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EFFECTS OF A DAIRY LOAFING LOT-BUFFER STRIP ON STREAM WATER QUALITY[1]

T. M. Younos, A. Mendez, E. R. Collins, and B. B. Ross[2]

ABSTRACT: A loafing or sacrifice lot is an area located outside of the free stall barn, where a dairy herd spends several hours per day. Sacrifice lots are usually denuded of vegetation and have high concentrations of manure and urine that can contribute significant amounts of sediment, nutrients, and pathogens to nearby surface waters. In this study, stream water quality impacted by direct runoff from a sacrifice lot was monitored for a period of 20 months. Ambient stream water quality was monitored by grab sampling upstream and downstream of the sacrifice lot. During runoff events, stream water quality downstream of the sacrifice lot was monitored with an automatic sampler. Laboratory analyses were conducted for total suspended solids and nutrients (nitrogen and phosphorus compounds). A grass filter strip (GFS) was installed as a buffer downslope of the sacrifice lot 10 months into the study period. The impact of the buffer strip on the standardized pollutant concentrations and loads was evaluated using the non-parametric Wilcoxon test. The Wilcoxon test indicated that there was no significant difference ($\alpha = 0.05$) in the standardized yield of sediment and dissolved pollutants before and after the GFS installation, except for phosphate-phosphorus and filtered total phosphorus concentrations, and sediment-bound total phosphorus and total kjeldahl nitrogen loads that decreased significantly. However, load decrease could have been partially caused by the smaller rainfall volumes after the GFS installation as compared to the existing condition.

(KEY TERMS: water quality; nonpoint source pollution; stream monitoring; dairy waste; grass buffer.)

INTRODUCTION

Most dairy systems include a loafing lot or sacrifice lot that is located outside of the free stall barn. Loafing lots have either a bare soil surface, or due to continuous cow traffic, are gradually denuded of vegetation. A typical dairy herd spends several hours per day on a loafing lot, causing the accumulation of manure and urine on these areas. Therefore, when subjected to runoff-producing rainfall events, loafing lots can contribute significant amounts of sediment, nitrogen, phosphorus, and pathogens through surface runoff to nearby surface water systems (Hollon *et al.*, 1982; Reese *et al.*, 1982; Baxter-Potter and Gilliand, 1988; Beck, 1989).

Several experimental studies have been conducted on the effectiveness of grass filter strips (GFS) on retaining dairy waste and sediment. Grass filter strips are bands of indigenous or planted vegetation established between pollution sources and receiving waters. Doyle *et al.* (1977) applied dairy manure to three 7 x 5 m fescue plots on a 10 percent slope. Surface runoff from five naturally occurring rainfall events was collected at 0.0 m, 0.5 m, 1.5 m, and 4.0 m from the downslope edge of the three plots and analyzed for nitrate nitrogen (NO_3^--N), ammonium nitrogen (NH_4^+-N) and total soluble phosphorus. Ammonium nitrogen losses from the 1.5 m and 4.0 m buffers were higher than NH_4^+-N losses from the downslope edge of the plots while NO_3^--N and total soluble phosphorus losses decreased after passing through the fescue buffers.

Thompson *et al.* (1978) applied manure to snow covered frozen soil of 3 x 24 m plots. Runoff from naturally occurring rainfall events was collected in winter and early spring 12, 36, and 60 m from the upper edge of the plots. It was observed that two-year average concentrations of total kjeldahl nitrogen (TKN), total phosphorus (TP), and ammonia (NH3) decreased significantly as the runoff water moved downslope. Average NO_3^- concentration decreased although not significantly as the runoff water moved downslope.

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[2] Respectively, Associate Director, Virginia Water Resources Research Center, 10 Sandy Hall, Virginia Tech, Blacksburg, Virginia 24061-0444; and Former Research Associate and Professors, Biological Systems Engineering Department, Seitz Hall, Virginia Tech, Blacksburg, Virginia 24061-0303 (E-Mail/Younos: tyounos@vt.edu).

Paterson *et al.* (1980) reported that a 35 m fescue filter, on a 3.4 percent slope, reduced ammonium (NH_4^+) and orthophosphate (PO_4^{3-}) losses from an area treated with dairy waste, while it increased the nitrate (NO_3^-) loss, presumably due to mineralization of organic nitrogen and nitrification of NH_4^+ that had been previously trapped in the filter.

Young *et al.* (1980) constructed field plots on a 4 percent slope with the upper 13.7 m in an active feedlot and the lower 27.4 m planted in either orchardgrass or a sorghum-sudangrass mixture. In two consecutive years, two events that simulated a 25-year, 24-hour duration storm events were generated. Total runoff, sediment, TP, orthophosphate phosphorus (PO_4^{3-}-P), NH_4^+-N, and total nitrogen (TKN plus NO_3^-) masses decreased after passing through the orchardgrass and the sorghum-sudangrass mixture filters while NO_3^- mass increased.

Edwards *et al.* (1983) monitored storm runoff from a paved feedlot passing through two consecutive 30.5 m long fescue filter strips for a period of three years. Total suspended solids (TSS), and total N (TN) were reduced by 81 to 89 percent after passing through the filters. Total runoff from the filters was greater than the incoming runoff because rainfall rates during runoff events exceeded the infiltration capacity of the filters.

Dillaha *et al.* (1988) applied dairy manure at a rate of 7500 kg/ha to nine 18.3 x 5.5 m plots that had either a 0, 4.5 or 9.1 m grass filter. An artificial rainfall of 1-hour duration and 50 mm/h intensity was applied 24 hours later. This rainfall event was followed by a second event of 0.5-hour duration and 50 mm/h rainfall intensity 24 hours later and by a third event also of 0.5-hour duration and 50 mm/h rainfall intensity half an hour after the second event. The first rainfall event approximated a two- to five-year recurrence interval, 1-hour duration storm in Virginia. Seven to 21 days after the last artificial rainfall, manure was applied to the plots at a rate of 15000 kg/ ha. Artificial rainfalls of the same duration and rainfall intensity, and with the same time lag were applied to the plots. The authors found that the GFS were effective in removing sediment from runoff, but the effectiveness of the GFS for sediment removal decreased with time as sediment accumulated within the filter. Total N and TP were not removed as effectively as sediment. In some cases, NO_3^- and PO_4^{3-} increased as the runoff passed through a filter. It was suggested that some N and P that was trapped in the filter during previous runs were released to the runoff.

In a Kentucky study (Schellinger and Clausen, 1992), a 22.9 m x 7.6 m grass filter was established downslope of a dairy barnyard. The filter was seeded with a mixture of fescue, perennial ryegrass, and Kentucky bluegrass. Two 48-hour and one 72-hour composite samples were collected of filter influent and surface and subsurface effluent weekly for 18 months during periods of flow. The concentrations of TSS, TP, TN, and bacteria in surface runoff were not significantly reduced after flowing across the filter strip. Mass retention varied greatly among runoff events. On some events, mass export from the filter exceeded mass inputs to the filter. The authors indicated that the experimental results seemed to support the hypothesis that the percentage mass retention declined as hydraulic loading increased.

According to the above studies, GFS are effective in retaining TSS, TKN, and TP. Contradictory results were reported regarding GFS trapping of NO_3^--N, NH_4^+-N, and PO_4^{3-}. Some researchers found that GFS release NO_3^--N, NH_4^+-N, and PO_4^{3-} while others found the opposite. The following facts have been established from experimental research on GFS: the larger the ratio of GFS to source area, the larger the trapping of pollutants in the filter (Bingham *et al.*, 1980); GFS effectiveness decreases as the number of runoff events increases (Magette *et al.*, 1989); GFS effectiveness regarding nutrient trapping is highly variable (Magette *et al.*, 1989); higher rainfall intensities increase TKN and NH_4^+-N mass losses (Edwards and Daniel, 1992); GFS are more effective in removing pollutants from runoff if flow through the GFS is slow and shallow (Lee *et al.*, 1989; Dillaha *et al.*, 1989); GFS slopes larger than 10 percent make the filter less effective (Hayes and Dillaha, 1992).

As described above, many investigators have reported on the effectiveness of grass filters. However, few have studied the impact of a grass filter strip on stream water quality. The objectives of this study were to evaluate the ambient water quality upstream and downstream of a loafing lot, to assess the impact of the loafing lot in the stream water quality during runoff events, and to investigate the effect of a GFS on stream water quality.

PROCEDURES

Field Investigations

Figure 1 shows the layout of the study site. The site, a 0.58 ha sacrifice lot and an adjacent stream, is part of a 60-head dairy operation located within the Mollie Creek watershed, in Franklin County, Virginia. The watershed is located on the Redwood and Boone Mill 7.5 minutes Series (Topographic), U. S. Geological Survey quadrangle maps (between 37°4′00″-37°6′00″N and 79°55′00″-79°51′00″W). Mollie Creek

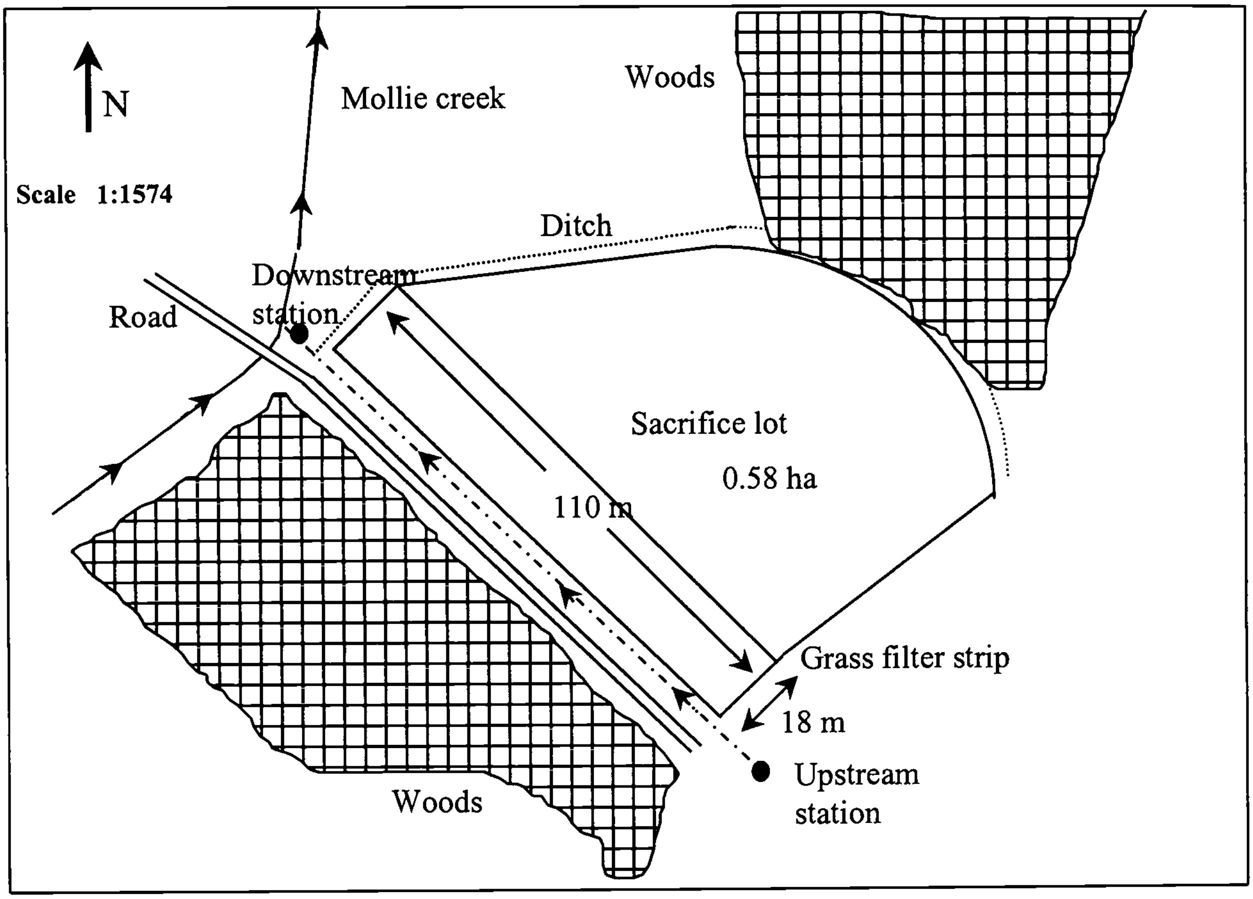

Figure 1. Description of Study Site.

is a tributary of the Blackwater River which drains in Smith Mountain Lake, the largest recreational lake in the area. The drainage area for the study stream is approximately 6.7 ha. The stream receives runoff from the sacrifice lot along 110 m of its eastern bank. A dirt road runs along the stream, buffered by riparian vegetation along the stream bank and a forested area on the other side. The sacrifice lot has been used for at least seven years and therefore the soil is compacted due to cow trafficking. The predominant soil type in the sacrifice lot area is Elioak fine sandy loam on a 6 to 16 percent slope, the higher slope being the area closer to the stream. The Natural Resources Conservation Service has rated the erosion potential of this area as medium to high.

An automatic sampling station was set on the stream, downslope from the sacrifice lot to sample stream water during runoff events. The station was equipped with a 60-cm H-flume, an FW-1 Belfort stage recorder, and a storm-event automatic water sampler (ISCO 3700). The sampler was programmed to collect a sample for each 3 cm change (rise and fall) in the stream water level due to occurrence of a runoff-producing rainfall event. A standard single-traverse rain gauge was used to record rainfall.

Monitoring of the stream water quality started on August 1, 1994, and ended on April 30, 1996. Ambient stream water quality was monitored biweekly at the sampling station and every 10 weeks upstream of the sacrifice lot by grab sampling. The pre-GFS monitoring period was from August 1, 1994, to March 31, 1995 (Period I). The GFS was established between April 1 to August 14, 1995. The post-GFS monitoring period started on August 15, 1995, and ended on April 30, 1996 (Period II).

In early April of 1995, a portion of the sacrifice lot (18 x 110 m) adjacent to the stream was transformed to a buffer strip. To establish the grass filter, the strip was seeded with Kentucky 31 tall fescue (62 kg/ha), a cool season grass that grows mainly in early spring and fall. The strip was fertilized with 340 kg/ha of 10-10-10. The post-GFS period was arbitrarily set to August 15, 1995, when the grass covered more than 60% of the filter.

Laboratory Methods and Computations

Water sampling, storage, and laboratory analyses were conducted according to a quality assurance/quality control plan developed for the project following the U.S. EPA procedures (Younos and Mendez, 1996). The samples were analyzed in the laboratory for NH_4^+-N, NO_3^--N, TKN, dissolved TKN (FTKN), total phosphorus (TP), dissolved TP (FTP), orthophosphate (PO_4^{3-}-P), and TSS (includes both particulate organic and inorganic matter) according to standard procedures (USEPA, 1979; APHA, 1992). Ammonium-N, FTKN, FTP, and PO_4^{3-}-P were determined in filtered subsamples of the original sample.

The total pollutant load (L) for each discharge event was computed as:

$$L = \sum_{1}^{n} (c_i \cdot q_i)\Delta t_i \qquad (1)$$

where c_i and q_i are the pollutant concentration ($[M][L]^{-3}$) and flow rate ($[L]^3[T]^{-1}$), respectively, during time increment Δt_i. A detailed description of the procedure is given in Younos and Mendez (1996).

Rainfall and stream stage charts were digitized and stored in a computer database. Data reduction, validation, and reporting for hydrologic analyses were conducted using an established data management system (Mostaghimi, 1989).

The Wilcoxon non-parametric test (Hollander and Wolfe, 1973) was used to determine if the concentrations and loads in the stream during a runoff event were significantly different for pre- and post-GFS conditions.

RESULTS AND DISCUSSION

The effectiveness of a grass filter is usually measured as a function of its capacity to reduce pollutant concentrations and loads passing through the filter (Schellinger and Clausen, 1992). This is normally achieved by comparing runoff loads and concentrations measured at the entrance of the filter with runoff loads and concentrations measured at the exit of the filter (Dillaha *et al.*, 1988; Schellinger and Clausen, 1992). In this study, the effectiveness of the GFS was also estimated as a function of the pollutant concentrations and loads, however, in this case, stream water quality was evaluated before and after the installation of the filter.

Factors that affect load and concentration of sediment and sediment-bound pollutants in runoff are the rainfall and runoff characteristics, topography, soil erodibility, transportability, soil cover, residual land use, and roughness (Foster, 1982). From these factors, for this study, only the rainfall and runoff characteristics changed substantially from Period I (8/1/1994-3/31/1995) to Period II (8/15/1995-4/30/1996). Sediment detachment is a function of the interrill erosivity, which, ultimately depends on the rainfall intensity (Foster, 1982). The transport capacity of overland flow depends on the runoff total volume and peak flow rate (Neibling and Foster, 1977); cited by Foster, 1982). The transport of sediment-bound P is a function of the amount of sediment in runoff, and the P concentrations in the parent topsoil and the eroded sediment. The concentration of P in the eroded material varies when sediment is transported downslope. Most of the N in the sacrifice lot is organic N and is present as manure particles; as such, the transport of N is a function of erosion (Novotny and Olem, 1994). The transport of dissolved P and N depends on the available soil P and N, the depth of the layer that mixes with runoff, and the volume of infiltrated water before runoff starts. The presence of dissolved P depends on the alkalinity of the soil. The availability of dissolved P and N depends on chemical, physical, and biological processes (Reddy, 1981). The chemical and physical processes depend on soil characteristics that do not change substantially over time. The biological processes depend on soil moisture content and temperature.

In this study, some of the above factors varied from Period I to Period II. To account for this variation, the loads and concentrations of sediment and sediment-bound pollutants (TSS, TKN-FTKN, TP-FTP) were standardized by those factors that affect pollutant transport and varied from Period I to Period II, namely, average rainfall intensity, peak flow rate, and total runoff volume. Likewise, the loads and concentrations of dissolved pollutants (PO_4^{3-}-P, NO_3^--N, NH_4^+-N, FTP, and FTKN) were divided by the total daily rainfall volume which varied from Period I to Period II. The nonparametric Wilcoxon test was applied to these quantities.

Following is a description of the rainfall and runoff events that occurred during the study period, the stream ambient pollutant concentrations upstream and downstream of the sacrifice lot, and the stream pollutant concentrations and loads during runoff events for Periods I and II.

Table 1 contains information on the runoff producing rainfall events and runoff events. The rain gauge recorded a total of 229 rainfall events (72 rainfall events larger or equal to 0.68 cm in four hours and 157 rainfall events smaller than 0.68 cm in four hours) for the duration of the project. The stream stage recorder registered 70 discharge episodes. Not

TABLE 1. Characteristics of Rainfall Producing Runoff Events and Runoff Events (– = missing data).

	RAINFALL					RUNOFF			
				Maximum Rainfall		Event			
Date	Total Duration (hr)	Total Volume (cm)	Average Intensity (cm/hr)	Duration (min)	Intensity (cm/hr)	Duration (hr)	Total (cm)	Peak Rate (cm/hr)	Daily Total (cm)
				PRE I GFS					
8/16/94	11.75	2.388	0.203	7	1.089	1.12	0.010	0.015	0.106
						1.03	0.004	0.004	
						1.82	0.005	0.005	
8/17/94	–	–	–	–	–	3.85	0.524	0.302	1.280
						2.70	0.284	0.295	
						1.77	0.184	0.203	
11/1/94	1.05	1.524	1.451	29	2.785	2.37	0.004	0.004	0.063
12/4/94	11.65	2.667	0.229	54	0.310	1.5	0.038	0.042	0.195
						0.85	0.011	0.015	
12/5/94	16.33	0.559	0.034	41	0.260	2.5	0.024	0.017	0.122
						0.87	0.001	0.002	
12/10/94	11.53	2.362	0.205	32	0.619	2.98	0.116	0.049	0.251
						0.92	0.006	0.008	
12/10-11/94	1.67	0.203	0.122	8	0.572	1	0.009	0.013	
						0.95	0.003	0.004	0.053
12/11/94						0.73	0.002	0.003	
1/14-15/95	12.4	3.073	0.248	5	7.315	2.95	0.534	0.474	2.525
1/15/95	5.52	2.108	0.382	3	5.620	1.43	0.577	0.775	
1/19-20/95	5.87	1.905	0.325	1	4.572	4.28	0.312	0.133	0.697
2/15/95	17.63	2.057	0.117	23	0.265	0.98	0.016	0.022	0.196
						0.73	0.005	0.013	
2/16/95	9.85	0.635	0.064	24	0.127	1	0.011	0.017	0.191
								TOTAL*	4.40
	TOTAL	19.48						TOTAL	5.68
				POST-I GFS					
10/5/95	6.62	1.905	0.288	1	24.384	1.75	0.0062	0.0810	0.017
11/11/95	11.78	2.794	0.237	1	9.144	3.27	0.0729	0.1465	0.078
1/18/96	6.57	3.759	0.572	2	30.480	1.22	0.0532	0.0767	0.248
						0.9	0.0326	0.0706	
						1.03	0.0688	0.0866	
1/19/96	–	–	–	–	–	0.63	0.0190	0.0406	0.406
						3.75	0.2987	0.3962	
3/16-17/96	4.55	1.168	0.257	6	2.032	2.12	0.0000	0.0005	0.006
3/19/96	13.67	3.835	0.281	1	6.096	1.93	0.0571	0.0487	0.083
						0.98	0.0009	0.0044	
4/1/96	2.72	0.559	0.206	3	1.016	1.23	0.0032	0.0067	0.100
						2.23	0.0210	0.0195	
								TOTAL*	0.531
	TOTAL	14.020						TOTAL	0.937

*Total runoff minus runoff from events with missing rainfall.

all the runoff events registered were large enough to be sampled and not all the runoff events that could have been sampled were sampled due to instrument malfunction. On occasion, the site was inaccessible and its servicing was not possible due to weather conditions (e.g., snow storm of January 1996). From the 70 runoff events, 34 stream stage and storm-event samples matched, from which 22 and 12 samples corresponded to Periods I and II, respectively. During Period I, the 22 runoff events were produced by rainfall falling on 12 days. During Period II, the 12 runoff events were produced by rainfall falling on eight days. Rainfall was not recorded for three of the 22 runoff events that occurred during Period I and not recorded for two of the 12 runoff events that occurred during Period II.

For Period I, volumes, average intensities, and duration of rainfall producing runoff events ranged from 0.2 to 3.1 cm, 0.06 to 1.45 cm/hr and 1.05 to 16.33 hours, respectively. The maximum rainfall intensity was 7.62 cm/hr during three minutes. This value is smaller than the three-minute duration maximum intensity for a two-year return period recorded in Chestnut Branch, a weather station close to Mollie creek (37°22′N, 79°23′W, Bedford County; Shanholtz and Lillard, 1973). The rainfalls producing runoff events that occurred during Period I were, intensity wise, standard yearly rainfalls. Five of these storms presented an advanced rainfall intensity histogram and the remaining six presented either an advanced-intermediate (two storms), an intermediate (two storms), or a delayed (two storms) rainfall intensity histogram.

For Period II, volumes, average intensities, and duration of rainfall producing runoff events ranged from 0.56 to 3.84 cm, 1.02 to 30.48 cm/hr and 2.72 to 16.33 hr, respectively. The maximum rainfall intensity was 30.48 cm/hr during two minutes, which corresponds to a storm with a return period larger than 25-years and smaller than 50-years (Shanholtz and Lillard, 1973). Three of these storms presented an advanced rainfall intensity histogram, two had an intermediate and one had a delayed rainfall intensity histogram. Overall, the maximum rainfall intensities were greater for Period II than Period I.

The volumes and duration of runoff events ranged from 0.001 to 0.58 cm, and 0.73 to 4.28 hours, respectively, for Period I. The maximum peak flow rate, 0.78 cm/hr, occurred during the storm of highest rainfall intensity. For Period II, the volumes and duration of runoff events ranged from 0.00002 to 0.30 cm, and 0.63 to 3.75 hours, respectively. The maximum peak flow rate was 0.40 cm/hr.

The total rainfall and runoff volumes (not counting the runoff volumes registered when the rainfall gauge failed) for Period I, 19.48 and 4.40 cm, respectively, were larger than the total rainfall and runoff volumes for Period II, 14.02 and 0.53 cm, respectively, (Table 1). While the total rainfall was 28 percent less after the GFS installation, the total runoff was 88 percent less. The decrease in runoff volume from loafing lot plus GFS, is probably not only due to the decrease in rainfall, but also due to an increase in the amount of runoff that infiltrates. The soil in the GFS has a higher infiltrability than in the sacrifice lot because it is more porous due to the channels created by the grass roots and because surface sealing is less due to the grass cover. More water can also infiltrate in the filter than in the sacrifice lot because the grass slows down runoff, allowing more time for infiltration.

The average concentrations of TP, TN, and TSS from undisturbed streams in the eastern USA (based on one station per state, Novotny and Olem, 1994) are 0.01-0.02, 0.05-0.2, and 5-10 mg/L, respectively. According to Barron (1997, personal communication), a stream water quality problem is likely to occur if TP and TN are above 0.13 and 0.92 mg/L, respectively, and severe problems are possible if TP and TN are above 1.3 and 9.2 mg/L, respectively. According to the same source, a TSS concentration higher than 30 mg/L on average over a 30-day period or higher than 45 mg/L on average over a seven-day period may cause stream water quality problems. According to Knepp and Arkin (1973; cited by USEPA, 1986) NO_3^--N concentrations below 10 mg/L have no adverse effects on human health and warm water fish. Table 2 shows average grab sample concentrations (ambient concentrations) upstream and downstream of the sacrifice lot. The stream TP, TN, and TSS concentrations were higher than 0.13, 0.92 mg/L, and 30 mg/L, respectively, upstream of the sacrifice lot. Mollie creek TP and TN concentrations downstream were higher than upstream. The TSS concentration was lower than 30 mg/L downstream of the sacrifice lot. The stream NO_3^--N concentrations upstream and downstream of the sacrifice lot were below 10 mg/L. The above information indicates that the quality of the water upstream of the sacrifice lot is lower than that of an undisturbed stream and that a water quality problem is likely to occur.

Tables 3 and 4 show the descriptive statistics for the flow-weighted concentrations and yields of N and P compounds and TSS in the stream during runoff events for the study period. During Periods I and II, median and mean concentrations of TP, TN, and TSS were higher than 1.3, 9.2, and 30 mg/L, respectively. The median and mean NO_3^--N concentrations were lower than 10 mg/L. The ambient NO_3^--N stream concentration downstream of the sacrifice lot was higher than the stream concentration during runoff events, which was unexpected. The ambient stream concentrations of PO_4^{3-}-P, FTP, NH_4^+-N, FTKN, and TKN

TABLE 2. Average Grab Sample Concentrations Upstream and Downstream of the Sacrifice Lot.

	PO4-P mg/L	FTP mg/L	TP mg/L	TSS g/L	NH4-N mg/L	NO3-N mg/L	FTKN mg/L	TKN mg/L	TN mg/L	COD mg/L
Upstream	0.10	0.38	0.37	0.05	0.13	4.03	3.32	3.54	3.68	41.50
No. of Samples	7	7	7	7	7	7	7	7	7	7
Downstream	0.16	0.37	0.55	0.01	0.38	5.63	3.54	4.25	4.63	56.07
No. of Samples	34	34	34	34	34	34	34	34	34	34

TABLE 3. Descriptive Statistics of the Concentrations Measured From August 1994 to April 1996.

	PO4-P mg/L	FTP mg/L	TP mg/L	TSS g/L	NH4-N mg/L	NO3-N mg/L	FTKN mg/L	TKN mg/L	TN mg/L
				PRE-GFS					
N*	22	19	19	22	22	22	22	22	22
Mean	1.64	1.98	6.84	0.95	1.42	4.80	6.33	15.97	17.39
Standard Deviation	0.95	1.03	5.87	1.76	0.96	1.91	2.29	11.33	12.04
Median	1.58	2.02	4.77	0.45	1.08	4.14	6.32	11.47	12.58
Minimum	0.13	0.36	0.94	0.04	0.01	0.88	1.94	3.50	3.52
Maximum	3.27	4.58	23.00	8.39	2.94	8.08	10.22	44.08	46.15
				POST-GFS					
N*	12	12	12	12	12	12	12	12	12
Mean	0.82	0.97	7.60	1.02	1.11	4.33	6.12	15.07	16.18
Standard Deviation	0.37	0.45	6.68	0.91	1.08	2.09	2.11	9.68	9.95
Median	0.78	0.93	4.46	0.62	0.67	5.12	5.21	12.69	14.66
Minimum	0.26	0.44	1.02	0.13	0.11	0.59	2.70	2.76	3.24
Maximum	1.51	1.82	20.56	2.59	3.20	6.69	9.59	32.85	33.81
Ratio of Means PRE-/POST-GFS	**2.01**	**2.03**	**0.90**	**0.93**	**1.28**	**1.11**	**1.03**	**1.06**	**1.07**

*Number of samples.

were lower than those concentrations during a runoff event for Periods I and II. When runoff events occur, the stream TP, TN, and TSS high concentrations may cause severe problems in the aquatic ecosystem. These peak concentrations may be the cause of the higher stream ambient concentrations downstream than upstream. Therefore, even though there is no federal or state regulation that sets maximum allowed loads and concentrations of TSS, TP, and TN from sacrifice lots (Lehner, 1997, personal communication) it is necessary to control runoff from the sacrifice lot to protect the already endangered stream water quality. The nonparametric Wilcoxon test indicated that there were no significant difference ($\alpha = 0.05$) in the standardized concentrations of sediment, sediment-bound, and dissolved pollutants before and after the installation of the GFS except for a significant decrease of PO_4^{3-}-P and FTP concentrations after the GFS installation. Although loads for all pollutants decreased by 15-83 percent, the same test indicated that there were no significant differences ($\alpha = 0.05$) in the standardized yields of sediment and dissolved pollutants before and after the installation of the GFS, except for particulate or sediment-bound TP (TP-FTP) and TKN (TKN-FTKN) that decreased significantly after the GFS installation. A longer study period would have provided more evidence of the effect of the GFS on runoff quality. There is no statistically conclusive evidence to support the argument that the GFS is the primary cause of smaller runoff volumes and loads. However, the impact of the GFS in runoff volume and peak, and hence, in pollutant loads, is manifested in the properties of storms that occurred on January 14-15, 1995, and January 18, 1996, before and after the GFS installation, respectively. The first storm was a 3.1 cm, 12.4-hour rainfall that presented an advanced rainfall intensity histogram and produced a runoff event with a peak flow of 0.47 cm/hr

TABLE 4. Descriptive Statistics of the Loadings and Runoff Measured From August 1994 to April 1996.

	PO4-P g/ha	**FTP g/ha**	**TP g/ha**	**TSS kg/ha**	**NH4-N g/ha**	**NO3-N g/ha**	**FTKN g/ha**	**TKN g/ha**	**TN g/ha**	**Runoff cm**
					PRE-GFS					
N*	22	19	19	22	22	22	22	22	22	22
Mean	28.12	39.25	157.31	11.84	19.33	36.63	77.31	252.39	271.79	0.1219
Standard Deviation	47.94	65.97	328.81	23.25	35.34	56.57	132.69	540.75	572.54	0.1943
Median	0.87	1.19	4.03	0.61	1.16	6.61	5.67	14.93	15.82	0.0102
Minimum	0.13	0.15	0.30	0.01	0.01	1.01	0.75	1.19	1.34	0.0025
Maximum	160.88	241.87	1238.06	89.73	117.16	182.66	531.49	2373.13	2484.63	0.5766
Total	**618.479**	**745.77**	**2989.758**	**260.32**	**425.25**	**805.651**	**1702.408**	**5552.815**	**5978.066**	**5.68**
					POST-GFS					
N*	12	12	12	12	12	12	12	12	12	12
Mean	4.82	6.18	78.81	10.04	5.07	16.10	28.85	132.69	137.76	0.0525
Standard Deviation	7.21	9.94	174.93	22.04	8.27	15.99	41.06	276.87	284.63	0.0824
Median	1.48	1.96	9.85	1.25	2.58	14.69	18.57	32.87	37.46	0.0267
Minimum	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.0009
Maximum	24.61	34.52	619.10	77.88	29.15	42.15	149.13	989.25	1018.36	0.2997
Total	**57.94**	**74.08**	**945.26**	**120.56**	**60.98**	**193.32**	**346.21**	**1592.46**	**1653.45**	**0.94**
Ratio of Totals PRE-/POST-GFS	**10.68**	**10.39**	**3.18**	**2.16**	**6.97**	**4.17**	**4.92**	**3.49**	**3.62**	**6.04**

*Number of samples.

and a volume of 0.53 cm while the second storm was a 3.8 cm, two-minute, 50-year recurrence storm that lasted 6.56 hours, had an advanced rainfall intensity histogram, and produced three runoff events with peak runoffs between 0.09 and 0.07 cm/hr and total accumulation of 0.16 cm. The lower peak flow rate and runoff volume for the second storm, compared to the first storm, were probably due, as mentioned above, to the GFS effect on the infiltration rate and runoff velocity.

CONCLUSIONS

Rainfall and runoff volumes were higher before than after the installation of the GFS. Results indicated increases in stream water concentration of pollutants following a rainfall event, for both pre- and post-GFS conditions, however, the pollutant concentration levels returned to the initial levels sometime after rainfall ceased. The loads to the stream were lower for the post-GFS condition than for the pre-GFS. The standardized concentrations of PO_4^{3-}-P and FTP, and the standardized loads of sediment-bound TP and sediment-bound TKN decreased significantly after the GFS installation. Due to the relatively short monitoring/sampling period for both pre- and post-GFS conditions, there is no statistically conclusive information on the impact of the GFS on runoff quality.

Monitoring of the ambient stream concentrations upstream and downstream of the sacrifice lot showed that due to the TP and TN concentrations, water quality problems are likely to occur. Although the water quality upstream of the sacrifice lot is already degraded, the installation of the GFS may prevent a further degradation of the water quality downstream of the sacrifice lot. Bioassays should be conducted to determine if the temporary increase in nutrient concentration is affecting the fauna and flora of the stream.

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