tural pavement section, especially if the subgrade is moderately permeable and the water table deep.

CONCLUSIONS

The conclusions of this study are as follows.

1. Significant relationships ($p = 0.05$) were found between precipitation and drainage outflow.
2. Drainage outflow was influenced by pavement type. The outflow for the continuously reinforced pavement was significantly different ($p = 0.05$) from the outflow of the jointed concrete pavement for both the unsealed and sealed edge-joint conditions in Illinois.
3. Edge-joint sealing significantly reduced ($p = 0.05$) drainage outflow in the jointed pavement test sections in Georgia and Illinois. Although edge sealing reduced outflow on the continuously reinforced pavement section in Illinois, there was not a significant improvement ($p = 0.05$).
4. No measurable drainage outflow occurred on the Georgia test section in which all longitudinal and transverse pavement joints and the pavement edge joints had been sealed.
5. Based on relationships between precipitation volume and pipe outflow volume, as well as on the response of pipe outflow to rainfall, the edge joint may be a major factor contributing to water infiltration in jointed pavement systems.
6. In this study the contribution of the transverse cracks in the continuously reinforced pavement section to infiltration was greater than the contribution of the edge joint. Further drainage studies need to be conducted on continuously reinforced pavement systems.

ACKNOWLEDGMENT

This report was prepared as part of a research study on improving subdrainage and shoulders of existing pavements being conducted at the Department of Civil Engineering of the University of Illinois at Urbana under the sponsorship of the Federal Highway Administration. George Ring III of the Federal Highway Administration is the project monitor.

Thanks are due to the Georgia Department of Transportation for its help in preparing the test site on I-85 and to David Morrill, a research assistant, for collecting and processing the data from the Illinois test site.

The contents of this paper reflect our views and we alone are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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Publication of this paper sponsored by Committee on Subsurface Drainage and Committee on Environmental Factors Except Frost.

Installation of Straw and Fabric Filter Barriers for Sediment Control

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Effective temporary erosion and sedimentation controls are critical during construction in the period between onset of earth-disturbing and final stabilizing by vegetation. Among the most common temporary controls used in Virginia and many other states are straw barriers, burlap filter barriers, and silt fences. Despite the large sums of money spent annually on these controls, high failure rates and low trapping efficiencies, particularly for straw barriers, have been reported. In an effort to improve field performance, experiments conducted in Virginia have led to the installation procedures reported in this paper. Procedures for inspection and maintenance of these controls are also described. Finally, it is concluded that the cost effectiveness of straw barriers has proved questionable in many cases; burlap filter barriers may well be an effective and inexpensive substitute for straw.

The early reestablishment of vegetation in areas denuded by construction is generally agreed to be the most effective method of controlling accelerated erosion and sedimentation. However, regardless of how conscientious the efforts at revegetation may be, there will be a critical period between the onset of land disturbance and the final stabilization by vegetation. It is during this critical period that temporary erosion- and sediment-control structures are required.

Through the years many types of temporary erosion- and sediment-control techniques have been developed by agencies concerned with soil conservation and water quality. These controls may be categorized as

1. Mulching of bare soil surfaces to protect from the impact of raindrops and runoff,
2. Structures designed to divert storm waters into stabilized areas,
3. Structures designed to impede and filter runoff, and
4. Structures designed to impound storm waters.

Straw barriers, burlap filters, and silt fences fall into category 3 and are among the most common temporary sediment-control methods in use today. Briefly, straw barriers refer generally to barriers constructed of straw or hay bales; burlap filters are barriers made by stapling burlap cloth to wooden stakes spaced from 0.9 to 1.2 m (3 to 4 ft) apart, and silt fences are barriers made by attaching woven fence wire and commercial filter fabric to fence posts set approximately 3.1 m (10 ft) apart.

PROBLEMS WITH FILTER BARRIERS

According to observations made in Virginia (1, 2), Pennsylvania (3), and other parts of the nation (4), filter barriers have not been as effective in controlling sediment as expected. For example, Weber and Wilson found that the sediment-trapping efficiency of straw barriers in Pennsylvania ranged from 0 to 5 percent (3). Reed, also working in Pennsylvania, noted a 5 percent reduction of sediment load when straw barriers were used on construction (5).

Improper use of filter barriers has been a widespread problem. For instance, straw barriers and silt fences have been used in streams and drainageways where high water velocities and volumes have destroyed or impaired their effectiveness. Another problem has been improper placement of barriers (Figure 1), which has caused undercutting and end flow that have actually increased rather than removed sediment in runoff waters (2). Finally, inadequate maintenance and cleaning have tended to greatly lower the trapping efficiency of all filter barriers.

Figure 1. Straw barrier placed by a contractor; arrows indicate failure by undercutting and end flow.

Because of these problems, straw barriers placed by contractors in Virginia and elsewhere have shown low trapping efficiencies and high failure rates. On one project in Virginia only 2 of 12 straw barriers installed in side ditches were found to be effective in trapping sediment. The poor performance observed statewide and in other states may not be atypical and raises serious questions concerning the continued use of straw barriers in the present manner. On the other hand, results of recent field experiments in Virginia strongly suggest that with proper installation the effectiveness of straw barriers can be greatly increased.

In addition to improved procedures for straw barriers, this paper includes procedures for installing burlap filters and silt fences. Although the failure rates of these last two types of barriers generally have been lower than that of straw barriers, they have been improperly installed occasionally. Experience has shown that following the installation methods outlined below can improve performance.

RECOMMENDED INSTALLATION PROCEDURES

Straw Barriers

The use of straw barriers must be limited to situations in which only low or moderate flows are to be intercepted. A recent Soil Conservation Service publication (6) states that the use of straw bales in Maryland should be limited to situations in which no other control is feasible and only sheet and rill erosion are expected. Also, a recent communication from Maryland authorities has brought to light plans to increase the depth of entrenchment for straw barriers from 0.10 to 0.15 m (4 to 6 in). Use of these barriers is specifically excluded for situations in which water is to be concentrated in a channel or drainageway. In view of the questionable performance of straw barriers thus far, use of these structures will be continued only if installation and maintenance procedures can be significantly improved. The following guidelines provide recommended step-by-step instructions for the installation of straw barriers exposed to moderate or low flows.

Entrenchment of Straw Barriers for Moderate Expected Flow

The term "moderate flow" encompasses sheet flow through channel flow, where rates are not to exceed 0.03 m^3/s (1 ft^3/s). Using the rational method for flow prediction and assuming average surface conditions and a rainfall rate of 0.03 m/hr (1 in/hr), an area of 8094 m^2 (2 acres) should provide approximately 0.03 m^3/s (1 ft^3/s) of flow. Low to moderate flow conditions will prevail in most drainage ditches of a less than 8 percent slope.

The installation procedure for locations with moderate flow rates is given below and illustrated in Figure 2.

1. Excavate a trench the width of a bale and the length of the proposed barrier to a minimum depth of 0.10-0.15 m (4-6 in).

2. Place bales tightly together in the trench. Drive two sturdy wooden stakes or steel pins through each bale and deep enough into the ground to securely anchor the bales.

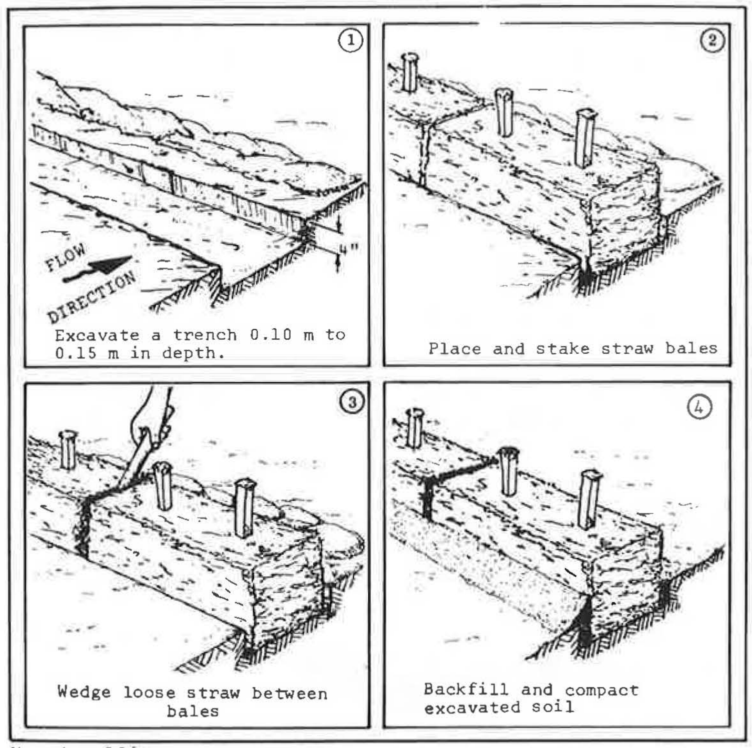
3. After staking, wedge loose straw between any cracks or other openings.

4. Backfill and compact the excavated soil against the barrier. Backfilled soil should conform to ground level on the downstream side and should be built up to 0.1 m (4 in) against the upstream side of the barrier.

Soil Sealing of Straw Barriers for Expected Low Flow

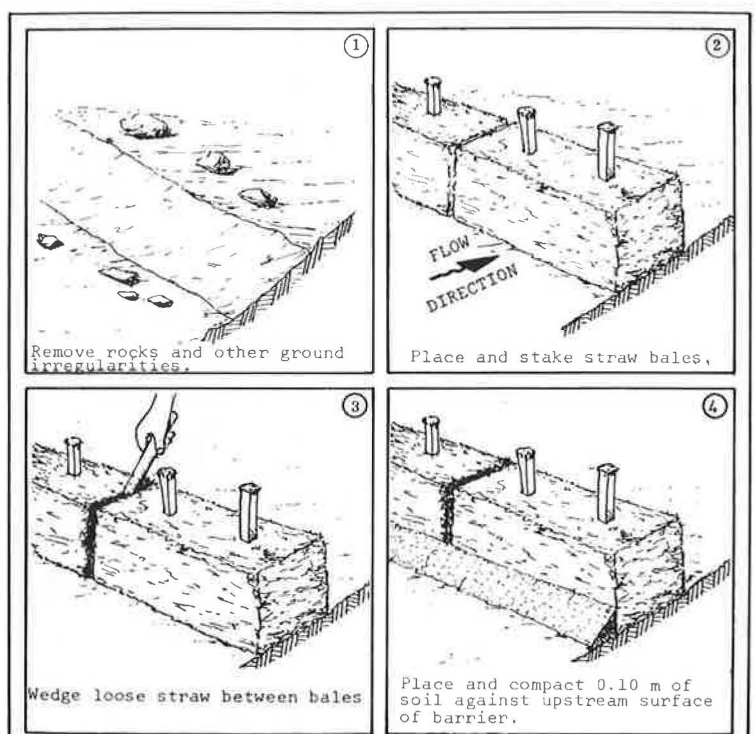
The term "low flow" is used here to describe sheet or

Figure 2. Placing a straw barrier at a location of moderate expected flows.



Note: 1 m = 3.3 ft.

Figure 3. Placing a straw barrier at a location of low expected flows.



Note: 1 m = 3.3 ft.

overland flow. Channel flows are specifically excluded.

The procedure for installing barriers in areas of low flow is described below and illustrated in Figure 3.

1. Prepare a smooth ground surface by removing rocks and leveling soil surface.
2. Place bales tightly together and drive sturdy wooden stakes or steel pins through each bale and into the ground deep enough to securely anchor the bales.
3. Wedge loose straw tightly between bales if required.
4. Place and compact a minimum of 0.1 m (4 in) of soil against the upstream surface of the barrier.

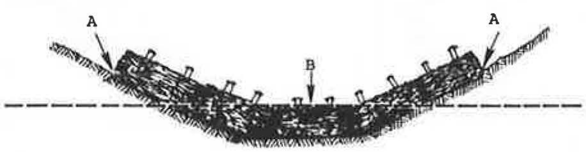
When a barrier is to be placed in a swale or a ditch line, the structure should be extended so that the bottoms of the end bales are higher in elevation than the top of the lowest middle bale (Figure 4).

Burlap Filter Barriers

Burlap filter barriers are inexpensive structures composed of burlap fabric stapled to wooden stakes. This type of barrier can be used interchangeably with straw barriers in many situations. Laboratory flume studies comparing straw bales (2), burlap, and filter fabrics have indicated that flow rates (1 m^3/min = 4.4 gal/min) through burlap are slightly slower and the filtering efficiency somewhat higher than for straw bales (see the table below).

Barrier	Flow Rate (m^3/min)	Filtering Efficiency (%)
Straw	0.021	67
Burlap	0.019	87
Typical filter fabric	0.002	97

Figure 4. Proper straw barrier placement; points A should be higher than point B.



Burlap filter barriers are designed for low or moderate flow situations. The height of these barriers should not exceed 0.50 m (20 in) and 0.30-0.38 m (12-15 in) will suffice in most situations. The burlap should be purchased in a continuous roll and cut to the length of the barrier; avoiding seams improves the strength and efficiency of the barrier.

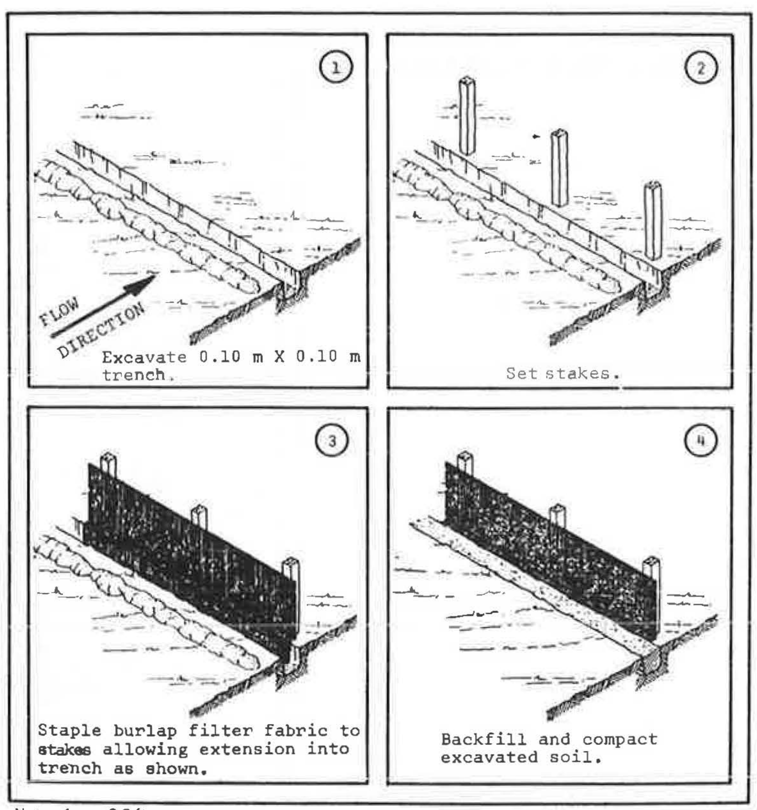
The procedure for installing a burlap filter barrier is given below and illustrated in Figure 5.

1. Excavate a 0.1x0.1-m (4x4-in) trench upstream of where the stakes will be driven.
2. Drive sturdy wooden stakes [at least 25x51 mm (1x2 in) and spaced 0.9 m (3 ft) apart] securely into the ground at the barrier site.
3. Staple the burlap to the wooden stakes. Extend 0.2 m (8 in) of the burlap into the trench. The height of the burlap must not exceed 0.5 m (20 in).
4. Backfill and compact soil in the trench over the burlap.

Silt Fences

The silt fence is a two-component barrier system comprising a support fence and an attached filter fabric. The support fence is made of 14-gage or finer woven

Figure 5. Installation of a burlap filter barrier.

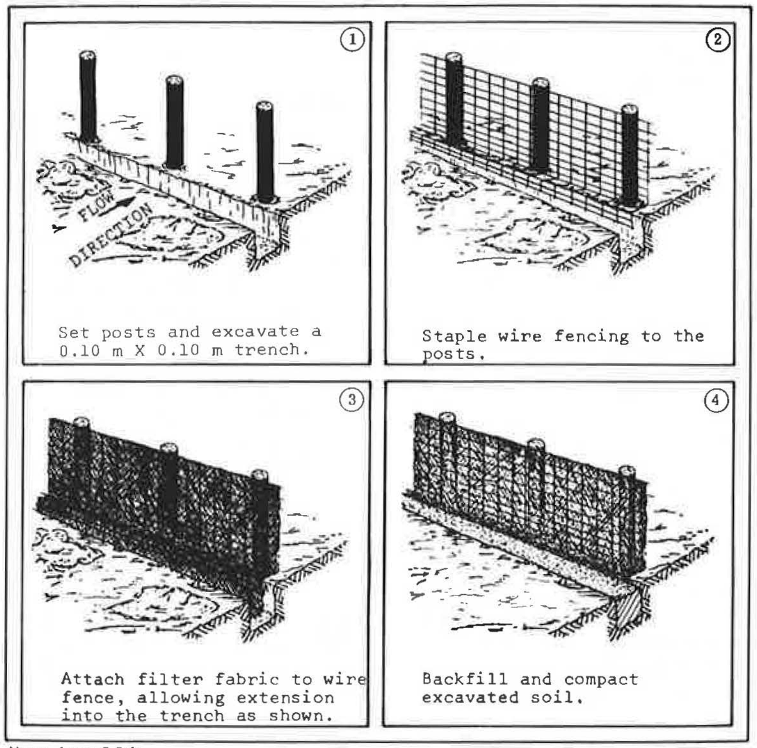


Note: 1 m = 3.3 ft.

wire attached to metal or wooden posts. The filter fabric (several companies manufacture suitable material) is stapled or wired securely to the support fence. Because the filter fabrics have a lower permeability (see the preceding table) than do straw bales and burlap, the use of silt fences should be limited to situations in which only sheet or overland flows are expected; they normally cannot filter the volumes of water generated by channel flows.

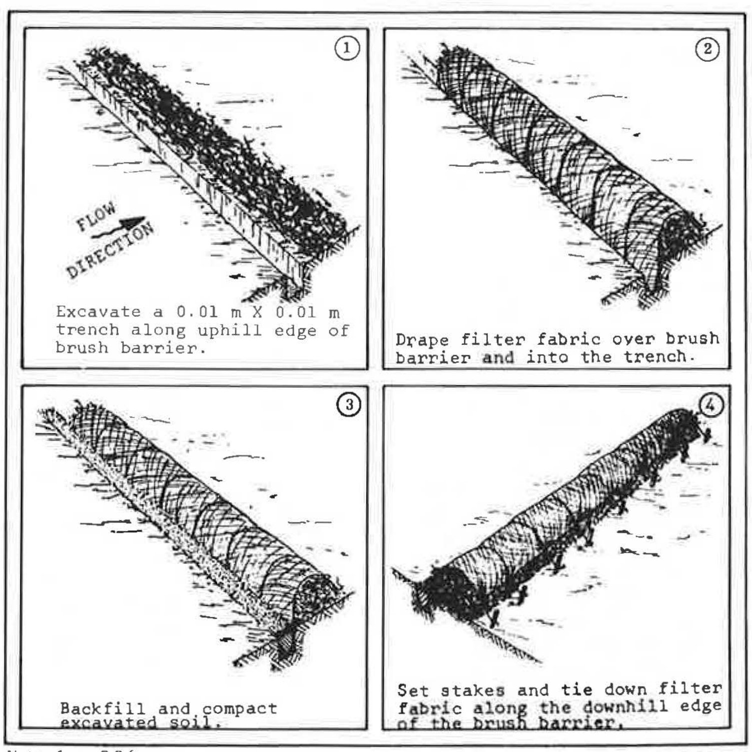
In most cases the fabric should not extend higher than 0.9 m (36 in); greater heights may back up enough water to cause the structure to fail. A 0.9-m (36-in) filter fence acts as a dam and traps sediment by the ponding action of inflowing, sediment-laden waters.

Figure 6. Building a silt fence.



Note: 1 m = 3.3 ft.

Figure 7. Building a silt fence with brush barrier support.



Note: 1 m = 3.3 ft.

The construction of silt fences should conform to the procedures illustrated in Figure 6 and listed below. The method of construction for filter fabric used in conjunction with a filter barrier made from materials such as brush or straw is shown in Figure 7.

1. Set wood or steel posts securely at intervals no greater than 3.1 m (10 ft) apart. Wood posts should be at least 76 mm (3 in) in diameter; with steel, use only the T-shaped posts or a post weighing more than 2.1 kg/m (1.4 lb/ft). Excavate a trench 0.1 m (4 in) wide by 0.1 m (4 in) deep along the upstream base of the fence.
2. Fasten fence wire securely to the upstream side of the posts. Wire should extend into the soil a minimum of 51 mm (2 in) and be at least 0.9 m (36 in) high.
3. Staple or wire the filter fabric to the fence, allowing the fabric to extend into the trench as shown in Figure 6. The fabric should not extend more than 0.9 m (36 in) above the original ground surface on the wire fence.
4. Backfill and compact the soil over the fabric extending into the trench.

If a filter fence is to be constructed across a ditch line or drainageway carrying a low flow, the barrier should be of sufficient length to eliminate end flow. Both the strength and the effectiveness of silt fences can be maximized by constructing the barrier in an arc or horseshoe shape whose ends point up slope.

COST DATA

A check of eight randomly selected construction projects in Virginia yielded a rather wide range in costs for straw barriers and silt fences. Burlap filter barriers are still in the experimental stage in Virginia, so specific field cost data are not yet available; the figures for burlap used here are estimates.

For the eight projects surveyed, costs for straw barriers ranged from a high of \$19.80 to a low of \$6.60/m (\$6.00 to \$2.00/ft), and the average cost was about \$12.00. These costs are based on contractor prices for materials, installation, and maintenance plus one cleanout. This price is up sharply from an estimated \$8.25/m (\$2.50/ft) of 1976 (7). Most of the recent increase has resulted from the very high cost of baled straw. Recent market prices for baled straw in Virginia have ranged up to \$2.75/bale.

The high cost of straw barriers, together with the relatively low average filter efficiencies of straw bales of 67 percent determined in laboratory flume studies (2), has raised serious questions concerning the future use of straw barriers in Virginia. The likely replacement for straw barriers may be the relatively inexpensive but effective burlap filter barriers. As noted in the table, recent tests in the laboratory flume have shown the average filtering efficiency of burlap to be 87 percent, some 20 percent higher than that of baled straw. While exact cost data are not yet available, it is estimated that the time required to install burlap filter barriers should run roughly the same as that for straw barriers. The burlap material at \$0.23/m (\$0.07/ft) costs less than the straw bales. Based on these figures, and the eight jobs surveyed, it is estimated that burlap filter barriers should cost approximately \$10.49/m (\$3.18/ft), which is less per meter than the present cost of straw barriers. This figure may well decrease as burlap barriers become more widely accepted and the users become more proficient in their installation and maintenance procedures.

Cost data for silt fences were also sought on the eight construction projects, and the records on six of the eight contained this information. Based on the same criteria as noted for the straw barriers—that is, materials, installation, maintenance, and one cleanout—silt fence prices ranged from \$10.23 to 18.15/m (\$3.10-5.50/ft). The average cost was slightly less than that for straw barriers. Considering the vastly greater filter efficiencies and life expectancy of silt fences as compared to straw barriers, it appears that filter fences are a significantly better investment at these prices. Interestingly, the cost for filter fences—\$3.77/0.31 m (1 linear ft)—is up only slightly from the \$3.50 cost in 1976 (7).

MAINTENANCE

Field experience has shown that, in addition to the proper construction of filter barriers, proper maintenance is absolutely necessary. Poché and Sherwood (2) found that trapping efficiencies of carefully placed straw barriers on one project in Virginia dropped from 57 to 16 percent in one month because of lack of maintenance. It is imperative that all filter barriers be checked after each storm event and that required repairs and alterations be made promptly. Also, frequent cleanouts are necessary if a barrier is to perform properly. Checking barriers during a storm event, although a wet and unpleasant job, can pay great dividends in information on water flow and sediment retention. If observations are not made during storms, information on the effectiveness must be gathered indirectly or after the fact, which can be misleading.

The value of careful and prompt maintenance of all types of filter barriers cannot be overemphasized. Even the most careful installation of these structures does not negate the need for constant and thorough maintenance and regular cleanouts if the sediment control system is to be effective.

CONCLUSIONS

Field and laboratory studies conducted in Virginia have indicated that significant improvements in performance can be attained for three common temporary erosion and sediment controls now in widespread use. The following conclusions have been drawn from investigations of straw barriers, burlap filter barriers, and silt fences.

1. Improper installation and the use of filter barriers in channels carrying high volumes of storm water have led to high rates of barrier failure.
2. The use of all filter barriers should be limited to situations in which either sheet flow or low channel flows of less than 0.03 m^3/s)(1 ft^3/s) are expected.
3. Common failures such as undercutting and end runs can be significantly reduced by following the installation procedures outlined in this paper.
4. All filter barriers should be inspected, cleaned out, and repaired as necessary after each storm event.
5. Inspection of filter barriers during storm events can yield valuable information on both installation and maintenance.
6. Cost and experimental data indicate that burlap filter barriers are less expensive and trap sediment more efficiently than straw barriers.
7. Silt fences, because of very low flow rates and high filtering efficiencies, are recommended for situations where only sheet flow is expected and very high sediment retention is desired.

ACKNOWLEDGMENT

We thank M. O. Harris and G. T. Gilbert, technicians in the Soils, Geology, and Physical Environment section of the Virginia Highway and Transportation Research Council for their help in the field installation and laboratory evaluations. Special thanks are extended to M. C. Anday and H. T. Craft of the Research Council for their technical guidance and editorial help, respectively. Finally, we express our appreciation to B. Turner of the Research Council for her clerical assistance.

The research on which this paper is based was funded by the Virginia Department of Highways and Transportation. The opinions, findings, and conclusions expressed are ours and not necessarily those of the sponsor.

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Publication of this paper sponsored by Committee on Subsurface Drainage and Committee on Environmental Factors Except Frost.