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THE EFFECTIVENESS OF A COMBINATION WEEP BERM-GRASS FILTER RIPARIAN CONTROL SYSTEM FOR REDUCING FECAL BACTERIA AND NUTRIENTS FROM GRAZED PASTURES

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ABSTRACT

Much of the pollution in our lakes and streams has been attributed to agricultural practices, with bacteria, nutrients, and sediment being the primary pollutants. Runoff from grazed pastures and manure-applied lands can contain high concentrations of fecal coliforms and nutrients. Riparian grass filters have proven successful in reducing pollutants reaching streams and wetlands but effectiveness is dependent upon achieving shallow, uniform flow. Most landforms have undulations that will concentrate flow, reducing grass filter efficacy. In an attempt to enhance the effectiveness of the riparian zone as a pollution control area, a low-cost control system, consisting of a combination weep berm-grass filter, was developed and tested under simulated continuous grazing and rotational grazing practices. Three replicate tests were conducted on three field plots subjected to simulator-generated rainfall. Plots were instrumented to enable monitoring of surface runoff up-gradient of the weep berm and down-gradient of the grass filter. The system achieved average reductions in fecal coliform concentrations (99%), total nitrogen (87%), total phosphorus (44%), and total suspended solids (90%). The control system also reduced peak runoff rate from high intensity, short duration rainfall events by 92%. Based on these results, the weep berm-grass filter system affords the following advantages over simple grass filters: 1) peak flows are highly dampened, 2) due to short-term storage, some settling and infiltration occurs above the berm, and 3) flow is passively and uniformly released through the weep berm to the grass filter at a slower rate, thereby allowing the grass filter to perform more effectively.

KEYWORDS. stream and wetland protection, riparian BMP, management of riparian zones.

INTRODUCTION

The National Water Quality Inventory: 2000 Report stated that 39% of rivers and 45% of lakes surveyed across the United States had pollution problems, primarily due to high levels of bacteria, nutrients, and sediments. The US EPA has associated these pollutants with agricultural activities and hydrologic modifications (USEPA, 2000).

To effectively meet the goals of the Clean Water Act, non-point source pollutants must be properly managed. Best Management Practices (BMPs), such as grass filter strips, have been shown to improve water quality; however, a 4.5 m grass filter strip alone cannot sufficiently improve runoff to meet water quality standards (Coyne et al., 1998). Additional BMP practices are necessary to sufficiently improve water quality. The addition of a simple structure, such as a weep berm, may prove to be effective in reducing runoff contaminants.

Grass Filters

Grass filter strips have been studied extensively for their effectiveness in improving the water quality in runoff. The parameters identified to impact grass filter performance are vegetation type

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and height, terrain area and slope, soil type and infiltration rate, rainfall intensity and duration, and antecedent moisture conditions (Deletic, 2001). A study by Gharabaghi, et al. (2001) suggests that the first five meters of a grass filter are the most efficient, providing 95% of the removal of aggregates larger than forty microns. A 4.5 m filter strip can reduce sediment concentrations by 96%, fecal coliform concentrations by 75% and fecal streptococci by 68% (Coyne, 1998). Dillaha et al. (1989) found that a 4.6 m strip reduced total suspended solids by 70%, phosphorus by 61%, and nitrogen by 54%. Although the pollutant reduction within a grass filter is significant, water quality standards may still be exceeded in the effluent, especially in areas where landform undulations concentrate flow, reducing the effective area of the grass filter.

Weep Berm

A weep berm is a small berm constructed perpendicular to the direction of runoff that performs as a temporary detention structure.

A weep berm – forested riparian area was used to retain sediment, reduce peak flow and infiltrate runoff at an active construction site at Alpharetta, Georgia (Warner and Collins-Camargo, 2001). Monitoring was conducted only immediately up and down-gradient of the weep berm since, by design, all discharge emanating from the weep berm infiltrated within the forested area. For the storm event of 3.7 inches occurring August 31 through September 1, 2000 the weep berm's effluent suspended sediment concentration (SSC) ranged between 78 and 30 mg/L. It was noted that runoff originating from small, highly intense rainfall events were contained by the berm and a large reduction in sediment loads was observed. The infiltrated water was incorporated as groundwater, which increased stream baseflow and improved conditions for aquatic life. Since the seep berm is a passive dewatering system, settled sediment was cost effectively removed.

A weep berm – grass filter control system was installed down-gradient of two elongated gradient sediment ponds placed in series at a site receiving sediment-laden flow in the mountains of Peru. The ponds were equipped with a flocculation system that was used during the wet season to enhance sediment-trapping efficiency. The reported effluent sediment concentration entering the adjacent stream was always below 50 NTU and averaged approximately 15 NTU during storm events. The passive weep berm – grass filter system was viewed as a control system that successfully achieved effluent requirements of the project (Warner and Torrealba, 2003).

Some parameters of concern when considering a grass filter as a single control are vegetation type, terrain characteristics, soil type, rainfall characteristic, and antecedent conditions (Deletic, 2001). The overall efficiency of the grass filter will be dependant on the area and slope of the land, the amount and rate of infiltration, the type and height of grass, the intensity and duration of the storm event, and the antecedent moisture condition of the soil.

Design Considerations for Combination Weep Berm –Grass Filter Control System

The design of a combination weep berm – grass filter control system to protect the water quality of a stream requires consideration of numerous parameters. The spatial location of the control system is a major consideration and should be integrated with stream geomorphic characteristics and cost components specifically associated with lost, or reduced use, of agriculturally productive lands. Design parameters include the design rainfall event, flow characteristics of the stream, contributing watershed area, pollutant load and concentration, type of pollutant to be treated, desired treatment efficiency, soil type, height and length of the weep berm, location, type and configuration of the outlets, and internal check dam spacing and height. It is important to understand the hydraulic properties of soils that exist both up and down-gradient of the weep berm. The infiltration characteristics of the soils help to define the period of time required to dewater the detained portion of the runoff. The infiltration rate will affect treatment efficiency, sizing of the weep berm and length of the down-gradient grass filter.

Preliminary design guidance was obtained from two combination weep berm – riparian filter systems that were implemented at an active construction site in Georgia and along the access road of a copper and zinc mine in Peru (Warner and Collins-Camargo, 2001 and Warner and Torrealba, 2003). At the Georgia site an experimental weep berm was designed, constructed, and tested to determine its performance with respect to sediment removal. The weep berm was designed to provide a controlled release of discharge to a forested riparian zone. Four discharge configurations were investigated: (1) a perforated riser wrapped in stone, (2) a perforated riser wrapped with a large-opening geotextile and stone, (3) a fixed siphon, and (4) an internal sand filter located within the side wall of the berm itself. A simple straight pipe configuration was employed as the Peruvian site. Approximately 60, 25-cm PVC pipes were located at various elevations along the length of the weep berm in Peru. At both projects the design storm to be retained with controlled release through the various outlet configurations was the 2-year 24-hour event. Larger storm events would be partially retained with the excess peak flow overflowing the weep berm. The weep berm was stabilized by vegetation on the contour; therefore, the overflow would simply enter the down-gradient riparian zone without eroding the weep berm.

The design discharge rate from the weep berm to the down-gradient natural filter is a function of the infiltration rate and length (in the flow direction) of the filter and the desired systems effectiveness. The highest efficiency is often a function of the amount of discharged water that is infiltrated within the filter. Generally, the longer the filter and the higher the infiltration rate in the filter, the better the performance. For the Georgia construction site the riparian zone consisted of a second growth mixed forest that was well established and had an infiltration rate that was expected to exceed 7.5 cm/hr. The Peruvian site had a natural grass filter that ranged in length from approximately 30m to 60m and had an infiltration rate estimated to be 0.5 cm/hr. If the discharge rate exceeds the infiltration rate then removal efficiency becomes a function of the filtering action of the riparian material.

The length and slope of the weep berm are two additional design parameters of concern. Longer weep berms enable discharging detained runoff to larger riparian filter area, thereby potentially enhancing system effectiveness. The slope of the weep berm is related to the weep berm height and the spacing and height of porous check dams located along the length of the weep berm. For the construction and mining projects, the weep berms were segmented into elongated chambers through use of porous check dams that were located along the length of the weep berm. In the case of the Georgia construction site, chambers were 40m in length and for the Peruvian site each chamber was approximately 80m in length.

OBJECTIVES

The objective of this project was to investigate the overall effectiveness of the combination weep berm - grass filter control system in reducing effluent concentrations of fecal coliforms and nutrients. The project also evaluated the hydraulic performance of the control system.

METHODS

The study was conducted at the University of Kentucky's Main Chance Farm located in Lexington, Kentucky. The predominate soil type was Maury Silt Loam. Three plots measuring 12.2 m in length and 2.4 m in width (Figure 1) were used. The average slope of the plots was 4% with a cross-slope of 1.3%. Each plot was bound by rust proof metal borders to insure that all runoff was contained in the desired area. Down-gradient of the grass filter, a wooden collection gutter intercepted surface runoff.

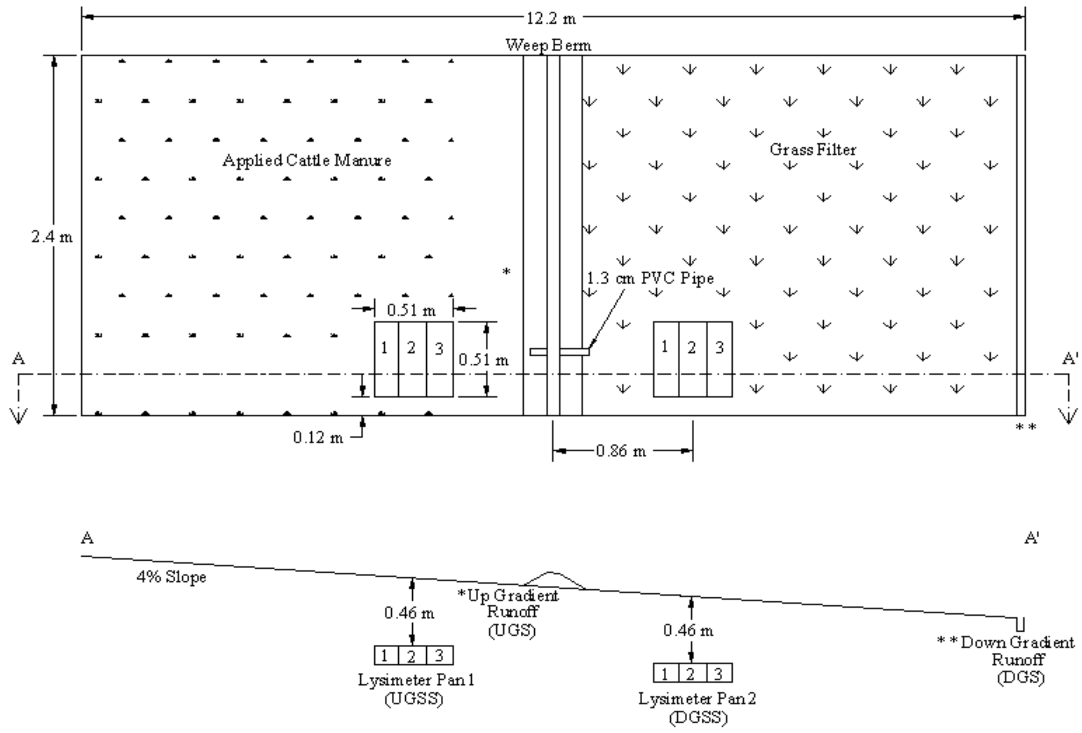

Figure 1. Plot Plan and Section Views

A weep berm 14 cm in height, with 2:1 side slopes, was constructed in the middle of each plot. The berm was constructed with moderate compaction using loamy topsoil. Fescue was sowed on the berm and covered with a coconut mat to promote growth and reduce the potential of erosion. A 12.7 mm diameter straight PVC pipe was installed through the berm, at an invert height of 8.9 cm, to facilitate dewatering at high flows. The weep berm and the outlet pipe were surveyed and an elevation-discharge relationship determined.

The desired rainfall rates and intensities were produced with two 2.7 m by 6.4 m rainfall simulators. Lexington municipal water served as the source for the rainfall. Since fecal coliforms were being monitored, it was necessary to eliminate the chlorine from the municipal water. This was accomplished by using 10 mg of anhydrous sodium thiosulfate per liter of source water.

Prior to each experiment, soil samples were collected from each plot above and below the berm to determine moisture content. Cattle manure was applied once at a rate of 0.94 kg/m2 to the upper 5.9 m of the plots following the background assessment and just prior to the first simulation. The manure was distributed evenly throughout the plots.

Rainfall was initially applied to the plots at an intensity of 5.1 cm per hour for a 20 minute duration. The intensity was then increased to 7.6 cm per hour for approximately 40 minutes. If no substantial runoff was detained by the berm, the intensity was increased to 10.2 cm per hour and maintained until discharge through the weep berm outlet occurred at full pipe flow for approximately 10 minutes.

Three runoff samples were taken uniformly throughout each simulation. The first sample was collected when runoff initially began, the second approximately twenty minutes later, and the third at the end of the experiment. Samples were collected at two locations: one from the backwater of the weep berm and the other down-gradient of the grass filter. A volume weighted composite sample was created from the samples collected at each sampling location.

A total of four simulations were conducted consisting of an initial background assessment and three replicated experiments. The initial background assessment was conducted to determine the existing level of contamination. Prior to the first experiment cattle manure was applied to each plot; therefore, the first simulation mimicked continuously grazed cattle pastures. The second and the third simulations were conducted in the same manner as the first; however, no additional manure was applied. These experiments thus simulated rotational grazing practices in which the cattle had been removed from the pasture.

Parameters monitored during the study included: fecal coliforms, total nitrogen, and total phosphorous.

EXPERIMENTAL RESULTS

Surface flow data was measured to assess the control system's hydraulic performance. Rainfall up-gradient of the berm was detained by the berm, infiltrated, evaporated, evapotranspirated, or discharged through the straight pipe at high stages. Stage data was recorded to determine both the volume retained up-gradient of the berm and the flow dewatered through the straight pipe located through the weep berm. The runoff rate was also measured down-gradient of the grass filter.

Fecal bacteria are naturally occurring bacteria found in animal excrement; therefore, a large increase in fecal coliforms was observed following the application of cattle manure. After the initial application of the cattle manure, the fecal coliform count increased to an overall average of 2.3×10^5 counts per 100mL.

Comparing the runoff up-gradient of the berm and the runoff down-gradient of the grass filter, high reduction rates were observed. The control system effectively reduced fecal coliform counts 99%, 64%, and 61% during each sequential rainfall simulation. After the third rainfall experiment, the average fecal coliforms exiting the weep berm – grass filter control system was 340 counts per 100mL illustrating nearly a 1,000 times decrease in concentration compared to the average of the first rainfall simulation, which was 230,000 counts per 100mL. Figure 2 illustrates the average fecal coliform concentrations up-gradient and down-gradient of the control system and the overall reduction achieved by the control system. Table 1 lists the averaged fecal coliform concentrations reported from each experiment.

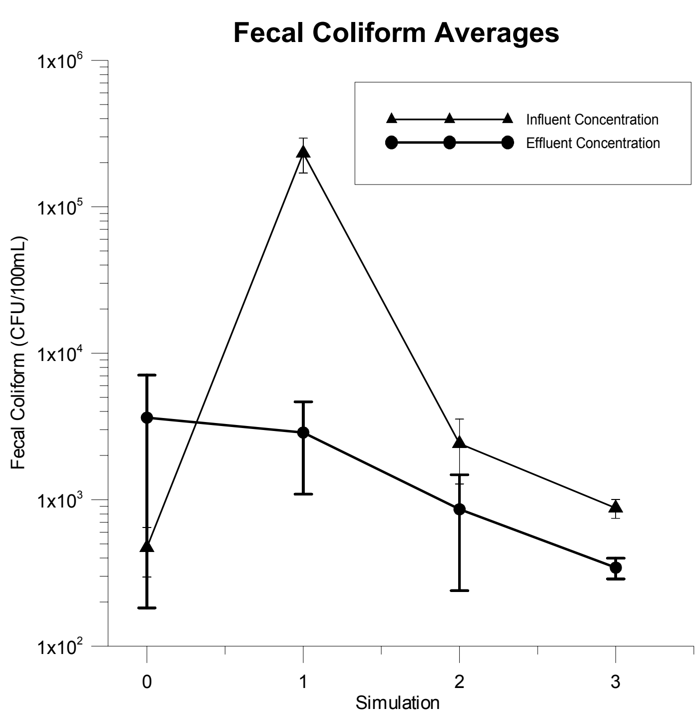

Figure 2. Fecal Coliform Concentrations

Table 1. Fecal Coliform Data

Run	Up-Gradient Concentration (CFU/100mL)	Down-Gradient Concentration (CFU/100mL)	Overall Reduction
1	2.9×10^5	2.9×10^3	98.8%
2	2.4×10^3	8.6×10^2	64.3%
3	8.8×10^2	3.4×10^2	60.8%

Nutrient reductions are listed in Table 2 and graphically displayed in Figure 3. The weep berm - grass filter control system was highly effective in reducing total phosphorous and total nitrogen by 44% and 87%, respectively during the first rainfall simulation. As anticipated, the nutrient data illustrated a diminishing incremental reduction in efficiency for the second and third experiments due to a large reduction observed during the first experiment. It is important to note that the weep berm – grass filter control system achieved a high reduction for the rainfall simulation immediately following application of waste material; therefore, the potential for off-site pollution is largely eliminated.

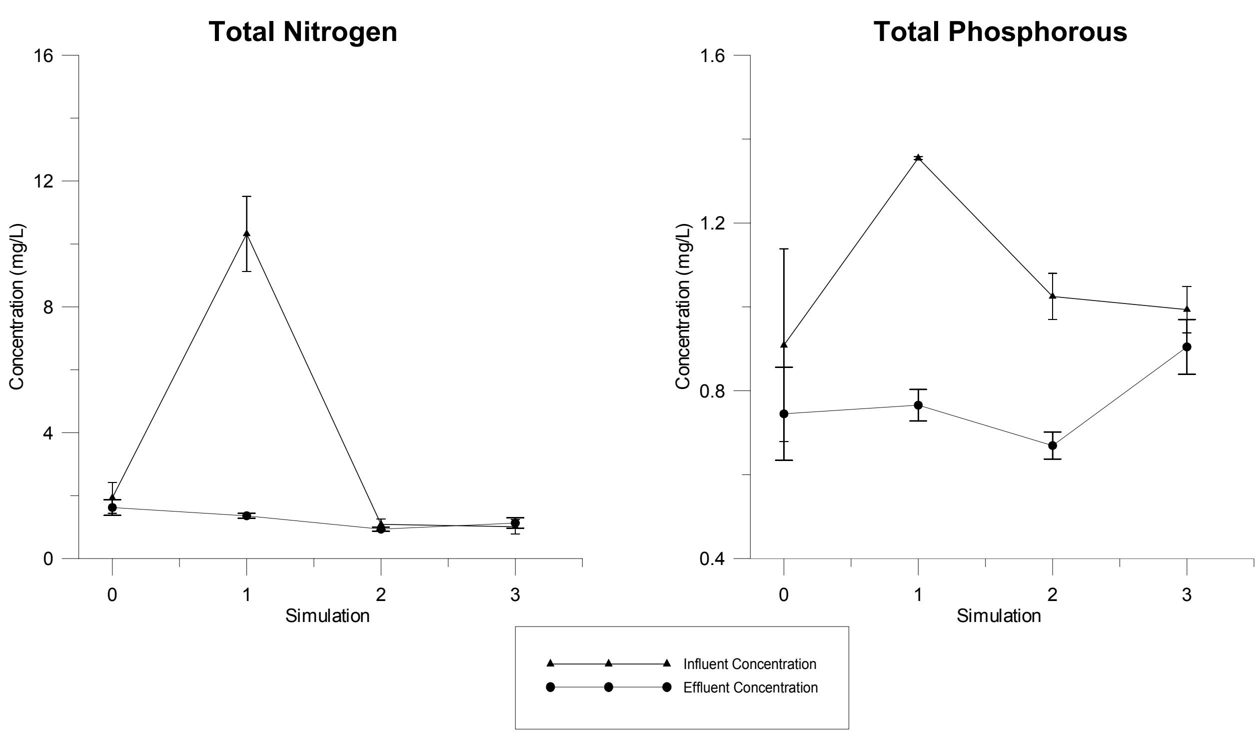

Figure 3. Runoff Nutrient Concentrations

Table 2. Nutrient Reductions

Total Nitrogen			
Run	Up-Gradient Concentration (mg/L)	Down-Gradient Concentration (mg/L)	Overall Reduction
1	10.32	1.13	86.8%
2	1.09	0.94	13.9%
3	1.02	1.36	0.0%
Total Phosphorous			
Run	Up-Gradient Concentration (mg/L)	Down-Gradient Concentration (mg/L)	Overall Reduction
1	1.35	0.77	43.5%
2	1.03	0.67	34.7%
3	0.99	0.91	9.0%

CONCLUSION

The effectiveness of a combination weep berm – grass filter control system was field-tested using three replicate plots subjected to three rainfall events. The three plots were instrumented to enable monitoring of surface runoff up-gradient of the weep berm and down-gradient of the grass filter. In this study, the control system was highly effective in reducing critical non-point source pollutants. Overall, the control system performed well hydraulically and improved effluent water quality, even under worst-case conditions. The control system achieved average reductions of fecal coliforms, total nitrogen, and total phosphorous 99%, 87%, and 44%, respectively. Based on these results, the weep berm-grass filter system affords the following advantages over simple grass filter when attempting to protect streams and wetlands: 1) peak flows are highly dampened, 2) due to short-term storage, some settling and infiltration occurs above the berm, and 3) flow is passively and uniformly released through the weep berm to the grass filter at a slower rate, thereby allowing the grass filter to perform more effectively.

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