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