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D. H. Vanderholm
University of Illinois

Elbert C. Dickey
University of Nebraska at Lincoln, edickey1@unl.edu

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D. H. Vanderholm, E. C. Dickey
ASSOC. MEMBER
ASAE

ABSTRACT

THE vegetative filter approach uses overland flow or shallow channelized flow to treat feedlot runoff by infiltration, dilution and filtration. Based on extensive monitoring of four field systems in Illinois over a two-year period, acceptable performance standards were selected. Design criteria to meet the standards were developed for both the overland flow vegetative filters and the channelized or serpentine terrace filters. A major design criterion for both types of vegetative filters is the time required for applied runoff to flow the length of the filter.

An alternative to using zero-discharge treatment systems to control feedlot runoff is to replace the holding pond and dewatering equipment with a vegetative filter treatment and infiltration area. This component has been called by various names but will be referred to here as a vegetative filter. A vegetated area such as a pasture, grass waterway, or terrace channel is used to treat feedlot runoff by providing an area in which settling, dilution, absorption of pollutants and infiltration can occur. Many existing small feedlots already have some form of a vegetative filter. At many others, such a component could be added with a minimum of expense and effort. While systems of this type would certainly not be advisable or practical for every situation, they could provide low-cost runoff control for many feedlots, especially small feedlots that are not close to streams or lakes.

Several types of overland flow systems for treating feedlot runoff have been tried with varying degrees of success. Some were designed to absorb most of the applied runoff by infiltration into the soil; others are intended to remove very little by infiltration but to provide treatment during the flow process.

A study was begun in Illinois in 1975 to evaluate vegetative filter systems and, if feasible, to develop design criteria for them. Four vegetative filter systems were installed, each consisting of a settling facility, a distribution component and the vegetative filter area, as illustrated in Fig. 1. No runoff storage unit was provided; the runoff from a storm event went directly to the filter area. Similar concrete settling basins were used at each location. Two of the systems were of the serpentine waterway configuration; similar to those reported by Swanson et al. (1975). These are termed *channelized-flow systems* in this paper. The remaining two systems comprised wide, mildly sloping areas which operated with a shallow overland flow. They are termed *overland-flow systems.*

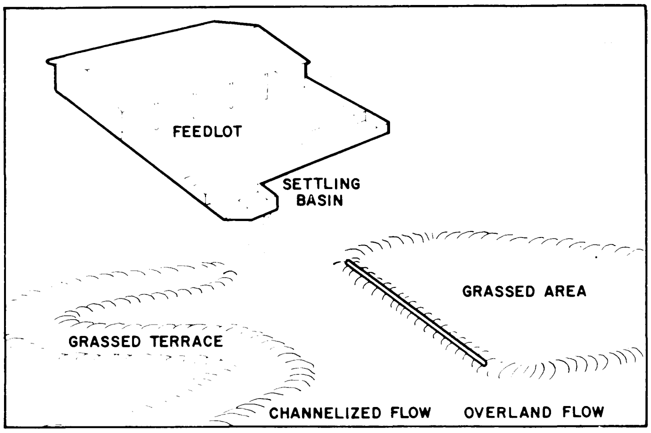

FIG. 1 Vegetative filter configurations for feedlot runoff treatment.

The systems were closely monitored over a period of two years. As reported in an earlier paper (Dickey et al., 1977), the performance of both types of systems was considered satisfactory in controlling feedlot runoff. For the design concepts to be usable on a wide scale, however, design criteria which will result in predictable performance under varying conditions are necessary. Criteria for both channelized and overland flow systems have been developed and are presented here.

DESIGN CRITERIA

To develop simplified, uniform criteria for the design of vegetative filters it was necessary to make some assumptions. In the past, some filters have been designed to accommodate the entire design storm runoff by infiltration. This approach results in large land area requirements and was not consistent with the philosophy of treating and discharging feedlot runoff, a concept which was basic to this study. It was decided that the most logical design would allow the feedlot runoff from small storms to be completely absorbed by infiltration with no vegetative filter discharge, whereas feedlot runoff from large storms would be handled partially by infiltration and partially by discharging the excess runoff after treatment and dilution in the vegetative filter.

The observed reductions of nutrients, solids and oxygen-demanding materials by the filter systems under study were over 80 percent on a concentration basis and over 95 percent on a mass-balance basis. These reductions are based on the characteristics of the runoff applied to the vegetative filters after pretreatment while passing through settling basins. Removal of solids and other constituents by the settling basins was not studied

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The authors are: D. H. VANDERHOLM, Associate Professor, Agricultural Engineering Dept., University of Illinois, Urbana; and E. C. DICKEY, Assistant Professor, Agricultural Engineering Dept., University of Nebraska, Lincoln.

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and is not included in the reduction values presented here. The bacteria levels in the feedlot runoff were not greatly reduced by the vegetative filter. High levels of fecal coliform and fecal streptococcus bacteria were found not only in the effluent from the filter areas but also in that from control areas to which no runoff or manure had been applied.

The effluent discharged from vegetative filters during large-runoff events at the four sites may not meet standards for stream quality. However, the discharges are usually at a relatively low rate and occur during periods of high streamflow and, therefore, high dilution rates. As a result, they have a negligible effect on stream quality, especially as compared to uncontrolled discharges from open feedlots.

With vegetative filters, it is thought that the major pollutant removal mechanisms are settling, filtration by the vegetation and absorption on soil and plant materials. Visual observation of settled solids on the vegetative filter confirms that removal by settling is occurring. For these removal mechanisms to be effective, the length of time that the runoff is in contact with the soil and vegetation is an important variable affecting pollutant removal. Thus, a major design criterion affecting the quantity of pollutants removed is the time required for the applied runoff to travel the length of the filter; in other words, the contact time. That time is a direct function of flow distance, flow velocity, slope, filter geometry and other factors of less importance.

Based on calculated flow velocities and verified by observation, it took approximately two hours for the basin effluent to travel the 91-m (300-ft) flow distance in the most closely studied overland-flow vegetative filter during larger runoff events with flow rates of approximately 8.8×10^{-4} m^3/s per meter (0.01 ft^3/s per foot) of filter width. This 2-h contact time resulted in mass pollutant removal efficiencies of slightly more than 95 percent. It took about five hours for the basin effluent to traverse the most closely studied channelized-flow vegetative filter, a path 533 m (1750 ft) long. About 92 percent of the pollutants were removed on a mass basis. Although mass removals were not developed for the second channelized-flow system, the calculated 1.5-h time for the 148-m (450-ft) flow distance was sufficient to remove about 86 percent of the pollutants on a concentration basis.

Data from both the overland-flow and channelized-flow vegetative filters suggest that it may not be practical to achieve removal efficiencies above approximately 95 percent with these systems because beyond that level, excessive filter length and size would be necessary. Given the pollutant removal efficiencies and associated contact times, the minimum contact time recommended for any vegetative filter system is 2 h.

Overland-flow Systems

Overland-flow vegetative filters apparently do not require longer contact times as the feedlot size increases, although the total filter size is dependent upon lot area, as the following design procedures indicate. Additional contact time is probably helpful, however, Therefore, a 2-h contact time is the recommended criterion for determining minimum filter length for overland-flow filters. Using Mannings equation (Schwab et al., 1966) and the 2-h contact time, we developed a set of minimum flow lengths for overland-flow vegetative filters with various slopes. These lengths are presented in Ta•.e 1. Because of low velocities, leveling and maintenance problems, slopes of less than 0.5 percent should be used with caution and only when precise construction is possible. Slopes of more than four percent should not be used because of high velocities, reduced filter effectiveness and possible erosion. The minimum recommended length for any vegetative filter using the overland-flow design is 91.4 m (300 ft). Sod-forming grasses and legumes should be used on filter areas rather than row crops.

TABLE 1. MINIMUM FLOW LENGTHS FOR VEGETATIVE FILTERS UTILIZING OVERLAND FLOW AND HAVING VARIOUS SLOPES*

Slope, percent	Flow length, m	(ft)
0.5	91.4	(300)
0.75	113	(372)
1.0	131	(430)
1.5	160	(526)
2.0	185	(608)
3.0	227	(744)
4.0	262	(860)

*Design flow depth is 1.3 cm (0.5 in.). The assumed Manning's roughness coefficient is 0.3.

Infiltration, settling, filtration and absorption are important in removing pollutants in overland-flow vegetative filters. Thus, the second phase in the design of an overland-flow filter is to determine the total size required.

The recommended criterion for determining the size is based on the principle that runoff from most small storms should be completely infiltrated into the soil in the vegetative filter area, resulting in no discharge. Winter and spring snowmelt runoff may also cause discharge, but this would occur during high streamflow periods. This emphasizes the need to enter winter periods with a good plant growth on the filter so that treatment still occurs even without active plant growth. Runoff from larger storms, however, should be allowed to discharge. The infiltration rate and soil type are the factors that determine how much runoff can be handled by infiltration during a given time, so the recommended filter area is partially a function of soil type.

The area required for an overland-flow filter is also a function of storm size. If filters can be allowed to discharge several times annually, the size of the infiltration area should be designed on the basis of a storm size having a short recurrence interval. From our initial experience, a 1-year recurrence interval seems suitable. Since the filter length should provide for a minimum contact time of two hours, selecting a 2-h storm duration is also recommended. This interval allows the runoff to flow over the complete length of the filter before rainfall ceases. Storm events larger than the 1-y, 2-h event or storms occurring when the vegetative filter is saturated would result in a discharge. The 2-h contact time would provide adequate treatment so that the filter discharge would be of similar quality to that from agricultural lands having no animal production or manure applications.

Rainfall-runoff relationships for Illinois feedlots have been developed in earlier studies (Dickey and Vanderholm, 1977; Dickey et al., 1977). Those relation-

TABLE 2. RECOMMENDED OVERLAND FLOW FILTER AREAS WITH VARIOUS SOIL TYPES (CLIMATIC CONDITIONS SIMILAR TO THOSE OF CENTRAL ILLINOIS)

Soil	Infiltration rate,		Minimum filter area
	mm/h	in./h	
Silty clay loam	30.5	(1.2)	1.6 X lot area
Silt loam	38.1	(1.5)	1.0 X lot area
Sandy loam	43.2	(1.7)	0.7 X lot area

TABLE 3. MINIMUM CONTACT TIMES FOR VEGETATIVE FILTERS UTILIZING CHANNELIZED FLOW FOR VARIOUS FEEDLOT SIZES

Lot size, m^2	(ft^2)	Minimum contact time, (h)
929 or less	(10,000)	2
1,394	(15,000)	3
1,858	(20,000)	4
2,323	(25,000)	5

ships were used to predict feedlot runoff volumes for use in these designs. In other areas, similar information may be available, or soil conservation service techniques or other established methods of predicting runoff volumes can be used.

For central Illinois, the rainfall from a 1-y, 2-h event is 40.6 mm (1.6 in.). A typical medium-textured silt loam soil in central Illinois (Drummer silt loam, maximum cover) has an infiltration rate of 38.1 mm/h (1.5 in./h). Using the 1-y, 2-h storm event and typical infiltration rates, the area of the overland-flow vegetative filter required to handle both the direct rainfall on the filter and the feedlot runoff from the system under study with a drainage area of 0.47 ha (1.15 ac) would be 0.44 ha (1.09 ac). The approximate ratio of required filter area to feedlot area for this system is 1:1. Thus, when sizing filters in areas with rainfall and soil characteristics similar to those of the system studied, the area of the overland-flow vegetative filter should be about the same as that of the feedlot. Table 2 lists the minimum ratios of overland-flow filter area to lot area for various soil types under climatic conditions similar to those in central Illinois.

With the 2-h minimum contact time dictating the flow distance and with a 1:1 ratio of filter area to feedlot area, the general vegetative filter configuration is thus specified. One other recommended criterion is a minimum flow width. Observations and management practices indicate that a vegetative filter using overland flow should be at least 6.1 m (20 ft) wide. Although there is no maximum width, the distribution of the basin effluent across the top of the filter area could become a problem at widths greater than 30.5 m (100 ft) unless pressure distribution systems are used. Gated irrigation pipe used in conjunction with float activated submersible sewage pumps in settling basins have performed satisfactorily for uniformly distributing the effluent across the top of overland flow vegetative filters. For gravity flow systems, rigid plastic pipe split in half and laid on the contour has provided adequate distribution of the settling basin effluent.

Channelized-flow Systems

Because of basic differences in the flow and infiltration patterns, contact time must be increased as the feedlot size increases for channelized-flow vegetative filters, whereas for overland-flow systems the filter area is increased with increasing feedlot sizes. On the basis of the data from the two channelized-flow systems, the 2-h minimum contact time would be appropriate for the smaller facility, but the larger one would need a contact time of approximately six hours to achieve a comparable reduction in pollutants. The size of the larger feedlot is 2,508 m^2 (27,000 ft^2), whereas the area of the smaller lot is approximately 836 m^2 (9,000 ft^2). Thus, it appears that for each additional 465 m^2 (5,000 ft^2) of lot area an additional hour of contact time is required. Table 3 lists various lot sizes and the contact times required for vegetative filters using channelized flow.

Manning's equation, as described by Schwab et al. (1966), and the minimum contact times (Table 3) were used to calculate minimum flow lengths for channelized-flow vegetative filters having various slopes; these flow lengths are shown in Fig. 2. As illustrated, the flow lengths for a vegetative filter using channelized flow would be very large on lot sizes larger than 0.4 ha (1 ac). It should be noted that the contact times shown are for a specific design flow rate, one which is relatively high. At lower flow rates, the velocity would be lower and the contact time higher.

The values shown in Fig. 2 were calculated using a design flow depth of 15.2 cm (6 in.) and assuming a parabolic channel shape. The somewhat arbitrary selection of this flow depth was based on the assumption that such a depth is about the maximum at which any filtration by channel vegetation would be effective. In the systems studied, peak flow from a 1-y, 2-h design storm would normally exceed this flow depth, but temporary storage in the settling basin and restricted basin outlet flow resulted in no channel flow depths of over 15.2 cm (6 in.) during the study period. For larger feedlots with higher peak flows, exceeding the design channel flow depth can be avoided by providing temporary storage and controlled discharge by means of a settling basin or by widening the channel sufficiently to handle larger peak flows without excessive depths. Channel design is somewhat arbitrary. The channel must be sized to carry the peak settling basin discharge plus accumulated direct precipitation in the channel area from a large design storm (e.g. 10 y or 25 y recurrence interval). Channel length, or contact time, however, as sized

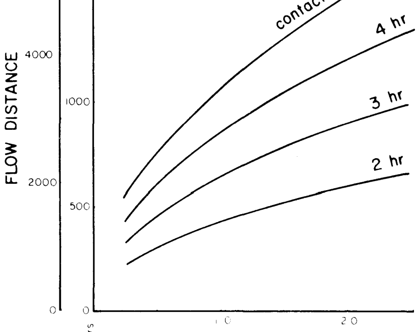

FIG. 2 Approximate channelized-flow distance required for various slopes and contact times.

above, was recommended on the basis of a smaller settling basin discharge such as experienced with smaller, more frequent (e.g., annual) storms.

Because of uncertainties in predicting the infiltration rate in a channelized-flow system, infiltration has not been included as a design variable. However, it was commonly observed in the channelized-flow systems that runoff from smaller storms infiltrated completely. This situation benefited total system performance in that the total quantity of nutrients discharged was zero for these storm events. As contact times become longer with the larger lot sizes, infiltration and dilution influence system performance. Since larger lots were not observed in this study, however, these additional effects were not evaluated. The design criteria presented may be adequate for large lots also, but without further study the recommendations in this report must be limited to lots in the size range shown in Table 1. It may be advantageous to use a trapezoidal channel with flat bottom to achieve a more uniform flow depth and less vegetation kill in the channel center as compared with the parabolic channel. This was not tested, however.

DESIGN EXAMPLE

The following example illustrates the use of the proposed design criteria for both overland-flow and channelized-flow vegetative filters. Assume that treatment is to be provided for runoff from a paved dairy lot located in central Illinois and having an area of approximately 0.2 ha (0.5 ac). The adjacent field area has a slope of one percent. The soil is a silty clay loam with an infiltration rate of 30.5 mm/h (1.2 in./h). (Information on infiltration rates can usually be found in state irrigation guides and soil handbooks for local areas.) The rainfall for the 1-y, 2-h storm is 40.6 mm (1.6 in.).

Procedure for an Overland-flow Filter

Step 1 Find the required flow distance. From Table 1, the required minimum distance should be 131 m (=430 ft).

Step 2 Find the required filter area. Using the Soil Conservation Service method with runoff curve number 97 for a paved dairy lot in Illinois (Dickey et al, 1977), the lot runoff is determined to be 33.86 mm. Multiplying that volume by the feedlot area gives:

Runoff volume = 33.86 mm x 0.2 ha = 6.77 ha·mm (=0.65 ac·in.)

The filter's infiltration capacity, IC, must equal or exceed the volume to be infiltrated, VR, for proper filter operation. The infiltration capacity is equal to the infiltration rate times the storm duration multiplied by the infiltration area. Substituting the appropriate values from our example, we have:

IC = 30.5 mm/h x 2 h x filter area

or IC = 61 mm x filter area

The volume to be infiltrated is equal to the lot runoff volume plus the volume of the rainfall on the filter area. For the example system:

VR = 6.77 ha·mm + (40.6 mm x filter area) Recalling that IC must be at least equal to VR, we have:

61 mm x filter area = 6.77 ha· + (40.6 mm x filter area)

or (61 mm x filter area) — (40.6 mm x filter area) = 6.77 ha·mm which is equivalent to:

20.4 mm x filter area = 6.77 ha·mm

Solving for the filter area, we find:

$$\text{filter area} = \frac{6.77 \text{ ha·mm}}{20.4 \text{ mm}} = 0.33 \text{ ha } (= 0.8 \text{ acre})$$

Step 3 Specify the filter area dimensions. Use a minimum length of 131 m (430 ft). The filter length times its width is equal to its area:

131 m x width = 0.33 ha = 3,238 m²

Solving the equation for width, we have: Width = 24.7 m (=81 ft)

Thus, the required minimum overland-flow filter size for this example is 24.7 m (81 ft) wide by 131 m (430 ft) long. If desired, the filter width could be reduced and the length increased to obtain the same area, as long as a minimum filter width of 6.1 m (20 ft) is maintained. The total filter size may be increased, too, if specific site conditions make a higher degree of treatment advisable.

Procedure for a Channelized-flow Filter

Step 1 Find the required contact time. From Table 3, the required contact time for a 0.2-ha (0.5-ac) lot is 4 h.

Step 2 Find the filter length from Fig. 2. For a 4-h contact time and a one percent slope, the minimum length is 792 m (=2600 ft).

To provide additional protection, the vegetative filter length could be increased as desired. By designing the vegetative filter such that it discharges onto adjacent cropland, the discharge of pollutants into receiving streams would be practically eliminated, even for large storms.

SUMMARY

Vegetative filters can provide a satisfactory, low-cost means of controlling feedlot runoff for many small and medium-sized livestock feedlots. Such filters are not adaptable to every situation, however, and some management is required for satisfactory performance. Proposed design criteria have been developed for overland-flow and channelized-flow systems and are presented here. Channelized-flow systems appear to be less effective than overland-flow systems, requiring a much greater flow length for a similar degree of treatment. However, achieving uniform distribution and true overland flow is difficult. Further research is needed to verify our results for other conditions and to refine the proposed design criteria.

The acceptance of the vegetative filter system by farmers appears to be much better than that for conventional treatment systems with holding ponds. Thus, the vegetative filter is likely to be adopted much more readily than conventional systems by operators of smaller feedlots, resulting in the reduction of pollution problems associated with feedlot runoff.

Although test results are not available, it is anticipated that this vegetative filter design criteria can be utilized in other geographical areas which have somewhat similar soils and rainfull patterns. For winter runoff and snowmelt conditions, dormant residues left on the filter have proved to be an effective filtering and settling mechanism.

State regulations and policies vary greatly, but many

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regard zero-discharge as the only acceptable concept. This study and other research indicates that well designed and maintained vegetative filters could be very effective in many situations for controlling feedlot runoff.

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