EFFECTS OF SPECIFIC LAND USES ON NONPOINT SOURCES OF SUSPENDED SEDIMENT, NUTRIENTS, AND HERBICIDES - PEQUEA CREEK BASIN, PENNSYLVANIA 1979-80

By Patricia L. Lietman, Janice R. Ward, and T. E. Behrendt

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4.047×10^3	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Discharge	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
quart (qt)	1.057	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	3.785×10^3	milliliter (mL)
	Mass	
pound (lb)	0.4545	kilogram (kg)
ton (short, 2,000 pounds)	0.9072	metric ton (t)
ton per square mile (ton/mi^2)	0.3503	metric ton per square kilometer (t/km^2)

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ABSTRACT

The Susquehanna River Basin Commission and the U.S. Environmental Protection Agency cooperated with the U.S. Geological Survey in a study to quantify nonpoint-source loadings from an agricultural area in Pennsylvania. Pequea Creek, a tributary to the Susquehanna River, drains a 154-square mile agricultural area in Lancaster County, Pennsylvania. Previous studies defined the Pequea Creek basin as a contributor of sediment, nutrients, and pesticides from nonpoint sources to the Susquehanna River.

The purpose of this intensive watershed investigation was to determine the effects of various land uses on water quality of receiving streams. Streamflow was measured and monthly base-flow samples and water-weighted composite storm samples were analyzed for suspended sediment, nutrients, organic carbon, and triazine herbicides. Constituent loadings were calculated to quantify their discharge from the entire Pequea Creek basin and from four specific subbasins: forest, cornfield, rural residential, and pasture. Soil samples were analyzed for nutrients and selected herbicides, and land use and application data were collected to determine the source of loadings. Precipitation amounts and chemistry were also measured.

Precipitation and streamflow were below average for much of the investigation period, May 1979 to December 1980. The annual precipitation for 1980 was 10 inches below normal, with drought conditions the last half of the year.

During base flow, the highest concentrations of individual constituents generally observed were: 4.0 milligrams per liter total organic nitrogen and 1.4 milligrams per liter total phosphorus from the downstream pasture site; 24 milligrams per liter total nitrate nitrogen and 3.9 micrograms per liter total atrazine from the cornfield site; and 0.5 micrograms per liter total prometone, and 2.3 micrograms per liter total simazine from the residential site. Nearly all total nitrate nitrogen concentrations from the cornfield site during base flow were about double the U.S. Environmental Protection Agency (1977) criterion of 10 milligrams per liter.

The highest constituent concentrations found in composite storm samples were nearly all in samples from the cornfield site. The highest concentrations found were: 16,000 milligrams per liter suspended sediment, 54 milligrams per liter total organic nitrogen, 41 milligrams per liter total nitrate nitrogen, 19 milligrams per liter total phophorus, and 200 micrograms per liter total atrazine. The highest concentrations found in

composite storm samples for total prometone was 6.4 micrograms per liter at the residential site and for total simazine was 4.8 micrograms per liter at the downstream pasture site.

Generally, concentrations of all the constituents, except nitrate, were higher during storms than during baseflow at all sites. Total concentrations of the constituents increase during storms predominantly due to increases in suspended concentrations. The highest storm concentrations of most constituents occurred at the cornfield site. Fertilizer and herbicide applications increase the available sources of nutrients and herbicides for transport to the stream. The highest phosphorus, atrazine, and suspended-sediment concentrations at the cornfield site occurred during intense storms soon after application and planting.

Constituent yields (tons per square mile) from storms, about evenly distributed throughout the basin, were compared from the other specific land-use sites to the forest site, which represents a relatively undisturbed land use. During storms, yields for suspended sediment, total organic nitrogen, and total phosphorus were highest for the pasture and lowest for the forest site. Total nitrate-nitrogen yields were highest for the cornfield and about the same for the forest and residential sites. Yields of total organic carbon were about the same for the cornfield and residential sites, which were both slightly higher than the forest site.

The total loads discharged into the Susquehanna River from Pequea Creek from January 1 to December 31, 1980 with 100,000 acre-feet of water were: 12,000 tons of suspended sediment, 840 tons of nitrate nitrogen, 72 tons of organic nitrogen, 21 tons of phosphorus, 540 tons of organic carbon, 93 pounds of atrazine, 52 pounds of simazine, and 5.0 pounds of prometone. Loads for 1980 were much lower than loads for 1978 and 1979 from the Pequea Creek basin, due to below normal precipitation. A comparison of data from Pequea Creek at Martic Forge and the Susquehanna River at Harrisburg shows that during some months, Pequea Creek significantly increased the loads of nitrate nitrogen and suspended sediment of the Susquehanna River.

INTRODUCTION

The Susquehanna River Basin Commission and the U.S. Environmental Protection Agency cooperated with the U.S. Geological Survey in a study to quantify nonpoint-source loadings from an agricultural area in Pennsylvania. Eutrophication and toxic substances are primary water-quality problems in the Chesapeake Bay (Chesapeake Bay Program, Environmental Protection Agency, written commun. 1982). The lower Susquehanna River basin has been identified as a primary source of sediment and nutrients to the Upper Chesapeake Bay (Clark and others, 1973, 1974). Levels of suspended sediment, nitrogen, and phosphorus in the past have been controlled only by regulating the quality of point discharges from industries and waste-water treatment plants. However, it has become evident that, in many areas, regulation of all point discharges cannot reduce levels of these constituents in receiving streams to acceptable limits. Therefore, nonpoint-source loadings need to be investigated.

Because agriculture was suspected of contributing much of the sediment and nutrients to the lower Susquehanna River and the Chesapeake Bay, a study of nonpoint-source discharges from an agricultural area was conducted from 1977 to 1981. Pequea Creek was selected for an investigation because the basin is typical of agricultural areas in southeastern Pennsylvania, and is a significant nonpoint-source contributor of suspended sediment, nitrogen, and phosphorus to the Susquehanna River (Ward and Eckhardt, 1979). Loads of these constituents and of triazine herbicides increased significantly during storms. High nitrate nitrogen concentrations during base flow in streams sampled from 1977 to 1979 (Ward and Eckhardt, 1979) tend to confirm studies in Lancaster County (Poth, 1977) which showed widespread nitrate nitrogen contamination of ground-water supplies. Contamination is generally confined to areas underlain by limestone and dolomite, as is most of the Pequea Creek basin. The factors found most influential in determining the transport of these nonpoint constituents are rainfall, runoff, and farming practices.

The purpose of this study was to determine the effects of agricultural practices and other land uses on water quality of receiving streams in the Pequea Creek basin by measuring streamflow and concentrations of suspended sediment, nutrients, organic carbon, and herbicides during various hydrologic conditions. Information concerning land use, application rates, and soil data were used to determine sources of loadings. Precipitation quantities and chemistry were also measured.

This report presents the results of data collected from May 1979 to December 1980. For ease in comparison of data, all references to species of nitrogen and phosphorus in this report are to be considered in their elemental form. For example, regardless of whether ammonium or nitrate is being discussed, the values and discussion all refer to their concentrations expressed as nitrogen. The information in this report should be useful to water managers and the agricultural community. Also, the Chesapeake Bay Program is using the data to develop runoff, transport, and routing models that can simulate water quality in the Chesapeake Bay and its major tributaries.

Acknowledgments

The authors acknowledge the dedicated efforts of many U.S. Geological Survey employees both in the field and laboratory, which enabled the successful completion of this study. Mr. Charles Takita and Mr. John Hauenstein of the Susquehanna River Basin Commission provided continuing technical and field assistance. The Chesapeake Bay Program, U.S. Environmental Protection Agency, spent many weeks identifying and digitizing land uses on aerial photographs to develop land use maps for the study area. The Pesticide Research Laboratory, Pennsylvania State University, analyzed soil pesticides. Mr. Marvin Herr and Mr. Kenneth Groff provided continuous land-use and application data for sites located on their properties.

General Basin Factors Affecting Streamflow and Constituent Transport

The streamflow and water-quality characteristics of streams are affected by numerous factors. These include physiography, geology, soils, climate, land use, and land cover.

Pequea Creek basin is in the southern part of the Conestoga Valley, a carbonate and shale section of the Appalachian Piedmont. The 154-mi^2 basin is long and narrow and stretches about 60 mi from the Welsh Mountains to the Susquehanna River (fig. 1). Basin slopes are mostly less than 15 percent.

Most of the basin is underlain by limestone and dolomite of Ordovician and Cambrian age. There is quartzite, schist, and gneiss of Cambrian and Precambrian age along the northeast border and schist of early Paleozoic age along the southern border of the basin.

Most soils are classed as silt loams belonging to the Conestoga-Hollinger, Duffield-Hagerstown, and Chester-Glenelg associations. They are productive, well-drained soils that have high moisture-holding capacities (U.S. Dept. of Agriculture, 1956). Because of intense farming practices, the soils are generally classified as moderately eroded with some cases of severe erosion.

The growing season generally lasts from May 3 to October 10 and averages 160 days. Monthly mean temperatures during the study period ranged from 78°F in July and August 1980 to 30°F in February 1980. Annual mean temperatures were 54°F in both 1979 and 1980 (National Oceanic and Atmospheric Administration, 1979, 1980). Subfreezing temperatures usually occur during December, January, and February. Average snow accumulations range from 0.3 in. in April to 9 in. in March. About 50 percent of the yearly precipitation falls from May to September.

Annual precipitation averages about 39 in., based on 23 years of record from a National Weather Service station at Holtwood. The maximum monthly precipitation during the period of study was 8.16 in. in September 1979 and the minimum monthly precipitation was 0.51 in. in December 1980. Total precipitation for 1980 was 10 in. below average.

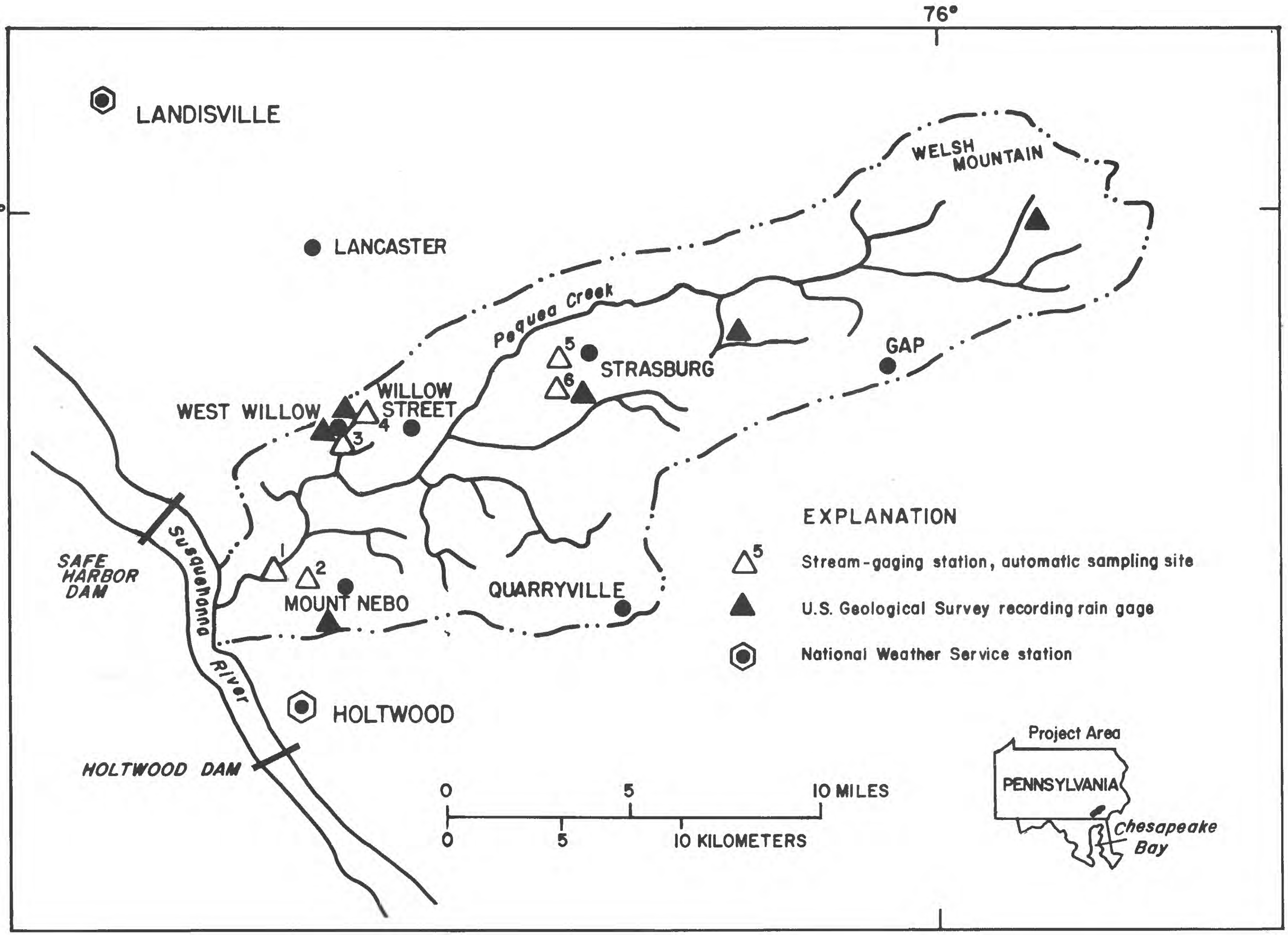


Figure 1.--Data-collection sites.

Land uses in the basin were digitized, using a grid size of 1 acre, from aerial photographs taken by the U.S. Environmental Protection Agency, Environmental Photographic Interpretation Center. About 68 percent of the basin is agricultural, of which almost half is used to grow corn and the remainder to grow small grains and for pasture (table 1). Pastures and farmsteads are usually concentrated near streams. Well-drained land away from streams is tilled. Forests, which cover 20 percent of the basin, are concentrated on steep slopes in the headwaters of streams. About 8 percent of the basin is residential, and the only two boroughs are Strasburg and Quarryville.

Table 1.--Land use in the Pequea Creek basin upstream from Pequea Creek at Martic Forge

Land Use	Percentage of basin		
Agricultural	68.4		
Pasture		11.8	
Small grains		22.2	
Row crops		31.4	
Corn			29.0
Tobacco			1.5
Soybeans			.4
Vegetables			.5
Orchard		.4	
Farmsteads		2.5	
Fallow		.1	
Idle	3.3		
Residential	7.6		
Industrial	.7		
Railroad	.2		
Highway	.1		
Forest	19.6		
Ponds and streams	.1		

Annual applications of fertilizer and pesticide to farmland were estimated by the Soil Conservation Service, Lancaster County District Office (SCS, oral commun., 1980). Nitrogen was applied at a rate of 31 lb/acre in commercial fertilizer and 94 lb/acre in manure. Phosphorus was applied at a rate of 34 lb/acre in commercial fertilizer and 73 lb/acre in manure. Triazine herbicides were applied at a rate of 0.6 lb/acre. Total annual applications of nitrogen, phosphorus, and triazines to the basin were estimated to be 4,200 tons, 3,600 tons, and 20 tons, respectively.

DATA COLLECTION NETWORK AND ANALYSES

Sampling Network

Six water-quality and stream-gaging stations were installed in Pequea Creek basin for measuring nonpoint discharges from different land uses (fig. 1) (table 2). Four major land uses were monitored (fig. 2) that represent those uses thought to have a significant impact on chemical quality of receiving streams.

The forest site is located on a Pequea Creek tributary near Mount Nebo. This 0.20-mi^2 subbasin is 77 percent forest, composed mostly of deciduous hardwoods. The remainder is cornfields, roads, and grassy areas (table 3). The average land slope is 13.3 percent. This forest site represents relatively undisturbed land, and so is considered a control site.

The cornfield site, a subbasin of 0.18-mi^2, is on Goods Run tributary at West Willow. Eighty-seven percent of this area is planted in corn with the remainder in barley, brush, and grass. The farming practices are best described as conservation tillage. After harvest in the fall, the remaining corn stalks are disked into the soil. The soil is left in this condition until late spring when the soil is chisel-plowed, planted, fertilized, and herbicide applied. Slopes in this subbasin average 9.2 percent.

The residential site, Goods Run tributary at Willow Street, is a 0.23-mi^2 area. The area is medium-density residential housing on about one-half acre lots. The area is sewered and on public water supply. The subbasin contains 36 percent impervious surfaces and 57 percent grassy area. Lawns are generally well maintained. Many residents apply fertilizers and pesticides to their lawns and small vegetable plots. The average slope of this area is 2.5 percent.

Two sites, upstream and downstream of a pasture were monitored on Pequea Creek tributary at Strasburg. The upstream pasture site drains a 0.56-mi^2 area of mixed land uses; 23 percent in cornfields, 21 percent impervious surfaces, and 32 percent pasture. The drainage area between the upstream and downstream pasture sites is 0.03-mi^2, which is 67 percent pasture and 25 percent other grassy areas. The remaining areas are impervious surfaces including farm buildings, a barnyard, and a vegetable garden. The barnyard area is barren, and runoff from the barnyard flows through erosion channels in the pasture and enters the stream about halfway between the two sites. Cows crossing the stream increase stream bank and stream bottom erosion and stir up sediment from the stream bottom. In the summer, heavy algae growth occurs in the reach of the stream flowing through the pasture. Slopes for the upstream site average 1.7 percent, and slopes in the pasture area average 8.4 percent.

The sixth site, Pequea Creek at Martic Forge represents the cumulative effect of all nonpoint sources in the entire basin. It is located approximately 3 miles from the creek mouth and drains 148-mi^2, 96 percent of the Pequea Creek basin.

Table 2.--Pequea Creek basin sites

Site No.	Site	Station identification No.	Station name	Drainage area (mi^2)
1	Pequea Creek	01576787	Pequea Creek at Martic Forge.	148
2	Forest	01576788	Pequea Creek tributary near Mount Nebo.	.20
3	Cornfield	01576783	Goods Run tributary at West Willow.	.18
4	Residential	01576782	Goods Run tributary at Willow Street.	.23
5	Downstream pasture.	01576772	Site No. 2 on Pequea Creek tributary at Strasburg.	.59
6	Upstream pasture.	01576771	Site No. 1 on Pequea Creek tributary at Strasburg.	.56
--	Pasture	--	Pasture (area between upstream and downstream pasture sites).	.03

Table 3.--Land use in subbasins selected for study.

Site	Drainage area (mi^2)	Land use, in percent							
		Cornfield	Small grain	Pasture	Forest	Impervious	Grass	Vegetable	Other
Forest	0.20	12.7	4.9	-	76.7	2.5	3.2	-	-
Cornfield	.18	87.4	5.0	-	-	2.1	4.4	-	1.1
Residential	.23	5.9	-	-	-	35.8	57.0	1.2	.1
Upstream pasture	.59	23.2	11.2	7.9	-	21.5	31.7	.7	3.8
Pasture 1/	.03	-	-	66.7	-	5.7	24.6	2.9	.1

1/ area between upstream and downstream pasture sites


-A


B


-C


-D

Figure 2.--Specific land-use sites in Pequea Creek basin: forest (A), cornfield (B), residential (C), and pasture(D).

Data Collection

Stream stage at each site was continuously measured with Stevens[1/] graphic recorders. Low-water weirs were installed in the small streams to create sampling pools and to stabilize the stream channel. Stormflow, for the purpose of this report, represents all streamflow which occurs from the initial rise in stream stage at the beginning of a storm until the stream stage stabilizes or returns to prestorm levels. Stream discharge measurements were made at all six sites through the range of stream stages occurring during base-flow and storm periods, according to techniques described by Buchanan and Somers (1969). Stream stages were converted to streamflow using methods described by Carter and Davidian (1965).

A time period was assigned to each base-flow sample based on changes in flow and seasonal land-use activities that might affect the constituent concentrations. The constituent concentrations measured in each sample were considered representative of the time period assigned. Average base flow for the periods and mean concentrations were used in the estimation of base-flow yields.

Storm samples were collected with modified automatic samplers, either the PS-69 or Manning[1/] (fig. 3). Intakes for the automatic samplers were positioned in the center of flow and samples were pulled into a length of perforated tubing which extended from the bottom to the surface of the stream. Each time a sample was collected, a mark was made on the graphic recorder to identify the streamflow which corresponded to that sample.

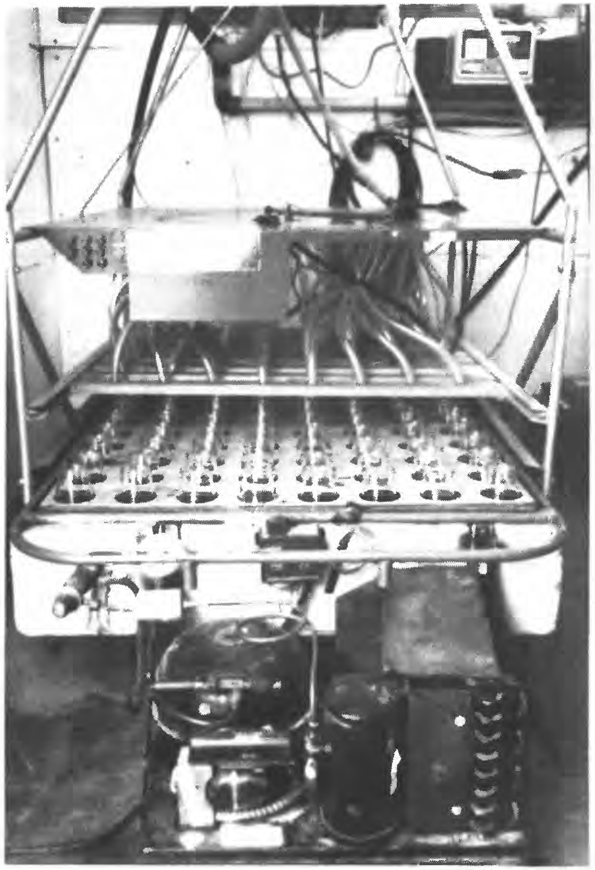
The storm samples were composited on a flow-weighted basis according to the equation:

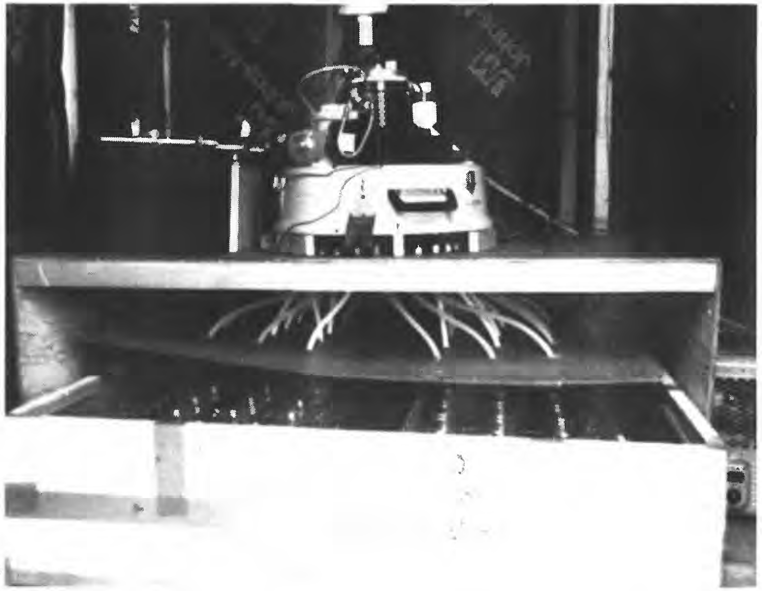
$$V_c = \frac{Q_i T_i V_f}{\Sigma\ Q_i T_i} \qquad (1)$$

where V_c = volume of sample to be composited, Q_i = mean discharge sample represents, T_i = time interval (hrs) sample represents, and V_f = final volume of composite sample. Samples were collected from the streams at various flows by hand using techniques described by Guy and Norman (1970), Culbertson and Feltz (1972) and the Federal Working Group on Pesticide Management (1974). Discrete samples were analyzed and graphs of resulting data drawn. The total storm discharge of each chemical constituent was computed for each site using streamflow and concentration integration techniques described by Porterfield (1972). The mean concentrations were then compared to those of the composited automatic samples. Samples were collected periodically by hand to compare concentrations to those collected automatically to insure that the automatic samples were representative of the quality in the stream.

Sampling began at the Pequea Creek site in April 1979 for both storms and base flow. Base-flow samples were collected at the other five sites beginning in May 1979; storm sampling began in November 1979. Table 4 shows the percentage of storm coverge at each site.

1/ Use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.


-A


B-


C-

Figure 3.--PS-69 automatic pumping sampler modified with refrigeration unit (A), Manning sampler modified to collect quart samples in insulated drawer (B), and sampler intake with float (C).

Table 4.--Storm coverage at each water-quality site

Site	Number of samples	Number of storms	Percentage of storms covered
Pequea Creek	61	70	93
Forest	62	57	87
Cornfield	49	50	90
Residential	136	121	85
Downstream pasture	103	111	77
Upstream pasture	106	111	72

Stream samples were analyzed to determine concentrations of suspended sediment, total and dissolved nutrients, dissolved and suspended organic carbon, and total alachlor and triazine herbicides (table 5). Total concentrations were determined on unfiltered samples, and concentrations of dissolved constituents were determined for samples filtered through a 0.45-micron filter. All samples were preserved by chilling to 4°C from time of collection to analysis.

Nine composite soil samples were collected beginning in May 1979 at each of the specific land-use sites. Samples were collected during different phases of the growing season from the top four inches of soil and composited from eight sites throughout each subbasin. Sampling was done on both sides of the streams; areas subject to road runoff and stream flooding were avoided. Soil samples collected for particle size, nutrients, and carbon analyses were kept chilled at 4°C. Samples collected for triazine herbicides were frozen until analysis (table 5).

Rain gages which recorded amounts and intensities of precipitation were operated throughout the investigation at the specific land-use sites beginning in May 1979. Two additional rain gages were installed in June and July 1979 in the upper Pequea Creek basin to enable the calculation of precipitation for the entire basin. This calculation was made according to the Theisson method (Theisson, 1911). Estimates for missing periods of record due to mechanical failure of the gages were made from rainfall records at nearby sites and National Weather Service information.

A precipitation sampler consisting of a 13 in. glass funnel and a sample bottle stored inside a portable ice-filled chest was used to collect precipitation-quality samples at the specific land-use sites during selected storms. This sampler was placed outside at the start of the storm and retrieved at the end of the storm. Samples were analyzed for total nutrients and total organic carbon (table 5).

Sediment and particle-size samples were analyzed at the U.S. Geological Survey sediment laboratory in Harrisburg, Pa. by methods described by Guy (1969). Soil samples were analyzed for triazine herbicides at Pennsylvania State University, according to Gunther (1970). All other samples were analyzed at the U.S. Geological Survey Central Laboratory in Atlanta, Ga. Inorganic chemical constituents were determined by methods described by Skougstad and others (1979), and organic carbon was determined by methods described by the U.S. Environmental Protection Agency (1974).

Table 5.--Constituents and characteristics analyzed in stream, soil, and precipitation samples

Base-flow and storm sample analyses		Soil sample analyses	Precipitation sample analyses
Suspended-sediment		Total:	Total:
Specific conductance		Ammonium	Organic carbon
Total and dissolved:		Ammonium plus organic nitrogen	Nitrite
Ammonium		Nitrite plus nitrate	Nitrite plus nitrate
Ammonium plus organic nitrogen		Phosphorus	Ammonium
Nitrite		Organic carbon	Ammonium plus organic nitrogen
Nitrite plus nitrate		Total triazine herbicides:	Phosphorus
Phosphorus		Atrazine	Orthophosphorus
Orthophosphorus		Simazine	
Dissolved and suspended organic carbon		Prometone	
Total triazine herbicides:		Prometryne	
Ametryne	Prometone	Propazine	
Atrazine	Propazine	Particle size	
Atratone	Simazine		
Cyanazine	Simetone		
Cyprazine	Simetryne		
Prometryne			
Total Alachlor			

Land Use and Application Data

Land-use data for the cornfield are shown in figures 4 and 5. In both 1979 and 1980, fertilizer and herbicides were applied in May at planting time. Fertilizer, 8-14-10 (percentage of nitrogen-phosphorus-potassium), was applied in the corn rows at a rate of 250 lb/acre in 1979 and 150 lb/acre in 1980. In addition, 150 lb/acre of anhydrous ammonia was injected into the soil in late April and early May 1980. Chicken manure was applied throughout the year in 1979, but none was spread on the fields in 1980. Nitrogen and phosphorus concentrations in manure shown in figures 4-6 were calculated according to U.S. Environmental Protection Agency (1978). Atrazine and cyanazine were applied to the cornfields in 1979 at rates of 1.0 and 2.0 qt/acre, respectively. In 1980, atrazine and alachlor were sprayed at rates of 1.25 and 2.0 qt/acre, respectively.

Land-use data for the pasture are shown in figure 6. Sixty cows were grazed in the pasture year round, weather permitting. Manure was occasionally spread on the pasture, however, this only made up about 4 percent of the total nitrogen and phosphorus the pasture received. Nitrogen was also applied to the pasture once, in April 1979. No pesticides were applied.

SOILS

Soil samples were collected throughout the year to examine seasonal variations and the effect of fertilizer application. By using the forest site as an indicator of naturally occurring conditions, the other sites were evaluated to determine the effects of different land uses on soil characteristics.

Types and Particle Size

The forest subbasin contains the Chester and Manor residual soils. Chester soil is deep and well drained, and Manor soil is shallow and well drained. These soils were derived from rapidly weathered, coarse-grained gneiss and slate with both rock formations containing a high percentage of mica. Particle-size analyses show that these soils have the highest sand content of any of the subbasin soils, averaging 32 percent sand, 37 percent silt, and 19 percent clay. The remaining material at all sites is gravel and organic matter.

The cornfield subbasin contains the Chester and Letort residual soils. Letort soil is deep, well drained, and productive. It was developed from dark-colored lime schist. The average particle size composition of the soils is 26 percent sand, 49 percent silt, and 19 percent clay.

Soils of the residential subbasin belong to the Conestoga series, which are underlain by micaceous limestone. They are highly productive, residual, deep, and well drained. The average particle size composition of the soils is 27 percent sand, 50 percent silt, and 20 percent clay.

The pasture subbasin contains the same soils as the residential subbasin. The average particle size composition is 17 percent sand, 63 percent silt, and 20 percent clay.

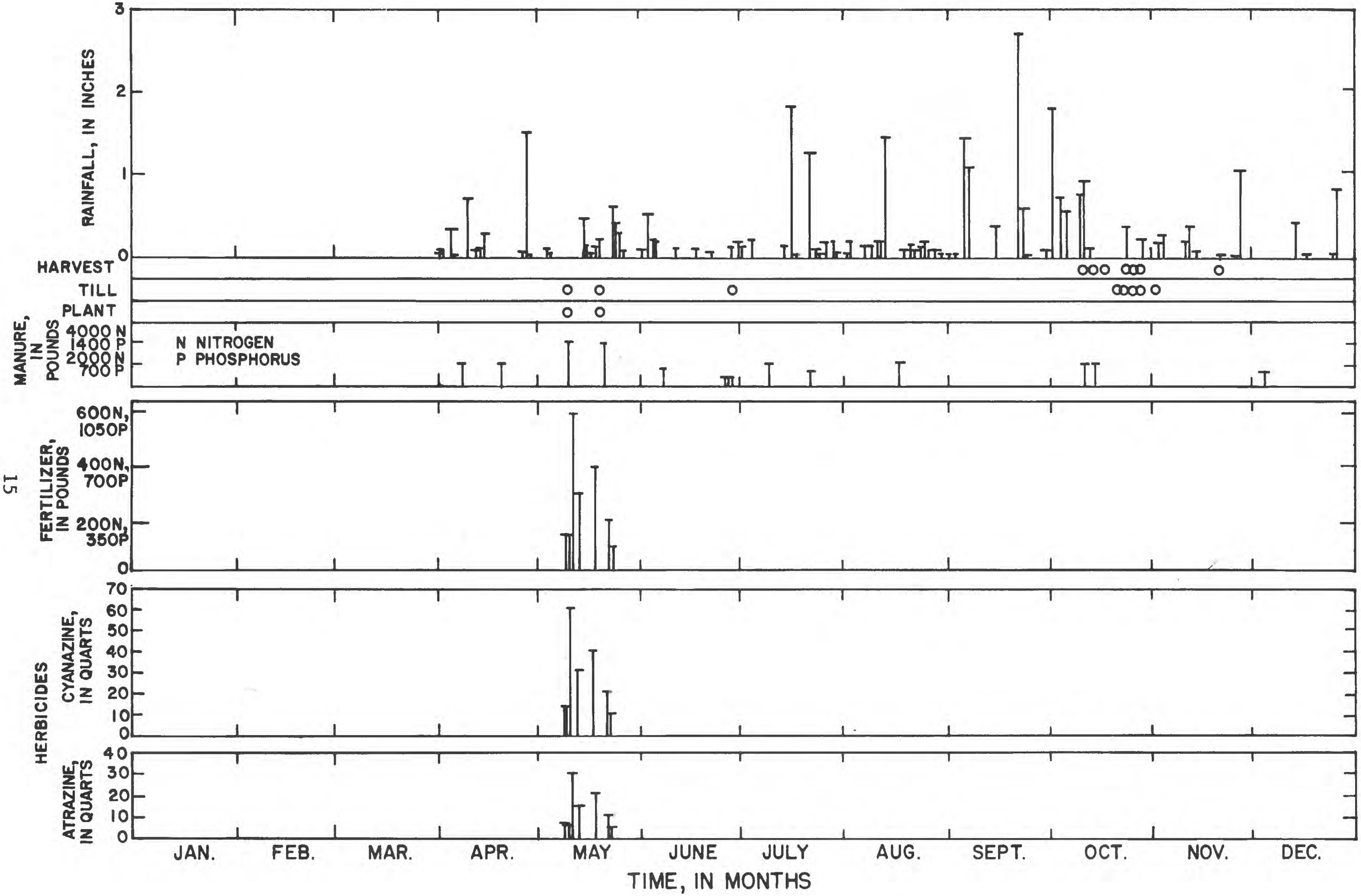


Figure 4.--Summary of precipitation, planting and harvesting schedule, and application schedule for fertilizer, manure, and herbicides for the cornfield site for 1979.

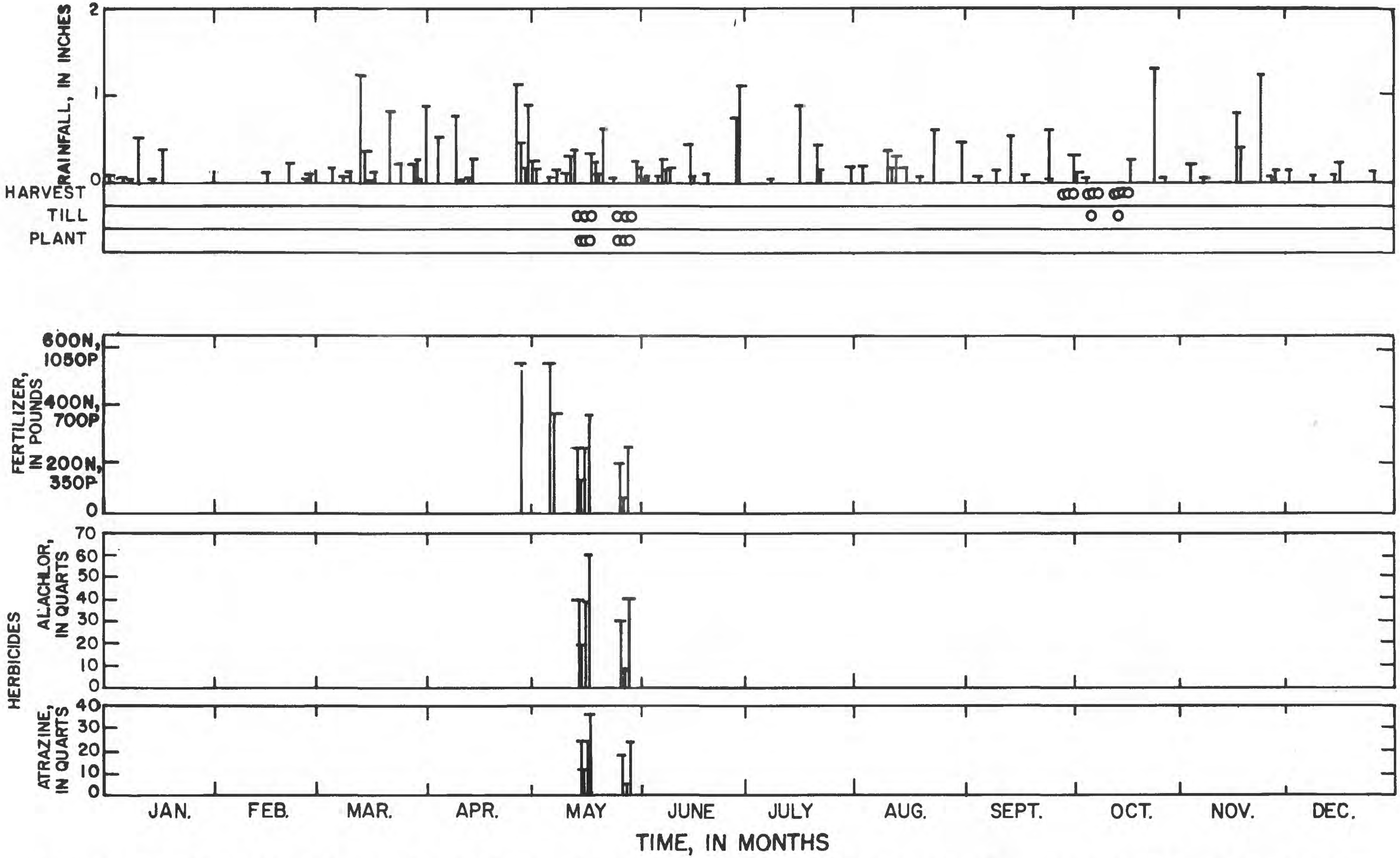


Figure 5.--Summary of precipitation, planting and harvesting schedule, and application schedule for fertilizer, manure, and herbicides for the cornfield site for 1980.

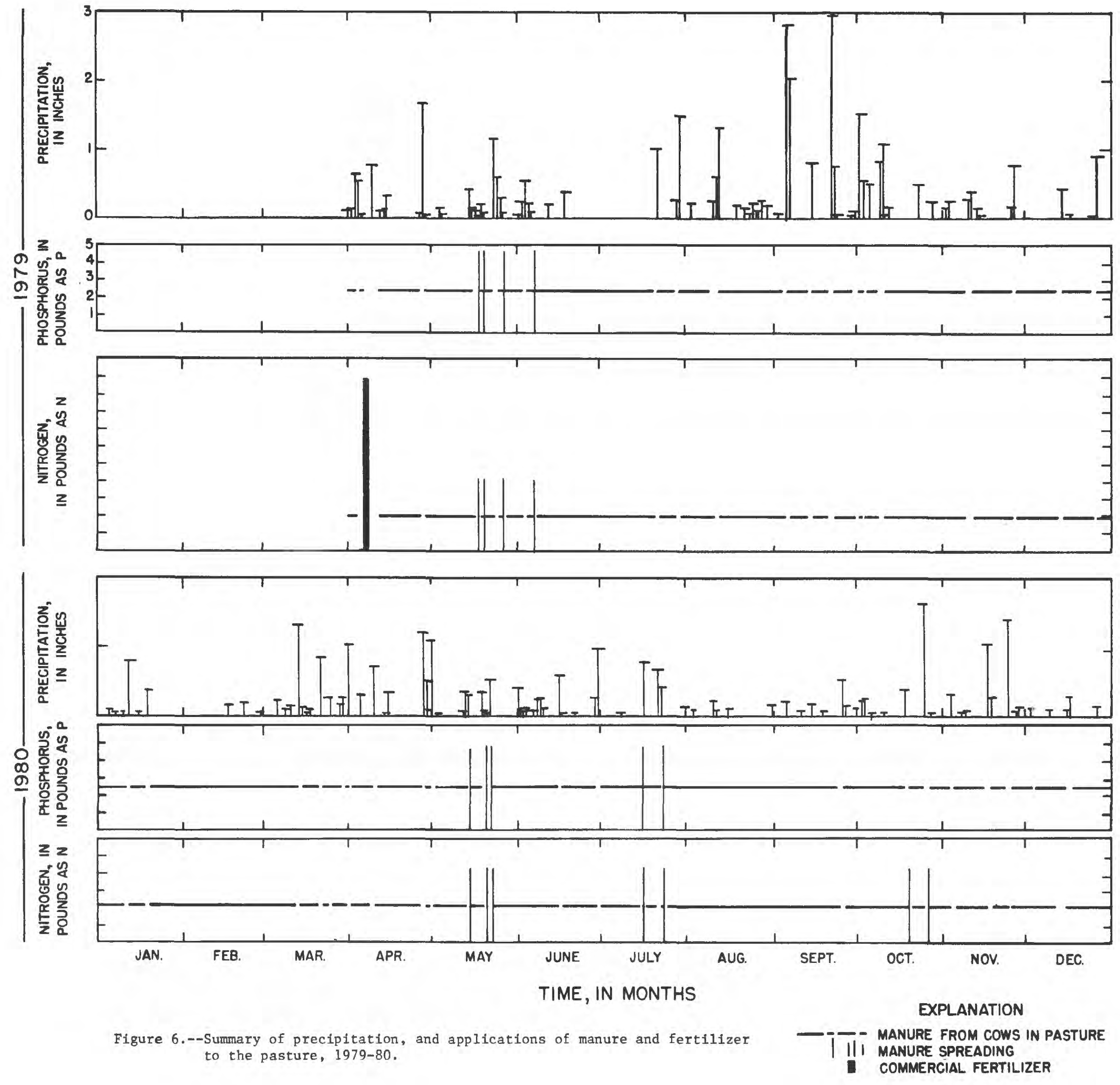


Figure 6.--Summary of precipitation, and applications of manure and fertilizer to the pasture, 1979-80.

Nutrients and Organic Carbon

Concentrations of indigenous soil nutrients and organic carbon are augmented by application of fertilizers, including manure and organic materials. Soil nutrients are depleted by plant uptake and by losses to percolation and runoff. All these factors vary according to land use.

The following compilation summarizes the mean carbon and nutrient concentrations for the soils of the four subbasins.

	Organic Carbon	Organic Nitrogen as N	Ammonium as N	Nitrite plus Nitrate as N	Phosphorus as P
	Percent		*Milligrams per kilogram*		
Forest	5.8	1.6	35	8.3	480
Residential	2.0	.7	8.4	9.7	449
Cornfield	1.7	.6	12	18	1,600
Pasture	3.5	1.6	11	32	2,030

Forest soils, having a yearly leaf fall with no tillage or additions of commercial fertilizer, showed the highest organic carbon, organic nitrogen, and ammonium content, and the lowest nitrite plus nitrate and phosphorus content. The high ammonium and low nitrate concentrations in the forest soils indicate that the process of nitrification proceeds at an unusually slow rate in contrast to the other subbasin soils. Residential soils are basically grass covered. When the soils are fertilized, a slow release, low nutrient fertilizer is used so as not to burn the lawn. The soils generally had lowest concentrations of all constituents. Cornfield soils had the lowest organic carbon and organic nitrogen contents. Because commercial fertilizer was applied at rates somewhat higher than that required for corn growth, the ammonium, nitrite plus nitrate, and phosphorus concentrations were intermediate to high. The pasture soils were continually subjected to application of manure from grazing cattle. They had the next highest organic carbon content, the same high organic nitrogen content as forest soils, the highest nitrite plus nitrate and phosphorus contents, and a relatively low ammonium content. An accumulation of phosphorus in the corn and pasture soils is probably due to phosphorus sorbing to soil particles, and thus becoming unavailable for plant uptake.

Organic nitrogen was the dominant nitrogen form and accounted for about 99 percent of the total nitrogen in all soil samples. Organic nitrogen occurs naturally as a component of the soil organic material. Commercial fertilizers containing urea or other forms of organic nitrogen, and plant material add to the natural concentrations. The forest soils had the highest maximum concentration of organic nitrogen of all the subbasin soils and also exhibited the greatest variations in concentration (fig. 7). Concentrations ranged from 8,200 to 31,000 mg/kg.

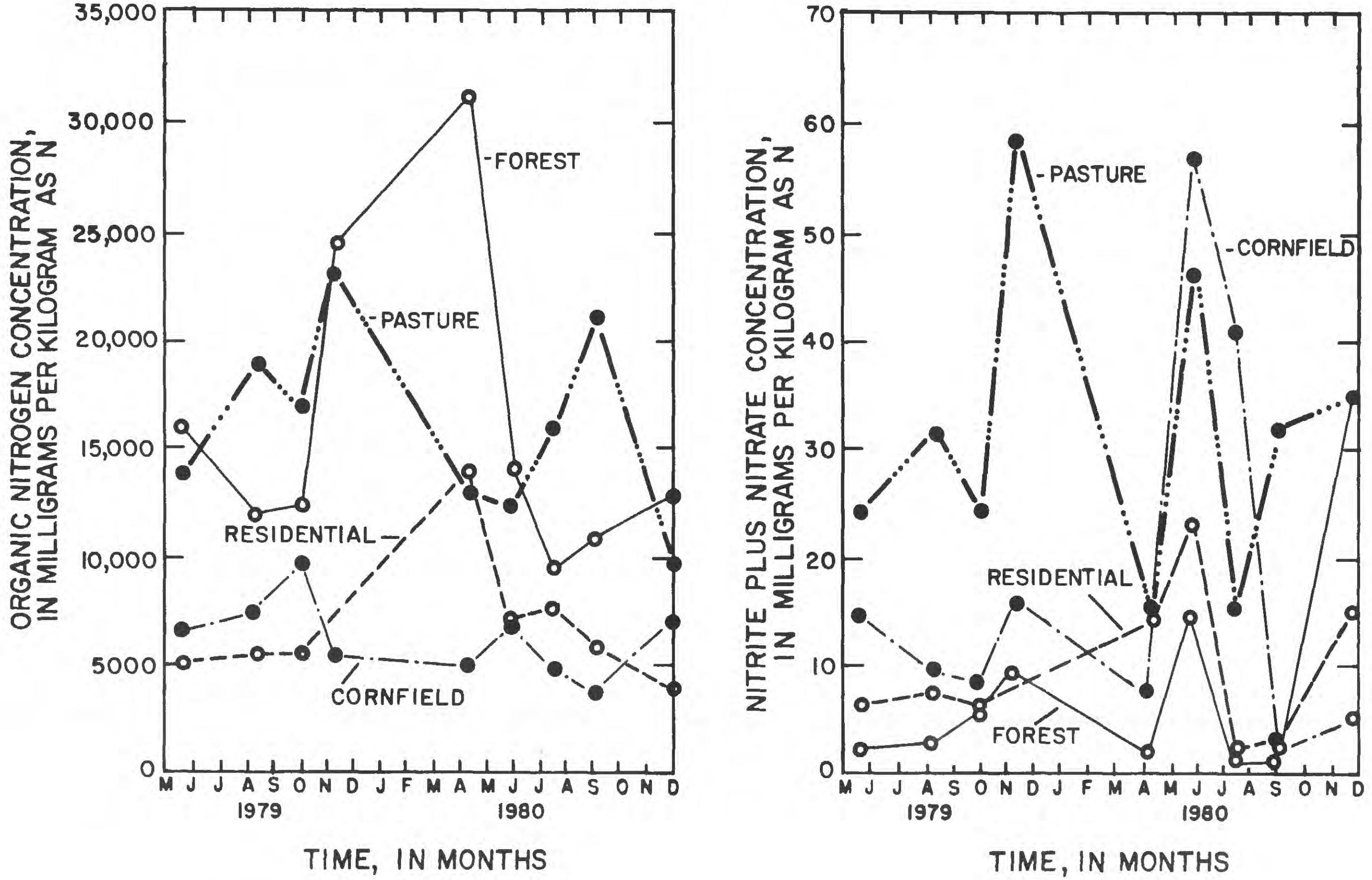


Figure 7.--Concentrations of organic nitrogen and nitrite plus nitrate in soil samples from specific land-use sites, May 1979 to December 1980.

Nitrite plus nitrate concentrations in soil were generally less than one percent of the total nitrogen concentrations. Soil nitrite and nitrate are derived from precipitation, commercial fertilizers, or through the process of nitrification (oxidation by microorganisms of ammonium to nitrites and then nitrates). Dramatic increases of nitrite plus nitrate concentrations in soil were observed at all sites in May 1980. The following increases in concentration were measured in soil samples from the April 8, 1980 to May 28, 1980 sampling dates: forest soil, 2.1 to 15 mg/kg, cornfield soil, 7.2 to 57 mg/kg, residential soil 14 to 23 mg/kg and pasture soil 17 to 46 mg/kg. These concentrations probably resulted from the application of fertilizer to the corn and pasture soils, and, as evidenced by an increase in the forest site, a higher than normal rate of nitrification accompanied by increased soil moisture from spring rains.

The primary source of phosphorus in soil is organic matter and fertilizer. The forest and residential soils had a narrow range of phosphorus concentrations and showed virtually no seasonal variation (fig. 8). The sites receiving nutrient enrichment contained higher and more variable concentrations. Concentrations of phosphorus in the cornfield soils ranged from 620 to 5,200 mg/kg and in the pasture soils from 640 to 9,800 mg/kg.

Organic carbon concentrations were higher and more variable in the soils of the two sites receiving the most organic matter. Organic content of the forest soils is augmented by tree leaves, and the pasture soils by manure.

Herbicides

The soil samples from all specific land-use sites were analyzed for five triazine herbicides: atrazine, simazine, prometone, prometryne, and propazine. Atrazine was the only herbicide detected, and it was only found in the cornfield soils (fig. 9). During both 1979 and 1980, the highest atrazine concentrations occurred in the May sample collected soon after herbicide application (figs. 4-5). The May 1979 and 1980 soil concentrations were 0.38 and 0.83 mg/kg, respectively. Differences in these atrazine concentrations may have been a result of higher application rates in 1980 coupled with varying rainfall and time between application and sampling. Later in the growing season, the soil sample concentrations of atrazine in 1979 and 1980 were about equal, regardless of the May concentration.

Literature indicates that the half-life of atrazine in soil is 1 to 2 months (Baker and Johnson, 1979). Atrazine concentrations in the cornfield soils steadily declined after application. In 1980 the half-life seemed to be 1 to 2 months until concentrations reached less than 0.2 mg/kg in late September. Colder temperatures may have affected the decay rate at this time. Atrazine concentrations in 1979 decreased at a slightly slower rate than in 1980. Varying amounts of rainfall and runoff during application, varying application rates, and varying soil temperatures and moisture levels probably caused different decay rates of atrazine concentrations between 1979 and 1980.

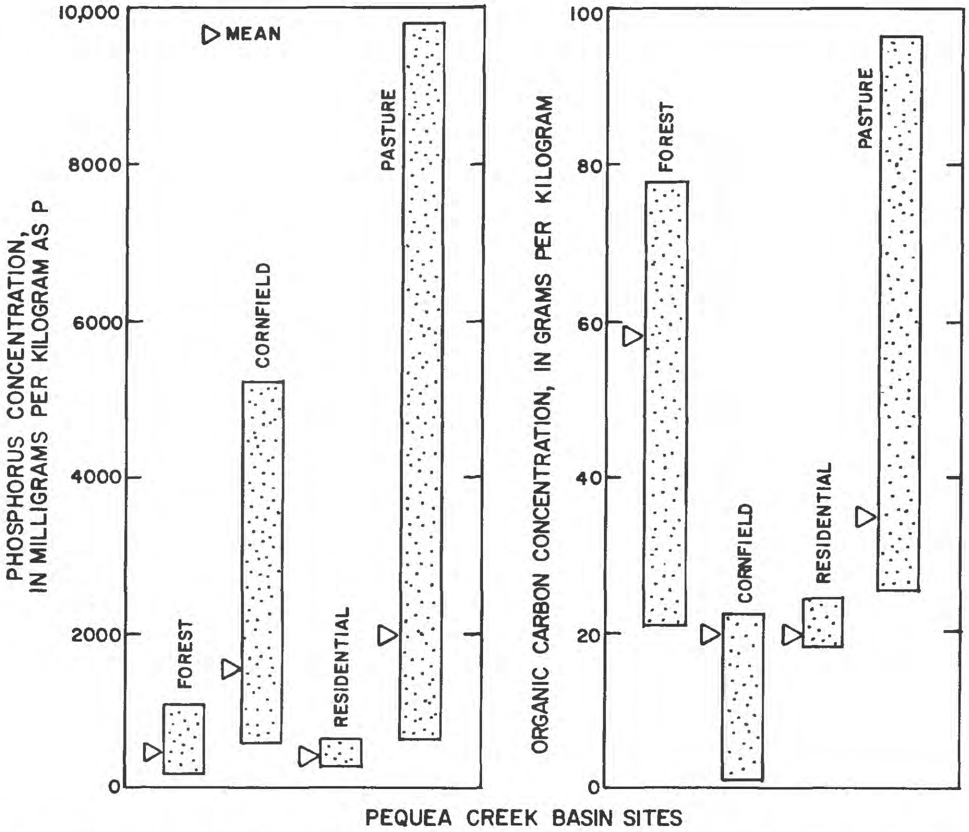


Figure 8.--Ranges and means of phosphorus and organic carbon concentrations in nine soil samples from each specific land-use site, May 1979 to December 1980.

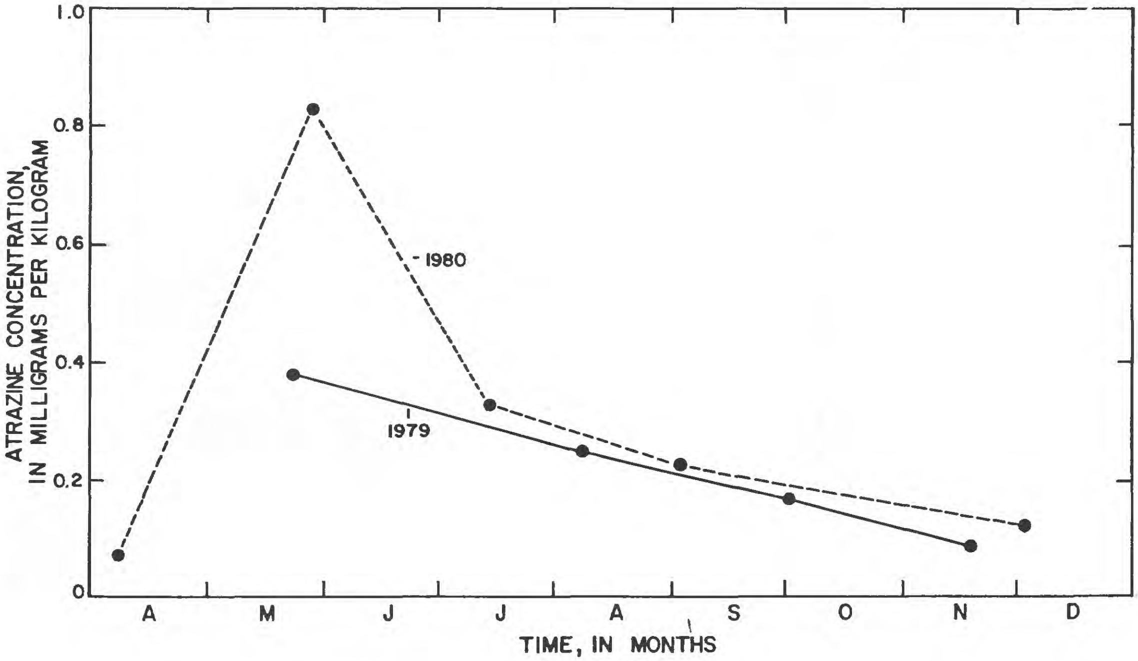


Figure 9.--Concentration of atrazine in soil samples from the cornfield site, 1979-80.

PRECIPITATION

Quantity and Intensity

Annual precipitation in Pequea Creek basin and at Holtwood, a nearby National Weather Service station, for 1980 was 27.2 and 29.4 in., respectively (National Oceanic and Atmospheric Adminstration, 1979, 1980). Precipitation in Pequea Creek basin for 1980 was estimated to be only about 70 percent of the mean annual precipitation based on long-term precipitation records at Holtwood. The distribution of precipitation was fairly even throughout the basin except during summer thunderstorms. Generally, the most intense rains occurred during June and July, although the frequency of precipitation was evenly spread throughout the year.

Rainfall Chemistry

Composite rainfall samples were collected at each basin for nutrient and carbon analyses during three storms in 1979 and 1980. Rainfall for these storms averaged 3.9, 0.2, and 0.3 in., respectively (table 6). Mean concentrations of all constituents measured except organic nitrogen were lower on September 5, 1979, than on either April 14 or August 11, 1980. Since these are mean concentrations, the lower values from the September 5, 1979 storm may be due to a dilution by the large volume of rainfall of the amount of particulate matter washed from the air.

Table 6.--Precipitation chemistry for Pequea Creek basin

		Concentration of constituents, in milligrams per liter				
Date	Amount of precipitation, in inches	Ammonia as N	Nitrate as N	Organic nitrogen as N	Phosphorus as P	Organic carbon
Sept. 5, 1979	3.90	0.05	0.07	0.48	0.03	1.7
April 14, 1980	.20	.46	.60	.31	.09	4.7
Aug. 11, 1980	.30	.37	.95	.42	.10	--

Unfortunately, there was not enough rainfall to analyze rainfall chemistry at all sites except for the September 5 storm. The relationships between rainfall and constituent load discussed below may vary significantly for other sizes, intensities, and times of storms.

Mean concentrations of ammonium, nitrate, organic nitrogen, phosphorus, and organic carbon were calculated for each of the five basins shown in table 7 for the September 5, 1979 storm. These concentrations were similar for all basins, and were used in conjunction with rainfall quantities in each basin to compute constituent loads of precipitation input. These loads were then compared to the constituent loads discharged by the stream from each basin during the storm.

In the forest and residential basins, precipitation input of organic nitrogen was 9.0 and 1.9 times higher, respectively, of the output discharged from the basin during the storm. Ammonium input in the residential basin was 5 times higher than the output, and organic carbon input at the forest was 2.1 times higher than the output. Except for these instances, precipitation input was less than stream output.

These ratios indicate that there is generally more material available from sources in each basin other than precipitation to be transported to streams and subsequently from the basins. Table 7 shows that in the Pequea, cornfield, and pasture basins, precipitation generally accounts for a smaller proportion of each constituent than in the forest and residential basins. In the Pequea, cornfield, and pasture basins, agricultural fertilizers are a source of nutrients and organic carbon, as well as the sources common to all the basins - natural soils, geology, and vegetation.

Table 7.--Ratio of the loads of precipitation input to stream discharge for a storm on September 5, 1979

Basin	Ammonium as N	Nitrate as N	Organic nitrogen as N	Phosphorus as P	Organic carbon
Pequea creek	0.84	0.17	0.44	0.05	0.23
Forest	.00	1.00	9.00 1/	.80	2.10 1/
Cornfield	.17	.07	.12	.02	.43
Residential	5.00 1/	.43	1.90 1/	.75	.68
Pasture	.13	.13	.01	.01	.03

1/ A number greater than 1.00 indicates that the load from precipitation into the basin was greater than the load discharged by the stream from the basin.

STREAMFLOW

The mean annual streamflow for Pequea Creek basin, measured at Martic Forge from January 1978 through December 1980, was 89,700 ft^3/s/day. The mean annual streamflow for the study period, April 1979 through December 1980, was 66,000 ft^3/s/day; instantaneous streamflows ranged from 6,200 ft^3/s during Hurricane David on September 5, 1979, to 44 ft^3/s in December 1980. The lowest flows measured at Martic Forge during the study period occurred from August through December 1980 (fig. 10).

Because long-term streamflow records are not available for Pequea Creek, streamflows in Pequea Creek were compared to those in Conestoga River, an adjacent basin with similar geology and land use. Flow-duration

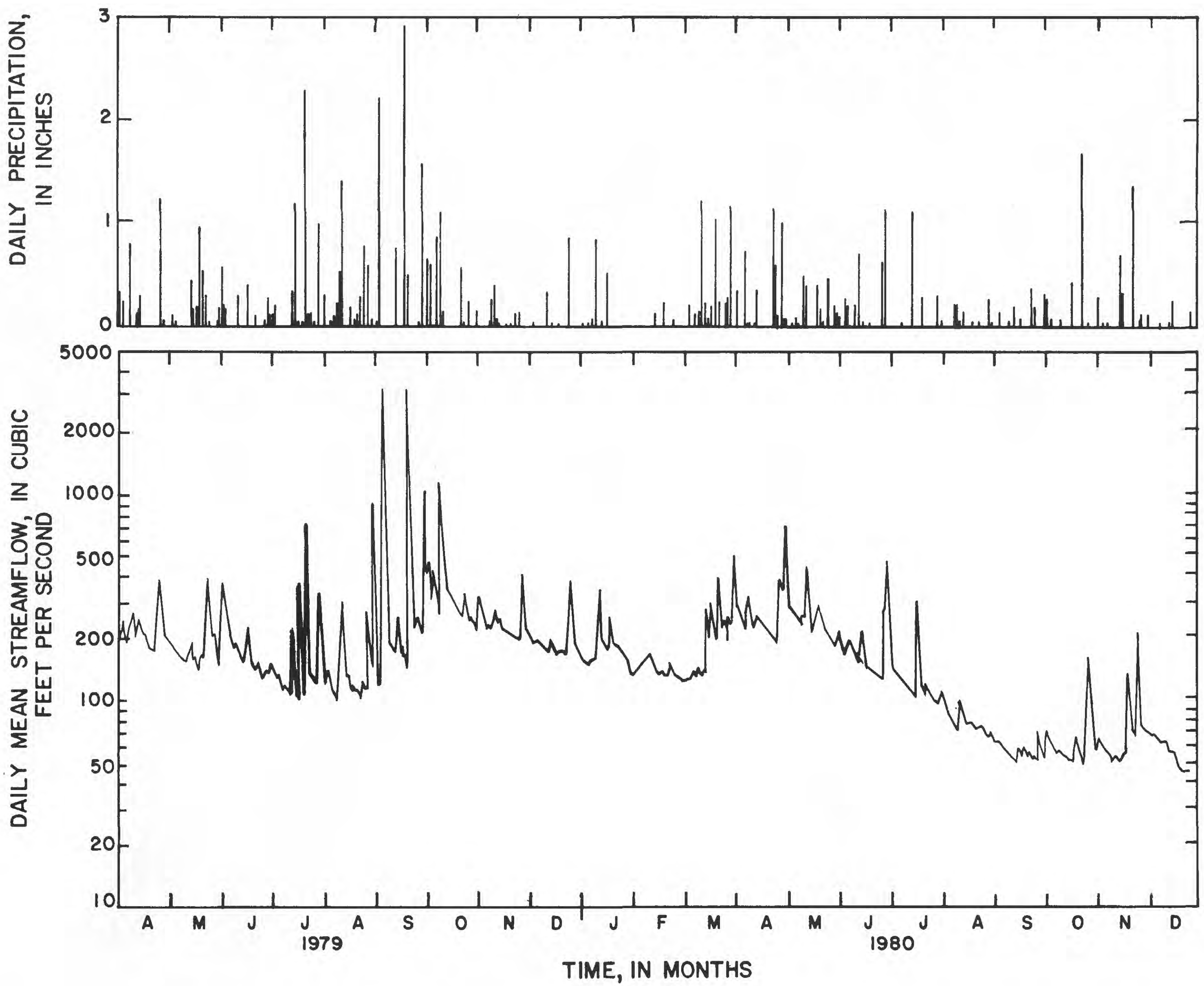


Figure 10.--Daily mean streamflow and precipitation for Pequea Creek at Martic Forge, April 1979 to December 1980.

curves for Conestoga River at Lancaster are shown in figure 11. Streamflow in Conestoga River was significantly lower in 1980 than the average observed from 1940 through 1980. Therefore, streamflow in Pequea Creek during the period of study was probably lower than normal.

Base Flow

Base flow, for the purpose of this report, represents all streamflow that did not occur during storms. This arbitrary definition of base flow means that base flows shown in this report are slightly lower than the true base flows, which include a part of the flow from storms.

Base flows in each basin (table 8) are determined by local ground-water supply. Base-flow yield at the forest site is the highest of all the sites and is almost twice that of the Pequea Creek basin. This is because most of the precipitation is absorbed into the forest soils before it can run off, thus increasing base flows. The residential and cornfield sites have nearly the same geology and soils, yet base-flow yield from the residential site is less than half of that from the cornfield site. One-third of the residential site is impervious; this reduces recharge to ground water and, ultimately, base flow. Base-flow yields were highest during the spring at all sites when frequent rainfall elevated ground-water levels. The lowest base-flow yields at each site were from September to December during drought conditions.

Table 8 also shows the average percentages of yearly base flow in total streamflow for 1980. Although these percentages may be elevated because 1980 was relatively dry, the relative rank of the percentages among the sites should not be affected.

Table 8.--Base-flow characteristics for 1980

Site	Average base-flow yield [$(ft^3/s)/d/mi^2$]	Range of base-flow yields [$(ft^3/s)/d/mi^2$]	Average percentage of base flow in total streamflow
Pequea Creek	0.98	0.32 - 1.82	85
Forest	1.79	.30 - 4.70	96
Cornfield	.77	.02 - 1.72	80
Residential	.30	.04 - .70	49
Upstream pasture	.27	.14 - 1.13	70
Pasture 1/	----	-----	84

1/ Pasture (area between upstream and downstream pasture sites)

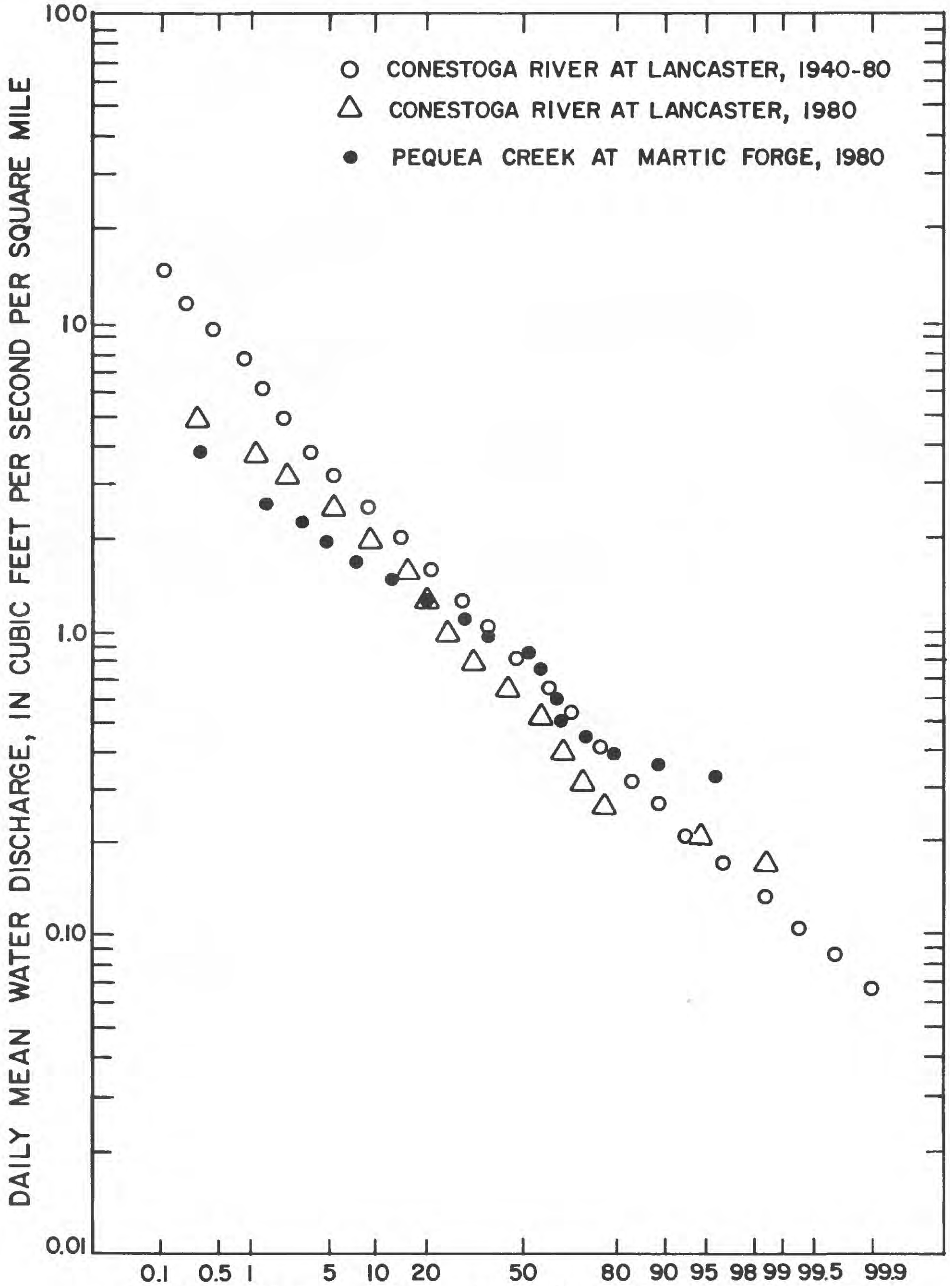


Figure 11.--The 1980 flow duration curve for Pequea Creek compared to 1980 and long-term duration curves for Conestoga River.

The residential site had the smallest percentage of base flow in total streamflow. Because of impervious cover, the stream quickly responded to rainfall as small as 0.10 in. Base flow is sustained predominantly by ground-water infiltration of the storm sewer system. Ground-water levels dropped low enough during several days each month from September through November 1980 that there was no measurable flow. The cornfield, pasture, and Pequea Creek basin sites had similar percentages of base flow in total streamflow. There was no flow at the cornfield site during many days each month from August through November 1980.

Stormflow

Stormflow, defined on p. 10, is composed of three components: (1) flow from the ground-water system, or saturated zone; (2) flow from the unsaturated zone between the ground-water system and land surface; and (3) surface runoff. The rapidity and magnitude of the response of a stream to precipitation can be measured by comparing the ratio of inches of stormflow to inches of precipitation. Monthly stormflow in 1980 ranged from 0.011 to 0.072 in. per inch of precipitation in Pequea Creek basin, as a whole (fig. 12). Stormflow was about 4 percent of precipitation for the year.

The stream at the forest site responded most slowly to rainfall. Only during extremely large storms was surface runoff observed. The yearly mean stormflow was 0.042 in. per inch of precipitation, the lowest of all the specific land-use sites.

Stormflow at the cornfield site varied more widely by season than any of the other sites (fig. 12). Stormflow was highest during the winter and spring when there was no ground cover. The yearly mean stormflow was 0.20 in. per inch of precipitation, highest of any of the sites.

The range of stormflows at the residential site was limited. Yearly mean stormflow, mostly surface runoff, was high in comparison to the other sites due to the high percentage of impervious surfaces. The range of stormflows at the upstream and downstream pasture sites is similar to the residential site. These sites also have a high percentage of impervious surfaces.

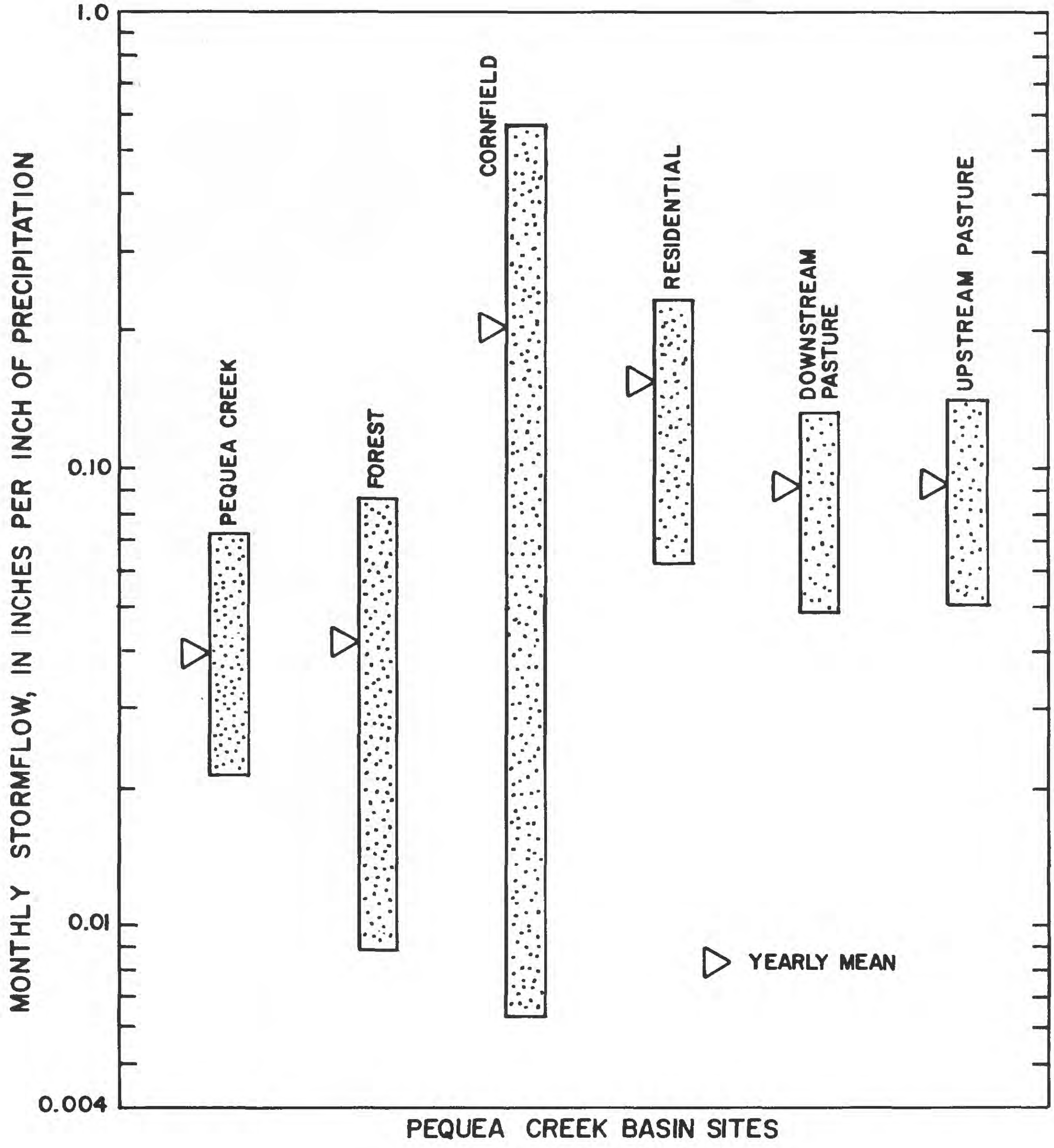


Figure 12.--Ranges of monthly stormflow.

WATER QUALITY

General Water-Quality Characteristics

In order to give a general overview of the nutrient, organic carbon, suspended-sediment, and herbicide data, the mean and range of concentrations for base-flow and storm samples are discussed below. Dissolved concentrations are discussed for base flow since they represent the predominant phase of constituents. Total concentrations are discussed for stormflow to include the suspended phase. Mean concentrations of suspended sediment, nutrients (except nitrate), and organic carbon were significantly higher both for total and dissolved constituents than mean concentrations in base-flow samples. The concentrations found at these specific land-use sites may vary from concentrations for the same land uses in other locations. Facts such as geology, soils, and application rates of fertilizers and pesticides, and the proximity of land use to the streams may vary and will influence water quality of the receiving streams.

For ease in comparison of data, all references to species of nitrogen and phosphorus are to be considered in their elemental form. For example, regardless of whether ammonium or nitrate is being discussed, the values and discussion all refer to their concentrations expressed as nitrogen. The detection limit of nitrogen and phosphorus is 0.01 mg/L. All herbicide data reported were analyzed from total water samples, and the detection limit is 0.1 μg/L. Samples containing less than detectable concentrations of all constituents are reported as zero.

Base Flow

The lowest mean base-flow concentrations for all forms of dissolved nitrogen was 3.2 mg/L at the forest site and 3.5 mg/L at the residential site (table 9). The mean concentration at the downstream pasture site was about twice as high, 7.1 mg/L, and at the cornfield site about 6 times higher, 20 mg/L, than at the forest and residential sites. Suspended nitrogen in streams is generally less than 10 per cent of total nitrogen. Nitrate was the dominant nitrogen species at all sites, constituting an average of 89 to 99 percent of total nitrogen. Ammonium and nitrite each constituted less than 2 percent of the total for all nitrogen species.

The highest concentration of dissolved phosphorus in base-flow samples, 1.1 mg/L, was found at the downstream pasture site. Not all of this phosphorus was contributed by the pasture because high concentrations also occurred at the upstream pasture site. Of the specific land-use sites, the cornfield site had the highest mean phosphorus concentration, 0.14 mg/L, and the forest the lowest, 0.01 mg/L. When concentrations of total phosphorus are greater than 0.1 mg/L, orthophosphorus constitutes the majority of total phosphorus, except at the forest and residential sites.

The highest mean concentration of dissolved organic carbon during base flow was found at the residential site, 5.6 mg/L. The lowest was at the forest site, 2.3 mg/L, followed closely by the cornfield site, 2.4 mg/L.

Table 9.--Maximum, minimum, and mean streamflow, and concentrations of nutrients, organic carbon, and suspended sediment in base-flow samples for six water-quality sites

Site		Streamflow (ft^3/s)	Nitrogen Tot	Nitrogen Diss	Organic nitrogen Tot	Organic nitrogen Diss	Ammonium Tot	Ammonium Diss	Nitrate Tot	Nitrate Diss	Nitrite Tot	Nitrite Diss	Phosphorus Tot	Phosphorus Diss	Orthophosphorus Tot	Orthophosphorus Diss	Organic carbon Tot	Organic carbon Diss	Suspended sediment Tot (mg/L)	Suspended sediment Finer than 0.062mm (percent)
							(mg/L as N)							(mg/L as P)			(mg/L)			
Pequea Creek	Max	248	8.6	7.6	0.67	0.55	0.11	0.11	8.3	7.5	0.10	0.09	0.22	0.18	0.12	0.12	11	10	52	100
	Min	55	5.0	4.5	.02	.00	.00	.00	4.8	4.4	.01	.01	.03	.02	.02	.02	.7	.3	6	52
	Mean	147	6.5	6.1	.37	.22	.04	.03	6.1	5.9	.03	.03	.10	.07	.06	.06	3.1	2.6	27	76
Forest	Max	.92	6.9	4.8	1.0	.42	.12	.12	6.7	4.6	.10	.09	.06	.02	.05	.03	6.3	5.6	75	100
	Min	.05	2.3	2.0	.05	.00	.00	.00	1.8	1.8	.00	.00	.01	.00	.00	.00	.2	.0	1	27
	Mean	.28	3.6	3.2	.25	.13	.03	.02	3.3	3.0	.01	.01	.03	.01	.01	.01	2.9	2.3	12	68
Cornfield	Max	.30	25	24	1.1	.23	.28	.17	24	24	.09	.06	.28	.22	.27	.20	8.8	8.7	156	100
	Min	.01	14	13	.00	.00	.00	.00	13	8.1	.00	.00	.09	.06	.01	.01	1.4	.9	1	18
	Mean	.13	21	20	.23	.08	.06	.04	21	20	.02	.02	.16	.14	.12	.11	2.8	2.4	73	51
Residential	Max	.11	5.4	5.1	.98	.98	.20	.08	5.0	4.8	.05	.05	.20	.04	.03	.03	28	27	135	100
	Min	.01	1.6	1.2	.12	.00	.01	.00	1.1	.99	.00	.00	.01	.00	.00	.00	1.5	1.4	5	4
	Mean	.06	3.7	3.5	.38	.23	.05	.03	3.3	3.2	.02	.02	.04	.02	.01	.01	6.2	5.6	65	47
Downstream pasture	Max	.77	12	11	4.0	3.0	.47	.29	9.1	8.0	.17	.17	1.4	1.1	.95	.89	13	12	151	100
	Min	.07	5.6	5.1	.21	.09	.04	.01	4.4	3.7	.02	.02	.07	.06	.04	.04	1.7	1.5	10	14
	Mean	.33	7.7	7.1	1.2	.77	.16	.08	6.3	6.1	.09	.09	.48	.40	.33	.31	4.6	3.6	49	69
Upstream pasture	Max	.74	9.0	8.6	1.1	1.1	.42	.17	8.5	8.5	.17	.16	1.1	.99	.89	.87	13	13	204	100
	Min	.07	3.7	3.4	.08	.00	.01	.00	3.0	3.0	.01	.01	.07	.04	.04	.02	1.6	1.2	1	14
	Mean	.31	7.2	6.7	.43	.29	.09	.05	6.6	6.3	.08	.06	.30	.27	.22	.21	3.8	3.2	51	52

The upstream pasture site had the highest suspended-sediment concentration in base-flow samples, 204 mg/L. The cornfield site had a maximum suspended-sediment concentration of 156 mg/L. The forest site had the lowest mean concentration, 12 mg/L. One-fourth to one-half of all the suspended sediment was silt and clay. Fine sand particles were found in many base-flow samples at all of the sites.

The herbicides detected most often in base-flow samples were atrazine, simazine, alachlor, and prometone (table 10). Atrazine, simazine, and alachlor are all selective agricultural pre-emergent herbicides used to control grasses and broad-leaf weeds. Atrazine and alachlor are widely used on cornfields, and simazine is used primarily on alfalfa fields. Prometone is a postemergent nonselective herbicide generally used around buildings and driveways to destroy all vegetation. The highest concentration of atrazine was detected at the cornfield site, 3.9 μg/L. The forest site contained very little atrazine. Simazine concentrations varied from a high of 2.3 μg/L at the residential site during base flows to below detection limits at all sites. Detectable concentrations of simazine were found at all sites except the cornfield and downstream pasture. Detectable alachlor concentrations in base flows were only found at Pequea Creek and the cornfield sites. Both had maximum concentrations of 0.2 μg/L. The largest concentration of prometone in base-flow samples was detected at the residential site, 0.5 μg/L. Mean concentrations of prometone were below detection limits at the Pequea Creek, forest, and cornfield sites.

Stormflow

At all the sites, dissolved nitrate concentration decreases were greater than increases in the other forms of dissolved nitrogen (organic nitrogen, ammonimum, and nitrite). The net effect was a decrease in dissolved nitrogen during storms. A comparison among sites of mean storm concentrations shows that the highest total nitrogen concentration was found at the cornfield site, 70 mg/L (table 11). The lowest mean storm concentration for total nitrogen was 3.6 mg/L at the forest site. The predominant form of nitrogen in the suspended phase at all sites was organic nitrogen; nitrate was the predominant form in the dissolved phase. About two-thirds of the ammonium was in the dissolved phase at all sites. Nitrite concentrations accounted for less than 2 percent of the total nitrogen concentrations at all sites.

The highest mean total phosphorus concentration was found at the cornfield site. Mean total phosphorus concentrations were lowest at the forest site and ranged from 0.02 to 0.42 mg/L. Orthophosphorus was generally about one-third of the total phosphorus at all sites, and occurred mainly in the dissolved phase.

The mean storm concentrations of total organic carbon were largest and smallest at the cornfield and forest sites, respectively. Concentrations at the cornfield site ranged from 7.9 to 148 mg/L and at the forest site from 2.5 to 27 mg/L. Mean organic carbon concentrations are about one-third dissolved, except at the residential site.

Table 10.--Maximum, minimum, and mean concentrations of herbicides in base-flow samples for six water-quality sites

Site		Herbicides, in micrograms per liter											
		Ame-tryne	Atra-zine	Atra-tone	Cyana-zine	Cypra-zine	Prome-tryne	Prome-tone	Propa-zine	Sima-zine	Sime-tone	Sime-tryne	Ala-chlor
Pequea Creek	Max	0.0	2.1	0.0	0.0	0.0	0.4	0.1	0.0	1.0	0.0	0.0	0.2
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.3	.0	.0	.0	.0	.0	.0	.2	.0	.0	.0
Forest	Max	.0	.1	.0	.0	.0	.0	.2	.0	.1	.1	.0	.0
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Corn-field	Max	.0	3.9	.1	.0	.0	.0	.5	.1	.1	.0	.0	.2
	Min	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	1.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
Resi-dential	Max	.0	.3	.2	.0	.0	.0	.5	.1	2.3	.0	.0	.0
	Min	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0
	Mean	.0	.0	.0	.0	.0	.0	.2	.0	.1	.0	.0	.0
Down-stream pasture	Max	.0	1.6	.1	.0	.0	.0	.2	.0	.1	.0	.0	.0
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.3	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0
Up-stream pasture	Max	.0	2.5	.0	.0	.0	.0	.2	.1	1.1	.0	.0	.0
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.3	.0	.0	.0	.0	.1	.0	.1	.0	.0	.0

Table 11.--Maximum, minimum, and mean streamflow, and concentrations of nutrients, organic carbon, and suspended sediment in composite storm samples for six water-quality sites

Site		Streamflow (ft^3/s)	Nitrogen Tot	Nitrogen Diss	Organic Nitrogen Tot	Organic Nitrogen Diss	Ammonium Tot	Ammonium Diss	Nitrate Tot	Nitrate Diss	Nitrite Tot	Nitrite Diss	Phosphorus Tot	Phosphorus Diss	Ortho-Phosphorus Tot	Ortho-Phosphorus Diss	Organic Carbon Tot	Organic Carbon Diss	Suspended Sediment Tot (mg/L)	Suspended Sediment Finer than 0.062mm (percent)
			(mg/L as N)										(mg/L as P)				(mg/L)			
Pequea Creek	Max	2,660	11	8.8	7.4	1.7	0.50	0.46	7.6	7.4	0.31	0.13	3.6	1.1	1.5	0.99	47	43	3,540	98
	Min	140	2.2	.96	.13	.03	.02	.00	1.3	.30	.03	.01	.05	.05	.02	.00	2.3	1.6	25	71
	Mean	453	6.8	5.1	1.9	.61	.19	.15	4.7	4.3	.09	.06	.79	.18	.19	.13	13	5.6	647	88
Forest	Max	1.7	5.8	4.4	3.1	1.8	.14	.10	3.6	3.2	.07	.02	.42	.10	.06	.02	27	15	734	96
	Min	.13	1.8	1.2	.17	.00	.00	.00	1.1	.96	.00	.00	.02	.01	.00	.00	2.5	2.2	17	43
	Mean	.56	3.6	2.7	1.3	.47	.06	.04	2.3	2.2	.01	.01	.15	.02	.02	.01	13	5.8	207	75
Cornfield	Max	3.8	70	43	54	6.1	3.4	2.9	41	39	1.5	1.4	19	4.1	4.5	3.3	148	28	16,000	98
	Min	.09	8.1	6.5	1.0	.15	.05	.00	3.2	3.2	.03	.02	1.6	.44	.02	.02	7.9	5.4	24	85
	Mean	1.4	25	17	8.1	2.0	.65	.49	16	14	.20	.15	4.9	2.0	1.8	1.6	33	12	2,080	92
Residential	Max	11	6.3	5.7	4.7	1.9	2.8	2.8	2.9	2.8	.24	.19	2.6	.73	1.9	.43	114	104	1,140	100
	Min	.15	.80	.64	.25	.01	.00	.00	.29	.24	.01	.01	.07	.03	.01	.00	5.0	3.9	13	60
	Mean	1.8	3.1	2.1	1.7	.60	.30	.26	1.3	1.2	.06	.04	.38	.11	.11	.07	19	12	189	85
Downstream pasture	Max	52	38	9.4	32	1.6	1.8	.78	8.5	8.5	.49	.24	4.2	2.0	1.8	1.6	86	22	3,840	99
	Min	.57	1.4	1.5	.78	.30	.05	.00	.20	.38	.01	.01	.14	.07	.05	.01	4.4	.3	56	67
	Mean	3.9	7.8	3.6	4.9	.82	.44	.28	2.5	2.4	.13	.09	1.4	.49	.44	.37	23	9.0	845	92
Upstream pasture	Max	44	20	7.9	13	3.9	1.7	.84	6.1	6.0	.79	.23	4.2	2.0	1.6	1.6	62	28	3,820	100
	Min	.34	1.5	.66	.47	.10	.01	.00	.62	.17	.02	.00	.24	.08	.05	.00	3.6	.8	18	60
	Mean	3.7	6.2	3.6	3.2	.86	.36	.25	2.5	2.4	.12	.08	1.3	.47	.40	.34	23	9.2	775	93

Suspended-sediment concentrations ranged from 24 to 16,000 mg/L at the cornfield site but only from 17 to 734 mg/L at the forest site. Sieve analyses run on selected storm samples showed that most of the sediment was silt and clay at all sites.

Herbicide concentrations in composite storm samples (table 12) were significantly higher than any concentrations detected in base-flow samples. Atrazine concentrations at the cornfield site ranged from 0.1 to 200 μg/L, and the mean concentration was 20 μg/L. The lowest atrazine concentrations were found at the forest site where composite storm concentrations ranged from 0.0 to 0.5 μg/L. Of the specific land uses, the residential site had the highest mean storm concentration of simazine, 3.2 μg/L. No simazine was detected in any composite storm samples from the forest site. The highest alachlor concentration, 52 μg/L, was detected at the cornfield site, which also had the highest mean storm concentration of 6.5 μg/L. No alachlor was detected at the forest site.

The highest prometone concentrations were detected at the residential site where the maximum was 6.4 μg/L. The Pequea Creek, forest, and cornfield sites all had mean prometone concentrations of <0.1 μg/L.

A comparison of ranges of base-flow and storm concentrations seems to indicate that most of the total nitrogen increase during storms is due to increased concentrations of organic nitrogen. Both total phosphorus and ortho-phosphorus increase during storms. However, the increase in total phosphorus is larger than that of orthophosphorus. Total organic carbon increases significantly during storms. Increases in all of the constituents mentioned above appear to be predominantly in the suspended phase. Increases of suspended-sediment concentrations during storms are the most significant of the constituents analyzed. Generally, concentrations of all the herbicides were significantly higher during storms than base flow. The most dramatic increases were seen in concentrations of atrazine and alachlor.

Temporal Variation in Water Quality

Pequea Creek Basin

Suspended-sediment concentrations for Pequea Creek at Martic Forge ranged from 6 to 52 mg/L during base flow and from 25 to 3,540 mg/L during stormflow (fig. 13). An average of 24 percent of the suspended sediment during base flow and 12 percent during storms was sand. Suspended-sediment concentrations seem to be highest during storms from June to September. Data from the six rain gages located throughout the basin indicate that for the storms having suspended-sediment concentrations above 2,000 mg/L at Pequea Creek, maximum precipitation intensities ranged from 0.47 to 1.02 in. of rain in 15 minutes.

Base-flow concentrations of total organic nitrogen ranged from 0.02 to 0.67 mg/L. Mean storm concentrations ranged from 0.13 to 7.4 mg/L (fig. 14). A seasonal trend in total organic nitrogen concentrations can be seen during storms in both 1979 and 1980, even though 1979 was a wetter than normal year, and 1980 was a dryer than normal year. The highest con-

Table 12.--Maximum, minimum, and mean concentrations of herbicides in composite storm samples for six water-quality sites

Site		Herbicides, in micrograms per liter											
		Ame-tryne	Atra-zine	Atra-tone	Cyana-zine	Cypra-zine	Prome-tryne	Prome-tone	Propa-zine	Sima-zine	Sime-tone	Sime-tryne	Ala-chlor
Pequea Creek	Max	0.0	4.6	0.1	0.0	0.0	0.2	0.3	0.1	0.8	0.0	0.0	0.8
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.9	.0	.0	.0	.0	.0	.0	.3	.0	.0	.2
Forest	Max	.0	.5	.1	.0	.0	.0	.3	.0	.0	.0	.0	.0
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Corn-field	Max	.0	200	.4	.0	.0	.1	.5	1.2	1.6	.0	.0	52
	Min	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	20	.0	.0	.0	.0	.0	.1	.2	.0	.0	6.5
Resi-dential	Max	.0	78	1.2	.2	3.8	1.6	6.4	1.0	3.2	.0	1.1	1.5
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	1.9	.0	.0	.3	.0	.4	.0	.3	.0	.0	.2
Down-stream pasture	Max	.0	5.2	1.2	.0	.0	.1	3.2	.1	4.8	.0	.0	1.5
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	.6	.0	.0	.0	.0	.3	.0	.3	.0	.0	.1
Up-stream pasture	Max	.1	28	1.0	.1	.1	.1	4.0	.8	3.6	.1	.1	1.6
	Min	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
	Mean	.0	1.1	.0	.0	.0	.0	.4	.0	.3	.0	.0	.1

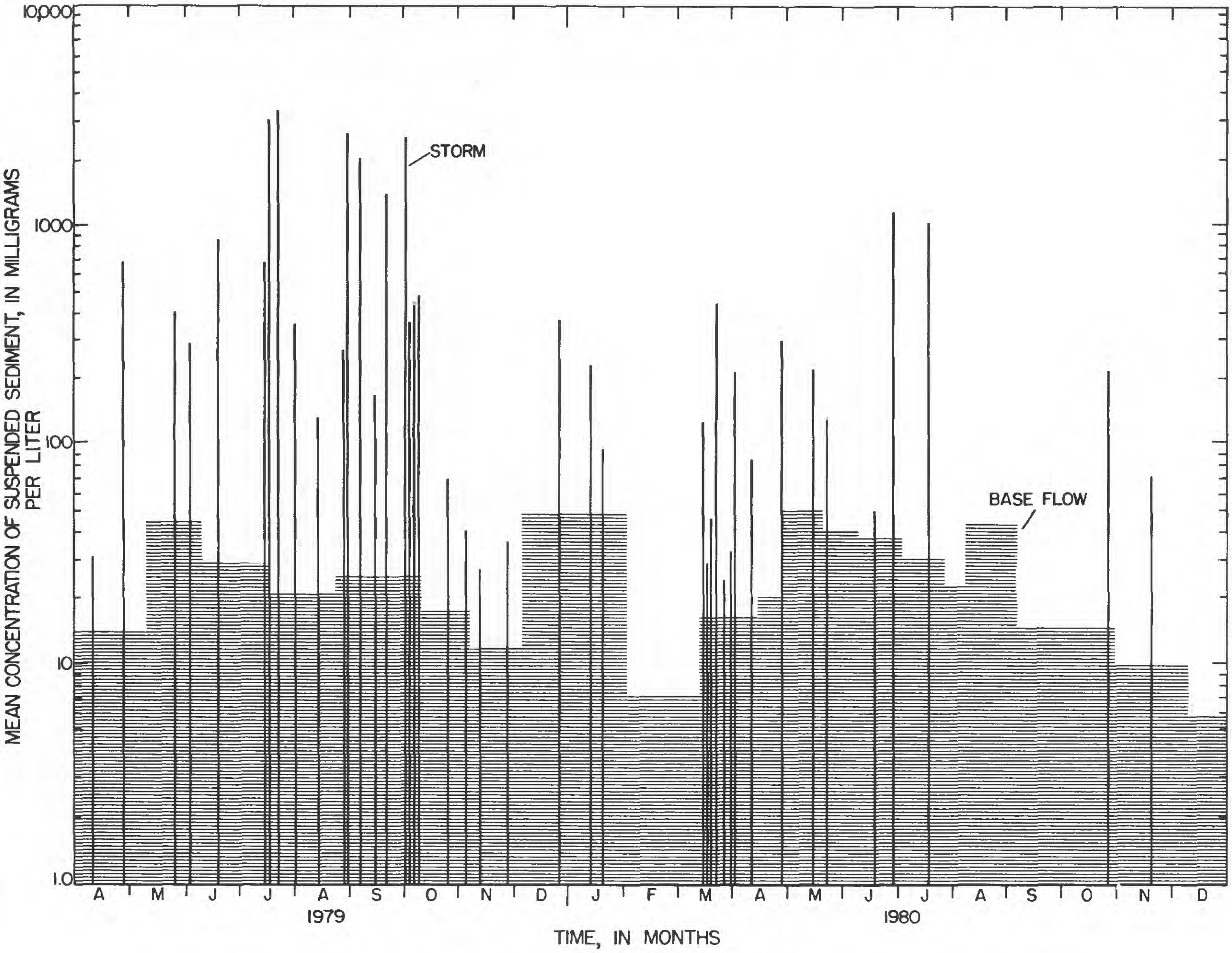


Figure 13.--Mean suspended-sediment concentrations during storms and base flows at Pequea Creek at Martic Forge, April 1979 to December 1980.

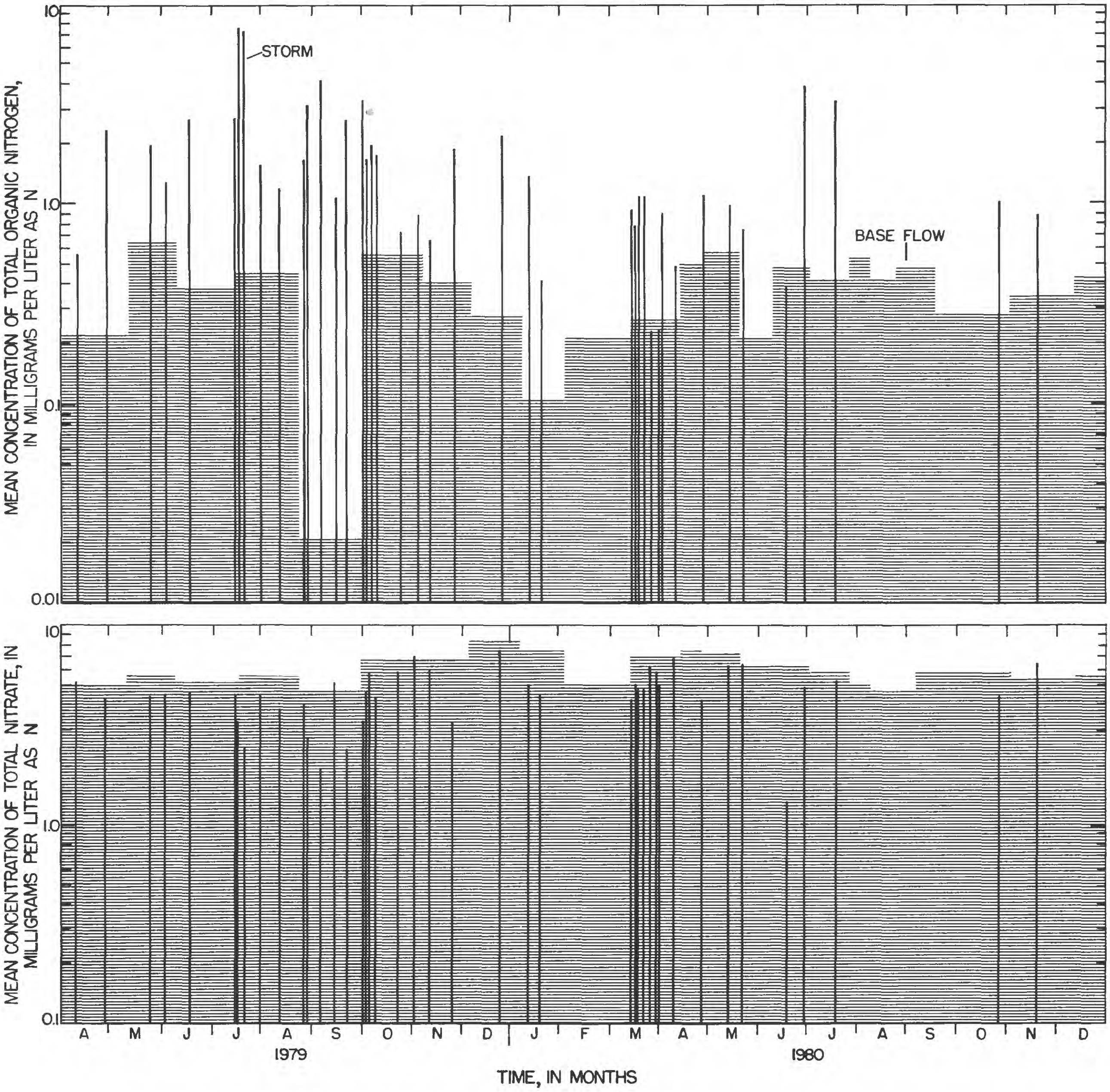


Figure 14.--Mean total organic nitrogen and total nitrate concentrations during storms and base flows at Pequea Creek at Martic Forge, April 1979 to December 1980.

centrations of organic nitrogen occurred in June and July, and storm concentrations slowly decreased through the summer. Changes in total organic nitrogen concentrations generally coincided with changes in suspended-sediment concentrations. This is supported by soil analyses at the specific land-use sites. Organic nitrogen was the main species of nitrogen associated with the upper four inches of soil, which is readily available for transport to streams.

During conditions of base flow, total nitrate concentrations ranged from 4.8 to 8.3 mg/L and made up 86 to 99 percent of total nitrogen. Total nitrate concentratrations during storms were lower than those in base flow, ranging from 1.3 to 7.6 mg/L (fig. 14). Storm concentrations of nitrate did not vary proportionally with flow or season, remaining consistently high through the study period.

During base flow, mean total ammonium and total nitrite concentrations were 0.04 and 0.03 mg/L, respectively. Mean total ammonium concentrations during storms ranged from 0.02 to 0.50 mg/L. Although ammonium concentrations during storms were generally higher than during base flow, they did not appear to vary either with season or storm intensity. Mean total nitrite concentrations during storms ranged from 0.03 to 0.31 mg/L. Storm concentrations were only slightly higher than base-flow concentrations. Generally, higher nitrite concentrations were found during storms occurring between April and July.

Base-flow concentrations of total phosphorus in Pequea Creek ranged from 0.03 to 0.22 mg/L, and were lowest during the winter. Base-flow concentrations were about equal during the summers of 1979 and 1980. Mean total phosphorus concentrations during storms in Pequea Creek ranged from 0.05 to 3.6 mg/L (fig. 15). Phosphorus concentrations during storms were directly related to suspended-sediment concentrations.

During base flow, total organic carbon concentrations varied throughout the year; most of the samples contained 1.5 to 5.0 mg/L organic carbon. Concentrations of total organic carbon during base flow, which were mostly dissolved, were significant compared with many of the storm concentrations. Mean storm concentrations of total organic carbon at Pequea Creek ranged from 2.3 to 47 mg/L. Storm concentrations in 1979 were significantly higher than in 1980. Organic carbon concentrations seemed to increase from April through September, and then decrease during late fall and winter.

The most significant herbicides found in Pequea Creek were atrazine, simazine, prometone and alachlor. Atrazine and alachlor are applied to cornfields, and simazine to alfalfa fields. Prometone is used as a weed killer in residential and commercial areas. Atrazine and simazine were found during base flow and storms, and prometone was found during storms (fig. 16).

Atrazine concentrations in base-flow samples were generally less than 0.5 μg/L, except during late July and August, when they were up to 2.1 μg/L. During storms, atrazine concentrations showed a definite seasonal trend. The highest concentrations, 2.4 to 4.5 μg/L, occurred from May through

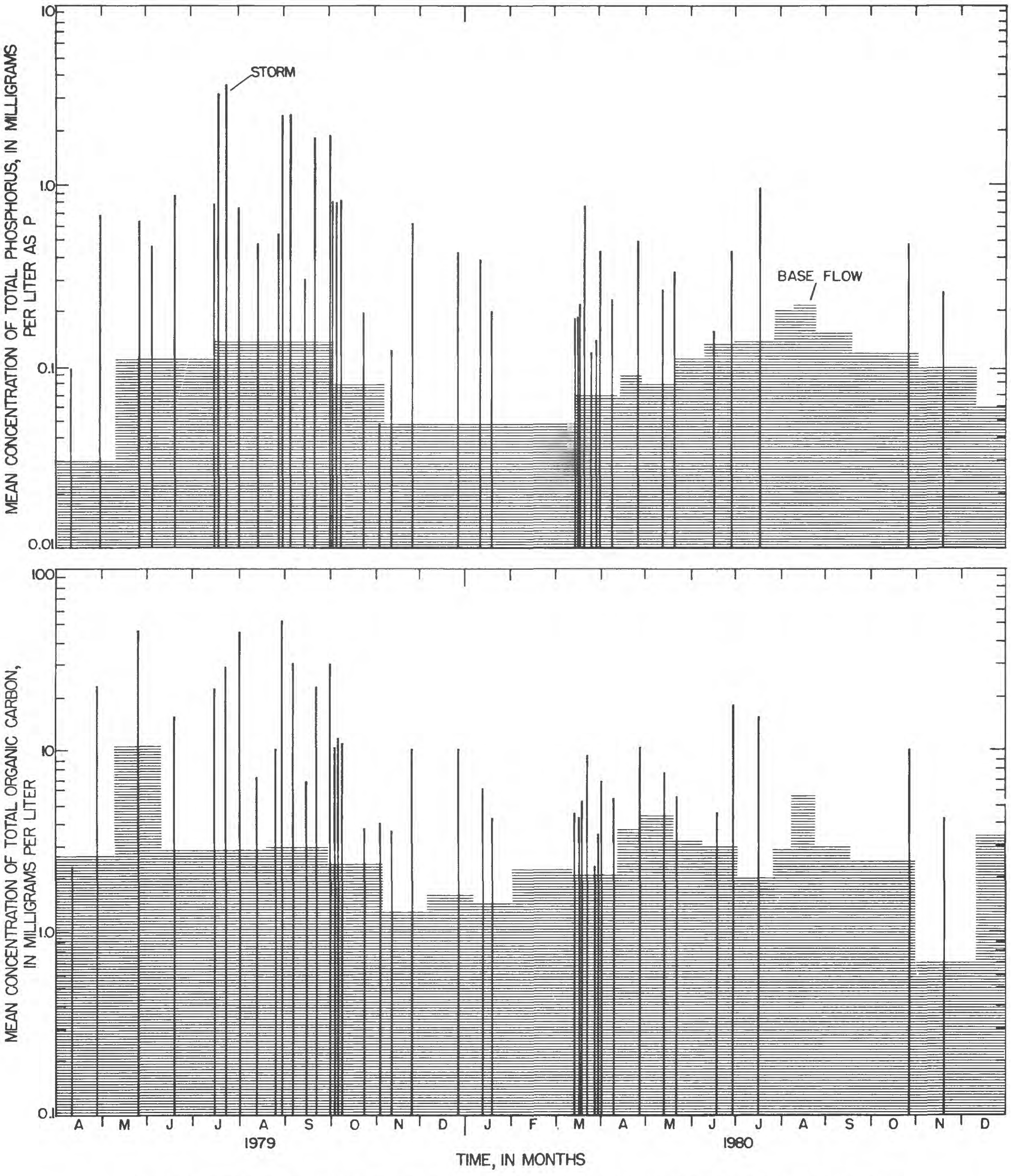


Figure 15.--Mean total phosphorus and total organic carbon concentrations during storms and base flows at Pequea Creek at Martic Forge, April 1979 to December 1980.

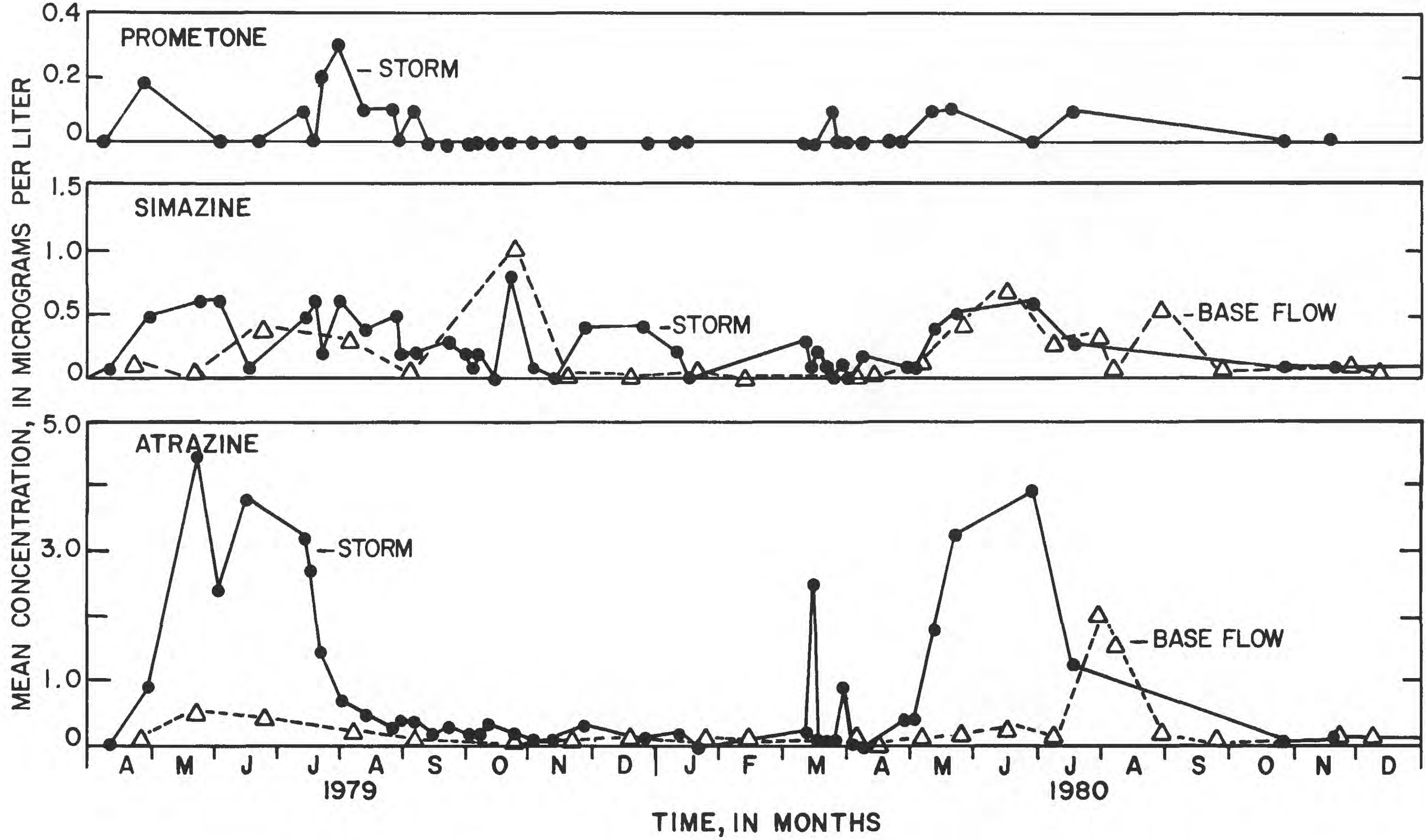


Figure 16.--Mean storm and base-flow concentrations of triazine herbicides at Pequea Creek at Martic Forge, April 1979 to December 1980.

mid-July followed by a definite decrease in concentration from mid-July until the following spring. This trend reflects a decreasing availability of atrazine to the stream due to degradation, infiltration, plant uptake and earlier runoff.

Simazine concentrations ranged from 0.0 to 1.0 μg/L during both base flow and storms. The highest concentrations in base-flow samples were found from May to October; however, concentrations remained relatively constant during storms throughout the year.

Prometone concentrations during storms were primarily detected during the growing season, from May through September. Concentrations ranged from 0.0 to 0.3 μg/L, significantly lower than either atrazine or simazine. The concentrations did not decrease through the growing season because prometone is applied throughout this time period.

The maximum base-flow concentration of alachlor was 0.2 μg/L. Mean concentrations of alachlor during storms ranged from 0.0 to 0.8 μg/L. The highest concentrations occurred in May of 1979 and 1980. This is the time period when the herbicide is usually applied.

Forest Subbasin

At the forest site, the mean concentration of suspended sediment ranged from 1 to 75 mg/L during base flow to between 17 and 734 mg/L during storms (fig. 17). Forest canopy and heavy leaf mulch over most of the basin protect the soil from raindrop impact and resulting soil erosion. The primary source of suspended sediment at this site is streambed and streambank erosion. The highest concentrations of suspended sediment occur during the most intense storms, although other factors such as the length of the storm and antecedent conditions also affect sediment transport. Intensities of storms that produced suspended-sediment concentrations over 300 mg/L ranged from 0.27 to 0.65 in. of rain in 15 minutes, whereas storms that produced concentrations between 200 and 300 mg/L ranged in intensity from 0.14 to 0.35 in. of rain in 15 minutes. The maximum suspended-sediment concentration occurred during a storm in August 1980 that had 0.48 in. of rain in 15 minutes and a total of 0.68 in. of rainfall. Since thunderstorms usually produce the most intense rainfalls, high concentrations of suspended sediment usually occurred during the summer months. Base-flow concentrations of suspended sediment were less than 30 mg/L and generally insignificant compared to storm concentrations.

Concentrations of total organic nitrogen ranged from between 0.05 and 1.0 mg/L during base flow to between 0.17 and 3.1 mg/L during storms (fig. 18). Concentrations of less than 1.0 mg/L generally occurred during the winter and spring.

Concentrations of total nitrate ranged from 1.8 to 6.7 mg/L during base flow, and from 1.1 to 3.6 mg/L during storms. Slightly higher concentrations were found during storms from March through July 1980 than during other periods. Except for one storm in March 1980, all mean storm concentrations of total nitrate were lower than base-flow concentrations.

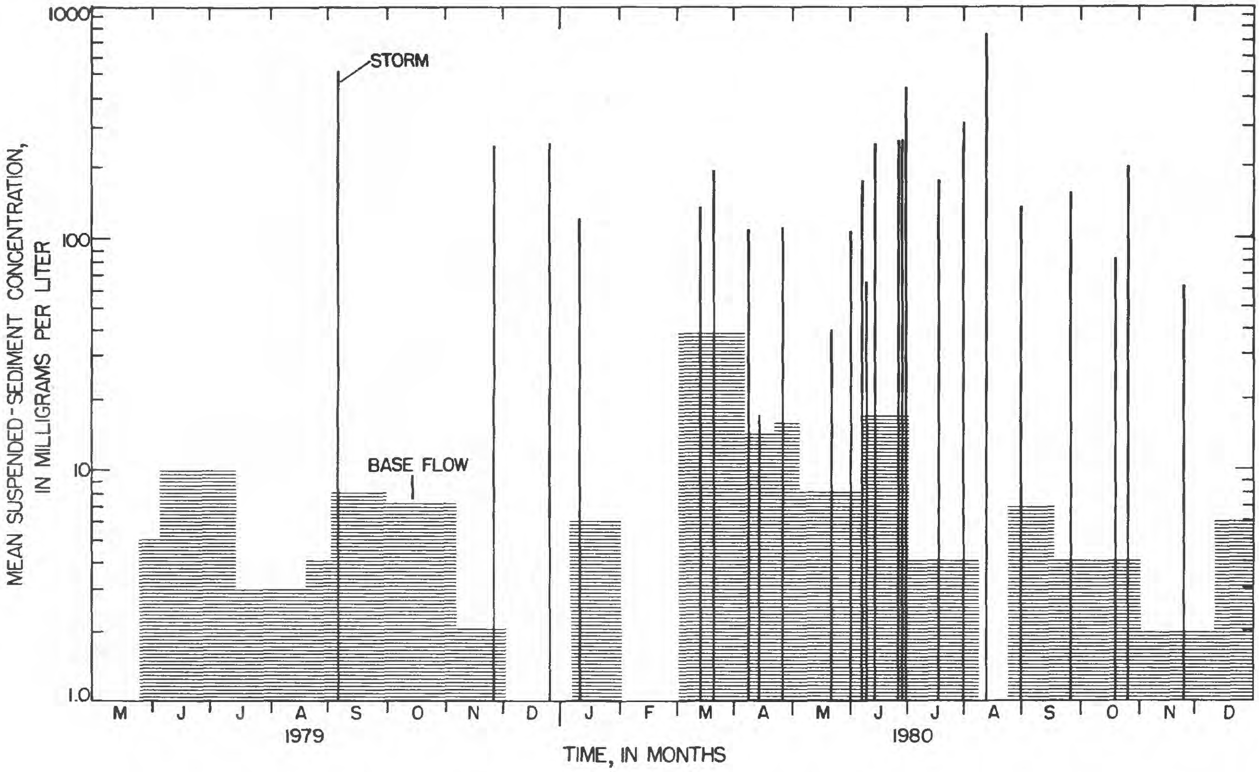


Figure 17.--Mean suspended-sediment concentrations during storms and base flows at the forest site, May 1979 to December 1980.

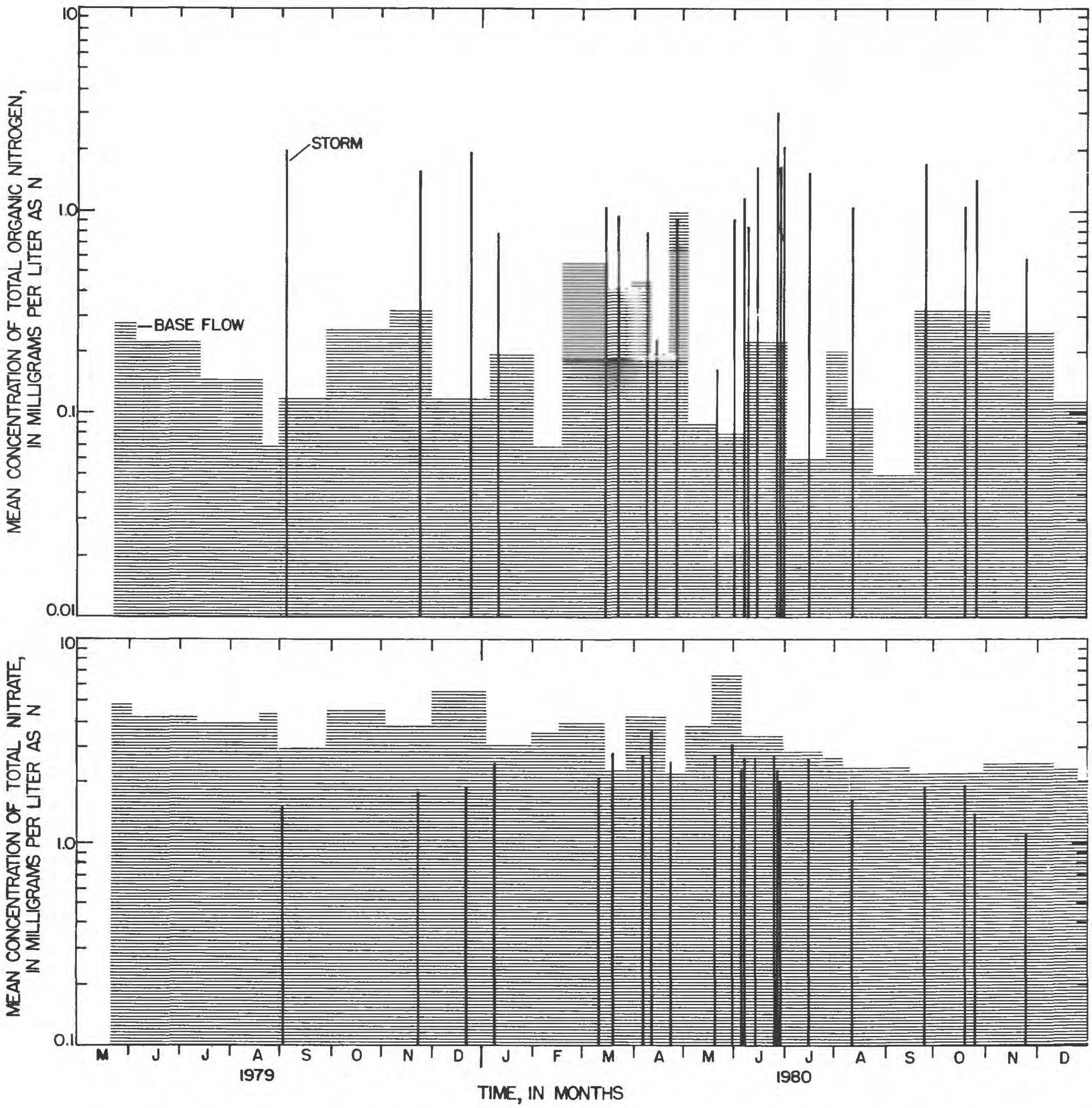


Figure 18.--Mean total organic nitrogen and total nitrate concentrations during storms and base flows at the forest site, May 1979 to December 1980.

Total ammonium and nitrate concentrations during storms were nearly always small compared to the total nitrogen concentrations. The main source of ammonium is denitrification of organic nitrogen in the soil. Nitrite is formed as an intermediate step in the oxidation of ammonium to nitrate, or by the reduction of nitrate. Base-flow and mean storm concentrations at the forest site were all less than 0.14 mg/L for ammonium and less than 0.10 mg/L for nitrite.

Total concentrations of phosphorus during storms ranged from 0.02 to 0.42 mg/L and were about 5 times higher than the base-flow concentrations (fig. 19). The primary sources of phosphorus are soils, plants, and tree leaves. There are no discernable seasonal variations in storm concentrations at this site. The highest base-flow concentrations occurred in February following a dry period. In March, following several storms, base-flow concentrations of phosphorus returned to levels consistent with those observed during other months.

The mean concentrations of total organic carbon ranged from 2.5 to 27 mg/L. Levels of total organic carbon during storms from June through November are higher than during the rest of the year. Leaves and decaying wood are the primary source of organic carbon. Higher concentrations of organic carbon observed during the summer and fall are attributable to higher rates of decomposition during the warm summer months. Concentrations during base flow were generally lower than storm concentrations.

Herbicide concentrations were below detection limits in most of the base-flow and storm samples collected at the forest site. The maximum concentrations of atrazine and prometone were 0.1 and 0.2 μg/L, respectively, during base flow and 0.5 and 0.3 μg/L, respectively, during storms. Simazine, 0.1 μg/L during base flow, and atratone, 0.1 μg/L during storms, were detected only once.

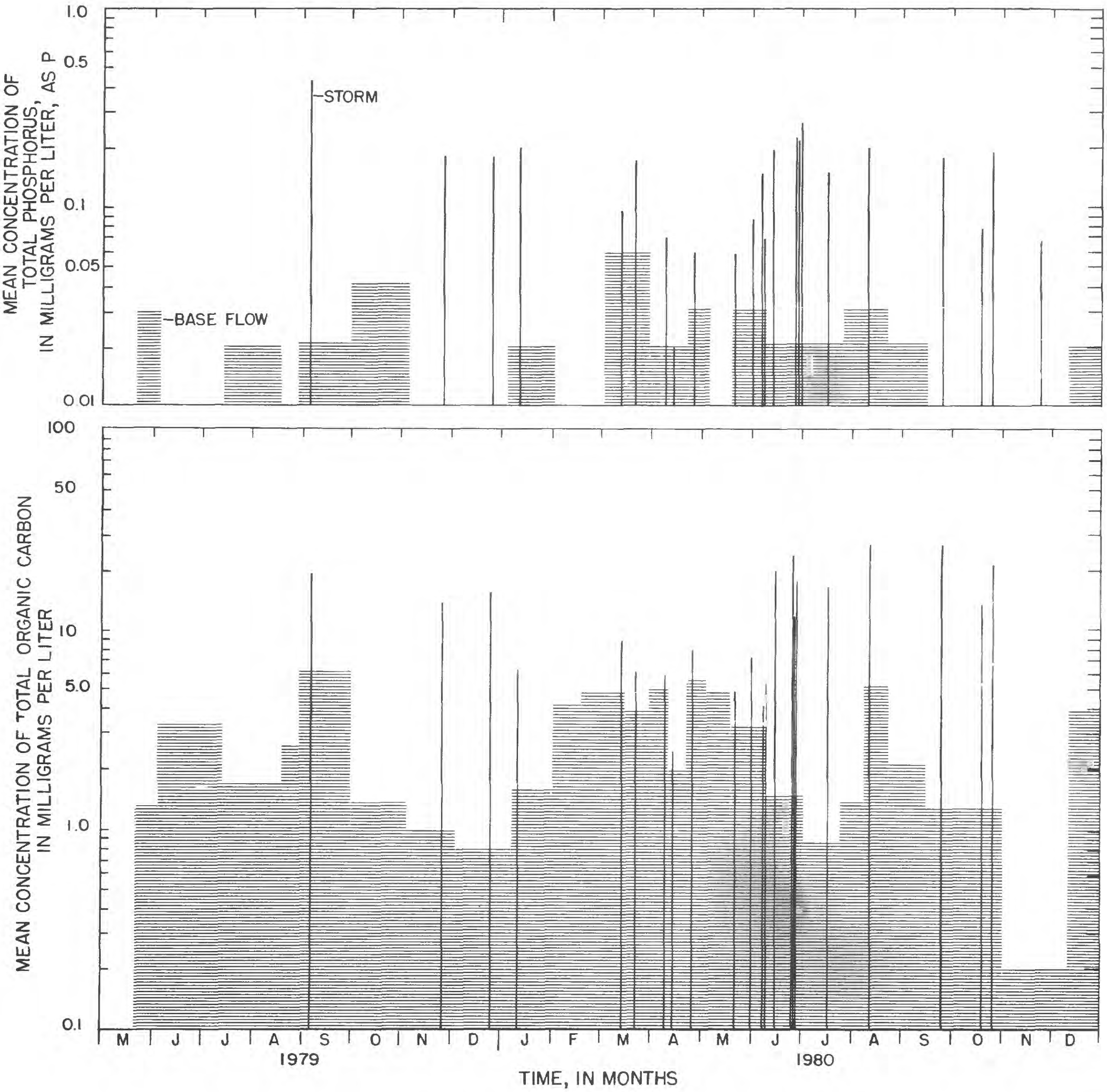


Figure 19.--Mean total phosphorus and total organic carbon concentrations during storms and base flows at the forest site, May 1979 to December 1980.

Cornfield Subbasin

The water quality of the stream draining the cornfield site varied considerably throughout the year in response to soil conditions, fertilizer and herbicide applications, and storms. Concentrations of all constituents except nitrate increased during storms.

During storms the mean concentrations of suspended sediment at the cornfield site ranged from 24 to 16,000 mg/L (fig. 20). Base-flow concentrations of suspended sediment generally were less than 100 mg/L. Storm intensity was one of the major factors in determining suspended-sediment concentrations. Maximum precipitation intensities during two June 1980 storms that had the highest suspended-sediment concentrations were 0.72 and 0.67 in. of rain in 15 minutes. Other summer storms with high suspended-sediment concentrations, from 2,100 to 3,400 mg/L, had rainfall intensities from 0.38 to 0.70 in. in 15 minutes.

Another major factor affecting suspended-sediment concentrations at the cornfield site was soil cover. In newly planted fields, the soil is bare and loose. The first rains after planting, if not too intense, are absorbed in the soil. This causes the soil to become more compact with each storm. When an intense thunderstorm occurs, as in late June 1980, the corn covered only 5 to 10 percent of the soil surface. Runoff caused by the intense rains carried large amounts of sediment to the stream channel. As the corn canopy increases, the soil becomes less vulnerable to erosion because increased leaf cover reduces the impact of raindrops on the soil surface. After the corn harvest in the fall, the corn stalks were incorporated into the soil. This helped to trap the sediment before it reached the stream if the rain was not too heavy.

Concentrations of total organic nitrogen ranged from 0.0 to 1.1 mg/L during base flow and from 1.0 to 54 mg/L during storms (fig. 21). The primary sources of organic nitrogen are soil, decomposition of manure and fertilizer, and cornstalks incorporated into the soil. The highest concentrations in storm samples occurred during the first storms after planting; concentrations of 41 and 52 mg/L occurred in late June 1980, and decreased to 13 and 5.9 mg/L during storms in July 1980. Total organic nitrogen concentrations continued to decrease, but at a much slower rate, through the next three storms in September and October. This same trend was previously observed with suspended sediment, and may be directly related to soil conditions. Organic nitrogen available for transport decreased due to plant uptake, conversion to other nitrogen forms, and runoff as the growing season progressed.

Total nitrate concentrations in base-flow samples from the cornfield site ranged from 13 to 24 mg/L. Storm concentrations ranged from 3.2 to 41 mg/L, and were generally lower than base-flow concentrations. The criterion for domestic water supplies is 10 mg/L nitrate as nitrogen (U.S. Environmental Protection Agency, 1977). All base-flow and most storm samples exceed this criteria, indicating persistent ground-water nitrate contamination. Plant uptake of nitrate during the growing season diminishes the source of available nitrates through the summer months. The

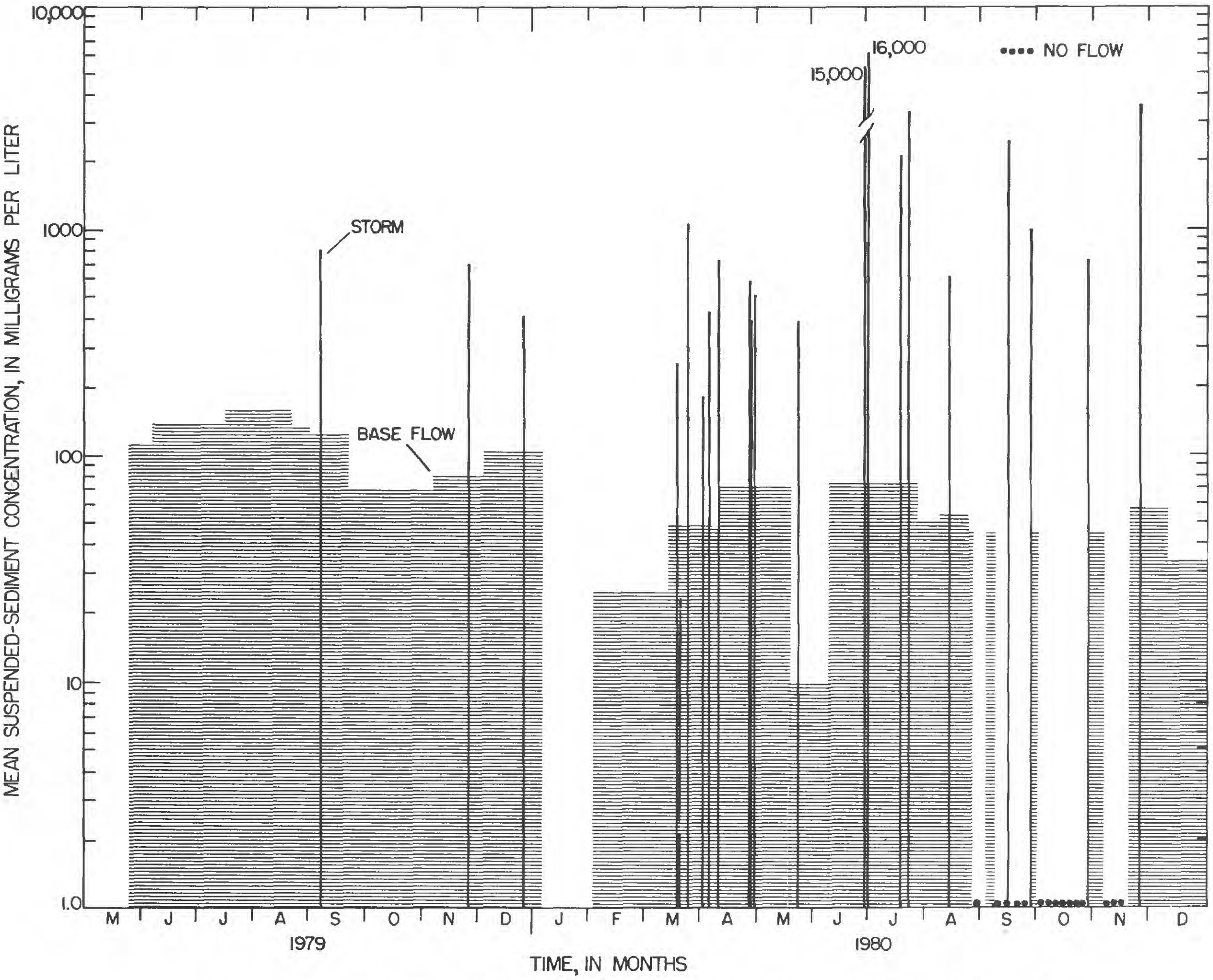


Figure 20.--Mean suspended-sediment concentrations during storms and base flows at the cornfield site, May 1979 to December 1980.

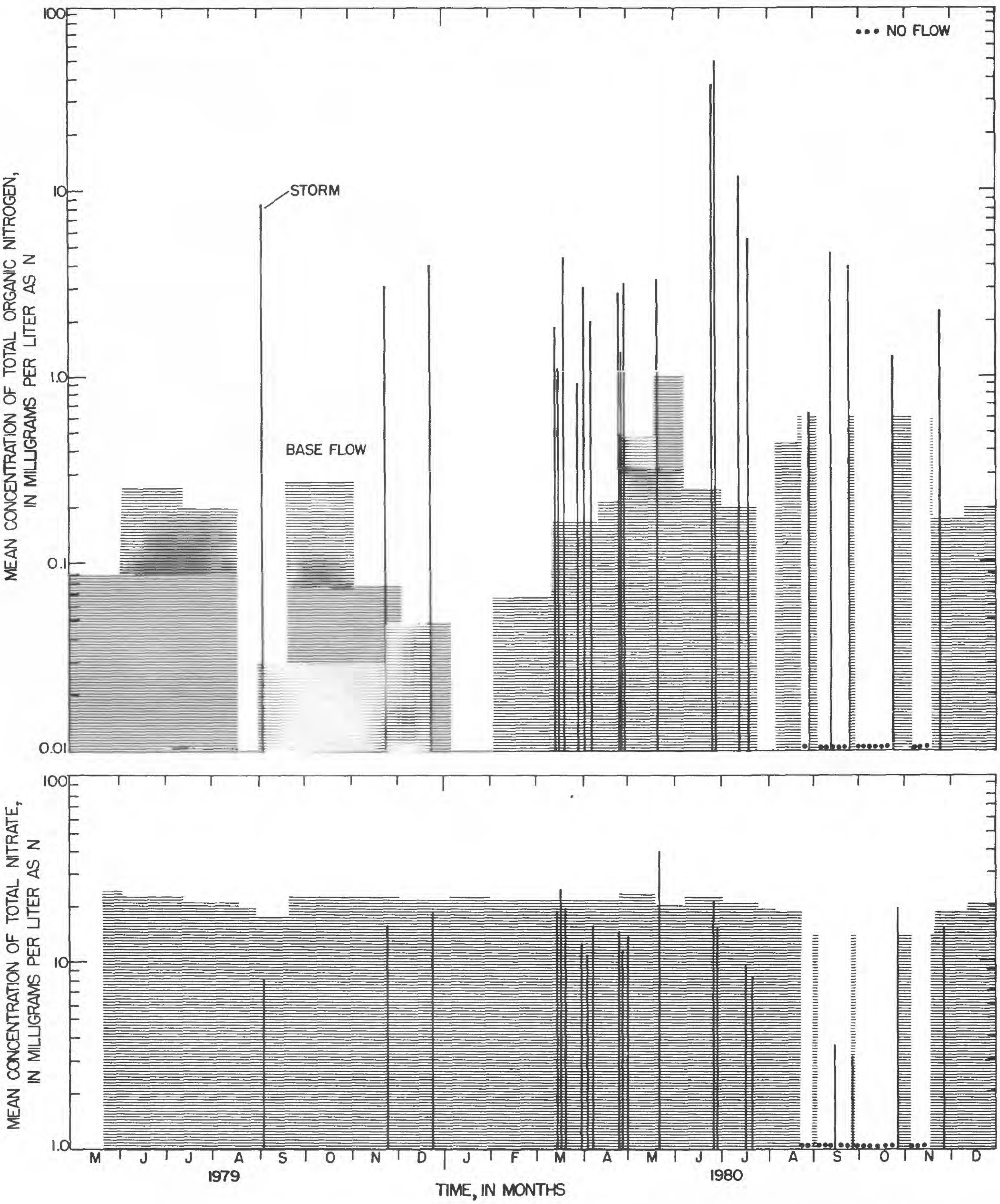


Figure 21.--Mean total organic nitrogen and total nitrate concentrations during storms and base flows at the cornfield site, May 1979 to December 1980.

lowest nitrate concentrations during base flow at the cornfield site, 18 and 13 mg/L, occurred during September of 1979 and 1980, respectively. The two lowest storm concentrations both occurred during September 1980.

Total ammonium and nitrite concentrations were significantly higher during storms than during base flow. Ammonium concentrations ranged from 0.00 to 0.28 mg/L during baseflow and from 0.05 to 3.4 mg/L during storms. Nitrite concentrations were less than 0.09 mg/L during base flow and generally less than 0.29 mg/L during storms. Two of the storms with high ammonium concentrations occurred in April when anhydrous ammonia was being applied as a fertilizer. Nitrite concentrations were less than 0.29 mg/L during all storms except two. One storm occurred in May 1980 shortly after the fertilizer application and contained 1.5 mg/L of nitrite and 41 mg/L of nitrate, the maximum concentration found at this site. The high nitrite and nitrate concentrations and low ammonia concentration reflect the rapid oxidation of the anhydrous ammonia to nitrite and nitrate.

Total phosphorus concentrations followed the same pattern as suspended sediment. Base-flow concentrations of total phosphorus were relatively low, 0.09 to 0.28 mg/L, compared to storm concentrations, 1.6 to 19 mg/L (fig. 22). The highest concentrations occurred during several intense storms following fertilizer applications in May. During storms in late June and July concentrations decreased from 19 to 15 to 12 to 5.6 mg/L. Storm concentrations continued to decrease through October because soil erosion also decreased due to increasing soil cover.

Total organic carbon concentrations ranged from 1.4 to 8.8 mg/L during base flow and from 7.9 to 148 mg/L during storms (fig. 22). Concentrations were highest during storms in June and July. These storms also produced high suspended-sediment concentrations. Decomposition of the fall-tilled cornstalks after spring plowing and fertilizing may have increased the availability of organic carbon for transport. Storm concentrations steadily decreased from June through November 1980.

Figure 23 shows the variation in the mean concentration of selected herbicides during storms between November 1979 and December 1980. Atrazine was the most prevalent herbicide; concentrations ranged from 0.5 to 3.9 μg/L during base flow (fig. 24) and from 0.1 to 200 μg/L during storms. The highest concentrations during both base flow and storms occurred from May to July after herbicide application. After a storm on June 28, algae and grasses in runoff channels, along stream banks, and in the stream bed were killed, probably by the high concentrations of herbicides transported during storms. Concentrations of atrazine were reduced by about 50 percent in each successive storm through the summer. By September, soil concentrations of atrazine had decreased to about 25 percent of the concentrations detected in May, and storm concentrations decreased to about 1 percent. This would indicate that while significant soil concentrations of atrazine remained, the quantity of atrazine available for transport to streams is greatly reduced over the growing season. This reduced availability may be due to a combination of atrazine being strongly adsorbed to soil particles and reduced soil erosion because of protective vegetative cover.

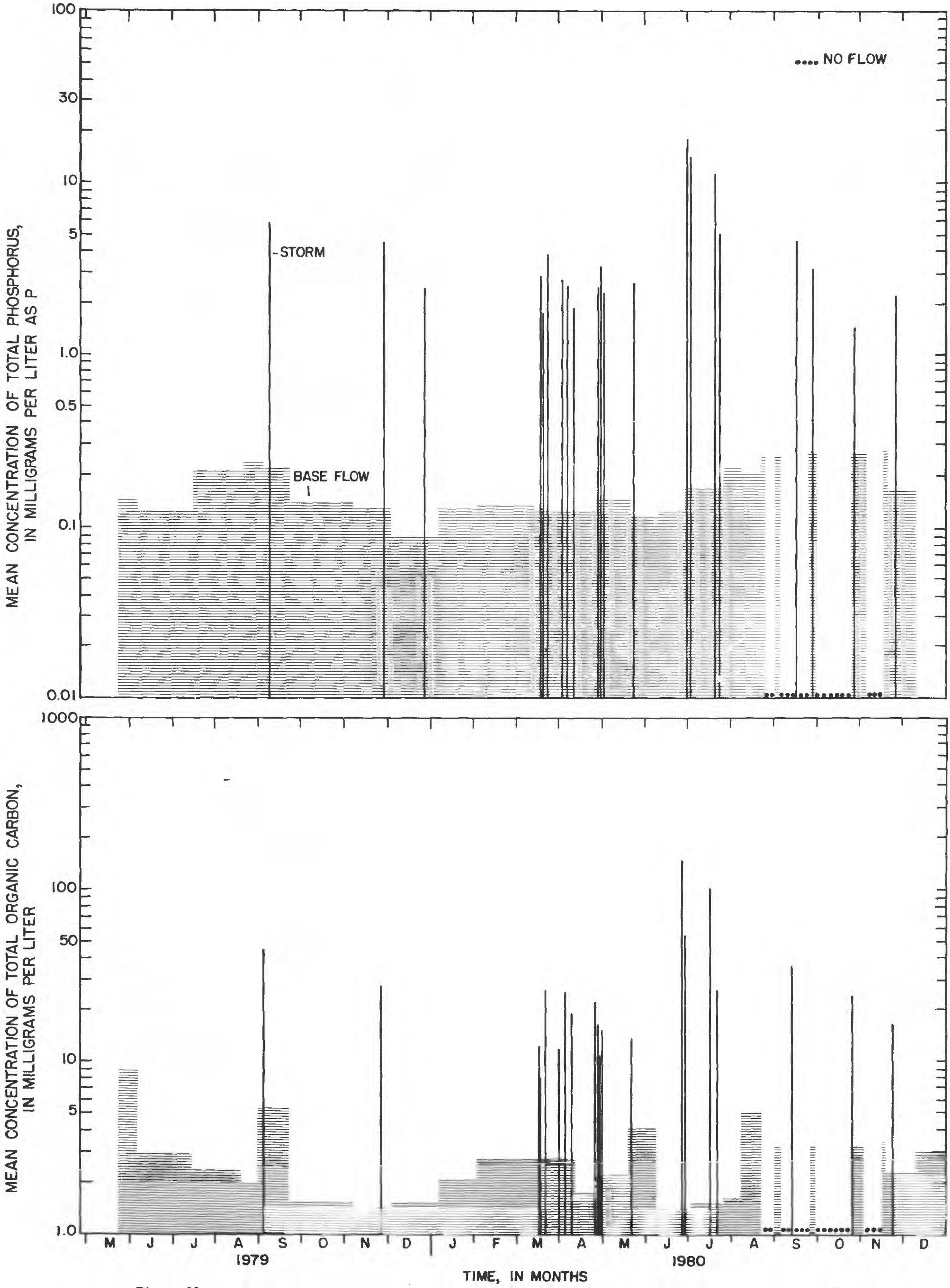


Figure 22.--Mean total phosphorus and total organic carbon concentrations during storms and base flows at the cornfield site, May 1979 to December 1980.

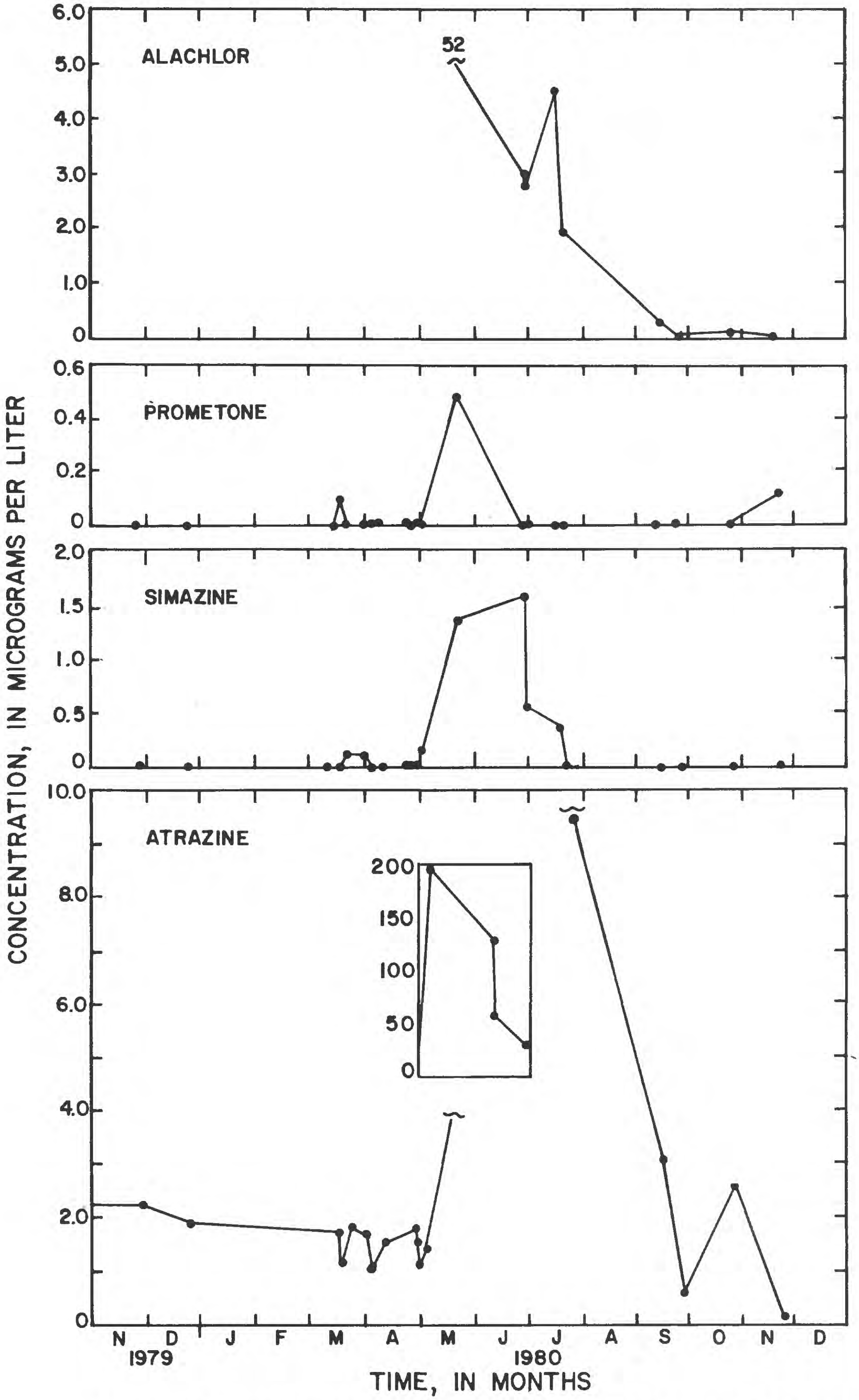


Figure 23.--Mean storm concentrations of herbicides at the cornfield site, November 1979 to December 1980.

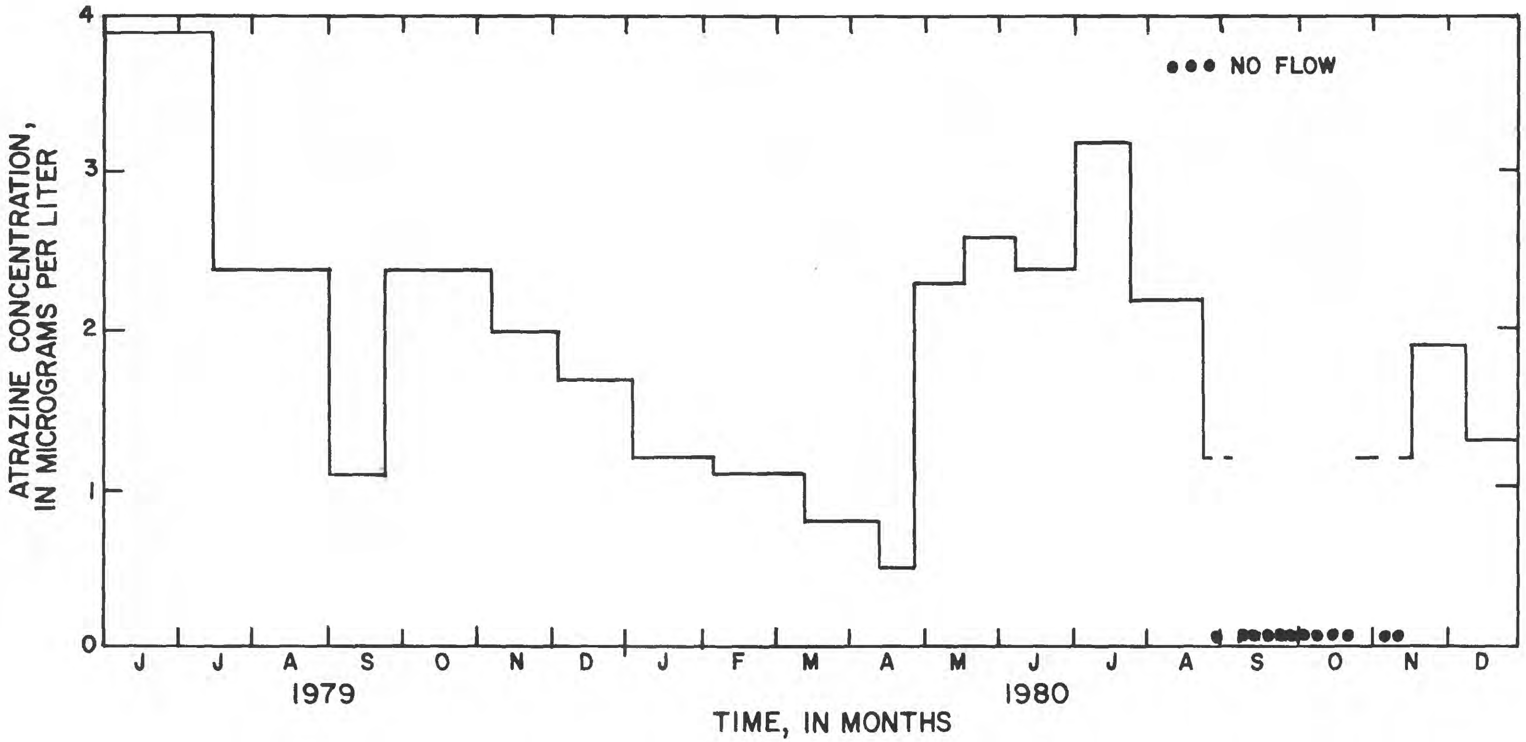


Figure 24.--Atrazine concentrations at the cornfield site during base flows, May 1979 to December 1980.

Concentrations of alachlor and simazine during storms followed the same pattern as atrazine, peaking in the spring following application and declining rapidly through the summer months. Although alachlor was applied to the fields at a higher rate than atrazine, storm concentrations were lower. Mean alachlor concentrations during storms ranged from 0.0 to 52 µg/L; base-flow concentrations ranged from 0.0 to 0.2 µg/L. Peak prometone and simazine concentrations were 0.5 and 1.6 µg/L, respectively, during storms. These herbicides were seldom detected during base-flow periods. Since simazine was probably an impurity in the applied atrazine, concentrations are understandably lower.

Residential Subbasin

Concentrations of all constituents except nitrate were higher during storms than during base-flow periods. Data from discrete samples collected throughout a storm indicated that the residential site, in contrast to the other sites, showed a first flush effect in the concentrations of the dissolved and suspended constituents. Small increases in streamflow at the beginning of the storm were accompanied by large increases in constituent concentrations (fig. 25). The first flush effect is caused by the large amount of impervious surfaces in this subbasin. Particulate matter from atmospheric deposition and road deposits are washed off the impervious surfaces at the beginning of the storm, quickly reducing the availability of constituents during the major part of the storm.

The mean concentrations of suspended sediment during storms ranged from 13 to 1,140 mg/L; however, mean storm concentrations generally exceeded 100 mg/L (fig. 26). Base-flow concentrations of suspended sediment were high, most exceeding 40 mg/L. The highest concentrations during storms occurred from March through September; however, suspended-sediment concentrations fluctuated greatly from storm to storm. The major sources of sediment are road deposits, lawns, and home vegetable gardens.

The frequency and intensity of storms affects suspended-sediment concentrations. Two storms in June 1980 had precipitation intensities twice that of any other storm during the sampling period. The intensities were 0.59 and 0.57 in. in 15 minutes, and suspended-sediment concentrations were 1,140 and 757 mg/L, respectively. Other storms with suspended-sediment concentrations over 500 mg/L had considerably lower intensities, ranging from 0.06 to 0.17 in. of rain in 15 minutes. The number of days between storms was proportional to the amount of readily available sediment to be transported to the stream.

Total organic nitrogen ranged from 0.25 to 4.7 mg/L during storms. Base-flow concentrations of total organic nitrogen were as much as one-quarter of the storm concentrations (fig. 27). Storm size, intensity, and frequency of storms are probably the predominant factors affecting variation in concentrations. During periods when storms occurred frequently, as in April to June 1980, organic nitrogen concentrations decreased in successive storms.

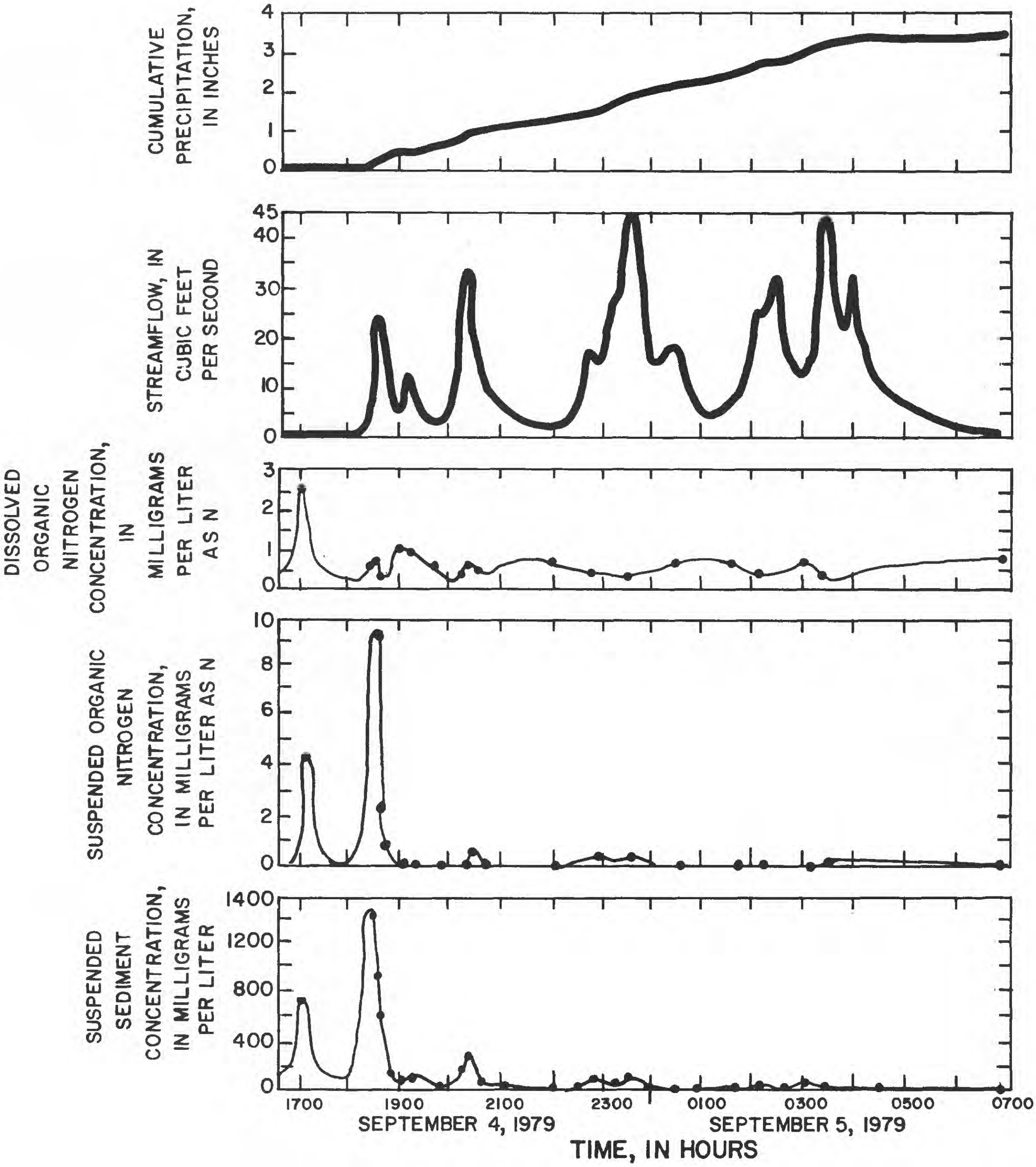


Figure 25.--Reaction of streamflow to precipitation and of suspended sediment and organic nitrogen to streamflow at the residential site, September 4-5, 1979.

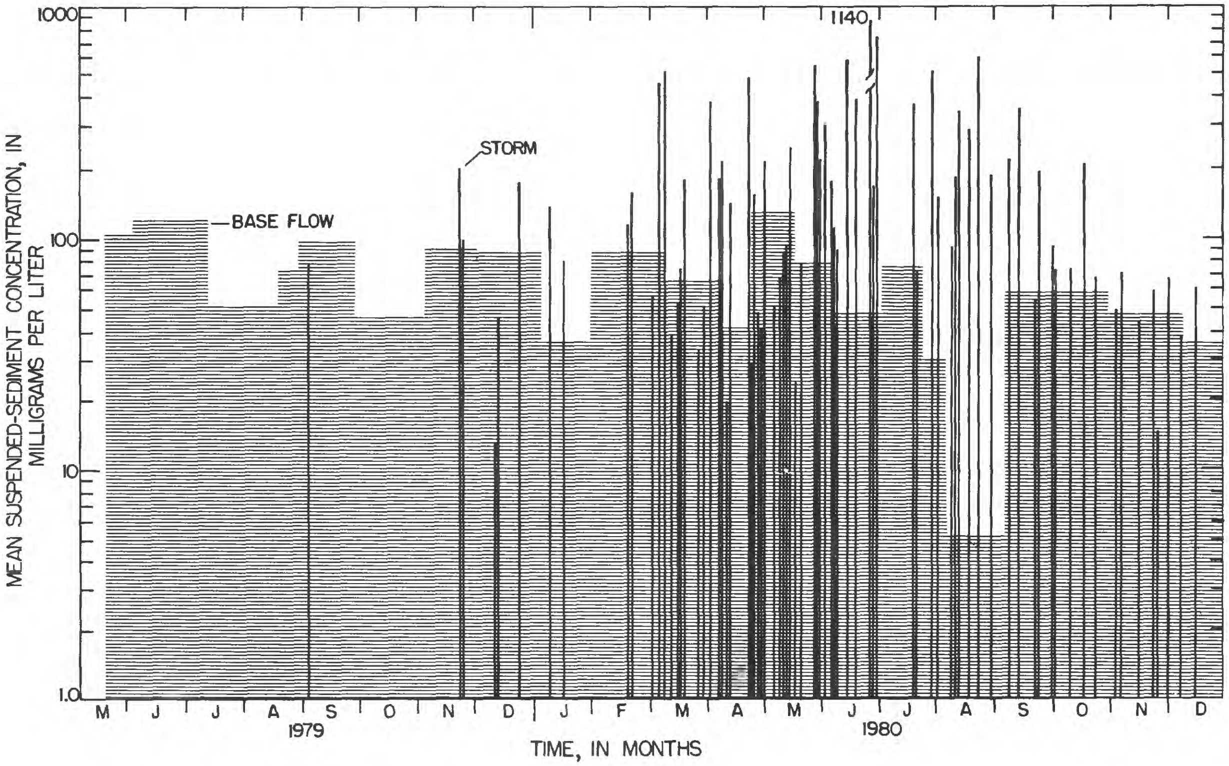


Figure 26.--Mean suspended-sediment concentrations during storms and base flows at the residential site, May 1979 to Decmber 1980.

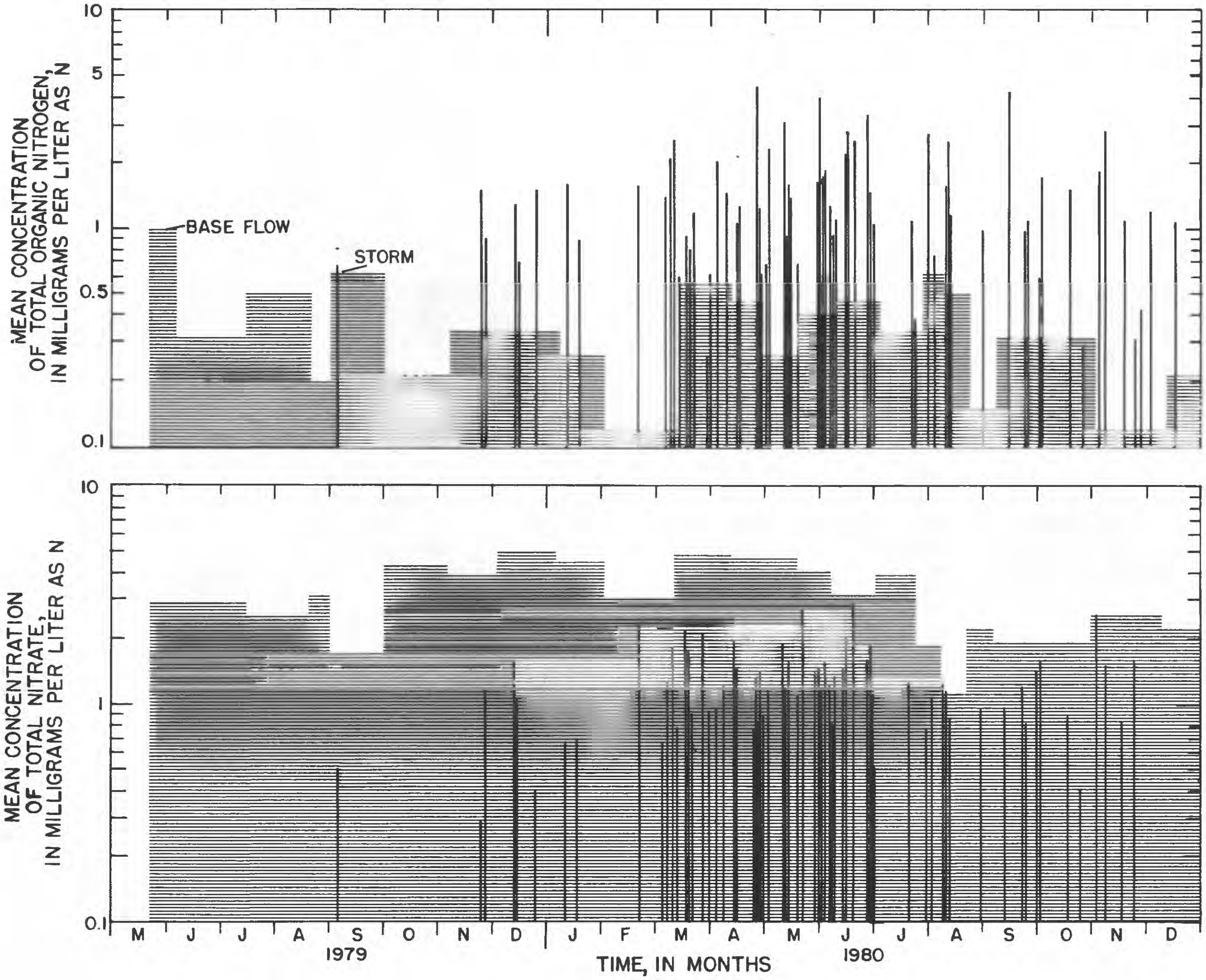


Figure 27.--Mean total organic nitrogen and total nitrate concentrations during storms and base flows at the residential site, May 1979 to December 1980.

Total nitrate concentrations ranged from 1.1 to 5.0 mg/L during base flow and from 0.29 to 2.9 mg/L during storms (fig. 27). Base-flow concentrations were higher than storm concentrations except for one storm in November 1980. Dilution of nitrate during storms is probably due to the large amount of direct runoff and limited availability of nitrate at the residential site. Fertilizer applications on lawns and gardens at the residential site are small, and no seasonal trends in nitrate concentrations are observed.

Several storms contained high total ammonium concentrations, up to 2.8 mg/L. Application of lawn fertilizer in the form of urea may have temporarily increased the source of ammonium. Total nitrite concentrations during storms at the residential site were all less than 0.24 mg/L.

During storms, mean total phosphorus concentrations ranged from 0.07 to 2.6 mg/L (fig. 28). Base-flow concentrations were generally less than 0.06 mg/L. Storms with phosphorus concentrations greater than 0.6 mg/L occurred from late May through early August and in November. Lawn and garden fertilizers applied intermittently throughout the summer months, as well as more intense storms during the summer, probably contributed to the higher storm concentrations found from May through August. Fall applications of lawn fertilizers might have been responsible for the higher storm concentrations in November.

Total organic carbon concentrations ranged from 1.5 to 28 mg/L during base flow and from 5.0 to 114 mg/L during storms. Concentrations during storms decreased slightly during rainy periods and then increased after several dry days. Organic carbon concentrations probably fluctuate at this site due to activities such as the accumulation of oils on road surfaces from automobiles, the disposal of motor oil in storm drains, and the spraying of oil-based pesticides on trees and shrubs. Deterioration of organic matter such as lawn clippings may also contribute to organic carbon concentrations.

The highest mean concentration of atrazine during a storm was 78 μg/L in May 1980 (fig. 29). This high concentration may have been due to runoff which crossed a small piece of cornfield. However, all other storms had concentrations of 2.0 μg/L or less of atrazine. Atrazine was found in only 30 percent of the base-flow samples; the maximum concentration was 0.3 μg/L. Atrazine was not detected in any of the soil samples in the residential basin.

Simazine and alachlor concentrations reached 3.2 and 1.5 μg/L, respectively, during storms. Detectable concentrations of prometone were found in every base-flow sample from the residential site, ranging from 0.1 to 0.5 μg/L. The highest prometone concentrations during storms, up to 6.4 μg/L, occurred during June and July when prometone was applied for weed control.

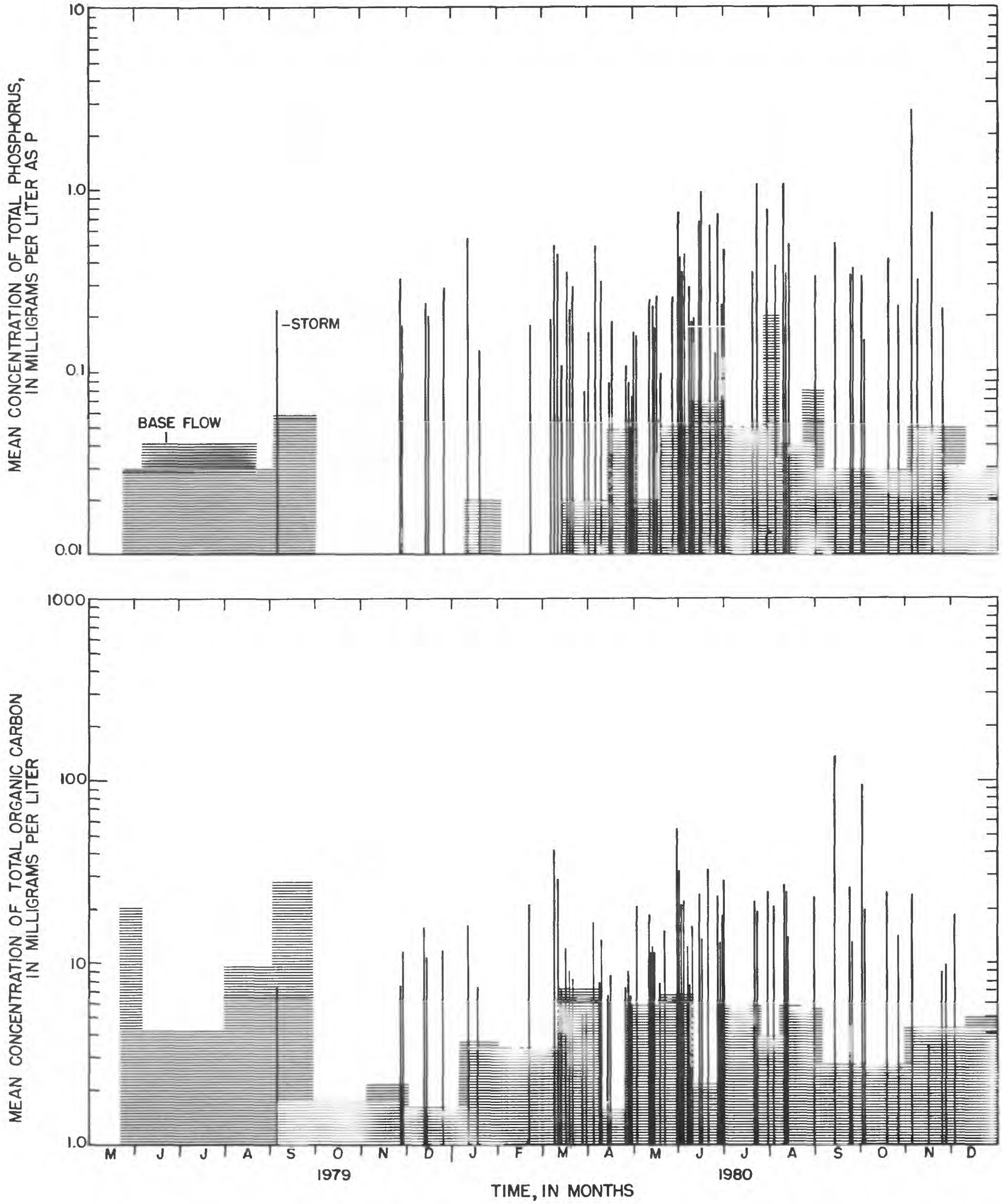


Figure 28.--Mean total phosphorus and total organic carbon concentrations during storms and base flows at the residential site, May 1979 to December 1980.

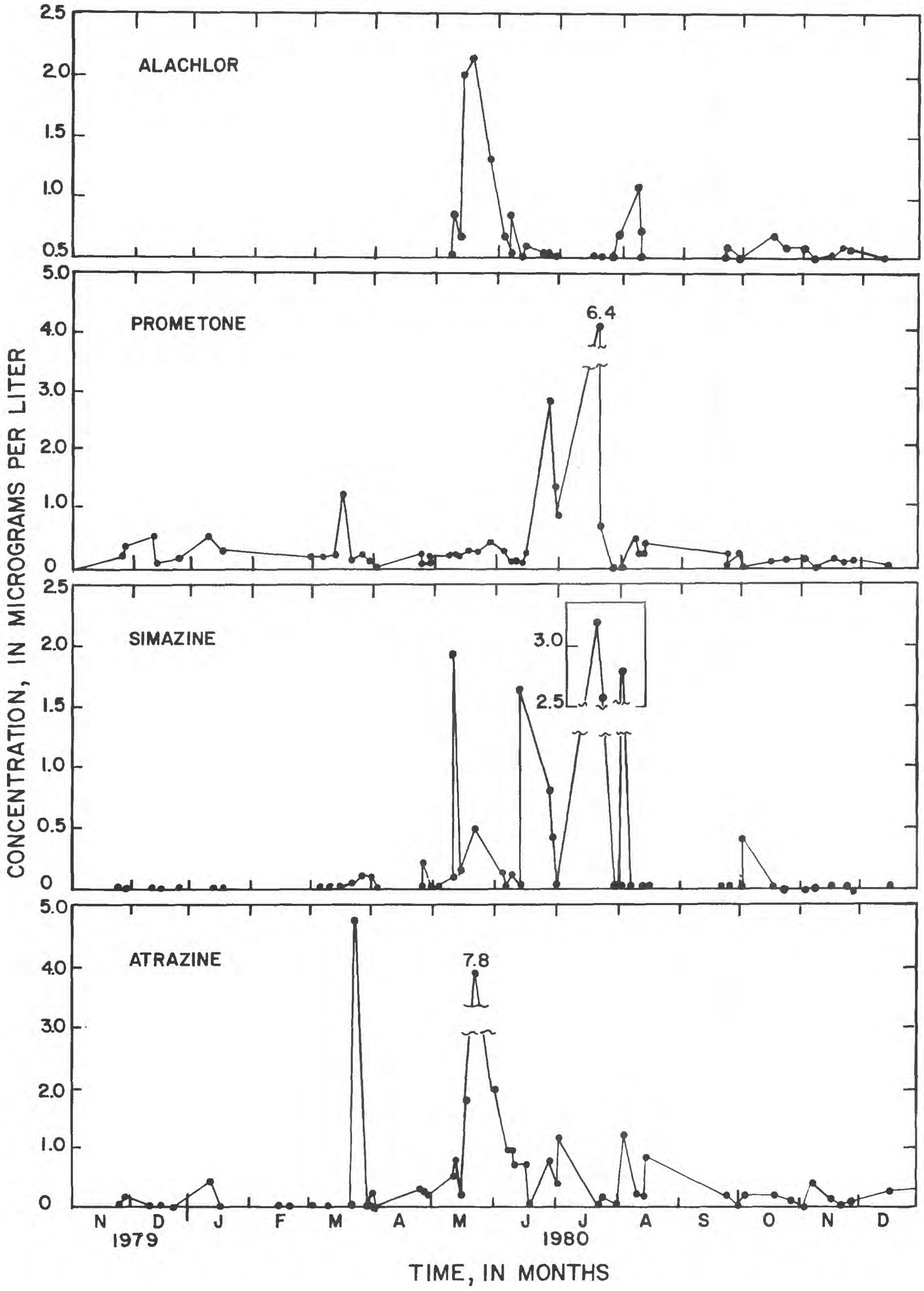


Figure 29.--Mean storm concentrations of herbicides at the residential site, November 1979 to December 1980.

Pasture Subbasin

The following section is a discussion of the variation in water quality observed at two sites on the same stream. The upstream pasture site drains 0.56-mi^2 of mixed land use. The intervening area of pasture between the two sites in 0.03-mi^2. The variation in water quality of the pasture was determined by analyzing the differences in the water-quality characteristics of the two sites.

Suspended-sediment concentrations at the two sites ranged from 11 to 204 mg/L during base flow and from 18 to 3,840 mg/L during storms (fig. 30). Except during September and October 1979, the base-flow and storm concentrations were higher at the downstream site. The difference in suspended-sediment concentrations between the upstream and downstream pasture sites is attributable to contributions from the pasture and the stream channel between the two sites. Runoff in a channel from the barnyard through the pasture generally carried high suspended-sediment concentrations, several samples contained more than 11,000 mg/L. The eroding banks of the stream channel in the pasture area is a large source of sediment. Cows walk through and across the stream, trampling the streambanks as they go and leaving additional sediment loosened and available for transport.

Rainfall intensity was a major factor affecting suspended-sediment concentrations at the upstream and downstream pasture sites. The storm with the highest concentration of suspended sediment had a rainfall intensity of 0.44 in. in 15 minutes. The seasonal trend shown in figure 30 of high suspended-sediment concentrations in the summer was caused mainly by intense summer thunderstorms. Total storm precipitation was also important. A December 1979 storm had high suspended-sediment concentrations, 2,070 mg/L at the downstream pasture site and 1,580 mg/L at the upstream site. This storm had a relatively low intensity, 0.17 in. of rain in 15 minutes, but totalled nearly 1.0 in.

Total organic nitrogen concentrations at the two pasture sites followed a pattern similar to suspended sediment. Organic nitrogen concentrations during storms at the downstream pasture site (fig. 31) ranged from 0.78 to 32 mg/L and at the upstream pasture site ranged from 0.47 to 13 mg/L. Concentrations at the downstream pasture site were as much as ten times higher than those at the upstream pasture site. Since the principal source of organic nitrogen in the pasture is soil enriched by cow manure, the stream flowing through the pasture area would be expected to contain significant concentrations of organic nitrogen. Concentrations of total organic nitrogen during base flow at the downstream pasture site exceeded concentrations at the upstream pasture site in 85 percent of the samples, indicating a contribution from the pasture. The highest base-flow concentrations at the downstream pasture site occurred during the early summer and late fall in both 1979 and 1980.

Total nitrate concentrations during base flow at the upstream and downstream pasture sites varied from 3.0 to 9.1 mg/L (fig. 32). During storms, mean concentrations of total nitrate at the upstream and downstream pasture sites ranged from 0.20 to 8.5 mg/L. Nearly all storm concentrations

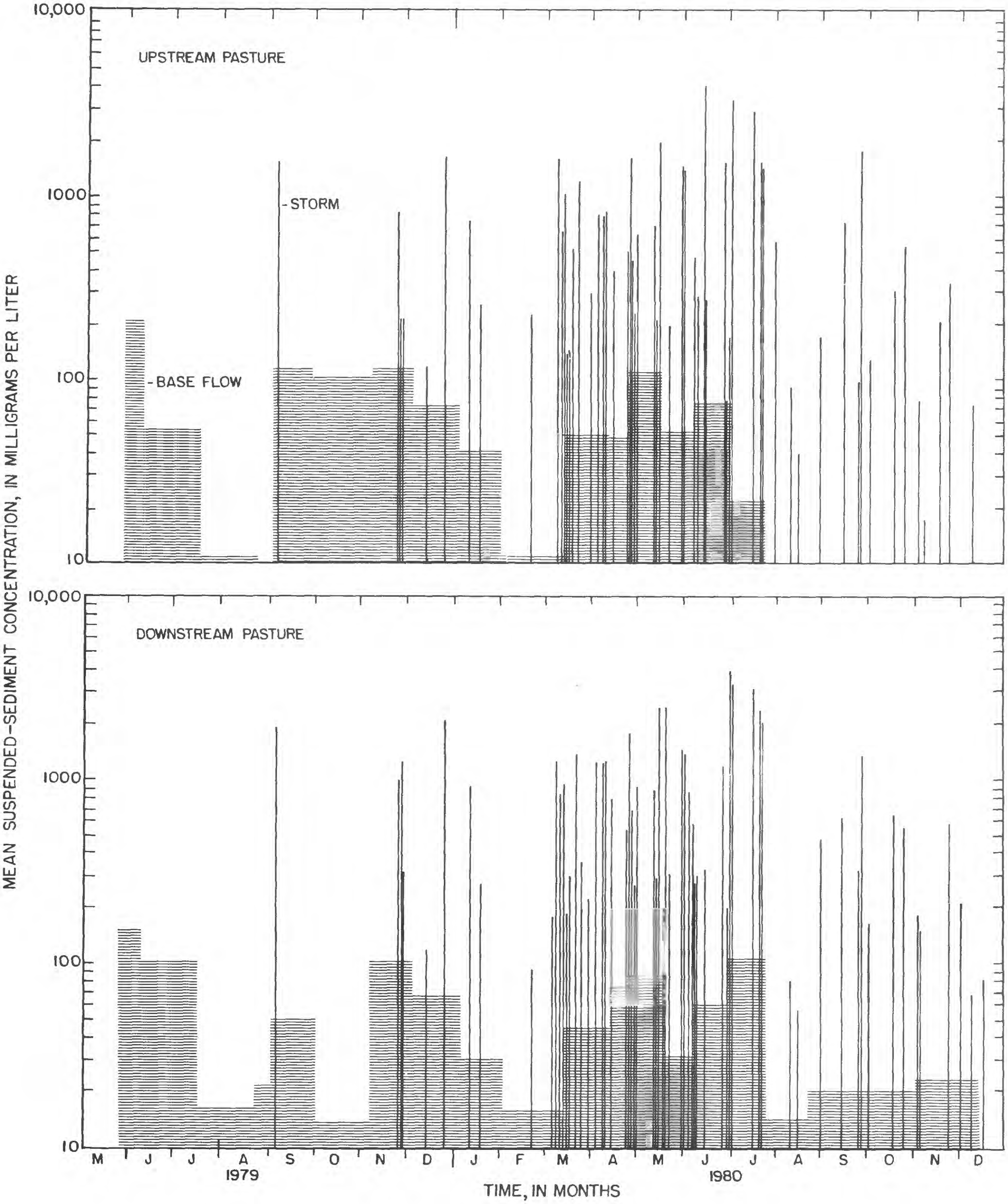


Figure 30.--Mean suspended-sediment concentrations during storms and base flows at the upstream and downstream pasture sites, May 1979 to December 1980.

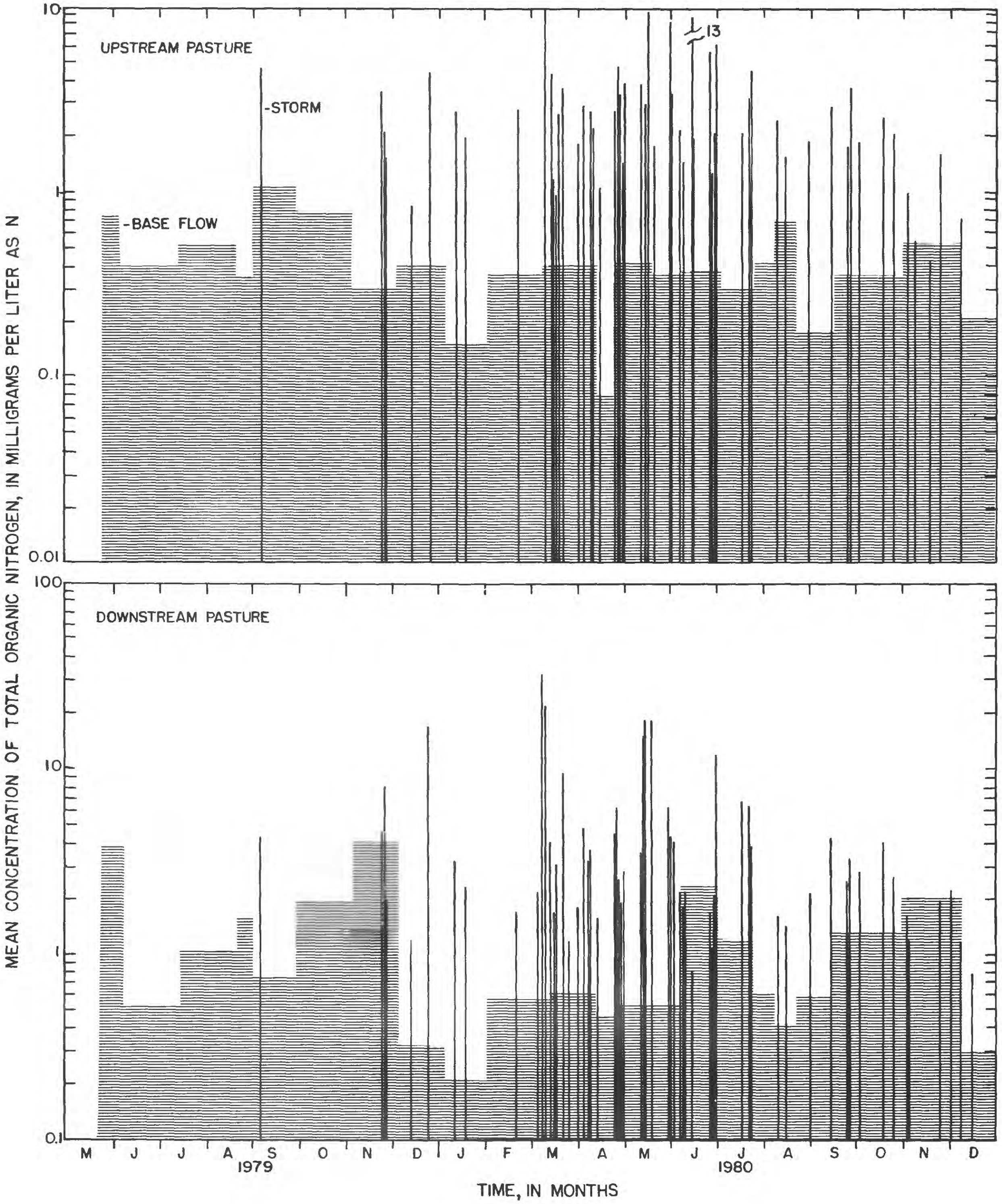


Figure 31.--Mean total organic nitrogen concentrations during storms and base flows at the upstream and downstream pasture sties, May 1979 to December 1980.

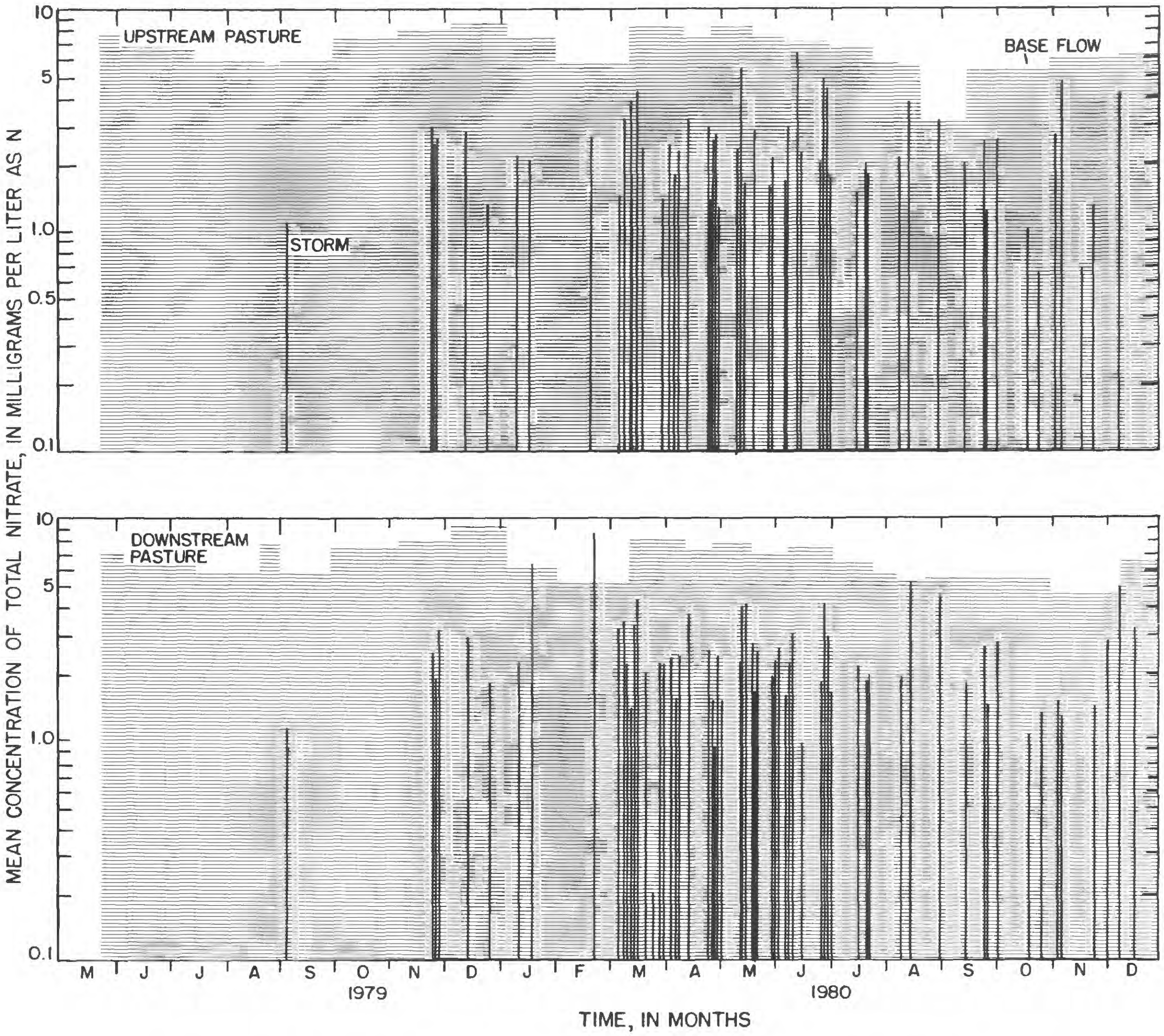


Figure 32.--Mean total nitrate concentrations during storms and base flows at the upstream and downstream pasture sites, May 1979 to December 1980.

of nitrate at both sites were less than base-flow concentrations. Total nitrate concentrations at the two pasture sites were not significantly different from each other either during base flow or storms. Therefore, the pasture contribution of nitrate was insigni-ficant in comparison to the concentrations measured at the upstream and downstream sites.

Concentrations of total ammonium and nitrite from the downstream pasture site generally exceeded those from the upstream site during base flow and storms. The close proximity of the ammonium source to the stream through the pasture would account for the differences in both constituent concentrations, since nitrite results from incomplete oxidation of ammonium. The highest concentrations of ammonium occurred during the summer months. Nitrite concentrations did not exhibit a seasonal trend.

Mean total phosphorus concentrations at the upstream and downstream pasture sites during storms ranged from 0.14 to 4.2 mg/L (fig. 33). Storm concentrations of phosphorus were generally slightly higher at the downstream pasture site than at the upstream site. Concentrations were highest from late April through July at both sites. Base-flow concentrations also were slightly higher at the downstream pasture site than at the upstream site, except for one sample collected in December 1980. The predominant sources of phosphorus from the pasture are manure and detergents used in dairy operations. The detergents in the wash water which flows through the pasture to the stream augment base-flow phosphorus concentrations and also accumulate in the soil and become available for transport to the stream during storms.

Total organic carbon concentrations at both pasture sites were influenced by a discharge of light-weight oil from a headwaters source. Concentrations during storms ranged from 3.6 to 86 mg/L at the upstream and downstream pasture sites (fig. 34). Average concentrations at both sites were nearly equal, and maximum base-flow concentrations were the same, 13 mg/L.

Herbicides in base-flow and storm samples from the two pasture sites were only detected infrequently and in relatively low concentrations. The downstream site generally was lower than the upstream site, indicating that there was no contribution from the pasture.

Comparison of Constituent Concentrations

During base flow, suspended-sediment concentrations were highest at the residential site, mostly due to fine sand particles. Concentrations of organic nitrogen and phosphorus at the downstream pasture site were generally much higher than any of the other sites. Large differences between the downstream and upstream pasture sites indicate a large pasture contribution. Nitrates were present in base-flow samples at the cornfield site in concentrations up to 24 mg/L, about three times more than found at the other specific land-use sites. The highest and most consistently detectable concentrations of atrazine were found in samples from the cornfield site.

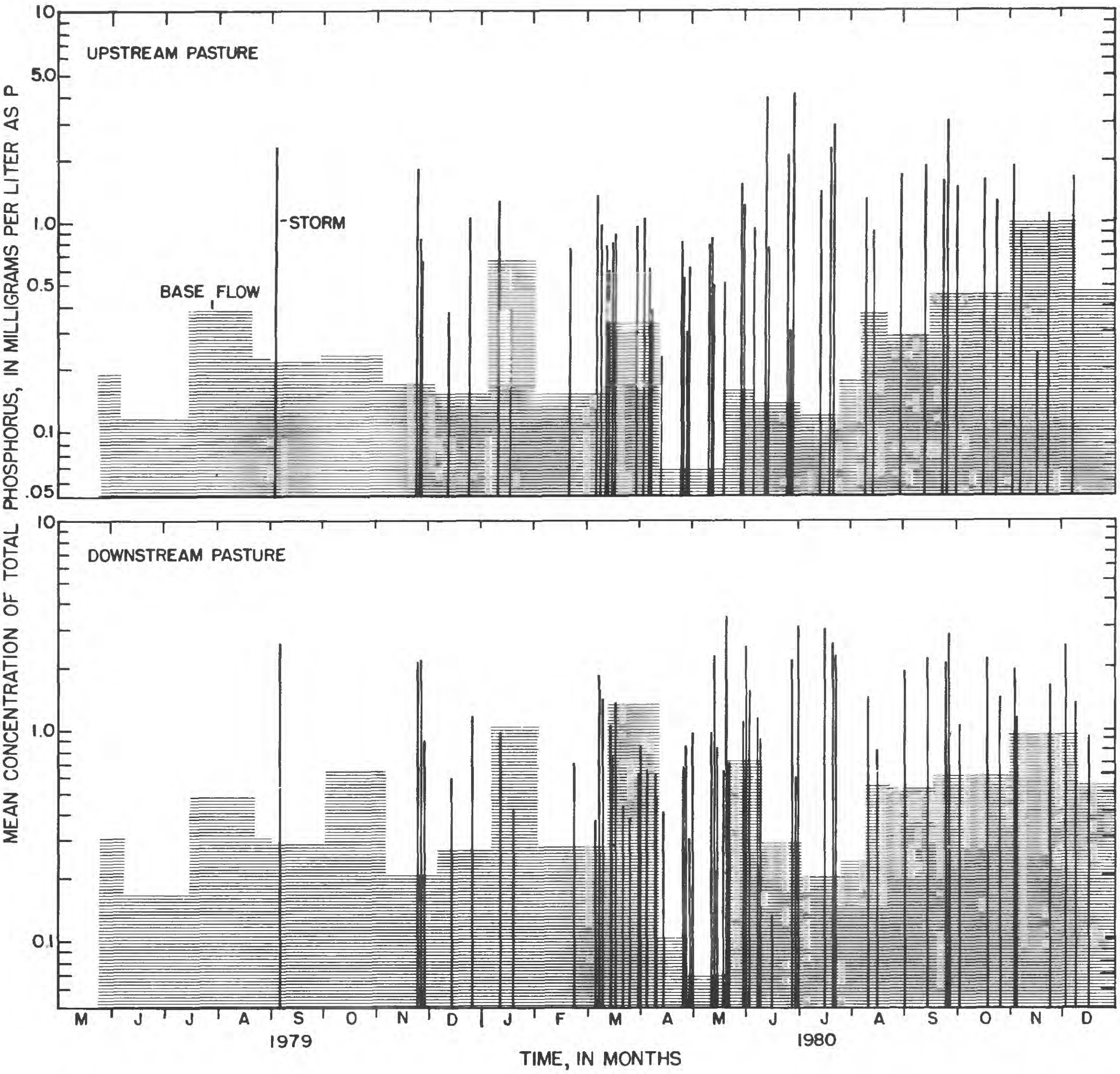


Figure 33.--Mean total phosphorus concentrations during storms and base flows at the upstream and downstream pasture sites, May 1979 to December 1980.

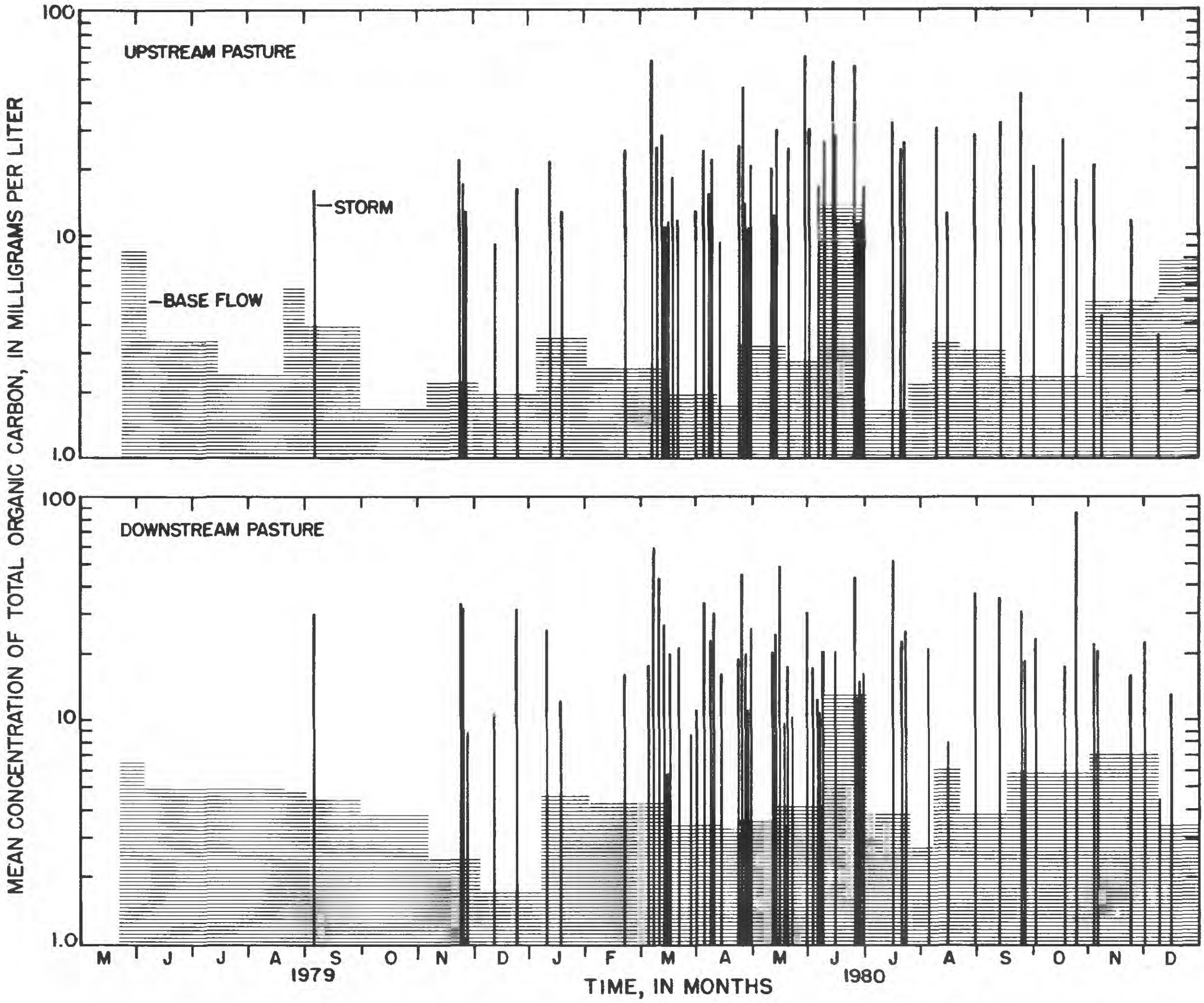


Figure 34.--Mean total organic carbon concentrations during storms and base flows at the upstream and downstream pasture sites, May 1979 to December 1980.

The residential site had detectable concentrations of prometone in every base-flow sample, unlike any of the other sites. Concentrations of simazine during base flow were most frequently detected at the Pequea Creek site.

During storms the highest mean concentration of suspended sediment from the specific land-use sites was found at the cornfield site. The highest organic nitrogen concentrations were also found at the cornfield site. High concentrations of organic nitrogen were also contributed from the pasture site. Nitrate and phosphorus concentrations were greatest from the cornfield site and occurred soon after fertilizer application. The highest concentrations of atrazine were found at the cornfield site and prometone at the residential site. Concentrations of these herbicides were much greater during storms than during base flow.

Variation in Constituent Storm Yields

To determine the effects of land use on stream quality during individual storms throughout the sampling period, mean storm yields, in tons per day per square mile, of the predominant constituents for each specific land-use site are compared to the forest site. Yields are only compared for storms which caused runoff at most sites and had comparable amounts and intensities of rainfall. Several storm concentrations were estimated for the forest site, since amounts of rainfall required to raise streamflow and collect storm samples were much greater at this site than at the other sites. These estimates were made based on mean streamflows which were measured for all storms and on suspended sediment and chemical concentrations from sampled storms which were similar in size and occurred during similar conditions.

The relationship between yields from the forest site and the cornfield, residential, and pasture sites is affected both by relative concentrations of constituents and streamflows. For most storms, the streamflow yield at the pasture and residential sites was greater than that at the forest site. The streamflow yield at the cornfield site was less than that at the forest site. However, variation in streamflow yield was greatest at the cornfield site due to changing soil conditions and crop growth.

Yields of suspended sediment during comparable storms were significantly higher for the pasture site than yields from the forest site (fig. 35). Interpretation of this large suspended-sediment yield must be done carefully, since the stream at the pasture site was part of a larger drainage area. A headwaters pasture area would have a much smaller stream and scour of the streambottom and streambanks may be much less.

Yields from the cornfield and residential sites for suspended sediment were similar, and slightly higher than yields from the forest site. There were fluctuations in this relationship for the cornfield site. Because of changing season and soil conditions caused by agricultural activites, the amount of sediment available for transport to the stream channel varied, as well as the amount of streamflow. Smaller fluctuations were found at the residential site due to more stable soil conditions.

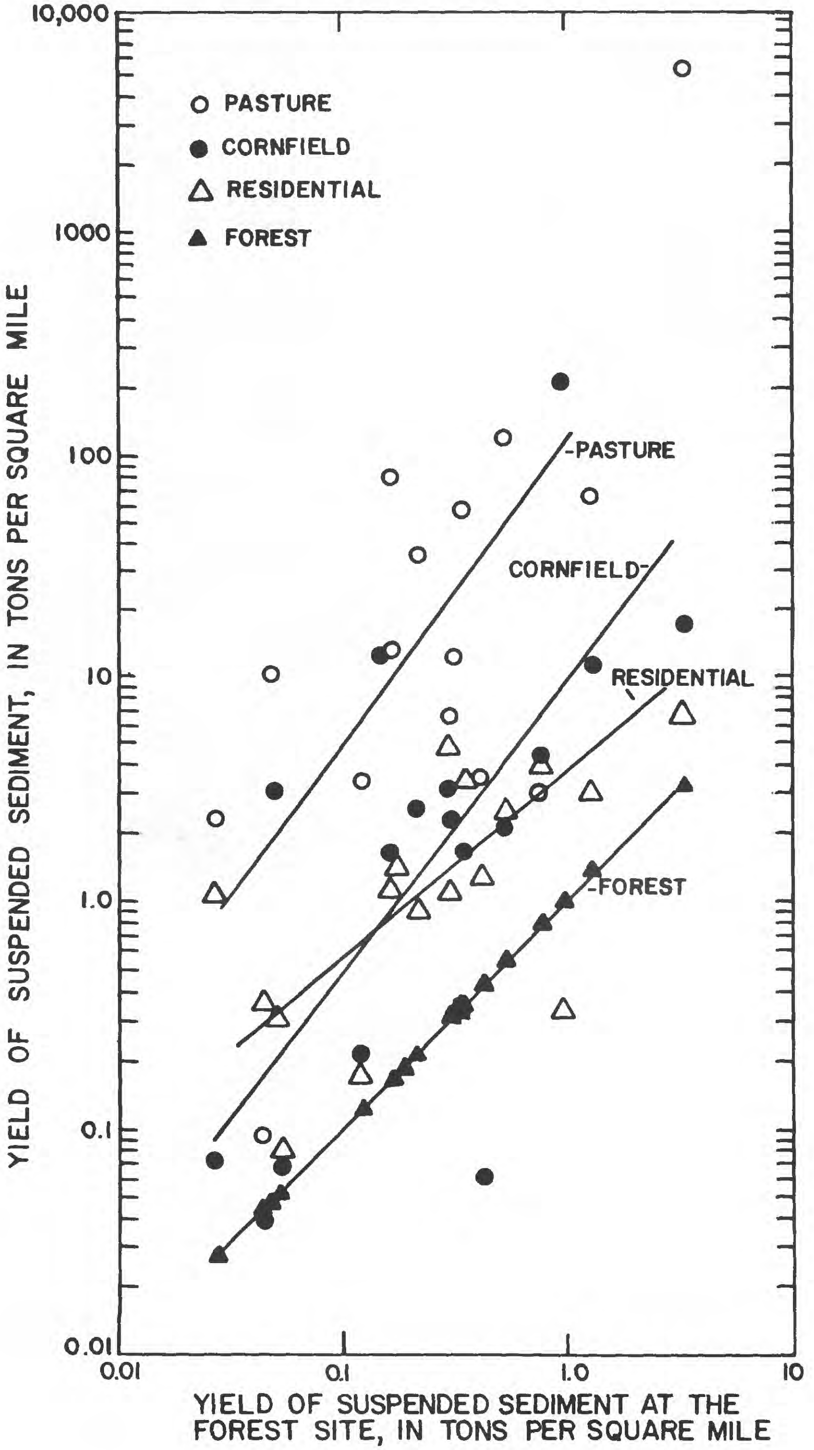


Figure 35.--Relationship during storms of suspended-sediment yields at the forest site to yields at the cornfield, residential, and pasture sites.

Yields of organic nitrogen for most storms at the pasture site were higher than those at the other sites and were more than 40 times the yields from comparable storms at the forest site (fig. 36). Most storms at the cornfield and residential sites also were higher yielding for organic nitrogen than storms at the forest site. The relationship of organic nitrogen yields among sites is similar to that of suspended sediment as most of the organic nitrogen yield during storms is in the suspended phase.

For nitrate, yields from the cornfield site were significantly higher than yields from the forest site for comparable storms (fig. 37). Yields from the residential site were about the same as the forest site. Yields from the pasture site were not calculated because this difference in nitrate at the upstream and downstream sites was negligible compared to the total nitrate loads at either site.

Total phosphorus yields (fig. 38) for comparable storms shows the pasture site produced significantly higher yields than any of the other sites. Yields from the cornfield site, although not as high as the pasture, were significantly higher than the residential or forest sites. The residential site had phosphorus yields that were slightly higher than the forest site.

Yields of organic carbon from the cornfield and residential sites were compared to the forested site yields in figure 39. Yields from both the cornfield site and the residential site were about the same and slightly higher than yields from the forest site. Yields from the pasture site were not calculated because the concentrations were periodically increased from an unknown upstream source of light-weight oil.

Annual Yields for 1980

Streamflow at the different sites in the basin varied considerably even though total precipitation for 1980 varied less than 5 percent between sites. The forest site had the greatest annual flow, 458 $(ft^3/s)/d/mi^2$, of any of the sites (fig. 40). Base flow accounted for about 96 percent of the water discharged from this basin. The leaf canopy, litter, and soil humus at the forest site caused high infiltration of precipitation and effectively lowered direct runoff. The lowest amount of total flow at any of the sites was measured at the residential site, about half that measured at the forest site. However, base flow was only 49 percent of the total flow. Total flows during storms at the residential site, 115 $(ft^3/s)/d/mi^2$ exceeded those at any other site. Streamflow at the other sites ranged from 274 to 346 $(ft^3/s)/d/mi^2$, and base flow accounted for 80 to 85 percent of total flow.

Yields, loads per square mile, were computed for selected constituents at each site for 1980 using base-flow and storm constituent concentrations, along with continuous streamflow. Almost all of the yields are based on actual concentrations. Occasionally, concentrations of one or two constituents for a sample were rejected since they seemed unreasonable. These concentrations were then estimated based on streamflow and concentrations

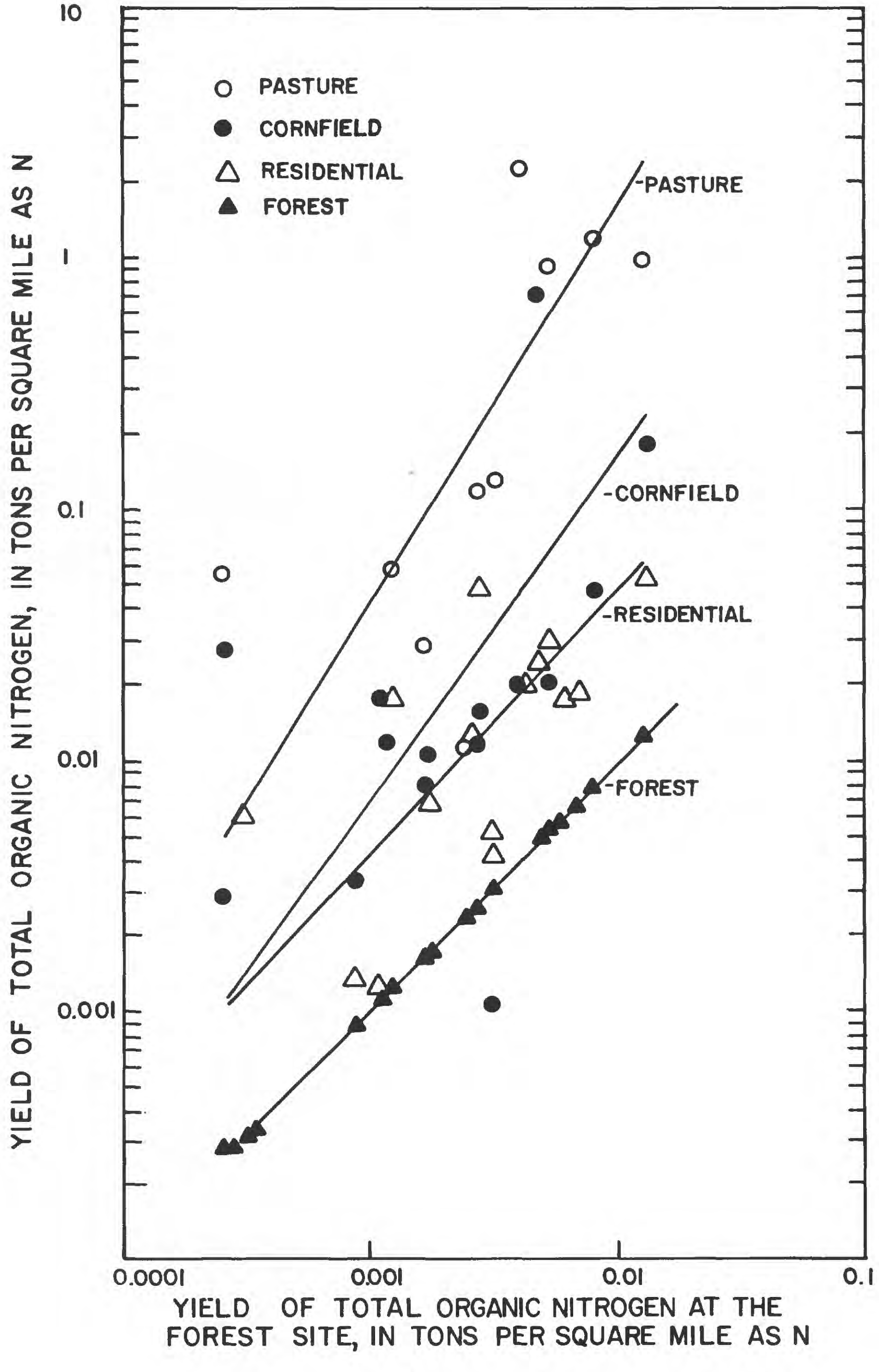


Figure 36.--Relationship during storms of total organic nitrogen yields at the forest site to yields at the cornfield, residential, and pasture sites.

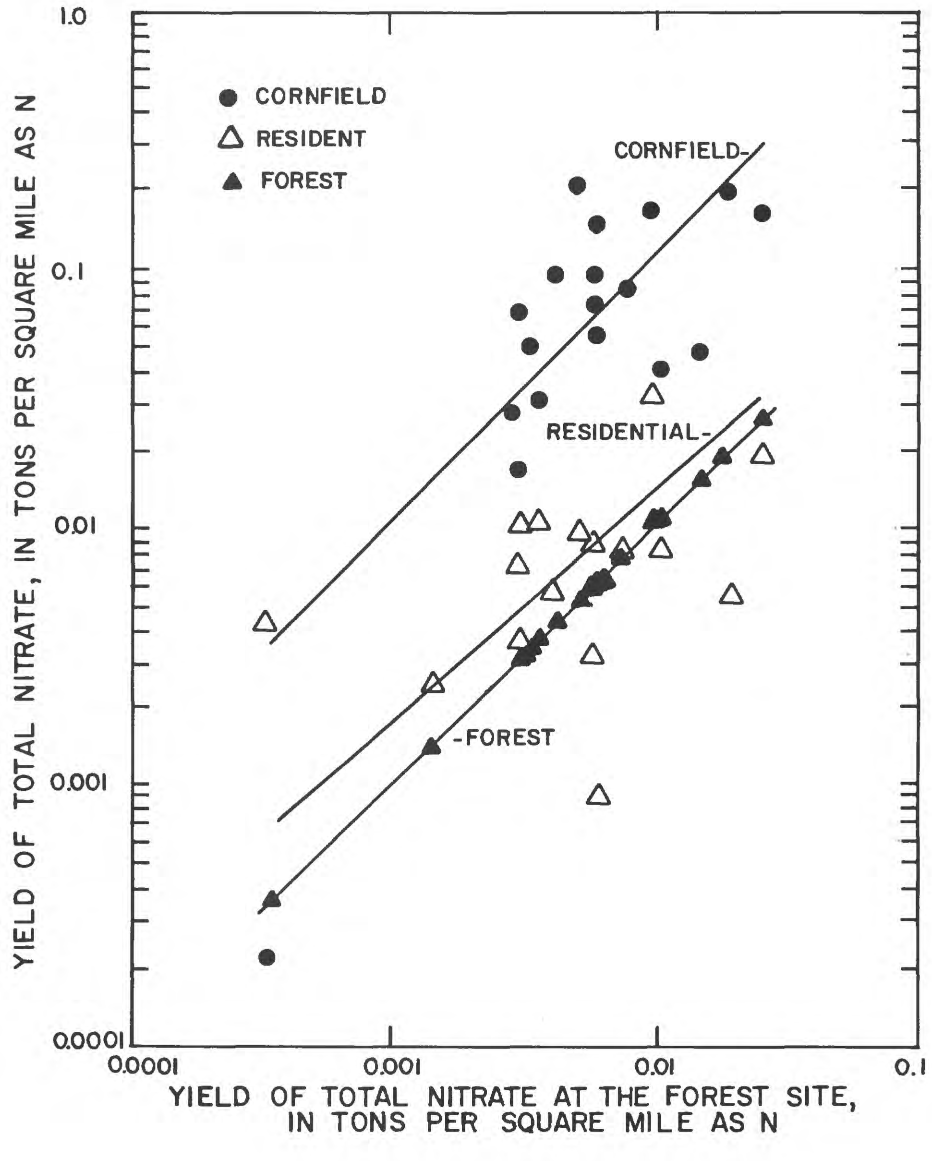


Figure 37.--Relationship during storms of total nitrate yields at the forest site to yields at the cornfield and residential sites.

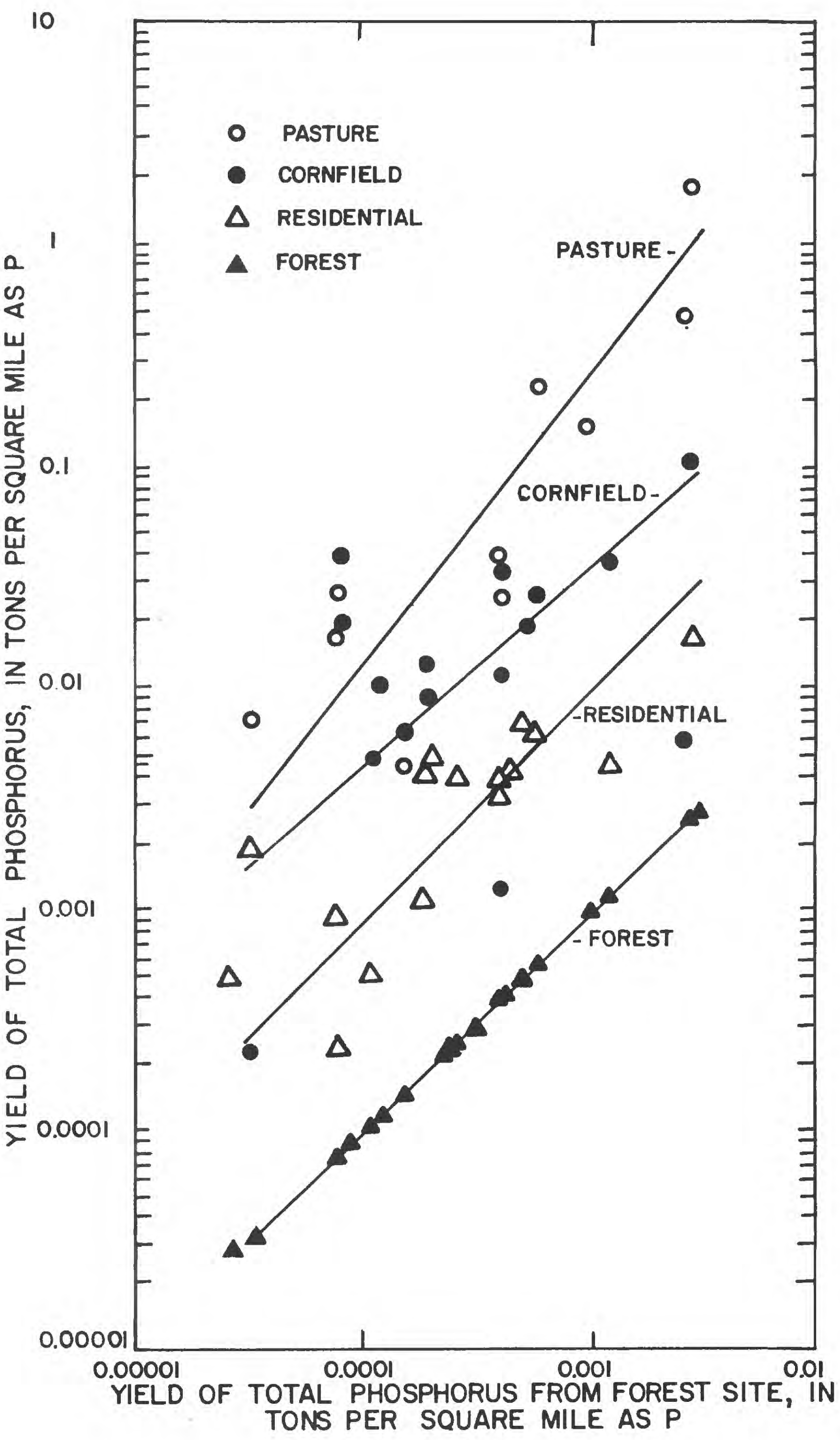


Figure 38.--Relationship during storms of total phosphorus yields at the forest site to yields at the cornfield, residential, and pasture sites.

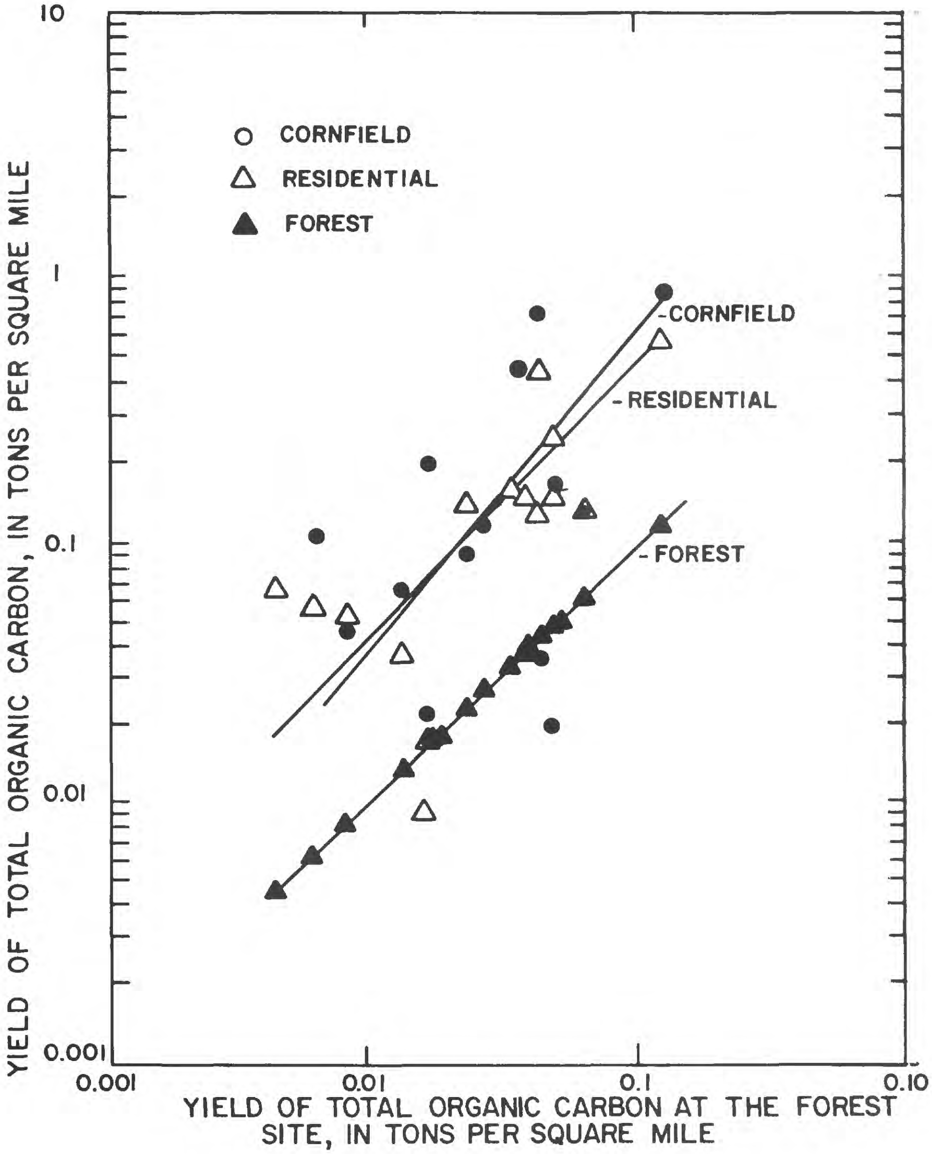


Figure 39.--Relationship during storms of total organic carbon yields at the forest site to yields at the cornfield and residential sites.

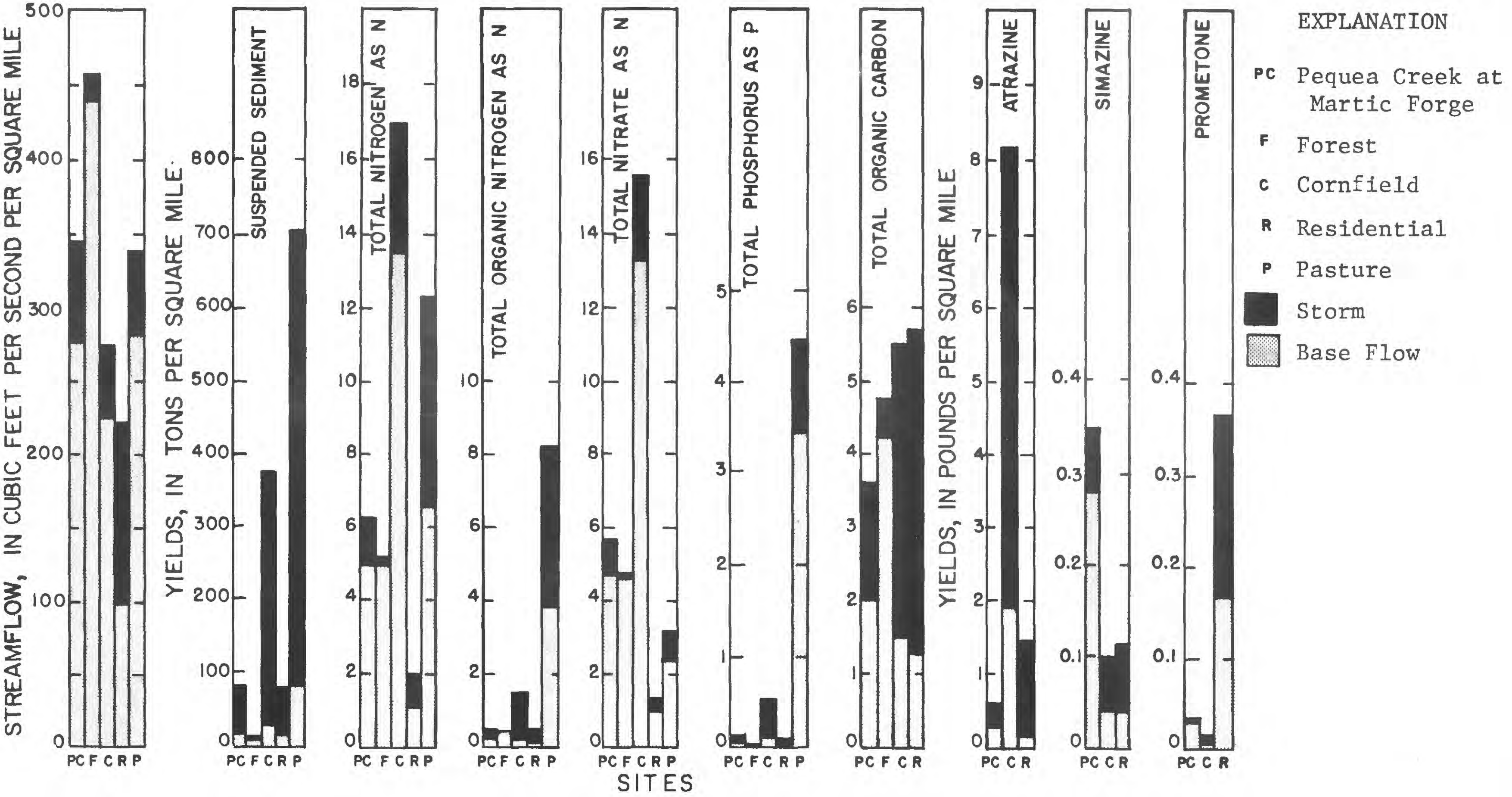


Figure 40.--Estimated yearly base-flow and storm yields from the specific land-use sites and Pequea Creek basin during 1980.

measured under similar conditions. For example, in base flow, only one percent of the data was estimated. Yields for storms that were not sampled or sampled over only part of the hydrograph were estimated by comparing streamflow data for these storms to streamflows and yields for storms which were sampled from the same month. Concentrations in 55 to 93 percent of the stormflow at each site were actually analyzed (table 13). The remainder were estimated as discussed above.

Table 13.--Amount of stormflow analyzed for suspended sediment and water quality during 1980

Site	Percentage of stormflow covered during 1980
Pequea Creek	93
Forest	55
Cornfield	72
Residential	74
Downstream pasture	85
Upstream pasture	75

The forest site had the lowest suspended-sediment yields, only 15 tons/mi^2, of which 54 percent was transported during storms. Suspended-sediment yields from the Pequea Creek and residential sites were about equal, 80 tons/mi^2, and were about 5 times higher than the forest site. Storms accounted for about 75 percent of the suspended-sediment yield at both sites. The cornfield site yielded about 25 times more suspended sediment than the forest site. The suspended-sediment yield at the cornfield site was 375 tons/mi^2, about 90 percent from storms. The pasture site yielded the highest amount of suspended sediment, about 700 tons/mi^2 which was about 50 times more than the forest site. Over 85 percent of the suspended-sediment yield from the pasture was produced during storms.

The total nitrogen yield at the forest site was 5.2 tons/mi^2. About 96 percent of the total yield was transported during base flow. Over 90 percent of the total nitrogen yield was nitrate, and 98 percent of the nitrate yield was due to base flow. About 8 percent of the total nitrogen yield was organic nitrogen, and it was contributed predominantly during base-flow periods. At all sites, the rest of the total nitrogen yield not accounted for by nitrate and organic nitrogen was due to ammonium and nitrite.

The residential site had the lowest yield of total nitrogen, 1.9 tons/mi^2, about one-third as much as the forest site. Storm yields accounted for almost 45 percent of the total yield. About 70 percent of the total nitrogen yield from the residential site was nitrate, and about 25 percent was organic nitrogen. The majority of the nitrate yield was transported primarily by base flow whereas 80 percent of the organic nitrogen yield at the residential site was transported by stormflow.

The total nitrogen yield from the Pequea Creek site was 6.2 tons/mi^2, slightly higher than the forest site. Storms accounted for 20 percent of the total yield. Over 90 percent of both the base-flow and storm yields of nitrogen was nitrate. Organic nitrogen yields were about equally divided between stormflow and base flow.

The estimated total nitrogen and total nitrate yields from the pasture site may not accurately reflect the actual values (fig. 40). This is due to small differences in nitrate yields between the upstream and downstream pasture sites for storm and base-flow samples from which loads were estimated. Total nitrogen yield was estimated to be 12 tons/mi^2, more than twice the yield from the forest site. Unlike any of the other sites, organic nitrogen made up two-thirds of the total nitrogen yield, and 54 percent was due to storms. Nitrates were estimated to be about 25 percent of the total nitrogen yield, and about 85 percent of the nitrate yield was transported by base flow.

Total nitrogen yield from the cornfield site was 17 tons/mi^2, significantly more than any other site and more than 3 times greater than the forest site yield. Seventy-five percent of the total nitrogen yield was due to base flow. The total nitrate yield was 16 tons/mi^2, about 3 times more than the forest site. Nitrate accounted for over 95 percent of the total nitrogen yield during base flow and about 60 percent during stormflow. Organic nitrogen was 9 percent of the total nitrogen yield, and 85 percent was transported during storms.

The total phosphorus yield at the forest site was only 0.03 ton/mi^2, about 25 percent of which was transported during storms. The Pequea Creek and residential sites also had relatively low phosphorus yields of 0.14 ton/mi^2 each. Storms accounted for 53 percent of the phosphorus yield at Pequea Creek and 90 percent of the total yield at the residential site. The cornfield site yielded 0.53 ton/mi^2 of total phosphorus, 18 times more than the forest site. About 80 percent of the total yield at the cornfield site was transported during storms. The pasture area had the largest yield of phosphorus, 4.5 tons/mi^2, which was 150 times more than the forest site. The storm yield at the pasture site, which was greater than those from the other sites, was 23 percent of the total yield.

The total organic carbon yield from the forest site was 4.8 tons/mi^2, and 90 percent was transported during base flow. The base-flow yield from the forest site was higher than all of the other sites. The total yield from Pequea Creek was 3.6 tons/mi^2, slightly less than the forest site, and about 45 percent was transported during storms. The cornfield and residential sites had about the same total yields of organic carbon, which were slightly higher than the forest site. The storm yields at both sites were about 75 percent of the total yields. Organic carbon yields were not calculated for the pasture site since light-weight oil was periodically found in the stream from an unknown upstream source.

The total atrazine yield from the cornfield site was 8.4 lb/mi^2. About 75 percent of this yield was transported during storms, and 88 percent of this yield was due to the first three storms after herbicide application. Yields of atrazine from Pequea Creek and the residential site were 0.63 and 1.5 lb/mi^2, respectively. Storms accounted for 50 percent of the Pequea Creek yield and nearly 90 percent of the residential site yield. More than 40 percent of the total yield of atrazine at the residential site was due to one storm.

Pequea Creek had the highest simazine yield of any site, 0.35 lb/mi^2, and 80 percent was due to base flow. The cornfield and residential sites had small yields of simazine, 0.10 and 0.11 lb/mi^2, respectively. This indicates that the yield from Pequea Creek was contributed from some land use other than those examined during this study. Simazine is frequently used as a weed control in newly planted alfalfa fields, and this use could have been a major source of simazine to the basin.

The largest yield of prometone, 0.37 lb/mi^2, was transported from the residential site. About 60 percent of the prometone was discharged during storms. Pequea Creek and the cornfield site had relatively low yields of prometone, 0.03 and 0.02 lb/mi^2, respectively. No prometone was found at the other sites.

Monthly Yields for 1980

Monthly yields of suspended sediment, nutrients, organic carbon, and herbicides from the Pequea Creek site during 1980 are shown in figure 41. Care must be taken in interpreting monthly variations when only one year of data are available for study. Some natural variations in precipitation cannot be adequately defined without additional data. Therefore, only large variations from which reasonable causes were identified are discussed.

Streamflow was highest during the spring and decreased to very low levels during the summer. Suspended-sediment yields generally followed the same variations as steamflow. Yields during the winter were low because of snow cover and frozen ground which reduced the availability of sediment for transport. In June, several intense thunderstorms produced high yields of suspended sediment. Yields of total nitrogen, nitrate, phosphorus, and organic carbon were mainly determined by streamflow, however, thunderstorms increased the June yield of organic nitrogen. The spreading of manure in March as soon as fields were passable probably increased the phosphorus and organic carbon yields in April. The herbicides showed very definite seasonal patterns: the highest yields occurred soon after application, and then decreased for the remainder of the year. Prometone was the only herbicide detected that had no measureable carryover from one growing season to the next, and it also had the lowest yields. Both simazine and atrazine had the highest yields in June, probably due to several thunderstorms.

Monthly distribution of streamflow at the forest site exemplifies the hydrologic conditions which existed in 1980 (table 14). January and February were average flow months. Spring rains raised base flows from March through May. During the summer, rainfall is usually more intense and

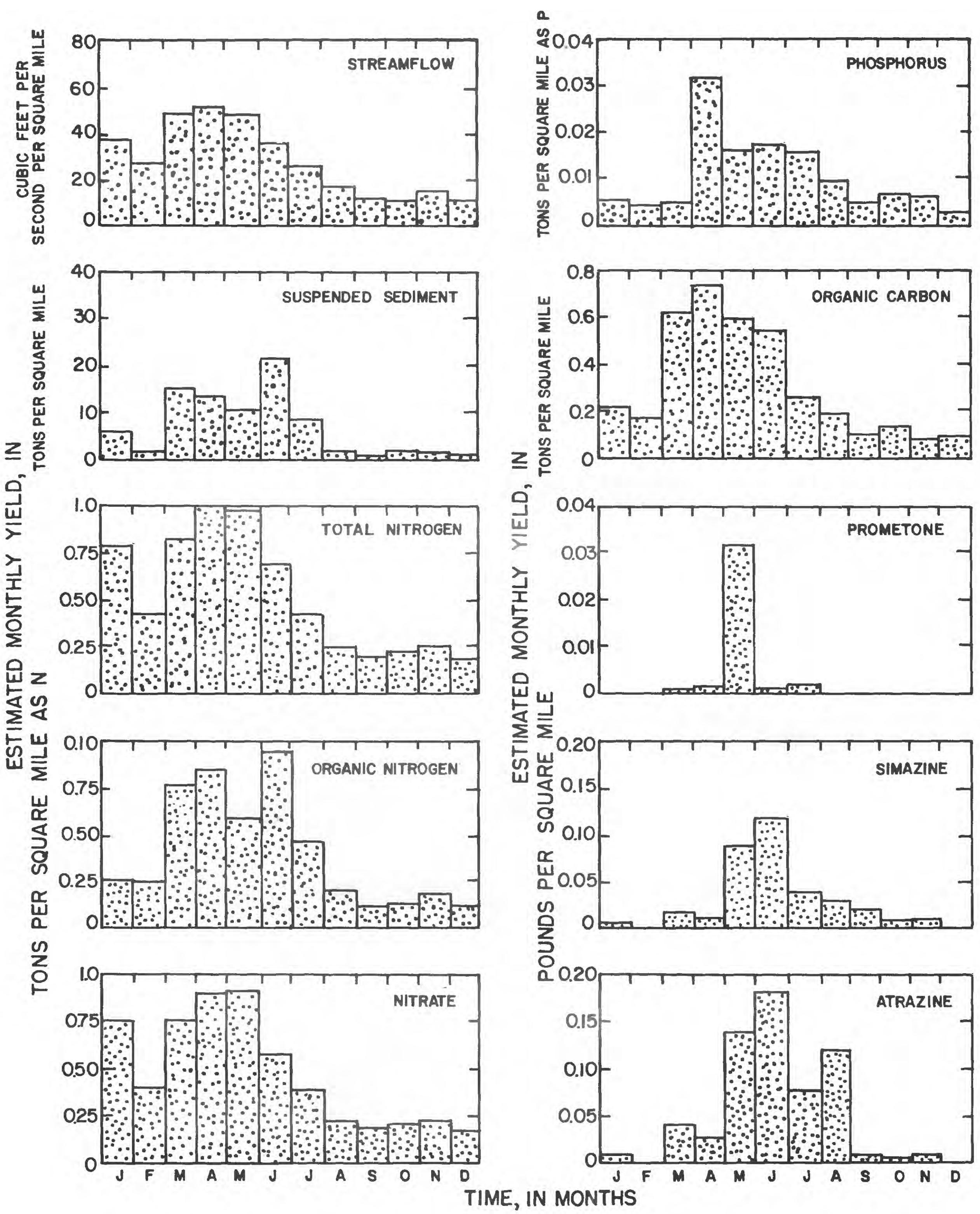


Figure 41.--Variation of estimated monthly yields of selected chemical constituents from the Pequea Creek basin during 1980.

Table 14.--Monthly streamflow and yields of suspended-sediment and chemical constituents at specific land-use sites, 1980

Constituent Yield

Month	Streamflow Forest [(ft³/s)/d/mi²]	Streamflow Cornfield	Streamflow Residential	Streamflow Pasture	Suspended Sediment Forest (ton/mi²)	Suspended Sediment Cornfield	Suspended Sediment Residential	Suspended Sediment Pasture	Total Nitrogen Forest (ton/mi² as N)	Total Nitrogen Cornfield	Total Nitrogen Residential	Total Nitrogen Pasture	Total Organic Nitrogen Forest (ton/mi² as N)	Total Organic Nitrogen Cornfield	Total Organic Nitrogen Residential	Total Organic Nitrogen Pasture
Jan.	37	31	15	31	0.62	6.4	25	38	0.38	1.9	0.16	0.46	0.014	0.026	0.023	0.14
Feb.	25	26	7.4	26	.10	1.0	1.8	4.7	.24	5.8	.065	.19	.006	.003	.005	.20
Mar.	88	57	40	57	3.0	20	10	56	1.1	2.3	.32	2.5	.12	.095	.078	2.0
Apr.	93	39	47	39	2.3	34	17	280	1.1	3.8	.44	.58	.11	.16	.15	.45
May	94	30	29	30	4.9	9.4	11	85	1.2	3.5	.34	1.2	.023	.13	.059	1.0
June	41	46	22	46	3.1	280	21	19	.53	3.2	.21	2.5	.030	.95	.072	1.8
July	18	38	10	38	.42	14	5.4	65	.15	.80	.082	1.8	.006	.072	.0024	1.3
Aug.	12	22	14	22	.72	1.3	3.2	8.8	.086	.61	.098	.44	.005	.003	.039	.041
Sept.	9.5	12	6.4	12	.17	2.4	2.8	5.1	.066	.022	.050	.71	.005	.006	.024	.19
Oct.	10	7.3	10	7.3	.56	.18	2.2	20	.071	.056	.036	.72	.012	.003	.012	.43
Nov.	17	17	19	17	1.6	2.3	2.9	130	.13	.73	.11	.88	.021	.015	.020	.48
Dec.	14	15	2.9	15	.19	.35	.38	4.0	.098	.17	.020	.31	.006	.002	.004	.18

Month	Total Nitrate Forest (ton/mi² as N)	Total Nitrate Cornfield	Total Nitrate Residential	Total Nitrate Pasture	Total Phosphorus Forest (ton/mi² as P)	Total Phosphorus Cornfield	Total Phosphorus Residential	Total Phosphorus Pasture	Total Organic Carbon Forest (ton/mi²)	Total Organic Carbon Cornfield	Total Organic Carbon Residential	Atrazine Cornfield (lb/mi²)	Atrazine Residential	Simazine Cornfield (lb/mi²)	Simazine Residential	Prometone Cornfield (lb/mi²)	Prometone Residential
Jan.	0.36	1.9	0.13	0.30	0.0005	0.035	0.0050	0.52	0.14	0.44	.25	0.22	0.0057	0.0000	0.0000	0.0000	0.027
Feb.	.23	.98	.059	.008	.0006	.0062	.0004	.15	.26	.12	.085	.098	.0000	.0000	.0000	.0000	.012
Mar.	.97	2.3	.24	.40	.0072	.11	.0016	1.2	1.2	.75	.76	.24	.17	.0050	.0061	.0006	.061
Apr.	1.0	3.6	.29	.12	.0054	.18	.016	.94	1.0	1.2	.89	.34	.019	.0044	.0022	.0000	.072
May	1.2	3.3	.26	.10	.0046	.039	.0087	.44	1.2	.50	.67	3.7	1.2	.048	.016	.0078	.043
June	.49	2.2	.12	.56	.0038	.040	.019	.38	.32	1.6	.81	3.2	.039	.037	.014	.0000	.060
July	.14	.72	.048	.37	.0019	.066	.0093	.24	.061	.55	.36	.47	.0043	.0078	.060	.0033	.065
Aug.	.080	.099	.056	.34	.0012	.0034	.0085	.084	.15	.034	.36	.024	.014	.0006	.014	.0022	.010
Sept.	.059	.016	.024	.46	.0004	.0050	.0046	.074	.050	.035	.52	.0072	.0030	.0000	.0013	.0000	.0061
Oct.	.058	.051	.019	.28	.0007	.0021	.0059	.086	.084	.028	.51	.011	.0052	.0000	.0013	.0000	.0078
Nov.	.10	.20	.084	.11	.0018	.043	.014	.32	.18	.10	.41	.031	.0000	.0000	.0000	.0011	.0074
Dec.	.092	.17	.015	.11	.0006	.0005	.0007	.046	.11	.023	.062	.013	.0009	.0000	.0000	.0000	.0026

of shorter duration, decreasing base-flow levels because of reduced recharge and high rates of evapotranspiration. Base-flow levels decreased from June to November, as rain occurred infrequently. Heavy November rains increased streamflows slightly, but below normal flows continued through December. The flow distribution at the other specific land-use sites exhibited nearly the same pattern as the forest site.

High suspended-sediment yields corresponded to the high flows measured from March through June at all the sites. However, suspended-sediment yields from the cornfield site increased dramatically in June. Recently plowed and planted fields, combined with intense June storms, produced 280 tons/mi^2 of suspended sediment. At the pasture site, suspended-sediment yields were highest in April when thawing soils and spring rains increased transport of suspended sediment to the stream.

Monthly total nitrogen yields were also highest from March to June at all sites. Yields of total nitrogen from the forest and cornfield sites were nearly all nitrate, and varied directly with streamflow. Higher levels of nitrate at the cornfield site were due to applications of fertilizer. Monthly nitrate yields at the residential site were 50 to 90 percent of the total nitrogen yield. Most of the total nitrogen yield from the pasture was organic nitrogen, predominantly due to manure.

Monthly total phosphorus yields were very low at both the forest and residential sites. Some fluctuations in the yields at the residential site may be due to application of lawn and garden fertilizers. Yields from the cornfield site were slightly higher due to application of commercial fertilizers. The monthly yields in March and April at the pasture site were twice the annual yield of any of the other sites. Phosphorus from manure and detergents used in dairy operations may be prime contributors to these high yields.

The highest yields of organic carbon were from March to June at the forest, cornfield, and residential sites. At the cornfield and residential sites, the organic carbon yields appear to vary directly with suspended-sediment yields. Organic carbon yields were not calculated for the pasture due to oil periodically found in the stream.

The cornfield and residential sites had the most consistently detectable triazine yields. Atrazine yields increased dramatically at the cornfield site during May and June, soon after herbicide application. At the residential site the highest atrazine yield also occurred in May. Detectable simazine yields occurred at both the cornfield and residential sites from March through August although most monthly yields were very low. Simazine was not applied at the cornfield site, but may have been an impurity in the atrazine which was applied, since simazine yields appear to increase and decrease correspondingly with atrazine yields. Monthly prometone yields were consistently detected at the residential site, and highest yields were from March through July.

Pequea Creek Basin Loads

Loads from January 1 through December 31, 1980, from Pequea Creek are shown on table 15 with loads from the 1978 and 1979 calendar years. Loads from 1980 are low compared with those of the two previous years. This was predominantly due to less annual precipitation for 1980. Base flow in 1980 was 92 percent of total streamflow, compared to 71 and 66 percent in 1978 and 1979, respectively. The ratio of nitrate load to base flow remained relatively constant all three years; this ratio was not affected by changes in annual precipitation. Nitrate comprised about half of the total nitrogen load in 1978 and 1979, and 91 percent of the total nitrogen load in 1980 because of increased base flow to total streamflow. Most of the organic nitrogen, phosphorus, organic carbon, and suspended-sediment loads were transported by runoff (total streamflow minus base flow). When the ratios of constituent loads to runoff are examined, except for nitrate, as runoff increases the constituent loads also increase, but at an accelerated rate.

Loads from Pequea Creek for triazine herbicide were calculated for the 1980 calendar year only. The 1980 loads of the three herbicides found frequently during sampling were as follows:

Herbicide	Load (lb)
Atrazine	93
Simazine	52
Prometone	5.0

Loads of these three herbicides may have been higher during 1978 and 1979 since all were transported during stormflow. However, loads of simazine may not have been as high as those of atrazine and prometone, since simazine was detected frequently both during base flow and storms.

Annual loads from Pequea Creek basin were compared to the estimated applications of nitrogen, phosphorus, and triazine herbicides (table 15) (p. 6). About 22 percent of the nitrogen applied to the basin as fertilizer and manure was discharged out of the basin. Phosphorus and triazine losses from the basin were much less, 0.6 and 0.4 percent, respectively, of the total applied.

Impact of Pequea Creek on Susquehanna River

The constituent loads discharged from Pequea Creek basin ultimately enter the Susquehanna River. The impact of Pequea Creek on the flow and water quality of the Susquehanna River is expected to be small, because the drainage area of Pequea Creek is only 148-mi^2 compared to 24,100-mi^2 for the Susquehanna River at Harrisburg. However, a comparison of yields from the two streams indicates the effects of geology and land use on water quality. Monthly yields measured concurrently at Pequea Creek at Martic Forge and 40 miles north, at the Susquehanna River at Harrisburg (D. K. Fishel, U.S. Geological Survey, oral commun. 1981), were compared for April through December 1980 (table 16).

Table 15.--Annual constituent loads for Pequea Creek basin, 1978-80

Year	Rainfall (inches)	Total Streamflow $[(ft^3/s)/d]$	Base flow $[(ft^3/s)/d]$	Total Nitrogen as N (ton)	Total Organic Nitrogen as N (ton)	Total Nitrate as N (ton)	Total Phosphorus as P (ton)	Total Organic Carbon (ton)	Suspended Sediment (ton)
1980	27.20	51,100	46,800	926	72.4	840	21.4	537	11,900
1979	45.09	117,000	77,400	2,530	1,130 1/	1,360 1/	363	4,470	343,000
1978	42.98	101,000	71,300	2,060	769 1/	1,290 1/	253	3,620	269,000

1/ The actual loads shown are total ammonia plus organic and nitrate nitrogen from 1978 to March 1979. These loads are close to actual loads of organic and nitrate nitrogen, based on data obtained in 1980. During storms in 1980, organic and nitrate nitrogen was 96 percent of total nitrogen; during base flow, organic and nitrate nitrogen was 99 percent of total nitrogen.

Table 16.--Comparison of nutrient and suspended-sediment yields of Pequea Creek at Martic Forge to Susquehanna River at Harrisburg

1980 Month	Streamflow [$(ft^3/s)/d/mi^2$]		Total Nitrogen (ton/mi^2 as N)		Total Organic Nitrogen (ton/mi^2 as N)		Total Nitrate (ton/mi^2 as N)		Total Phosphorus (ton/mi^2 as P)		Suspended sediment (ton/mi^2)	
	P	S	P	S	P	S	P	S	P	S	P	S
April	51	116	1.0	0.42	0.084	0.088	0.90	0.32	0.029	0.030	14	27
May	49	50	.99	.18	.059	.052	.90	.12	.016	.0053	9.4	5.4
June	36	18	.69	.049	.091	.016	.58	.028	.017	.0019	22	.47
July	25	13	.43	.033	.047	.020	.38	.012	.015	.0018	8.4	.38
Aug.	17	9.0	.25	.019	.020	.010	.22	.006	.0088	.0012	1.2	.33
Sept.	12	5.1	.19	.010	.012	.006	.18	.003	.0043	.0011	.24	.11
Oct.	13	5.7	.22	.017	.014	.007	.21	.010	.0062	.0008	1.6	.16
Nov.	15	11	.25	.047	.019	.014	.23	.031	.0056	.0021	1.0	.38
Dec.	11	19	.18	.078	.012	.015	.17	.059	.0023	.0028	.23	.62

Constituent Yield, at Pequea Creek (P) and Susquehanna River (S)

Streamflow yields in the Susquehanna River basin varied more than those in Pequea Creek basin because of differing geology and land use. Carbonate geology, which constitutes most of Pequea Creek basin, also helped to sustain base-flow levels during drought conditions in 1980.

Most of the differences in nutrient and suspended-sediment yields between the two basins are related to agriculture in the Pequea Creek basin. In nearly all cases, the yields in Pequea Creek exceeded those in the Susquehanna River. During the spring and summer, yields in Pequea Creek were as much as 60 times more than those in the Susquehanna River. The largest yields from Pequea Creek were nitrate from June to October, phosphorus in November, and suspended sediment in June and July. These yields from Pequea Creek can become large enough to overcome the drainage area differences at the two sites and actually impact the water quality of the Susquehanna River. In the example cited above for nitrate in September, the yield contributed by Pequea Creek to the Susquehanna River increased the amount of nitrate already present by nearly 40 percent. Also, in June, Pequea Creek increased the suspended-sediment yield of the Susquehanna River by nearly 30 percent.

SUMMARY AND CONCLUSIONS

An intensive watershed investigation of nonpoint sources of suspended sediment, nutrients, and herbicides in the Pequea Creek basin, Lancaster County, Pennsylvania, was conducted by the U.S. Geological Survey in cooperation with the Susquehanna River Basin Commission, and supported by the Chesapeake Bay Program, Environmental Protection Agency. Pequea Creek is a tributary to the Susquehanna River, which has been identified as a major contributor of suspended sediment and nutrients to the upper Chesapeake Bay. The Pequea Creek basin is predominantly an agricultural area, and is nearly free of industrial and waste-water treatment point discharges.

The purpose of this investigation was to determine the effects of agricultural practices and related land uses on receiving streams by quantifying the yields of selected chemical contituents from specific land uses. To determine yields, streamflow and water quality were measured from streams draining four single land uses and from the main stem of Pequea Creek near the mouth. The four single land uses examined in this study from May 1979 to December 1980 were forest, cornfield, residential, and pasture. The forest site is considered a control since it represents an area relatively undisturbed by man. Base flows and storms were monitored at six sites for streamflow, suspended sediment, nutrients, organic carbon, and triazine herbicides. Land-use and application data, soil particle size, and chemical data were collected to determine sources of loadings. Amounts and chemistry of precipitation were also measured. The constituent concentrations and yields observed may vary for similar land uses in different locations due to geology, soils, proximity to streams, and application of fertilizers and pesticides.

Precipitation during 1980 was 10 inches below normal, the mean monthly precipitation amounting to 2.7 inches over the entire basin. Streamflow in Pequea Creek was also significantly below average. Amounts of rainfall and response of streamflow to rainfall for the small subbasins varied significantly from site to site. Flows from the forest site were least responsive to rainfall, while flows from the residential site were most responsive; annual mean values were 0.042 and 0.20 in. of runoff per inch of precipitation, respectively.

For soil samples from the single land-use sites, the highest concentrations of organic nitrogen, ammonium, and organic carbon were generally found at the forest site. The highest concentrations of nitrate plus nitrite and phosphorus were found in soil from the pasture site. Of the herbicides analyzed in soil samples, only atrazine was detected, and it was only found in soil from the cornfield site. The highest atrazine concentrations occurred immediately after application, and steadily declined the rest of the year.

In stream samples, the highest constituent concentrations found during base flow were those of total organic nitrogen (4.0 mg/L) and total phosphorus (1.4 mg/L) from the downstream pasture site, total nitrate (24 mg/L) and atrazine (3.9 μg/L) from the cornfield site, prometone (0.5 μg/L) and simazine (2.3 μg/L) from the residential site. Nitrate concentrations from the cornfield site ranged from 13 to 24 mg/L as nitrogen, every sample exceeding the U.S. Environmental Protection Agency (1977) criterion of 10 mg/L.

Most of the storm samples were composited and analyzed for mean water-weighted concentrations. The Pequea Creek basin showed seasonal variations in suspended sediment, total organic nitrogen, total organic carbon, and atrazine concentrations. High concentrations of all these constituents occurred during the summer months. The residential site exhibited a first flush effect during storms, the highest concentrations coinciding with the first amounts of rainfall.

For the specific land-use sites, the highest suspended-sediment concentrations during storms were found at the cornfield site, up to 16,000 mg/L. Storm intensity, as well as soil cover, appeared to be an important factor influencing suspended-sediment concentrations. The highest concentrations of total organic nitrogen during storms were from the cornfield (54 mg/L) and downstream pasture (32 mg/L) sites, due to the availability of fertilizers, manure, and organic matter. Nitrate concentrations during storms were greatest from the cornfield site, up to 41 mg/L. Mean nitrate storm concentrations at all the sites were nearly always lower than base-flow concentrations. The highest mean phosphorus concentration during storms was also at the cornfield site (19 mg/L), with the highest storm concentrations occurring during intense storms following fertilizer application. Total organic carbon concentrations fluctuated greatly from storm to storm at all sites. No one particular land use had consistently higher concentrations than the other land uses. Atrazine concentrations were greatest during storms at the cornfield site, 200 μg/L for the first storm following application. Prometone concentrations during storms were highest (up to 6.4 μg/L) at the residential site, and due primarily to home use of the pesticide during the weed growing season.

Yields (on a unit-area basis) from the specific land-use sites for storms of about equal rainfall throughout the basin, ranked from highest to lowest, were: pasture, cornfield and residential, and forest for suspended sediment and total organic nitrogen; cornfield, residential and forest for total nitrate; pasture, cornfield, residential, and forest for total phosphorus; and cornfield and residential, and forest for total organic carbon.

When total yields were estimated for 1980, it was found that the pasture site yielded the most suspended sediment, 710 tons/mi^2; organic nitrogen, 8.3 tons/mi^2 as nitrogen; and phosphorus, 4.4 tons/mi^2 as phosphorus. The cornfield site yielded the most nitrate, 16 tons/mi^2 as nitrogen; and atrazine, 8.2 lb/mi^2. The highest yield for simazine, 0.35 lb/mi^2, was measured on the main stem of Pequea Creek. In general, most of the suspended sediment, organic nitrogen, and atrazine was discharged during storms, whereas most of the nitrate was discharged during base-flow periods. The other constituents analyzed were transported in varying proportions of storm and base-flow discharges from site to site.

The loads discharged into the Susquehanna River from Pequea Creek from January 1 to December 31, 1980, with 100,000 acre-ft of water were 12,000 tons of suspended sediment, 840 tons of nitrate as nitrogen, 72 tons of organic nitrogen as nitrogen, 21 tons of phosphorus as phosphorus, 540 tons of organic carbon, 93 pounds of atrazine, 52 pounds of simazine, and 5.0 pounds of prometone. The 1980 loads of suspended sediment, nutrients, and organic carbon were significantly less than 1978 and 1979 loads, probably due to decreased precipitation during 1980. Loads from Pequea Creek indicate a loss of 926 tons of total nitrogen for 1980, about 22 percent of the average annual nitrogen application to the basin. A comparison of monthly yields from Pequea Creek at Martic Forge and from the Susquehanna River at Harrisburg (40 mi. north) shows that for April to December 1980, monthly yields from Pequea Creek nearly always exceeded yields from the Susquehanna River for nutrients and suspended sediment. During some high yielding months, Pequea Creek had significant impact on the Susquehanna River, increasing monthly nitrate loads by up to 40 percent and suspended-sediment loads by up to 30 percent.

REFERENCES

Baker, J. L., and Johnson, H. P., 1979, The effect of tillage systems on pesticides in runoff from small watersheds: Transactions of the American Society of Agricultural Engineers, p. 554-558.

Buchanan, T. J., and Somers, W. P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter A8, 65 p.

Carter, R. W., and Davidian, Jacob, 1965, Discharge ratings at gaging stations: Book 1, Chapter 12, U.S. Geological Survey Water Techniques, 36 p.

Clark, L. J., Donnelly, D. K., and Villa, Orterio, 1973, Nutrient enrichment and control requirements in the upper Chesapeake Bay: U.S. Environmental Protection Agency, Region III, Annapolis field office, Technical Report 56, 58 p.

Clark, L. J., Guide, Victor, and Phieffer, T. H., 1974, Summary and Conclusions-Nutrient transport and accountability in the lower Susquehanna River basin: U.S. Environmental Protection Agency, Region III, Annapolis field office, Technical Report 60, 91 p.

Culbertson, J. K., and Feltz, H. R., 1972, Sampling procedures and problems in determining pesticide residues in the hydrologic environment: Pesticides Monitoring Journal, v. 6, no. 3, p. 171-178.

Federal Working Group on Pesticide Management, 1974, Guidelines on sampling and statistical methodologies for ambient pesticide monitoring: U.S. Government Printing Office - 1975-626-592/216 3-1, 50 p.

Feltz, H. R., 1980, Significance of bottom material data on evaluating water quality: Contaminants and Sediments, v. 1, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, p. 271-287.

Goerlitz, D. F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A3, 40 p.

Goerlitz, D. F., and Law, L. M., 1974, Distribution of chlorinated hydrocarbons in stream-bottom material: U.S. Geological Survey Journal of Research, v. 2, no. 5, p. 541-543.

Guy, H. P., 1969, Laboratory theory and methods for sediment analyis: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter C1, 58 p.

Guy, H. P., and Norman, V. W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, 59 p.

Gunther, F. A., 1970, Quantitative determination of triazine herbicides in soils by chemical analysis: Residue Review, v. 32, p. 371-390.

National Oceanic and Atmospheric Administration, 1979, Climatological Data, Annual Summary, v. 84, no. 13, 15 p.

----1980, Climatological Data, Annual Summary, v. 1, no. 1, 18 p.

Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C3, 66 p.

Poth, C. W., 1977, Summary of ground-water resources of Lancaster County, Pennsylvania: Pennsylvania Geological Survey Water-Resources Report 43, 80 p.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S. (eds), 1979, Methods for the determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.

Theissen, A. H., 1911, Precipitation averages for large areas: Monthly Weather Review, v. 39, p. 1082-1084.

U.S. Department of Agriculture, 1956, Soil Survey, Lancaster County: Pennsylvania Soil Conservation Service Report, ser. 1956, no. 4, 131 p.

U.S. Environmental Protection Agency, 1974, Methods for chemical analysis of water and wastes: EPA-625-16-74-003, 298 p.

----1977, Quality Criteria for Water: 256 p.

----1978, A manual on: evaluation and economic analysis of livestock waste management systems: EPA-600/2-78-102, 157 p.

Ward, J. R., and Eckhardt, D. A., 1979, Nonpoint-source discharges in Pequea Creek basin, Pennsylvania, 1977: U.S. Geological Survey Water-Resources Investigations 79-88, 110 p.