1989

Performance and Design of Vegetative Filters for Feedlot Runoff Treatment

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

D. H. Vanderholm
University of Illinois

Dickey, Elbert C. and Vanderholm, D. H., "Performance and Design of Vegetative Filters for Feedlot Runoff Treatment" (1989). *Biological Systems Engineering: Papers and Publications*. 267.
http://digitalcommons.unl.edu/biosysengfacpub/267

Performance and Design of Vegetative Filters for Feedlot Runoff Treatment

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

INSTALLATION of a zero-discharge, runoff-control system is one method for solving potential water pollution problems from many feedlot operations. Even though the zero-discharge system is required by regulation in several states, this approach may be economically prohibitive for many small operations. An alternative is to install a vegetative filter system to adequately control the runoff so that violations of water quality standards will not occur during storm runoff. Vegetative filters are systems in which a vegetative area such as pasture, grassed waterways, or even cropland is used for treating feedlot runoff by settling, filtration, dilution, adsorption of pollutants and infiltration.

Generally, vegetative filters have either channelized or overland flow. Channelized-flow systems have various configurations such as a graded terrace channel or grassed waterways, but are simply systems in which flow is concentrated in a relatively narrow channel. In overland flow systems flow occurs as sheet flow less than 30 mm (1.2 in.) deep, with widths ranging from 5 to 6 m (16 or 20 ft) up to possibly 30 m (98 ft).

LITERATURE REVIEW

Much early use of vegetative filter treatment was for the disposal of canning-industry wastes. Mather (1969) reported removal of biochemical oxygen demand (BOD) from cannery wastes of 94 to 99 percent during overland flow in a disposal area, although Bendixen et al. (1969) reported only 66 percent BOD removal. Nitrogen removals of 61 to 94 percent and phosphorus removals of 39 to 81 percent were also reported in these two studies.

Sievers et al. (1975) used a grassed waterway filter to treat anaerobic swine lagoon effluent. Willrich and Boda (1976) also treated swine lagoon effluent with sloping grass strips. Open feedlot runoff-treatment systems have been reported by Sutton et al. (1976) and Swanson et al. (1975). While the degree of treatment varied, these studies indicated that vegetative filters were effective and potentially acceptable treatment alternatives. No uniform criteria evolved from these studies, however, and variable performance has made environmental authorities hesitate to give blanket approval to this concept. Lybecker (1977) showed that vegetative filters are generally more economical than zero-discharge systems, making them an attractive alternative to small feedlots with minimum capital.

OBJECTIVES AND FIELD INSTALLATIONS

A study was begun in 1975 to continue the evaluation of vegetative-filter systems. The study lasted for two years and was conducted year-round. The objectives were:

1 To determine whether vegetative filters are a feasible alternative for management of feedlot runoff.

2 To develop design standards and management recommendations for successful vegetative-filter systems.

Four feedlots, described in Table 1, were selected for which vegetative filters adapted well to the physical situation and appeared to have a reasonable chance for managing feedlot runoff. At all locations, the basic system consists of a settling facility, a distribution component, and either of the two types of vegetative filter illustrated in Fig. 1. No storage unit for runoff is involved. Runoff from storm events goes directly to the filter area after passing through the settling basin. Similar concrete settling basins are used at each location, but each vegetative filter is quite different.

System 1 was installed on the University of Illinois dairy farm, where construction and management could be carefully controlled and observed, also data could be collected easily. The other three systems are at commercial livestock production facilities. More complete descriptions of these systems are reported in the final project report (Vanderholm et al., 1979).

TABLE 1. CHARACTERISTICS OF VEGETATIVE FILTER SYSTEMS STUDIED

System	Feedlot capacity Animal units	Filter type	Ratio feedlot area to filter area	Slope %	Filter surface area ha	(acre)	Filter length m	(ft)
1	100 dairy	Overland flow	1.0	0.5	0.33	(0.83)	91	(300)
2	450 beef	Overland flow	0.7	0.5	0.7	(0.41)	61	(200)
3	500 beef	Channelized flow						
		terraced channel		0.25			564	(1,850)
4	480 swine	Channelized flow						
		terraced channel		0.25			152	(500)
		grassed waterway		2.0			457	(1,500)

Contribution from U.S. Environmental Protection Agency, Illinois Institute for Environmental Quality, The Illinois Agricultural Experiment Station and the Illinois Beef Industry Council.

The authors are: E. C. DICKEY, Assistant Professor, Agricultural Engineering, University of Nebraska, Lincoln; and D. H. VANDERHOLM, Associate Professor, Agricultural Engineering, University of Illinois, Urbana. Published as Paper Number 6007, Journal Series, Nebraska Agricultural Experiment Station.

This article is reprinted from The Proceedings of the 4th International Symposium on Livestock Wastes (pp. 257-260)
Published by the American Society of Agricultural Engineers, St. Joseph, MI 49085.

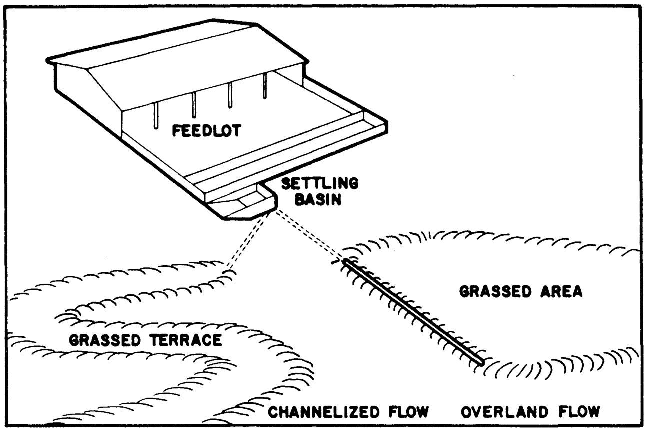

FIG. 1 Vegetative filter configurations for feedlot runoff treatment.

RESULTS AND DISCUSSION

Vegetative Filter Performance

Concentration reductions of settling basin effluent by vegetative filter treatment are shown in Table 2. More complete data including soil and crop data are available in the final project report by Vanderholm et al. (1979). Average concentration reductions by vegetative filter treatment of feedlot runoff are similar for the systems studied, and represent a reduction of about 75 percent of constituent concentrations in the settling basin effluent. However, flow distances of the systems are considerably different. Comparing the reduction between the two overland flow systems indicates comparable and fairly consistent performance even though the animal population and densities were different (Table 1). Comparing the reductions of the overland flow systems to System 3, a channelized flow system, indicates differences between the types of flow. The channelized flow system required a flow length over 5 times longer than the overland flow systems to achieve a similar concentration reduction. System 4, also channelized flow, performed better than System 3. Average constituent reduction after 148 m (500 ft) of flow distance was about 86 percent. Data from Systems 3 and 4 show that equivalent treatment requires longer flow lengths when channelized flow rather than overland flow is used.

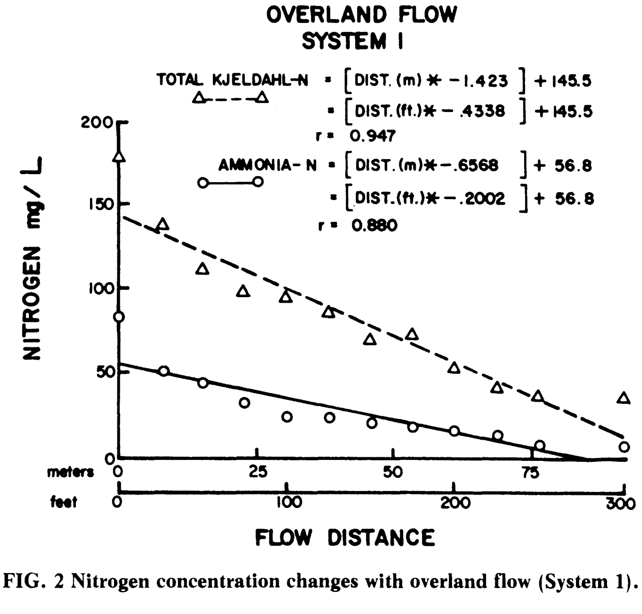

FIG. 2 Nitrogen concentration changes with overland flow (System 1).

TABLE 2. CONCENTRATION REDUCTIONS OF SETTLING BASIN EFFLUENT BY VEGETATIVE FILTER TREATMENT

	Flow distance		Percent concentration reduction					
	m	(ft)	NH_3-N	TKN	Total solids	COD	P	K
Overland flow								
System 1	91	(300)	86.2	80.1	73.1	85.4	78.2	74.7
System 2	61	(200)	71.5	71.1	63.1	81.2		
Channelized flow								
System 3	533	(1,750)	83.4	83.1	79.7	86.0		
System 4	148	(450)	85.2	88.9	78.7	92.1		

Figs. 2 and 3 clearly show decreases in constituent concentrations as basin effluent traversed the vegetative filters on Systems 1 and 3. Data points on Fig. 2 are averages of grab samples obtained during seven different runoff events and data points on Fig. 3 represent sampler locations. While the filters were effective in reducing constituent concentrations, the filter effluent still had sufficiently high pollutant concentrations to cause a violation of stream water quality standards in some instances. As an example, the average ammonia-N concentration in the filter discharges from System 1 was 18.5 mg/L, but the Illinois stream standard is 10 mg/L. Filter discharge rates were quite low relative to many receiving stream flows during storm events, thus adequate dilution would generally occur so that stream standards would not be violated.

Mass balance studies were conducted on 19 runoff events on System 1 and three runoff events on System 3 (Table 3). On a weight basis, an average of about 96 percent of the constituents applied were retained by System 1. Ammonia-N had the greatest reduction, showing a removal of 97.7 percent; total solids had the least reduction, a removal of 95.5 percent. About 30 percent of the measured constituents at System 3 were removed in the first 229 m (750 ft) of flow, with the next 152 m of vegetative filter removing about 50 percent of the constituents. The resulting total constituent removal for System 3 was about 92 percent on a weight basis.

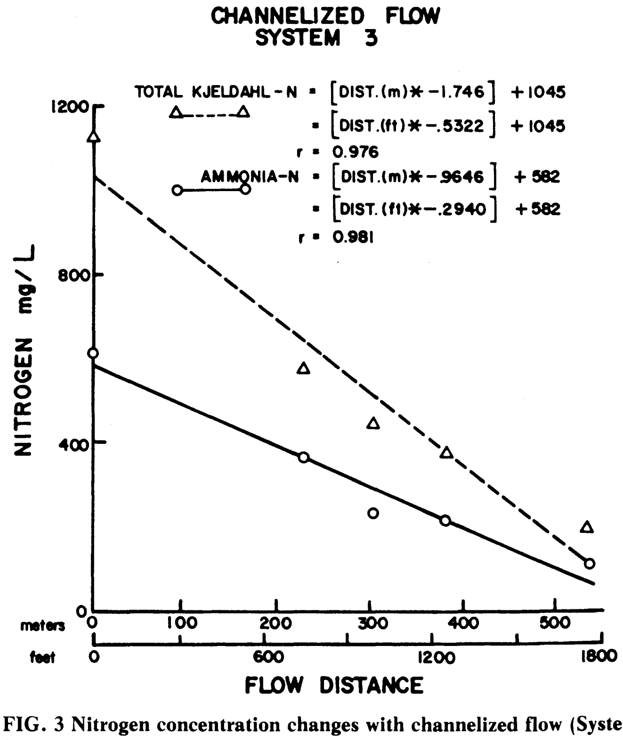

FIG. 3 Nitrogen concentration changes with channelized flow (System 3)

TABLE 3. CONSTITUENT REMOVAL ON A WEIGHT BASIS BY VEGETATIVE FILTER TREATMENT OF FEEDLOT RUNOFF

	Flow distance		Percent reduction, weight basis					
	m	(ft)	NH_3-N	TKN	Total solids	COD	P	K
System 1	91	(300)	97.7	96.7	95.5	97.5	96.3	95.7
System 3	229	(750)	24.3	35.8	23.4	34.0		
	381	(1,250)	80.0	81.2	75.6	81.8		
	533	(1,750)	92.3	92.2	90.7	93.5		

Low removal rates at the upper end of System 3 reflect an inherent problem with a parabolic channel. Flow width in the waterway seldom exceeded 1.5 m (5 ft), primarily because of the controlled outflow from the settling basin. Grass in the waterway bottom has been killed in a 0.3-0.9 m (1-3 ft) width for about 9 m (30 ft), and, beyond the killed area, vegetation was stunted for another 150 m (492 ft). Nutrients, solids and water from most small events are deposited or infiltrated in the waterway segment where vegetation is killed or stunted. A waterway segment with a larger flow width (such as a flat bottom channel) would distribute basin effluent more evenly and alleviate the vegetation kill resulting from excessive nutrients and water in the narrow channel bottom.

Vegetative Filter Design

Major pollutant removal mechanisms with vegetative filter treatment are settling, filtration by vegetation and adsorption on soil and plant materials. For these mechanisms to be effective, the length of time that runoff is in contact with the vegetation and soil is an important variable affecting pollutant removal. This time or contact time is a function of slope, flow velocity and other factors. 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 of System 1. Similarly, it took about 5 h for basin effluent to traverse the 533 m (1750 ft) flow length of System 3.

Data from both the overland flow and channelized flow vegetative filters suggest that it may not be practical to achieve removal efficiencies above 95 percent due to excessive filter length and size. Given the pollutant removal efficiencies and associated contact times, the minimum recommended contact time for any vegetative filter system is 2 h. Table 4 illustrates minimum flow lengths for various slopes and were calculated using Manning's equation (Schwab et al., 1966).

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. The recommended criterion for determining overland flow filter size is based on the principle that runoff from small storms should completely infiltrate into the soil in the filter area, resulting in zero discharge. Runoff from larger storms or snowmelt would discharge after being in contact with the filter for a minimum of two hours, thus obtaining desired treatment. This emphasizes the need to enter winter with a good plant growth on the filter so that treatment still occurs even without active plant growth.

Overland flow filter size is thus a function of soil infiltration rate and storm size. If annual discharges are allowable, then the infiltration area should be designed for a short recurrence interval. Since the minimum flow length should provide a 2-h contact time, a 2-h duration is recommended for the design storm. From our initial experience, sizing the filter to infiltrate both the rainfall and runoff from a one year, 2-h storm results in reasonable vegetative filter sizes. As an example, the filter area in central Illinois for a typical silt loam soil is equivalent to the feedlot area. Soils with slower infiltration rates would require larger filter areas. Thus the design storm size and soil infiltration rate dictate total filter area and the 2-h contact time and filter slope dictate the minimum length. Although no specific width is recommended, overland flow vegetative filters should be wider than 6.1 m (20 ft). Widths greater than 30.5 m (100 ft) could pose basin effluent distribution problems unless pressure distribution systems are used.

TABLE 4. MINIMUM FLOW LENGTHS FOR OVERLAND FLOW VEGETATIVE FILTERS HAVING VARIOUS SLOPES*

Slope	Flow length	
%	m	(ft)
0.5	91.4	(300)
0.75	113	(372)
1	131	(430)
2	185	(608)
3	227	(744)
4	262	(860)

*Design flow depth is 13 mm (0.5 in.) and Manning's roughness coefficient is assumed to be 0.3.

Because of the basic differences in the flow and infiltration patterns, contact time must be increased as feedlot size increases for channelized flow vegetative filters. On the basis of the data from the channelized flow systems, the 2-h contact time would be appropriate for System 4, but System 3 needs about a 6-h contact time to achieve a comparable reduction in pollutants. The size of the larger feedlot (System 3) is 2508 m^2 (27,000 ft^2), whereas the smaller lot area (System 4) is 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 needed. Fig. 4 illustrates minimum flow distances for channelized flow vegetative filters with various shapes and lot sizes and their respective contact times. It should be noted that the values shown in Fig. 4 were calculated using a design flow depth of 15.2 cm (6 in.) and assuming a parabolic channel shape. For the systems studied, peak flows from one year, 2-h storm would normally exceed this design depth, but temporary storage in the settling basin and restricted basin outlet flow resulted in small channel flow depths. As illustrated in Fig. 4, the flow lengths for a vegetative filter using channelized flow would be very large for lot sizes larger than 0.4 ha (1 acre). Because of uncertainties in predicting the infiltration rate in channelized flow systems, infiltration has not been included as a design variable. However, it was commonly observed that runoff from smaller storms infiltrated completely.

CONCLUSIONS

Vegetative filters can reduce nutrients, solids, and oxygen demanding materials from feedlot runof by over 80 percent on a concentration basis and over 95 percent on a weight basis. Removal levels above these are not practical since the quality of the treated runoff is approaching that of the runoff from agricultural land which is diluting the applied runoff.

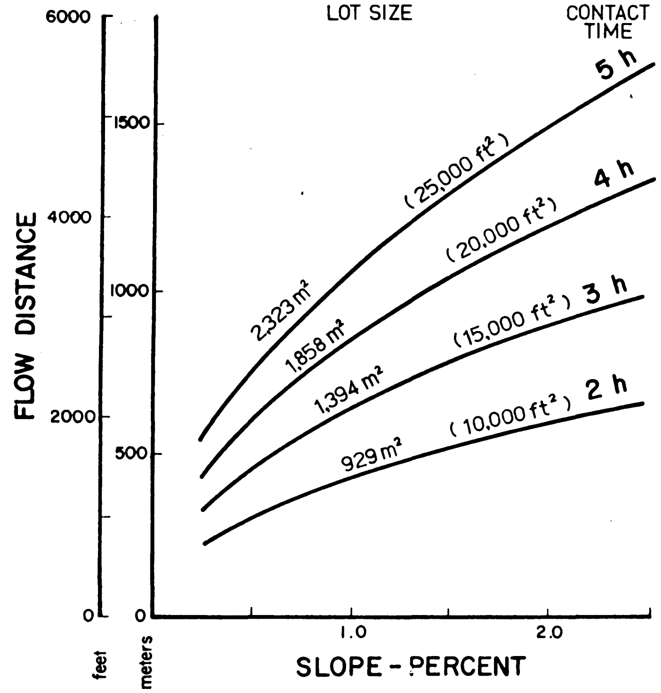

FIG. 4. Approximate channelized flow distance required for various slopes, lot sizes and contact times.

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.

Although test results are not available, it is anticipated that these vegetative filter design criteria can be utilized in other geographical areas which have somewhat similar soils and rainfall patterns. For winter runoff and snow melt 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 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.

References

1 Bendixen, T. W., R. D. Hill, F. T. DuByne, and G. G. Robeck. 1969. Cannery waste treatment by spray irrigation—runoff. J. Water Poll. Control Fed. 41:385-391.

2 Lybecker, D. 1977. Comparative surface runoff control system investment and operating costs for six Illinois demonstration-research sites. Unpublished paper presented at Southern Illinois Univ. Liquid Livestock Waste Disposal Field Day, Dept. of Ag. Ind. Southern Illnois Univ., Carbondale.

3 Mather, R. J. (Editor). 1969. An evaluation of cannery waste disposal by overland flow spray irrigation. Publ. in Climatology, C. W. Thornthwaite Ass., XXII(2).

4 Schwab, G. O., R. K. Frevert, T. W. Edminster, and K. K. Barnes. 1966. Soil and water conservation engineering. John Wiley and Sons, Inc., New York, 2nd edition. 683 pp.

5 Sievers, D. M., G. B. Garner, and E. E. Picket. 1975. A lagoon-grass terrace system to treat swine waste. pp. 541-543. In: Managing livestock wastes. (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-275. ASAE, St. Joseph, MI 49085.

6 Sutton, A. L., D. D. Jones, and M. C. Brumm. 1976. A low cost settling basin and infiltration channel for controlling runoff from an open swine feedlot. ASAE Paper No. 76-4516, St. Joseph, MI 49085.

7 Swanson, N. P., C. L. Linderman, and L. N. Mielke. 1975. Direct land disposal of feedlot runoff. pp. 255-257. In: Managing livestock Wastes. (Proceedings, International Symposium). American Society of Agricultural Engineers PROC-275. ASAE, St. Joseph, MI 49085.

8 Vanderholm, D. H., E. C. Dickey, J. A. Jacobs, R. W. Elmore, and S. L. Spahr. 1979. Livestock feedlot runoff control by vegetative filters. U.S. Environmental Protection Agency. EPA-600/2-79-143. 66 pp.

9 Willrich, T. L., and J. O. Boda. 1976. Overland flow treatment of swine lagoon effluent. ASAE Paper No. 76-4515, St. Joseph, MI 49085.