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Effects of Streambank Fencing of Near-Stream Pasture Land on a Small Watershed in Lancaster County, Pennsylvania

by Daniel G. Galeone, Dennis J. Low, and Robin A. Brightbill

Why Study Streambank Fencing?

Streambank fencing to exclude animal access is a best-management practice (BMP) targeted to reduce suspended-sediment and nutrient inputs to streams. Exclusion of animals from the fenced area reduces direct nutrient inputs to the stream, denudation of riparian vegetation, and streambank trampling. A stream vegetative buffer also can reduce the input of nutrients and sediment to the stream channel by filtration of overland flow and through the retention of nutrients in the subsurface of the riparian zone. The water-quality effects of specific BMP implementation on a basin scale are not well documented. The quantification of specific BMP effects on water quality is critical to agencies or programs concerned with protection of water resources.

Where was Streambank Fencing Studied?

Two basins within the predominantly carbonate Big Spring Run Basin, a subbasin of Mill Creek Basin, Lancaster County (fig. 1) were studied from 1993-2001. The control basin was 1.77 square miles (mi^2) with 2.7 total stream miles (mi) and 1.9 mi of stream running through open pasture. The treatment basin was 1.42 mi^2 with 2.8 total stream mi and 2.0 mi of stream running through open pasture.

Land use in the study basins was about 80-90 percent agricultural with the remaining predominantly developed (residential, industrial, or commercial use) (fig. 1). The agricultural land in both basins was predominantly row crop (about 60 percent). Each basin had about 50-55 acres of pasture land adjacent to stream channels.

Agricultural activity differed somewhat between basins from the pre- to post-treatment period. The average annual estimated amount of nitrogen (N) and phosphorus (P) applied in the treatment basin was 42,800 and 7,300 pounds per square mile (lb/mi^2), respectively. The average annual estimated amount of N and P applied in the control basin was 64,200 and 12,600 lb/mi^2, respectively. The percentage decrease from the pre- to post-treatment periods in the annual amount of N and P applied in the treatment basin was 27 and 33 percent, respectively; the control basin showed a 3-percent decrease in N and a 7-percent increase in P over the same period. About 150 to 250 cows were pastured per basin until 2000. The number of cows in both basins decreased by about 50 percent from 2000 to 2001.

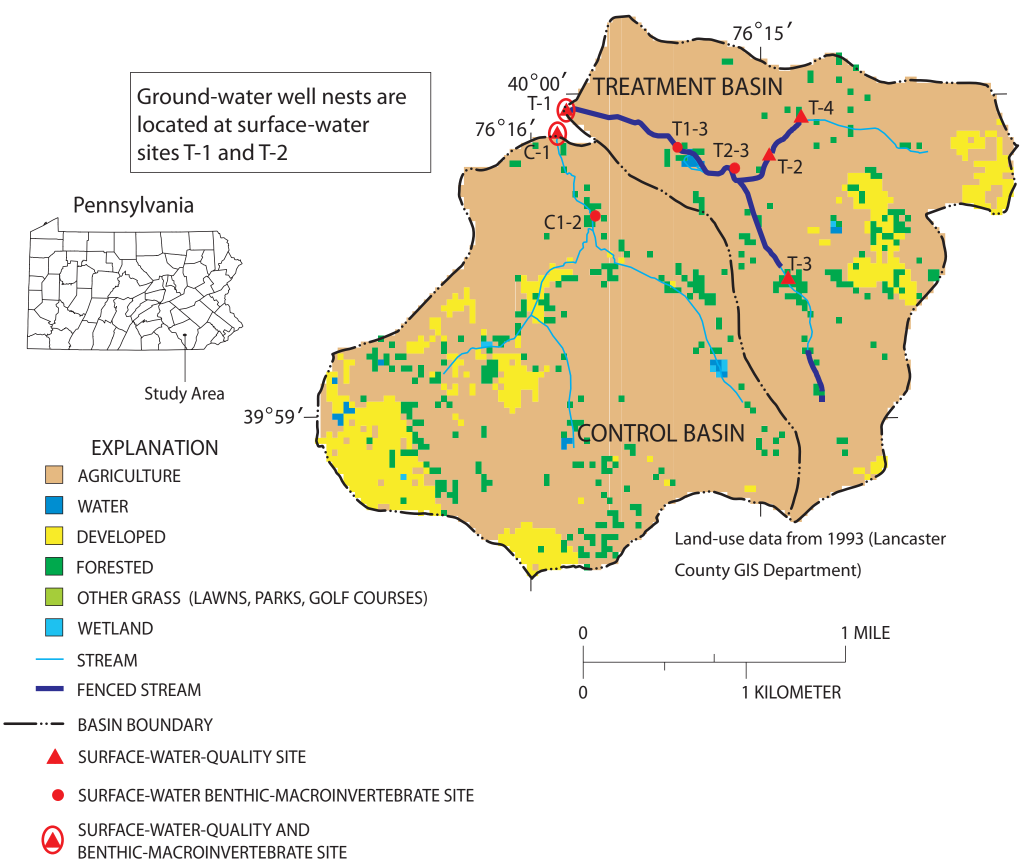

Figure 1. Land-use map of study area and location of surface-water sites, ground-water well nests, and fenced stream segments in the Big Spring Run Basin, Lancaster County, Pa.

How was Streambank Fencing Studied?

The effects of streambank fencing were documented for surface-water quality, benthic macroinvertebrates, and shallow ground-water quality. A nested experimental design was used to study streambank-fencing effects on surface water and benthic macroinvertebrates. The primary design was a paired-basin approach that required the use of two similar basins where one basin was a control and the other had treatment applied. The secondary approach for documenting surface-water changes included collecting pre- and post-treatment data at sites within the treatment basin upstream and downstream of fence installation. For shallow ground water, a paired-well design was used to determine if streambank fencing affected the wells inside the fence as opposed to the well outside the fenced area. A detailed description of the study design, methods, and results is presented in Galeone and others (2006).

Data were collected from 1993 to 2001. Calibration data were collected from October 1993 through mid-July 1997; fencing was installed from May 1997 through July 1997. All pasture areas in the treatment basin along the stream network were fenced with a buffer width ranging from 5 to 12 feet (ft).

For surface-water quality, low-flow and stormflow samples were collected at four continuous stream-gaging sites: T-1, C-1, T-2, and T-4 (fig. 1). Only low-flow samples were collected at T-3. Treated sites T-1 (at the outlet of the treatment basin) and T-2 (upstream site in the treatment basin that was a visually degraded pasture) were statistically compared to data collected from the outlet of the control basin (C-1) and to untreated upstream sites in the treatment basin (T-3 and T-4). Surface-water-quality samples were analyzed for total and dissolved forms of nutrients and suspended sediment.

Benthic-macroinvertebrate samples were collected in May and September of each year at T-1 and C-1 (the basin-outlet sites), and T1-3, T2-3, and C1-2 (upstream sites with C1-2 in the control basin). Benthic-macroinvertebrate statistical comparisons were conducted separately between outlet and upstream sites because benthic-macroinvertebrate communities showed similarities when comparing outlet to outlet and upstream to upstream site. Habitat was qualitatively assessed during the benthic-macroinvertebrate sampling.

Two nests of ground-water wells were installed in the treatment basin to document effects of riparian vegetation on shallow near-stream ground-water quality, one nest at the outlet of the treatment basin adjacent to T-1, and the other upstream adjacent to T-2 (fig. 1). At each well nest, two shallow ground-water wells were near the stream channel (treatment wells) and one shallow well was at a distance away from the channel (control well) that was outside the fenced area. Well depths ranged from 6 to 12 ft. Ground-water samples were analyzed for dissolved nutrients, fecal streptococcus, and field characteristics.

Changes from the pre- to post-treatment periods in constituents during low flow and storm events for surface water and for shallow ground water at treated sites were quantified using analysis of covariance (ANCOVA). The effects of fencing on the benthic-macroinvertebrate community were determined by comparing sites in the treatment and control basins and using benthic-macroinvertebrate indices.

What were the Effects of Streambank Fencing

The primary factors affecting water quality from the pre- to post-treatment period were fence installation and changes in precipitation. The most visually noticeable effect of streambank fencing was the establishment of a herbaceous riparian zone (fig. 2). Decreased precipitation amounts during the post-treatment period caused stream discharge to be 56-63 percent less than the pre-treatment period. Changes in stream discharge were accounted for by ANCOVA so that the effects of fencing could be quantified.

Did Streambank Fencing Affect Surface-Water Quality?

Low-flow data generally showed similar responses from the pre- to post-treatment period for untreated and treated sites for nutrients and suspended sediment (table 1); however, fencing effects were evident. About 96 percent of the total-N concentration for all low-flow samples was in the form of nitrate N. Low-flow periods contributed from 84 to 91 percent of the total-N yield at the continuous monitoring sites. From the pre- to post-treatment period, all sites showed decreased yields of N during low-flow periods because of lower stream discharge and lower concentrations. Yield reductions were greater at treated sites (25-26 percent) than at the control/upstream sites (11 percent) (table 1). On the basis of ANCOVA analysis, relative reductions from the pre- to post-treatment period in low-flow yields of total N and nitrate N were 17 percent for T-1; conversely, relative increases in low-flow yields of total N and nitrate N were 9 to 11 percent for T-2. P concentrations for low-flow samples showed significant increases of 0.03 and 0.54 mg/L from the pre- to post-treatment period at T-1 and T-2, respectively. Most of this increase was caused by increased concentrations of dissolved P; the likely source was an agricultural field immediately upgradient from T-2. The low-flow yield of total P showed average relative percent increases during the post-treatment period at T-1 and T-2 of 51 and 220 percent, respectively; however, only 3-10 percent of the total-P yield for these sites occurred during low-flow periods. Suspended-sediment concentrations for low-flow samples decreased at all sites from the pre- to post-treatment period (table 1); however, low flow only contributed about 5-10 percent of the suspended-sediment yield.

Stormflow data showed significant reductions in suspended-sediment concentrations and yields from the pre- to post-treatment period; N and P yields showed varied results. Larger percentage decreases in suspended-sediment concentrations were seen at treated sites (56-69 percent) rather than untreated sites (40-54 percent) (table 2). The average percentage relative reductions in the suspended-sediment yield from the pre- to post-treatment period at treated sites was 36 and 46 percent, respectively. Changes in N and P yields for stormflow samples differed by site. The average reduction in stormflow yield of total N for T-1 was 19 percent during the post-treatment period; the average relative increase in yield of total N for T-2 was 28 percent. Similarly, the average reduction in stormflow yield of total P for T-1 was 22 percent during the post-treatment period, and the average relative increase in yield of total P for T-2 was 46 percent.

Pre-treatment photo, May 1996

Post-treatment photo, May 1998

Figure 2. Tributary site (T-2) in treatment basin in the Big Spring Run Basin, Lancaster County, Pa., before (top) and after (bottom) fence installation.

Table 1. Mean concentrations (in milligrams per liter) and estimated daily yields (in pounds per day per square mile) for low-flow samples collected during the pre- and post-treatment periods at the five surface-water sites.

Constituent	C-1		T-1		T-2		T-3		T-4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Total-nitrogen concentration	10.6	9.47	11.7	8.61	11.4	8.60	12.0	11.4	12.7	10.1
Total-nitrogen yield	69.0	45.2	53.5	29.9	41.2	29.9	77.2	47.2	34.4	26.0
Total-phosphorus concentration	.05	.06	.06	.09	.09	.63	.03	.05	.04	.04
Total-phosphorus yield	.339	.312	.238	.350	.259	1.14	.228	.246	.156	.122
Suspended-sediment concentration	42	24	28	13	46	37	21	16	21	11
Suspended-sediment yield	286	107	134	41.1	154	93.1	139	69.9	73.6	33.5
Number of samples	95	108	96	107	92	82	92	107	59	71

Table 2. Mean concentrations (in milligrams per liter) and yields (in pounds per square mile) for stormflow samples collected during the pre- and post-treatment periods at the four continuous surface-water sites.

Constituent	C-1		T-1		T-2		T-4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Total-nitrogen concentration	5.55	5.76	7.25	7.09	5.19	5.34	3.93	4.11
Total-nitrogen yield	153	103	143	87.2	138	126	119	88.7
Total-phosphorus concentration	.76	.99	.97	1.00	.71	.86	.46	.51
Total-phosphorus yield	35.1	29.2	32.2	22.4	34.8	34.0	24.1	20.5
Suspended-sediment concentration	608	457	708	313	673	263	344	219
Suspended-sediment yield	29,100	12,500	27,000	9,630	30,500	15,700	16,400	10,800
Number of samples	71	89	71	83	62	101	30	86

Changes in yields at the treatment basin outlet, T-1, relative to control/upstream sites showed a reduction during the post-treatment period for all constituents except dissolved P. The overall yield reductions at T-1 were 37 percent for suspended sediment, 19 percent for total N, and 14 percent for total P (table 3). These results indicate that 2 mi of stream fencing with cattle exclusion in a small (1.42 mi^2 drainage) basin can significantly reduce nutrient and suspended-sediment loads to the stream system.

Table 3. Overall water-quality changes in constituent yields for the treated sites relative to control/upstream sites for the post-treatment period based on analysis of covariance (ANCOVA) results.

Constituent	T-1 (percent change)	T-2 (percent change)
Total nitrogen	-19	+21
Dissolved nitrate	-18	+15
Dissolved ammonia	-36	+10
Dissolved phosphorus	+19	+94
Total phosphorus	-14	+51
Suspended sediment	-37	-44

In contrast, all constituent yields for T-2 (0.36 mi^2 drainage) relative to control/upstream sites increased during the post-treatment period except for suspended sediment. The overall post-treatment changes at T-2 showed a 44 percent decrease in suspended-sediment yield while total-N and total-P yields increased by 21 and 51 percent, respectively. The dissolved-P yield was the largest increase (94 percent) of all constituents listed. These increases were not only due to an upgradient field contributing dissolved P through subsurface pathways, but also to cattle excreting waste at the cattle crossings. Water samples collected in the stream channel upgradient of the T-2 stream gage indicated that concentrations of dissolved ammonia and organic N and dissolved P were higher downstream relative to upstream of the crossings.

Did Streambank Fencing Affect Benthic Macroinvertebrates?

The qualitative assessment of habitat during benthic-macroinvertebrate sampling indicated habitat improved after fence installation. The most noticeable effects on habitat characteristics were for the primary and tertiary categories (see Plafkin and others, 1989, for a detailed description of parameters) (table 4). Of the tertiary characteristics, streamside-cover scores were least affected by fence installation, primarily because only herbaceous vegetation was established inside the fenced area, and streamside-cover scores increase as tree cover increases. The secondary category of habitat variables appeared to be least affected by fence installation; nevertheless, these variables showed some improvements. These variables are affected by flow regime, and it may be that the lower stream discharge during the post-treatment period reduced any changes that might have taken place.

Table 4. Post-treatment changes in habitat characteristics at the outlet and upstream sites in the treatment basin relative to control sites.

[Change less than one score unit was defined as NC (no change)]

	Habitat characteristic	Outlet/Upstream
Primary	Bottom substrate available cover	+/+
	Embeddedness	+/NC
	Velocity to depth ratio	NC/+
Secondary	Channel alteration	-/+
	Bottom scouring and deposition	+/-
	Pool/riffle, run/bend ratio	+/+
Tertiary	Bank stability	+/NC
	Bank vegetative stability	+/+
	Streamside cover	NC/+
	Total habitat score	+/+

The fence installation allowed vegetation to establish itself along the streambanks, which helped to trap sediment in overland runoff prior to reaching the stream channel. The habitat along the banks and within the stream improved, allowing for less sedimentation of the stream bottom and more niches for benthic macroinvertebrates. When looking at the overall numbers for total habitat (table 4), the results were positive and the habitat improved at the outlet and at upstream sites in the treatment basin.

Selected benthic-macroinvertebrate indices are presented in table 5. Taxa richness, EPT (**E**phemeroptera, **P**lecoptera, and **T**richoptera) index, and percent oligochaetes improved during the post-treatment period at the outlet and upstream sites in the treatment basin relative to control sites (table 5). The relative number of taxa showed a larger increase at the upstream sites than outlet sites. The EPT index and percent oligochaetes showed more improvement at the outlet than the upstream sites (relative to control sites). An increase in taxa richness was likely related to habitat improvement. Positive changes in the EPT index and a decrease in the percent oligochaetes usually are correlated with improving water quality.

Other benthic-macroinvertebrate metrics showed contradictory responses during the post-treatment period. The HBI (Hilsenhoff biotic index) scores showed improvement at T-1 compared to C-1 meaning that more pollution-sensitive benthic macroinvertebrates inhabited T-1; conversely, the upstream sites showed degradation in HBI scores during the post-treatment period. The percent dominant taxa decreased at T-1 relative to C-1 and increased at upstream sites (T1-3 and T2-3) relative to C1-2 during the post-treatment period. A decline in this percentage indicates more evenness and a healthier community.

Did Streambank Fencing Affect Shallow Ground-Water Quality?

Differences in shallow ground-water flow paths were at least partly responsible for the large differences in chemistry and physical character-

Table 5. Post-treatment changes in benthic-macroinvertebrate indices at the outlet and upstream sites in the treatment basin relative to control sites.

[+ indicates improvement in conditions based on that index]

Index	Outlet/Upstream
Taxa richness	+/+
Hilsenhoff biotic	+/-
EPT	+/+
Percent dominant taxa	+/-
Percent oligochaetes	+/+

istics between the two well pairs. Dissolved-nitrate concentrations at the T-2 well nest were about one order of magnitude higher than for the T-1 well nest (table 6). Low dissolved-nitrate concentrations at the T-1 well nest were partially attributable to denitrification. Other differences between shallow wells at T-1 and T-2 were evident for dissolved ammonia and P, but in this case, concentrations were higher for the T-1 well nest. One similarity between the well nests was the relative decrease in water temperature during the post-treatment period.

ANCOVA results from the paired-well comparisons indicated fence installation significantly affected shallow ground-water quality. The concentrations of dissolved ammonia, dissolved nitrate plus nitrite, and fecal-streptococcus counts decreased in the two shallow wells at site T-2 but increased in the shallow wells at site T-1 relative to control wells during the post-treatment period (table 6). The one constituent that showed relative increases at the T-2 well nest and not at T-1 during the post-treatment period was dissolved P. It appeared the source of the P was an upgradient field where animal manure had historically been applied. The likely reason for the opposite post-treatment responses (except dissolved P) was the difference in shallow ground-water flow paths. At the T-2 well nest, the shallow ground water moved from outside the fence to the stream (gaining stream), while the opposite was true at T-1, where the stream was actually losing water to the shallow ground-water system; thus, at T-1, any impacts of vegetative establishment inside the fence on water quality were not impacting the shallow wells inside the fence, but moving away from them. The reductions apparent for the shallow wells at the T-2 well nest would be somewhat expected given that the cows were not allowed to access the area near these wells after fence installation.

Table 6. Mean values for shallow ground-water samples collected during the pre- and post-treatment periods at the two well nests in the treatment basin and percentage change for treatment wells relative to control wells during the post-treatment period based on analysis of covariance for shallow well pairs.

[mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; positive percent change indicates the treatment wells increased relative to the control well during the post-treatment period]

Constituent	T-1 well pairs					T-2 well pairs				
	Treatment		Control		Percent change	Treatment		Control		Percent change
	Pre	Post	Pre	Post		Pre	Post	Pre	Post	
Temperature, degrees Celsius	12.0	11.9	11.9	12.5	-5.7	11.8	11.8	11.7	12.5	-4.1
Dissolved nitrate plus nitrite, mg/L	1.13	.62	1.67	1.40	15	13.9	15.4	14.9	16.6	-2.3
Dissolved ammonia, mg/L	.40	.46	.31	.24	38	.082	.016	.035	.036	-51
Dissolved phosphorus, mg/L	.08	.19	.01	.01	-7.8	.01	.01	.01	.04	33
Fecal streptococcus, col/100 mL	1,270	1,900	200	43	5.8	694	2,360	858	4,620	-56
Range in number of samples	20-43	12-44	20-43	15-44		18-42	12-41	20-43	15-44	

Conclusions

This study indicated that a small buffer width along a stream in pasture land can have a positive influence on surface-water quality, benthic macroinvertebrates, and near-stream shallow ground-water quality. Overland runoff processes that move suspended sediment to the stream were controlled (or reduced) to some extent by the vegetative buffer established

Results indicated streambank fencing resulted in decreases in N-species, total-P, and suspended-sediment concentrations and yields at the outlet of the treatment basin relative to untreated sites; however, dissolved-P concentrations and yields increased. These results indicate that nutrient management, in conjunction with streambank fencing, is important in helping to control nutrient loadings to streams in this agricultural setting.

An upstream site (T-2) in the treatment basin showed post-treatment reductions in suspended-sediment yields and increases in N and P yields. The different results for these treated sites indicates the effects of streambank fencing should be studied at as large a scale as possible because field-scale influences on water quality as drainage area decreases can mute the effects of fencing.

Benthic-macroinvertebrate data indicated streambank fencing had a positive influence on benthic macroinvertebrates and their habitat. More improvement was detected at the outlet of the treatment basin than the upstream sites. Probably the most important biological metric, taxa richness, indicated a greater number of benthic-macroinvertebrate taxa at treated relative to control sites after fencing.

Results indicated fencing improved shallow ground-water quality (for the well nest in a stream-gaining area), as noted by decreased concentrations of N species and fecal-streptococcus counts. This improvement only occurred at the well nest where the stream was gaining water from the shallow ground-water system.

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This project was a cooperative effort between the USGS and the PaDEP. PaDEP funding was through the National Monitoring Program (NMP) of the U.S. Environmental Protection Agency. The NMP was developed to document the effects of nonpoint-source pollution-control measures and associated land-use modifications on water quality.

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