EVALUATION OF AGRICULTURAL BEST-MANAGEMENT PRACTICES IN THE CONESTOGA RIVER HEADWATERS, PENNSYLVANIA: Effects of Nutrient Management on Water Quality in the Little Conestoga Creek Headwaters, 1983-89

WATER-QUALITY STUDY OF THE CONESTOGA RIVER HEADWATERS, PENNSYLVANIA

By

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer
	Discharge	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
	Mass	
pound (lb)	0.4545	kilogram
ton (short, 2,000 pounds)	0.9072	metric ton
pound per acre (lb/acre)	1.123	kilogram per hectare
ton per square mile (ton/mi^2)	2.241	metric ton per square kilometer
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 (°F – 32)	degree Celsius

Abbreviated water-quality units used in report:

milligrams per liter (mg/L)
micrograms per liter (µg/L)
microsiemens per centimeter at 25 degrees Celsius (µS/cm)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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Effects of Nutrient Management on Water Quality in the Little Conestoga Creek Headwaters

Edward H. Koerkle, David K. Fishel,
Mary Jo Brown, and Kevin M. Kostelnik

ABSTRACT

Water quality in the headwaters of the Little Conestoga Creek, Lancaster County, Pa., was investigated from April 1986 through September 1989 to determine possible effects of agricultural nutrient management on water quality. Nutrient management, an agricultural Best-Management Practice, was promoted in the 5.8-square-mile watershed by the U.S. Department of Agriculture Rural Clean Water Program. Nonpoint-source-agricultural contamination was evident in surface water and ground water in the watershed; the greatest contamination was in areas underlain by carbonate rock and with intensive row-crop and animal production.

Initial implementation of nutrient management covered about 30 percent of applicable land and was concentrated in the Nutrient-Management Subbasin. By 1989, nutrient management covered about 45 percent of the entire Small Watershed, about 85 percent of the Nutrient-Management Subbasin, and less than 10 percent of the Nonnutrient-Management Subbasin. The number of farms implementing nutrient management increased from 14 in 1986 to 25 by 1989. Nutrient applications to cropland in the Nutrient-Management Subbasin decreased by an average of 35 percent after implementation.

Comparison of base-flow surface-water quality from before and after implementation suggests that nutrient management was effective in slowing or reversing increases in concentrations of dissolved nitrate plus nitrite in the Nutrient-Management Subbasin. Although not statistically significant, the Mann-Whitney step-trend coefficient for the Nutrient-Management Subbasin was 0.8 milligram per liter, whereas trend coefficients for the Nonnutrient-Management Subbasin and the Small Watershed were 0.4 and 1.4 milligrams per liter, respectively, for the period of study. Analysis of covariance comparison of concurrent concentrations from the two subbasins showed a significant decrease in concentrations from the Nutrient-Management Subbasin compared to the Nonnutrient-Management Subbasin.

The small, positive effect of nutrient management on base-flow water quality should be interpreted with caution. Lack of statistical significance for most tests, short-term variation in climate and agricultural activities, unknown ground-water flow rates, and insufficient agricultural-activity data for farms outside of the Nutrient-Management Subbasin were potential problems. A regression model relating nutrient applications to concentrations of dissolved nitrate plus nitrite showed no significant explanatory relation.

INTRODUCTION

The Conestoga River discharges to the Susquehanna River. The U.S. Environmental Protection Agency's (USEPA) Chesapeake Bay Study reported that the Susquehanna River contributes 40 percent of the nitrogen and 21 percent of the phosphorus that are discharged to the Chesapeake Bay. Of this contribution, 85 percent of the nitrogen and 60 percent of the phosphorus were estimated to have come from cropland runoff (U.S. Environmental Protection Agency, 1983). The Chesapeake Bay Study recommended implementation of agricultural Best-Management Practices (BMP's) to reduce nonpoint-source nutrient discharges.

The U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Protection (PaDEP)[1] and as part of the Rural Clean Water Program (RCWP) administered by the U.S. Department of Agriculture (USDA), studied the effects of agricultural BMP's on water quality in the headwaters of the Conestoga River Basin in south-central Pennsylvania. The Conestoga River Headwaters was 1 of 20 RCWP projects nationwide. These projects were designed to accelerate the installation of agricultural BMP's for the purpose of reducing agricultural nonpoint-source contamination. In addition, the Conestoga River Headwaters RCWP was one of five RCWP projects selected for Comprehensive Monitoring and Evaluation (CM&E) of the effects of BMP's in improving water quality. CM&E in the Conestoga River Headwaters RCWP was conducted at three scales: regional, small watershed, and field. CM&E in the project area began in 1982 with the establishment of the 188-mi^2 Regional Network component. Data collected from the Regional Network during 1982–83 indicated that the major water-quality problem in the upper Conestoga River Basin is elevated nitrate concentrations in surface and ground water. Concentrations of nitrate as great as 40 mg/L as N were measured in ground water closely associated with intensively farmed areas having carbonate geology (Fishel and Lietman, 1986). This report presents the results of CM&E at the small watershed scale.

A detailed presentation of the background of the Conestoga River Headwaters RCWP project can be found in "Evaluation of Agricultural Best-Management Practices in the Conestoga River Headwaters, Pennsylvania: Methods of Data Collection and Analysis, and Description of Study Areas," by Chichester (1988). Abbreviated discussions of background and methodology are included here for clarity.

Nutrient management is a BMP intended to reduce the occurrence of excess nutrients on cropland. Under nutrient management, application rates and application timing of manures and commercial fertilizer are chosen to satisfy crop nutrient requirements while reducing the availability of fertilizer nutrients for transport to surface and ground water. For this study, nutrient management was a combination of fertilizer management and animal-waste management.

Purpose and Scope

This report describes the effects of nutrient management on water quality in a 5.82-mi^2 drainage basin designated the Small Watershed (fig. 1) in the Conestoga River headwaters, Pa. Data used in the evaluation were collected from April 1, 1984, through September 30, 1989, after implementation of nutrient management. Data include precipitation, agricultural activity, soil nutrient, streamflow, surface water, base-flow and stormflow quality, monthly loads, and annual yields of nutrients and suspended sediment. The effects of nutrient management on water quality are evaluated by statistical and qualitative comparison of the data collected from April 1, 1984, through March 31, 1986 (pre-BMP period), to the data collected from April 1, 1986, through September 30, 1989 (post-BMP period). Data for the pre-BMP period were previously published in "Evaluation of Agricultural Best-Management Practices in the Conestoga River Headwaters, Pennsylvania: Description and Water Quality of the Little Conestoga Creek Headwaters Prior to the Implementation of Nutrient Management," by Fishel and others (1992).

The study was conducted as a pre- and post-treatment experimental design; nutrient management was the treatment. A pre-BMP period from April 1, 1984, to April 1, 1986 (2 years), and a post-BMP period from April 1986 to September 1989 (3.5 years) defined the treatment periods. Data from the post-BMP period were compared to data from the pre-BMP period to determine the effects of BMP implementation on water quality and nutrient inputs. By delineation of two smaller subbasins within the Small Watershed, three different levels of implementation were included in the experimental design.

Additionally, a paired-basin experiment was conducted in two subbasins of approximately 1.4 mi^2 each. The use of paired subbasins that are geologically, hydrologically, and climatically similar helps in distinguishing water-quality changes resulting from BMP implementation from those changes resulting from factors other than BMP's.

[1]Prior to 1995, the Pennsylvania Department of Environmental Protection was the Pennsylvania Department of Environmental Resources.

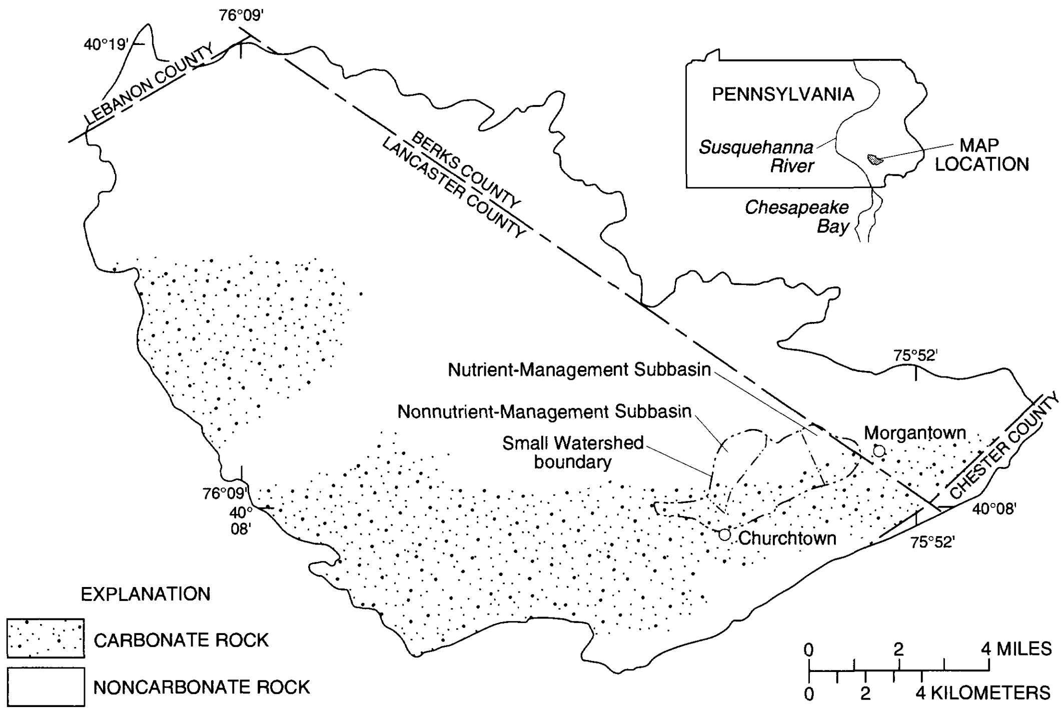

Figure 1.--Location of the Small Watershed.
(From Chichester, 1988, fig. 1.)

Acknowledgments

The following individuals and their respective agencies are acknowledged for their assistance: Farm operators in the Small Watershed study area, for voluntarily assisting with project objectives and providing land-use data; Robert J. Anderson and Jeffrey Stoltzfus from the Pennsylvania State University Cooperative Extension, for developing nutrient management plans; Richard A. Pennay from USDA, Agricultural Stabilization and Conservation Service (ASCS), for coordinating the transfer of information among the cooperating agencies; Omer Brubaker from the USDA, ASCS, for collecting agricultural-activity data from farm operators and making annual field inspections; Vincent C. White, Lynn B. Schaffer, and John H. Maljevac from the PaDEP, Bureau of Laboratories, for analyzing water-quality samples; and Dr. Dale E. Baker and Leon E. Marshall from the Pennsylvania State University Department of Agronomy, for the collection and analysis of soil samples.

Description of the Study Area

The 5.82-mi^2 Small Watershed is located in parts of Lancaster and Berks Counties in south-central Pennsylvania (fig. 1) and lies in two sections of the Piedmont Physiographic Province. The northern half, characterized by broad highlands and ridges, is in the Gettysburg-Newark Lowland Section and is underlain by Triassic- and Jurassic-age conglomerate, mudstone, sandstone, shale, and diabase. The southern half of the watershed, characterized by rolling lowlands, is in the Piedmont Lowland Section and is underlain by carbonate rock of Cambrian and Ordovician ages. The two subbasins delineated for the paired-subbasins experiment within the Small Watershed are similar in size and geology. The Nutrient-Management Subbasin covers 1.42 mi^2 and is underlain by the Hammer Creek, Stockton, and Buffalo Springs Formations. About 50 percent of the subbasin is underlain by carbonate rock of the Buffalo Springs Formation. The Nonnutrient-Management Subbasin covers 1.43 mi^2 and is underlain by the Hammer Creek, Stockton, and Buffalo Springs Formations. About 25 percent of the subbasin is underlain by carbonate rock of the Buffalo Springs Formation.

Soils in the Small Watershed are of three compositions: noncarbonate, carbonate, or alluvial. All are fine to medium textured and well drained. The major noncarbonate soils are of the Brecknock, Bucks, and Unger series (U.S. Department of Agriculture, 1985). The major carbonate soils are of the Duffield and Hagerstown series and are cited as prime farmland in the Lancaster County Soil Survey (U.S. Department of Agriculture, 1985). The alluvial soils are of the Rowland and Readington series and are located along the streambanks and in the flood plains.

Soils in the Small Watershed and the Nutrient-Management Subbasin are proportioned similarly among noncarbonate, carbonate, and alluvial soils, as shown in table 1. The Nonnutrient-Management Subbasin has a higher percentage of noncarbonate soils than the Nutrient-Management Subbasin.

Table 1.--Soil compositions in the Small Watershed, as percentages of total soil-covered area

Soil composition	Small Watershed	Nutrient-Management Subbasin	Nonnutrient-Management Subbasin
Noncarbonate	47	50	71
Carbonate	41	36	18
Alluvial	12	14	11

Land use in the Small Watershed is predominantly agricultural (table 2). Agricultural land is concentrated in the southern half of the watershed. Woodland is concentrated in the northern half of the watershed. Urban and residential land use are concentrated along the southern boundary of the study area. Land use in the Nonnutrient-Management Subbasin (identified as the Control Subbasin in the pre-BMP report) includes about 20 percent less agricultural land than in the Nutrient-Management Subbasin. Sixty-eight percent of the land in the Small Watershed and 78 percent of the land in the Nutrient-Management Subbasin were used for agriculture and related purposes. Row crops, consisting primarily of corn and limited amounts of small grains, were the largest agricultural land use. Hay cropping, the next largest use of agricultural land, consisted mostly of alfalfa. Up to 40 percent of the row-crop land was rotated to hay each year. The rotation schedule was typically 2 years of corn followed by 3 years of alfalfa. Only about 6 percent of the land was in pasture. Ninety percent of the pastureland was adjacent to the stream channel. Noncropland uses consisted of areas surrounding farm buildings and roadways. Other land uses included residential and commercial. Because only 1 percent of the land in the Nutrient-Management Subbasin is used for purposes other than agriculture or forest, the human population is small compared to the animal populations. As a result, the potential for nutrient-related water-quality problems caused by septic systems was considered minimal.

Table 2.--Estimated land use in the Small Watershed and Nutrient-Management Subbasin, as a percentage of total land area

Land use	Small Watershed	Nutrient-Management Subbasin
Agriculture		
Row crops	34	41
Hay	15	17
Pasture	5	6
Noncropland	14	14
Forest	24	21
Other	8	1

The Small Watershed contains all or parts of 43 farms. The Nutrient-Management Subbasin contains 16 farms. The Nonnutrient-Management Subbasin contains 8 farms.

Site Identification System

All water-quality-sampling sites were assigned USGS identification numbers (table 3). In addition, each site was given a code to simplify identification when referenced in the text.

Table 3.--Small Watershed study area surface-water data-collection stations

[mi^2, square mile; °, degree; ', minute; ", second; --, not applicable]

USGS identification number	Site code	Station name	Station type	Drainage area (mi^2)	Latitude	Longitude
015760831	NM1	Little Conestoga Creek,[1] site NM1, near Morgantown, Pa.	Partial record	0.34	40°09'22"	75°55'14"
015760832	NM2	Little Conestoga Creek, site NM2, near Morgantown, Pa. (discontinued October 1984)	Partial record	.60	40°09'06"	75°55'05"
0157608325	NM3	Little Conestoga Creek, site NM3, near Morgantown, Pa.	Partial record	.99	40°08'58"	75°55'06"
015760833	NM4	Little Conestoga Creek, site NM4, near Morgantown, Pa. (discontinued October 1984)	Partial record	1.34	40°08'50"	75°55'24"
0157608335	NM5	Little Conestoga Creek, site NM5, near Morgantown, Pa. (Nutrient-Management Subbasin)	Continuous record	1.42	40°08'47"	75°55'37"
01576089	NC1	Unnamed tributary to Little Conestoga Creek, site NC1, at Churchtown, Pa. (Nonnutrient-Management Subbasin)	Partial record	1.43	40°08'20"	75°58'14"
01576085	SW1	Little Conestoga Creek, site SW1, near Churchtown, Pa. (Small Watershed study area)	Continuous record	5.82	40°08'41"	75°58'20"

[1] The original source of reference for the Little Conestoga Creek referred to in this report comes from the U.S. Geological Survey Morgantown Quadrangle of 1939. The 1975 photorevision of the Morgantown Quadrangle designates the stream as an unnamed tributary to the Conestoga River. The Little Conestoga Creek referred to in this report should not be confused with the Little Conestoga Creek that discharges to the Conestoga River near Safe Harbor and is found on the Conestoga Quadrangle.

Nutrient Management

Nutrient management BMP is the manipulation of applications of nutrients such that applications meet, but not exceed, crop needs. By minimizing application of nutrients, the supply of unused nutrients that are potentially available for runoff to streams and for infiltration to ground water is reduced.

Nutrient management in the Small Watershed consisted of fertilizer management and animal-waste management. Fertilizer management was implemented through the use of plans that recommended nitrogen application rates for individual farm fields. The recommendations were determined by factoring in crop acreage, the quantity and nutrient content of manures collected and commercial fertilizers, estimates of soil-nutrient reserves, and any reliable historical data on nutrient applications. Uncollected manure, which was produced by pastured animals, was not included in the plans. Animal-waste management was implemented through the use of manure storage facilities and scheduling of manure application times. Prior to nutrient management, manure storage capacities of about 35 days were typical. Routine field applications were necessary to prevent overloading of limited storage, regardless of field conditions. Under nutrient-management guidelines, scheduled manure applications may require manure storage for up to 180 days.

Nutrient-management implementation in the Small Watershed began in April 1986. By the end of the 1986 calendar year, 14 farms covering about 30 percent of applicable cropland in the watershed had nutrient-management plans. Eleven of the first 14 farms with plans, covering about 80 percent of the applicable land, were located in the Nutrient-Management Subbasin. None were in the Nonnutrient-Management Subbasin. An additional 11 farms received plans by 1989. Coverage by plans averaged less than 10 percent in the Nonnutrient-Management Subbasin, 85 percent in the Nutrient-Management Subbasin, and 45 percent in the Small Watershed. Some farm operators not participating in the RCWP program did change their nutrient-management practices as a result of discussions or interaction with USDA, Soil Conservation Service, or Pennsylvania State University Cooperative Extension personnel. All plans addressed fertilizer management, but not all recommended reductions in nitrogen applications. Only one farm, farm H (fig. 2), located in the Nutrient-Management Subbasin, constructed a manure-storage tank. The manure-storage tank permitted up to 200 days of manure storage.

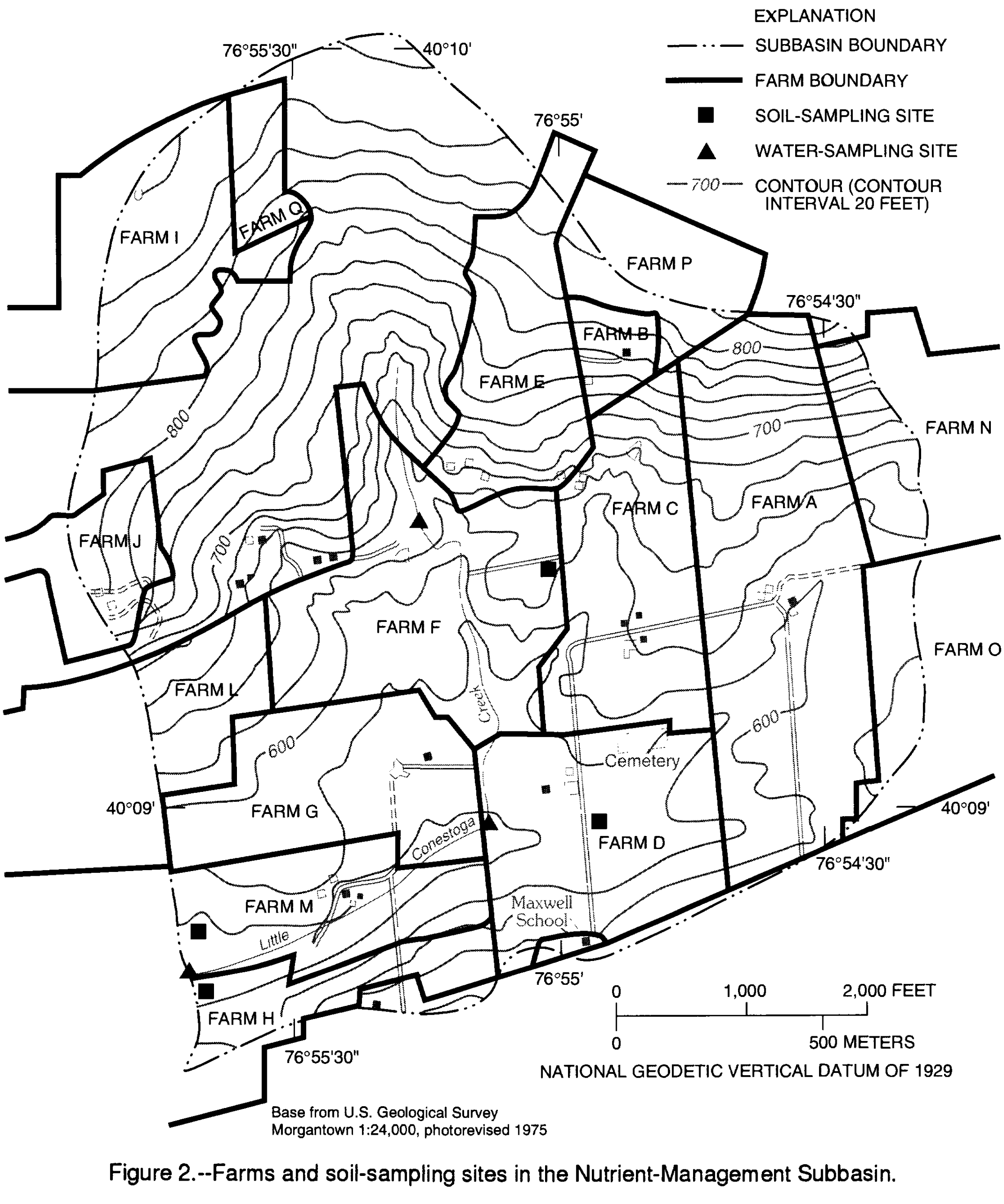

Figure 2.--Farms and soil-sampling sites in the Nutrient-Management Subbasin.

Animal populations in the Nutrient-Management Subbasin were large and diverse; they included beef and dairy cattle, sheep, swine, chickens, turkeys, horses, and mules. Total animal populations varied from year to year and within a year, but the ratios of numbers of animals by type generally were stable in proportion. On average, most of the population, by weight, consisted of about 40 percent dairy cows, 20 percent poultry, and 20 percent swine. The Conestoga Headwaters Plan of Work (U.S. Department of Agriculture, 1982) classified farms with more than 1.5 animal units per acre (AU/acre) as being critical areas in terms of nonpoint-source agricultural pollution. One animal unit is equal to 1,000 lb of animal, regardless of type. Animal densities on many farms in the Nutrient-Management Subbasin exceeded this critical value (table 4).

Table 4.--Animal densities prior to nutrient management on farms in the Nutrient-Management Subbasin, on the basis of total crop acreage where manure may be applied

[From Fishel and others, 1992; AU/acre, animal units per acre]

Farm[1]	Crop acreage (acres)	Animal density (AU/acre)
A	106	1.2
B	75	1.2
D	55	2.4
E	27	.9
G	82	1.2
H	32	3.1
I	44	1.6
J	126	1.1
L	70	1.6
M	34	1.8

[1] Location on figure 2.

METHODS OF INVESTIGATION

Methods of data collection and analysis for precipitation, agricultural activity, soil nutrients, and surface and ground water are discussed in Chichester (1988) and in Fishel and others (1992). A summary of and modifications to those methods are included in this section. A summary of the data-collection protocol is presented in table 5.

Table 5.--Data-collection schedule for the Small Watershed study from April 1984 through September 1989

Location	Constituent or parameter	Frequency
Two continuous-record stations	Suspended sediment and nutrients	Monthly base flow and major storms
	Pesticides	Monthly during growing season
Five partial-record stations (reduced to three in October 1984)	Suspended sediment, nutrients, and pesticides (at one station)	Monthly base flow
Seven soil-sample locations (reduced to four in July 1987)	Nutrients	Spring and fall
One precipitation station	Precipitation intensity and total accumulation	5-minute intervals
Fourteen farms	Agricultural activity	Spring and fall

The following conventions are used:

- Data presented as annual values are for the 12-month period April 1 through March 30, and, unless otherwise noted, are identified by the calendar year in which the April through December period occurs
- All species of nitrogen or phosphorus are expressed in elemental form
- The term ammonium refers to the ammonium ion plus free ammonia

All statistical tests are evaluated with a significance level of α=0.05 (a confidence level of 95 percent). Results of the tests are stated in terms of p-value—the significance level attained from the actual data; thus, p-values equal to or less than 0.05 (α-value) are considered significant.

Precipitation

Precipitation data were collected at a gage near the southern boundary of the study area (fig. 3). The gage recorded accumulated precipitation at 5-minute intervals. Missing data were estimated from precipitation data collected at the Conestoga River Headwaters RCWP field site near Churchtown, Pa., and from National Oceanic and Atmospheric Administration (NOAA) gages at Honeybrook and Glenmoore, Pa. The field site was located 2.5 mi west-southwest of the Small Watershed precipitation gage. The gages at Honeybrook and Glenmoore were located about 7 and 10 mi, respectively, southeast of the Small Watershed precipitation gage.

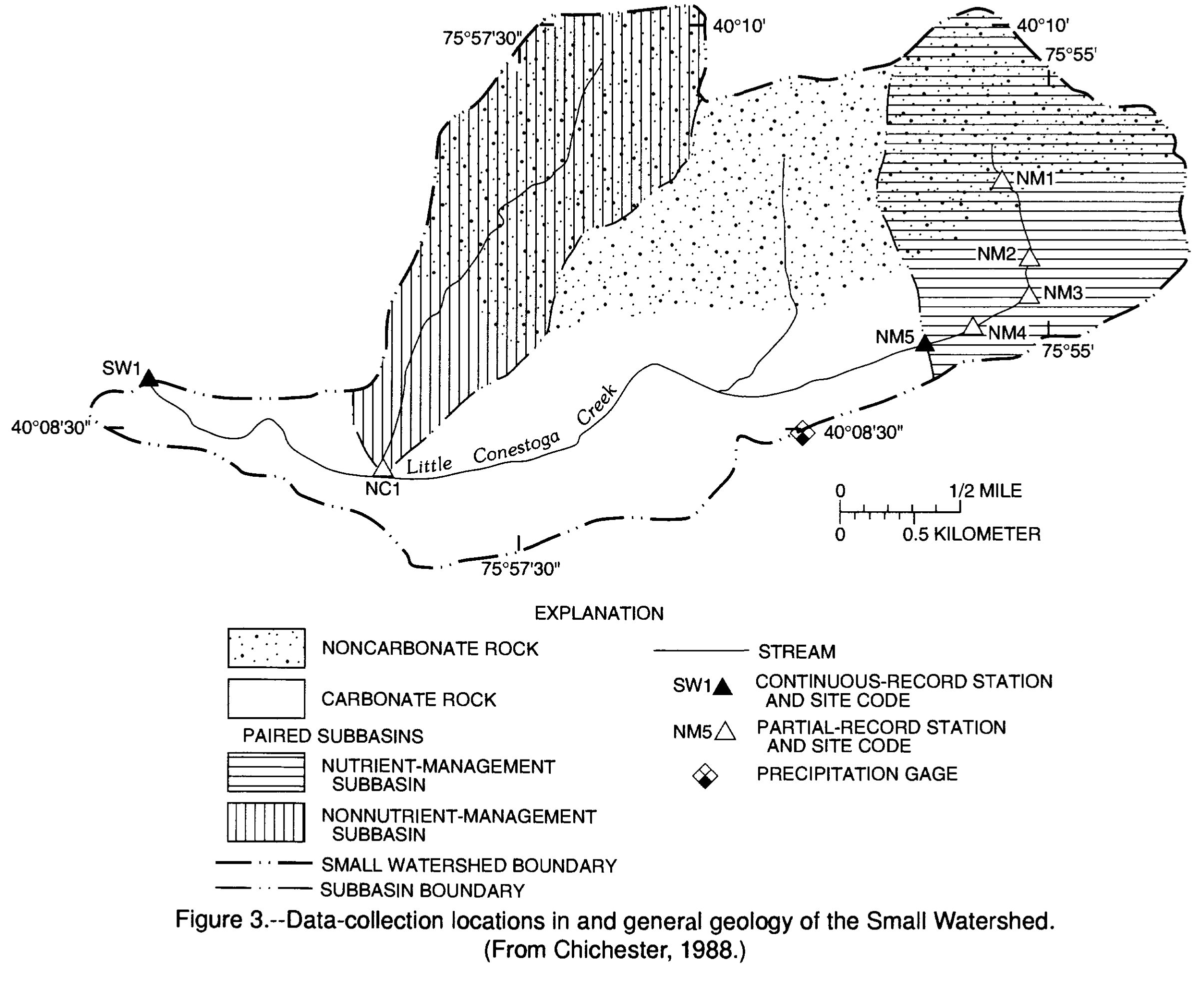

Figure 3.--Data-collection locations in and general geology of the Small Watershed. (From Chichester, 1988.)

Streamflow

Streamflow data were collected at two continuous-record gaging stations and three partial-record gaging stations (table 3). Sites NM1, NM3, and NM5 were located in the Nutrient-Management Subbasin, and site NC1 was located in the Nonnutrient-Management Subbasin. At the continuous-record stations (SW1 and NM5), stream stage was recorded on graphic and analog digital recorders. Streamflow hydrographs for the continuous-record stations were separated into ground water (base flow) and surface runoff (stormflow) components by use of the local-minimum technique described by Pettyjohn and Henning (1979). At the partial-record stations, instantaneous streamflow was measured at the time of base-flow sampling.

Water Quality

Network Description

The water-quality-sampling network consisted of seven sites in the Small Watershed (fig. 3). The Small Watershed, the Nutrient-Management Subbasin, and the Nonnutrient-Management Subbasin each had a water-quality site located at the most downstream location. The remaining four sites were located in the Nutrient-Management Subbasin.

Sampling and Analysis

Water quality was determined by chemical analysis and physical measurements of surface-water samples. The chemical constituents and physical characteristics measured and the detection limits are listed in table 6. Base-flow water samples were grab samples collected at the centroid of streamflow. Stormflow water samples were collected at the centroid of streamflow by stage-operated automatic-pumping samplers located at the continuous-record stations. Because a large number of water samples were collected for most stormflow events, a subset of the stormflow samples was selected for water-quality analyses. The criteria for subset selection was maximizing the accuracy of stormload estimates for a given number of storm samples.

All water samples were analyzed by use of USGS- and USEPA-approved procedures (Skougstad and others, 1979; U.S. Environmental Protection Agency, 1979, 1985). All nutrient water samples were preserved with mercuric chloride and analyzed by the PaDEP, Bureau of Laboratories, in Harrisburg, Pa. Pesticide water samples also were analyzed by the PaDEP, Bureau of Laboratories. Preliminary analytical results were retrieved and reviewed. Depending on the constituents involved, any questionable analyses were either re-analyzed or analytical calculations checked and recalculated. Suspended-sediment samples were analyzed by the USGS sediment laboratory in Lemoyne, Pa. Water-quality data collected during the BMP period of the study are published in USGS Water-Resources Reports PA–86–2, PA–87–2, PA–88–2, PA–89–2 (Loper and others, 1988a, 1988b, 1989, 1990). The data are catalogued by the USGS identification numbers listed in this report.

Monthly and annual loads and yields of nutrients and suspended sediment were estimated for sites NM5 and SW1. Daily loads for days on which no stormflow occurred were computed by the following equation:

$$L = kCQ, \tag{1}$$

where

L is load, in pounds per day;

k is 5.4, unit conversion factor;

C is daily mean concentration, in milligrams per liter; and

Q is daily mean streamflow, in cubic feet per second.

Daily mean base-flow concentrations were estimated by use of straight-line interpolation between days on which base-flow samples had been collected. Daily loads for days on which stormflow occurred and samples were collected were computed by the subdivided-day method described by Porterfield (1972). Estimated constituent loads were calculated for unsampled storm days by use of regression equations (table 7) derived from the relation between constituent loads and daily streamflow for sampled storm days. Estimated loads for storm days were calculated independently for the pre-BMP and post-BMP periods. Yields were calculated by dividing loads by the drainage area for the site.

Table 6.--Primary characteristics and chemical constituents for which surface-water and ground-water samples in the Small Watershed were analyzed during the post-Best-Management Practice period

[°C, degree Celsius; µS/cm, microsiemen per centimeter at 25 degrees Celsius; mg/L, milligram per liter; µg/L, microgram per liter; mL, milliliter]

Characteristic or constituent	Laboratory minimum reporting levels[1]	U.S. Environmental Protection Agency Primary Drinking Water Regulation
Temperature (field)	Measured to nearest 0.5°C	
Specific conductance (field)	1 to 10 µS/cm dependent on value	
Suspended sediment	1 mg/L	
Total and dissolved nutrients:		
Ammonium[2] plus organic nitrogen	0.2 mg/L	
Ammonium[2]	0.02 mg/L	
Organic nitrogen (calculated)	0.2 mg/L	
Nitrate plus nitrite	0.04 mg/L	
Nitrite	0.01 mg/L	
Nitrate (calculated)	0.04 mg/L	[3]10 mg/L
Phosphorus	0.02 mg/L	
Total herbicides:[4]		
Atrazine	0.1 µg/L for October 1984 through March 1987	[3, 5]3 µg/L
	0.3 µg/L for April 1987 through September 1989	
Cyanazine	0.2 µg/L for October 1984 through March 1987	[5]10 µg/L
Propazine	0.2 µg/L for April 1987 through September 1989	[3]0 µg/L
Alachlor	0.05 µg/L	[5]2 µg/L
Metolachlor	0.1 µg/L	[5]100 µg/L

[1] The smallest measured concentration of a constituent that may be reliably reported by the use of a given analytical method.

[2] Ammonium in this report represents ammonia plus ammonium.

[3] Maximum Contaminant Level (U.S. Environmental Protection Agency, 1990).

[4] The detection limit of herbicides is as described above if the recommended 1,900 mL of sample is used in analysis. For samples with substantial sediment concentrations, such as was the case with many runoff samples, a smaller volume of sample was used for analysis because of interferences caused by the suspended material. For samples with less than 1,900 mL of sample, the detection limit increased as the amount of sample used for analysis decreased.

[5] Lifetime health advisory level (U.S. Environmental Protection Agency, 1990).

Table 7.--Regression equations used for estimation of daily nitrogen, phosphorus, and suspended-sediment loads at sites NM5 and SW1 in the Small Watershed on unsampled stormflow days

[Constituent load (L) is in pounds per day for nitrogen and phosphorus and in tons per day for suspended sediment; streamflow (Q) is in cubic feet per day; pre-Best-Management Practice (pre-BMP) period is April 1, 1984, through March 31, 1986; post-Best-Management Practice (post-BMP) period is April 1, 1986, through September 30, 1986; <, less than]

Constituent	Period	Number of storms sampled	Equation	Statistics for coefficient of log Q		Coefficient of determination (adjusted R^2)	Standard error, in percent	
				t	p-value		Plus	Minus
			Site NM5					
Total nitrate plus nitrite	Pre-BMP	37	$L = \log^{-1}(0.891 \log Q - 2.960)$	12.81	<0.001	0.82	53	35
	Post-BMP	65	$L = \log^{-1}(0.788 \log Q - 2.430)$	19.13	<.001	.85	38	28
Total ammonium[1] plus organic nitrogen	Pre-BMP	37	$L = \log^{-1}(0.923 \log Q - 3.113)$	10.26	<.001	.75	73	42
	Post-BMP	65	$L = \log^{-1}(0.977 \log Q - 3.473)$	12.00	<.001	.69	90	47
Total phosphorus	Pre-BMP	37	$L = \log^{-1}(1.096 \log Q - 4.583)$	10.82	<.001	.76	86	46
	Post-BMP	65	$L = \log^{-1}(0.977 \log Q - 3.875)$	10.63	<.001	.64	107	52
Suspended sediment	Pre-BMP	33	$L = \log^{-1}(1.297 \log Q - 6.438)$	5.58	<.001	.48	225	69
	Post-BMP	82	$L = \log^{-1}(1.447 \log Q - 7.275)$	11.32	<.001	.61	197	66
			Site SW1					
Total nitrate plus nitrite	Pre-BMP	36	$L = (5.826 \log Q - 28.297)^3$	14.56	<.001	.86	24	24
	Post-BMP	83	$L = (5.645 \log Q - 26.841)^3$	16.53	<.001	.76	74	74
Total ammonium[1] plus organic nitrogen	Pre-BMP	36	$L = \log^{-1}(0.948 \log Q - 3.284)$	11.12	<.001	.78	70	41
	Post-BMP	83	$L = \log^{-1}(1.224 \log Q - 5.069)$	14.14	<.001	.71	102	50
Total phosphorus	Pre-BMP	36	$L = \log^{-1}(1.069 \log Q - 4.467)$	9.63	<.001	.72	99	50
	Post-BMP	83	$L = \log^{-1}(1.311 \log Q - 6.056)$	13.85	<.001	.70	115	54
Suspended sediment	Pre-BMP	40	$L = \log^{-1}(1.641 \log Q - 8.728)$	9.23	<.001	.68	206	67
	Post-BMP	113	$L = \log^{-1}(1.741 \log Q - 9.434)$	13.44	<.001	.52	229	70

[1] Ammonium refers to ammonia plus ammonium.

Water-quality data from base-flow water samples were analyzed by use of summary statistics, time-series trend analyses, and paired-watershed comparison. Time-series plots were used to examine trends in, and relations among, precipitation, nutrient applications, streamflow, and water-quality concentrations of nutrients. Correlations between water quality at the Nutrient-Management and the Nonnutrient-Management Subbasins were determined by paired-watershed comparison. The paired-subbasins comparison was used to minimize the influence of climatic variation on the detection of changes in water quality (Spooner and others, 1985).

Water-quality data from stormflow events were analyzed by comparing pre-BMP to post-BMP mean constituent concentrations. Stormflow events were grouped into four 3-month seasons and each group was tested for significant change.

Quality Assurance

A quality-assurance (QA) plan for nutrient water-quality analyses was maintained for the purpose of monitoring the analytical performance of the PaDEP laboratory. Analytical performance was evaluated by use of QA data from all the Conestoga Headwaters RCWP water-quality studies and pooled with data from the USGS National Water Quality Laboratory (NWQL), Standard Reference Water Sample Program (SRWS).

Protocol for the QA plan called for 10 percent of the water-quality samples analyzed to be QA samples. Three types of QA samples were used: preservation blank, reference, and field-split duplicate. Preservation blanks consisting of distilled water preserved in the same manner as field samples were used to evaluate the laboratory's baseline analytical capabilities near minimum reporting levels.[2] Reference samples, which included those prepared in the USGS laboratory in Harrisburg, Pa., from USEPA Quality Control and SWRS samples, were used for determining analytical accuracy. Field-split duplicate samples were used in the evaluation of analytical precision. QA data were monitored during the project and corrective steps were taken if the data indicated analytical process problems. QA-sample data for the April 1, 1986, through September 30, 1989, post-BMP period are summarized in table 8.

Distilled-water preservation blanks were preserved in the same manner as the nutrient samples and analyzed for all total- and dissolved-nutrient species listed in table 7. Measured concentrations of the blank samples should be at the minimum reporting level. Acceptable results, however, will report within two times the minimum reporting level. For total and dissolved nitrite, total and dissolved nitrate, and dissolved phosphorus, all analyses were within two times the minimum reporting level stated for that constituent. For total phosphorus, 96 percent of the results were within two times the minimum reporting level. Dissolved ammonium and dissolved ammonium plus organic nitrogen were within two times the minimum reporting level for 92 percent of the analyses. Total ammonium and total ammonium plus organic nitrogen were within two times the minimum reporting level for 83 percent of the analyses. A comparison of median concentrations of dissolved ammonium in blank-water and ground-water samples showed a positive bias for the blank samples. Because more than half of the ground-water samples had measured concentrations of dissolved ammonium at or below the minimum reporting level, a bias in blank samples was suspected. Further investigation determined that ammonium contamination of the blank water probably occurred when blank-water samples were transported in close proximity to surface-water samples that contained measurable concentrations of ammonium.

[2]The smallest measured concentration of a constituent that may be reliably reported by the use of a given analytical method.

Table 8.--Summary statistics for quality-assurance analyses

[Detection limits, ranges, and median differences are in milligrams per liter; n, number of observations; <, less than; --, no data]

Constituent	Detection limit	Samples		Blanks			Reference samples				Duplicates		
		n	Concentration range	n	Range of reported values	Median difference from detection limit	n	Range of known values	Absolute value of difference between known and reported values: Maximum	Absolute value of difference between known and reported values: Median	n	Concentration range	Absolute value of differences between pairs[1] (maximum)
Total nitrate plus nitrite	0.04	949	0.04/19	25	<0.04/<0.04	0.00	--	--	--	--	62	1.0/18	4.5
Dissolved nitrate plus nitrite	.04	335	.12/28	13	<.04/.08	.00	--	--	--	--	170	.96/74	10
Total nitrite	.01	938	<.01/2.6	24	<.01/.01	.00	--	--	--	--	60	<.01/.50	.07
Dissolved nitrite	.01	334	<.01/1.5	13	<.01/.01	.00	--	--	--	--	53	<.01/.35	.05
Total nitrite	--	--	--	--	--	--	38	0.14/17	2.4	0.00	--	--	--
Dissolved nitrate	--	--	--	--	--	--	14	.14/17	1.0	.03	--	--	--
Total ammonium[2] plus organic nitrogen	.20	946	<.20/37	24	<.20/1.0	.10	34	.33/21	7.7	.36	62	<.20/21	5.5
Dissolved ammonium[2] plus organic nitrogen	.20	334	<.20/15	12	<.20/1.0	.15	13	.66/5.2	2.1	.30	133	<.20/3.3	.56
Total ammonium[2]	.02	936	<.02/8.6	24	<.02/.11	.02	34	.07/23	4.0	.00	60	<.02/1.8	.18
Dissolved ammonium[2]	.02	334	<.02/7.9	13	<.02/.08	.02	14	.28/23	2.5	.10	53	<.02/1.5	.10
Total phosphorus	.02	948	<.02/24	24	<.02/.05	.00	42	.02/4.7	3.5	.03	62	<.02/9.8	4.8
Dissolved phosphorus	.02	335	<.02/4.5	12	<.02/.04	.00	13	.20/1.5	.40	.10	53	<.02/1.9	.14

[1] Difference between pairs was determined by subtracting concentration value for blind duplicate from concentration value for sample.
[2] Ammonium refers to ammonia plus ammonium.

Reference samples were analyzed for concentrations of total and dissolved nitrate, ammonium plus organic nitrogen, ammonium, and phosphorus. Results from the USEPA reference samples were pooled with data from the NWQL Standard Reference Water Sample Program and evaluated as a group. A Wilcoxon Signed-Rank test showed a significant positive bias between the measured and the expected concentrations for dissolved nitrate, total ammonium plus organic nitrogen, and total and dissolved phosphorus. A significant negative bias was found for dissolved ammonium. Except for total ammonium plus organic nitrogen, the median difference between the known and reported concentrations was 0.10 mg/L or less.

For reference samples, a relative percent difference (RPD) was calculated for each measured concentration and expected concentration pair. The RPD was calculated as follows:

$$RPD = \frac{|\text{Measured concentration} - \text{expected concentration}|}{\left(\frac{\text{Measured concentration} + \text{expected concentration}}{2}\right)} \times 100 \qquad (2)$$

The RPD's indicated that overall analytical accuracy varied considerably. Total and dissolved ammonium plus organic nitrogen and total and dissolved phosphorus had the least accuracy. RPD's for these four constituents were greater than 15 percent for more than 50 percent of the samples. A Wilcoxon Signed-Rank test indicated significant bias for all constituents except dissolved ammonium plus organic nitrogen and dissolved ammonium. All significant biases were positive except for total ammonium. The constituent biases represented less than 5 percent of their respective median measured concentrations; the exception was total and dissolved ammonium plus organic nitrogen. The estimated bias for total ammonium plus organic nitrogen represented about 20 percent of the median concentration measured in runoff. For ground-water data, estimated biases in the reported concentrations of total and dissolved ammonium plus organic nitrogen and total and dissolved phosphorus represent a large source of error, and caution should be used in interpreting the data. However, in this study, nitrate in ground water was of primary concern. The estimated bias for concentrations of total and dissolved nitrate represented 2 percent or less of the nitrate concentrations measured in ground-water samples.

For duplicate samples, RPD's were calculated for each duplicate pair. Determination of acceptable analytical repeatability was made by comparing the RPD for each duplicate pair with RPD goals. RPD goals ranged from 100 percent for concentrations at the minimum reporting level to 10 percent for concentrations equal to or greater than 20 times the minimum reporting level (table 9). The RPD's for all constituents, with the exception of total ammonium plus organic nitrogen, total and dissolved nitrate plus nitrite, and total phosphorus, were within RPD goals for 90 percent or more of the duplicate samples analyzed. Total phosphorus samples exceeded the RPD goal most often. Seventy-six percent of the total phosphorus samples were within RPD goals.

Table 9.--Relative percent difference goals for analytical results from duplicate samples

Sample concentration range, in minimum reporting levels	Relative percent difference goal, in minimum reporting levels or percent
0–5	1
5–20	2 or 20 percent[1]
20 or greater	10 percent

[1] Whichever is greater.

Results from the QA program indicate that bias and accuracy limitations existed for most of the constituents. Therefore, in terms of accuracy, the water-quality data for nutrients should be interpreted with caution. Caution should particularly be used when concentrations are approaching the detection limit. However, in the framework of this study, the accuracy and precision limitations are of minor concern when compared to the magnitude of natural variation in concentrations of those constituents that were likely to be affected by BMP's.

Nutrient Applications and Exports

Agricultural-activity data collected during the study included animal populations and type, applications of manure and commercial fertilizer, and manure exports. Animal information and fertilizer-application information were recorded by farm operators, ASCS, and RCWP personnel on worksheets.

Nutrient-applications and exports data were collected from farms throughout the entire watershed but at different levels of detail. Nutrient-applications and exports data from most of the farms in the Small Watershed were collected, one time, during initial contact with farm operators at the start of the study, whereas in the Nutrient-Management Subbasin, farm operators recorded nutrient applications and exports on a continuous basis detailing the specifics of individual activities. This information was collected and reviewed by ASCS personnel during periodic visits to the farm. Data were collected from 14 of the 16 farms in the Nutrient-Management Subbasin (fig. 3). Of the two farms at which no nutrient-applications and exports data were collected, one, farm C, represented 8 percent of the Nutrient-Management Subbasin and operated (on the basis of a drive-by evaluation) much like other farms in the subbasin. The other farm, farm B, comprised less than 2 percent of the subbasin and operated without the use of commercial fertilizers. Because most farm operators in the Nonnutrient-Management Subbasin chose not to contract with the RCWP, extensive nutrient-applications and exports data were not collected there. However, during the study period, some farm operators in the Nonnutrient-Management Subbasin are believed to have modified their nutrient-handling practices (Jeffrey Stoltzfus, Pennsylvania State University Cooperative Extension, oral commun., 1989).

Soil Nutrients

Soil-nutrient data were collected for the purposes of estimating the amount of soluble nutrients in reserve in the soil, locating areas of elevated concentrations of nutrients in the soil, and determining changes in nutrient reserves in the soil caused by nutrient management. Because of the large variation observed in concentrations of soil nutrients during the pre-BMP period, soil-nutrient-data analysis was limited to general, descriptive summaries. In the post-BMP period, soil samples were collected first at seven locations (farms A, E, F, G, H, I, and O) and then, to reduce costs and eliminate inconsistencies in the location of soil-sampling sites, at four locations (farms D, F, H, and M) after the spring 1986 sampling (fig. 2). From 1986 through 1989, soil samples were collected twice a year: once prior to spring planting and again after fall harvest. Sample soil cores were collected from the top 4 ft of soil. In the spring of 1987, the top 6 ft of soil was sampled at farms D and M. Concentrations of soluble orthophosphorus and nitrate in the soil cores were determined by the Pennsylvania State University, Soils and Environmental Chemistry Laboratory. From these concentrations, pounds per acre of soluble orthophosphorus and nitrate were calculated.

DESCRIPTIONS OF FACTORS RELATED TO WATER QUALITY

Precipitation

The long-term (1951–80) average annual precipitation for the Small Watershed is approximately 41.5 in. on the basis of precipitation records for the NOAA precipitation station near Morgantown, Pa. Annual precipitation measured in the Small Watershed is listed in table 10, along with the deviation from long-term normal. Precipitation for 3 of the 5 years was within 5 percent of the long-term average. The two remaining years, which were the first year of the pre-BMP period and the first year of the post-BMP period, were 14 percent and 25 percent below the long-term average, respectively.

Table 10.--Annual precipitation in the Small Watershed and deviation from long-term average for Morgantown, Pa.

Period	Precipitation (inches)	Deviation from long-term average[1] (inches)
April 1984 through March 1985	35.7	−5.8
April 1985 through March 1986	39.6	−1.9
April 1986 through March 1987	31.0	−10.5
April 1987 through March 1988	40.8	−.7
April 1988 through March 1989	41.8	.3
April 1989 through September 1989	28.4	[2]5.5

[1] Long-term average precipitation is 41.5 in. annually, on the basis of 30 years (1951–80) of record from the National Oceanic and Atmospheric Administration weather station at Morgantown, Pa.

[2] Long-term average for the 6-month period.

Streamflow

Water quality in the Small Watershed was affected by streamflow in two primary ways: first, base flow yielded water quality distinctly different from stormflow. Second, total flows were the controlling factor in determining constituent loads discharged from the watershed (Fishel and others, 1992). Streamflow was measured continuously at the Nutrient-Management Subbasin (site NM5) and the Small Watershed (site SW1).

Daily mean streamflows for the two continuous-record sites have been published in USGS annual water-resources data reports (Loper and others, 1988a, 1988b, 1989, 1990). At site NM5, the maximum daily mean discharge was 70 ft^3/s (September 8, 1987), and the minimum daily discharge was 0.05 ft^3/s (measured on 7 days in October and November 1985). The mean daily discharge for the period was 1.3 ft^3/s or 0.92 $(ft^3/s)/mi^2$. At site SW1, the maximum daily mean discharge was 259 ft^3/s (September 8, 1987) and the minimum daily discharge was 0.66 ft^3/s (September 17, 1986). The mean daily discharge for the period was 7.1 ft^3/s or 1.22 $(ft^3/s)/mi^2$. Maximum discharges were most likely to occur from May through September at both sites. Minimum daily mean discharges occurred from September to January.

Mean growing-season streamflows for sites NM5 and SW1 increased substantially every year of the post-BMP period (tables 11 and 12). From 1986 through 1989, growing-season streamflow increased 340 percent at NM5 and 350 percent at SW1. Most of the increase occurred when nutrient application and planting activity are the greatest—May, June, and July.

Average annual discharge, expressed as inches of precipitation, for the five complete years of the study period (April 1984 through March 1989) was 11.4 in. at site NM5 and 15.4 in. at site SW1. Annual discharges were within 20 percent of the 5-year average except for the year-3 discharge at site NM5, which was 30 percent below average.

A seasonal Kendall test of monthly streamflows at sites NM5 and SW1 (table 13) indicated a significant increasing trend in monthly streamflows at site SW1 over the study period. The seasonally corrected Kendall test is a rank-based nonparametric test for monotonic trend over time (Hirsch and others, 1982). This increase corresponds with an increase in precipitation during the last 30 months of the study (table 10). However, there was no corresponding increase in either total discharge or base-flow discharge at site NM5. The lack of increase at site NM5 was probably caused, at least in part, by problems with the streamflow-gage control structure. Because water quality depends on streamflow, changes in streamflow could result in changes in loads that are unrelated to nutrient management, and in constituent concentrations, particularly during base flow.

Table 11.--Mean monthly, seasonal, and annual streamflow and base flow at site NM5 in the Nutrient-Management Subbasin

[All values are in cubic foot per second; --, no data]

Month	1986–87		1987–88		1988–89		1989	
	Streamflow	Base flow	Streamflow	Base flow	Streamflow	Base flow	Streamflow	Base flow
April	1.40	0.98	0.92	0.79	0.75	0.70	1.33	1.24
May	.79	.68	.72	.59	2.95	1.33	4.16	2
June	.35	.31	.59	.48	1.08	1.04	3.54	1.86
July	.54	.23	.51	.30	2.74	1.34	2.14	1.53
August	.42	.25	.37	.19	.90	.78	.82	.74
September	.18	.14	4.08	.77	.49	.30	.51	.43
October	.10	.08	.77	.68	.33	.16	--	--
November	.76	.22	1.10	.56	.92	.30	--	--
December	1.45	.52	.98	.90	.52	.50	--	--
January	1.32	1.15	1.42	.80	.80	.64	--	--
February	.93	.84	3.30	1.86	1.04	.78	--	--
March	1.66	.79	1.33	1.19	1.34	1.13	--	--
Growing season	.61	.43	1.19	.52	1.50	.92	2.09	1.32
Nongrowing season	1.04	.60	1.47	.99	.82	.58	--	--
Annual	.83	.51	1.33	.75	1.16	.75	--	--

Table 12.--Mean monthly, seasonal, and annual streamflow and base flow at site SW1 in the Small Watershed

[All values are in cubic foot per second; --, no data]

Month	1986–87		1987–88		1988–89		1989	
	Streamflow	Base flow	Streamflow	Base flow	Streamflow	Base flow	Streamflow	Base flow
April	6.71	5.15	7.29	6.00	3.71	3.27	7.44	6.81
May	4.16	3.59	4.91	3.55	15.91	8.78	23.57	11.39
June	2.15	2.03	3.51	2.87	3.47	3.44	20.78	9.49
July	3.11	1.38	4.11	1.97	18.83	10.08	11.25	7.41
August	2.82	1.62	2.37	1.22	3.84	3.40	4.12	3.84
September	1.16	.94	20.33	4.88	3.24	1.90	2.98	2.45
October	1.07	.90	3.93	3.14	2.36	1.49	--	--
November	6.74	2.78	7.27	3.53	7.84	2.95	--	--
December	12.06	6.03	5.80	4.08	3.44	2.97	--	--
January	9.91	7.39	7.06	3.92	5.63	3.90	--	--
February	6.23	5.73	17.01	9.63	6.46	3.73	--	--
March	10.04	4.38	6.36	4.92	8.60	6.62	--	--
Growing season	3.35	2.45	7.03	3.40	8.24	5.18	11.70	6.91
Nongrowing season	7.70	4.52	7.81	4.83	5.70	3.61	--	--
Annual	5.52	3.48	7.42	4.11	6.97	4.40	--	--

Table 13.--Results of seasonal Kendall tests for total monthly streamflow and base flow from April 1986 through September 1989 at sites NM5 and SW1 in the Small Watershed

Site	Total discharge			Base-flow discharge		
	Trend	p-value	Slope	Trend	p-value	Slope
NM5	None	0.714	--	None	0.329	--
SW1	Increase	.43	8.5	Increase	.006	13

Daily mean streamflows were separated into base-flow and stormflow components by use of the hydrograph-separation techniques of Pettyjohn and Henning (1979). Base flow was the primary contributor to total streamflow; base flow contributed 80 percent or more to total streamflow 75 percent of the time.

A seasonal Kendall test was performed to determine the existence of temporal trends in base-flow discharge over the study period (table 13). At site SW1, monthly base-flow discharge had an increasing trend (p=0.006) of about 2 percent (0.09 in.) per year. No trend was detected at site NM5.

Hydrograph separation indicated the occurrence of stormflow on 65 percent of the days at site SW1 and on 60 percent of the days at site NM5. Maximum stormflow discharge was 22,210,000 ft^3 at site SW1 and 6,024,000 ft^3 at site NM5. About 90 percent of the stormflow discharges were no greater than the median daily base-flow discharges.

A comparison of pre-BMP and post-BMP mean, maximum, and minimum stormflow and duration of stormflows revealed a change in the largest 30 percent of stormflows at site SW1 and in the largest 20 percent of stormflows at site NM5. At site SW1, the largest 30 percent of stormflows tended to have decreased mean discharge, to be of shorter duration, and to have more rapid changes in flow for a given amount of precipitation during the post-BMP period. At site NM5, mean stormflow discharges and rate of change in flow decreased in the post-BMP period. These differing changes in post-BMP stormflow responses could have resulted from changes in land use or cropping patterns on one or both of the drainage areas. Peak flows generally transport the largest loads; thus, any change in stormflow response could change constituent yields for stormflow independent of nutrient management.

Nutrient Applications and Exports

Estimates of manure and manure nutrient production in the Nutrient-Management Subbasin were made to verify reported application and export data, to account for nutrient contributions from grazing livestock, and to estimate changes in nutrient applications. Estimates of manure production were made by multiplying annual manure production per animal unit per animal type (table 14) by the average number of animal units for the pre-BMP and post-BMP periods. Averages for each period were used because the actual number of animal units varied throughout the study period. Estimates of nitrogen and phosphorus in manure production were calculated by multiplying manure production values by the nutrient content values listed in table 14. Estimates of average annual manure nutrient production in the Nutrient-Management Subbasin are shown in table 15. Annual post-BMP nutrient production decreased by 6 percent because of a decrease in the number of animal units. Manures produced during the post-BMP period on farms in the Nutrient-Management Subbasin contained a total of about 685,000 lb of nitrogen and 169,000 lb of phosphorus.

Table 14.--Manure production and nutrient content of manure by animal type

[ton/yr, ton per year; lb/ton, pound per ton]

Animal type	Estimated manure produced by one animal unit[1]		Nutrient content[3] (lb/ton)	
	[2]ton/yr	Percent solids[3]	Nitrogen	Phosphorus
Dairy cows	15.5	15	10	1.8
Beef cattle	11.0	15	11	3.5
Swine	8.8	14	14	4.4
Poultry	11.0	25	30	8.8
Sheep	6.6	25	22	3.5
Horse/mule	16.6	21	12	2.2

[1] From Fishel and others, 1992. One animal unit is equivalent to 1,000 lb of animal weight.

[2] U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, written commun., 1985.

[3] Pennsylvania Department of Environmental Resources, Bureau of Water-Quality Management, Manure Management for Environmental Protection, 1986.

Table 15.--Average annual manure and nutrient production in the Nutrient-Management Subbasin

[pre-Best-Management Practice (pre-BMP) period is April 1, 1984, through March 31, 1986; post-Best-Management Practice (post-BMP) period is April 1, 1986, through September 30, 1989]

Manure type	Period	Animal units	Manure production (tons)	Nitrogen produced (pounds)	Phosphorus produced (pounds)
Dairy	Pre-BMP	476	7,380	73,800	13,300
	Post-BMP	472	7,320	73,200	13,200
Beef	Pre-BMP	120	1,320	14,500	4,620
	Post-BMP	107	1,180	13,000	4,120
Swine	Pre-BMP	218	1,920	26,900	8,440
	Post-BMP	188	1,650	23,200	7,280
Poultry	Pre-BMP	254	2,790	83,800	24,600
	Post-BMP	247	2,720	81,500	23,900
Sheep	Pre-BMP	30	200	4,360	693
	Post-BMP	0	0	0	0
Horse/mule	Pre-BMP	26	432	5,180	950
	Post-BMP	26	432	5,180	950
Annual totals	Pre-BMP	1,124	14,000	209,000	52,600
	Post-BMP	1,040	13,300	196,000	48,400

Sources of nutrient input to the Nutrient-Management Subbasin included manure, commercial fertilizer, legumes, and precipitation. Manure and commercial-fertilizer applications to cropland were the two largest inputs. Pastureland deposition of manure by grazing livestock was the third largest input. Precipitation and plowdown of legumes were estimated to input a small (less than 6 percent), additional amount of nitrogen. Cropland application of nitrogen and phosphorus as recorded by farmers in the Nutrient-Management Subbasin is summarized by month in figure 4 and by year in table 16. Average annual cropland applications of nitrogen and phosphorus decreased 32 and 35 percent, respectively, from the pre-BMP to the post-BMP period. However, actual annual nutrient applications varied substantially. About 78 percent of both the 534,000 lb of nitrogen and 135,700 lb of phosphorus applied in the Nutrient-Management Subbasin came from manure. Nutrients deposited by grazing livestock were estimated on the basis of the number of days livestock were expected to be in pasture. An estimated 22,000 and 18,000 lb of nitrogen and 4,200 and 3,500 lb of phosphorus were deposited annually in the pre-BMP and post-BMP periods, respectively.

Manure exports from the Nutrient-Management Subbasin are summarized in table 17. In 1984, reported manure exports accounted for 3 percent of the total manure nitrogen production and 4 percent of the total manure phosphorus production. In 1985, reported manure exports accounted for 9 percent of the total manure nitrogen production and 11 percent of the total manure phosphorus production. Manure exports decreased in the post-BMP period. In 1986, the largest export year in the post-BMP period, reported manure exports were the same as they were in 1984. In 1987, exports accounted for 1 percent of total nitrogen and phosphorus production. No exports were reported after 1987. The occurrence of a decrease in manure exports at the same time as a reduction in manure application appears contradictory. However, judging from agricultural-activity reports, it appears that export data were not recorded during the late post-BMP period. Although the data on manure exports are inconclusive, they suggest exports were not a substantial part of total manure production.

In addition to reported exports, 3,000 to 6,000 lb of nitrogen and 1,000 to 3,000 lb of phosphorus are estimated to have been applied annually to areas outside of the subbasin on fields that straddled the subbasin boundary. Because no record was kept on these applications, these estimates are made on the basis of uniform nutrient application to those fields that straddled the subbasin boundary.

Although an effort was made to collect comprehensive data on the production and disposition of manure nutrients within the subbasin, between 30 and 50 percent of the estimated manure production could not be accounted for as application or exportation. Some of the "missing" manure was, as previously mentioned, probably applied to parts of fields outside of the subbasin that straddled the subbasin boundary. Because this manure did not leave the farm on which it was produced, it would not have been recorded as an export. The discrepancy between estimated total production and reported total applications and exports is large enough that the difference reported between pre-BMP and post-BMP applications may not be reliable. In particular, the possibility of substantial variation in the amount of manure nutrients deposited in pastures cannot be ruled out.

In addition, methods of applying manure and the timing of applications affect the amount of nutrients that ultimately becomes available for the crops, surface runoff, or leaching to the ground water. For example, if manure is simply applied to the surface, then a significant amount of the nitrogen can volatilize to the atmosphere in the form of ammonium. As much as 30 percent of the nitrogen can be lost within 7 days by volatilization if the manure is not incorporated into the soil shortly after it is applied (Pennsylvania Department of Environmental Resources, 1986). As a consequence, the amounts reported for nutrient applications in the Nutrient-Management Subbasin may differ from the actual amounts by as much as 25 to 30 percent.

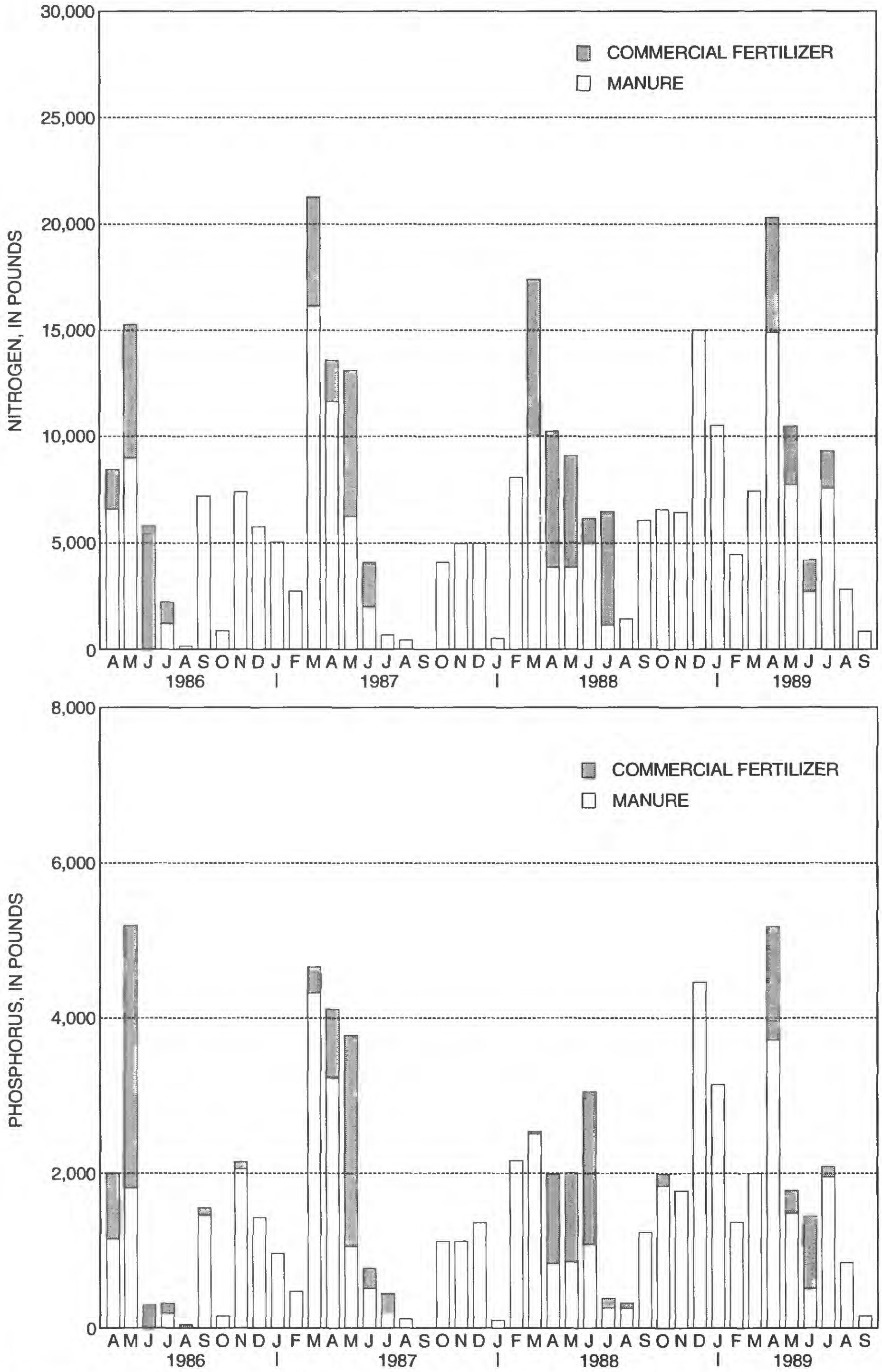

Figure 4.--Monthly inputs of nitrogen (above) and phosphorus (below) from manure- and commercial-fertilizer applications in the Nutrient-Management Subbasin.

Table 16.--Annual nutrient applications to cropland in the Nutrient-Management Subbasin from April through March of the following year

[All applications are in pounds; pre-Best-Management Practice (pre-BMP) period is April 1, 1984, through March 31, 1986; post-Best-Management Practice (post-BMP) period is April 1, 1986, through September 30, 1989]

Date	Period	Nitrogen					Phosphorus				
		Manure	+	Commercial fertilizer	=	Total	Manure	+	Commercial fertilizer	=	Total
1984	Pre-BMP	83,500		25,100		108,600	21,200		7,100		28,300
1985	Pre-BMP	107,000		24,600		131,600	28,400		6,100		34,500
1986	Post-BMP	62,300		20,200		82,500	14,300		5,300		19,600
1987	Post-BMP	53,800		18,300		72,100	13,700		4,200		17,900
1988	Post-BMP	73,000		18,300		91,300	19,200		4,700		23,900
1989[1]	Post-BMP	37,400		10,900		48,300	8,700		2,800		11,500
Annual average	Pre-BMP	95,250		24,850		120,100	24,800		6,600		31,400
	Post-BMP[2]	63,000		18,900		81,900	15,700		4,700		20,400

[1] April through September 1989.
[2] Averages do not include April through September 1989.

Table 17.--Annual exports of nitrogen and phosphorus in manure from the Nutrient-Management Subbasin from April through March of the following year

[All values are in pounds; pre-Best-Management Practice (pre-BMP) period is April 1, 1984, through March 31, 1986; post-Best-Management Practice (post-BMP) period is April 1, 1986, through September 30, 1989; --, none reported]

Date	Period	Nitrogen	Phosphorus
1984	Pre-BMP	6,000	1,900
1985	Pre-BMP	19,300	5,800
1986	Post-BMP	6,200	1,900
1987	Post-BMP	2,800	630
1988	Post-BMP	--	--
1989[1]	Post-BMP	--	--

[1] April through September 1989.

Soil Nutrients

Soils at four farms (D, F, H, and M) in the Nutrient-Management Subbasin were sampled for nitrate and orthophosphorus eight times in the post-BMP period (figs. 5 and 6). Median concentrations of nitrate for farms F, H, and M were between 100 and 125 lb/acre of nitrate as nitrogen. Farm D had a median concentration of 66 lb/acre of nitrate as nitrogen. Median concentrations of orthophosphorus were between 10 and 16 lb/acre of orthophosphorus as P_2O_5 at farms D, H, and M. Farm F had a median concentration of 5 lb/acre of orthophosphorus as P_2O_5. Minimum concentrations of nitrate and orthophosphorus in the soil were measured in the period from the fall 1988 sampling through the fall 1989 sampling. The only substantial decrease in soil nitrate from the pre-BMP to the post-BMP period was measured at farm F. Fishel and others (1992) reported nitrate concentrations in the soil that averaged 298 lb/acre over the pre-BMP period. Baker (1986) has suggested that fertilization rates that result in acceptable ground-water quality will limit nitrate in the top 4 ft of soil to 50 lb or less at the end of the growing season. All of the soil samples collected during the study contained concentrations of nitrate greater than 50 lb/acre.

Soil samples were collected to depths of 8 ft at two farms in the spring of 1987 to determine if a substantial amount of nitrate was present below the 4-ft depth. At farms D and M, an additional 37 and 51 lb/acre, respectively, of nitrate was detected in the soil column 4 to 8 ft below the surface. This nitrate plus any additional nitrate below 8 ft represents a sizable potential reservoir available for leaching to the ground water. The capacity of this sink is unknown but could delay improvements in water quality expected as a result of nutrient management.

The vertical distribution of nitrate in the 4-ft soil column was distinctly different from the distribution of orthophosphorus. Typically, nitrate was distributed throughout the 4-ft soil column (fig. 5). In contrast, orthophosphorus was primarily found in the 0- to 8-in. depth (fig. 6). Only at farm H and early in the post-BMP period was orthophosphorus found in any substantial amount at the 24- to 48-in. depth. Phosphorus typically has limited mobility in soils characteristic of the Small Watershed.

Concentrations of nitrate and orthophosphorus in the soil varied considerably throughout the study period. Even in consecutive samplings, concentrations of nitrate varied as much as 400 percent, and concentrations of orthophosphorus varied as much as 1,700 percent. Logic suggests that large increases in concentrations are associated with nutrient applications, but agricultural-activity data do not support this conclusion. Recorded applications of nitrogen and phosphorus were not correlated with the concentrations in the soil samples. Because of the large variation in concentrations and the limited number of soil samples analyzed, no statistical inference could be drawn about changes in concentrations of nitrate and orthophosphorus in the soil as a result of nutrient management.

The results of the soil samplings suggest that, except at farm F, nutrient management has not resulted in substantial reductions in median nitrate concentrations in the top 4 ft of soil. The occurrence of extremely large concentrations, however, was less frequent during the post-BMP years of 1987–89. If concentrations of nitrate in ground water are associated with concentrations of nitrate in the soil as measured in the top 4 ft, then it seems unlikely that a significant change in base-flow concentrations of nitrate would be expected in the post-BMP period.

Results of the orthophosphorus samplings suggest a possible reduction in concentrations of orthophosphorus in the soil at farms F and H; however, agricultural-activity data for farm H indicates larger, although less frequent, applications of phosphorus in the post-BMP period. Concentrations of orthophosphorus in the soil at farm D were consistently greater in the post-BMP period than in the pre-BMP period, even though only one application of phosphorus was recorded after the spring of 1986. Because phosphorus is normally below detection limits in ground waters of the Small Watershed, any reductions (or increases) in phosphorus concentrations in the soil will primarily affect stormflow only.

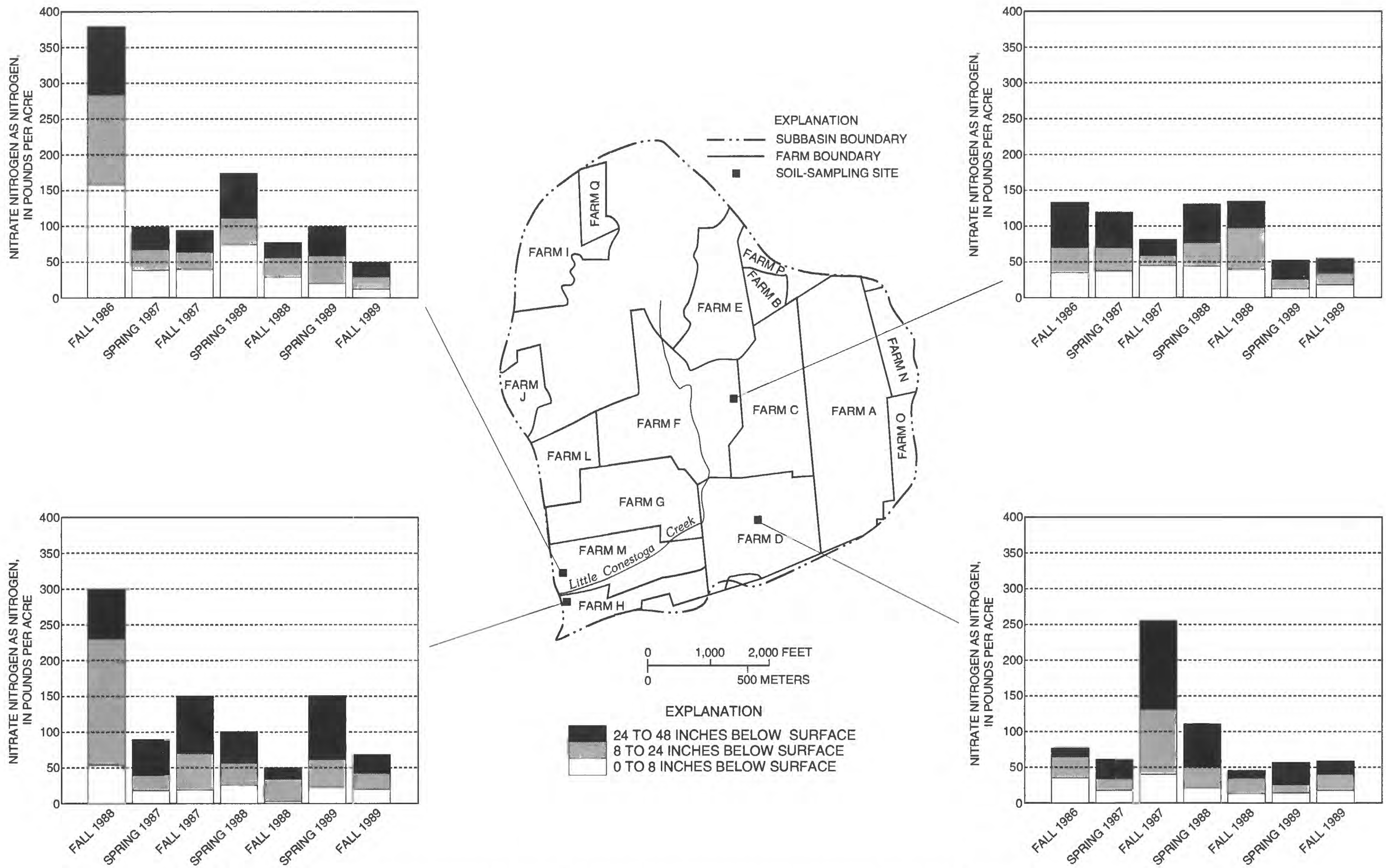

Figure 5.--Soluble nitrate concentrations in the soil during nutrient management on four fields in the Nutrient-Management Subbasin.

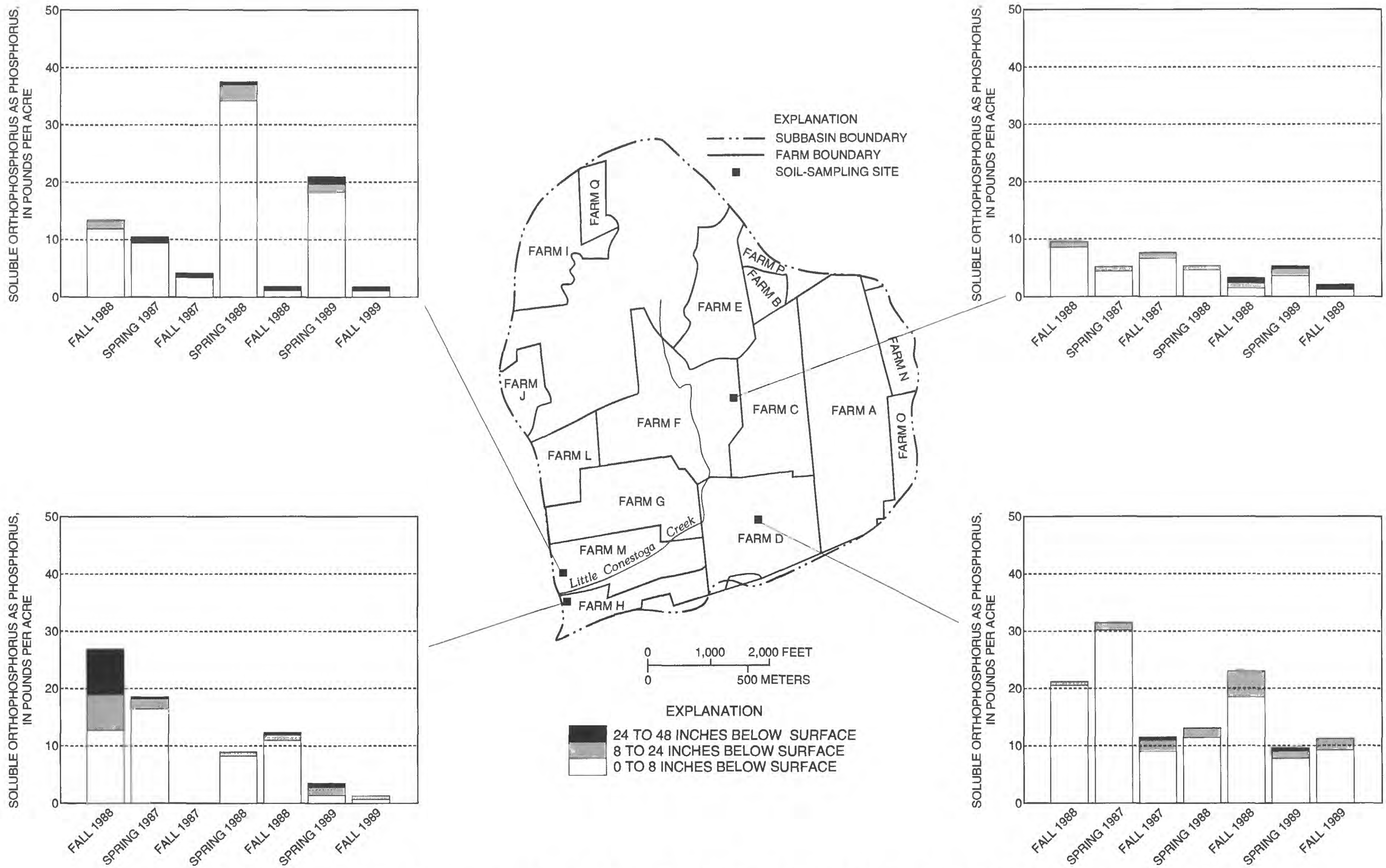

Figure 6.--Soluble orthophosphorus concentrations in the soil during nutrient management on four fields in the Nutrient-Management Subbasin.

WATER QUALITY DURING NUTRIENT MANAGEMENT

Water quality was measured at five sites during base-flow conditions and at two sites during stormflow conditions. Nitrogen was the predominant nutrient in streamflow, and nitrate was the predominant nitrogen species. The largest nitrogen concentrations generally were detected at the most downstream site during base-flow conditions. During periods of stormflow, ammonium plus organic nitrogen was commonly predominant. Concentrations of total phosphorus were largest during stormflow. Nutrient concentrations had substantial seasonal variation at all sites except at NM1, the forested site. Seasonal variation was greatest at the most downstream sites. Herbicides were detected in base flow and stormflow.

As discussed in the quality-assurance section, reported nutrient concentrations near the minimum reporting level should be used with caution because of probable bias and accuracy limitation. However, the magnitude and range of concentrations of nitrate, the constituent most likely to be affected by nutrient management, are large in comparison to bias and accuracy limitations and are believed to satisfactorily represent surface-water conditions in the study area.

Base Flow

Base-flow water quality in the Small Watershed was characterized by a predominance of nitrate. Concentrations of dissolved nitrate plus nitrite in base flow ranged from 1.8 to 14 mg/L. Total ammonia plus organic nitrogen was the next most prevalent constituent in base flow, followed by total phosphorus and dissolved ammonium.

Concentrations of dissolved nitrate plus nitrite in general (fig. 7) showed a positive correlation with the percentage of agricultural land use in the drainage area for each sampling site. Concentrations of dissolved nitrate plus nitrite were greatest in base flow from the Nutrient-Management Subbasin (site NM5) and the Small Watershed (site SW1), whereas sites NM1 and NM3 in the Nutrient-Management Subbasin had the lowest percentage of agricultural land use and the lowest median concentrations of nitrate. The percentage of agricultural land use in the Nonnutrient-Management Subbasin (site NC1) was between that of the other sites.

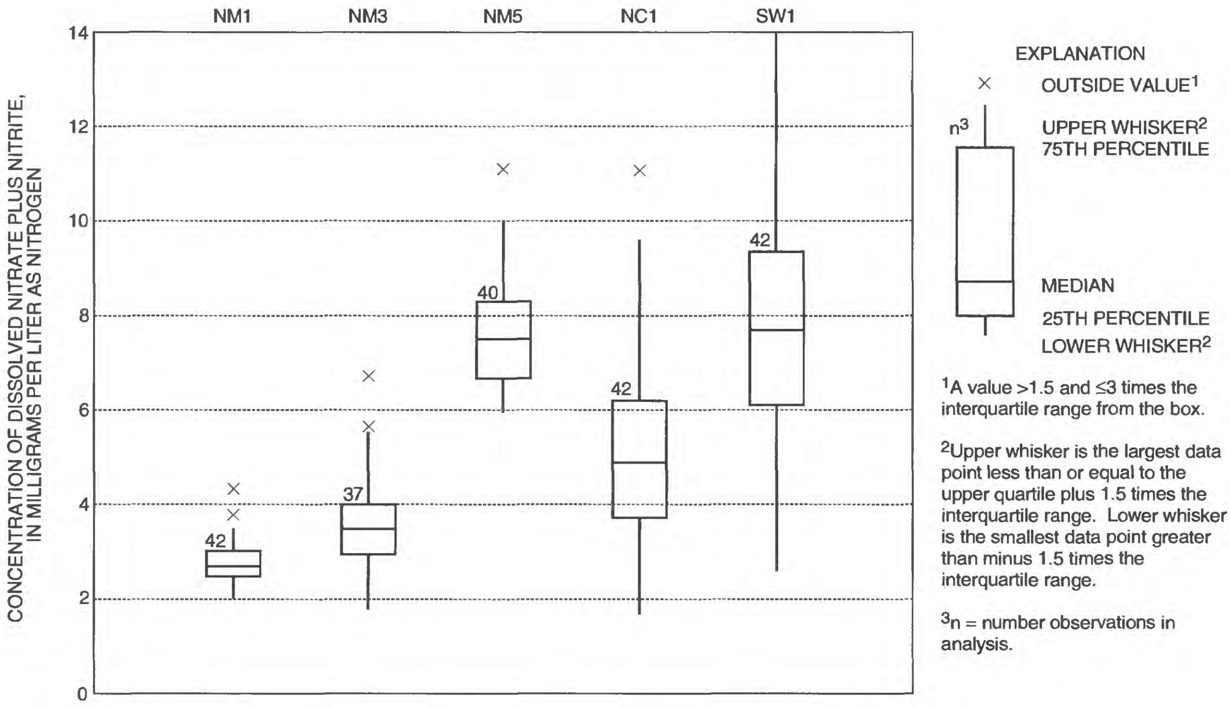

Figure 7.--Concentrations of dissolved nitrate plus nitrite in base flow at sites NM1, NM3, NM5, NC1, and SW1 in the Small Watershed.

In contrast, concentrations of dissolved ammonium nitrogen, total ammonium plus organic nitrogen, and total phosphorus (figs. 8, 9, and 10) were similar among all sites, except at site NM1 in the Nutrient-Management Subbasin, and showed no correlation to the percentage of land use, with the exception of site NM1. Unlike nitrate, these constituents were typically detected only in low or trace concentrations in ground waters of the area. Slightly greater (about 0.05 mg/L) dissolved ammonium concentrations at site NM3 in the Nutrient-Management Subbasin were probably the result of the livestock at farm D having year-round access to the stream at that site.

Concentrations of nutrients in base flow varied widely. Much of the variation was seasonal. Figure 11 shows examples of the seasonal variation of concentrations of dissolved nitrate plus nitrite and total phosphorus at site SW1. Concentrations of dissolved nitrate plus nitrite were greatest in the winter months and least in the summer months. In contrast, concentrations of total phosphorus were greatest during the summer months. Seasonal variation was evident at all stations, although the range of variation was not the same at all stations; site NM1 had the least seasonal variation and site SW1 had the greatest variation.

Concentrations of dissolved nitrate plus nitrite and total phosphorus in base flow were flow dependent. Flow dependency was demonstrated by a locally weighted scatterplot smooth (LOWESS) of base-flow concentrations as a function of base-flow discharge (fig. 12). The LOWESS smooth represents the approximate center of the scatterplot data (Helsel and Hirsch, 1992). At site SW1, concentrations of dissolved nitrate plus nitrite increased as base-flow discharge increased; however, after base-flow discharge increased to about 5 ft^3/s, further increases in base-flow discharge did not appear to affect concentrations of dissolved nitrate plus nitrite. A similar relation was also seen at site NC1. At sites NM1 and NM5, only a minor dilution effect was seen with increases in discharge. Concentrations of total phosphorus at all sites decreased with increasing discharge.

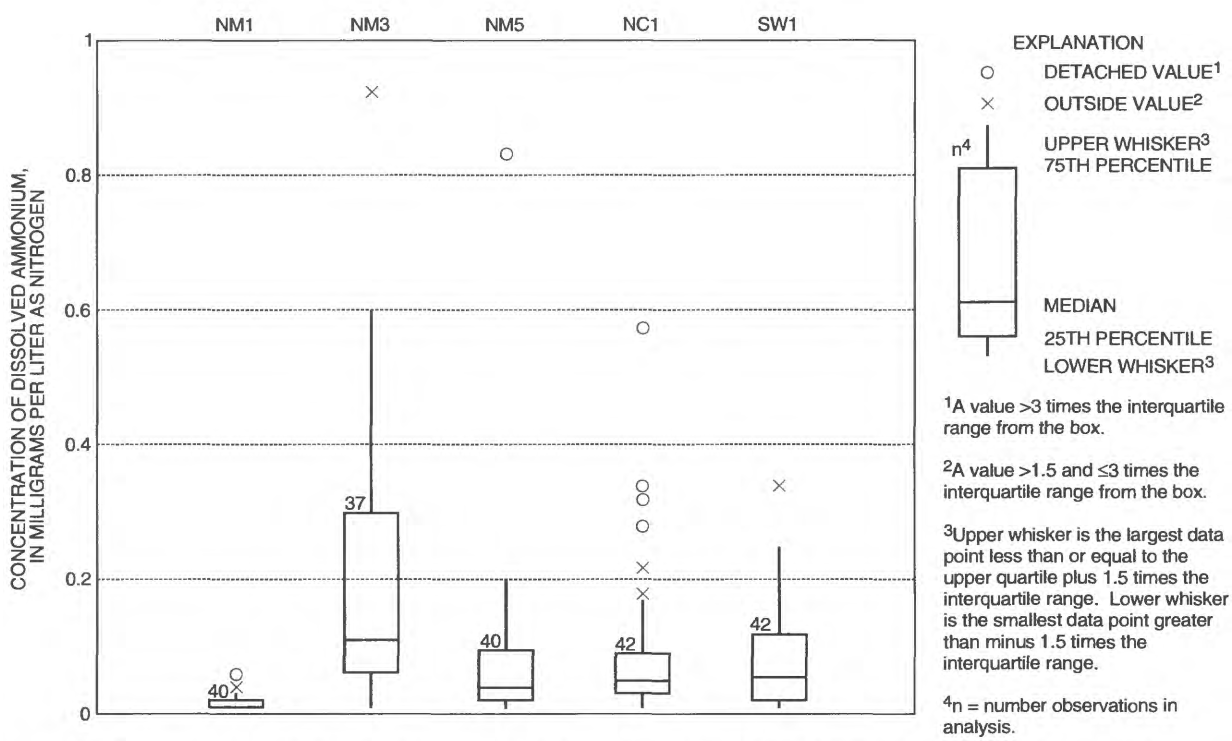

Figure 8.--Concentrations of dissolved ammonium in base flow at sites NM1, NM3, NM5, NC1, and SW1 in the Small Watershed.

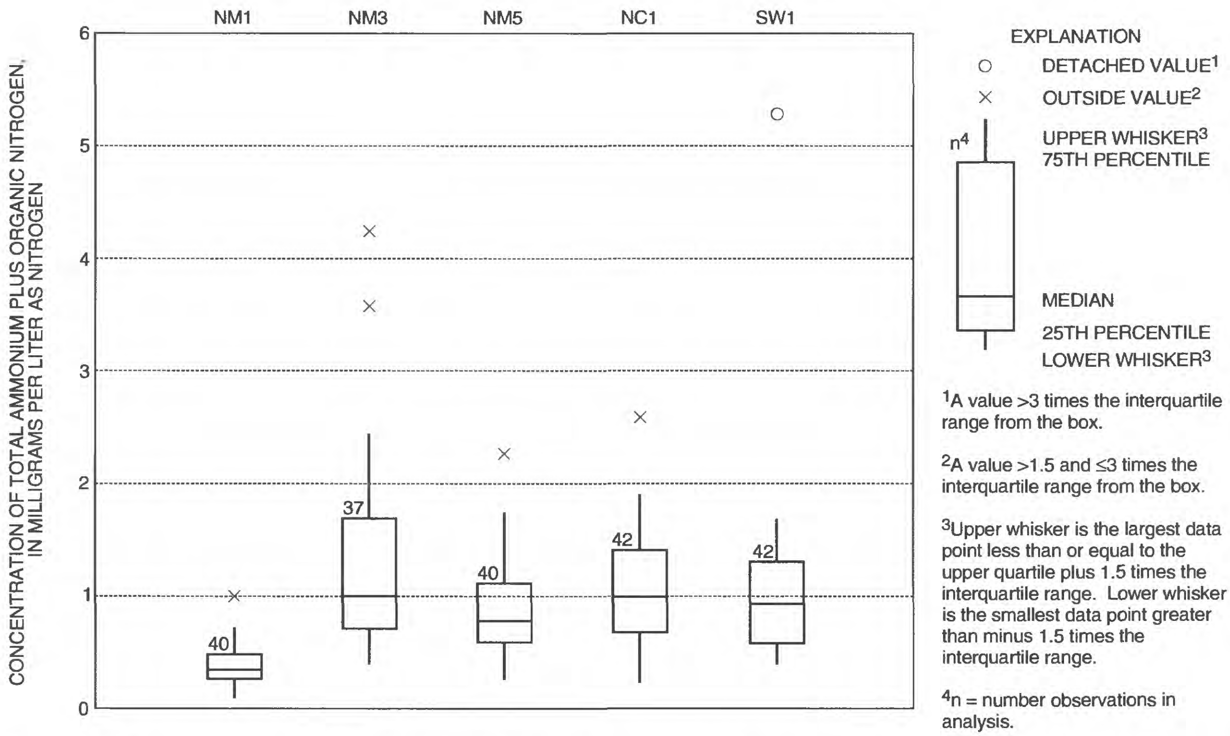

Figure 9.--Concentrations of total ammonium plus organic nitrogen in base flow at sites NM1, NM3, NM5, NC1, and SW1 in the Small Watershed.

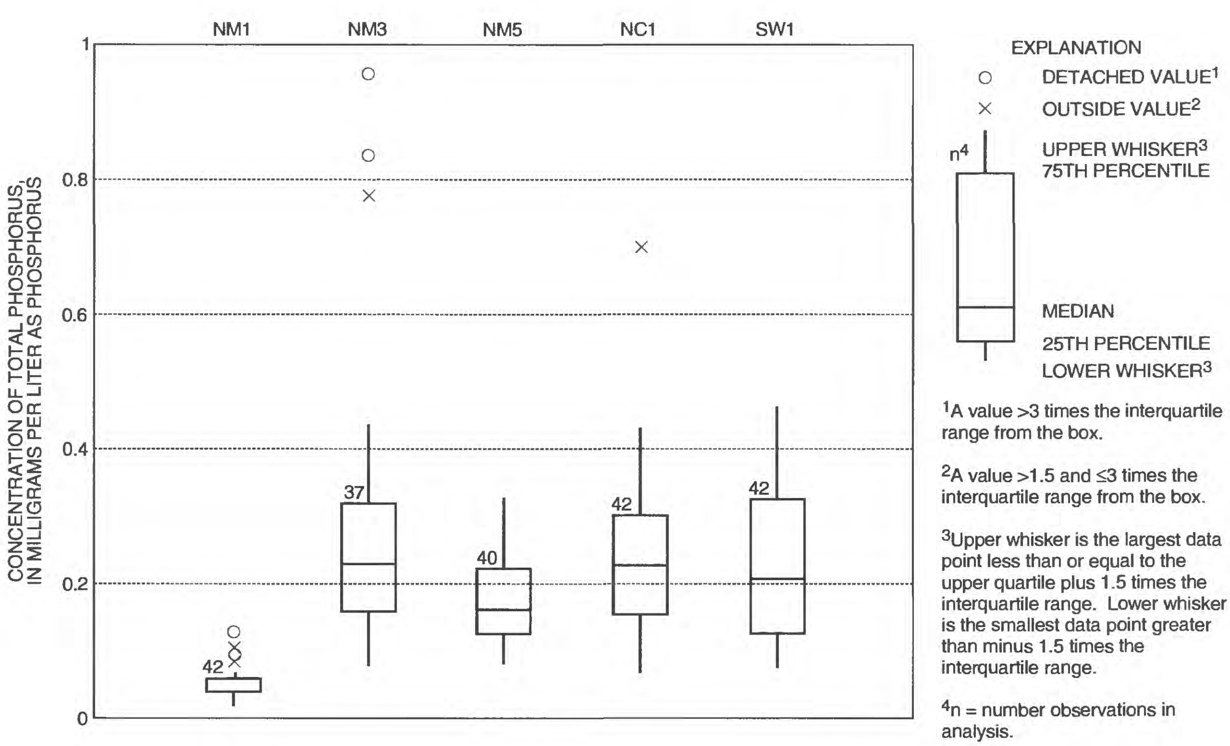

Figure 10.--Concentrations of total phosphorus in base flow at sites NM1, NM3, NM5, NC1, and SW1 in the Small Watershed.

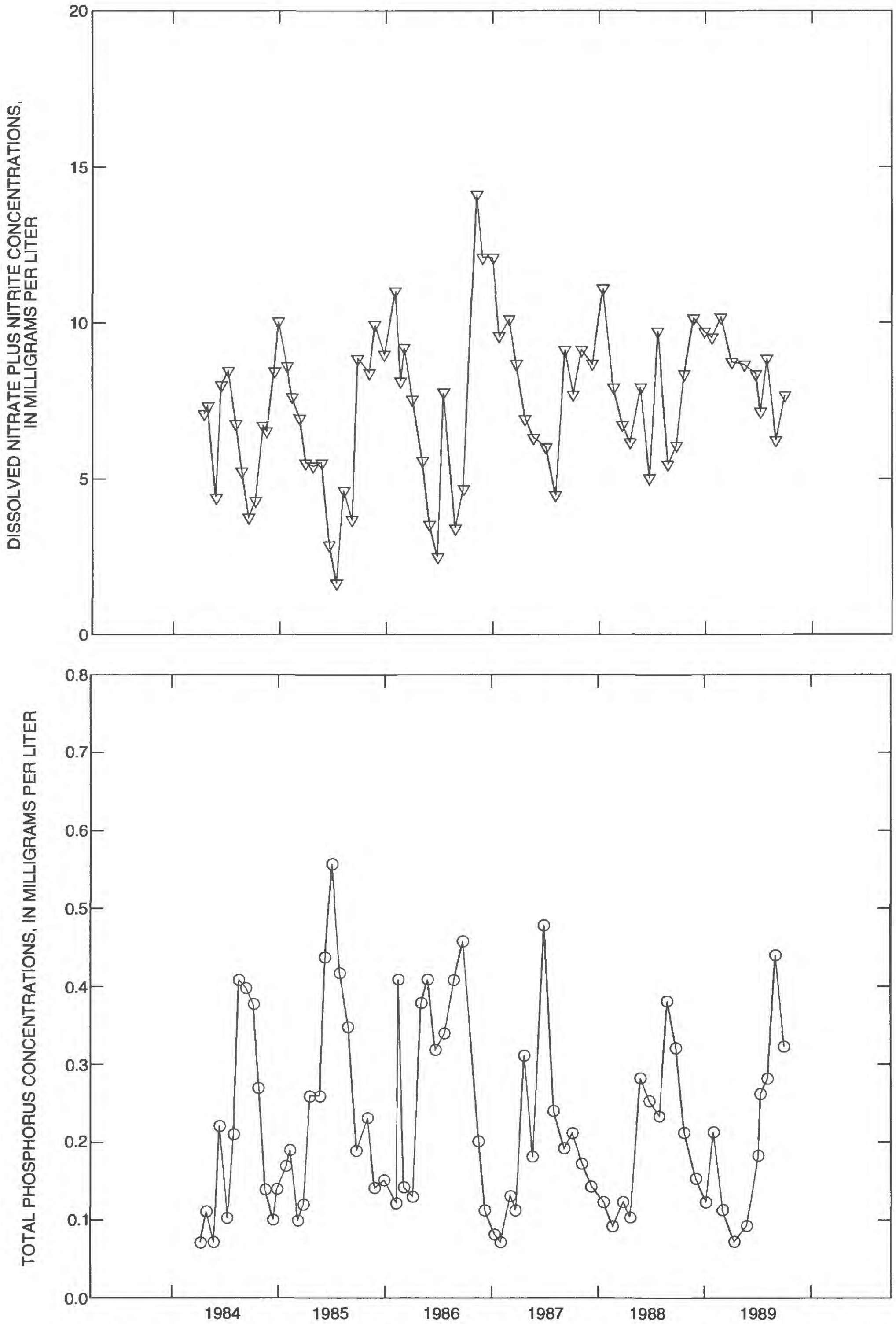

Figure 11.--Dissolved nitrate plus nitrite (above) and total phosphorus (below) concentrations in base flow at site SW1 in the Small Watershed, April 1984 through September 1989.

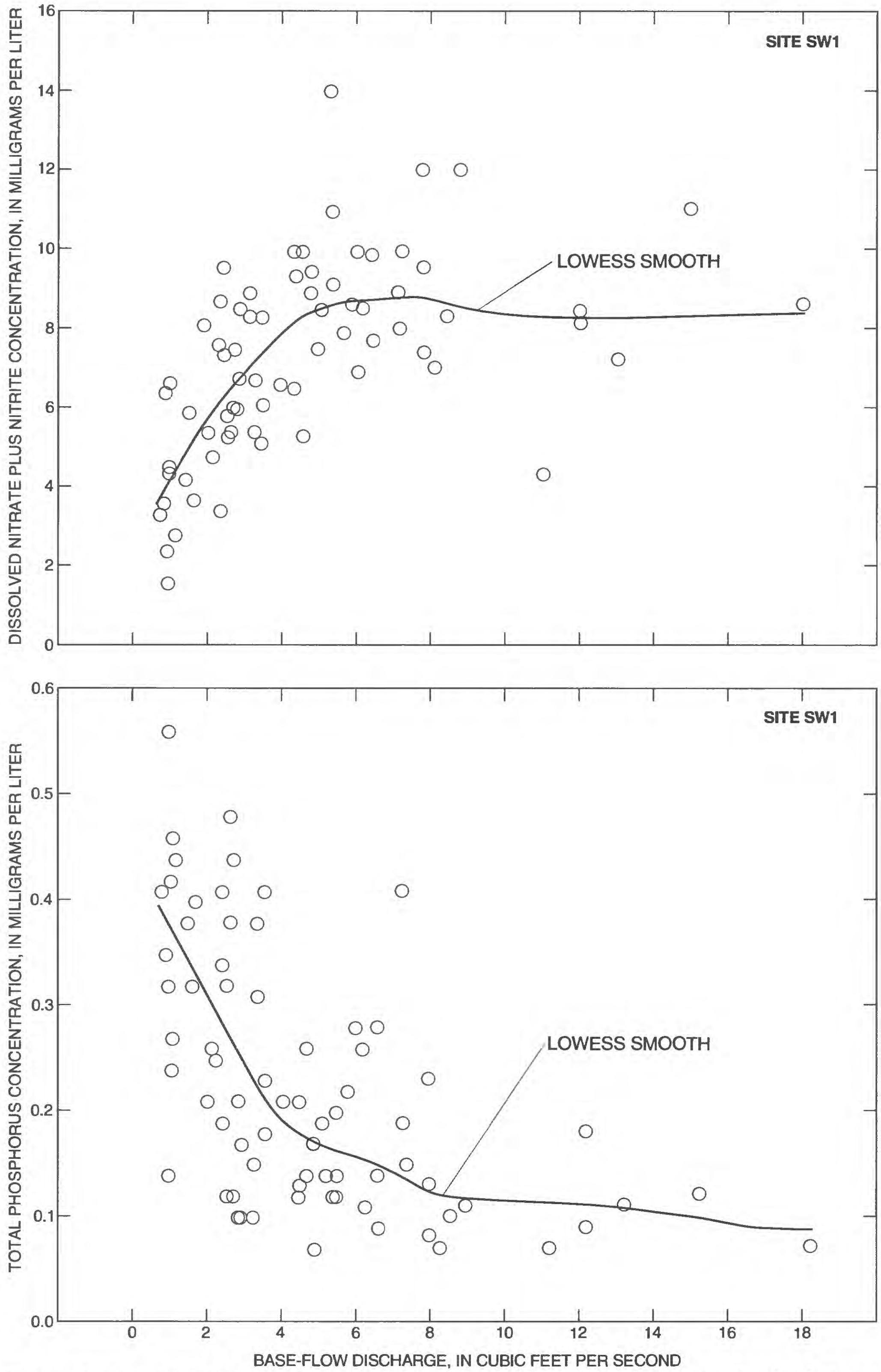

Figure 12.--Locally weighted scatterplot smooth (LOWESS) of relation between dissolved nitrate plus nitrite and discharge (above) and between total phosphorus and discharge (below) in base flow at site SW1 in the Small Watershed, April 1984 through September 1989.

Water samples for pesticide analyses were collected from base-flow discharge from the noncarbonate area of the Nutrient-Management Subbasin (site NM1), the entire Nutrient-Management Subbasin (site NM5), and the entire Small Watershed (site SW1). The most frequently detected pesticides were atrazine, metolachlor, cyanazine, and alachlor (table 18). At site NM1, atrazine was detected in 1988, and metolachlor, which was not previously detected, was present in 1989. Pesticides were consistently detected at sites NM5 and SW1. At site NM5, 48 percent of the 23 base-flow samples collected contained pesticides. At site SW1, 70 percent of the 23 base-flow samples collected contained pesticides. Atrazine was the pesticide most frequently detected at sites NM5 and SW1. About 40 percent of the base-flow samples at site NM5 and 55 percent of the base-flow samples at site SW1 contained detectable concentrations of atrazine. Maximum base-flow concentrations of total atrazine at sites NM5 and SW1 generally occurred within 3 months of the spring-planting application of atrazine (fig. 13). Maximum concentrations of atrazine in base flow at sites NM5 and SW1 were measured in 1989 and 1987, respectively. Unlike other years, atrazine concentrations in 1989 showed multiple peaks at both sites. Except for 1989, base-flow concentrations at site SW1 were slightly greater than base-flow concentrations at site NM5. Although concentrations of atrazine in base flow were generally near the minimum reporting level by October, small concentrations were sometimes detected into December.

Table 18.--Pesticide concentrations in base-flow samples from the Small Watershed from April 1986 through September 1989

[μg/L, microgram per liter; --, none detected]

Pesticide	Base flow		
	Number of times detected	Number of analyses	Maximum concentration (μg/L)
	Site NM1 (015760831)		
Atrazine	1	22	0.4
Propazine	0	22	--
Simazine	0	22	--
Cyanazine	0	22	--
Alachlor	0	23	--
Metolachlor	1	23	.2
Toxaphene	0	21	--
	Site NM5 (0157608335)		
Atrazine	9	22	2.7
Propazine	0	22	--
Simazine	0	22	--
Cyanazine	7	22	.9
Alachlor	1	23	.1
Metolachlor	9	23	.4
Toxaphene	0	21	--
	Site SW1 (01576085)		
Atrazine	12	22	2.6
Propazine	0	22	--
Simazine	3	22	1.3
Cyanazine	4	22	.6
Alachlor	0	23	--
Metolachlor	8	23	.5
Toxaphene	0	21	--

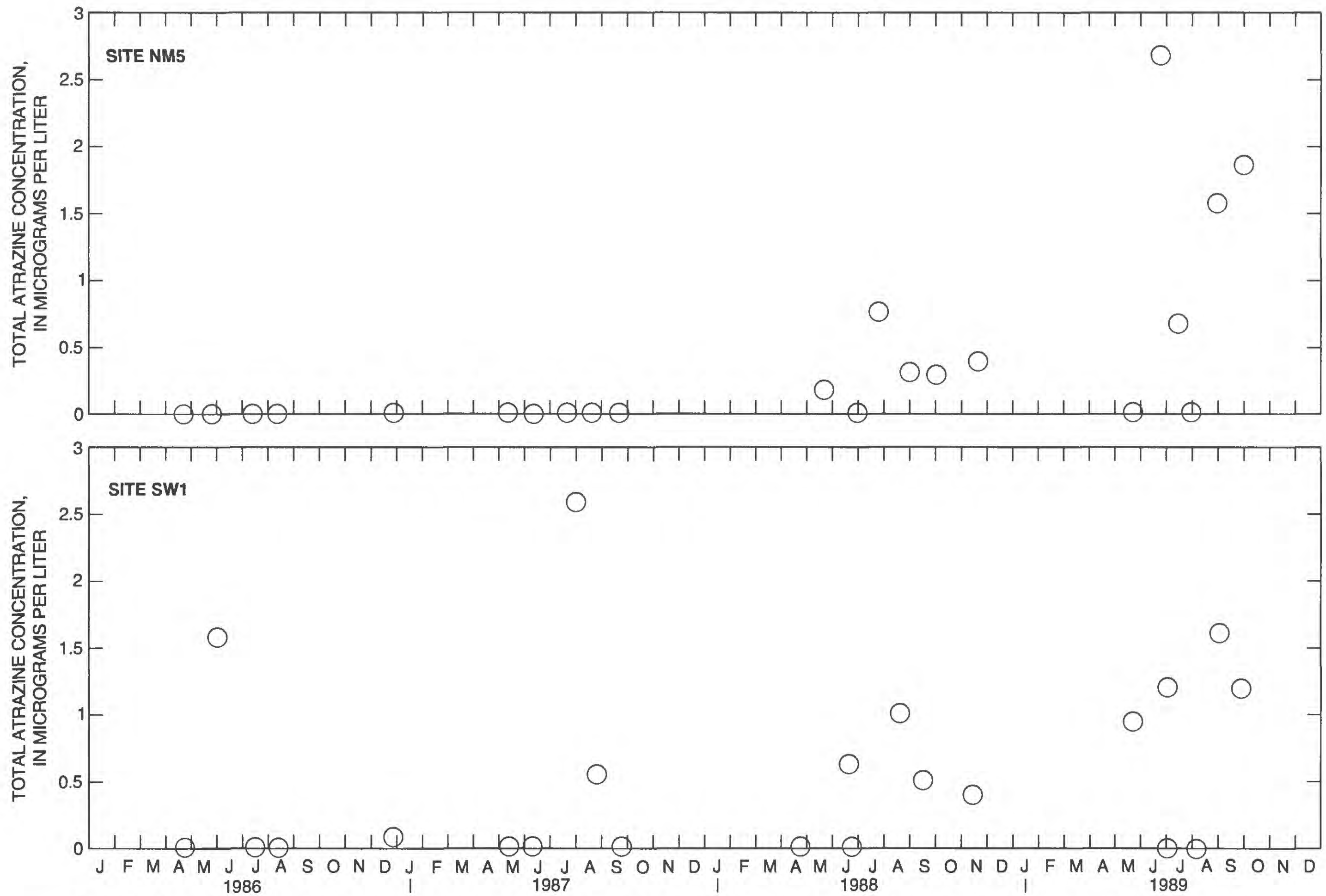

Figure 13.--Total atrazine concentrations in base flow at site NM5 (above) and site SW1 (below) in the Small Watershed.

Stormflow

Samples of stormflow were collected from the Nutrient-Management Subbasin (site NM5) and from the Small Watershed (site SW1). Samples from 55 percent of 164 stormflow events in the Nutrient-Management Subbasin and from 62 percent of 171 stormflow events in the Small Watershed were analyzed for nutrients and suspended sediment or for suspended sediment only. An average of eight nutrient and seven suspended-sediment samples were analyzed for each event.

Concentrations of nutrients and suspended sediment in stormflow varied in response to discharge as reported by Fishel and others (1992). Typically, concentrations of total organic plus ammonium nitrogen, total phosphorus, and suspended sediment increased and decreased with discharge. Concentrations of nitrate plus nitrite nitrogen increased and decreased in opposition to discharge.

A comparison of the range and median values of mean storm concentrations between the Nutrient-Management Subbasin and the Small Watershed showed some differences in water quality (fig. 14). Median values for mean storm concentrations of dissolved nitrate plus nitrite were about 1.2 mg/L (40 percent) greater in the Small Watershed overall than in the Nutrient-Management Subbasin. Median values for mean storm concentrations of total ammonium plus organic nitrogen, total phosphorus, and suspended sediment were nearly identical.

Maximum instantaneous constituent concentrations in stormflow generally were detected in spring and early fall. These maximums were associated with tillage and with manure and fertilizer applications that occurred during the start of the crop-growing season. Maximum concentrations of total organic plus ammonium nitrogen were measured in July at site NM5 and in June at site SW1 (37 and 35 mg/L, respectively). Maximum concentrations of suspended sediment and total phosphorus were measured in May at both stations (16,700 mg/L of suspended sediment and 24 mg/L of total phosphorus at site NM5, and 34,300 mg/L of suspended sediment and 17 mg/L of total phosphorus at site SW1).

Four pesticides were detected in stormflow in the Nutrient-Management Subbasin and the Small Watershed (table 19). Atrazine, cyanazine, alachlor, and metolachlor were detected in 20–40 percent of the samples from the Nutrient-Management Subbasin (site NM5) and in 50–75 percent of the samples from the Small Watershed (site SW1). Maximum concentrations of pesticides were detected in stormflow after spring application of these compounds.

Loads and Yields

Monthly loads and annual yields of nitrogen, phosphorus, and suspended sediment were calculated for the Nutrient-Management Subbasin (site NM5) and for the Small Watershed (site SW1). The monthly load is an estimate of the total amount of a constituent transported by streamflow per month. Annual yield is the annual total of monthly loads expressed on a per square mile basis. Yields allow for a more equitable comparison of loads from drainage areas of different sizes.

Maximum monthly loads of nitrogen, phosphorus, and suspended sediment (figs. 15, 16, and 17) increased over the post-BMP period, with the exceptions of total phosphorus and suspended sediment at site NM5. The increases in loads were in response to increases in monthly streamflows (tables 11 and 12). At site NM5, maximum monthly loads of total phosphorus and suspended sediment declined after reaching a peak in September 1987. Because phosphorus and sediment are transported primarily by surface runoff, the observed reductions suggest a change in land-use patterns, rather than nutrient management, as a cause.

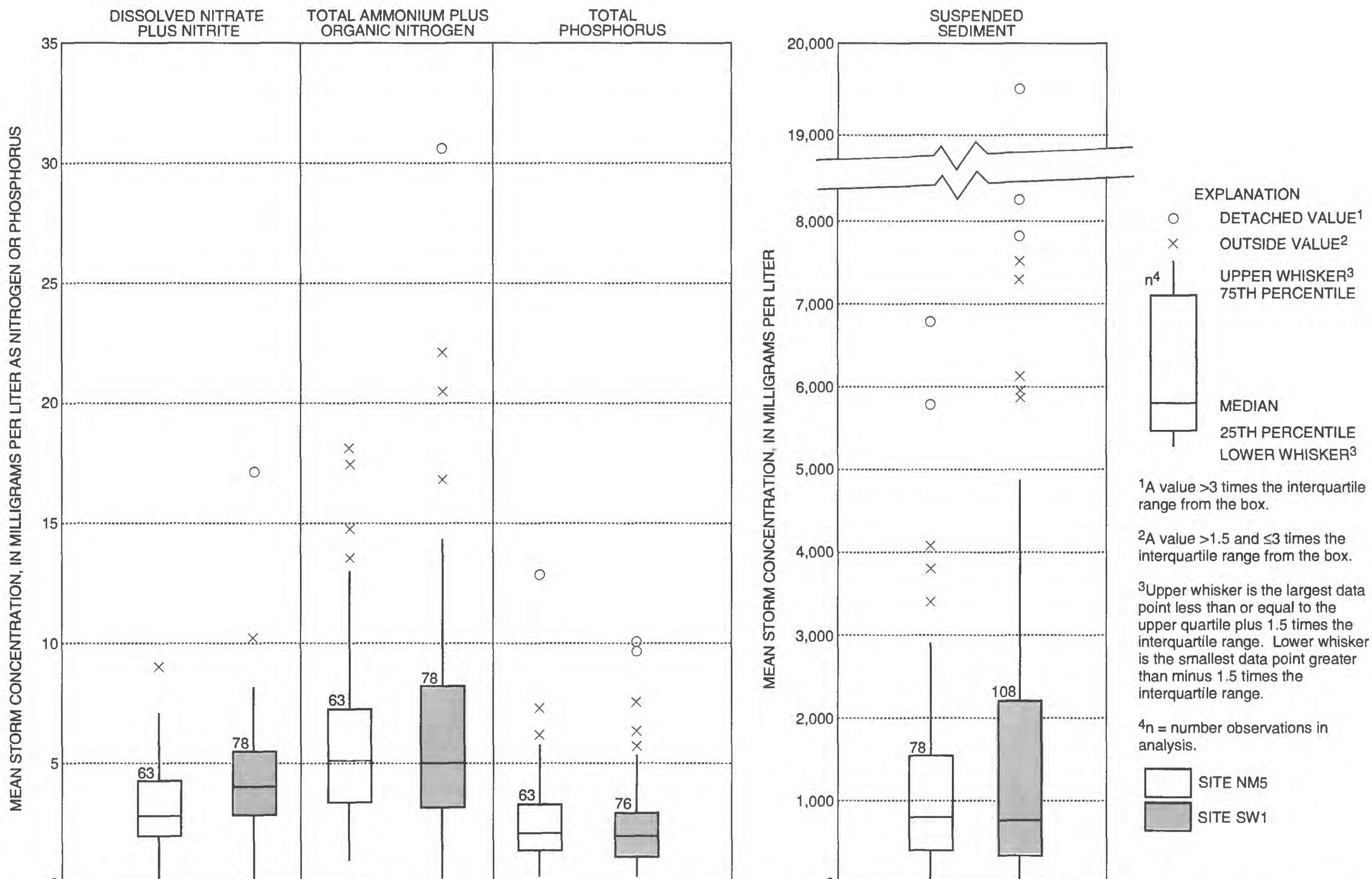

Figure 14.--Mean concentrations of dissolved nitrate plus nitrite, total ammonium plus organic nitrogen, total phosphorus, and suspended sediment for sampled storm days at sites NM5 and SW1 in the Small Watershed.

Table 19.--Pesticide concentrations detected in stormflow samples from sites NM5 and SW1 in the Small Watershed from April 1986 through September 1989

[µg/L, microgram per liter; --, none detected]

Pesticide	Number of times detected	Number of analyses	Maximum concentration (µg/L)
	Site NM5 (0157608335)		
Atrazine	2	5	11
Propazine	0	5	--
Simazine	0	5	--
Cyanazine	1	5	.7
Alachlor	1	5	.2
Metolachlor	2	5	4.6
Toxaphene	0	5	--
	Site SW1 (01576085)		
Atrazine	6	8	30
Propazine	0	8	--
Simazine	0	8	--
Cyanazine	5	8	6.0
Alachlor	4	8	4.6
Metolachlor	5	8	10
Toxaphene	0	8	--

Nutrient and suspended-sediment loads were not transported equally by base flow and stormflow. Seventy-two percent of the nitrogen load was discharged in base flow, whereas 89 percent of the phosphorus load and 97 percent of the suspended-sediment load were discharged in stormflow. Nitrate plus nitrite in base flow contributed most to the load of total nitrogen. An average of 55 percent of the load of total nitrogen discharged from the Small Watershed was base-flow nitrate plus nitrite.

A comparison of annual yields (tables 20 and 21) between the Nutrient-Management Subbasin and the Small Watershed suggests, as did the monthly load data, a change in land use or cropping patterns. The ratio of site NM5 yields to site SW1 yields (table 22) varied from year to year for nitrate plus nitrite and total nitrogen but did not change much over the post-BMP period. In contrast, yield ratios decreased about 50 percent for total phosphorus and about 65 percent for suspended sediment. The greatest decrease in yield ratios for total phosphorus and suspended sediment was in the last 6 months of the period. Notably, yields from the Small Watershed for the last 6 months of the period were nearly equivalent to or, in some cases, greater than annual yields from all previous years in the post-BMP period.

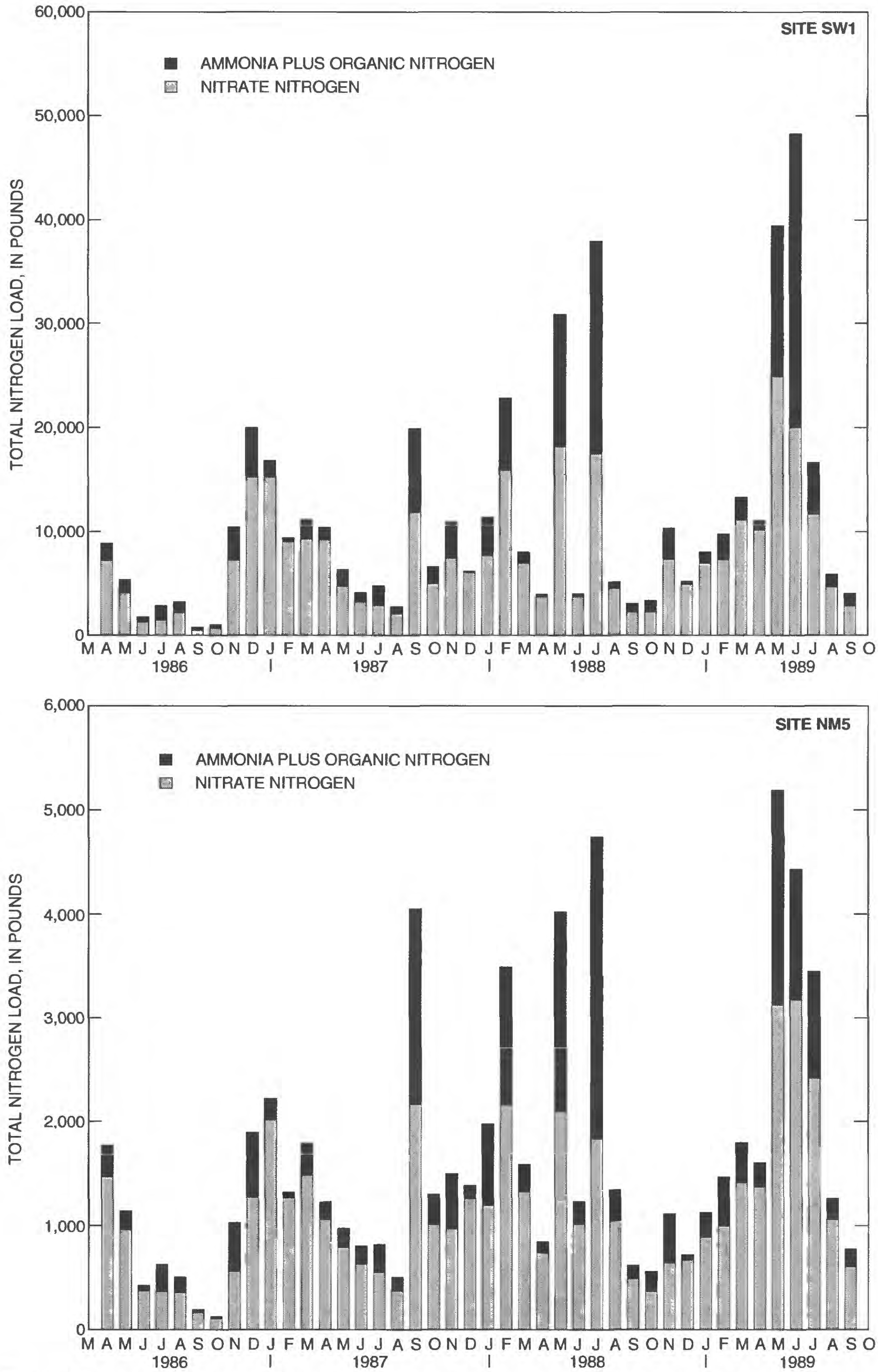

Figure 15.--Monthly loads of nitrogen at site SW1 (above) and site NM5 (below) in the Small Watershed.

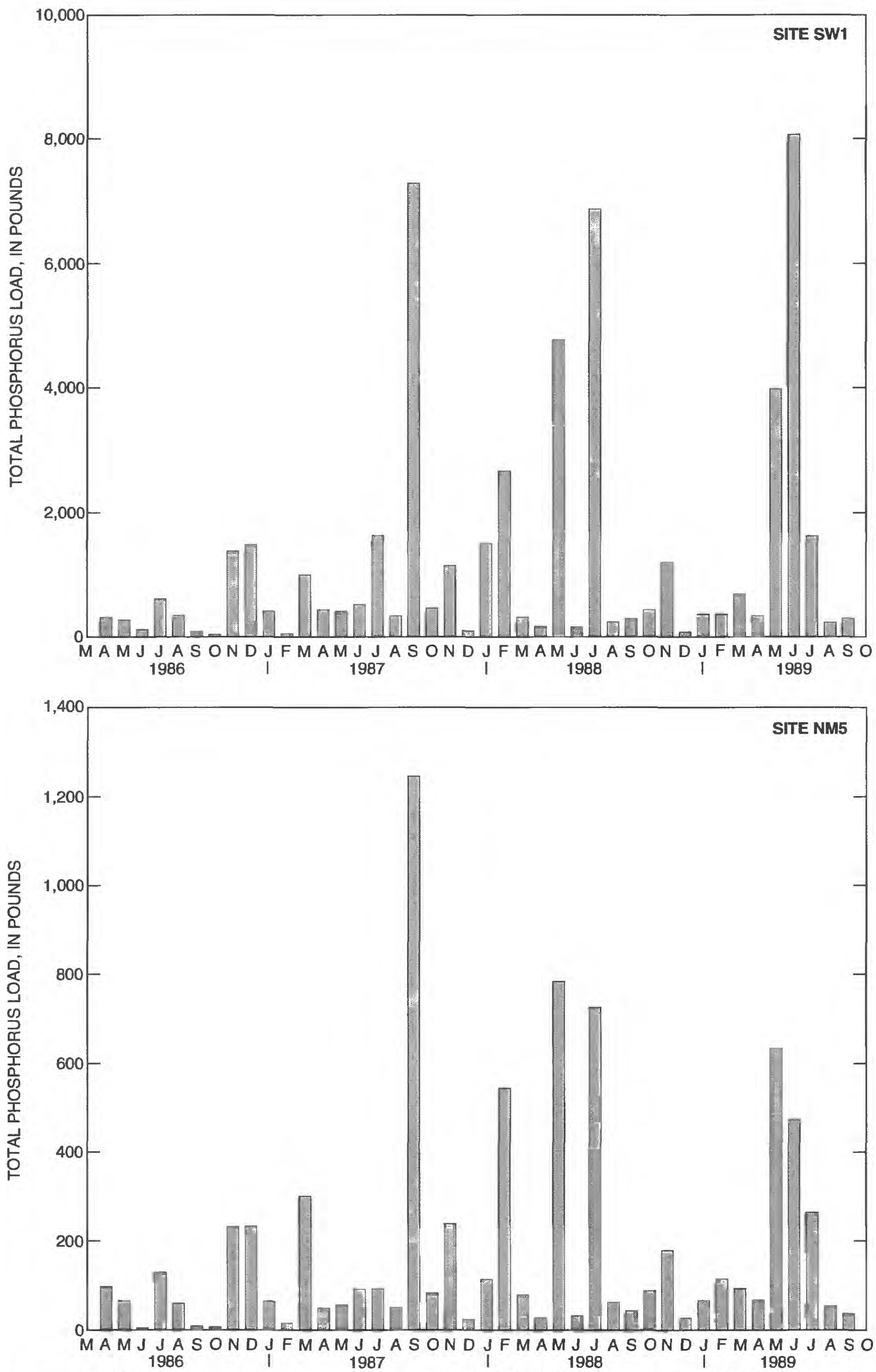

Figure 16.--Monthly loads of total phosphorus at site SW1 (above) and site NM5 (below) in the Small Watershed.

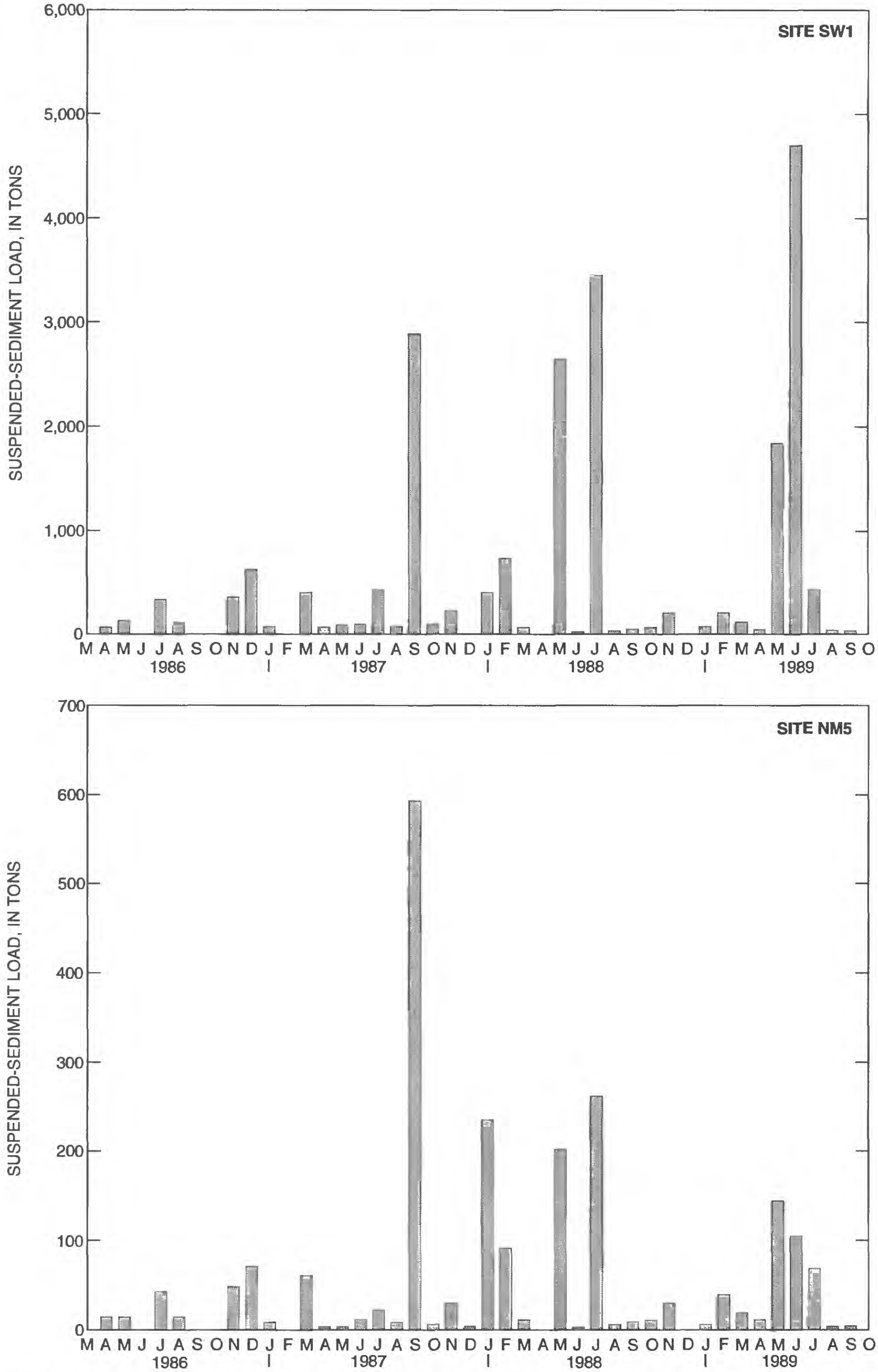

Figure 17.--Monthly loads of suspended sediment at site SW1 (above) and site NM5 (below) in the Small Watershed.

Table 20.--Annual yields of nitrogen, phosphorus, and suspended sediment in streamflow at site NM5 in the Nutrient-Management Subbasin

[Yields are in pounds per square mile for nitrogen and phosphorus and in tons per square mile for suspended sediment; ft^3/s, cubic foot per second]

Year	Mean streamflow (ft^3/s)	Mean base flow (ft^3/s)	Nitrate plus nitrite			Total nitrogen			Total phosphorus			Suspended sediment		
			Stream-flow	Base flow	Base-flow contribution (in percent)	Stream-flow	Base flow	Base-flow contribution (in percent)	Stream-flow	Base flow	Base-flow contribution (in percent)	Stream-flow	Base flow	Base-flow contribution (in percent)
April 1986–March 1987	0.83	0.51	7,300	6,300	86	9,200	6,800	74	880	110	12	200	5	2
April 1987–March 1988	1.33	.75	9,500	8,100	85	13,800	8,900	64	1,900	160	8	720	10	1
April 1988–March 1989	1.16	.75	8,500	7,300	86	13,800	8,700	63	1,600	210	13	410	20	5
April 1989–September 1989[1]	2.09	1.32	8,400	6,800	81	11,800	7,500	64	1,100	140	13	230	18	8
Average[2]			8,400	7,200	86	12,300	8,100	66	1,500	160	11	440	12	3

[1] Yields and mean flows are for 6-month period.
[2] Averages do not include April through September 1989.

Table 21.--Annual yields of nitrogen, phosphorus, and suspended sediment in streamflow at site SW1 in the Small Watershed

[Yields are in pounds per square mile for nitrogen and phosphorus and in tons per square mile for suspended sediment; ft^3/s, cubic foot per second]

Year	Mean streamflow (ft^3/s)	Mean base flow (ft^3/s)	Nitrate plus nitrite			Total nitrogen			Total phosphorus			Suspended sediment		
			Stream-flow	Base flow	Base-flow contribution (in percent)	Stream-flow	Base flow	Base-flow contribution (in percent)	Stream-flow	Base flow	Base-flow contribution (in percent)	Stream-flow	Base flow	Base-flow contribution (in percent)
April 1986–March 1987	5.52	3.48	12,900	11,200	87	15,900	12,400	78	1,100	218	20	350	10	3
April 1987–March 1988	7.42	4.11	14,200	11,600	82	19,900	12,700	64	2,900	250	9	870	19	2
April 1988–March 1989	6.97	4.40	15,300	12,300	80	23,400	13,400	57	2,700	300	11	1,200	29	2
April 1989–September 1989[1]	11.70	6.91	12,900	10,000	78	21,500	11,000	51	2,500	224	9	1,200	29	2
Average[2]			14,100	11,700	83	19,700	12,800	65	2,200	256	12	810	19	2

[1] Yields and mean flows are for 6-month period.
[2] Averages do not include April through September 1989.

Table 22.--Ratio of yields of nitrogen, phosphorus, and suspended sediment from site NM5 in the Nutrient-Management Subbasin to yields from site SW1 in the Small Watershed

Year	Nitrate plus nitrite	Total nitrogen	Total phosphorus	Suspended sediment
April 1986–March 1987	0.57	0.58	0.80	0.57
April 1987–March 1988	.67	.69	.66	.88
April 1988–March 1989	.56	.59	.59	.34
April 1989–September 1989	.65	.55	.44	.19

EFFECTS OF NUTRIENT MANAGEMENT ON WATER QUALITY

Evaluation of the effects of nutrient management on water quality was conducted to determine (1) if water quality had changed, and (2) if variable nutrient application rates could be statistically related to varying water quality. Changes in water quality were evaluated by two methods: first, pre-BMP concentrations of nutrients were compared to post-BMP concentrations at each water-quality-sampling site. Second, concentrations of nutrients in surface-water samples from the Nutrient-Management Subbasin were compared to concurrent surface-water samples from the Nonnutrient-Management Subbasin. The relation between nutrient applications and water quality was examined by developing linear regression models.

Pre-BMP to post-BMP comparisons of nutrient concentrations were made for base flow and stormflow. Mean nutrient concentrations in stormflow were grouped into four seasons, and a seasonally grouped Wilcoxon Mann-Whitney Rank-Sum test (Bradley, 1968) was used to determine whether a step trend in median concentrations of nutrients had occurred from the pre-BMP to post-BMP period. The Mann-Whitney rank sum is a nonparametric test on ranks to determine whether one data set comes from a different population than the other. Prior to testing for step trends, the first year of post-BMP base-flow data (April 1986 through March 1987) was excluded for the following reasons: (1) Not all farms in the Nutrient-Management Subbasin received their nutrient-management plans at the start of the post-BMP period, and (2) a minimum, although undetermined, amount of time elapsed before infiltrating water and nutrients were discharged as base flow. Constituents with flow dependency were flow adjusted. Flow dependency was removed from the data by subtracting observed nutrient concentrations from concentrations predicted by a LOWESS (Cleveland, 1979) smooth of the concentration/discharge function. The median value of mean nutrient concentrations for the study period was then added to the differences (Hirsch and others, 1991).

Results of the pre-BMP to post-BMP comparison tests for unadjusted and flow-adjusted nutrient concentrations in base flow are listed in table 23. About 20 percent of the step trends were statistically significant. A significant, increasing trend of 1.4 mg/L in dissolved nitrate plus nitrite from the Small Watershed (site SW1) was reduced to a nearly significant (p=0.06) increase of 0.7 mg/L after flow adjustment. Concentrations of dissolved ammonium decreased significantly at sites NM1, SW1, and NC1. A nearly significant (p=0.09) decrease in concentrations of dissolved ammonium was detected at site NM5. Concentrations of total ammonium plus organic nitrogen decreased significantly only at site SW1. This 0.26-mg/L reduction represented about 3 percent of the mean concentration of total nitrogen in base flow from the Small Watershed. Concentrations of total phosphorus did not change significantly at any site. Notably, all constituents, with the exceptions of dissolved nitrate plus nitrite at sites NM2, SW1, and NC1, had negative trend coefficients whether significant or not.

Table 23.--Results of seasonal rank-sum test for step trends in pre-Best-Management Practice to post-Best-Management Practice unadjusted and flow-adjusted base-flow nutrient concentrations in the Small Watershed

[mg/L, milligram per liter; p, probability; <, less than; --, no data]

Constituent	Unadjusted data		Flow-adjusted data	
	Step trend (mg/L)	Probability (p)	Step trend (mg/L)	Probability (p)
Site NM1				
Dissolved nitrate plus nitrite	−0.10	0.21	−0.22	0.21
Dissolved ammonium	−.01	[1]<.01	--	--
Total ammonium plus organic nitrogen	−.08	.15	--	--
Total phosphorus	<−.01	.35	<−.01	.83
Site NM3				
Dissolved nitrate plus nitrite	.00	.90	−.25	.41
Dissolved ammonium	−.01	.64	--	--
Total ammonium plus organic nitrogen	−.15	.19	--	--
Total phosphorus	−.04	.11	−.03	.39
Site NM5				
Dissolved nitrate plus nitrite	−.78	.20	−.50	.20
Dissolved ammonium	−.03	.09	--	--
Total ammonium plus organic nitrogen	−.19	.30	--	--
Total phosphorus	−.01	.28	<−.01	.83
Site SW1				
Dissolved nitrate plus nitrite	1.4	[1].03	.69	.06
Dissolved ammonium	−.04	[1].01	--	--
Total ammonium plus organic nitrogen	−.26	[1]<.01	--	--
Total phosphorus	−.02	.11	<−.01	.76
Site NC1				
Dissolved nitrate plus nitrite	.40	.36	.37	.30
Dissolved ammonium	−.03	[1].01	--	--
Total ammonium plus organic nitrogen	−.22	.15	--	--
Total phosphorus	−.02	.90	−.03	.16

[1] Significant at the 95-percent confidence level.

The step-trend coefficients indicated nonsignificant changes of 5 to 10 percent in median concentrations of flow-adjusted dissolved nitrate plus nitrite at all sites. That these changes were not determined significant was principally attributed to the substantial variation observed in the concentrations. Large variance in data used in the Mann-Whitney test increased the width of the test confidence interval. Within this wide confidence interval, a sufficiently large percentage of both pre-BMP and post-BMP data were included and could not be distinguished. Moreover, there is the concern that the reported trend coefficients resulted from environmental factors affecting seasonal changes in water quality rather than a change in nutrient inputs. However, the opposing signs of the trend coefficients for nitrate plus nitrite between the Nutrient-Management Subbasin and the Nonnutrient-Management Subbasin and the entire Small Watershed argue for an effect of nutrient management. For example, trend coefficients for dissolved nitrate plus nitrite at sites SW1 and NC1 suggest increasing concentrations. In contrast, coefficients indicating decreasing concentrations were calculated for sites NM1, NM3, and NM5. With the exception of site NM1, this result agrees with the general pattern of nutrient-management implementation in the Small Watershed. Trends coefficients for concentrations of total ammonium plus organic nitrogen and total phosphorus in base flow did not follow this pattern and were probably affected mostly by changes in near-stream or in-stream conditions rather than by nutrient management.

Fishel and others (1992) examined what changes in base-flow nutrient concentrations would be statistically detectable, given pre-BMP period water quality. By the use of Monte Carlo simulation, the reductions in median concentrations needed to attain the desired statistical significance ($p \leq 0.05$) when using the Wilcoxon Mann-Whitney Rank-Sum test were estimated. The required reductions estimated for dissolved nitrate plus nitrite and total phosphorus were at least several times larger than the reductions in post-BMP period median concentrations (table 24) estimated by use of the step-trend coefficients. Results of the Monte Carlo simulation exemplify the effects of large seasonal variation on the power of the rank-sum test to detect small changes in water quality.

Table 24.--Comparison of changes in pre-Best-Management Practice base-flow concentrations in the Small Watershed (1) required to achieve statistically significant reductions (Fishel and others, 1992), and (2) to the observed post-Best-Management Practice base-flow concentrations

[Changes are in percent; <, less than]

Site	Dissolved nitrate plus nitrite		Total phosphorus	
	Required	Observed	Required	Observed
NM1	–17	–8	–48	<–20
NM3	–31	–7	–54	–16
NM5	–17	–6	–36	<–6
NC1	–50	+8	–45	–13
SW1	–33	+10	–51	<–5

Although results of the rank-sum test suggest that nutrient management did affect base-flow water quality, not all changes in water quality resulted from nutrient management. For example, significant or nearly significant decreasing trends were detected in concentrations of dissolved ammonium at sites NM1, NM5, SW1, and NC1. However, the lack of agricultural land use above site NM1 suggests that another mechanism, possibly climate, was the cause of the decrease.

The negative trend coefficients for dissolved nitrate plus nitrite at sites NM2 and NM3, in combination with the significant increasing trend at site SW1 and the positive trend coefficient for site NC1, suggest that the effect of nutrient management in the Nutrient-Management Subbasin was to slow or reverse increases in concentrations of dissolved nitrate plus nitrite that would have occurred otherwise.

Another important consideration for base-flow water quality is that rates of ground-water flow are unknown. Time of travel for ground water could have exceeded the time allotted for post-BMP monitoring of water quality, particularly from fields farther from the stream. In this case, the full effect of nutrient management on water quality would not occur until after water-quality monitoring was finished.

Results of rank-sum tests on mean stormflow concentrations are listed in table 25. A nearly significant decrease in concentrations of total ammonium plus organic nitrogen ($p=0.07$) was detected at site NM5. A significant decrease in total phosphorus and a nearly significant increase ($p=0.06$) in total nitrate plus nitrite was detected in fall mean concentrations in stormflow at site SW1. Although limited to the fall season, changes in mean concentrations in stormflow at site SW1 corresponded to step trends detected in base flow, suggesting a similar, although unknown, cause. Considering the extreme variability in stormflow characteristics, it is unlikely that the Mann-Whitney Rank-Sum test would detect changes in stormflow water quality caused by nutrient management as implemented in the Small Watershed and Nutrient-Management Subbasin.

Table 25.--Results of rank-sum test for differences between pre-Best-Management Practice and post-Best-Management Practice mean concentrations for stormflow days at sites NM5 and SW1 in the Small Watershed

[NC, no change; DEC, significant decrease; p, probability]

Season	Total nitrate plus nitrite	Total ammonium plus organic nitrogen	Total phosphorus	Suspended sediment
Site NM5				
Spring	NC (p=0.76)	NC (p=0.07)	NC (p=0.94)	NC (p=0.30)
Summer	NC (p=0.31)	NC (p=0.38)	NC (p=0.36)	NC (p=0.20)
Fall	NC (p=0.60)	NC (p=0.88)	NC (p=0.71)	NC (p=0.42)
Winter	NC (p=0.92)	NC (p=0.27)	NC (p=0.84)	NC (p=0.92)
Site SW1				
Spring	NC (p=0.22)	NC (p=0.53)	NC (p=0.57)	NC (p=0.29)
Summer	NC (p=0.41)	NC (p=0.22)	NC (p=0.19)	NC (p=0.94)
Fall	NC (p=0.06)	NC (p=0.53)	DEC (p=0.02)	NC (p=0.70)
Winter	NC (p=0.18)	NC (p=0.94)	NC (p=0.76)	NC (p=0.94)

The paired-subbasins evaluation and regression model were completed only for dissolved nitrate plus nitrite in base flow for the following reasons: (1) Dissolved nitrate plus nitrite was the primary nitrogen source in ground water and stream base flow; (2) nitrate plus nitrite in base flow is an integrator of ground-water contributions of nitrate from all locations within the watershed, whereas other nitrogen species and phosphorus originate primarily in or near the stream channel; (3) nitrate was the nutrient constituent least affected by upstream disturbances occurring at the time of sampling; (4) nutrient-management plans for the Small Watershed were developed to manage nitrogen; and (5) the variability and temporal distribution of base-flow water quality was much less erratic than that of stormflow, thereby improving the probability of detecting changes in the water quality.

The pre-BMP and post-BMP relation between concentrations of dissolved nitrate plus nitrite from the Nutrient-Management (site NM5) and Nonnutrient-Management (site NC1) Subbasins was derived by linear regression and was tested for significant change from the pre-BMP to post-BMP period by use of analysis of covariance (fig. 18). Although a significant change (p=<0.01) in the relation was detected, results of the test did not indicate whether the change was a decrease in concentrations in the Nutrient-Management Subbasin, an increase in concentrations in the Nonnutrient-Management Subbasin, or both.

The question of where significant changes in dissolved nitrate plus nitrite in base flow had occurred was resolved by use of graphical analysis. Figure 19 presents time-series plots and LOWESS smooths of base-flow concentrations of dissolved nitrate plus nitrite from sites NM5, NC1, and SW1. The smooths show movement over time of the middle of the data (Helsel and Hirsch, 1992). The smooth for site NM5 shows little change during the study period, whereas the smooth for site NC1 increases with time and suggests that the change detected by the analysis of covariance was an increase in concentrations of dissolved nitrate plus nitrite in the Nonnutrient-Management Subbasin.

An increase in concentrations of dissolved nitrate plus nitrite in the Nonnutrient-Management Subbasin was unexpected. This subbasin was not expected to have any sizable change in farming practices because of the reluctance of farm operators there to adopt nutrient management or other BMP's. In addition, documentation and verification of changing farm practices in the subbasin were not possible because of the lack of any agricultural-activity data from the subbasin. However, the increase may have resulted from an environmental factor other than changes in farming practices. A time-series plot of water-quality data from site SW1 (fig. 19) suggests that concentrations of dissolved nitrate plus nitrite were also increasing in other areas of the Small Watershed. Comparison of the LOWESS smooths shows the center of the data behaving almost identically over time at SW1 and NC1. Whatever caused changes in water quality in the Nonnutrient-Management Subbasin appears to have affected a substantial part of the entire Small Watershed, except the Nutrient-Management Subbasin.

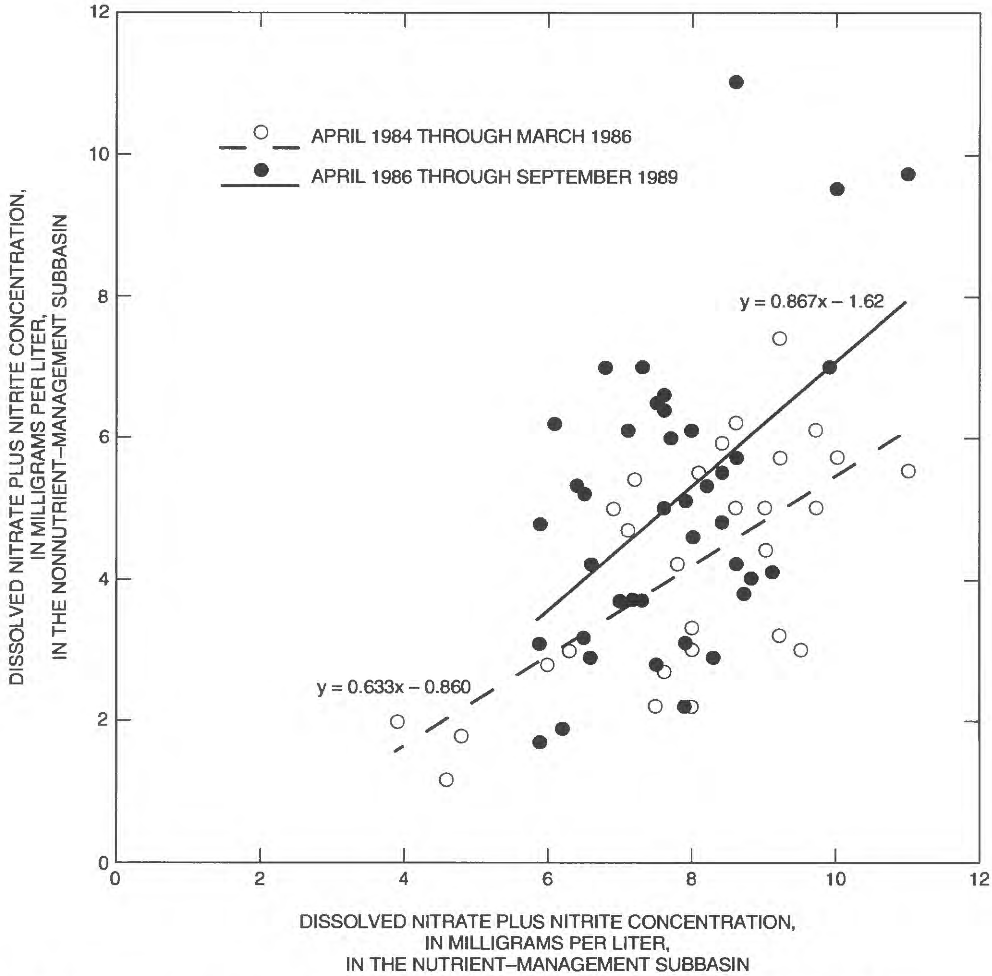

Figure 18.--Relation between concentrations of dissolved nitrate plus nitrite in base flow from the Nutrient-Management Subbasin (site NM5) and in base flow from the Nonnutrient-Management Subbasin (site NC1).

Regression models were developed to determine if any of the variation observed in water-quality data was in response to variation in nutrient-application rates. Demonstrating a responsive relation between nutrient-application rates and water quality gives stronger support for cause and effect than just detecting changes in water quality (Spooner, 1991). In addition, a valid regression model can be helpful in detecting trends in water quality.

The models define the mathematical relation between two or more variables (Iman and Conover, 1983). In these models, water quality was the response variable, and the variables listed in table 26 were the explanatory (independent) variables.

Two regression models of base-flow concentrations of dissolved nitrate plus nitrite were examined. Both models included the same explanatory variables except that for one of the models, the nitrogen-application variable was shifted forward about 9 months (leading) to allow for transit time of nitrate plus nitrite from the application point to the stream (table 26). Neither concurrent or leading nitrogen applications successfully explained a significant part of the observed variation in concentrations of dissolved nitrate plus nitrite. Seasonal variability was represented by the sine and cosine functions of time since the beginning of data collection. In both models, the sine of time was the only significant explanatory variable. The significance of the sine of time variable underscores the large effect seasonal changes had on concentrations of dissolved nitrate plus nitrite in base flow.

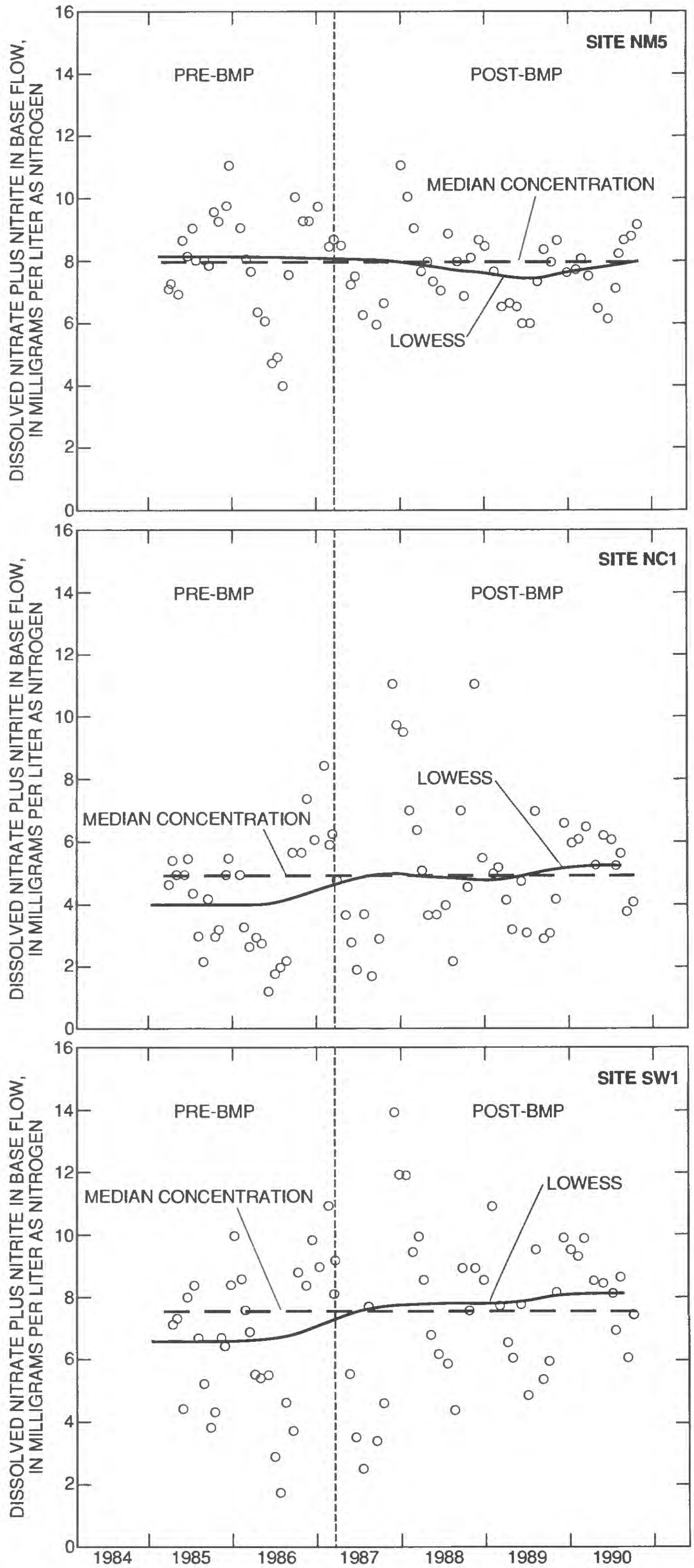

Figure 19.--Dissolved nitrate plus nitrite concentrations in base flow at site NM5 in the Nutrient-Management Subbasin, site NC1 in the Nonnutrient-Management Subbasin, and site SW1 in the Small Watershed.

Table 26.--Regression statistics for concentrations of dissolved nitrate plus nitrite in base flow at site NM5 in the Nutrient-Management Subbasin as a function of monthly nitrogen applications, discharge, monthly precipitation, and seasonality

Data set	Number of data points	Independent variable	Coefficient	t-statistic	p-value	Coefficient of determination (adjusted R^2)	Standard error of estimate
Concurrent nitrogen applications	66	Nitrogen application	0.000	−0.326	0.74	0.34	1.145
		Discharge	.137	.591	.56		
		Precipitation	−.088	−1.276	.21		
		Sine of time	−1.092	−4.970	.00		
		Cosine of time	−.149	−.624	.54		
		Time	−.128	−1.352	.18		
		Intercept	8.398	20.612	.00		
Leading nitrogen applications	57	Nitrogen application	.000	.244	.81	.37	1.187
		Discharge	.061	.206	.84		
		Precipitation	−.064	−.851	.40		
		Sine of time	−1.217	−4.718	.00		
		Cosine of time	−.121	−.497	.62		
		Time	−.053	−.404	.69		
		Intercept	8.013	16.152	.00		

SUMMARY AND CONCLUSIONS

Hydrologic and agricultural-activity data were collected from April 1986 through September 1989 (post-BMP period) in the Small Watershed drainage basin to study the effects of nutrient management on water quality. These data were compared to data collected from April 1984 through April 1986 before implementation of nutrient management. A paired-basins experiment was conducted with water-quality data from two subbasins, the Nutrient-Management and Nonnutrient-Management Subbasins, within the Small Watershed.

Implementation of nutrient-management plans resulted in coverage of agricultural land averaging 85 percent in the Nutrient-Management Subbasin, 45 percent in the Small Watershed overall, and less than 10 percent in the Nonnutrient-Management Subbasin. After implementation, total annual cropland application of nitrogen from manure and commercial fertilizer decreased from an average of 120,000 to 81,900 lb/yr in the Nutrient-Management Subbasin.

The top 4 ft of soil at three of four sampling locations in the Nutrient-Management Subbasin had median concentrations of nitrate of 100 to 125 lb/acre. Median concentrations of orthophosphorus in the top 4 ft of soil were 10 to 16 lb/acre. Minimum concentrations of nitrate and orthophosphorus in the top 4 ft of soil were measured in the final 12 months of the study at all sampling locations.

Dissolved nitrate plus nitrite was the dominant nutrient in base flow. Median concentrations of dissolved nitrate plus nitrite were smallest (2.5 mg/L) at the most upstream site and largest (7.8 mg/L) at the most downstream site. Seasonal variation in nutrient concentrations was present at all sampling sites and was largest at the most downstream site. Ammonia plus organic nitrogen and phosphorus were the dominant nutrients in stormflow.

Pesticides were detected in base flow and stormflow. Atrazine was the pesticide detected most frequently and was most often detected at the farthest downstream site. Maximum atrazine concentrations were 2.7 mg/L in base flow and 30 mg/L in stormflow.

Nutrient management appeared to effect a small, positive response in base-flow surface-water quality in the Nutrient-Management Subbasin, primarily by preventing an increase in dissolved nitrate plus nitrite concentrations that was observed for the Small Watershed as a whole. Nonflow-adjusted concentrations of dissolved nitrate plus nitrite in base flow increased 1.4 mg/L in the Small Watershed overall. Flow-adjusted concentrations of dissolved nitrate plus nitrite increased 0.7 mg/L; this increase is significant at a confidence level of 95 percent. No significant change was detected in either unadjusted or flow-adjusted concentrations of dissolved nitrate plus nitrite from the Nutrient-Management and Nonnutrient-Management Subbasins. Comparison of LOWESS smooths of time-series plots showed that the central tendency of concentrations of dissolved nitrate plus nitrite increased similarly in the Small Watershed and the Nonnutrient-Management Subbasin. The central tendency of concentrations of dissolved nitrate plus nitrite in the Nutrient-Management Subbasin decreased slightly. Average annual yields of total nitrogen and nitrate plus nitrite in base flow from the Nutrient-Management Subbasin decreased 28 and 14 percent, respectively, from the pre-BMP to the post-BMP period. Yields of total nitrogen and nitrate plus nitrite in base flow from the entire Small Watershed decreased just 8 and 0.6 percent, respectively. Total phosphorus yields decreased 8 percent in the Nutrient-Management Subbasin and increased 1.5 percent in the entire Small Watershed.

Significant decreases detected in concentrations of dissolved ammonia in base flow were possibly unrelated to nutrient management. Reductions in dissolved ammonia occurred in areas with little or no nutrient management, as well as in areas with widespread implementation of nutrient management.

Although the data suggest that nutrient management had a positive effect on water quality in the Nutrient-Management Subbasin, there are reasons to be cautious with this conclusion. First, seasonal variations were so large and changeable that changes in water quality attributed to nutrient management may be artifacts of environmental factors. At a minimum, this large variation greatly reduced the power of the statistical tests to detect changes in water quality. Second, ground-water travel times are unknown. The time required for the effects of reduced nutrient inputs to travel from the land surface to the ground water, then to be discharged as base flow, could have exceeded the 3.5-year post-BMP monitoring period. Third, the lack of agricultural-activity data for farms outside of the Nutrient-Management Subbasin allows for the possibility, although unlikely, of increased nutrient applications in these areas. These concerns do, however, suggest ways to improve a monitoring and evaluation program of this type.

A more effective monitoring and evaluation program would include the following: (1) Nutrient-application data for the entire watershed. The data would document nutrient import, application, and export at the whole-farm level only; and (2) low-frequency, long-term water-quality-data collection. Lower collection frequency reduces costs and redundant information, whereas long-term collection minimizes the effects of short-term climatic cycles and ground-water transit times on water-quality trend analysis.

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