes variable side inlets so that the same discharge observed might have created erosive velocities in steeper segments. This is especially true if local irregularities such as knickpoints existed.

To provide a basis for inlet design and a context for the observed runoff amounts, we used NRCS curve number method (NRCS, 1989) employing the following assumptions for a flatland location in Mississippi: curve number=75, soil hydrologic group="B," slope length=400 m, and slope gradient=0.01. Estimated field-edge peak specific discharges, without flow concentration, are given in Table 1.

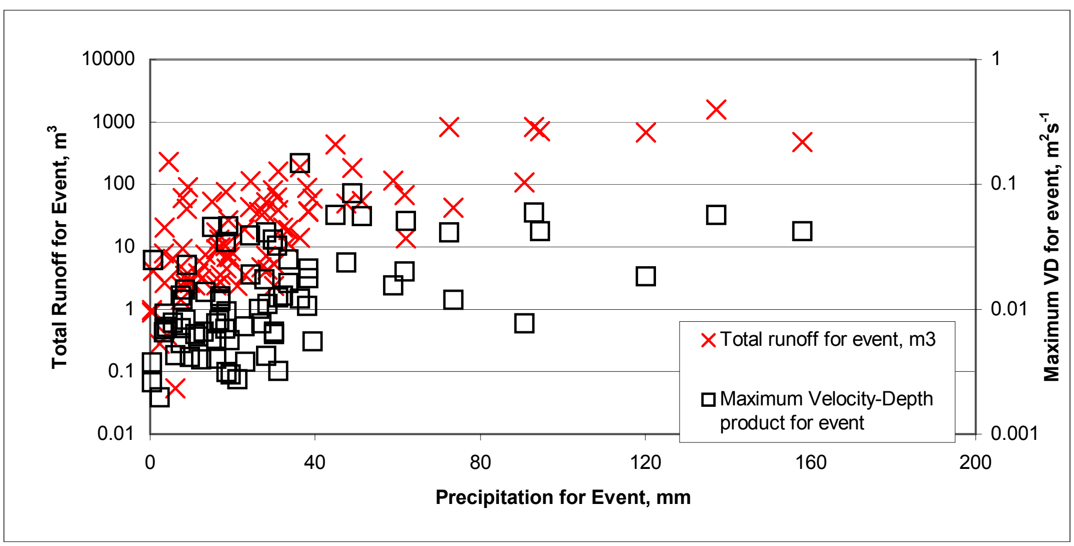

Figure 5. Total runoff volume and specific discharge measured with acoustic Doppler sensors in side inlets along Little Topashaw Creek (Fig. 3) plotted against storm rainfall.

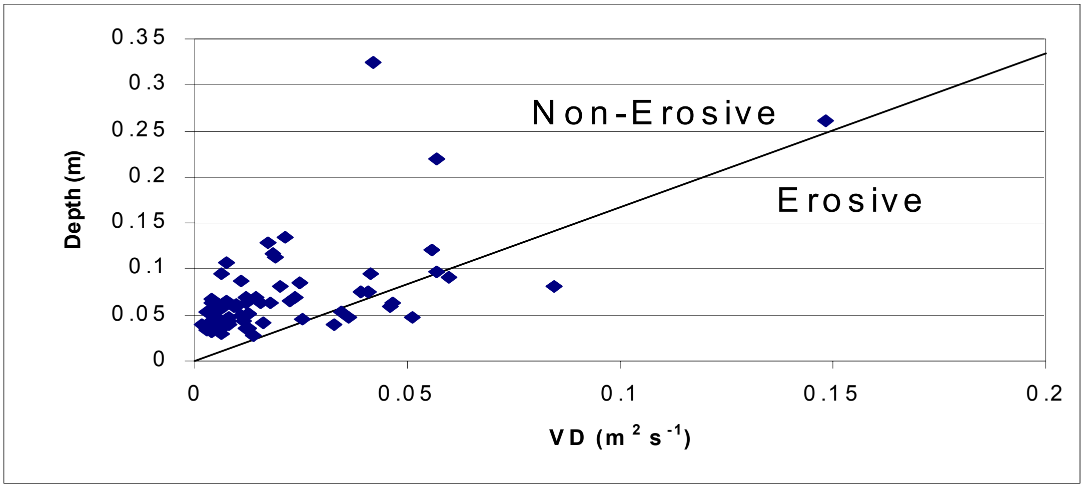

Figure 6. Observed flow depth plotted against the product of maximum runoff velocity and coincident depth for 85 inlet-events along Little Topashaw Creek. Depth below the line would be erosive of a smooth bare-soil channel. Because flow was measured in relatively uniform segments of each inlet, shallower flows may have caused more frequent erosive conditions at other points in irregular inlets.

Table 1. Peak discharges at the edge of a 400 m long, 1% slope field in Mississippi for various size storms.

Storm Return Interval (y)	1	2	5	10	25	50	100
Peak Discharge ($m^3 s^{-1} m^{-1}$)	0.0022	0.0030	0.0045	0.0058	0.0073	0.0083	0.0096

To estimate specific discharge through the flow sections of the side inlets along Little Topashaw Creek, the information in Table 1 were combined with field sizes, number of outlets (Table 2), and average side inlet dimensions. In the absence of a sufficiently detailed topographic survey to define actual drainage areas from these flat ($S < 0.01$) fields, we estimated contributing areas to inlets in each field by dividing field area by number of observable surface water inlets at the field margins. The actual drainage area contributing to an individual inlet is controlled by row orientation, which has varied between fields and years, because row ridge heights are large compared to natural relief. Side-inlet surveys indicated an average flow width of 3.2 m wide (SD = 0.76 m) at a height of 0.5 m above the bed thalweg, and a top bank width of 13.2 m (SD = 8.8 m). We calculated the return interval of storms that would not cause specific flow conditions to exceed a design discharge of 0.2 $m^2 s^{-1}$ within the inlets by multiplying the specific peak discharge (Table 1) times each field's flow concentration factor (effective width, Table 2), and dividing by an average effective flow width of 3.0 m. Results indicate that hedges in side inlets draining fields 3 and 4 could withstand a 100-year storm, while field 5 could withstand only a 2-year storm (Table 2). It is therefore reasonable that the land owners should have opted for the installation of two new pipes to control the large runoff amounts expected from field 5 while we focused our hedge research mainly on inlets with smaller drainage areas in fields 3 and 4.

Table 2. Field size (Fig. 3), number of surface runoff inlets, drainage area per inlet, effective field width per inlet assuming 400m field length, and return interval of storms causing specific discharges in a 3-m wide flow zone to be < 0.2 $m^2 s^{-1}$.

Field #	Field Size (ha)	Number of Inlets	Drainage Area (ha/inlet)	Effective Field Width/Inlet (m)	Return Interval of VD<0.2 $m^2 s^{-1}$ (y)
1	15.2	5	3.0	76	25
2	17.9	5	3.6	89	10
3	10.4	5	2.1	52	100
4	4.8	7	0.7	17	100
5	26.0	4	6.5	163	2

The largest flow events through the inlets may not occur from rainfall/runoff events, but from return flows when flood events have inundated the floodplain. If the creek level quickly drops below bank full stage, water on the floodplain will rapidly flow back into the creek through local swales in the natural levee lining the creek. The initial rates of such discharges were estimated for different ponded depths using an approximate weir equation, $q = 3\ H^{3/2}$ (Chow, 1959). Even with the conservative assumption that the inlets intercept floodplain return flow only through a zone equal to their top bank gully widths, results indicate that discharges from 0.1 m ponded depth on the floodplain would result in specific discharges of from 0.2 to 1.0 $m^2\ s^{-1}$. These flows are larger than those from predicted (Tables 1 and 2) or observed (Fig. 5) rainfall/runoff events and such flows may have been historically important in gully formation. The future impact of flood return flows on grass hedges might be mitigated by the fact that most of the inlet hedges will still be submerged with creek waters when floodplain return flows begin. During the 2.5 years that we have been studying the reach of Little Topashaw Creek, there has been one out-of-bank flood event.

A final complexity observed concerning with the establishment of hedges at Little Topashaw Creek is the migration of in-creek sand bars. Two meter tall sand bars first buried some hedges, only to be subsequently dissected by side-inlet runoff during low creek stages. In other situations, removal of sand bars by large creek flows destroyed hedges planted on top of them, leaving large headcuts that threaten to migrate up into the side inlet. These observations point out the need to consider two scales of sediment transporting flows: that associated with the side-inlets and that associated with the creek. Successful design of vegetative side inlets along dynamic streams may require stabilization of the adjacent stream bedforms. One approach being investigated is the placement of a large woody debris structure at the outlet of the side inlet (Shields et al., 2001).

Summary

The concept of using a series of grass hedges, with a vertical spacing of less than 0.45 m, to control the growth of edge-of-field gullies has been proposed. Preliminary design calls for specific flow rates through the gullies to be $< 0.2\ m^2\ s^{-1}$. Under Mississippi conditions this translates into contributing areas being limited to about 3 ha for 3 m wide gullies; and larger contributing areas would require wider gullies. Vegetation planted across concentrated flow areas must be protected for one year while its roots become established. Protection may be either by diverting runoff to another outlet or by constructing check dams downslope of each hedge. Shaping of gullies facilitates grass planting and reduces risks of mass failure, but filled areas may be more easily eroded than undisturbed soil. Overall success of the practice depends on the stability of stream channels at the base of each gully. More research is needed before the limitations of the approach will be well understood.

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