EFFECTS OF LIVESTOCK EXCLUSION AND STREAM RESTORATION ON THE WATER QUALITY OF A NORTH CAROLINA STREAM

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ABSTRACT. *The objective of this project was to document the effect of livestock exclusion and stream restoration on the water quality of two streams. Water quality monitoring was conducted prior to and after the installation of livestock exclusion fencing and varying degrees of stream restoration on the two streams. The monitored reaches of both streams were located in a dairy cow pasture with the same management in that, prior to fencing and stream restoration (pre-BMP) implementation, cows had unlimited access to the stream channel and after (post-BMP) the cows were fenced out. Rainfall and discharge were monitored continuously, and flow-proportional samples were collected upstream and downstream of the two monitored reaches during storm events. Non-storm grab samples were also collected at each monitoring station. Samples were analyzed for nitrogen, phosphorus, and sediment concentrations. Water quality monitoring occurred for approximately three years prior to (pre-BMP) and 1.7 years following (post-BMP) fencing and stream restoration. Livestock exclusion fencing and limited stream restoration on a 488 m long reach of one stream resulted in statistically significant reductions in total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), total phosphorus (TP), and total suspended residue (TSR) storm event loads of 41%, 59%, 54%, and 67%, respectively, compared to the pre-BMP loads. However, the proportion of the reduction attributable to exclusion fencing, stream restoration, or fewer cows in the pasture could not be determined. The second stream had a full restoration in that the streambed was raised, moved, and completely reconstructed over the entire 134 m long monitored reach. Post-BMP monitoring documented significant differences in NH_3-N (decreased), and NOx-N (increased) loads and no change in TKN, TP, TSR, and total nitrogen (TN) loads from the upstream to the downstream monitoring station. These results indicated that there was no significant treatment effect of the restored stream channel on instream pollutant loads.*

Keywords. *Best management practice, Stream restoration, Water quality monitoring.*

Dairy and beef cattle grazing on pastures is an important agricultural practice throughout the U.S., especially in the southeast where growing seasons are relatively long. These pastures, as well as those in many other states, are often located on land adjacent to or encompassing streams. In many cases cattle, have unlimited access to streams, which can result in increased nitrogen, phosphorus, and sediment loading to surface waters (Line et al., 2002; Owens et al., 1989). Cattle waste deposited in and near the stream is easily transported to the stream channel during storm events, while grazing and hoof traffic on the beds and banks of streams inhibits vegetation growth and dislodges soil, thereby increasing erosion potential. Excessive channel erosion and nutrient loading can result in degraded streams with poor habitat for some aquatic organisms.

Best management practices (BMPs) such as livestock exclusion fencing and alternate water supply have been shown to reduce nutrient and sediment loading from pastures to streams. Exclusion fencing along with the establishment of a 15 m buffer was shown to reduce total nitrogen, phosphorus, and sediment loading from an intensively grazed dairy cow pasture in North Carolina by 75%, 76%, and 82%, respectively (Line et al., 2000). In Vermont, Meals and Hopkins (2002) documented a 20% to 50% reduction in total phosphorus loading as a result of installing primarily livestock exclusion fencing to create a 2 to 5 m wide protected zone along a stream in a watershed where dairy and beef cattle and sheep were grazed. In Ohio, monitoring of runoff from a small, pastured watershed for 13 years documented that livestock exclusion fencing reduced sediment yield by up to 40% (Owens et al., 1996). In Pennsylvania, Galeone et al. (2006) reported that installing exclusion fencing to provide a 1.5 to 3.7 m wide buffer was effective in reducing nitrogen, phosphorus, and sediment export from a dairy cow pasture; however, dissolved phosphorus export increased. Further, the authors stated that nutrient management was needed in concert with fencing to control all species of nitrogen and phosphorus export.

While exclusion fencing eliminates the livestock's physical stressors on the stream, thereby allowing vegetation to grow and help stabilize the channel, additional measures may be needed for severely eroded stream channels, such

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as stream restoration to stabilize the stream channel and restore in-stream habitat for aquatic organisms. This stream restoration involves reconstructing the pattern and profile of the stream channel according to geomorphic principles (Rosgen, 2007) and installing structures to protect the stream's bank and bed. While this type of stream restoration has become accepted and quite common, monitoring data on the water quality benefits of the practice are sparse and not definitive. For example, researchers have reported that restored first-order to third-order streams have the highest potential to reduce nitrogen levels in stream discharge (Craig et al., 2008; Ensign and Doyle, 2005), but no monitoring data were provided to document reductions in actual streams. Further, Kaushal et al. (2008) reported that denitrification in riparian areas was enhanced when floodplains were "reconnected" to surface water flow, which increases groundwater-surface water interactions in the hyporheic zone. However, these findings were based on only limited monitoring data and anecdotal evidence.

To quantify stream restoration effectiveness, reach studies with frequent sampling during both storm and base flow conditions over multiple years are required to derive adequate estimates of nutrient and sediment fluxes. Filoso and Palmer (2011) monitored base flow and storm flow over three years for eight low-order stream reaches in Anne Arundel County, Maryland. The study reaches included six restored stream reaches and two unrestored control reaches ranging from 152 to 457 m in length. The results suggested that two of the six restored reaches were clearly effective in reducing the export of total nitrogen (TN) to downstream waters. Further, the capacity of stream restoration projects to reduce fluxes during periods of elevated flow was essential because most of the observed total suspended solids (TSS) and nitrogen export occurred during high water conditions. Filoso and Palmer (2011) also reported that lowland channels were found to be more effective than upland channels, and projects that restored wetland-stream complexes were observed to be the most effective. However, the storm event monitoring was fixed-interval and not flow-proportional, and there was no pre-restoration monitoring data, so they could not conclude with confidence that the upland streams were effective. Thus, while limited monitoring data suggest that restored streams may be effective in reducing instream nitrogen and phosphorus levels, a need exists for more intensive monitoring of restored stream reaches to evaluate the effectiveness of the practice.

The objective of this project was to document the effectiveness of stream restoration for reducing in-stream nitrogen, phosphorus, and suspended sediment loads. A secondary objective was to assess the effect of the combination of livestock exclusion fencing, a wide riparian buffer, and stream restoration on the water quality of a stream in a dairy cow pasture.

METHODS

The project was located in the Carolina Slate Belt area of the Piedmont physiographic region of North Carolina (35.786° N, 79.852° W). The area contains low to moderate gradient streams with mostly cobble and boulder substrates. The valleys are moderately sloped (5% to 20%) with well-developed colluvial wash-slopes or valley toe-slopes. The majority of soils in the project area are classified as Badin-Tarrus complex (8% to 15% slope), which are described as silty clay loam. Depth to bedrock is 102 to 152 cm, and the erodibility of the soils is characterized as a management concern. Soil samples, collected from riparian areas before the start of the project, had a mean phosphorus index (PI) of 51.5, as determined by the North Carolina Department of Agricultures' Soils Analysis Laboratory. In April 2013, two soil samples, collected from the riparian corridor along the monitored reach of Back Creek, had PI values of 30 and 23. These results indicate that the phosphorus levels in the riparian soil are moderate to low compared to many cropland areas of North Carolina.

The stream reaches monitored were on Back Creek and a tributary stream, referred to as North Branch, both of which flowed through a pasture where adult (>2200 kg) dairy cows had unlimited access to the streams from 2006 to 2012 (fig. 1). During this period, the vegetation was often grazed close to the ground, and the stream channel was disturbed by cow traffic (fig. 2). In the summer of 2012, livestock exclusion fencing was installed along Back Creek and North Branch, and stream restoration was conducted on both streams (fig. 3).

BACK CREEK

Land use in the drainage area upstream of the Back Creek reach was predominantly beef cattle pasture and woods/forest in 2007, as determined from aerial photographs and observation (table 1). The beef cattle grazing density was light to moderate, with cattle having unlimited access to the stream. The 21 ha of land draining to the stream between the stations was all cropland and pasture, which did not change significantly from the pre- to the post-BMP period, except that the pasture area between the stations was generally abandoned as a pasture, with part of it fenced and allowed to become a riparian buffer and the other part temporarily pastured. During the pre-BMP period, the pasture between the stations was grazed moderately to heavily by dairy cows. The stocking density was difficult to quantify, as dry cows and heifers were moved and removed from the grazing area, but was estimated at about 2.5 cows ha^{-1}. The stream channel in the monitored reach had an average slope of 0.006 m m^{-1} and was severely incised in some sections (fig. 2) but was stable in others.

During the post-BMP period, livestock exclusion fencing reduced the pastured area between the monitoring stations from 14.2 to 2.0 ha and provided at least a 15 m wide buffer between the remaining pasture and the 488 m long stream channel (fig. 1). The cows were completely excluded from the east side of the monitored reach and from about half of the length of the west side. A lush stand of volunteer vegetation, mostly grass species, grew in the buffer and eventually in the stream channel. Stream restoration efforts were purposely limited to in-channel work and augmentation of the existing stream channel such that "priority 1" stream restoration (moving and reconstructing the stream channel) occurred on only about half of the monitored

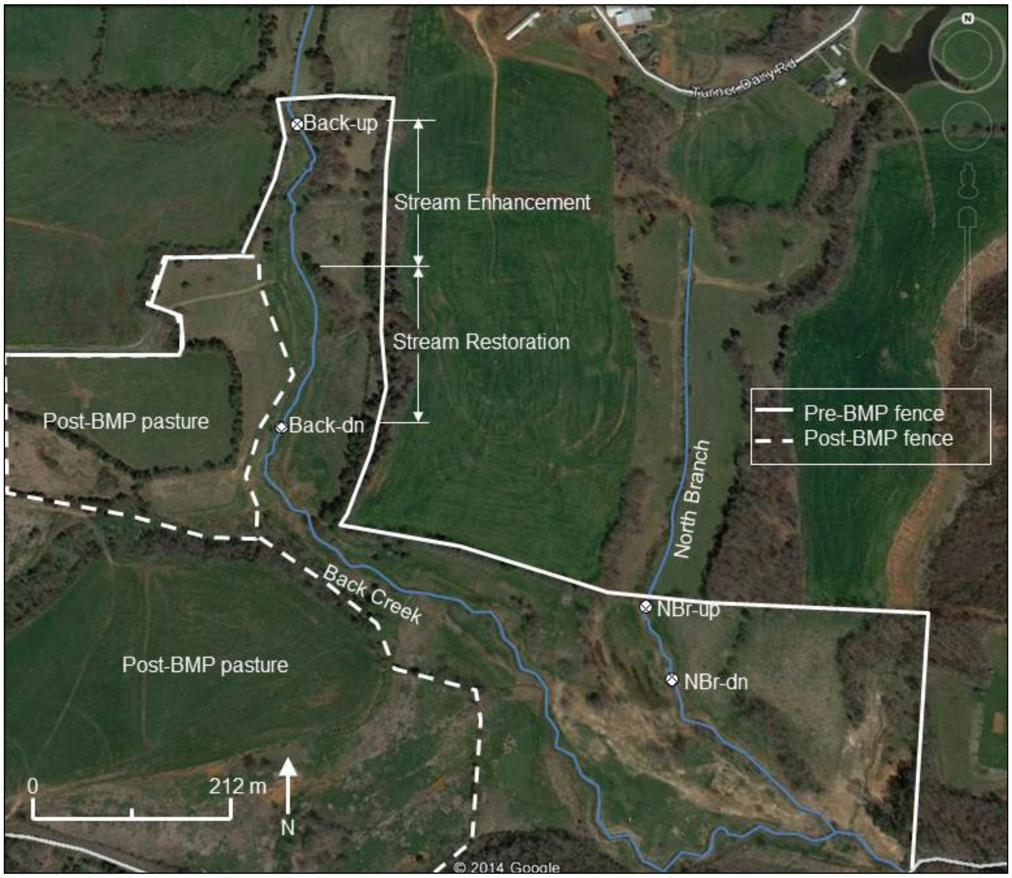


Figure 1. Map of the pasture, streams, and monitoring stations.

Figure 2. Stream channels for Back Creek (left) and North Branch (right) during pre-BMP period.

reach (fig. 1). In the restored section, the dimensions, pattern, and profile of the restored stream channel were designed to a Type B4c stream (Rosgen, 1996) using hydraulic relationships and morphological dimensionless ratios of nearby reference reaches as a guide (NCDENR, 2009). Structures in the restored section included 23 log vanes located primarily on the outside banks of curves, one rock cross vane, four log sills in the stream bed, and brush toe protection. The restored stream pattern and positions of structures were similar to North Branch, which is shown in figure 4. On the remaining length of the reach, channel "enhancement" was conducted, which included construction of in-stream structures and stabilization of existing banks. Hereafter, the period after the combination of fencing and stream restoration/enhancement was implemented will be referred to as the post-BMP period and the period before as the pre-BMP period.

While all of the pasture along the east side of the Back Creek reach was eliminated by the fencing, there remained

Figure 3. Restored stream channels at Back-dn (top) and NBr-up (bottom) monitoring stations.

Table 1. Drainage area characteristics for each site pre-BMP.

Site	Location		Watershed Area (ha)	Pasture (%)	Cropland (%)	Woods (%)	Other[a] (%)	Mean Slope[b] (%)
	Latitude	Longitude						
Back-up	35.788	-79.853	262	47.0	3.5	45.0	4.5	9.7
Back-dn	35.784	-79.852	283	46.8	7.8	41.1	4.3	9.7
NBr-up	35.782	-79.847	298	34.2	8.0	48.1	10.7	10.5
NBr-dn	35.781	-79.847	300	34.3	8.0	48.0	10.7	10.5
Back-end	35.779	-79.845	705	56.0	6.1	40.5	9.4	10.1

[a] Home sites, barns, and surface water.
[b] Average slope of the watershed area.

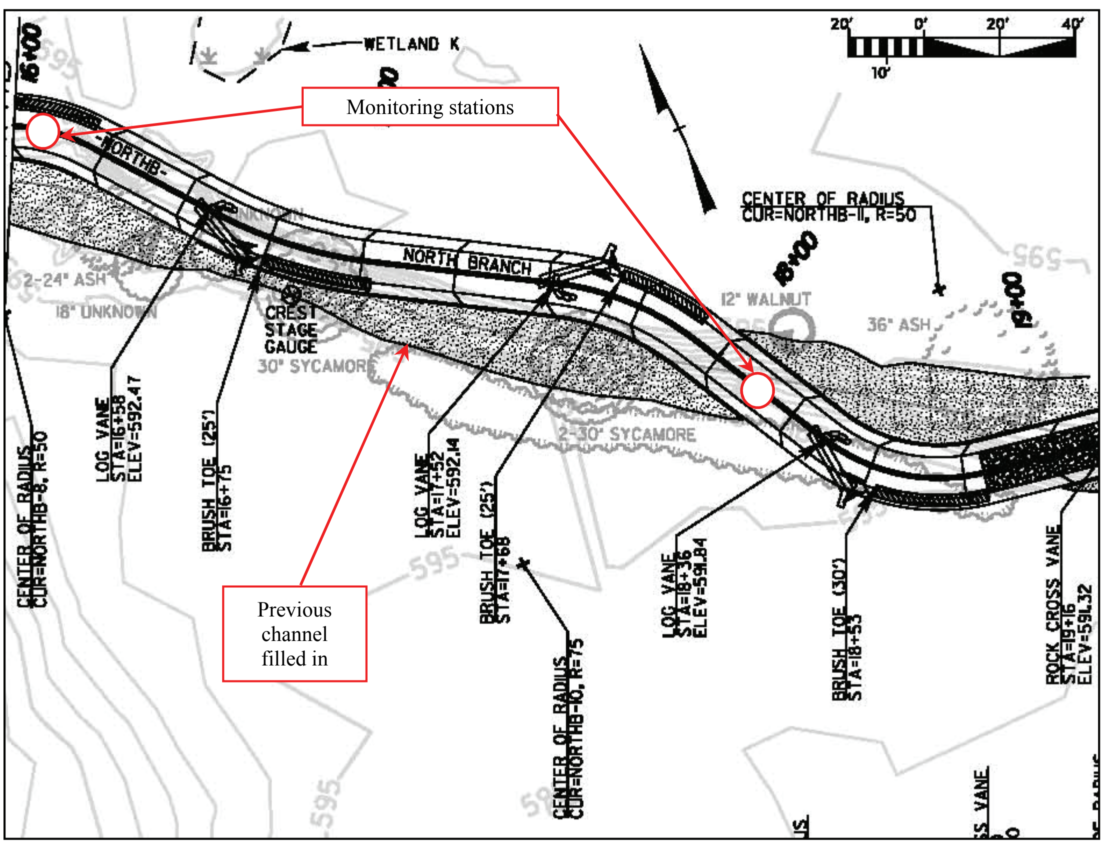


Figure 4. Schematic of restored reach of North Branch stream.

a pasture area along the west side of the stream reach for a distance of about 250 m upstream from the downstream end of the monitored reach (fig. 1). The pasture fence still excluded the cattle from within about 15 m of the stream; hence, the cattle had no direct access to the stream. In November 2013, 32 feeder cows (880 to 1300 kg) were observed in this pasture (~13 cows ha^{-1}) and were observed several more times until they were removed in March 2014. During this period, grass was grazed relatively short, and there were obvious signs of cattle activity. During the summer of 2014, it appeared that ~30 young cattle (400 to 800 kg) had access to this pasture as part of a larger pasture (~2 cows ha^{-1}, assuming young cattle = 0.5 × adult cow) but were rarely observed in the pasture area and likely spent little time there, as the grass was tall. Thus, cow density in the whole area between the monitoring stations decreased from 2.4 cows ha^{-1} during the pre-BMP period to about 0.6 cows ha^{-1}.

NORTH BRANCH

Prior to restoration, the North Branch stream reach had little to no sinuosity and was moderately incised. Although the bed profile was vertically stable due to downstream limits on degradation, there was little variation in the profile features. Pools and riffles were almost indistinguishable from runs and glides, and therefore the stream reach provided little to no habitat for aquatic organisms. Bed material exhibited a strong bimodal distribution, with 32% of the surface bed material composed of silt and sand. In 2012, cattle were fenced out of the area, and a "priority 1" stream restoration was conducted on the entire 134 m long monitored reach. This included raising the stream bed elevation to reconnect it with the floodplain, changing the pattern and profile of the channel, and installing structures such log vanes and rock cross vanes (fig. 3). The restored channel alignment was established to provide maximum conformance to the existing valley form. Where stream channels had been previously moved away from the low point in the valley, the alignments repositioned the channel. Where the valley width narrowed, the channel sinuosity was reduced. Where rock outcrops were present at the surface, channel alignments were kept near their pre-restoration locations (NCDENR, 2009).

Two monitoring stations were established about 134 m apart in August 2007 on North Branch (fig. 1). The drainage area to the upstream station (NBr-up) was 298 ha, consisting of mostly pasture and woods in 2007 (table 1). About 2 ha of pasture drained to the stream between NBr-up and NBr-dn in 2007. Land use appeared to change little between 2007 and 2014, except that the 2 ha of land between the stations was fenced and converted from pasture to riparian area. The average slope in the drainage areas to NBr-up and NBr-dn was 10.5% (table 1). Soils in the drainage area to the stations were similar to those of the Back Creek stations.

During the pre-BMP monitoring period, the stream channel between the monitoring stations was incised (fig. 2), and cattle had unlimited access. The channel width ranged from 1 to 9 m, with an average bed slope of 0.0045 ft ft^{-1}. There was some vegetation along portions of the channel banks; however, the dairy cattle trampled the banks wherever they could easily access.

In 2012, fencing was installed to exclude cattle from the stream, and in 2013 a "priority 1" stream restoration was conducted on the North Branch stream. Because the stream channel was moved and completely reshaped, the NBr-dn station could not be located exactly where the pre-BMP monitoring station had been, but it was located as close as possible while still being located where accurate monitoring could be accomplished with reasonable certainty. After restoration, the stream length from station to station was found to be 134 m according to a land survey.

WATER QUALITY MONITORING

Upstream and downstream monitoring stations were installed on Back Creek and North Branch (fig. 1) in 2007 for pre-BMP monitoring and then again in 2013 for post-BMP monitoring. The four stations were installed as close as possible to the same locations during the pre- and post-BMP monitoring periods (fig. 1); however, both stream channels were moved during restoration, and thus the stations could not be installed in exactly the same locations. Each station was located in a relatively straight section of channel just downstream of a pool in a stable riffle. Each station consisted of an automated sampler with an integrated flowmeter and a stream staff gauge. The sampler's flowmeter readings of stage were compared to the staff gauge during each visit to adjust the flowmeter for drift and assess the accuracy of the previous two weeks of stage readings. A tipping-bucket rain gauge was installed at one monitoring station on Back Creek and at one station on North Branch to record rainfall accumulation continuously. When one of the rain gauges was clogged or malfunctioned, data from the other gauge were used; otherwise, data from each gauge were used for the appropriate stream reach.

Stage-discharge rating tables were developed for each site and entered into the samplers, enabling them to monitor discharge continuously and collect flow-proportional samples. The rating tables were developed from a combination of depth and velocity measured with Doppler flowmeters and manual discharge measurements using a pygmy-type stream current meter with standard stream gauging techniques (Buchanan and Somers, 1969). The Doppler flowmeters measured velocity only over a vertical or horizontal portion of the stream cross-section; hence, these measurements over a range of stages were adjusted based on the one or two manual discharge measurements made in the range. The stream cross-section at each monitoring station was surveyed to provide cross-sectional area data to aid in the development of the stage-discharge rating table. Periodic discharge measurements at all four sites were made throughout the monitoring period to update and more accurately establish the rating tables. The differences between the growing (vegetated) and dormant (no vegetation) seasons' rating tables were significant; thus, new ratings were developed for each season.

During both the pre- and post-BMP periods, the monitoring procedures were the same in that the automated samplers were programmed to collect flow-proportional

Table 2. Methods of sample analysis.

Parameter	Method	Reportable Limit (mg L^{-1})
Volatile residue (VR)	EPA 160.4[a]	12
Fixed residue (FR)	EPA 160.4[a]	12
Total suspended residue (TSR)	SM 2540 D[b]	6.2
TP	EPA 365.1[a]	0.02
TKN	EPA 351.2[a]	0.20
NH_3-N	EPA 350.1[a]	0.02
$NO_3 + NO_2$ (NOx-N)	EPA 353.2[a]	0.02

[a] EPA (1983).

[b] Eaton et al. (1995).

Table 3. Results of assessment of extended holding time.

Statistic	TKN (mg L^{-1})	NH_3-N (mg L^{-1})	NOx-N (mg L^{-1})	TP (mg L^{-1})	TSR (mg L^{-1})
Delivered to laboratory within 24 h					
Mean	0.91	0.12	1.86	0.17	359
Median	0.69	0.07	0.74	0.10	169
Range	0.1 to 2.2	0.0 to 0.3	0.0 to 8.3	0.0 to 0.7	42 to 940
Count	7	8	8	8	7
Delivered after 14 days in sampler					
Mean	0.93	0.15	1.97	0.18	385
Median	0.69	0.10	0.73	0.13	151
Range	0.1 to 2.3	0.0 to 0.3	0.0 to 9.0	0.1 to 0.7	40 to 934
Count	7	8	8	8	7

samples during storm events only. This was accomplished by entering an enable level (set ~4 to 6 mm above the current level during most visits) above which the sampler collected samples based on discharge and below which no samples were collected. During storms, samples were collected from the stream via a sampler intake that was located in a well-mixed section of the stream channel.

Baseflow grab samples were collected monthly with some exceptions during the pre-BMP period, with ten occurring during the growing season (May to October) and ten during the dormant season (November to April). Post-BMP grab samples were collected quarterly. Samples were not collected when discharge was low (less than 50 mm deep). Samples were collected by plunging an open bottle to the horizontal and vertical center of flow and allowing it to fill, taking care not to disturb the channel bed or bank.

To preserve storm samples, odd-numbered bottles in the sampler were pre-acidified (with H_2SO_4 to bring a full bottle to pH < 2) to inhibit biological activity in the samples until retrieval. Even-numbered bottles received no acid. Every two-weeks, samples from the sampler were retrieved, composited, and transported to a state-certified laboratory for analysis, making sure to keep subsamples from odd- and even-numbered bottles separate. Acid (H_2SO_4 to bring a full bottle to pH < 2) was also added to grab samples upon collection. In the laboratory, all samples were refrigerated (1°C to 4°C) until analysis. Composite samples from odd-numbered sampler bottles (pH < 2) were analyzed for TKN, NH_3-N, NOx-N, and TP, while even-numbered bottles were analyzed for total suspended residue (TSR), volatile residue (VR), and fixed residue (FR). All sample analysis was conducted by a state-certified lab using the standard methods shown in table 2.

QUALITY ASSURANCE

Analysis results of three field blanks documented concentrations less than the reportable limit for all analytes. Duplicates were made by shaking and transferring portions of the sampler bottles to laboratory containers and then repeating this from the same set of sampler bottles. Differences in the duplicate samples ranged from 4.7% to 16.0%, which was well within the range of the cumulative probably uncertainty (3% to 35%) reported by Harmel et al. (2006) for storm water quality concentrations in stream monitoring.

Because the storm samples collected by the automated sampler had the potential to sit in the sampler for two weeks prior to delivery to the laboratory, thereby not meeting preservation requirements of standard methods (Eaton et al., 1995), eight trial grab samples were collected from the streams to assess the effects of an extended time at ambient temperatures. The grab samples were collected at various discharges to mimic the nutrient and TSS concentrations found in storm samples. A grab sample of the same volume as the storm samples was collected, and acid (H_2SO_4 to bring pH < 2.0) was added. Half the sample was then left in the automated sampler for two weeks, and the other half was cooled to 1°C to 4°C and delivered to the lab within 24 h for analysis of TKN, NH_3-N, NOx-N, and TP. The same procedure was conducted for another grab sample, except that nothing was added and it was analyzed for TSR. At the laboratory, all standard methods of preservation and analysis (Eaton et al., 1995) were followed. The trial was conducted during warm weather months and for the maximum of 14 days to test the worst-case scenario, as cool weather months would have temperatures similar to refrigeration. Summary statistics for results from samples delivered to the lab within 24 h are shown in the upper half of table 3, while those delivered after two weeks are shown in the lower half. Overall, there was a considerable range in concentrations for each analyte, and there appeared to be no consistent trend of increased or decreased concentrations with the extended time before delivery to the lab. Paired t-tests conducted on the data for each analyte showed that there were no significant differences (lowest p-value = 0.29) between the 24-hour and 14-day analysis results at the 0.05 level of significance. This result agreed with Kotlash 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 nitrogen forms in samples of surface water collected by automated samplers. Further, Etheridge (2013) reported that TP concentrations in samples collected from a North Carolina stream did not change significantly when held unpreserved for up to 14 days in an automated sampler. Thus, these data showed that the maximum 14-day holding time in the samplers did not significantly affect sample concentrations, thereby confirming the validity of this preservation method.

DATA ANALYSIS

Sample analysis and discharge data were used to compute storm event pollutant loads for each station. Pollutant export rates were computed by summing the loads and dividing by the drainage area associated with the monitoring station and then by the monitoring duration. To minimize skew in the distribution of the data, all data used in the statistical analyses were log-transformed. Because this transformation produced an error when storm loads were zero and there would no effect of BMPs when there was no discharge, these data were excluded from the statistical analyses. This occurred for less than 10% of the storms during the pre-BMP period and for none of the storms during the post-BMP period. In addition, data for storms in which there were problems in both discharge monitoring and sample collection from one or both stations were omitted from the statistical analysis. Data for storms that were very large (discharge overflowed the stream banks and was much greater than the stage-discharge rating) were deleted because the uncertainty in the load calculation was high.

The statistical tests used to analyze the data depended on the experimental design (Spooner and Line, 1993). For Back-up and Back-dn, a paired watershed approach using analysis of covariance (ANCOVA) was employed because the land use and management in the drainage area to the upstream station appeared to remain relatively unchanged; hence, it could be used as a control. For NBr-up and NBr-dn, a paired watershed approach could not be used because too few storms were successfully monitored at NBr-up during the pre-BMP period. Observation indicated that this approach may not have been appropriate anyway due to the significant amount and variability of nutrients and sediment coming from the NBr-up drainage area. Hence, a paired t-test was used to compare the post-BMP loads at NBr-up and NBr-dn to determine if the BMPs were reducing loads. This approach was appropriate because the data were paired, meaning there were loads for the same events. In addition, a paired watershed approach using Back-up as the control with NBr-dn to assess the changes from pre- to post-BMP periods was used.

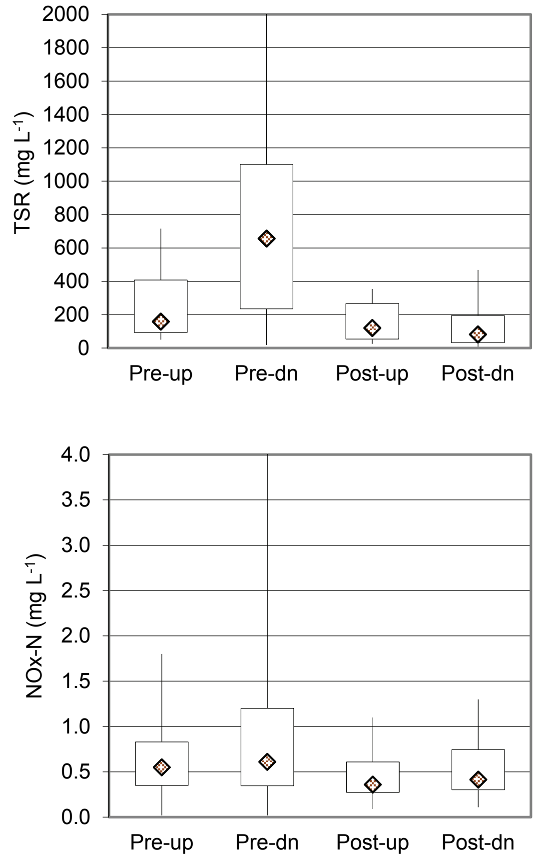


Figure 5. Storm event TSR (top) and NOx-N (bottom) concentrations at Back-up and Back-dn during pre- and post-BMP periods.

RESULTS AND DISCUSSION

The pre-BMP monitoring was conducted during two periods: from June 2007 to March 2009 and from October 2010 to June 2012. During both pre-BMP periods, limited resources and cow activity resulted in relatively high uncertainty in the discharge data for 48 storms at the Back-up station. For this reason and because the upstream watershed remained basically unchanged from pre- to post-BMP, rainfall-discharge relationships developed from the 70 storms monitored during the post-BMP period were used, with rainfall measured during the pre-BMP period, to estimate storm discharge for the 48 storms occurring during the pre-BMP period that had high uncertainty in their discharge measurements. As a check, discharge was estimated for the successfully monitored storms, and there was good agreement (r^2 = 0.93) between the estimated storm discharges and the monitored discharges for 28 pre-BMP period storms.

STORM SAMPLE CONCENTRATIONS

Box plots of storm sample TSR and NOx-N concentrations at Back-up and Back-dn are shown in figure 5. During the pre-BMP period, the median and interquartile range for TSR in Back-dn samples were greater than those for Back-up, while during the post-BMP period, the median and interquartile range were similar or less at Back-dn compared to Back-up. Medians and interquartile ranges for TKN, NH_3-N, and TP (not shown) followed the same trends as TSR, while only NOx-N had a higher median and interquartile range at Back-dn compared to Back-up during the post-BMP period. A greater median and range in concentrations of TSR, TKN, NH_3-N, and TP in the pre-BMP period was expected, as spikes in concentrations can occur when cows are in and immediately around the stream. After fencing to exclude cattle from the stream, this effect was reduced. For NOx-N, the differences in medians and interquartile ranges for Back-up and Back-dn during the pre-BMP compared to the post-BMP period were much less, indicating that the BMPs implemented had little effect on storm event NOx-N concentrations.

Because only nine pre-BMP storm samples from NBr-up were collected, these data were not included. However, comparisons during the post-BMP period only showed that concentrations at NBr-dn were less than those at NBr-up (i.e., NH_3-N in fig. 6), except for NOx-N (fig. 6), which was slightly greater at NBr-dn. Further, the differences in the means and medians between NBr-up and NBr-dn were generally small, indicating that the differences may not be significant.

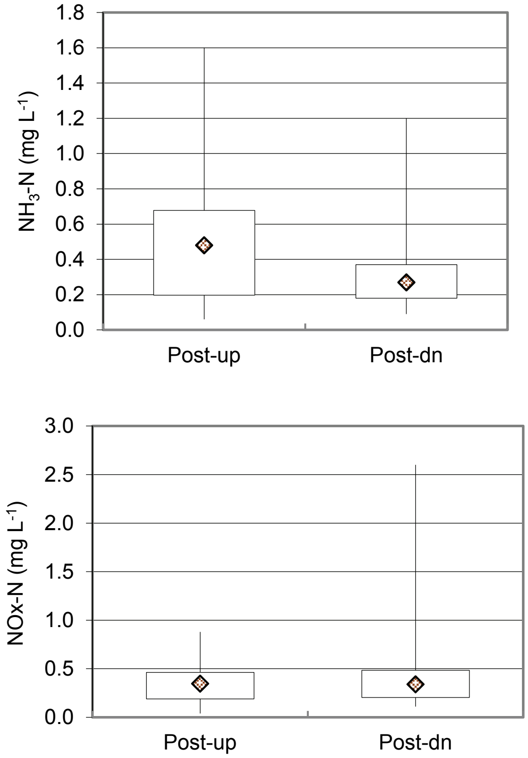


Figure 6. Concentrations of storm event NH_3-N (top) and NOx-N (bottom) at NBr-up and NBr-dn during the post-BMP period.

RUNOFF AND POLLUTANT EXPORT RATES

Annual rainfall, discharge, and pollutant export are shown in table 4. Because of few samples and poor discharge data, export rates for NBr-up during the pre-BMP period were not computed. The total annualized rainfall for each period is shown in table 4, column 3. The 30-year average annual rainfall for Randolph County was 1158 mm. Although total rainfall during the pre-BMP period was less than during the post-BMP period, analysis of variance documented that there was no significant (0.05 level) difference in rainfall between the two periods. The pre-BMP period included the summer of 2007, which was very dry. In fact, there was no discharge at any of the four stations from July to October 25, 2007.

For the Back Creek stations, annual storm discharge was greater during the post-BMP period compared to the pre-BMP period (table 3, column 4). Similarly, the ratio of discharge/runoff to rainfall was greater during the post-BMP period for both stations and for the area between the stations ("Between" in table 3). The runoff to rainfall ratio for the area between the stations was expected to decrease, as the removal of the cows should have increased vegetation and infiltration (through less compaction of the soil), both of which typically result in less runoff (Line et al., 2000). However, this effect was likely overwhelmed by the drought of 2007. To add perspective, the pre- and post-BMP runoff to rainfall ratios for the area between the stations were similar to the 0.31 to 0.53 ratios reported by Line et al. (2000) for an intensively grazed dairy cow pasture in Gaston County, North Carolina.

The export rates at Back-dn were greater than at Back-up during both the pre- and post-BMP periods (table 4); however, the differences during the post-BMP period were much less than during the pre-BMP period. Hence, the export rates from the area between the stations for the six pollutants decreased by 55.8% to 87.5% from the pre- to post-BMP periods. These decreases are similar to those for TKN, TP, and suspended solids (75.6% to 82.3%) reported by Line et al. (2000) for a dairy cow pasture in North Carolina. The similar reductions indicated that stream restoration, reduced cow grazing density (from 2.4 to 0.6 cow ha^{-1}), and the large riparian buffer added little to the effectiveness of livestock exclusion fencing alone. Further, the fact that the buffer between the pasture that was still in the drainage area post-BMP was 15 to 20 m and the buffer width in the Line et al. (2000) study was 15 m indicated that the minimum buffer width may be the most critical factor in determining the pollutant reducing effectiveness of livestock exclusion fencing.

The TSR export rate at Back-dn during the pre-BMP period was more than twice the rate at Back-up, whereas during the post-BMP period the TSR export rates at Back-up and Back-dn were nearly equal. While the percentage of the TSR export originating from upland versus the channel for both periods was unknown, stream channel erosion must

Table 4. Summary of runoff and pollutant export rates.

Site	Duration (years)	Rainfall (mm $year^{-1}$)	Discharge (mm $year^{-1}$)	Runoff to Rainfall Ratio[a]	TKN (kg ha^{-1} $year^{-1}$)	NH_3-N (kg ha^{-1} $year^{-1}$)	NOx-N (kg ha^{-1} $year^{-1}$)	TN (kg ha^{-1} $year^{-1}$)	TP (kg ha^{-1} $year^{-1}$)	TSR (kg ha^{-1} $year^{-1}$)
Back Creek pre-BMP										
Back-up	2.98	1015	81.0	0.08	2.59	0.30	0.54	3.13	0.91	321
Back-dn	2.98	1015	99.0	0.10	4.15	0.55	1.00	5.15	1.84	784
Between	2.98	1015	307	0.30	23.7	3.62	6.74	30.4	13.5	6596
Back Creek post-BMP										
Back-up	1.66	1211	209	0.17	4.16	0.49	0.98	5.14	1.43	431
Back-dn	1.66	1211	220	0.18	4.43	0.51	1.13	5.56	1.54	460
Between	1.66	1211	472	0.39	7.84	0.74	2.98	10.8	2.91	825
			Reduction between[b] (%):		66.9	79.6	55.8	64.5	78.4	87.5
North Branch pre-BMP										
NBr-up	2.95	1014	na	na	na	na	na	na	na	na
NBr-dn	2.95	1014	103	0.10	5.61	0.61	0.53	6.14	1.92	2042
North Branch post-BMP										
NBr-up	1.59	1180	269	0.23	11.7	1.32	0.74	12.4	3.44	1922
NBr-dn	1.59	1180	269	0.23	11.6	1.07	0.92	12.5	3.28	2120

[a] Ratio of storm discharge to total rainfall.
[b] Reduction for the area between the stations from pre-BMP to post-BMP.

have been greatly reduced by the stream restoration and enhancement because downstream TSR export was only slightly greater than upstream TSR export during the post-BMP period. Observation indicated that the stream channel was neither aggrading nor degrading and some upland erosion was still occurring on the remaining pasture, which could account for much of the slight increase in TSR export from Back-up to Back-dn.

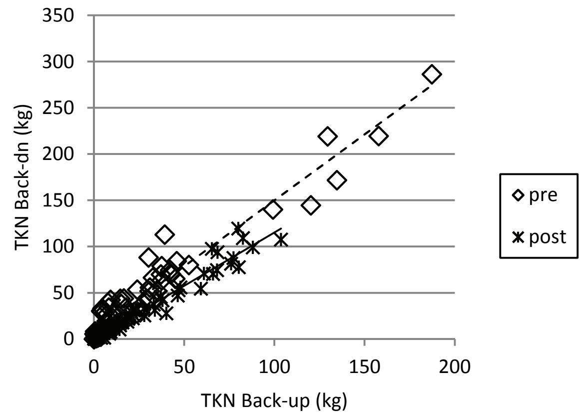
For the North Branch stations, the runoff to rainfall ratio was similar to the Back Creek stations. However, export rates for TKN, NH_3-N, TN, TP, and TSR were greater for the North Branch stations than for the corresponding Back Creek stations during both the pre- and post-BMP periods. This was expected, as the North Branch drainage area contains a large dairy cattle operation upstream of NBr-up, whereas the Back-up watershed contains a beef cattle pasture, which employed less intensive grazing. Like Back Creek, export rates for NBr-dn also increased from the pre- to post-BMP periods, which in combination with the Back Creek data indicated a weather/drought effect. During the post-BMP period, the TKN, NH_3-N, TN, and TP export rates decreased from upstream to downstream; however, the NOx-N and TSR rates increased.

Statistical Analyses

The statistical analyses were conducted on storm event loads. For the Back Creek paired watershed approach, changes in the relationships between loads at Back-up and Back-dn were the basis for documenting the effectiveness of the restoration (BMPs). The correlations for TKN and TP are shown in figure 7 as examples. As shown, the correlations were strong (r^2 > 0.90); however, the differences between the pre- and post-BMP periods were relatively small. Both of these observations were expected given that more than 92% of the drainage area to Back-dn was included in Back-up.

Table 5 contains the results of the ANCOVA for Back-up and Back-dn. For discharge, 76 pre-BMP storms and 70 post-BMP storms were used in the analysis. For other parameters, the counts were slightly less depending on whether the load for a storm for that parameter was 0 kg or if the storm was deleted due to no sample being collected. Columns 3 and 4 contain the p-values derived from comparing the slope (interaction term) and intercept of the lines of best fit for the pre- and post-BMP periods. As shown, the slope and/or the intercept were significantly different (0.05 level of significance) for each parameter, except for TSR, for which the difference in intercepts (p = 0.082) was marginally significant. The least squares (LS) means analysis, which evaluates the load for Back-dn at the average value of the control (Back-up) station for the entire period of monitoring (both pre- and post-BMP combined), was used to quantify the mean difference in periods. These values, which are shown in column 5 of table 5, are the best statistical estimate of the overall reductions in loads and export rates. The reduction for NOx-N was omitted because the pre- and post-BMP values were not significantly different (P >> 0.05). This result agreed with the findings of Line et al. (2000), who reported no significant change in NOx-N while documenting significant decreases in TKN, NH_3-N, TP, and TSS as a result of installing livestock exclusion fencing in a dairy cow pasture. The reductions in post-BMP loads for Back-dn cannot be attributed solely to livestock exclusion fencing, as stream restoration, an unusually wide riparian buffer, and a more than four-fold decrease in cow density also occurred in the monitored drainage area.

While there is no way to differentiate between the effectiveness of the exclusion fencing and the stream restoration, by comparing upstream and downstream loads during the



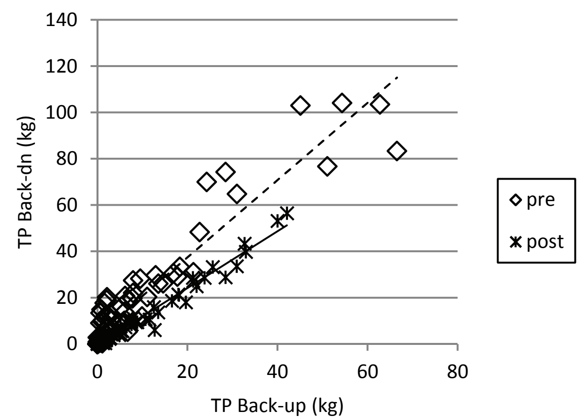


Figure 7. Correlation between storm loads for TKN (top) and TP (right) at Back-up and Back-dn.

Table 5. Results of ANCOVA and least squares (LS) means analysis.

Parameter[a]	Count	Slope p-Value	Intercept p-Value	LS Means Reduction (%)	LS Means p-Value
Back-up vs. Back-dn					
Discharge	146	0.000	0.000	19.2	0.000
TKN	141	0.737	0.001	42.3	0.000
NH_3-N	142	0.001	0.351	56.0	0.000
NOx-N	139	0.549	0.000	-	0.223
TP	142	0.453	0.000	56.0	0.000
TSR	141	0.162	0.082	67.6	0.000
NBr-dn vs. Back-up					
Discharge	136	0.309	0.003	-	0.873
TKN	134	0.349	0.263	-	0.511
NH_3-N	134	0.000	0.029	-	0.976
NOx-N	132	0.558	0.594	-	0.302
TN	131	0.001	0.219	-	0.200
TP	134	0.587	0.291	-	0.508
TSR	134	0.979	0.473	-	0.214

[a] Units for discharge were m^3 per storm and others were kg per storm.

post-BMP period only it may be possible to isolate the effect of stream restoration alone on in-stream loads. During the post-BMP period, pollutant export increased from Back-up to Back-dn, albeit by a relatively small amount. Paired t-tests documented that the increases from Back-up to Back-dn for each parameter, except NH_3-N, were statistically significant. The increases were expected because, while most of the area between the stations had grown volunteer vegetation with no fertilizer inputs, some runoff from the remaining pasture and some cropland still entered the stream channel between the stations, as well as residual nitrogen (N) and phosphorus (P) in the riparian soils. Observation during rainfall events revealed that runoff from the remaining pasture traveled to the stream via small channels through the riparian buffer.

For North Branch, the relationship between Back-up (control watershed) and NBr-dn for TKN, NOx-N, TP, and TSR did not change from the pre- to the post-BMP period, indicating that the BMPs had no effect on the export load of these parameters. For discharge and NH_3-N, a possible effect was indicated by the significant differences in slope and/or intercept. However, the LS means analysis showed that there was no significant difference from the pre- to post-BMP periods. The lack of effect can be attributed to the relatively short length (125 m) of exclusion combined with the lack of pre-BMP load data at the upstream station and the relatively high upstream pollutant loads.

To assess the effect of stream restoration alone, a paired t-test was conducted on the NBr-up and NBr-dn storm data during the post-BMP period. No significant differences were found for TKN, TN, TP, and TSR; however, significant differences were found for NH_3-N (decreased) and NOx-N (increased), which for NH_3-N agreed with the paired watershed ANCOVA. Thus, while not definitive, the statistical evidence suggested that the differences in NH_3-N and NOx-N export shown in table 4 were significant. A possible explanation for this is that the NH_3-N was converted to NOx-N in the restored reach, which is reasonable given the relatively high NH_3-N concentrations at NBR-up and the vegetation, riffles, and pools in the stream channel. The lack of significant difference in TSR loading confirmed observations and cross-section surveys that documented the stream channel between the stations was neither aggrading nor degrading during the post-BMP period, which is one of the goals of stream restoration. These data indicate that a restored stream channel is not effective in reducing in-stream nitrogen, phosphorus, or suspended sediment loads; however, given the combination of relatively high upstream loads and short distance between monitoring stations, a substantial reduction in loads would be less likely. In addition, from a monitoring standpoint, the considerable stream discharge reduced the probability of documenting subtle changes in pollutant loading.

Summary and Conclusions

The objective of this project was to document changes in the water quality of two streams in a large dairy cow pasture resulting from the implementation of livestock exclusion fencing and stream restoration together and from stream restoration itself. Rainfall and discharge were monitored continuously, and flow-proportional samples were collected for 3.0 years prior to and 1.7 years after exclusion fencing and restoration were implemented. Samples were analyzed for nitrogen forms, total phosphorus, and residues, and storm loads were computed for each. Statistical analyses of load data were conducted. From the analyses, the following conclusions can be drawn:

- For the Back Creek stations, exclusion fencing and limited stream restoration on the 488 m long reach resulted in significant reductions (42% to 68%) in TKN, NH_3-N, TP, and TSS storm loads and annual export rates. While the combination of exclusion fencing, reduced grazing animal density, and stream restoration was effective in reducing pollutant loads and export from the pasture, the reductions were similar to a previous study (Line et al., 2000) of exclusion fencing alone, indicating that stream restoration and animal grazing reductions may have added little to the effectiveness of the exclusion fencing.
- For the 134 m monitored reach of North Branch, post-BMP monitoring documented significant differences in NH_3-N (decreased) and NOx-N (increased) loads, while there was no significant difference in TKN, TN, TP, or TSR loading. These data indicated that the restored stream channel was not effective in reducing in-stream nitrogen, phosphorus, or sediment loading for the combination of upstream loading, stream size, and length of stream reach.
- For North Branch, post-BMP sediment and residue (TSR) load data and observation documented that the restored stream channel neither aggraded nor degraded throughout the post-BMP monitoring period.

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