HYDROLOGY AND THE HYPOTHETICAL EFFECTS OF REDUCING NUTRIENT APPLICATIONS ON WATER QUALITY IN THE BALD EAGLE CREEK HEADWATERS, SOUTHEASTERN PENNSYLVANIA PRIOR TO IMPLEMENTATION OF AGRICULTURAL BEST-MANAGEMENT PRACTICES

Water-Quality Study for the
Chesapeake Bay Program

By David K. Fishel, Michael J. Langland, and Mark V. Truhlar

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1895	meter per kilometer (m/km)
	Area	
acre	0.004047	square kilometer (km^2)
	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.028317	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
	Volume	
gallon (gal)	3.785	liter (L)
	3,785	milliliter (mL)
	Mass	
pound (lb)	0.4536	kilogram (kg)
ton, short	0.9072	megagram (Mg)
	Specific Capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
	0.00345	liter per minute per meter [(L/min)/m]
pound per acre	1.121	kilogram per hectare (kg/ha)
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)

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

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ABSTRACT

The report characterizes a 0.43-square-mile agricultural watershed in York County, underlain by albite-chlorite and oligoclase-mica schist in the Lower Susquehanna River basin, that is being studied as part of the U.S. Environmental Protection Agency's Chesapeake Bay Program. The water quality of Bald Eagle Creek was studied from October 1985 through September 1987 prior to the implementation of Best-Management Practices to reduce nutrient and sediment discharge into Muddy Creek, a tributary to the Chesapeake Bay. About 88 percent of the watershed is cropland and pasture, and nearly 33 percent of the cropland is used for corn. The animal population is entirely dairy cattle. About 85,640 pounds of nitrogen (460 pounds per acre) and 21,800 pounds of phosphorus (117 pounds per acre) were applied to fields; 52 percent of the nitrogen and 69 percent of the phosphorus was from commercial fertilizer. Prior to fertilization, nitrate nitrogen in the soil ranged from 36 to 136 pounds per acre and phosphorus ranged from 0.89 to 5.7 pounds per acre in the top 4 feet of soil. Precipitation was about 18 percent below normal and streamflow about 35 percent below normal during the 2-year study. Eighty-four percent of the 20.44 inches of runoff was base flow. Median concentrations of total nitrogen and dissolved nitrate plus nitrite in base flow were 4.9 and 4.2 milligrams per liter as nitrogen, respectively. Median concentrations of total and dissolved phosphorus in base flow were 0.05 and 0.04 milligrams per liter as phosphorus, respectively.

Concentrations of dissolved nitrate in base flow increased following wet periods after crops were harvested and manure was applied. During the growing season, concentrations decreased similarly to those observed in carbonate-rock areas as nutrient uptake and evapotranspiration by corn increased. About 4,550 pounds of suspended sediment, 5,250 pounds of nitrogen, and 66.6 pounds of phosphorus discharged in base flow during the 2-year period. The suspended sediment load was about 232,000 pounds in stormflow from 26 storms that contributed 51 percent of the total stormflow. The nitrogen load was about 651 pounds and the phosphorus load was about 74 pounds in stormflow from 16 storms that contributed 28 percent of the total stormflow. It is estimated that concentrations of total nitrogen and phosphorus in base flow need to be reduced by 12 and 48 percent, respectively, to detect changes during the nutrient-management phase. Likewise, loads of total nitrogen and phosphorus in base flow need to be reduced by 62 and 57 percent.

INTRODUCTION

This study is part of the U.S. Environmental Protection Agency (USEPA) Chesapeake Bay Program and was done in cooperation with the Susquehanna River Basin Commission (SRBC) and the Pennsylvania Department of Environmental Resources (PaDER), Bureau of Soil and Water Conservation. This report characterizes the Bald Eagle Creek site (one, in figure 1), which is one of two small agricultural watersheds in noncarbonate-rock areas in the Lower Susquehanna River basin being studied prior to the implementation of agricultural Best-Management Practices (BMPs) at the sites. A second site is being studied as part of this project, Brush Run (two, in figure 1). Data from each characterization study will be compared with data from the Nutrient-Management Subbasin in the carbonate-rock area (three, in figure 1) which is part of the Conestoga River Headwaters Project and the Rural Clean Water Program (RCWP).

The USEPA Chesapeake Bay Study identified the Susquehanna River as a major source of nutrients that discharge to the bay. The Susquehanna River contributes 40 percent of the nitrogen and 21 percent of the phosphorus discharged to the bay (U.S. Environmental Protection Agency, 1983). Eighty-five percent of the nitrogen and sixty percent of the phosphorus contribution from the Susquehanna River has been reported to have come from cropland runoff (U.S. Environmental Protection Agency, 1983).

The Chesapeake Bay Study recommended the implementation of agricultural BMPs to reduce nonpoint-source nutrient discharges. These management practices are recommended to farmers who request technical expertise from the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS).

In 1979, Pennsylvania's Agricultural 208 Plan identified priority areas in need of study on nonpoint-source contamination of surface water and ground water (Schueller, 1983). The Conestoga River basin was designated the top-priority watershed in Pennsylvania. In 1982, the RCWP initiated a 10-year study of the Conestoga River headwaters to determine the effects of BMPs on surface-water and ground-water quality. One of three components of the Conestoga River Headwaters Project is to evaluate the effects of BMPs in a small, intensively farmed watershed underlain by carbonate rock. Inasmuch as a corresponding program was needed in noncarbonate-rock areas in the Lower Susquehanna River basin, the Bald Eagle Creek headwaters study was initiated by the U.S. Geological Survey (USGS) under the Chesapeake Bay Program in 1985. The results could then be compared to results from carbonate-rock areas like the Nutrient-Management Subbasin in the Little Conestoga Creek headwaters being studied for the RCWP.

Agricultural-management plans are to be designed for farms at each site and may consist of a combination of BMPs that are implemented to reduce soil and nutrient loss in surface runoff to the streams. Other BMPs may be recommended by the nutrient management specialist to balance nutrient applications with crop requirements to obtain maximum crop yields without permitting excessive nutrients to leach to the ground water and be released in base flow to streams. BMPs may include use of terraces, diversions, sediment-detention ponds, animal-waste storage facilities, barn gutters, and other innovative techniques.

Purpose and Scope

This report documents the water quality of surface runoff and base flow of a 0.43-mi^2 (square mile) watershed (fig. 2) in the most upstream part of the Bald Eagle Creek watershed near Fawn Grove, York County, from October 1985 through September 1987 (pre-BMP phase). The report describes the study area, methods used, the area's geohydrology including soil chemistry, and hypothetical effects of BMPs on surface-water quality. Data in this report will aid agricultural managers in developing management plans for farms and in evaluating whether voluntary implementation of BMPs will be successful in improving the water quality of the Lower Susquehanna River basin.

Approach

Extensive land-use, hydrologic, and soil data were collected and used to characterize and interpret the water quality of surface runoff and base flow at the Bald Eagle Creek site during the pre-BMP phase. Both historical and current data were used for the characterization. Land-use data, collected from three farms at the site, include crop acreage and yields, animal density, manure production, and nutrient applications. Hydrologic data were collected and used to determine the quantity and quality of precipitation, base flow, and stormflow. Soil-chemistry samples were used to identify areas where nutrient management may be most beneficial. Water-quality samples of base flow and stormflow were collected to document the water chemistry during the pre-BMP phase. Nutrient and suspended-sediment loads were calculated to characterize the water quality of base flow and stormflow.

Data were plotted and parametric and nonparametric statistics were calculated to identify seasonal variations and trends. Data were grouped into growing (April through September) and nongrowing (October through March) seasons. A modified form of the nonparametric-Wilcoxon (Mann-Whitney) rank-sum test for seasonal data (Crawford, Slack, and Hirsch, 1983) and Monte-Carlo simulation (R.M. Hirsch, U.S. Geological Survey, written commun., 1989) was used to estimate reductions in nitrogen and phosphorus concentrations and discharges in base flow required for detecting statistically significant changes under the proposed BMPs. Hypothetical effects of BMPs on surface-water quality are then presented on the basis of simulated (Monte-Carlo) results.

Related Studies

Studies related to this project include the comprehensive RCWP monitoring projects to determine the effects of BMPs on water quality being done in Idaho, Illinois, South Dakota, and Vermont (P.L. Lietman, U.S. Geological Survey, oral commun., 1984). The Pennsylvania and South Dakota projects are the only RCWP projects investigating nutrient transport in ground water.

Other related studies include a study being done by the U.S. Geological Survey (USGS) in the Patuxent River basin in Maryland (G.T. Fisher, U.S. Geological Survey, oral commun., 1987) in which nonpoint-source nutrient contamination and sediment loads in a 980-mi^2 watershed are being monitored. A joint study by the USGS and the SRBC is assessing the sources of nutrients from the main stem and selected watersheds of the Susquehanna River basin and their movement to the Chesapeake Bay. Studies by the PaDER, Bureau of Forestry, with the Lancaster and Lebanon County Conservation Districts (David Gregg, Pennsylvania Department of Environmental Resources, Bureau of Forestry, written commun., 1986) also are being done to determine the effect of manure disposal on ground water and undisturbed soils.

Acknowledgements

The authors thank the following individuals and respective agencies for cooperating to make this project a success.

1. John Wilcox, Amos King, and Kenny Moore, farmers at the Bald Eagle Creek site, who volunteered to provide land-use data and access to their farms.

2. Riggs Harwell, District Conservationist for the United States Department of Agriculture, Soil Conservation Service, who assisted with project planning, gathering crop-yield data, and developing management plans.

3. Dr. Dale Baker and Leon Marshall from the Pennsylvania State University, Department of Agronomy, who collected and analyzed soil samples.

DESCRIPTION OF STUDY AREA

Location

Bald Eagle Creek is located in south-central Pennsylvania and is part of the Susquehanna River basin (fig. 1). The stream flows northeastward and drains into Muddy Creek. Muddy Creek flows southeastward, draining into the Susquehanna River approximately 6 mi (miles) upstream from the Maryland-Pennsylvania state line.

The 0.43-mi² watershed is located in southern York County and is about 1.5 mi northwest of Fawn Grove. The gaging station (fig. 2) is 0.6 mi downstream from the headwaters. A V-notch weir is located at the gage where water-quality samples are collected manually; automatic samples are collected during stormflow and in the pool created by the weir.

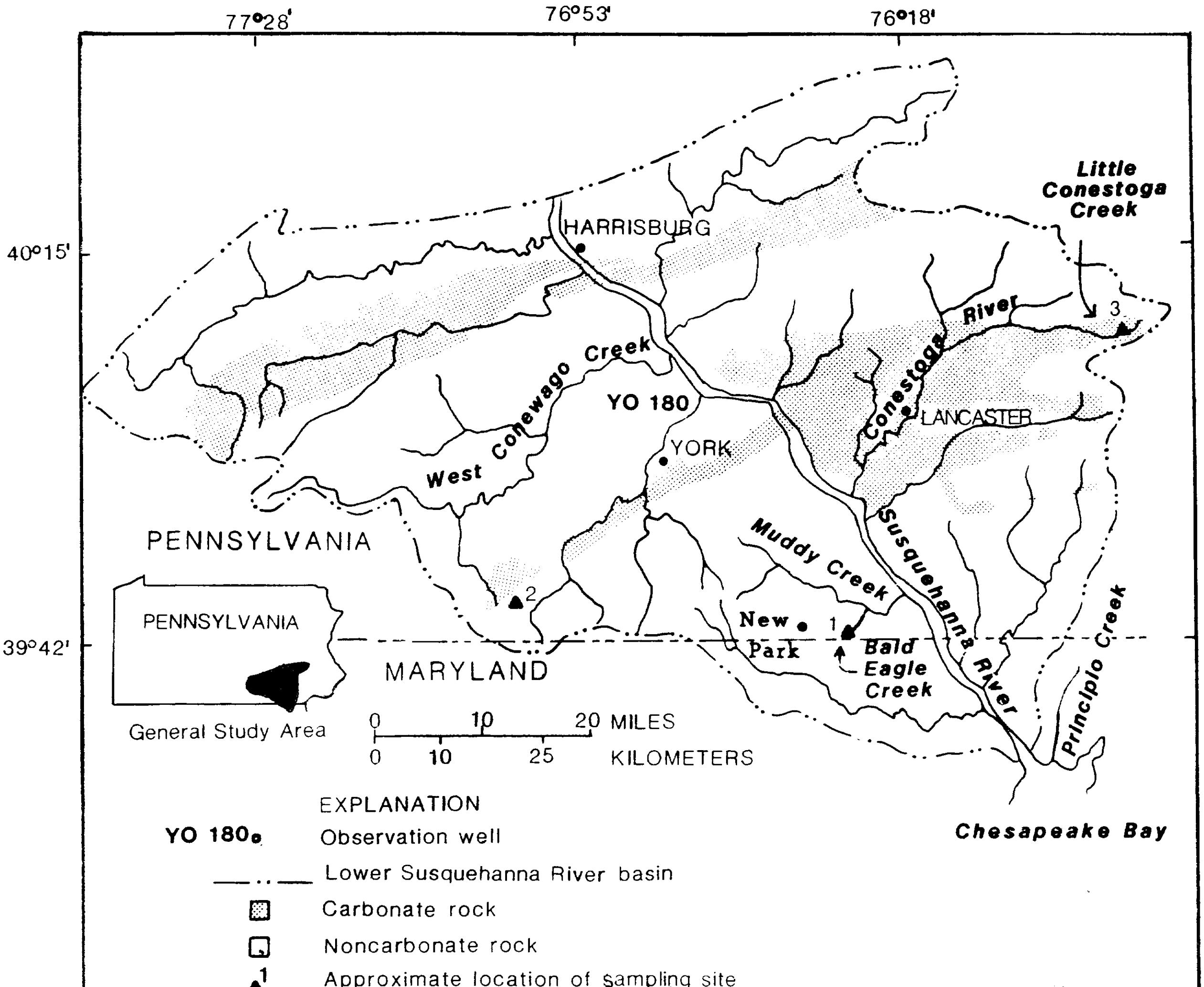

Figure 1.--Locations of Bald Eagle Creek Site 1, Brush Run Site 2, and Little Conestoga Creek (Nutrient-Management Subbasin) Site 3 in the Lower Susquehanna River basin.

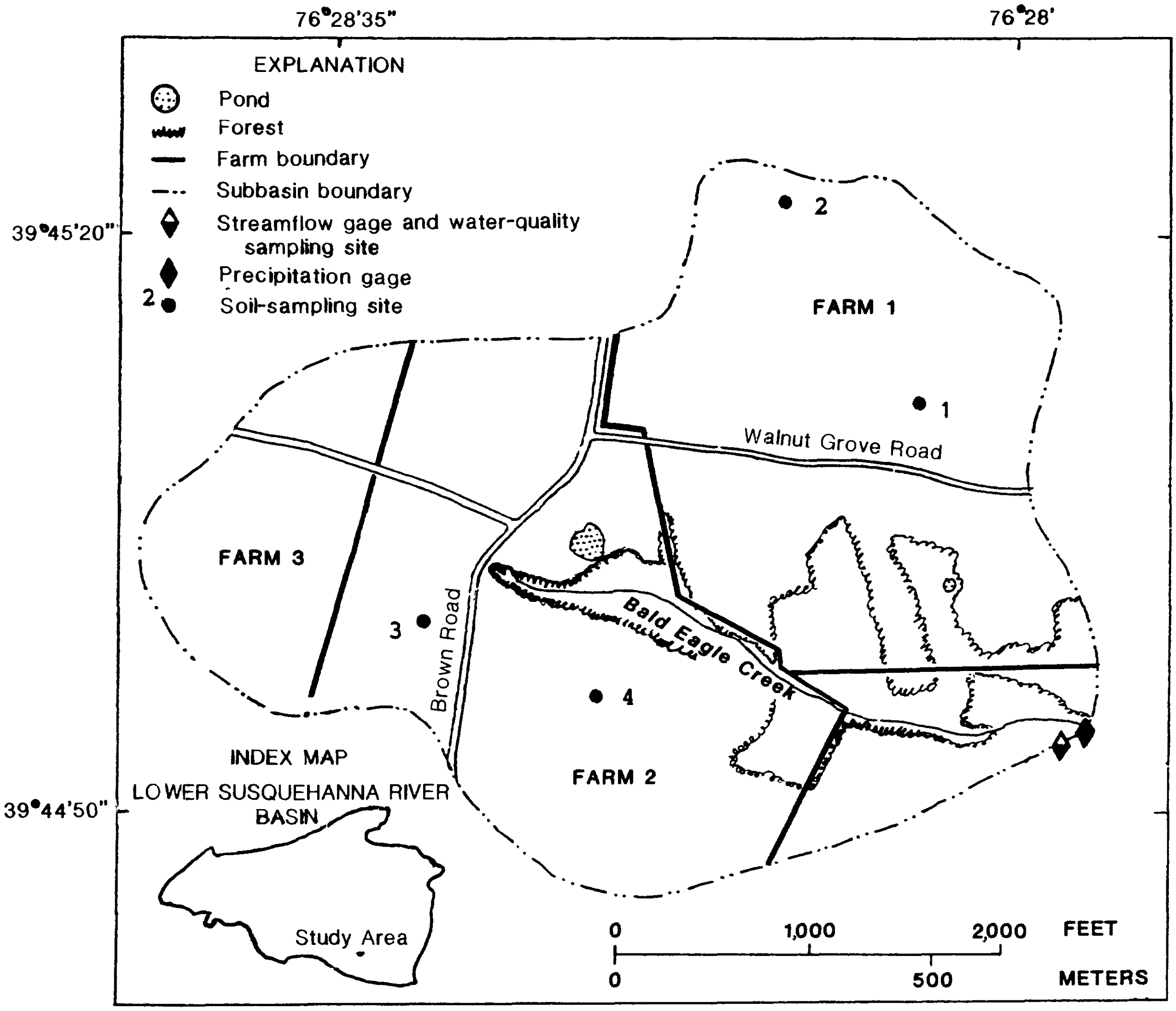

Figure 2.--Locations of farms, streamflow and precipitation gages and sampling sites, and soil sampling sites.

Topography

The watershed lies in the Southeastern Upland subdivision of the Piedmont physiographic province of the Appalachian Highlands. The topography consists of broad ridgetops and steep hillsides. The underlying rocks are largely erosion-resistant schist and quartzite.

Generally, elevations range from 800 ft (feet) above sea level at the upper end of the watershed to 591 ft above sea level at the gaging site. Bald Eagle Creek descends rapidly from its headwaters to the gaging site at a gradient of 152 ft/mi (feet per mile). Immediately downstream from the gage, elevations decrease and the gradient flattens to about 55 ft/mi from the gage to Muddy Creek.

Geology

The geologic setting of the Piedmont Uplands in which the study area lies is described by Hall (1934), Lloyd and Growitz (1977), Taylor and Workheiser (1984), and Gerhart and Lazorchick (1984). In summary, each describe the geology of the Piedmont Uplands section as being extremely complex. The general area is composed primarily of metamorphosed sedimentary rocks but also contains some igneous rocks. The Bald Eagle Creek site is located in the lower Paleozoic Wissahickon Formation which consists primarily of albite-chlorite schist and oligoclase-mica schist. The major geologic structure in the area is the Martic overthrust--a block of rock that is believed to have been thrust into position from the southeast by mountain-building forces. Other minor structural features within the area are the Tuncquan anticline and the Peach Bottom, Wentz, and Yoe synclines. Within these features the rocks are complexly folded and may be broken by minor faults.

Land Use, Crop Yield, and Nutrient Applications

The predominant land use within the drainage basin is agriculture. Cropland comprises 67.5 percent of the land, pasture comprises 20.9 percent, and forest comprises 11.6 percent (table 1). About 33 percent of the crop land is planted in corn (fig. 3). Parts of three farms are located within the watershed. Two of the farms have dairy herds with 97 and 80 cows (table 2). At the dairy farms, crops generally are rotated on a 2-year corn and 3-year alfalfa sequence. The third farm has no animals and relies entirely on commercial fertilizer for nutrient sources. The animal density, based on crop acreage within the entire subbasin that is available for disposal of manure, is about 1.07 AU/acre (animal units per acre) which is less than the 2.50 AU/acre average for 10 farms in the Nutrient-Management Subbasin in the carbonate valley of the Little Conestoga Creek headwaters (D.K. Fishel, U.S. Geological Survey, written commun., 1989). It also is less than the 1.5 AU/acre recommended in the Conestoga Headwaters Plan of Work (U.S. Department of Agriculture, 1982) for nonpoint-source discharges.

Crop yields varied between the three farms at the Bald Eagle Creek site, and corn yields (table 3) were slightly less than the average of 146 bushels per acre reported for 11 farms in the Nutrient-Management Subbasin in Lancaster and Berks Counties (D.K. Fishel, U.S. Geological Survey, written commun., 1989).

Most of the nutrients were applied to the cropland between March and June (fig. 4). However, nitrogen and phosphorus in manure that was stored during the growing season was applied in September after the corn was harvested. Farmers reported that approximately 61,740 lb (pounds) of nitrogen and 16,610 lb of phosphorus were applied as manure and commercial fertilizer during the pre-BMP phase (table 4). It is estimated that an additional 23,900 lb of nitrogen and 4,210 lb of phosphorus were deposited by cattle in pastures near the stream (Omer Brubaker, United States Department of Agriculture, Agricultural Stabilization and Conservation Service, written commun., 1985). Thus, a total of 85,640 lb of nitrogen [460 lb/acre (pounds per acre)] and 21,800 lb of phosphorus (117 lb/acre) were applied to fields; 52 percent of the nitrogen and 69 percent of the phosphorus was from commercial inorganic fertilizer.

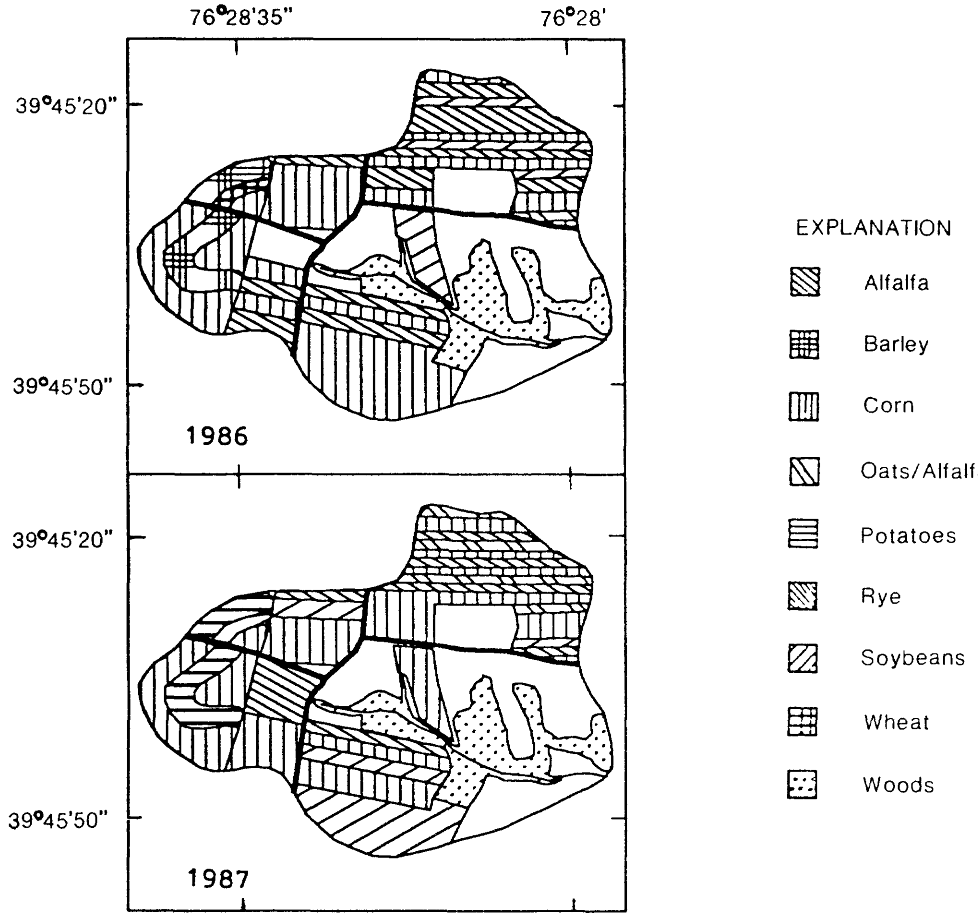

Figure 3.--Land use in the Bald Eagle Creek headwaters.

Table 1.--Land use at the Bald Eagle Creek site

Land use	Prior to Nutrient Management 1986 (Acres)	(Percent)	1987 (Acres)	(Percent)
Cropland				
Alfalfa	45.5	16.6	30.0	10.9
Barley	12.8	4.7	--	--
Corn	94.2	32.7	92.6	33.6
Oats/Alfalfa	1.7	.6	11.7	4.3
Potatoes	--	--	12.8	4.7
Rye	--	--	--	--
Soybeans	18.3	6.6	34.2	12.4
Wheat	3.3	1.2	--	--
Subtotal	175.8	63.9	181.3	65.9
Pasture	64.1	23.3	58.6	21.3
Forest	35.3	12.8	35.3	12.8
Total	275.2	100.0	275.2	100.0

Table 2.--Animal density at the Bald Eagle Creek site

[Animal units, in thousands of pounds of body weight; cropland, in acres; animal density, in animal units per acre of cropland]

Farm	Animal Units		Cropland	Animal Density
1	dairy			
	cows	63.5		
	heifers	36.0		
	Subtotal	99.5	71.15	1.40
2	dairy			
	cows	87.5		
	heifers	12.0		
	Subtotal	99.5	80.4	1.24
3		0	34.05	0
Total		199	185.6	1.07

Table 3.--Crop yields at farms at the Bald Eagle Creek site
[--, no data provided]

Farm	Crop	Yield	
1	corn	100	bushels per acre
	silage	20	tons per acre
	soybeans	50	bushels per acre
	alfalfa	3.5	tons per acre
	oats	1	ton per acre
2	corn	--	
	silage	18	tons per acre
	rye	4	tons per acre
3	corn	140	bushels per acre
	potatoes	2,000	pounds per acre
	barley	70	bushels per acre
	wheat	60	bushels per acre

The farmers reported that they applied about 31 percent less nitrogen and 3 percent more phosphorus during the second year than during the first year. The reduction in nitrogen was made voluntarily before recommendations were made by a nutrient-management specialist from the Bureau of Soil and Water Conservation. Similar unsolicited reductions in applications of nutrients to cropland, especially commercial fertilizer, occurred in the Nutrient-Management Subbasin for the RCWP (D.K. Fishel, U.S. Geological Survey, written commun., 1989). Therefore, distinguishing trends during the pre-management phase is difficult because the farmers constantly change application rates. The contribution of nutrients from human waste was not considered to be a major source because the population density is extremely sparse at the site.

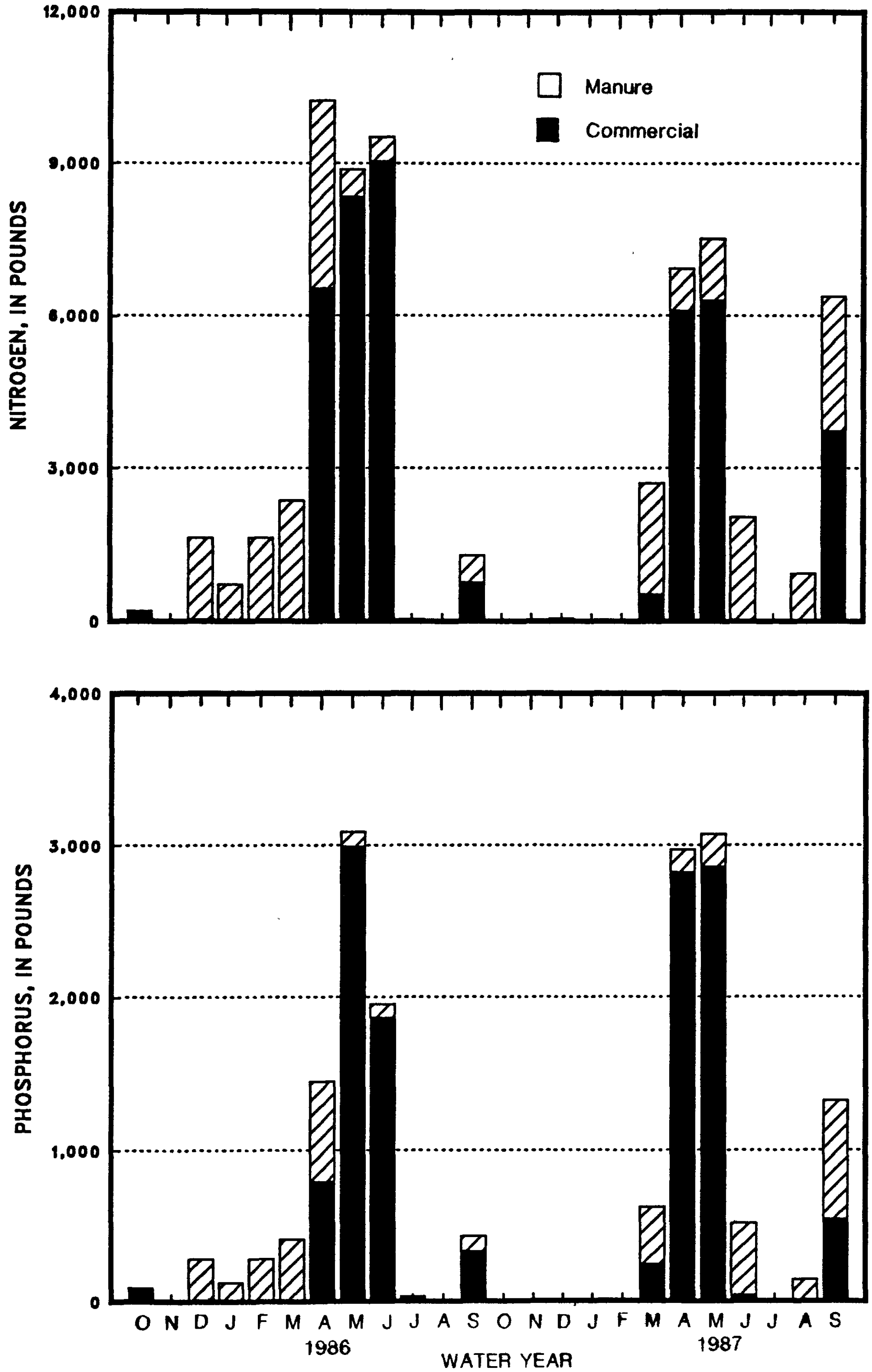

Figure 4.--Monthly applications of nitrogen and phosphorus.

Table 4.--Manure and commercial-fertilizer applications reported by farmers

[Nitrogen and phosphorus in pounds; M, manure; F, commercial fertilizer]

Farm		Year 1		Year 2		Total	
		Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
1	M	1,730	300	1,950	780	3,680	1,080
	F	2,710	860	2,630	1,970	5,340	2,830
	Total	4,440	1,160	4,580	2,750	9,020	3,910
2	M	9,860	1,740	6,490	1,140	16,350	2,880
	F	16,550	2,430	9,750	1,430	26,300	3,860
	Total	26,410	4,170	16,240	2,570	42,650	6,740
3	M	0	0	0	0	0	0
	F	5,690	2,830	4,380	3,130	10,070	5,960
	Total	5,690	2,830	4,380	3,130	10,070	5,960
Total	M	11,590	2,040	8,440	1,920	20,030	3,960
	F	24,950	6,120	16,760	6,530	41,710	12,650
Grand total		36,540	8,160	25,200	8,450	61,740	16,610

Soils

The soils at the site are predominantly Glenelg channery and Elioak silt loam (fig. 5). Glenville and Chewacla silt loams and Manor channery loam also are present in smaller amounts, primarily in the valleys. These soils are described as being deep and well drained (U.S. Department of Agriculture, 1963, p. 99-101). However, when soil samples were collected at farm 2, bedrock was commonly less than 3 ft below the surface. The parent material for the soils weathered from schist and phyllite. The Elioak silt loams have slopes ranging from 3 to 15 percent, the Glenville silt loams, from 0 to 3 percent, and the Manor channery loam, from 8 to 25 percent.

Climate

Climate at the Bald Eagle Creek site is relatively mild but humid and may be classified as humid continental. Winters are relatively short, whereas summers are comparatively long and warm as evidenced by a growing season that begins in April and ends in October. Normal precipitation [44 in/yr (inches per year) at New Park] typically provides for sufficient rain during the growing season; however, occasional dry periods may occur.

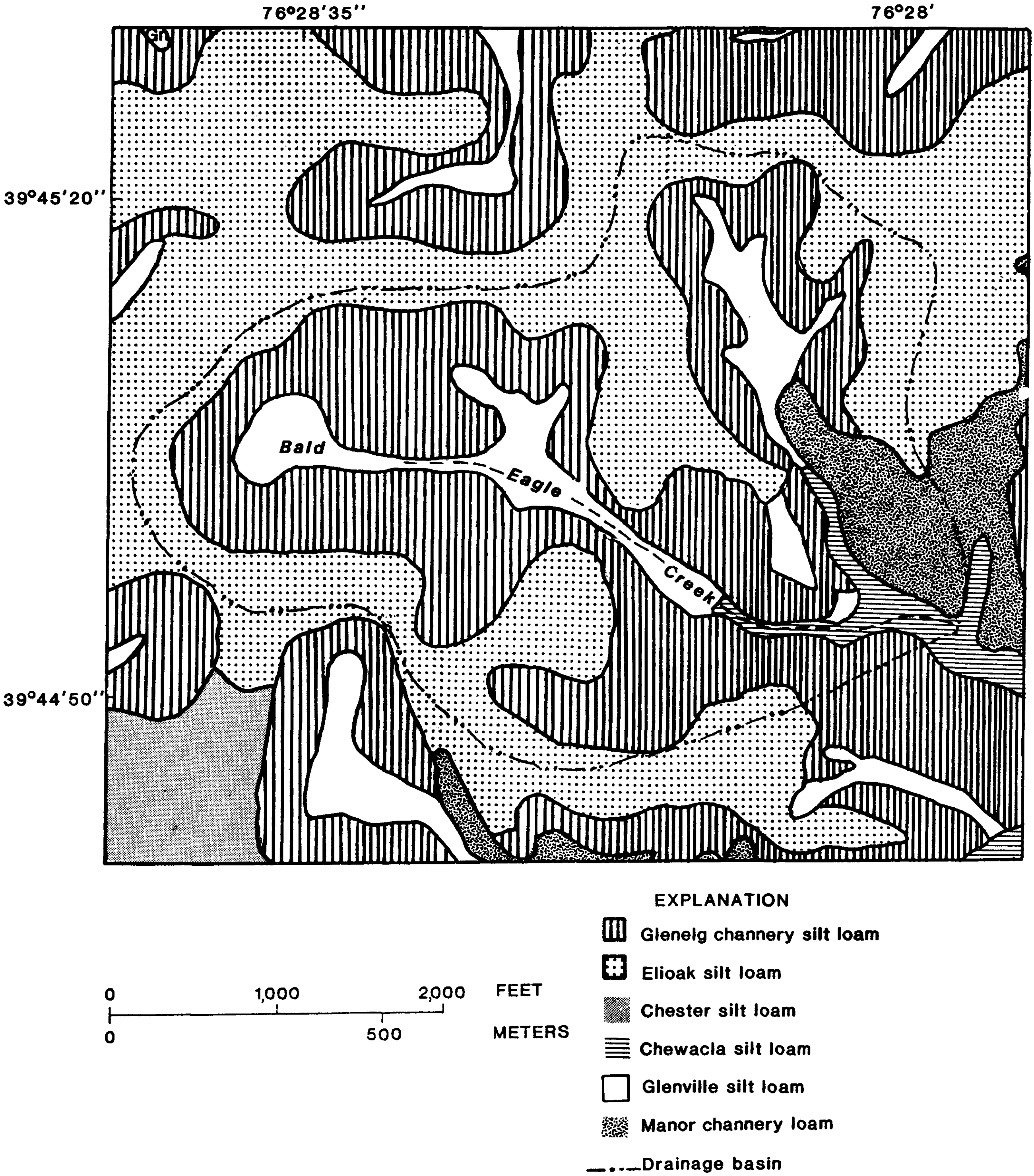

Figure 5.--Distribution of soil types at the Bald Eagle Creek site.

METHODS

Network Design, Instrumentation, Sampling, and Analytical Techniques

Precipitation

Precipitation data were collected at one location (fig. 2) by a tipping-bucket rain gage in conjunction with an analog digital recorder. The precipitation gage is located approximately 25 ft from the streamflow gage near the eastern boundary of the site. Precipitation is recorded at 5-minute intervals to determine the duration and intensity of storms, and the daily, monthly, and annual totals. Precipitation was estimated for periods of missing record by use of data from the National Oceanic and Atmospheric (NOAA) stations at New Park and Holtwood, and from reliable daily records kept by the landowner of farm 3 (fig. 2).

Precipitation measured at the Bald Eagle Creek site was compared to normal precipitation measured at the NOAA station at New Park. The station at New Park is approximately 2.5 mi southwest of the site.

Precipitation samples were collected using a 13 in. (inch) glass funnel. The funnel collected rainfall into a 1-L (liter) precombusted glass bottle that was placed at ground level in a metal can packed with ice.

Two precipitation samples were collected during the pre-BMP phase. The first sample was collected in May 1987, near the beginning of the growing season, and the second was collected in September 1987, near the end of the growing season. The pH and specific conductance was determined for each sample immediately after sample collection. Samples were kept at 4 °C (degrees Celsius), preserved with mercuric chloride, and sent to the USGS laboratory in Arvada, Colorado, for analyses of total nitrate plus nitrite, ammonia, ammonia plus organic nitrogen, and total phosphorus. Nutrients were analyzed according to methods described by Skougstad and others (1979).

Streamflow

Continuous streamflow data were recorded beginning October 24, 1985, at the gaging station located on the right bank (fig. 2) at latitude 39°44'54" and longitude 76°27'50", about 15 ft upstream from Kunkle Road. The gaging station is equipped with a digital water-stage recorder and a continuous strip-chart recorder. Water-stage data are recorded at 15-minute intervals by the digital recorder. The gage has a 36 in. diameter pipewell with 2 intakes of 2-in. pipe and a flushing system. A wooden V-notch weir was installed to provide a control during low flows at the gaging site. The control during high flows is a 5.8-ft-diameter culvert with nonstandard geometry that is located at the bridge at Kunkle Road.

Stage-discharge relations were defined by making streamflow measurements upstream from or at the weir using methods described by Buchanan and Somers (1968; 1969). Streamflow measurements were made upstream from the weir by use of a current meter. Low-flow measurements were made at the weir by making volumetric measurements with a graduated cylinder. Stream stages were converted to streamflow using methods described in Carter and Davidian (1968).

Missing streamflow data were estimated by comparing hydrographics of NOAA meterological data collected at York, with streamflow data collected at the Codorus Creek at Spring Grove and Pequea Creek near Mount Nebo continuous-record gaging stations.

The measured streamflow for Bald Eagle Creek was compared with long-term streamflow record for the nearby continuous-record gaging station at Principio Creek near Principio Furnace, Maryland (USGS station no. 01496200), since long-term record was not available for the gage at Bald Eagle Creek. The gage at the Principio Creek is about 21 mi southeast of the study area and has been in operation since June 1967.

Streamflow data were used to calculate nutrient and suspended-sediment discharges in base flow and stormflow. Streamflow hydrographs were separated to determine the contribution of base flow and surface runoff to the annual discharge. Hydrograph separations were performed using three techniques--the fixed-interval, the sliding-interval, and the local-minimum techniques--described by Pettyjohn and Henning (1979).

Water Quality

Water-quality data collection began in November 1985. Water-quality samples are collected manually at the V-notch weir at the gage during base flow. A float/stage-triggered PS-69 automatic pumping sampler is used to collect stormwater samples at 30-minute intervals. The perforated intake for the sampler is located near the centroid of flow in the pool created by the weir so that representative samples can be collected. Samples are collected monthly during base flow and at selected stages during storms to characterize stormflow. Storms are selected so that seasonal relations between water quality and streamflow can be determined.

Water-quality samples were collected during base flow using methods described by Guy and Norman (1970). Manual samples were collected and compared with discrete automatic samples to assure that the automatic samplers were operating properly. Samples to be analyzed for dissolved constituents were filtered using a 0.45-micrometer membrane filter mounted in a peristaltic filter assembly. Base-flow samples were filtered in the field and stormflow samples were filtered in the laboratory at Harrisburg before being sent to the laboratory in Colorado. Like the precipitation samples, all base-flow and stormflow samples were preserved with mercuric chloride and kept chilled at 4 °C.

Water-quality samples were analyzed for concentrations of suspended sediment, total and dissolved nitrate plus nitrite, ammonia plus organic nitrogen, ammonia, phosphorus, and dissolved orthophosphorus. Suspended-sediment samples were analyzed at the USGS Sediment Laboratory in Harrisburg, Pa., using methods described by Guy (1969). Water-quality samples for nutrient analysis were sent to the USGS laboratory in Colorado within 24 hours after collection and analyzed using the same methods as described for the precipitation samples.

Nutrient and suspended-sediment loads in stormflow were computed using discharge and concentration-integration methods described by Porterfield (1972). Concentration data that were missing for storms were estimated using hydrograph comparisons of storm-runoff hydrographs having similar magnitudes at similar times of the year.

Nutrient and suspended-sediment loads in base flow were computed using two different methods. The first method was to compute loads by means of the formula

$$L = C \times Q \times 5.4, \tag{1}$$

where L = loads, in pounds per day;
C = concentration, in milligrams per liter;
and Q = discharge, in cubic feet per second.

Concentration data necessary to compute daily constituent loads in base flow were estimated by straight-line interpolation between measured data.

The second method involved use of a seven-parameter log-linear mathematical model developed by Cohn and others (1989) to describe nutrient and sediment loads from the four river-input monitoring stations to the Chesapeake Bay. This model was validated by Cohn and others (U.S. Geological Survey, written commun., 1990) with repeated split-sample studies, and for concentrations is of the form

$$\ln[C] = \beta_0 + \beta_1 \ln[Q/\bar{Q}] + \beta_2 (\ln[Q/\bar{Q}])^2 + \beta_3 [T-\bar{T}] + \beta_4 [T-\bar{T}]^2 + \beta_5 \cdot \sin[2\pi T] + \beta_6 \cdot \cos[2\pi T] + \epsilon, \tag{2}$$

where ln denotes natural logarithm function,
Q = discharge, in cubic feet per second,
C = concentration, in milligrams per liter,
T = time, in years (decimal form),
β_0 through β_6 are the parameters of the model that were estimated from the data, and
ϵ denotes the model errors, which are assumed to be independent, and normally distributed with zero mean and variance σ^2_ϵ.

Loads were calculated by substituting ln[C] from equation (2) into equation (1) to give

$$L = \text{antilog } \ln[C] \times Q \times 5.4. \tag{3}$$

Soil Nutrients

Soil samples were collected from two fields at two farms (fig. 2) to determine the nutrient content of the soil where manure and commercial fertilizer are applied. Results of soil-nutrient analyses provided information for the development of management plans for each farm by the nutrient-management specialist.

Soil-nutrient samples were collected on November 20, 1985, from the top 4 ft of soil. The 4-ft samples were collected with the aid of the Pennsylvania State University, College of Agronomy, using a tractor-mounted, deep-soil probe. Each 4-ft sample core was divided into segments that represented depth intervals of 0 to 8 in., 8 to 24 in., and 24 to 48 in. below the surface. Three cores were collected at each location, and the segments from each core were composited in the field. Each segment was analyzed for average soluble nitrate-nitrogen and phosphorus by the Pennsylvania State University, Soils and Environmental Chemistry Laboratory, using methods described by Corey (1977) and by the USEPA (1979). Results were plotted to determine depths at which soil nutrients were concentrated.

Data Analysis

Descriptive Statistics

In order to discuss the hydrology of the Bald Eagle Creek, numerous basic descriptive statistics including maximum, minimum, and median values for streamflow, chemical concentrations, discharges, and yields were calculated using statistical programs of the Statistical Analysis System (SAS) Institute, Inc. (1979; 1982a; 1982b) and P-STAT, Inc. (1986). Descriptive statistics were calculated for the entire pre-BMP phase and the growing and nongrowing seasons. Frequency distributions were plotted to determine whether chemical quality data were normally distributed and to decide if data should be analyzed by parametric or nonparametric-statistical procedures.

Correlation Analysis

Correlation analyses were performed to examine relations among concentrations and discharges of suspended sediment and nutrients, and streamflow and time. Relations were considered good if the correlation coefficient (r) was equal to or greater than 0.80, a value commonly used for chemical and biological studies.

Seasonal Rank-Sum Test and Monte-Carlo Simulation

Estimates were made of the necessary amount of reduction needed to detect statistically significant changes in concentrations and discharges of total nitrogen, dissolved nitrite plus nitrate nitrogen, and total and dissolved phosphorus in base flow. Pre-BMP data were grouped into growing and nongrowing seasons when examination of time-series plots indicated visual differences between these periods. A null hypothesis of no difference between pre-BMP data and simulated post-BMP data was tested by means of a modified Wilcoxon-Mann-Whitney rank-sum test for seasonal data at the 0.05 alpha level (R.M. Hirsch, U.S. Geological Survey, written commun., 1989; and Crawford and others, 1983). The null hypothesis stated that the means of two populations, comprised of data from two separate periods in a time series (pre-BMP phase and post-BMP phase), were identical. The alternative hypothesis stated that the two populations were not identical--that is, to satisfy the alternative hypothesis, there would be a significant change in the data between the pre- and post-BMP phases.

Monte Carlo simulation was used to synthesize pre- and post-BMP data because of the limited amount of measured data, and to perform the rank-sum test. The pre-BMP data were synthesized by randomly generating 1,000 data sets of each chemical constituent tested, based on the statistical characteristics of the measured data: the number of seasons, the total number of observations in each season, and the mean and standard deviations for each season during the pre-BMP phase. Post-BMP data were synthesized by reducing the mean and the standard deviation of the pre-BMP data by a selected percentage. A second approach for generating post-BMP data from pre-BMP data for normally-distributed data was to reduce the mean by a selected percentage without changing the standard deviation. The percentage by which the means of the post-BMP data were reduced was increased until the power of the test reached 1.0, which represented the greatest probability of rejecting the null hypothesis. Because the mean of the synthesized post-BMP data could only be lower than the mean of the pre-BMP data, the null hypothesis could only be rejected from one direction; thus, a one-tailed test was performed.

HYDROLOGY

Precipitation

Quantity

During the study, about 72.3 in. of precipitation were recorded at the site (table 5). Precipitation at the Bald Eagle Creek site was 15.59 in. or 18 percent less than the long-term (1950-80) normal at the NOAA station at New Park. Precipitation at the site ranged from 0.27 in. in September 1986 to 8.50 in. in December 1986 (fig. 6).

During the 1986 water year, precipitation was about 16 in. or 37 percent less than normal (table 6). The range in precipitation during the 1986 water year[1] was from 0.27 in. in September 1986 to 5.61 in. in November 1985. Precipitation was 57 percent less than normal during the growing season from April through September (table 6), and was more than 1 in. less than normal each month except April (table 5).

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[1] Water year is the period October 1 through September 30 and is designated by the calendar year in which it ends.

During the 1987 water year, precipitation was 1 percent greater than normal because of the precipitation in November and December 1986 and September 1987, which was 3.29, 5.09, and 2.69 in. greater than normal, respectively (table 5). The range in precipitation was from 0.98 in. in February 1987 to 8.50 in. in December 1986. Precipitation was 13 percent less than normal during the growing season (table 6), and was more than 1 in. less than normal in April, June, and August (table 5). Prior to the wet September, the growing season was 29 percent drier than normal.

Table 5.--Precipitation at the Bald Eagle Creek site and New Park and long-term normal precipitation at New Park

[Precipitation, in inches]

		New Park			Bald Eagle Creek	
Month	Year	Measured	Normal	Deviation from normal at New Park	Measured	Deviation from normal at New Park
October	1985	2.08	3.04	-0.96	2.08	-0.96
November		6.02	3.56	2.46	5.61	2.05
December		1.65	3.41	-1.76	1.39	-2.02
January	1986	2.73	2.86	- .13	3.05	.19
February		3.48	2.67	.81	3.15	.48
March		1.82	3.86	-2.04	1.97	-1.89
April		4.04	3.80	.24	3.93	.13
May		1.42	3.95	-2.53	1.45	-2.50
June		1.07	4.16	-3.09	.90	-3.26
July		1.74	4.09	-2.35	1.79	-2.30
August		3.28	4.44	-1.16	2.11	-2.33
September		.89	4.09	-3.20	.27	-3.82
October		2.75	3.04	- .29	2.80	- .24
November		6.86	3.56	3.30	6.85	3.29
December		5.85	3.41	2.44	8.50	5.09
January	1987	5.13	2.86	2.27	2.96	.10
February		1.67	2.67	-1.00	.98	-1.69
March		2.34	3.86	-1.52	1.17	-2.69
April		2.66	3.80	-1.14	2.10	-1.70
May		4.12	3.95	.17	3.67	- .28
June		2.53	4.16	-1.63	1.94	-2.22
July		5.07	4.09	.98	3.81	- .28
August		3.07	4.44	-1.37	3.01	-1.43
September		8.28	4.09	4.19	6.78	2.69
Total		80.55	87.86	-7.31	72.27	-15.59

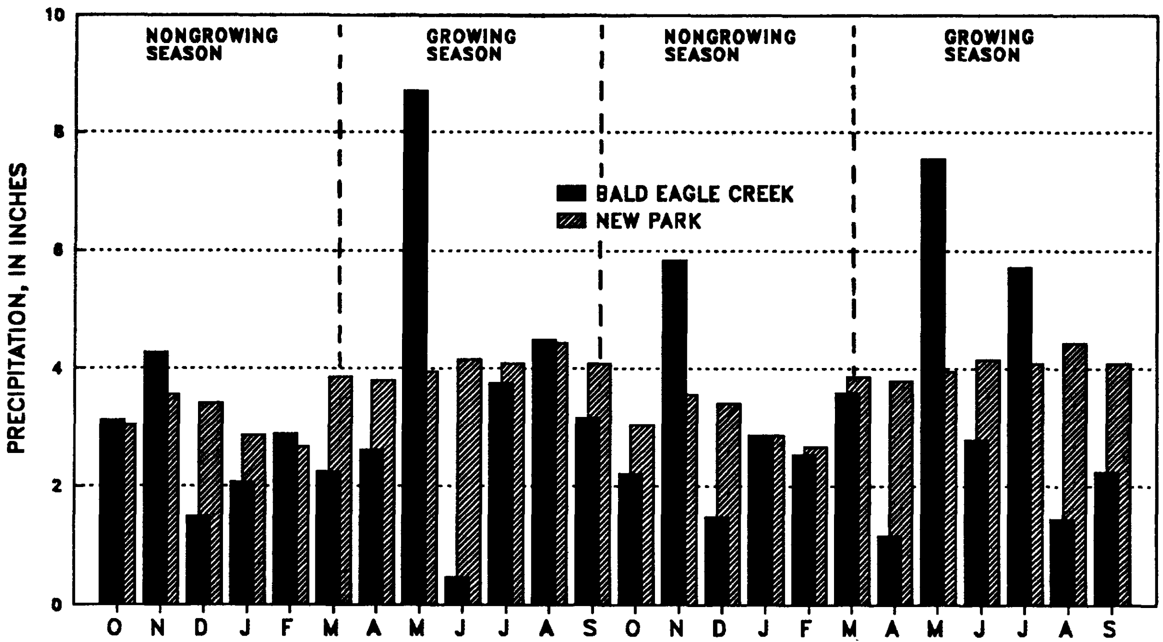


Figure 6.--Precipitation measured at the Bald Eagle Creek site and normal precipitation at New Park.

Table 6.--Precipitation during the growing and nongrowing seasons in the 1986-87 water years

[Precipitation, in inches; nongrowing season, October through March; growing season, April through September]

Location	1986 Water year			1987 Water year		
	Nongrowing season	Growing season	Total	Nongrowing season	Growing season	Total
Bald Eagle Creek (measured)	17.25	10.45	27.70	23.26	21.31	44.56
New Park, Pa. (normal)	19.40	24.53	43.93	19.40	24.53	43.93
Deviation between measured and normal						
(total)	-2.15	-14.08	-16.23	3.86	-3.22	.63
(percent)[1]	-11	-57	-37	+20	-13	1

[1] Percent = $\left(\frac{\text{normal - measured}}{\text{measured}} \right) \times 100.$

Quality

Significant amounts of nitrogen in various forms are released to the atmosphere, carried great distances, and are deposited on the land surface by precipitation. For this reason, samples were collected twice in the 1987 water year (table 7) to determine the quality of precipitation. The first sample was collected in May, near the beginning of the growing season, and the second sample was collected in September, near the end of the growing season. Concentrations of nitrogen and pH values were greater, and total concentrations of phosphorus were lower in precipitation in May than in precipitation in September. About 1.52 in. of precipitation was measured during the storm of May 20, 1987, and 2.81 in. during the storm of September 8, 1987.

These data suggest that the contribution of nitrogen from atmospheric deposition may not be as significant or seasonally variable at Bald Eagle Creek as other areas within the Lower Susquehanna River basin, where animal densities are high and concentrations of total nitrogen and total ammonia were significantly elevated. For example, at Brush Run (site 1 in figure 1) where 57,000 chickens and 1,460 hogs are housed within a 0.32 mi^2 area of the sampling site, concentrations of total nitrogen and total ammonia in the atmospheric deposition were 3.4 mg/L and 2.8 mg/L, respectively, on May 20, 1987. Because animal densities are lower at the Bald Eagle Creek site, less nitrate and ammonia vapor enters the atmosphere from animal waste. Therefore, less nitrate and ammonia was carried from the atmosphere back to the land surface in precipitation at Bald Eagle Creek where the animal density is low than at Brush Run where the animal density is high.

Table 7.--Water quality of precipitation at the Bald Eagle Creek site

[Precipitation, in inches; specific conductance in microsiemens per centimeter at 25 degrees Celsius; nitrogen and phosphorus in milligrams per liter; all nitrogen species as N, phosphorus as P]

Constituent	May 20, 1987	September 8, 1987
Precipitation	1.52	2.81
Specific conductance	30	8.5
pH	4.3	7.4
Nitrogen, total	.80	.30
organic, total	.25	.18
ammonia, total	.25	.02
nitrate + nitrite, total	.30	.10
Phosphorus, total	.01	.30

Streamflow

Quantity

Daily streamflows at the Bald Eagle Creek site ranged from a minimum of 0.00 ft^3/s (cubic foot per second) on several days in January and February 1986 to a maximum of 2.6 ft^3/s on December 24, 1986 (fig. 7). The average annual instantaneous streamflows were 0.33 and 0.32 ft^3/s for the 1986 and 1987 water years, respectively. The total streamflow from the site for the 2 years was 20.44 in.; 10.47 in. discharged during the 1986 water year and 9.97 in. discharged during 1987 water year.

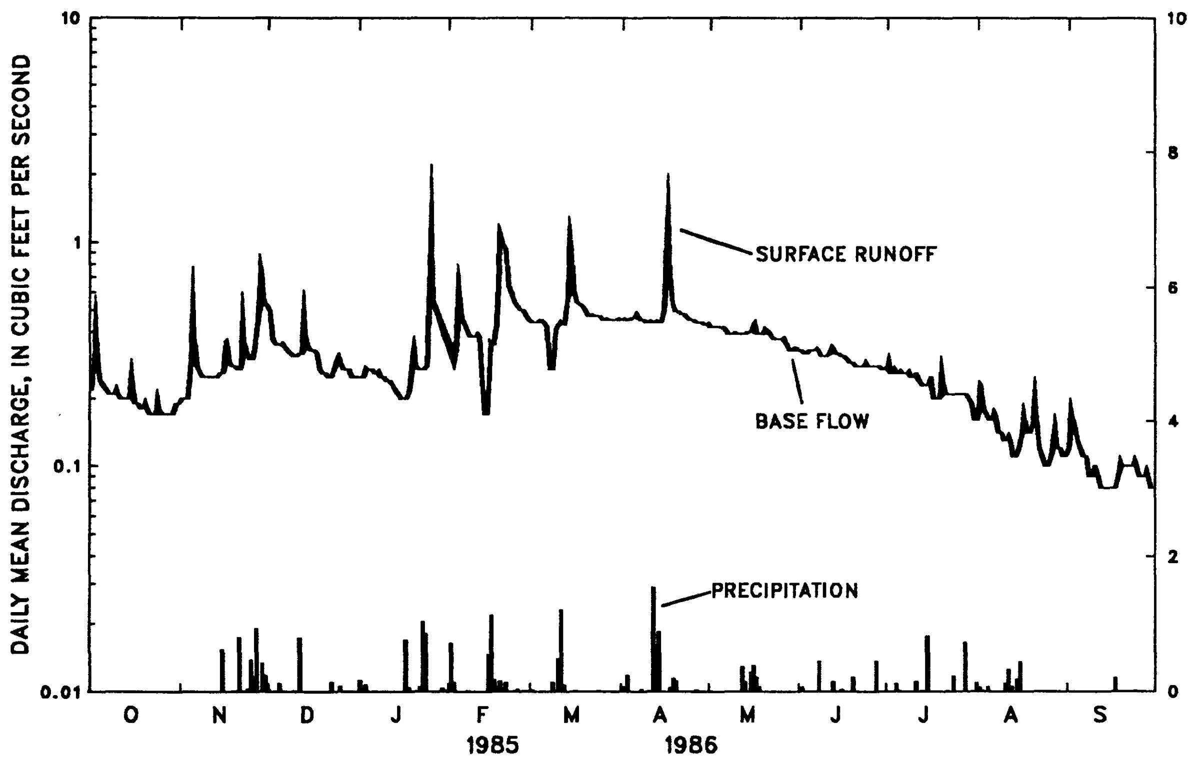
Streamflow data collected at the Bald Eagle Creek site were correlated with data collected at Principio Creek (fig. 1). Correlation between log-transformed daily streamflows at the Bald Eagle Creek site and the Principio Creek station for the 2 years of record was good ($r = 0.81$, and standard error = 0.22). At Principio Creek, streamflow was estimated to be about 35 percent below normal for the 2 years. Thus, streamflow at Bald Eagle Creek during the study period also was assumed to be about 35 percent below normal.

Base flow

Results from the three techniques to determine the quantity of base flow through hydrograph separations were within 4 percent of each other; therefore, the average of the three methods was used as an estimate of daily base flow. Base flow comprised about 84 percent of the total streamflow during the 2 years (table 8). About 87 percent of the total streamflow during the nongrowing seasons was base flow, and 81 percent of the total streamflow during the growing seasons was base flow. Base flow ranged from 58 to 98 percent of the monthly streamflow and depended on precipitation quantity and intensity.

Stormflow

Stormflow comprised about 16 percent of total streamflow during the 2 years. The hydrograph separations (fig. 7) of the continuous streamflow data show that most of the overland runoff (stormflow) was discharged during the nongrowing season in January, February, March, and December 1986. Although 63 percent of the stormflow was during the nongrowing season, about 13 percent of the stormflow resulted from the 6.78 in. of precipitation in September 1987. Figure 7 also reflects the rapid response of stormflow shortly after precipitation began and the short stormflow durations. The annual maximum instantaneous peak flows at the Bald Eagle Creek at the field site for the 1986 and 1987 water years were 6.9 ft^3/s on November 5, 1985, and 25 ft^3/s on September 18, 1987 (based on a slope/area indirect measurement).



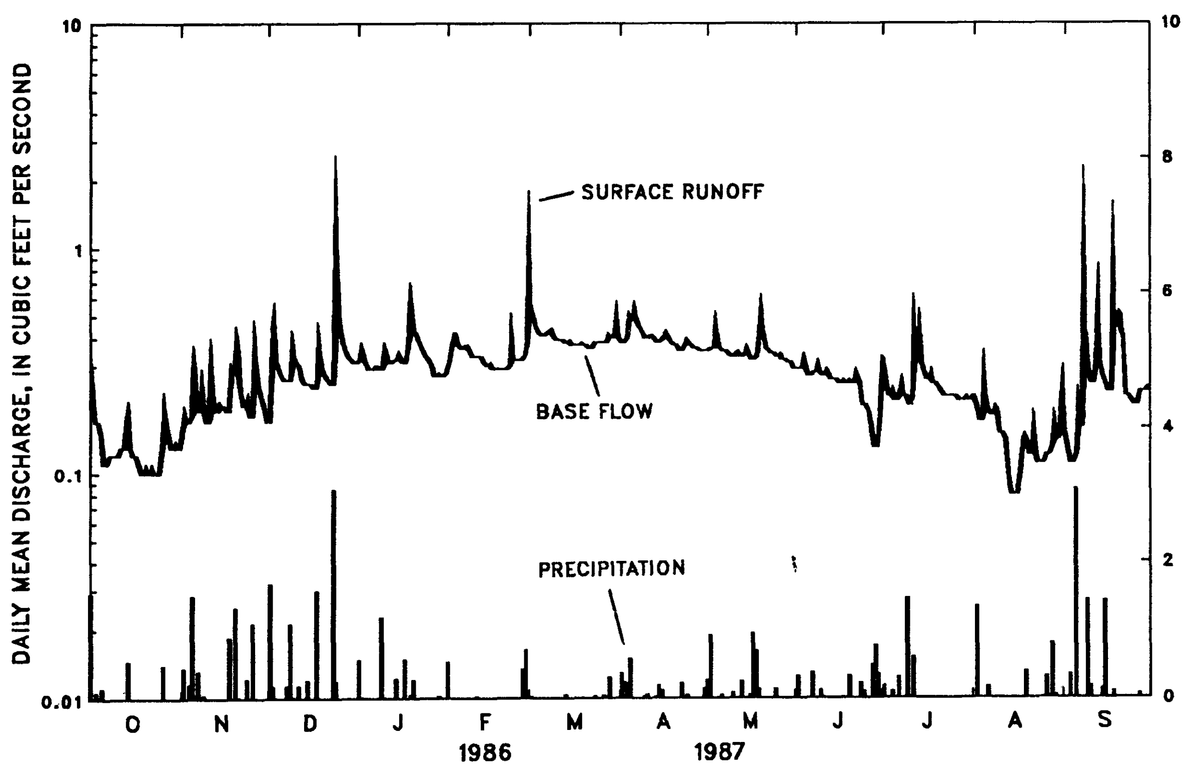


Figure 7.--Relations among surface-runoff and base-flow components of total streamflow.

Table 8.--Contribution of base flow to total streamflow

Month	Year	Base flow (inches)	Stormflow (inches)	Total streamflow (inches)	Percentage of base flow in total streamflow
Nongrowing Season					
October	1985	0.52	0.07	0.59	88
	1986	.33	.06	.39	85
November	1985	.72	.21	.93	77
	1986	.50	.16	.66	76
December	1985	.82	.06	.88	93
	1986	.73	.37	1.1	66
January	1986	.55	.30	.85	65
	1987	.82	.10	.92	89
February	1986	.90	.30	1.2	75
	1987	.77	.05	.82	94
March	1986	1.2	.20	1.4	86
	1987	1.0	.20	1.2	86
Growing Season					
April	1986	1.2	.20	1.4	86
	1987	1.0	.10	1.1	91
May	1986	1.0	.10	1.1	91
	1987	.90	.07	.97	93
June	1986	.78	.02	.80	98
	1987	.63	.04	.67	94
July	1986	.61	.03	.64	95
	1987	.62	.09	.71	87
August	1986	.35	.06	.41	85
	1987	.36	.07	.43	84
September	1986	.24	.03	.27	89
	1987	.58	.42	1.0	58
Subtotals					
1986 Water Year		8.89	1.58	10.47	85
1987 Water Year		8.24	1.73	9.97	83
Growing season		8.86	2.08	10.94	81
Nongrowing season		8.27	1.23	9.50	87
Study period		17.13	3.31	20.44	84

Quality

Base flow

Table 9 lists descriptive statistics of streamflow and chemical constituent concentrations, and discharges in base flow at Bald Eagle Creek during the study period by season and by water year. Concentrations and calculated discharges listed in the table are from manually collected depth-integrated discrete samples. A summary of monthly and annual nutrient and sediment loads in base flow that were calculated using the methods described earlier are given in table 10.

Constituent loads in base flow estimated by the straight-line interpolation method and the seven-parameter log-linear model were within 5 to 13 percent (table 10). Estimates with the seven-parameter model were usually lower than estimates using straight-line interpolation, probably because of the terms added to reduce the variance caused by streamflow and seasonality. The greater percent differences between the monthly loads calculated with method one and method two for dissolved orthophosphorus probably resulted from the lower magnitudes of the loads. Table 11 lists the parameters, the coefficients used for each parameter to determine the concentrations and the discharges, and T value (a measure of the significance of the parameter in the seven-parameter log linear model). A T value with an absolute value greater than 2 was considered to be significant.

The models described by equations (2) and (3) were found to be more desirable than use of straight-line interpolation to calculate constituent discharges in base flow for several reasons. The seven-parameter model was flexible and reflected the characteristics of the real data; it was easy to use because it used ordinary least squares to fit the data; the statistical properties of the estimates are well understood; it used only seven parameters to adjust for flow dependence, seasonality, and time trends; it explained 17 to 78 percent of the variability observed in the logarithms of the constituent concentration and 40 to 99 percent of the variability observed in the logarithms of the constituent load data; and lastly, it added uniformity in methodology between projects for the Chesapeake Bay Program.

Concentrations of total nitrogen and dissolved nitrate plus nitrite in base flow (fig. 8) followed a seasonal pattern. Maximum concentrations were in February during the nongrowing season. Minimum concentrations were in June and July during the growing season when nitrogen uptake for crop growth, especially corn, was at a maximum. Maximum concentrations of total nitrogen and dissolved nitrate plus nitrite were 6.2 and 5.3 mg/L, respectively.

Ranges in concentrations of total nitrogen were similar during the dry 1986 water year and the wet 1987 water year; the differences between the minimum and maximum concentrations during both years was 1.9 mg/L (table 9). However, the range in concentrations during the growing season (4.0 to 5.4 mg/L) was greater than the range in concentrations during the nongrowing season (5.3 to 6.2 mg/L). Concentrations of total nitrogen and dissolved nitrate plus nitrite increased slightly during the 2 years, but the trend was not statistically significant.

Discharges of total nitrogen (fig. 9) varied with season and with concentrations of total nitrogen. However, the discharges were more closely related to baseflow than were concentrations. Discharges of total nitrogen decreased during the growing season and coincided with increases in nitrogen uptake by corn (decreasing nitrogen concentrations in base flow) and decreases in precipitation as evapotranspiration losses increased (decreasing base flow). Decreases in total nitrogen discharges from the 1986 water year to the 1987 water year are not statistically significant. Of the approximate 5,251 lb of total nitrogen discharged in base flow, about 4,380 lb or 83 percent was dissolved nitrate plus nitrite (table 10, fig. 9).

Concentrations of total and dissolved organic nitrogen and ammonia nitrogen in base flow exhibit only slight seasonal trends which suggests that the transport mechanisms for the organic nitrogen and ammonia nitrogen are probably different than the transport mechanism for the nitrate plus nitrite nitrogen (figs. 10 and 11). Concentrations of ammonia and organic nitrogen during the wetter 1987 water year were not significantly different from the concentrations in the 1986 water year. Maximum concentrations of total and dissolved ammonia (0.23 mg/L) were measured on December 12, 1986, probably because of the combination of snow melt and an application of 15 tons of manure 2 days prior to sampling. Therefore, the sample was not representative of the base flow or ground water, and was not included in figure 11 or tables 9-10. The ranges in concentrations of organic nitrogen were nearly the same both years, and the ranges in concentrations of ammonia were slightly higher during the 1987 water year (table 9). About 87 percent of the organic nitrogen and 84 percent of the ammonia in base flow was dissolved.

Concentrations of total and dissolved phosphorus in base flow did not exhibit seasonal trends (fig. 12) and ranged from 0.03 to 0.11 mg/L and 0.02 to 0.09 mg/L, respectively. Concentrations of dissolved orthophosphorus ranged from 0.01 to 0.06 mg/L and were slightly lower during the second year (table 9). About 70 percent of the dissolved phosphorus in base flow was orthophoshorus.

About 66 lb of total phosphorus was discharged in base flow during the 2-year period pre-BMP phase (table 10). About 59 percent of the phosphorus was dissolved, and 41 percent was dissolved orthophosphorus in base flow. The maximum discharge of total phosphorus [0.181 lb/d (pounds per day)] in base flow was measured during the growing season on May 1, 1986 (fig. 13). The maximum discharges of dissolved phosphorus (0.141 lb/d) and orthophosphorus (0.125 lb/d) were measured in the nongrowing season on December 12, 1986 (table 9).

Concentrations of suspended sediment in base flow were greater in the growing season after plowing than in the nongrowing season (fig. 14) but were lower than concentrations measured in other intensively farmed basins in Pennsylvania. For example, Fishel and others (U.S. Geological Survey, written commun., 1990) reported that, in the 1.42-mi^2 Nutrient-Management Subbasin in the Little Conestoga Creek headwaters (site 3, fig. 1), concentrations of suspended sediment in base flow ranged from 3 to 97 mg/L from April 1984 through March 1986; the median concentration was 17 mg/L. The low concentrations of suspended sediment in base flow at Bald Eagle Creek probably occur because few animals have direct access to the stream at the sampling site, cover crops are used on steep slopes during the nongrowing season, minimum or no-till plowing is practiced, and a forested buffer borders the stream in the downstream area of the basin.

Suspended-sediment concentrations in base flow at Bald Eagle Creek were greatest in May and July 1987, possibly in response to modifications made by the property owner to the stream channel immediately upstream from the gage. However, the elevated concentrations during the 1987 water year were not significantly different from the concentrations measured during the 1986 water year. A total of about 4,548 lb of suspended sediment was discharged in base flow during the 2-year study period.

Table 9.--Water-quality characteristics of base flow by growing and nongrowing season and by water year

[Max, maximum; Min, minimum; Med, median; n, number of samples; ft^3/s, cubic feet per second; concentrations, in milligrams per liter; discharges, in pounds per day]

Constituent characteristic	Entire Pre-BMP Period				Growing Season				Nongrowing Season				1986 Water Year				1987 Water Year			
	Max	Min	Med	n	Max	Min	Med	n	Max	Min	Med	n	Max	Min	Med	n	Max	Min	Med	n
Instantaneous streamflow																				
(ft^3/s)	0.50	0.10	0.29	22	0.42	0.10	0.27	12	0.50	0.13	0.31	10	0.50	0.10	0.30	10	0.42	0.13	0.29	12
Nitrate + nitrite, dissolved as N																				
concentration	5.3	3.4	4.1	22	4.6	3.4	3.9	12	5.3	4.1	4.6	10	4.9	3.6	4.0	10	5.3	3.4	4.2	12
discharge	12.7	2.21	6.93	22	9.19	5.69	2.21	12	12.7	2.88	7.75	10	12.7	2.21	7.07	10	10.6	2.88	6.72	12
Nitrate + nitrite, total as N																				
concentration	5.3	3.7	4.2	22	4.6	3.7	4.0	12	5.3	4.2	4.7	10	5.1	3.7	4.1	10	5.3	3.8	4.2	12
discharge	12.7	2.21	7.18	22	9.19	2.21	5.98	12	12.7	2.95	8.17	10	12.7	2.21	7.18	10	10.6	2.95	7.03	12
Ammonia, dissolved as N																				
concentration	.08	.01	.03	22	.06	.01	.03	12	.08	.01	.04	10	.08	.01	.04	10	.04	.01	.03	12
discharge	.189	.007	.052	22	.136	.009	.045	12	.189	.007	.075	10	.189	.009	.056	10	.086	.007	.049	12
Ammonia, total as N																				
concentration	.08	.01	.04	22	.07	.01	.04	12	.08	.01	.04	10	.08	.01	.05	10	.05	.01	.04	12
discharge	.189	.007	.067	22	.136	.009	.056	12	.189	.007	.089	10	.189	.009	.081	10	.086	.007	.060	12
Ammonia + organic, dissolved as N																				
concentration	.90	.20	.60	22	.80	.20	.60	12	.90	.20	.50	10	.80	.30	.60	10	.90	.20	.65	12
discharge	2.16	.275	.923	22	1.60	.275	.813	12	2.16	.335	1.05	10	2.16	.275	.980	10	1.60	.292	.832	12
Ammonia + organic, total as N																				
concentration	1.2	.30	.70	22	1.0	.30	.65	12	1.2	.50	.70	10	1.2	.30	.70	10	1.0	.40	.70	12
discharge	3.24	.275	1.10	22	1.60	.275	1.01	12	3.24	.632	1.21	10	3.24	.275	1.13	10	1.60	.583	1.08	12

Table 9.--Water-quality characteristics of base flow by growing and nongrowing season, and by water year--Continued

[Max, maximum; Min, minimum; Med, median; n, number of samples; ft^3/s, cubic feet per second; concentrations, in milligrams per liter; and discharges, in pounds per day]

Constituent characteristic	Entire Pre-BMP Period				Growing Season				Nongrowing Season				1986 Water Year				1987 Water Year			
	Max	Min	Med	n	Max	Min	Med	n	Max	Min	Med	n	Max	Min	Med	n	Max	Min	Med	n
Nitrogen, total as N																				
concentration	6.2	4.0	4.9	22	5.4	4.0	4.5	12	6.2	4.9	5.3	10	5.9	4.0	4.7	10	6.2	4.3	5.0	12
discharge	15.9	2.59	8.48	22	10.8	2.59	6.56	12	15.9	3.44	9.29	10	15.9	2.59	8.48	10	12.0	3.44	8.28	12
Phosphorus, total as P																				
concentration	.11	.03	.05	21	.10	.04	.06	11	.11	.03	.05	10	.09	.03	.06	9	.11	.03	.05	12
discharge	.181	.021	.084	21	.181	.038	.080	11	.172	.021	.105	10	.181	.038	.127	9	.172	.021	.081	12
Phosphorus, dissolved as P																				
concentration	.09	.02	.04	22	.07	.02	.04	12	.09	.02	.03	10	.06	.02	.04	10	.09	.02	.04	12
discharge	.141	.011	.053	22	.102	.011	.053	12	.141	.021	.062	10	.108	.011	.053	10	.141	.020	.060	12
Orthophosphorus, dissolved as P																				
concentration	.08	.01	.02	21	.03	.01	.02	11	.08	.01	.03	10	.06	.02	.03	9	.08	.01	.02	12
discharge	.125	.010	.032	21	.068	.010	.029	11	.125	.021	.058	10	.100	.025	.038	9	.125	.010	.031	12
Sediment, suspended																				
concentration	13	1.0	4.0	22	9.0	2.0	6.0	12	13	1.0	4.0	10	6.0	1.0	4.0	10	13	2.0	6.0	12
discharge	16.0	1.08	7.96	22	16.0	1.08	8.58	12	15.2	1.46	7.96	10	15.2	1.08	6.86	10	16.0	2.05	9.10	12

Table 10.--Nitrogen, phosphorus, and suspended-sediment loads in base flow

[Base flow, in inches; loads, in pounds; (1), straight-line interpolation; (2), 7-parameter log-linear model]

Month	Year	Base flow	Dissolved nitrate plus nitrite (1)	Dissolved nitrate plus nitrite (2)	Total nitrogen (1)	Total nitrogen (2)	Total phosphorus (1)	Total phosphorus (2)	Dissolved phosphorus (1)	Dissolved phosphorus (2)	Dissolved ortho-phosphorus (1)	Dissolved ortho-phosphorus (2)	Suspended sediment (1)	Suspended sediment (2)
October	1985	0.52	120	120	150	160	1.0	1.6	1.0	1.3	0.7	0.9	98	110
	1986	.33	86	80	110	97	.8	1.7	.7	.6	.7	.5	21	34
November	1985	.72	190	170	220	220	2.4	2.8	1.9	1.8	1.6	1.4	140	130
	1986	.50	130	130	160	150	2.3	2.8	2.0	1.1	1.8	.9	31	55
December	1985	.82	220	210	260	270	3.9	3.2	2.6	2.0	2.6	1.7	136	130
	1986	.73	190	180	240	220	4.0	3.6	2.9	1.5	2.6	1.3	46	74
January	1986	.55	180	170	210	210	1.4	1.2	.9	.9	.9	.9	49	59
	1987	.82	230	230	280	270	2.9	3.7	1.8	1.6	1.4	1.4	165	92
February	1986	.90	280	220	350	270	3.2	2.5	2.2	1.4	1.8	1.4	163	130
	1987	.77	250	230	290	270	1.8	3.0	1.6	1.5	1.4	1.2	152	110
March	1986	1.2	360	330	430	380	4.2	4.5	2.6	2.4	2.3	2.2	374	280
	1987	1.0	320	300	360	350	2.0	4.3	1.5	2.2	1.3	1.5	172	220
April	1986	1.2	320	320	360	370	5.1	5.4	2.8	2.8	2.3	2.2	451	420
	1987	1.0	290	280	340	320	2.5	4.2	2.2	2.3	1.3	1.4	326	320
May	1986	1.0	240	260	290	310	5.5	4.6	2.3	2.5	1.6	1.7	386	460
	1987	.90	240	230	280	270	2.6	3.5	1.8	2.2	.7	1.1	455	370
June	1986	.78	190	180	220	220	3.0	3.4	1.5	1.9	1.0	1.2	227	360
	1987	.63	160	150	190	180	2.4	2.1	1.8	1.5	.6	.6	298	270
July	1986	.61	140	140	170	170	1.9	2.8	1.4	1.4	.8	.9	203	240
	1987	.62	130	140	180	170	3.5	2.6	1.1	1.7	1.0	.6	294	290
August	1986	.35	81	79	93	95	1.3	1.5	.8	.6	.6	.5	57	72
	1987	.36	79	83	98	100	1.5	1.3	.5	.8	.3	.3	73	99
September	1986	.24	63	58	75	69	1.0	1.1	.3	.4	.5	.3	30	26
	1987	.58	150	130	180	160	3.1	3.0	2.4	2.1	.8	.6	147	200
Subtotal	year 1	8.89	2,384	2,257	2,828	2,744	33.9	34.6	20.3	19.4	16.7	15.3	2,314	2,417
	year 2	8.24	2,255	2,163	2,708	2,557	29.4	35.8	20.3	19.1	13.9	11.4	2,180	2,134
Total		17.13	4,639	4,420	5,536	5,301	63.3	70.4	40.6	38.5	30.6	26.7	4,494	4,551
Percent difference			-6		-5		+9		-5		-13		+1	

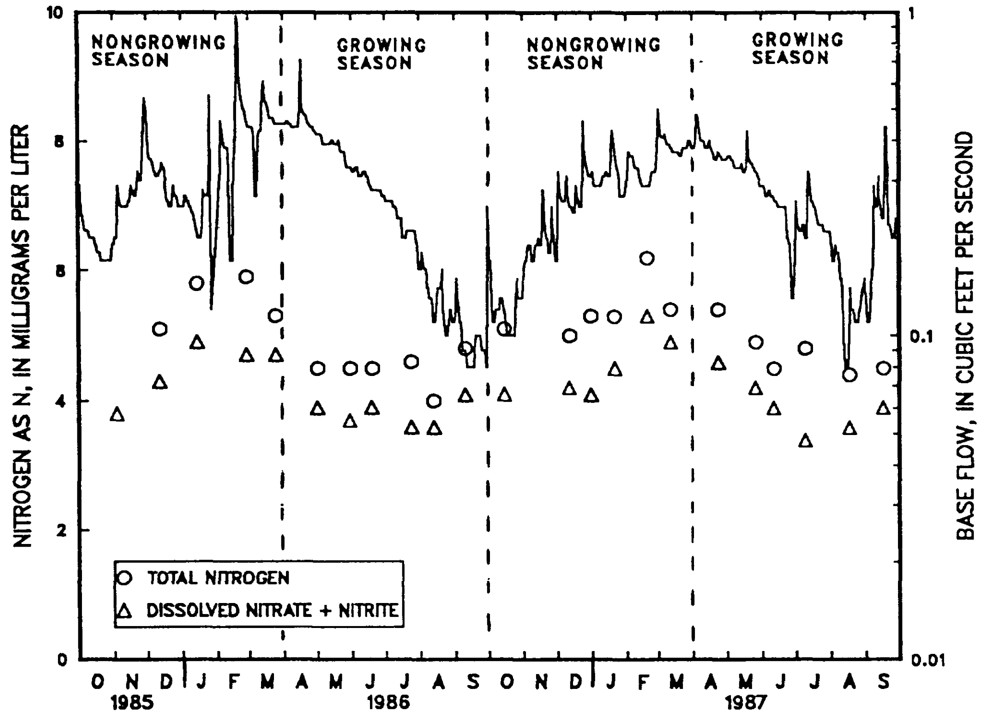


Figure 8.--Total-nitrogen and dissolved-nitrate plus nitrite concentrations in base flow.

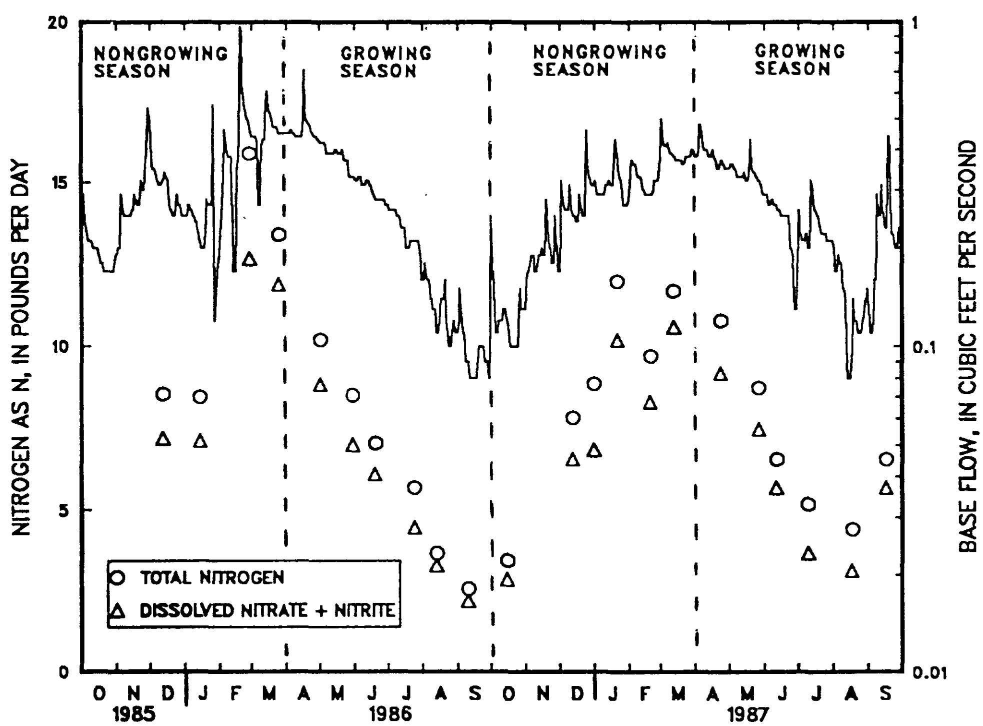


Figure 9.--Total-nitrogen and dissolved-nitrate plus nitrite discharges in base flow.

Table 11.--Coefficients, standard deviations, and T values for the seven-parameter log-linear model used to estimate concentrations and loads in base flow

[β_0, constant; β_1, log of streamflow; β_2, log of streamflow squared; β_3, decimal time; β_4, decimal time squared; β_5, sin (time); β_6, cos (time)]

Constituent	Parameter	Coefficient	Standard deviation	T value
Dissolved nitrite plus nitrite concentration				
	β_0	1.4270	0.0273	52.26
	β_1	-.0990	.0616	-1.62
	β_2	.0213	.0594	.36
	β_3	.0178	.0252	.70
	β_4	.0085	.0487	.17
	β_5	.1486	.0433	3.43
	β_6	.1152	.0196	5.87
load	β_0	.7434	.0273	27.22
	β_1	.9003	.0616	14.62
	β_2	.0213	.0594	.36
	β_3	.0178	.0252	.70
	β_4	.0085	.0487	.17
	β_5	.1486	.0433	3.43
	β_6	.1152	.0196	5.87
Total nitrogen concentration				
	β_0	1.6078	.0206	61.78
	β_1	-.0905	.0607	-1.49
	β_2	-.0391	.0588	-.67
	β_3	-.0135	.0249	-.54
	β_4	.0805	.0456	1.76
	β_5	.1172	.0415	2.82
	β_6	.1127	.0193	5.83
load	β_0	.9308	.0260	35.77
	β_1	.9095	.0607	14.97
	β_2	-.0391	.0588	-.67
	β_3	-.0135	.0249	-.54
	β_4	.0805	.0456	1.76
	β_5	.1172	.0415	2.82
	β_6	.1127	.0193	5.83
Dissolved phosphorus concentration				
	β_0	-3.6066	.1962	-18.38
	β_1	.8233	.4580	1.80
	β_2	-.0102	.4437	-.02
	β_3	.0971	.1874	.52
	β_4	.1070	.3442	.31
	β_5	-.4054	.3133	-1.29
	β_6	-.1146	.1459	-.79
load	β_0	-4.2836	.1962	-21.83
	β_1	1.8233	.4580	3.98
	β_2	-.0102	.4437	-.02
	β_3	.0971	.1874	.52
	β_4	.1070	.3442	.31
	β_5	-.4054	.3133	-1.29
	β_6	-.1146	.1459	-.79

Constituent	Parameter	Coefficient	Standard deviation	T value
Dissolved orthophosphorus concentration				
	β_0	-3.8487	0.2484	-15.50
	β_1	.4268	.6505	.66
	β_2	.1407	.6451	.22
	β_3	- .2139	.2514	- .85
	β_4	- .2405	.4724	- .51
	β_5	- .2139	.4198	- .51
	β_6	.1352	.1951	.69
load	β_0	-4.4681	.2484	-17.99
	β_1	1.4269	.6505	2.19
	β_2	.1407	.6451	.22
	β_3	- .2139	.2514	- .85
	β_4	- .2405	.4724	- .51
	β_5	- .2139	.4198	- .51
	β_6	.1352	.1951	.69
Total phosphorus concentration				
	β_0	-3.0864	.3542	-8.71
	β_1	.9275	.8267	1.12
	β_2	.5532	.8009	.69
	β_3	.2051	.3383	.61
	β_4	- .5562	.6213	- .90
	β_5	- .6739	.5655	-1.19
	β_6	.0319	.2633	- .12
load	β_0	-3.7634	.3542	-10.63
	β_1	1.9275	.8267	2.33
	β_2	.5532	.8009	.69
	β_3	.2051	.3383	.61
	β_4	- .5562	.6213	- .90
	β_5	- .6739	.5655	-1.19
	β_6	- .0319	.2633	- .12
Suspended sediment concentration				
	β_0	.9318	.2192	4.25
	β_1	.9607	.5034	1.91
	β_2	- .1535	.4846	- .32
	β_3	- .0251	.1952	- .13
	β_4	.3330	.3566	.93
	β_5	- .1862	.3564	- .52
	β_6	- .7128	.1607	-4.44
load	β_0	.2589	.2192	1.18
	β_1	1.9607	.5034	3.89
	β_2	- .1535	.4846	- .32
	β_3	- .0251	.1952	- .13
	β_4	.3330	.3566	.93
	β_5	- .1862	.3564	- .52
	β_6	- .7128	.1607	-4.44

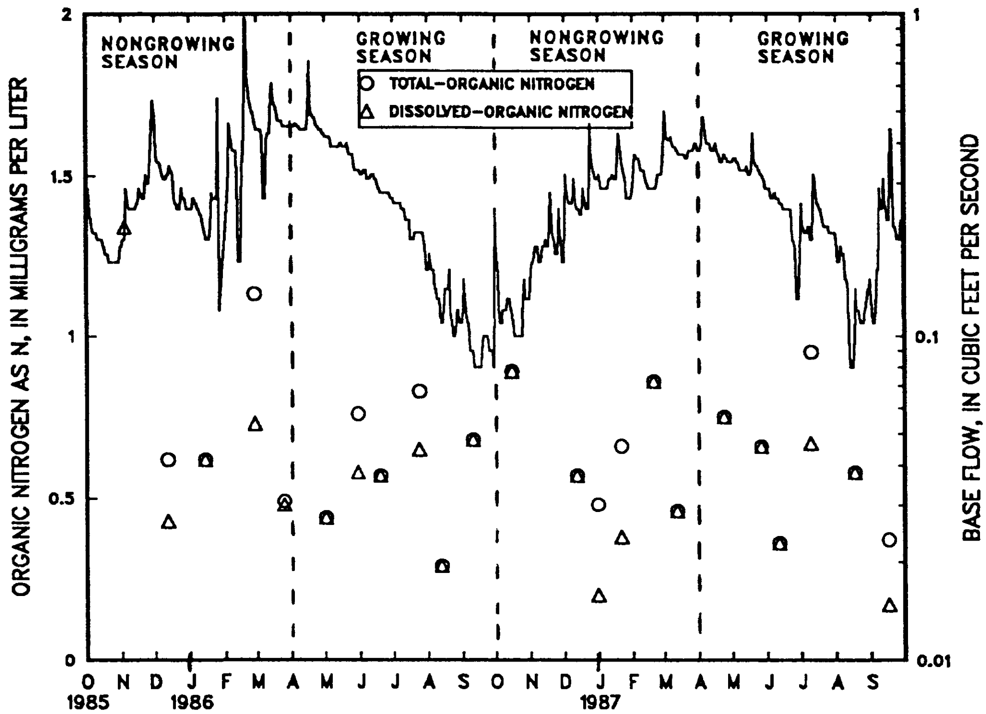


Figure 10.--Total- and dissolved-organic nitrogen concentrations in base flow.

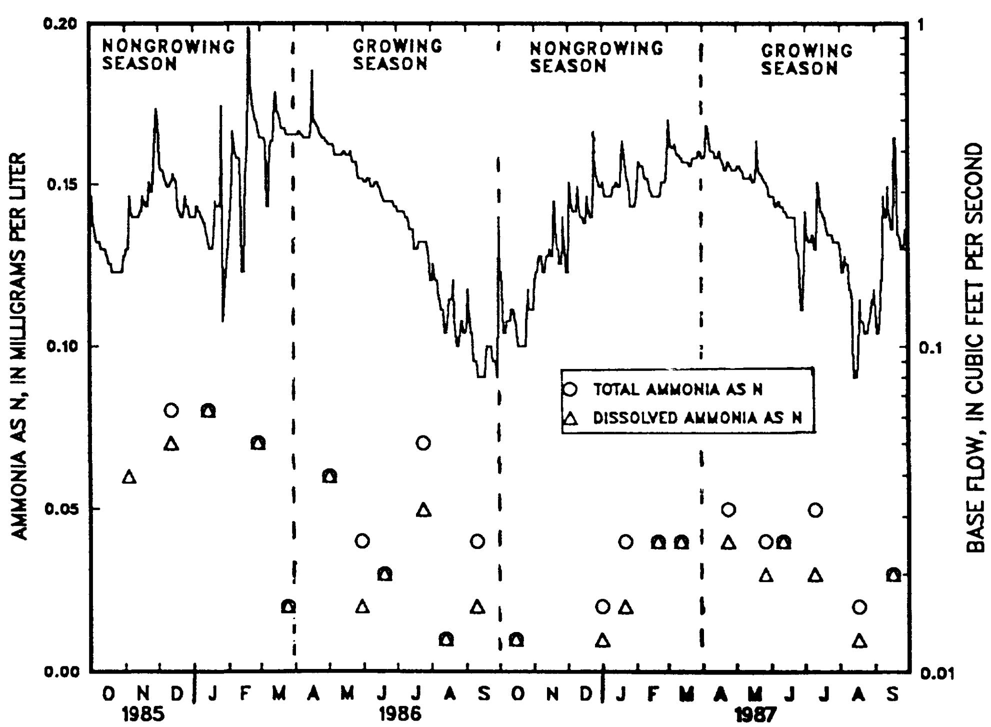


Figure 11.--Total- and dissolved-ammonia concentrations in base flow.

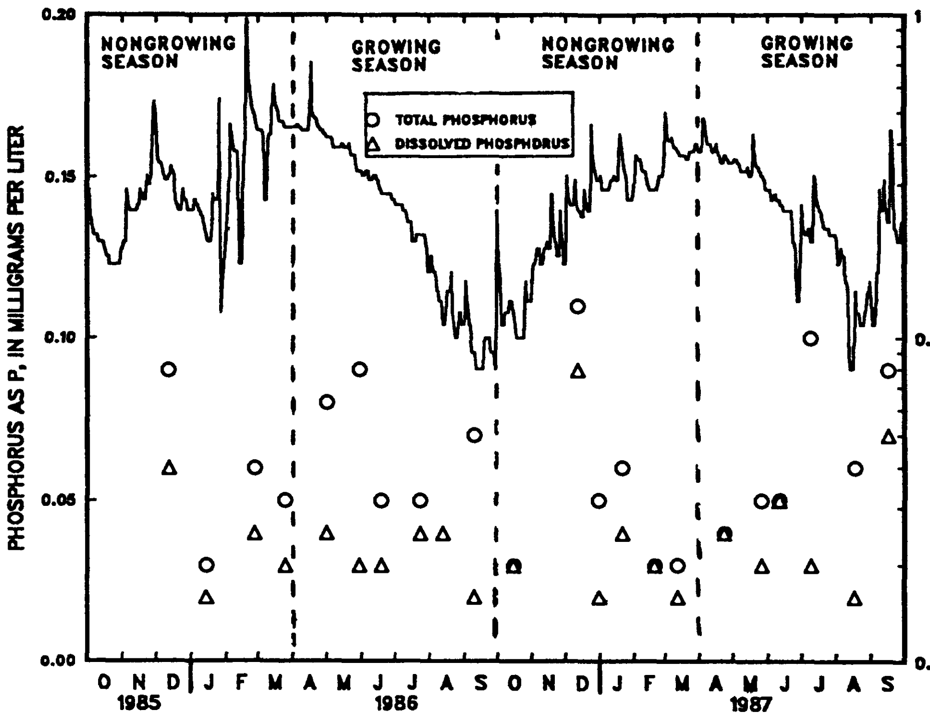


Figure 12.--Total- and dissolved-phosphorus concentrations in base flow.

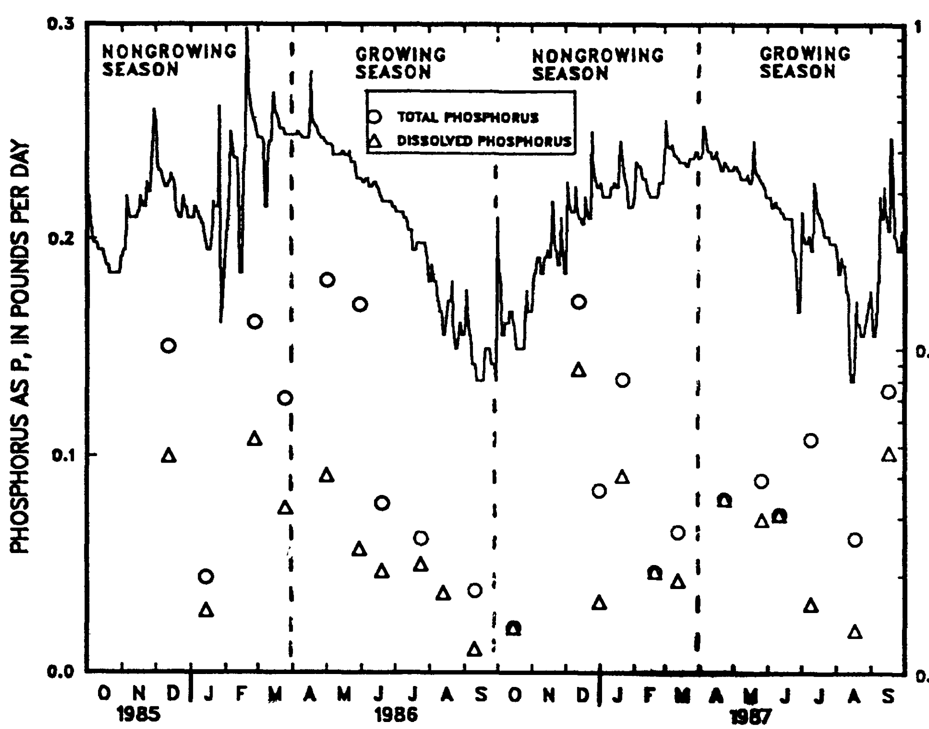


Figure 13.--Total- and dissolved-phosphorus discharges in base flow.

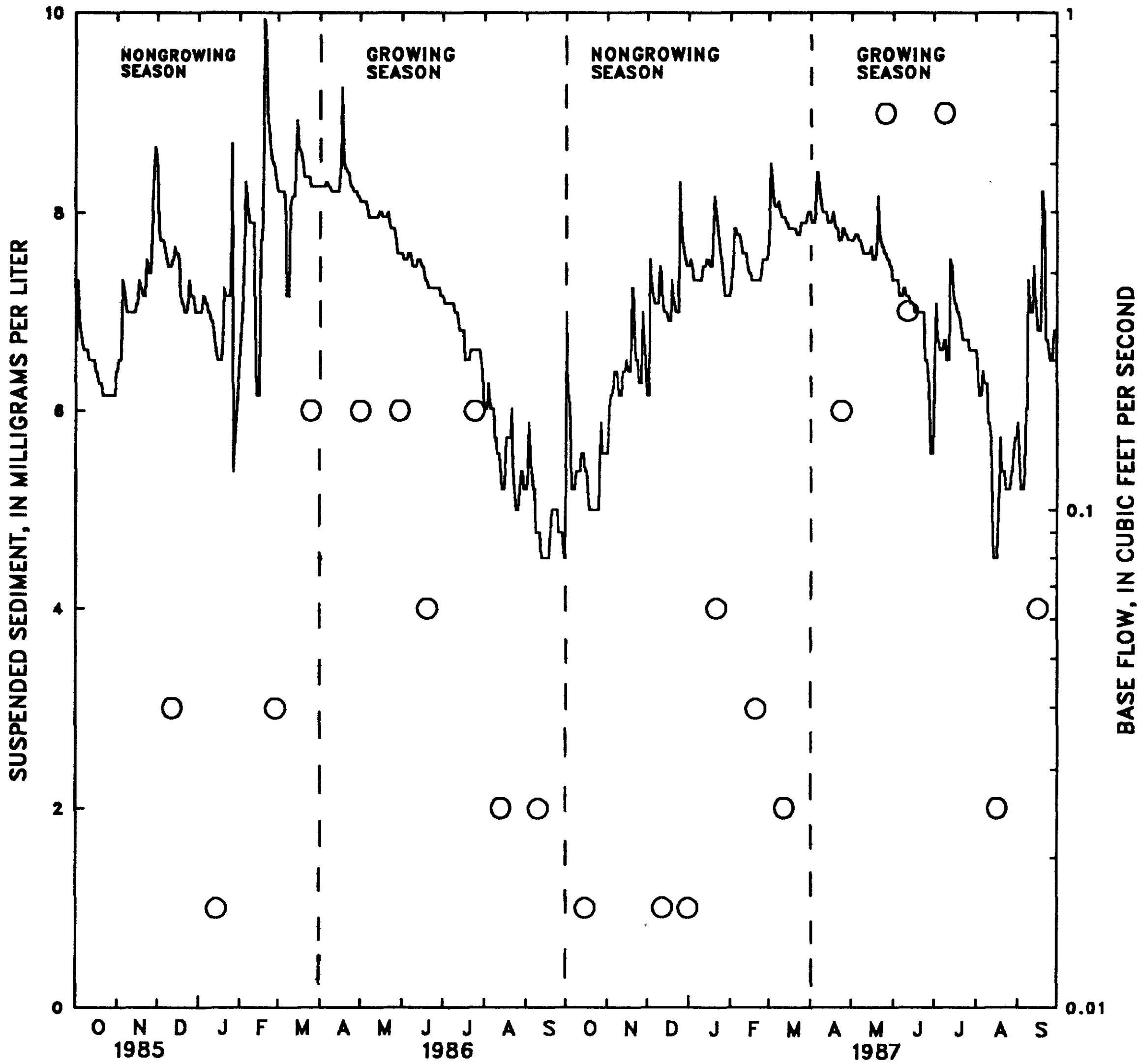


Figure 14.--Suspended-sediment concentrations in base flow.

Stormflow

Stormflow quality was difficult to document because of the sparse precipitation during the 1986 water year and because runoff from only a limited number of storms was sampled. Ninety-five stormflow samples were collected during seven storms in the 1986 water year. Stormflow samples during these storms reflect the quality of only 28 percent of the stormflow in that year. One-hundred eighty stormflow samples collected during 19 storms in the 1987 water year reflect the quality of 75 percent of the stormflow in that year. Fifteen of the 26 storms sampled were during the nongrowing seasons and 11 were during the growing seasons. Stormflow from these storms represent 51 percent of the total stormflow during the study.

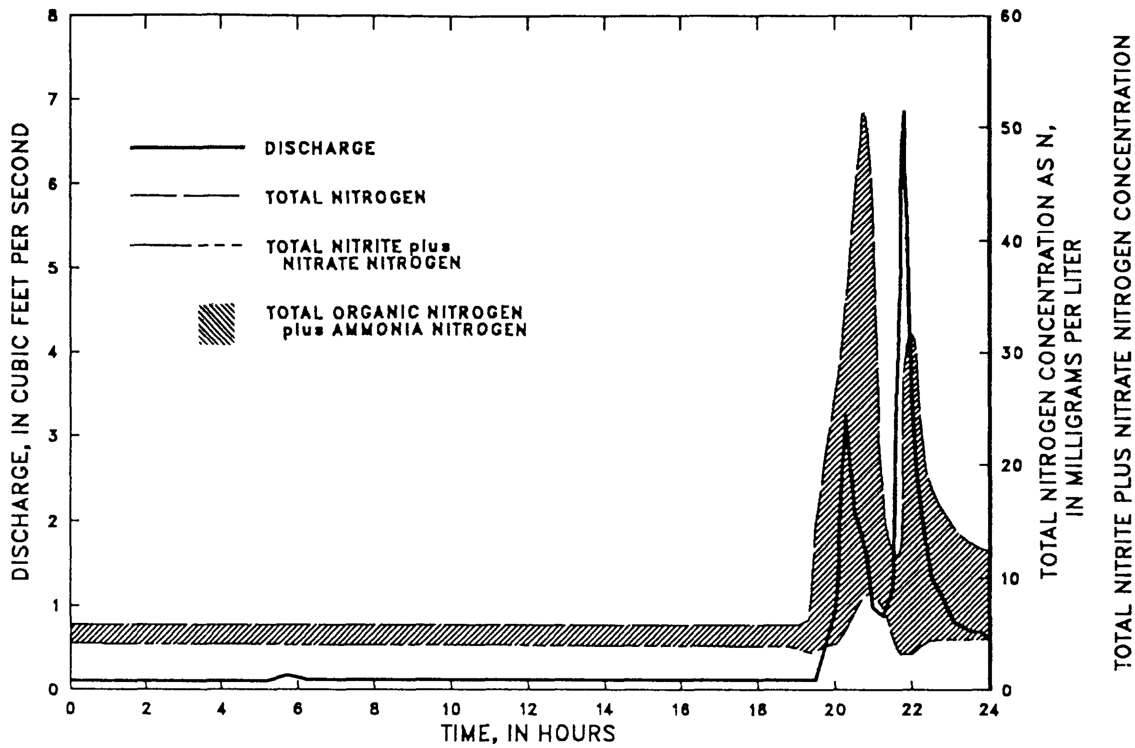
Concentrations of total nitrogen, nitrite plus nitrate nitrogen, phosphorus, and suspended sediment increased as stormflow increased, during the beginning of the storms (figs. 15 and 16). This suggests that nitrogen, phosphorus, and suspended sediment were transported overland from multiple sources rather than from a single source which would have been diminished as the stormflow increased and transported the nitrogen, phosphorus, and suspended sediment downstream. However, as the maximum stormflow peaked, the concentration of nitrite plus nitrate decreased suddenly, suggesting that there was a limiting or smaller source of nitrite plus nitrate than there was for organic plus ammonia nitrogen. Concentrations of total nitrogen, phosphorus, and suspended sediment peaked shortly before or at the same time as the stormflow.

The maximum measured concentration of total nitrogen in stormflow was 61 mg/L in the nongrowing season of the study on November 5, 1985 (table 12). About 82 percent of that nitrogen was suspended organic nitrogen. The maximum concentration of total nitrite plus nitrate was 4.5 mg/L in November 1985, and that of total ammonia was 6.7 mg/L in February 1987; both concentrations were measured during stormflow in nongrowing seasons.

Concentrations of phosphorus increased as stormflow and concentrations of suspended sediment increased. Concentrations of dissolved phosphorus also increased in stormflow. The maximum concentrations of total and dissolved phosphorus and orthophosphorus were 24, 6.0, and 3.7 mg/L, respectively. These concentrations were measured on November 5, 1985, in the nongrowing season.

Sediment concentrations usually reached their peak prior to or during the peak streamflow. The maximum sediment concentration was 8,730 mg/L and occurred on July 14, 1987, with a peak water discharge of 7.5 ft^3/s.

Table 13 lists daily storm loads of nitrogen, phosphorus, and suspended sediment that were measured during water years 1986 and 1987 (October 1, 1985-September 30, 1987).



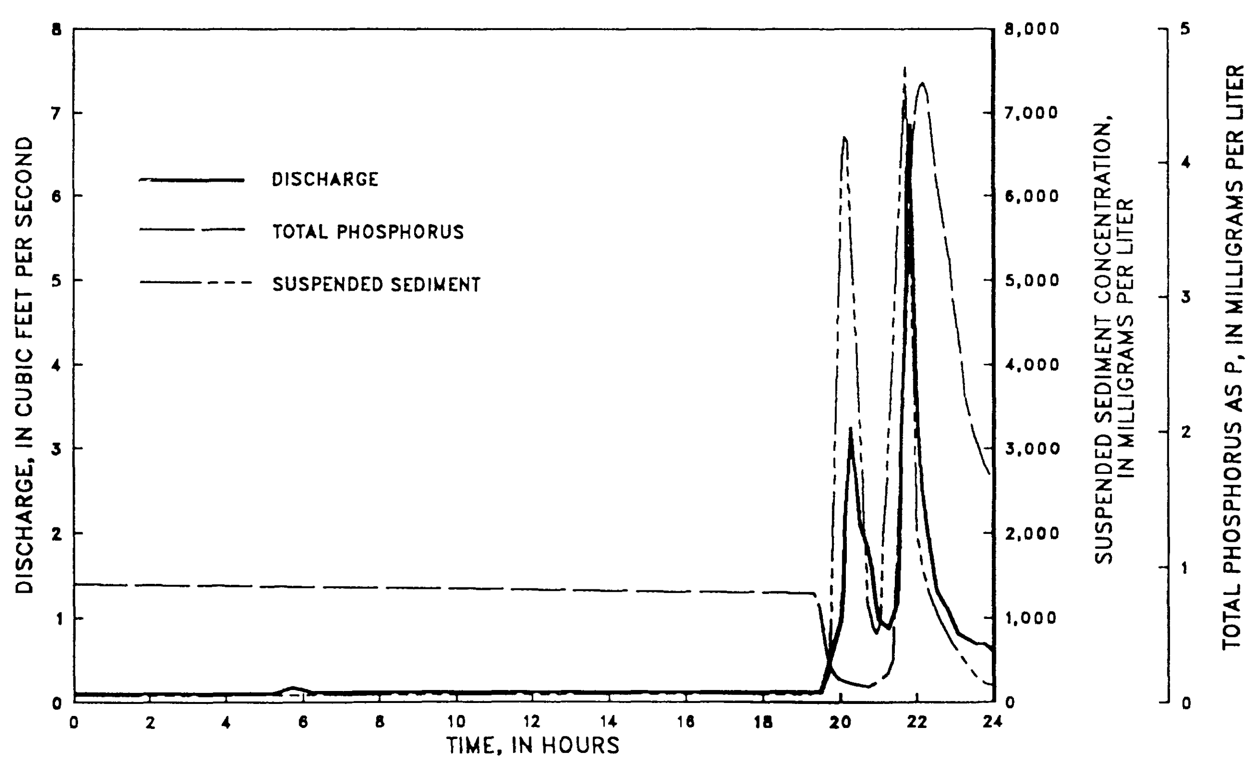


Figure 15.--Streamflow hydrograph and concentrations of total nitrogen, nitrite plus nitrate, ammonia plus organic nitrogen, total phosphorus, and suspended sediment on October 1, 1986.

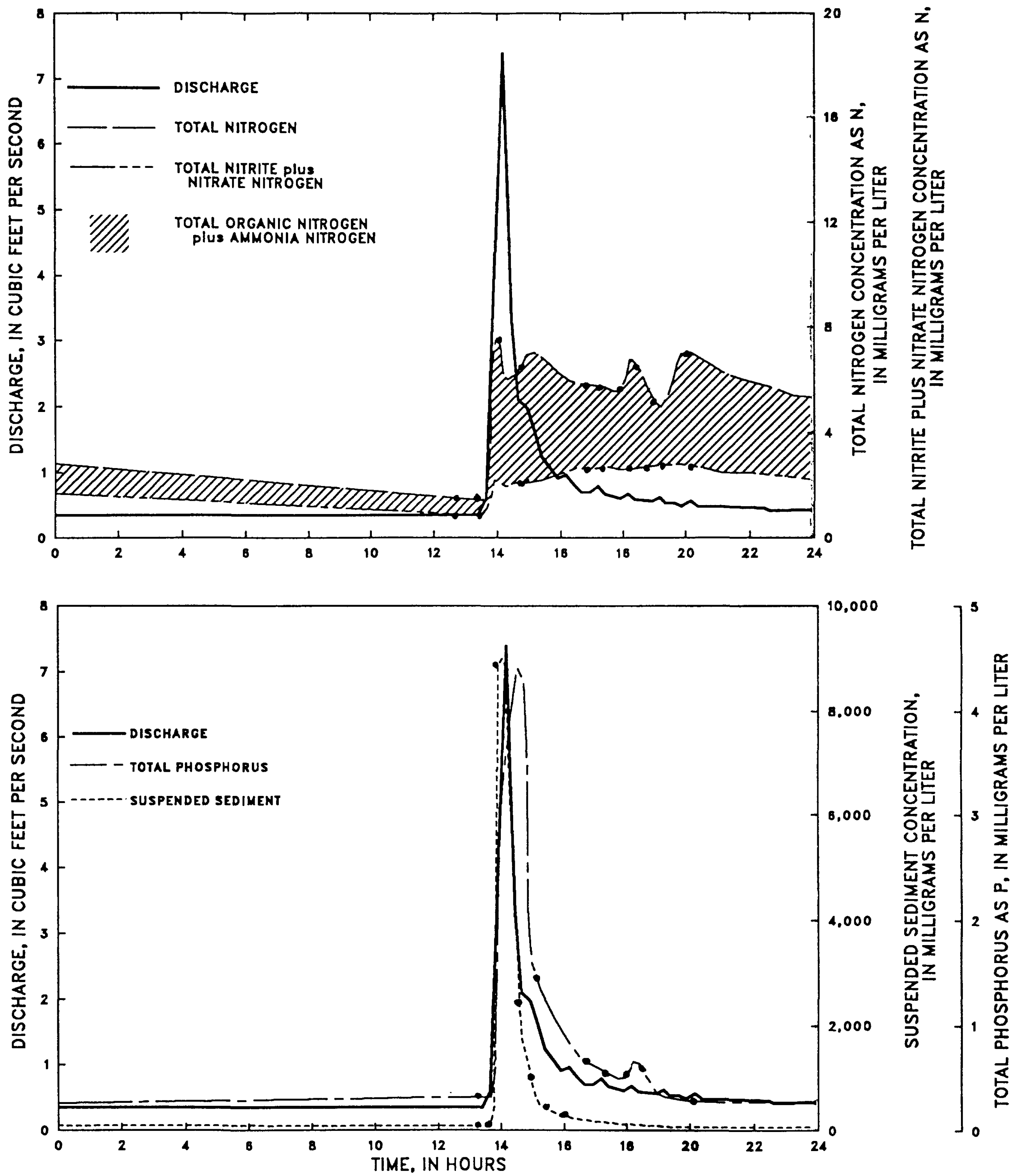


Figure 16.--Streamflow hydrograph and concentrations of total nitrogen, nitrite plus nitrate, ammonia plus organic nitrogen, total phosphorus, and suspended sediment on July 14, 1987.

Table 12.--Ranges of instantaneous streamflow, specific conductance, and concentrations of nitrogen, phosphorus, and suspended sediment in stormflow at Bald Eagle Creek in water years 1986 and 1987

[Streamflow, in cubic feet per second; specific conductance in microsiemens per centimeter; concentration, in milligrams per liter; n, number of instantaneous measurements; Min, minimum; Max, maximum; <, less than]

Constituent	1986 Water Year			1987 Water Year		
	n	Min	Max	n	Min	Max
Streamflow	95	0.21	6.9	180	0.08	12
Nitrite + nitrate, total as N	19	1.5	4.5	77	<.10	4.3
Nitrite + nitrate, dissolved as N	19	1.3	4.3	13	.60	3.8
Ammonia, total as N	19	.06	4.9	77	<.01	6.7
Ammonia, dissolved as N	18	.06	4.6	77	.06	1.3
Ammonia + organic nitrogen, total as N	19	.90	60	75	.40	28
Ammonia + organic nitrogen, dissolved as N	18	.70	10	13	<.20	7.9
Nitrogen, total as N	19	4.8	61	73	3.8	32
Phosphorus, total as P	19	.03	24	77	.09	4.9
Phosphorus, dissolved as P	18	.03	6	13	.15	1.5
Orthophosphorus dissolved as P	18	.02	3.7	13	.12	1.1
Sediment, suspended	81	3	4,350	150	<1	8,730

Table 13.--Daily nitrogen, phosphorus, and suspended-sediment loads during storms at the Bald Eagle Creek site

[Streamflow, in cubic feet per second; loads, in pounds; --, not determined; {, consecutive storm days]

Date	Daily streamflow	Total nitrate plus nitrite	Dissolved nitrate plus nitrite	Total ammonia	Dissolved ammonia	Total organic nitrogen	Dissolved organic nitrogen	Total nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phosphorus	Suspended sediment
{11/04/85	0.29	6	6	0.3	0.3	2	2	8.3	0.3	0.1	0.1	23
{11/05/85	.78	13	12	8	6	61	13	82	23	9	6	2,660
01/26/86	2.2	--	--	--	--	--	--	--	--	--	--	16,500
02/18/86	1.2	--	--	--	--	--	--	--	--	--	--	8,260
03/15/86	1.0	24	24	3	3	8	7	35	2	1	1	235
07/20/86	.31	5	5	1	1	7	3	13	.9	.3	.2	236
08/02/86	.24	--	--	--	--	--	--	--	--	--	--	386
{10/01/86	.34	8	6	2	2	28	10	38	4	1	1	5,290
{10/02/86	.25	4	4	1	1	5	5	10	.4	.3	.2	34
11/05/86	.37	7	--	2	--	1	--	24	2	--	--	134
11/18/86	.31	--	--	--	--	--	--	--	--	--	--	810
11/20/86	.45	--	--	--	--	--	--	--	--	--	--	4,090
11/26/86	.48	--	--	--	--	--	--	--	--	--	--	1,300
12/18/86	.47	8	--	4	--	13	--	25	1	--	--	524
12/24/86	2.6	--	--	--	--	--	--	--	--	--	--	39,100
02/23/87	.51	--	--	--	--	--	--	--	--	--	--	80
03/01/87	1.8	20	--	17	--	116	--	153	8	--	--	25,700
{05/19/87	.43	4	--	1	--	4	--	9	1	--	--	233
{05/20/87	.62	11	--	2	--	10	--	23	2	--	--	510
07/01/87	.33	--	--	--	--	--	--	--	--	--	--	730
07/12/87	1.9	--	--	--	--	--	--	--	--	--	--	27,100
07/14/87	.53	6	5	1	1	8	6	15	4	.6	.4	6,000
08/05/87	.35	6	--	3	--	23	--	32	3	--	--	3,230
09/01/87	.30	4	--	1	--	3	--	8	2	--	--	509
09/08/87	2.3	22	--	8	--	76	--	106	16	6	4	52,200
09/18/87	1.6	15	--	4	--	51	--	70	3	--	--	36,100

Ground Water

Occurrence

In basins where surface water is largely comprised of base flow, factors influencing the occurrence of ground water and recharge are important. Ground-water recharge is dependent upon the size and shape of the ground water basin, the annual precipitation, surface runoff, and evapotranspiration. The size and shape of the ground-water boundary at the site is assumed to be approximated by the surface-water subbasin boundary (fig. 2) based on topographic relief. Precipitation is the single input to recharge the ground-water system, whereas ground-water seepage (base flow) to the Bald Eagle Creek, seepage to the pond (fig. 2), and evapotranspiration are the three outputs that discharge from the ground-water system.

Typically, most ground-water recharge occurs between March and April (after the spring thaw but before the growing season), and between October and December (after crops are harvested but before the ground freezes). Ground-water levels usually decrease during the growing season from April through September because only a small amount of infiltration reaches the saturated zone as a result of evapotranspiration. Therefore, seasonal variations in precipitation can be more critical to the quantity of ground water than can annual total precipitation. The relation between precipitation and base flow measured at Bald Eagle Creek, and the ground-water level at observation well YO-180 (fig. 1), located about 20 mi north of the study area, is shown in figure 17. Well YO-180 is part of an observation-well network and represents typical ground-water conditions in the study-site area. The figure suggests a positive correlation between precipitation and ground-water levels, and with a lag time between precipitation and rise in ground-water levels of about 1 to 2 months. Ground-water levels increased rapidly in November 1985 and 1986 in response to increased precipitation. Ground-water levels decreased steadily in May, June, and July 1986, and May, June, July, and August 1987 during the growing season when evapotranspiration increased. The correlation between ground-water levels and base flow suggests the seasonal effects on both are similar.

Availability

The availability of ground water depends on the capacity, storage characteristics, and transmissivity of the underlying rock structure. Wells drilled into the Wissahickon formation usually provide sufficient water for domestic purposes, and water-bearing zones are located consistently between land surface and about 400 ft below land surface. Lloyd and Growitz (1977) report that 1-hr (hour) specific capacities of 72 wells in the Wissahickon formation ranged from 0.03 to 50 (gal/min)/ft (gallons per minute per foot) and the median was 0.95 (gal/min)/ft. The yield for an average well drilled 400 ft deep is about 45 gal/min (gallons per minute) with 50 ft of drawdown after pumping 1 hr; after pumping for 24 hrs, the yield is about 30 gal/min. The maximum yield measured for a well in this formation is 150 gal/min (Lloyd and Growitz, 1977).

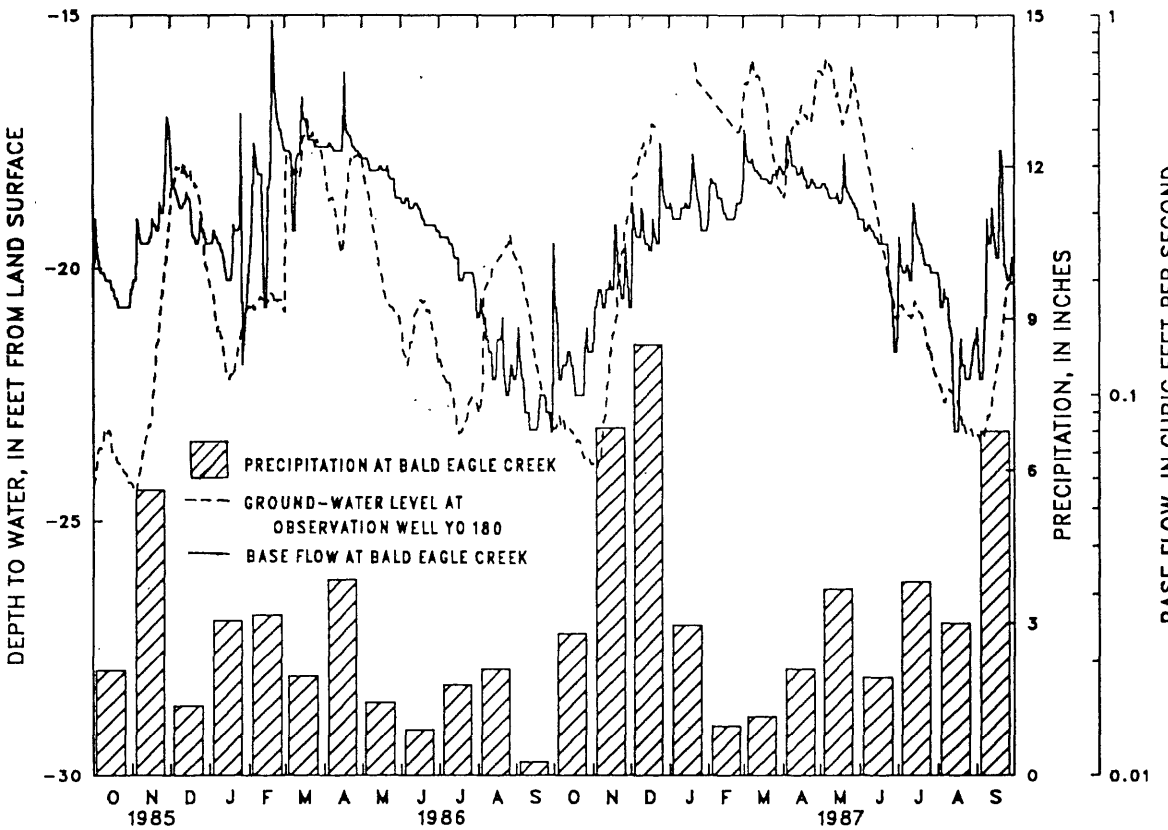


Figure 17.--Relations among precipitation, ground-water levels, and base flow.

Quality

The quality of ground water is determined by the precipitation quality, composition of the rock and soil through which it flows, and the residence time. Historical data indicate ground water from water-bearing zones in the Wissahickon formation is generally soft and low in dissolved solids (Lloyd and Growitz, 1977). Hardness ranges from 17 to 170 mg/L as $CaCO_3$ in 92 ground-water samples collected between November 1968 and December 1970; the median hardness is 34 mg/L. The field pH ranges from 5.9 to 7.0 in 48 ground-water samples collected from the Wissahickon formation. Specific conductance ranges from 250 to 560 μS/cm (microsiemens per centimeter at 25 degrees Celsius) in 115 samples; the median specific conductance is 125 μS/cm. Concentrations of iron and nitrate in the ground water commonly are elevated. Concentrations of nitrate nitrogen as NO_3 range from 2.0 to 94 mg/L in 34 samples; the median concentration is 28 mg/L. This value is greater than any individual nitrate concentration measured in samples from any of the other noncarbonate rocks in southern York County.

SOIL DEPTH AND CHEMISTRY

Soils at the site are commonly less than 36 in. thick, especially at Farm 2 (fig. 2). Attempts to collect core samples to depths of 48 in. were not always successful. Therefore, the total nutrient content of the soils at some fields at the Bald Eagle Creek site were inherently lower than in other fields or other agricultural areas, such as the carbonate-rock sites of the RCWP Nutrient-Management Subbasin (site 3, fig. 1), simply because of the difference in soil depths or amounts of soil analyzed.

Available nitrogen (nitrate) and phosphorus concentrations of soils were sampled after the growing season on November 20, 1985, at Farm 1; before the growing season on May 20, 1987, at Farms 1 and 2; and after the 1984 and 1985 growing seasons at farms A, E, F, G, H, I, and O (fig. 18) in the Nutrient-Management Subbasin (figs. 19 and 20).

The concentrations in figure 19 only reflect the amount of nitrate immediately available to the plants. They do not account for nitrogen from ammonia or nitrogen that may become available from mineralization and nitrification of residual organic nitrogen in the soil which Stevenson (1982) indicates may comprise more than 90 percent of the nitrogen in surface layers of most soils. Also included in the figures are analyses of soils from seven farms in the RCWP Nutrient-Management Subbasin (fig. 18) which show that nitrate and phosphorus concentrations in the soil at the Bald Eagle Creek site are generally lower than those in the soil at the Nutrient-Management Subbasin. The total amount of nitrate nitrogen in the top 48 in. of soil ranged from 36 to 135 lb/acre in the Bald Eagle Creek basin and from 45 to 372 lb/acre at the Nutrient-Management Subbasin. The lower concentrations in soil at Bald Eagle Creek probably result from reduced applications of manure, and use of manure from dairy animals, that is not as nutrient-rich as the poultry and hog manure applied in the Nutrient-Management Subbasin.

Nitrate concentrations were generally smaller and more uniform throughout the soil column at the Bald Eagle Creek site than at the Nutrient-Management Subbasin. On the basis of data from the Bald Eagle Creek site, the highly soluble nitrate infiltrates readily through the soil profile, as suggested by nitrate concentrations that were, at times, largest at depths of 24 to 48 in. below the surface. Similar observations were made in the deeper carbonate-rock soils at the Nutrient-Management Subbasin of the RCWP project.

Results of soil-monitoring studies in Nebraska, Iowa, and Wisconsin (Halberg and others, 1984, and Rehm and others, 1983, p. 8-10) suggest that less than 100 lb/acre of nitrate nitrogen needs to remain in the top 48 in. of soil to insure that leachate to the ground water will not exceed 20 mg/L of nitrate nitrogen. However, Baker (Pennsylvania State University, College of Agriculture, Department of Agronomy, written commun., 1985) states that a preferable environmental level for nitrate-nitrogen is 50 lb/acre in the upper 48 in. of soil. Both fields at Farm 1 had more than 70 lb/acre of nitrate nitrogen in the top 48 in. after the growing season in 1985 (fig. 19).

The total amount of phosphorus in the top 48 in. of soil ranged from 0.89 to 5.7 lb/acre at the Bald Eagle Creek site and from 1.4 to 23 lb/acre at the Nutrient-Management Subbasin (fig. 20). In contrast to the nitrate concentrations, phosphorus concentrations were always greatest near the surface of the soil and perhaps reflect the affinity of fine soil particles for adsorbing phosphorus (Finkl and Simonson, 1979, p. 374). The soils at Bald Eagle Creek are not as rich in phosphorus as are soils in the Nutrient-Management Subbasin, possibly because of differences in the type of manure that was applied. For example, the concentration of phosphorus as phosphate, (P_2O_5) in dairy manure at Farm 1 was 4.9 lb/ton (pounds per ton) as compared to 54 lb/ton of phosphorus in turkey manure at Farm A in the Nutrient-Management Subbasin.

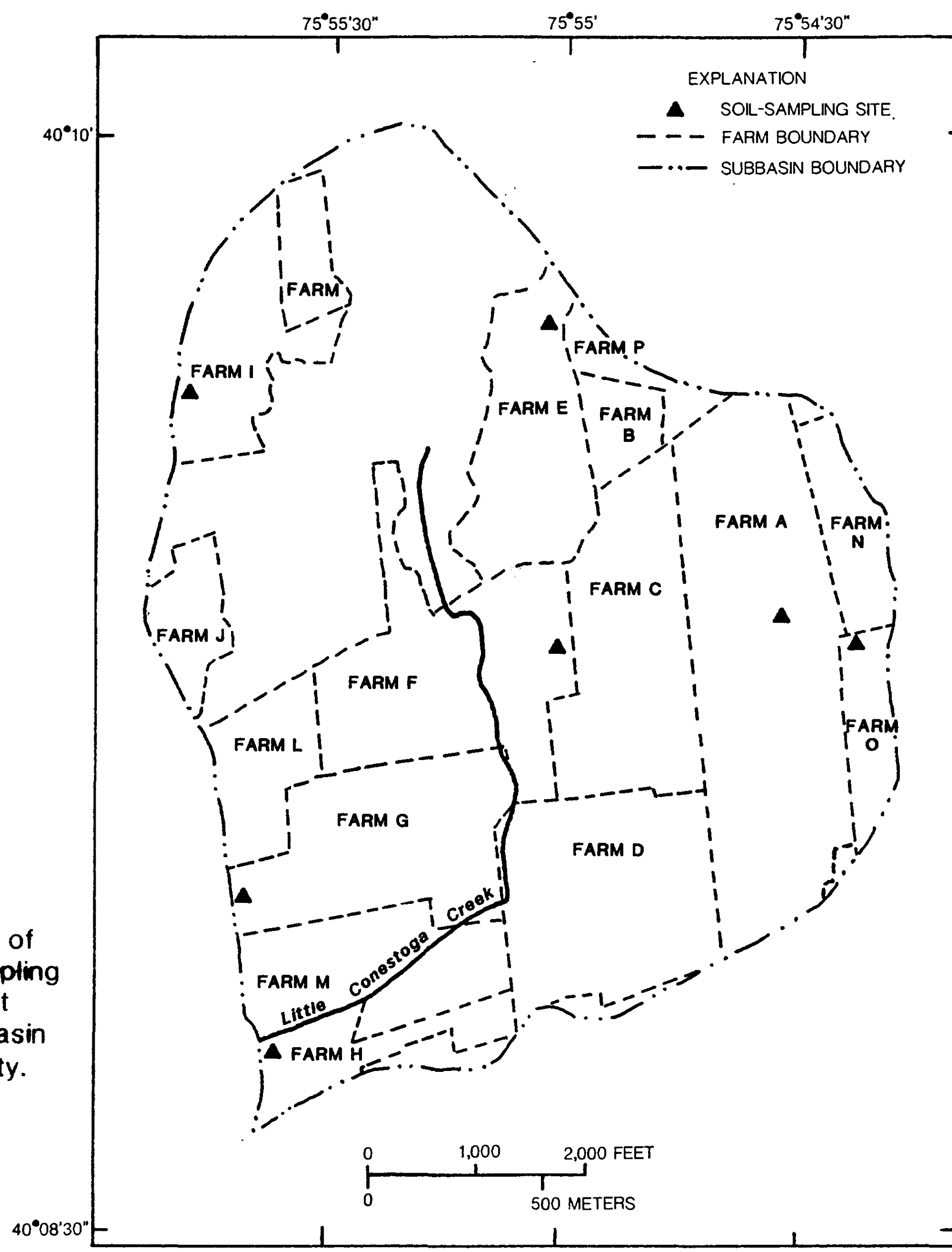


Figure 18.--Locations of farms and soil-sampling sites in the Nutrient Management Subbasin in Lancaster County.

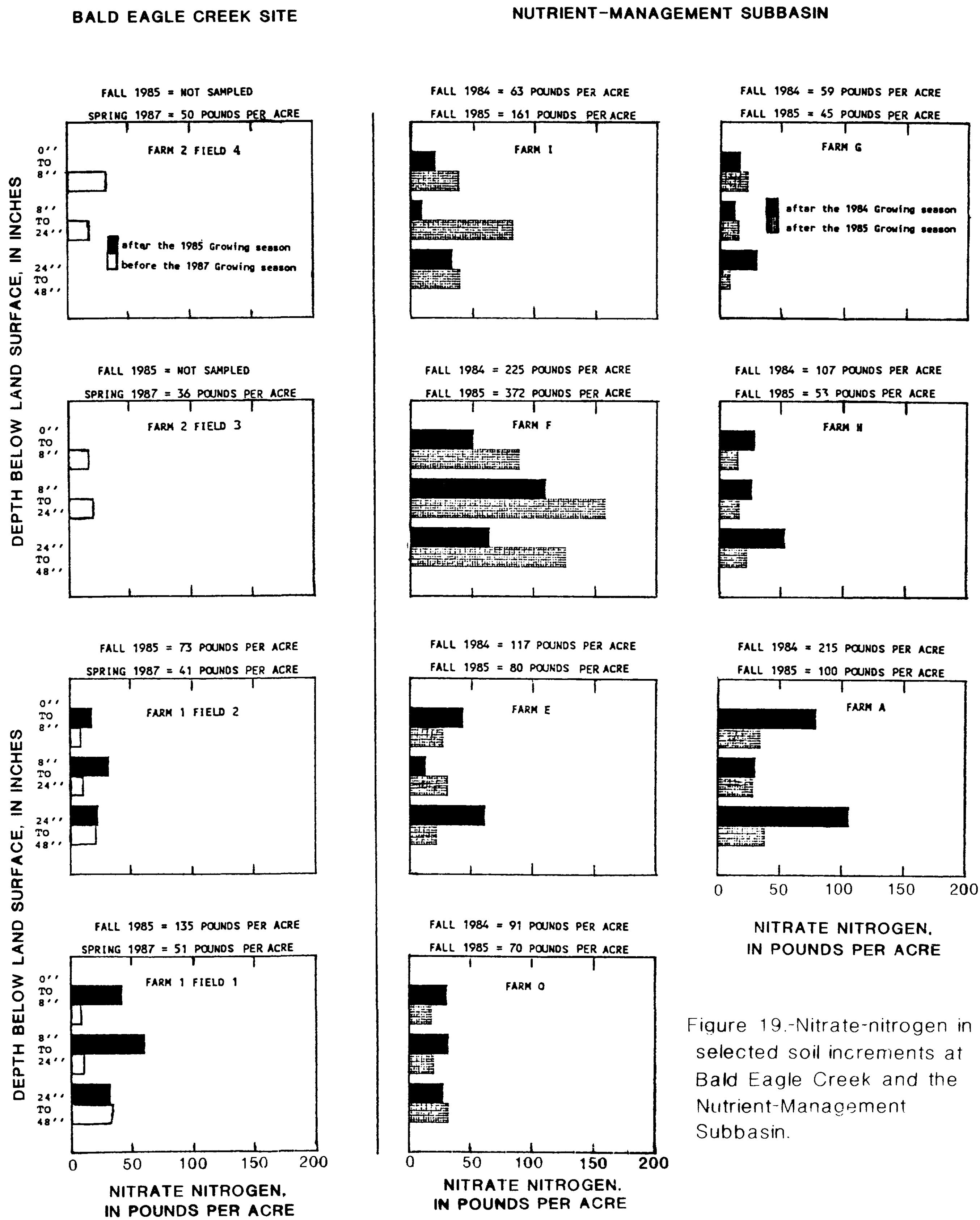


Figure 19.-Nitrate-nitrogen in selected soil increments at Bald Eagle Creek and the Nutrient-Management Subbasin.

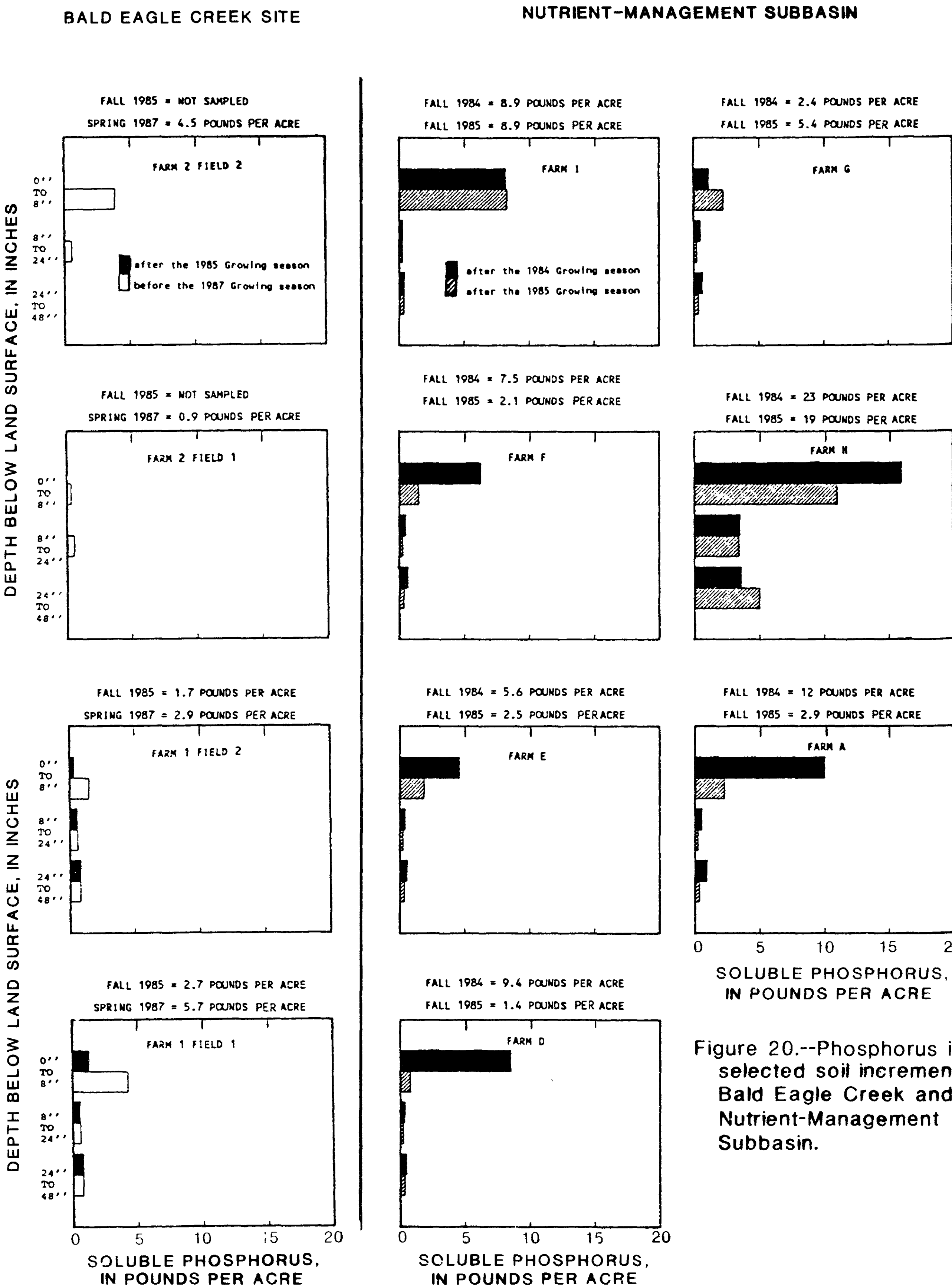


Figure 20.--Phosphorus in selected soil increments at Bald Eagle Creek and Nutrient-Management Subbasin.

ESTIMATES OF NUTRIENT REDUCTIONS REQUIRED FOR STATISTICALLY SIGNIFICANT CHANGES

The executive summary of the Conestoga River Headwaters RCWP 1982 Plan of Work (U.S. Department of Agriculture, 1982, p. 1) stated that the first objective of the RCWP is "to significantly reduce agricultural pollutants: nitrogen, phosphorus, pesticides, sediment, and other pollutants, entering public and private waters of the Conestoga Headwaters Watershed." Specific objectives are to reduce nitrates, phosphates, and sediments in solution from entering receiving streams and lakes by implementing the fertilizer management (nutrient management) BMP and other innovative techniques. The goal of these objectives is to improve the quality of potable water and the aquatic environment within and downstream from the lower Susquehanna River basin.

The USEPA Chesapeake Bay Program (U.S. Environmental Protection Agency, 1983) is interested in achieving the same goal but for the entire Susquehanna River basin and other tributaries discharging to the bay. The 1987 Chesapeake Bay Agreement calls for a 40-percent reduction by the year 2000 in nitrogen and phosphorus entering the main stem of the bay from point sources, relative to the loading from 1985, and from controllable nonpoint sources, assuming average rainfall. This reduction was formulated from results of computer simulations of the bay. No target goals were recommended for the small watersheds draining into the bay, nor is it known what the water quality would be in the small watersheds if a 40-percent reduction were realized throughout the Chesapeake Bay watershed.

Because no target goals for nutrient reduction have been established for the small watersheds, one of the purposes of this study is to evaluate the effectiveness of BMPs in reducing nutrient loads. Estimates were made of the reductions required to detect changes in the water quality of base flow. Changes in water quality are not expected unless there are changes in land use. These estimates are based on background levels and pre-BMP trends. A preliminary discussion of the relation between statistical changes and environmental changes is included later in the section "HYPOTHETICAL EFFECTS OF REDUCTIONS IN NUTRIENT APPLICATIONS ON SURFACE-WATER QUALITY AND IMPORTANCE OF LAND-USE CHANGES AND RANDOM EVENTS."

Richards (1985) used the Student t-test (two-sample, one-tailed) in reverse to establish target goals. He estimated that a minimum reduction of 35.6 percent in average phosphorus loads would be required in the Sandusky River basin, a tributary to Lake Erie, to cause statistically significant changes from the pre-BMP loads. Richards used the t-test because it was a technique familiar to most workers and was readily adaptable to the problem of estimating the needed reduction. However, he acknowledged, as suggested by Hirsch and others (1982), Helsel (1987), and the National Water Quality Evaluation Project (1988), that nonparametric techniques would be more appropriate and may be more powerful than parametric techniques. The suggestion of using nonparametric techniques was made primarily because most hydrologic data are not normally distributed (they usually are positively skewed) and have unequal variances. Therefore, the data do not meet the first criterion for use of parametric techniques. Although transformations of the data can enhance the shape of distributions, biased estimates of the mean may result from nonnormally distributed data. Richards made no attempt to determine the relation between changes that were considered "statistically significant" and improvements in potable water or aquatic environments.

Fishel, Brown, Kostelnik, and Howse (U.S. Geological Survey, written commun., 1989) used a modified form of the nonparametric Wilcoxon-Mann-Whitney rank-sum test (alpha = 0.05) to establish target goals for subbasins in the Little Conestoga Creek headwaters. Estimates of the amount of nutrient reduction in base-flow concentrations and loads required to detect statistically-significant changes in water-quality concentrations and discharges at the Bald Eagle Creek site and the Forested and Nutrient-Management Subbasins in the Little Conestoga Creek headwaters are listed in table 14. It is important to note that the estimates are expressed in percent; to make valid comparisons between subbasins, the percentages should be converted to actual reductions in milligrams per liter or pounds from the mean concentrations or discharges. For example, a reduction of 57 percent from the daily mean total-phosphorus load in base flow required at Bald Eagle Creek would require a 0.06 lb reduction in total phosphorus. But a similar reduction of 56 percent at the Nutrient-Management Subbasin would require a reduction of about 0.29 lb. The estimates were obtained by using the means, standard deviations, and number of observations of the raw concentration and discharge data for the growing and nongrowing seasons listed in table 14 as input to the Monte Carlo simulation of the nonparametric seasonal rank-sum test. Standard deviations for concentration and discharge data that are log normal are listed in the table as positive and negative percentages.

Figures 21 and 22 show the power of the seasonal rank-sum test, $(1-\beta)$, which represents the probability of rejecting the null hypothesis when in fact it is false and the alternative hypothesis is true. The null hypotheses is that there is no difference in the mean of the pre-BMP and post-BMP water-quality data when the post-BMP data are reduced by the indicated percentages. Therefore, the power of the test gives the probability of detecting a change during a 2-year post-BMP phase if the constituents are reduced by the indicated percentage.

Bald Eagle Creek requires an estimated 12- and 48-percent reduction, in concentrations of total nitrogen and total phosphorus in base flow, respectively (table 14 and figures 21 and 22); the percent reduction required in corresponding loads are 62 and 57 percent, respectively. Greater reductions are required in nutrient loads than in concentrations because of increased variability of load data. Greater reductions also are required in phosphorus concentrations than in nitrogen concentrations at all three subbasins, and in actual loads required at the Nutrient-Management Subbasin than in actual loads required at Bald Eagle Creek and the Forested Subbasin. Data for Bald Eagle Creek are more similar to those for small forested and undisturbed watersheds in the lower Susquehanna River basin where the effects of animal density are minimal, than they are for the intensive agricultural watersheds where animal densities are high (Lietman and others, 1983). At the Bald Eagle Creek site where the steep slopes are comprised of schist, such as that at the RCWP Forested Subbasin where triassic sandstone ridges predominate, the geology and topography permit rapid transport of ground water through shallow subsurface soils with little leaching before the water discharges as base flow. In contrast, at the Nutrient-Management Subbasin, which lies within a carbonate-rock valley, the geology and topography increase the duration and distance of subsurface transport of ground-water flow before the water discharges as base flow.

Although the required reductions in the base-flow loads appear large (table 14 and figures 21-22), the reductions are relatively small compared with the amount of nutrient applications. For example, the total-nitrogen load in base flow needs to be reduced by 62 percent before effects of BMPs could be detected (table 14). This percent reduction represents a reduction of 3,256 lb of the 5,251 lb of total nitrogen (table 10) discharged during the 2-year study as compared to the 85,640 lb of nitrogen that were applied to the soil from the spreading of manure, commercial fertilizer, and the grazing of animals during the same period. It should also be stressed that, if nutrient management or a reduction in animal units are the only practices implemented, reductions in base-flow loads can only be achieved by reducing the nutrient and sediment concentrations in the stream, because these management practices do not affect streamflow or stream velocities, which in turn, also control the magnitude of the loads.

Table 14.--Water-quality characteristics of base flow and estimates of reductions required for statistically-significant changes at the Bald Eagle Creek site, and the Rural Clean Water Program (RCWP) Nutrient-Management and Forested Subbasins

[Concentration, in milligrams per liter; load, in pounds; standard deviation, in percent except where noted; estimated reductions, in percent; n, number of samples]

Constituent	Study period				Nongrowing season				Growing season				Estimated reductions required
	Mean	Standard deviation		n	Mean	Standard deviation		n	Mean	Standard deviation		n	
		Plus	Minus			Plus	Minus			Plus	Minus		
						BALD EAGLE CREEK							
Nitrite plus nitrate, dissolved as N													
concentration	4.2	12	12	22	4.6	9	8	10	3.9	8	8	12	14
load	6.9	[a]2.9	[a]2.9	22	8.4	[a]2.9	[a]2.9	10	5.6	[a]2.2	[a]2.2	12	65
Nitrogen, total as N													
concentration	4.9	12	10	22	5.4	8	7	10	4.6	8	7	12	12
load	8.2	[a]3.4	[a]3.4	22	8.4	[a]4.1	[a]4.1	10	8.0	[a]2.8	[a]2.8	12	62
Phosphorus, total as P													
concentration	.06	33	33	21	.05	60	40	10	.06	36	26	11	48
load	.09	67	44	21	.08	110	50	10	.09	56	33	11	57
Phosphorus, dissolved as P													
concentration	.03	67	33	22	.03	64	39	10	.03	43	30	12	43
load	.06	[a].03	[a].03	22	.07	[a].04	[a].04	10	.06	[a].03	[a].03	12	90
						FORESTED SUBBASIN							
Nitrite plus nitrate, dissolved as N													
concentration	2.7	15	13	30	3.0	10	10	15	2.6	14	13	15	17
load	3.7	120	57	30	3.5	130	57	15	3.8	140	57	15	69
Nitrogen, total as N													
concentration	3.3	[a].52	[a].52	30	3.5	12	10	15	3.0	20	16	15	18
load	4.4	120	55	30	4.2	120	55	15	4.5	130	56	15	68
Phosphorus, total as P													
concentration	.05	60	40	30	.05	47	28	15	.05	77	44	15	48
load	.07	86	47	30	.06	87	46	15	.07	93	47	15	57
Phosphorus, dissolved as P													
concentration	.04	76	43	30	.04	49	33	15	.03	98	47	15	46
load	.05	88	47	30	.05	77	44	15	.05	94	53	15	58
						NUTRIENT-MANAGEMENT SUBBASIN							
Nitrite plus nitrate, dissolved as N													
concentration	7.8	27	22	29	9.1	10	9	14	6.7	28	21	15	17
load	24	150	60	29	26	150	58	14	22	160	62	15	68
Nitrogen, total as N													
concentration	9.0	22	18	28	10	[a].85	[a].85	13	8.3	[a]1.6	[a]1.6	15	15
load	26	140	58	28	26	130	58	13	27	150	59	15	63
Phosphorus, total as P													
concentration	.18	50	33	28	.16	25	19	13	.20	70	40	15	36
load	.52	98	50	28	.40	130	55	13	.66	71	41	15	56
Phosphorus, dissolved as P													
concentration	.14	49	33	28	.13	180	23	13	.15	60	40	15	35
load	.40	98	50	28	.33	120	55	13	.48	75	44	15	56

[a] Results for these constituents come from normally distributed data.

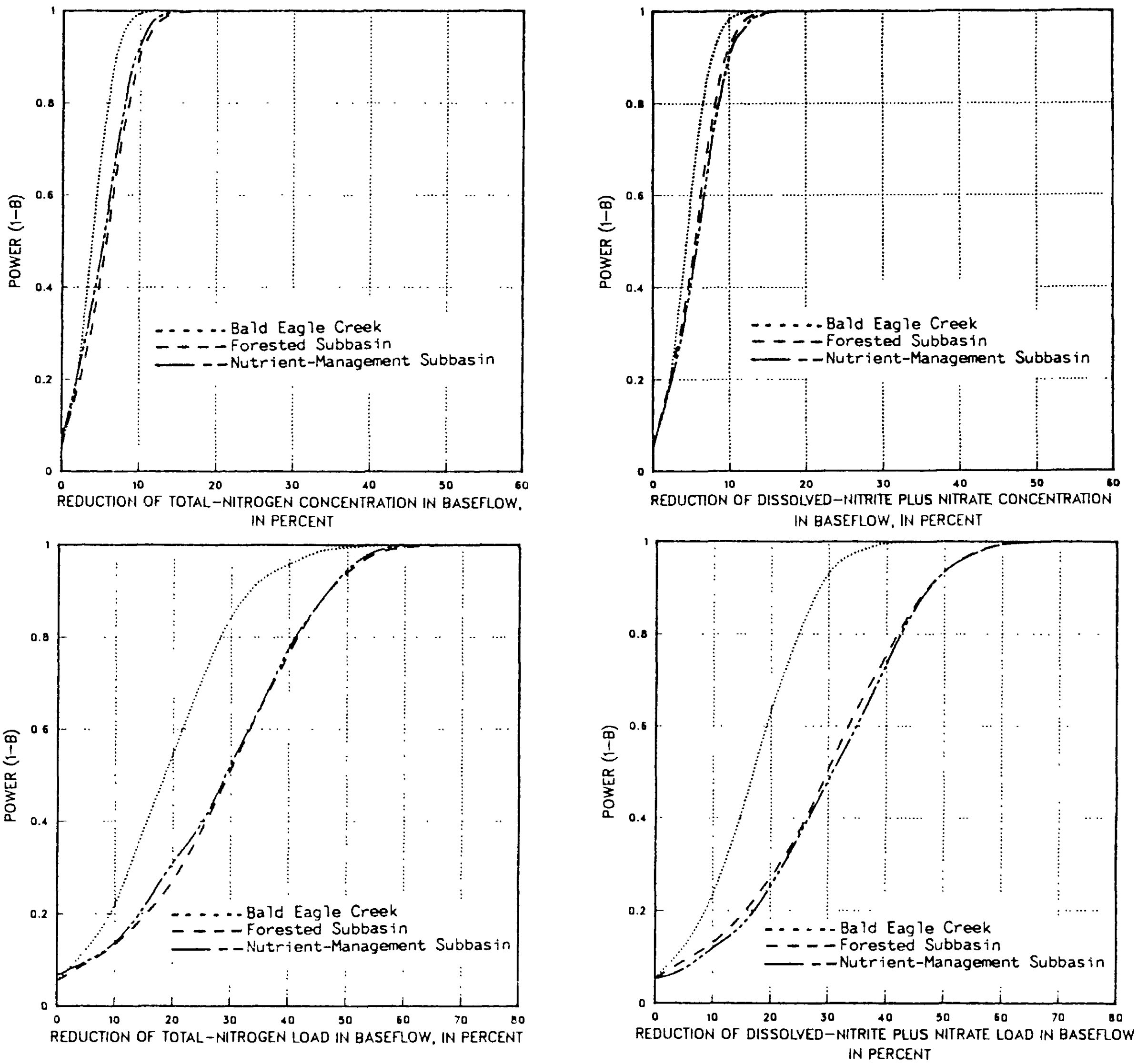


Figure 21.--Probability of achieving statistically significant changes at selected reductions in total-nitrogen and dissolved-nitrite plus nitrate concentrations and loads in base flow.

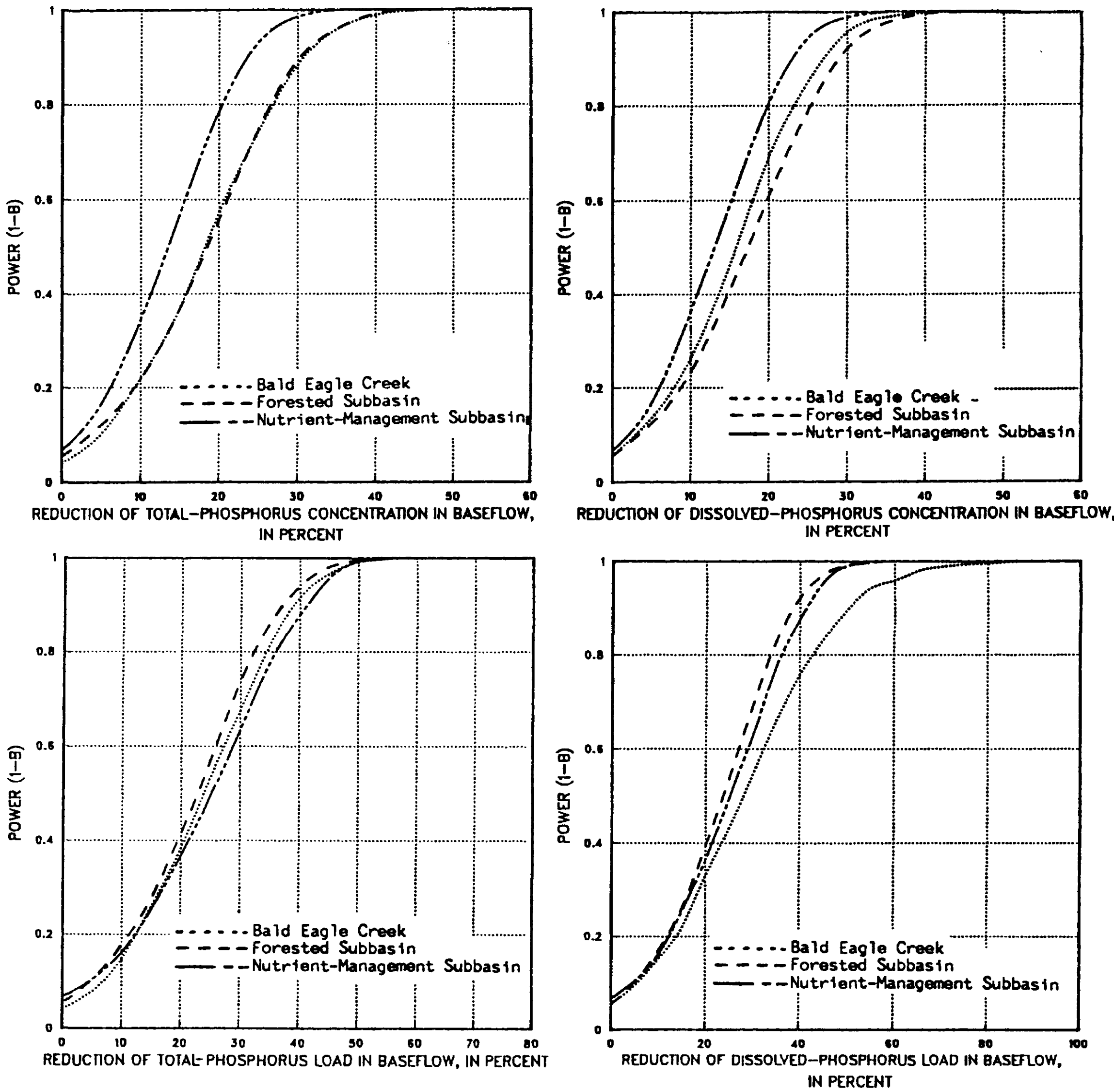


Figure 22.--Probability of achieving statistically significant changes at selected reductions in total- and dissolved-phosphorus concentrations and loads in base flow.

HYPOTHETICAL EFFECTS OF REDUCTIONS IN NUTRIENT APPLICATIONS ON SURFACE-WATER QUALITY, AND IMPORTANCE OF LAND-USE CHANGES AND RANDOM EVENTS

The characterization of the Bald Eagle Creek, like the Small Watershed of the RCWP project in Lancaster County (D.K. Fishel, U.S. Geological Survey, written commun., 1989), points out the complexity of attempting to improve water quality by implementing agricultural management practices. The difficulty in improving water quality arises from the current variability in land use (nutrient applications), other land-use changes (construction, crop rotation, animal populations, and so forth), and random events such as precipitation, which affects transport in base flow and surface runoff. Variability in nutrient applications is caused by the timing of applications, which may be governed by precipitation, crop requirements, manure-storage capacities, animal populations, and size of the watershed.

Changes in the timing of the applications will alter the estimates required for significant changes. If seasonal variations in nutrient applications change, as is expected when nutrient management is implemented, then the utilization of nutrients by crops also will change. As a result, a change would be expected to occur in the amount of nutrients available for transport to the stream in surface runoff or in ground water released as base flow.

Improvement of Water Quality

As suggested by the estimates required for significant changes in table 14, the effects of nutrient management on water quality at the Bald Eagle Creek site as in the Little Conestoga Creek headwaters likely will be minimal if nutrient applications are not reduced substantially on a regional basis within the 2-year time frame of the project. Inasmuch as nutrient management will not affect streamflow or stream velocities, and the amount and timing of precipitation can not be controlled, water quality will only be improved by nutrient management if nutrient concentrations in the water are reduced.

In addition to statistical testing, hypothetical effects of nutrient management need to be evaluated separately for each constituent on the basis of the constituent's chemical or physical contribution to water quality and its interaction with other constituents. Specific concentrations of nitrogen and phosphorus have been associated with particular environmental conditions. For example, 0.3 mg/L of inorganic nitrogen (nitrite, nitrate, and ammonia), and 0.01 mg/L of phosphorus are critical values which, when exceeded, can stimulate excessive growth of algae in streams (McKee and Wolf, 1963; Harms and others, 1974). MacKenthum (1969) indicates that total phosphorus should not exceed 0.1 mg/L if nuisance growths in free-flowing streams are to be prevented. The USEPA recommends that total phosphorus should not exceed 0.05 mg/L in streams in order to prevent biological nuisances (U.S. Environmental Protection Agency, 1986). All of the samples collected at Bald Eagle Creek exceeded the critical value for inorganic nitrogen, and 82 percent of the total 118 samples of base flow and stormflow exceeded the total phosphorus concentration suggested by MacKenthum (1969). These results suggest that any reduction in concentrations of nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen, or phosphorus would improve the water quality even if statistical tests do not indicate a significant change. Because no criteria have been established for nutrient loadings from nonpoint sources, the effects of reducing nitrogen and phosphorus loads on aquatic environments in stream reaches cannot be evaluated at this time.

Finally, it should be noted that characterization of the Bald Eagle Creek site, as was done at the RCWP Nutrient-Management Subbasin, suggests that any significant improvement in water quality at the site may have little effect on downstream water quality if nutrients are discharged to the stream downstream from the sampling site at a greater rate than they were measured at the site. Therefore, even though nutrient management can affect local water quality, regional implementation of nutrient management may be needed to affect regional inflows to the Chesapeake Bay.

Effects of Land-Use Changes

The preceding discussion was based on the assumption that no major changes in land use or management practices other than those recommended by the nutrient-management specialist are implemented within the study area during the post-BMP phase. However, during the pre-BMP phase, the landowner at the gaging site made modifications to the stream channel. Plans also are being made by the highway department to install a second culvert at the bridge that will act as the high-water control. These changes may affect water quality because the potential for transport of sediment and associated nutrients increases when soils are exposed.

The use of manure storage-facilities also may affect nutrient application rates. If open storage facilities gain increased acceptance in the study area, the amount of nutrients applied from atmospheric deposition may increase. In addition, the timing of applications will change. Recent studies by van Breeman and others (1982) and data collected by Fishel, Truhlar, and Langland (U.S. Geological Survey, written commun., 1988) indicate that nitrogen concentrations in precipitation, especially ammonia, can be significant near manure-storage facilities.

Changes in cropping patterns also affect soil nutrients. If the amount of alfalfa increases in the subbasin, (as may be recommended as part of the total management or farm-conservation plan to reduce soil loss), soil-nitrogen concentrations also may increase. If not used by other crops, the nitrogen from the atmosphere fixed in the soil by the alfalfa and soybeans will become available for leaching to the ground water.

Impacts of Random Events

Random events that might affect nutrient management and water quality include, but are not limited to, large storms, changes in animal population or types, outbreaks of animal diseases, and changes in market demands. The effects of hurricanes or other large tropical storms on nutrient transport have been demonstrated by Fishel, Brown, Kostelnik, and Howse (U.S. Geological Survey, written commun., 1989). Such storms can substantially affect water quality by altering surface runoff, infiltration, recharge, crop uptake, evapotranspiration, and the timing of most farm operations.

Rapid changes in market demands or outbreaks of animal disease can cause changes in animal populations. If animal populations increase or changes are made in the type of animals raised--for example, if the animal population changes from predominantly poultry to dairy, additional manure and associated nutrients will likely be applied to the soil or exported. If animal diseases, such as avian influenza or pseudorabies break out in the subbasin, depopulation of the animals and quarantine of the farm could cause sudden changes in nutrient availability, and hence, restrictions on the transport of nutrients within the subbasin.

Future studies should also be aware of random events that may have an effect on the direction that their study takes like the random events that are beginning to affect the voluntary farmer cooperation during this study. Changes in the financial status of the agricultural community, the health of the land owners, and the religious and cultural mores of the farmers are causing the project to take new directions. For example, one of the farmers within the subbasin probably will sell his dairy herd because of sudden changes in his health, and others are hesitant to sign government contracts to install conservation practices, and are considering selling their farms. These changes will necessitate a reevaluation of the objectives of the project and may require some flexibility in project planning.

SUMMARY AND CONCLUSIONS

Hydrologic and land-use data were collected at the Bald Eagle Creek site from October 1985 through September 1987 in cooperation with the Susquehanna River Basin Commission as part of the United States Environmental Protection Agency's Chesapeake Bay Program. The study documents the water quality of small watersheds underlain by noncarbonate rock in the lower Susquehanna River basin during a 2-year period prior to the implementation of agricultural Best-Management Practices. This report describes a 0.43-mi^2 watershed underlain by albite-chlorite schist and oligoclase-mica schist.

Precipitation was 18 percent less than normal for the 2 years; during the 1986 water year, it was 37 percent less than normal and during the 1987 water year, it was 1 percent greater than normal. The growing seasons (April through September) were drier than normal by 57 percent in 1986 and by 13 percent in 1987.

About 88 percent of the land is used for cropland and pasture, and nearly 33 percent is planted in corn. Three small farms are located in the subbasin with a total crop acreage of about 185 acres. Dairy farms at the site generally rotate crops on a 2-year corn and 3-year alfalfa sequence.

The animal population is comprised entirely of dairy cattle. Animal density is about 1.07 AU/acre based on crop acreage available for disposal of manure as compared to the maximum of 1.5 AU/acre recommended by the Pennsylvania Department of Environmental Resources to control or mitigate nonpoint-source discharges (1 AU = 1,000 lb of body weight).

Nitrogen and phosphorus were applied primarily from March through June as commercial fertilizers. About 85,640 lb of nitrogen and 20,800 lb of phosphorus were applied; 52 percent of the nitrogen and 69 percent of the phosphorus were from commercial fertilizer. Farmers reported that they applied about 31 percent less nitrogen and 3 percent more phosphorus during water year 1987 than during water year 1986. The reduction in the amount of nitrogen applied during the second year was made voluntarily before recommendations were made by a nutrient-management specialist.

Soils at some fields were less than 36 in. deep. Therefore, the total nutrient content of the soils at Bald Eagle Creek may be inherently lower than that of soils in the carbonate areas of the Rural Clean Water Program study area in Lancaster County. Nitrate nitrogen concentrations were generally uniform throughout the soil column, suggesting that nitrate is highly mobile, whereas phosphorus consistently remained in the top 8 in. of the soil. Nitrate nitrogen ranged from 36 to 135 lb/acre and phosphorus ranged from 0.89 to 5.7 lb/acre in the top 4.0 ft of soil.

Streamflow was about 35 percent less than normal for the 2 years, reflecting below-normal precipitation. Annual mean streamflows were 0.33 and 0.32 ft^3/s for the 1986 and 1987 water years, respectively. Eighty-four percent of the total discharge was base flow.

Median concentrations of total nitrogen and dissolved-nitrate plus nitrite in base flow were 5.0 mg/L and 4.2 mg/L, respectively. Concentrations and discharges of dissolved-nitrate plus nitrite in base flow were greatest in February during the nongrowing season when base flow was high. Concentrations of total and dissolved organic nitrogen and ammonia nitrogen in base flow exhibited only slight seasonal trends. About 83 percent of the 5,251 lb of total nitrogen discharged in base flow was dissolved nitrate plus nitrite. About 651 lb of total nitrogen were discharged in the 28 percent of the stormflow that was sampled.

Concentrations of total phosphorus, unlike concentrations of nitrogen, did not exhibit a seasonal trend, whereas discharges of phosphorus were more closely associated with base flow. About 66.3 lb of total phosphorus were discharged in base flow; 59 percent was dissolved and 41 percent was orthophosphorus. Another 74 lb of total phosphorus were measured in the 28 percent of the stormflow that was sampled.

Median sediment concentrations were greatest in the growing season months of April and May, when the majority of the plowing was done. About 4,548 lb of sediment were discharged in base flow, while 232,000 lb of sediment were discharged in 51 percent of the sampled stormflow.

Results from nonparametric seasonal rank-sum tests indicate that concentrations of total nitrogen and phosphorus in base flow need to be reduced by 12 and 48 percent, respectively, and loads of total nitrogen and phosphorus in base flow need to be reduced by 62 and 57 percent, respectively, to detect a change in water quality. Reductions of these magnitudes are substantially smaller than the reductions required at the Nutrient-Management Subbasin in the carbonate valley of the Rural Clean Water Program study area, partly because of differences in geology, topography, nutrient content of the soils, and animal densities at the Bald Eagle Creek site.

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