Effectiveness of Livestock Exclusion in a Pasture of Central North Carolina

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Abstract
Reducing the export of nitrogen (N), phosphorus (P), and sediment from agricultural land in water-supply watersheds is a continuing goal in central North Carolina. The objective of this project was to document the effectiveness of a combination of livestock exclusion fencing and nutrient management implemented on a beef cattle pasture located in the Piedmont region of North Carolina. The quantity and quality of discharge from two predominantly pasture watersheds were monitored simultaneously for 3.8 yr before and after implementation of the exclusion fencing and nutrient management in the treatment watershed; a control watershed remained unchanged. The excluded stream corridor was intentionally minimized by constructing the fence line about 3 m from the top of the streambank on either side and limiting it to the main stream channel only. Monitoring included collecting flow-proportional samples during storm events and analyzing them for total Kjeldahl nitrogen (TKN), ammonia (NH₃–N), and inorganic (NOₓ–N) N as well as total P (TP) and total suspended solids (TSS). Statistically significant reductions were observed in TKN (34%), NH₃–N (54%), TP (47%), and TSS (60%) loads in the treatment relative to the control watershed after fencing, whereas storm discharge and NOₓ–N loads were not significantly different. These data show that even a relatively narrow exclusion corridor implemented on only the main stream channel can significantly reduce the export of N, P, and sediment from a beef cattle pasture.

Core Ideas
- Document, through water quality monitoring, the effectiveness of livestock exclusion fencing
- Livestock exclusion reduced nitrogen, phosphorus, and sediment export from a pasture.
- Statistical analysis is required to assess trends in water quality monitoring data.

JOORDAN LAKE (Reservoir), located in central North Carolina, is a 5650-ha impoundment with a 436,860-ha watershed of which 18% was urban, 20% agricultural, and 56% forested. Like many lakes in the eastern United States, the use of this water resource is being threatened by excessive nutrient inputs. A proposed nutrient reduction strategy set overall nitrogen (N) and phosphorus (P) load reduction goals for the watershed at 18% for N and 5% for P. As a result, the agricultural and urban communities began to look for ways of reducing N and P loads to surface waters. Agricultural land use in the Jordan Lake watershed consisted of a plurality of acres in pasture or hay (75%); thus, the focus of N and P reduction efforts was directed toward cost-effective best management practices (BMPs) for pastures (Osmond and Neas, 2007).

Among the BMPs considered, livestock exclusion fencing was chosen as the preferred BMP because pastures in the watershed, like many around the world, often have streams that livestock access regularly, which makes them potential sources of N, P, and sediment to surface waters (Line et al., 2002; Owens et al., 1996; Vidon et al., 2008). Further, exclusion fencing has been shown in several studies to reduce nutrient and sediment export from dairy cattle pastures (Galeone et al., 2006; Line et al., 2000; Meals and Hopkins, 2002; Osmond et al., 2012). In addition, Owens et al. (1996) documented reductions in sediment export of up to 40% from a beef cattle pasture in Ohio. In Australia and New Zealand, where there are extensive areas of livestock grazing, greater than 85% reductions in suspended sediment export after excluding sheep and/or beef cattle from streams in two watersheds were documented, whereas reductions in P and N export were mixed (McKergow et al., 2003; Williamson et al., 1996). However, the water quality monitoring used in both of these studies was limited. In one study, 40% of the discharge record was missed, and the sampling method changed during the study (McKergow et al., 2003); for the other study, only fixed-interval samples at varying rates during storms were collected over a relatively short duration (Williamson et al., 1996).

Because many of the pastures in this watershed had biosolids and/or animal waste application, nutrient management was
included for possible implementation and study. There have been few published studies on the effectiveness of nutrient management and none involving only pasture. Hall and Risser (1993) monitored N export from a 22.3-ha cropland field over 6 yr and found that virtually all of the N leaving the site occurred through subsurface flow, which was reduced by 30% as a result of nutrient management. Brannan et al. (2000) documented 36 and 62% reductions in TP and TN export, respectively, via streamflow from a 462-ha cropland watershed in Virginia as a result of nutrient management. Both studies showed that implementation of nutrient management can reduce N and P in stream discharge.

The purpose of this project was to evaluate, through intensive water quality monitoring, the effectiveness of livestock exclusion fencing and nutrient management in reducing N, P, and sediment export in surface water from a beef cattle pasture. The three studies cited above that included intensive long-term water quality monitoring (i.e., Galeone et al., 2006; Line et al., 2000; Meals and Hopkins, 2002) either involved a dairy cattle pasture or were located in the northern half of the United States; thus, this study will add to the literature by providing effectiveness data on livestock exclusion and nutrient management in a beef cattle pasture in a warmer, more humid region where the grazing and growing seasons are longer.

**Materials and Methods**

The paired watershed experimental approach (Clausen and Spooner, 1993; USEPA, 1997) used in this project requires simultaneous monitoring of two watersheds (treatment and control) during a calibration and a treatment or post-BMP period. In this project, the calibration or pre-BMP period was from 30 Dec. 2007 to 5 Oct. 2011, and the treatment or post-BMP period was from 6 Oct. 2011 to 18 Dec. 2015. During both periods, the rainfall and quantity and quality of discharge were monitored continuously. Land use information (i.e., number of cattle, fertilization, and soil test results) was collected annually.

Both the control (Past-cont) and treatment (Past-treat) watersheds were located in the Slate Belt region of central North Carolina. Streams in this region are characterized by low baseflow, which was true for the streams draining both watersheds. The watersheds were chosen because they were in close proximity to each other (1.6 km apart), had beef cattle pastures in which the cattle had unlimited access to the streams, had similar soils and topography, had cooperative landowners, and had accessible monitoring locations.

The Past-cont watershed, located in the Jordan Lake watershed, encompassed 78 ha (Fig. 1a) of cattle pastures, woods, hay field (most of the “other” category), and cropland fields (Table 1). There were three ponds in this watershed, two of which were on the mainstem of the stream. These two ponds had the effect of reducing the stream discharge for small storms during dry periods when they had maximum storage.

Observation and landowner communication documented that between 30 and 40 beef cows and calves resided in the watershed and 30 to 40 more were cycled through pastures of the watershed during each monitoring period. Although it varied spatially and temporally, the average stocking rate was about 1.3 cows ha⁻¹, which is about the recommended rate in North Carolina. The cropland in the Past-cont watershed was planted in no-till corn in most years, except in 2010, when the ground was chisel plowed and disked before corn was planted. Runoff from the cropland had to pass through woodland and a pond before entering the watershed stream, which tended to minimize its effect on stream quality. Typically, the cropland received 336 kg ha⁻¹ of 17–17–17 fertilizer at plant along with urea–ammonium nitrate at 95 kg N ha⁻¹ as sidedress when corn was grown. Both the cropland and the beef cattle pastures had a history of chicken litter application. The hay fields and most

**Table 1. Drainage area characteristics for each site.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Overall area</th>
<th>Pasture</th>
<th>Cropland</th>
<th>Woods</th>
<th>Other†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past-cont</td>
<td>78.1</td>
<td>34.4</td>
<td>8.9</td>
<td>27.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Past-treat</td>
<td>54.5</td>
<td>39.5</td>
<td>0.0</td>
<td>7.3</td>
<td>7.7</td>
</tr>
</tbody>
</table>

† Home sites, hayfields, barns, ponds.
of the pastures received chicken litter in the spring about every other year at varying rates averaging 20, 32, and 44 kg ha$^{-1}$ of N, P, and K. The 27.3 ha of woods, which was located mostly on the steeper slopes of the southwest corner of the watershed, received no fertilizer.

Soils in the watershed were mostly Cid-Lignon complex (fine, mixed, thermic Aquic Hapludults). On the steeper slopes, soils were classified as Nanford (fine, kaolinitic, thermic Typic Kahapludults)-Badin (fine, mixed semiactive thermic Typic Hapludults) complex, with a silt loam in the top 178 mm of the profile and a silt clay at 178 mm or greater. Land slopes were generally less than 6% for the pasture and cropland and ranged up to 15% for the wooded land. Test results (Mehlich 3) for 11 soil samples collected in 2013 from fields and pastures throughout the watershed indicated that the average P (205 mg kg$^{-1}$) and K (123 mg kg$^{-1}$) were very high. Soil sampling in 2015 resulted in similar levels of P and K. The composition of the pasture grass was mixed but appeared to be predominantly tall fescue (Festuca arundinacea (Schreb.) Dumort., nom. cons.). The vegetation in the pastures was grazed regularly, although it did not appear to be overgrazed. The stream channel was generally 0.6 to 1.0 m wide and 0.6 to 1.2 m deep within sight of the monitoring station, but dimensions were unknown further upstream.

The Past-treat watershed encompassed 54.3 ha of largely beef cattle pasture (Fig. 1b) and a small area of woods and grass/hay (Table 1). The pasture grass appeared to be mostly tall fescue, which was often 75 to 150 mm tall indicating that grazing pressure was moderate. Observation and landowner confirmation documented nominally 75 cows and their calves were rotated on a monthly basis through the various pasture areas of the watershed. Counting a calf as 0.25 cows, the average grazing density was 1.2 cows ha$^{-1}$; however, cattle were rotated between pastures and two of the pastures extended beyond the watershed boundary, making the density difficult to determine accurately.

Land use analysis and the areal extent of the pasture were confirmed by observation. The majority of soil in the watershed was mapped as Georgeville silty clay loam (fine kaolinitic thermic Typic Kahapludults), but there was also areas mapped as the Cid-Lignon complex (28%), Georgeville silt loam (5%), and Nanford-Badin complex (5%). Land slopes in the watershed ranged from 3 to 6%. The stream draining the watershed, referred to as Mud Lick Creek, flowed much of the year drying up for periods during late summer and early fall. The stream channel was 0.1 to 0.8 m deep and 0.1 to 1.0 m wide in the upper third of the watershed, increasing to 0.6 to 1.0 m wide and 0.6 to 1.5 m deep near the outlet of the watershed. The main channel and upland channels were eroded and had several denuded areas before exclusion fencing was installed.

Exclusion fencing was installed during late September 2011 along approximately 520 m of the mainstem of Mud Lick Creek in the watershed. The fence line was generally 3.0 m from the top of the streambank on either side. An 83-m-long section near the middle of the pasture (area around #1 in Fig. 1b) and the uppermost 240 m of the mainstem were not fenced; the remaining 520 m was fenced. Hence, the cattle still had unlimited access to a considerable length of the stream channel but not to the deeper, incised downstream section, which was where the channel began to exhibit the properties of a stream. On this downstream section, cattle were allowed to graze the exclusion zone only twice per year for a short period of time (1 or 2 d).

The channel upstream from the exclusion was nominally less than 0.6 m deep and 1 m wide and had running water in it only during and immediately after precipitation events. None of the tributary channels was fenced to cattle. Fencing these channels likely would have benefited water quality to some extent, but it is unclear if the improvement would have been significant. The excluded area was intentionally minimized because landowners in this area resisted fencing areas of their pasture(s). Hence, evaluating the effectiveness of excluding cattle from less area and length than is commonly recommended was a high priority. Alternate water supplies were in place in the pasture before the start of the project, so none was added as part of this project.

In addition to the fencing, nutrient management was implemented in the pasture in the spring of 2011. Chicken litter had historically been applied to southern half of the pasture (Fig. 1b) along with 336 kg ha$^{-1}$ of 15–15–15 fertilizer. Biosolids from a municipal wastewater treatment plant were applied to the northern 16.4-ha section of the pasture (Fig. 1b) at a rate not to exceed 269 kg N yr$^{-1}$. Analyses for one application in April 2010 showed that 130, 116, and 23.5 kg ha$^{-1}$ of N, P, and potassium (K) were applied in the biosolids. The biosolids along with other historic fertilization resulted in very high soil test P levels (Mehlich 3, 369 mg kg$^{-1}$, or 7 times what is considered adequate) in representative soil samples collected in 2010. Hence, in the spring of 2010, the biosolids and animal waste applications were replaced by a granular N only fertilizer (21–0–0) applied at a rate of 70.6 kg N ha$^{-1}$ to about 80% of the pasture in the watershed. This fertilizer application rate was also applied in the spring of 2011, 2012, and 2014. In 2013, due mostly to wet weather, only 75% of the fertilizer was applied in April, with the rest applied in September. In 2015, 336 kg ha$^{-1}$ of 17–0–10 was applied once in March and once in August. Despite the cessation of P application, there appeared to be no decrease in the growth of fescue in the pasture. Soil pH averaged 5.9 for five samples collected in 2010 but dropped to 5.7 for soil samples collected in 2013. Likewise, soil test P only dropped from 369 mg kg$^{-1}$ (2010) to 328 mg kg$^{-1}$ (2013) even though no P was applied during the period. Further soil test P collected from the same areas in 2015 was 334 mg kg$^{-1}$. Although the nutrient management BMP started in the spring of 2010, for the purposes of this analysis, the post-BMP period started in October 2011 when the exclusion fencing was installed.

Water Quality Monitoring

Monitoring stations for the paired watersheds were installed early in 2008 at the outlet to each watershed. Each monitoring station consisted of a stream staff gauge and an automated sampler with an integrated flowmeter, which continuously measured water depth and stage. A stage–discharge rating table was developed for each station by measuring discharge, using standard stream gaging techniques (Buchanan and Somers, 1969), for a wide range of stages. During the first year of monitoring and occasionally thereafter, manual measurements were supplemented by those from an automated Doppler-based velocity meter installed in the stream channel. A recording rain gage was installed at the Past-treat monitoring station, which had no trees or other tall objects within 15 m of the rain gage.

Discharge proportional samples were collected during storm events, whereas during nonstorm periods sampling was inhibited.
by entering an “enable stage” 6 to 9 mm greater than the typical stage for baseflow during the period. Duplicate samples were collected during storm discharge, with one of the samples being placed in a preacidified (H₂SO₄ to pH < 2) bottle (odd-numbered bottles), and immediately thereafter the duplicate was placed in a non-acidified bottle. At least once every 2 wk the sampler was visited, and an equal-volume aliquot from each acidified and nonacidified sampler bottle was transferred to an appropriate laboratory bottle. The acidified samples were analyzed for N and P, and the nonacidified samples were analyzed for TSS using standard methods (Eaton et al., 1995). Grab samples were collected quarterly when there was discharge. These samples were filtered (0.45-µm pore membrane) immediately and analyzed for dissolved P (DP) concentrations using a direct colorimetric method in which a Quick Chem 8000 Automated Ion Analyzer was used (Eaton et al., 1995).

Because the storm samples remained at ambient temperatures in the samplers for longer than the time recommended by standard methods (Eaton et al., 1995), 17 grab samples were collected and split. Half of each sample was delivered to the laboratory within 4 h, and the other half was preserved by acidification (H₂SO₄ to pH < 2) and left in the sampler for 14 d. Statistical analysis of analytical results via a paired t test documented no significant difference between any analytes for the two sets of samples. These results agreed with Koolash and Chessman (1998), who reported that, when refrigeration or cooling to less than 4°C was impractical, acidification alone was a suitable method for the preservation of N forms in samples of surface water collected by automated samplers. Furthermore, Etheridge (2013) reported that concentrations of TP in samples collected from a coastal North Carolina stream did not change significantly when held unpreserved for up to 14 d in an automated sampler. Thus, these data documented that acidification (H₂SO₄ to pH < 2.0) alone preserved the N and P in samples held for 14 d in a sampler and that no preservation was needed for the TSS.

To quantify measurement uncertainty, several field blank, split, and duplicate samples were collected and analyzed. The quality assurance samples collected documented that the uncertainty for this project was well within ranges considered typical of storm event water quality monitoring (Harmel et al., 2006).

Concentrations of analytes in the 2-wk composite sample were multiplied by storm discharge during the 2-wk period to compute loads. If more than one storm occurred during the 2 wk, the same concentration data were used with the discharge from each storm to compute the storm loads.

About 3 to 6 wk of data for the Past-cont and Past-treat watersheds were lost due to the replacement of road culverts at the outlet of each watershed. In addition, either discharge or sample collection for several storms (<10% of the total) at each watershed was missed due to equipment failure, flooding, or other circumstances. Discharges for these events were estimated using rainfall–discharge regression relationships developed from storms that were monitored and concentrations using concentrations from monitored storms that were similar in season, peak discharge, and total rainfall accumulation. Estimated loads were then computed and used in computing export but not in determining BMP effectiveness. Overall, 107 and 183 storms of greater than 7.6 mm of rainfall accumulation occurred during the pre- and post-BMP periods, respectively. Of these, discharge monitoring and sample collection from 82 (77%) and 165 (90%) were successfully completed. Of these, there were 20 and 40 storms during the pre- and post-BMP periods that did not produce a “measurable load” from one or both watersheds (i.e., there was <30 m³ of discharge, which was not sufficient to initiate sample collection). More than 90% of these storms occurred during the growing season (May–September), and the other 10% were storms with total rainfall accumulations of less than 13 mm. These storms were not used in the statistical analysis to determine BMP effectiveness because they had little effect on overall loading and produced too little discharge for the BMPs to significantly affect.

Statistical Analysis

Statistical analyses were conducted on load data only because these data combine discharge and concentration to best represent the effect of the BMP. Because the load data were skewed, log₁₀ transformations were performed on all data before statistical analyses were performed. In addition, storms that had discharge but no sample collected either because there was not enough discharge or because there was an equipment malfunction at either paired station were deleted from the statistical analysis. For the remaining data, analysis of covariance (ANCOVA) was used to test whether the relationships between the Past-treat and Past-cont storm discharge and loads had changed significantly from the pre-BMP to the post-BMP period. If there was a significant change, the least square (LS) means test was used to quantify the change by comparing the pre- and post-BMP loads computed from the best-fit equations at the midpoint of the population of loads for the control watershed (Grabow et al., 1999). The 0.05 level of significance was used in all statistical analyses.

Results and Discussion

Sample Concentration Data

Box plots for storm N, P, and TSS concentrations during the pre- and post-BMP implementation periods are shown in Fig. 2. The median and interquartile range for TKN, NH₃–N, TP, and TSS concentrations in samples from the treatment watershed were greater than those for the control during the pre-BMP period, whereas during the post-BMP period the differences were much less. The decreases in median and/or interquartile range in concentrations for the treatment watershed from the pre- to post-BMP periods were greater than the control, whereas the differences in the control were more subtle, suggesting that the BMPs were effective at reducing TKN, NH₃–N, TP, and TSS export from the control watershed. Statistical analysis, however, was needed for confirmation. The median of the NOₓ–N concentrations in samples from the treatment watershed increased slightly from the pre- to post-BMP period, indicating that the BMPs were not effective at reducing NOₓ–N export. The median concentration of DP in grab samples from the treatment watershed decreased from the pre- to post-BMP period, whereas those from the control watershed were similar. These data suggest that the BMPs were also effective at reducing DP in discharge from the treatment watershed.

Rainfall, Discharge, and Export Rates

The durations of each period along with rainfall, discharge, and nutrient and sediment export rates for each monitoring station are shown in Table 2. The duration of monitoring was greater than 3 yr for both periods, which exceeds the minimum
recommended length (USEPA, 1997) for an evaluation with appropriate statistics. Annualized rainfall increased from the pre- to post-BMP period, but even during the post-BMP period it was still less than the 30-yr annual average of 1224 mm yr⁻¹. Two sample t tests conducted using monthly totals showed that rainfall during the pre-BMP period was not significantly different from the post-BMP period.

For the watersheds, about 80% of the total discharge occurred during or within 48 h of the end of precipitation events. For this reason and because nutrient and sediment export from nonpoint sources is storm event driven, only storm event data were used in the determination of BMP effectiveness. The total storm discharge and runoff to rainfall ratios for the Past-treat watershed were greater than the Past-cont during both the pre- and post-BMP periods (Table 2). Discharges from the two watersheds for individual storms are shown in Fig. 3a. The linear regression correlations between storm discharges from Past-treat and Past-cont were strong ($r^2 = 0.91$ for pre-BMP and 0.84 for post-BMP) and similar during the pre- and post-BMP periods. Analysis of covariance confirmed that there was no significant difference between the slopes of the regression lines, and the LS means test confirmed that there was no significant difference between the pre- and post-BMP discharges. Hence, the relationship between storm discharges from the watersheds remained the same from the pre- to post-BMP periods.

For the Past-treat watershed, annual export rates of TKN, NO₃–N, and TN were greater during the post-BMP period compared with the pre-BMP period (Table 2), which initially indicated that the BMPs were not effective at controlling the export of these N forms; however, export of all N forms, TP, and TSS from the Past-cont watershed were greater during the post-BMP compared with the pre-BMP period, which indicated a climatic effect. Further, the annual export rates for TKN, NH₃–N, TN, TP, and TSS were greater for the Past-treat compared with the Past-cont watershed during the post-BMP period, whereas only the TKN and TN rates were greater during the post-BMP period. Hence, simple arithmetic comparisons of preand post-BMP export rates could not be used to characterize the effectiveness of the BMPs, which emphasizes the need for using ANCOVA where data from the control watershed can be used to account for changes in climate.

The effect of the BMP was statistically shown by testing for significant differences in the linear relationships between the control (Past-cont) and treatment (Past-treat) loads for the pre-BMP and post-BMP periods. An example (other analytes were similar) of the change in relationships between storm event NH₃–N loads...
from the pre- to post-BMP periods is shown in Fig. 3b, where both the slope and intercepts of the regression lines for the pre- and post-BMP periods are considerably different. The ANCOVA tests whether the observed differences in intercept and/or slope are statistically significant given the variability and thereby documents the effect of the BMP. For NH$_3$–N, the variability in storm loads from the Past-treat watershed decreased dramatically from the pre- to post-BMP period, especially for smaller storms. This was expected because the fencing prevented fresh waste, the source of most of the NH$_3$–N, from being deposited in and on the banks of the stream channel, which would quickly be carried into the water during small- to medium-sized storms. The ANCOVA results for discharge and all the nutrients and TSS documented significant differences in slope and/or intercept from the pre- to post-BMP periods, indicating a possible BMP effect.

The LS means analysis was used to quantify the differences from the pre- to post-BMP periods. Significant decreases in TKN, NH$_3$–N, TN, TP, and TSS of 34, 54, 33, 47, and 60%, respectively, were determined, whereas there were no significant differences in discharge and NOx–N. These data show that the greatest effect was on NH$_3$–N, TP, and TSS, which was expected because the fencing prohibited the cattle’s direct access to the stream, thereby reducing fresh manure and urine, the source of most NH$_3$–N, in the water. The fencing also reduced streambank disturbance, thereby reducing streambank erosion and the associated TSS and TP export.

The added effect of nutrient management in the Past-treat watershed likely had little influence on NH$_3$–N and TSS export; thus, the reductions were attributed to livestock exclusion fencing alone. For TP, some of the reductions might be attributed to nutrient management because P application was eliminated during the post-BMP period; however, because there was a considerable reservoir of P in the soil, as documented by the soil testing results, the short-term effect of eliminating P application on P export via discharge was considered negligible. Further, although the number of samples was limited, the significant (according to a t test) decrease in DP concentrations in grab samples from the Past-treat watershed during the pre- to post-BMP periods indicated that much of the decrease in TP could be from a decrease in DP, which is most often associated with relatively fresh animal waste (Table 2); there was no decrease in DP from the Past-cont watershed. Thus, evaluation of nutrient management would require several additional years of monitoring.

The 34 to 60% reductions in N forms, TP, and TSS were less than those (75–82%) reported by Line et al. (2000) for livestock exclusion in a North Carolina dairy pasture; however, the pre-BMP grazing density and the width of the exclusion area in the Line et al. (2000) study were much greater than in the Past-treat

### Table 2. Duration of monitoring, rainfall, discharge, and export rates.

<table>
<thead>
<tr>
<th>Site</th>
<th>Duration</th>
<th>Rain†</th>
<th>Discharge</th>
<th>Runoff/rain‡</th>
<th>TKN§</th>
<th>NH$_3$–N</th>
<th>NO$_x$–N</th>
<th>Total N</th>
<th>Total P</th>
<th>TSS¶</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>yr</td>
<td>mm yr$^{-1}$</td>
<td>kg ha$^{-1}$ yr$^{-1}$</td>
<td>kg ha$^{-1}$ yr$^{-1}$</td>
<td>kg ha$^{-1}$ yr$^{-1}$</td>
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<td></td>
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<td></td>
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<tr>
<td>Past-cont</td>
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<td>907</td>
<td>118</td>
<td>0.15</td>
<td>3.31</td>
<td>0.78</td>
<td>1.34</td>
<td>4.65</td>
<td>2.20</td>
<td>273</td>
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<tr>
<td>Past-treat</td>
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<td>170</td>
<td>0.22</td>
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<td>1.67</td>
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<td>485</td>
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<tr>
<td>Post-BMP implementation period</td>
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<td></td>
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<tr>
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<td>7.33</td>
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<td>955</td>
<td>221</td>
<td>0.23</td>
<td>7.11</td>
<td>1.00</td>
<td>1.21</td>
<td>8.31</td>
<td>3.20</td>
<td>305</td>
</tr>
</tbody>
</table>

† Rainfall measured on-site and supplemented as needed with data from nearby NC State Climate Office station in Siler City, NC.
‡ Ratio of storm discharge to rainfall.
§ Total Kjeldahl nitrogen.
¶ Total suspended solids.
# BMP, best management practice.
†† Dairy cow pasture from Line et al. (2002).
‡‡ Beef cow pasture from Line (2015).

Fig. 3. (a) Storm discharge rates for the paired watersheds during the pre- and post-best management practice (BMP) periods. (b) Storm NH$_3$–N loads for the paired watersheds during the pre- and post-BMP periods.
pasture. In addition, the buffer in the Line et al. (2000) study was planted in trees and the beef cattle in the Past-treat pasture had an alternate water source during the pre-BMP period, whereas the dairy cows in Line et al. (2000) did not. The 47% reduction in TP was similar to that (20–50%) reported by Meals and Hopkins (2002) for exclusion fencing with a 2- to 5-m-wide protected zone along a stream where dairy and beef cattle were grazed. Decreases in TSS loads of 40 to 90% (Owens et al., 1996) and concentrations (Osmond et al., 2012) as a result of exclusion zones along streams located in pastures have been reported. Like this project, the decreases in TSS loads most likely were associated with a decrease in stream channel erosion because the rest of the pasture was untreated and the small vegetated buffer would have limited capacity to filter sediment from upland areas. The rapid growth of vegetation after the exclusion appeared to stabilize the streambed and banks quickly, with no additional measures needed.

In a New Zealand watershed, livestock exclusion fencing reduced sediment export by 85% and particulate P by 27% (Williamson et al., 1996). In Australia, exclusion fencing reduced sediment export by 90%, whereas no change was documented in P export (McKergow et al., 2003). The reason of the greater reductions in sediment export (85–90% vs. 60% for this study) could be that these streambanks were described as being heavily grazed and trampled or actively eroding and that the soils were either sandy and unconsolidated or derived from volcanic ash. The lesser P reduction (27 and 0% vs. 47% for this study) could be attributed to differences in soils and water quality monitoring.

### Summary and Conclusions

This project was designed to quantify the effectiveness of relatively narrow and limited livestock exclusion fencing implemented in a beef cattle pasture of North Carolina. Rainfall and discharge were monitored continuously at the outlets of two predominantly pasture watershed for at least 3 yr before and after the implementation of exclusion fencing in the treatment watershed. The discharge monitoring included collecting flow-proportional samples during storm events and analyzing them for TKN, NH$_4$–N, NO$_3$–N, TP, and TSS. Analysis of covariance conducted on the storm event load data from the pasture watersheds documented significant changes in all nutrients and sediment during the post-BMP period. Statistically significant reductions in TKN (34%), NH$_4$–N (54%), TN (33%), TP (47%), and TSS (60%) were determined using the LS means analysis on the storm event load data. Thus, these data show that a relatively narrow (~3 m from the streambank on either side) livestock exclusion zone on only the mainstem of the stream network can significantly reduce N, P, and TSS export from a pasture watershed.

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### References


