NUTRIENT AND SUSPENDED SEDIMENT MONITORING ON THE UPPER MONOCACY RIVER, 1990-1992

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INTRODUCTION

Background and Goals

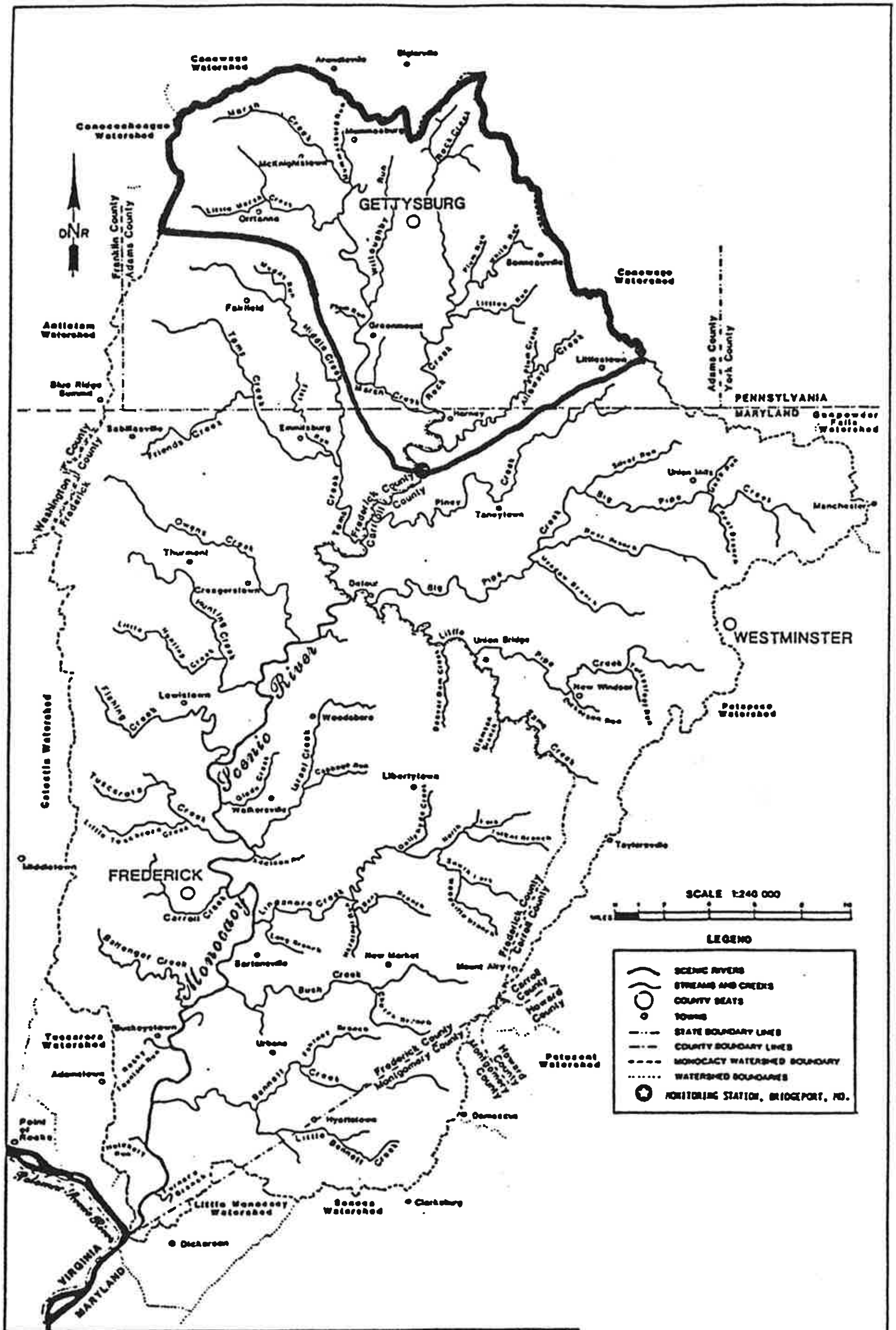
Pennsylvania has joined with Maryland, Virginia, the District of Columbia, and the U.S. EPA to work toward reducing nutrient loads in the Chesapeake Bay by 40%. The Monocacy watershed has been shown to be a significant contributor of nonpoint source nutrients and sediments to the Bay. Programs to reduce nutrient loss from croplands in the upper Monocacy are being implemented under various state and federal programs, and are likely to continue in order to achieve the Bay Program's nutrient reduction goal. To evaluate the progress of pollution reduction programs in the upper Monocacy, it is necessary to establish current loads of nutrients and suspended sediments and to maintain a monitoring program from which annual loads and trends can be calculated.

In 1989, the Pennsylvania Department of Environmental Resources (DER) asked the Interstate Commission on the Potomac River Basin (ICPRB) to establish a monitoring program on the upper Monocacy River. The goals of the monitoring project are (1) to provide baseline nutrient and suspended sediment loading data for the Pennsylvania drainage of the Monocacy River basin and (2) to estimate the relative contributions of point and nonpoint sources of nutrients and sediments. The monitoring program commenced in October, 1989 and is ongoing. In this report, annual nutrient and suspended sediment loads are estimated based on the results of monitoring during the water years 1990-1992. In addition, the relative contributions of point and nonpoint sources to the total nutrient load are estimated.

Monitoring was conducted on the Monocacy River near Bridgeport, Md., at the site of the U.S. Geological Survey's (USGS) gage (ID: 01639000). The site is 60 feet downstream of the bridge on State Highway 140, 4.8 miles downstream of the confluence of Rock and Marsh Creeks at the Pennsylvania-Maryland state line, and 52 miles upstream from the confluence of the Monocacy with the Potomac River [James et al., 1992]. The constituents of primary interest are total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS). Table 1 lists all the monitored water quality parameters.

Basin Characteristics

The Monocacy watershed, depicted in Figure 1, encompasses 971 square miles, of which 221 lay in Pennsylvania and the remainder in Maryland. The Bridgeport site is advantageous for monitoring because (1) it encompasses more than three-fourths of the Pennsylvania portion of the Monocacy watershed, and (2) it has been the site of a USGS gage since 1942. The site receives drainage from approximately 173 square miles, with 93% in Adams County, Pennsylvania and the remainder in Frederick and Carroll Counties, Maryland. The Bridgeport drainage area is comprised of the Rock, Alloway, and Marsh Creek watersheds, with a small fraction draining directly into the Monocacy mainstem. The monitored sub-basin is bounded by the Tom's Creek watershed to the southwest, the Conococheague basin



MONOCACY SCENIC RIVER WATERSHED

Table 1. Water quality parameters monitored at the Bridgeport site.

Parameter	ID Number
Water temperature	00010
Air temperature	00020
Specific conductance	00095
pH, whole water, field	00400
pH, whole water, lab	00403
Nitrogen, total, as N	00600
Nitrogen, dissolved, as N	00602
Nitrogen, organic, total, as N	00605
Nitrogen, organic, dissolved, as N	00607
Nitrogen, ammonia, dissolved, as N	00608
Nitrogen, ammonia, total, as N	00610
Nitrogen, nitrite, dissolved, as N	00613
Nitrogen, nitrite, total, as N	00615
Nitrogen, nitrate, dissolved, as N	00618
Nitrogen, nitrate, total, as N	00620
Nitrogen, ammonia + organic, dissolved, as N	00623
Nitrogen, ammonia + organic, total, as N	00625
Nitrogen, nitrite + nitrate, total, as N	00630
Nitrogen, nitrite + nitrate, dissolved, as N	00631
Phosphate, total, as PO_4	00650
Phosphate, ortho, dissolved, as PO_4	00660
Phosphorus, total, as P	00665
Phosphorus, dissolved, as P	00666
Phosphorus, ortho, dissolved, as P	00671
Nitrogen, ammonia, total, as NH_4	71845
Nitrogen, ammonia, dissolved, as NH_4	71846
Nitrogen, nitrate, dissolved, as NO_3	71851
Nitrogen, nitrite, dissolved, as NO_2	71856
Nitrogen, total, as NO_3	71887
Specific conductance, lab	90095

to the west, the Conowago to the north and east, and the Piney Creek basin to the southeast. Land use in the watershed is predominantly agricultural (Table 2). Total agricultural uses, including row and non-row crops, hay, pasture and animal feedlot lands, represent 65% of the Bridgeport drainage area. Only 6% of the drainage is from urban/suburban uses, with the remaining 29% from forest. The Marsh Creek sub-watershed, draining portions of the Catoctin Mountains, contains the bulk of the forest land, while the Alloway and Rock Creek basins are more than three-fourths agricultural. Five point source dischargers with flows greater than 0.05 mgd were identified as within the monitored drainage area. These dischargers are the wastewater treatment plants (WWTPs) at Gettysburg, Littlestown, Cumberland Township North and South, and Bonneauville. Gettysburg and Littlestown are the largest municipalities in the watershed; the Gettysburg WWTP accounts for 65% of the total point source flow, and the Littlestown plant for about 17%.

MONITORING METHODOLOGY

Sampling

Sampling commenced in October, 1989 (the start of water year 1990) and is ongoing. Collection of samples using automated equipment and field work, and laboratory analysis were performed by the USGS Towson Field Office. Sampling procedures were similar to those used at the Chesapeake Bay Program's Fall Line Monitoring stations. Samples were collected at five verticals across the section, and composited using the equal discharge sampling procedure. All samples were depth-integrated using USGS-standard equipment and techniques.

Nutrient sampling was conducted for base flows and for storm flows. Base flow samples were taken approximately monthly. During major storms, samples were collected over the storms's duration using an automatic sampler. The sampler engaged when stage exceeded five feet. Subsequent samples were taken at equal flow volumes (approximately 17 million cubic feet). Samples in the automatic sampler were refrigerated at 4° C until collection by USGS field personnel, usually during the storm. In some cases, where field personnel were not immediately available, samples were collected within one or two days. At the time of collection, the samples were filtered, treated with mercuric chloride ($HgCl_2$), and packed in ice for transport to the USGS National Water Quality Laboratory in Denver, Colorado. Samples were shipped via UPS at the earliest possible time (within a day of collection). The low temperatures and the $HgCl_2$ minimize biological activity in the samples (e.g. uptake/ nitrification). While the nutrient speciation can change (e.g. adsorption/desorption of NH_4^+) when more than one day elapses between sample collection and filtration, total nitrogen and phosphorus concentrations should not have been significantly changed by the delay in analysis.

For six storm events, field personnel collected manual samples in conjunction with those taken by the automatic sampler to check the representativeness of the automated process. These samples were taken on the rising limb, at the peak, and throughout the storm recession. In addition, for three storms, samples collected by the automatic sampler were composited over an interval of 1-12 hours. Suspended sediment samples were collected on a near-daily basis by a local observer, with "missing" days being interpolated by the USGS [James et al., 1991; 1992; 1993]. Discharge data were collected continuously, and reported as average daily flows.

Table 2. Land uses in the Bridgeport drainage area.

Land Use Category	Area (acres)
Agricultural	**72,110**
No-till cropland	11,375
Conventional-till cropland	25,673
Non-row crops and hay	26,499
Pasture and animal feedlots	8,563
Forest	**31,419**
Urban	**6,972**
Urban, pervious (lawns, parks, etc.)	5,247
Urban, impervious (roads, buildings, etc.)	1,725
Total sub-basin land area	**110,502**

Source: Casman (1985).

Load Calculation

Daily loads for TSS were obtained from the USGS Water-Data Reports for water years 1990-92, which include estimated values for "missing" days. Loads of total nitrogen and total phosphorus were calculated from the sampling and daily discharge data using the multivariate equation of Cohn et al. (1992):

$$\ln(C)=a_0+a_1\ln(Q/Q_c)+a_2\ln(Q/Q_c)^2+a_3(T-T_c)+a_4(T-T_c)^2+a_5\sin(2\pi T)+a_6\cos(2\pi T)+\varepsilon \qquad (1)$$

where:

C = Concentration of the nutrient,
Q = Flow (discharge),
T = Time (in years),
Q_c, T_c = "Centering" variables used to simplify the numerical work,
$a_0, \ldots, a_6$ = coefficients that are fit to the available data,
ϵ = an error function, assumed normally-distributed with mean zero.

Equation (1) is empirical, and not derived from any mechanistic understanding of the underlying processes [Cohn et al., 1992]. The two Q terms account for the effects of flow, the polynomial T terms for time trends, and the trigonometric terms for seasonality. An advantage of this estimation equation is that it utilizes two variables, flow and time, that are readily available on a daily basis. Concentration of the nutrient is calculated from the ln(C) using the Minimum Variance Unbiased Estimator (MVUE) of Cohn et al. (1989, 1992) which removes the retransformation bias that can occur with log-linear relationships. Daily load can then be calculated from the relationship

$$L = k\,Q\,C \tag{2}$$

where:

L = load (in mass units),
k = a conversion constant.

For loads expressed in pounds, flow in cfs, and concentration in mg/L, $k=5.39$. Monthly and annual loads can be calculated by summing the daily loads.

Actual calculation of nutrient loads were performed using an implementation of the MVUE of Cohn et al. (1989) developed using a Quattro Pro spreadsheet on an 80486 computer. The implementation was verified by comparing the results of load calculation with the output of the ESTIMATOR program written by Tim Cohn and running on a Prime computer at the USGS Towson Office. For both of two different input datasets, the total load calculated by the two implementations differed by less than 0.5%, indicating no significant differences in the way the MVUE model was implemented between the spreadsheet and the ESTIMATOR program. There was, however, one major difference in the handling of the sample datasets. The ESTIMATOR program treats each sample within a storm event (one storm had 22 samples) as an independent observation. However, the samples taken at regular intervals during a storm are serially correlated and cannot be treated as independent observations. In addition, it is possible to bias the regression in favor of the storm data, because the number of storm samples is about twice the base flow samples while the number of base flow days far outnumber storm days. Therefore, for the regression calculations in this report, all samples within a given storm were aggregated into a single observation, using the average flow and a flow-weighted average concentration.

Calculating Point Source Loads

One goal of the monitoring program was to determine the relative contributions of point and nonpoint sources of nutrients and sediments. To that end, data on point source discharges were compiled from the records of the Pennsylvania Department of Environmental Resources (DER), Harrisburg regional office. Five municipal wastewater treatment plants plants were identified within the Bridgeport drainage area as significant (>0.05 mgd) dischargers. For each plant, daily Discharge Monitoring Reports (DMRs) contained daily discharge and TSS data (2-4 samples monthly) reported by the discharger as part of the permit process. For one plant (Gettysburg), TP was also reported on the DMRs. In addition, DER inspected the plants from one to three times annually and collected "grab samples" which were analyzed for CBOD, ammonia, nitrate/nitrite, total phosphorus, and other parameters.

For each of the plants, monthly average discharge and monthly loads of TSS, TN and TP were compiled. Monthly discharge and TSS loadings were taken directly from the DMRs. For Gettysburg, the monthly average TP concentration from the DMRs was used to calculate the monthly TP load. For the other plants, the average concentration from the grab samples for each water year was used to calculate an annual loading of TP.

TN is normally calculated by summing solid and dissolved phases of ammonia-nitrogen, nitrate/nitrite-nitrogen and organic-nitrogen (Org-N). However, the grab sample data do not include Org-N. Thus, there is no way to calculate the exact value of TN for each grab sample. For the purposes of load estimation, Org-N was estimated by using BOD as a surrogate for the organic matter in the sample. Viessman and Hammer (1985) indicate that Org-N is approximately 7-10% of BOD in wastewater effluents. Due to the imprecision in these numbers, Org-N was estimated here to be 10% of BOD. It should be noted that with low levels of BOD in the effluents of the plants evaluated here (generally < 5 mg/L), the estimated Org-N concentrations were generally less than 5% of total nitrogen.

Another potential source of error in both TN and TP loads is the small number of samples (1-3 annually) forming the basis of the load calculation for the entire year. In particular, where the concentrations varied widely among the grab samples, the representativeness of the sample data is highly questionable. However, these grab samples represent the only available TN and TP effluent data for these plants.

RESULTS AND DISCUSSION

Results are reported here for monitoring during water years 1990-1992 (October, 1989 to September, 1992), representing 1096 days. Sediment (TSS) samples were taken on 781 days, while nutrient samples were collected on 57 days, including 13 storm days when multiple samples were drawn. Unless otherwise noted, all references to years should be interpreted to mean water years, in accord with the reporting practices of the USGS.

Stream Flow (Discharge)

Average daily flow was measured and reported throughout the monitoring period. Figure 2 shows average daily flow for the three years, while Table 3 contains summary statistics. The data indicate that discharge at Bridgeport is predominantly low flows, but that large storm events can increase flow by three orders of magnitude. For example, 78% of the daily flows were below the overall mean flow of 176 cfs. Mean daily flows above 1000 cfs were recorded for only 30 of the 1096 total days recorded. Despite the predominance of low flow days, overall discharge was dominated by the highest flows. The 10% of days with highest flow accounted for 54% of the water flowing past Bridgeport. Overall, the mean daily flow for the three years was below the historic mean of 202 cfs (James et al., 1992). Mean flow for water year 1991 (214 cfs) was slightly above the historic average, but flows for 1990 and 1992 (158 and 157 cfs) were well below average. Point source discharges were stable over the three-year monitoring period, averaging 3.5 cfs (2.3 mgd).

The winter months were the wettest overall, followed by the fall. The first half of water year 1991 was the wettest period during the three years, with average daily flows above 350 cfs. In contrast, the spring and summer of 1991 were the driest seasons.

Suspended Sediments

Daily measurements of total suspended solids (TSS) were made at Bridgeport on about 71% of the days within the monitoring period, and were reported in the USGS Water Data Reports [James et al., 1991, 1992, 1993]. When flow conditions were changing, multiple TSS samples were collected in a single day, and load was calculated using the subdivided-day method. Missing TSS values were estimated by the USGS, based upon adjacent values, using the graphical trace method [James, 1993]. Table 3 summarizes the TSS data.

Daily concentrations of TSS ranged over two orders of magnitude, from 1 to 565 mg/L. Daily loads of TSS ranged over five orders of magnitude, reflecting the fact that high flows greatly increase TSS concentrations. Runoff during storms was by far the dominant contributor of TSS load, with only eleven days accounting for half of the TSS load passing through the sampling site over three years. The daily load at the 95th percentile is less than 1% of the maximum daily load. The contribution of point sources to TSS load was negligible. The TSS load was lower in 1991 than 1990, despite the increase in mean daily flow from 158 to 214. This anomaly is accounted for by the January 30, 1990 load of over 7000 tons, the largest single day's load in the three-year interval. TSS load declined again between 1991 to 1992.

Nutrients

Nutrient sampling was performed at near-monthly intervals during base flow, and during selected storms as described above. The nutrient data are summarized in Table 4, with the full data listed in Appendix A. The instantaneous concentrations of TN ranged from 0.8 to

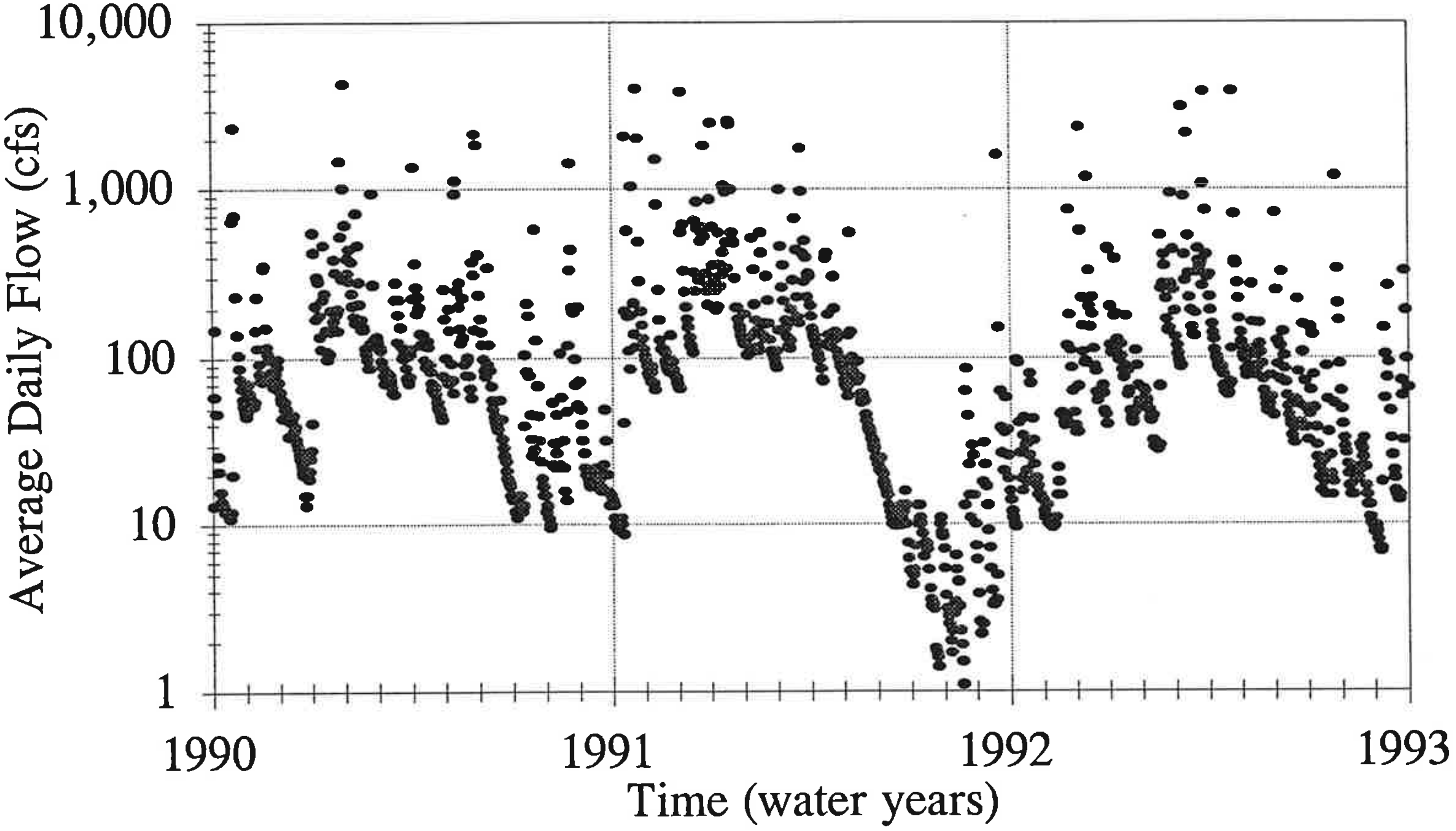


Figure 2. Average daily flow at Bridgeport for water years 1990-1992.

Table 3. Statistics on stream flow and total suspended solids (TSS) concentrations and loads at Bridgeport, Md.

	Mean Daily Flow (cfs)	Mean Daily TSS Conc'n (mg/L)	Mean Daily TSS Load (tons)	Total TSS Load (tons)
1990-1992 (All sources)	176	20	49	53,200
1990 (All sources)	158	25	53	19,300
1991 (All sources)	214	19	48	17,700
1992 (All sources)	157	15	44	16,200
1990-1992 (Point sources)	3.5	---	0.08	83
Historic (1942-92)	202	---	---	---
Minimum	1.1	1	0.04	---
Lower quartile	24	5	0.54	---
Median	76	10	1.3	---
Upper quartile	154	20	4.7	---
Maximum	4300	565	7230	---

Source: James et al. (1991, 1992, 1993).

Table 4. Summary of flow, runoff, loads and loading factors (LF) for water years 1990-1992

	1990	1991	1992	Total
Average daily flow (cfs)	158	214	157	176
Annual runoff (inches)	12.4	16.8	12.4	13.9
Average daily flow , point sources (cfs)	3.5	3.5	3.6	3.5
TSS load (tons)	19,300	17,700	16,200	53,200
TSS load, point sources (tons)	36	25	21	83
TSS, percentage from point sources	0.2	0.1	0.1	0.2
TSS loading factor (tons/acre/year)	174	160	146	160
TN load (1000 lbs)	874	1225	904	3003
TN, load from point sources (1000 lbs)	122	113	95	330
TN, percentage from point sources	14.0	9.2	10.6	11.0
TN loading factor (lbs/acre/year)	6.8	10.1	7.3	8.1
TP load (1000 lbs)	42.5	52.6	36.2	131.3
TP load from point sources (1000 lbs)	7.3	6.7	6.0	20.0
TP, percentage from point sources	17.3	12.8	16.7	15.3
TP loading factor (lbs/acre/year)	0.32	0.42	0.27	0.34

5.2 mg/L, and of TP from 0.03 to 0.53 mg/L. As would be expected, the ranges were narrower for daily average concentrations; TN ranged from 1.0 to 2.4 mg/L, and TP from 0.04 to 0.20 mg/L. In contrast to the flow and TSS values, the nutrient concentration ranges are small, with maximum and minimum values within an order of magnitude. Annual loads of TN and TP are presented in Table 4, with flow and TSS data included for reference. Table 5 is a statistical summary of the nutrient concentration.

Nonpoint sources of nutrients predominated over point sources. Only 11% of nitrogen and 15% of phosphorus over the three years derived from point sources. One source of uncertainty in the point source loads lies in the limited data on TN and TP concentrations. However, the concentrations of TN and TP were generally in the range one would expect from secondary effluent, with the exception of the Gettysburg plant, where estimated TN levels (10-15 mg/L) were somewhat lower than the expected (~18-19 mg/L). However, even if a more "typical" effluent of 19 mg/L TN is assumed, the overall point source fraction of TN is still less than 15%. In addition, the major point sources are all some distance upstream of Bridgeport, and the extent of nutrient losses in transport is not known. If nutrient losses were occurring in transport, the point source contribution might actually be less than suggested by the data.

For purposes of analysis, the base flow nutrient data were divided into seasons by calendar quarter, which approximates true seasons. Storm data were grouped by spring/summer and fall/winter, as there were too few summer and winter samples to allow separate analysis of those seasons. Tables 6 and 7 summarize the nutrient concentrations by season. Seasonally, there was a difference in the behavior of nitrogen and phosphorus. Nitrogen concentrations tended to follow flow. The average base flow TN concentration was highest (3.1 mg/L) in winter (the wettest quarter overall), and second highest in fall (the next wettest quarter). In contrast, base flow TP concentrations were highest (0.13 mg/L) in summer, and next highest (0.08 mg/L) in spring, the driest and second driest seasons respectively. Nitrogen and phosphorus also differed in the importance of storms. Figures 3 and 4 show time series of nitrogen and phosphorus over the three-year sampling period. Figure 4 clearly indicates that phosphorus concentrations are nearly always higher in storm flows than in base flows. The picture is less clear for nitrogen. Nitrogen storm concentrations tend to exceed base levels in the spring and summer, with no clear difference in winter and fall.

Manual vs. Automatic Sampling

One goal of this study is to evaluate the automatic sampling process. For six storm events occurring during the three-year monitoring period, nutrient samples were taken both manually and by the automatic sampler. Two bases for comparison of the two sampling techniques were examined. First, for each individual storm and each nutrient, two flow-weighted average concentrations were calculated, one for each sampling method. This

Table 5. Statistics on nutrient concentrations at Bridgeport, Md during the sampling period.

	TN	TP
Number of observations	126	119
Number of base flow observations	44	39
Number of storm flow observations	82	80
Mean concentration (mg/L)	2.7	0.22
Minimum concentration (mg/L)	0.8	0.03
Lower quartile concentration (mg/L)	2.1	0.11
Median concentration (mg/L)	2.7	0.23
Upper quartile concentration (mg/L)	3.3	0.30
Maximum concentration (mg/L)	5.2	0.53

Table 6. Seasonal nutrient concentrations for base flow samples.

Season	Avg Flow (cfs)	TN (mg/L)	TP (mg/L)
Oct-Dec	54	2.5	0.06
Jan-Mar	125	3.1	0.05
Apr-Jun	65	1.6	0.08
Jul-Sep	14	1.8	0.13

Table 7. Seasonal nutrient concentrations for storm flow samples.

Season	Avg Flow (cfs)	TN (mg/L)	TP (mg/L)
Oct-Mar	4521	2.8	0.29
Apr-Sep	3960	3.5	0.26

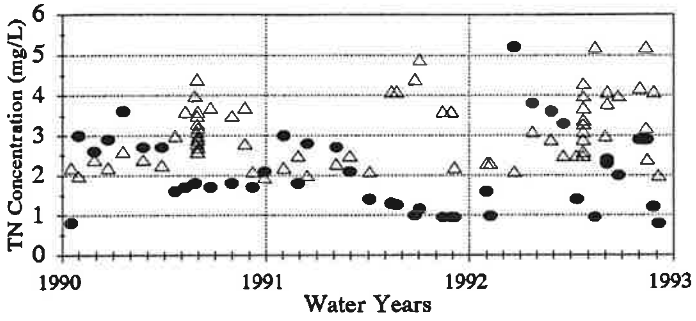


Figure 3. Total nitrogen concentrations vs. time.

● Base flows △ Storms

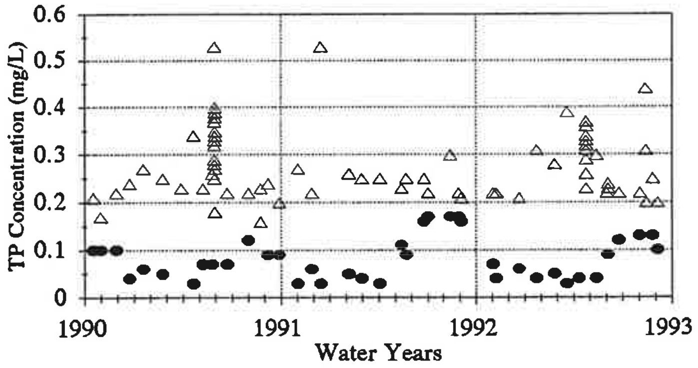


Figure 4. Total phosphorus concentrations vs. time.

● Base flows △ Storms

resulted in two sets of six average concentrations for each nutrient. Using a standard t-test, there was no significant difference between the two sets of concentrations.[1] One problem with the above approach is that the manual and automatic samples were often taken at different times, with different intervals between samples, and with different instantaneous flow rates. To allow better comparison of the sampling methods, a series of sample pairs were evaluated, where the samples in each pair were taken very near in time (less than 30 minutes apart) with similar flows. Table 8 shows the available data pairs. Again, a t-test indicated no significant difference between the two sampling techniques.[2]

SUMMARY AND CONCLUSIONS

Over the three-year monitoring period at Bridgeport, a total load of approximately 3.0 million pounds of nitrogen and 139 thousand pounds of phosphorus were generated in the watershed. Nonpoint sources accounted for 89% of the nitrogen and 85% of the phosphorus in the basin.. The total load of TSS was about 53,000 tons, with point source contributions representing less than 0.2%. TSS loads were almost entirely from runoff during large storms.

Point source data for this basin are of mixed quality. Flow data are excellent, based on daily Discharge Monitoring Reports, while TSS data are very good, with four samples being drawn monthly. Based on comparison of paired samples taken during six storms, there does not appear to be any significant difference between samples collected by the automatic sampler and by the manual cross-section method. This suggests that manual collection of samples may be discontinued for the purpose of annual nutrient load calculation.

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[1] For TN: t=0.49, DF=10. For TP: t=0.50, DF=10.

[2] For TN: t=-0.27, DF=18. For TP: t=-0.37, DF=18.

Table 8. Comparison of nutrient concentrations from manual and automatic samples.

Date	Time	Type	Flow	TN	TP
May 29 90	1725	A	4850	4.00	0.26
	1718	M	4790	3.60	0.23
May 29 90	1918	A	5400	4.10	0.23
	1935	M	5430	4.10	0.24
May 30 90	33	A	4670	4.20	0.22
	27	M	4700	3.50	0.22
Oct 14 90	200	A	1200	2.20	0.27
	150	M	1260	2.50	0.22
Oct 23 90	1405	A	6620	2.60	0.33
	1425	M	6890	3.90	0.33
Oct 23 90	1850	A	8810	2.60	0.29
	1830	M	8810	3.00	0.3
Oct 23 90	2314	A	7940	2.50	0.25
	2340	M	7740	2.20	0.24
Dec 4 90	940	A	5410	2.90	0.35
	950	M	5390	2.70	0.38
Apr 22 92	900	A	7020	2.10	0.25
	910	M	6960	2.50	0.39
Apr 22 92	1200	A	4680	2.30	0.26
	1145	M	5080	2.40	0.25

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Appendix A. Full nutrient data set.

Table A1 contains the full nutrient data set reported by the USGS for water years 1990-1992 at the Bridgeport site. The parameters on the table are:

Flow	Instantaneous flow at the time of sampling (cfs).
NH4	Dissolved ammonia nitrogen (mg/L).
NO23	Dissolved nitrate/nitrite nitrogen (mg/L).
TKNW	Total ammonia + organic nitrogen (mg/L).
TKNF	Dissolved ammonia + organic nitrogen (mg/L).
TN	Total nitrogen (mg/L).
PO4	Dissolved orthophosphate phosphorus (mg/L).
TDP	Dissolved phosphorus (mg/L).
TP	Total phosphorus (mg/L).
TOC	Total organic carbon (mg/L).

Table A1. Complete nutrient data from Bridgeport, water years 1990-1992.

Year	Mon	Day	Time	Flow	NH4	NO23	TKNW	TKNF	TN	PO4	TDP	TP	TOC
1989	10	16	1415	11	0.02	0.31	0.50	0.30	0.81	0.07	0.06	0.10	6.0
1989	10	30	1100	48	0.03	2.20	0.80	0.50	3.00	0.05	0.08	0.10	4.1
1989	11	27	1215	85	0.02	2.00	0.60	0.40	2.60	0.05	0.05	0.10	3.1
1989	12	22	1045	33	0.02	2.30	0.60	0.80	2.90	0.03	0.04	0.04	3.6
1990	1	17	1400	158	0.07	3.00	0.60	0.70	3.60	0.04	0.04	0.06	3.0
1990	1	30	1115	3950	0.18	1.90	0.90	0.80	2.80	0.16	0.16	0.23	13.0
1990	1	30	1315	2340	0.15	2.10	0.90	0.60	3.00	0.15	0.15	0.22	9.6
1990	1	30	1600	1520	0.11	2.30	0.90	0.60	3.20	0.11	0.11	0.18	8.3
1990	1	30	1900	1160	0.09	2.60	1.10	0.40	3.70	0.09	0.09	0.16	7.6
1990	2	22	1025	86	0.01	2.20	0.50	0.30	2.70	0.03	0.01	0.05	2.7
1990	3	28	845	76					2.70				
1990	4	20	1000	64	0.02	0.80	0.80	0.60	1.60	0.01	0.02	0.03	3.5
1990	5	8	1315	73	0.02	1.00	0.70	0.60	1.70	0.05	0.05	0.07	5.6
1990	5	25	1315	57	0.03	1.40	0.40	0.30	1.80	0.04	0.04	0.07	3.5
1990	5	29	1423	2460	0.14	2.40	1.70	0.70	4.10	0.16	0.18	0.25	22.0
1990	5	29	1506	3170	0.23	2.30	2.90	0.90	5.20	0.18	0.19	0.30	
1990	5	29	1718	4790	0.22	1.60	2.00	1.00	3.60	0.16	0.18	0.23	16.0
1990	5	29	1725	4850	0.20	1.60	2.40	1.20	4.00	0.15	0.17	0.26	
1990	5	29	1918	5400	0.15	1.70	2.40	1.20	4.10	0.13	0.17	0.23	
1990	5	29	1935	5430	0.21	1.70	2.40	0.80	4.10	0.14	0.17	0.24	20.0
1990	5	29	2100	5460	0.18	1.80	2.20	1.20	4.00	0.14	0.16	0.22	
1990	5	29	2243	5190	0.16	2.00	1.80	0.80	3.80	0.14	0.14	0.23	
1990	5	30	27	4700	0.17	2.20	1.30	1.10	3.50	0.14	0.16	0.22	13.0
1990	5	30	33	4670	0.14	2.10	2.10	1.00	4.20	0.14	0.15	0.22	
1990	5	30	255	3640	0.15	2.40	1.30	0.70	3.70	0.15	0.16	0.22	
1990	5	30	445	2840	0.17	2.50	1.10	1.10	3.60	0.15	0.17	0.22	11.0
1990	5	30	604	2400	0.16	2.60	1.50	1.30	4.10	0.15	0.17	0.25	
1990	5	30	945	1650	0.20	2.80	2.10	1.10	4.90	0.15	0.17	0.22	9.6
1990	5	30	1114	1480	0.19	2.80	1.60	1.20	4.40	0.14	0.16	0.25	
1990	6	22	935	33	0.05	1.10	0.60	0.70	1.70	0.07	0.08	0.07	4.3
1990	7	31	1215	15	0.02	0.50	1.30	0.60	1.80	0.04	0.06	0.12	9.2
1990	8	23	30	1940	0.11	1.60	3.60	1.00	5.20	0.17	0.19	0.44	
1990	8	23	515	1680	0.10	1.60	2.00	1.00	3.60	0.18	0.21	0.30	
1990	8	23	1130	1520	0.10	1.70	1.50	1.00	3.20	0.18	0.22	0.31	15.0
1990	9	6	945	21	0.04	1.00	0.70	0.80	1.70	0.06	0.08	0.09	5.8
1990	9	27	1015	13	0.02	1.60	0.50	0.40	2.10	0.07	0.07	0.09	4.1
1990	10	13	1125	2330	0.10	0.80	1.60	1.00	2.40	0.14	0.14	0.22	27.0
1990	10	13	1250	2820	0.08	0.90	1.30	1.40	2.20	0.19	0.19	0.21	22.0
1990	10	13	1440	3270	0.04	0.90	1.30	0.90	2.20	0.14	0.2	0.21	
1990	10	13	1555	3480	0.05	1.00	1.30	1.00	2.30	0.16	0.16	0.22	21.0
1990	10	13	1720	3710	0.03	0.90	1.40	0.90	2.30	0.14	0.16	0.22	
1990	10	13	1945	4180	0.03	0.90	1.20	0.90	2.10	0.12	0.12	0.24	
1990	10	13	2040	4200	0.03	0.90	1.10	1.00	2.00	0.12	0.12	0.20	20.0
1990	10	13	2200	3850	0.02	0.85	1.10	0.90	1.95	0.11	0.12	0.20	
1990	10	13	2250	3280	0.03	0.90	1.10	0.90	2.00	0.13	0.14	0.17	14.0
1990	10	14	20	2020	0.04	1.00	1.10	0.90	2.10	0.06	0.18	0.21	13.0
1990	10	14	150	1260	0.04	1.10	1.40	1.10	2.50	0.08	0.18	0.22	15.0
1990	10	14	200	1200	0.05	1.10	1.10	1.20	2.20	0.15	0.15	0.27	
1990	10	19	120	2240	0.03	0.90	1.10	0.90	2.00	0.15	0.14	0.53	
1990	10	23	1140	2800	0.08	2.30	2.00	0.80	4.30	0.19	0.19	0.34	18.0
1990	10	23	1224	4150	0.14	1.90	1.80	0.80	3.70	0.2	0.21	0.23	
1990	10	23	1305	5470	0.18	1.60	1.80	0.90	3.40	0.22	0.23	0.33	26.0

(continued)

1990	10	23	1405	6620	0.14	1.40	1.20	0.70	2.60	0.2	0.22	0.33	
1990	10	23	1425	6890	0.16	1.40	2.50	0.90	3.90	0.21	0.22	0.33	20.0
1990	10	23	1526	7530	0.14	1.30	1.70	0.70	3.00	0.2	0.21	0.31	
1990	10	23	1635	8130					3.00				
1990	10	23	1637	8150	0.12	1.20	1.70	0.70	2.90	0.19	0.21	0.32	
1990	10	23	1745	8590	0.12	1.20	1.70	0.70	2.90	0.19	0.21	0.36	
1990	10	23	1830	8810	0.14	1.10	1.90	0.80	3.00	0.2	0.21	0.30	14.0
1990	10	23	1850	8810	0.12	1.10	1.50	0.60	2.60	0.18	0.21	0.29	
1990	10	23	1955	8840	0.12	1.10	1.70	0.60	2.80	0.18	0.19	0.30	
1990	10	23	2058	8720	0.10	1.10	1.40	0.60	2.50	0.17	0.21	0.29	
1990	10	23	2204	8410	0.10	1.20	1.90	0.70	3.10	0.17	0.2	0.26	
1990	10	23	2314	7940	0.10	1.20	1.30	0.60	2.50	0.16	0.18	0.25	
1990	10	23	2340	7740	0.10	1.20	1.00	0.90	2.20	0.16	0.18	0.24	11.0
1990	10	24	27	7230	0.09	1.30	1.20	0.70	2.50	0.15	0.16	0.29	
1990	10	24	158	5690	0.30	1.40	1.40	0.80	2.80	0.18	0.19	0.28	
1990	10	24	305	4400	0.49	1.60	1.70	1.20	3.30	0.21	0.23	0.31	13.0
1990	10	24	355	3260	0.45	1.90	1.50	1.20	3.40	0.21	0.23	0.33	
1990	10	24	610	2110	0.89	1.80	2.20	1.50	4.00	0.24	0.25	0.37	11.0
1990	10	24	755	1690	0.86	2.30	2.10	1.50	4.40	0.25	0.28	0.37	
1990	11	1	850	100	0.02	2.40	0.60	0.70	3.00	0.02	0.02	0.03	2.9
1990	11	10	1525	3350	0.06	1.70	1.80	0.70	3.50	0.2	0.23	0.37	
1990	11	10	1800	4000	0.06	1.40	1.20	1.00	2.60	0.19	0.22	0.33	
1990	11	10	2320	1780	0.11	2.00	1.30	1.10	3.30	0.2	0.23	0.32	
1990	11	27	1115	78	0.05	1.40	0.40	0.50	1.80	0.03	0.03	0.06	4.4
1990	12	3	2220	3970	0.16	1.50	1.60	1.00	3.10	0.18	0.19	0.53	
1990	12	4	145	4580	0.19	1.30	1.30	0.80	2.60	0.19	0.2	0.39	
1990	12	4	650	5000	0.17	1.50	1.50	0.90	3.00	0.21	0.22	0.40	
1990	12	4	940	5410	0.14	1.60	1.30	0.80	2.90	0.2	0.21	0.35	
1990	12	4	950	5390	0.15	1.40	1.30	1.00	2.70	0.22	0.21	0.38	13.0
1990	12	4	1215	2670	0.09	2.50	1.10	0.80	3.60	0.16	0.15	0.27	
1990	12	4	1350	4700	0.09	1.40	1.30	1.00	2.70	0.19	0.18	0.34	12.0
1990	12	4	1710	2970	0.12	1.60	1.20	0.90	2.80	0.17	0.17	0.29	12.0
1990	12	4	2050	1560	0.10	1.80	1.10	0.80	2.90	0.16	0.15	0.25	11.0
1990	12	14	1045	110	0.02	2.20	0.60	0.30	2.80	0.02	0.02	0.03	3.1
1991	2	4	1200	110	0.04	2.00	0.70	0.50	2.70	0.02	0.05	0.05	2.4
1991	2	28	1030	93	0.03	1.80	0.30	0.40	2.10	0.02	0.02	0.04	2.9
1991	4	3	1020	150	0.02	1.10	0.30	0.30	1.40	0.01	0.02	0.03	3.0
1991	5	13	930	69	0.06	0.59	0.70	0.70	1.29	0.07	0.08	0.11	4.6
1991	5	22	945	43	0.08	0.85	0.40	0.60	1.25	0.05	0.07	0.09	4.4
1991	6	24	1005	9.9	0.07	0.10	0.90	0.60	1.00	0.08	0.08	0.16	5.0
1991	7	2	945	3.5	0.07	0.15	1.00	0.60	1.15	0.1	0.1	0.17	5.9
1991	8	13	1015	3.5	0.01	0.05	0.90	0.50	0.95	0.04	0.05	0.17	8.3
1991	8	29	645	7.6			0.70		0.95			0.17	
1991	9	3	945	1.9	0.01	0.05	0.90	0.60	0.95	0.03	0.06	0.16	7.9
1991	9	30	1000						0.95				
1991	11	1	1050	12	0.03	0.99	0.60	0.80	1.59	0.02	0.05	0.07	7.0
1991	11	7	945	11	0.02	0.48	0.50	0.50	0.98	0.03	0.02	0.04	6.6
1991	12	20	1130	54	0.03	4.80	0.40	0.50	5.20	0.05	0.05	0.06	3.3
1992	1	22	1045	44	0.01	3.50	0.30	0.30	3.80	0.02	0.02	0.04	3.5
1992	2	25	1115	298	0.03	3.10	0.50	0.60	3.60	0.03	0.05	0.05	4.8
1992	3	18	1320	137	0.03	3.10	0.20	0.20	3.30	0.03	0.02	0.03	3.1
1992	4	10	1050	86	0.01	1.00	0.40	0.30	1.40	0.01	0.01	0.04	3.5
1992	4	22	130	3910	0.18	0.96	1.30	1.00	2.26	0.06	0.09	0.23	
1992	4	22	325	5800	0.16	1.00	1.60	1.00	2.60	0.08	0.1	0.27	
1992	4	22	900	7020	0.22	1.00	1.10	1.20	2.10	0.11	0.12	0.25	

(continued)

1992	4	22	910	6960	0.20	1.00	1.50	0.90	2.50	0.11	0.13	0.39	19.0
1992	4	22	1020	6480	0.19	1.10	1.90	1.10	3.00	0.11	0.14	0.34	
1992	4	22	1145	5080	0.17	1.20	1.20	0.90	2.40	0.12	0.15	0.25	15.0
1992	4	22	1200	4680	0.18	1.20	1.10	1.10	2.30	0.12	0.16	0.26	
1992	4	22	1325	3340	0.17	1.30	1.20	1.10	2.50	0.13	0.16	0.25	14.0
1992	4	22	1450	2240	0.21	1.50	1.60	1.30	3.10	0.12	0.15	0.31	
1992	4	22	1535	1980	0.19	1.40	1.50	1.00	2.90	0.14	0.15	0.28	16.0
1992	4	22	950	6790					2.50				
1992	5	12	1045	90	0.03	0.55	0.40	0.30	0.95	0.03	0.02	0.04	5.4
1992	5	31	1215	1250	0.11	1.50	0.90	0.60	2.40	0.1	0.13	0.20	
1992	6	3	1020	43					2.40				
1992	6	3	1430						2.30				
1992	6	23	1020	43	0.05	1.30	0.70	0.60	2.00	0.09	0.1	0.12	7.1
1992	7	31	1000	48	0.08	2.20	0.70	0.60	2.90	0.1	0.11	0.13	6.9
1992	8	10	1000	15					2.90				
1992	8	11	1430	15					2.90				
1992	8	13	1700	22					2.90				
1992	8	24	1140	13	0.07	0.61	0.60	0.40	1.21	0.08	0.1	0.13	4.8
1992	9	2	1045	8	0.08	0.09	0.70	0.50	0.79	0.08	0.1	0.10	5.0

Appendix B. Nutrient data used in regression.

Table B1 contains the data used in regression calculations based on equation (1). The data were extracted from Table A1. For base flow samples, no changes were made. For storm flow samples, all samples for the same storm were aggregated such that a single flow, TN and TP concentration represented the entire event. Flow was the mean of the instanteous flows for each sample. The nutrient concentrations were calculated on a flow-weighted basis:

$$C = \frac{\Sigma(C_i\, Q_i)}{\Sigma Q_i}$$

The parameters on the table are:

T	Elapsed time (years) from the reference day, Sept. 30, 1989.
Q	Flow (cfs).
TN	Total nitrogen (mg/L).
TP	Total phosphorus (mg/L).

Table B1. Nutrient data used in regression.

Year	Mo	Da	T	Q	TN	TP
1989	10	16	0.044	11	0.81	0.10
1989	10	30	0.082	48	3.00	0.10
1989	11	27	0.159	85	2.60	0.10
1989	12	22	0.227	33	2.90	0.04
1990	1	17	0.299	158	3.60	0.06
1990	1	30	0.334	2243	3.04	0.21
1990	2	22	0.397	86	2.70	0.05
1990	3	28	0.490	76	2.70	NA
1990	4	20	0.553	64	1.60	0.03
1990	5	8	0.603	73	1.70	0.07
1990	5	25	0.649	57	1.80	0.07
1990	5	30	0.663	1199	4.01	0.24
1990	6	22	0.726	33	1.70	0.07
1990	7	31	0.833	15	1.80	0.12
1990	8	23	0.896	1713	4.09	0.36
1990	9	6	0.934	21	1.70	0.09
1990	9	27	0.992	13	2.10	0.09
1990	10	14	1.038	2967	2.16	0.21
1990	10	19	1.052	2240	2.00	0.53
1990	10	24	1.066	6454	2.96	0.30
1990	11	1	1.088	100	3.00	0.03
1990	11	10	1.112	3043	3.07	0.34
1990	11	27	1.159	78	1.80	0.06
1990	12	4	1.178	4028	2.89	0.37
1990	12	14	1.205	110	2.80	0.03
1991	2	4	1.348	110	2.70	0.05
1991	2	28	1.414	93	2.10	0.04
1991	4	3	1.507	150	1.40	0.03
1991	5	13	1.616	69	1.29	0.11
1991	5	22	1.641	43	1.25	0.09
1991	6	24	1.732	10	1.00	0.16
1991	7	2	1.753	4	1.15	0.17
1991	8	13	1.868	4	0.95	0.17
1991	8	29	1.912	8	0.95	0.17
1991	9	3	1.926	2	0.95	0.16
1991	11	1	2.088	12	1.59	0.07
1991	11	7	2.104	11	0.98	0.04
1991	12	20	2.222	54	5.20	0.06
1992	1	22	2.312	44	3.80	0.04
1992	2	25	2.405	298	3.60	0.05
1992	3	18	2.466	137	3.30	0.03
1992	4	10	2.529	86	1.40	0.04
1992	4	22	2.562	4935	2.51	0.29
1992	5	12	2.616	90	0.95	0.04
1992	5	31	2.668	1250	2.40	0.20
1992	6	3	2.677	43	2.40	NA
1992	6	23	2.732	43	2.00	0.12
1992	7	31	2.836	48	2.90	0.13
1992	8	10	2.863	15	2.90	NA
1992	8	11	2.866	15	2.90	NA
1992	8	13	2.871	22	2.90	NA
1992	8	24	2.901	13	1.21	0.13
1992	9	2	2.926	8	0.79	0.10

Appendix C. Nutrient regression results.

Table C1 shows the results of fitting the data in Appendix B (TN and TP) to equation (1). The calculations were performed using Quattro Pro for Windows on a 80486 computer. The centering variables Q_c and T_c were set to one and zero respectively for simplicity of calculation. These parameters have no effect on the final results [Cohn et al., 1992]; they are advantageous when performing non-linear fitting of the regression data.

Table C1. Results of nutrient regression.

Coeff.	TN	TP
N	53	48
a_0	-0.494	-1.414
a_1	0.475	-0.600
a_2	-0.034	0.081
a_3	-0.236	-0.365
a_4	0.093	0.094
a_5	0.146	-0.445
a_6	0.093	0.330
R^2	0.49	0.81

Appendix D. Point sources.

Five point source dischargers, all in Pennsylvania, were included in the load calculations in this report. Table C1 lists the five plants, with mean flow and nutrient concentrations for water years 1990-1992.

Table D1. List of point sources in the monitored sub-basin with flows > 0.05 mgd.

NPDES[1] ID	Name	Mean flow (cfs)	Mean TN Conc.[2] (mg/L)	Mean TP Conc. (mg/L)
21563	Gettysburg	1.56	13.1	0.42
21229	Littlestown	0.36	19.2	0.42
24147	Cumberland Township South	0.13	15.7	3.17
24139	Cumberland Township North	0.12	19.2	3.03
28592	Bonneauville	0.12	37.5	2.68

Based on data provided by Pennsylvania's Department of Environmental Resources.

[1] National Pollutant Discharge Elimination System

[2] TN concentration based upon estimate of organic nitrogen based on BOD.