NUTRIENTS AND SUSPENDED SEDIMENT TRANSPORTED IN THE SUSQUEHANNA RIVER BASIN, 1999, AND TRENDS, JANUARY 1985 THROUGH DECEMBER 1999

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SUSQUEHANNA RIVER BASIN COMMISSION

Paul O. Swartz, Executive Director

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to effect coordinated planning, conservation, management, utilization, development and control of basin water resources among the government and private sectors.

**Statutory Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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TABLE OF CONTENTS

FIGURES

TABLES

NUTRIENT AND SUSPENDED SEDIMENT TRANSPORTED IN THE SUSQUEHANNA RIVER BASIN, 1999 AND TRENDS, JANUARY 1985 THROUGH DECEMBER 1999

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ABSTRACT

Nutrient and suspended-sediment samples were collected in calendar year 1999 during baseflow and stormflow from the Susquehanna River at Towanda, Danville, and Marietta, the West Branch Susquehanna River at Lewisburg, the Juniata River at Newport, and the Conestoga River at Conestoga, Pennsylvania.

Annual loads of nutrients and suspended sediment were highest in the Susquehanna River at Marietta, followed by the Susquehanna River at Danville. The Conestoga River at Conestoga had the smallest load, in pounds per year, but had the greatest yield, in pounds per acre per year, of total nitrogen, total phosphorus and suspended sediment. Seasonal loads of nutrients and suspended sediment generally varied according to the variations in the seasonal water discharges.

Comparison of the 1999 yields and the five-year baseline yields indicates that total nitrogen loads decreased at all of the monitoring sites. Total phosphorus loads decreased at four sites. Suspended-sediment loads increased at one site, decreased at another, and remained the same at three sites.

Trends were computed for the period January 1985 to December 1999 for total and dissolved nitrogen, total and dissolved organic nitrogen, total and dissolved ammonia, total and dissolved kjeldahl nitrogen, total and dissolved nitrite plus nitrate, total phosphorus and dissolved phosphorus, dissolved inorganic phosphorus, total organic carbon, suspended sediment and flow. Results were reported for monthly mean flow, monthly load, monthly flow-weighted concentration, and flow-adjusted concentration. The results showed improving conditions in total nitrogen and total phosphorus throughout the Susquehanna River Basin. Improving conditions in suspended sediment occurred at three of the six stations in the basin.

INTRODUCTION

The Pennsylvania Department of Environmental Protection (Pa. DEP), Bureau of Land and Water Conservation and Bureau of Laboratories, the U.S. Environmental Protection Agency (USEPA), and the Susquehanna River Basin Commission (SRBC) cooperated in a study to quantify nutrient and suspended-sediment transport in the Susquehanna River Basin. Nutrients and suspended sediment entering the Chesapeake Bay from the Susquehanna River Basin contribute toward nutrient enrichment problems in the bay (USEPA, 1982).

Background

Pennsylvania, Maryland, Virginia, and the District of Columbia have agreed to reduce nutrient loads to the Chesapeake Bay. The 1987 Chesapeake Bay Agreement states that, by the year 2000, controllable nutrient loads are to be reduced to 60 percent of the loads transported in 1985. The Chesapeake Bay 2000 Agreement maintains this objective. Much of the nutrient and suspended sediment that enters the

Chesapeake Bay is thought to originate from the lower Susquehanna River Basin.

The SRBC, in cooperation with the Pa. DEP, USEPA, and the U.S. Geological Survey (USGS), conducted a 5-year intensive study at 14 sites during the period 1985-89. The scope of the initial 5-year study was reduced in 1990 to five long-term monitoring stations. An additional site was included in 1994, and sampling at these sites was continued. Calculated annual loads and yields of nutrient and suspended sediment showed year-to-year variability that was highly correlated with the variability of the annual water discharge (Ott and others, 1991; Takita, 1996; Takita, 1998). These studies also reinforced the indications from earlier studies that the highest nutrient yields come from the lower basin.

Objective of the Study

The objective of this study was to collect monthly base flow and daily, or more frequent, samples during selected storms from the six long-term monitoring sites in the Susquehanna River Basin. The data were used to compute annual nutrient and suspended-sediment loads and to evaluate the results of nutrient reduction efforts.

Purpose of Report

The purpose of this report is to present basic information on annual and seasonal loads and yields of nutrients and suspended sediment measured during calendar year 1999, and to compare the total nitrogen, total phosphorus, and suspended-sediment loads with the baseline established from the 1985-89 study. Seasonal and annual variation in loads is discussed. The results of statistical trend analysis for the period January 1985 to December 1999 for nitrogen, phosphorus, suspended sediment, and water discharge also are discussed.

DESCRIPTION OF THE SUSQUEHANNA RIVER BASIN

The Susquehanna River (Figure 1) drains an area of 27,510 square miles (Susquehanna River Basin Study Coordination Committee, 1970), and is the largest tributary to the Chesapeake Bay. The climate in the Susquehanna River Basin varies considerably from the low lands adjacent to the Chesapeake Bay in Maryland to the high elevations, above 2,000 feet, of the northern headwaters in central New York State. The annual mean temperature ranges from 53°F (degrees Fahrenheit) near the Pennsylvania-Maryland border to 45° F in the northern part of the basin. Precipitation in the basin averages 39.15 inches per year, and is fairly well distributed throughout the year.

Land use in the Susquehanna River Basin is predominantly rural. Woodland accounts for 65 percent; cultivated, 18 percent; urban, 9 percent; and grassland, 7 percent of land use (Ott and others, 1991). Woodland occupies the higher elevations of the northern and western parts of the basin and much of the mountain and ridge land in the Juniata and the Lower Susquehanna Subbasins. Most of the grassland is in the northern part of the basin. Farmers in the north use more land for pasture and hay, and less for cultivated crops because of the shorter and more uncertain growing season. Woods and grasslands occupy areas in the lower part of the basin that are unsuitable for cultivation because the slopes are too steep, the soils are too stony, or the soils are poorly drained.

Most of the cultivated land is in the lower part of the basin. However, extensive areas are cultivated along the river valleys in southern New York and along the West Branch Susquehanna River from Northumberland, Pa., to Lock Haven, Pa., including the Bald Eagle Creek valley.

Major urban areas in the Lower Susquehanna Subbasin include York, Lancaster, Harrisburg, and Sunbury, Pa. Most of the urban areas in the northern part of the basin are located along river valleys. These urban areas include Binghamton and Elmira-Corning in New York and Scranton and Wilkes-Barre in Pennsylvania. The major urban areas in the West Branch Susquehanna River Basin are Williamsport and Lock Haven.

Figure 1. The Susquehanna River Basin

NUTRIENT MONITORING SITES

Data were collected from three sites on the Susquehanna River and three major tributaries in the basin. These six sites, selected for long-term monitoring of nutrient and suspended-sediment transport in the basin, are listed in Table 1, and their general locations are shown in Figure 2.

The Susquehanna River at Towanda, Pa., was selected because it represents the contribution from New York State, although the drainage area does include the Tioga River Watershed in northern Pennsylvania and an area along the northern tier counties of eastern Pennsylvania. The drainage area at Towanda is 7,797 square miles.

The Susquehanna River at Danville, Pa., has a drainage area of 11,220 square miles, and includes part of northcentral Pennsylvania (the Tioga River Watershed) and much of southcentral New York. Data collected at Danville represent the loadings from a major tributary to the main stem Susquehanna River.

Data collected from the West Branch Susquehanna River at Lewisburg, Pa., represent the loadings from another major tributary to the main stem. The West Branch includes much of northcentral Pennsylvania and has a drainage area of 6,847 square miles. The combined drainage areas above Lewisburg and Danville represent 65.7 percent of the total Susquehanna River Basin.

The Juniata River, a major tributary to the main stem, includes much of southcentral Pennsylvania, and has a drainage area, above Newport, Pa., of 3,354 square miles. The combined drainage areas at Danville, Lewisburg, and Newport represent 77.9 percent of the Susquehanna River Basin.

The Susquehanna River at Marietta, Pa., is the southern-most sampling site upstream from the reservoirs on the lower Susquehanna River, and represents the inflow to the reservoirs from its 25,990-square-mile drainage area. This drainage area represents 94.5 percent of the total Susquehanna River Basin.

Data collected from the Conestoga River at Conestoga, Pa., provide loadings from a major tributary watershed that is actively farmed and is experiencing an increase in agricultural nutrient management programs. Additionally, this watershed is experiencing an increase in development. The drainage area of this basin at the sampling site is 470 square miles.

Table 1. Data Collection Sites and Their Drainage Areas

USGS Identification Number	Station Name	Short Name	Drainage Area (square mile)
01531500	Susquehanna River at Towanda, Pa.	Towanda	7,797
01540500	Susquehanna River at Danville, Pa.	Danville	11,220
01553500	West Branch Susquehanna River at Lewisburg, Pa.	Lewisburg	6,847
01567000	Juniata River at Newport, Pa.	Newport	3,354
01576000	Susquehanna River at Marietta, Pa.	Marietta	25,990
01576754	Conestoga River at Conestoga, Pa.	Conestoga	470

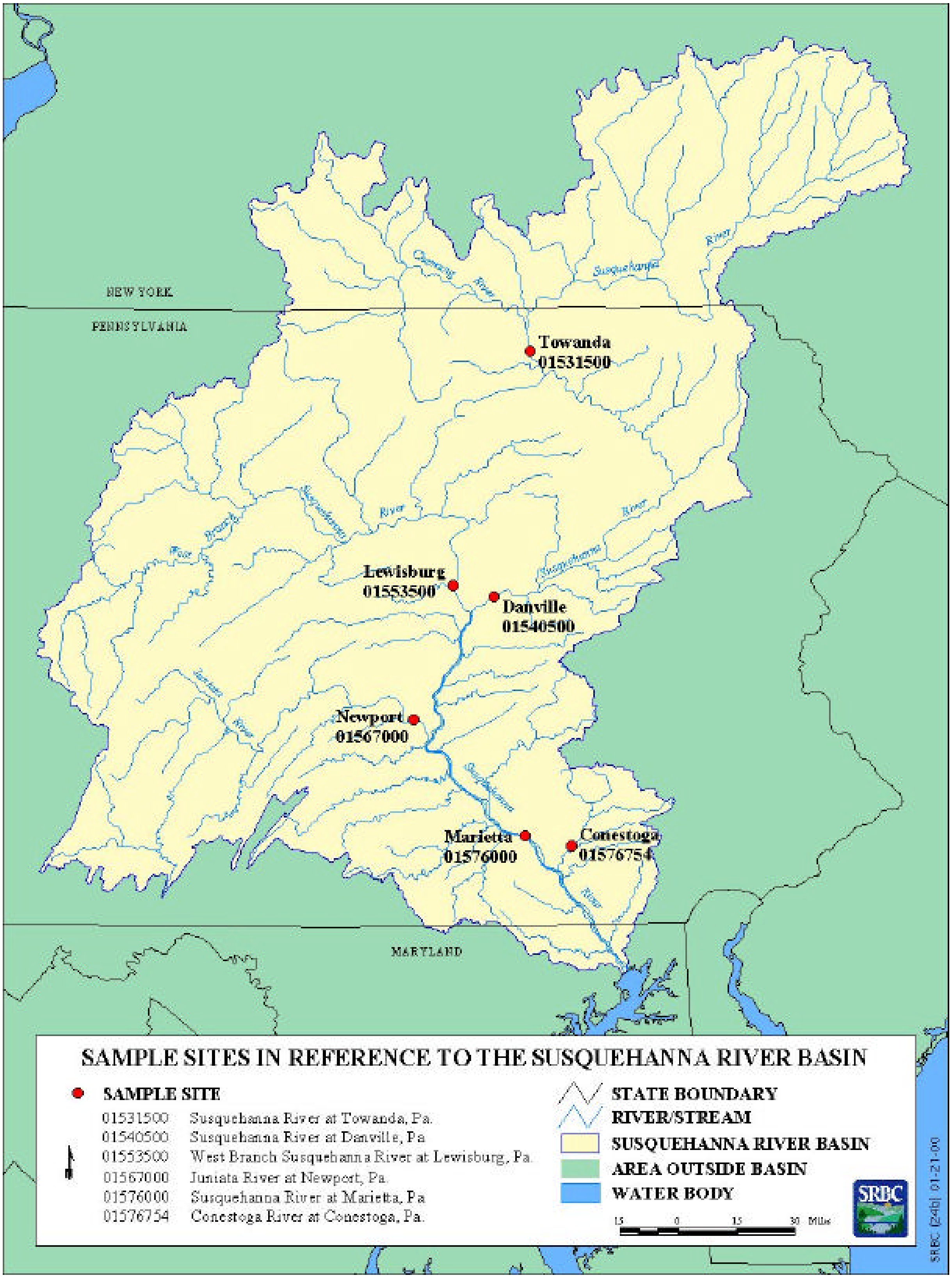

Figure 2. Locations of Sampling Sites on the Susquehanna River and Three Major Tributaries in the Basin

SAMPLE COLLECTION AND ANALYSIS

Samples were collected at each of the sites to measure nutrient and suspended-sediment concentrations during periods of low and high flow. Samples of low flow were collected monthly. Collection of low flow samples was delayed 7 to 10 days after a period of high flow until moderate flows prevailed. All low flow samples were collected by hand with depth-integrating samplers. Two major rainfall events that caused significant rises in streamflow at all six monitoring sites occurred during the year. Samples were collected daily with depth-integrating samplers from the start of the storm to the time when the flow receded to near its pre-storm rate. An attempt was made to collect a sample at or near peak flow.

A portion of each sample was filtered, and the filtrate was analyzed for dissolved nitrogen and phosphorus species. Whole-water samples were analyzed for total nitrogen species, total phosphorus, total organic carbon, and suspended sediment. Samples for nutrient analysis were delivered to the Pa. DEP Laboratory in Harrisburg the day after sample collection. The parameters and laboratory methods used are listed in Table 2. Samples collected for suspended-sediment concentration were analyzed by the SRBC.

PRECIPITATION

Precipitation data were obtained from long-term stations operated by the U.S. Department of Commerce. The data are published monthly as Climatological Data—Pennsylvania and as Climatological Data—New York by the National Oceanic and Atmospheric Administration at the National Climatic Data Center in Asheville, North Carolina. Quarterly and annual precipitation data from these sources were summarized for 1999 for the Susquehanna River Watershed above Towanda and Danville, Pa., the West Branch Susquehanna Subbasin, the Juniata Subbasin, the Susquehanna River Watershed above Marietta, Pa., and the Conestoga River Watershed. This summary is shown in Table 3, along with the long-term mean precipitation values. The 1999 annual precipitation was less than the long-term annual average in all basins, except the Conestoga River Watershed. Precipitation ranged from 12.56 inches below normal in the Juniata Subbasin to 1.59 inches above normal in the Conestoga River Watershed. Seasonal precipitation was above normal during the winter and summer and below normal during the spring in nearly all basins. Precipitation in the Juniata River above Newport was below nomal during all seasons.

Table 2. Water Quality Parameters, Laboratory Methods, and Detection Limits

Parameter	Laboratory	Methodology	Detection Limit (mg/l)	References
Ammonia (total)	Pa. DEP	Colorimetry	0.020	USEPA 350.1
Ammonia (dissolved)	Pa. DEP	Block Digest, Colorimetry	0.200	USEPA 350.1
Nitrogen (total)	Pa. DEP	Persulfate Digestion for TN	0.040	Standard Methods #4500-N_{org}-D
Nitrite plus Nitrate	Pa. DEP	Cd-reduction, Colorimetry	0.010	USEPA 353.2
Organic Carbon (total)	Pa. DEP	Wet Oxidation	0.100	USEPA 415.2
Orthophosphate (dissolved)	Pa. DEP	Colorimetry	0.002	USEPA 365.1
Phosphorus (dissolved)	Pa. DEP	Block Digest, Colorimetry	0.020	USEPA 365.3
Phosphorus (total)	Pa. DEP	Persulfate Digest, Colorimetry	0.020	USEPA 365.3

Table 3. Summary for Annual Precipitation for Selected Areas in the Susquehanna River Basin, Calendar Year 1999

Area	Season	Average Long-Term Precipitation inches	Calendar Year 1999 Precipitation inches
Susquehanna River above Towanda, Pa.	January-March	7.96	9.00
	April-June	9.92	7.30
	July-September	10.23	12.16
	October-December	8.74	6.53
	Yearly Total	**36.85**	**34.99**
Susquehanna River above Danville, Pa.	January-March	7.90	9.05
	April-June	10.02	7.33
	July-September	10.38	12.30
	October-December	8.77	6.43
	Yearly Total	**37.07**	**35.11**
West Branch Susquehanna River above Lewisburg, Pa.	January-March	8.96	10.62
	April-June	11.38	8.18
	July-September	11.59	12.38
	October-December	9.47	8.28
	Yearly Total	**41.40**	**39.46**
Juniata River above Newport, Pa.	January-March	8.96	8.01
	April-June	11.03	6.91
	July-September	10.99	7.24
	October-December	9.22	5.49
	Yearly Total	**40.20**	**27.65`**
Susquehanna River above Marietta, Pa.	January-March	8.53	10.17
	April-June	10.63	7.80
	July-September	10.78	12.92
	October-December	9.08	7.08
	Yearly Total	**39.02**	**37.97**
Conestoga River above Conestoga, Pa.	January-March	8.57	11.63
	April-June	10.84	6.85
	July-September	11.84	15.76
	October-December	9.46	8.06
	Yearly Total	**40.71**	**42.30**

WATER DISCHARGE

Mean water discharges for calendar year 1999 are listed in Table 4, along with the long-term annual mean discharges and the percent of long-term annual mean discharge for each site.

As shown in Table 4 and Figure 3, the annual mean water discharge was below normal at all sites. Streamflow ranged from 69.5 percent of normal at Towanda to 86.9 percent of normal at Danville.

Table 4. Annual Water Discharge, Calendar Year 1999

Site Short Name	Years of Record	Long-term Annual Mean cfs[1]	1999 Mean cfs	1999 Percent of Long-Term Mean
Towanda	86	10,600	7,370	69.5
Danville	95	15,300	13,300	86.9
Lewisburg	60	10,900	7,770	71.3
Newport	27	4,570	3,200	70.0
Marietta	68	37,200	27,600	74.2
Conestoga	15	667	546	81.8

[1] Cubic feet per second

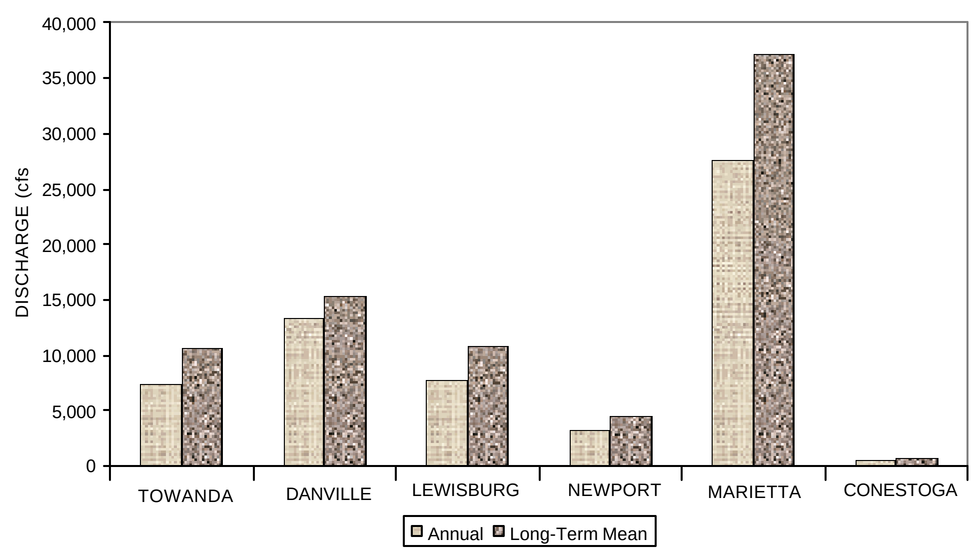

Figure 3. Annual and Long-Term Mean Water Discharge at Towanda, Danville, Lewisburg, Marietta, and Conestoga, Pa., Calendar Year 1999

ANNUAL NUTRIENT AND SUSPENDED–SEDIMENT LOADS AND YIELDS

Nutrient and suspended-sediment loads were computed for total nitrogen (TN), dissolved nitrogen (DN), total phosphorus (TP), dissolved phosphorus (DP), suspended sediment (SS), total ammonia (TNH), dissolved ammonia (DNH), total organic nitrogen (TON), dissolved organic nitrogen (DON), total nitrite plus nitrate (TNO23), dissolved nitrite plus nitrate (DNO23), dissolved orthophosphate (DOP), and total organic carbon (TOC). The minimum variance unbiased estimator described by Cohn and others (1989) was used to compute the loads. This estimator relates constituent concentration to water discharge, seasonal effects, and long-term trends, and computes the best-fit regression equation. Daily loads of the constituents were then calculated from the daily mean water discharge records. The loads were reported, along with the estimates of accuracy.

Tables 5 through 17 list the computed loads, in pounds per year (lb/yr), and corresponding yields, in pounds per acre per year (lb/ac/yr), of the constituents measured at each of the sites. Loads and yields are discussed together because they are mathematically the same values, with different connotations. Load values are equated to the quantity of material carried past a given point during a specific time period. Yield values are equated to the quantity of material derived from a unit of area over a specific time period. Yield values, therefore, readily can be compared between subbasins, regardless of size variations.

The calendar year 1999 and the long-term mean annual loads and yields of TN are shown in Figures 4A and 4B, respectively.

The 1999 annual loads and yields of TN were smaller than the long-term mean at all sites. The greatest TN loads were measured at Marietta, followed by Danville. The Conestoga River at Conestoga had the smallest TN loads.

The Conestoga River Watershed, with 62.7 percent agricultural and 22.4 percent forest lands (Ott and others, 1991), had the highest yield of TN, 28.30 lb/ac/yr. Annual yields of TN, shown in Figure 4B and Table 5, indicate that the Susquehanna River at Danville yielded more nitrogen per unit area than the West Branch Susquehanna River at Lewisburg. The West Branch Susquehanna River Watershed consists of 81 percent forest and 13.9 percent agricultural lands, as compared to 59.8 percent forest and 26.9 percent agricultural lands above Danville. The long-term mean yield indicates that the Susquehanna River at Danville normally yields more nitrogen per unit area.

The 1999 annual loads and yields of TP also were smaller than the long-term mean loads and yields, as illustrated in Figure 5A and 5B, respectively. The annual TP load was greatest at Marietta, followed by Danville, and the smallest annual TP load was measured at Newport. The greatest yield of TP occurred at Conestoga, followed by Marietta.

The annual loads and yields of SS are illustrated in Figure 6A and 6B, respectively. The 1999 loads and yields were smaller than the respective long-term mean loads and yields at all sites, except Conestoga. The highest SS loads were measured at Marietta, followed by Danville. The Juniata River had the smallest SS load. The Conestoga River had the highest suspended-sediment yield.

Annual loads of TNH, DNH, TNO23, DNO23, TON, DON, DN, DP, DOP, and TOC were greatest at Marietta. Annual loads of TNH, DNH, TNO23, DNO23, DP, DOP, TON, DON, DN, and TOC were greater at Danville than at Lewisburg. The Conestoga River had the highest yields of all parameters.

Table 5. Annual Water Discharges and Annual Loads and Yields of Total Nitrogen, Calendar Year 1999

Site Short Name	Annual Discharge	Total Nitrogen as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	18,000	3.92	3.60
Danville	13,300	35,000	4.18	4.88
Lewisburg	7,770	16000	4.55	3.65
Newport	3,200	10,700	3.12	5.01
Marietta	27,600	90,200	4.04	5.43
Conestoga	546	8,510	3.38	28.30

Table 6. Annual Water Discharges and Annual Loads and Yields of Total Phosphorus, Calendar Year 1999

Site Short Name	Annual Discharge	Total Phosphorus as P 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	1,030	11.47	0.21
Danville	13,300	1,800	10.17	0.25
Lewisburg	7,770	608	12.36	0.14
Newport	3,200	363	9.40	0.17
Marietta	27,600	4,350	9.55	0.26
Conestoga	546	580	31.98	1.93

Table 7. Annual Water Discharges and Annual Loads and Yields of Suspended Sediment, Calendar Year 1999

Site Short Name	Annual Discharge	Suspended Sediment 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	905,000	33.62	181.40
Danville	13,300	1,220,000	21.85	169.83
Lewisburg	7,770	612,000	28.88	139.63
Newport	3,200	174,000	19.98	81.29
Marietta	27,600	3,500,000	16.40	210.67
Conestoga	546	330,000	82.76	1,098.29

Table 8. Annual Water Discharges and Annual Loads and Yields of Total Ammonia, Calendar Year 1999

Site Short Name	Annual Discharge	Total Ammonia as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	769	12.81	0.15
Danville	13,300	1,550	11.67	0.22
Lewisburg	7,770	857	11.8	0.20
Newport	3,200	211	11.23	0.10
Marietta	27,600	2,750	10.69	0.17
Conestoga	546	156	18.96	0.52

Table 9. Annual Water Discharges and Annual Loads and Yields of Total Nitrite Plus Nitrate Nitrogen, Calendar Year 1999

Site Short Name	Annual Discharge	Total Nitrite Plus Nitrate as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	9,710	4.54	1.95
Danville	13,300	21,200	4.30	2.95
Lewisburg	7,770	9,460	3.68	2.12
Newport	3,200	7,460	3.06	3.48
Marietta	27,600	59,400	4.06	3.57
Conestoga	546	6,650	3.81	22.09

Table 10. Annual Water Discharges and Annual Loads and Yields of Total Organic Nitrogen, Calendar Year 1999

Site Short Name	Annual Discharge	Total Organic Nitrogen as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	7,950	8.74	1.59
Danville	13,300	13,300	8.76	1.85
Lewisburg	7,770	6,190	10.98	1.41
Newport	3,200	3,110	7.98	1.45
Marietta	27,600	75,800	10.29	4.56
Conestoga	546	2,250	19.97	7.48

Table 11. Annual Water Discharges and Annual Loads and Yields of Dissolved Phosphorus, Calendar Year 1999

Site Short Name	Annual Discharge	Dissolved Phosphorus as P 1999 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	434	7.99	0.09
Danville	13,300	491	8.20	0.07
Lewisburg	7,770	223	8.79	0.05
Newport	3,200	234	8.54	0.11
Marietta	27,600	1,690	7.59	0.10
Conestoga	546	205	9.51	0.68

Table 12. Annual Water Discharges and Loads and Yields of Dissolved Orthophosphate, Calendar Year 1999

Site Short Name	Annual Discharge	Dissolved Orthophosphate as P 1999 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	334	14.01	0.07
Danville	13,300	460	13.89	0.06
Lewisburg	7,770	183	15.85	0.04
Newport	3,200	363	18.31	0.17
Marietta	27,600	1,880	17.13	0.11
Conestoga	546	201	15.60	0.67

Table 13. Annual Water Discharges and Annual Loads and Yields of Dissolved Ammonia, Calendar Year 1999

Site Short Name	Annual Discharge	Dissolved Ammonia as N 1999 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	679	9.17	0.14
Danville	13,300	1,510	9.38	0.21
Lewisburg	7,770	718	11.56	0.16
Newport	3,200	173	12.02	0.08
Marietta	27,600	2,760	10.29	0.17
Conestoga	546	149	17.80	0.49

Table 14. Annual Water Discharges and Annual Loads and Yields of Dissolved Nitrogen, Calendar Year 1999

Site Short Name	Annual Discharge	Dissolved Nitrogen as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	16,700	3.68	3.35
Danville	13,300	33,200	4.09	4.63
Lewisburg	7,770	14,900	3.54	3.40
Newport	3,200	9,980	2.75	4.65
Marietta	27,600	81,800	3.73	4.92
Conestoga	546	8,080	3.02	26.87

Table 15. Annual Water Discharges and Annual Loads and Yields of Dissolved Nitrite Plus Nitrate Nitrogen, Calendar Year 1999

Site Short Name	Annual Discharge	Dissolved Nitrite Plus Nitrate Nitrogen as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	9,520	4.38	1.91
Danville	13,300	20,800	4.25	2.90
Lewisburg	7,770	9,410	3.61	2.15
Newport	3,200	7,380	3.05	3.44
Marietta	27,600	59,800	4.12	3.59
Conestoga	546	6,410	3.84	21.31

Table 16. Annual Water Discharges and Annual Loads and Yields of Dissolved Organic Nitrogen, Calendar Year 1999

Site Short Name	Annual Discharge	Dissolved Organic Nitrogen as N 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	6,480	8.32	1.30
Danville	13,300	10,800	7.39	1.50
Lewisburg	7,770	5,090	8.06	1.16
Newport	3,200	2,590	6.14	1.21
Marietta	27,600	92,000	11.22	5.53
Conestoga	546	1,540	11.33	5.10

Table 17. Annual Water Discharges and Annual Loads and Yields of Total Organic Carbon, Calendar Year 1999

Site Short Name	Annual Discharge	Total Organic Carbon 1999		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,370	51,100	3.96	10.24
Danville	13,300	86,000	3.90	11.98
Lewisburg	7,770	33,400	5.49	7.63
Newport	3,200	19,800	5.83	9.20
Marietta	27,600	177,000	3.71	10.66
Conestoga	546	6,250	9.05	20.78

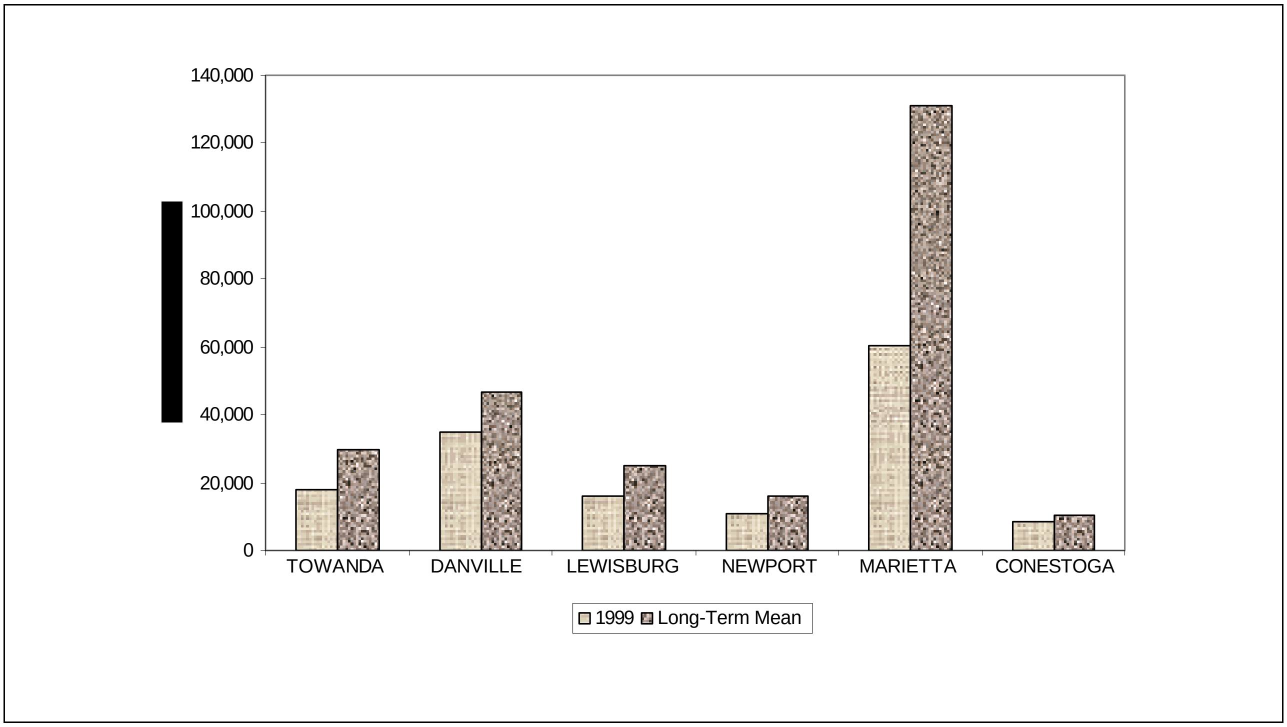

Figure 4A. ***Annual Loads of Total Nitrogen (TN) at Towanda, Danville, Lewisburg, Newport, Marietta and Conestoga, Pa., Calendar Year 1999***

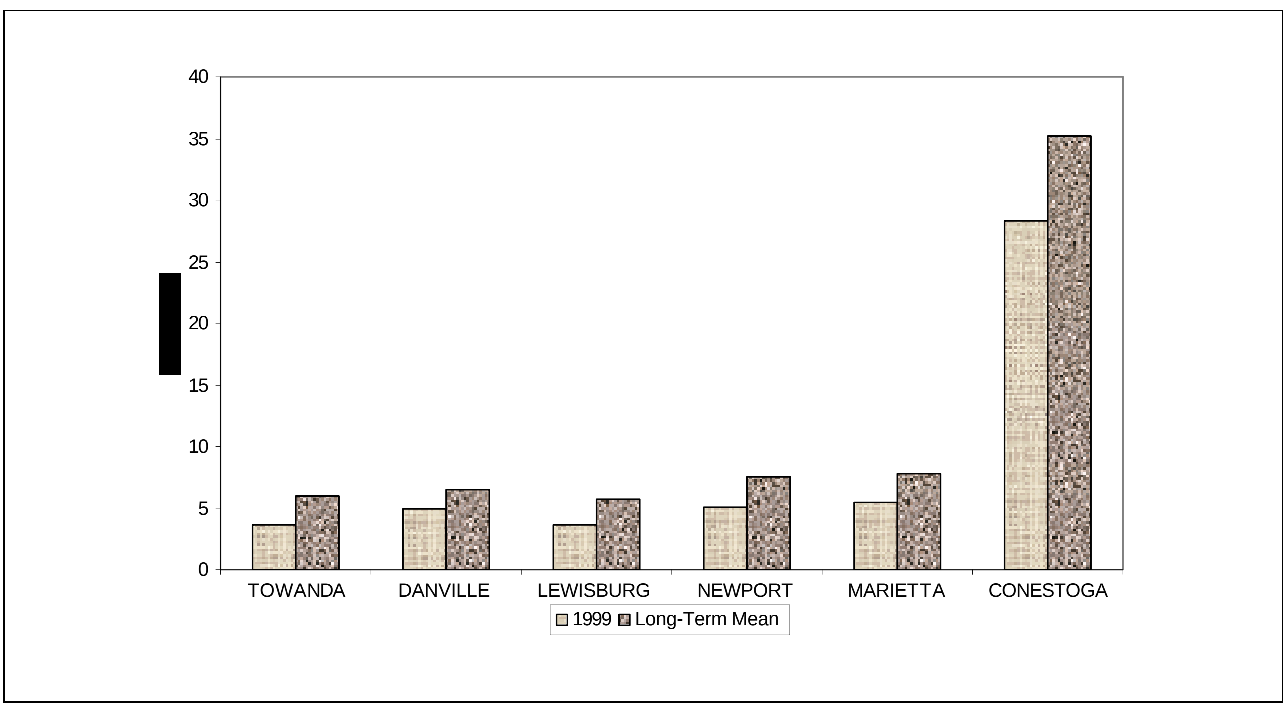

Figure 4B. ***Total Nitrogen (TN) Yields at Towanda, Danville, Lewisburg, Newport, Marietta and Conestoga, Pa., Calendar Year 1999***

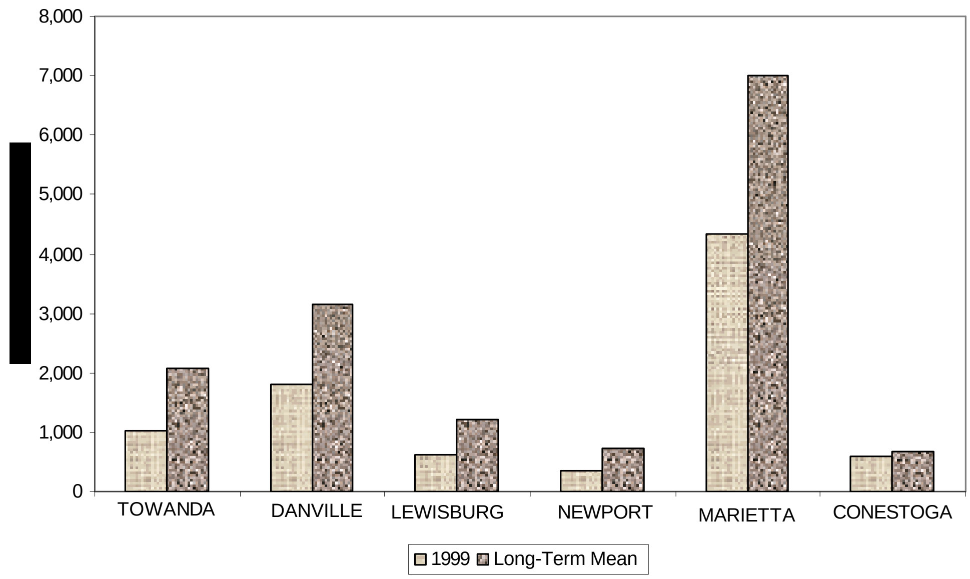

Figure 5A. ***Annual Loads of Total Phosphorus (TP) at Towanda, Danville, Lewisburg, Newport, Marietta and Conestoga, Pa., Calendar Year 1999***

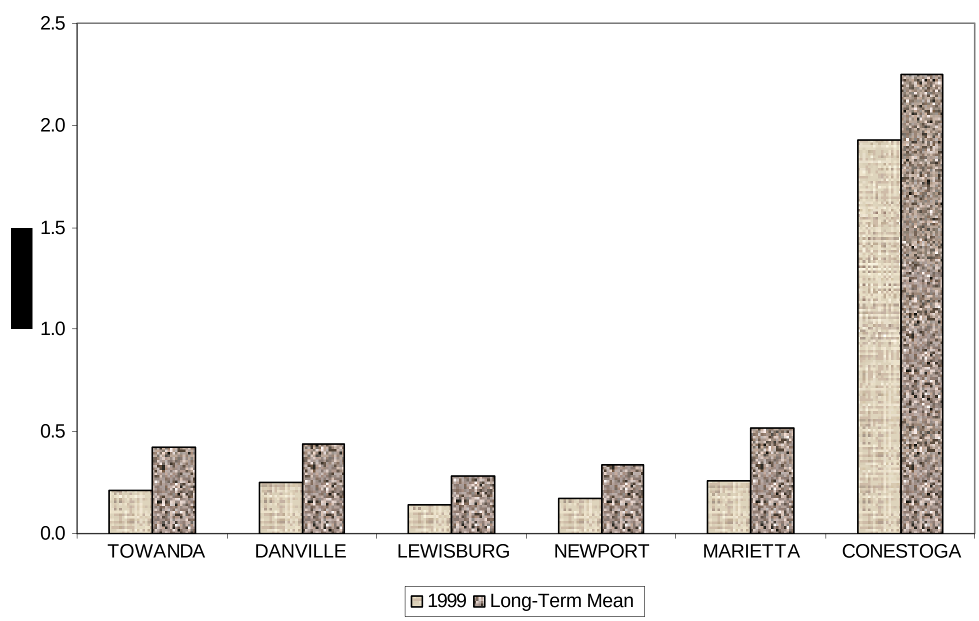

Figure 5B. ***Total Phosphorus (TP) Yields at Towanda, Danville, Lewisburg, Newport, Marietta and Conestoga, Pa., Calendar Year 1999***

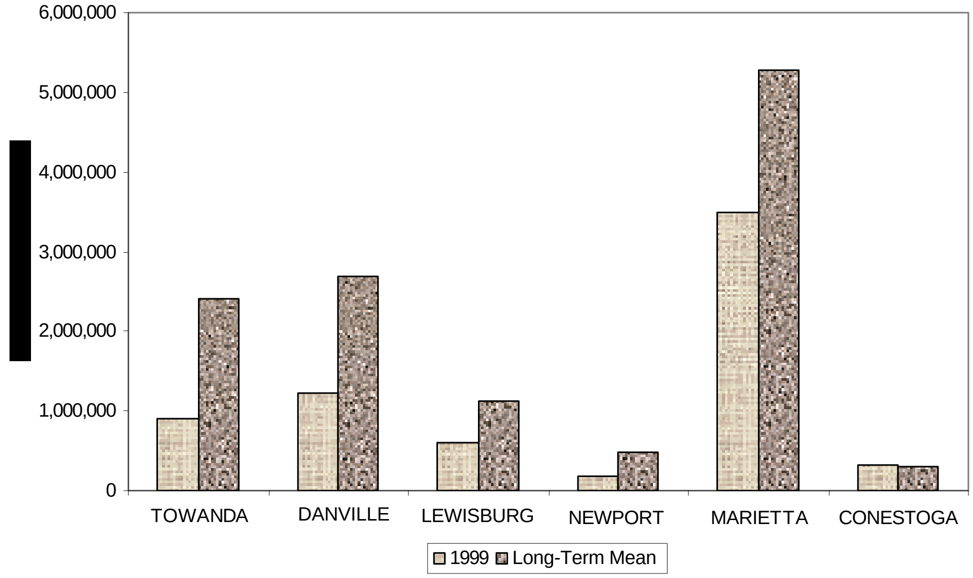

Figure 6A. ***Annual Loads of Suspended Sediment (SS) at Towanda, Danville, Lewisburg, Newport, Marietta and Conestoga, Pa., Calendar Year 1999***

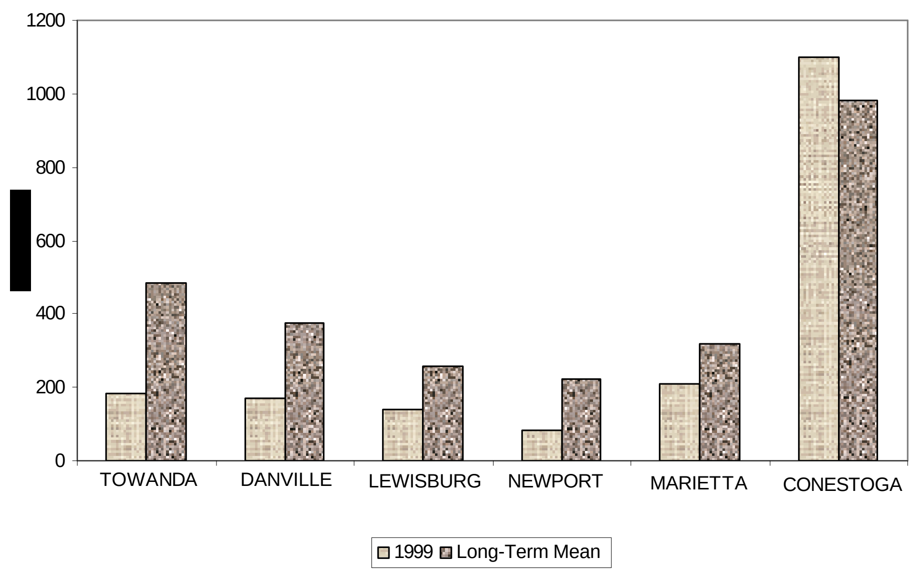

Figure 6B. ***Suspended-Sediment (SS) Yield at Towanda, Danville, Lewisburg, Newport, Marietta and Conestoga, Pa., Calendar Year 1999***

SEASONAL WATER DISCHARGES AND NUTRIENT AND SUSPENDED-SEDIMENT LOADS AND YIELDS

Seasonal water discharges and loads of nutrients and SS for calendar year 1999 are listed in Table 18. The calendar year 1999 and long-term seasonal water discharges and loads of TN, TP, and SS are illustrated in Figures 7 through 12.

Seasonal mean water discharges for calendar year 1999 at Towanda, Lewisburg, Newport and Marietta were highest in the winter (January-March), followed by spring (April-June), fall (October-December), then summer (July-September). The seasonal discharges for 1999 were smaller than the long-term discharges for all seasons at these sites. The 1999 seasonal discharges at Danville were highest in the winter, then fall, followed by spring and summer. The discharges were greater than long-term during the winter and fall and smaller in the spring and summer. Seasonal discharges at Conestoga were highest in the winter, followed by fall, summer, then spring. The discharge was greater than long-term in the summer and smaller during the other seasons.

TN consists mostly of the highly-soluble nitrite plus nitrate fraction; therefore, the seasonal variation of TN loads for 1999 corresponded with the seasonal variation of water discharges. With the exception of the summer load at Conestoga, the loads for 1999 were smaller than the long-term seasonal loads for all seasons at all sites.

The variations in seasonal loads of TP were consistent with seasonal variations of water discharges at Danville, Lewisburg, and Conestoga. TP loads at Towanda and Marietta were highest in the winter, followed by fall, then spring and summer, and the discharge was highest in the winter, followed by spring, fall, and summer. Newport had the highest TP load in the spring, followed by winter, and the discharge was highest in the winter, followed by spring. TP loads in 1999 were smaller than the long-term seasonal loads for all seasons at all sites, except for the summer load at Conestoga.

Seasonal variations in SS loads generally corresponded with discharge. Exceptions were at Newport and Conestoga. The SS load at Newport was highest in the spring, followed by winter, while the discharge was highest in the winter, then spring. At Conestoga, the SS load was highest in the summer, followed by spring, then fall. Discharge at Conestoga was highest in the winter, followed by fall, then summer. Seasonal loads in 1999 were smaller than the long-term loads, except for the winter load at Marietta and the summer load at Conestoga.

The long-term seasonal water discharges at most of the sites are highest in the winter, followed by spring, fall, then summer. The seasonal variations of the long-term TN loads are consistent with the seasonal discharges at all sites. The TP and SS loads in the Susquehanna River at Towanda, Danville and Marietta show the same seasonal variability. The greatest loads occur in the spring, then in the winter, followed by fall and summer, while the highest discharge occurs in the winter, followed by spring, fall, and summer. TP loads at Lewisburg, Newport, and Conestoga show the same seasonal fluctuations as their respective seasonal discharges.

Figures 13 through 15 provide a comparison of the seasonal yields among the monitoring sites for calendar year 1999 and the long-term seasonal average. The long-term seasonal averages indicate that the Conestoga River at Conestoga has the greatest yields of TN, TP, and SS for all seasons. The long-term TN yields in the Susquehanna River at Towanda, Danville, and Marietta generally increased in the downstream order. The West Branch Susquehanna River at Lewisburg, which has the greatest forested area, had the lowest TN yield among the tributary sites. TN yields for 1999 followed the same pattern during the winter, spring, and summer. The 1999 TN yields in the Susquehanna River increased between Towanda and Danville, and decreased between Danville and Marietta during the fall. Lewisburg had the smallest TN yield among the tributary sites.

Table 18. Seasonal Mean Water Discharges and Loads of Nutrients and Suspended Sediment, Calendar Year 1999

Station	Season	Mean Water Discharge	Total Ammonia as N	Total-Organic Nitrogen as N	Total Nitrite Plus Nitrate as N	Total Nitrogen as N	Dissolved Ortho-phosphate as P	Dissolved Phosphorus as P	Total Phosphorus as P	Dissolved Ammonia as N	Suspended Sediment	Dissolve Nitrogen as N	Dissolved Nitrite Plus Nitrate as N	Dissolved Organic Nitrogen as N	Total Organic Carbon
		cfs	thousands of pounds												
Towanda	Winter	14,800	466.0	3,830	5,330	9,490	120.0	202.0	562.0	415.0	663,000	8,880	5,220	3,110	24,100
	Spring	7,370	145.0	1,840	2,250	4,140	48.4	82.3	189.0	117.0	146,000	3,860	2,230	1,520	11,800
	Summer	1,810	25.6	641	371	914	37.3	37.4	80.0	18.5	26,900	746	366	464	4,140
	Fall	5,660	132.0	1,630	1,760	3,430	128.0	112.0	197.0	129.0	69,000	3,210	1,710	1,390	11,100
Danville	Winter	22,000	800.0	5,040	9,750	15,300	167.0	200.0	758.0	734.0	678,000	14,700	9,650	4,200	32,400
	Spring	12,000	255.0	2,740	4,190	7,150	73.5	93.6	321.0	272.0	219,000	6,630	4,160	2,210	17,700
	Summer	3,000	37.0	1,020	722	1,590	24.9	28.6	112.0	43.6	37,500	1,290	704	658	6,200
	Fall	16,300	455.0	4,470	6,500	11,000	195.0	168	608.0	457.0	285,000	10,600	6,320	3,710	29,700
Lewisburg	Winter	14,400	440.0	2,890	4,550	7,660	63.7	95.5	293.0	373.0	392,000	7,030	4,530	2,240	14,300
	Spring	8,180	200.0	1,510	2,260	3,890	34.8	51.9	145.0	169.0	125,000	3,590	2,250	1,250	8,260
	Summer	2,290	41.2	483	650	1,110	24.4	22.2	50.0	30.9	17,700	1,050	639	410	3,220
	Fall	6,360	175.0	1,310	1,990	3,330	59.9	54.0	121.0	145.0	77,900	3,230	2,000	1,190	7,680
Newport	Winter	4,920	77.2	962	2,960	4,040	91.9	74.9	119.0	63.7	59,400	3,800	2,930	813	6,890
	Spring	4,130	72.4	1,030	2,410	3,540	78.9	66.7	123.0	58.7	80,600	3,200	2,380	793	6,540
	Summer	1,410	20.0	396	552	900	50.1	31.9	45.0	15.7	11,000	829	550	323	2,140
	Fall	2,400	41.7	717	1,540	2,270	142.0	60.6	76.7	34.8	23,500	2,150	1,520	665	4,190
Marietta	Winter	49,200	1,530.0	30,600	28,700	41,500	633.0	697.0	2,000.0	1,500.0	1,890,000	37,800	28,900	35,400	71,400
	Spring	29,100	512.0	17,900	13,900	21,000	316.0	379.0	935.0	528.0	759,000	19,300	12,900	22,800	43,000
	Summer	9,700	132.0	8,120	4,010	7,330	224.0	176.0	438.0	124.0	285,000	6,340	4,040	9,680	20,600
	Fall	23,000	574.0	19,200	12,800	20,400	703.0	433.0	971.0	603.0	572,000	18,300	12,900	24,200	42,300
Conestoga	Winter	816	78.2	759	2,680	3,340	47.4	58.6	159.0	76.6	67,600	3,240	2,590	557	2,290
	Spring	376	17.7	261	1,340	1,550	21.4	23.5	48.9	17.1	9,730	1,560	1,300	248	852
	Summer	459	30.2	796	979	1,600	73.9	69.5	286.0	25.5	232,000	1,260	933	339	1,650
	Fall	532	29.9	434	1,640	2,030	58.8	53.7	85.8	29.5	20,500	2,030	1,590	392	1,460

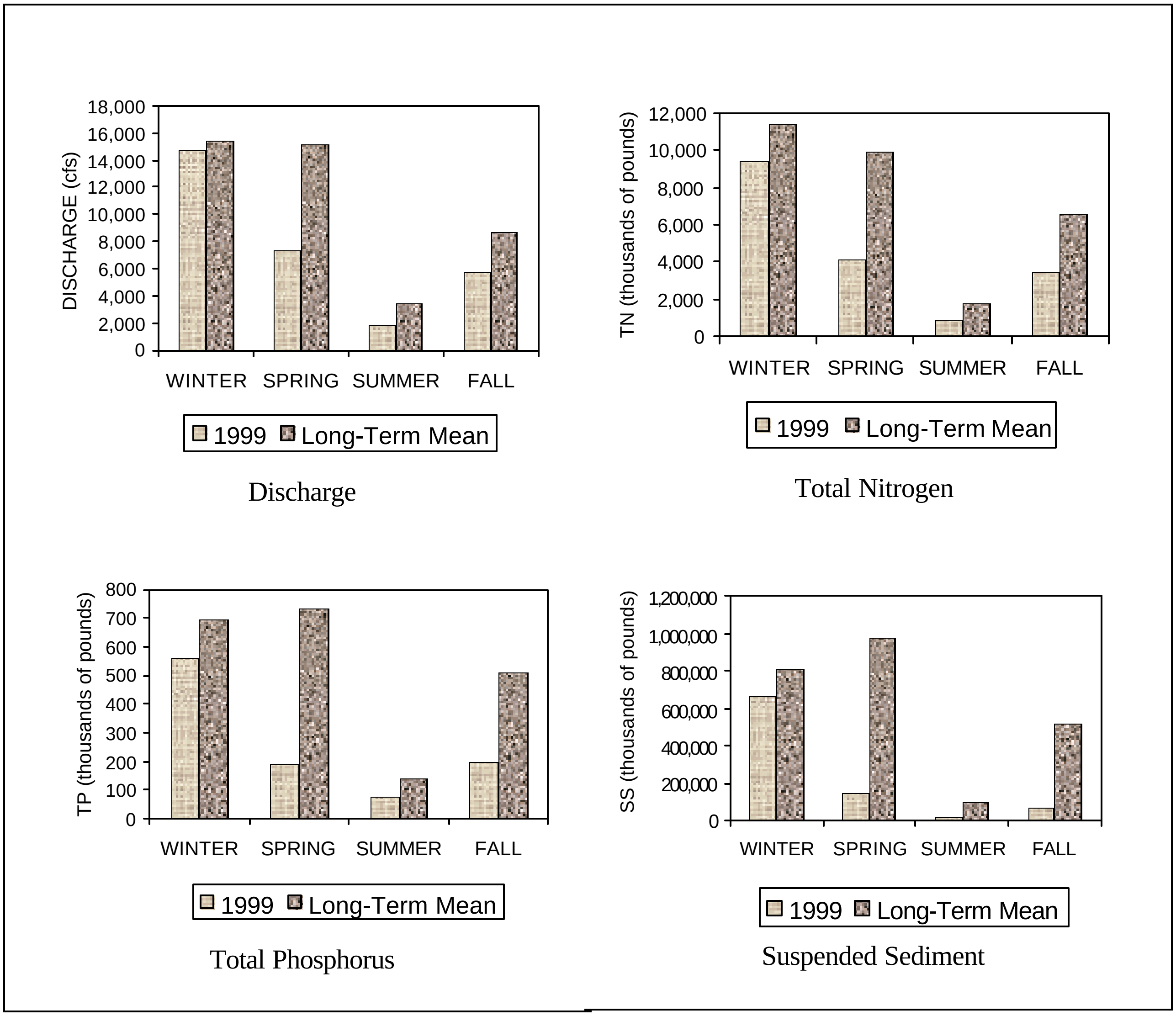

Figure 7. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Towanda, Pa., Calendar Year 1999***

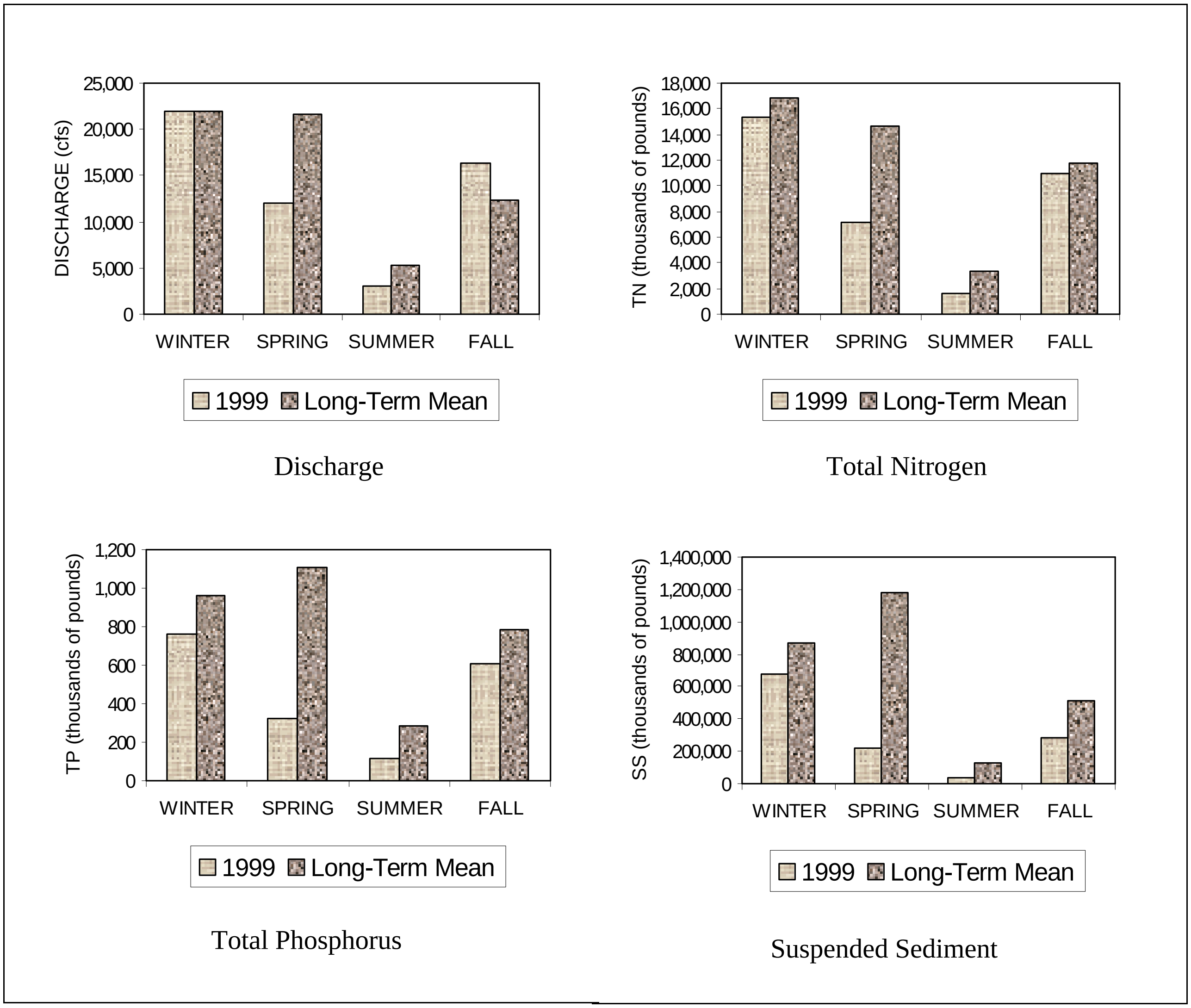

Figure 8. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Danville, Pa., Calendar Year 1999***

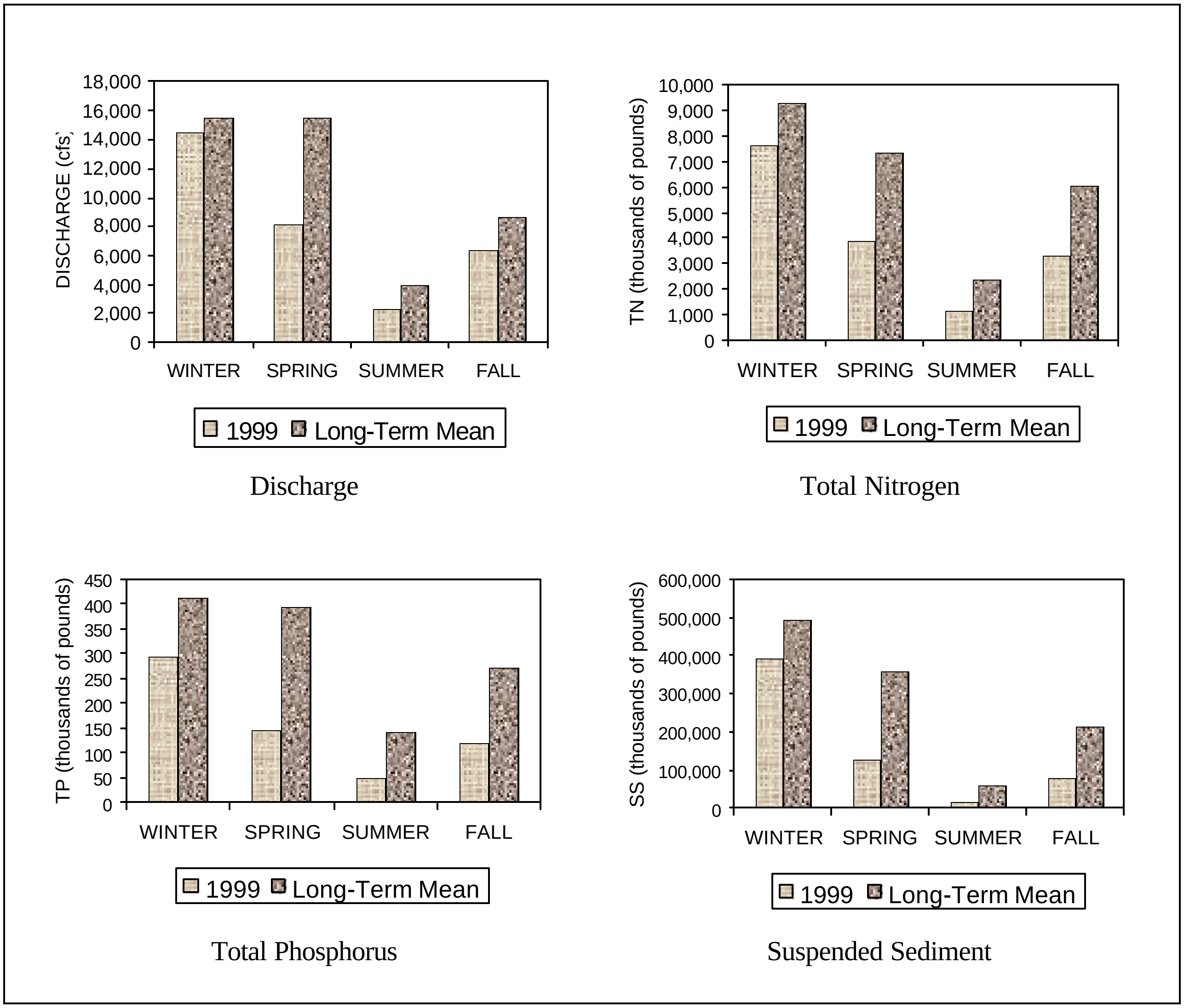

Figure 9. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Lewisburg, Pa., Calendar Year 1999***

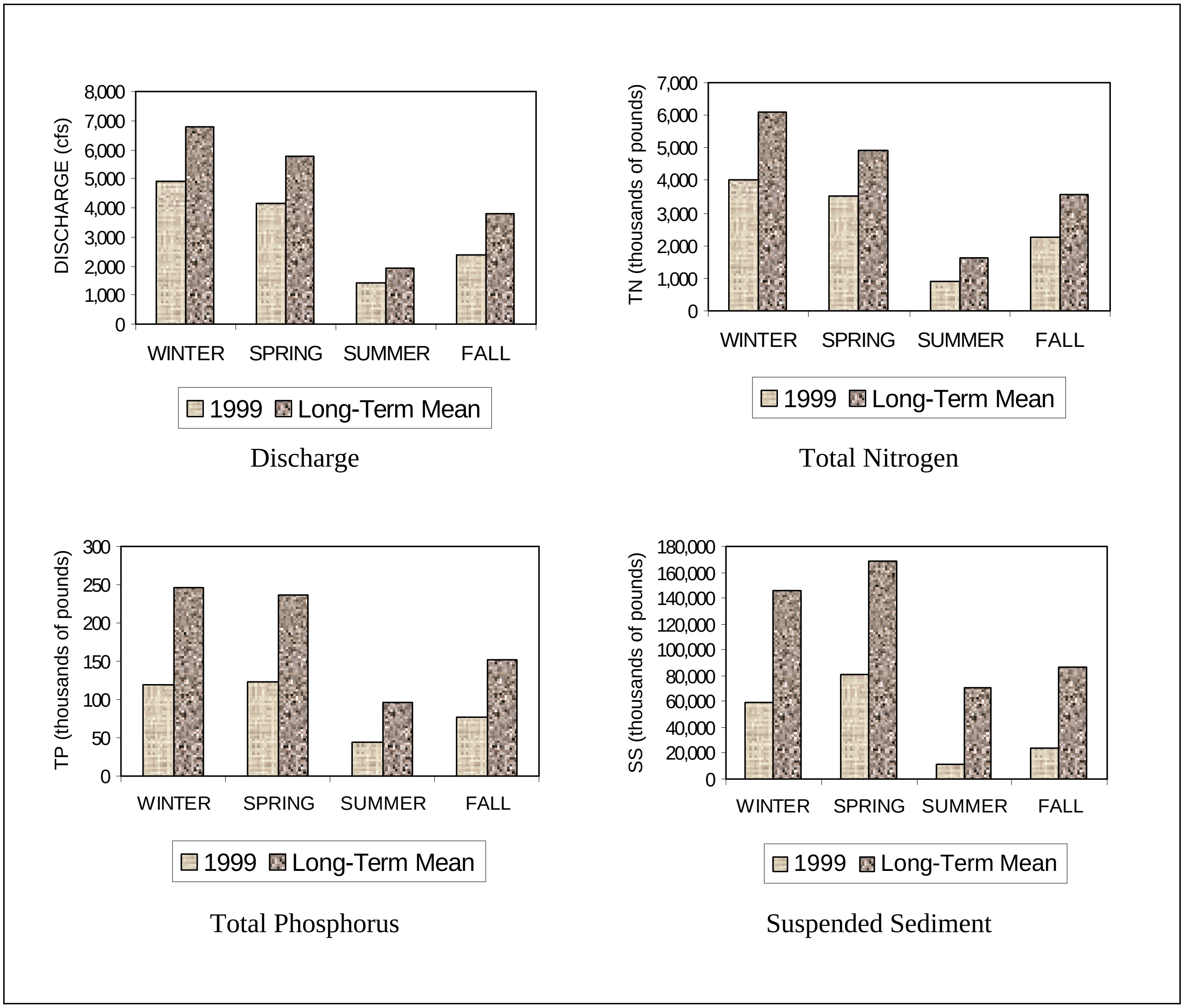

Figure 10. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Newport, Pa., Calendar Year 1999***

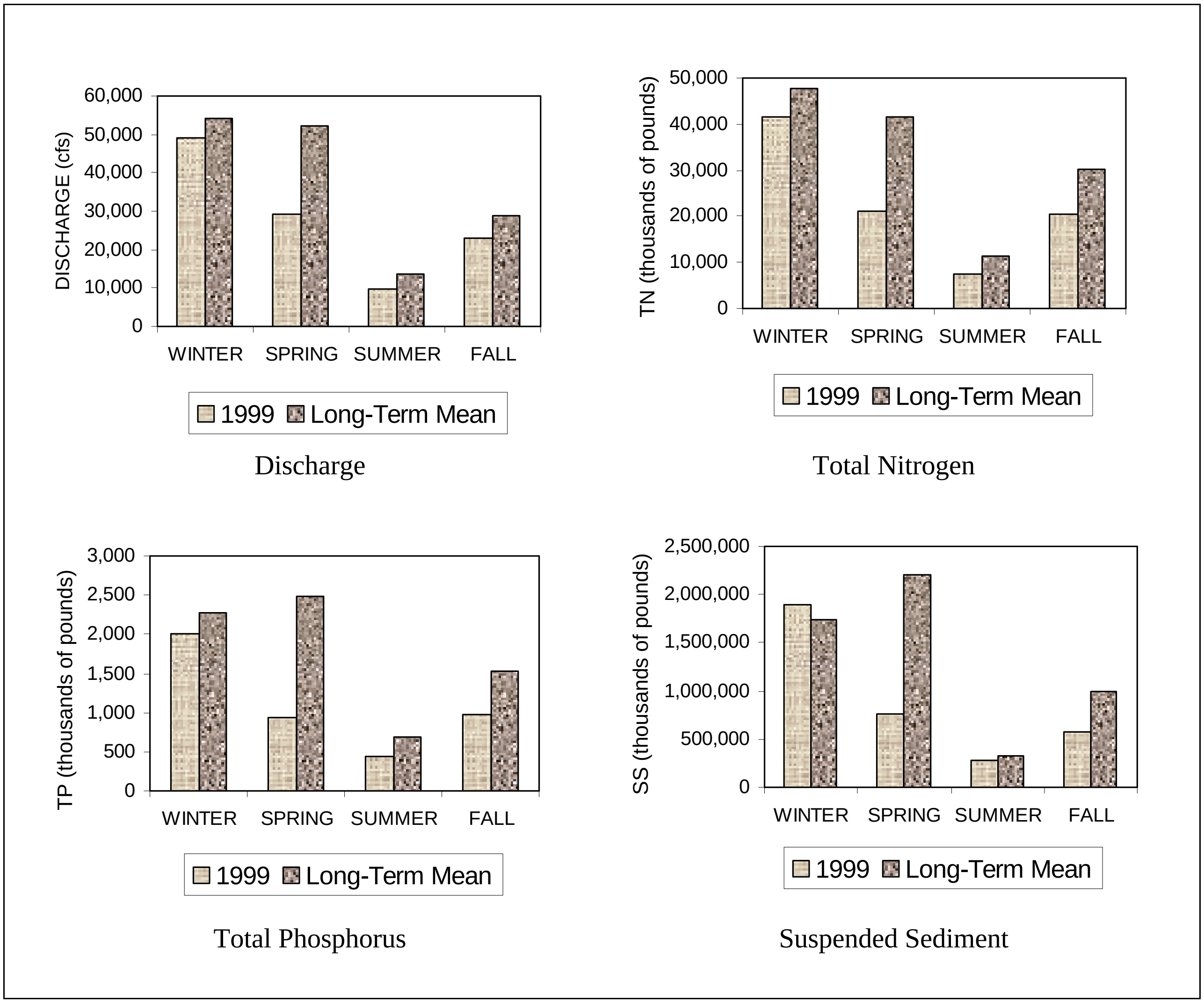

Figure 11. Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Marietta, Pa., Calendar Year 1999

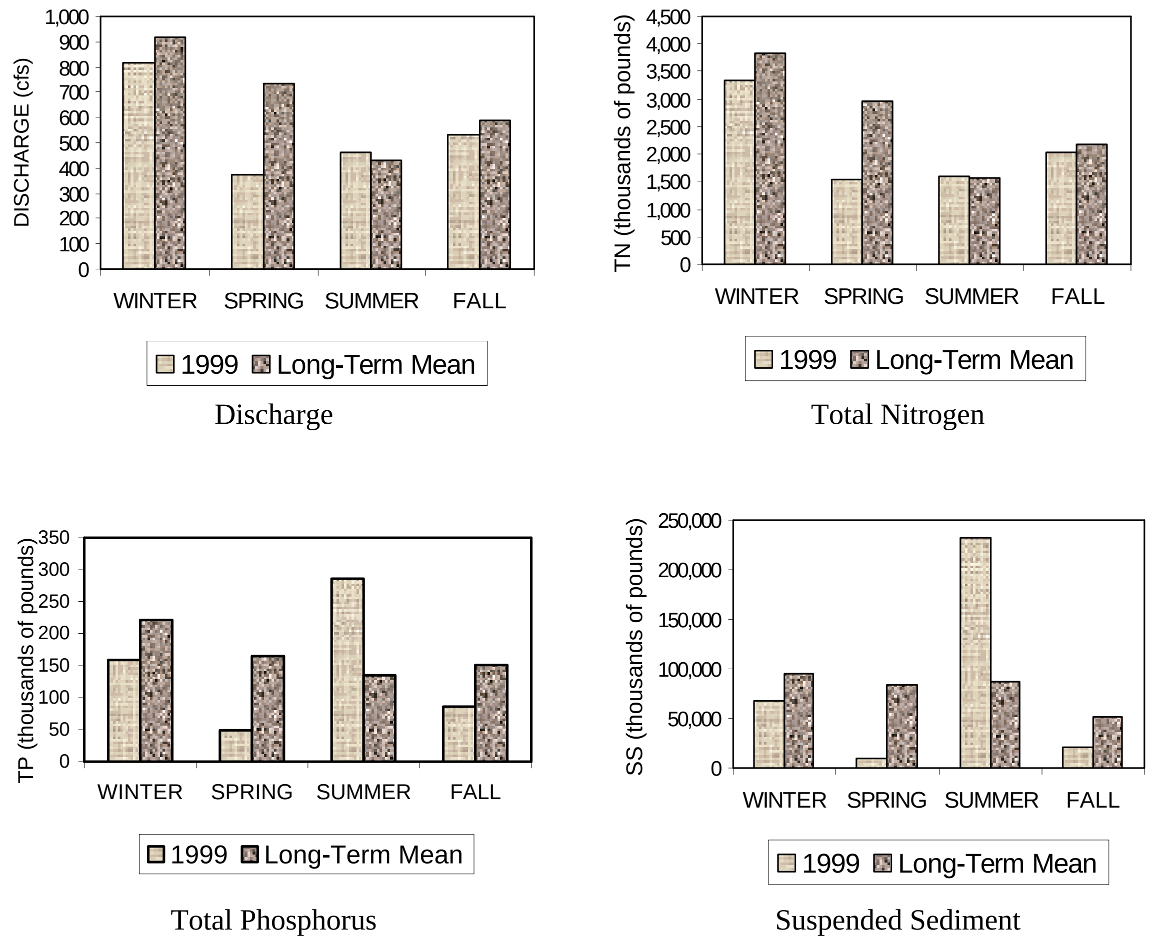

Figure 12. Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Conestoga, Pa., Calendar Year 1999

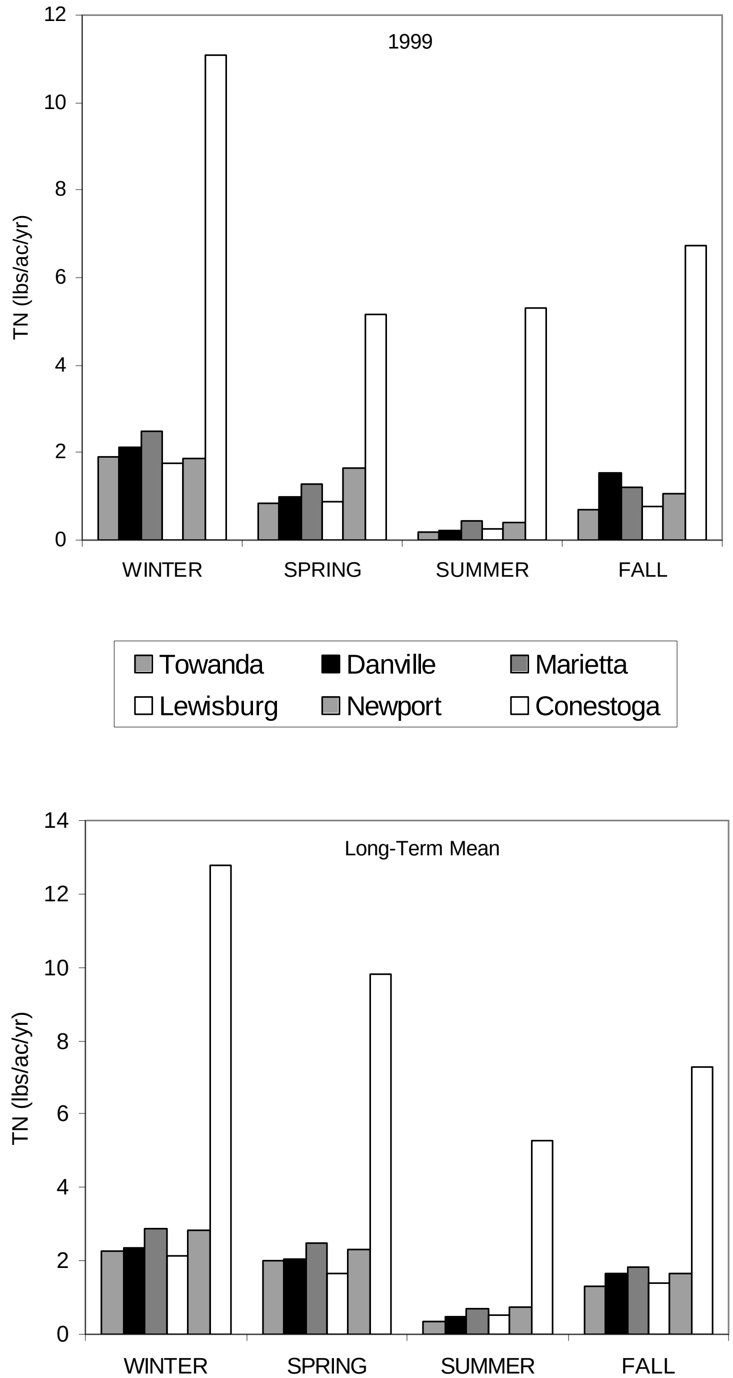

Figure 13. Comparison of Seasonal Yields of Total Nitrogen at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, Pa.

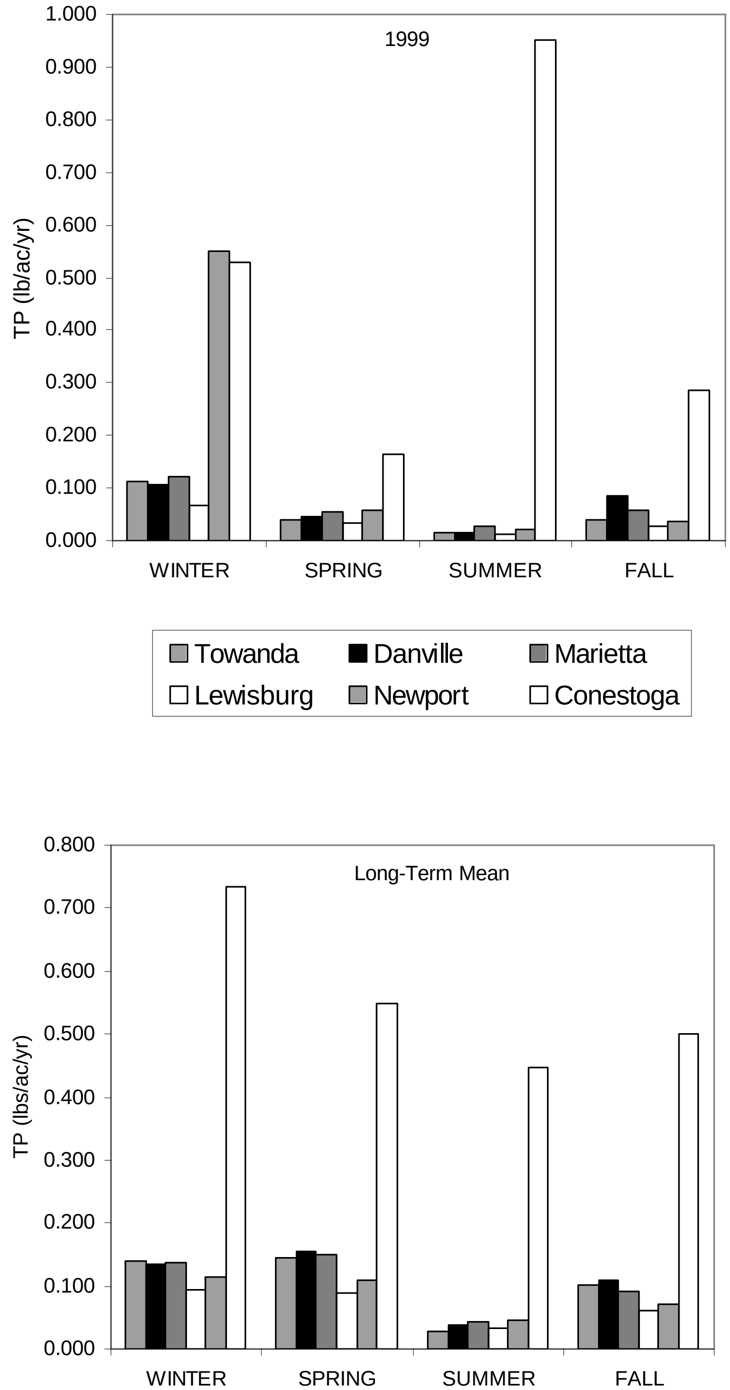

Figure 14. Comparison of Seasonal Yields of Total Phosphorus at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, Pa

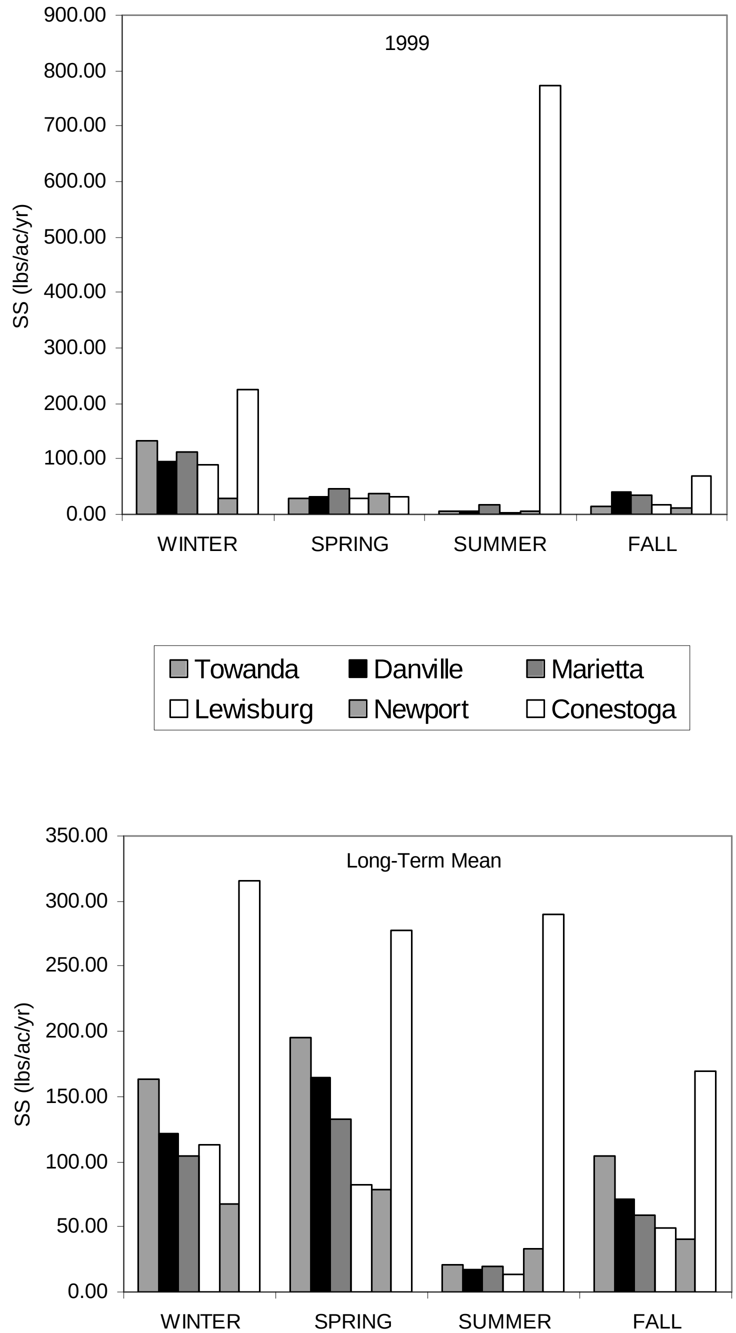

Figure 15. Comparison of Seasonal Yields of Suspended Sediment at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, Pa.

The long-term TP yields in the Susquehanna River at Towanda, Danville, and Marietta do not show any consistent seasonal pattern among the sites. TP yields among the tributary sites show that Lewisburg has the smallest yield during all seasons. The 1999 TP yields also do not show any consistent patterns among the sites. The smallest TP yield in 1999 occurred at Lewisburg.

Long-term SS yields in the Susquehanna River generally decrease in the downstream order. SS yields among the tributary sites are smallest at Newport in the winter, spring, and fall. The SS yield is smallest at Lewisburg in the summer. The 1999 seasonal SS yields do not show any consistent relationships among the sites.

COMPARISON OF THE 1999 LOADS AND YIELDS OF TOTAL NITROGEN, TOTAL PHOSPHORUS AND SUSPENDED SEDIMENT WITH THE BASELINES

Several studies, Ott and others (1991), Takita and Edwards (1993), and Takita (1998) have shown that annual loads of TN, TP, and SS change with annual fluctuations in water discharge. The annual fluctuations of nutrient and SS loads and water discharge make it difficult to determine whether the changes are related to land use, nutrient availability, or simply annual water discharge. Ott and others (1991) used the functional relationship between annual loads and annual water discharge to provide a method to reduce the variability of loadings due to discharge. This was accomplished by plotting the annual loads or yields against the water-discharge ratio. This water-discharge ratio is the ratio of the annual mean discharge to the long-term mean discharge. Data for the five years (1985-89) were used to provide a best-fit linear regression line to be used as the baseline relationship between annual loads and water discharge. It was hypothesized that, as future loads and water-discharge ratios were plotted against the baseline, any significant deviation from the baseline would indicate that some change in the annual load had occurred, and that further evaluations to determine the reason for the change were warranted. The data collected in 1999 were compared with the 1985-89 baseline, where possible. Monitoring at some of the stations was started after 1987; therefore, a baseline was established for the 5-year period following the start of monitoring.

Susquehanna River at Towanda, Pa.

The 5-year baselines for TN, TP, and SS for the Susquehanna River at Towanda are shown in Figure 16 with the 1999 annual yield. Best-fit lines were drawn through the initial 5-year data sets using the following equations:

Total Nitrogen (TN)
TN Yield = 0.7484 + 6.0967x $R^2 = 0.86$

Total Phosphorus (TP)
TP Yield = -0.1419 + 0.4999x $R^2 = 0.52$

Suspended Sediment (SS)
SS Yield = -612.879 + 918.165x $R^2 = 0.43$

Where x = water-discharge ratio and R2 = correlation coefficient

The 1999 TN yield plotted significantly below the 5-year baseline suggesting that the TN load decreased. The TN yield was estimated to be 4.99 lb/ac/yr at a water discharge ratio of 0.70 for the initial five years of monitoring while the yield for 1999 was 3.60 lb/ac/yr at the same discharge ratio. There was no change in the TP load. The baseline TP yield was 0.21 lb/ac/yr compared to 0.21 lb/ac/yr for 1999. The SS yields in Figure 16 indicate that there was a significant increase in 1999. The baseline yield was 25.3 lb/ac/yr and the yield for 1999 was 181.4 lb/ac/yr.

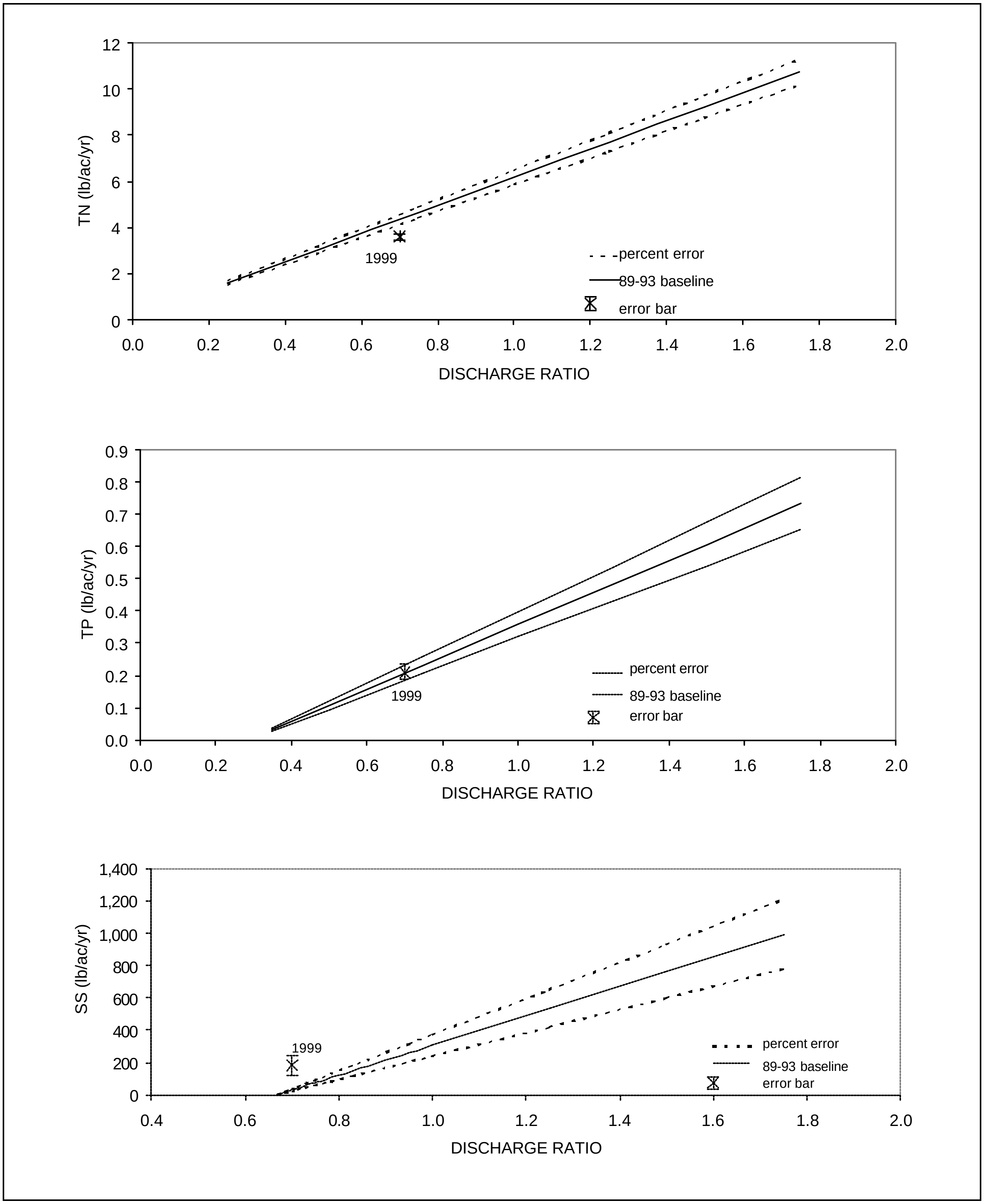

Figure 16. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS)Yields, Susquehanna River at Towanda, Pa., 1989-93 and 1999

Susquehanna River at Danville, Pa.

Figure 17 shows the 5-year (1985-89) baselines for TN, TP, and SS and the 1999 yields for the Susquehanna River at Danville. The regression equations used to establish the baselines were:

Total Nitrogen (TN)
TN Yield = -0.1792 + 7.2989x $R^2 = 0.85$

Total Phosphorus (TP)
TP Yield = -0.1496 + 0.6586x $R^2 = 0.94$

Suspended Sediment (SS)
SS Yield = -471.893 + 862.484x $R^2 = 0.99$

TN, TP, and SS yields for 1999 plotted significantly below the baseline, indicating that there was a decrease in the loads. The baseline yields of TN and TP were 6.16 and 0.42 lb/ac/yr at the water-discharge ratio of 0.87, compared to 4.88 and 0.25 lb/ac/yr for 1999, respectively. The baseline SS yield was 277.6 lb/ac/yr, compared to 169.8 lb/ac/yr for 1999.

West Branch Susquehanna River at Lewisburg, Pa.

The 1985-89 baselines and the 1999 yields for TN, TP, and SS are shown in Figure 18. The baselines were defined by the following equations:

Total Nitrogen (TN)
TN Yield = -1.3773 + 7.8447x $R^2 = 0.73$

Total Phosphorus (TP)
TP Yield = 0.0399 + 0.2660x $R^2 = 0.50$

Suspended Sediment (SS)

SS Yield = -152.859 + 344.025x $R^2 = 0.66$

TN and TP for 1999 plotted significantly below the baseline, indicating that the nitrogen and phosphorus loads decreased. The baseline TN yield was 4.22 lb/ac/yr at the water-discharge ratio of 0.71, compared to 3.65 lb/ac/yr for 1999. The TP yield was 0.15 lb/ac/yr for the baseline and 0.14 lb/ac/yr for 1999. SS data suggested that there was a slight increase in 1999, but this increase may not be significant since the margins of error overlap. The baseline yield was 92.4 lb/ac/yr, and the 1999 yield was 139.6 lb/ac/yr.

Juniata River at Newport, Pa.

The 1985-89 baselines and 1999 yields for TN, TP, and SS at Newport, shown in Figure 19, were plotted using the following equations:

Total Nitrogen (TN)
TN Yield = -0.2937 + 8.9052x $R^2 = 0.80$

Total Phosphorus (TP)
TP Yield = -0.0892 + 0.5268x $R^2 = 0.95$

Suspended Sediment (SS)
SS Yield = -293.255 + 563.920x $R^2 = 0.89$

TN and TP yields for 1999 show significant decreases from the baseline. The TN baseline yield was 5.94 lb/ac/yr at a water-discharge ratio of 0.70 and the 1999 yield was 5.01 lb/ac/yr. TP yields were 0.28 and 0.17 lb/ac/yr for the baseline and 1999, respectively. There was no change in the SS load for 1999 because the yield fell within the margin of error for the baseline.

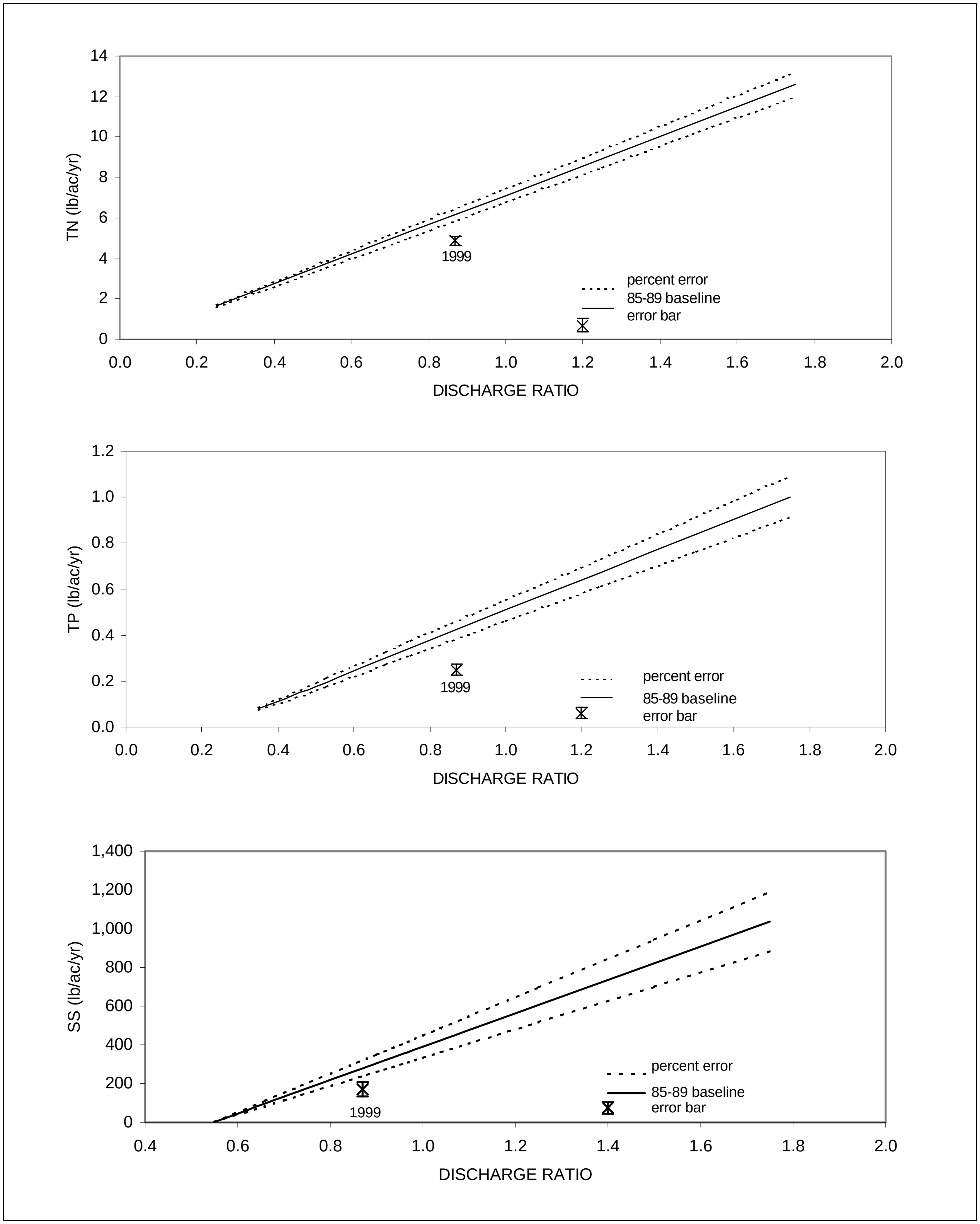

Figure 17. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Danville, Pa., 1985-89 and 1999

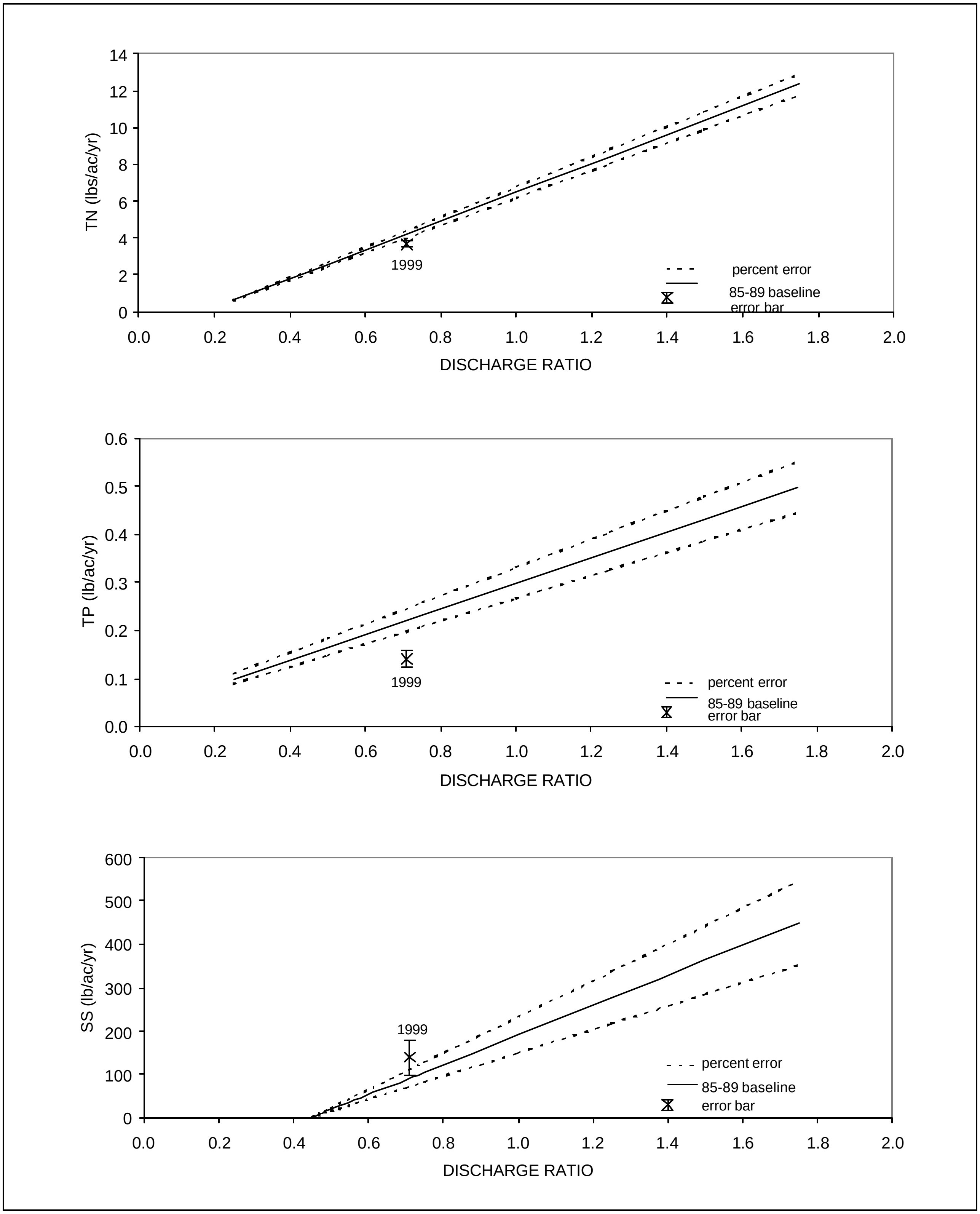

Figure 18. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, West Branch Susquehanna River at Lewisburg, Pa., 1985-89 and 1999

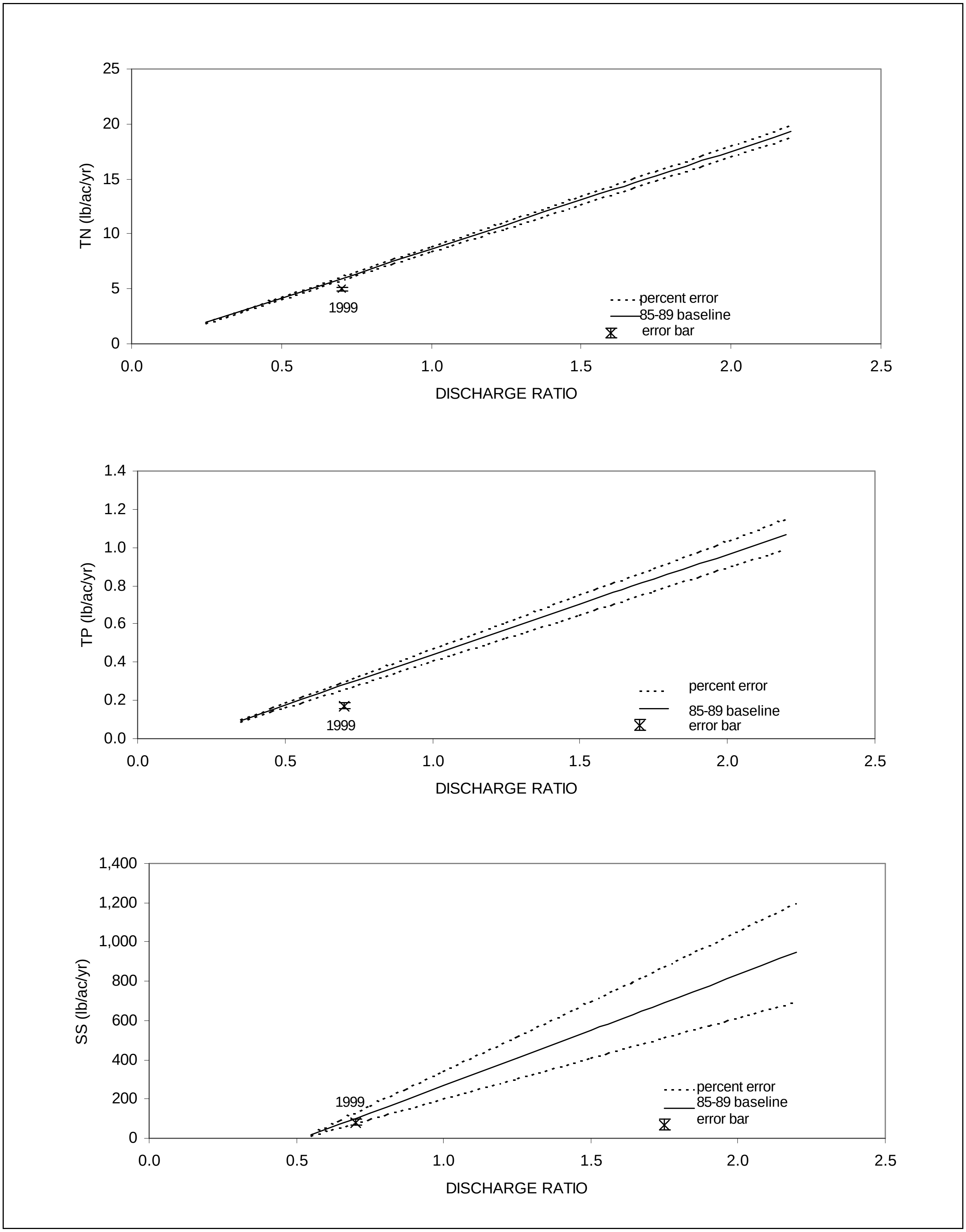

Figure 19. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Juniata River at Newport, Pa., 1985-89 and 1999

Susquehanna River at Marietta, Pa.

The TN, TP, and SS baseline for the 5-year period 1987-91 at Marietta and the 1999 yield are shown in Figure 20. The baselines were plotted using the following equations:

Total Nitrogen TN)
TN Yield = -0.8300 + 9.3087x $R^2 = 0.99$

Total Phosphorus (TP)
TP Yield = 0.1330 + 0.2405x $R^2 = 0.28$

Suspended Sediment (SS)
SS Yield = -97.8555 + 385.9816x $R^2 = 0.48$

TN and TP yields for 1999 plotted significantly below their respective baselines, indicating that there was a decrease in loads. The TN baseline yield was 6.08 lb/ac/yr at a discharge ratio of 0.74, and the 1999 yield was 5.43. TP baseline yield was 0.31 lb/ac/yr, compared to 0.26 lb/ac/yr for 1999. The 1999 SS yield plotted within the percent error for the baseline, indicating that there probably was no change.

Conestoga River at Conestoga, Pa.

Figure 21 shows the TN, TP, and SS baselines. These baselines were plotted using the following equations:

Total Nitrogen (TN)
TN Yield = 2.3343 + 35.3217x $R^2 = 0.97$

Total Phosphorus (TP)
TP Yield = -1.4013 + 3.3216x $R^2 = 0.92$

Suspended Sediment (SS)
SS Yield = -617.301 + 1978.075x $R^2 = 0.72$

The 1999 TN yield shows a significant decrease from the baseline yields. The baseline and 1999 yields of TN were 31.23 and 28.3 lb/ac/yr, respectively, at a water-discharge ratio of 0.82. The TP yield increased in 1999, but may not be significant since the margins of error overlap. The baseline yield was 1.32 lb/ac/yr, and the 1999 yield was 1.93 lb/ac/yr. There was no change in SS load.

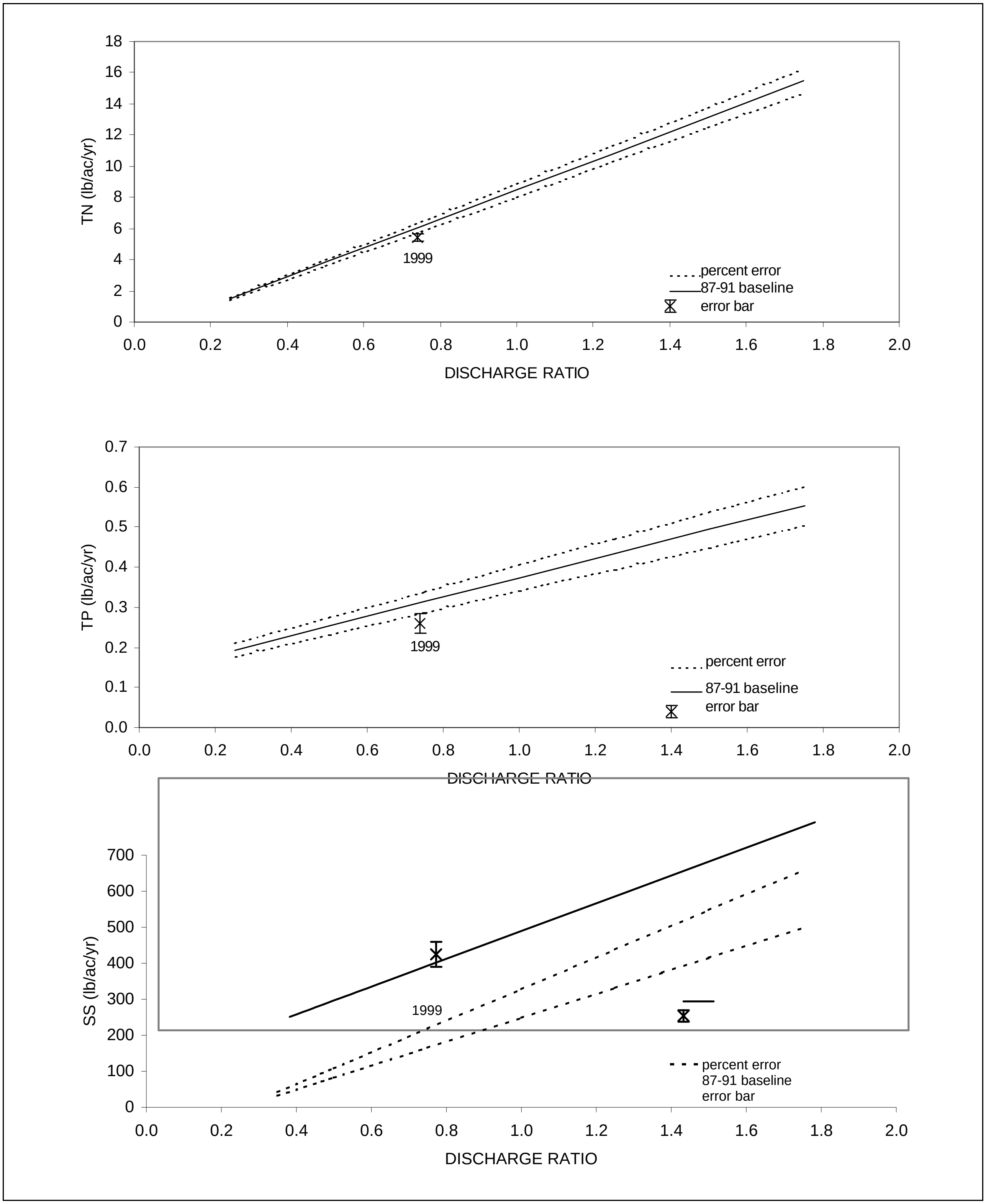

Figure 20. ***Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Marietta, Pa., 1985-89 and 1999***

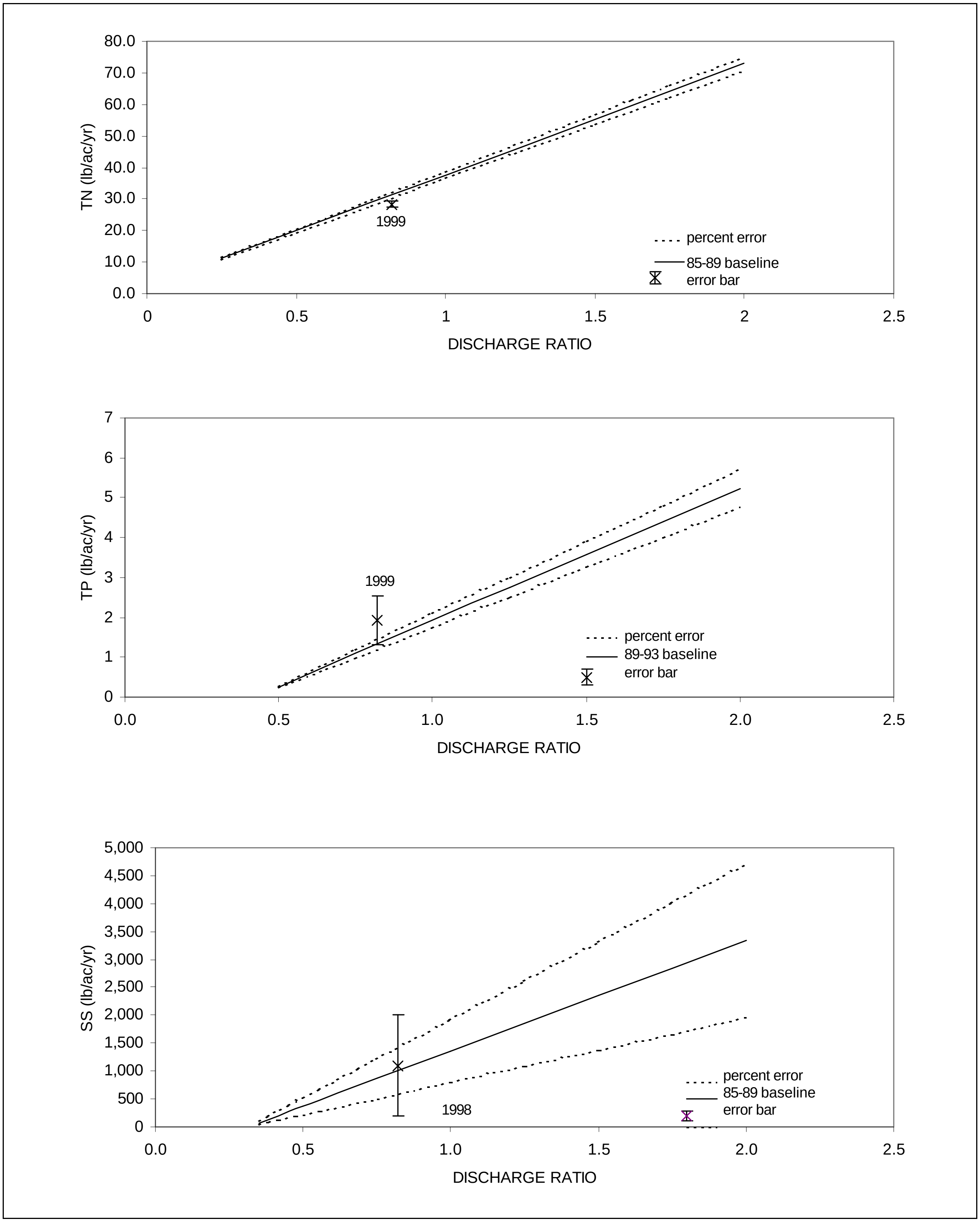

Figure 21. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Conestoga River at Conestoga, Pa., 1985-89 and 1999

DISCHARGE, NUTRIENT, AND SUSPENDED–SEDIMENT TRENDS

Trend analyses of water quality and flow data collected at the six monitoring sites were completed for the period January 1985 through December 1999. Trends were estimated using linear regression techniques and the USGS estimator model (Cohn and others, 1989). These tests were used to estimate the direction and magnitude of trends for monthly mean flow (FLOW), TN, DN, TON, DON, TNH, DNH, total kjeldahl nitrogen (TKN), dissolved kjeldahl nitrogen (DKN), TNO23, DNO23, TP, DP, dissolved inorganic phosphorus (DIP), TOC, and SS. Results are reported for FLOW, monthly load (LOAD), flow-weighted concentration (FWC), and flow-adjusted concentration FAC. The FWC is the result of the LOAD divided by the monthly flow, while the FAC is the concentration after the effects of flow are removed from the concentration time series. A description of the methodology is included in Langland and others (1999, in draft). Trends in FLOW, LOAD, FWC, and FAC represent four diverse approaches to evaluating stream quality. While each trend will not reveal the specific cause of water quality changes, the combined information can improve our understanding of the causes influencing water quality trends.

Trends in FLOW indicate the natural changes in hydrology. Changes in flow and the cumulative sources of flow (base flow and over land runoff) affect the observed concentrations and the estimated loads of nutrients and SS. Trends in LOAD indicate the flux of constituents through the system or rates of output. When loads are expressed as yields (load per unit area), the rates of output among watersheds can be compared. Trends in FWC indicate changes in stream quality over the period being investigated. The FWC is an average monthly concentration, rather than a single observed concentration, and is more representative of monthly stream quality conditions. This is the concentration that affects the biological processes of the stream. Trends in FAC indicate that changes have occurred in the processes that deliver constituents to the stream system. After the effects of flow are removed, this is the concentration that relates to the effects of nutrient-reduction activities and other actions taking place in the watershed.

Trend results for each monitoring site are presented in Tables 19 through 24. Each table lists the results for flow (Q), the various nitrogen and phosphorus species, organic carbon and SS. The level of significance was set by the p-value of 0.01 for LOAD and FWC, and a p-value of 0.05 for FAC (Langland and others, 1999). The magnitude of the slope incorporates a confidence interval and was reported as a range (minimum and maximum). The slope direction was reported as inconclusive (I), not significant (NS) or, when significant, as downward (DN), defined as improving conditions, or upward (UP), defined as degrading conditions. The baseline and status condition was the median value of the FWC in milligram per liter (mg/l), LOAD expressed as a yield in lb/ac, and FLOW in cubic feet per second (cfs) for the first two years (BASE) and the last three years (STATUS) for the time series being tested, respectively. Because the FAC is a residual of a flow and concentration relationship, the base and status conditions are not reported. When a time series had greater than 20 percent of its observations below the method detection level (BMDL), a trend analysis could not be completed. This occurred in the FAC time series for 6 of the 90 FAC time series analyzed for trend and are noted in the table as BMDL.

Susquehanna River at Towanda, Pa.

Table 19 shows the trends for the Susquehanna River at Towanda for the period 1989 to 1999. While a comparison of baseline and status flow indicated a change in the flow record (11,505 cfs vs. 9,063 cfs), the test on the FLOWs did not detect ($p = 0.1083$) a trend in the discharge time series.

The transport record (LOAD) for TN showed a base yield of 5.4 lb/ac during the first 24 months, decreasing to a status yield of

Table 19. Trend Statistics for the Susquehanna River at Towanda, Pa., January 1989 Through December 1999

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.1083	-55	8	NS	11,505.00	9063.00
TN	FAC	0.0000	-35	-23	DN	-	-
TN	FWC	0.0001	-30	-25	DN	2.92	1.19
TN	LOAD	0.0044	-68	-20	DN	5.36	3.12
DN	FAC	0.0000	-29	-15	DN	-	-
DN	FWC	0.0001	-25	-19	DN	2.40	1.06
DN	LOAD	0.0097	-66	-14	DN	4.58	2.81
TON	FAC	0.1374	-28	5	NS	-	-
TON	FWC	0.9279	-10	13	NS	1.13	0.49
TON	LOAD	0.1570	-57	14	NS	2.33	1.20
DON	FAC	0.0717	-2	42	NS	-	-
DON	FWC	0.0001	15	38	UP	0.68	0.37
DON	LOAD	0.5858	-46	41	NS	1.62	1.04
DNH	FAC				BMDL	-	-
DNH	FWC	0.0001	-37	-30	DN	0.11	0.04
DNH	LOAD	0.0023	-72	-25	DN	0.18	0.09
TNH	FAC	0.0578	-36	1	NS	-	-
TNH	FWC	0.0001	-43	-27	DN	0.10	0.04
TNH	LOAD	0.0061	-75	-21	DN	0.17	0.10
DKN	FAC	0.1694	-5	35	NS	-	-
DKN	FWC	0.0009	7	29	UP	0.77	0.41
DKN	LOAD	0.4370	-51	36	NS	1.66	1.13
TKN	FAC	0.0579	-29	1	NS	-	-
TKN	FWC	0.9270	-11	11	NS	1.25	0.54
TKN	LOAD	0.1473	-58	14	NS	2.64	1.40
TNO23	FAC	0.0000	-40	-27	DN	-	-
TNO23	FWC	0.0001	-40	-34	DN	1.88	0.64
TNO23	LOAD	0.0005	-72	-31	DN	4.44	1.68
DNO23	FAC	0.0000	-40	-27	DN	-	-
DNO23	FWC	0.0001	-36	-29	DN	1.86	0.64
DNO23	LOAD	0.0004	-72	-32	DN	4.37	1.66
TP	FAC	0.0417	-34	-1	DN	-	-
TP	FWC	0.0450	-	-	I	0.14	0.07
TP	LOAD	0.0562	-68	1	NS	0.30	0.18
DP	FAC	0.0000	-52	-32	DN	-	-
DP	FWC	0.0001	-40	-29	DN	0.10	0.03
DP	LOAD	0.0005	-71	-30	DN	0.21	0.08
DIP	FAC				BMDL	-	-
DIP	FWC	0.0001	-	-	I	0.03	0.01
DIP	LOAD	0.1163	-8	118	NS	0.08	0.04
TOC	FAC	0.5485	-11	6	NS	-	-
TOC	FWC	0.4240	-11	5	NS	6.54	3.26
TOC	LOAD	0.1272	-60	12	NS	15.63	9.12
SS	FAC	0.0520	-1	89	NS	-	-
SS	FWC	0.9622	-47	96	NS	85.07	35.82
SS	LOAD	0.5232	-76	105	NS	152.16	62.89

*Condition for FWC and FAC is concentration in mg/l; LOAD is yield in lb/ac.

3.1 lb/ac during the last 36 months. The trend analysis indicated the existence of a trend ($p = 0.0044$) with a downward slope, ranging from -68 to -20 percent for the period. A significant trend ($p = 0.0001$) occurred in the FWC, where the base and status concentrations decreased from 2.9 mg/l to 1.2 mg/l. After correcting for the effects of flow, the TN FACs indicated a significant ($p < 0.0001$) downward trend. Similar trend results occurred in the inorganic nitrogen fractions (nitrite plus nitrate and ammonia). However, downward trends in organic nitrogen were not detected and a significant ($p = 0.0001$) increasing trend occurred in the FWCs for DON. The slope magnitude ranged from 15 to 38 percent. Overall, the results for TN suggested that some change had taken place, resulting in decreased inputs of nitrogen to the streams upstream of Towanda. Although there was an indication that organic nitrogen could be increasing, this could have been an artifact of flow conditions, as supported by the lack of trend ($p = 0.0717$) in FACs for dissolved organic nitrogen.

The LOAD and FWC analyses for TP did not indicate any significant trends. However, the results on the TP FACs indicated that the sequence of flows at Towanda may have masked changes in LOAD and FWC. A significant ($p=0.0417$) downward trend did occur in the FAC time series. A stronger trend signal was detected in the DP fraction, where trends were detected in the LOAD, FWC, and FAC time series. The time series for DP yields indicated a reduction from 0.21 lb/ac to 0.08 lb/ac, with a significant ($p < 0.0005$) downward trend and a slope ranging from -30 to -70 percent. The FWC record also showed a significant ($p = 0.0001$) downward trend, with the slope magnitude from -29 to -40 percent. Although there was not a significant trend in flow, the significant downward trends in LOAD and FWC could be influenced by dilution from higher flows towards the end of the flow time series. However, the analysis of the FACs indicated a significant ($p < 0.0001$) downward trend of -37 to -65 percent in DP, once the effects of flow were removed. This suggested that some process had occurred, resulting in reduced DP in the river, but that the change was not apparent in TP. Although the TP did show a trend in the FACs, the dissolved fraction could have influenced that trend. This may indicate that particulate phosphorus may not have changed significantly.

The transport characteristics of SS were similar to those of phosphorus, namely particulate phosphorus; therefore, one would expect the trend results for SS to behave similar to that of TP. Because the phosphorus trend results supported the hypothesis that particulate phosphorus may not have changed during the period, the same could have occured in the SS record. SS LOAD and FWC decreased from 152 lb/ac and 85 mg/l to 63 lb/ac and 36 mg/l, respectively. However, trend analyses did not show the existence of a trend for LOAD ($p = 0.5232$) or FWC ($p = 0.9622$). After removing the effect of flow on the concentration, the analysis of FAC indicated a nonsignificant ($p = 0.0520$) trend. These results suggested that the process of sediment delivery and transport in the Susquehanna watershed, upstream of Towanda, had not changed sufficiently to cause a trend in the delivery of SS.

Susquehanna River at Danville, Pa.

Table 20 shows the results for the Susquehanna River at Danville. While the status discharge (13,825 cfs) was higher than the base discharge (12,010 cfs), the test on the FLOWs did not detect ($p = 0.9500$) a trend in the discharge time series.

The transport record (LOAD) for TN shows a decrease from a base yield of 5.6 lb/ac to a status yield of 4.4 lb/ac. However, the trend analysis did not indicate the existence of a trend ($p = 0.1254$). The FWC results were inconclusive, where the base and status monthly mean concentrations decreased from 2.5 mg/l to 1.5 mg/l, respectively. However, the results for TN FACs indicated a significant ($p < 0.0001$) downward trend, with a slope magnitude between 22 to -35 percent. This suggested that some change had taken place, resulting in decreased

Table 20. Trend Statistics for the Susquehanna River at Danville, Pa., January 1985 Through December 1999

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.9500	-30	40	NS	12,010.00	13,825.00
TN	FAC	0.0000	-35	-22	DN	-	-
TN	FWC	0.0001	-	-	I	2.45	1.47
TN	LOAD	0.1254	-48	8	NS	5.64	4.35
DN	FAC	0.0000	-30	-15	DN	-	-
DN	FWC	0.0001	-	-	I	2.26	1.29
DN	LOAD	0.1953	-46	13	NS	4.87	3.81
TON	FAC	0.0000	-48	-24	DN	-	-
TON	FWC	0.0001	-39	-25	DN	1.15	0.55
TON	LOAD	0.0390	-55	-2	NS	2.48	1.47
DON	FAC	0.0044	-33	-7	DN	-	-
DON	FWC	0.0004	-	-	I	0.74	0.39
DON	LOAD	0.2276	-46	16	NS	1.65	1.17
DNH	FAC	0.0000	-62	-43	DN	-	-
DNH	FWC	0.0001	-	-	I	0.18	0.05
DNH	LOAD	0.0001	-68	-32	DN	0.35	0.13
TNH	FAC				BMDL	-	-
TNH	FWC	0.0001	-63	-54	DN	0.21	0.05
TNH	LOAD	0.0001	-73	-38	DN	0.38	0.12
DKN	FAC	0.0000	-46	-25	DN	-	-
DKN	FWC	0.0001	-43	-27	DN	0.89	0.39
DKN	LOAD	0.0257	-57	-6	NS	2.03	1.26
TKN	FAC	0.0000	-48	-27	DN	-	-
TKN	FWC	0.0001	-40	-27	DN	1.30	0.61
TKN	LOAD	0.0279	-55	-5	NS	2.83	1.77
TNO23	FAC	0.0002	-24	-8	DN	-	-
TNO23	FWC	0.0003	-	-	I	1.35	0.85
TNO23	LOAD	0.4326	-41	25	NS	2.79	2.28
DNO23	FAC	0.0000	-25	-10	DN	-	-
DNO23	FWC	0.0001	-	-	I	1.36	0.84
DNO23	LOAD	0.3743	-42	22	NS	2.82	2.22
TP	FAC	0.0000	-58	-36	DN	-	-
TP	FWC	0.0001	-49	-32	DN	0.16	0.08
TP	LOAD	0.0223	-63	-8	NS	0.38	0.23
DP	FAC	0.0000	-66	-51	DN	-	-
DP	FWC	0.0001	-	-	I	0.06	0.02
DP	LOAD	0.0001	-70	-36	DN	0.13	0.07
DIP	FAC	0.2390	-11	58	NS	-	-
DIP	FWC	0.3869	-	-	I	0.02	0.01
DIP	LOAD	0.7105	-28	61	NS	0.04	0.04
TOC	FAC	0.0000	-35	-23	DN	-	-
TOC	FWC	0.0001	-31	-18	DN	6.82	3.59
TOC	LOAD	0.1186	-49	8	NS	14.58	10.55
SS	FAC	0.0001	-59	-25	DN	-	-
SS	FWC	0.0149	-64	-11	NS	115.64	33.69
SS	LOAD	0.1418	-74	21	NS	228.00	78.11

*Condition for FWC and FAC is concentration in mg/l; LOAD is yield in lb/ac.

inputs of nitrogen to the streams between Towanda and Danville, but flow conditions from 1985 through 1998 had masked the effects of this change in the LOAD and FWC records.

Trend analysis for phosphorus indicated trends in both the total and dissolved forms. For TP, the results did not indicate a significant ($p = 0.0223$) LOAD trend. However, significant trends did occur in the FWC ($p = 0.0001$) and FAC ($p < 0.0001$) time series. Slope magnitudes for TP, FWC, and FAC were -32 to -49 percent and -36 to -58 percent, respectively. Median monthly concentration changed from a base of 0.16 mg/l to a status of 0.08 mg/l. Trends for DP were significant in the LOAD ($p = 0.0001$) and FAC ($p = 0.0001$) time series. The status yields and concentrations also decreased from the base yields and concentrations. Slope magnitudes ranged from -36 to -70 percent for the LOAD time series and -51 to -66 percent for the FAC time series. No trends were present in DIP. When one considered the TP and DP trend results together, the trends in concentration and transport were not due to a particular sequence of flows. This suggested that some change had taken place, resulting in reduced inputs of phosphorus to the river upstream of Danville.

Analysis for SS did not indicate the presence of trends in LOAD ($p = 0.1418$) or FWC ($p = 0.0149$). After removing the effect of flow on concentration, the analysis of FAC indicated a significant ($p = 0.0001$) downward trend in SS. This trend was not apparent at the Towanda station, 135 miles upstream of the Danville station. These results suggested that the process of sediment delivery and transport in the Susquehanna watershed between Towanda and Danville had changed sufficiently to cause a trend in SS, but that the sequence of flows from January 1985 through December 1999 had masked the effects of this change in the LOAD and FWC time series.

West Branch Susquehanna River at Lewisburg, Pa.

Table 21 shows the results for the West Branch Susquehanna River at Lewisburg. Although the base and status flows indicated a decrease in flow from 9,818 cfs to 8,223 cfs, analysis of the discharge record did not detect ($p = 0.3238$) the presence of a trend in monthly flow from 1985 through 1999.

Analysis of the nitrogen time series indicated the presence of trends in the organic and inorganic fractions. Significant downward trends occurred in the TON LOAD ($p = 0.0009$), FWC ($p = 0.0001$), and FAC ($p<0.0001$), which was a strong indication that organic nitrogen delivered to the river was being reduced.

For the inorganic fraction, FAC trend results indicated that changes occurred in the delivery of nitrite plus nitrate nitrogen, but not in ammonia nitrogen. Significant downward trends occurred in TNH FWC ($p = 0.0001$) and DNH FWC ($p = 0.0001$), but lack of trends in the FACs suggested that the FWC trends are flow-related. The total and dissolved forms of nitrite plus nitrate nitrogen showed downward trends in both the FWC and FAC time series, but not in the LOAD time series (Table 21). The effect of flow was more pronounced on the concentration record (FWC) than the transport record (LOAD), and the FACs suggested a change had taken place reducing nitrite plus nitrate delivery to the river.

Trend analysis results for both TP and DP showed a strong indication that phosphorus delivered to the West Branch Susquehanna River had been reduced. No trends were present in DIP for LOAD and FWC. Because the number of observations below the level of detection exceeded 20 percent (34 percent), an analysis of the FAC trend could not be completed for DIP.

Significant trends for TP occurred in the LOAD ($p = 0.0042$), FWC ($p = 0.0001$), and FAC ($p < 0.0001$) time series. Slope magnitudes for LOAD, FWC, and FAC ranged from -19 to -66 percent, -29 to -44 percent, and -23 to

Table 21. Trend Statistics for the West Branch Susquehanna River at Lewisburg, Pa. January 1985 Through December 1999

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.3238	-41	19	NS	9,817.50	8,222.50
TN	FAC	0.0000	-31	-15	DN	-	-
TN	FWC	0.0001	-	-	I	1.43	1.26
TN	LOAD	0.0166	-54	-8	NS	6.01	2.49
DN	FAC	0.0000	-22	-9	DN	-	-
DN	FWC	0.0001	-16	-13	DN	1.24	1.10
DN	LOAD	0.0485	-48	0	NS	5.14	2.57
TON	FAC	0.0000	-51	-23	DN	-	-
TON	FWC	0.0001	-49	-34	DN	0.65	0.38
TON	LOAD	0.0009	-67	-26	DN	2.97	0.87
DON	FAC	0.0274	-32	-2	DN	-	-
DON	FWC	0.0001	-34	-18	DN	0.43	0.33
DON	LOAD	0.0118	-57	-10	NS	1.92	0.75
DNH	FAC	0.6002	-45	-9	NS	-	-
DNH	FWC	0.0001	-38	-32	DN	0.07	0.04
DNH	LOAD	0.0008	-62	-23	DN	0.28	0.09
TNH	FAC	0.0770	-38	3	NS	-	-
TNH	FWC	0.0001	-29	-22	DN	0.07	0.06
TNH	LOAD	0.0117	-55	-10	NS	0.30	0.11
DKN	FAC				BMDL	-	-
DKN	FWC	0.0002	-33	-12	DN	0.48	0.36
DKN	LOAD	0.0289	-56	-5	NS	2.17	0.84
TKN	FAC	0.0008	-44	-14	DN	-	-
TKN	FWC	0.0001	-44	-26	DN	0.70	0.44
TKN	LOAD	0.0043	-64	-18	DN	3.24	0.99
TNO23	FAC	0.0014	-20	-5	DN	-	-
TNO23	FWC	0.0007	-13	-4	DN	0.75	0.70
TNO23	LOAD	0.1083	-44	6	NS	3.04	1.64
DNO23	FAC	0.0009	-20	-6	DN	-	-
DNO23	FWC	0.0003	-13	-4	DN	0.75	0.70
DNO23	LOAD	0.1033	-44	5	NS	3.03	1.65
TP	FAC	0.0000	-53	-23	DN	-	-
TP	FWC	0.0001	-44	-29	DN	0.07	0.05
TP	LOAD	0.0042	-66	-19	DN	0.27	0.10
DP	FAC	0.0000	-70	-56	DN	-	-
DP	FWC	0.0001	-69	-63	DN	0.04	0.02
DP	LOAD	0.0001	-78	-57	DN	0.17	0.04
DIP	FAC				BMDL	-	-
DIP	FWC	0.8421	-20	32	NS	0.01	0.01
DIP	LOAD	0.3466	-37	17	NS	0.04	0.02
TOC	FAC	0.7477	-13	11	NS	-	-
TOC	FWC	0.1198	-12	1	NS	2.46	2.35
TOC	LOAD	0.2437	-46	17	NS	9.62	5.67
SS	FAC	0.3512	-16	61	NS	-	-
SS	FWC	0.8670	-40	53	NS	33.63	17.91
SS	LOAD	0.5965	-63	78	NS	137.77	43.10

*Condition for FWC and FAC is concentration in mg/l; LOAD is yield in lb/ac.

-53 percent, respectively. TP concentrations and yields from the West Branch Susquehanna River are among the lowest, when compared to the other major subbasins in the study area. Yields changed from a base of 0.27 lb/ac to a status of 0.10 lb/ac. Median monthly concentrations changed from a base of 0.07 mg/l to a status of 0.05 mg/l. As presented in Table 21, the analysis of DP LOAD, FWC, and FAC time series indicated the presence of significant downward trends, with slope magnitudes slightly greater than that for TP. The presence of trends in all three time series for both TP and DP suggested that the trends in transport and concentration were due to a change in the process contributing phosphorus to the West Branch Susquehanna River.

SS base and status yields (LOAD) and concentrations (FWC) showed a reduction (Table 21); however, trend analyses did not show the existence of a trend in LOAD ($p = 0.5965$) or FWC ($p = 0.8670$). After removing the effect of flow on the concentration, the analysis of FAC also indicated no significant ($p = 0.3512$) trend. These results suggested that the process of sediment delivery and transport in the West Branch Susquehanna Subbasin upstream of Lewisburg has remained the same since 1985. Because the subbasin is predominantly forested (approximately 80 percent), sediment production and delivery are very low, as compared to other areas in the Susquehanna River Basin.

Juniata River at Newport, Pa.

Table 22 shows the results for the Juniata River at Newport. The status discharge (3,233 cfs) was higher than the base discharge (2,561 cfs), but the test on the FLOWs did not detect the presence ($p = 0.1218$) of a trend.

Trends were not detected in the LOAD record for TN and DN and its inorganic and organic fractions. However, trends in FWC and FAC were detected in every nitrogen species. Significant downward trends occurred in the TN FWC ($p=0.0001$) and FAC ($p < 0.0001$) time series, with a slope magnitude of -8 to -21 percent and -12 to -23 percent, respectively. The FAC trends in TNO23 and TNH also were significant ($p = 0.0003$ and $p < 0.0001$, respectively).

Although no trend was detected in the TP LOAD time series ($p = 0.0424$), the presence of a downward trend ($p = 0.0001$) was detected in the FWC time series. Once the effect of flow was removed, the FAC time series showed a very significant ($p < 0.0001$) downward trend. The slope magnitudes for TP in the FWC and FAC time series ranged from -44 to -55 percent and -43 to -61 percent, respectively. The analysis of DP FAC time series indicated the presence of a significant ($p < 0.0001$) downward trend. For DIP, no trend was detected in the LOAD or FAC time series and results were inconclusive for the FWC time series.

The SS results in LOAD and FWC did not indicate a significant change (Table 22). However, trend analyses did show the existence of a significant ($p = 0.0004$) downward trend for the FAC time series. The FAC results suggested that the process of sediment delivery in the Juniata River upstream of Newport had changed.

In the Juniata River from 1985 to 1999, there was a strong influence of flow on the transport and concentration time series. With the exception of DIP, every parameter indicated a presence of trend in the FAC record, and most of the concentration (FWC) time series indicated the presence of a trend as well. This indicated that flow variability had a pronounced effect on concentration for the various constituents, and the presence of downward FAC trends was a consequence of some change in the process that supplies nitrogen, phosphorus, organic carbon and SS to the Juniata River. For the 15 parameters tested, trends were not detected in the transport (LOAD) time series, indicating that flow conditions had masked the effect of this change.

Susquehanna River at Marietta, Pa.

The station at Marietta represents the response of the Susquehanna River to the cumulative effects of activities affecting water

Table 22. Trend Statistics for the Juniata River at Newport, Pa., January 1985 Through December 1999

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.1218	-6	79	NS	2,561.00	3,233.00
TN	FAC	0.0000	-23	-12	DN	-	-
TN	FWC	0.0001	-21	-8	DN	2.46	1.73
TN	LOAD	0.6195	-25	63	NS	4.44	4.25
DN	FAC	0.0001	-16	-6	DN	-	-
DN	FWC	0.0006	-14	-4	DN	2.08	1.64
DN	LOAD	0.4040	-19	69	NS	4.02	3.91
TON	FAC	0.0000	-44	-22	DN	-	-
TON	FWC	0.0001	-44	-23	DN	0.90	0.48
TON	LOAD	0.4420	-44	29	NS	1.69	1.18
DON	FAC	0.0223	-25	-2	DN	-	-
DON	FWC	0.0050	-	-	I	0.55	0.40
DON	LOAD	0.8658	-29	51	NS	1.18	0.99
DNH	FAC	0.0000	-64	-43	DN	-	-
DNH	FWC	0.0001	-57	-48	DN	0.07	0.03
DNH	LOAD	0.0180	-59	-8	NS	0.12	0.07
TNH	FAC	0.0000	-59	-35	DN	-	-
TNH	FWC	0.0001	-51	-41	DN	0.08	0.04
TNH	LOAD	0.0818	-53	4	NS	0.13	0.08
DKN	FAC	0.0029	-29	-7	DN	-	-
DKN	FWC	0.0028	-35	-9	DN	0.64	0.43
DKN	LOAD	0.9701	-33	47	NS	1.34	1.08
TKN	FAC	0.0000	-44	-22	DN	-	-
TKN	FWC	0.0001	-44	-21	DN	1.00	0.52
TKN	LOAD	0.4937	-44	32	NS	1.85	1.29
TNO23	FAC	0.0003	-17	-5	DN	-	-
TNO23	FWC	0.0099	-13	-2	DN	1.53	1.24
TNO23	LOAD	0.3559	-18	74	NS	3.00	3.02
DNO23	FAC	0.0047	-14	-3	DN	-	-
DNO23	FWC	0.0746	-11	0	NS	1.47	1.23
DNO23	LOAD	0.2870	-16	78	NS	2.89	3.01
TP	FAC	0.0000	-61	-43	DN	-	-
TP	FWC	0.0001	-55	-44	DN	0.14	0.07
TP	LOAD	0.0424	-57	-2	NS	0.26	0.14
DP	FAC	0.0000	-54	-34	DN	-	-
DP	FWC	0.0001	-	-	I	0.08	0.04
DP	LOAD	0.0304	-49	-4	NS	0.15	0.10
DIP	FAC	0.2313	-13	76	NS	-	-
DIP	FWC	0.7021	-	-	I	0.05	0.04
DIP	LOAD	0.1986	-16	129	NS	0.12	0.10
TOC	FAC	0.0000	-39	-22	DN	-	-
TOC	FWC	0.0001	-36	-25	DN	5.34	3.54
TOC	LOAD	0.5499	-38	29	NS	9.83	7.82
SS	FAC	0.0004	-56	-21	DN	-	-
SS	FWC	0.2855	-48	21	NS	51.27	26.09
SS	LOAD	0.9474	-51	114	NS	83.13	46.05

*Condition for FWC and FAC is concentration in mg/l; LOAD is yield in lb/ac.

quality in the basin before the impact of several reservoirs on the lower reach of the river. Table 2 3 shows the results for the Susquehanna River at Marietta. While the status flow was higher than the base flow (30,700 cfs vs. 22,330 cfs), the test on the FLOWs did not detect ($p = 0.9135$) a trend in the discharge time series.

For the period 1987 to 1999, there was a significant ($p < 0.0001$) downward trend in the TN FACs, suggesting that improving water quality conditions were not flow-related, but were a consequence of some change in the process delivering nitrogen to the Susquehanna River.

Although the overall trend was improving for TN, there were opposing trends in the inorganic and organic fractions of nitrogen. The major fraction of TN is the inorganic species, nitrite plus nitrate nitrogen and ammonia nitrogen. Both the TNO23 and DNO23 monthly median concentrations (FWC) showed significant downward trends ($p = 0.0001$ and $p = 0.0001$, repectively). As presented in the base and status flow conditions, higher flows toward the end of the period may have caused a dilutional effect on the FWCs. However, a significant ($p < 0.0314$) downward trend (-1 to -17 percent) in the TNO23 FAC time series occurred indicating that some process other than flow caused this downward trend. Downward trends also were detected in the TNH, DNH, FWC, and FAC record (Table 23).

Conversely, the significant trend results for TON LOAD ($p = 0.0010$), FWC ($p = 0.0001$), and FAC ($p < 0.0001$) indicated strong increasing trends, with slopes of 39 to 244, 84 to 149, and 59 to 145 percent, respectively. This same trend pattern also was detected in DON (Table 23). Although the major fraction of TN was the inorganic species, the increasing trends in organic nitrogen could have reversed the direction for TN. What was not clear was if the opposing trends were due to instream processing of inorganic nitrogen, to organic nitrogen or if the delivery of organic nitrogen to the river had increased. The significant upward trends in the organic nitrogen LOAD record suggested a transport and delivery mechanism.

For TP and DP, a small change occurred in base and status yield, but the trend analysis did not indicate ($p = 0.3572$ and $p = 0.0542$, respectively) the presence of a trend in LOAD. However, trends were detected in the FWC and FAC records. Significant trends occurred in TP FWC ($p = 0.0037$) and FAC ($p = 0.0001$) records, with downward slopes of –8 to –35 and –18 to -43 percent, respectively. For DP, a significant ($p = 0.0001$) downward trend (-27 to -37 percent) occurred in the FWC record. A significant ($p < 0.0001$) downward trend (-23 to -45 percent) also occurred in the FAC record.

Analysis of DIP time series indicated significant upward trends in LOAD ($p = 0.0001$) and FWC ($p = 0.0001$). Because 25 percent of the observations were below the detection level, an analysis of the FAC trend could not be completed for DIP. Although the corresponding DIP LOAD and FWC slope magnitudes were very large, the overall trends in TP and DP were downward. The strong presence of trends in the TP and DP FAC time series indicated that there was a change in the process contributing phosphorus to the Susquehanna River, and that the lack of trend in the LOAD and FWC may have been due to a particular sequence of flows. Trends in the TP and DP FWC record indicated that flow variability had a pronounced effect on concentration, and the presence of downward FAC trends were indications of changes in the delivery processes that supply phosphorus to the river.

SS base and status yields for LOAD showed an increase, while concentrations for FWC decreased (Table 23). Trend analyses indicated a lack of trend in LOAD ($p = 0.8999$) and in FWC ($p = 0.8935$). After removing the effect of flow on the concentration, the analysis of FAC showed no trend ($p = 0.2605$). These results suggested that the process of sediment delivery and transport, as recorded on the Susquehanna River at Marietta from 1987 to 1999, had not significantly changed; therefore, no trend was detected.

Table 23. Trend Statistics for the Susquehanna River at Marietta, Pa., January 1987 Through December 1999

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.9135	-29	46	NS	22,330.00	30,700.00
TN	FAC	0.0000	-29	-16	DN	-	-
TN	FWC	0.0001	-26	-18	DN	2.68	1.39
TN	LOAD	0.2636	-47	19	NS	5.24	4.20
DN	FAC	0.0030	-19	-4	DN	-	-
DN	FWC	0.0001	-15	-9	DN	2.16	1.28
DN	LOAD	0.5685	-39	31	NS	4.41	3.71
TON	FAC	0.0000	59	145	UP	-	-
TON	FWC	0.0001	84	149	UP	0.79	0.82
TON	LOAD	0.0010	39	244	UP	1.80	3.35
DON	FAC	0.0000	281	512	UP	-	-
DON	FWC	0.0001	340	510	UP	0.44	0.93
DON	LOAD	0.0001	245	709	UP	0.95	3.72
DNH	FAC	0.0000	-53	-28	DN	-	-
DNH	FWC	0.0001	-44	-37	DN	0.09	0.05
DNH	LOAD	0.0133	-60	-10	NS	0.19	0.09
TNH	FAC	0.0000	-50	-24	DN	-	-
TNH	FWC	0.0001	-40	-32	DN	0.08	0.05
TNH	LOAD	0.0441	-57	-1	NS	0.19	0.09
DKN	FAC	0.1948	-24	6	NS	-	-
DKN	FWC	0.6432	-14	9	NS	0.56	0.40
DKN	LOAD	0.9667	-32	44	NS	1.16	1.14
TKN	FAC	0.0000	-46	-22	DN	-	-
TKN	FWC	0.0001	-36	-18	DN	0.88	0.52
TKN	LOAD	0.1700	-52	14	NS	2.12	1.65
TNO23	FAC	0.0314	-17	-1	DN	-	-
TNO23	FWC	0.0001	-19	-8	DN	1.52	1.04
TNO23	LOAD	0.5544	-41	33	NS	3.16	2.70
DNO23	FAC	0.0559	-16	0	NS	-	-
DNO23	FWC	0.0001	-17	-7	DN	1.50	1.03
DNO23	LOAD	0.5931	-41	35	NS	3.15	2.68
TP	FAC	0.0001	-43	-18	DN	-	-
TP	FWC	0.0037	-35	-8	DN	0.11	0.06
TP	LOAD	0.3572	-53	31	NS	0.24	0.21
DP	FAC	0.0000	-45	-23	DN	-	-
DP	FWC	0.0001	-37	-27	DN	0.06	0.03
DP	LOAD	0.0542	-52	0	NS	0.12	0.09
DIP	FAC				BMDL	-	-
DIP	FWC	0.0001	192	392	UP	0.01	0.01
DIP	LOAD	0.0001	142	519	UP	0.02	0.05
TOC	FAC	0.0046	-18	-4	DN	-	-
TOC	FWC	0.0411	-12	0	NS	4.47	3.31
TOC	LOAD	0.8189	-35	41	NS	9.72	9.85
SS	FAC	0.2605	-32	11	NS	-	-
SS	FWC	0.8935	-36	66	NS	50.40	25.55
SS	LOAD	0.8999	-53	138	NS	110.31	123.85

*Condition for FWC and FAC is concentration in mg/l; LOAD is yield in lb/ac.

Conestoga River at Conestoga, Pa.

Table 24 shows the trend results for the Conestoga River at Conestoga. Although the base and status flows indicated an increase in flow from 473 cfs to 596 cfs, an analysis of the discharge record did not detect ($p = 0.7892$) the presence of a trend in the FLOWs.

A significant downward trend of –10 to -19 percent was detected in TN FACs ($p < 0.0001$). No trend was detected in the TN LOAD record and the result was inconclusive in the FWC record. Results from the DN analysis did not detect the presence of any trends. In the nitrogen data set, several more trends were detected in the total species fraction than in the dissolved species fraction, suggesting that particulate forms play an important role in the delivery of nitrogen in the Conestoga River. In fact, for the dissolved fraction, significant trends only were detected in DNH for LOAD ($p = 0.0001$), FWC ($p = 0.0001$), and FAC ($p < 0.0001$), which may have been due to an upgrade in a regional wastewater treatment plant in the City of Lancaster. The lack of any trends in nitrite plus nitrate nitrogen indicates that the downward trend in TN was influenced by the improving conditions in ammonia and TON.

For TP, significant trends occurred in the FAC ($p < 0.0001$) time series, but not in LOAD ($p = 0.1177$). The TP FWC results were inconclusive. As presented in Table 24, the analysis of DP and DIP LOAD, FWC, and FAC time series indicated the presence of significant downward trends, with moderate slope magnitudes. The strong presence of trends in the dissolved species of phosphorus suggested that the trends in transport and concentration were due to a change in the process contributing phosphorus to the Conestoga River. Ott (1991) demonstrated that a step change in phosphorus load occurred during the period 1985 to 1989, when the phosphorus load showed a decrease in 1988 and 1989. The step change occurred between May and June 1988 in the monthly base flow phosphorus concentrations, when a new regional sewage treatment plant (STP) came online. Ott (1991) also stated that the STP reduction in 1989 accounted for only part of the 1989 phosphorus reductions monitored at the Conestoga River station, suggesting that remaining reductions were from agricultural best management practices**.**

SS trend results did not show the existence of a trend for LOAD ($p = 0.0641$), but a trend in FWCs ($p = 0.0030$) was detected. After removing the effect of flow, the analysis of FAC indicated a significant ($p < 0.0001$) downward trend. These results suggested that flow affects the concentration record more than the transport record. The FAC results suggested a nonflow-related reduction in the delivery of sediment to the river, but that flow conditions had masked the effect of this change in the transport record.

Discussion

For many water quality constituents, the concentration is often related to streamflow. This relationship varies from stream to stream and can be very complex. In point-source-dominated watersheds, any increases in streamflow may tend to dilute constituent concentrations (i.e. nitrogen and phosphorus concentrations would decrease). However, large precipitation events in a watershed may cause erosion, transport and delivery of organic matter, sediment, and chemicals that have a high affinity for fine particles. Thus, increasing concentration may be associated with increasing streamflows. The dilution and erosion processes in a watershed can vary over time as land-use practices change. Therefore, the changes in concentration (FWC) and transport (LOAD) to the stream should be monitored. However, one also would want to determine if there was a change in the processes that cause a constituent to enter the stream system. The FAC approach is applied to help identify changes in processes. These processes include those affected by the implementation of management actions recommended by the Chesapeake Bay Program.

Table 24. Trend Statistics for the Conestoga River at Conestoga, Pa., January 1985 Through December 1999

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.7892	-21	36	NS	472.50	596.35
TN	FAC	0.0000	-19	-10	DN	-	-
TN	FWC	0.0001			I	12.13	5.97
TN	LOAD	0.3788	-31	15	NS	28.11	25.60
DN	FAC	0.6112	-4	7	NS	-	-
DN	FWC	0.6873	-3	5	NS	9.84	6.10
DN	LOAD	0.6954	-17	32	NS	23.07	24.55
TON	FAC	0.0003	-36	-13	DN	-	-
TON	FWC	0.0004	-35	-12	DN	2.55	1.06
TON	LOAD	0.2399	-47	17	NS	6.28	4.97
DON	FAC	0.1358	-4	32	NS	-	-
DON	FWC	0.0233	2	28	NS	1.46	0.91
DON	LOAD	0.2928	-14	63	NS	3.70	4.05
DNH	FAC	0.0000	-76	-65	DN	-	-
DNH	FWC	0.0001	-74	-67	DN	0.36	0.09
DNH	LOAD	0.0001	-79	-56	DN	0.93	0.26
TNH	FAC	0.0000	-76	-64	DN	-	-
TNH	FWC	0.0001	-74	-67	DN	0.37	0.09
TNH	LOAD	0.0001	-79	-56	DN	0.95	0.28
DKN	FAC	0.1067	-22	2	NS	-	-
DKN	FWC	0.1190	-20	3	NS	1.94	0.97
DKN	LOAD	0.6965	-32	29	NS	5.04	4.18
TKN	FAC	0.0000	-48	-30	DN	-	-
TKN	FWC	0.0001	-48	-28	DN	3.13	1.16
TKN	LOAD	0.0269	-57	-5	NS	8.13	5.01
TNO23	FAC	0.3124	-3	11	NS	-	-
TNO23	FWC	0.3814	-3	8	NS	7.86	5.16
TNO23	LOAD	0.6061	-16	34	NS	18.83	21.87
DNO23	FAC	0.5508	-5	10	NS	-	-
DNO23	FWC	0.7426	-5	7	NS	7.66	5.03
DNO23	LOAD	0.6864	-16	31	NS	18.56	21.00
TP	FAC	0.0000	-41	-19	DN	-	-
TP	FWC	0.0001			I	0.84	0.28
TP	LOAD	0.1177	-52	8	NS	1.68	1.26
DP	FAC	0.0000	-50	-40	DN	-	-
DP	FWC	0.0001	-47	-42	DN	0.39	0.14
DP	LOAD	0.0003	-57	-23	DN	0.88	0.55
DIP	FAC	0.0000	-52	-35	DN	-	-
DIP	FWC	0.0001	-48	-40	DN	0.32	0.13
DIP	LOAD	0.0002	-57	-23	DN	0.77	0.46
TOC	FAC	0.0000	-57	-47	DN	-	-
TOC	FWC	0.0001	-57	-47	DN	12.61	3.58
TOC	LOAD	0.0001	-65	-30	DN	31.12	16.13
SS	FAC	0.0000	-58	-32	DN	-	-
SS	FWC	0.0030	-71	-23	DN	185.08	63.78
SS	LOAD	0.0641	-77	4	NS	484.53	281.97

*Condition for FWC and FAC is concentration in mg/l; LOAD is yield in lb/ac.

The LOAD, FWC, FAC, and Q time series each represent separate ways of evaluating stream water quality. Comparing the results together can enhance our understanding of changes that occurred. For the six stations evaluated for trends in the Susquehanna River Basin, the FACs generally indicated that there was a downward (improving) trend in TN, TP, and SS. Activities that change the delivery of nutrients and sediment, such as phosphate detergent bans, erosion and sedimentation control, nutrient reductions from agricultural management practices, and point-source loading rates, contributed to these changes.

While the trend results do not point to a specific cause of a change in stream quality, they can indicate that changes have occurred in the processes that deliver nutrients and sediment to the river. This should lead the investigator to identify activities in the watershed that can lead to these changes.

The pattern of trends in the Conestoga River suggested that management activities related to nonpoint erosion, transport and delivery processes, along with pointsource inputs, play an important role in the reduction of nutrients and sediment in the watershed. Strong downward trends in organic carbon suggested that nonpoint management practices may be contributing to reduction of organic material being delivered to the stream. Comparisons of the trends in the TN and DN species suggested that particulate forms greatly affect TN trends. The strong presence of downward LOAD, FWC, and FAC trends in dissolved forms of phosphorus and DNH coincided with new regional STP that began operating in the City of Lancaster.

SS trends varied regionally. Trends did not occur from the drainage areas upstream of Towanda and Lewisburg. For Towanda, the lack of trend might be expected because the watershed is characterized by post-glacial, unconsolidated material that is easily eroded. The predominantly forested area within the West Branch Susquehanna River Watershed, upstream of Lewisburg, lends itself to low sediment yields and little change over the last 15 years. The lack of sediment trends at Marietta from 1987 to 1999 may be a sign of progress, given that the lower Susquehanna River Basin contains the largest area of agricultural activity and urban growth within the basin.

Overall, the trend analyses indicated improving conditions for TN and TP throughout the Susquehanna River Basin. Improving conditions for SS occurred at three of the six stations in the basin. The results of the FAC trends indicated that the improving water quality conditions were from changes in the processes that deliver nutrients and sediment to the streams and rivers of the Susquehanna River Basin, and that these reductions were from the implementation of management actions.

SUMMARY

Nutrient and SS samples were collected during baseflow and stormflow in calendar year 1999. The samples were collected from the Susquehanna River at Towanda, Danville, and Marietta, the West Branch Susquehanna River at Lewisburg, the Juniata River at Newport, and the Conestoga River at Conestoga, Pennsylvania.

Annual precipitation was below normal in 1999 in all areas, except the Conestoga River Watershed. Rainfall ranged from 12.56 inches below normal in the Juniata River above Newport to 1.59 inches above normal in the Conestoga River Watershed. Water discharges ranged from 69.5 to 86.9 percent of long-term mean discharges.

Annual loads of TN, TP, and SS were highest in the Susquehanna River at Marietta, followed by the Susquehanna River at Danville. The Conestoga River at Conestoga had the smallest loads of TN, TP, and SS, but had the highest yields, in lb/ac/yr, of TN, TP, and SS. The TN yield from the Susquehanna River at Danville, with 59.8 percent forest and 26.9 percent agriculture, was greater than from the West Branch Susquehanna River at Lewisburg, with 81 percent forest and 13.9 percent agriculture.

Seasonal mean water discharges in 1999 were highest in the winter (January-March), followed by spring (April-June), then fall (July-September) at Towanda, Lewisburg, Newport and Marietta. Seasonal discharges at Danville were highest in the winter, followed by fall, then spring, while at Conestoga, the highest discharge occurred in the winter, followed by fall, then summer and spring. Seasonal variation of TN corresponded with seasonal discharge at all sites. Seasonal variation of TP and SS generally corresponded with seasonal discharge at most sites.

Comparison of seasonal yields among the Susquehanna River monitoring sites indicated that the long-term TN yields in the Susquehanna River at Towanda, Danville, and Marietta increased in the downstream order for all seasons. The 1999 TN yields showed the same relationship among the sites in the winter, spring, and summer. TN yields in the fall increased between Towanda and Danville and decreased between Danville and Marietta. The long-term and 1999 TP yields did not show any consistent pattern among the Susquehanna River sites. The long-term SS yields at Towanda, Danville and Marietta decreased in the downstream order, but the 1999 seasonal yields did not show any consistent relationships among the sites. Comparison of long-term and 1999 seasonal yields among the tributary sites at Lewisburg, Newport and Conestoga indicated that the TN and TP yields were smallest at Lewisburg for all seasons. The long-term SS seasonal yields indicated that Newport normally had the smallest yield among the tributary sites in the winter, spring, and fall, and that Lewisburg had the smallest yield in the summer. The relationships of the 1999 SS yields among the tributary sites were not consistent with the long-term yields.

Comparison of the 1999 annual yields and the 5-year baselines indicates that there were significant decreases of TN at all sites. TP yields were significantly lower than the baseline yields at Danville, Lewisburg, Newport, and Marietta. The 1999 TP yield at Towanda showed no change from the baseline. TP increased at Conestoga, but this increase may not be significant. Comparisons of SS yields indicated that there was a significant increase at Towanda and a significant decrease at Danville. There were no changes in the yield at Newport, Marietta, and Conestoga. The SS data suggested that there was an increase in yield at Lewisburg, but this change may not be significant because of an overlap in the margin of errors.

Trends were computed for the period January 1985 to December 1999 for TN and DN, TON, DON, TNH and DNH, TKN and DKN, TNO23 and DNO23, TP and DP, DIP, TOC, and SS. Linear regression techniques and the USGS estimator model were used to estimate the direction and magnitude of trends in water quality. Analyses for trend were performed on the FLOW, LOAD, FWC, and FAC.

Trends in FLOW indicated the natural changes in hydrology. Changes in flow and the cumulative sources of flow (baseflow and over land runoff) affect the observed concentrations and the estimated loads of nutrients and SS. Trends in LOAD indicate the flux of constituents through the system or rates of output. When loads are expressed as yields (load per unit area), the rates of output among watersheds can be compared. Trends in FWC indicate changes in stream quality over the period being investigated. The FWC indicates an average monthly concentration, rather than a single observed concentration, and is more representative of monthly stream quality conditions. This is the concentration that affects the biological processes of the stream. Trends in FAC indicate that changes have occurred in the processes that deliver constituents to the stream system. After the effects of flow are removed, this is the concentration that relates to the implementation of nutrient reduction activities and other actions taking place in the watershed. Trends in FLOW, LOAD, FWC, and FAC represent four diverse approaches to evaluating stream quality. While each trend will not reveal the specific cause of water quality changes, the combined information can improve our understanding of the causes influencing water quality trends.

The trend analyses indicated improving conditions in TN and TP throughout the Susquehanna River Basin. Improving conditions in SS occurred at three of the six stations in the basin. The results of the FAC trends indicated that the improving water quality conditions were from changes in the processes that deliver nutrients and SS to the streams and rivers of the Susquehanna River Basin.

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