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Impact of Riparian Grass Filter Strips on Surface-Water Quality

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UNIVERSITY OF KENTUCKY, LEXINGTON

IMPACT OF RIPARIAN GRASS FILTER STRIPS ON SURFACE-WATER QUALITY

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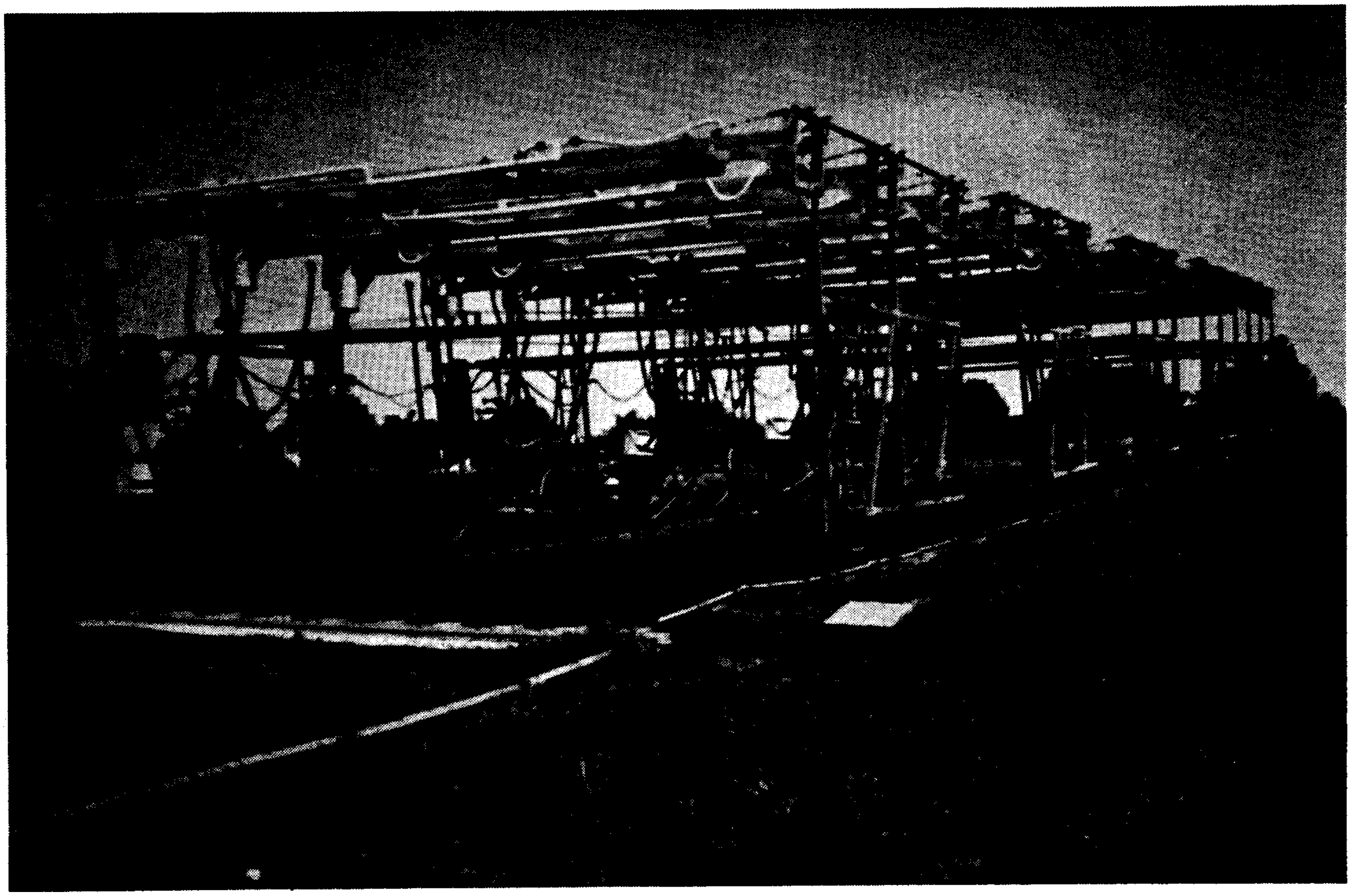

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IMPACT OF RIPARIAN GRASS FILTER STRIPS ON SURFACE-WATER QUALITY

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ABSTRACT

The effectiveness of natural riparian grass filter strips in removing sediment and agricultural chemicals from surface runoff was studied using no-tillage and conventional-tillage erosion plots. Runoff from the tillage plots was directed onto 4.57, 9.14, and 13.72 m (15, 30, and 45 ft.) length filter strips, where the inflow and outflow concentrations and sediment size distributions were measured. Trapping efficiencies for sediment and agricultural chemicals typically ranged near or above 90 percent, mainly because of high infiltration rates. The filters also significantly reduced peak discharge concentrations, which reduced the impact of sediment and agricultural chemicals on receiving surface waters.

INTRODUCTION

In just the past few decades the issue of maintaining and protecting the environment has become headline news. The result of such public discussion has been the enactment of legislation designed to protect unpolluted natural resources or enhance the quality of those resources already compromised. The majority of such legislation has dealt with end-of-pipe or point-source pollution. Recently, however, the focus of discussion has shifted to another category known as nonpoint-source pollution. Nonpoint-source pollution is defined as pollution whose origin is diffuse and cannot be limited to a single point such as a pipe, leaking tank, or smokestack.

The natural entity most affected by nonpoint-source pollution is the water in lakes and streams. Sediment from agricultural runoff is the single largest pollutant of our surface waters. In addition, it is estimated that on the average 50 kg of nutrients are added to surface waters for every metric ton of sediment eroded from agricultural lands (Clark and others, 1985). Pesticides and herbicides also make their way into the water via eroded sediment.

Because of the diffuse nature of nonpoint-source pollution, conventional measures used to control point source pollution are inappropriate. Through physical reasoning and analysis of limited data, several researchers have concluded that the best way to control nonpoint-source pollution is better land management and the use of best management practices (BMP's), which control pollution at its source. A BMP is defined as a practice or combination of practices determined to be the most effective and practicable means of controlling point and nonpoint-source pollutants at levels compatible with environmental-quality goals (Inamdar, 1992). A goal of BMP utilization is to diminish the environmental impact of land-use activities while maintaining the productivity and use of the land. One BMP recommended by the Soil Conservation Service to control nonpoint-source pollution is the use of a riparian zone.

The Riparian Zone

A riparian zone, as shown in Figure 1, is a zone of planted or indigenous vegetation on the bank of a natural water course. The riparian zone is situated between the pollutant source area and receiving waters and therefore filters sediment and other pollutants from surface runoff before they reach the stream. Until recently, landowners and farmers have resisted establishing riparian zones because they take arable land out of production. Recent changes in the Conservation Reserve Program (CRP) and cost-sharing programs such as the one started in Virginia (Dillaha and others, 1986) have resulted in increasing use of riparian zones, especially grass filter strips (GFS's). Also, landowners are increasingly recognizing that products such as hay or wood can be harvested from riparian zones, thus puffing the land back into some type of production. Harvesting biomass from riparian zones has also been found to increase nutrient removal and enhance the

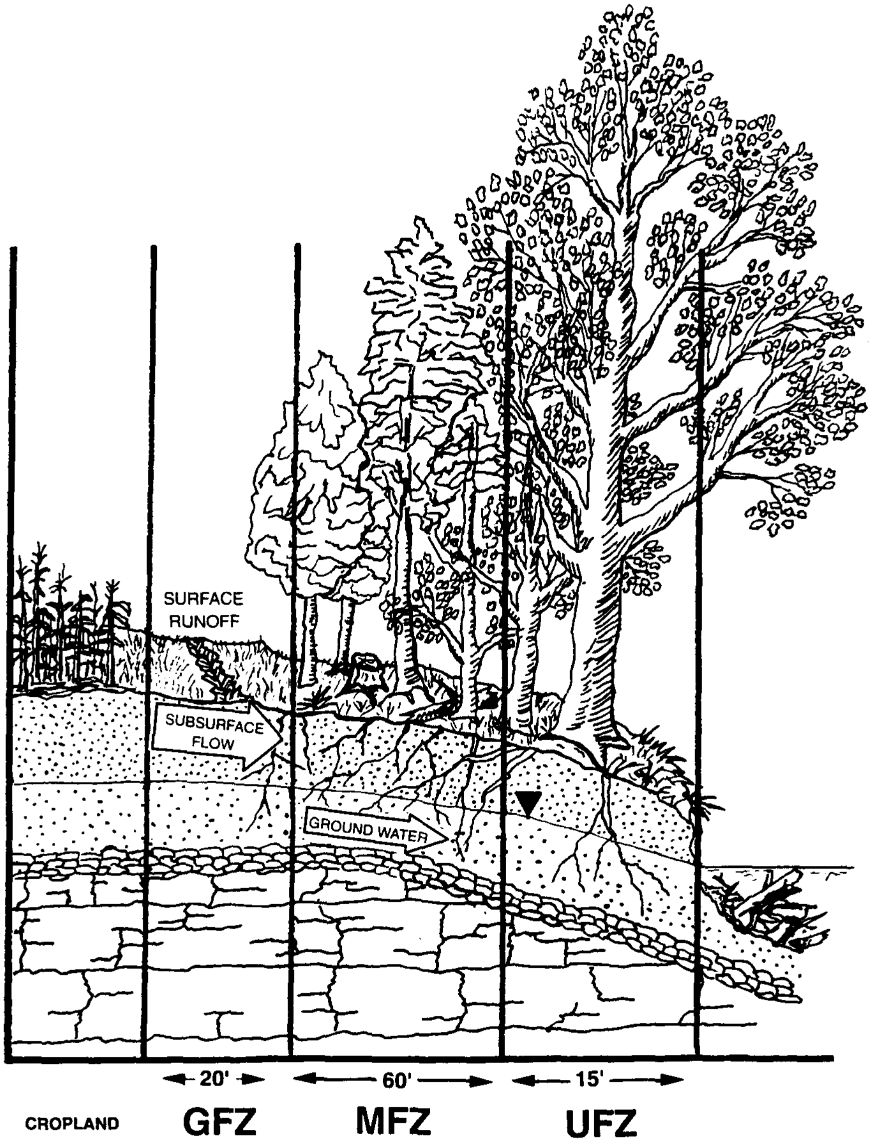

Figure 1. Riparian management zone broken into three subzones: a grass filter zone (GFZ), a managed forest zone (MFZ), and an undisturbed forest zone (UFZ) (*after* Welsch, 1991).

performance of the zones as nonpoint-source pollution controls (Dillaha and others, 1986).

How Grass Filter Strips Enhance Water Quality

Grass filter strips perform several functions that help enhance the water quality of receiving surface waters. First, they reduce runoff flow velocity, which results in a reduced capacity for transport of suspended sediment to the stream. This leads to deposition of the sediment and decreased sediment concentration in the runoff and keeps the soil on site. Any sediment-adsorbed chemicals are also deposited, thus decreasing chemical loading of the stream. Second, GFS's enhance infiltration of water, sediment, and chemicals into the soil itself. Third, the increased detention time of flow across GFS's results in enhanced adsorption of chemicals onto the vegetation, litter, and surface layer of soil. Fourth, more chemicals are stored in the water in the soil surface layer for subsequent biological or chemical transformation or plant uptake between runoff events. All of these functions are complex and interrelated. The movement of water, sediment, and chemicals through grass filter strips is a complex problem, which needs input from a number of disciplinary areas for ultimate definition.

A number of studies on trapping of sediment and chemicals in natural and constructed grass filter strips have been conducted. These studies not only evaluate the effectiveness of GFSs, but highlight some of the unique problems associated with GFSs. A summary of selected studies is given in Table 1. Studies on the movement of sediment have been the most definitive; a number of investigators have developed laboratory and field data as well as process-based models. Empirical studies have been conducted on grasslands of varying slopes, from flat lands near 0 percent slope to steep slopes near 30 percent. Trapping efficiencies were frequently greater than 90 percent, depending on sediment size, slope steepness and length, propensity to channelize, and density of vegetation (Wilson, 1967; Neibling and Alberts, 1979; Barfield and Albrecht, 1982; Hayes and Hairston, 1983; Hayes and others, 1984; Dillaha and others, 1986, 1989). These studies, along with computer models, have shown that coarser sediments (both primary particles and aggregates) are deposited in a delta at the leading (upper) edge of a filter strip, causing channelization to occur after significant deposition. Downstream of the delta, silt-size aggregates and primary particles are trapped by settling and infiltration; actual percentages depend on velocity, flow depth, and media density. Clay-size primary particles are typically only trapped by movement of particles into the soil matrix with infiltrating water. The studies also show that the effectiveness of the filter strips for trapping sediment decreased with time, particularly it the filter strip became inundated with sediment.

Table 1.—Examples of Previous Studies on Sediment Trapping.

Filter Description	*Sediment Source*	*Plot Length (m)*	*Trapping Efficiency (%)*
Bluegrass sod (7% slope)[1]	Prepared bare soil plots	0.6–4.9	> 90
Fescue (3–20% slope)[2]	Strip-mine spoil	30	87–99
Kentucky 31 fescue (3% slope)[3]	Fallow crop-land	30	>90
Orchard grass (5–16% slope)[4]	Silt loam cropland	4.6 9.1	70 91
Bermuda and crabgrass[5]	Cropland	4.3–5.3	70
Fescue[6]	Cropland	4.6 5.2	52 75

[1] Neibling and Alberts, 1979—West Lafayette, Indiana

[2] Hayes and others, 1984—Lexington, Kentucky

[3] Hayes and Hairston, 1983—Starkville, Mississippi

[4] Dillaha and others, 1989—Blacksburg, Virginia

[5] Parsons and others, 1991—Raleigh, North Carolina

[6] Magette and others, 1989—Maryland

Studies by Dillaha and others (1986, 1989) on 4.6and 9.1 -m-long plots indicate that trapping is most efficient when flow is spread over the filter strip and that channelization reduces trapping significantly Even with channelization, trapping was in the range of 30 to 60 percent. Studies by Cooper and others (11987) and Lowrance and others (1984, 1988) on naturally occurring riparian vegetation also indicate that these zones are major sinks for sediment.

In other studies, the effectiveness of grass filter strips in controlling nutrients in runoff was evaluated. Examples, given in Table 2, illustrate the highly variable results. In general, the fraction of nutrients trapped increased with filter length; however, nutrients were not trapped as effectively as sediment. In general, the very short filter strips were not highly effective in trapping nutrients, and in fact sometimes became a nutrient source of soluble nitrogen and phosphorus.

The objective of this study was to determine the effectiveness of grass filter strips as a best management practice in filtration of surface runoff.

EXPERIMENTAL PROCEDURES

Grass filter strips on a natural mixture of bluegrass and fescue sod were selected for this study in 1990. These filter strips were located immediately downslope from erosion plots that had first been established in 1984 and modified in 1989. A schematic drawing of the plot and filter-strip layout is given in Figure 2. All of the erosion plots and filter strips were located on the Kentucky Agricultural Experiment Station Spindletop Research Farm (Fig. 3) on a well-drained Maury silt loam soil with an average slope of approximately 9 percent. The erosion plots consisted of three conventional-tillage plots and three no-tillage plots. The filter strips consisted of one set of duplicates for each filter-strip length of 4.57, 9.14, and 13.72 m (15, 30, and 45 ft.). Each erosion plot was 4.57 m wide by 22.1 m long. Metal borders were placed on the two sides and the uphill end. Determination of the effectiveness of the filter strips in trapping sediment and chemicals required that flows onto and off of the GFS plots be sampled. In order to accomplish this sampling, the lower end of the erosion plot had a narrow (approximately 21 cm) excavated trench across its lower width

Table 2.—Examples of Previous Studies on Nutrient Trapping.

Reference	*Study Location*	*Filter Description*	*Nutrient Source*	*Plot Length (m)*	*Nutrient*	*Trapping Efficiency (%)*
Dillaha and others, 1989	Blacksburg, Virginia	Orchard grass (5–16% slope)	Cropland runoff	4.6	P_{total}	75
					N_{total}	61
				9.1	P_{total}	87
					N_{total}	61
Dillaha and others, 1986	Blacksburg, Virginia	Orchard grass (5–16% slope)	Simulated feedlot	4.6	P_{total}	39
					N_{total}	43
				9.1	P_{total}	52
					N_{total}	52
Doyle and others, 1977	Maryland	Fescue (10% slope)	Dairy waste on silt loam soil	1.5	$P_{dissolved}$	8
					NO_3	57
				4.0	$P_{dissolved}$	62
					NO_3	68
Young and others, 1980	Minnesota	Corn–orchard grass and oats–orchard grass mixtures (4% slope)	Feedlot	13.7	P_{total}	88
					N_{total}	87
		Sorghum–sudan grass mixture (4% slope)	Feedlot	13.7	P_{total}	81
					N_{total}	84
Thompson and others, 1978	Minnesota	Orchard grass (4% slope)	Dairy manure on frozen orchard grass	12	P_{total}	55
					N_{total}	45
				30	P_{total}	61
					N_{total}	69
Magette and others, 1989	Maryland	Fescue (plot slope varied)	Cropland runoff	4.6	P_{total}	6
					N_{total}	–15
				9.2	P_{total}	20
					N_{total}	35
Parsons and others, 1991	Raleigh, North Carolina	Bermuda–crab-grass mixture	Cropland runoff	4.3–5.3	P_{total}	26
					N_{total}	50

and the lower end of each filter strip had a narrow (approximately 21 cm) excavated trench across its width; a combination wood and metal abutment prevented the upslope face from eroding. A 10-cm-wide gutter was placed on the downslope side of the wood abutment to facilitate sampling. The gutters are shown in Figures 4 and 5. Sampling of the flow from the erosion plot onto the filter strip without significantly disturbing the flow distribution across the plot was a problem. To accomplish this, a metal sampling device (Fig. 6) with 10 controllable sampling slots was placed over the trench. The slots were normally closed, diverting flow directly onto the filter. When the slots were opened, the flow moved directly into the gutter, where flow rate was measured and flow samples for sediment and nutrient concentration measurements were collected. Further details of this sampling device are given in Fogle and Barfield (1993).

The Kentucky Rainfall Simulator (Moore and others, 1983), shown in Figure 7, was used to deliver 6.35 cm (2.5 in.) of simulated rainfall per hour for 2 hours on the erosion plots to simulate a storm with an energy content approximating a 2-hour, 1-in-10-year rainstorm intensity. This rainfall event was repeated once on each plot approximately 3 weeks later. The erosion plots and the filter strips were saturated prior to conducting each rainfall. Immediately before run 1 on each plot, chemicals

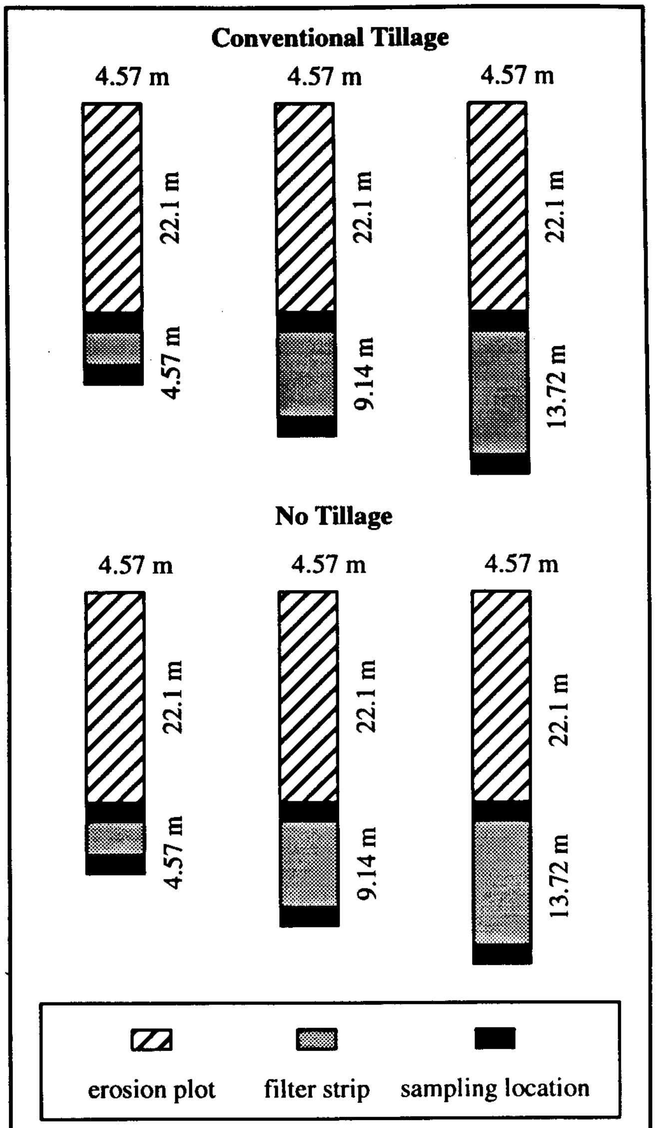

Figure 2. Schematic diagram of the erosion plot and filter-strip arrangement.

were broadcast on the erosion plot at rates shown in Table 3.

Runoff from both the erosion plots and the filter strips was sampled periodically throughout both runs. Runoff from the erosion plots onto the filter strips and from the filter strips themselves was measured and sampled for 10 seconds at 5-minute intervals. Flow rates were measured volumetrically, and separate samples were taken for laboratory determination of sediment and chemical concentrations. One-liter samples were taken for sediment analysis and 0.5-liter samples for chemical analysis. Samples taken to determine chemical concentrations were stored at 28°F to prevent atrazine degradation and nitrogen transformations.

Sediment analyses were measured gravimetrically. Soluble nitrate and ammonium analyses were measured with a Technicon Auto Analyzer System 11 with Al-400 computer software. Soluble phosphorus was measured with an automated microplate reader, model EL 311, using a colorimetric method. Bromide was measured with an ion-specific electrode, and soluble atrazine was measured using an immunoassay method. Further details are given in Madison (1992).

RESULTS

Trapping Efficiency

Using the concentrations and flow rates measured at the end of the erosion plot and filter, the inflow and outflow mass was calculated and utilized to determine the trapping efficiency for sediment and dissolved solids and the mass of water infiltrated. These values are summarized in Tables 4 and 5. The trapping efficiencies for sediment and chemicals were generally higher in this study than in other studies using similar-size plots. This is not surprising, since the plots in this study were in an area of karst topography, characterized by well-structured soils with rapid infiltration rates. Although the grass plots were saturated prior to the test to the point of runoff, the infiltration rates were extremely high, as evidenced by the high fraction of runoff that infiltrated

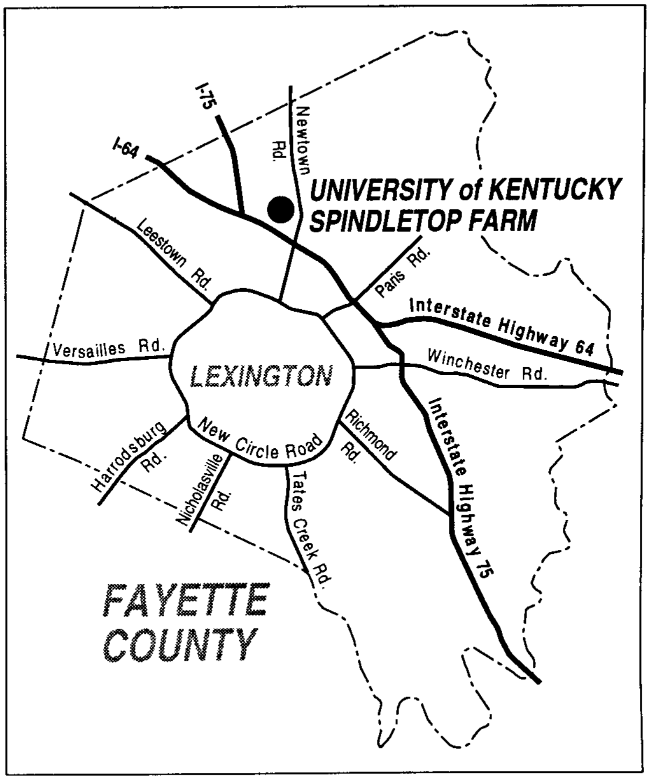

Figure 3. Location of research site.

Table 3.—Characteristics of Filter Strips.

	Plot 1	*Plot 2*	*Plot 3*	*Plot 4*	*Plot 5*	*Plot 6*
Filter length (m)	9.14	9.14	13.72	4.57	4.57	13
Slope (%)	9	9	9	9	9	9
Source plot tillage	CT	NT	NT	CT	NT	CT

Chemicals applied to erosion plots:
- **170 kg N/ha as granular ammonium nitrate**
- **44 kg P_2O_5/ha as triple super phosphate**
- **33.6 kg Br/ha as granular potassium bromide**
- **2.24 kg atrazine/ha**

Soil type—Maury silt loam

Simulated rainfall intensity: **Event 1—63.5 mm/h for 2 hours**
Event 2—63.5 mm/h for 2 hours approximately 3 weeks after event 1

CT—Conventional Tillage; NT—No Tillage

into the filter strip (see Table 5). We believe that much of the trapping was a result of infiltration into the soil matrix.

Comparison of the effect of filter strip length upon filter performance reveals that trapping efficiency was improved when the length of the strip was increased from 4.57 m to 9.14 m. However, nothing was gained by increasing the filter length from 9.14 m to 13.72 m. The better performance of the 9.14 m filters over the 4.57 m filters can be attributed to the additional area available for runoff filtration. However, the microtopography of the 13.72 m filters caused runoff to be directed into small natural channels, thus reducing the filtration effectiveness. Filter length is not the sole variable in determining filter strip performance.

Inflow and Outflow Concentrations

Peak Concentrations

An important impact of riparian grass filter strips is to decrease the peak concentrations of sediment and chemicals in runoff. Such a decrease results in a lowered

Table 4.—Mass of Sediment and Chemicals in Runoff from Erosion Plots and Filter Strips.

Strip Length and Event No.	*Runoff (kg)*		*Atrazine (mg)*		*Phosphorus (mg)*		*NO_3–N (mg)*		*NH_4–N (mg)*		*Sediment (kg)*	
	EP	*FS*	*EP*	*FS*	*EP*	*FS*	*EP*	*FS*	*EP*	*FS*	*EP*	*FS*
4.57 m length–CT												
Event 1	6,073	713	288	23.2	10,140	1,270	5,232	574	21,840	2,678	103	2.62
Event 2	9,268	942	197	15.8	1,710	203	11,300	539	23,670	1,814	258	8.44
4.57 m length–NT												
Event 1	9,230	470	2,049	97.1	34,850	2,513	117,300	1,970	120,000	2,974	55.7	.018
Event 2	9,009	720	292	13.5	6,658	387	20,840	466	22,320	1,750	67.4	4.13
9.14 m length–CT												
Event 1	3,223	27.7	49.8	.007	11,940	45.0	7,570	8.24	23,220	49.3	26.6	.0188
Event 2	6,982	617	361	.534	26,890	21,110	304,000	23,060	307,300	21,540	21.2	1.10
9.14 m length–NT												
Event 1	4,306	*	15.5	*	1,446	*	1,506	*	3,852	*	19.6	*
Event 2	473	11.6	40.6	.252	1,377	1.3	10,220	7.10	10,470	6.80	21.5	.00105
13.72 m length–CT												
Event 1	8,859	623	35.29	78.6	40,640	1,713	63,770	3,274	114,400	59,360	28.4	2.09
Event 2	11,634	706	456	17.9	2,982	232	15,220	3,269	42,210	2,149	36.1	2.06
13.72 m length–NT												
Event 1	609	*	46.8	*	452	*	591	*	1,337	*	.098	*
Event 2	4,932	478	111.3	.405	1,300	30.0	1,350	48.7	9,973	33.8	10.3	.00244

EP—Mass discharged from erosion plot; FS—Mass discharged from filter strip; CT—Erosion plot treated with conventional tillage; NT—Erosion plot treated with no tillage; *—No discharge from the filter strip.

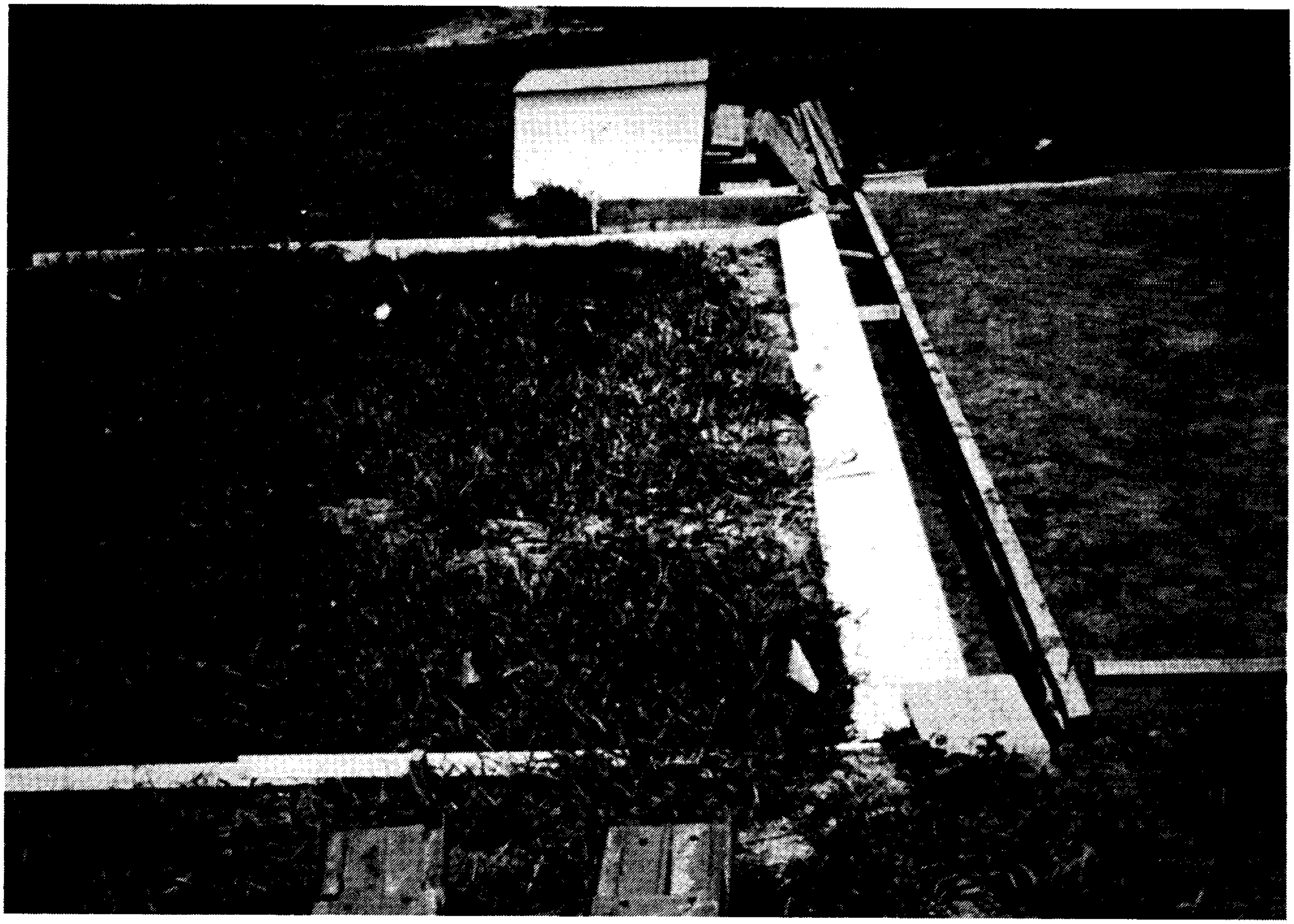

Figure 4. Gutter placement below erosion plot.

Table 5.—Trapping Efficiencies for Sediment and Chemicals.

Plot Length (m)	*% Runoff Infil-trated*	*Trapping Efficiencies (%)*[1]				
		Atra-zine	*Phos-phate*	*NO_3–N*	*NH_4–N*	*Sedi-ment*
4.57						
event 1	91.4	93.5	89.9	93.6	92.5	98.6
event 2	90.8	93.6	88.2	95.3	92.1	95.2
avg.	91.1	93.5	89.1	94.4	92.3	96.9
9.14						
event 1	99.6	99.9	99.8	99.9	99.9	99.7
event 2	95.4	99.6	96.4	96.1	99.4	99.7
avg.	97.5	99.8	98.1	98.0	99.7	99.7
13.72						
event 1	96.4	98.9	97.4	97.4	97.4	99.6
event 2	96.9	97.8	97.3	97.0	97.3	99.7
avg.	96.7	98.4	97.3	97.2	97.3	99.7

[1] Average of no-tillage and conventional-tillage plots.

peak discharge in the receiving stream and, it is hoped, a lesser impact on water quality. An example of the impact of the riparian grass vegetation on the concentration of atrazine for the 4.57 m filter strips is given in Figure 8. The results show a significantly reduced peak discharge concentration. The ratio of peak outflow to peak inflow concentrations was evaluated in this study and is presented graphically in Figure 9 for all tests. Based on peak concentration reduction, the filter strips had a significant impact on water quality.

An interesting phenomenon apparent in the data is the increase in phosphorus concentration in the filter strip outflow, especially during event 2. The filter became a source for phosphorus, rather than a sink. During event 1, super triple phosphate granules were observed being washed from the erosion plots onto the filter strips, loading the strips with phosphorus. Phosphorus was also moved onto the filter strips by the sediment deposited during event 1. This phosphorus was available to be picked up by runoff during event 2.

Average Concentrations

Much of the reduction in peak concentration shown in Figure 9 is a result of early infiltration of high-concentration runoff from the erosion plot. As can be seen in Figure 8, there is a delay between the start of runoff onto the filter and when discharge begins to occur from the filter. During this time, essentially all of the water and accompanying highly concentrated chemicals are infiltrated into the soil beneath the filter. With passing time, the concentration of chemicals in the inflow from the erosion plot approaches a pseudo-steady-state value, and the reduction in concentration must be caused by dilution from interchange with the surface layer. An indication of the impact of this later dilution in reducing the concentration in runoff is the ratio of concentrations for time periods after discharge occurs from the filter. The ratio of average concentration f rom the filter to concentration from the erosion plots for this later time period is give in Figure 10. With the exception of phosphorus, the average concentration ratios are generally less than 1, indicating some filtering of chemicals. Phosphorous concentration ratios are generally greater than 1, indicating that the filter is a source of phosphorus after the inflows and outflows reach some quasi-equilibrium. The atrazine concentration ratio greater than 1 in Figure 10 (4.57 m filter strip, no-tillage source plot, run 1) is an anomaly Atrazine concentrations from the filter strips were occasionally higher than those recorded from the erosion plots at times when the infiltration and surface storage capacities of the filters were exceeded. This phenomenon may be attributable to 'flushing" (Magette and others, 1989) or the removal of atrazine previously deposited earlier in the run.

SUMMARY

The impact of natural riparian grass strips on discharge of water, sediment, and agricultural chemicals was studied. Filter strips of a naturally occurring mixture of bluegrass and fescue of lengths

Figure 5. Gutter below filter strip.

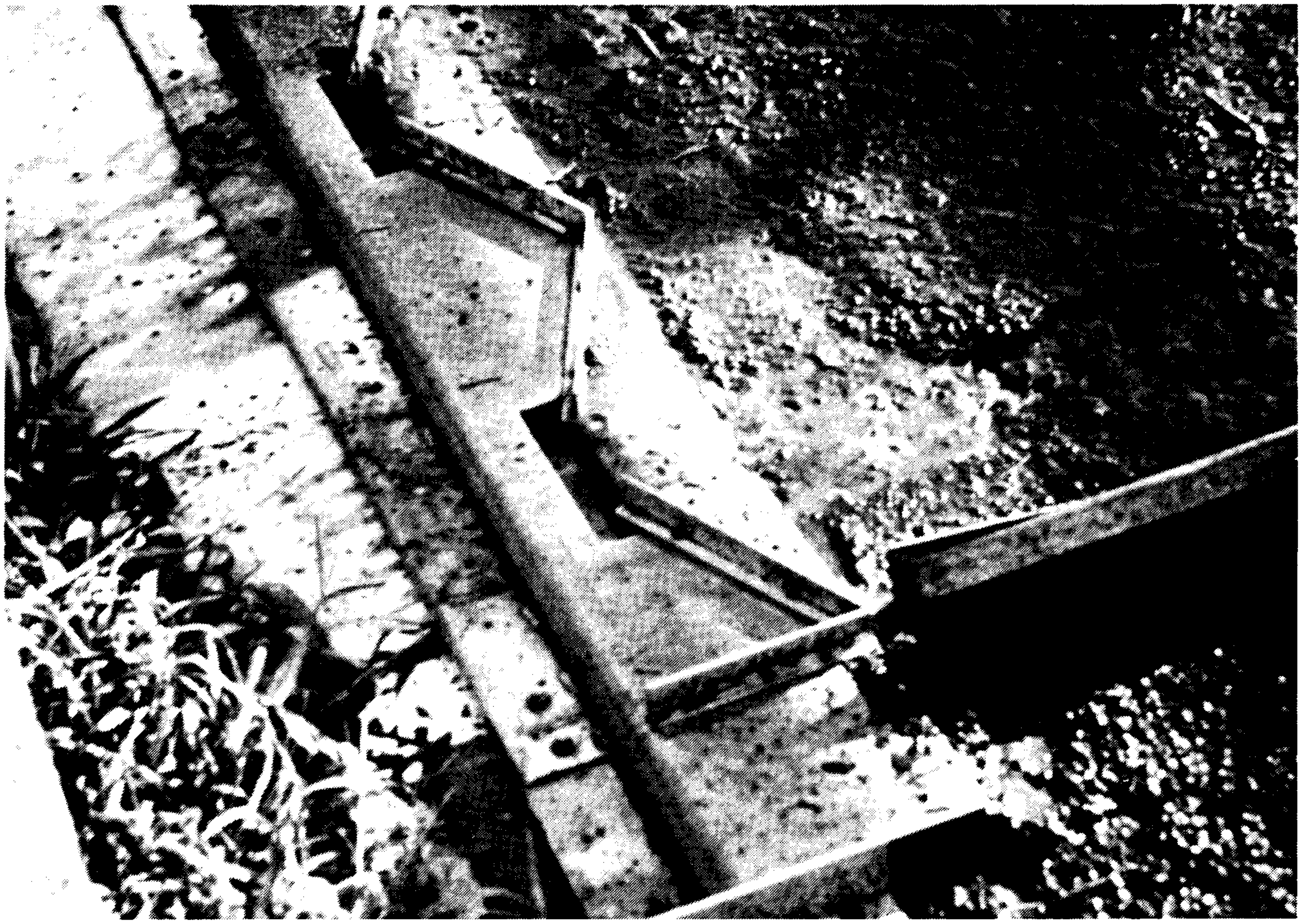

Figure 6. Flow passing through one end of the sampling device.

varying from 4.57, 9.14, and 13.72 m were utilized downslope from standard universal soil loss equation erosion plots to trap sediment and chemicals contained in runoff. The erosion plots were treated with atrazine, nitrogen, phosphorus, and bromide. Simulated rainfall was applied to the plots using the University of Kentucky Rainfall Simulator. Runoff from the erosion plots was directed onto the filter, and the flow into the filter and off the filter was measured. The filters generally trapped over 90 percent of sediment and chemicals. The major trapping mechanism was determined to be infiltration, followed by temporary storage in the surface layer. The high trapping efficiencies produced in this study would not be expected in soils where infiltration rates are significantly lower.

Application of the data collected in this project to specific field situations is difficult because factors other than filter length affect filter performance. Factors such as soil type, field geology, land slope, filter microtopography, filter maintenance, and field tillage practices all affect filter strip performance. Therefore, specific recommendations for filter design can only be made on a site-by-site basis. However, a few general recommendations can be made:

> Filter strip length should always be greater than 4.57 m.
>
> Filter strip length should be as great as is feasible. Again, the maximum length is dependent upon several factors, all of which should be taken into design consideration.

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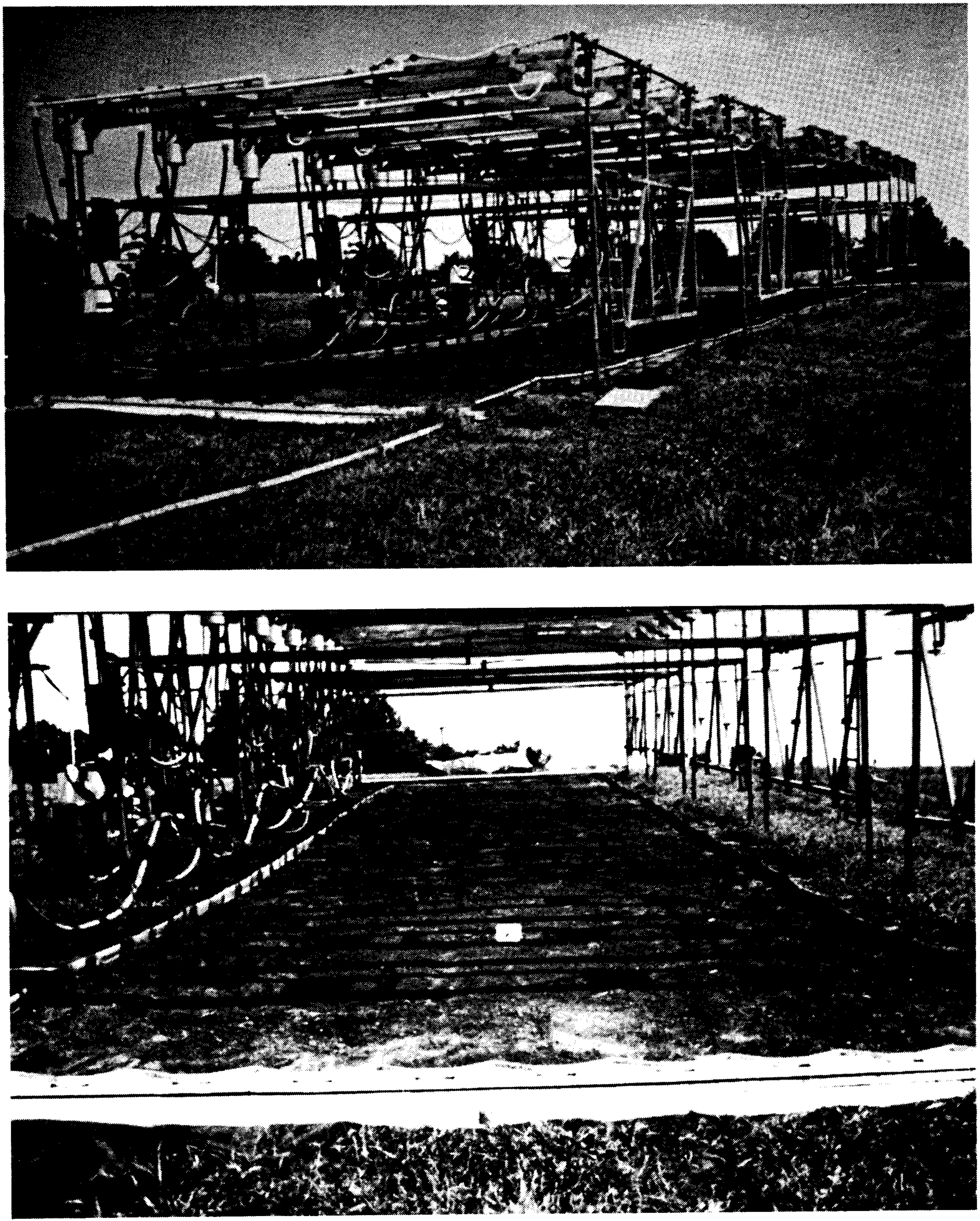

Figure 7. The Kentucky Rainfall Simulator.

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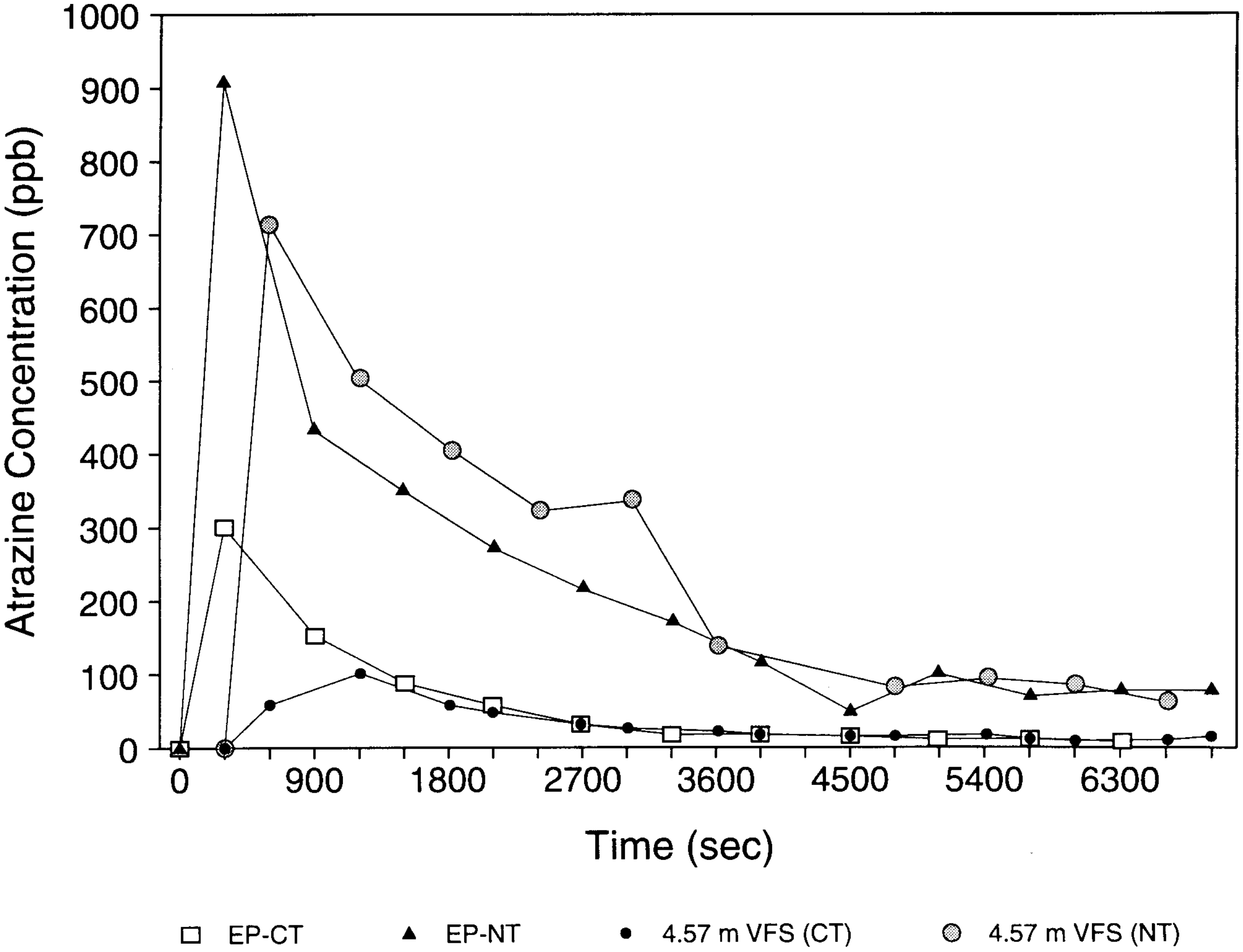

Figure 8. Inflow and outflow concentration for atrazine on the 4.57 m plots during run 1.

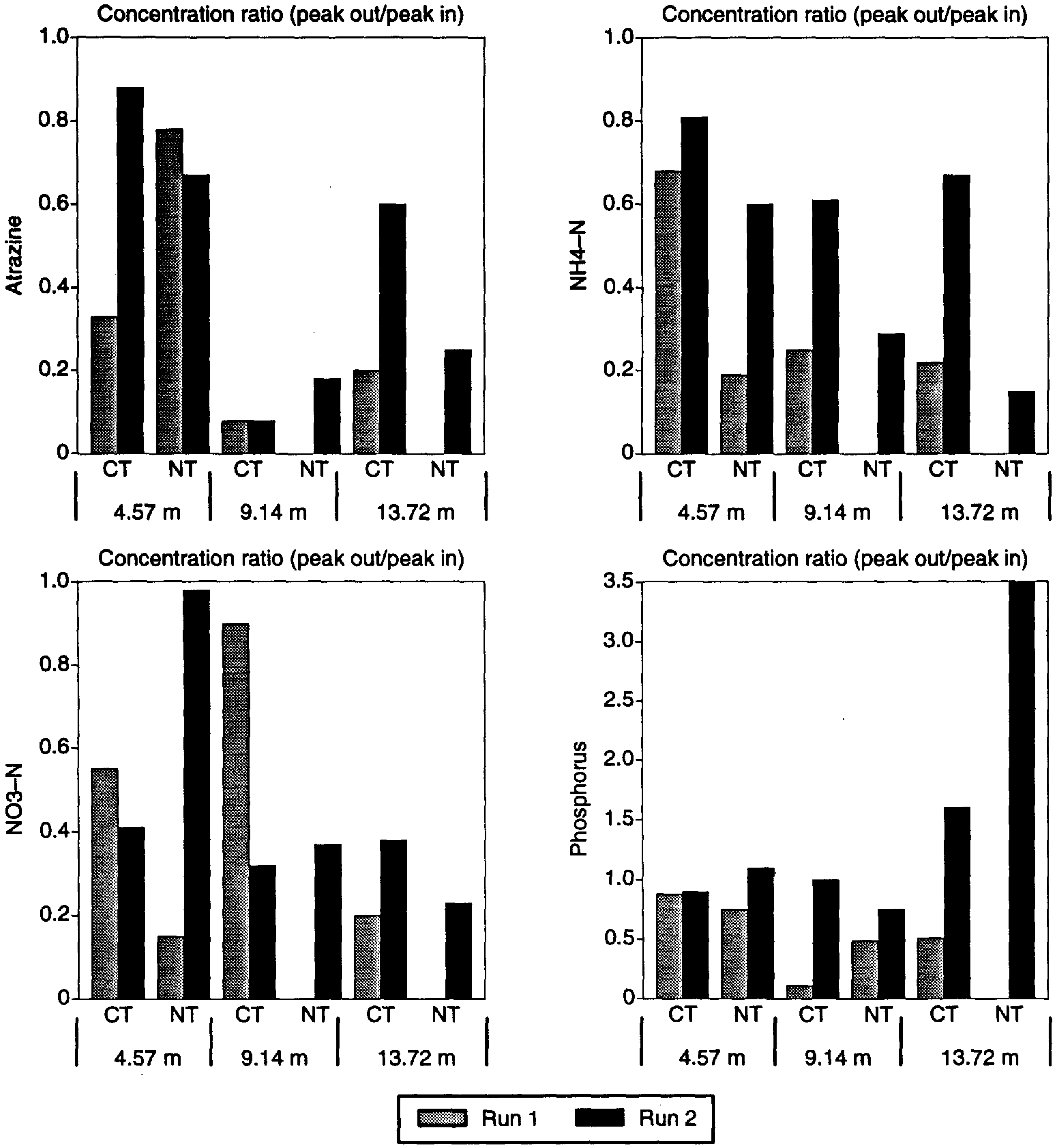

Figure 9. Ratio of peak outflow to inflow concentrations.

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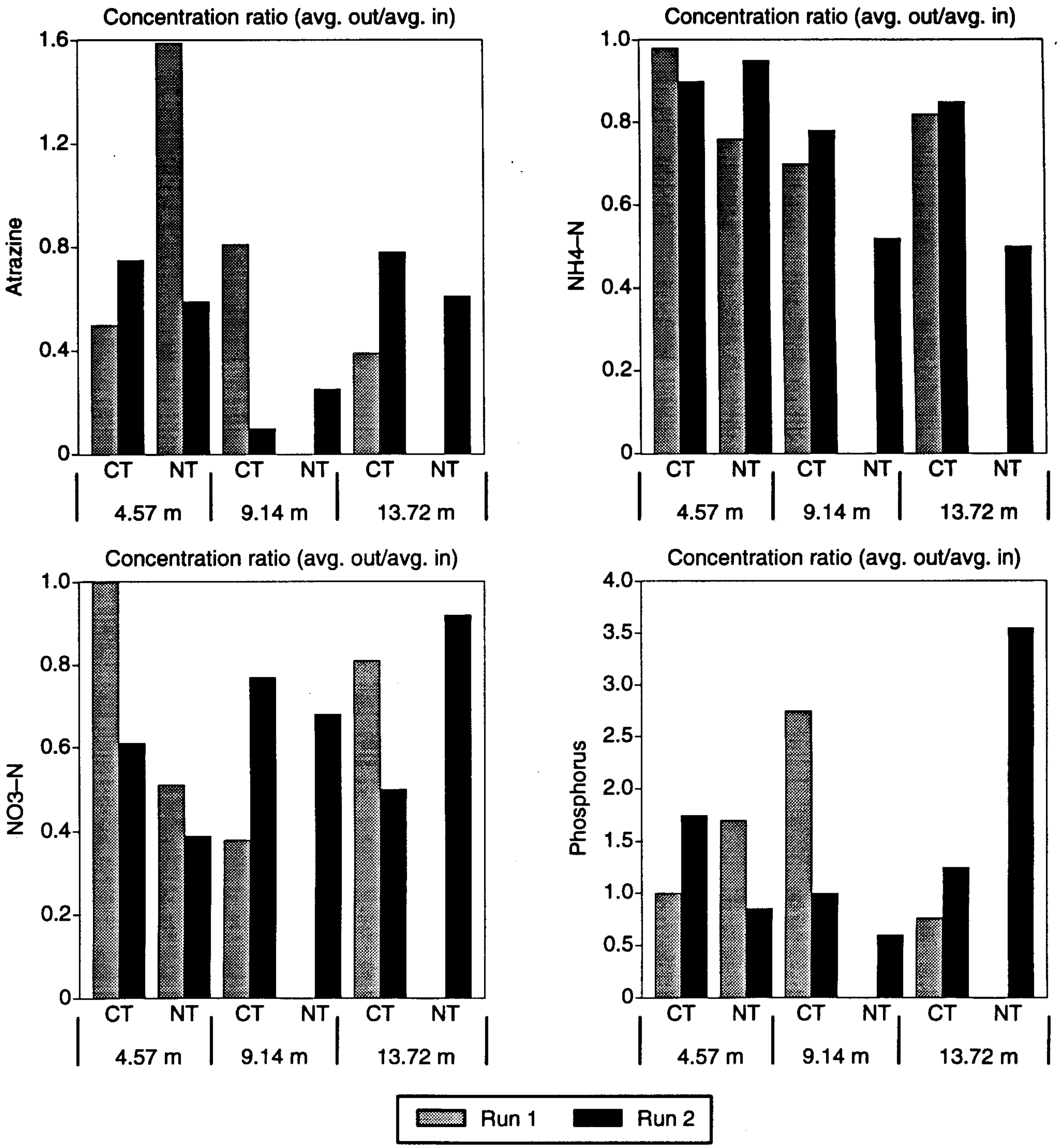

Figure 10. Ratio of average outflow to average inflow concentration after flow begins.

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Mission Statement

The Kentucky Geological Survey at the University of Kentucky is a State mandated organization whose mission is the collection, preservation, and dissemination of information about mineral and water resources and the geology of the Commonwealth. KGS has conducted research on the geology and mineral resources of Kentucky for more than 150 years, and has developed extensive public data bases for oil and gas, coal, water, and industrial minerals that are used by thousands of citizens each year. The Survey's efforts have resulted in topographic and geologic map coverage for Kentucky that has not been matched by any other state in the Nation.

One of the major goals of the Kentucky Geological Survey is to make the results of basic and applied research easily accessible to the public. This is accomplished through the publication of both technical and non-technical reports and maps, as well as providing information through open-file reports and public data bases.