LOADS AND YIELDS OF NUTRIENTS AND SUSPENDED SEDIMENT IN THE SUSQUEHANNA RIVER BASIN, 1985-89

by Lloyd A. Reed, Charles S. Takita, and Gary Barton

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BRUCE BABBITT, ***Secretary***

U.S. GEOLOGICAL SURVEY

Mark Schaefer, ***Acting Director***

For additional information write to:

District Chief
U.S. Geological Survey
840 Market Street
Lemoyne, Pennsylvania 17043-1586

Copies of this report may be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
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Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Discharge	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
pound (lb)	0.4536	kilogram
pound per acre (lb/acre)	1.123	kilogram per hectare
ton per acre (ton/acre)	2.241	metric ton per hectare
	Temperature	
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius

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ABSTRACT

The Susquehanna River, which drains an area of 27,510 square miles in New York, Pennsylvania, and Maryland, is the largest tributary to Chesapeake Bay. Nutrients and sediments from the river are suspected of contributing to a marked decrease in the productivity of the bay. A disproportionately large percentage of these nutrients and sediments originate in the lower part of the Susquehanna River Basin. The lower Susquehanna River Basin is a 5,439-square-mile area between the confluence of the West Branch Susquehanna River at Northumberland, Pa., and the mouth of the river below Conowingo, Md., excluding the Juniata River Basin. Three large hydroelectric dams span the river, at Safe Harbor (Lake Clarke) and Holtwood (Lake Aldred) in southern Pennsylvania, and at Conowingo (Conowingo Reservoir) in northern Maryland. The drainage area of the river at Conowingo Dam is 27,100 square miles.

The annual loads (1985-89) of total nitrogen, total phosphorus, and suspended sediment transported from the upper Susquehanna (the area above Northumberland including the West Branch Susquehanna River Basin) and the Juniata River Basins combined averaged 86.6 million, 5.11 million, and 3,170 million pounds. Total nitrogen, total phosphorus, and suspended-sediment loads entering the reservoir system averaged 135 million, 7.71 million, and 5,040 million pounds per year. Most of the nitrogen (131 million pounds), about 60 percent of the phosphorus (4.40 million pounds), and about 25 percent of the sediment (1,400 million pounds) that entered the reservoirs were discharged to Chesapeake Bay.

Average yields (1985-89) for total nitrogen, total phosphorus, and suspended sediments in the upper Susquehanna and Juniata River Basins combined averaged 6.1 lb/acre, 0.36 lb/acre, and 224 lb/acre (pounds per acre) per year and yields in the lower basin averaged 15.1 lb/acre, 0.81 lb/acre, and 582 lb/acre per year. Multiple-regression equations developed from relations between land use and measured loads predict annual yields of total nitrogen for a 100-percent urban basin to be 51.6 lb/acre, for a 100-percent agricultural basin to be 37.1 lb/acre, and for a 100-percent forested basin to be 1.78 lb/acre. The annual sediment yield predicted for a 100-percent urban area is 1,960 lb/acre; for a 100-percent agricultural area, 1,100 lb/acre; and for a 100-percent forested area, 91 lb/acre.

Yields of total nitrogen, total phosphorus, and suspended sediment for the Susquehanna River Basin upstream from the reservoir system are probably about 3 to 4.5 times the yields prior to the clearing of forests and development in the basin during the 1800's. In addition, the total nitrogen, total phosphorus, and suspended-sediment yields for the upper basin are probably about two to four times the yields when the basin was forested, and yields for the lower basin are probably about seven to eight times the yields prior to early development.

INTRODUCTION

The District of Columbia and the States of Pennsylvania, Maryland, and Virginia have agreed to a 40-percent reduction in controllable nutrient loads to Chesapeake Bay by the year 2000. Nutrients and sediments that enter Chesapeake Bay by way of the Susquehanna River are suspected of contributing to a marked decrease in the productivity of the Bay. A disproportionately large percentage of these nutrients and sediments are thought to originate in the lower part of the Susquehanna River Basin (Clark and others 1973, 1974; Lang, 1982).

As part of the Chesapeake Bay Program (U.S. Environmental Protection Agency, 1994), the Bureau of Soil and Water Conservation of the Pennsylvania Department of Environmental Protection (PaDEP), the Susquehanna River Basin Commission (SRBC), and the U.S. Geological Survey (USGS) cooperated in a study to quantify nutrient and suspended-sediment transport and yields in the Susquehanna River Basin.

Purpose and Scope

This report describes the loads and yields of nutrients and suspended sediment originating in the Susquehanna River Basin. In addition, relations between nutrient and suspended-sediment yields and land use are examined. These relations are used to estimate loads transported to Chesapeake Bay prior to clearing of forest and development in the basin during the 1800's.

The data for this report were collected during 1985-89. Loads and yields are given for 16 sites on the Susquehanna River and tributaries that drain the lower Susquehanna River Basin. This report also documents loads of nutrients and suspended sediment transported to the reservoirs on the Susquehanna River and loads transported to Chesapeake Bay. In this report, the average load or yield for the period of data collection is not necessarily the same as the long-term average annual loads and yields reported by Ott and others (1991).

Description of the Susquehanna River Basin

The Susquehanna River (fig. 1) drains an area of 27,510 mi^2 in central New York, central Pennsylvania, and a small part of Maryland. It is the largest tributary to Chesapeake Bay. The long-term mean streamflow of the river where it enters the bay is nearly 40,000 ft^3/s.

The upper Susquehanna River Basin is a 22,071-mi^2 area that includes the area above the confluence of the West Branch Susquehanna River and the main stem at Northumberland, Pa., as well as the Juniata River Basin. The lower Susquehanna River Basin is a 5,439-mi^2 area between the confluence at Northumberland, Pa., and the mouth of the river below Conowingo, Md., excluding the Juniata River Basin. Three large hydroelectric dams span the river, at Safe Harbor (Lake Clarke) and Holtwood (Lake Aldred) in southern Pennsylvania and at Conowingo (Conowingo Reservoir) in northern Maryland (fig. 1). The drainage area at the Conowingo Dam is 27,100 mi^2. The reservoirs behind the dams have trapped large quantities of sediments, nitrogen, and phosphorus. Lake Aldred and Lake Clarke reached equilibrium with incoming river sediments by 1950, and they are no longer storing sediment. Conowingo Reservoir is currently storing sediment; it will probably reach an equilibrium and cease to store sediments within the next 20-30 years (Hainly and others, 1995, p. 37).

Woodland accounts for 63.1 percent of the area in the Susquehanna River Basin; tilled cropland, 19.4 percent; pastureland, 6.7 percent; urban land, 9.3 percent; and water, 1.47 percent (Hannawald, 1989). Average annual manure production in the basin is 0.91 ton/acre for the total basin area. Woodlands are concentrated in the northern and western parts of the basin, and agriculture (including manure production) and urban land are concentrated in the lower basin.

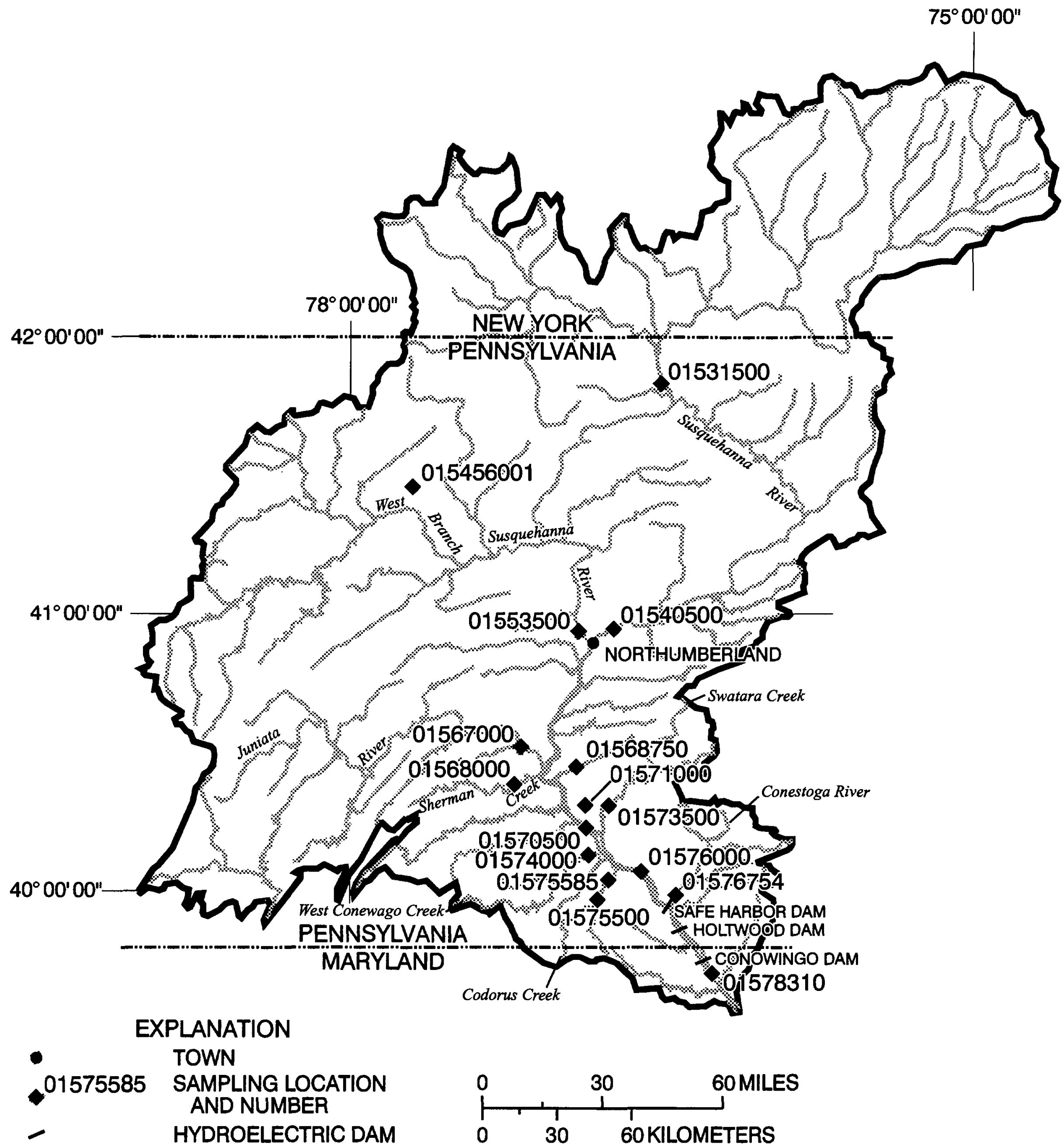

Figure 1. Data-collection sites for monitoring nutrient and suspended-sediment loads and yields in the Susquehanna River Basin, 1985-89.

Temperature and precipitation vary considerably within the Susquehanna River Basin. Mean annual temperatures range from 53°F in the southern part to 45°F in the northern part. Annual precipitation totals are highest in eastern Pennsylvania and are lowest in central and southern New York (Hainly and others, 1995, p. 2). During 1985-89, average annual precipitation for the basin on the whole was about 37.8 in. The driest year was 1988, when only 32.4 in. of precipitation fell. The two wettest years were 1986 (41.3 in.) and 1989 (40.8 in.). For each of the subbasins, annual precipitation exceeded the normal annual mean during at least 1 year of the study. The maximum annual precipitation during the study period was measured in the Sherman Creek Basin in 1989; precipitation total was 54.5 in., 12.5 in. above normal. In the Conestoga River Basin, variations in annual precipitation were large. Precipitation totaled 36.6 in. for 1985 and 45.6 in. for 1986.

DATA COLLECTION AND ANALYSIS

The surface-water monitoring network for this study (fig. 1 and table 1) consisted of 5 stations on the main stem of the Susquehanna River and 11 stations on 10 tributaries, including the West Branch Susquehanna River and the Juniata River. At 14 sites, environmental data (streamwater quantity and quality) were collected from 1985 through 1989. Data were collected by the SRBC, PaDEP, and the USGS. All streamflow and water-quality data collected by the participants in this study, including quality-control data, are stored in computerized data bases in the USGS National Water Information System.

Stations at Danville, Lewisburg, and Newport monitored the nutrient and sediment load transported from the upper Susquehanna and Juniata River Basins into the lower basin. Downstream from the Juniata River, seven tributaries were monitored. Five of the seven tributaries—Sherman, Swatara, West Conewago, and Codorus Creeks, and the Conestoga River—represent a total of 38.4 percent of the land area in the lower basin. The Conestoga River, the largest and southernmost major tributary, enters the Susquehanna River downstream of Safe Harbor Dam. The most downstream station on the Susquehanna River is at Conowingo, Md., about 10 mi from Chesapeake Bay.

The monitoring network included four stations on three streams that were selected to help determine the effects of land use on loads and yields (fig. 1 and table 1). The streams drain subbasins that are less than 100 mi^2 and are representative of a particular predominant land use. The station on Stony Creek at Water Tank Trail near Dauphin drains a 100-percent-forested area in the lower basin. The long-term USGS hydrologic benchmark station on Young Womans Creek near Renova (tributary to the West Branch Susquehanna River in the upper basin) is included in the monitoring network because the stream drains a 46.2-mi^2 area that also is 100 percent forest. The station on Paxton Creek near Penbrook drains an area that is largely (41 percent) urban. In addition, the 45-mi^2 drainage basin between the stations at Codorus Creek at York and at Pleasureville is predominantly (69 percent) urban. The station on the Conestoga River at Conestoga drains the Conestoga River Basin, which is the subbasin most intensively tilled for crops (51.9 percent of the basin). Manure production in the Conestoga River Basin, which averages 5.24 ton/acre annually, is the highest among the subbasins.

Streamflow

Streamflow throughout the network was monitored at continuous-record streamflow-gaging stations. Twelve stations had been established prior to this study and four were specifically constructed for the study. Estimates of long-term mean streamflow for newly constructed stations were computed on the basis of comparison and configuration of flows at the new station with flows at nearby long-term stations.

Table 1. *Data-collection sites in the nutrient and suspended-sediment monitoring network and land use in the corresponding subbasins, Susquehanna River Basin, 1985-89*

[Land-use percentages may not add to 100 percent because not all land-use categories are included in the table]

U.S. Geological Survey identification number	Station name	Site short name	Drainage area (square miles)	Land use (percent)			Annual manure production (tons per acre of total area)
				Agriculture	Forest	Urban	
01531500	Susquehanna River at Towanda, Pa.	Towanda	7,797	27.1	58.7	12.7	0.87
01540500	Susquehanna River at Danville, Pa.	Danville	11,220	26.4	59.8	11.3	.80
015456001	Young Womans Creek near Renovo, Pa.	Young Womans	46	.01	99.7	.0	.00
01553500	West Branch Susquehanna River at Lewisburg, Pa.	Lewisburg	6,847	13.9	81.0	4.6	.34
01567000	Juniata River at Newport, Pa.	Newport	3,354	25.2	68.8	5.1	.81
01568000	Sherman Creek at Shermans Dale, Pa.	Sherman	200	24.4	70.1	.0	.76
01568750	Stony Creek at Water Tank Trail near Dauphin, Pa.	Dauphin	21.9	.01	99.7	.0	.00
01570500	Susquehanna River at Harrisburg, Pa.	Harrisburg	24,100	23.0	67.0	8.4	.68
01571000	Paxton Creek near Penbrook, Pa.	Penbrook	11	39.8	18.6	41.2	.02
01573560	Swatara Creek near Hershey, Pa.	Hershey	483	45.6	37.2	16.9	1.77
01574000	West Conewago Creek near Manchester, Pa.	Manchester	510	57.1	35.4	7.0	1.40
01575500	Codorus Creek near York, Pa.	York	222	50.6	39.7	8.4	1.30
01575585	Codorus Creek at Pleasureville, Pa.	Pleasureville	267	44.9	35.2	18.7	1.10
01576000	Susquehanna River at Marietta, Pa.	Marietta	25,990	24.9	64.7	8.9	.76
01576754	Conestoga River at Conestoga, Pa.	Conestoga	470	62.7	14.6	22.4	5.24
01578310	Susquehanna River at Conowingo, Md.	Conowingo	27,100	26.1	63.1	9.3	.91

Water Quality

Sample Collection and Analysis

Water samples were collected monthly at each monitoring station in the network to determine concentrations of nitrogen and phosphorus species, total organic carbon, and suspended sediment during periods of base flow and storm runoff. Base flow was sampled monthly, generally from 7 to 10 days after the most recent storm. Water samples were collected during three to eight periods of storm runoff each year. Storm-runoff samples were generally collected on a 4-hour interval, from the start of the storm until flow receded to near pre-storm levels; often, a water sample was collected at peak flow. All base-flow samples and most storm-runoff samples were collected with depth-integrating samplers. Four sites were equipped with automatic pumping samplers. In addition, nearly all water samples at Conowingo Reservoir were collected from the dam's turbine discharges, although a few samples were collected from flow through the floodgates.

Concentrations of nutrients and total organics were determined by the PaDEP laboratory in Harrisburg and at the USGS National Water Quality Laboratory in Arvada, Colo. Suspended-sediment concentrations were determined by the USGS sediment laboratory in Lemoyne, Pa.

Computation of Nutrient and Suspended-Sediment Loads and Yields

Loads and yields of nitrogen, phosphorus, total organic carbon, and suspended sediment were computed for each station for the period of data collection. Concentrations of total ammonia, total organic nitrogen, and total nitrite plus nitrate were used to compute total nitrogen loads. A minimum-variance, unbiased estimator, described by Cohn and others (1988), was used to compute the loads. This load estimator relates constituent concentration to streamflow, seasonal effects, and long-term trends and computes the best-fit regression equation. The regression equation is used to compute daily loads from the daily mean streamflow. Estimates of accuracy (standard errors of prediction) accompany the load computation. All concentrations reported as less than the analytical detection limit of the analytical procedure were treated as one-half the analytical detection limit. Yield is the load for a basin divided by the area of the basin and is reported as pounds per acre per unit of time.

Load computations for the upper Susquehanna and Juniata River Basins are the sums of loads at the Susquehanna River at Danville, Susquehanna River at Lewisburg, and the Juniata River at Newport. Loads at Danville and Lewisburg were adjusted to include loads from the unsampled drainage area between the sampling stations and Northumberland and loads for Newport were adjusted to include loads from the unsampled drainage area from Newport to the mouth of the Juniata River. Computations of loads into the reservoir system are the sums of loads at the Susquehanna River at Marietta, the Conestoga River at Conestoga, and unsampled tributaries. Loads for unsampled tributaries below Marietta were estimated by assuming that yields from tributaries east of the Susquehanna River are similar to average yields from the Swatara Creek and Conestoga River Basins, and that yields from tributaries west of the Susquehanna River are similar to average yields from the West Conewago Creek and Codorus Creek Basins.

Computation of Relation Between Nutrient Yield and Land Use

The relation between nutrient yield and land use was examined for selected subbasins by use of scatter diagrams showing the relation of yield and land use and by a stepwise multiple-regression analysis on four land-use categories—percentage of forest land, percentage of agricultural land, percentage of urban land, and amount of manure production (in tons per acre of total area). The multiple-regression analysis was done on subbasins in the monitoring network whose drainage areas do not overlap. Several land uses that could affect yields were not included in the analysis because the data are not available (fertilizer application rates, acres planted in corn, and acres planted in small grains and hay).

LOADS OF NUTRIENTS AND SUSPENDED SEDIMENT

Average loads of nutrients, total organic carbon, and suspended sediment transported during 1985-89 are shown in figure 2 for (1) the upper Susquehanna and Juniata River Basins combined, (2) the Susquehanna River at Harrisburg, (3) the Susquehanna River entering the reservoir system in southern Pennsylvania, and (4) the Susquehanna River at Conowingo, Md. (the outflow from the reservoirs). Nutrient and organic carbon loads deposited and produced in the reservoir system during 1985-89 are shown in figure 3. Seasonal mean streamflows and seasonal loads of nutrients and suspended sediment for the Susquehanna River at Conowingo are shown in figure 4.

During 1985-89, streamflows of all tributaries monitored in the lower basin were below their respective long-term means for 20 of the 29 station years and above the long-term means for 9 of the 29 station years. Codorus Creek was the only tributary that had streamflow below the long-term mean for all 5 years.

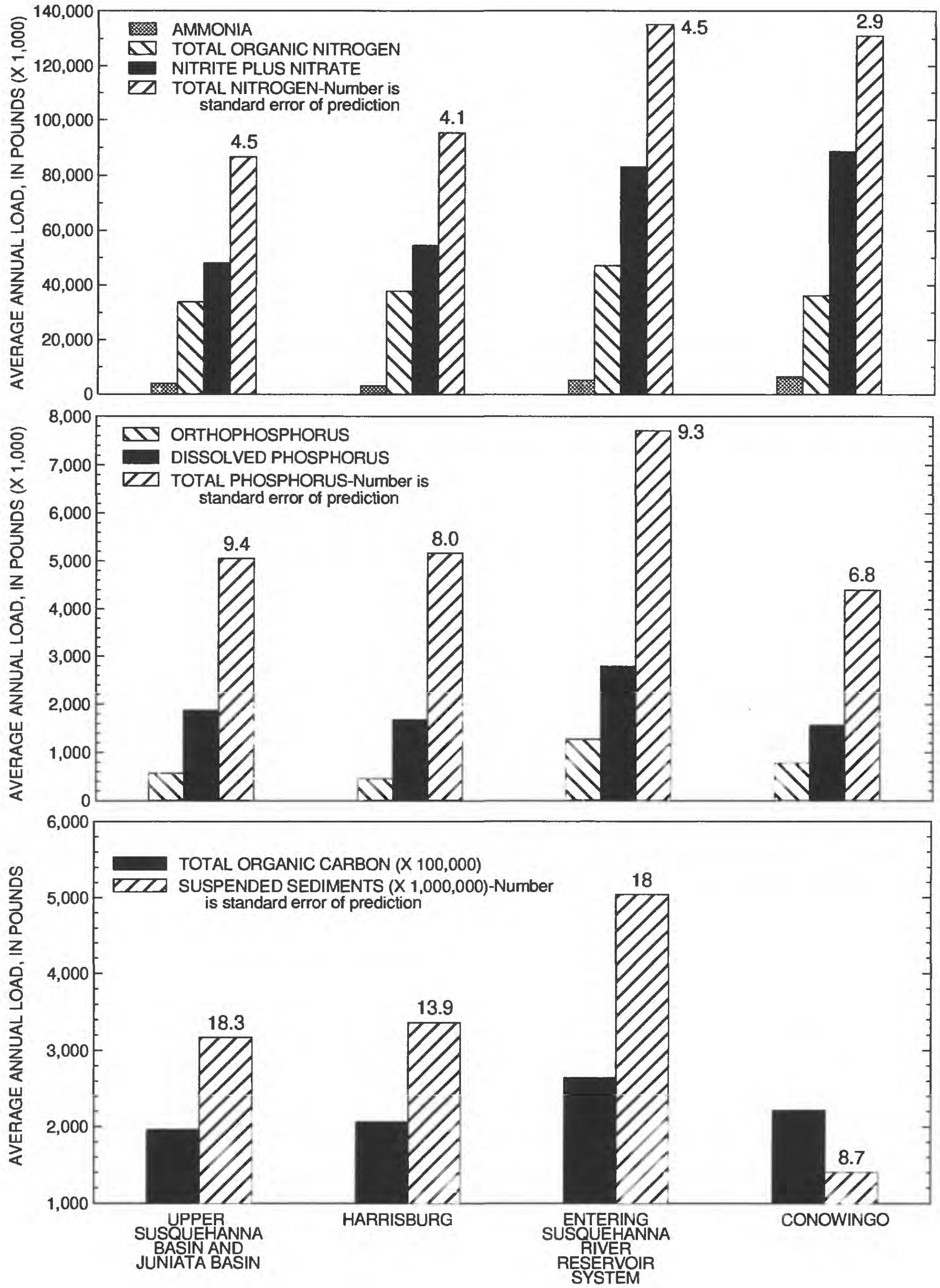

Figure 2. Loads of nitrogen, phosphorus, total organic carbon, and suspended sediments transported in the Susquehanna River Basin, 1985-89.

Annual Loads

Nutrient and suspended-sediment loads transported by the Susquehanna River increased substantially downstream of Northumberland. Most of the nitrogen and organic carbon loads transported by the river were transported through the reservoir system and discharged to Chesapeake Bay. However, most suspended sediments and part of the phosphorus load transported by the river were deposited in the reservoir system. The average errors for computations of the total nitrogen, total phosphorus, and suspended sediment loads are 4.1, 6.6, and 11.2 percent. The standard error of prediction computed for loads of total nitrogen, total phosphorus, and suspended sediment for the upper Susquehanna and Juniata River Basins combined, Susquehanna River at Harrisburg, Susquehanna River where it enters the reservoir system, and Susquehanna River at Conowingo are given in figure 2.

Loads From the Upper Susquehanna and Juniata River Basins

Annual loads of total nitrogen, total phosphorus, total organic carbon, and suspended sediment transported from the upper Susquehanna and Juniata River Basins combined averaged 86.6 million, 5.11 million, 195 million and 3,170 million lb per year, respectively. The annual loads of dissolved nitrite plus nitrate, ammonia, and orthophosphorus averaged 48.5 million, 3.84 million, 0.566 million lb per year, respectively.

Loads for the Susquehanna River at Harrisburg

When loads from the upper Susquehanna and Juniata River Basins are compared to loads for the Susquehanna River at Harrisburg, the increases at Harrisburg appear modest. Loads of total nitrogen, total phosphorus, total organic carbon, and suspended sediment at Harrisburg averaged 95.4, 5.17, 206, and 3,360 million lb per year, respectively. Increases in loads ranged from 1.2 to 10.2 percent and the increase in drainage area was 9.2 percent. However, loads of ammonia, dissolved phosphorus, and orthophosphorus decreased by about 20, 10, and 20 percent downstream. Reductions in the ammonia load were probably caused by oxidation of ammonia to nitrate and consumption of ammonia by plants and algae in the river. Reductions in the orthophosphorus and dissolved phosphorus loads were probably caused by the reaction of phosphorus with calcium to form precipitates (Hem, 1985). Additional data and analyses of loads at Harrisburg are given in Fishel (1984).

Loads From an Urban Area Along the Codorus Creek

Data from stations on Codorus Creek near York and Pleasureville were used to compute loads for the drainage area between the two stations, a 45-mi^2 area that is 69.5 percent urban. Loads of nutrients discharged from a regional sewage-treatment plant originate from within the 45-mi^2 urban area but enter Codorus Creek below the station at Pleasureville. These unmeasured loads were included in the estimated loads for the 45-mi^2 area. Annual loads of total nitrogen, total phosphorus, and suspended sediment for the 45-mi^2 area averaged 1.1 million, 0.13 million and 41.2 million lb.

Loads into the Susquehanna River Reservoir System

Annual nutrient and suspended-sediment loads increased substantially downstream from Harrisburg (fig. 2). Total nitrogen, total phosphorus, total organic carbon, and suspended-sediment loads entering the reservoir system averaged 135 million, 7.71 million, 264 million, and 5,040 million pounds per year, which are 42, 49, 28, and 50 percent greater than loads at Harrisburg, respectively. Differences in loads of total nitrite plus nitrate, dissolved and total organic nitrogen, ammonia, orthophosphorus, and dissolved phosphorus also were similar. This increase in load was the result of runoff from larger urban areas, the application of agrochemical fertilizers and manure to croplands in areas downstream from Harrisburg, such as in the Conestoga River Basin, and fewer forested areas.

Deposition of Loads in the Susquehanna River Reservoir System

Deposition in the reservoir system (fig. 2 and 3) occurs primarily in Conowingo Reservoir (Hainly and others, 1995, p. 37). Deposition in the reservoir system on the whole (fig. 3) averaged approximately 3 percent of the annual incoming total nitrogen load (4.1 million lb), 43 percent of the incoming phosphorus load (3.3 million lb), 16 percent of the incoming total organic carbon load (43 million lb), and 72 percent of the incoming suspended-sediment load (3,640 million lb). The median standard errors associated with the computed phosphorus and suspended-sediment loads entering and leaving the reservoir system are 12 and 18 percent. The median standard error associated with the nitrogen loads entering and leaving the reservoir system was 7 percent. Most phosphorus deposition was probably caused by the reaction of dissolved phosphorus with dissolved calcium to form precipitates. Deposition of suspended sediments and total organic carbon was caused by the decrease in the water velocity in Conowingo Reservoir.

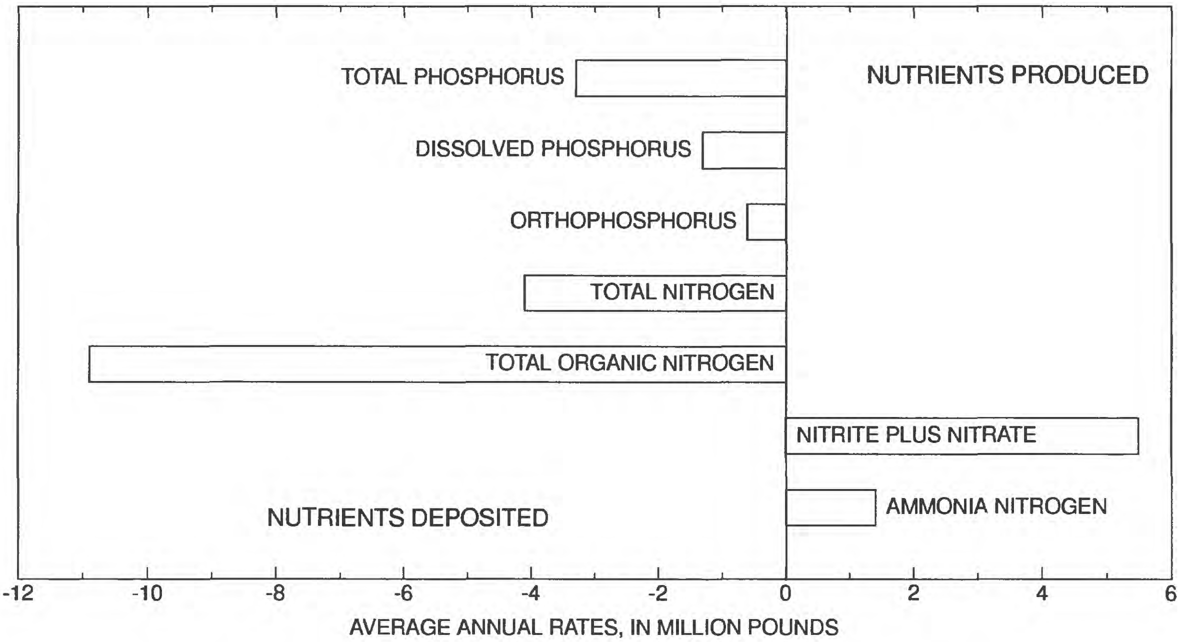

Figure 3. Average annual rates of deposition and production of nutrients in the Susquehanna River reservoir system, 1985-89.

On the average, about 10.9 million lb of total organic nitrogen was deposited in the reservoir system each year, and 1.4 million lb of ammonia and 5.5 million lb of total nitrite plus nitrate were produced. The load of ammonia leaving the reservoir system at Conowingo increased by about 27 percent compared to the load entering the system. Ammonia is probably produced in the reservoirs by the decomposition of organic nitrogen in anoxic sediments. Part of the deposited organic nitrogen load is available for producing ammonia, nitrite, and nitrate. Nitrite and nitrate are probably produced by the conversion of organic nitrogen to ammonia in the anoxic bottom sediments, followed by the oxidation of ammonia to nitrate and nitrite.

Earlier studies have shown that sediment deposition occurs in the reservoirs at flows of less than 0.4 million ft^3/s and that scour is sufficient to cause net losses in sediment content at flows greater than 0.4 million ft^3/s (Hainly and others, 1995). The storage of suspended sediment in the reservoir system is a dynamic process that depends on streamflow, concentration and particle size of suspended sediment, water temperature, and amount and distribution of sediment in storage. One large storm can scour sediment deposited over a period of many years.

Loads for the Susquehanna River Near Chesapeake Bay

The annual loads of total nitrogen, total phosphorus, total organic carbon, and suspended sediments in the Susquehanna River at Conowingo (fig. 2), which presumably enter Chesapeake Bay, averaged 131 million, 4.4 million, 221 million, and 1,400 million lb per year during the 5-year period. The total nitrogen load was about 30 times that of total phosphorus.

From 1986 through 1989, loads of ammonia at Conowingo, Md., decreased by about 10 percent. The decline in loads of ammonia may be due in part to construction of more efficient sewage treatment plants. During the study, loads of ammonia declined on the Susquehanna River at Danville, Codorus Creek at Pleasureville, and Conestoga River at Conestoga. Annual loads of total ammonia transported by the Susquehanna River at Danville decreased by 60 percent (from 3.46 million lb per year during 1985-86 to 1.38 million lb per year during 1988-89).

Seasonal Loads

Streamflows and nutrient loads were generally greater during the winter and spring than during the summer (fig. 4). At Conowingo, Md., seasonal loads of total nitrogen ranged from 7.9 million lb (summer 1985) to 76.1 million lb (spring 1989), and seasonal loads of total phosphorus ranged from 0.27 million lb (summer 1985) to 3.3 million lb (spring 1989). Seasonal loads of suspended sediments ranged from 40.9 million lb (summer 1985) to 1,520 million lb (spring 1989).

YIELDS OF NUTRIENTS AND SUSPENDED SEDIMENT

Yields of total nitrogen, total phosphorus, total organic carbon, and suspended sediment for the seven subbasins that were monitored in the lower basin are shown in figure 5. In three northernmost subbasins—Sherman Creek, Stony Creek, and Paxton Creek—yields were about one-third those of the four southernmost subbasins—Swatara Creek, Conewago Creek, Codorus Creek, and the Conestoga River. Yields from the Conestoga River Basin were the highest.

Nitrogen and Phosphorus

Yields of total nitrogen and total phosphorus from the upper Susquehanna and Juniata River Basins combined averaged 6.1 and 0.36 lb/acre per year, and yields from the lower basin upstream from the reservoir system averaged 15.1 and 0.81 lb/acre. In the lower basin, the lowest yields of total nitrogen and total phosphorus (fig. 5) were from Stony Creek Basin (2.9 and 0.14 lb/acre per year), and the highest yields were from the Conestoga River Basin (35.6 and 2.42 lb/acre per year). This range in yields reflects land use: the Stony Creek Basin is 100 percent forest and largely pristine, whereas the Conestoga River Basin is mostly agricultural and has the highest manure-production rate in the Susquehanna River Basin. In addition to the high yields of total phosphorus for the basin drained by the Conestoga River at Conestoga, high yields also were measured for the basins drained by West Conewago Creek near Manchester (0.90 lb/acre per year) and Codorus Creek at Pleasureville (0.92 lb/acre per year).

The average annual yield of total ammonia from the upper Susquehanna and Juniata River Basins combined was 0.27 lb/acre and from the lower basin was 0.38 lb/acre. The highest annual yield of total ammonia was from the Codorus Creek Basin above Pleasureville (1.94 lb/acre), and the second highest yield was from the Conestoga River Basin (1.53 lb/acre).

Average annual yields of dissolved organic nitrogen did not differ appreciably among the sites. The average yields from the upper Susquehanna River and Juniata River Basins combined and the lower Susquehanna River Basin were 1.58 and 2.30 lb/acre. For most sites, yields of total organic nitrogen were about 75 percent greater than the yields of dissolved organic nitrogen.

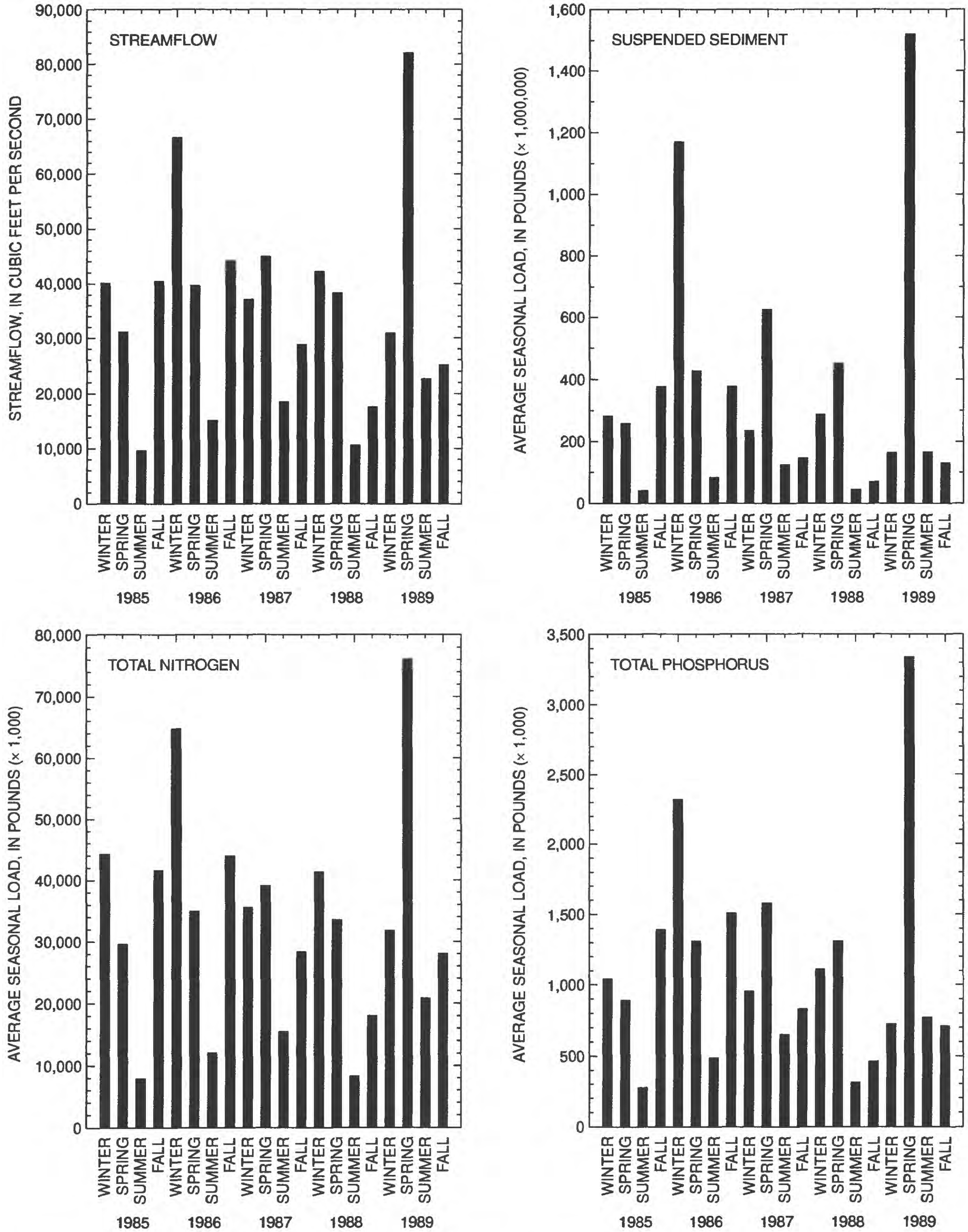

Figure 4. Seasonal mean streamflow and seasonal loads of nutrients and suspended sediment on the Susquehanna River at Conowingo, Maryland, 1985-89.

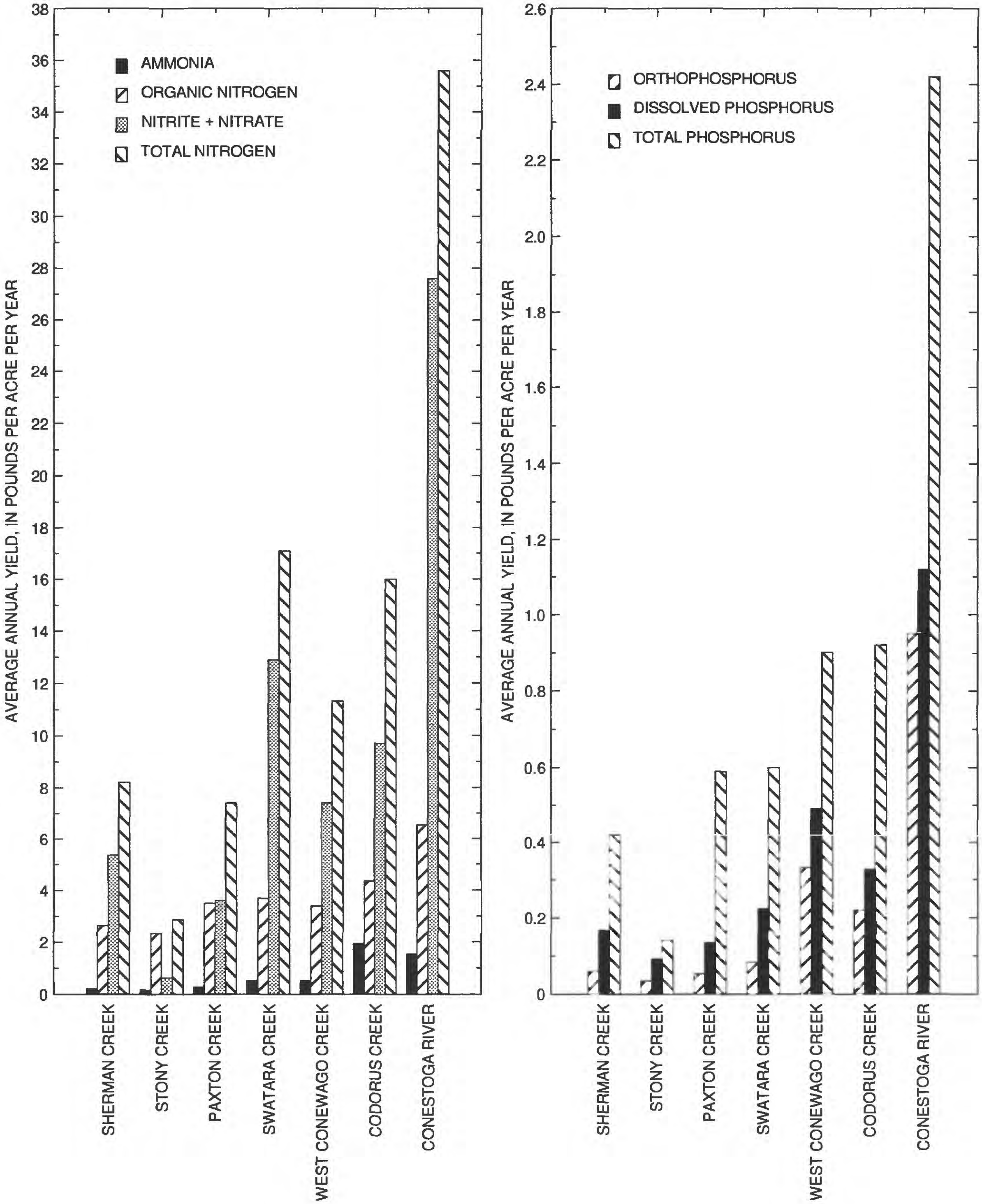

Figure 5. Average annual yields of nitrogen and phosphorus in selected basins in the lower Susquehanna River Basin, 1985-89.

Total Organic Carbon and Suspended Sediments

Yields of total organic carbon from the upper Susquehanna and the Juniata River Basins combined and from the lower basin upstream from the reservoir system were 13.8 and 21.3 lb/acre per year. In the lower basin, the highest yield (39.0 lb/acre) was from the basin drained by Codorus Creek at Pleasureville.

Average annual yields of suspended sediments from the upper Susquehanna and Juniata River Basins combined and from the lower basin upstream from the reservoir system were 224 and 582 lb/acre. In the lower basin, the lowest yields of suspended sediments (fig. 5) were from Stony Creek Basin (66 lb/acre), and the highest yields were from the Paxton Creek Basin (1,880 lb/acre). The second highest yield, 1,250 lb/acre, was from the Conestoga River Basin. High annual suspended-sediment yields also were computed for the basin drained by Swatara Creek near Hershey (701 lb/acre) and for the basin drained by West Conewago Creek near Manchester (858 lb/acre).

Relation of Nutrient and Suspended-Sediment Yields and Land Use

The relation between nutrient and suspended-sediment yields and that of land use for most stations in the monitoring network is shown in figure 6. The relation of load and land use was analyzed for basins where urban land use ranged from 0 to 25 percent, agricultural land ranged from 0 to 61 percent, and forested land ranged from 14 to 100 percent and for basins where annual manure production ranged from 0 to 5.2 ton/acre. The analysis showed that the yield of total nitrogen is proportional to manure production and to urban land use and is inversely related to the percentage of a basin that is forested. Yields of nitrite plus nitrate (fig. 6), total organic nitrogen, ammonia, dissolved phosphorus, and orthophosphorus relate similarly to land use and manure production. Suspended-sediment yield is proportional to percentage of land in a basin that is agricultural (grain, hay, and pasture). The relation of yield to land use is similar to that found in the Pequea Creek Basin in the lower Susquehanna River Basin (Lietman and others, 1983).

Multiple-regression equations were developed by relating land use in 11 of the basins to the respective long-term yields of nitrite plus nitrate, total nitrogen, total phosphorus, and suspended sediment (Ott and others, 1991). The intended use of the multiple-regression equations listed in table 2 is for estimating annual yields of nutrients and suspended sediment for subbasins in the Susquehanna River Basin where data on land use are available but where streamflow and water-quality data have not been collected. The best predictors of yields of nitrite plus nitrate, total nitrogen, and total phosphorus were percentage of urban land and agricultural manure production. The best predictors of suspended-sediment yields were percentages of urban, agricultural, and forested land. Regression equations (parameters listed in table 2) predict annual total nitrogen yields for a 100-percent urban basin to be 51.6 lb/acre, for a 100-percent agricultural basin with manure production of 8.3 tons/acre to be 37.1 lb/acre, and for a 100-percent forested basin to be 1.78 lb/acre. The annual sediment yield predicted for a 100-percent urban area is 1,960 lb/acre; for a 100-percent agricultural area, 1,100 lb/acre; and for a 100-percent forested area, 91 lb/acre. The level of confidence in use of the regression equations to estimate nitrogen yields is relatively high, but that for phosphorus and suspended sediments is low to moderate.

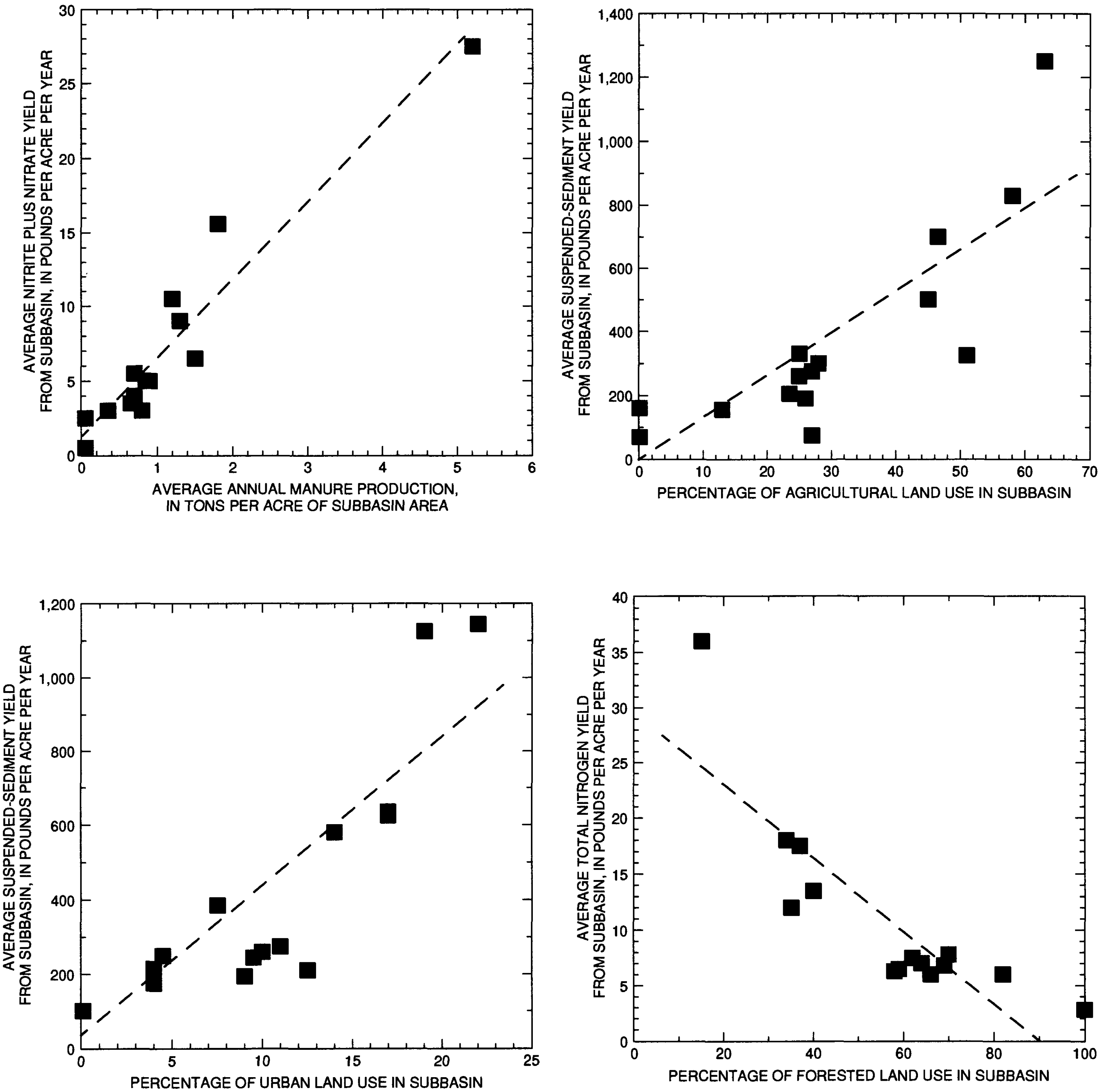

Figure 6. Relation of land use to nutrient and suspended-sediment yields in the lower Susquehanna River Basin, 1985-89.

***Table 2.** Results of multiple-regression analyses of nutrient and suspended-sediment yields as functions of three land uses and animal manure production for selected subbasins of the Susquehanna River Basin, 1985-89*

[Dependent variable is annual yield, in pounds per acre; land use is in percent of subbasin area; manure production is annual tonnage per acre of total area]

Dependent variable	Regression parameters: Intercept	Land use: Agricultural	Land use: Forest	Land use: Urban	Manure production	Regression statistics: R^2	F	Prob>F	Root mean square error
Nitrite plus nitrate	0.013	–	–	0.173	4.60	0.95	80.9	0.0001	1.9
Total nitrogen	1.78	–	–	.498	4.26	.98	211	.0001	1.8
Total phosphorus	.000	–	.001	.063	.172	.95	80.9	.0001	39.0
Suspended sediment	.000	11.0	.910	19.6	--	.93	30.8	.0002	149

PREDEVELOPMENT YIELDS OF THE SUSQUEHANNA RIVER BASIN

Development, such as urbanization and agriculture, in the lower basin has greatly increased nutrient yields. Predevelopment yields for total nitrogen, total phosphorus, and suspended sediments were estimated for the Susquehanna River Basin by use of multiple-regression equations that equate land use and yields, as well as by use of the yields measured in the 100-percent-forested Young Womans Creek and Stony Creek Basins.

The total nitrogen, total phosphorus, and suspended-sediment yields for the Susquehanna River Basin upstream from the reservoir system are probably about 3 to 4.5 times the yields prior to clearing of forests and development in the basin during the 1800's. In addition, the total nitrogen, total phosphorus, and suspended-sediment yields for the upper basin are probably about two to four times the yields prior to development. The total nitrogen, total phosphorus, and suspended-sediment yields for the lower basin upstream from the reservoir system are probably about seven to eight times the yields prior to development. The construction of the reservoir system created a large temporary sink for phosphorus and suspended sediments, which greatly reduces yields below Conowingo; however, as previously mentioned, the reservoir system is predicted to reach equilibrium with the nutrient and sediment load during the next 20-30 years (Hainly and others, 1995).

SUMMARY AND CONCLUSIONS

For the period 1985-89, loads of total nitrogen, total phosphorus, total organic carbon, and suspended sediment transported from the upper Susquehanna River and the Juniata River Basins combined averaged 86.6 million, 5.11 million, 195 million and 3,170 million lb per year. The loads of dissolved nitrite plus nitrate, ammonia, and orthophosphorus averaged 48.5 million, 3.84 million, and 0.566 million lb. Loads increased substantially downstream from Harrisburg and loads of total nitrogen, total phosphorus, total organic carbon, and suspended sediment entering the reservoir system were 42, 49, 28, and 50 percent greater than loads at Harrisburg. This increase in load along the Susquehanna River below Harrisburg is the result of larger urban areas, the application of agrochemical fertilizers and manure, and fewer forested areas.

Annual loads of nitrogen, phosphorus, and suspended sediment transported to the reservoirs on the lower Susquehanna River averaged 135 million, 7.71 million, and 5,040 million lb. Most of the nitrogen (131 million lb), about 60 percent of the phosphorus (4.4 million lb), and about 25 percent of the sediment (1,400 million lb) that entered the reservoirs were discharged to Chesapeake Bay.

Yields (1985-89) for total nitrogen and total phosphorus in the upper Susquehanna and Juniata River Basins combined averaged 6.1 and 0.36 lb/acre per year, and yields from the lower basin averaged 15.1 and 0.81 lb/acre per year. In the lower basin, the lowest annual yields of total nitrogen and total phosphorus were from Stony Creek Basin (2.9 and 0.14 lb/acre), which is 100 percent forest and largely pristine, and the highest yields were from the Conestoga River Basin (35.6 and 2.42 lb/acre), which is mostly agricultural and has the highest manure-production rate in the Susquehanna River Basin. Average annual yields of suspended sediments from the upper Susquehanna and Juniata River Basins combined and from the lower basin upstream from the reservoir system were 224 and 582 lb/acre.

Multiple-regression equations were developed by relating land use in 11 subbasins to the respective yields of nitrite plus nitrate, total nitrogen, total phosphorus, and suspended sediment. The regression equations predict annual total nitrogen yields for a 100-percent urban basin to be 51.6 lb/acre, for a 100-percent agricultural basin to be 37.1 lb/acre, and for a 100-percent forested basin to be 1.78 lb/acre. The annual sediment yield predicted for a 100-percent urban area is 1,960 lb/acre; for a 100-percent agricultural area; 1,100 lb/acre; and for a 100-percent forested area; 91 lb/acre.

Yields of total nitrogen, total phosphorus, and suspended sediment for the Susquehanna River Basin upstream from the reservoir system are probably about 3 to 4.5 times the yields prior to clearing of forests and development in the basin during the 1800's. In addition, the total nitrogen, total phosphorus, and suspended-sediment yields for the upper basin are probably about two to four times the yields prior to development. The total nitrogen, total phosphorus, and suspended-sediment yields for the lower basin upstream from the reservoir system are probably about seven to eight times the yields prior to development. The construction of the reservoir system created a large temporary sink for phosphorus and suspended sediments, which greatly reduces yields below Conowingo; however, as previously mentioned, the reservoir system is predicted to reach equilibrium with the nutrient and sediment loads during the next 20-30 years.

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