NUTRIENTS AND SUSPENDED SEDIMENT TRANSPORTED IN THE SUSQUEHANNA RIVER BASIN, 2001, AND TRENDS, JANUARY 1985 THROUGH DECEMBER 2001

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ABSTRACT

Nutrient and suspended-sediment samples were collected in calendar year 2001 during base flow and stormflow conditions at six sites located across the Susquehanna River Basin. Samples were taken 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.

The Susquehanna River at Marietta had the highest loads for both nutrients and suspended sediment. The Susquehanna River at Danville had the next highest nutrient loads while the Susquehanna River at Towanda followed Marietta in suspended-sediment loads. While the Conestoga River at Conestoga had the smallest load, in pounds per year, it 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 2001 annual yields and the 5-year baselines indicated that there were decreases of total nitrogen at all sites. Total phosphorus yields were higher than the baseline yields at Marietta, Towanda Newport, and Conestoga and remained the same at Lewisburg and Danville. Comparisons of suspend sediment yields indicated that there was an increase at Newport and Towanda and no change at the remaining four sites.

Trends were computed for the period January 1985 through December 2001 for flow, suspended sediment, total organic carbon, and several forms of 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 throughout the Susquehanna River Basin. Total phosphorus showed no trend at Towanda and at Marietta while all other sites showed improving conditions in total phosphorus for 2001. Improving conditions in suspended sediment occurred at Danville and Conestoga while all other sites showed no trend.

INTRODUCTION

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

Background

Pennsylvania entered into the Chesapeake Bay Agreement in 1983 with Maryland, Virginia, the District of Columbia, the USEPA, and the Chesapeake Bay Commission to assist in the effort to restore the Bay. This agreement was reaffirmed in 1987 and 1992, and significant efforts were undertaken to reduce nitrogen and phosphorus loads to the Bay.

Portions of the Bay and its tidal tributaries were included in Maryland's 1996 and 1998 lists of impaired waters and in Virginia's 1998 list of impaired waters, as required by the federal Clean Water Act. Normally, this action would result in development of a regulatory "total maximum daily load" or TMDL for the affected watershed. For the Bay, this would mean that the TMDL would have to address the upstream causes of impairment in all the states with land areas draining into the Bay, including Delaware, New York, and West Virginia, which did not sign the agreement in 1983 or in later years.

The success of USEPA's Chesapeake Bay Program is largely due to the cooperative nature of the partnerships involved. Although the Chesapeake Bay Program is taking the lead to coordinate the Bay restoration effort, the nonsignatory states are involved in the Bay cleanup through the Chesapeake Bay Water Quality Steering Committee, which was formed in August 1999. SRBC and the Interstate Commission on the Potomac River Basin both participate on the steering committee in an advisory capacity, but only the states, the District of Columbia, and USEPA have official voting status.

In addition to the steering committee work, the Chesapeake 2000 Agreement and a subsequent 6-state Memorandum of Understanding committed all six Bay watershed states, the District of Columbia, and USEPA to work together to restore Bay water quality using a jointly defined set of water quality conditions needed to protect aquatic living resources. The new agreement seeks to avoid regulatory approaches by achieving water quality improvements prior to the timeframe when a baywide TMDL would need to be established. The agreement calls for its signatories to, "by 2010, correct the nutrient and sediment-related impairments in the Bay and its tidal tributaries sufficiently to remove the Bay and the tidal portions of its tributaries from the list of impaired waters under the Clean Water Act."

Given that the lower Susquehanna River Basin is thought to be the single greatest source of suspended sediment to the Bay, 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. In 1990, the number of sampling sites was reduced to five long-term monitoring stations. An additional site was included in 1994, and sampling at these six sites has continued to the present day. 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.

The existing Susquehanna River sediment and nutrient sites are important in documenting Pennsylvania's real progress in the Bay cleanup effort. These sites have been used to keep track of trends in water quality improvement. With 50 percent of the Bay's total freshwater inflow coming from the Susquehanna River, these sites are critical calibration sites for the Chesapeake Bay Model, which is being used as a major tool in planning the restoration effort.

Objective of the Study

The objective of SRBC's monitoring program is 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 are then used to compute annual nutrient and suspended-sediment loads and trends 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 2001, 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, as well as the results of statistical trend analysis for the period January 1985 through December 2001 for nitrogen, phosphorus, suspended sediment, total organic carbon, and water discharge.

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 Bay. The climate in the Susquehanna River Basin varies considerably from the low lands adjacent to the 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^{o} F (degrees Fahrenheit) near the Pennsylvania-Maryland border to 45^{o} 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 with woodland accounting for 65 percent; cultivated, 18 percent; urban, 9 percent; and grassland, 7 percent (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 Lower Susquehanna Subbasins. Most of the grassland is in the northern part of the basin as the shorter and more uncertain growing season is better suited to pasture and hay production. 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, and they include Binghamton and Elmira-Corning, NY and Scranton and Wilkes-Barre, PA. The major urban areas in the West Branch Susquehanna River Basin are Williamsport and Lock Haven.

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.

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 1. The Susquehanna River Basin, Subbasins, and Population Centers

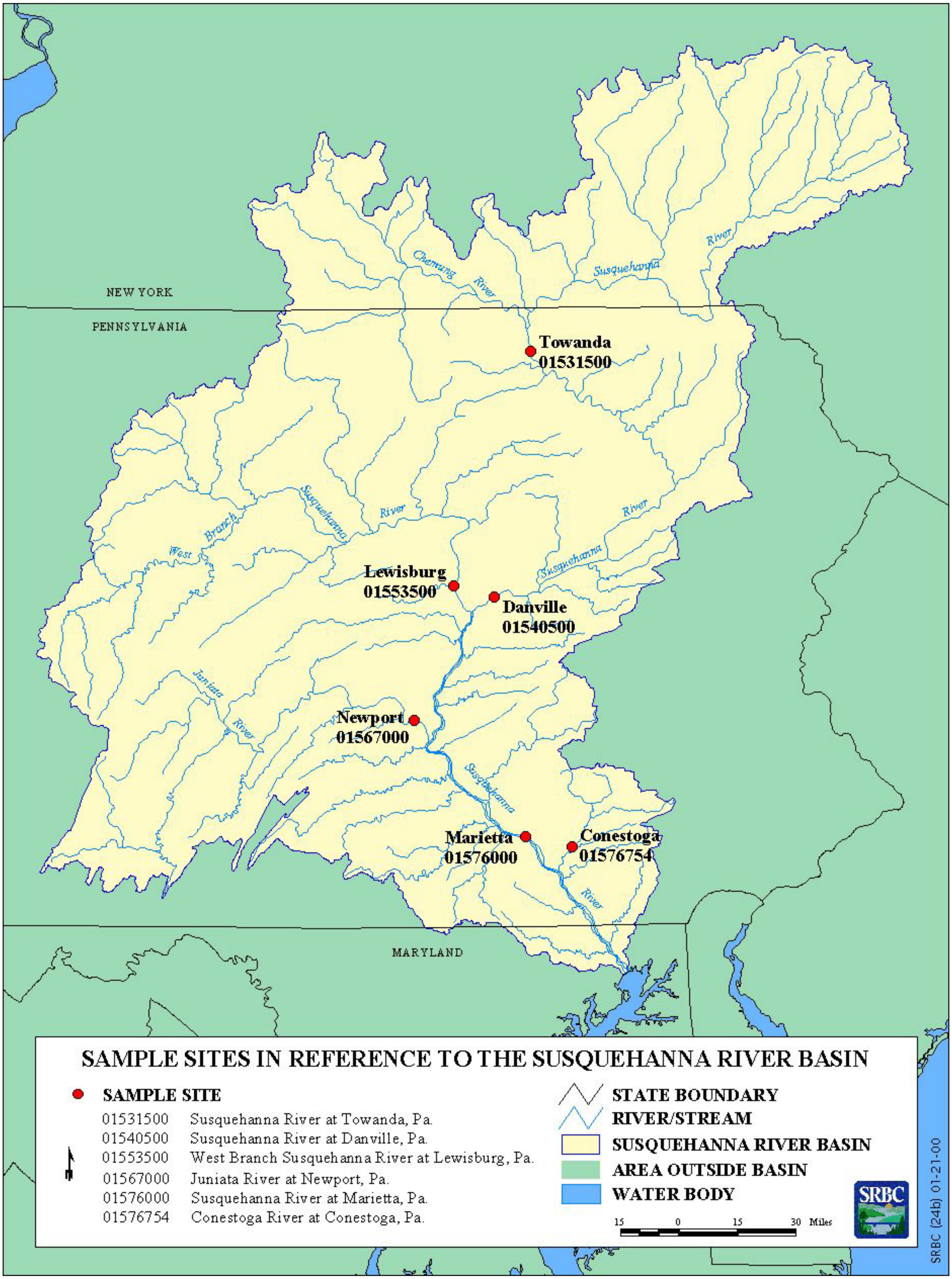


Figure 2. Locations of Sampling Sites on the Susquehanna River and Three Major Tributaries in the Basin

The drainage area at Towanda is 7,797 square miles of which, 6,262 square miles lie in New York.

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 tributaries between Towanda and Danville.

Data collected from the West Branch Susquehanna River at Lewisburg, Pa., represent the loadings from this major tributary to the mainstem. 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 mainstem, includes much of southcentral Pennsylvania, and has a drainage area, above Newport, Pa., of 3,354 square miles. This station represents the loadings from the Juniata River. 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.

SAMPLE COLLECTION AND ANALYSIS

SRBC staff collected samples at each of the six sites to measure nutrient and suspended-sediment concentrations during periods of low and high flow. Random samples were collected on or near the 12th of the month regardless of flow. Low flow samples were collected at the end of the month during base flow conditions. In the wake of high flow events, collection of low flow samples was delayed until moderate flows prevailed, typically 7 to 10 days. All low flow and random samples were collected by hand with depth-integrating samplers. Storm samples were also taken during high flow events throughout the year. Samples were collected 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.

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

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

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 2001 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 and departure from the long-term values. The 2001 annual precipitation was less than the long-term annual average at all six sites. Precipitation ranged from 19.75 inches below normal in the Juniata Subbasin to 4.46 inches below normal in the watershed above Towanda. Seasonal precipitation was below normal during all seasons for all stations except summer at Towanda, which was above average.

Table 3. Summary for Annual Precipitation for Selected Areas in the Susquehanna River Basin, Calendar Year 2001

		Average Long-term Precipitation inches	Calendar Year 2001 Precipitation inches	Departure From Long Term inches
Susquehanna River above Towanda, Pa.	January-March	7.96	6.95	-1.01
	April-June	9.98	8.82	-1.16
	July-September	10.22	10.48	+0.26
	October-December	8.70	6.15	-2.55
	Yearly Total	**36.86**	**32.40**	**-4.46**
Susquehanna River above Danville, Pa.	January-March	7.90	6.78	-1.12
	April-June	10.07	8.68	-1.39
	July-September	10.36	10.36	0
	October-December	8.72	6.03	-2.69
	Yearly Total	**37.05**	**31.85**	**-5.2**
West Branch Susquehanna River above Lewisburg, Pa.	January-March	8.90	5.75	-3.15
	April-June	11.38	9.08	-2.3
	July-September	11.53	10.19	-1.34
	October-December	9.38	5.6	-3.78
	Yearly Total	**41.19**	**30.62**	**-10.57**
Juniata River above Newport, Pa.	January-March	8.84	4.67	-4.17
	April-June	10.95	7.12	-3.83
	July-September	10.83	4.73	-6.1
	October-December	9.07	3.42	-5.65
	Yearly Total	**39.69**	**19.94**	**-19.75**
Susquehanna River above Marietta, Pa.	January-March	8.51	6.94	-1.57
	April-June	10.66	8.92	-1.74
	July-September	10.75	9.40	-1.35
	October-December	9.01	5.37	-3.64
	Yearly Total	**38.93**	**30.63**	**-8.3**
Conestoga River above Conestoga, Pa.	January-March	8.58	7.08	-1.5
	April-June	10.80	6.52	-4.28
	July-September	11.78	6.59	-5.19
	October-December	9.35	2.49	-6.86
	Yearly Total	**40.51**	**22.68**	**-17.83**

WATER DISCHARGE

Mean water discharges for calendar year 2001 are listed in Table 4, along with the long-term annual mean discharges and the percent of long-term annual mean discharge for each site. As shown in Table 4 and Figure 3, the annual mean water discharge was below normal for all sites. Streamflow ranged from 57.9 percent of the long-term mean at Conestoga to 72.8 percent at Towanda.

Table 4. Annual Water Discharge, Calendar Year 2001

Site Short Name	Years of Record	Long-term Annual Mean cfs[1]	2001 Mean cfs	2001 Percent of Long-term Mean
Towanda	88	10,617	7,727	72.8
Danville	97	15,224	11,067	72.7
Lewisburg	62	10,809	6,749	62.4
Newport	102	4,305	2,499	58.0
Marietta	70	37,038	24,378	65.8
Conestoga	17	634	367	57.9

[1] Cubic feet per second

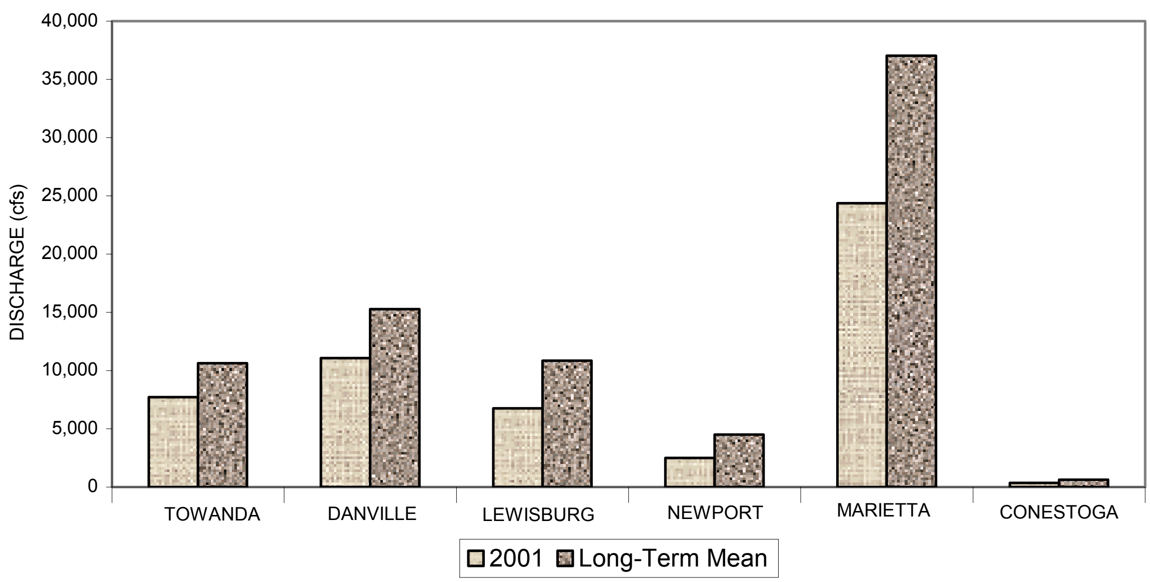


Figure 3. Annual and Long-Term Mean Water Discharge at Towanda, Danville, Lewisburg, Marietta, and Conestoga, Pa., Calendar Year 2001

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. Therefore, yield values can be compared between subbasins, regardless of differences in watershed size.

The calendar year 2001 and the long-term mean annual loads and yields of TN are shown in Figures 4A and 4B, respectively. The 2001 annual loads and yields of TN were lower than the long-term mean at all sites. The greatest TN loads were measured at Marietta, followed by Danville. The Conestoga River at Conestoga had the smallest TN loads.

The Conestoga River Watershed, with 62.7 percent agricultural and 22.4 percent forest lands (Ott and others, 1991), had the highest yield of TN, 19.38 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 2001 annual loads and yields of TP were lower than the long-term mean loads and yields at all sites, as illustrated in Figures 5A and 5B. 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 Marietta.

The annual loads and yields of SS are illustrated in Figures 6A and 6B, respectively. The 2001 loads and yields were lower than the respective long-term mean loads and yields at all sites. The highest 2001 SS loads were measured at Marietta, followed by Towanda. The Conestoga River had the smallest 2001 SS load and the highest 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 except TOC, which was highest at Danville.

Table 5. Annual Water Discharges and Annual Loads and Yields of Total Nitrogen, Calendar Year 2001

Site Short Name	Annual Discharge	Total Nitrogen as N 2001 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	18,461	11.59	3.70
Danville	11,067	28,725	12.28	4.00
Lewisburg	6,749	13,196	14.74	3.01
Newport	2,499	8,240	9.58	3.84
Marietta	24,378	74,547	12.1	4.48
Conestoga	367	5,828	9.79	19.38

Table 6. Annual Water Discharges and Annual Loads and Yields of Total Phosphorus, Calendar Year 2001

Site Short Name	Annual Discharge	Total Phosphorus as P 2001 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	1,799	38.79	0.36
Danville	11,067	2,307	38.63	0.32
Lewisburg	6,749	901	43.23	0.21
Newport	2,499	664	39.17	0.31
Marietta	24,378	6,774	32.42	0.41
Conestoga	367	305	46.02	1.01

Table 7. Annual Water Discharges and Annual Loads and Yields of Suspended Sediment, Calendar Year 2001

Site Short Name	Annual Discharge	Suspended Sediment 2001 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	1,307,225	89.33	261.96
Danville	11,067	1,146,902	64.22	159.72
Lewisburg	6,749	253,169	62.99	57.77
Newport	2,499	245,733	78.15	114.48
Marietta	24,378	3,171,338	44.79	190.66
Conestoga	367	86,056	123.47	286.09

Table 8. Annual Water Discharges and Annual Loads and Yields of Total Ammonia, Calendar Year 2001

Site Short Name	Annual Discharge	Total Ammonia as N 2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	746	36.9	0.15
Danville	11,067	978	38.8	0.14
Lewisburg	6,749	573	41.06	0.13
Newport	2,499	112	41.88	0.05
Marietta	24,378	2,005	34.38	0.12
Conestoga	367	55	49.3	0.18

Table 9. Annual Water Discharges and Annual Loads and Yields of Total Nitrite Plus Nitrate Nitrogen, Calendar Year 2001

Site Short Name	Annual Discharge	Total Nitrite Plus Nitrate as N 2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	10,119	13.96	2.03
Danville	11,067	17,310	14.7	2.41
Lewisburg	6,749	7,722	14.95	1.76
Newport	2,499	5,603	9.41	2.61
Marietta	24,378	46,599	14.02	2.80
Conestoga	367	4,864	13.56	16.17

Table 10. Annual Water Discharges and Annual Loads and Yields of Total Organic Nitrogen, Calendar Year 2001

Site Short Name	Annual Discharge	Total Organic Nitrogen as N 2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	7,810	23.32	1.57
Danville	11,067	11,277	25.87	1.57
Lewisburg	6,749	5,206	32.98	1.19
Newport	2,499	2,563	24.35	1.19
Marietta	24,378	31,040	27.73	1.87
Conestoga	367	1,023	41.66	3.40

Table 11. Annual Water Discharges and Annual Loads and Yields of Dissolved Phosphorus, Calendar Year 2001

Site Short Name	Annual Discharge	Dissolved Phosphorus as P 2001 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	797	31.54	0.16
Danville	11,067	873	34.23	0.12
Lewisburg	6,749	380	33.87	0.09
Newport	2,499	380	40.23	0.18
Marietta	24,378	3,278	30.26	0.20
Conestoga	367	148	23.56	0.49

Table 12. Annual Water Discharges and Loads and Yields of Dissolved Orthophosphate, Calendar Year 2001

Site Short Name	Annual Discharge	Dissolved Orthophosphate as P 2001 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	952	58.53	0.19
Danville	11,067	1,070	59.35	0.15
Lewisburg	6,749	382	62.59	0.09
Newport	2,499	433	73.72	0.20
Marietta	24,378	5,383	64.63	0.32
Conestoga	367	161	34.53	0.54

Table 13. Annual Water Discharges and Annual Loads and Yields of Dissolved Ammonia, Calendar Year 2001

Site Short Name	Annual Discharge	Dissolved Ammonia as N 2001 Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	886	33.7	0.18
Danville	11,067	1,290	35.72	0.18
Lewisburg	6,749	643	35.08	0.15
Newport	2,499	158	31.97	0.07
Marietta	24,378	2,254	25.9	0.14
Conestoga	367	58	46.45	0.19

Table 14. Annual Water Discharges and Annual Loads and Yields of Dissolved Nitrogen, Calendar Year 2001

Site Short Name	Annual Discharge	Dissolved Nitrogen as N		
		2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	17,125	11.55	3.43
Danville	11,067	26,893	12.62	3.75
Lewisburg	6,749	12,018	13.33	2.74
Newport	2,499	7,685	9.38	3.58
Marietta	24,378	67,406	12.59	4.05
Conestoga	367	5,507	10.95	18.31

Table 15. Annual Water Discharges and Annual Loads and Yields of Dissolved Nitrite Plus Nitrate Nitrogen, Calendar Year 2001

Site Short Name	Annual Discharge	Dissolved Nitrite Plus Nitrate Nitrogen as N		
		2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	10,203	14.26	2.04
Danville	11,067	17,491	14.92	2.44
Lewisburg	6,749	7,688	14.6	1.75
Newport	2,499	5,641	9.48	2.63
Marietta	24,378	46,722	14.29	2.81
Conestoga	367	4,846	13.9	16.11

Table 16. Annual Water Discharges and Annual Loads and Yields of Dissolved Organic Nitrogen, Calendar Year 2001

Site Short Name	Annual Discharge	Dissolved Organic Nitrogen as N		
		2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	6,227	22.58	1.25
Danville	11,067	8,716	21.59	1.21
Lewisburg	6,749	3,851	22.62	0.88
Newport	2,499	1,993	19.94	0.93
Marietta	24,378	20,355	24.06	1.22
Conestoga	367	611	36.15	2.03

Table 17. Annual Water Discharges and Annual Loads and Yields of Total Organic Carbon, Calendar Year 2001

Site Short Name	Annual Discharge	Total Organic Carbon 2001		
		Annual Load	Prediction Error	Annual Yield
	cfs	thousands of pounds	percent	pounds per acre per year
Towanda	7,727	49,512	8.90	9.92
Danville	11,067	65,492	9.32	13.12
Lewisburg	6,749	27,757	13.00	6.33
Newport	2,499	15,357	12.07	7.15
Marietta	24,378	149,819	11.15	9.00
Conestoga	367	3,378	19.71	11.23

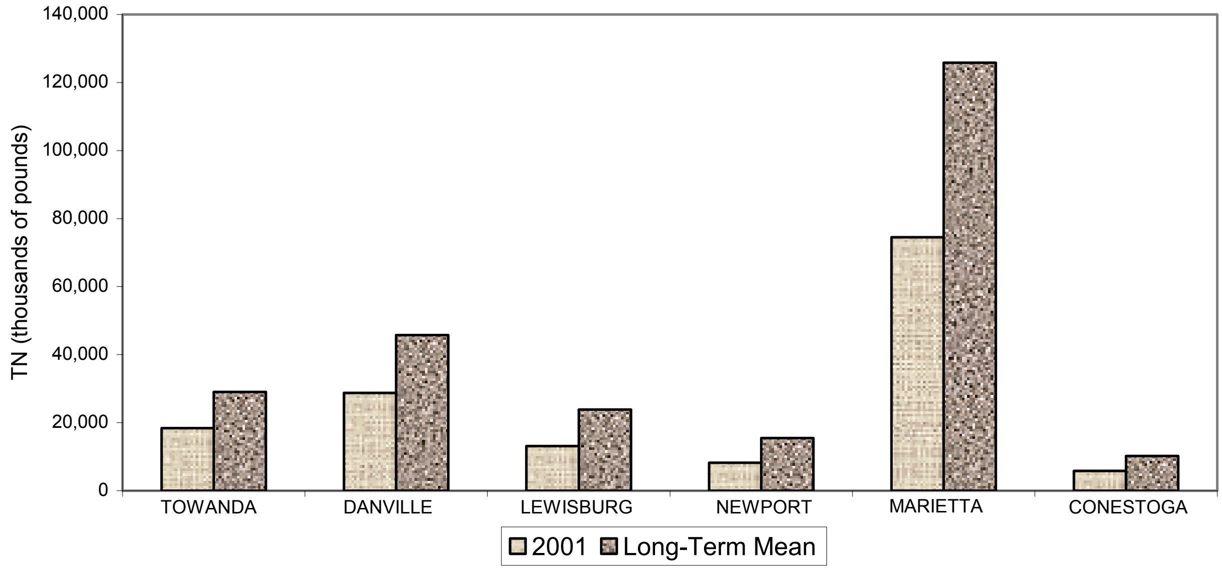


Figure 4A. Annual Loads of Total Nitrogen (TN) at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2001

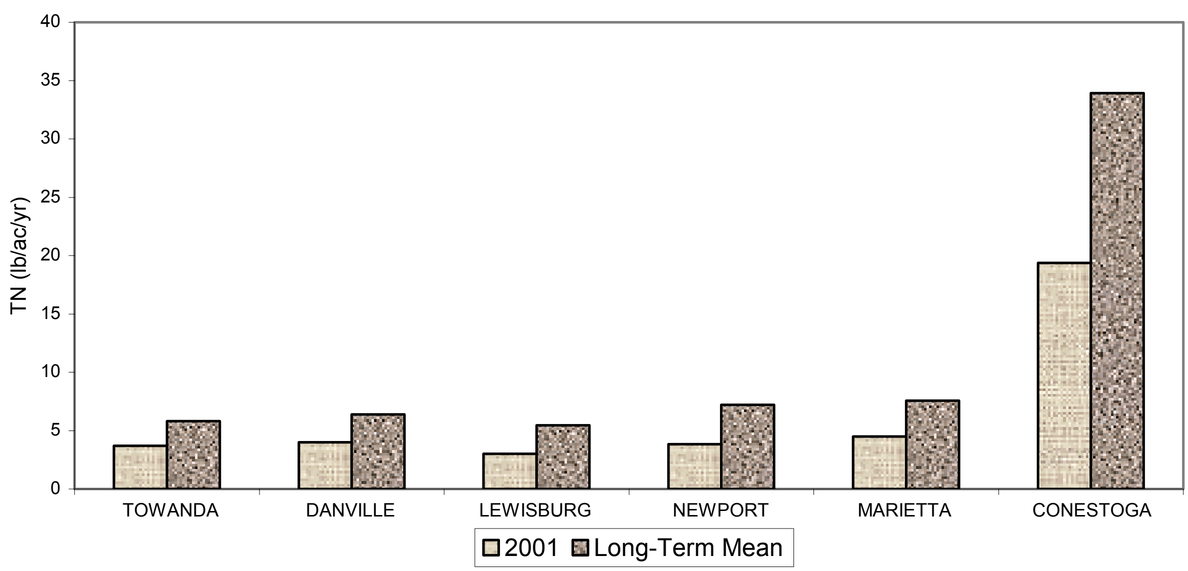


Figure 4B. Total Nitrogen (TN) Yields at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2001

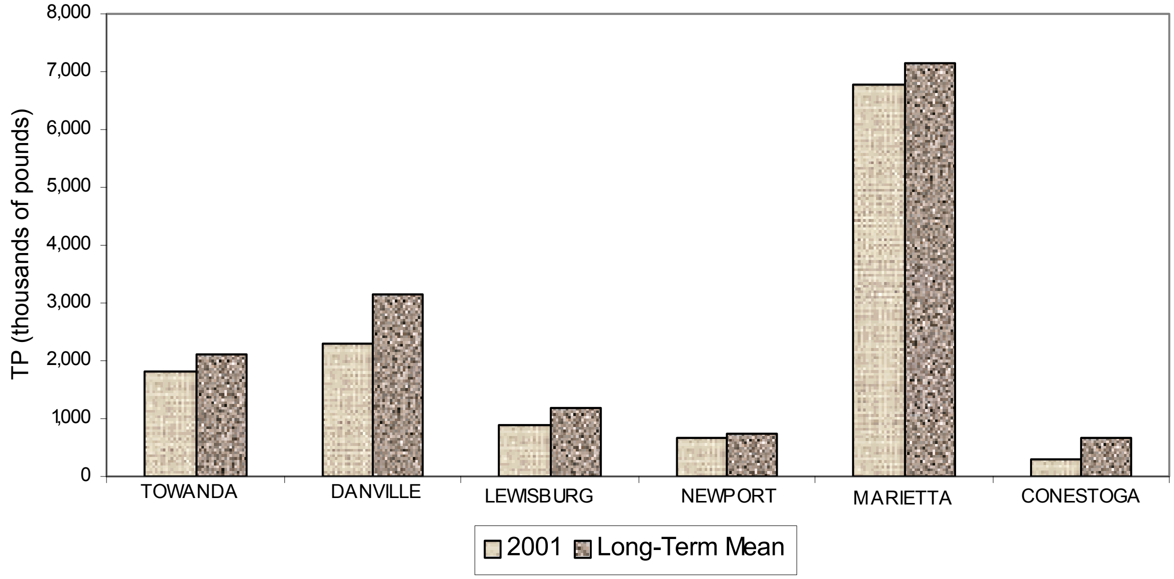


Figure 5A. Annual Loads of Total Phosphorus (TP) at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2001

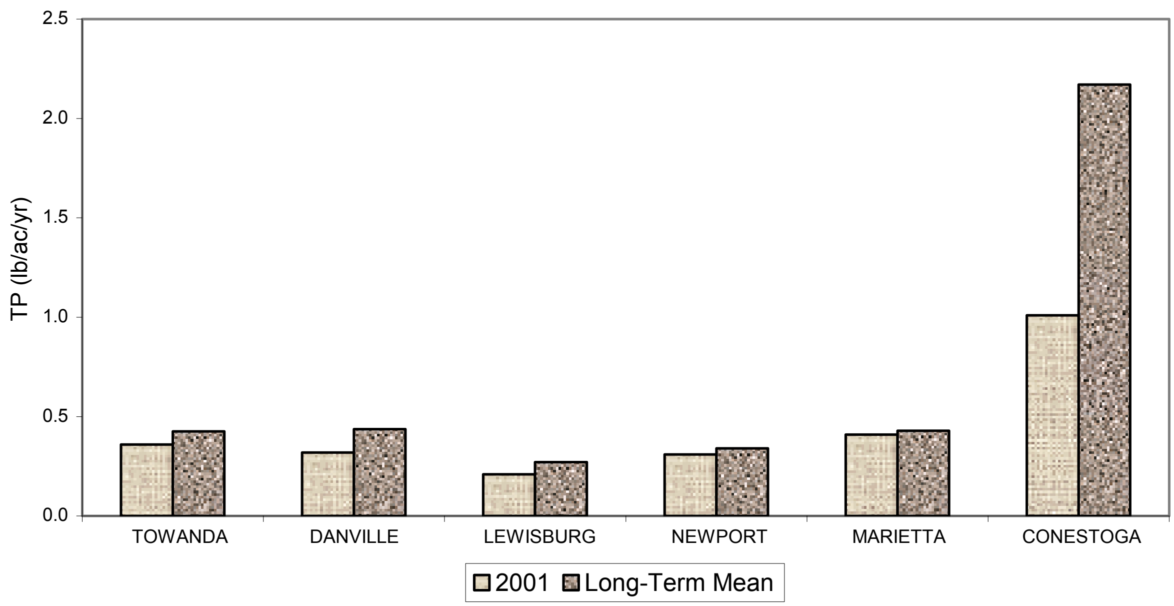


Figure 5B. Total Phosphorus (TP) Yields at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2001

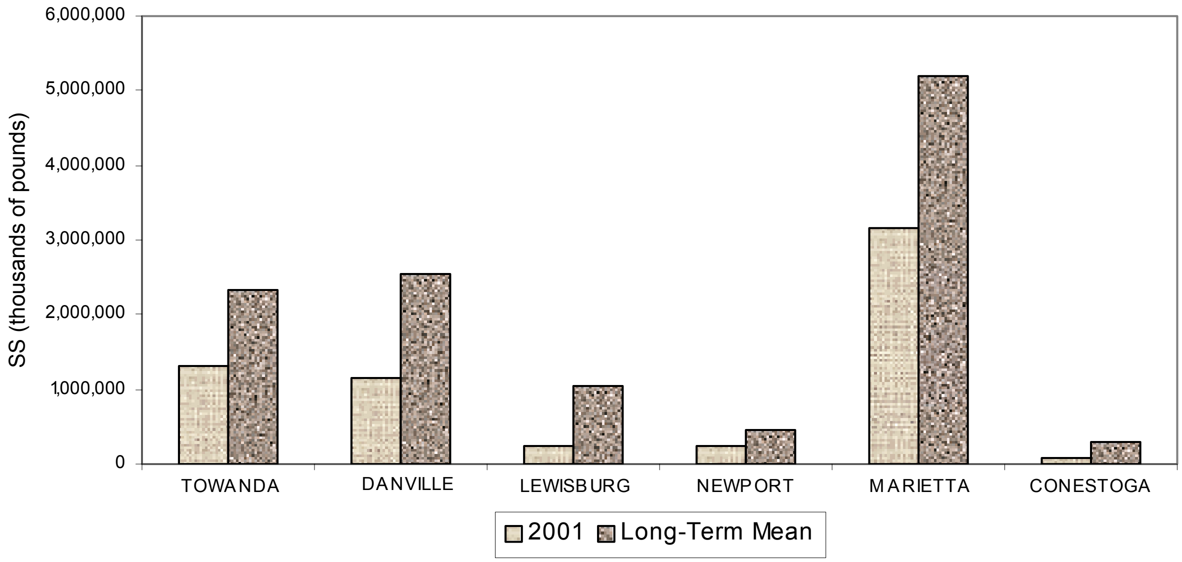


Figure 6A. ***Annual Loads of Suspended Sediment (SS) at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2001***

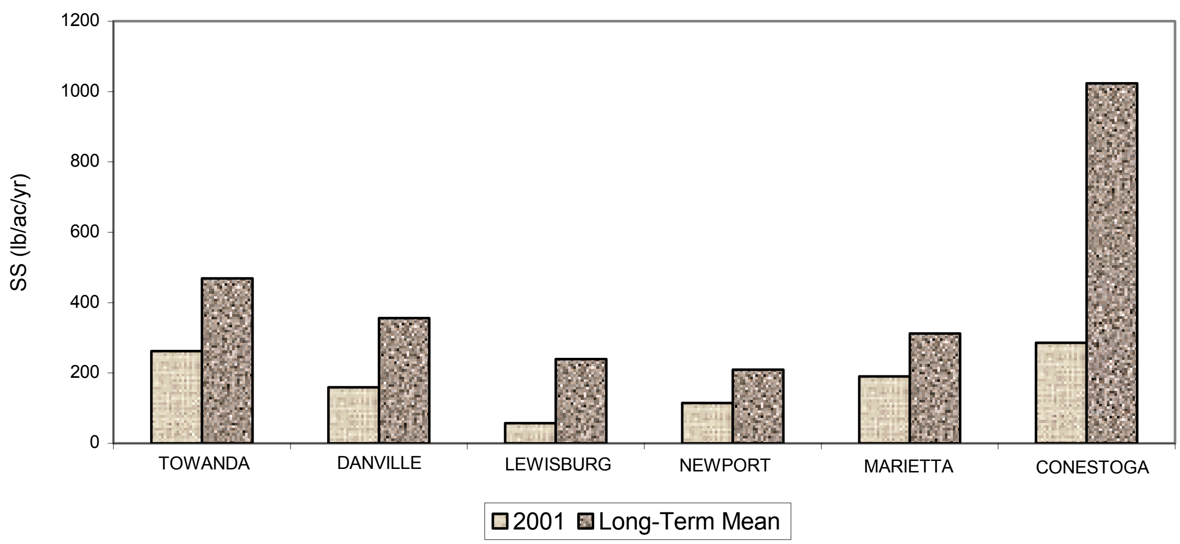


Figure 6B. ***Suspended Sediment (SS) Yield at Towanda, Danville, Lewisburg, Newport, Marietta, and Conestoga, Pa., Calendar Year 2001***

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

Seasonal water discharges and loads of nutrients and SS for calendar year 2001 are listed in Table 18. The calendar year 2001 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 2001 at Towanda, Danville, Lewisburg, Newport, and Marietta were highest in the spring (April-June), followed by winter (January-March), fall (October-December), then summer (July-September). The 2001 seasonal discharges at Conestoga were highest in the winter, followed by spring, summer, and fall. The 2001 seasonal discharges were greater than long-term discharges during the spring at Towanda. The seasonal discharges were smaller than the long-term mean for all seasons at all other sites.

TN consists mostly of the highly soluble nitrite plus nitrate fraction; therefore, the seasonal variation of TN loads for 2001 corresponded with the seasonal variation of water discharges at all sites except at Newport and Lewisburg. Both sites showed the highest discharges during spring, followed by winter, while showing higher concentrations of TN during winter, followed by spring.

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, summer, and fall, while the discharge was highest in the spring, followed by winter, fall, and summer. TP loads for spring 2001 were greater than the long-term seasonal loads at Towanda, Danville, Newport, and Marietta. All other TP seasonal loads were lower than the corresponding long-term means.

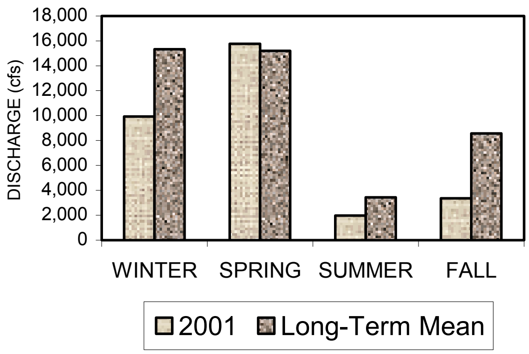
Seasonal variations in SS loads generally corresponded with discharge. The exception was at Newport. The SS load at Newport was highest in the spring, followed by winter, summer, and fall, while the discharge was highest in the spring, followed by winter, fall, and summer. All 2001 SS loads were lower than the seasonal long-term means except for spring at Towanda.

The long-term seasonal water discharges for all sites except Lewisburg are highest in the winter, followed by spring, fall, than summer. The long-term high discharge at Lewisburg was during spring followed by winter. The seasonal variations of the long-term TN loads are consistent with the seasonal discharges, except at Lewisburg. The long-term TP and SS loads in the Susquehanna River at Towanda, Danville, and the Juniata River at Newport 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 Conestoga show the same seasonal fluctuations as their respective seasonal discharges.

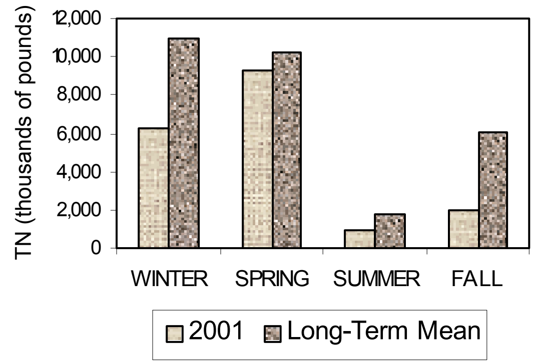
Figures 13 through 15 provide a comparison of the seasonal yields among the monitoring sites for calendar year 2001 and for the long-term seasonal average. The long-term seasonal averages indicate that the Conestoga River at Conestoga has the greatest yields of TN, TP, and SS for all seasons. The long-term TN yields in the Susquehanna River at Towanda, Danville, and Marietta generally increased in the downstream order. The 2001 TN yields for these sites maintained the same pattern during winter, summer, and fall. The West Branch Susquehanna River at Lewisburg, which has the greatest forested area, had the lowest long-term TN yield among the tributary sites. Lewisburg maintained the smallest TN yields among all sites during winter and spring of 2001.

Table 18. Seasonal Mean Water Discharges and Loads of Nutrients and Suspended Sediment, Calendar Year 2001

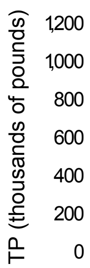
Station	Season	Mean Water Discharge	Total Ammonia as N	Total-Organic Nitrogen as N	Total Nitrite Plus Nitrate as N	Total Nitrogen as N	Dissolved Ortho-phosphate as P	Dissolved Phosphorus as P	Total Phosphorus as P	Dissolved Ammonia as N	Suspended Sediment	Dissolved Nitrogen as N	Dissolved Nitrite Plus Nitrate as N	Dissolved Organic Nitrogen as N	Total Organic Carbon
		cfs	thousands of pounds												
Towanda	Winter	9,929	259.1	2,045	3,901	6,211	255.9	228.2	402.5	327.5	170,359	6,112	3,959	1,807	13,865
	Spring	15,781	384.6	4,415	4,642	9,297	358.7	348.8	1,099.0	410.2	1,102,616	8,193	4,660	3,299	26,876
	Summer	1,978	22.3	573	428	953	92.4	67.2	108.9	26.0	13,055	839	429	427	3,598
	Fall	3,356	79.8	777	1,148	1,999	244.6	152.5	189.0	122.4	21,195	1,980	1,155	694	5,173
Danville	Winter	14,781	406.3	3,054	6,997	10,301	361.8	277.2	585.3	561.4	208,795	10,180	7,107	2,616	18,629
	Spring	20,990	433.0	5,719	7,417	13,212	407.1	366.7	1,289.3	525.1	877,762	11,899	7,459	4,175	32,927
	Summer	3,462	28.5	1,100	800	1,738	74.0	66.4	155.8	36.4	22,120	1,454	803	752	6,161
	Fall	5,223	110.2	1,404	2,096	3,474	226.6	162.8	276.2	167.9	38,226	3,361	2,122	1,173	7,775
Lewisburg	Winter	9,062	332.0	1,635	2,810	4,578	107.7	115.2	277.9	271.3	86,194	4,300	2,812	1,258	8,285
	Spring	10,014	241.0	1,827	2,569	4,462	106.9	104.3	298.3	192.3	107,395	3,993	2,555	1,324	9,992
	Summer	2,476	30.1	539	659	1,183	44.6	39.9	80.0	31.2	13,270	1,048	649	389	3,111
	Fall	5,529	103.0	1,205	1,685	2,973	122.4	120.7	245.2	147.8	46,311	2,676	1,672	880	6,368
Newport	Winter	4,054	46.9	920	2,494	3,524	154.6	132.7	221.4	61.8	80,589	3,352	2,515	755	5,676
	Spring	4,202	49.1	1105	2,283	3,432	184.8	152.7	305.6	71.1	149,541	3,140	2,294	812	6,501
	Summer	883	8.0	283	364	588	46.1	45.1	71.4	12.4	9,730	531	365	211	1,640
	Fall	912	7.8	255	462	695	47.5	49.4	65.5	12.3	5,873	662	467	214	1,539
Marietta	Winter	33,127	829.7	8,599	18,225	27,089	1,452.3	966.3	1,813.1	935.4	786,776	24,951	18,280	5,914	43,722
	Spring	42,905	780.7	13,965	18,856	30,894	2,329.9	1,374.4	3,402.7	850.3	1,948,548	27,395	18,800	8,729	67,466
	Summer	8,382	82.4	3,396	2,742	5,248	463.9	311.9	552.0	106.2	150,945	4,697	2,777	2,273	16,153
	Fall	13,490	312.0	5,081	6,776	11,315	1,136.6	625.8	1,006.3	362.4	285,069	10,364	6,865	3,439	22,488
Conestoga	Winter	635	30.2	487	2,104	2,587	49.7	52.6	122.6	31.5	42,775	2,438	2,092	295	1,456
	Spring	521	19.0	342	1,715	2,003	53.5	46.3	111.8	19.5	35,897	1,896	1,706	193	1,170
	Summer	200	4.4	116	635	737	38.9	30.6	50.2	4.5	6,754	696	636	68	488
	Fall	120	1.7	78	410	502	18.7	18.4	20.8	2.1	630	478	412	54	264



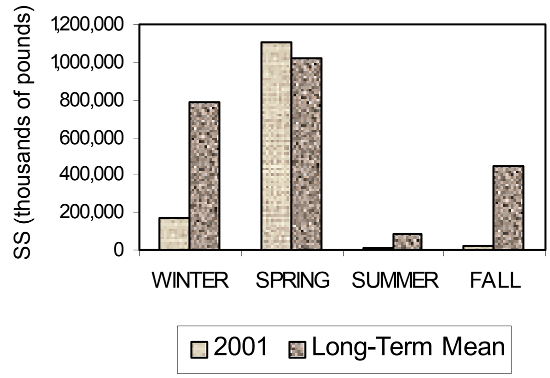
Discharge



Total Nitrogen



Total Phosphorus



Suspended Sediment

Figure 7. ***Seasonal Discharges and Loads of Total Nitrogen (TN), Total Phosphorus (TP), and Suspended Sediment (SS) at Towanda, Pa., Calendar Year 2001***

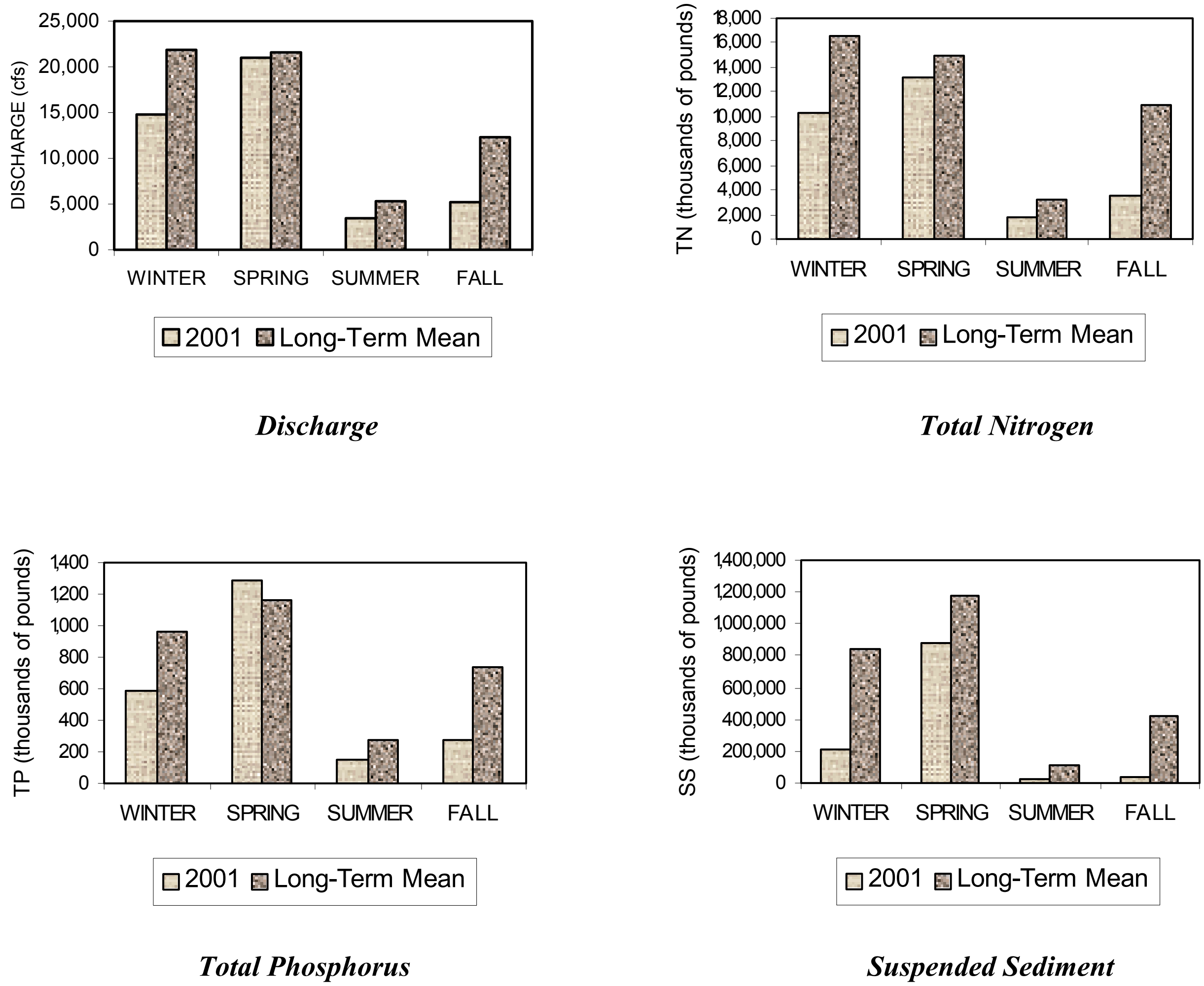


Figure 8. Seasonal Discharges and Loads of Total Nitrogen(TN), Total Phosphorus(TP), and Suspended Sediment (SS) at Danville, Pa., Calendar Year 2001

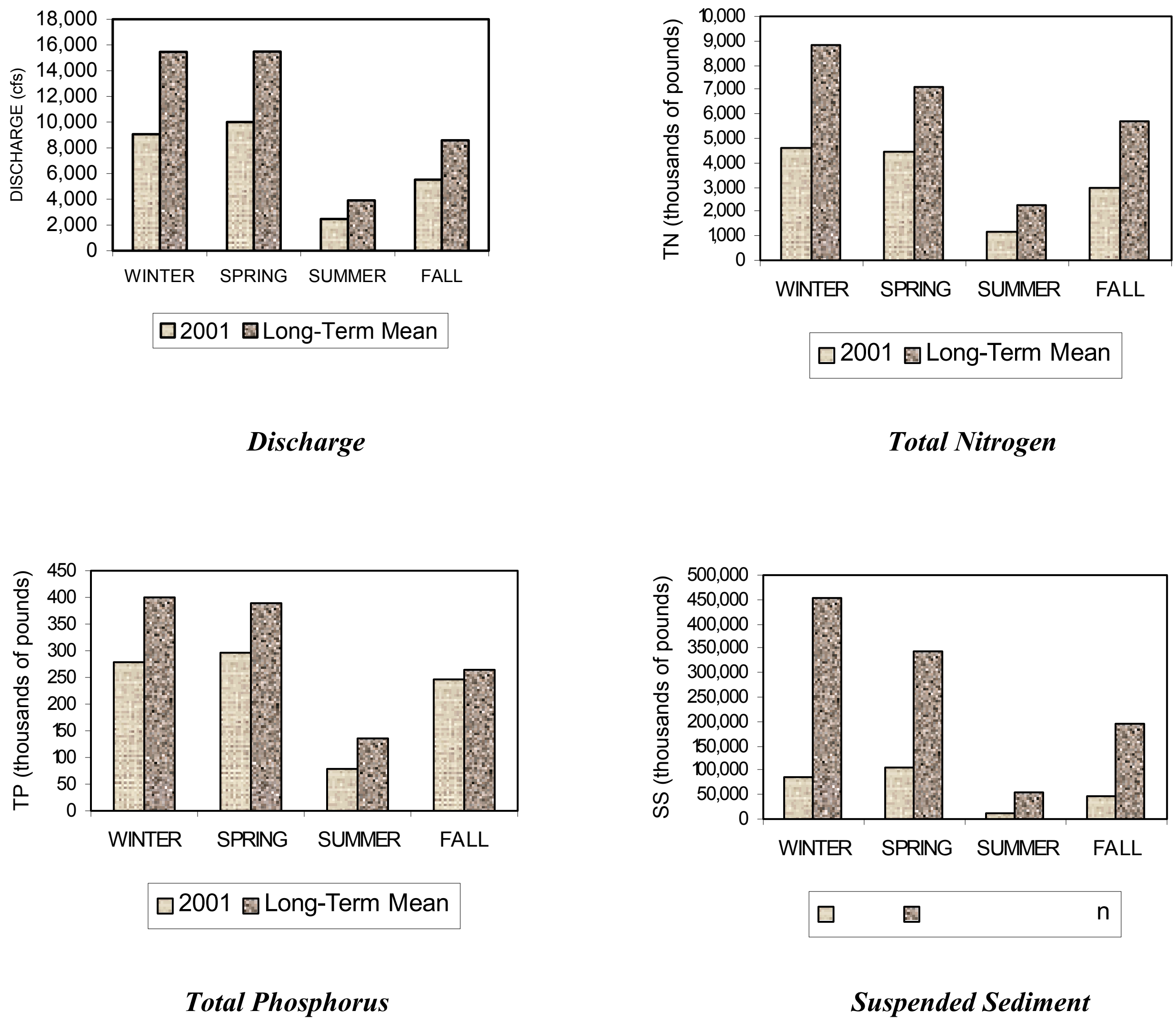
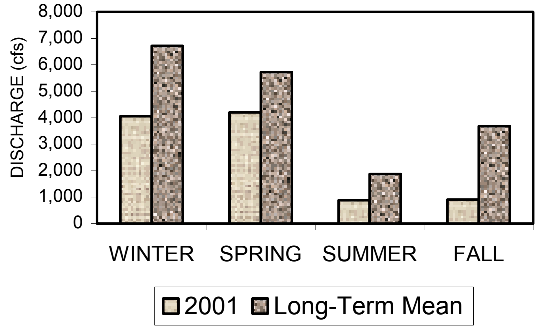
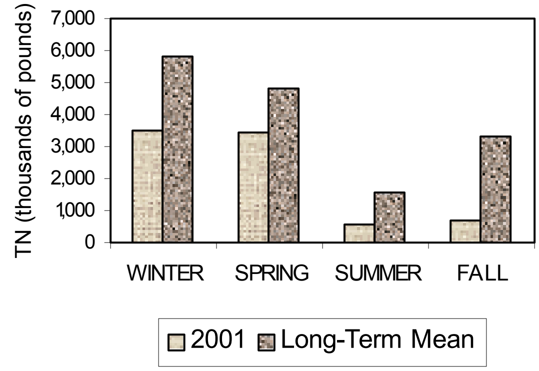


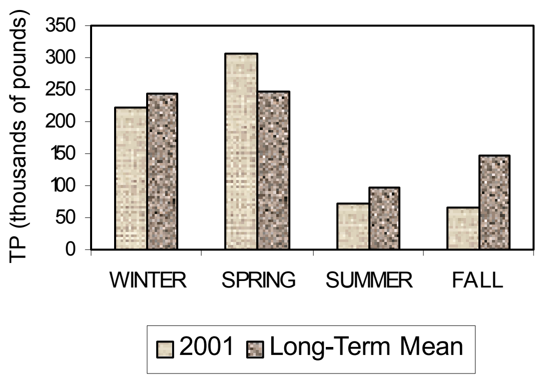
Figure 9. ***Seasonal Discharges and Loads of Total Nitrogen (TN), Total Phosphorus (TP), and Suspended Sediment (SS) at Lewisburg, Pa., Calendar Year 2001***



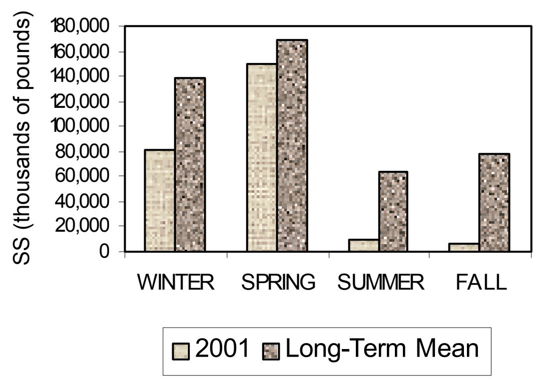
Discharge



Total Nitrogen

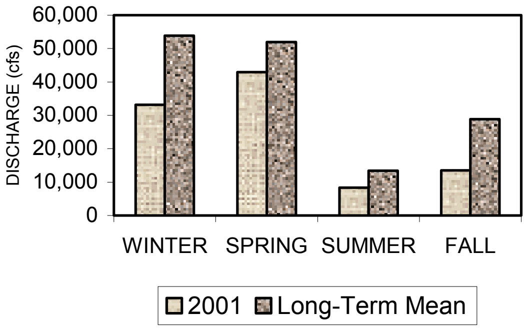


Total Phosphorus

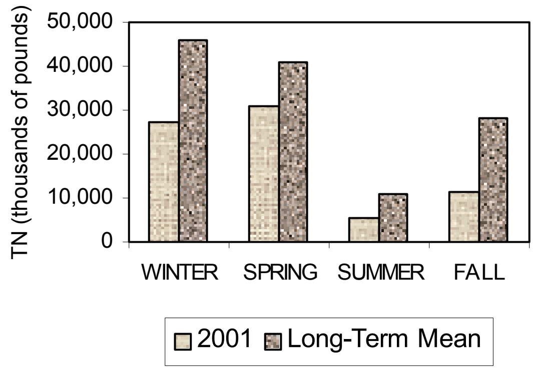


Suspended Sediment

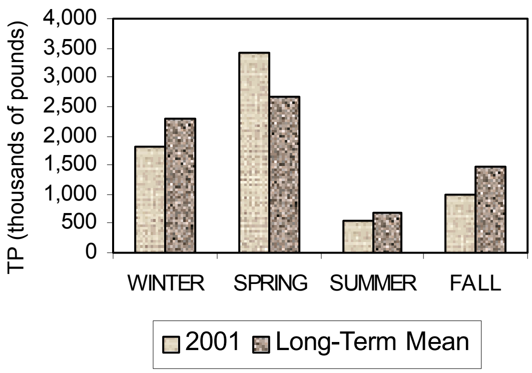
Figure 10. Seasonal Discharges and Loads of Total Nitrogen (TN), Total Phosphorus (TP), and Suspended Sediment (SS) at Newport, Pa., Calendar Year 2001



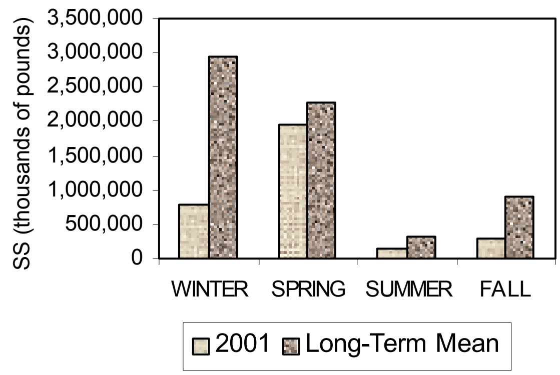
Discharge



Total Nitrogen

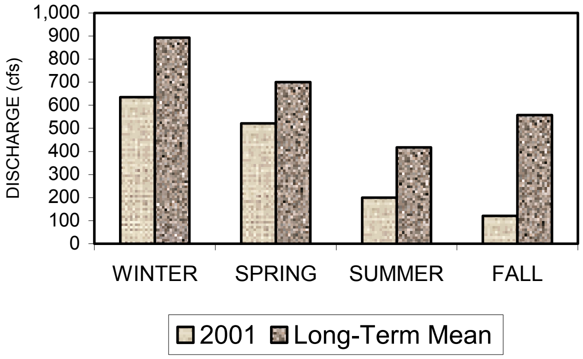


Total Phosphorus

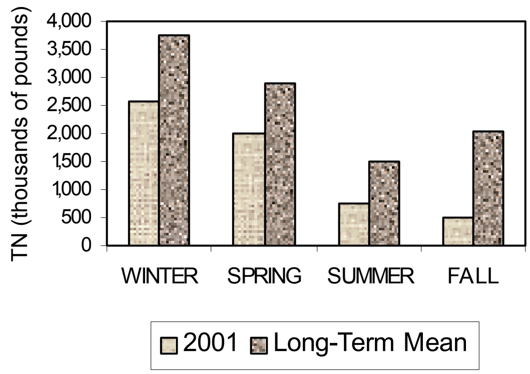


Suspended Sediment

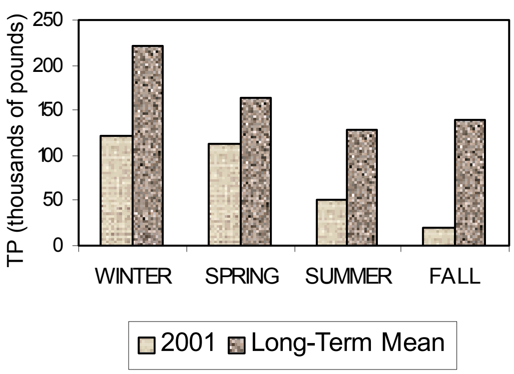
Figure 11. Seasonal Discharges and Loads of Total Nitrogen (TN), Total Phosphorus (TP), and Suspended Sediment (SS) at Marietta, Pa., Calendar Year 2001



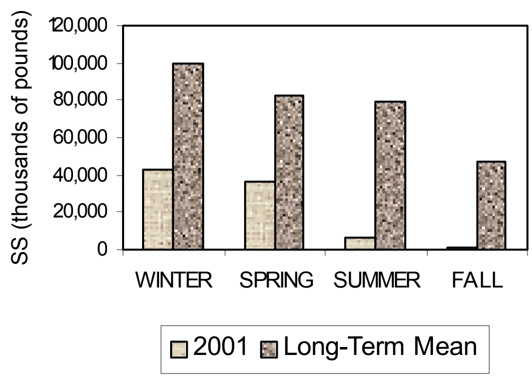
Discharge



Total nitrogen

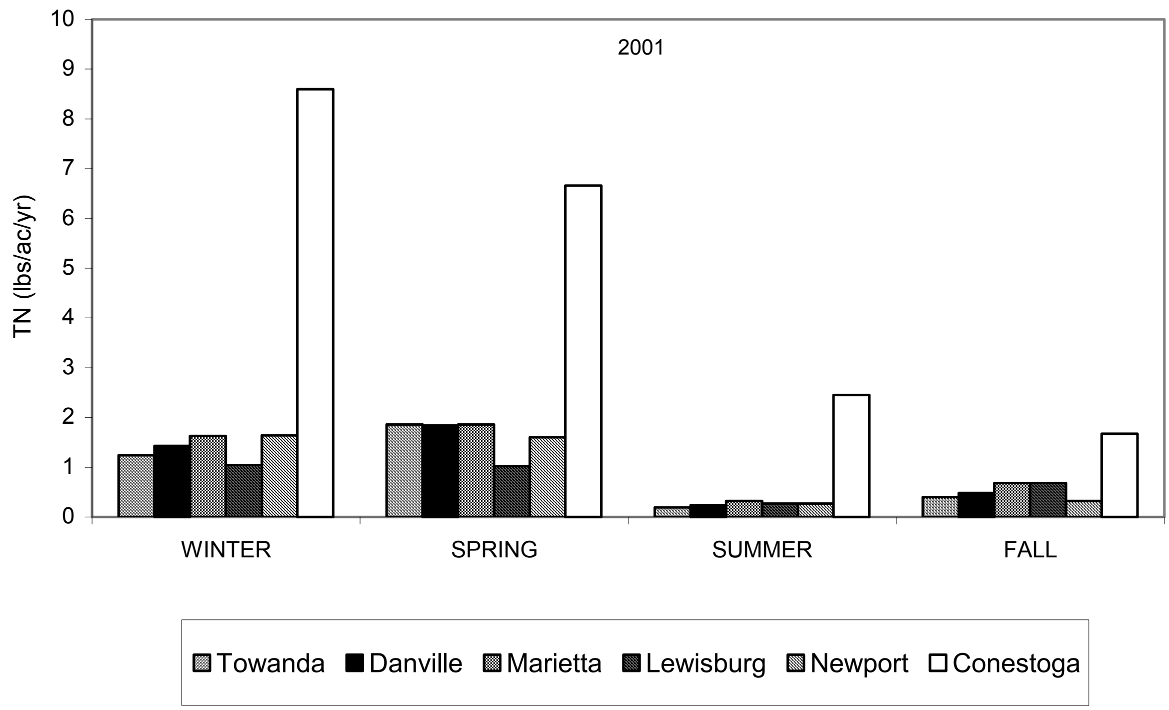


Total Phosphorus



Suspended Sediment

Figure 12. ***Seasonal Discharges and Loads of Total Nitrogen (TN), Total Phosphorus (TP), and Suspended Sediment (SS) at Conestoga, Pa., Calendar Year 2001***



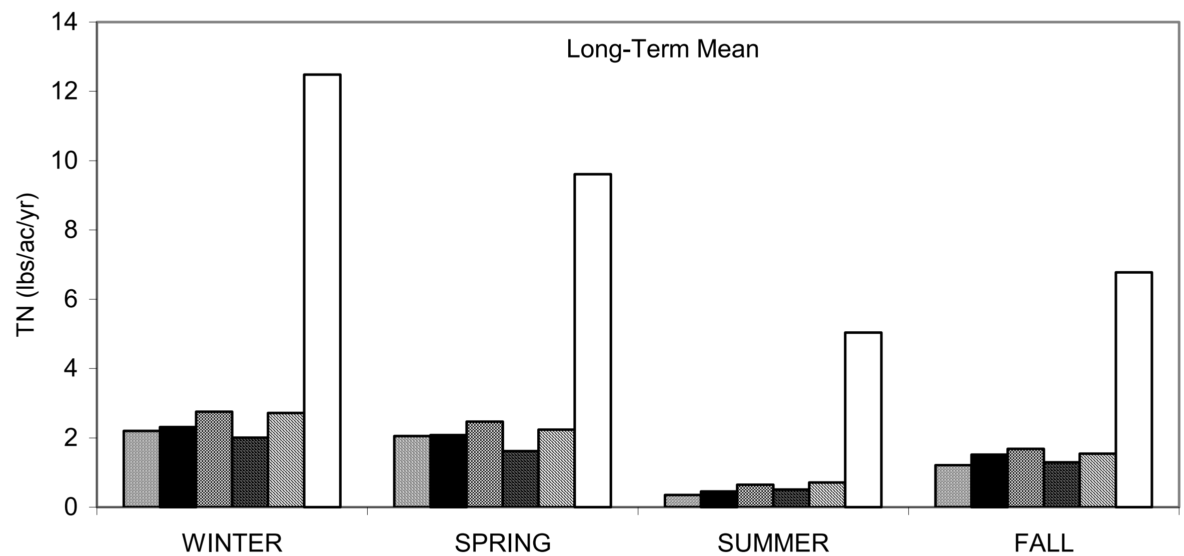


Figure 13. ***Comparison of Seasonal Yields of Total Nitrogen (TN) at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, PA***

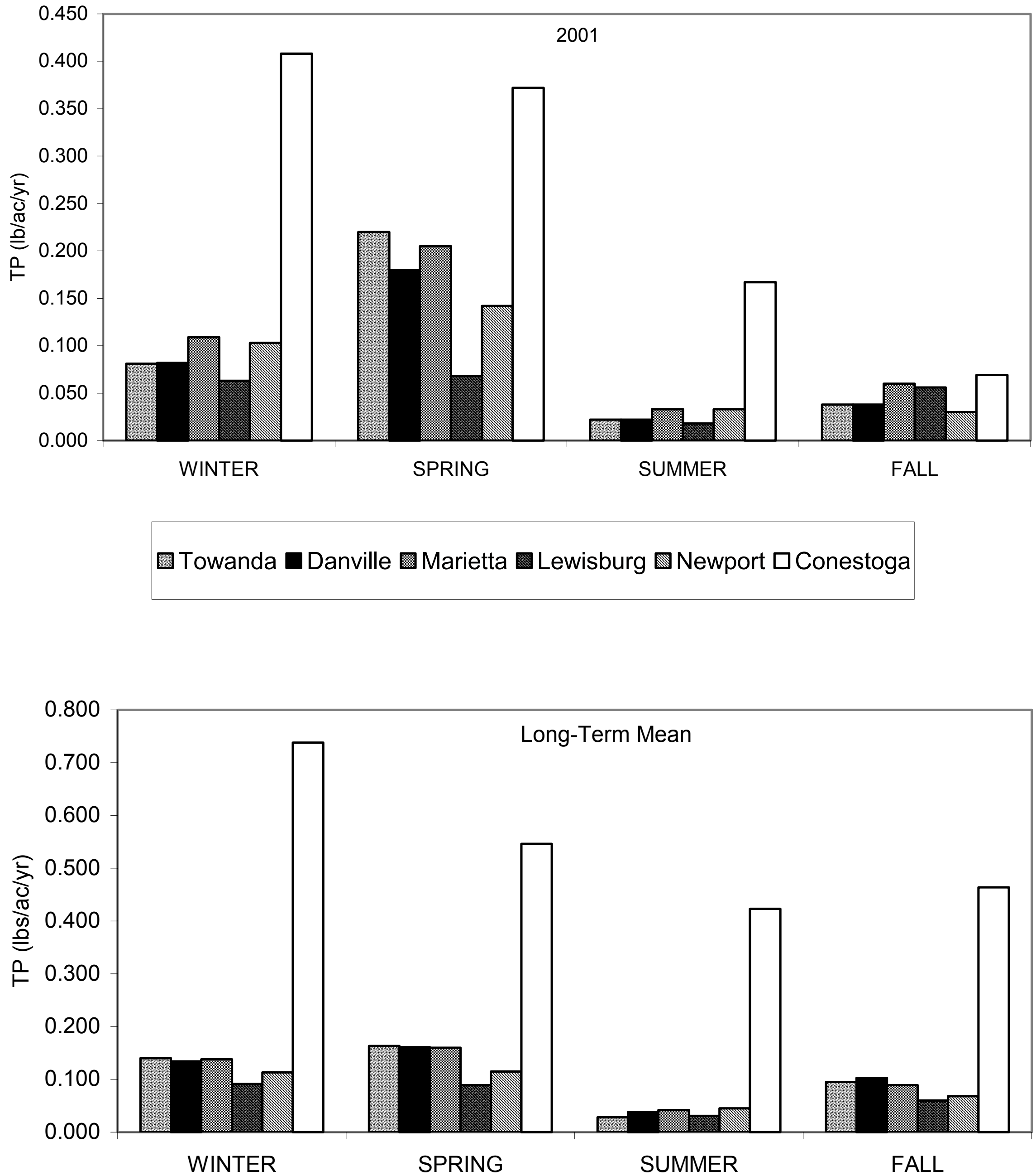
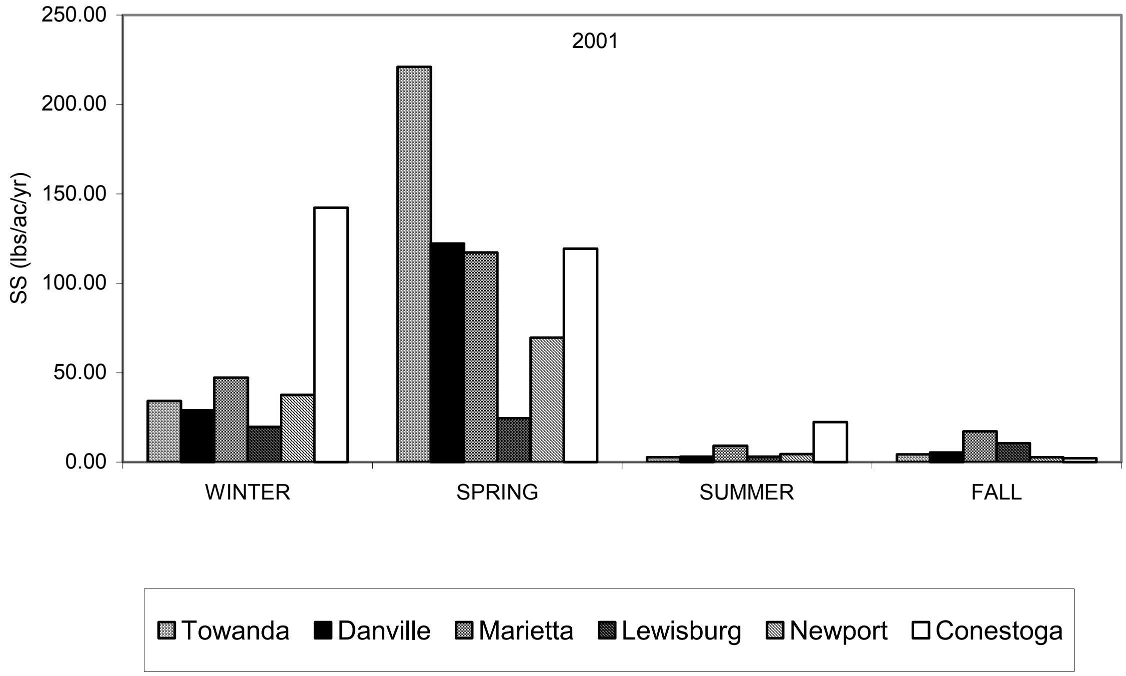


Figure 14. ***Comparison of Seasonal Yields of Total Phosphorus (TP) at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, PA***



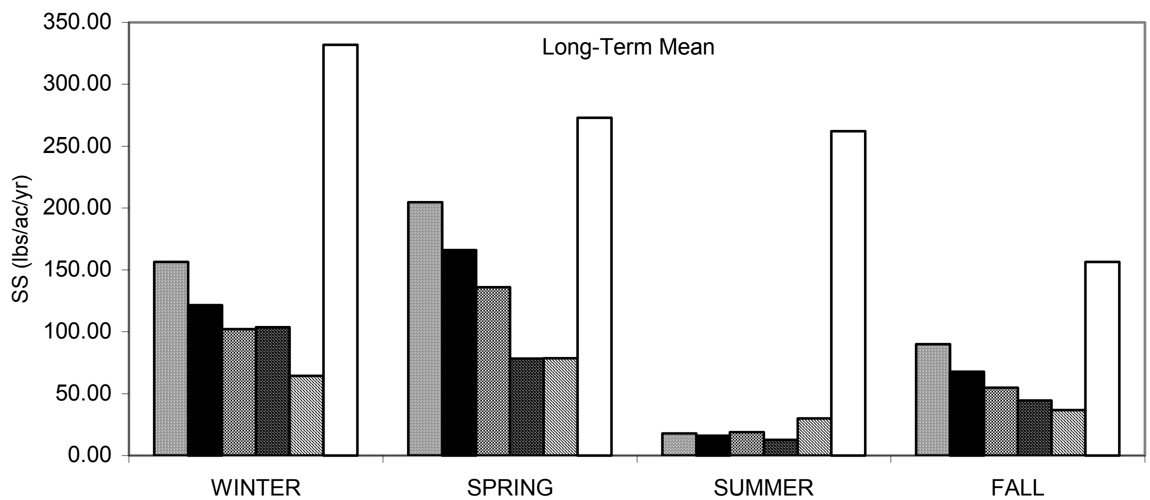


Figure 15. Comparison of Seasonal Yields of Suspended Sediment (SS) at Towanda, Danville, Marietta, Lewisburg, Newport, and Conestoga, PA

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 had the smallest yield during all seasons. The 2001 TP yields for Towanda, Danville, and Marietta followed the same pattern during the winter, summer, and fall months with Towanda and Danville having similar yields and Marietta slightly higher. The smallest TP yield in 2001 occurred at Lewisburg during winter, spring, and summer. Newport showed the lowest TP yield values during the fall. Conestoga had the highest TP yields for all sites during all seasons.

Long-term SS yields in the Susquehanna River generally decreased in the downstream order with the summer at Marietta as the exception. SS yields among the tributary sites were smallest at Newport in the winter and fall, and at Lewisburg during spring and summer. The 2001 seasonal SS yields did not show any consistent relationships among the sites.

COMPARISON OF THE 2001 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 made it difficult to determine whether the changes were 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 from the initial 5-year study (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 2001 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 2001 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 2001 TN yield plotted below the 5-year baseline suggesting that the TN load decreased. The TN yield was estimated to be 4.47 lb/ac/yr at a water-discharge ratio of 0.7278 for the initial five years of monitoring, while the yield for 2001 was 3.7 lb/ac/yr at the same discharge ratio. The TP load increased in 2001. The baseline TP yield was 0.22 lb/ac/yr, compared to 0.36 lb/ac/yr for 2001. The SS yields in Figure 16 indicate that there was an increase in yields for 2001. The baseline yield was 55.3 lb/ac/yr, and the yield for 2001 was 261.96 lb/ac/yr.

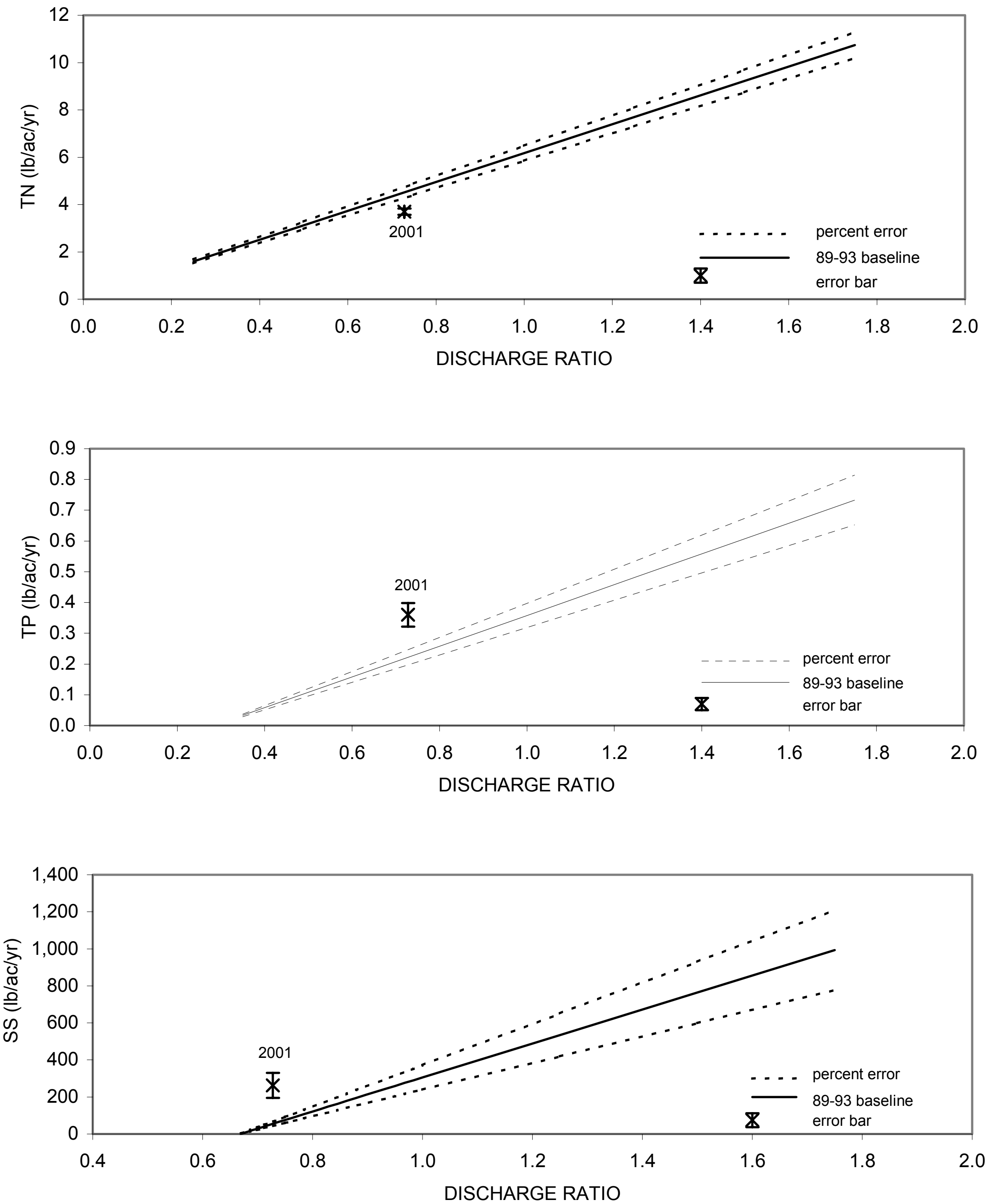


Figure 16. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Towanda, Pa., 1989-93 and 2001

Susquehanna River at Danville, Pa.

Figure 17 shows the 5-year (1985-89) baselines for TN, TP, and SS and the 2001 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 yields for 2001 plotted below the baseline, indicating that there was a decrease in the loads. TP and SS for 2001 had no significant change from the baseline. The baseline TN yield was 5.13 lb/ac/yr at the water-discharge ratio of 0.7269, compared to 4.0 lb/ac/yr for 2001. The baseline yields of TP and SS were 0.33 and 155.0 lb/ac/yr compared to 0.32 and 159.72 lb/ac/yr for 2001, respectively.

West Branch Susquehanna River at Lewisburg, Pa.

The 1985-89 baselines and the 2001 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 2001 plotted slightly below the baseline, indicating that the nitrogen load decreased. The baseline TN yield was 3.50 lb/ac/yr at the water-discharge ratio of 0.6244, compared to 3.01 lb/ac/yr for 2001. The TP yield was 0.20 lb/ac/yr for the baseline and 0.21 lb/ac/yr for 2001. SS data suggested that there was a decrease in 2001, but this decrease may not be significant since the margins of error overlap. The baseline yield was 62.0 lb/ac/yr, and the 2001 yield was 57.8 lb/ac/yr.

Juniata River at Newport, Pa.

The 1985-89 baselines and 2001 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 2001 showed a decrease from the baseline. The TN baseline yield was 4.9 lb/ac/yr at a water-discharge ratio of 0.5805, and the 2001 yield was 3.84 lb/ac/yr. The TP and SS yields increased in 2001. TP yields were 0.22 and 0.31 lb/ac/yr for the baseline and 2001, respectively. The SS yields were 34.1 and 114.5 lb/ac/yr for the baseline and 2001, respectively.

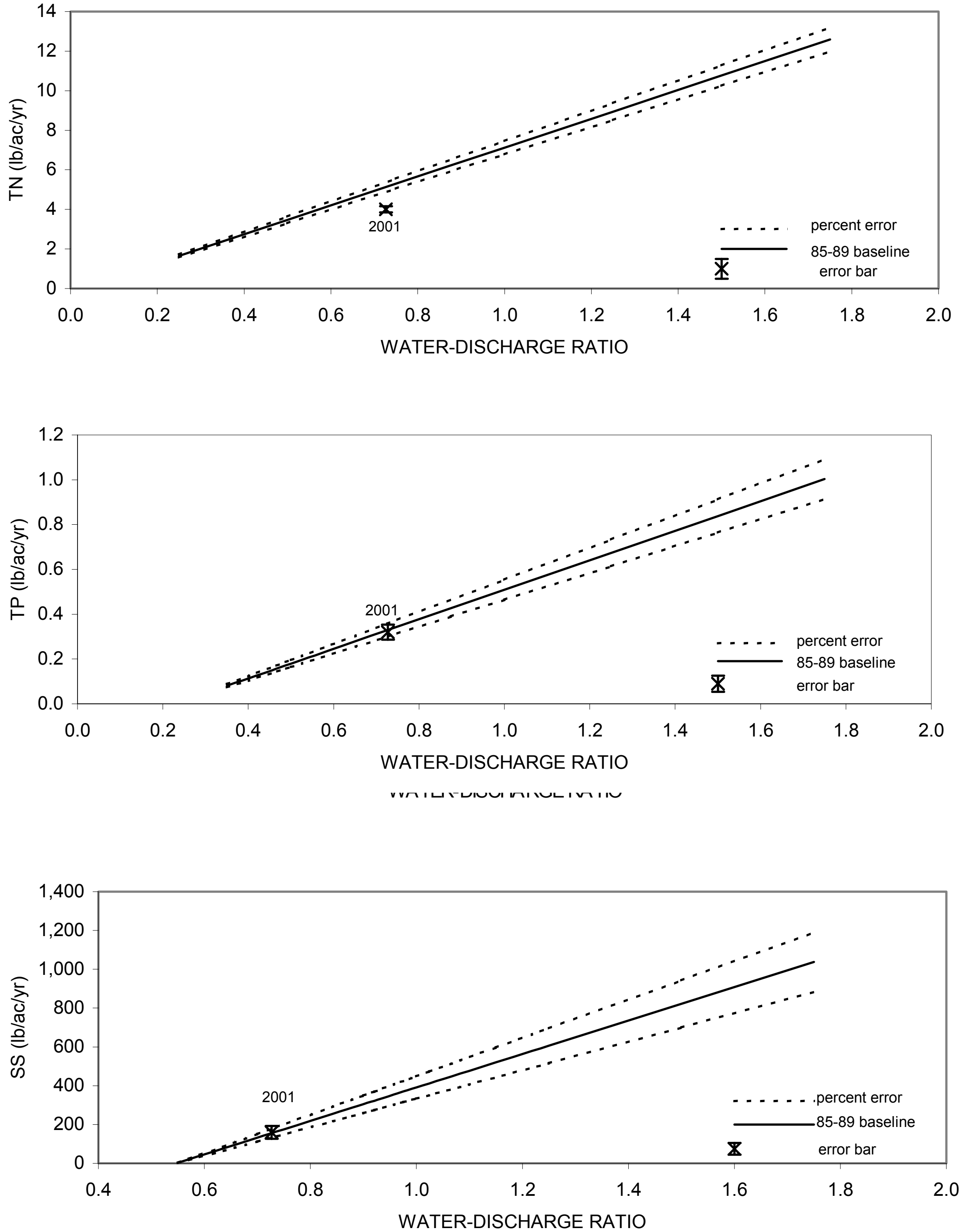


Figure 17. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Danville, Pa., 1985-89 and 2001

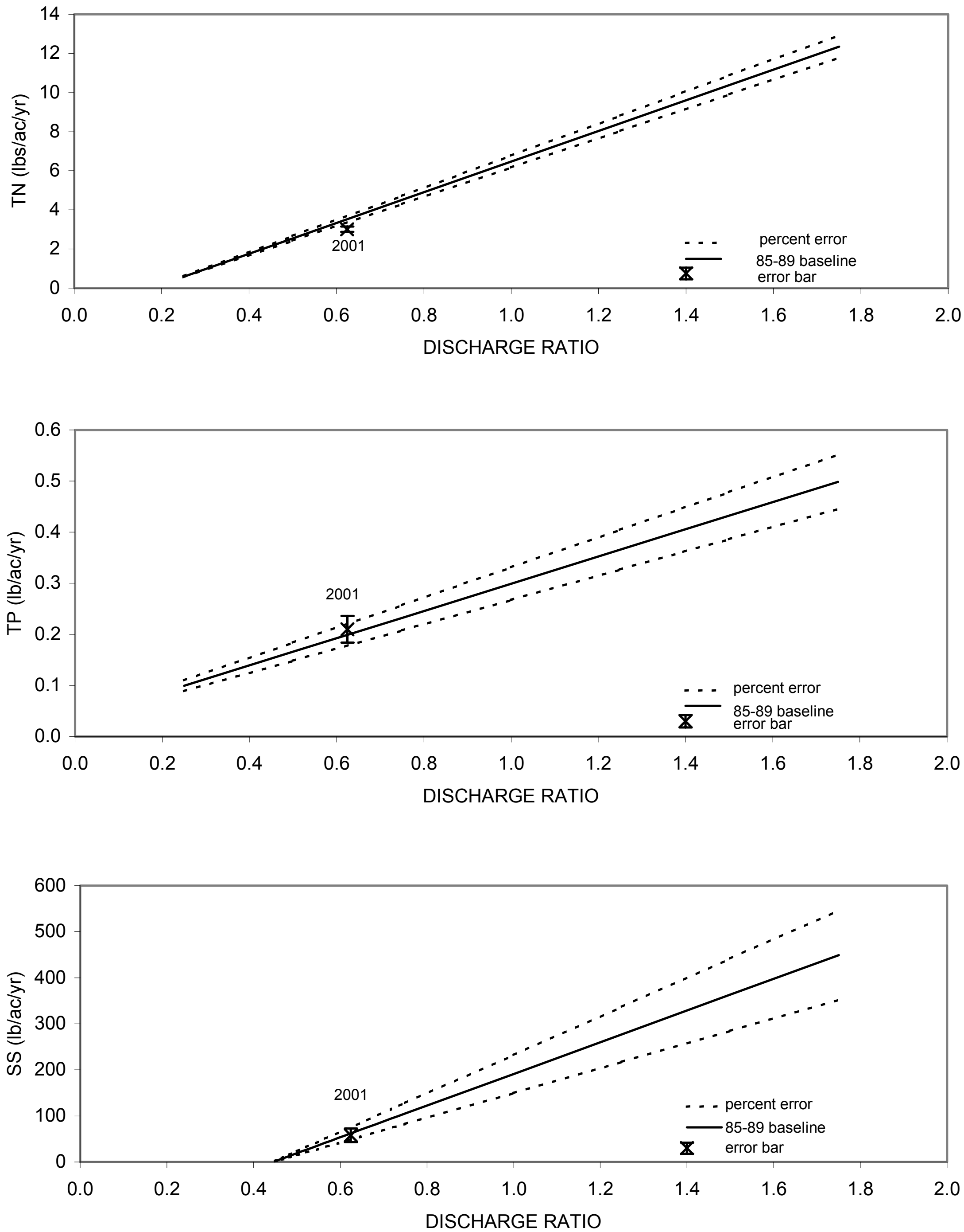


Figure 18. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, West Branch Susquehanna River at Lewisburg, Pa., 1985-89 and 2001

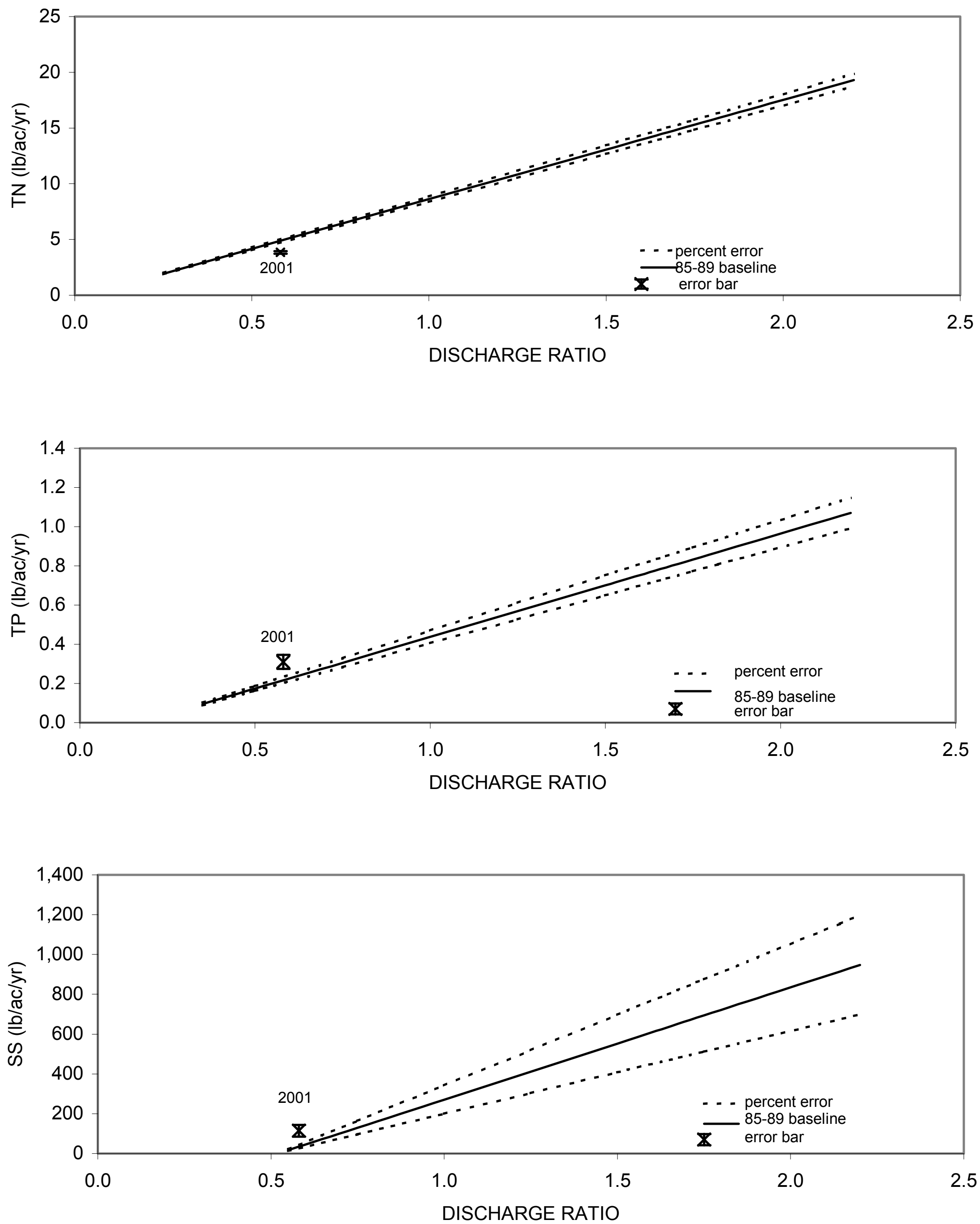


Figure 19. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Juniata River at Newport, Pa., 1985-89 and 2001

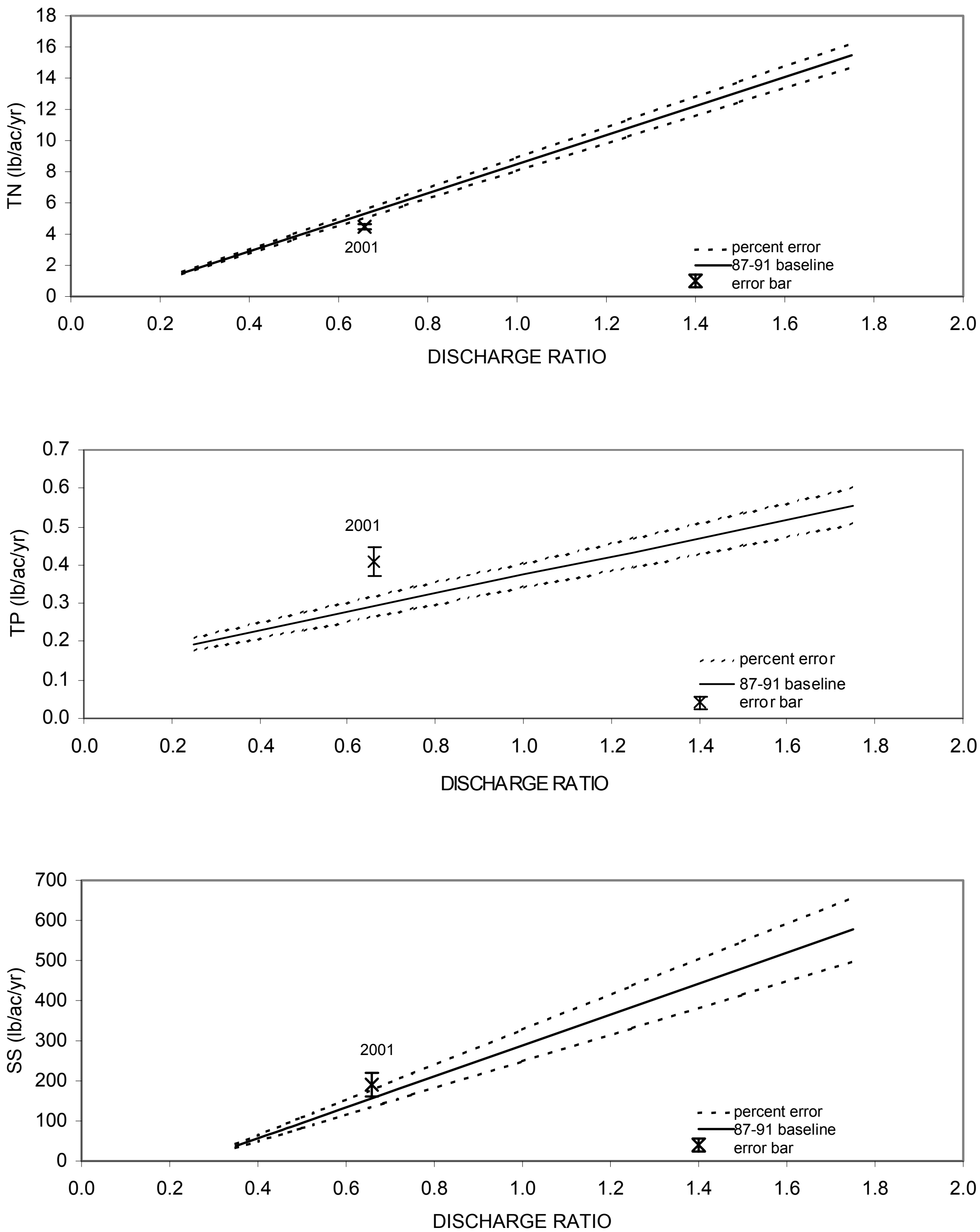


Figure 20. Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Susquehanna River at Marietta, Pa., 1985-89 and 2001

Susquehanna River at Marietta, Pa.

The TN, TP, and SS baseline for the 5-year period 1987-91 at Marietta and the 2001 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 2001 plotted below the baseline, indicating that there was a decrease in the load. The TN baseline yield was 5.32 lb/ac/yr at a water-discharge ratio of 0.6582, and the 2001 yield was 4.48. The TP data showed increases in the 2001 loads. The TP baseline yield was 0.29 lb/ac/yr, compared to 0.41 lb/ac/yr for 2001. The SS baseline yield was 156.2 lb/ac/yr, compared to 190.66 lb/ac/yr in 2001.

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 2001 TN yield showed a decrease from the baseline yields. The baseline and 2001 yields of TN were 22.78 and 19.38 lb/ac/yr, respectively, at a water-discharge ratio of 0.5789. The TP yield increased in 2001. The baseline yield was 0.55 lb/ac/yr, and the 2001 yield was 1.01 lb/ac/yr. The baseline and 2001 yields of SS were 527.762 and 286.09 lb/ac/yr, respectively. This may not indicate an increase in SS transport as the error bars overlap.

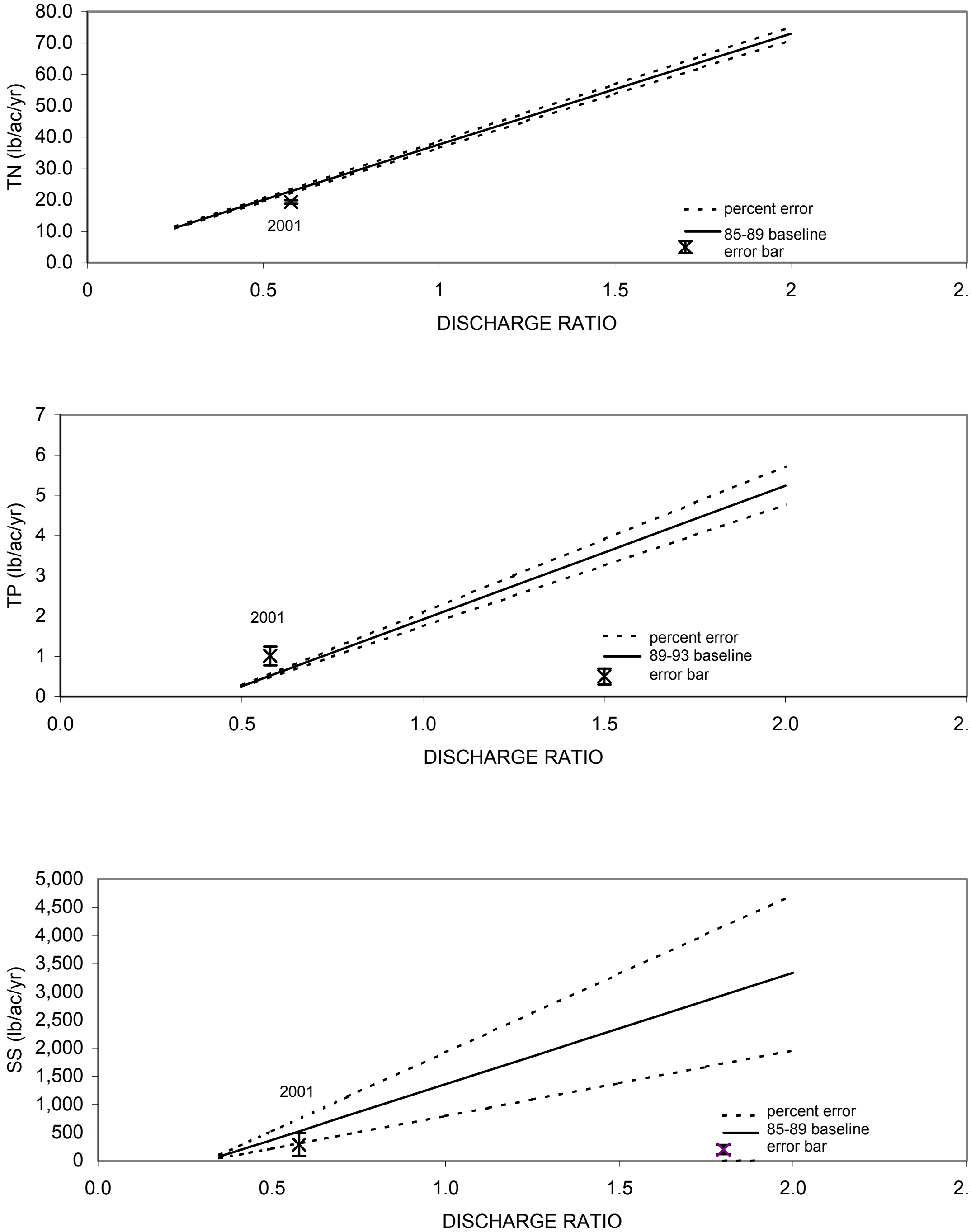


Figure 21. ***Total Nitrogen (TN), Total Phosphorus (TP), and Suspended-Sediment (SS) Yields, Conestoga River at Conestoga, Pa., 1985-89 and 2001***

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 2001. 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, SS, TOC, and several forms of 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 5 of the 90 FAC time series analyzed for trend and are noted in the table as BMDL.

Linear regression techniques were applied to the monthly FWC and LOAD time series to test for trend. The data must be normally distributed in order to apply this parametric test. In most cases, the data were log-transformed to meet the assumption of normality. To test this, the probability plot correlation coefficient (PPCC) was used to test for normality (Looney and Gulledge, 1985). If the data set failed the test for normality, then trend test results are invalid. Those parameters that failed the test for normality are listed in the tables as NN (Not Normal) and therefore have no trend designation.

Susquehanna River at Towanda, Pa.

Table 19 shows the trends for the Susquehanna River at Towanda for the period 1989 to 2001. While a comparison of baseline and status flow indicated a change in the flow record (11,500 cfs vs. 4,501 cfs), the test on the FLOWs did not detect ($p = 0.078$) a trend in the discharge time series.

Table 19. Trend Statistics for the Susquehanna River at Towanda, Pa., January 1985 through December 2001

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.078	-50	3	ns	11,500	4,501
TN	FAC	<0.001	-34	-23	DN	--	--
TN	FWC	<0.001	-28	-24	DN	2.92	1.00
TN	LOAD	0.001	-64	-23	DN	5.36	2.14
DN	FAC	<0.001	-25	-13	DN	--	--
DN	FWC	<0.001	-20	-15	DN	2.40	0.90
DN	LOAD	0.007	-59	-14	DN	4.58	2.07
TON	FAC	0.185	-24	5	ns	--	--
TON	FWC	0.139	-14	2	ns	1.13	0.46
TON	LOAD	0.055	-55	0	ns	2.33	0.89
DON	FAC	0.005	7	47	UP	--	--
DON	FWC	<0.001	20	33	UP	0.68	0.36
DON	LOAD	0.627	-38	34	ns	1.62	0.72
TNH	FAC	<0.001	-46	-17	DN	--	--
TNH	FWC	<0.001	-42	-31	DN	0.11	0.030
TNH	LOAD	0.001	-71	-29	DN	0.18	0.080
DNH	FAC	0.017	-37	-4	DN	--	--
DNH	FWC	<0.001	-28	-15	DN	0.10	0.030
DNH	LOAD	0.009	-63	-14	DN	0.17	0.12
DKN	FAC	0.290	-7	28	ns	--	--
DKN	FWC	<0.001	4	14	UP	0.77	0.36
DKN	LOAD	0.222	-47	16	ns	1.66	0.73
TKN	FAC	0.066	-25	1	ns	--	--
TKN	FWC	0.018	-16	-2	ns	1.25	0.49
TKN	LOAD	0.038	-56	-3	ns	2.64	0.96
TNO23	FAC	<0.001	-39	-28	DN	--	--
TNO23	FWC	<0.001	-34	-30	NN	1.88	0.52
TNO23	LOAD	<0.001	-66	-30	DN	4.44	1.29
DNO23	FAC	<0.001	-39	-27	DN	--	--
DNO23	FWC	<0.001	-34	-29	NN	1.86	0.52
DNO23	LOAD	<0.001	-66	-30	DN	4.37	1.29
TP	FAC	0.431	-11	31	ns	--	--
TP	FWC	0.378	-8	24	ns	0.14	0.08
TP	LOAD	0.273	-52	23	ns	0.30	0.17
DP	FAC	0.468	-21	12	ns	--	--
DP	FWC	0.463	-7	16	ns	0.10	0.040
DP	LOAD	0.125	-48	8	ns	0.21	0.10
DIP	FAC	<0.001	259	555	UP	--	--
DIP	FWC	<0.001	316	601	NN	0.033	0.040
DIP	LOAD	<0.001	157	486	UP	0.075	0.100
TOC	FAC	0.290	-9	3	ns	--	--
TOC	FWC	0.015	-10	-1	ns	6.54	3.02
TOC	LOAD	0.064	-55	2	ns	15.6	6.6
SS	FAC	0.623	-21	47	ns	--	--
SS	FWC	0.275	-55	25	ns	85.1	17.8
SS	LOAD	0.161	-77	27	ns	152.2	43.3

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

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 2.14 lb/ac during the last 36 months. The trend analysis indicates the presence of a decreasing trend ($p = 0.001$). Downward trends also were apparent for FWC ($p < 0.0001$) and FAC ($p < 0.0001$) after the effects of flow had been removed. Tests on the TNH and DNH indicated significant downward trends for FAC, FWC, and LOAD. Total and dissolved nitrate + nitrate (TNO23 and DNO23) also showed significant downward trends. While no trends were detected in TON, an increase ($p=0.005$) was observed in the dissolved fraction (DON) 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 transport characteristics of SS are 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. SS trend analyses did not show the existence of a trend for LOAD ($p = 0.161$) or FWC ($p = 0.275$). After removing the effect of flow on the concentration, the analysis of FAC also indicated no significant ($p = 0.623$) trend for SS. 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 (7,695 cfs) was lower than the base discharge (12,000 cfs), the test on the FLOWs did not detect ($p = 0.078$) a trend in the discharge time series.

Significant downward trends were shown in all three time series for TN, TKN, TON, DNH, and TNH. Downward trends also were apparent for FACs, DKN, TNO23 and DNO23, and both FAC and FWC for DN. Although no significant trends were found among the other nitrogen fractions, reductions from base conditions to status conditions were shown for all, including significant reductions in DN from a base of 4.87 mg/l to a current status of 2.39 mg/l. Downward trends in TON coupled with no trends in the dissolved fraction indicated reductions of particulate organic nitrogen. Reductions in inorganic nitrogen were most apparent within the dissolved fraction with downward trends shown in all three-time series. Nitrate and nitrite constituents showed downward trends for FAC alone, indicating that variations in flow for the given year might have masked any trends in FWC and LOAD.

Trend analysis for phosphorus indicated downward trends in FWC and FAC for both TP and DP. A significant trend in DP LOAD was also apparent ($p < 0.0001$) with a change in base condition of 0.13 lbs/ac to a current condition of 0.06 lbs/ac. DIP LOAD showed an increasing trend with a slope range of 35 to 210 percent and base to status condition of 0.045 mg/l and 0.08 mg/l, respectively. This suggested that reductions in DP stem from the organic fraction. The significance of these trend results suggested that some change has taken place, resulting in reduced inputs of phosphorus to the river upstream of Danville.

Significant downward trends were shown by the FAC and FWC for SS at Danville. Although there was no apparent trend for SS LOAD, the change from a base condition of 228 lbs/ac to a current status of 48.3 lbs/ac was quite notable. Coupled with the FAC and FWC trends, this change indicated that there was a significant reduction in SS inputs to the river system at Danville. Given that trends were not apparent at Towanda, 135 miles upstream of this site, some changes in the delivery processes have occurred in the watershed between the two sites.

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 a decrease in flow from 9,820 cfs to 5,329 cfs, analysis of the discharge record did not detect (p = 0.039) the presence of a trend in FLOW from 1985 through 2001.

Overall, significant downward trends existed in TN LOAD (p< 0.0001), FWC (p<0.0001), and FAC (P<0.0001). The base and status condition in concentration decreased from 1.4 mg/l to 0.88 mg/l, while yield decreased from 6.0 lbs/ac to 2.16 lbs/ac. Analysis of the organic and inorganic nitrogen time series indicated the presence of trends. Significant downward trends existed in the TON LOAD (p < 0.0001), FWC (p< 0.0001), and FAC (p<0.0001), which were strong indications that organic nitrogen delivered to the river had decreased. For the inorganic fraction, FAC trend results indicated that changes occurred in the delivery of TNO23, DNO23, TNH, and DNH. These constituents also showed downward trends in both the LOAD and FWC time series as well. These trends led to the reduction in TN in the river.

Decreasing trends in TP were apparent for FWC (p< 0.0001) and LOAD (p= 0.002) with slope magnitudes from -17 to -30 percent and -20 to -61 percent, respectively. There were no significant trends for FAC. Decreasing trends in DP also were apparent for FAC and LOAD. DIP showed an increasing trend for LOAD, while FAC showed no trend due to the number of observations below the level of detection exceeding 20 percent.

SS base and status yields (LOAD) and concentrations (FWC) showed a reduction (Table 21); however, trend analyses did not show the existence of a significant trend in LOAD (p = 0.038) or FWC (p = 0.047). After removing the effect of flow on the concentration, the analysis of FAC also indicated no significant (p = 0.744) trend. These results suggested that the process of sediment delivery and transport in the West Branch Susquehanna Subbasin upstream of Lewisburg has remained relatively the same since 1985. Because the subbasin is predominantly forested (approximately 80 percent), sediment production and delivery were 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 (1,965 cfs) was slightly lower than the base discharge (2,560 cfs). The test on FLOW did not detect the presence (p = 0.203) of a trend.

Downward trends were shown for TN and DN for FWC and FAC (p< 0.0001 for all four). There were no significant trends for organic nitrogen for any of the three-time series, indicating that reductions most likely occurred in the inorganic fraction. In fact, all three-time series for DNH showed decreasing trends, while FAC and LOAD showed decreasing trends for TNH. FACs and FWCs also showed decreasing trends for total and dissolved NO23. Although LOADS for total and dissolved NO23 showed no significant trends, yields decreased from a base condition of 3.0 mg/l and 2.89 mg/l to a status condition of 2.08 mg/l and 2.08 mg/l, respectively.

TP showed decreasing trends for both FAC (p = 0.0010) and FWC (p< 0.0001). DP also showed a decreasing trend for FAC (p = 0.031). LOAD for TP and DP showed no significant trends. Although reductions in DP concentrations for FWC were observed, no trends could be reported as the data failed the test for normality. DIP showed increasing trends for FAC and LOAD and no trend for FWC due to not normal distribution of data, although concentrations did increase.

There were no significant trends for any time series for SS indicating that there have been no changes to delivery mechanisms within the Juniata River Subbasin.

Table 20. Trend Statistics for the Susquehanna River at Danville, Pa., January 1985 through December 2001

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.078	-32	23	ns	12,000	7,695
TN	FAC	<0.001	-35	-23	DN	--	--
TN	FWC	<0.001	-32	-28	DN	2.45	1.06
TN	LOAD	0.008	-54	-11	DN	5.64	2.47
DN	FAC	<0.001	-24	-12	DN	--	--
DN	FWC	<0.001	-25	-19	DN	2.26	0.94
DN	LOAD	0.042	-48	-2	ns	4.87	2.39
TON	FAC	<0.001	-43	-21	DN	--	--
TON	FWC	<0.001	-38	-28	DN	1.15	0.47
TON	LOAD	0.004	-56	-15	DN	2.48	1.18
DON	FAC	0.266	-20	7	ns	--	--
DON	FWC	0.001	-20	-6	NN	0.74	0.35
DON	LOAD	0.155	-43	9	ns	1.65	0.81
TNH	FAC	<0.001	-67	-50	DN	--	--
TNH	FWC	<0.001	-62	-56	DN	0.18	0.030
TNH	LOAD	<0.001	-74	-46	DN	0.35	0.080
DNH	FAC	<0.001	-64	-46	DN	--	--
DNH	FWC	<0.001	-63	-54	DN	0.21	0.030
DNH	LOAD	<0.001	-74	-47	DN	0.38	0.08
DKN	FAC	0.001	-33	-10	DN	--	--
DKN	FWC	<0.001	-32	-20	NN	0.89	0.36
DKN	LOAD	0.020	-52	-7	ns	2.03	0.80
TKN	FAC	<0.001	-45	-26	DN	--	--
TKN	FWC	<0.001	-40	-32	DN	1.30	0.51
TKN	LOAD	0.002	-58	-19	DN	2.83	1.19
TNO23	FAC	<0.001	-23	-10	DN	--	--
TNO23	FWC	<0.001	-22	-16	NN	1.35	0.57
TNO23	LOAD	0.068	-47	2	ns	2.79	1.51
DNO23	FAC	<0.001	-24	-10	DN	--	--
DNO23	FWC	<0.001	-22	-16	NN	1.36	0.57
DNO23	LOAD	0.063	-47	1	ns	2.82	1.50
TP	FAC	<0.001	-45	-20	DN	--	--
TP	FWC	<0.001	-42	-27	DN	0.16	0.07
TP	LOAD	0.011	-61	-12	ns	0.38	0.17
DP	FAC	<0.001	-48	-26	DN	--	--
DP	FWC	<0.001	-45	-37	DN	0.060	0.030
DP	LOAD	<0.001	-62	-25	DN	0.13	0.060
DIP	FAC	<0.001	144	341	BMDL	--	--
DIP	FWC	<0.001	71	196	NN	0.021	0.030
DIP	LOAD	0.001	35	210	UP	0.045	0.080
TOC	FAC	<0.001	-31	-20	DN	--	--
TOC	FWC	<0.001	-29	-23	DN	6.82	2.90
TOC	LOAD	0.017	-51	-7	ns	14.6	7.7
SS	FAC	<0.001	-56	-29	DN	--	--
SS	FWC	0.001	-66	-26	DN	115.6	18.6
SS	LOAD	0.023	-77	-11	ns	228.0	48.3

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

Table 21. Trend Statistics for the West Branch Susquehanna River at Lewisburg, Pa., January 1985 through December 2001

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.039	-46	-2	ns	9,820	5,329
TN	FAC	<0.001	-33	-21	DN	--	--
TN	FWC	<0.001	-27	-24	DN	1.43	0.88
TN	LOAD	<0.001	-59	-27	DN	6.01	2.16
DN	FAC	<0.001	-26	-14	DN	--	--
DN	FWC	<0.001	-18	-15	NN	1.24	0.83
DN	LOAD	0.001	-54	-20	DN	5.14	2.02
TON	FAC	<0.001	-41	-14	DN	--	--
TON	FWC	<0.001	-40	-26	DN	0.65	0.31
TON	LOAD	<0.001	-65	-32	DN	2.97	0.81
DON	FAC	0.493	-18	10	ns	--	--
DON	FWC	0.001	-17	-5	NN	0.43	0.26
DON	LOAD	0.006	-52	-12	DN	1.92	0.73
TNH	FAC	0.001	-46	-14	DN	--	--
TNH	FWC	<0.001	-31	-30	DN	0.067	0.040
TNH	LOAD	<0.001	-62	-32	DN	0.28	0.08
DNH	FAC	0.028	-37	-2	DN	--	--
DNH	FWC	<0.001	-27	-20	DN	0.072	0.040
DNH	LOAD	<0.001	-58	-26	DN	0.30	0.09
DKN	FAC	0.191	-25	6	BMDL	--	--
DKN	FWC	<0.001	-24	-10	NN	0.48	0.29
DKN	LOAD	0.002	-56	-18	DN	2.17	0.79
TKN	FAC	0.011	-35	-5	DN	--	--
TKN	FWC	<0.001	-35	-19	DN	0.70	0.36
TKN	LOAD	<0.001	-62	-25	DN	3.24	0.98
TNO23	FAC	<0.001	-27	-15	DN	--	--
TNO23	FWC	<0.001	-18	-11	DN	0.75	0.54
TNO23	LOAD	0.001	-53	-18	DN	3.04	1.31
DNO23	FAC	<0.001	-28	-15	DN	--	--
DNO23	FWC	<0.001	-18	-12	DN	0.75	0.54
DNO23	LOAD	0.001	-53	-18	DN	3.03	1.30
TP	FAC	0.055	-37	1	ns	--	--
TP	FWC	<0.001	-30	-17	DN	0.069	0.050
TP	LOAD	0.002	-61	-20	DN	0.27	0.11
DP	FAC	<0.001	-59	-39	DN	--	--
DP	FWC	<0.001	-52	-46	NN	0.039	0.020
DP	LOAD	<0.001	-72	-51	DN	0.17	0.050
DIP	FAC	<0.001	137	345	BMDL	--	--
DIP	FWC	<0.001	102	251	NN	0.012	0.020
DIP	LOAD	<0.001	44	164	UP	0.043	0.060
TOC	FAC	0.309	-4	15	ns	--	--
TOC	FWC	0.939	-5	5	ns	2.46	1.94
TOC	LOAD	0.150	-47	1	ns	9.62	4.84
SS	FAC	0.744	-27	25	ns	--	--
SS	FWC	0.047	-51	-1	ns	33.6	12.7
SS	LOAD	0.038	-73	-4	ns	137.8	29.5

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

Table 22. Trend Statistics for the Juniata River at Newport, Pa., January 1985 through December 2001

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.203	-29	25	ns	2,560	1,965
TN	FAC	<0.001	-21	-11	DN	--	--
TN	FWC	<0.001	-21	-11	DN	2.46	1.42
TN	LOAD	0.170	-43	10	ns	4.44	3.15
DN	FAC	<0.001	-16	-6	DN	--	--
DN	FWC	<0.001	-16	-8	DN	2.08	1.36
DN	LOAD	0.266	-40	15	ns	4.02	2.91
TON	FAC	0.068	-25	1	ns	--	--
TON	FWC	0.026	-25	-2	ns	0.90	0.50
TON	LOAD	0.239	-43	15	ns	1.69	0.96
DON	FAC	0.310	-6	21	ns	--	--
DON	FWC	0.597	-8	16	ns	0.55	0.39
DON	LOAD	0.873	-29	33	ns	1.18	0.82
TNH	FAC	<0.001	-65	-46	DN	--	--
TNH	FWC	<0.001	-58	-52	NN	0.072	0.020
TNH	LOAD	<0.001	-70	-40	DN	0.12	0.050
DNH	FAC	<0.001	-56	-33	DN	--	--
DNH	FWC	<0.001	-50	-40	DN	0.077	0.030
DNH	LOAD	<0.001	-63	-26	DN	0.13	0.060
DKN	FAC	0.214	-20	5	ns	--	--
DKN	FWC	0.048	-20	0	ns	0.64	0.38
DKN	LOAD	0.306	-39	16	ns	1.34	0.82
TKN	FAC	0.041	-26	-1	DN	--	--
TKN	FWC	0.020	-25	-3	ns	1.00	0.54
TKN	LOAD	0.232	-43	14	ns	1.85	1.00
TNO23	FAC	<0.001	-19	-9	DN	--	--
TNO23	FWC	<0.001	-19	-10	DN	1.53	0.96
TNO23	LOAD	0.201	-42	12	ns	3.00	2.08
DNO23	FAC	<0.001	-17	-6	DN	--	--
DNO23	FWC	<0.001	-17	-8	DN	1.47	0.96
DNO23	LOAD	0.261	-41	15	ns	2.89	2.08
TP	FAC	0.001	-39	-12	DN	--	--
TP	FWC	<0.001	-35	-16	DN	0.14	0.080
TP	LOAD	0.062	-51	1	ns	0.26	0.15
DP	FAC	0.031	-32	-2	DN	--	--
DP	FWC	<0.001	-25	-9	NN	0.079	0.050
DP	LOAD	0.100	-42	4	ns	0.15	0.11
DIP	FAC	<0.001	116	315	UP	--	--
DIP	FWC	<0.001	95	267	NN	0.049	0.070
DIP	LOAD	<0.001	68	281	UP	0.12	0.13
TOC	FAC	0.002	-22	-6	DN	--	--
TOC	FWC	<0.001	-19	-9	DN	5.34	2.90
TOC	LOAD	0.186	-41	10	ns	9.83	6.12
SS	FAC	0.310	-35	15	ns	--	--
SS	FWC	0.274	-43	17	ns	51.3	19.5
SS	LOAD	0.418	-59	45	ns	83.1	35.6

*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 20,235 cfs was lower than the base flow of 22,300 cfs, the test on the FLOW did not detect ($p = 0.394$) a trend in the discharge time series.

For the period 1987 to 2001, there were downward trends in FAC for all fractions of nitrogen except DON. Downward trends in TN ($p<0.0001$) and DN ($p<0.0001$) for FAC suggested 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. These reductions were apparent the most within the inorganic fraction, including ammonia nitrogen and nitrate plus nitrite nitrogen. All three-time series for DNH showed downward trends, while TNH downward trends existed for FAC and LOAD. Although not showing a significant trend, FWC for TNH decreased from a base condition of 0.088 mg/l to 0.03 mg/l. TNO23 and DNO23 also showed downward trends for FAC and FWC ($p< 0.0001$ for all four).

There were no apparent trends for TP for 2001. However, DP showed an increasing trend for FAC. This trend also was apparent in the LOAD time series for DIP indicating that inorganic phosphorus was the influence on the increasing trend. Due to greater than 20 percent of the observations being below the detection level for FAC, and not normal distribution of data for FWC, an analysis of the FAC and FWC trends could not be completed for DIP.

SS base and status yield and concentration indicated a slight decrease, but trend analyses indicated a lack of trend in LOAD ($p = 0.668$) and FWC ($p = 0.969$). After removing the effect of flow on the concentration, the analysis of FAC showed no trend ($p = 0.976$). These results suggested that the process of sediment delivery and transport, as recorded on the Susquehanna River at Marietta from 1987 to 2001, 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 a decrease in flow from 472 cfs to 430.8 cfs, an analysis of the discharge record did not detect ($p = 0.148$) the presence of a trend in FLOW.

Significant downward trends were apparent in all three-time series for TN. Although reductions in base to status conditions existed for DN, no significant trends existed. This suggests that particulate forms played an important role in the delivery of nitrogen, although significant downward trends also were apparent in all three-time series for DNH and TNH. TON also showed downward trends for FAC and LOAD. The lack of any trends in nitrite plus nitrate nitrogen indicated that the downward trend in TN was influenced by the reductions of ammonia and TON.

Downward trends in phosphorus at Conestoga were mostly apparent in the dissolved inorganic fraction. DP showed downward trends in both the FAC and LOAD time series, as well as downward trends for both time series for DIP. 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.

Table 23. Trend Statistics for the Susquehanna River at Marietta, Pa., January 1985 through December 2001

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.394	-35	19	ns	22,300	20,235
TN	FAC	<0.001	-31	-19	DN	--	--
TN	FWC	<0.001	-27	-22	DN	2.68	1.33
TN	LOAD	0.017	-53	-8	ns	5.24	3.48
DN	FAC	<0.001	-21	-8	DN	--	--
DN	FWC	<0.001	-18	-13	DN	2.16	1.21
DN	LOAD	0.071	-46	2	ns	4.41	3.07
TON	FAC	0.036	-31	-1	DN	--	--
TON	FWC	0.024	-22	-2	ns	0.79	0.52
TON	LOAD	0.153	-46	10	ns	1.80	1.29
DON	FAC	0.468	-10	25	ns	--	--
DON	FWC	0.065	0	21	ns	0.44	0.35
DON	LOAD	0.815	-29	31	ns	0.95	0.89
TNH	FAC	<0.001	-55	-32	DN	--	--
TNH	FWC	<0.001	-46	-40	NN	0.088	0.030
TNH	LOAD	<0.001	-65	-29	DN	0.19	0.090
DNH	FAC	<0.001	-45	-21	DN	--	--
DNH	FWC	<0.001	-36	-29	DN	0.079	0.040
DNH	LOAD	0.002	-57	-18	DN	0.19	0.090
DKN	FAC	0.091	-30	3	BMDL	--	--
DKN	FWC	0.021	-18	-2	NN	0.56	0.32
DKN	LOAD	0.139	-42	8	ns	1.16	0.82
TKN	FAC	0.005	-34	-7	DN	--	--
TKN	FWC	0.001	-25	-8	DN	0.88	0.54
TKN	LOAD	0.083	-49	4	ns	2.12	1.46
TNO23	FAC	<0.001	-24	-10	DN	--	--
TNO23	FWC	<0.001	-24	-16	DN	1.52	0.84
TNO23	LOAD	0.045	-51	-1	ns	3.16	2.14
DNO23	FAC	<0.001	-23	-9	DN	--	--
DNO23	FWC	<0.001	-23	-15	DN	1.50	0.84
DNO23	LOAD	0.051	-50	0	ns	3.15	2.13
TP	FAC	0.314	-8	29	ns	--	--
TP	FWC	0.241	-6	29	ns	0.11	0.090
TP	LOAD	0.872	-37	49	ns	0.24	0.24
DP	FAC	0.010	5	45	UP	--	--
DP	FWC	0.001	10	40	NN	0.055	0.040
DP	LOAD	0.608	-22	52	ns	0.12	0.11
DIP	FAC	<0.001	881	1686	BMDL	--	--
DIP	FWC	<0.001	756	1382	NN	0.010	0.050
DIP	LOAD	<0.001	542	1419	UP	0.022	0.13
TOC	FAC	0.153	-12	2	ns	--	--
TOC	FWC	0.158	-8	1	ns	4.47	2.94
TOC	LOAD	0.324	-39	17	ns	9.72	8.35
SS	FAC	0.976	-19	24	ns	--	--
SS	FWC	0.969	-30	40	ns	50.4	30.8
SS	LOAD	0.668	-54	64	ns	110.3	80.8

*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 2001

Parameter	Time Series	p-Value	Slope Magnitude (%)		Trend Direction	Condition*	
			Minimum	Maximum		Base	Status
Q	FLOW	0.148	-34	6	ns	472.0	430.8
TN	FAC	<0.001	-22	-14	DN	--	--
TN	FWC	<0.001	-17	-14	DN	12.1	6.82
TN	LOAD	0.003	-44	-12	DN	28.1	21.0
DN	FAC	0.269	-7	2	ns	--	--
DN	FWC	0.600	-5	3	ns	9.84	6.69
DN	LOAD	0.075	-33	2	ns	23.1	21.4
TON	FAC	<0.001	-40	-19	DN	--	--
TON	FWC	<0.001	-39	-24	NN	2.55	1.07
TON	LOAD	0.001	-59	-20	DN	6.28	3.43
DON	FAC	0.529	-16	9	ns	--	--
DON	FWC	0.004	-10	-2	DN	1.46	0.73
DON	LOAD	0.080	-41	3	ns	3.70	2.40
TNH	FAC	<0.001	-78	-68	DN	--	--
TNH	FWC	<0.001	-77	-71	DN	0.36	0.080
TNH	LOAD	<0.001	-85	-69	DN	0.93	0.27
DNH	FAC	<0.001	-77	-68	DN	--	--
DNH	FWC	<0.001	-76	-70	DN	0.37	0.070
DNH	LOAD	<0.001	-84	-69	DN	0.95	0.26
DKN	FAC	0.001	-30	-9	DN	--	--
DKN	FWC	<0.001	-25	-16	DN	1.94	0.86
DKN	LOAD	0.004	-50	-13	DN	5.04	2.76
TKN	FAC	<0.001	-48	-31	DN	--	--
TKN	FWC	<0.001	-47	-33	NN	3.13	1.20
TKN	LOAD	<0.001	-64	-30	DN	8.13	3.89
TNO23	FAC	0.832	-7	6	ns	--	--
TNO23	FWC	0.855	-4	5	ns	7.86	5.86
TNO23	LOAD	0.094	-32	3	ns	18.8	19.1
DNO23	FAC	0.828	-5	7	ns	--	--
DNO23	FWC	0.463	-3	7	ns	7.66	5.77
DNO23	LOAD	0.120	-30	4	ns	18.6	18.9
TP	FAC	0.006	-30	-6	DN	--	--
TP	FWC	<0.001	-33	-11	NN	0.84	0.37
TP	LOAD	0.020	-55	-7	ns	1.68	1.21
DP	FAC	<0.001	-40	-27	DN	--	--
DP	FWC	<0.001	-35	-26	NN	0.39	0.19
DP	LOAD	<0.001	-55	-25	DN	0.88	0.60
DIP	FAC	0.012	-28	-4	DN	--	--
DIP	FWC	<0.001	-24	-8	NN	0.32	0.18
DIP	LOAD	0.007	-46	-10	DN	0.77	0.54
TOC	FAC	<0.001	-53	-42	DN	--	--
TOC	FWC	<0.001	-52	-43	DN	12.6	4.13
TOC	LOAD	<0.001	-68	-41	DN	31.1	13.5
SS	FAC	0.006	-42	-9	DN	--	--
SS	FWC	0.003	-68	-22	DN	185.1	75.6
SS	LOAD	0.012	-79	-18	ns	484.5	255.7

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

Downward trends in SS were apparent for FAC (p = 0.006) and FWC (p = 0.003) suggesting that some change in the delivery of SS had occurred. No trends were shown for the LOAD time series.

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. For 2001, streamflow at all sites was well below the long-term flows, i.e., a dry year. Stream discharge ranged from 58 percent of the long-term flow at Conestoga and Newport to 73 percent of the long-term flow at Towanda and Danville.

This relationship between 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 changes 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, are playing 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 materials 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 operation of a new regional STP in the City of Lancaster.

SS trends varied regionally. Trends were not apparent in the drainage areas upstream of Towanda and Lewisburg. For Towanda, the lack of trends 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 2001 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 in TN throughout the Susquehanna River Basin. TP showed no significant trends at Towanda and Marietta, while all other sites showed decreasing trends in TP for 2001. Improving conditions in SS occurred at Conestoga and Danville, while all other sites showed no trends for 2001. 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, and that these reductions were from the implementation of management actions.

SUMMARY

Nutrient and suspended-sediment samples were collected during base flow and stormflow in calendar year 2001. The samples were collected from the Susquehanna River at Towanda, Danville, and Marietta, the West Branch Susquehanna River at Lewisburg, the Juniata River at Newport, and the Conestoga River at Conestoga, Pennsylvania.

Annual precipitation was below normal in 2001 at all sites. Precipitation ranged from 19.77 inches below normal in the Juniata Subbasin to 4.46 inches below normal in the watershed above Towanda. Water discharges ranged from 58 percent to 73 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 for TN and TP, and Towanda for SS. 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, were greater than from the West Branch Susquehanna River at Lewisburg, with 81 percent forest and 13.9 percent agriculture.

Seasonal mean water discharges in 2001 were highest in the spring (April-June), followed by winter (January-March), then fall (October-December) at Towanda, Danville, Lewisburg, Newport, and Marietta. Seasonal discharges at Conestoga were highest in the winter, followed by spring. Seasonal variation of TN, TP, and SS corresponded with seasonal discharge at all sites except TN at Newport and at Lewisburg, which both recorded higher values in winter, followed by spring, fall, then summer. SS at Newport also didn't correspond with seasonal discharge and was highest during spring, followed by winter, summer, and then fall.

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 2001 TN yields showed the same relationship among the sites in the winter, summer, and fall. TN yields in the spring decreased between Towanda and Danville and increased between Danville and Marietta. The long-term TP yields did not show any consistent pattern among the Susquehanna River sites. The 2001 TP yields showed no change from Towanda to Danville, except for the spring, which showed a decrease. All seasons showed a yield increase from Danville to Marietta for TP. The long-term SS yields at Towanda, Danville, and Marietta decreased in the downstream order for all seasons, except summer. Spring 2001 yields also decreased in the downstream order, but the summer and fall yields showed increases in the downstream order. Comparison of long-term seasonal yields among the tributary sites at Lewisburg, Newport, and Conestoga indicated that the TN and TP yields were smallest at Lewisburg for all seasons. Long-term yields of SS were lowest at Lewisburg during the spring and summer and where lowest at Newport during the winter and fall. The 2001 SS yield values show Lewisburg with the lowest values for all three parameters during all seasons except fall. Newport recorded the lowest TN and TP values for the fall season of 2001 while

Conestoga recorded the lowest SS value for the fall.

Comparison of the 2001 annual yields and the 5-year baselines indicates that there were decreases of TN at all sites. TP yields were higher than the baseline yields at Towanda, Newport, Marietta, and Conestoga. The 2001 TP yields at Danville and Lewisburg showed no significant change from the baseline. Comparisons of SS yields indicated that there was an increase at Towanda and Newport. There were no significant changes in the SS yields at Danville, Lewisburg, Marietta, 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 2001. 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 nitrogen and phosphorus. Analyses for trends were performed on the FLOW, LOAD, FWC, and FAC.

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 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 delivered 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 that took 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 2001 trend analyses indicated TN conditions improving throughout the Susquehanna River Basin. TP showed no significant trends at Marietta and Towanda while all other sites showed decreasing trends for 2001. Improving conditions in SS occurred at Towanda and Newport, while remaining the same at the remaining four stations. 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.

The sediment and nutrient monitoring sites on the Susquehanna River will be one of the first places where water quality improvements will be observed due to Pennsylvania's restoration efforts. Because of the threat of a regulatory TMDL cited previously in this report, it will be extremely important to document this progress. Because of the delay time, it is almost certain that observable water quality improvements in the Bay will occur after improvements in the Susquehanna, and that biological responses in the Bay due to improved water quality will occur even later.

Presently, it is difficult to document the portion of the load at Towanda that is coming from the Chemung River drainage area in New York and the mainstem of the Susquehanna River, upstream of the mouth of the Chemung River. If an additional sediment and nutrient monitoring site were to be established at the USGS gaging station at Chemung, the loads from the eastern and western portions of the Susquehanna River Basin in New York could be identified. SRBC has initiated discussions with the New York State Department of Environmental Conservation regarding this matter, and will continue this discussion under separate funding as part of SRBC's Chesapeake Bay Water Quality Steering Committee activities.

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