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Preliminary Effects of Streambank Fencing of Pasture Land on the Quality of Surface Water in a Small Watershed in Lancaster County, Pennsylvania

by Daniel G. Galeone

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ILLUSTRATIONS

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.011	cubic meter per second per square kilometer
	Mass	
pound (lb)	0.4536	kilogram
	Application rate	
pound per square mile (lb/mi^2)	0.1751	kilogram per square kilometer

Water-quality units used in report:

milligrams per liter (mg/L)

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ABSTRACT

The use of fencing to exclude pastured animals from streams has been recognized as an agricultural best-management practice. Streambank fencing was installed in a small basin within the Mill Creek Watershed of Lancaster County, Pa., during summer 1997 to evaluate the effectiveness of fencing on surface-water quality. A preliminary review of data collected during a pre-treatment, or calibration period (October 1993 through June 1997), and part of the post-treatment period (July 1997 through November 1998) has identified a varied instream nutrient response to streambank fencing.

Concentrations of total nitrogen (N) during low-flow periods were significantly reduced by 20 to 31 percent at treated relative to untreated sites, but the yield of total N during low-flow conditions did not change significantly. Low-flow concentrations and yields of total phosphorus (P) did not change significantly at the outlet of the treatment basin, but data from a tributary site (T-2) in the treatment basin showed a 19- to 79-percent increase in the concentration and yield of total P relative to those at untreated sites. The total-P increase was due to increased concentrations of dissolved P. The processes causing the decrease in the concentration of total N and an increase in the concentration of total P were related to stream discharge, which declined after fencing to about one-third lower than the period-of-record mean. Declines in stream discharge after fence installation were caused by lower than normal precipitation. As concentrations of dissolved oxygen decreased in the stream channel as flows decreased, there was increased potential for instream denitrification and solubilization of P from sediments in the stream channel. Vegetative uptake of nitrate could also have contributed to decreased N concentrations. There were few significant changes in concentrations and yields of nutrients during stormflow except for significant reductions of 16 percent for total-N concentrations and 26 percent for total-P concentrations at site T-2 relative to the site at the outlet of the control basin.

Suspended-sediment concentrations in the stream were significantly reduced by fencing. These reductions were partially caused by reduced cow access to the stream and hence reduced potential for the cows to destabilize streambanks through trampling. Development of a vegetative buffer along the stream channel after fence installation also helped to retain soil eroding from upgradient land. Reductions in suspended sediment during low flow ranged from 17 to 26 percent; stormflow reductions in suspended sediment ranged from 21 to 54 percent at treated relative to untreated sites. Suspended-sediment yields, however, were significantly reduced only at site T-2, where low-flow and stormflow yields were reduced by about 25 and 10 percent, respectively, relative to untreated sites.

Benthic-macroinvertebrate sampling has identified increased number of taxa in the treatment basin after fence installation. Relative to the control basin, there was about a 30-percent increase in the total number of taxa. This increase was most likely related to improved instream habitat as a result of channel revegetation.

INTRODUCTION

Nonpoint-source contamination of water resources used for public and private drinking-water supplies, livestock watering, and aquatic and wildlife habitat has been documented in studies in carbonate rock, agricultural areas of the lower Susquehanna River Basin. As a consequence, the U.S. Department of Agriculture has targeted a number of agricultural watersheds for implementation of agricultural management practices designed to improve water quality while effectively utilizing agricultural resources. The Mill Creek Basin in Lancaster County, Pa., is one of these watersheds. Pastured areas in the Mill Creek Basin commonly are located adjacent to streams so that animals have a readily accessible water supply. Streambank fencing to exclude animal access is a best-management practice (BMP) targeted to reduce suspended-sediment and nutrient inputs to streams by reducing direct nutrient inputs to streams, stopping streambank trampling, and promoting revegetation of streambanks.

A cooperative project between the U.S. Geological Survey (USGS) and the Pennsylvania Department of Environmental Protection was started in 1993 to quantify the effects of streambank fencing on surface-water quality on a basin-wide scale. Results from the study could be used by watershed planners to estimate changes in nutrient and suspended-sediment loads with the installation of streambank fencing in pastured areas.

This report describes the initial effects of streambank fencing on the chemical, physical, and biological components of the surface-water system for a small drainage basin within the Mill Creek Basin of Lancaster County, Pa. (fig. 1). The report discusses the pre-treatment (calibration) relation developed from October 1993 through June 1997 for surface water in both control (untreated) and treatment (fenced) basins and compares the relation to the post-treatment data collected from July 1997 through November 1998. Water-quality relations between basins were determined by pairing data collected on the same day and determining the difference between sites for particular constituents such as nitrogen (N). These differences were compared prior to and after fence installation to determine effects of streambank fencing on water quality.

SITE DESCRIPTION

The treatment and control watersheds are adjacent to each other within the Mill Creek Basin of Lancaster County (fig. 1). The control watershed is 1.77 mi^2 with 2.7 perennial stream miles and approximately 1.3 mi of pasture along the stream. The treatment watershed is 1.42 mi^2 with 2.5 perennial stream miles and approximately 1.6 mi of pasture along the stream. Agriculture in the two basins, consisting of 10-15 major farming operations, primarily involves crop production and

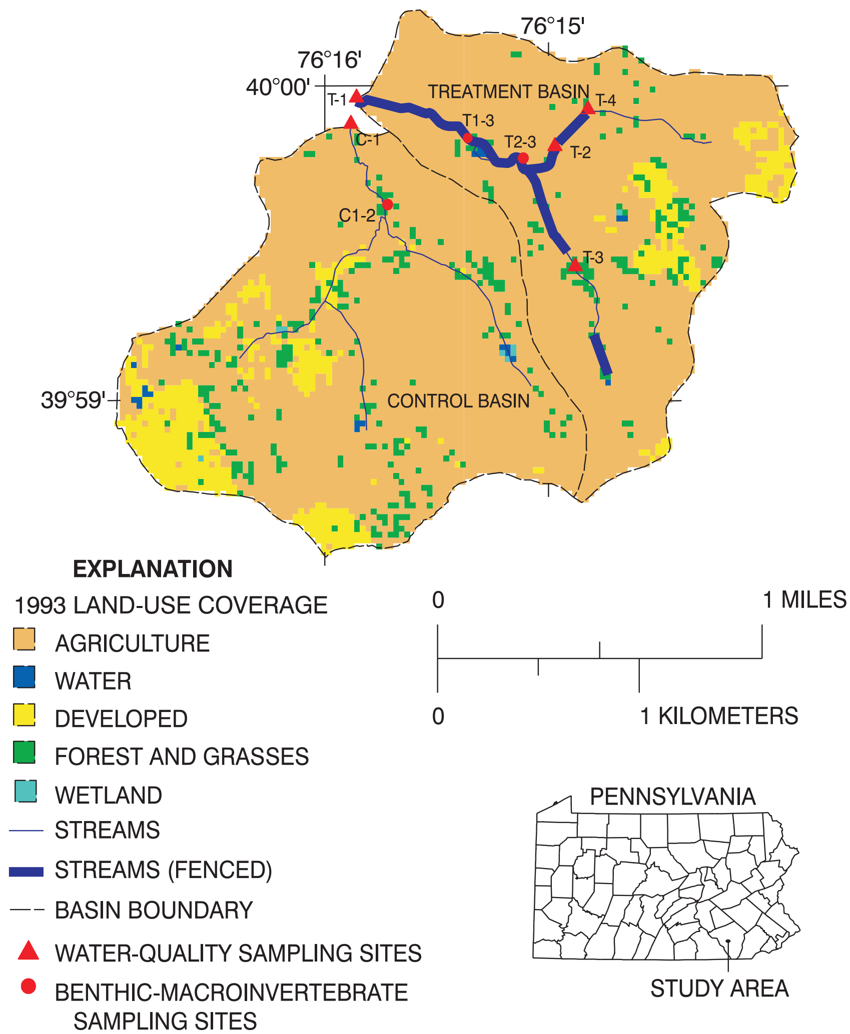


Figure 1. Study area.

dairy farming. The watersheds are underlain by carbonate rock of the Conestoga Formation (Poth, 1977). The principal soils of the basins are the fine, loamy, well-drained soils of the Lehigh and Conestoga series (Custer, 1985). Annual precipitation averages 41 in. at a long-term recording site about 2 mi northeast of the study area (National Oceanic and Atmospheric Administration, 1993).

Streambank fences were installed in the treatment watershed in 1997, with all construction completed by June. Approximately 1.6 mi of stream length were fenced to prevent cows from accessing the stream channel in pastured areas. One- or two-strand, high-tensile wire was used with an electrical current supplied by batteries charged with solar power. On either side of the stream, the distance between the streambank and the fence ranges from 5 to 12 ft. For each pasture fenced, approximately two crossings were installed to allow the animals access to pasture on either side of the stream and also to supply the cows with a location for water consumption. Since the fence installation, a variety of brushy, herbaceous vegetation has established naturally (fig. 2).

Figure 2. Tributary site (T-2) in treatment basin before (top) and following (bottom) fence installation.

STUDY DESIGN

Both paired-watershed and upstream-downstream monitoring designs (Spooner and others, 1985) were implemented to document water-quality changes following streambank-fence installation (table 1). Both monitoring designs help account for climatic and hydrologic variability when monitoring before and after a specific event or action, in this case streambank-fence installation. The design incorporates multiple opportunities for comparisons to ensure that the effects of fencing can be documented. It is common for land uses to change in agricultural areas of Lancaster County with the progression of residential development. The ability to compare numerous sites in the treatment and control basins can alleviate problems associated with changes in land use.

The calibration period for the study was from October 1993 through June 1997. During this period, water-quality relations were developed between paired watershed and upstream/downstream sites. Post-treatment data collection began July 1997 and is scheduled to continue through November 2001. Deviations in relations after the fence installation can be attributed to effects of streambank fencing as long as other major land-use and climatic changes do not occur.

Chemical and Physical Data

Fixed-interval (grab) and stormflow samples were collected from streams in both the treatment and control basins. Fixed-interval samples were collected approximately every 10 days from April through November and monthly during the remainder of the year. These samples were collected at T-1, C-1, T-2, T-3, and T-4 irrespective of flow conditions. Fixed-interval samples were analyzed for selected N and phosphorus (P) species, suspended-sediment concentration, fecal streptococcus, and field parameters (pH, specific conduc-

Table 1. *Description of water-quality sampling sites in study area and use of data in project design*
[mi^2, square miles; ft^3/s, cubic feet per second]

Site	Drainage area (mi^2)	Daily mean discharge (ft^3/s) (Oct. 1993 - Sept. 1998)	Description	Data use
C-1	1.77	3.20	Outlet of control basin	Compare to T-1 and T-2 for paired watershed analysis
C1-2	1.62	--	Upstream site in control basin	Benthic-macroinvertebrate sampling location for comparison with T1-3 and T2-3
T-1	1.42	1.91	Outlet of treatment basin	Compare to C-1 for paired-watershed analysis and T-3 for upstream / downstream analysis
T1-3	1.21	--	Upstream site in treatment basin	Benthic-macroinvertebrate sampling location for comparison with C1-2
T-2	.36	.54	Visually degraded upstream tributary site in treatment basin	Compare to C-1 for paired-watershed analysis and T-4 for upstream / downstream analysis
T2-3	1.13	--	Upstream site in treatment basin	Benthic-macroinvertebrate sampling location for comparison with C1-2
T-3	.33	--	Upstream site in treatment basin located above most pasture land (approximately 1,000 feet of stream is fenced above T-3)	Compare to T-1 for upstream / downstream analysis
T-4	.32	.46 (Oct. 1994 - Sept. 1998)	Upstream tributary site in treatment basin located downstream of new residential development and above all pasture land	Compare to T-2 for upstream / downstream analysis

tance, alkalinity, dissolved oxygen, and temperature) (Galeone and Koerkle, 1996). Samples also were collected during 15 to 30 storms per year at each of these 4 sites: T-1, C-1, T-2, and T-4. Storm samples were collected using automatic samplers, with sampling initiated either by the stage exceeding a certain height or by a stage increase exceeding some threshold in the rate of a stage change over a 5-minute interval. Sampler intakes are positioned above the weir used to control flow at each of the sites. Samples were collected over the hydrograph of each storm, and these samples were composited using flow-weighting techniques prior to chemical analysis. Storm samples were analyzed for selected N and P species and suspended-sediment concentrations. Stage, the water height in the stream channel, was continuously recorded at T-1, C-1, T-2, and T-4. Streamflow measurements over a range of stages were used to develop a stage-discharge relation at the sites with continuous recorders.

Data collected before and after fence installation at the five surface-water sites were compared using boxplots and paired-comparison tests. The Wilcoxon rank-sum test was applied to determine if streambank fencing had a significant effect on surface-water quality. The Wilcoxon rank-sum test is a nonparametric procedure used to determine if the median difference between two data sets is significantly different from zero (Helsel and Hirsch, 1995). In this case, the difference in paired data for two sites was separated into pre- and post-treatment periods, and these differences were tested for significance. Statistical comparisons were made for paired watershed sites (T-1 versus C-1 and T-2 versus C-1) and upstream/downstream sites (T-1 versus T-3 and T-2 versus T-4). The structure of the Wilcoxon rank-sum test was the same for all comparisons.

Biological Data

Five sites in the study basin were sampled for benthic macroinvertebrates: T-1, T1-3, T2-3, C-1, and C1-2 (fig. 1). Macroinvertebrates were collected in May and September, and selected nutrients, field water-quality parameters, and discharge were measured at the time of sampling. Macroinvertebrates were collected using the kick-screen method. At each site, a riffle/run and a pool area were sampled. The riffle/run and pool samples were then combined and a subsample of approximately 200 organisms was used to identify invertebrates to the species level if possible.

Physical characteristics of the sampling sites were qualitatively documented using U.S. Environmental Protection Agency Rapid Bioassessment Protocols (RBPIII) (Plafkin and others, 1989).

Benthic-macroinvertebrate data for the five sites were compared using biological metrics. The metrics used to compare the data include taxa richness, percent dominant taxa, and the EPT (**E**phemeroptera, **P**lecoptera, and **T**richoptera)/Chironomidae abundance ratio. Taxa richness is the total number of taxa present. Generally, larger taxa richness values denote better water quality. Percent dominant taxa is a measure of the percent of dominant taxa relative to the total number of organisms. As this number increases, community health typically decreases. The EPT/Chironomidae abundance ratio compares the relative abundance of three orders of aquatic insects that require clean water to a family of aquatic insects (Chironomidae) that generally is tolerant of degraded water quality. Thus, the higher the metric score, the better the water quality (Plafkin and others, 1989).

Statistically significant changes in the biological metrics from pre- to post-treatment periods were tested by applying the Wilcoxon rank-sum test. The tests indicate if the relation in biological metrics between treated and control sites significantly changed (at an alpha level equal to 0.10) after fence installation. Relational changes in biological metrics between sites were tested at the outlets (T-1 versus C-1) and upstream sites (T1-3 and T2-3 versus C1-2).

BASIN CHARACTERIZATION

Land Use

Approximately 80-90 percent of the land use in both the treatment and control basins was agriculture, with the remaining land use residential/commercial (about 7-10 percent) and forest (4-7 percent) (fig. 1). Agricultural land in the basins was primarily used for row crops (corn and alfalfa), hay fields, and cow pasture. The average annual additions of N and P to the control basin from agricultural sources for 1994 through 1998 were estimated to be 90,000 lbs of N per mi^2 and 16,000 lbs of P per mi^2. The average annual additions of N and P to the treatment basin from agricultural sources for 1994 through 1998 were estimated to be 57,000 lbs of N per mi^2 and 9,000 lbs of P per mi^2 (fig. 3). These nutrient additions to the basins included applications of inorganic and organic fertilizer (organic fertilizer equals animal manure) by farmers and manure directly deposited in pastures by dairy cows. The primary source of nutrients added to the land was dairy-cow manure and the higher density of animals in the control basin was the primary reason for increased nutrient additions in the control relative to the treatment basin. Other manure sources included chickens and pigs. The nutrient applications to the basins were documented by the farmers, and the concentrations of nutrients in the manure were estimated on the basis of literature values (Pennsylvania Department of Environmental Resources, 1986).

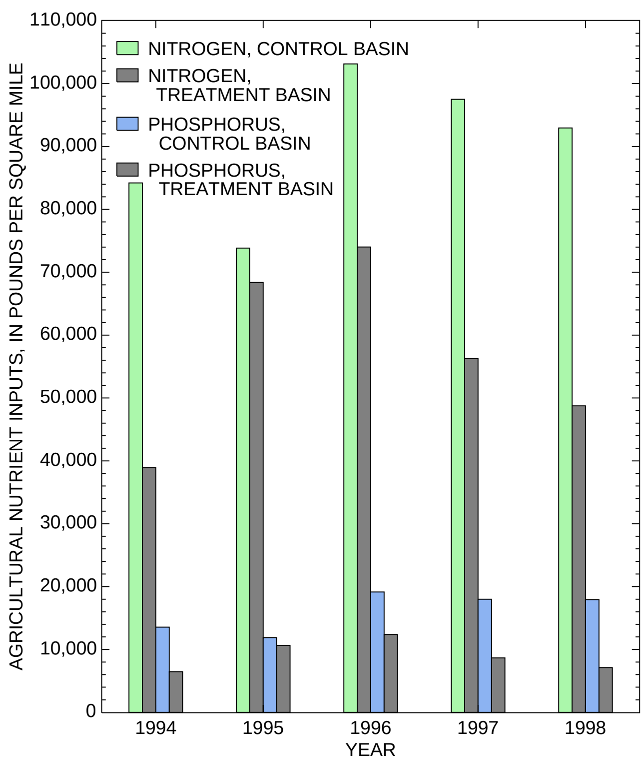


Figure 3. Estimated annual applications of nitrogen and phosphorus from inorganic and organic fertilizers to the control and treatment basins from 1994 through 1998. (The estimates include manure deposited by dairy cows when pastured.)

Most pasture in the basins was along the stream channel, primarily to provide drinking water to pastured dairy cows. There were approximately 140 and 80 acres of pasture in the control and treatment basins, respectively. The number of cows in each basin varied due to operational logistics, but the average number of cows was about 400 and 200 in the control and treatment basins, respectively, from 1994 through 1998. On average, the cows were in pasture about 40-50 percent of the time, which means that about 50 percent of the total nutrients excreted by the dairy cows was deposited in pasture. The number of cows in pasture from 1994 through 1998 did not change significantly from year to year.

Hydrology

Precipitation recorded from 1993 to 1998 using a weighing-bucket gauge at the outlet of the treatment basin showed that water year (WY) 1996 was the wettest (fig. 4). Precipitation for WY1996 exceeded the annual average precipitation (41 in.) for Lancaster (National Oceanic and Atmospheric Administration, 1993) by 33 percent; conversely, precipitation for WY1995 measured at the site was 17 percent below the annual average. Prior to streambank-fence installation in the treatment basin, precipitation was 17 percent above normal; after fence installation through November 1998, precipitation was 7 percent below normal.

Stream discharge at the outlet of the study basins reflected the variation in precipitation (fig. 5). Prior to fence installation (October 1993 through June 1997), discharge for both basins was about 9 percent above the period of record mean. After fence installation (July 1997 through September 1998), discharge for both basins was about 33 percent below the period of record mean. The similar fluctuations in flow for both basins in response to precipitation variability indicate the hydrologic frameworks in both basins are comparable.

The annual yield of nutrients leaving the basins in surface water was similar for data collected for WY 1994 through 1996. The approximate annual yields of N, P, and suspended sediment were about 30,000, 1,600, and 1,500,000 lbs/mi^2, respectively, at the outlet of each basin (Galeone, 1999). Approximately 90 percent of the total-N yield was nitrate-nitrogen (NO_3-N), and 90 percent of that total left the basins in non-stormflow. Conversely, approximately 90 percent of the total-P yield left the basins in stormflow, with about 60-70 percent of the total-P yield in suspended form. Suspended P is any P associated with sediment particles that are greater in diameter than 0.45 microns.

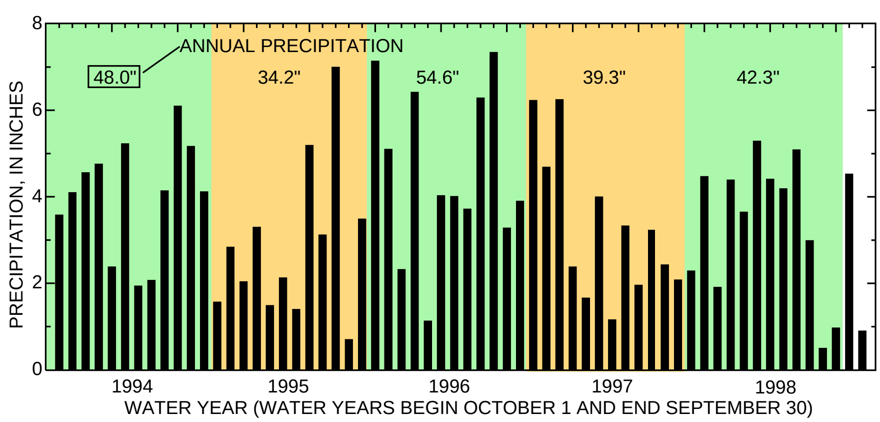


Figure 4. Monthly and annual precipitation totals recorded at the outlet of the treatment basin from October 1993 through November 1998.

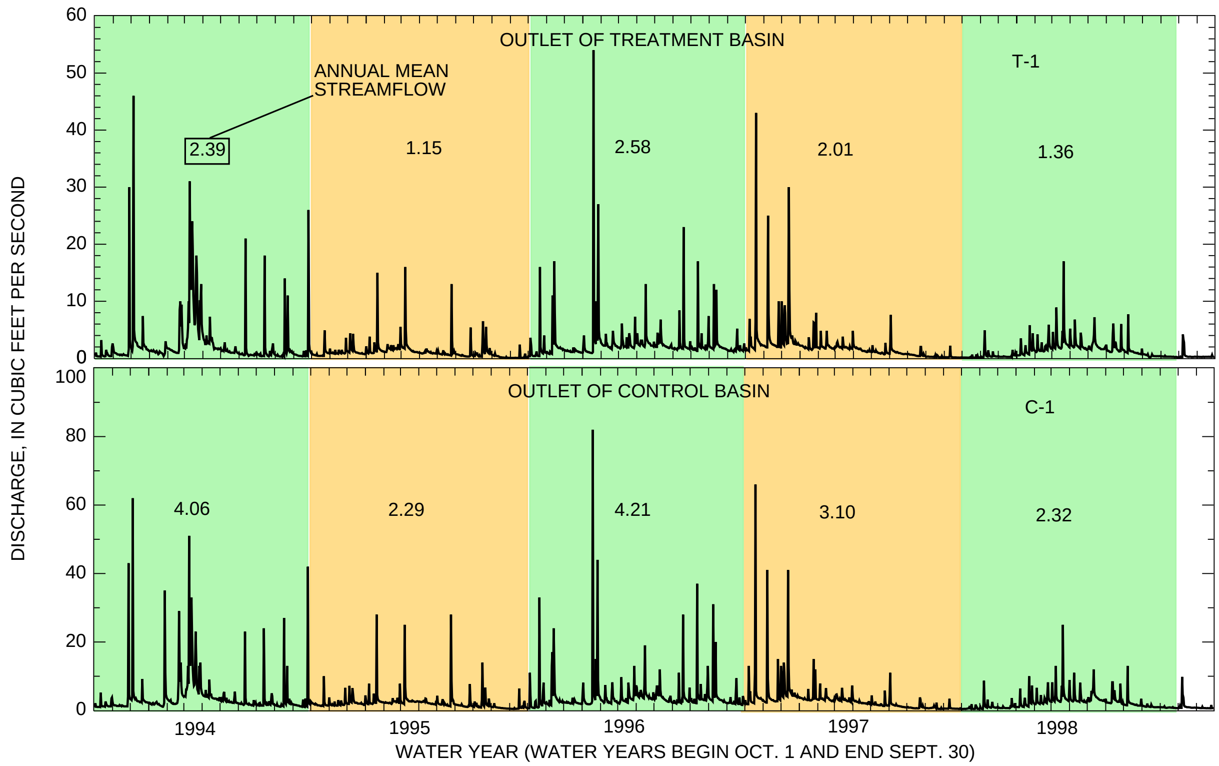


Figure 5. Daily and annual mean discharges for the outlets of the treatment and control basins from October 1993 through December 1998.

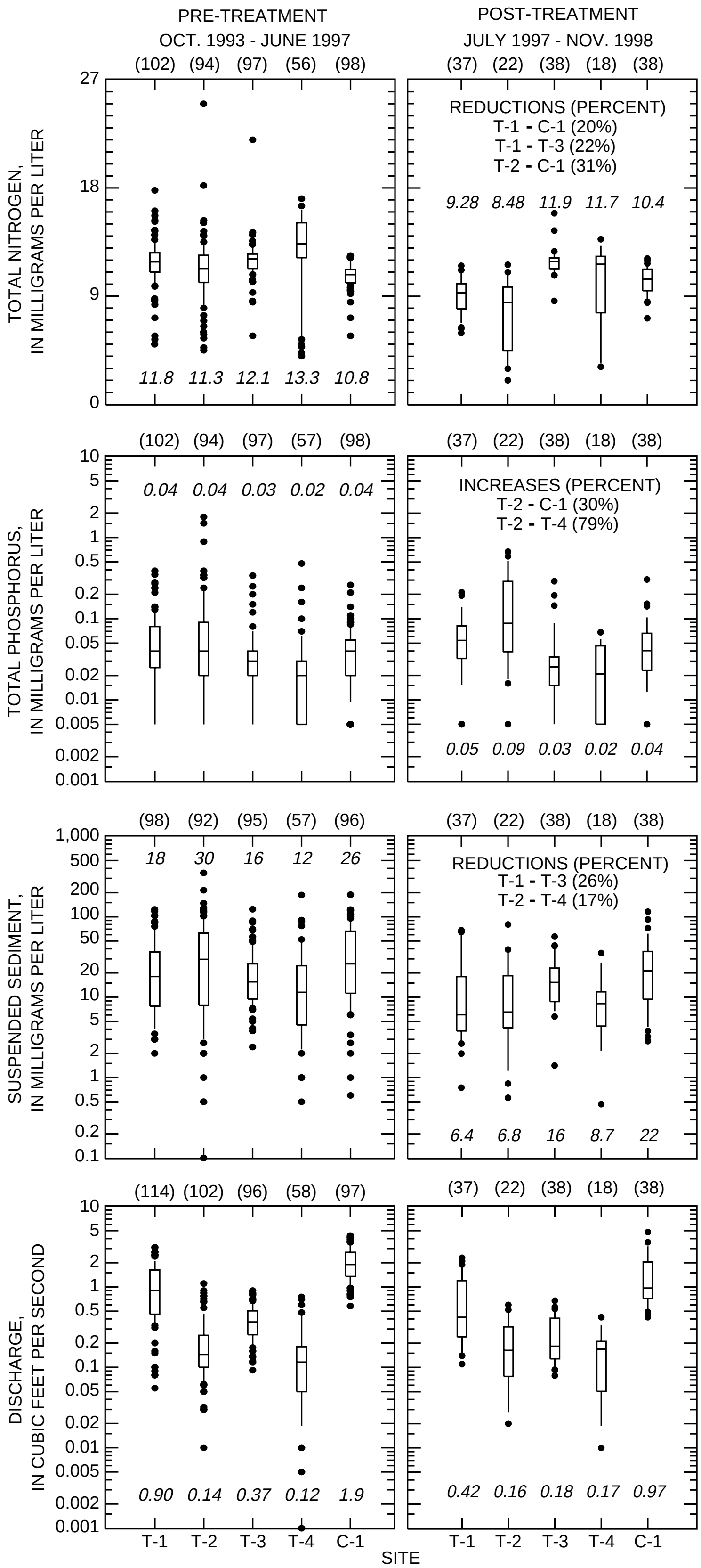
PRELIMINARY EFFECTS OF STREAMBANK FENCING

Chemical and Physical Data

Water-quality data from the surface-water sites in the study area were statistically compared after separating the data into fixed-interval and storm samples. Fixed-interval samples collected when the streamflow exceeded the 90th percentile of flow for that site were not used in statistical analyses. The subset of fixed-interval samples below the 90th percentile is referred to as low-flow samples.

Low Flow

Concentrations of total N and suspended sediment were significantly reduced in low-flow samples collected at sites affected by streambank fencing (fig. 6). The reduction in total N, which ranged from 20 to 31 percent at treated (T-1 and T-2) relative to untreated sites (C-1, T-3, and T-4), was attributable to decreased concentrations of NO_3-N. The percent decrease in NO_3-N and total-N concentrations from the pre- to post-treatment period for T-1 was 24 percent. The lower than normal flows during the treatment period would help to promote denitrification, which is a process that converts nitrate to N gas. Denitrification in stream channels would tend to increase with an increase in anoxic conditions, and recent literature has identified denitrification in stream channels as a potential cause for the instream loss of nitrate in the Mississippi River Basin (Alexander and others, 2000). Other processes such as vegetative uptake of nitrate could also contribute to decreased N concentrations in the treatment basin. Total-N yields for low-flow samples did not significantly change at treated sites relative to untreated sites from the pre- to post-treatment period (fig. 7). Significant reductions in suspended-sediment concentrations occurred at T-1 and T-2 relative to upstream sites, but the paired-watershed comparisons were not significantly different, likely because of the decrease in the mean suspended-sediment concentration from 41 to 29 mg/L at C-1 from the pre- to post-treatment period.



EXPLANATION

(37) NUMBER OF OBSERVATIONS

• DATA VALUES OUTSIDE THE 10TH AND 90TH PERCENTILES

90TH PERCENTILE
75TH PERCENTILE
MEDIAN
25TH PERCENTILE
10TH PERCENTILE

10.4 MEDIAN VALUE

Significant differences in the pre- and post-treatment data between sites were determined using the Wilcoxon rank-sum test. A significant difference between T-1 and C-1 from the pre- to post-treatment period would indicate that there was a significant change in the matched paired relations between the sites. For example, if the concentration for T-1 before fencing was 5 mg/L and the concentration for C-1 was 8 mg/L for matched samples (samples collected on the same day), the difference would be -3 mg/L. If the concentrations for T-1 and C-1 after fencing were 1 and 7 mg/L, respectively, then the difference would be -6 mg/L. These differences are calculated for each matched pair of samples. The Wilcoxon rank-sum test was run on the differences for these matched samples to determine if pre-treatment differences were significantly different from post-treatment differences. A significant reduction would indicate that the concentration data for T-1 had decreased relative to the concentration data for C-1.

Figure 6. Ranges of discharge and concentrations of nutrients and suspended sediment for low-flow samples collected during the pre- and post-treatment periods from October 1993 through November 1998 at five sites in the study basin. (Significant reductions and increases between sites are based on an alpha equal to 0.10.)

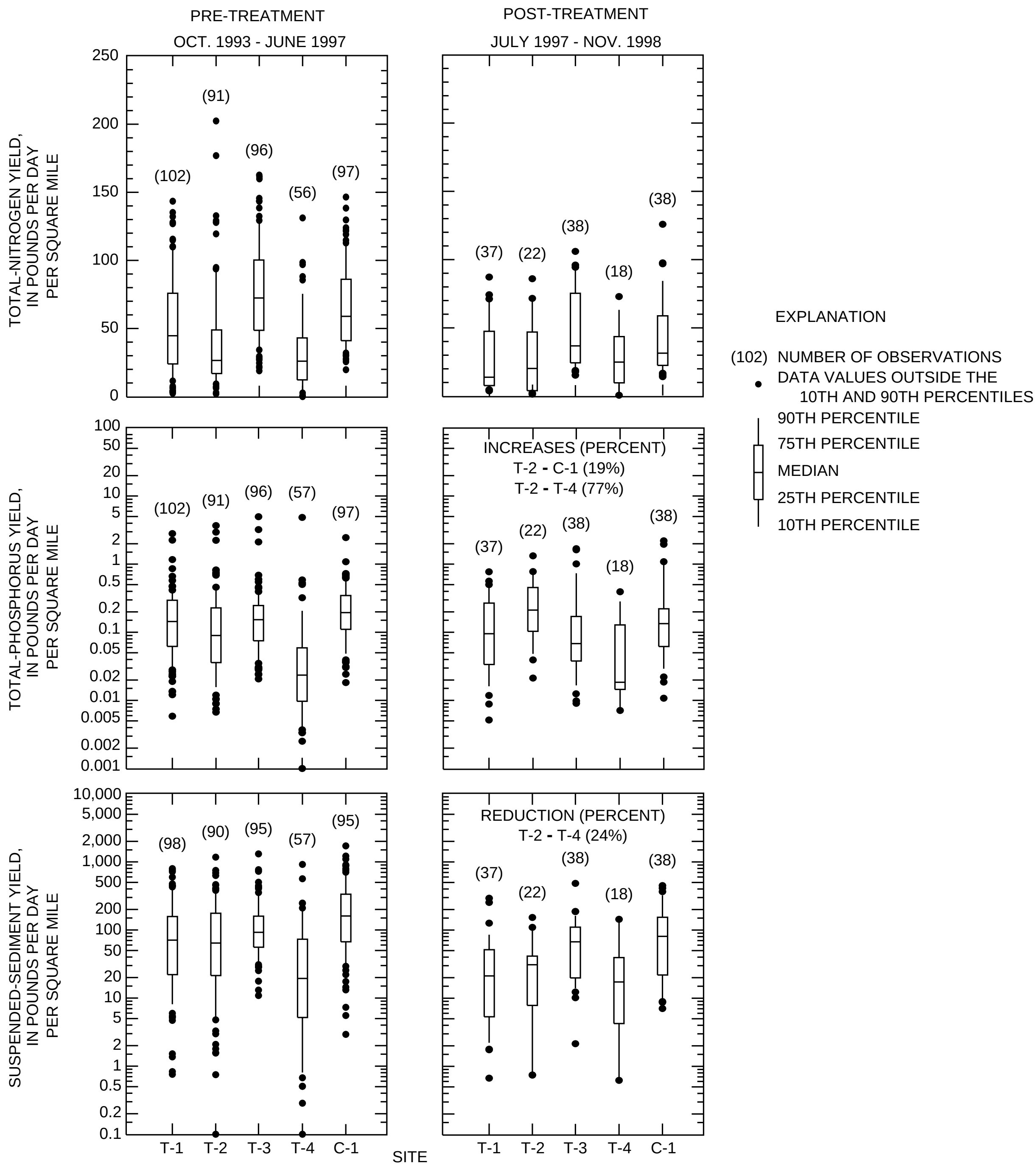


Figure 7. Ranges of instantaneous yields for total nitrogen, total phosphorus, and suspended sediment for low-flow samples collected during the pre- and post-treatment periods from October 1993 through November 1998 at five sites in the study basin. (Daily yields were estimated by multiplying the instantaneous discharge at time of sample collection by the measured concentration and dividing by drainage area. Significant reductions and increases between sites are based on an alpha equal to 0.10.)

Conversely, concentrations of total P showed either significant increases or no reductions for low-flow samples at treated relative to untreated sites (fig. 6). T-2 was the only site that showed a significant increase in total-P concentration and yield relative to untreated sites after fence installation. This relative increase in total P was due to increased dissolved-P concentrations at T-2. The mean concentration of dissolved P at T-2 increased from 0.05 to 0.13 mg/L from the pre- to post-treatment period; the concentration of suspended P decreased by 0.01 mg/L. The increase in dissolved P at T-2 is related to the lower than normal flows and the solubilization of orthophosphorus from sediments in parts of the basins where flows were at or near zero. As flows decrease, it is common for stagnant pools to develop in the stream channel above T-2. These pools approach anoxic conditions over time and this condition can promote reduction of iron hydroxides. As these hydroxides are reduced, the P bound to the hydroxides is released (Vadas and Sims, 1999). The solubilized P is subsequently transported downstream when streamflow increases.

Low-flow conditions at outlet of treatment basin.

Stormflow

Concentrations of suspended sediment were significantly reduced in stormflow samples collected at all treated sites (T-1 and T-2) relative to untreated sites (C-1 and T-4) (fig. 8). The relative reductions in the suspended-sediment concentrations at the treated sites ranged from 21 to 54 percent. This reduction was expected with the revegetation of stream corridors and reduced trampling of streambanks by pastured animals in the treatment basin. Suspended-sediment yields at T-2 were significantly reduced by 8 to 14 percent relative to untreated sites; however, there was no significant change in suspended-sediment yields at T-1 relative to untreated sites (fig. 9).

Significant reductions in concentrations of total N and total P for storm-composite samples were limited to those at T-2 relative to C-1 (fig. 9). A decrease in the concentrations of total N and total P was evident at all sites in both basins, and this is at least partially attributable to reduced flows during the post-treatment relative to the pre-treatment period. Generally, the concentration of suspended materials in stormflow increased with an increase in stormflow. The percent decrease in nutrients from the pre- to post-treatment periods differed from sites at the outlets (T-1 and C-1) as opposed to upstream tributary sites (T-2 and T-4) in the treatment basin. The decreases in the total-N and total-P concentrations were about 10 and 25 percent, respectively, from pre- to post-treatment periods for both T-1 and C-1. The decrease in the total-N concentrations from the pre- to the post-treatment period at tributary sites ranged from 21 percent at T-4 to 25 percent at T-2, and the percent decrease in total-P concentrations ranged from 44 percent at T-4 to 52 percent at T-2. The significant reduction in the total-N concentration at T-2 relative to C-1 was partially attributable to a 65-percent decrease in the concentration of suspended organic N at T-2 from the pre- to post-treatment period. The significant reduction in the concentration of total P at T-2 relative to C-1 was due to a 73-percent decrease in the concentration of suspended P at T-2 from the pre- to post-treatment period. There were no significant changes in yields of total N and total P for stormflow at treated relative to untreated sites (fig. 9).

High-flow conditions at outlet of treatment basin.

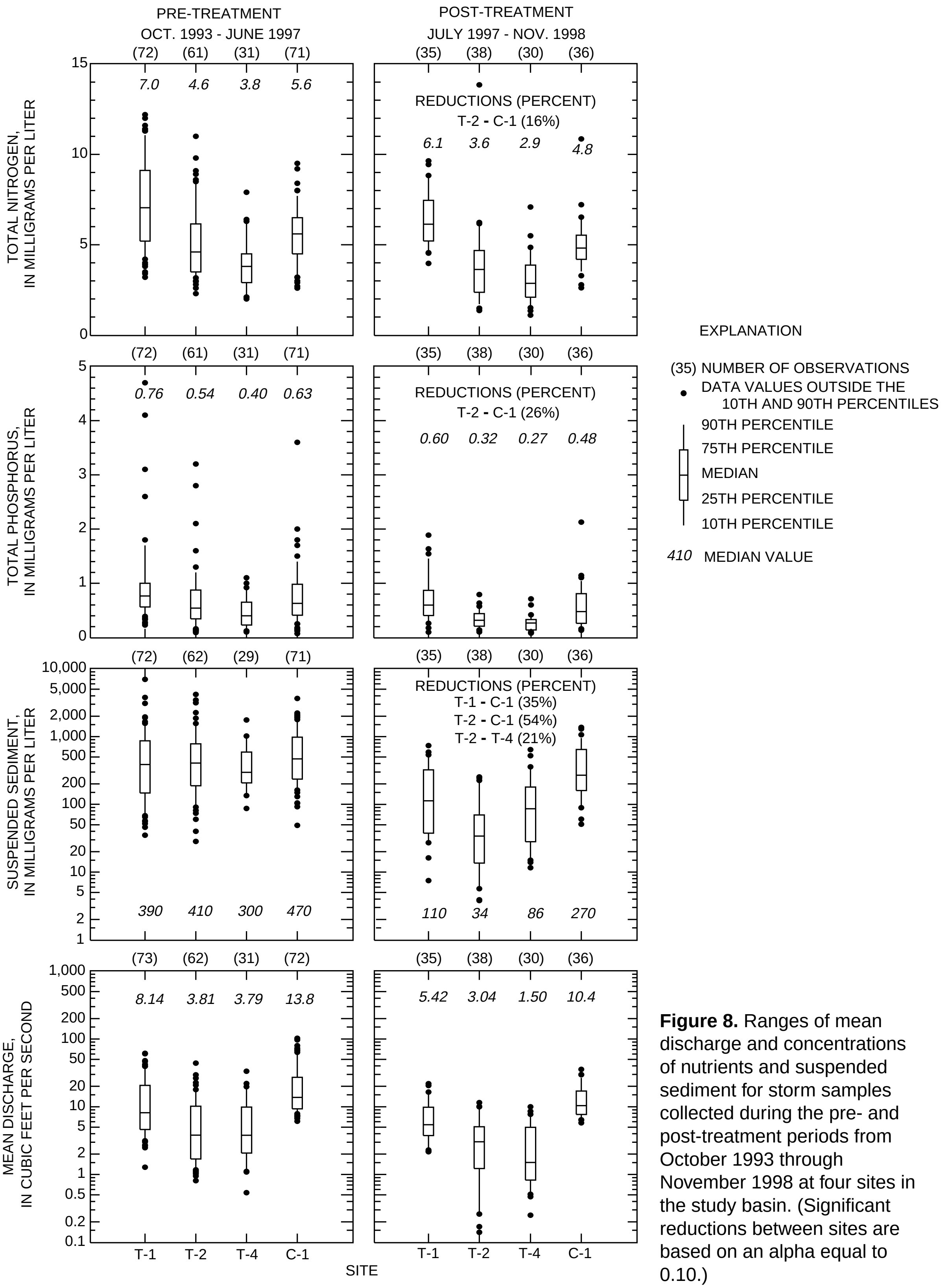


Figure 8. Ranges of mean discharge and concentrations of nutrients and suspended sediment for storm samples collected during the pre- and post-treatment periods from October 1993 through November 1998 at four sites in the study basin. (Significant reductions between sites are based on an alpha equal to 0.10.)

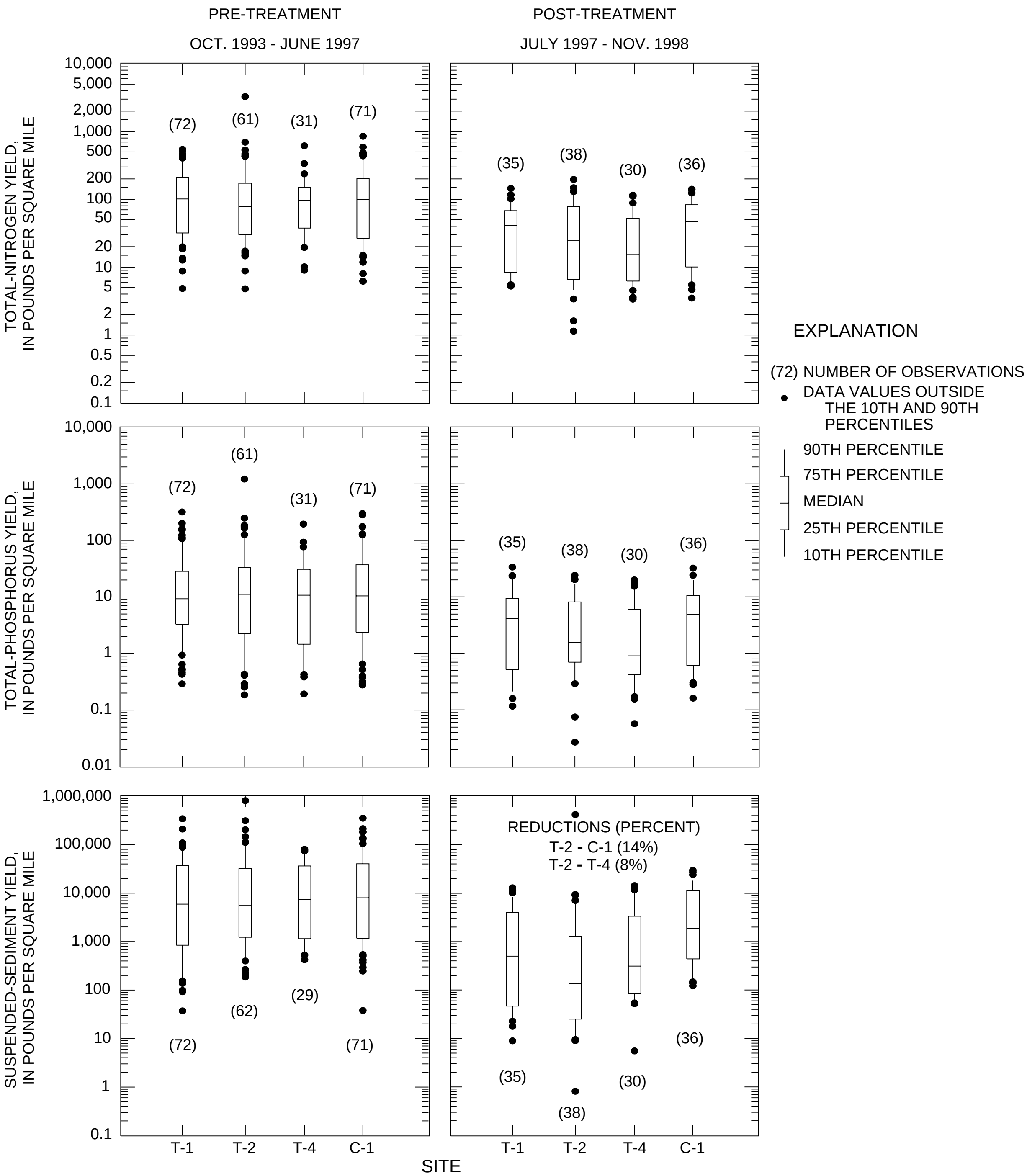


Figure 9. Ranges of stormflow yields for total nitrogen, total phosphorus, and suspended sediment for storm samples collected during the pre- and post-treatment periods from October 1993 through November 1998 at four sites in the study basin. (Stormflow yields were calculated by multiplying mean storm discharge by storm duration and mean storm concentration and dividing by drainage area. Significant reductions between sites are based on an alpha equal to 0.10.)

Biological Data

Benthic-macroinvertebrate data indicated some differences in upstream and downstream sites (fig. 10). The three metrics used to summarize the data generally indicated that the health or status of the benthic-macroinvertebrate community at the outlets of both basins was of better quality than the upstream sites. Water quality at all five sampling sites generally was the same, so the apparent increased health of the system as one moves downstream was because of physical factors. Differences within basins could be related to changes in stream depth, stream width, substrate sizes, and vegetative structure. Assuming other factors such as water quality are relatively constant, increased habitat heterogeneity generally is related to increases in taxa richness (Beisel and others, 1998).

Biological metrics indicate streambank fencing improved the apparent health of the benthic-macroinvertebrate community. The most dramatic difference between pre- and post-treatment benthic-macroinvertebrate data was the increased taxa richness in the treatment basin after fence installation (fig. 10). The mean taxa richness at each of the two sites in the control basin was 20 before and after fence installation. The mean number of taxa identified at each of the sites in the treatment basin increased from 23 during the pre-treatment to 31 after fence installation. The increased taxa richness at upstream sites in the treatment basin relative to the upstream site in the control basin was significant.

The higher EPT/Chironomidae abundance ratio for T-1 after fence installation was due to an increased number of Baetidae (a family of mayfly or Ephemeroptera) identified during September 1997 and 1998. Conversely, fewer Baetidae were collected from upstream sites in the treatment basin after fence installation, and subsequently, the EPT/Chironomidae ratios decreased from the pre- to the post-treatment period.

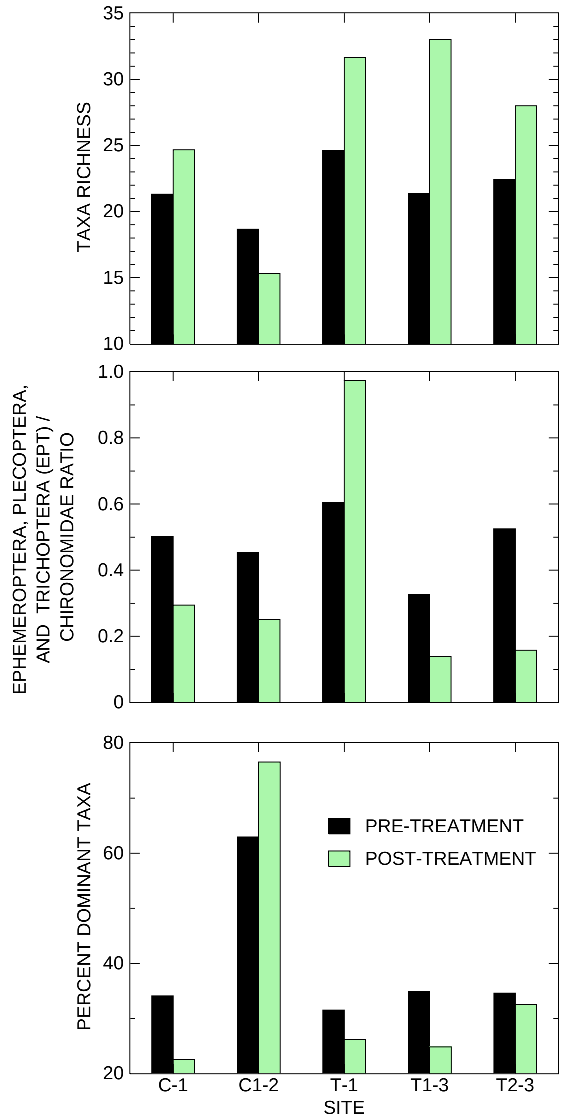


Figure 10. Benthic-macroinvertebrate metrics for samples collected during the pre- (September 1993 - June 1997) (8 sample events) and post-treatment period (July 1997 - November 1998) (3 sample events) at five sites in the study basin.

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