NUTRIENTS AND SUSPENDED SEDIMENT TRANSPORTED IN THE SUSQUEHANNA RIVER BASIN, 2000, AND TRENDS, JANUARY 1985 THROUGH DECEMBER 2000

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**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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ABSTRACT

Nutrient and suspended-sediment samples were collected in calendar year 2000 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 2000 yields and the 5-year baseline yields indicates that total nitrogen loads decreased at all of the monitoring sites. Total phosphorus loads increased at four sites and remained the same at two sites. Suspended-sediment loads increased at one site, decreased at another, and remained the same at four sites.

Trends were computed for the period January 1985 through December 2000 for flow, suspended sediment, total organic carbon, and several forms of the nutrients, nitrogen and phosphorus. 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) 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, 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 2000, 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 through December 2000 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

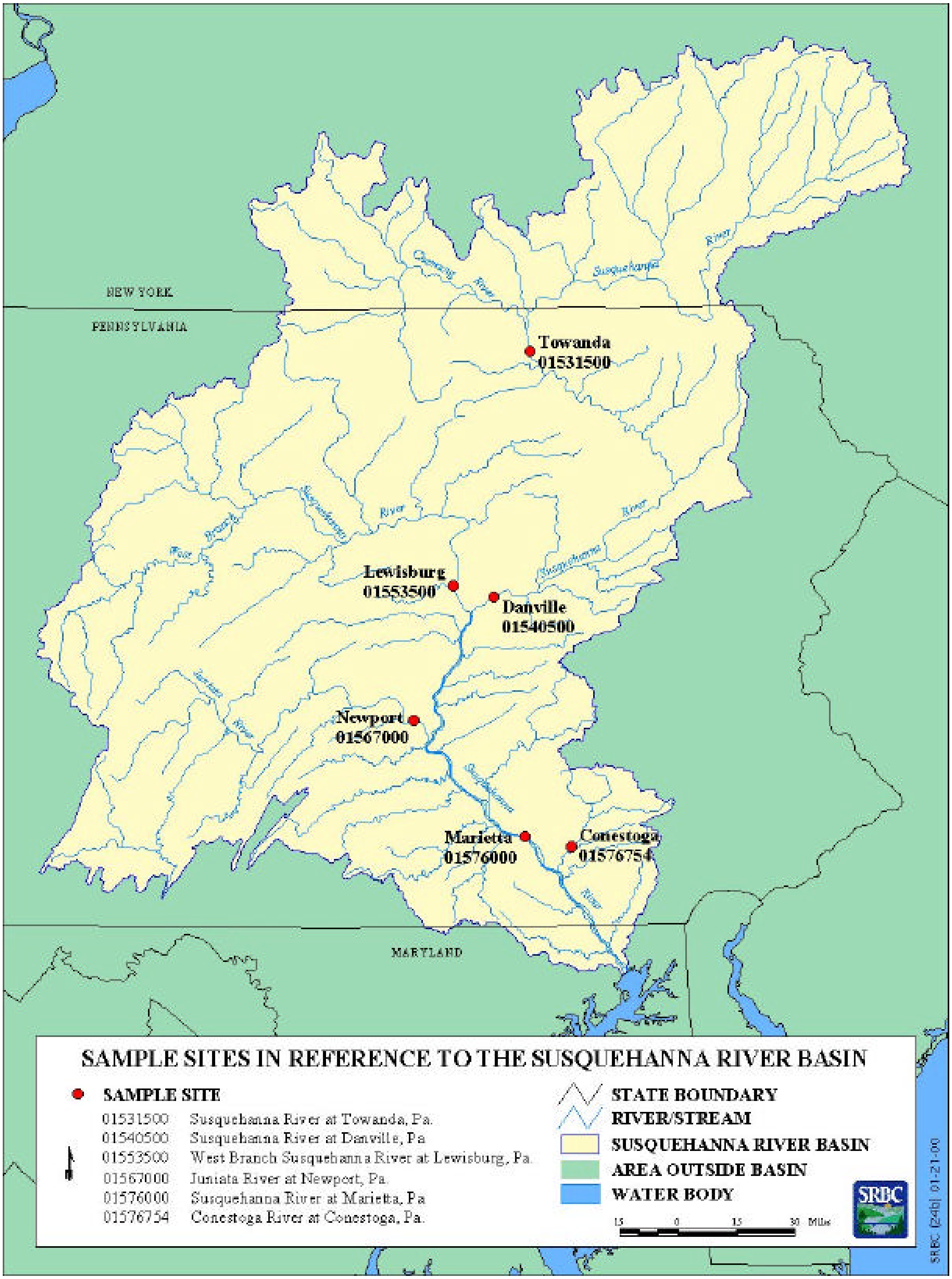


Figure 2. Locations of Sampling Sites on the Susquehanna River and Three Major Tributaries in the Basin

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. One major rainfall event 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 prestorm 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 2000 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 2000 annual precipitation was greater than the long-term annual average in the Towanda, Danville, Marietta, and Conestoga Watersheds and less than the long-term average in the West Branch Susquehanna and Juniata Subbasins. Precipitation ranged from 14.58 inches below normal in the Juniata Subbasin to 4.45 inches above normal in the watershed above Towanda. Seasonal precipitation was above normal during the winter and spring and below normal during the summer and fall in nearly all watersheds. Precipitation in the Juniata Subbasin above Newport was below normal 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 2000***

Area	Season	Average Long-Term Precipitation inches	Calendar Year 1999 Precipitation inches
Susquehanna River above Towanda, Pa.	January-March	7.97	8.64
	April-June	9.99	16.30
	July-September	10.22	8.89
	October-December	8.73	7.55
	Yearly Total	**36.91**	**41.38**
Susquehanna River above Danville, Pa.	January-March	7.91	8.68
	April-June	10.09	15.83
	July-September	10.36	9.02
	October-December	8.75	7.41
	Yearly Total	**37.11**	**40.94**
West Branch Susquehanna River above Lewisburg, Pa.	January-March	8.94	7.73
	April-June	11.42	14.31
	July-September	11.54	8.68
	October-December	9.43	6.72
	Yearly Total	**41.33**	**37.44**
Juniata River above Newport, Pa.	January-March	8.91	5.10
	April-June	11.01	9.50
	July-September	10.92	6.03
	October-December	9.16	4.79
	Yearly Total	**40.00**	**25.42**
Susquehanna River above Marietta, Pa.	January-March	8.53	8.65
	April-June	10.68	14.34
	July-September	10.77	9.63
	October-December	9.05	6.88
	Yearly Total	**39.03**	**39.50**
Conestoga River above Conestoga, Pa.	January-March	8.60	10.77
	April-June	10.85	11.96
	July-September	11.84	11.83
	October-December	9.43	6.80
	Yearly Total	**40.72**	**41.36**

WATER DISCHARGE

Mean water discharges for calendar year 2000 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 above normal at Towanda and Danville and below normal at Lewisburg, Newport, Marietta, and Conestoga. Streamflow ranged from 75.5 percent of normal at Newport to 120.6 percent of normal at Towanda.

Table 4. Annual Water Discharge, Calendar Year 2000

Site Short Name	**Years of Record**	**Long-term Annual Mean cfs[1]**	**2000 Mean cfs**	**2000 Percent of Long-Term Mean**
Towanda	87	10,700	12,900	120.6
Danville	96	15,300	18,100	118.3
Lewisburg	61	10,900	8,530	78.3
Newport	28	4,530	3,420	75.5
Marietta	69	37,200	36,100	97.0
Conestoga	16	699	608	87.0

[1] Cubic feet per second

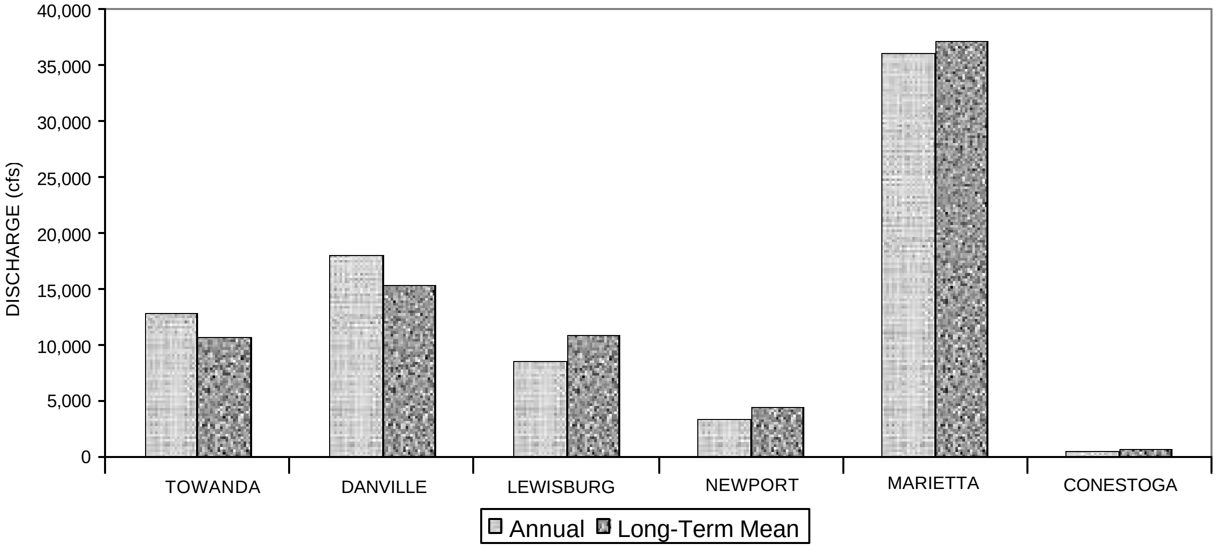


Figure 3. Annual and Long-Term Mean Water Discharge at Towanda, Danville, Lewisburg, Marietta, and Conestoga, Pa., Calendar Year 2000

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 2000 and the long-term mean annual loads and yields of TN are shown in Figures 4A and 4B, respectively.

The 2000 annual loads and yields of TN were greater than the long-term mean at Towanda and Danville and smaller than the long-term mean at Lewisburg, Newport, Marietta, and Conestoga. 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, 30.20 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 2000 annual loads and yields of TP were greater than the long-term mean loads and yields at Towanda, Danville, Newport, Marietta, and Conestoga, as illustrated in Figures 5A and 5B, respectively. The annual TP load was greatest at Marietta, followed by Danville, and the smallest annual TP load was measured at Conestoga. The greatest yield of TP occurred at Conestoga, followed by Towanda.

The annual loads and yields of SS are illustrated in Figures 6A and 6B, respectively. The 2000 loads and yields were greater than the respective long-term mean loads and yields at Towanda, Danville, Marietta, and Conestoga, and smaller at Lewisburg and Newport. 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 2000

Site Short Name	Annual Discharge	Total Nitrogen as N		
		2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	30,900	3.43	6.19
Danville	18,100	47,600	3.86	6.64
Lewisburg	8,530	15,700	4.66	3.58
Newport	3,420	11,100	3.15	5.16
Marietta	36,100	115,000	3.69	6.88
Conestoga	608	9,080	2.89	30.20

Table 6. Annual Water Discharges and Annual Loads and Yields of Total Phosphorus, Calendar Year 2000

Site Short Name	Annual Discharge	Total Phosphorus as P		
		2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	3,010	10.7	0.60
Danville	18,100	3,980	10.61	0.55
Lewisburg	8,530	940	12.53	0.21
Newport	3,420	811	11.64	0.38
Marietta	36,100	9,420	9.28	0.57
Conestoga	608	722	23.37	2.40

Table 7. Annual Water Discharges and Annual Loads and Yields of Suspended Sediment, Calendar Year 2000

Site Short Name	Annual Discharge	Suspended Sediment		
		2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	2,590,000	25.86	518.85
Danville	18,100	2,770,000	20.78	385.50
Lewisburg	8,530	607,000	25.46	138.61
Newport	3,420	311,000	25.33	145.04
Marietta	36,100	6,230,000	15.44	374.35
Conestoga	608	397,000	71.75	1,320.44

Table 8. Annual Water Discharges and Annual Loads and Yields of Total Ammonia, Calendar Year 2000

Site Short Name	Annual Discharge	Total Ammonia as N		
		2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	1,340	10.77	0.27
Danville	18,100	1,760	11.17	0.24
Lewisburg	8,530	705	11.87	0.16
Newport	3,420	201	13.38	0.09
Marietta	36,100	3,140	10.75	0.19
Conestoga	608	120	18.89	0.40

Table 9. Annual Water Discharges and Annual Loads and Yields of Total Nitrite Plus Nitrate Nitrogen, Calendar Year 2000

Site Short Name	Annual Discharge	Total Nitrite Plus Nitrate as N		
		2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	16,100	4.22	3.23
Danville	18,100	27,100	4.18	3.78
Lewisburg	8,530	9,270	4.08	2.12
Newport	3,420	7,580	3.28	3.53
Marietta	36,100	70,500	3.93	4.24
Conestoga	608	7,070	3.84	23.51

Table 10. Annual Water Discharges and Annual Loads and Yields of Total Organic Nitrogen, Calendar Year 2000

Site Short Name	Annual Discharge	Total Organic Nitrogen as N		
		2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	14,500	7.08	2.91
Danville	18,100	20,600	7.61	2.87
Lewisburg	8,530	6,510	10.80	1.49
Newport	3,420	3,500	7.88	1.63
Marietta	36,100	58,700	9.84	3.53
Conestoga	608	2,100	16.43	6.97

Table 11. Annual Water Discharges and Annual Loads and Yields of Dissolved Phosphorus, Calendar Year 2000

Site Short Name	Annual Discharge	Dissolved Phosphorus as P 2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	1,110	8.22	0.22
Danville	18,100	1,220	9.24	0.17
Lewisburg	8,530	405	9.11	0.09
Newport	3,420	517	10.99	0.24
Marietta	36,100	4,100	7.96	0.25
Conestoga	608	255	7.29	0.85

Table 12. Annual Water Discharges and Loads and Yields of Dissolved Orthophosphate, Calendar Year 2000

Site Short Name	Annual Discharge	Dissolved Orthophosphate as P 2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	1,150	15.37	0.23
Danville	18,100	1,360	15.85	0.19
Lewisburg	8,530	460	17.71	0.11
Newport	3,420	610	20.99	0.28
Marietta	36,100	6,260	16.78	0.38
Conestoga	608	275	10.66	0.91

Table 13. Annual Water Discharges and Annual Loads and Yields of Dissolved Ammonia, Calendar Year 2000

Site Short Name	Annual Discharge	Dissolved Ammonia as N 2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	1,330	10.26	0.27
Danville	18,100	1,930	10.54	0.27
Lewisburg	8,530	733	10.57	0.17
Newport	3,420	224	12.09	0.10
Marietta	36,100	3,440	9.68	0.21
Conestoga	608	122	18.14	0.40

Table 14. Annual Water Discharges and Annual Loads and Yields of Dissolved Nitrogen, Calendar Year 2000

Site Short Name	Annual Discharge	Dissolved Nitrogen as N 2000 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	28,300	3.62	5.68
Danville	18,100	44,200	4.09	6.15
Lewisburg	8,530	14,800	3.77	3.38
Newport	3,420	10,500	2.82	4.88
Marietta	36,100	102,000	3.62	6.16
Conestoga	608	8,310	3.19	27.61

Table 15. Annual Water Discharges and Annual Loads and Yields of Dissolved Nitrite Plus Nitrate Nitrogen, Calendar Year 2000

Site Short Name	Annual Discharge	Dissolved Nitrite Plus Nitrate Nitrogen as N 2000 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	16,000	4.16	3.20
Danville	18,100	27,200	4.27	3.79
Lewisburg	8,530	9,220	4.00	2.11
Newport	3,420	7,610	3.29	3.54
Marietta	36,100	70,600	4.02	4.25
Conestoga	608	6,950	4.03	23.11

Table 16. Annual Water Discharges and Annual Loads and Yields of Dissolved Organic Nitrogen, Calendar Year 2000

Site Short Name	Annual Discharge	Dissolved Organic Nitrogen as N 2000 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	11,600	7.27	2.32
Danville	18,100	15,500	6.39	2.17
Lewisburg	8,530	5,280	7.97	1.21
Newport	3,420	2,740	5.75	1.28
Marietta	36,100	58,700	9.84	3.53
Conestoga	608	1,420	13.94	4.72

Table 17. Annual Water Discharges and Annual Loads and Yields of Total Organic Carbon, Calendar Year 2000

Site Short Name	Annual Discharge	Total Organic Carbon 2000		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	12,900	91,100	3.35	18.27
Danville	18,100	129,000	3.64	17.92
Lewisburg	8,530	33,900	4.35	7.75
Newport	3,420	20,400	4.25	9.50
Marietta	36,100	235,000	3.30	14.11
Conestoga	608	6,430	6.59	21.37

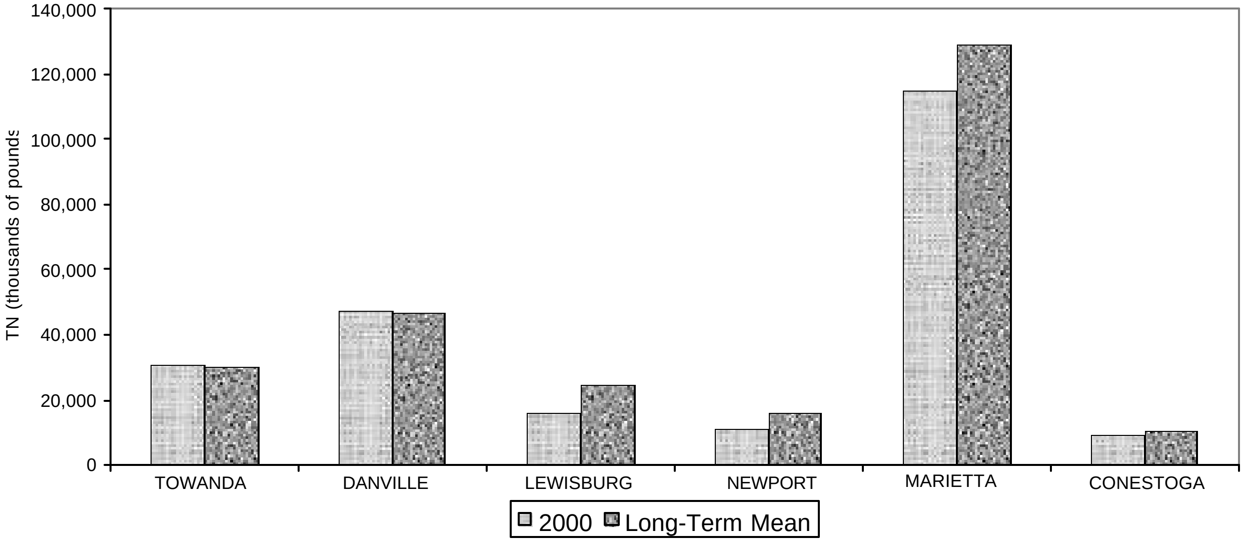


Figure 4A. ***Annual Loads of Total Nitrogen (TN) at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2000***

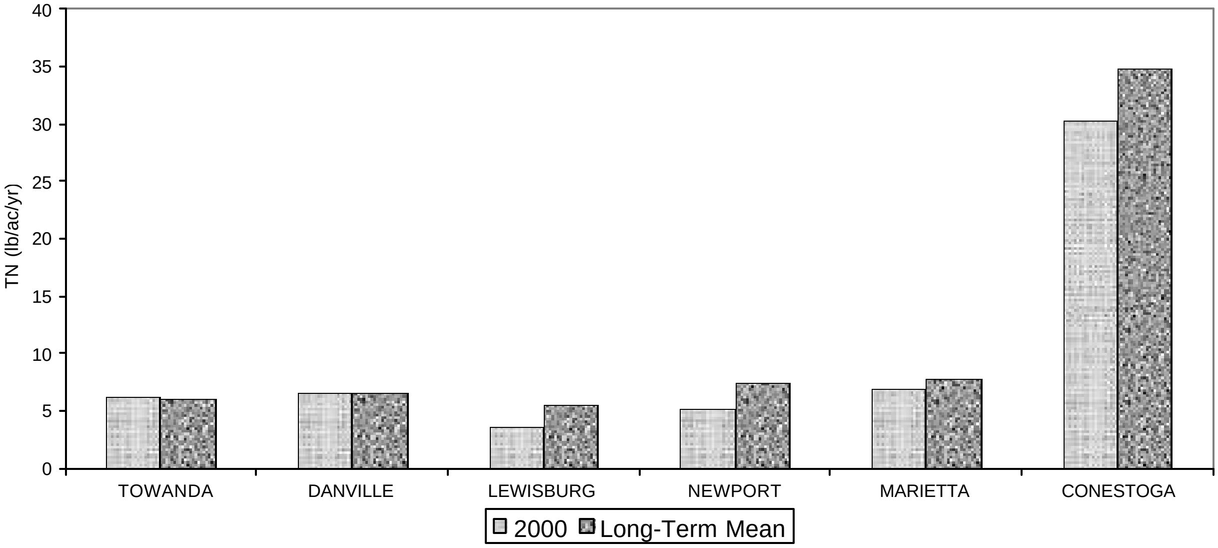


Figure 4B. ***Total Nitrogen (TN) Yields at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2000***

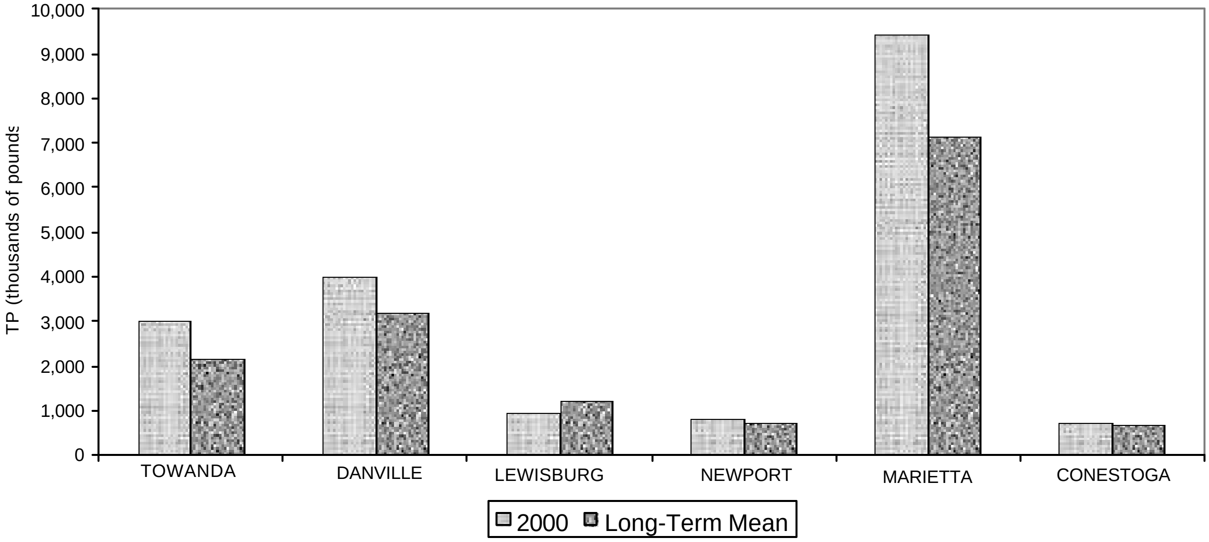


Figure 5A. ***Annual Loads of Total Phosphorus (TP) at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2000***

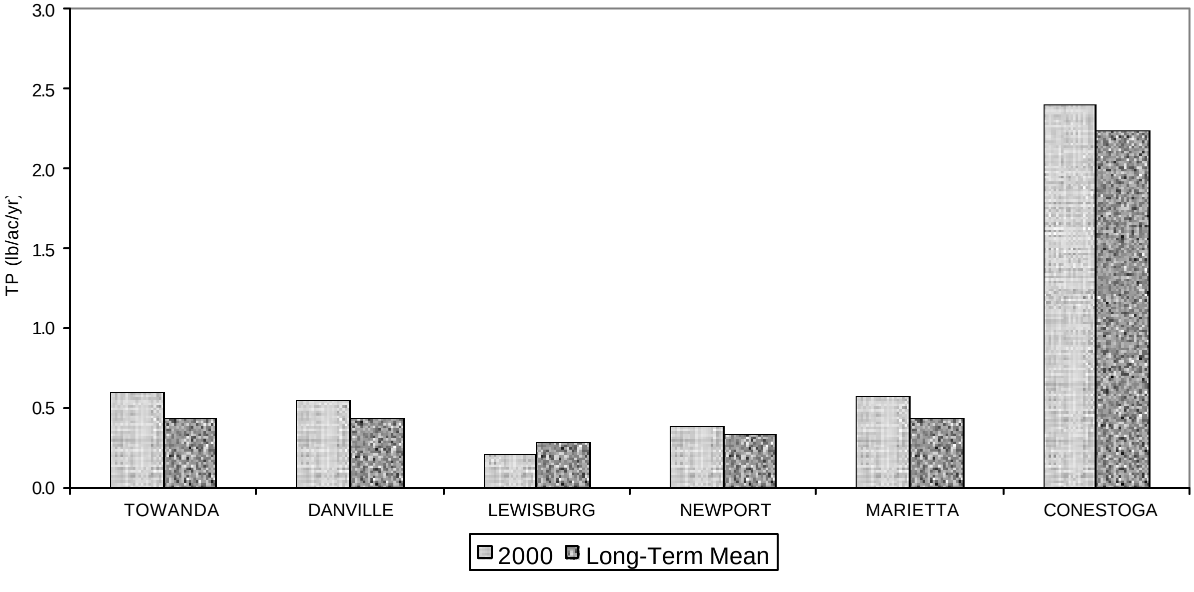


Figure 5B. ***Total Phosphorus (TP) Yields at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2000***

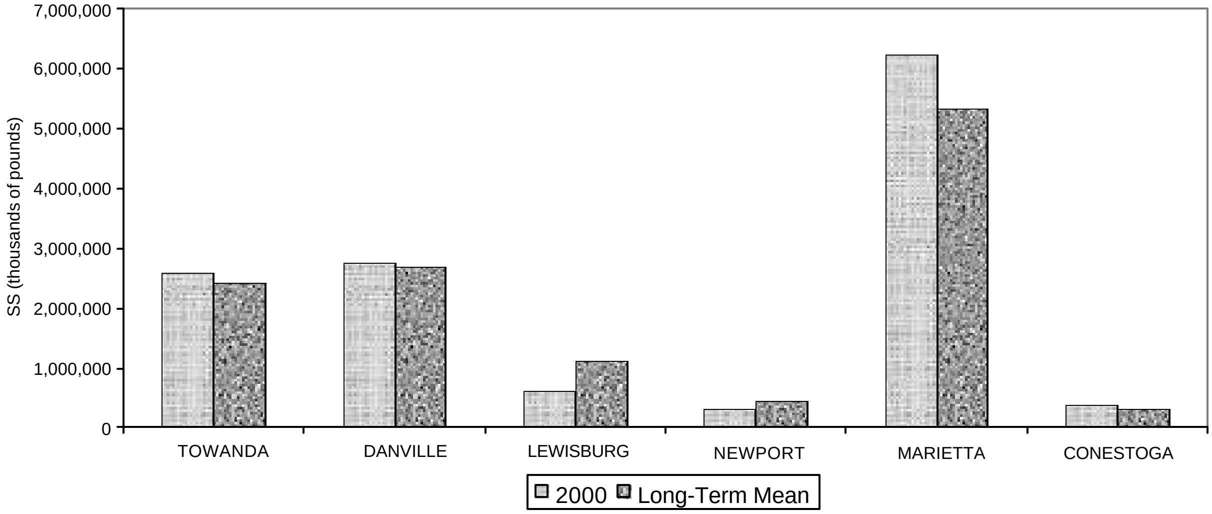


Figure 6A. ***Annual Loads of Suspended Sediment (SS) at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2000***

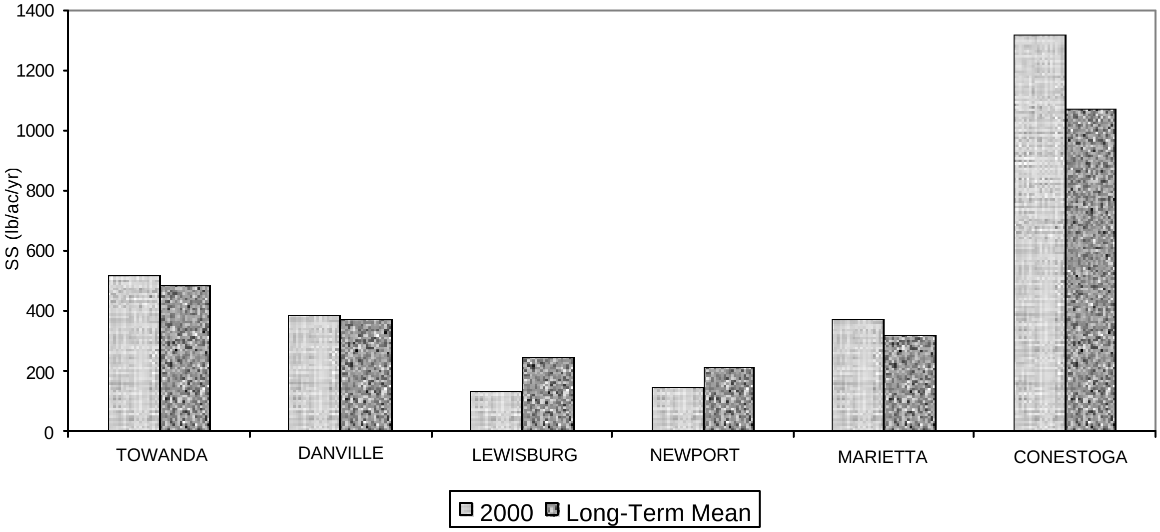


Figure 6B. ***Suspended-Sediment (SS) Yield at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2000***

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

Seasonal water discharges and loads of nutrients and SS for calendar year 2000 are listed in Table 18. The calendar year 2000 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 2000 at Towanda, Danville, Lewisburg, and Marietta were highest in the spring (April-June), followed by winter (January-March), fall (October-December), then summer (July-September). The 2000 seasonal discharges at Newport and Conestoga were highest in the winter, followed by spring. The 2000 seasonal discharges were greater than long-term during the winter and spring at Towanda and during the winter, spring and summer at Danville. The seasonal discharges were smaller than the long-term mean for all seasons at Lewisburg and Newport. Seasonal discharges were greater than long-term discharges in the spring at Marietta and Conestoga.

TN consists mostly of the highly-soluble nitrite plus nitrate fraction; therefore, the seasonal variation of TN loads for 2000 corresponded with the seasonal variation of water discharges at all sites except at Newport. Comparison of the 2000 TN loads with the long-term loads generally corresponded with discharge. Where the discharge was higher than long-term, the TN load also was higher.

The variations in seasonal loads of TP were consistent with seasonal variations of water discharges at all sites, except Newport. 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 2000 were greater than the long-term seasonal loads in the winter, spring, and summer at Towanda and Danville; in the spring at Lewisburg; in the spring, summer, and fall at Newport; in the winter, spring and summer at Marietta; and winter and spring at Conestoga

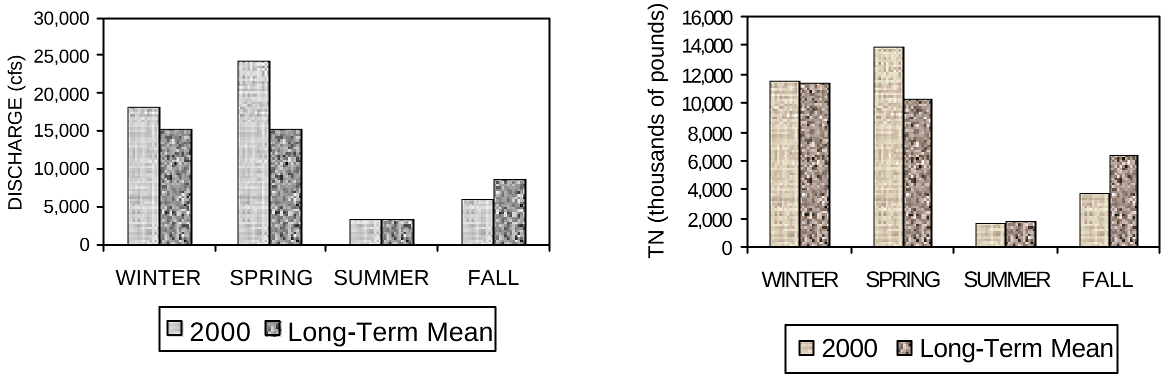
Seasonal variations in SS loads generally corresponded with discharge. The exception was at Newport. The SS load at Newport was highest in the spring, followed by winter, while the discharge was highest in the winter, then spring. Comparisons of the 2000 loads with the long-term loads showed that the SS loads followed the same patterns as TP.

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, except at Lewisburg. 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 Newport and Conestoga show the same seasonal fluctuations as their respective seasonal discharges.

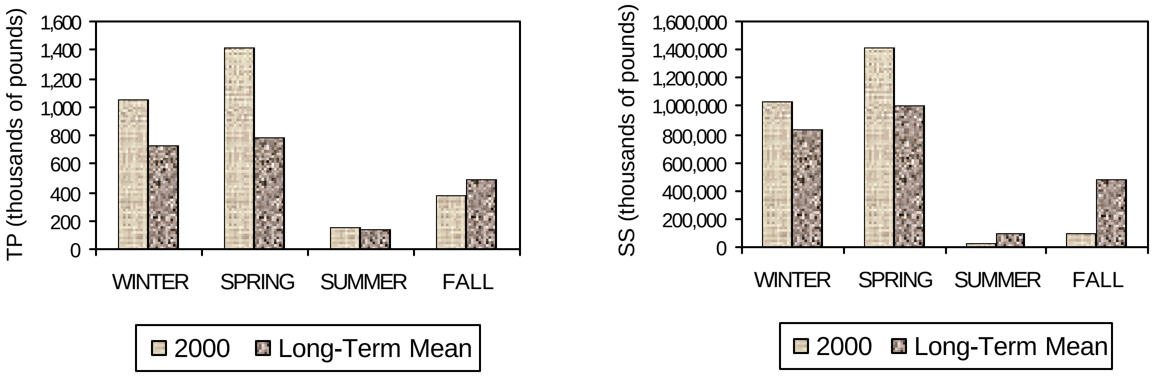
Figures 13 through 15 provide a comparison of the seasonal yields among the monitoring sites for calendar year 2000 and for the long-term seasonal average. The long-term seasonal averages indicate that the Conestoga River at Conestoga has the greatest yields of TN, TP, and SS for all seasons. The long-term 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 2000 followed the same pattern during the winter, summer, and fall. The 2000 TN yields in the Susquehanna River increased between Towanda and Danville, and decreased between Danville and Marietta during the spring. 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 2000

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	18,300	590.0	4,650	6,580	11,600	334.0	364.0	1,050.0	602.0	1,040,000	10,900	6,510	3,800	27,800
	Spring	24,300	545.0	7,230	6,800	13,900	375.0	440.0	1,420.0	487.0	1,420,000	12,400	6,770	5,490	45,500
	Summer	3,380	41.8	1,000	742	1,640	107.0	91.0	160.0	38.7	27,000	1,440	744	794	6,870
	Fall	6,090	162.0	1,650	2,000	3,690	331.0	221.0	379.0	200.0	104,000	3,560	1,960	1,490	10,900
Danville	Winter	25,800	840.0	6,310	11,300	18,000	437.0	412.0	1,390.0	937.0	1,160,000	17,300	11,300	5,040	38,700
	Spring	33,200	632.0	9,540	10,700	20,100	455.0	452.0	1,760.0	652.0	1,390,000	17,900	10,700	6,840	58,900
	Summer	6,500	61.3	2,050	1,550	3,310	116.0	108.0	285.0	62.3	61,400	2,840	1,540	1,430	13,600
	Fall	7,370	222.0	2,680	3,590	6,230	348.0	249.0	550.0	276.0	152,000	6,100`	3,600	2,240	17,500
Lewisburg	Winter	12,300	332.0	2,220	3,570	5,870	133.0	132.0	323.0	335.0	234,000	5,610	3,570	1,830	10,300
	Spring	14,800	241.0	2,790	3,570	6,310	149.0	141.0	404.0	256.0	326,000	5,770	3,540	2,150	15,300
	Summer	2,760	30.1	535	719	1,200	51.8	39.9	68.9	31.2	11,800	1,140	705	453	3,400
	Fall	4,410	103.0	968	1,410	2,320	127.0	92.1	145.0	111.0	35,300	2,280	1,400	848	4,900
Newport	Winter	5,600	70.4	1,020	2,850	3,930	151.0	132.0	205.0	74.7	78,600	3,770	2,870	827	6,170
	Spring	5,100	86.7	1,480	2,980	4,470	234.0	190.0	350.0	97.5	187,000	4,140	2,980	1,100	8,500
	Summer	1,270	17.5	431	585	968	85.1	75.1	104.0	20.0	17,800	901	584	340	2,450
	Fall	1,750	26.6	567	1,160	1,710	139.0	120.0	152.0	32.3	27,400	1,660	1,170	479	3,280
Marietta	Winter	51,700	1,470.0	21,900	28,400	43,200	1,690.0	1,240.0	3,070.0	1,590.0	2,100,000	39,500	28,400	20,400	72,400
	Spring	62,300	1,030.0	24,400	27,400	45,700	2,340.0	1,660.0	4,240.0	1,120.0	3,350,000	39,900	27,200	21,800	103,000
	Summer	13,200	145.0	4,800	4,900	9,080	651.0	449.0	760.0	158.0	257,000	7,970	4,940	4,370	26,500
	Fall	18,000	492.0	7,530	9,840	16,500	1,580.0	755.0	1,350.0	564.0	514,000	15,000	9,840	6,570	32,800
Conestoga	Winter	966	60.7	1,000	2,670	3,650	73.8	85.9	333.0	62.0	231,000	3,260	2,620	627	2,550
	Spring	772	33.0	581	2,320	2,840	80.9	70.7	202.0	32.9	110,000	2,630	2,280	417	1,900
	Summer	369	11.1	231	1,080	1,290	68.2	50.8	95.0	10.9	22,300	1,200	1,060	172	979
	Fall	334	14.9	283	1,000	1,310	52.2	47.2	92.5	15.7	33,600	1,210	992	205	994

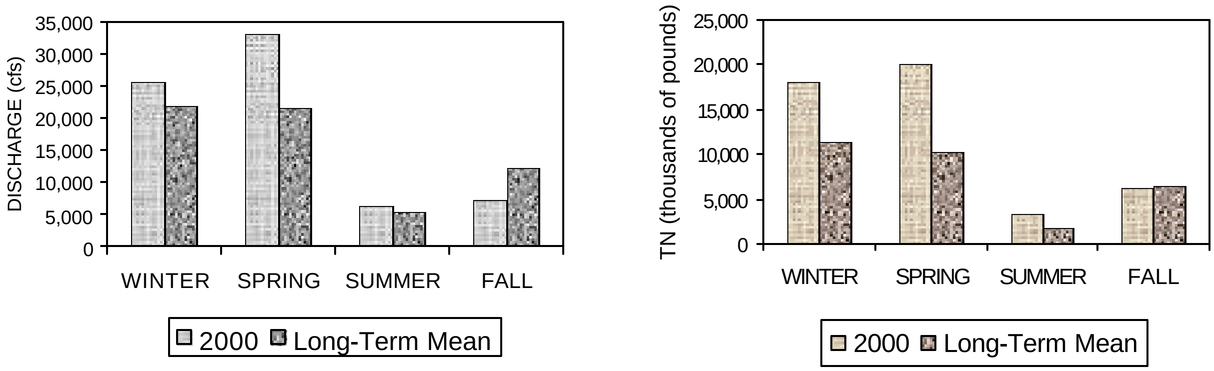


Discharge *Total Nitrogen*



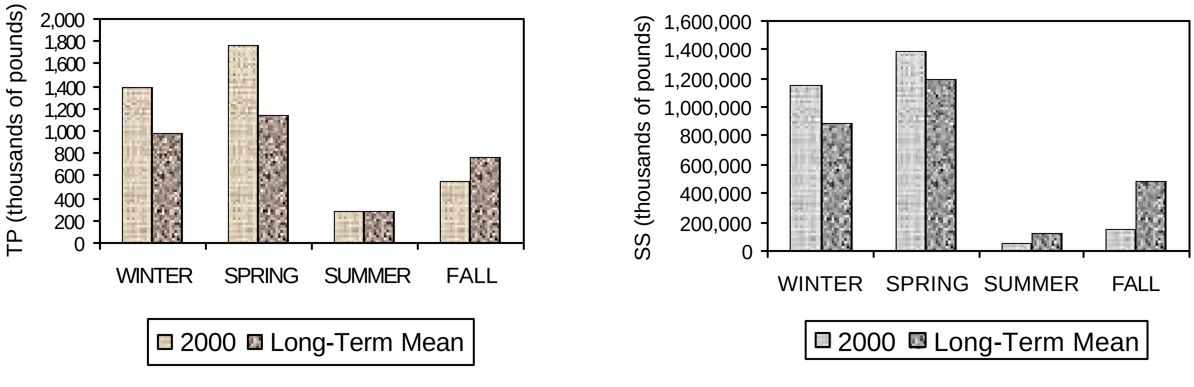
Total Phosphorus *Suspended Sediment*

Figure 7. Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Towanda, Pa., Calendar Year 2000



Discharge

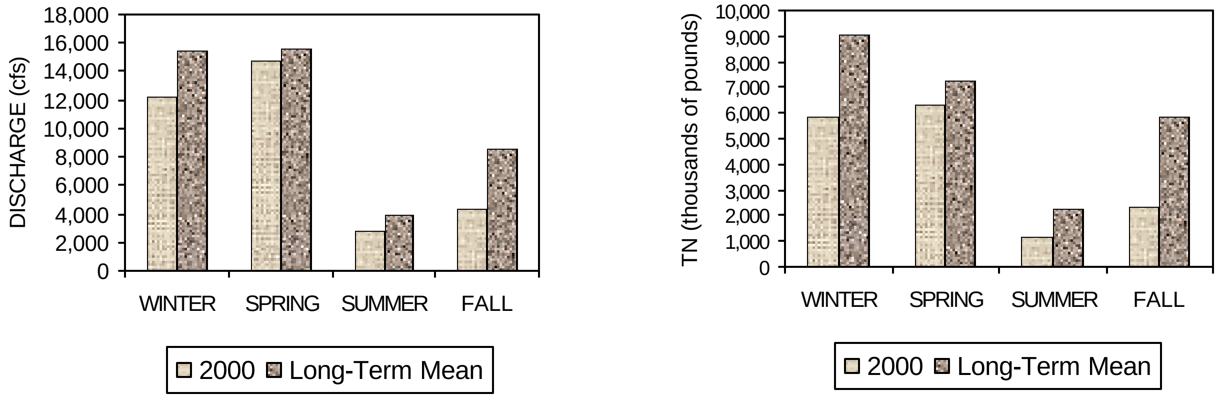
Total Nitrogen



Total Phosphorus

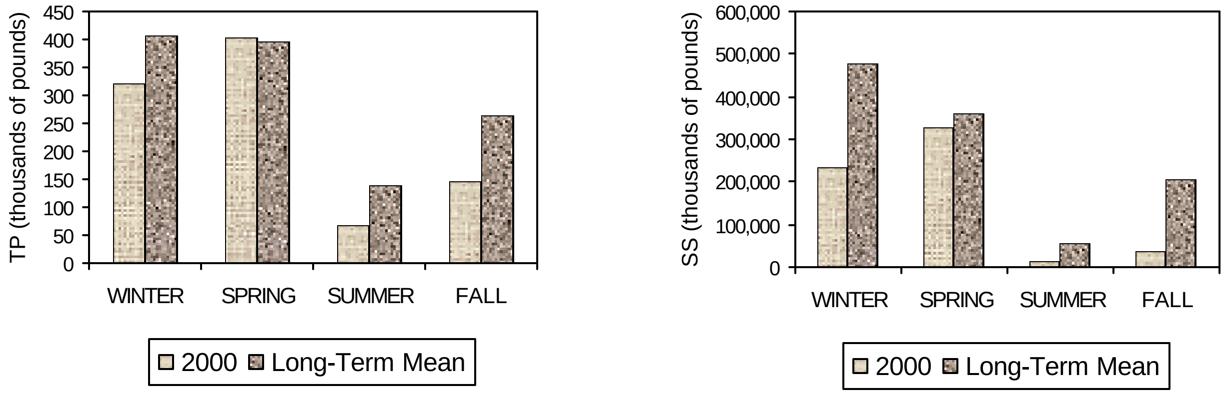
Suspended Sediment

Figure 8. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Danville, Pa., Calendar Year 2000***



Discharge

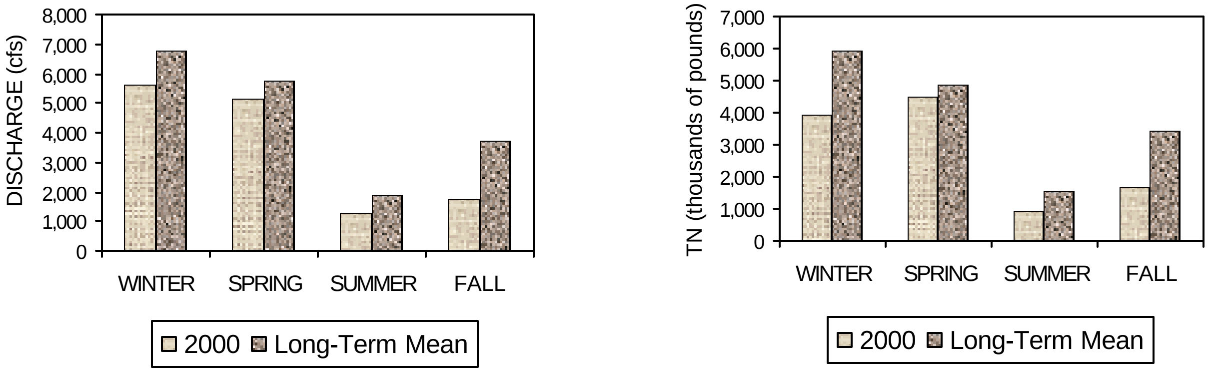
Total Nitrogen



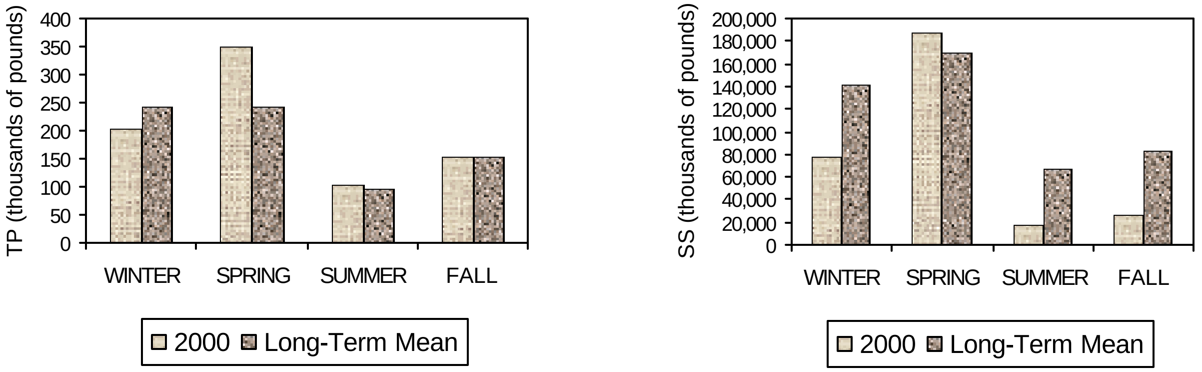
Total Phosphorus

Suspended Sediment

Figure 9. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Lewisburg, Pa., Calendar Year 2000***

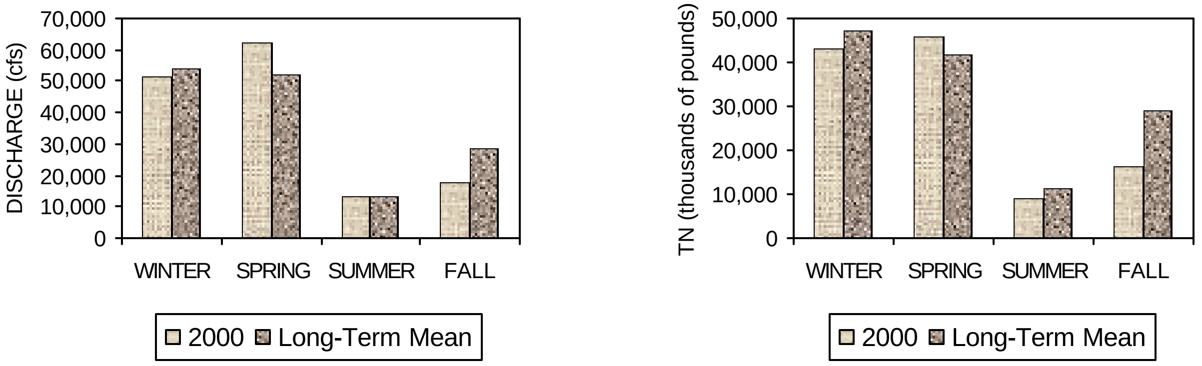


Discharge ***Total Nitrogen***



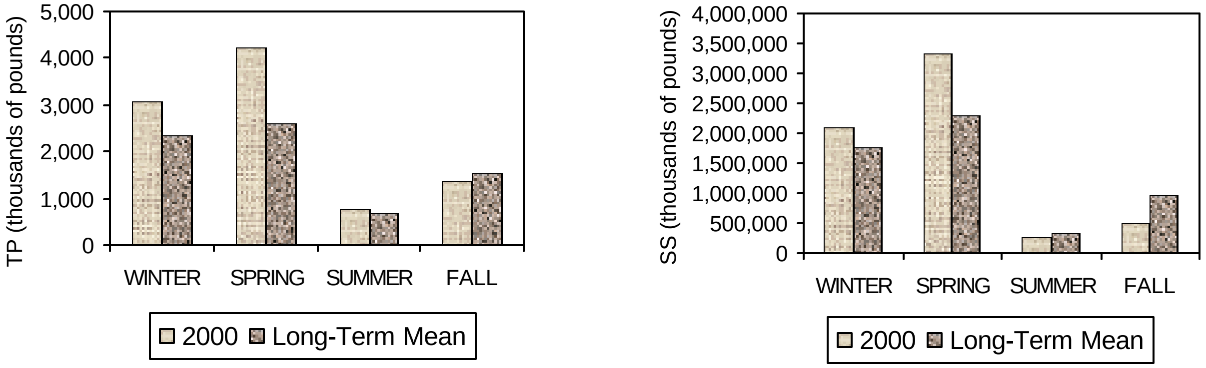
Total Phosphorus ***Suspended Sediment***

Figure 10. Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Newport, Pa., Calendar Year 2000



Discharge

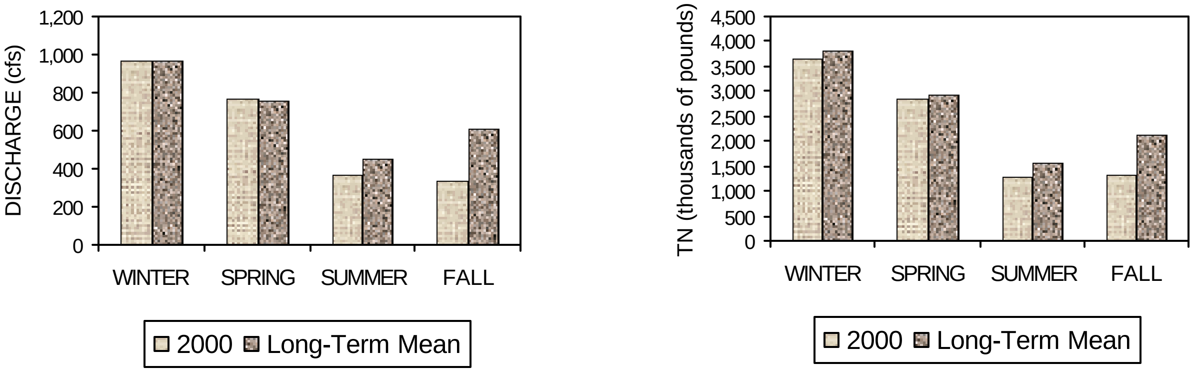
Total Nitrogen



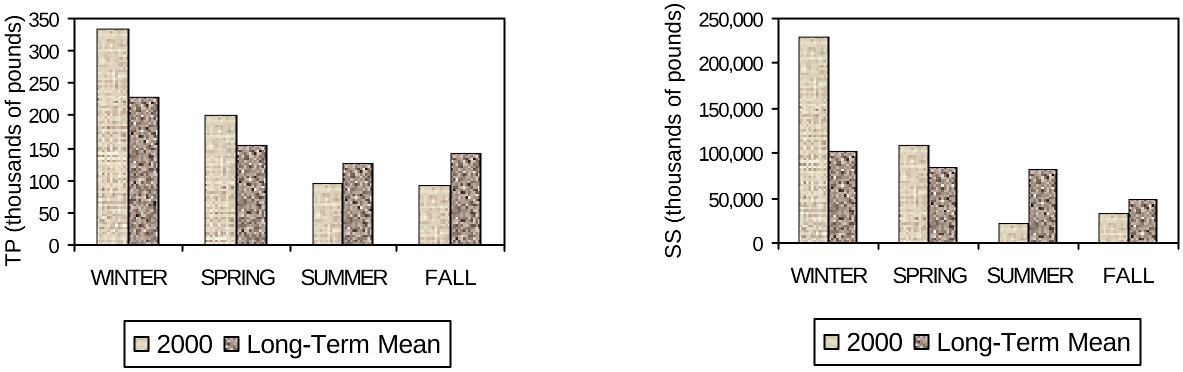
Total Phosphorus

Suspended Sediment

Figure 11. ***Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Marietta, Pa., Calendar Year 2000***



Discharge ***Total Nitrogen***



Total Phosphorus ***Suspended Sediment***

Figure 12. Seasonal Discharges and Loads of Total Nitrogen, Total Phosphorus, and Suspended Sediment at Conestoga, Pa., Calendar Year 2000

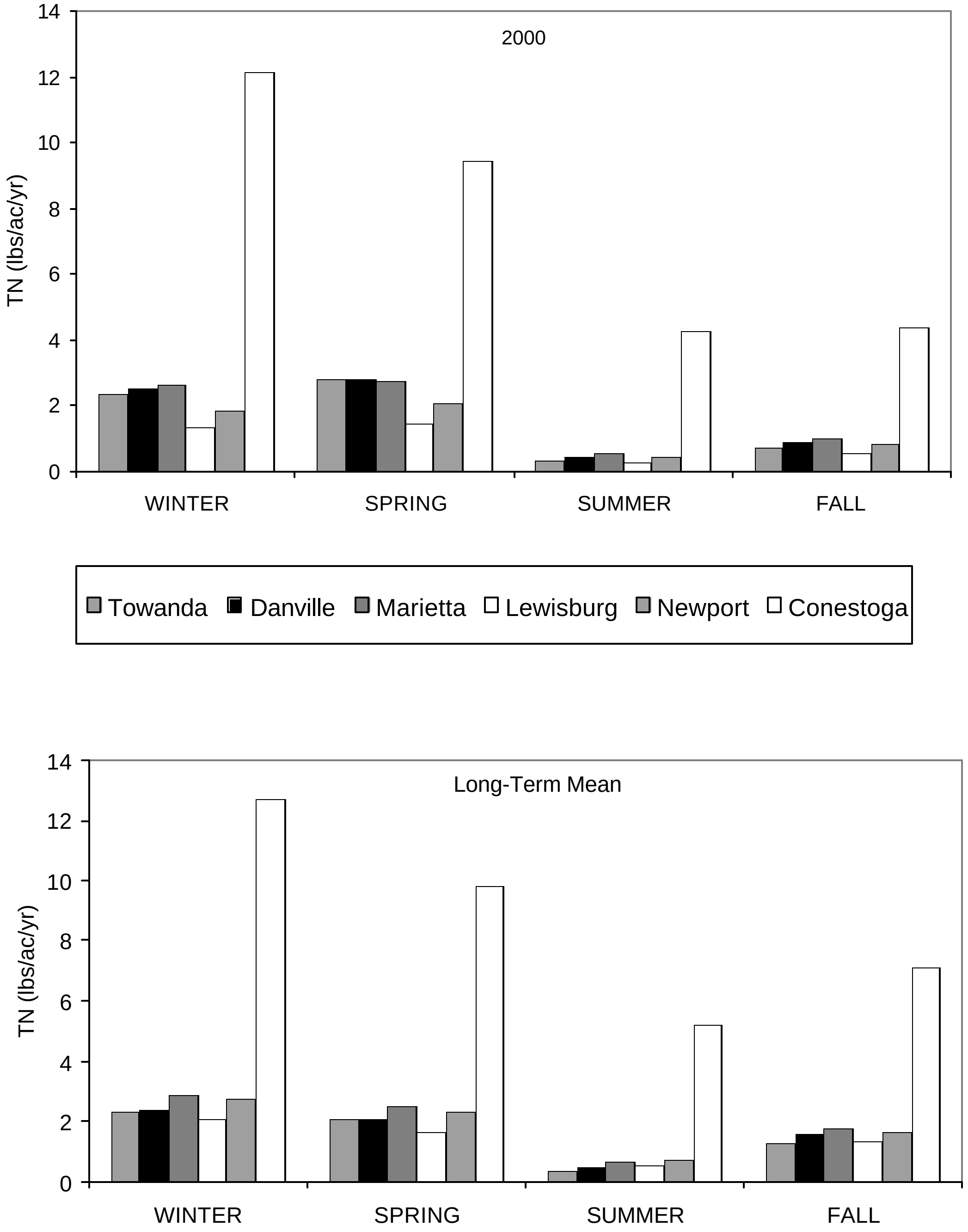
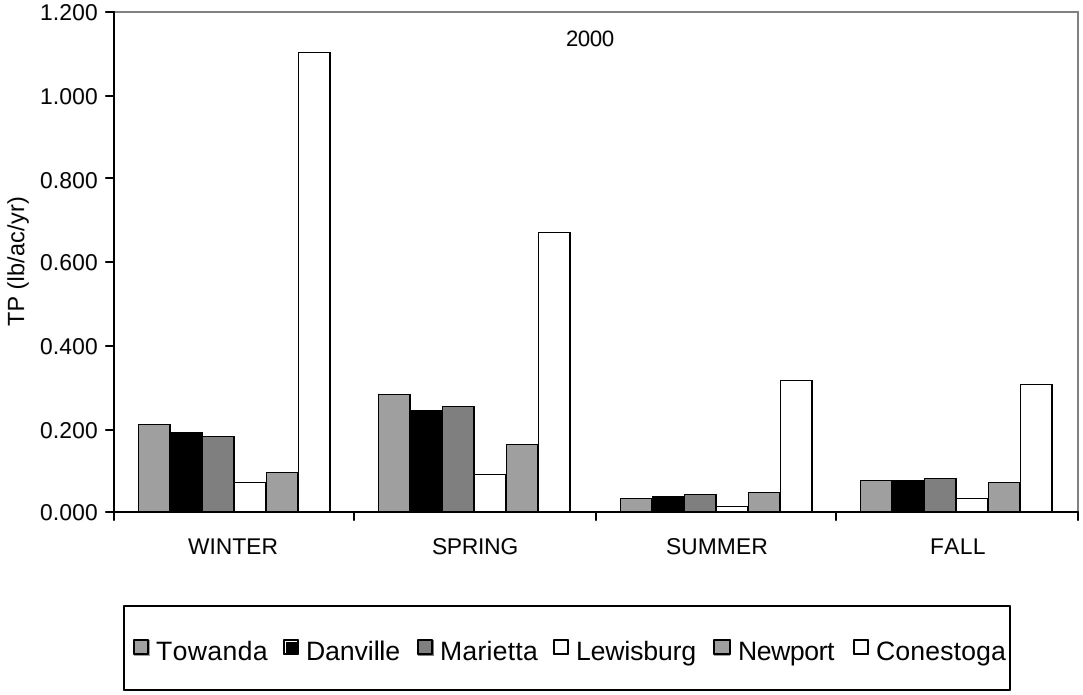


Figure 13. Comparison of Seasonal Yields of Total Nitrogen at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, Pa.



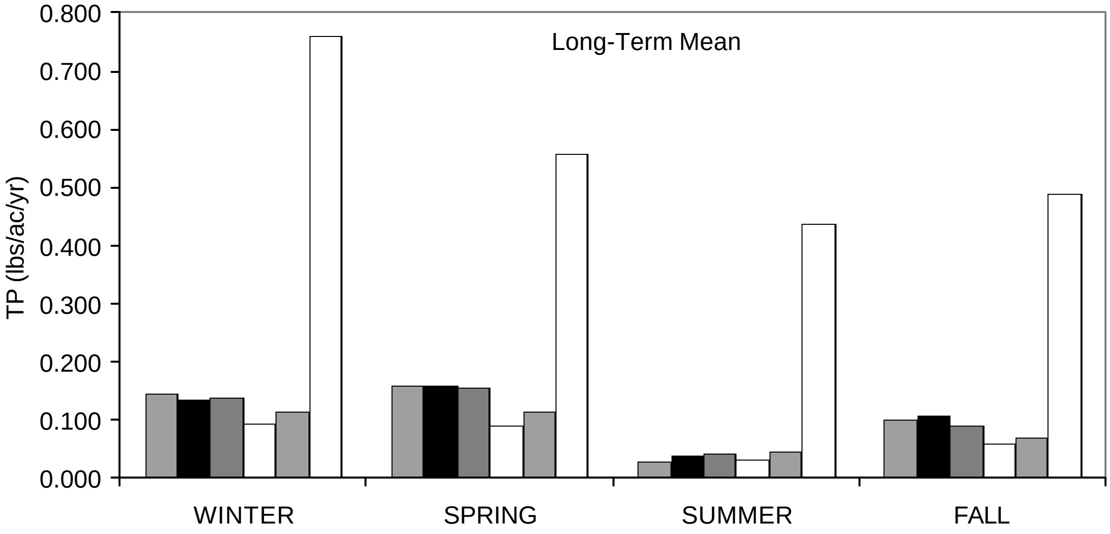


Figure 14. Comparison of Seasonal Yields of Total Phosphorus at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, Pa

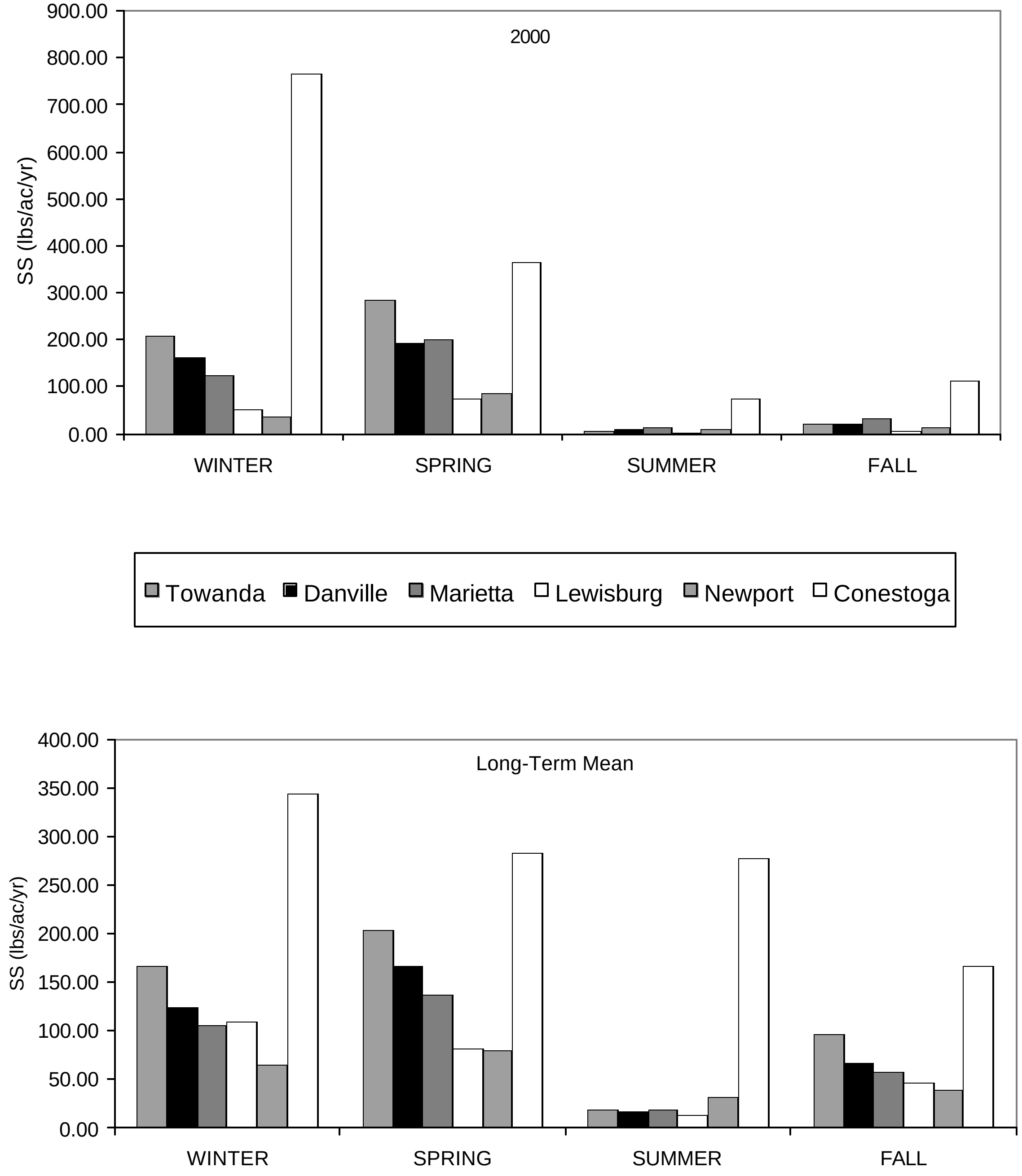


Figure 15. ***Comparison of Seasonal Yields of Suspended Sediment at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, Pa.***

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 2000 TP yields also do not show any consistent patterns among the sites. The smallest TP yield in 2000 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 2000 seasonal SS yields do not show any consistent relationships among the sites.

COMPARISON OF THE 2000 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 2000 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 2000 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 2000 TN yield plotted significantly below the 5-year baseline suggesting that the TN load decreased. The TN yield was estimated to be 8.10 lb/ac/yr at a water-discharge ratio of 1.21 for the initial five years of monitoring, while the yield for 2000 was 6.19 lb/ac/yr at the same discharge ratio. The TP load increased in 2000. The baseline TP yield was 0.46 lb/ac/yr, compared to 0.60 lb/ac/yr for 2000. The SS yields in Figure 16 indicate that there was no significant change in 2000. The baseline yield was 494.4 lb/ac/yr, and the yield for 2000 was 518.8 lb/ac/yr.

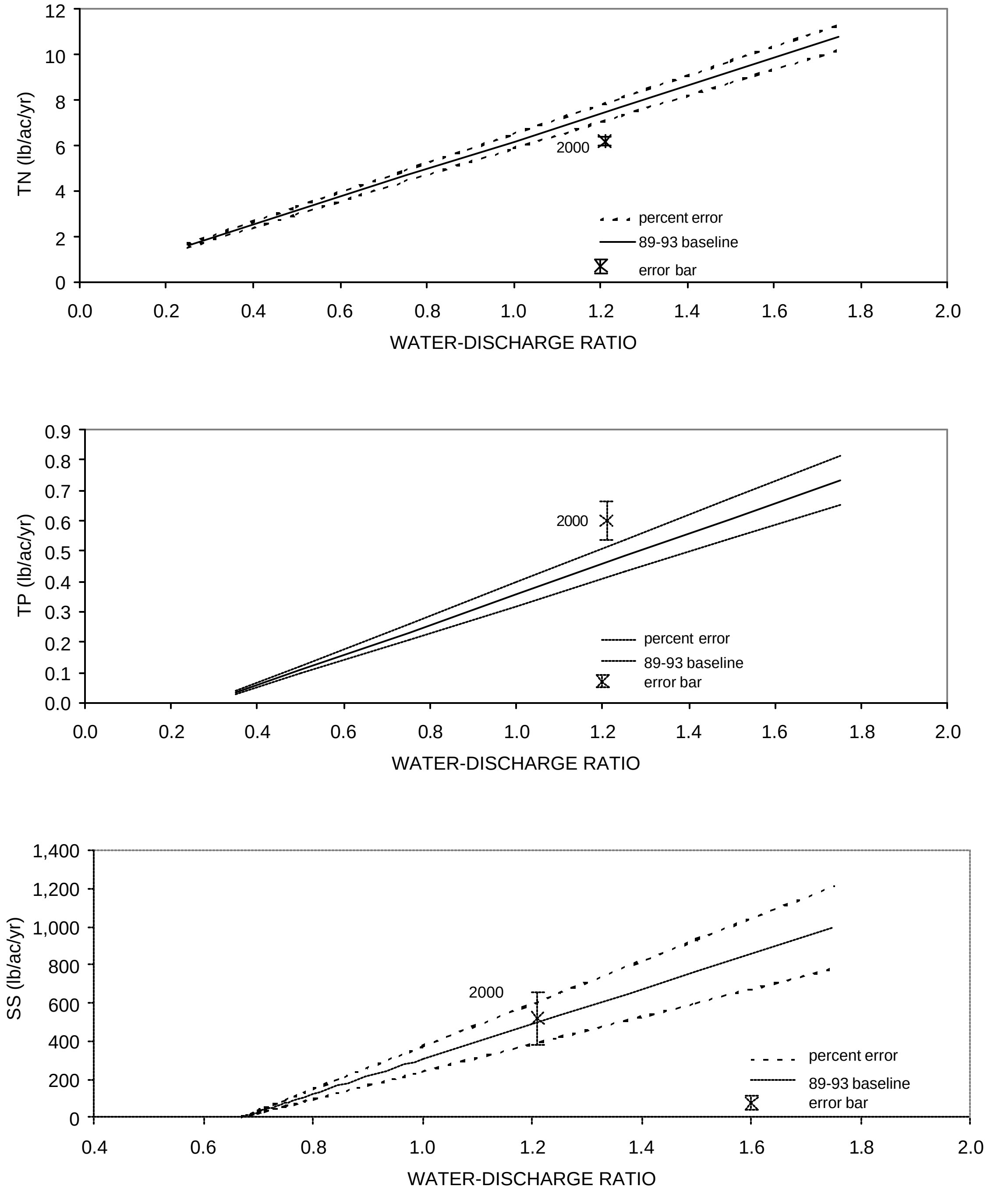


Figure 16. ***Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Towanda, Pa., 1989-93 and 2000***

Susquehanna River at Danville, Pa.

Figure 17 shows the 5-year (1985-89) baselines for TN, TP, and SS and the 2000 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 2000 plotted significantly below the baseline, indicating that there was a decrease in the loads. The baseline yields of TN and SS were 8.46 and 548.4 lb/ac/yr at the water-discharge ratio of 1.18, compared to 6.64 and 385.5 lb/ac/yr for 2000, respectively. The data in Figure 17 suggests that TP decreased in 2000, but the decrease may not be significant since it fell within the margin of error. The baseline TP yield was 0.63 lb/ac/yr, compared to 0.55 lb/ac/yr for 2000.

West Branch Susquehanna River at Lewisburg, Pa.

The 1985-89 baselines and the 2000 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 for 2000 plotted significantly below the baseline, indicating that the nitrogen load decreased. The baseline TN yield was 4.77 lb/ac/yr at the water-discharge ratio of 0.78, compared to 3.58 lb/ac/yr for 2000. The TP yield was 0.25 lb/ac/yr for the baseline and 0.21 lb/ac/yr for 2000. The 2000 TP yield plotted within the margin of error; therefore, the change may not be significant. SS data suggested that there was an increase in 2000, but this increase may not be significant since the margins of error overlap. The baseline yield was 116.5 lb/ac/yr, and the 2000 yield was 138.6 lb/ac/yr.

Juniata River at Newport, Pa.

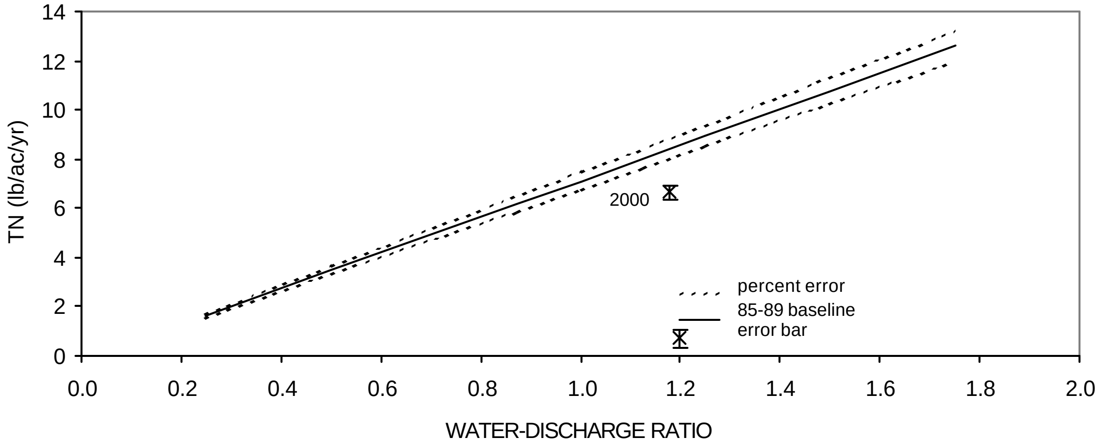
The 1985-89 baselines and 2000 yields for TN, TP, and SS at Newport, shown in Figure 19, were plotted using the following equations:

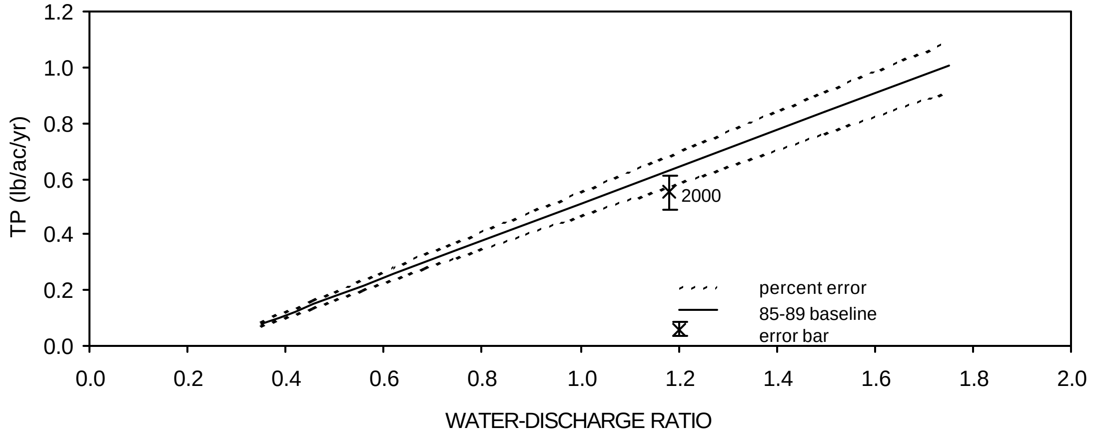
Total Nitrogen (TN)
TN Yield = -0.2937 + 8.9052x $R^2 = 0.80$

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

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

The TN yield for 2000 showed significant decrease from the baseline. The TN baseline yield was 6.43 lb/ac/yr at a water-discharge ratio of 0.75, and the 2000 yield was 5.16 lb/ac/yr. The TP yield increased in 2000. TP yields were 0.31 and 0.38 lb/ac/yr for the baseline and 2000, respectively. There was no change in the SS load for 2000.





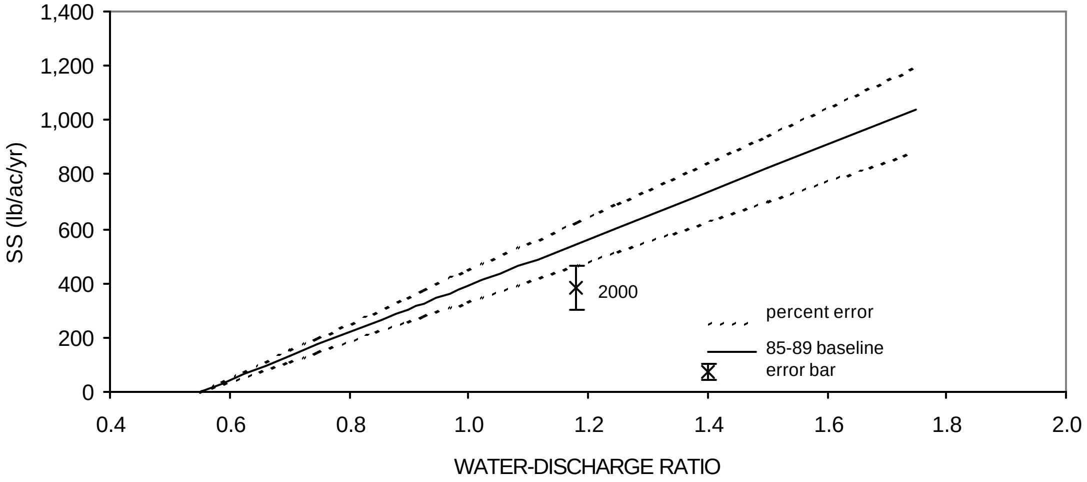


Figure 17. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Danville, Pa., 1985-89 and 2000

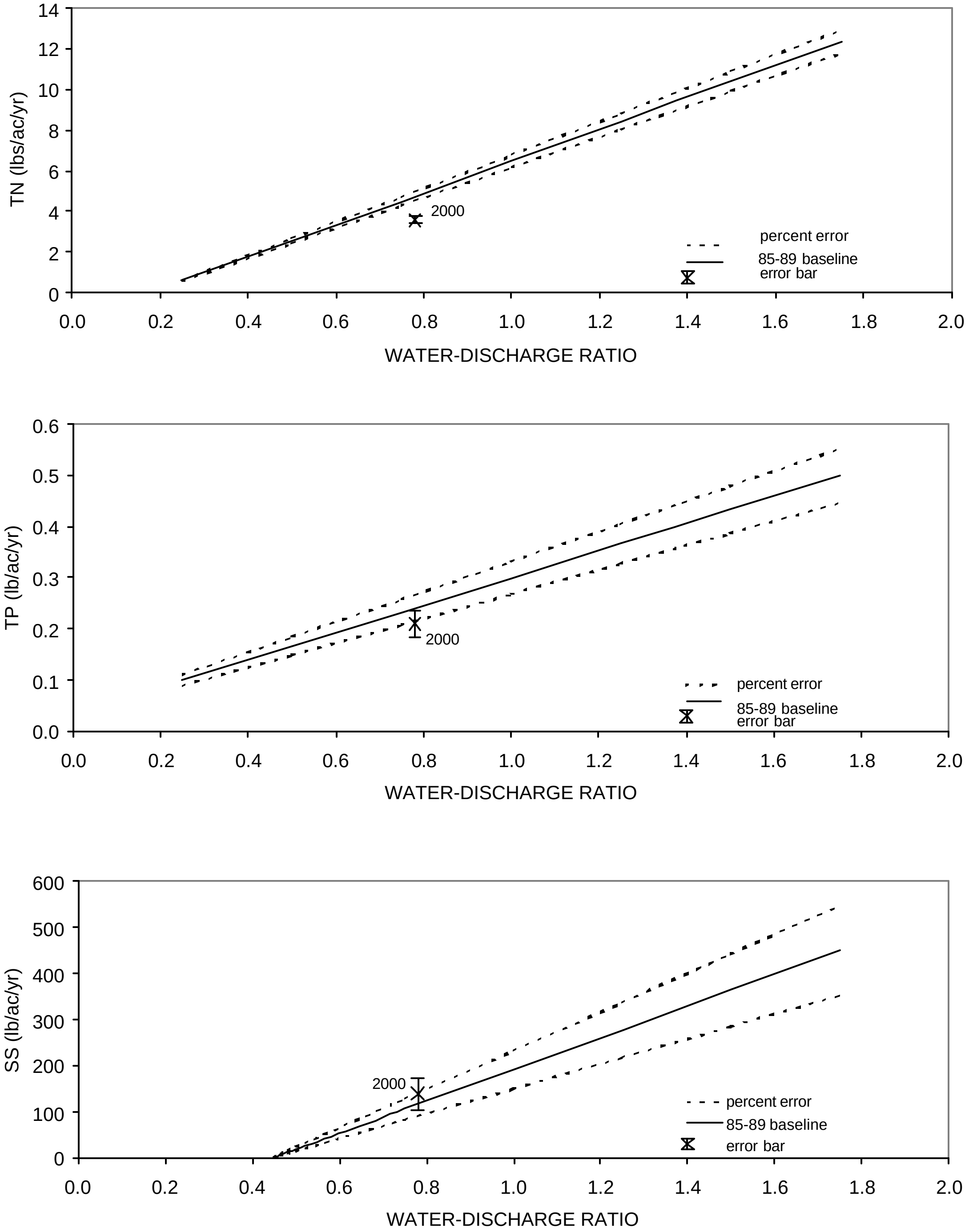


Figure 18. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, West Branch Susquehanna River at Lewisburg, Pa., 1985-89 and 2000

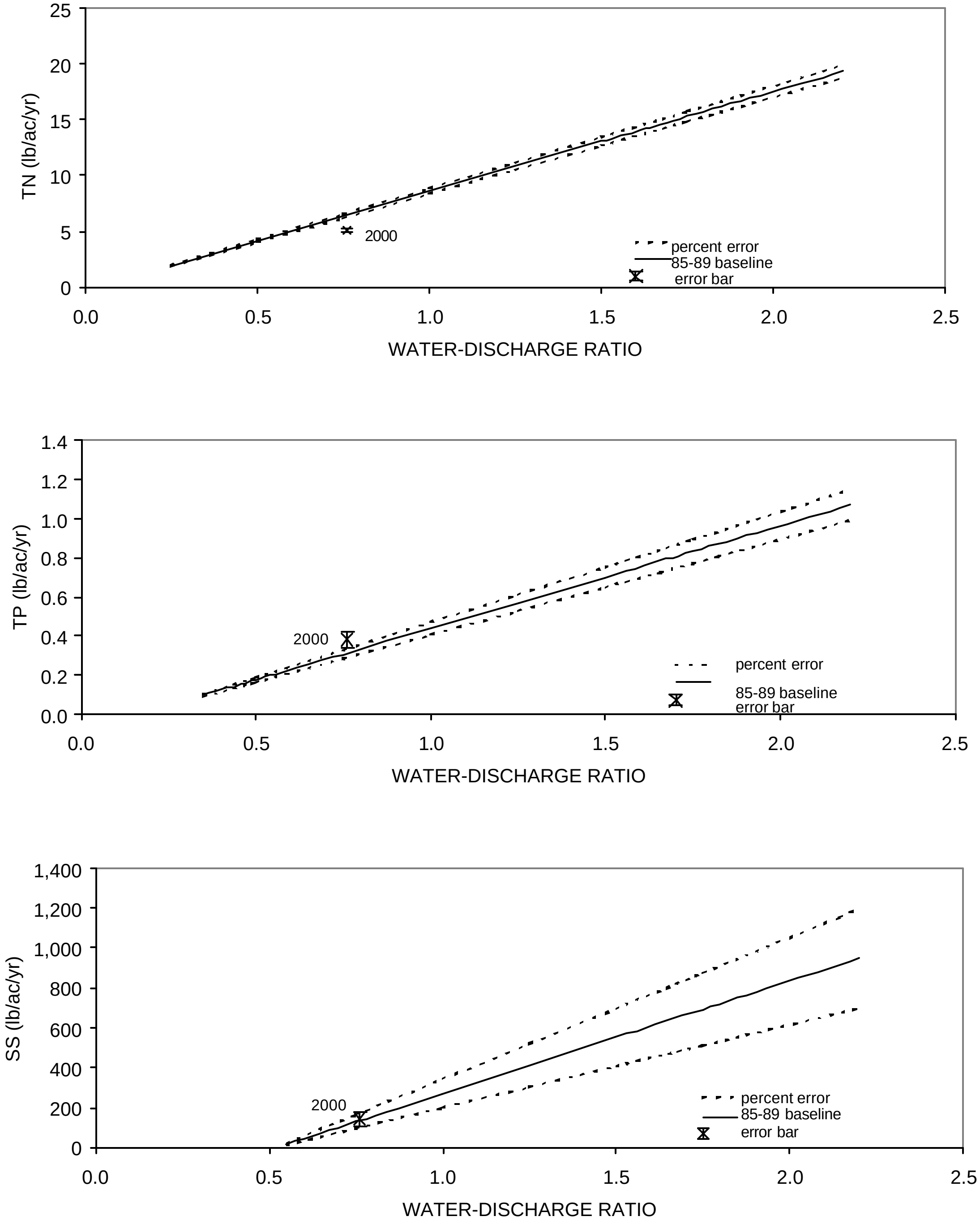


Figure 19. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Juniata River at Newport, Pa., 1985-89 and 2000

Susquehanna River at Marietta, Pa.

The TN, TP, and SS baseline for the 5-year period 1987-91 at Marietta and the 2000 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 $R^2 = 0.48$

The TN yield for 2000 plotted significantly below the baseline, indicating that there was a decrease in the load. The TN baseline yield was 8.20 lb/ac/yr at a water-discharge ratio of 0.97, and the 2000 yield was 6.88. The TP and SS data show significant increases in the 2000 loads. The TP baseline yield was 0.37 lb/ac/yr, compared to 0.57 lb/ac/yr for 2000. The 2000 baseline SS yield was 276.6 lb/ac/yr, compared to 145.0 lb/ac/yr in 2000.

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 2000 TN yield shows a decrease from the baseline yields. The baseline and 2000 yields of TN were 33.06 and 30.20 lb/ac/yr, respectively, at a water-discharge ratio of 0.87. The TP yield increased in 2000. The baseline yield was 1.49 lb/ac/yr, and the 2000 yield was 2.40 lb/ac/yr. There was no change in SS load.

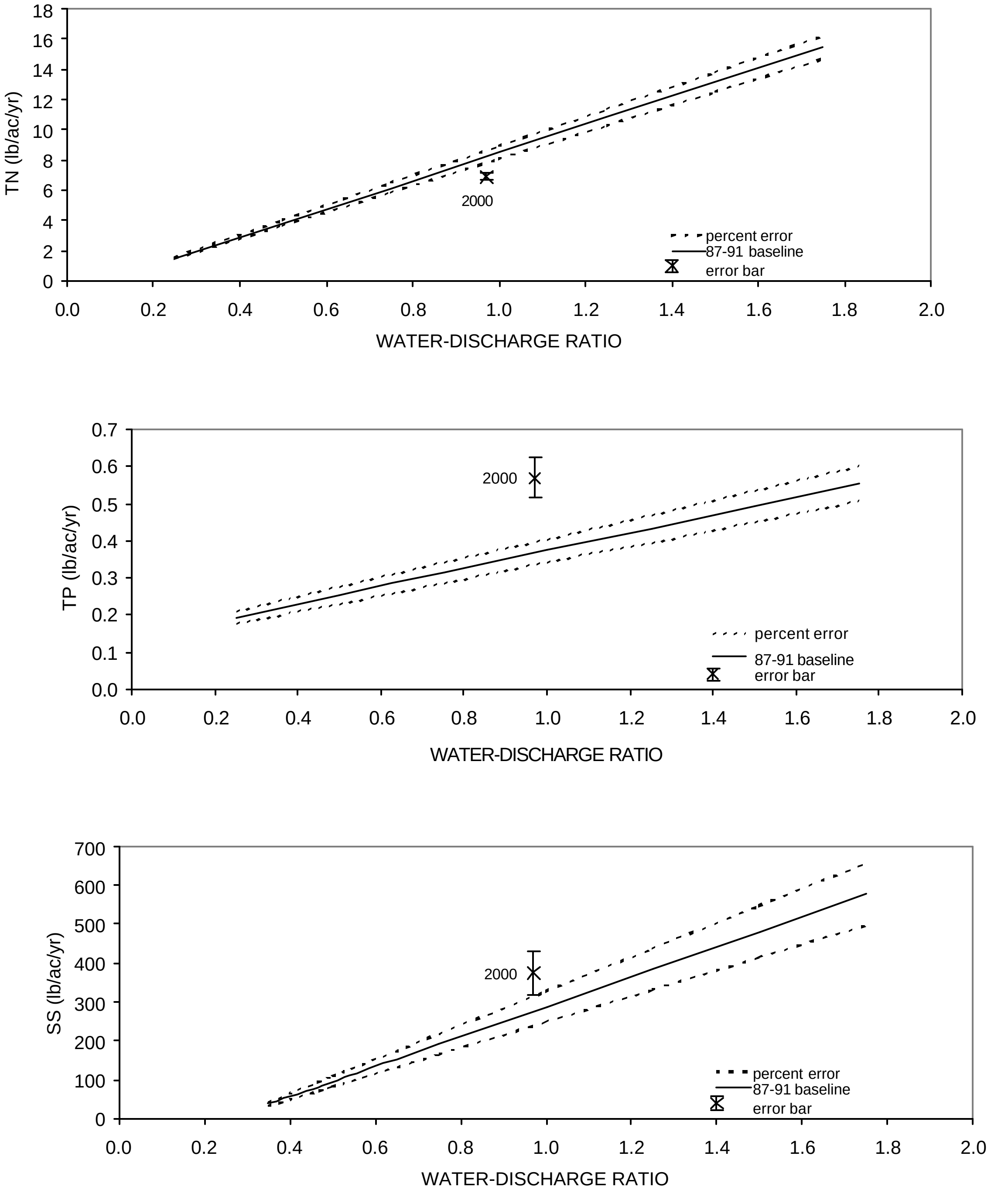


Figure 20. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Marietta, Pa., 1985-89 and 2000

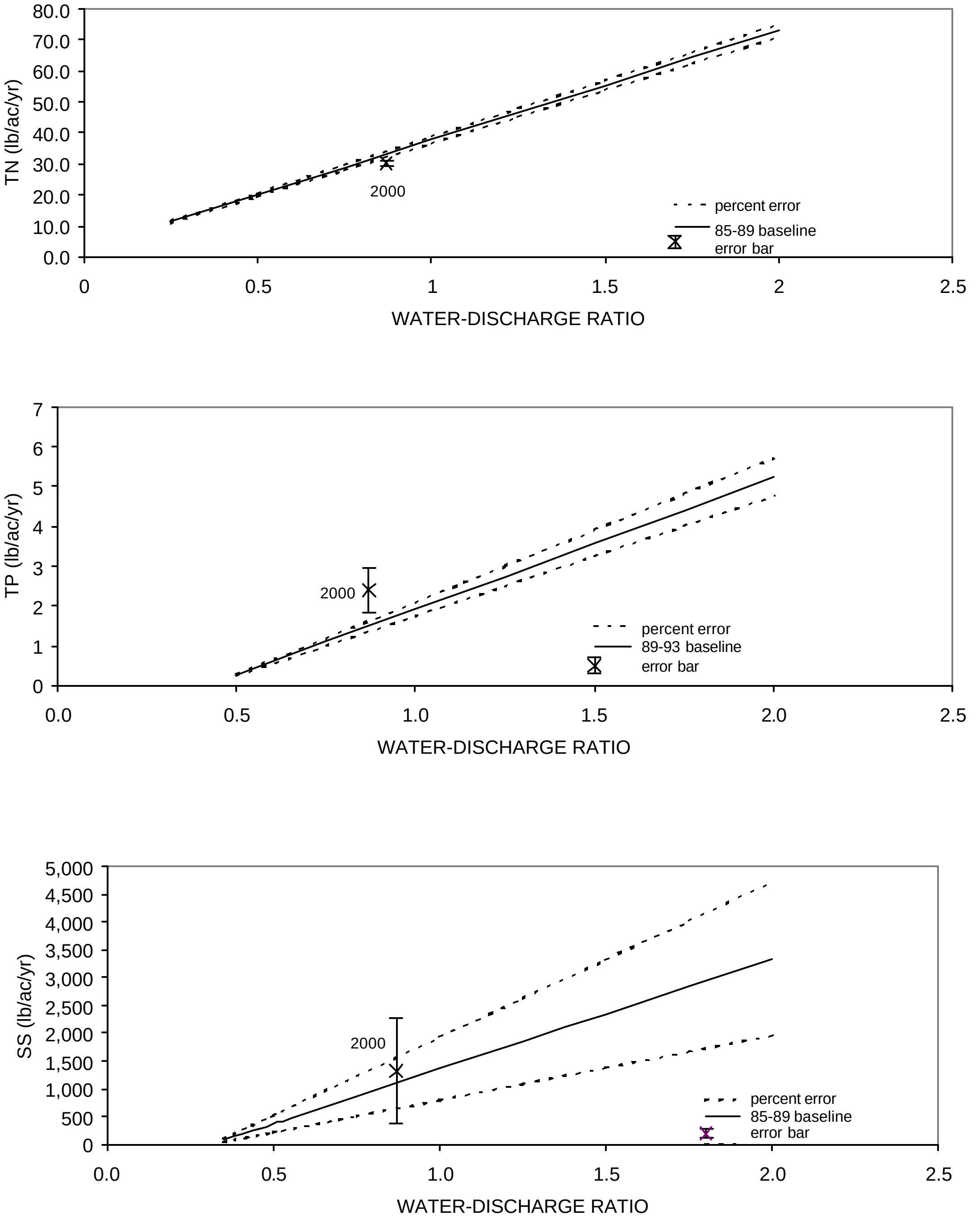


Figure 21. ***Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Conestoga River at Conestoga, Pa., 1985-89 and 2000***

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 2000. 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 discharge, suspended sediment, total organic carbon, and several forms of the nutrients nitrogen and phosphorus. Results are reported for monthly mean discharge (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). 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 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 4 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 2000. While a comparison of baseline and status flow indicated a change in the flow record (11,505 cfs vs. 8,514 cfs), the test on the FLOWs did not detect ($p = 0.376$) 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 3.8 lb/ac during the last 36 months. The trend analysis did not indicate the existence of a trend ($p = 0.018$). No trend was detected in the TN FWC ($p=0.248$). Trends were detected in the TN LOAD and FWC for the period 1989 to 1999 (Takita and Edwards,

Table 19. Trend Statistics for the Susquehanna River at Towanda, Pa., January 1985 through December 2000

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.376	-32	4	NS	11,500	8,514
TN	FAC	0.000	-34	-23	DN	--	--
TN	FWC	0.248	-52	13	NS	2.92	1.320
TN	LOAD	0.018	-50	-23	NS	5.36	3.790
DN	FAC	0.000	-26	-14	DN	--	--
DN	FWC	0.423	-48	24	NS	2.40	1.250
DN	LOAD	0.056	-45	-16	NS	4.58	3.320
TON	FAC	0.152	-25	5	NS	--	--
TON	FWC	0.798	-39	43	NS	1.13	0.570
TON	LOAD	0.254	-37	-3	NS	2.33	1.600
DON	FAC	0.011	5	45	UP	--	--
DON	FWC	0.431	-20	91	NS	0.68	0.470
DON	LOAD	0.842	-16	29	NS	1.62	1.330
DNH	FAC	0.002	-41	-11	DN	--	--
DNH	FWC	0.284	-52	13	NS	0.11	0.048
DNH	LOAD	0.038	-60	-5	NS	0.18	0.092
TNH	FAC	0.002	-41	-11	DN	--	--
TNH	FWC	0.250	-54	10	NS	0.10	0.049
TNH	LOAD	0.032	-61	-8	NS	0.17	0.120
DKN	FAC	0.140	-4	32	NS	--	--
DKN	FWC	0.640	-26	75	NS	0.77	0.490
DKN	LOAD	0.827	-23	19	NS	1.66	1.430
TKN	FAC	0.054	-26	0	NS	--	--
TKN	FWC	0.722	-41	39	NS	1.25	0.620
TKN	LOAD	0.205	-39	-5	NS	2.64	1.760
TNO23	FAC	0.000	-38	-26	DN	--	--
TNO23	FWC	0.148	-56	5	NS	1.88	0.730
TNO23	LOAD	0.006	-54	-29	DN	4.44	1.940
DNO23	FAC	0.000	-38	-26	DN	--	--
DNO23	FWC	0.149	-56	5	NS	1.86	0.720
DNO23	LOAD	0.005	-54	-29	DN	4.37	1.930
TP	FAC	0.886	-16	23	NS	--	--
TP	FWC	0.888	-32	61	NS	0.14	0.100
TP	LOAD	0.603	-43	35	NS	0.30	0.250
DP	FAC	0.029	-30	-2	DN	--	--
DP	FWC	0.695	-41	39	NS	0.10	0.055
DP	LOAD	0.160	-39	-6	NS	0.21	0.110
DIP	FAC	0.000	152	358	UP	--	--
DIP	FWC	0.000	130	446	UP	0.033	0.037
DIP	LOAD	0.000	94	359	UP	0.075	0.084
TOC	FAC	0.295	-12	4	NS	--	--
TOC	FWC	0.866	-38	47	NS	6.54	4.010
TOC	LOAD	0.324	-48	23	NS	15.60	12.200
SS	FAC	0.537	-19	48	NS	--	--
SS	FWC	0.858	-61	117	NS	85.10	46.200
SS	LOAD	0.569	-67	83	NS	152.20	78.300

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

2001). The lack of trend for 1989 to 2000 suggests that trends are very sensitive to flow conditions. Stream discharges for calendar year 2000 in the upper areas of the Susquehanna River Basin, such as the Susquehanna River at Waverly, N.Y., Susquehanna River at Wilkes-Barre, Pa. and Tunkhannock Creek at Tunkhannock, Pa. were above the long-term normal at 139, 141, and 126 percent, respectively (Lazorchick, 2001). After correcting for the effects of flow, the TN FACs indicated a significant ($p < 0.0001$) downward trend. Tests on the TNH and DNH FAC and the TNO23 and DNO23 FAC time series indicated significant downward trends. Although stream discharges were above normal in 2000, trends were detected in the TNO23 LOAD ($p=0.006$) and DNO23 ($p=0.005$) time series with downward slope ranges of –29 to -54 percent. While no trends were detected in TON, a significant ($p=0.011$) increase was observed in the dissolved fraction for the FACs. The overall results for nitrogen suggested that some change had taken place, resulting in decreased inputs of nitrogen to the streams upstream of Towanda, even though there was an indication that DON could be increasing.

The LOAD, FWC, and FAC analyses for TP and the LOAD and FWC analyses for DP did not indicate any significant trends. However, the results on the DP FACs indicated that the sequence of flows at Towanda may have masked changes in the delivery of DP. A significant ($p=0.029$) downward trend did occur in the DP FAC time series with a slope of –2 to –30 percent, when 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. This may indicate that processes contributing particulate phosphorus may not have changed significantly. Although organic phosphate forms constitute the major fraction of dissolved and particulate phosphorus in water, trends in the inorganic forms (i.e., orthophosphate) can indicate changes in biological processes. Significant increasing trends were detected in dissolved inorganic phosphorus (DIP) LOAD ($p<0.0001$), FWC ($p<0.0001$), and FAC ($p<0.0001$). DIP base and status conditions for LOAD and FWC increased from 0.075 lb/ac to 0.084 lb/ac and from 0.033 mg/l to 0.037 mg/l, respectively. These results indicate a change in DIP delivery and phosphorus cycling in the watershed and surface waters. R.E. Carlson, and J. Simpson (1996) suggest that as concentrations of orthophosphate increase, one can infer that phosphorus is either not needed by algae or orthophosphate is being supplied at rates faster than the biota can take it up. Orthophosphate also can be released from organic matter and sediment by bacterial decay (Oliver, Dr. R. and I. Webster, 1999). While orthophosphate does occur naturally at background rates of 0.01 mg/l, it also is found in fertilizers and has been used in drinking water operations to suppress lead concentrations (City of Winnipeg, 2001).

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 occurred in the SS record. Trend analyses did not show the existence of a trend for LOAD ($p = 0.569$) or FWC ($p = 0.858$). After removing the effect of flow on the concentration, the analysis of FAC indicated a nonsignificant ($p = 0.537$) trend. These results suggested that the processes of sediment delivery and transport in the Susquehanna watershed, upstream of Towanda, have 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 (5,862 cfs) was lower than the base discharge (12,010 cfs), the test on the FLOWs did not detect ($p = 0.266$) a trend in the discharge time series.

With the exception of DON, trends were detected in the FAC time series for all nitrogen forms. The transport record (LOAD) for TN shows a decrease from a base yield of 5.6 lb/ac to a status yield of 4.1 lb/ac. However, the trend analysis did not indicate the existence of a trend ($p = 0.075$). A trend in TN FWC was not detected ($p= 0.537$), where the base and status monthly

Table 20. Trend Statistics for the Susquehanna River at Danville, Pa., January 1985 through December 2000

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.266	-37	13	NS	12,000	5,862
TN	FAC	0.000	-35	-23	DN	--	--
TN	FWC	0.537	-35	18	NS	2.450	2.430
TN	LOAD	0.075	-45	-1	NS	5.640	4.130
DN	FAC	0.000	-27	-14	DN	--	--
DN	FWC	0.784	-30	26	NS	2.260	2.290
DN	LOAD	0.178	-41	6	NS	4.870	3.410
TON	FAC	0.000	-45	-22	DN	--	--
TON	FWC	0.353	-39	10	NS	1.150	0.890
TON	LOAD	0.033	-49	-8	NS	2.480	1.720
DON	FAC	0.097	-24	2	NS	--	--
DON	FWC	0.958	-25	36	NS	0.740	0.730
DON	LOAD	0.346	-37	14	NS	1.650	1.310
DNH	FAC	0.000	-67	-50	DN	--	--
DNH	FWC	0.001	-65	-37	DN	0.180	0.086
DNH	LOAD	0.000	-71	-47	DN	0.350	0.085
TNH	FAC	0.000	-65	-47	DN	--	--
TNH	FWC	0.009	-60	-27	DN	0.210	0.086
TNH	LOAD	0.000	-66	-39	DN	0.380	0.100
DKN	FAC	0.001	-34	-11	DN	--	--
DKN	FWC	0.580	-34	19	NS	0.890	0.790
DKN	LOAD	0.093	-45	0	NS	2.030	1.320
TKN	FAC	0.000	-46	-27	DN	--	--
TKN	FWC	0.270	-41	6	NS	1.300	0.990
TKN	LOAD	0.019	-51	-11	NS	2.830	1.930
TNO23	FAC	0.000	-25	-11	DN	--	--
TNO23	FWC	0.992	-25	34	NS	1.350	1.450
TNO23	LOAD	0.315	-37	13	NS	2.790	2.080
DNO23	FAC	0.000	-25	-11	DN	--	--
DNO23	FWC	0.986	-26	34	NS	1.360	1.440
DNO23	LOAD	0.296	-38	12	NS	2.820	2.060
TP	FAC	0.000	-48	-24	DN	--	--
TP	FWC	0.384	-40	9	NS	0.16	0.140
TP	LOAD	0.069	-49	-9	NS	0.38	0.280
DP	FAC	0.000	-53	-33	DN	--	--
DP	FWC	0.072	-50	-10	NS	0.060	0.051
DP	LOAD	0.002	-58	-24	DN	0.130	0.089
DIP	FAC	0.000	70	210	BMDL	--	--
DIP	FWC	0.019	39	149	NS	0.021	0.043
DIP	LOAD	0.043	16	109	NS	0.045	0.071
TOC	FAC	0.000	-31	-18	DN	--	--
TOC	FWC	0.685	-32	23	NS	6.820	6.190
TOC	LOAD	0.131	-43	3	NS	14.600	12.200
SS	FAC	0.000	-54	-26	DN	--	--
SS	FWC	0.423	-58	35	NS	115.600	75.600
SS	LOAD	0.184	-65	13	NS	228.000	88.200

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

mean concentrations showed little change from 2.4 mg/l to 2.4 mg/l, respectively. However, the result for TN FAC indicated a significant ($p < 0.0001$) downward trend, with a slope magnitude between -23 to -35 percent. The result for DN FAC also showed a significant ($p<0.0001$) downward trend of –14 to –27 percent. This suggested that some change had taken place, resulting in decreased inputs of nitrogen to the streams between Towanda and Danville, but flow conditions from 1985 through 2000 had masked the effects of this change in the LOAD and FWC records.

Trend analysis for phosphorus indicated trends in both the TP FAC ($P<0.0001$) and DP FAC ($P<0.0001$), with slope magnitudes ranging from –24 to –48 percent and –33 to –53 percent, respectively. A significant trend in DP LOAD ($p = 0.002$) also was detected. The DP status yield of 0.09 lbs/ac decreased from the base yield of 0.13 lbs/ac, with a slope range from -24 to -58 percent. No trends were present in the other time series for TP, DP, or DIP. The significance of the TP FAC and DP FAC trend results suggested that some change had taken place, resulting in reduced inputs of phosphorus to the river upstream of Danville.

Although there was a yield and concentration decrease in the base and status conditions, the analysis for SS at Danville did not indicate the presence of trends in LOAD ($p = 0.184$) or FWC ($p = 0.423$). 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 a change in the sediment delivery processes had occurred in the watershed between Towanda and Danville, but that the sequence of flows from January 1985 through December 2000 had masked the effects of this change in the LOAD and FWC time series.

West Branch Susquehanna River at Lewisburg, Pa.

Table 21 presents the results for the West Branch Susquehanna River at Lewisburg. Although the base and status flows indicated an increase in flow from 9,820 cfs to 12,500 cfs, analysis of the discharge record did not detect ($p = 0.670$) the presence of a trend in monthly mean discharge (FLOW) from 1985 through 2000. For calendar 2000, the discharge record at the West Branch Susquehanna River gage at Williamsport, Pa. showed a drier-than-normal year, with flows estimated at 81 percent of the long-term normal (Lazorchick, 2001).

Overall, significant downward trends occurred in TN LOAD ($p=0.002$), FWC ($p=0.01$), and FAC ($P<0.0001$). The base and status condition in concentration decreased from 1.4 mg/l to 0.7 mg/l, while yield decreased from 6.0 lbs/ac to 2.3 lbs/ac. Analysis of the organic and inorganic nitrogen time series indicated the presence of trends. Significant downward trends occurred in the TON LOAD ($p < 0.0001$), FWC ($p = 0.001$), and FAC ($p<0.0001$), which were strong indications 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 TNO23, DNO23 and ammonia nitrogen. Besides the trends in the FACs, the total and dissolved forms of ammonia nitrogen showed downward trends in both the LOAD and FWC time series as well. Trends were not detected in the LOAD and FWC time series for total and dissolved NO23. Below normal flows in 2000 could have had a more pronounced effect on the NO23 concentration record (FWC) and the NO23 transport record (LOAD), masking any trends in these time series. However, the FAC results suggested a change had taken place, reducing nitrite plus nitrate delivery to the river.

Trend analysis 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 obser-

Table 21. ***Trend Statistics for the West Branch Susquehanna River at Lewisburg, Pa., January 1985 through December 2000***

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.670	-20	43	NS	9,820	12,500
TN	FAC	0.000	-34	-21	DN	--	--
TN	FWC	0.010	-57	-23	DN	1.430	0.690
TN	LOAD	0.002	-54	-18	DN	6.010	2.320
DN	FAC	0.000	-26	-14	DN	--	--
DN	FWC	0.028	-53	-15	NS	1.240	0.620
DN	LOAD	0.009	-32	-32	DN	5.140	2.220
TON	FAC	0.000	-48	-22	DN	--	--
TON	FWC	0.001	-66	-38	DN	0.650	0.250
TON	LOAD	0.000	-63	-34	DN	2.970	0.760
DON	FAC	0.073	-27	1	NS	--	--
DON	FWC	0.020	-55	-20	NS	0.430	0.190
DON	LOAD	0.007	-52	-14	DN	1.920	0.700
DNH	FAC	0.009	-40	-6	DN	--	--
DNH	FWC	0.004	-60	-28	DN	0.067	0.027
DNH	LOAD	0.001	-57	-23	DN	0.280	0.100
TNH	FAC	0.003	-44	-11	DN	--	--
TNH	FWC	0.004	-60	-28	DN	0.072	0.030
TNH	LOAD	0.001	-57	-23	DN	0.300	0.100
DKN	FAC	0.150	-26	5	BMDL	--	--
DKN	FWC	0.025	-55	-19	NS	0.480	0.210
DKN	LOAD	0.010	-52	-13	DN	2.170	0.780
TKN	FAC	0.000	-42	-15	DN	--	--
TKN	FWC	0.004	-63	-33	DN	0.700	0.280
TKN	LOAD	0.001	-60	-28	DN	3.240	0.880
TNO23	FAC	0.000	-26	-14	DN	--	--
TNO23	FWC	0.042	-51	-11	NS	0.750	0.430
TNO23	LOAD	0.017	-29	-29	NS	3.040	1.470
DNO23	FAC	0.000	-26	-14	DN	--	--
DNO23	FWC	0.040	-51	-12	NS	0.750	0.420
DNO23	LOAD	0.016	-30	-30	NS	3.030	1.460
TP	FAC	0.004	-43	-10	DN	--	--
TP	FWC	0.012	-59	-27	NS	0.069	0.036
TP	LOAD	0.005	-57	-22	DN	0.270	0.110
DP	FAC	0.000	-60	-41	DN	--	--
DP	FWC	0.000	-73	-51	DN	0.039	0.014
DP	LOAD	0.000	-61	-61	DN	0.170	0.056
DIP	FAC	0.000	70	220	BMDL	--	--
DIP	FWC	0.196	0	80	NS	0.012	0.014
DIP	LOAD	0.027	7	92	NS	0.043	0.064
TOC	FAC	0.972	-11	11	NS	--	--
TOC	FWC	0.159	-46	-2	NS	2.460	1.410
TOC	LOAD	0.150	-42	4	NS	9.620	5.030
SS	FAC	0.600	-20	48	NS	--	--
SS	FWC	0.301	-62	22	NS	33.600	11.000
SS	LOAD	0.359	-60	30	NS	137.800	33.600

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

vations below the level of detection exceeded 20 percent, an analysis of the FAC trend could not be completed for DIP.

Significant trends for TP occurred in the LOAD ($p = 0005$) and FAC ($p = 0.004$) time series, but did not occur in the FWCs. Slope magnitudes for LOAD and FAC ranged from –22 to -57 percent and -10 to -43 percent, respectively. TP concentrations and yields from the West Branch Susquehanna River are among the lowest, when compared to the other major rivers in the study area. Yields changed from a base of 0.27 lb/ac to a status of 0.11 lb/ac. Median monthly concentrations changed from a base of 0.07 mg/l to a status of 0.04 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 ($p = 0.359$) or FWC ($p = 0.301$). After removing the effect of flow on the concentration, the analysis of FAC also indicated no significant ($p = 0.600$) 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 (2,883 cfs) was only slightly higher than the base discharge (2,560 cfs). The test on FLOW did not detect the presence ($p = 0.203$) of a trend. Calendar year 2000 discharges at the Newport gage were 80 percent of the long-term normal (Lazorchick, 2001).

Trends were detected in the FAC time series for every nitrogen species, except the dissolved organic fraction. Other than ammonia, the LOAD and FWC time series lacked the presence of trend for the various inorganic and organic nitrogen forms. Significant downward trends occurred in the TNH FWC ($p=0.002$) and FAC ($p < 0.0001$) time series, with a slope magnitude of –31 to -62 percent and –37 to –59 percent, respectively. The DNH trends in LOAD, FWC and FAC also were significant ($p = 0.007$, $p= 0.001$ and $p < 0.0001$, respectively).

Trend analysis for phosphorus showed a pattern similar to that in the nitrogen time series; trends in the FAC and not in LOAD and FWC. However, there were significant upward trends in the DIP LOAD ($p = 0.001$) and FAC ($p<0.0001$). Once the effect of flow was removed in the TP and DP time series, significant downward trends were present in TP FAC ($p<0.0001$) and DP FAC ($p=0.002$).

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 ($p = 0.012$) 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.

There was a strong influence of flow on the transport and concentration time series in the Juniata River from 1985 to 2000. The lack of trend in the LOAD and FWC time series indicated that flow variability had a pronounced effect on concentration for the various constituents, and the dominant presence of 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, the pattern in the trend results for the 45 time series analyzed indicate that flow conditions had masked the underlying changes of delivery and transport since 1985.

Table 22. Trend Statistics for the Juniata River at Newport, Pa., January 1985 through December 2000

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.203	21	21	NS	2,560	2,883
TN	FAC	0.000	-21	-11	DN	--	--
TN	FWC	0.351	-38	11	NS	2.460	1.600
TN	LOAD	0.985	-26	34	NS	4.440	3.690
DN	FAC	0.000	-15	-5	DN	--	--
DN	FWC	0.511	-35	18	NS	2.080	1.510
DN	LOAD	0.733	-21	42	NS	4.020	3.470
TON	FAC	0.001	-34	-11	DN	--	--
TON	FWC	0.151	-46	-2	NS	0.900	0.500
TON	LOAD	0.504	-34	18	NS	1.690	1.080
DON	FAC	0.919	-12	12	NS	--	--
DON	FWC	0.581	-33	20	NS	0.550	0.390
DON	LOAD	0.653	-20	45	NS	1.180	0.890
DNH	FAC	0.000	-59	-37	DN	--	--
DNH	FWC	0.002	-62	-31	DN	0.072	0.029
DNH	LOAD	0.012	-54	-16	NS	0.120	0.065
TNH	FAC	0.000	-61	-39	DN	--	--
TNH	FWC	0.001	-63	-33	DN	0.077	0.029
TNH	LOAD	0.007	-55	-19	DN	0.130	0.067
DKN	FAC	0.120	-21	3	NS	--	--
DKN	FWC	0.358	-38	11	NS	0.640	0.400
DKN	LOAD	0.988	-26	34	NS	1.340	0.920
TKN	FAC	0.000	-34	-11	DN	--	--
TKN	FWC	0.157	-45	-2	NS	1.000	0.550
TKN	LOAD	0.519	-34	19	NS	1.850	1.150
TNO23	FAC	0.000	-18	-8	DN	--	--
TNO23	FWC	0.459	-36	16	NS	1.530	1.100
TNO23	LOAD	0.820	-23	39	NS	3.000	2.540
DNO23	FAC	0.000	-16	-5	DN	--	--
DNO23	FWC	0.539	-34	19	NS	1.470	1.100
DNO23	LOAD	0.703	-20	43	NS	2.890	2.550
TP	FAC	0.000	-47	-23	DN	--	--
TP	FWC	0.044	-52	-14	NS	0.140	0.082
TP	LOAD	0.186	-42	4	NS	0.260	0.170
DP	FAC	0.002	-37	-9	DN	--	--
DP	FWC	0.084	-47	-4	NS	0.079	0.053
DP	LOAD	0.340	-36	16	NS	0.150	0.120
DIP	FAC	0.000	60	207	UP	--	--
DIP	FWC	0.030	33	139	NS	0.049	0.052
DIP	LOAD	0.001	60	188	UP	0.120	0.180
TOC	FAC	0.000	-33	-16	DN	--	--
TOC	FWC	0.104	-46	-3	NS	5.340	3.140
TOC	LOAD	0.412	-35	17	NS	9.830	7.070
SS	FAC	0.012	-48	-8	DN	--	--
SS	FWC	0.513	-56	44	NS	51.300	23.700
SS	LOAD	0.917	-46	74	NS	83.100	48.600

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

Susquehanna River at Marietta, Pa.

The station at Marietta represents the response of the Susquehanna River to the cumulative effects of activities affecting water quality in the basin before the impact of several reservoirs on the lower reach of the river. Table 23 shows the results for the Susquehanna River at Marietta. While the status flow of 25,710 cfs was higher than the base flow of 22,330 cfs, the test on the FLOW did not detect ($p = 0.989$) a trend in the discharge time series.

For the period 1987 to 2000, there were significant downward trends in the TN FAC ($p < 0.0001$) and DN FAC ($p < 0.0001$), suggesting that the water quality improvements 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 FAC and DNO23 FAC showed significant downward trends ($p <0.0001$ and $p =<00001$, respectively). Downward trends also were detected in the FAC record for TNH and DNH (Table 23).

Conversely, significant upward trends occurred for organic nitrogen (Table 23). There is a strong presence of increasing trends in total and dissolved organic nitrogen (TON FAC, $p < 0.0001$ and DON FAC, $p < 0.0001$) indicated by steep slope ranges associated with the trends. Although the major fraction of TN was the inorganic species, the increasing trends in organic nitrogen may influence the direction for TN. What was not clear was whether 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 DON LOAD and DON FWC time series suggested an organic nitrogen transport and delivery mechanism.

For TP and DP, relatively no change occurred in base and status yields and concentration. The trend analyses did not indicate the presence of a trend in LOAD, FWC, and FAC time series. However, the analysis of DIP time series indicated significant upward trends in LOAD ($p < 0.0001$) and FWC ($p < 0.0001$). The slope magnitudes associated with the DIP LOAD and FWC time series were extremely large, suggesting a heavy influence of transport and delivery processes on the trends. Although the corresponding DIP LOAD and FWC slope magnitudes were very large, the overall trends in TP and DP did not change. Perhaps the decreasing nitrogen trends have suppressed algal growth making orthophosphate (DIP) more bioavailable, resulting in what we observed as increasing DIP trends. Because greater than 20 percent of the observations were below the detection level, an analysis of the FAC trend could not be completed for DIP.

SS base and status yield and concentration indicated a slight increase, but trend analyses indicated a lack of trend in LOAD ($p = 0.810$) and FWC ($p = 0.812$). After removing the effect of flow on the concentration, the analysis of FAC showed no trend ($p = 0.706$). These results suggested that the process of sediment delivery and transport, as recorded on the Susquehanna River at Marietta from 1987 to 2000, had not significantly changed; therefore, no trend was detected.

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 472 cfs to 584 cfs, an analysis of the discharge record did not detect ($p = 0.567$) the presence of a trend in FLOW.

A significant downward trend of –13 to -22 percent was detected in TN FAC ($p < 0.0001$). No trend was detected in the TN LOAD and FWC record. Results from the DN analysis did not detect the presence of any trends. Most of the trends in the nitrogen data set were detected in the total fraction rather than in the dissolved fraction,

Table 23. ***Trend Statistics for the Susquehanna River at Marietta, Pa., January 1985 through December 2000***

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.989	-23	29	NS	22,300	25,710
TN	FAC	0.000	-30	-18	DN	--	--
TN	FWC	0.306	-38	3	NS	2.680	1.650
TN	LOAD	0.203	-38	3	NS	5.204	4.00
DN	FAC	0.000	-20	-6	DN	--	--
DN	FWC	0.602	-31	15	NS	2.160	1.480
DN	LOAD	0.503	-31	15	NS	4.410	3.580
TON	FAC	0.000	26	91	UP	--	--
TON	FWC	0.046	24	106	NS	0.790	0.850
TON	LOAD	0.018	23	106	NS	1.800	2.390
DON	FAC	0.000	161	323	UP	--	--
DON	FWC	0.000	147	310	UP	0.440	0.860
DON	LOAD	0.000	146	310	UP	0.950	2.310
DNH	FAC	0.000	-48	-24	DN	--	--
DNH	FWC	0.069	-48	-14	NS	0.088	0.040
DNH	LOAD	0.022	-48	-14	NS	0.190	0.090
TNH	FAC	0.000	-53	-29	DN	--	--
TNH	FWC	0.041	-51	-18	NS	0.079	0.042
TNH	LOAD	0.012	-51	-19	NS	0.190	0.088
DKN	FAC	0.563	-19	12	NS	--	--
DKN	FWC	0.933	-21	31	NS	0.560	0.420
DKN	LOAD	0.924	-21	31	NS	1.160	1.030
TKN	FAC	0.000	-40	-16	DN	--	--
TKN	FWC	0.316	-39	2	NS	0.880	0.560
TKN	LOAD	0.218	-39	2	NS	2.120	1.550
TNO23	FAC	0.000	-21	-7	DN	--	--
TNO23	FWC	0.518	-33	12	NS	1.520	1.080
TNO23	LOAD	0.423	-33	12	NS	3.160	2.560
DNO23	FAC	0.000	-21	-6	DN	--	--
DNO23	FWC	0.540	-32	13	NS	1.500	1.070
DNO23	LOAD	0.445	-32	12	NS	3.150	2.550
TP	FAC	0.379	-22	10	NS	--	--
TP	FWC	0.907	-38	72	NS	0.110	0.094
TP	LOAD	0.902	-20	33	NS	0.240	0.250
DP	FAC	0.546	-10	23	NS	--	--
DP	FWC	0.680	-15	41	NS	0.055	0.047
DP	LOAD	0.609	-15	41	NS	0.120	0.120
DIP	FAC	0.000	529	1,050	BMDL	--	--
DIP	FWC	0.000	350	1,147	UP	0.010	0.034
DIP	LOAD	0.000	479	864	UP	0.022	0.150
TOC	FAC	0.045	-14	0	UP	--	--
TOC	FWC	0.942	-24	27	NS	4.470	3.350
TOC	LOAD	0.917	-24	27	NS	9.720	9.160
SS	FAC	0.706	-24	21	NS	--	--
SS	FWC	0.812	-34	82	NS	50.400	55.600
SS	LOAD	0.810	-34	82	NS	110.300	116.600

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

Table 24. Trend Statistics for the Conestoga River at Conestoga, Pa., January 1985 through December 2000

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.567	7	7	NS	472.00	584.300
TN	FAC	0.000	-22	-13	DN	--	--
TN	FWC	0.116	-21	-21	NS	12.10	5.590
TN	LOAD	0.161	-15	-15	NS	28.10	27.800
DN	FAC	0.390	-7	3	NS	--	--
DN	FWC	0.550	-8	-8	NS	9.84	5.850
DN	LOAD	0.895	-1	-1	NS	23.10	26.500
TON	FAC	0.000	-42	-21	DN	--	--
TON	FWC	0.031	-51	-12	NS	2.55	0.830
TON	LOAD	0.048	-48	-6	NS	6.28	4.840
DON	FAC	0.932	-15	16	NS	--	--
DON	FWC	0.643	-31	24	NS	1.46	0.610
DON	LOAD	0.966	-1	-1	NS	3.70	3.810
DNH	FAC	0.000	-75	-65	DN	--	--
DNH	FWC	0.000	-78	-61	DN	0.36	0.067
DNH	LOAD	0.000	-77	-58	DN	0.93	0.360
TNH	FAC	0.000	-76	-66	DN	--	--
TNH	FWC	0.000	-79	-62	DN	0.37	0.067
TNH	LOAD	0.000	-77	-59	DN	0.95	0.380
DKN	FAC	0.000	-32	-11	DN	--	--
DKN	FWC	0.076	-45	-1	NS	1.94	0.680
DKN	LOAD	0.108	-21	-21	NS	5.04	4.220
TKN	FAC	0.000	-48	-32	DN	--	--
TKN	FWC	0.006	-57	-23	DN	3.13	0.870
TKN	LOAD	0.008	-54	-17	DN	8.13	5.450
TNO23	FAC	0.792	-6	8	NS	--	--
TNO23	FWC	0.674	-6	-6	NS	7.86	4.960
TNO23	LOAD	0.911	1	1	NS	18.80	22.900
DNO23	FAC	0.950	-6	7	NS	--	--
DNO23	FWC	0.641	-6	-6	NS	7.66	4.940
DNO23	LOAD	0.955	1	1	NS	18.60	22.100
TP	FAC	0.001	-33	-10	DN	--	--
TP	FWC	0.155	-45	0	NS	0.84	0.340
TP	LOAD	0.240	-41	7	NS	1.68	1.660
DP	FAC	0.000	-41	-30	DN	--	--
DP	FWC	0.005	-54	-17	DN	0.39	0.170
DP	LOAD	0.004	-33	-33	DN	0.88	0.720
DIP	FAC	0.000	-38	-18	DN	--	--
DIP	FWC	0.016	-50	-11	NS	0.32	0.170
DIP	LOAD	0.015	-29	-29	NS	0.77	0.660
TOC	FAC	0.000	-54	-44	DN	--	--
TOC	FWC	0.000	-64	-35	DN	12.60	3.310
TOC	LOAD	0.000	-61	-30	DN	31.10	19.200
SS	FAC	0.000	-49	-20	DN	--	--
SS	FWC	0.088	-70	-1	NS	185.10	120.500
SS	LOAD	0.132	-67	6	NS	484.50	413.100

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

suggesting that particulate forms play an important role in the delivery of nitrogen in the Conestoga River. Significant trends for the dissolved fraction 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 reductions of ammonia and TON.

For TP, significant trends occurred in the FAC ($p = 0.001$) time series, but not in LOAD ($p = 0.240$) and FWC ($p = 0.155$). As presented in Table 24, the analysis of DP 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 ($p = 0.132$) and FWC ($p = 0.088$) 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 and transport records. 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 concentration (FWC) and transport (LOAD) record.

Discussion

For many water quality constituents, the concentration is often related to streamflow. Extremes in stream discharge (wet years and dry years) that occur at the beginning or end of a time series period can have a great influence on trends in concentration and load. This was observed in the LOAD and FWC time series where calendar year 2000 discharges varied throughout the basin. In the northern areas of the Susquehanna River Basin where the stations at Towanda and Danville are located, flows were greater than long-term normal flows, i.e., a wet year. The subbasins in the west, such as the West Branch Susquehanna and Juniata Subbasins, stream flows were significantly less than long-term normal flows, i.e., a dry year. The middle and lower watersheds of the Susquehanna River Basin experienced near normal to slightly less than normal flows.

This relationship of concentration and load varies from stream to stream and can be very complex depending on the type of flow year and the dominant activities in the watershed. 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 concentrations 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.

The LOAD, FWC, FAC, and FLOW 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. Significant changes in particular parameters, such as the increases seen in DIP, should lend themselves to more study on nutrient processing within the stream as the mass of nutrients entering the stream system change over time.

The pattern of trends in the Conestoga River suggested that management activities related to nonpoint erosion, transport and delivery processes, along with point-source 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 2000 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 2000. 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 above normal in 2000 in all areas, except the West Branch Susquehanna and the Juniata Subbasins. Rainfall ranged from 14.58 inches below normal in the Juniata Subbasin above Newport to 4.45 inches above normal in the watershed above Towanda. Water discharges ranged from 75.5 to 120.6 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, TP and SS yields 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 2000 were highest in the spring (April-June), followed by winter (January-March), then fall (October-December) at Towanda, Danville, Lewisburg, and Marietta. Seasonal discharges at Newport and Conestoga were highest in the winter, followed by spring. Seasonal variation of TN, TP, and SS corresponded with seasonal discharge at all sites except Newport

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 2000 TN yields showed the same relationship among the sites in the winter, summer, and fall. TN yields in the spring increased between Towanda and Danville and decreased between Danville and Marietta. The long-term and 2000 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 2000 seasonal yields did not show any consistent relationships among the sites. Comparison of long-term and 2000 seasonal yields among the tributary sites at Lewisburg, Newport, and Conestoga indicated that the TN, TP, and SS 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 2000 SS yields among the tributary sites were not consistent with the long-term yields.

Comparison of the 2000 annual yields and the 5-year baselines indicates that there were significant decreases of TN at all sites. TP yields were significantly higher than the baseline yields at Towanda, Newport, Marietta, and Conestoga. The 2000 TP yield at Danville and Lewisburg showed no significant change from the baseline. Comparisons of SS yields indicated that there was a significant increase at Marietta and a significant decrease at Danville. There were no significant changes in the yields at Towanda, Lewisburg, Newport and Conestoga.

Trend analyses of water quality and flow data collected at the six monitoring sites were completed for the period January 1985 through December 2000. Linear regression techniques and the USGS estimator model were used to estimate the direction and magnitude of trends for discharge, SS, TOC, and several forms of the nutrients, nitrogen, and phosphorus. Analyses for trends 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. The FLOW, LOAD, FWC, and FAC time series represent four separate 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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