

Nonpoint-Source Pollutant Load Reductions Associated with Livestock Exclusion

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ABSTRACT

Cattle (*Bos taurus*) grazing on unimproved pastures can be a significant, yet often overlooked, source of pollutants to surface waters, especially when the cattle have unlimited access to streams in the pastures. Livestock exclusion from streams has been demonstrated to reduce sediment and possibly nutrient yield from streams draining pastures. The purpose of this study was to evaluate the effects of excluding dairy cows from, and planting trees in, a 335-m-long and 10- to 16-m- wide riparian corridor along a small North Carolina stream. Analysis of 81 wk of pre-exclusion and 137 wk of post-exclusion fencing data documented 33, 78, 76, and 82% reductions in weekly nitrate + nitrite, total Kjeldahl nitrogen (TKN), total phosphorus (TP), and sediment loads, respectively, from the 14.9-ha pasture area adjacent to the fenced section of stream. Statistical analyses by *t*-tests and analysis of variance suggested that the reductions in mean weekly loads post-fencing were significant ($P < 0.05$) for all pollutants except nitrate + nitrite. Thus, the results indicated that livestock exclusion and subsequent riparian vegetation establishment was effective at reducing pollutant export from an intensively grazed pasture.

CATTLE grazing on unimproved pastures is a widespread and important agricultural management practice throughout the USA. These pastures can be significant, yet often overlooked, sources of pollutants to surface waters, especially when they are stocked near or above their carrying capacity. Heavy stocking often results in decreased vegetative cover and consequently increased runoff and erosion. Because pastures tend to be located in wetter land along streams or on steeply sloping land, pollutants from pastures can be washed relatively easily and quickly to surface waters. A major source of pollutants in pastures is associated with livestock in and around perennial and intermittent streams (Line et al., 1998). Nutrients from cattle wastes deposited close to a stream are much more likely to enter the surface water and cause degradation of the water resource.

Studies of grazed rangeland areas indicate that cattle with unlimited access to streams contribute to stream-bank alteration and retreat (Marlow et al., 1987). To minimize pollution from pastures and rangeland, livestock exclusion fencing has been proposed (Davis et al., 1991). The fencing keeps livestock away from stream-banks, thereby preventing the mechanical breakdown of banks by livestock hooves and facilitating the establishment of a vegetative filter along the streams. The vegetative filter can help reduce the movement of sediment and nutrients from source areas on uplands to the stream (Daniels and Gilliam, 1996). Livestock exclusion

fencing has been shown, through 13 yr of monitoring, to reduce sediment yield from a beef cow pasture by up to 40% (Owens et al., 1996). Alternatively, simply providing an off-stream water supply without fencing was shown to reduce sediment from streambank erosion by 77% and concentrations of total nitrogen and phosphorus by more than 50% in a cow-calf pasture; however, this study was relatively short-term and included only limited monitoring of streams (Sheffield et al., 1997). Thus, while relatively large reductions in sediment yield as a result of livestock exclusion fencing have been documented by a few studies, reductions in nitrogen and phosphorus yields are much less certain.

The goal of this study was to evaluate the effectiveness of the livestock exclusion best management practice (BMP) in reducing the sediment, nitrogen, and phosphorus loading rates from a dairy cattle pasture in the Piedmont region of North Carolina. Additionally, the effect of installing an alternate watering system without fencing was evaluated. This study is part of a larger watershed project, the Long Creek 319 National Monitoring Program Project, which has the objective of evaluating the effectiveness of a variety of BMPs. The Long Creek Project is one of 30 projects in the USEPA's National Monitoring Program, which has a goal of evaluating sources, transport, and control of nonpoint-source pollution in variety of settings throughout the USA (Osmond et al., 1997).

DESCRIPTION OF THE STUDY SITE

This study was conducted in a 56.7-ha watershed that contained residential homes (4.0 ha), apartments (0.9 ha), small businesses (2.0 ha), and farmstead (4.4 ha) along its periphery, but was predominantly pasture for dairy cows and replacement heifers (Fig. 1). Because the nonpasture areas were less than 20% of the watershed and the management of these areas remained relatively constant throughout the entire period of monitoring, the effects of these land uses were considered insignificant, except to increase the absolute loads during both the pre- and post-BMP periods. The exception to this was that a small apartment complex, shown as the square shaded area at the bottom of Fig. 1, was constructed just before the beginning of the start of monitoring and may have had some effect on the results.

The 56.7-ha watershed was divided into an upper pasture (41.8 ha upstream of Site D) that was lightly grazed by 75 to 100 heifers and calves and a lower pasture (14.9 ha between Sites D and E) that was heavily grazed by adult cows. The dairy farm has been at this location for at least 100 yr; therefore, there is a long history of grazing on these pastures. In both pastures the livestock had unlimited access to the small stream draining the pastures that was the only source of water

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Abbreviations: BMP, best management practice; NO_2^- and NO_3^- , nitrite + nitrate nitrogen; TKN, total Kjeldahl nitrogen; TP, total phosphorus; TSS, total suspended solids; TS, total solids.

for the animals prior to BMP implementation. The small stream, known as Kiser Branch, originates in the upper pasture and flows about 180 m before entering the lower pasture. The typical nonstorm daily mean discharge at both upstream and downstream monitoring sites was 8 L/s with peak instantaneous discharges as high as 3100 L/s during some storm events. Due to trampling and grazing of riparian vegetation and buildout in the headwaters, the streambanks and channel bed were degrading rapidly in places. Erosion of the 2- to 3-m-high streambanks in the lower pasture was particularly severe due to the increased stocking density and size of the cows. The streambed had two or three natural stabilization points in the form of rock outcrops, but degradation between these points was considerable.

The average annual rainfall for the general area around the study watershed is 1090 mm. The watershed geology is typical of the western Piedmont region of North Carolina with a saprolite layer of varying thickness overlaying fractured igneous and metamorphic rock. The predominant soils were Tatum silt loam (fine, mixed, semiactive, thermic Typic Hapludult) and Vance sandy loam (fine, mixed, semiactive, thermic Typic Hapludult), which are generally well drained and moderately to slowly permeable. Both soils have a loamy A horizon and a predominantly clayey Bt horizon that extend to a depth of between 36 to 100 cm. The depth to bedrock for these soils was typically 1.1 to 1.8 m. The watershed area was hilly with land slopes of 5 to 15% with a few flatter areas on the tops of ridges and along the stream. A survey of Kiser Branch between Sites D and E determined that the average slope of the channel was 1.3%.

Vegetation in the 41.8-ha upper pasture (upstream of Site D) was primarily common bermudagrass [*Cynodon dactylon* (L.) Pers.] and some areas of trees along the main stream channel. The bermudagrass pasture provided supplemental forage for between 75 and 100 replacement heifers. The grass was generally lightly grazed and therefore provided good ground cover throughout most of the upper pasture, except in off-stream areas where the heifers were fed and along the stream under trees where there was essentially no ground cover. The grounds around the homes, apartment complex, and small business along the drainage area periphery had generally good stable cover, except for the 2-ha area around the business that included gravel lots. Runoff from the small business flowed across the pasture in a small intermittent channel that was severely eroding in some places.

The 14.9-ha lower pasture between Sites D and E was grazed regularly by between 50 and 60 adult dry cows and occasionally by another 50 to 100 milking cows. Due to the heavy stocking density, grass in the area between Sites D and E was sparse overall with denuded areas in places where the cows were fed. Approximately one-half of the area between the monitoring sites was either denuded or covered with impervious surfaces. Two large unlined ponds that store milk-house waste and runoff from holding areas also were located in this area. Several intermittent stream channels, two of which were severely eroding, entered Kiser Branch in the lower pasture.

Following the collection of 81 wk of monitoring data (August 1994 to February 1996), an alternate watering system was installed in both pasture areas. Watering tanks were installed at upland locations at least 50 m away from the stream and were surrounded by a geotextile fabric overlain with gravel. Additionally, livestock exclusion fencing was installed in the lower pasture in February 1996 (shaded area in Fig. 1). The fence excluded cows from a 10- to 16-m-wide and 335-m-

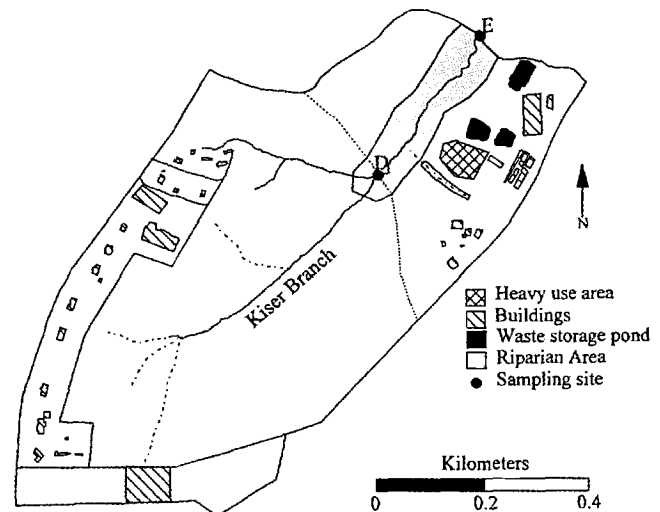


Fig. 1. Map of watershed area.

long section of pasture along either side of the Kiser Branch between Sites D and E. At the request of the landowner, a farm road, which bisected the riparian corridor and allowed cows access to pasture on both sides of Kiser Branch, was provided. The road crossed the riparian area directly downslope of the heavy use area, thereby providing a channel for runoff from this area to flow into Kiser Branch. Installation of culverts and raising the road to divert runoff into the riparian vegetation was planned, but was not implemented during the period of monitoring.

Shortly after the fence was constructed, various hard- and softwood trees were planted in the riparian corridor and a severely eroding section of streambank was reshaped and seeded. In a zone within 3 m of the Branch, button bush (*Cephalanthus occidentalis* L.), hazel alder [*Alnus serrulata* (Aiton) Willd.], red maple (*Acer rubrum* L.), and bald cypress [*Taxodium distichum* (L.) Rich.] trees were planted while on the drier upland areas green ash (*Fraxinus pennsylvanica* Marshall), red and white oak (*Quercus rubra* L. and *Q. alba* L.), and loblolly pine (*Pinus taeda* L.) trees were planted. All trees were planted in rows on 3-m centers in holes drilled with a post hole digger, except for the loblolly pine, which were planted by a dibble. The post hole digger was necessary because the soil had become compacted from years of heavy cow traffic. One application of herbicide around the trees, to release them from the competition of volunteer vegetation, was the only followup work performed after planting the trees. The tree varieties and planting methods were recommended by the North Carolina Division of Forest Resources. After 3 yr, observation has documented excellent survival and vigorous growth of all trees, especially the green ash, which have reached 3 to 5 m in height.

A considerable amount of volunteer vegetation has grown in the riparian corridor. Along and in the stream, willows (*Salix* spp.) and cattails (*Typha* spp.) have proliferated while on the banks a variety of weeds and grasses have become established. The vegetation has provided a stable cover for the soil, filtering of sediment and nutrients from incoming runoff, and resistance for slowing runoff in the side and main channels.

Fencing to exclude cows from a 6-m-wide riparian corridor containing a major tributary to Kiser Branch also was installed in February 1996 (Fig. 1, thin shaded area perpendicular to Kiser Branch). The volunteer vegetation inside the fenceline provided about a 3-m grassed filter strip along either side

of the 94-m-long intermittent channel. This vegetated strip filtered runoff from a dry cow heavy use area next to the channel and helped stabilize the channel against erosion. Because the tributary's channel was on a relatively steep slope (4.3%), scour and downcutting had become a significant problem.

In addition to the fencing, the lower pasture has had numerous management practices implemented to properly contain and store waste from the dairy operation; however, most of these were installed prior to or near the beginning of monitoring and thus, should not have had a significant effect on the evaluation of the livestock exclusion. The installation of a large waste holding pond and a waste irrigation system during the pre-BMP period significantly reduced the chances of milkhouse and barnyard waste running directly into the stream, but may have increased sediment influx to the stream during the relatively short construction phase. The implementation of improved stock trails and heavy use area protection during the pre-BMP period probably reduced sediment input to the stream to a limited extent.

DATA COLLECTION METHODS

Continuous discharge measurements were made at upstream (Site D) and downstream (Site E) monitoring stations from August 1994 through September 1998 by the U.S. Geological Survey. Two recording raingages, one located along the periphery of the watershed and the other located about 1.3 km away measured rainfall continuously during the study.

Grab samples from the overfall of a V-notch weir at Site D and a large culvert at Site E were collected weekly, iced within 15 min, and transported to a nearby USEPA-certified laboratory. Samples were analyzed for nitrite + nitrate nitrogen (NO_2^- and NO_3^-), TKN, TP, total suspended solids (TSS), and total solids (TS) concentrations using Methods 353.1, 351.2, and 365.4 from the USEPA (1983) for NO_2^- and NO_3^- , TKN, and TP and 2540D and 2540B from Anonymous (1989) for TSS and TS. Split, blank, and spiked samples were prepared and analyzed to verify the quality and representativeness of the samples.

Samples were collected during storm events at Sites D and E using automated samplers activated by the stage recording equipment. Samplers were programmed to collect two samples on the rising limb, one near the peak, and one at a stage approximately halfway between the first grab sample collected on the rising limb and the peak of the hydrograph. Although the automated samplers at Sites D and E were independent of each other, they were set to sample at stage heights corresponding to about the same initial discharge rates at each site. This initial rate was set at more than three times the baseflow discharge to ensure that samples were collected only during significant storm events. Each sample was placed in two bottles, one that was pre-acidified for preservation of nitrogen and phosphorus forms and one that was non-acidified for storage of the solids or sediment. Samples were transported to the laboratory as soon after the events as possible and analyzed using the same methods as those used for grab samples.

Due to irregular hydrographs from extended-duration storms or storms with multiple peak discharges and equipment malfunction, significant portions of storm flows were not sampled. However, at least one sample was collected from 102 of the 118 storms occurring during the period of monitoring. Estimations of pollutant concentrations for sections of the storm hydrograph that were not sampled were then based on concentrations from previous storms with similar characteris-

tics or previous similar parts of the same storm, if applicable. Hydrographs were divided into sections that corresponded to when samples were collected. Sample concentrations were multiplied by runoff volumes for the corresponding section of the hydrograph and summed to yield the pollutant load for the entire storm. When summed, the estimated load from missed events accounted for between 11 to 15% of the total load for all pollutants from Sites D and E. The net effect of unsampled events on load calculations was probably somewhat less, because the load from certain events was probably underestimated in some cases and overestimated in others.

To assess changes in soil properties that might help explain trends in hydrologic response, soil samples were collected from the riparian corridor. Twenty intact soil cores were taken in June 1996 (just after riparian area establishment) and May 1999 (3 yr after riparian establishment) using a Uhland ring (7.62 cm diameter and 7.62 cm height) (Utah Research Foundation, Logan). The soil cores were collected on either side of the stream in an alternating pattern. Ten samples were collected on the low banks near the stream (floodplain) and 10 samples were collected on the higher upland areas (terrace) further away from the stream. A soil water characteristic curve was developed (Klute, 1965) and saturated hydraulic conductivity was measured for each soil core using standard pressure and hydraulic conductivity apparatuses (Klute and Dirksen, 1965). Soil bulk density was determined by oven-drying the known volume of soil in the cores at 105°C for 24 h and weighing the samples.

RESULTS AND DISCUSSION

Combining weekly grab and storm event samples with continuous daily mean discharges and storm event discharges to compute pollutant loading rates was not straightforward because some of the weekly grab samples were collected during storm events and the daily mean discharges included storm event runoff from the pasture. Consequently, the volume of runoff associated with grab samples had to be separated from the storm event runoff. This was accomplished by subtracting the storm runoff volume from the total weekly runoff volume and multiplying this volume by the pollutant concentration in the weekly grab sample. This procedure was used for all weeks, except for four in which the weekly grab samples were collected during relatively high flows associated with storm events. For these weeks, the grab sample concentrations from the previous and next weeks were averaged and used to compute loads for the nonstorm part of the week. Nonstorm and storm pollutant loads were summed to yield total pollutant loads for each week of the pre- and post-BMP implementation periods. During the pre-BMP period 38 of 81 weeks (47%) had at least one runoff-producing storm event whereas during the post-BMP period 68 of 137 weeks (50%) had a storm.

Because the effects of the BMPs were expected to vary with growing seasons, the weekly data were grouped into 3-mo periods according to season. Mean weekly discharges for 3-mo periods are shown in Fig. 2. The hatched section of the bars represents the average discharge to Site D while the blank section represents the difference in loads between Sites E and D; therefore,

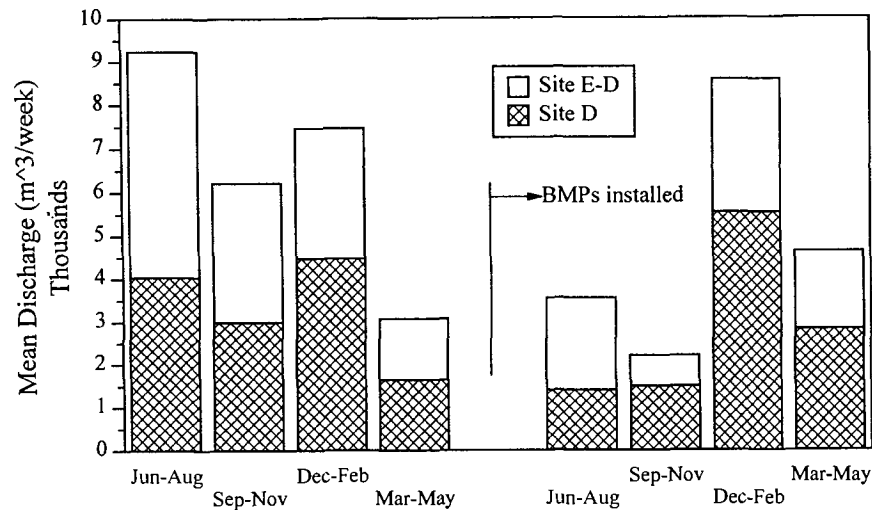


Fig. 2. Mean weekly discharge for each season of the year.

the top of the bar represents the discharge at Site E. The June–August and March–May quarters in the pre-BMP monitoring period (Bars 1 and 4) had only 13 and 17 wk of data, respectively, because only one spring and summer were included in the monitoring period (August 1994 to February 1996). The other two quarters had at least 26 wk of data.

Mean weekly discharge during the pre-BMP June–August and September–November periods was greater than the post-BMP period, due to several large summer storms (>100 mm) in 1994 and 1995 and the abnormally wet fall of 1995. While average weekly rainfall during these periods (Fig. 3) was slightly greater in the pre-versus the post-BMP period, the difference is much less than the differences in discharge. This apparent discrepancy was caused by four storms of greater than 100 mm occurring during the pre-BMP period, while no storms of greater than 100 mm occurred during the post-BMP period. Hurricane-size storms tend to produce more discharge per millimeter of rainfall because after the

ground becomes saturated all additional rainfall runs off. The effect of these unusually large storms on pollutant loads is difficult to assess, because they were not particularly intense, just long in duration. In comparison, there were more than 10 storms of greater than 50 mm occurring during the post-BMP period, which produced peak discharges similar to the hurricane-sized events of the pre-BMP period. The differences in load resulting from 50- and 100-mm storms may be relatively small because both produce enough runoff to carry pollutants from the all parts of the watershed.

The reduction in discharge during the post-BMP period can be attributed to increased infiltration and evapotranspiration associated with the planting of trees and proliferation of other vegetation in the riparian corridor following the installation of fencing. This vegetation would be expected to have the greatest effect during the growing season, which is consistent with the large decrease in post- as compared with pre-BMP discharge during the June–August and September–

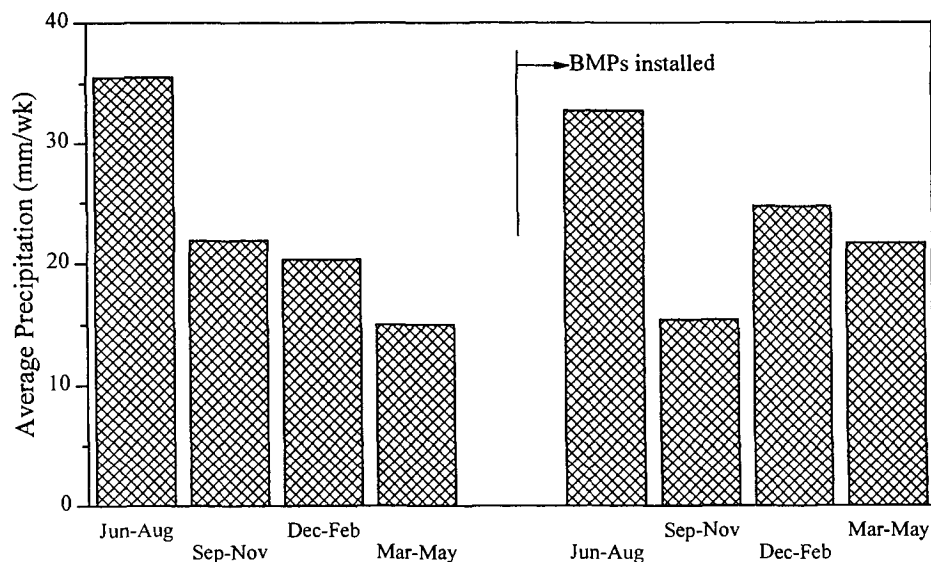


Fig. 3. Mean weekly precipitation by season of the year.

Table 1. Soil bulk density by location and sampling year.

Landscape position	1996			1999		
	Mean	Min.	Max.	Mean	Min.	Max.
	g/cm ³					
Terrace	1.50	1.20	1.73	1.25	0.97	1.58
Floodplain	1.41	1.02	1.71	1.17	0.80	1.44
Overall	1.45			1.21		

November periods, as shown in Fig. 2. Much of the decrease in discharge can be attributed to the decline in contributions of the area between Sites D and E (white section of bar). Because the discharge and loads at Site D will be factored out, the considerable decrease in pre- versus post-BMP discharge at Site D should not affect the analysis of BMP effectiveness.

The mean weekly discharge during the December–February and March–May periods was greater in the post-BMP compared with the pre-BMP period. The difference was relatively small compared with the other two quarters and can be attributed to natural variability. The contribution of discharge from the area between Sites D and E was nearly the same pre- versus post-BMP, which was expected given that the vegetation in the riparian corridor was dormant during most of this period.

Changes in soil properties during the post-BMP period tend to confirm the assumption of increased rainwater infiltration. After fencing, bulk density of soils in the riparian corridor between Sites D and E decreased for both the terrace and the floodplain landscape positions (Table 1). Because, however, the range and variability in sample values were large for both positions, changes in bulk density from the pre- to post-BMP period were not significant ($P > 0.10$) according to a t -test. Soil saturated hydraulic conductivity increased during the post-BMP period (Table 2), thereby indicating increased infiltration. This increase was statistically significant ($P < 0.01$) for the terrace, but not for the floodplain. The range in saturated hydraulic conductivity val-

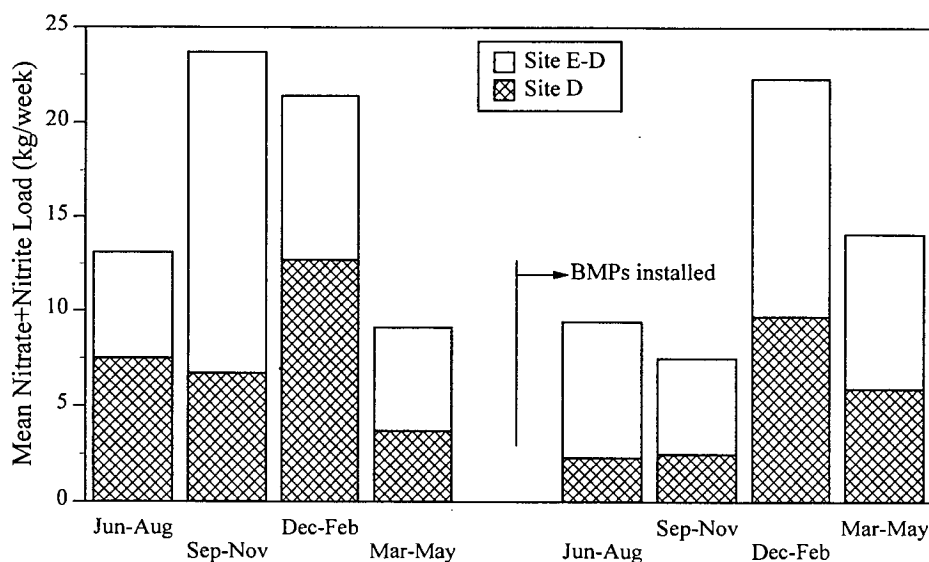
Table 2. Soil saturated hydraulic conductivity by location and sampling year.

Landscape position	1996			1999		
	Mean	Min.	Max.	Mean	Min.	Max.
	cm/h					
Terrace	2.40	0.0	11.50	8.71	0.03	36.93
Floodplain	7.08	0.26	16.80	7.33	0.14	26.94
Overall	4.74			8.02		

ues from the 20 sites varied by four orders of magnitude, a relatively common occurrence. Although most of the data were not statistically significant because of the sample variability and small numbers of samples, the trend of decreasing bulk density and increasing hydraulic conductivity confirms the expected effects of revegetating the area. By removing the cows and associated trampling and replacing the pasture grass with deeper-rooted vegetation, soil pore space should increase (decreasing bulk density), which leads to increased movement of water into the soil (increasing hydraulic conductivity).

Mean weekly NO_2^- and NO_3^- loads (Fig. 4) follow discharge except for the June–August pre-BMP period that had the greatest discharge, but considerably less NO_2^- and NO_3^- load than either the September–November or December–February quarters. The greater NO_2^- and NO_3^- load during the winter months was probably the result of increased baseflow associated with low-intensity storms and evapotranspiration, as compared with low baseflow associated with high-intensity storms and evapotranspiration of summer months. The NO_2^- and NO_3^- loads during the post-BMP period generally followed the discharge because fewer large storm events occurred.

The pre-BMP TKN load (Fig. 5) was nearly the converse of the NO_2^- and NO_3^- load, in that although the December–February discharge was relatively high, the load was considerably less than either the June–August or September–November quarters. This difference was probably due to the lesser percentage of total discharge

**Fig. 4. Mean weekly nitrate + nitrite load by season of the year.**

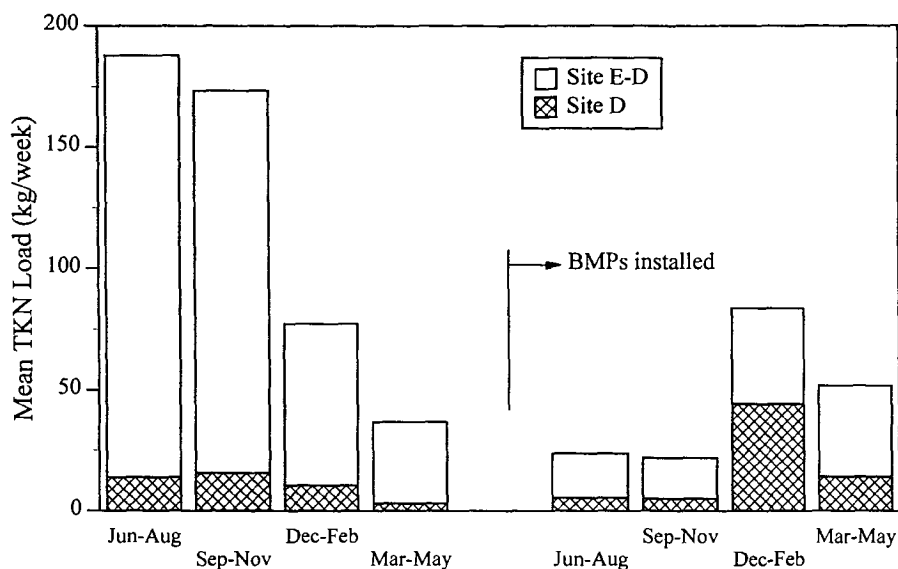


Fig. 5. Mean weekly total Kjeldahl nitrogen (TKN) load by season of the year.

occurring as storm runoff, which often transports the bulk of the TKN load. Additionally, cows tend to be in and near the stream during hotter summer and fall months, thereby increasing the TKN load in the stream. During the post-BMP period, because cows were excluded from the stream, a significant storm event was required to move TKN over land to the stream. Therefore, TKN loads more closely followed discharge trends. Trends in the TP, TSS, and TS, although not shown, were similar to TKN.

Effectiveness of Alternate Watering System

Table 3 contains the mean weekly discharge and pollutant loads for the pre- and post-BMP monitoring periods at Sites D and E and the differences between loads at D and E. At Site D, mean weekly discharge and pollutant loads, except TKN and TP, decreased during the post-BMP monitoring period; however, the decreases in discharge, NO_2^- and NO_3^- , TSS, and TS and increase in TKN were relatively small. In fact, statistical analysis using a *t*-test on log-transformed data confirmed

that the differences in pre- and post-BMP discharge and loads were not statistically significant at the 0.05 level (Table 3). The *t*-test was conducted on log-transformed data because the computed loads had a positive skew and thus were not normally distributed. The results of the *t*-tests were not surprising considering that the only BMP implemented in the pasture upstream of Site D was an alternate watering system. While some studies (Sheffield et al., 1997; Marlow and Pogacnik, 1986) have suggested, based on only limited monitoring data, that off-stream water sources are an effective water quality BMP, results of this study indicate that the effect of this BMP by itself is not significant. This conclusion must be qualified due to the relatively low stocking rate (3.8 heifers/ha) of the upper pasture and the age of the cattle. Observation has indicated that older cows tend to spend more time in the stream because they drink more and seek relief from heat more readily. Also, there was a considerable decrease in weekly sediment load, which continued monitoring over time may document as significant.

Table 3. Mean weekly discharge and pollutant loads for Sites D and E.

Period	Discharge	NO ₂ ⁻ and NO ₃ ⁻	TKN†	TP‡	TSS§	TS¶
	m ³ /wk	kg/wk				
Site D, upstream						
Pre-BMP#	3 594a††	8.2a	11.8a	3.9a	1 657a	2 736a
Post-BMP	2 612a	4.8a	15.0a	4.4a	1 031a	1 531a
Site E, downstream						
Pre-BMP	6 997a	18.7a	127.8a	54.2a	12 733a	17 846a
Post-BMP	4 135b	11.8b	39.9b	16.6b	2 988b	4 302b
Between Sites D and E						
Pre-BMP	3 403a	10.3a	115.9a	50.2a	11 076a	15 105a
Post-BMP	1 523b	7.0a	25.0b	12.3b	1 957b	2 772b
% decrease	55.2	32.6	78.5	75.6	82.3	81.7
% mean‡‡	27.3	12.9	69.7	58.0	80.8	51.1

† Total Kjeldahl nitrogen.

‡ Total phosphorus.

§ Total suspended solids.

¶ Total solids.

BMP, best management practice.

†† Within factors and sites, means followed by the same letter are not significantly different at the 0.05 level.

‡‡ Decrease in means computed using analysis of covariance.

The apparent decrease in TSS and TS loads from pre- to post-BMP periods may have resulted from changes in land use and agricultural activities in the area draining to Site D or climatic differences. A small apartment complex (0.8 ha) was constructed in the area upstream of Site D just before the start of pre-BMP monitoring. This complex probably temporarily contributed excess sediment load to Site D during its construction. The complex was seeded and soil stabilized by the time the post-BMP monitoring period began and thus the area would have contributed less sediment during that period.

Effectiveness of Livestock Exclusion Fencing

At Site E, discharge and all weekly loads decreased significantly from the pre- to post-BMP periods. Because the decrease in discharge and loads at Site E included the changes at Site D, corresponding discharge and loads and Site D were subtracted from those at Site E. The differences in discharge and pollutant loads (Table 3) were greater during the pre- versus the post-BMP period indicating that the BMPs may have been effective at reducing pollutant export. The decrease in discharge may not be surprising considering that mean weekly precipitation (not shown in Table 3) also decreased from 23.4 mm/wk during the pre-BMP period to 20.5 mm/wk during the post-BMP period. However, statistical analysis of pre- and post-BMP weekly precipitation totals using a *t*-test suggested that the decrease in precipitation was not significant ($P = 0.43$). As discussed earlier, the decrease in discharge during the post-BMP period probably resulted from increased evapotranspiration by the plant community in the riparian corridor. Thus, much if not all of the reduction in discharge can be attributed to the BMP and not natural hydrologic variability.

In an effort to further examine the change in discharge, storm event discharge data were separated from the weekly average discharge. Analysis of discharge from the 44 pre-BMP and 74 post-BMP storms monitored using a *t*-test indicated that there was no statistically significant difference between pre- and post-BMP runoff at either Site D or E. This result tends to support the suggestion that the decrease in total discharge was the result of increased evapotranspiration, as this process would be insignificant during the relatively short and wet period of a storm event.

The focus of the analysis of BMP effectiveness was on the differences between loads at Sites D and E. The BMPs were installed between the sites and therefore should have the greatest effect on the loading between the monitoring sites. The weekly loads and the percent decreases in weekly discharge and pollutant loads after BMP implementation for the area between Sites D and E are shown in the last three rows of Table 3. Before statistical analysis, the discharges and pollutant loads had to be log-transformed because they were not normally distributed. The differences in the log-transformed data were used in the analysis rather than the log

of the differences because occasionally the differences were slightly negative. Therefore, technically the question the *t*-test was answering was, Is there a difference in the log-transformed runoff and pollutant load ratios at Site D and E before as compared with after BMP implementation? The *t*-tests indicated that the differences in discharge and all loads, except NO_2^- and NO_3^- , were significantly less ($P < 0.001$) during the post-BMP period as compared with the pre-BMP period. Therefore, there was sufficient evidence to conclude that the BMPs reduced discharge and pollutant export.

The monitoring data also were analyzed for a discrete change using a two-way analysis of variance (ANOVA). The data still had to be log-transformed to remove the skew, but computing the differences between D and E was unnecessary. The question this analysis considered was, Has there been a change in post-BMP loads relative to pre-BMP loads at the downstream station (Site E) while adjusting for loads at the upstream station (Site D)? The results of the ANOVA were similar to the *t*-test, in that mean weekly NO_2^- and NO_3^- loads were not different and TKN, TP, and TSS loads were significantly different ($P < 0.05$) for the pre- and post-BMP periods. However, unlike the *t*-test, the ANOVA indicated that the mean weekly discharge and TS loads were not significantly different during the pre- and post-BMP periods. The TS loads were nearly significantly different ($P = 0.06$), but the discharge was not ($P = 0.14$). Thus, while the two statistical analyses confirm significant reductions in TKN, TP, and TSS and no significant reduction in NO_2^- and NO_3^- , the results are mixed on whether reductions in TS and discharge are significant.

The weekly load data also were evaluated using an analysis of covariance on the logarithms of the pre- and post-BMP data. In this method the best-fit line between the loads at Sites D and E for the pre- and post-BMP periods were computed and then the slopes and intercepts of the lines were compared. The intercepts for all pollutants were significantly less for the post-BMP period, whereas the slopes of the lines for only NO_2^- and NO_3^- and TSS were significantly different for the post- compared with the pre-BMP period. The differences between the pre- and post-BMP regression lines also were evaluated at the mean of the load range for each pollutant. This involved computing the mean weekly load for Site D and using the regression equation to compute the corresponding weekly load for Site E. The percent decrease in each of these weekly loads is shown in Table 3 at the bottom. These decreases are significantly different for all pollutants and discharge. Only NO_2^- and NO_3^- ($P = 0.049$) had a *P* value greater than 0.0001.

The continued loading of NO_2^- and NO_3^- was not surprising given that increased soil hydraulic conductivity will result, at least temporarily, in increased leaching of nutrients from the soil profile to near-surface ground water and into the stream. Nutrient loading from ground water to the stream was probably only significant for NO_2^- and NO_3^- , because storm event loads accounted for more than 90% of the total load of TKN, TP, TSS,

and TS for Sites D and E during both the pre- and post-BMP periods. Storm event load accounted for only 45 to 58% of the total load for NO_2^- and NO_3^- at Sites D and E; therefore, baseflow or ground water loading was important. Ground water NO_2^- and NO_3^- from a waste application field and a waste storage pond along either side of the riparian corridor probably masked any reduction in loading resulting from the livestock exclusion. The livestock exclusion BMP was not expected to reduce NO_2^- and NO_3^- load as it is designed to reduce pollutants in surface runoff. The trees planted in the riparian zone may eventually reduce NO_2^- and NO_3^- load from outside sources to the stream after their root systems become more established and subsequent nutrient uptake and denitrification increase.

The magnitudes of the reductions in TKN, TP, TSS, and TS loads provide strong evidence that the BMPs, particularly livestock exclusion fencing, were effective at reducing pollutant loads from the area between Sites D and E. Some of the reduction in loads may be attributed to climatic changes resulting in changes in discharge; however, the evidence is mixed on whether the decrease in discharge from the pre- to post-BMP periods was statistically significant.

The greater than 75% decreases in weekly TKN, TP, TSS, and TS loads were probably all related to a decrease in erosion or the filtering of sediment from runoff in the area between Sites D and E. The TKN and TP are often associated with sediment, therefore it is not surprising that their decreases are similar to the reduction in sediment (TSS) load. The decrease in sediment load was more than twice the 40% reduction reported by Owens et al. (1996) for livestock exclusion in a beef cow pasture. The greater reduction was probably due to a combination of increased stocking rate, a larger stream, and more severely eroding streambanks.

For comparison purposes, annual pollutant export rates were computed for the areas draining to Sites D and E and between D and E (Table 4). Annual sediment export from a beef cow pasture in Ohio before and after fencing for livestock exclusion was from 2.5 to 1.5 Mg/ha (Owens et al., 1996). These annual export rates are slightly higher than the corresponding rates (TSS) at Site D and slightly less than the post-BMP sediment export rate at Site E as shown in the sixth column of

Table 4. Considering that the Kiser Branch watershed had higher annual discharge than the 126-mm pre-BMP and 160-mm post-BMP levels of the Ohio watershed, the greater post-BMP sediment export rate at Site E could be expected.

The nitrogen and phosphorus export rates post-BMP at Site E are still quite high compared with those of 5.19 and 0.81 kg/ha/yr reported by Reckhow et al. (1980) for pastures in general, and 6.6 and 1.1 kg/ha/yr reported for a mainly dairy cow pasture in Australia (Nelson et al., 1996). This indicates that, while significant reductions in pollutant loads have occurred, pollutant export from the watershed is still relatively high. Additionally, BMPs are being planned and implemented in both the upper and lower pasture areas. In the upper pasture, livestock exclusion fencing is planned and in the lower area, two roofed fenceline feeding systems have been installed. The fenceline feeding system should help reduce pollutant export considerably because the area around the feeding troughs was a significant source of nutrients that should be eliminated. Continued monitoring of discharge from the watershed will document the effects of these practices.

CONCLUSIONS

Weekly discharge and loading rates of NO_2^- and NO_3^- , TKN, TP, TSS, and TS were reduced in a dairy pasture following the implementation of an alternate watering system and livestock exclusion fencing. The alternate watering system alone was somewhat effective at reducing NO_2^- and NO_3^- and TSS loads, but the decreases were not statistically significant. The decrease in pollutant loads occurred mainly for the section of pasture where the fencing was installed. The 55.2, 78.5, 75.6, 82.3, and 81.7% reductions in post-BMP mean weekly discharge and TKN, TP, TSS, and TS loads for the area where exclusion fencing was installed was statistically significant; however, the 32.6% reduction in weekly NO_2^- and NO_3^- loads was not significant. The NO_2^- and NO_3^- load will probably decrease in the future as the trees become established and denitrification and nutrient uptake in the riparian corridor increase. Thus, the BMPs were effective at reducing loads of TKN, TP, and TSS, but were much less effective at reducing the

Table 4. Annual discharge and pollutant export from Sites D and E.

Period	Discharge	NO_2^- and NO_3^-	TKN†	TP‡	TSS§	TS¶
	mm/yr	kg/ha/yr		Mg/ha/yr		
Site D, upstream						
Pre-BMP#	452	10.2	14.7	4.9	2.1	3.4
Post-BMP	328	6.0	18.7	5.4	1.3	1.9
Site E, downstream						
Pre-BMP	643	17.1	117.2	49.7	11.7	16.4
Post-BMP	380	10.8	36.6	15.2	2.7	3.9
Between Sites D and E						
Pre-BMP	1189	36.0	404.6	175.3	38.7	52.7
Post-BMP	532	24.3	87.1	42.8	6.8	9.7

† Total Kjeldahl nitrogen.

‡ Total phosphorus.

§ Total suspended solids.

¶ Total solids.

BMP, best management practice.

NO_2^- and NO_3^- load. Sediment and nutrient export from the watershed was still relatively high compared with some other predominantly pasture watersheds, indicating that additional BMPs are needed.

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