Changes in Streamflow, Concentrations, and Loads in Selected Nontidal Basins in the Chesapeake Bay Watershed, 1985-2006

In Cooperation with the U.S. Environmental Protection Agency, Chesapeake Bay Program Office; the Maryland Department of Natural Resources; and the Virginia Department of Environmental Quality

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

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Conversion Factors

Multiply	By	To obtain
Area		
square mile (mi2)	2.590	square kilometer
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
Mass		
pound, avoirdupois (lb) ton per year (ton/yr)	0.4536 0.9072	kilogram metric ton per year

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations used in this report -

Agencies

CBP	U.S. Environmental Protection Agency Chesapeake Bay Program
RIM	USGS River Monitoring Program
MDDNR	Maryland Department of Natural resources
MWCOG	Metropolitan Washington Council of Governments
SRBC	Susquehanna River Basin Commission
USGS	U.S. Geological Survey
VADEQ	Virginia Department of Environmental Protection

Types of Trends

FAC	Flow-adjusted concentration
FWC	Flow-weighted concentration
NFAC	Non-flow-adjusted concentration

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Abstract

Water-quality and streamflow data from 34 sites in nontidal parts of the Chesapeake Bay watershed are presented to document annual nutrient and sediment loads and trends for 1985 through 2006, as part of an annual evaluation of water-quality conditions by the U.S. EPA Chesapeake Bay Program. This study presents the results of trends analysis for streamflow, loads, and concentrations. Annual mean flow to the bay for 2006 (78,650 cubic feet per second) was approximately 1 percent above the long-term annual mean flow from 1937 to 2005. Total freshwater flow entering the bay for the summer season (July-August-September) was the only season classified as "wet" in 2006. For the period 1985 through 2006, streamflow was significantly increasing at two of the 34 sites. Observed (bias-corrected) concentration summaries indicate higher ranges in concentrations of total nitrogen in the northern major river basins (Pennsylvania, Maryland, and northern Virginia) than in the southern basins in Virginia. Results indicate almost half of the monitoring sites in the northern basins exhibited significant downward bias-corrected concentration trends in total nitrogen over time; results were similar for total phosphorus and sediment. Generally, loads for all constituents at the nine River Input Monitoring Program (RIM) sites, which comprise 78 percent of the streamflow entering the bay, were lower in 2006 than in 2005. The loads for total nitrogen are below the long-term average loads at eight of the nine RIM sites and total phosphorus and sediment loads are also below the long-term average at seven RIM sites. Combined annual mean total nitrogen flow-weighted concentrations from the nine RIM sites indicated an upward tendency in 2006; in contrast, total

phosphorus and sediment indicated a downward tendency.

From 1990 to 2006 for the 9 RIM sites, the mean concentrations of total nitrogen, total phosphorus, and sediment were 3.49, 0.195, and 116 milligrams per liter, respectively. Flow-weighted concentrations for phosphorus and sediment were lowest in the Susquehanna River at Conowingo, Md., most likely because of the trapping efficiency of three large reservoirs upstream from the sampling point.

For all 34 sites and all constituents, trends in concentrations (not adjusted for flow) showed 12 statistically significant upward trends and 59 statistically significant downward trends for the period 1985 through 2006. When trends in concentrations are adjusted for flow, they can be used as indicators of human activity and effectiveness of management actions. The flow-adjusted trends indicated significant downward trends at approximately 74, 68, and 32 percent of the sites for total nitrogen, total phosphorus, and sediment, respectively. This may indicate that management actions are having some effect in reducing nutrients and sediments.

Introduction

The Chesapeake Bay has been adversely affected by nitrogen and phosphorus enrichment. Excess nutrients stimulate algal blooms that decay and consume dissolved oxygen, causing areas with low concentrations of dissolved oxygen in the bay. Algal blooms and sediment block sunlight needed by underwater grasses. In the mid-1980s, the Chesapeake Bay Program (CBP), a partnership among the Commonwealths of Pennsylvania and Virginia, the State of Maryland, the District of Columbia, the Federal Government, and the Chesapeake Bay Commission, began efforts to reduce nutrients and sediments in the bay. Improvement in water-quality conditions in the bay has been slow, however, and the bay was listed as an "impaired" water body under the regulatory statutes related to the Clean Water Act. The CBP developed water-quality criteria for the bay (U.S. Environmental Protection Agency, 2003) and is implementing measures to reduce nutrients and sediments entering the bay in an attempt to meet these criteria by 2010.

Water-quality and living-resource data are compiled annually and analyzed to assess the response of the watershed and the bay to nutrient-reduction strategies and other factors affecting water quality and living resources. These results are used to update data on environmental indicators that are distributed to the public annually by the CBP and to help refine restoration strategies.

The U.S. Geological Survey (USGS) has been involved in the annual evaluation of water-quality trends in the Chesapeake Bay watershed since the early 1990s. The USGS reported trends originally from the River Input Monitoring (RIM) Program sites (fig. 1) using multivariate regression techniques (ESTIMATOR Model) developed by Cohn and others (1992) and further explained in Darrell and others (1998). The technique produced a trend adjusted for flow by adjusting for the influences of streamflow and season to improve understanding of concentration trends as they relate to resource-management actions. Although this technique is useful in assessing the water-quality changes resulting primarily from resource-management actions, results cannot be appropriately compared to trends in the tidal waters because tidal water trends are not adjusted for flow. In addition, the ESTIMATOR Model is a parametric technique while tidal trend analysis is estimated using non-parametric techniques. Therefore, the USGS developed additional trend techniques to aid in the comparison of tidal and nontidal data

(Langland and others, 2000), which were further evaluated to address the ongoing need to improve and update trend techniques (Langland and others, 2004). These methods can be used to estimate trends in streamflow, load, flow-weighted concentration, and non-flow-adjusted and flow-adjusted concentration.

This report presents nutrient and sediment loads, bias-corrected observed concentrations and trends in streamflow, and non-flow-adjusted and flow-adjusted trends of nutrients and sediment from 34 sites for water year 1985 through water year 2006[1]. The 34 sites include 9 sites that are part of the RIM Program delivering approximately 78 percent of the mean annual streamflow to the bay. The other 25 sites, part of the Multi-Agency Nontidal Monitoring Program, serve as indicator sites to evaluate trends throughout upstream subbasins in the Chesapeake Bay watershed. The Multi-Agency Nontidal Monitoring Program is a group composed all the partners in the CBP. This group collects and maintains a monitoring network to provide the water-quality data analyzed in this report. The concentration and load as well as data-analysis results are presented graphically and in tabular format and are intended to support the continuing review of Chesapeake Bay watershed and resource-management activities. This report is an annual update based on ongoing monitoring and not intended to evaluate the causes and effects of observed trends. Appendixes provide additional graphical and tabular information.

Method of Study

This section includes a discussion of how data sets used to assess streamflow and water quality were constructed and provides a brief description of the methods used to analyze the data sets for streamflow and water quality. Additional refinements to the trend methods (techniques) are discussed in more detail in this section.

Data-Set Construction

The USGS maintains and annually updates a "nontidal database" containing selected water-quality and biological data from approximately 2,100 sites in the Chesapeake Bay watershed. The database consists of water-quality and streamflow data from sites with a minimum of 3 consecutive years of sampling from 1972 through 2006. Although many sites are sampled on a routine (usually monthly) basis, many of these sites do not have continuous streamflow record, which is necessary to compute annual loads. Water-quality data are generally updated annually at approximately 1,000 sites. About every 3-4 years, an update is initiated at as many additional sites in the database as possible. New sites are added to the database if the site has at least 12 samples collected over 3 continuous years and at least 1 sample from each season in the 3 years (spring, summer, fall, and winter).

The sites are divided into two groups for data analysis, the RIM Program sites and the Multi-Agency Nontidal Monitoring Program sites; both groups provide information from the nontidal areas of the bay. A subset of 34 sites with long-term (15-20 years) water-quality and continuous streamflow data are used to determine annual and seasonal changes in streamflow and to estimate long-term nutrient and sediment trends. As part of the RIM Program, water-quality and streamflow data at nine sites near the most downstream limit of nontidal waters are collected and analyzed by the USGS (fig. 1). Through the Multi-Agency Nontidal Monitoring Program, long-term water-quality data are collected by several agencies at approximately 100 sites in the nontidal watershed. Trends were calculated at 25 of these sites (fig. 1) by the USGS in cooperation with the Maryland Department of Natural Resources (MDDNR), Virginia Department of Environmental Quality (VADEQ), the Metropolitan Washington Council of Governments (MWCOG), and the Susquehanna River Basin Commission (SRBC). The 34 sites selected for analysis this year are slightly different from previous years (prior to 2004). These sites are part of a nontidal water-quality monitoring network, designed by the Nontidal Workgroup, part of the CBP (U.S. Environmental Protection Agency, 2004). The primary goal of the network is to provide managers with water-quality information that shows progress toward meeting nutrient and sediment tributary-strategy reduction goals. Site information for the sites analyzed as part of this study is listed in table 1.

A total of 48 physical, biological, and chemical water-quality constituents are stored in the nontidal database. These constituents include 22 nutrient species, suspended sediment (SED), and total suspended solids (TSS) (table 2). A time series of daily mean streamflow was retrieved from the USGS National Water Information System (NWIS) database. The updated water-quality database and the USGS streamflow database provide the input data files to estimate trends. Concentration data were quality-assured using a statistical program that identifies suspect

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[1] A water year begins on October 1 and ends September 30 of a given year.

remark codes (such as less than detection), missing dates, and (or) missing times associated with the sample before being added to the database. In addition, statistical tests and visual examination of the raw data and model residuals from ESTIMATOR (Cohn and others, 1992) were made before and during their use in the various trend-analysis programs.

Because of analytical differences between determinations of SED and TSS, concentrations of SED tend to be higher and more accurate than those of TSS; this is especially true at higher flows (Kammerer and others, 1998). Therefore, TSS and SED samples were analyzed independently where possible, and results were labeled as TSS or SED; otherwise results were combined and labeled SED with no TSS.

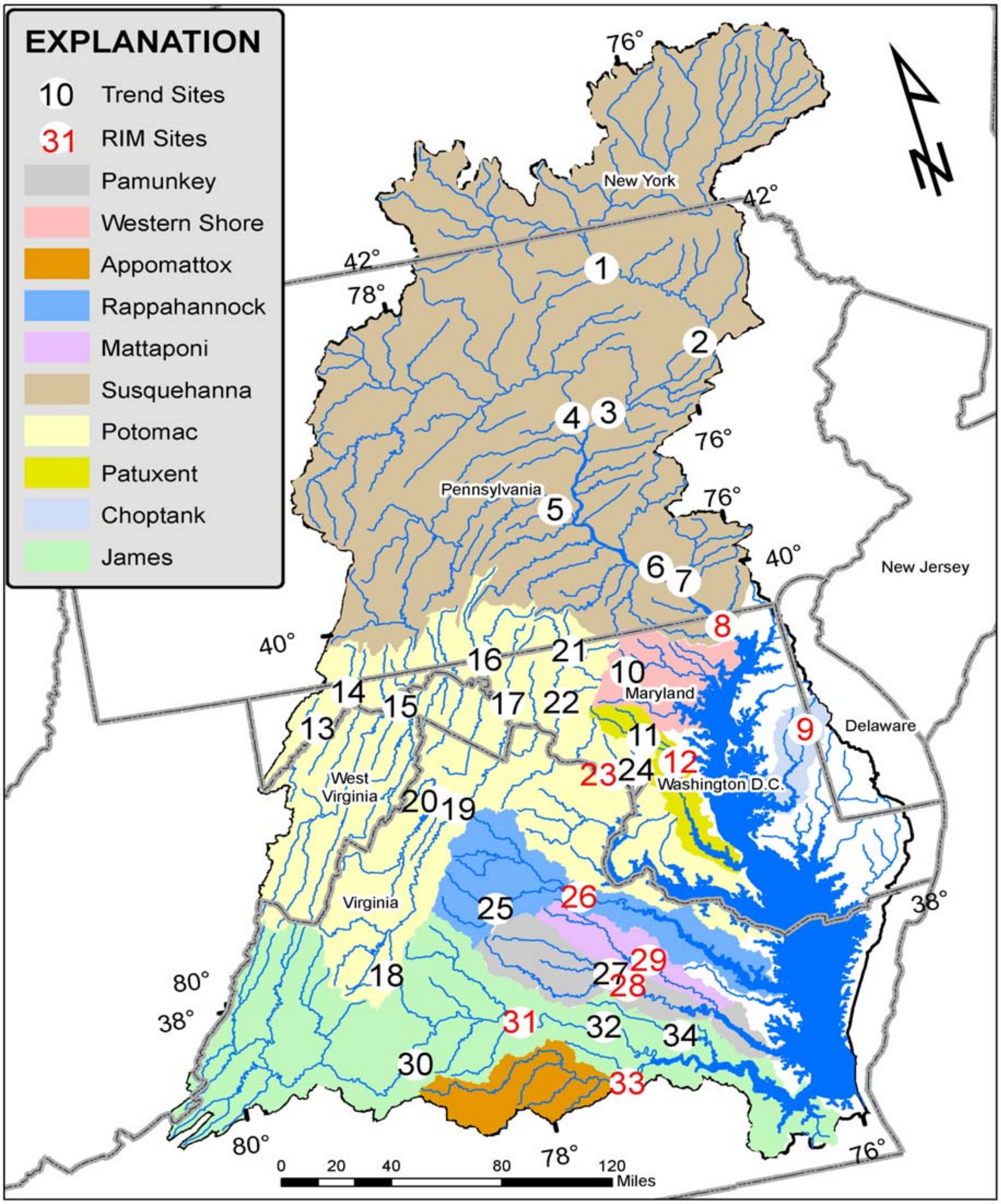


Figure 1. Locations of the 9 River Input Monitoring sites and the 25 Multi-Agency sites in the Chesapeake Bay watershed used in the study.

[Numbers indicate site identification numbers; red numbers indicate the River Input Monitoring Program sites; site information is presented in table 1]

Table 1. Streamflow and water-quality site information for the 9 River Input Monitoring Program sites and 25 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed. [Map ID, figure 1 identification number; Latitude and longitude in degrees minutes and seconds; mi^2, square miles]

USGS streamflow station	Non-tidal program water-quality sites	Non-tidal program co-located water-quality sites	Latitude (DDMMSS)	Longitude (DDMMSS)	Map ID (fig. 1)	Drainage area (mi^2)	Site name
River Input Program Sites							
01491000	01491000		385950	754710	9	113	Choptank River near Greensboro, Md.
01578310	01578310		393928	761029	8	27,100	Susquehanna River at Conowingo, Md.
01594440	01594440		385721	764136	12	348	Patuxent River near Bowie, Md.
01646580	PR01		385546	770701	23	11,600	Potomac River at Chain Bridge, Md.
01668000	01668000		381920	773105	26	1,596	Rappahannock River near Fredericksburg, Va.
01673000	01673000		374603	771957	28	1,081	Pamunkey River near Hanover, Va.
01674500	01674500		375316	770948	29	601	Mattaponi River near Beulahville, Va.
02035000	02035000		374015	780510	31	6,257	James River at Cartersville, Va.
02041650	02041650		371330	772832	33	1,344	Appomattox River at Matoaca, Va.
Multi-Agency Nontidal Program Sites							
01531500	01531500	WQN0305	414555	762628	1	7,797	Susquehanna River at Towanda, Pa.
01536500	01536500	WQN0302	411503	755252	2	9,960	Susquehanna River at Wilkes-Barre, Pa.
01540500	01540500	WQN0301	405729	763710	3	11,220	Susquehanna River at Danville, Pa.
01553500	01553500	WQN0401	405803	765236	4	6,859	West Branch Susquehanna River at Lewisburg, Pa.
01567000	01567000	WQN0214	402842	770746	5	3,354	Juniata River at Newport, Pa.
01576000	01576000	WQN0201	400316	763152	6	25,990	Susquehanna River at Marietta, Pa.
01576754	01576754	WQN0231	395647	762205	7	470	Conestoga River at Conestoga, Pa.
01586000	NPA0165	01586000	393000	765300	10	56.6	Patapsco River at Cedarhurst, Md.
01592500	PXT0809	01592500	390700	765231	11	132	Patuxent River at Laurel, Md.
01599000	GEO0009	01599000	392936	790242	13	47	Georges Creek near Franklin, Md.
01601500	WIL0013	01601500, BDK0000	393941	784650	14	247	Wills Creek near Cumberland, Md.
01610000	POT2766	01610000	393218	782717	15	3,109	Potomac River at Paw Paw, W.Va.
01614500	CON0180	01614500	394256	774931	16	501	Conococheague Creek at Fairview, Md.
01619500	ANT0044	01619500	392701	774352	17	281	Antietem Creek near Sharpsburg, Md.
01626000	1BSTH027.85	01626000	380326	785429	18	127	South River near Waynesboro, Va.
01631000	1BSSF003.56	01631000	385449	781240	19	1,642	S F Shenandoah River at Front Royal, Va.
01634000	1BNFS010.34	01634000	385836	782011	20	768	N F Shenandoah River near Strasburg, Va.
01639000	MON0528	01639000	394043	771406	21	173	Monocacy River at Bridgeport, Md.
01643000	MON0155	01643000, MON0167, 01643020	392313	772158	22	817	Monocacy River at Reels Mill, Rd., Md.
01651000	ANA0082	01651000, A4	385708	765778	24	49.4	NW Branch Anaacostia River nr Hyattsville, Md.
01666500	3-ROB001.90	01666500	381930	780545	25	179	Robinson Creek near Locast Dale, Va.
01671020	8-NAR005.42	01671020	375100	772541	27	463	North Anna at Hart Corner near Doswel, Va.
02026000	2-JMS229.14	02026000	373211	773250	30	3,680	James River at Bent Creek, Va.
02037500	2-JMS117.35	02037500, 2-JMS127.50	373347	773250	32	6,758	James River at Richmond, Va.
02042500	02042500		372610	770340	34	252	Chickahominy River near Providence Forge, Va

Table 2. Nitrogen, phosphorus, and sediment constituents used for load and trend computation. [N, nitrogen; mg/L, milligrams per liter]

Constituent	Species (USGS Parameter code)	Units	Abbreviation
Nitrogen	Total nitrogen (00600)	mg/L	TN
	Total or dissolved nitrate, or, total or dissolved nitrite plus nitrate (00618, 00620, 00630, or 00631, respectively) as N	mg/L	NOx
Phosphorus	Total phosphorus (00665) as P	mg/L	TP
	Dissolved inorganic phosphorus (00671) as P	mg/L	DIP
Sediments	Suspended sediment (80154)	mg/L	SED
	Total suspended solids (00530)	mg/L	TSS

Records were missing for some water-quality constituents. Where possible, values for these missing constituents were calculated as the sum of reported analyses; for example, total nitrogen (TN) may be calculated as the sum of total dissolved and total particulate nitrogen or ammonia plus organic and nitrate nitrogen. Missing constituent values were estimated <u>only</u> for the input data files used to estimate loads and trends and were not populated in the nontidal database. If the concentration of more than one of the nitrogen or phosphorus species used in calculating TN or total phosphorus (TP) was below the detection limit, the estimate was censored and reported as one-half the maximum detection limit for that sample.

The optimum period for reporting trend results for this study extends from October 1984 and ends September 2006. Shorter time-series data were used if they met certain criteria. For the water-quality trend tests, the data set must contain a minimum of 10 years and approximately 100 samples representing "monthly" intervals, 10 years and approximately 40 quarterly samples, or a mixture of both types with at least 10 years and approximately 75 samples. Ideally, the collection of samples would represent the full range of the stream hydrograph during the estimation time period.

While the majority of trends were estimated on data sets of 20 or more years, several sites and constituents had less than the optimum record (October 1985 and October 1989 and continuing through September 2006) due to later monitoring starting periods and laboratory detection limit changes. Therefore, the shorter time period trends presented in several cases are for specific time periods and may not be directly comparable to the optimum time period trends.

Streamflow

Streamflow and streamflow variation have important consequences for water quality in the Chesapeake Bay and its watershed. Trends in streamflow usually indicate changes in climatological and hydrologic conditions over time. These changes can be caused by natural and anthropogenic factors. The quantity of flow affects salinity levels, freshwater/saltwater interface location, and stratification of tidal water in the bay. Estimates of annual flow to the Chesapeake Bay from 1937 to 2006 are based on a computation method described in Bue (1968). The method is based on analysis of long-term streamflow records, estimates of streamflow at five cross sections in the bay, rainfall and evaporation estimates, and water diversions.

Nutrient and sediment loads are a function of streamflow and vary as streamflow changes from year to year. The concentration of a chemical in a stream or river is affected by streamflow as dilution occurs or as the contributions from different flow paths or sources vary. It is important, therefore, to examine trends in streamflow because these trends may help explain trends in water quality.

Previous evaluation of time series of daily mean and monthly mean streamflow determined that the data residuals generally were autocorrelated thereby complicating trend detection (Langland and others, 2006). An approach used to overcome autocorrelation problems involves the use of time-series models that included autoregressive (AR) and moving-average (MA) terms, such as an autoregressive integrated moving-average process model (ARIMA) or seasonal ARIMA (Box and Jenkins, 1976; G. E. Schwarz, USGS, written commum., 2007). Time-series models efficiently estimate model coefficients with autocorrelated errors and provide meaningful inference of the coefficient estimates.

Models were built and fitted to the daily mean streamflow time series that included a 60-term autoregressive process, as well as trend and seasonal harmonic terms. The general form of the model is:

$$\ln(q)=\hat{\alpha}_0+\hat{\alpha}_1\sin(2\pi t)+\hat{\alpha}_2\cos(2\pi t)+\hat{\alpha}_3\sin(4\pi t)+\hat{\alpha}_4\cos(4\pi t)+\hat{\alpha}_5 t+\hat{\alpha}_6 t^2+u_t \qquad (1)$$

where

ln is the natural logarithm function;

q is daily mean streamflow, in cubic feet per second;

$\hat{\alpha}_0 ... \hat{\alpha}_6$ are coefficient estimates;

t is time, in years; and

u_t is the unexplained noise or error in the data, assumed to have a 60-day serial correlation process

$u_t = \sum_{i=1}^{60} \rho_i u_{t-i} + \varepsilon_t$, where p_i is the serial correlation coefficient and ε_t is an independent, identically distributed error term.

The trend was estimated from the coefficient on time ($\hat{\alpha}_5$), and a null hypothesis of zero trend was tested. If the coefficient was significantly different from zero in a two-tailed test, the null hypothesis was rejected, and it was concluded that a linear trend over time exists. A *p*-value of 0.05 or less was considered significant for this study. In addition, this flow model also was used in conjunction with a 6-parameter water-quality model to estimate non-flow-adjusted trends in concentration and load.

A trend, as defined in this report, is not a year-to-year variation, but the overall change between the start date and the end date based on modeled flow. Changes (trends) were considered significant if the confidence interval of the modeled value at the end of 2006 was entirely greater than (SIG-UP) or entirely less than (SIG-DOWN) the modeled starting value. Trend analysis results are included in attached appendixes.

For each of the 34 sites, a time series of total freshwater flow to the bay was constructed. The annual-mean streamflow time series provided a basis for evaluating inter-annual variability. Seasonal mean streamflow were constructed on the basis of four "seasons"—January-February-March, April-May-June, July-August-September, and October-November-December. The seasonal mean time series allowed for evaluating variability in a particular season.

Graphical depiction of the data and summary statistics can provide insights into variations in streamflow in the Chesapeake Bay watershed. For each time series, the 25th, 50th (or median), and 75th percentiles of the data were calculated and plotted as bars. The bars were colored blue if the mean streamflow for that time period was above the 75th percentile, red if it was below the 25th percentile, and black if it was within the 25th and 75th percentiles).

Water Quality

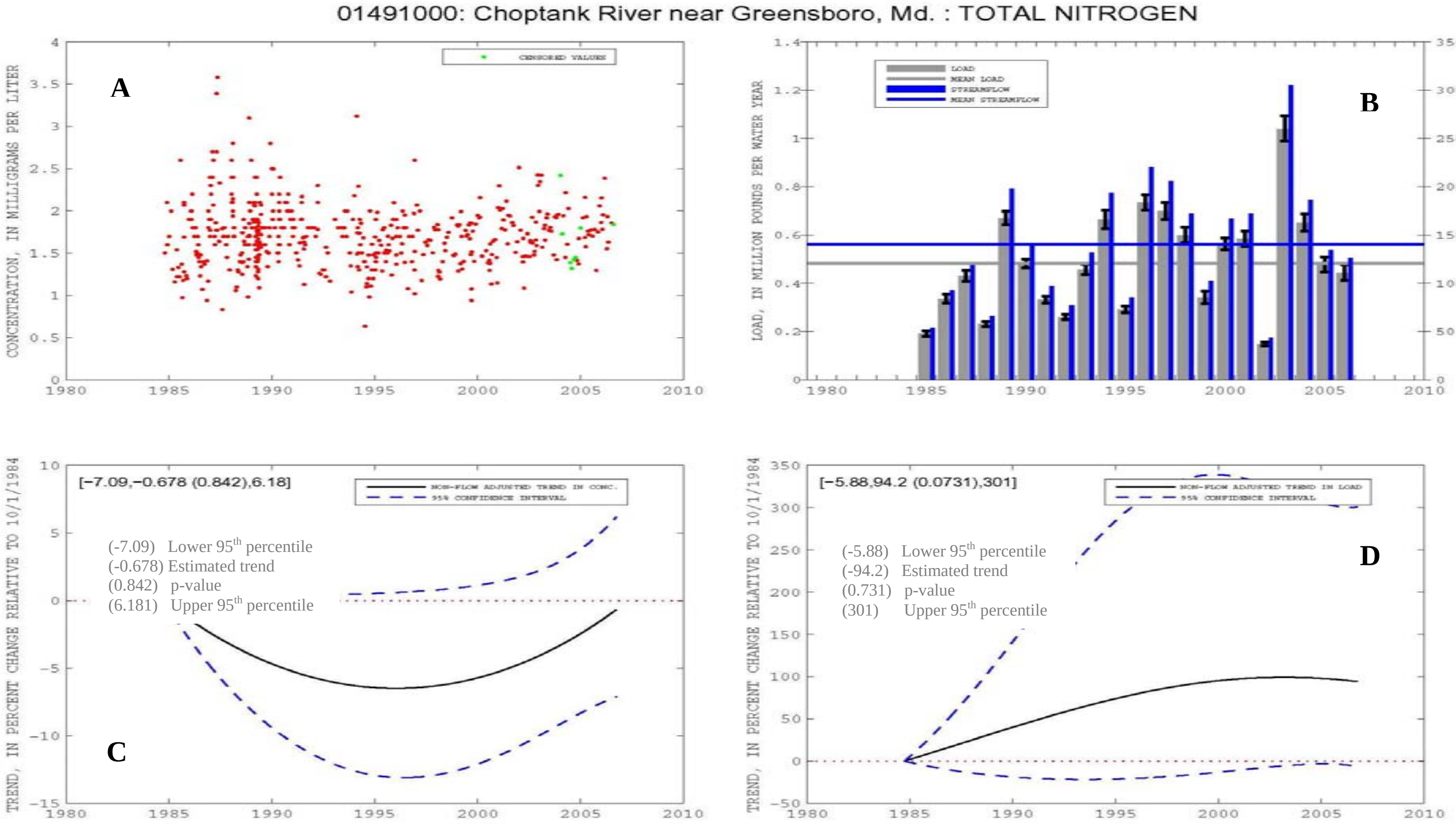
Data retrieved from the nontidal database were the basis for analysis of the observed concentrations used in this study. Descriptive statistics were used to indicate the distribution of concentration data by site and by year. Annual loads were estimated using the USGS water-quality model ESTIMATOR (Cohn and others, 1989) for the 9 USGS RIM Program sites and the 25 Multi-Agency Nontidal Monitoring sites. Output from the ESTIMATOR model was used to estimate both flow-adjusted and non-flow-adjusted trends for the 34 sites.

A series of water-quality models based on the USGS log-linear regression model (ESTIMATOR) developed by Cohn and others (1989) were used to estimate loads, flow-weighted concentrations, and trends in loads, flow-adjusted concentrations, and non-flow-adjusted concentrations. A more detailed explanation of the ESTIMATOR procedure and calculations of trend and errors is provided in Langland and others (2006). The load and trend models use multiple linear regression to relate observed concentration to predictor variables of streamflow and time. Models were developed for all 34 sites for a period of record from 1985 through 2006, when possible. In some cases, data limitations (such as large breaks in the record, lack of calibration data, or a starting date much later than 1985) and other aspects of the models including residual non-normality or heteroscedasticity (non-constancy of the variance of the residuals over the levels of the predictor variables), low R^2 values, or high model mean square errors resulted in a model being eliminated from consideration.

Observed Concentrations and Bias-Corrected Trends

Observed concentrations of TN, NOx, TP, DIP, and SED were routinely monitored at 25 multi-agency sites and 9 RIM sites (table 1). Typically, water-quality samples were collected monthly at all monitoring sites. Additionally, targeted water-quality samples were collected during high-flow periods at the 9 RIM sites and many of the 25 multi-agency sites. The period of the monitoring record considered for this report extended from water years 1985 through 2006. Observed concentrations through time are included in attached appendixes for all sites and all constituents. An example concentration time-series plot is shown in figure 2.

To help minimize errors in the load estimates, samples were collected during high-flow events in addition to the scheduled monthly sampling. This targeted high-flow event sampling produced a record of observations that did not represent a random sample of conditions over this time period. If the sample record is used to compute descriptive statistics, such as a mean, median, or other quantiles, or is used in the estimation of simple empirical relations not primarily conditioned on streamflow, such as concentration in a river compared to load carried by a river, the estimates will be biased. An approach using an algorithm that is robust with respect to censored observations for removing the flow bias is described in Langland and others (2006).



01491000: Choptank River near Greensboro, Md. : TOTAL NITROGEN

(-7.09) Lower 95th percentile
(-0.678) Estimated trend
(0.842) p-value
(6.181) Upper 95th percentile

(-5.88) Lower 95th percentile
(-94.2) Estimated trend
(0.731) p-value
(301) Upper 95th percentile

Figure 2. Example 4-panel plot used to display the non-flow-adjusted results from the ESTIMATOR model (Cohn and others, 1989) for all 34 sites presented in appendix 8.

[Upper left (A) shows the "raw" sample concentration data, upper right (B) shows annual and mean loads and streamflow from 1985-2006, lower left (C) shows the continuous non-flow-adjusted trend in concentration, and lower right (D) shows the continuous non-flow-adjusted trend in load. Statistical results are presented in the top left of C and D and represent lower confidence range (lower blue dashed line), actual trend (black line), significance, and upper confidence range (upper blue dashed line), respectively, for the period t_0 through 2006, red dashed line is for reference (0 percent)]

Water-quality data collected at the monitoring sites is in tabular and graphical form. Bias-corrected concentrations are used when presenting descriptive statistics for each water-quality constituent collected at each of the sites. Boxplots of TN, NOx, TP, DIP, and SED collected from 1985 through 2006 provide information on the mean, median, and other quantiles for each constituent and allow for the comparison of observed water-quality conditions between the nine RIM Program sites. Boxplots of annual TN, NOx, TP, DIP, and SED are presented for each of the sites. These annual boxplots provide information for each constituent and allow for the comparison of observed water-quality conditions from year to year. Spearman's rho rank correlation coefficient was calculated for the mean, median, and other quantiles of TN, NOx, TP, DIP, and SED versus time (years) for each of the water-quality monitoring sites (Helsel and Hirsch, 1992). The rho coefficient is a measure of the strength of the relation between each water-quality constituent and time. Only significant rho coefficients ($p < 0.05$), which provide insight into whether the concentrations associated with the mean, median, and other quantiles are increasing (positive coefficients) or decreasing (negative coefficients) over time, are presented.

Flow-Weighted Concentration

The flow-weighted concentration (FWC) is an estimate of the mean actual concentration in a total volume of water flowing past a specific location in a specific time period, such as month or year. The FWC represents a value in which individual concentration values are not adjusted for flow and may be useful in evaluating concentration variability in the Chesapeake Bay and its tributary rivers. It is important to account for streamflow variability, because the volume of streamflow occurring in short periods between sample intervals is likely to have a more pronounced and longer effect on average concentrations in the tidal waters. Because ESTIMATOR uses daily mean streamflow to predict a daily concentration, which is summed to a monthly load, the resultant FWC should provide a more accurate estimate of the average concentration than the single monthly sample. A monthly FWC is calculated by dividing the monthly load (from ESTIMATOR) by the monthly streamflow. Conducting trend analyses on estimated loads (from which FWCs are derived) can potentially produce biased and unreliable trend statistics. Therefore, trends in monthly FWC were not estimated. Instead, annual FWC results are summarized and presented in attached appendixes. The FWC data are useful in visual examining changes over time within a river basin, making comparisons among different river basins, and making comparisons to tidal concentration data.

Non-Flow-Adjusted Trend

Non-flow-adjusted trends in concentrations (NFAC) and trends in load are used extensively to quantify changes in water-quality conditions affecting a particular environmental resource and are appropriate for determining changes in water quality at the monitoring site. In this report, NFAC were estimated in two ways. First, a nonparametric method was used to assess monotonic change in observed concentration, not adjusted for flow, over time, using the Spearman rho. Second, a parametric method whereby the ESTIMATOR model was used to regress concentration with time (eq. 2). Non-flow-adjusted trends were estimated from a 6-parameter water-quality model of the form:

$$\ln(c) = \hat{\beta}_0 + \hat{\beta}_1 \ln(q/q_c) + \hat{\beta}_2 (t - t_c) + \hat{\beta}_3 (t - t_c)^2 + \hat{\beta}_4 \sin(2\pi t) + \hat{\beta}_5 \cos(2\pi t) + \varepsilon \qquad (2)^2$$

in conjunction with a streamflow model. The 6-parameter model does not include the streamflow-squared ($\left[\ln(q/q_c)\right]^2$) term. The parametric method and results presented in this report are intended to complement the Spearman rho results and potentially provide additional insight through the inclusion of nonlinearity in trend. This method was used to also estimate the trend in load.

The trend was estimated using both the linear and quadratic coefficients on time ($\hat{\beta}_2$, $\hat{\beta}_3$), coefficient variances were used to estimate confidence intervals in the trend estimates, and significant results are reported at the $p < 0.05$ level. Concentration and load models were identical in their coefficients and variances, with the exception of ($\hat{\beta}_1$), which in the load model is equal to the value of the coefficient in the concentration model plus one. All other calculations and significance tests are unchanged. Therefore, the magnitude of trend is equal between the NFAC and load models, however, the standard error of the load model is greater.

Trends were defined in this report as the overall change between the start date and the

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[2] The beta coefficients are defined the same as in equation 3 except beta3 through beta6 are now beta2 through beta5.

end date based on modeled concentration, flow, and time, not an estimate of year-to-year change. A more detailed mathematical description of the estimation of NFAC trends can be found in Langland and others (2006). Changes (trends) were considered significant if the confidence intervals at the end of the modeled period were entirely greater than (SIG-UP) or entirely less than (SIG-DOWN) the modeled starting value of zero (no change). Trend results for NFAC concentrations and loads through time are presented in attached appendices for all sites and all constituents. An example time series is shown in figure 2. These graphs illustrate the percentage change over time and *p*-value for the estimated NFAC and load trend and the standard error.

Flow-Adjusted Trend

Concentrations of water-quality constituents commonly are correlated with streamflow and season. For analysis of trends, concentrations commonly were adjusted to remove the effects of streamflow. A common approach to estimating flow-adjusted trend (FAC) is based on the residual value (the difference between the measured concentration and the value estimated from a streamflow-concentration relation) (Helsel, 1993). The nature of the relation between streamflow and concentration varies by constituent and individual river basin. In point-source dominated basins, for example, the input of constituent sources is relatively constant. An increase in streamflow will most likely result in decreased concentration as a result of dilution. In nonpoint-source dominated basins, constituent concentrations entering the stream from overland flow most likely will increase as flow increases (Shertz and others, 1991). This flow-related variability must be reduced or removed to obtain water-quality concentrations independent of flow. The USGS has developed techniques to compensate for the influence of flow variability, to better understand changes in concentrations that may be the result of human activities (Hirsch and others, 1991; Helsel and Hirsch, 1992).

The estimation of a flow-adjusted trend is based on results from the 7-parameter load model (eq. 3). The linear and quadric coefficients ($\hat{\beta}_3, \hat{\beta}_4$) were used in similar fashion to estimate the trend and confidence intervals as for the NFAC. Differences arise in the determination of significance for FAC depending upon the presence of censored values. A more detailed mathematical description of the estimation of FAC trends can be found in Langland and others (2006). As with the NFAC, changes (trends) were considered significant if the $p<0.05$

level and if the confidence interval of the modeled value at the end of the estimation period were entirely greater than (SIG-UP) or entirely less than (SIG-DOWN) the modeled starting value. Results of the FAC for all 34 sites are presented in an attached appendix and are very similar to NFA concentrations and loads presented in figure 2.

Modeling water-quality trends using linear and quadratic terms allows for the possibility of testing for an extremum (maximum or minimum inflection point represented by a date) during the period of analysis. The test is constructed by taking the derivative with respect to time of the trend function. If $\hat{\ }_4$ is positive, the data show evidence of concavity (with respect to the origin, T_0), and a minimum is implied. If $\hat{\ }_4$ is negative, the data show evidence of convexity, and a maximum is implied. If the calculated *p*-value is less than or equal to 0.05, the null hypothesis is rejected, and an extremum has occurred before or during the period of analysis. Conversely, a calculated *p*-value greater than 0.05 indicates the null hypothesis is not rejected, and, therefore, an extremum has not occurred before or during the period of analysis.

Load Computation

The load represents the amount of a given constituent transported and delivered downstream of the point at which measurements of concentration and streamflow are made. The USGS log-linear regression model (ESTIMATOR) developed by Cohn and others (1989) was used by the USGS RIM Program to estimate loads of nutrients and sediments. Loads at the additional 25 sites also are estimated using ESTIMATOR. The RIM program utilizes a 10-year moving-window strategy to reduce error in the estimated loads whereby loads are considered final in years 1 through 6 and provisional in years 7 through 10, 10 being the last year of estimation, usually the current year (Yochum, 2000). The program computes loads in two steps. First, a center-estimate linear model is fit to the logarithms of the concentration and model coefficients estimated. Second, daily concentrations are computed on the basis of model coefficients. Daily concentrations are then used to estimate daily loads (and variances) using daily mean streamflow. Daily loads are summed to produce monthly and annual loads. The 7-parameter load model is of the form:

$$\ln(c)=\hat{\beta}_0+\hat{\beta}_1\ln(q/q_c)+\hat{\beta}_2\left[\ln(q/q_c)\right]^2+\hat{\beta}_3(t-t_c)+\hat{\beta}_4(t-t_c)^2+\hat{\beta}_5\sin(2\pi t)+\hat{\beta}_6\cos(2\pi t)+\varepsilon \quad (3)$$

where

ln	is the natural logarithm function;
c	is measured concentration, in milligrams per liter;
q	is measured daily mean streamflow, in cubic feet per second;
t	is time, in decimal years;
q_c, t_c	are centering variables for streamflow and time;
$\hat{\beta}_i$	are coefficients estimated by ordinary least squares (non-censored observations) and AMLE (censored observations);
$\hat{\beta}_0$	is a constant;
$\hat{\beta}_1, \hat{\beta}_2$	describe the relation between concentration and streamflow;
$\hat{\beta}_3, \hat{\beta}_4$	describe the relation between concentration and time, independent of flow;
$\hat{\beta}_5, \hat{\beta}_6$	describe seasonal variation in concentration data; and
	is residual error, assumed to be normally distributed with zero mean and variance σ_{ε}^2.

Estimated annual loads (barcharts) through time are included in attached appendixes for all sites and all constituents. An example concentration time series plot is shown in figure 2.

Changes in Streamflow

Variability in streamflow is one of the primary factors affecting water quality in the Chesapeake Bay and its watershed. Variability in streamflow can be caused by natural and anthropogenic factors. The spatial and temporal patterns of precipitation; evapotranspiration; and recharge, storage, and discharge of ground water are the primary natural factors affecting streamflow. Diversions, land-use changes, and other anthropogenic factors in the watershed also affect streamflow. Variability in flow affects the observed concentrations and the average load and concentration of chemical constituents and sediments delivered to the bay and tidal parts of tributary rivers.

Trends in flow primarily indicate natural changes in hydrology in combination with anthropogenic influences. These natural fluctuations in flow affect the observed concentrations, the average concentrations, and the load delivered to the tidal estuaries. Estimates of annual-mean flow to the Chesapeake Bay are based on methods described in Bue (1968).

Annual flow to the bay for 2006 was approximately 78,650 ft^3/s or (18.5 trillion gallons). This is less than 1 percent greater than the long-term annual mean from 1937 to 2005 of 78,600 ft^3/s (fig. 3). Estimated total freshwater flow entering the bay in 2006 was normal (as defined by the inter-quartile range, between the 25th and 75th percentiles), similar to 2005, as compared to below-normal annual mean flows in 2001 and 2002, followed by above-normal flows in 2003 and 2004 (fig. 3). Extremes in monthly flows in water year 2006 ranged from 154,300 ft^3/s in January to 25,800 ft^3/s in August, indicating a large variability in flows to the bay. For the period 1937 through 2006, the 25th, 50th, and 75th percentiles were approximately 63,400, 76,700, and 89,600 ft^3/s, respectively.

Generally, the long-term annual flows to the bay could be described as near-normal (1940-1960), dry in the 1960s, wet in the 1970s, near-normal in the 1980s, and, since the 1990s, the most annual fluctuations from wet to dry. The wetter conditions observed from 1970 to 2006 (12 of 35 years were above the 75th percentile), combined with the effects of increased nutrients and sediment from human activities, have been cited as possible causes for the declines in dissolved oxygen and water clarity in the bay that were documented in the 1970s (Phillips, 2002) and that currently (2006) persist.

Examining the results for tends in streamflow at the 34 sites indicated statistically significant increasing trends at two sites (Susquehanna River at Wilkes-Barre and Patuxent River near Bowie) for daily mean streamflow over the trend-estimation period (table 3). Trends are reported for those sites where the residuals of the model were normal and results reliable. Annual and seasonal mean streamflow time series were developed for all 34 sites in this study and are presented in appendix 1.

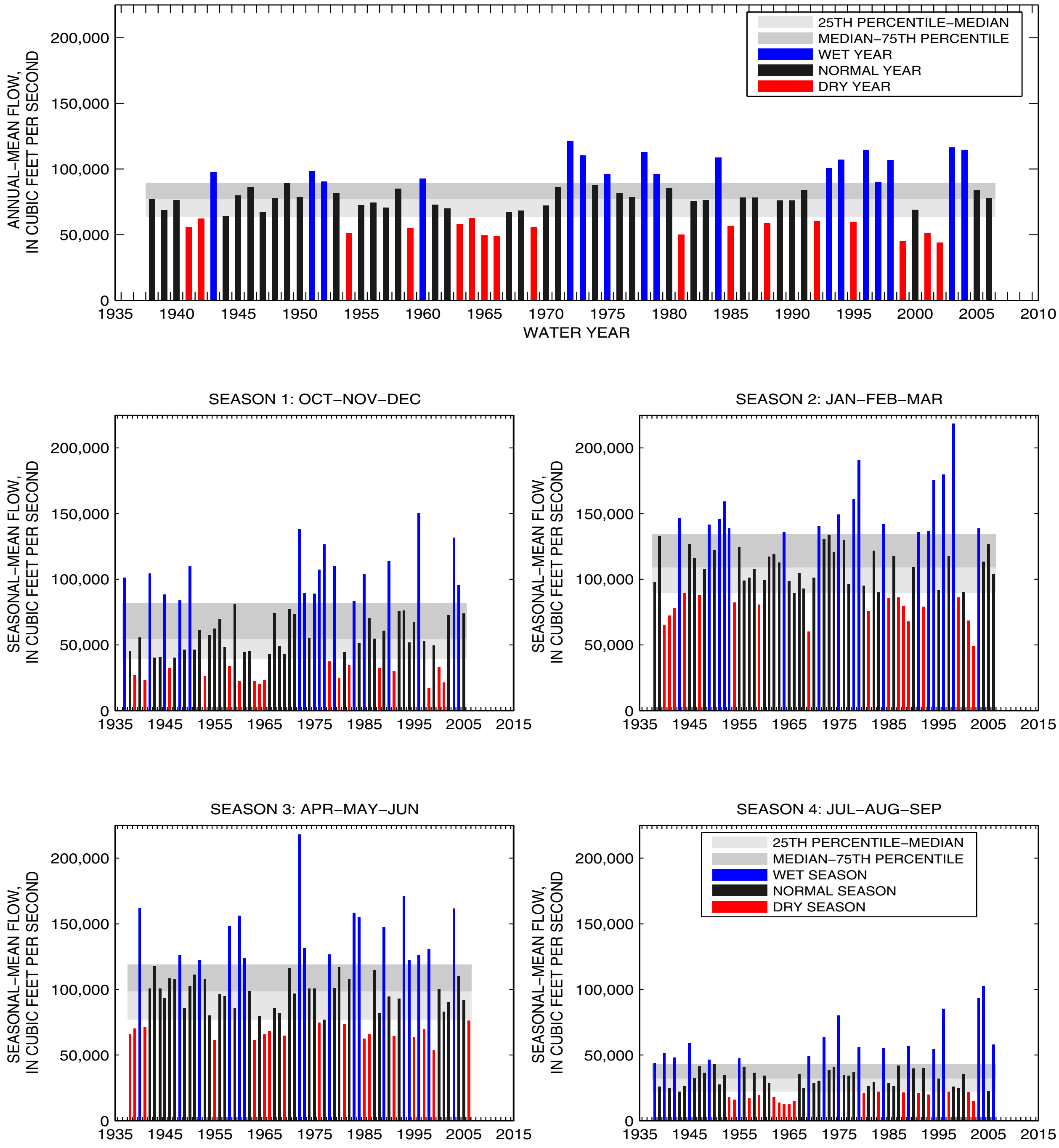


Figure 3. Estimated total annual and seasonal freshwater flow to Chesapeake Bay for 1937-2006. [using methods as described in Bue (1968)]

Table 3. Streamflow trends for the 34 stations in this study, 1985-2006.

[Map ID, location of site on figure 1; start and end date, period of trend estimation; *p*-value, measure of significance at the 0.05 level; SIG-UP, shaded and statistically significantly increasing trend; ns, no statistically significantly detectable trend.]

Station Number	Map ID	Start date	End date	*p*-value	Significance
01491000	9	10/1/1984	9/30/2006	0.083	ns
01531500	1	10/1/1984	9/30/2006	0.068	ns
01536500	2	**10/1/1984**	**9/30/2006**	**0.036**	**SIG-UP**
01540500	3	10/1/1984	9/30/2006	0.087	ns
01553500	4	10/1/1984	9/30/2006	0.683	ns
01567000	5	10/1/1984	9/30/2006	0.330	ns
01576000	6	10/1/1984	9/30/2006	0.164	ns
01576754	7	1/1/1985	9/30/2006	0.461	ns
01578310	8	10/1/1984	9/30/2006	0.129	ns
01586000	10	10/1/1984	9/30/2006	0.612	ns
01592500	11	10/1/1984	9/30/2006	0.152	ns
01594440	12	**10/1/1984**	**9/30/2006**	**0.046**	**SIG-UP**
01599000	13	10/1/1984	9/30/2006	0.746	ns
01601500	14	10/1/1984	9/30/2006	0.640	ns
01610000	15	10/1/1984	9/30/2006	0.809	ns
01614500	16	10/1/1984	9/30/2006	0.282	ns
01619500	17	10/1/1984	9/30/2006	0.658	ns
01626000	18	10/1/1984	9/30/2006	0.808	ns
01631000	19	10/1/1984	9/30/2006	0.837	ns
01634000	20	10/1/1984	9/30/2006	0.308	ns
01639000	21	10/1/1984	9/30/2006	0.626	ns
01643000	22	10/1/1984	9/30/2006	0.615	ns
01646580	23	10/1/1984	9/30/2006	0.589	ns
01651000	24	10/1/1984	9/30/2006	0.395	ns
01666500	25	10/1/1984	9/30/2006	0.828	ns
01668000	26	10/1/1984	9/30/2006	0.515	ns
01671020	27	10/1/1984	9/30/2006	0.792	ns
01673000	28	10/1/1984	9/30/2006	0.833	ns
01674500	29	10/1/1984	9/30/2006	0.840	ns
02026000	30	10/1/1984	9/30/2006	0.768	ns
02035000	31	10/1/1984	9/30/2006	0.801	ns
02037500	32	10/1/1984	9/30/2006	0.947	ns
02041650	33	10/1/1984	9/30/2006	0.886	ns
02042500	34	10/1/1984	9/30/2006	0.599	ns

Changes in Concentration

Changes in water quality are shown by descriptive statistics for observed concentration, non-flow-adjusted trends, and flow-adjusted trends generally for 1985-2006 for all 34 of the study sites. Because of variable starting times in flow or water-quality data, some sites have shorter data-collection and analysis periods. Graphical displays of annual loads are presented in this report. Numerical loads are not reported in this report but are available from the USGS web site for the nine RIM Program sites at http://va.water.usgs.gov/chesbay/RIMP/index.html. Flow-weighted concentrations for the nine RIM Program sites are provided in this report.

Observed Concentration

The most direct measure of change in water quality is observed concentration data. Concentration time series plots for all constituents for all 34 sites are presented in appendix 2. The bias-corrected percentiles for the observed concentrations of TN, NOx, TP, DIP, and SED for the 34 water-quality monitoring sites are listed in appendix 3. Annual time-series boxplots for the bias-corrected concentrations are presented in appendix 4. Concentrations of TN and NOx generally were elevated in the northern five river basins (Susquehanna, Choptank, Western Shore, Patuxent, and Potomac Rivers) compared to concentrations of TN and NOx in the southern five river basins (Rappahannock, Mattaponi, Pamunkey, James, and Appomattox Rivers). The median (50th percentile) concentrations of TN in the northern five basins ranged from 0.98 to 8.1 mg/L and NOx ranged from 0.51 to 6.9 mg/L, compared to the median concentrations of TN in the southern five basins that ranged from 0.44 to 1.84 mg/L and NOx that ranged from 0.05 to 1.43 mg/L (appendixes 3-4). The Conestoga River at Conestoga, Pa., exhibited the greatest concentrations of TN and NOx for all percentiles (10th, 25th, 50th, 75th, and 90th).

On the basis of the bias-corrected 50th percentiles, the Spearman's rho rank correlation analysis identified 43 percent of the monitoring sites in the northern five basins exhibited significant decreasing trends in TN over time (appendix 3). In the southern five basins, the Spearman's rho rank correlation analysis determined that 4 of the 13 sites had significant decreasing trends in the 50th percentile of TN over time.

Concentrations of TP were elevated in the northern five river basins compared to concentrations in the southern five river basins. The median concentrations of TP in the northern five basins ranged from 0.017 to 0.24 mg/L, compared to the median concentrations of TP in the southern five basins that ranged from approximately 0.02 to 0.16 mg/L (appendixes 3-4). Median concentrations of DIP in the northern five basins were nearly double the median concentrations observed in the southern five basins. The range of median concentrations of DIP in the northern and southern basins was approximately 0.01 to 0.13 mg/L and approximately 0.01 to 0.08 mg/L, respectively.

The Spearman's rho rank correlation analysis identified a significant decreasing trend in TP over time in 7 of the 21 monitoring sites in the northern five basins (appendix 3). There were no sites in the northern five basins that had a significant increasing trend in TP over time. In the southern 5 basins, 4 of the 13 sites had significant trends over time for median concentrations of TP. Three of the sites exhibited significant decreasing trends in TP, and the Pamunkey River near Hanover, Va. (01673000), exhibited a significant increasing trend in TP over time.

Concentrations of SED were comparable across all 10 major river basins. The two monitoring sites with the greatest concentrations of SED for all bias-corrected percentiles (10th, 25th, 50th, 75th, and 90th) are the Conestoga River at Conestoga, Pa., with a concentration range of 4 to 187 mg/L, and the Patuxent River near Bowie, Md., with a concentration range of 6 to 41 mg/L (appendixes 3-4). The two sites with the lowest concentrations of SED for all percentiles are the North Anna River at Hart Corner near Doswel, Va., with a concentration range of <5 to 8 mg/L and the Chickahominy River near Providence Forge, Va., with a concentration range of <5 to 8 mg/L. The Spearman's rho rank correlation analysis identified a significant decreasing trend in median SED concentrations over time in 5 of the 34 monitoring sites (appendix 3). Three of the sites were in the northern basins and two in the southern basins.

The RIM Program sites have been established in 9 of the 10 major river basins (in this report) within the Chesapeake Bay watershed. The Western Shore River Basin is the only major basin not represented by the RIM program. The bias-corrected percentiles (10th, 25th, 50th, 75th, and 90th percentiles) and bias-corrected means for TN, NOx, TP, DIP, and SED collected at the nine RIM sites during 1985-2006 are shown in figure 4. Concentrations of TN and NOx generally were elevated at the Choptank, Susquehanna, Patuxent, and Potomac RIM Program sites compared to the concentrations observed at the Rappahannock, Mattaponi, Pamunkey, James, and Appomattox RIM Program sites. Concentrations of TP and DIP were similar at each of the nine

RIM Program sites. TP concentrations typically ranged from 0.02 to 0.30 mg/L; concentrations of DIP typically ranged from 0.01 to 0.08 mg/L. Concentrations of SED also were similar at each of the nine RIM Program sites and typically ranged from 3 to 100 mg/L.

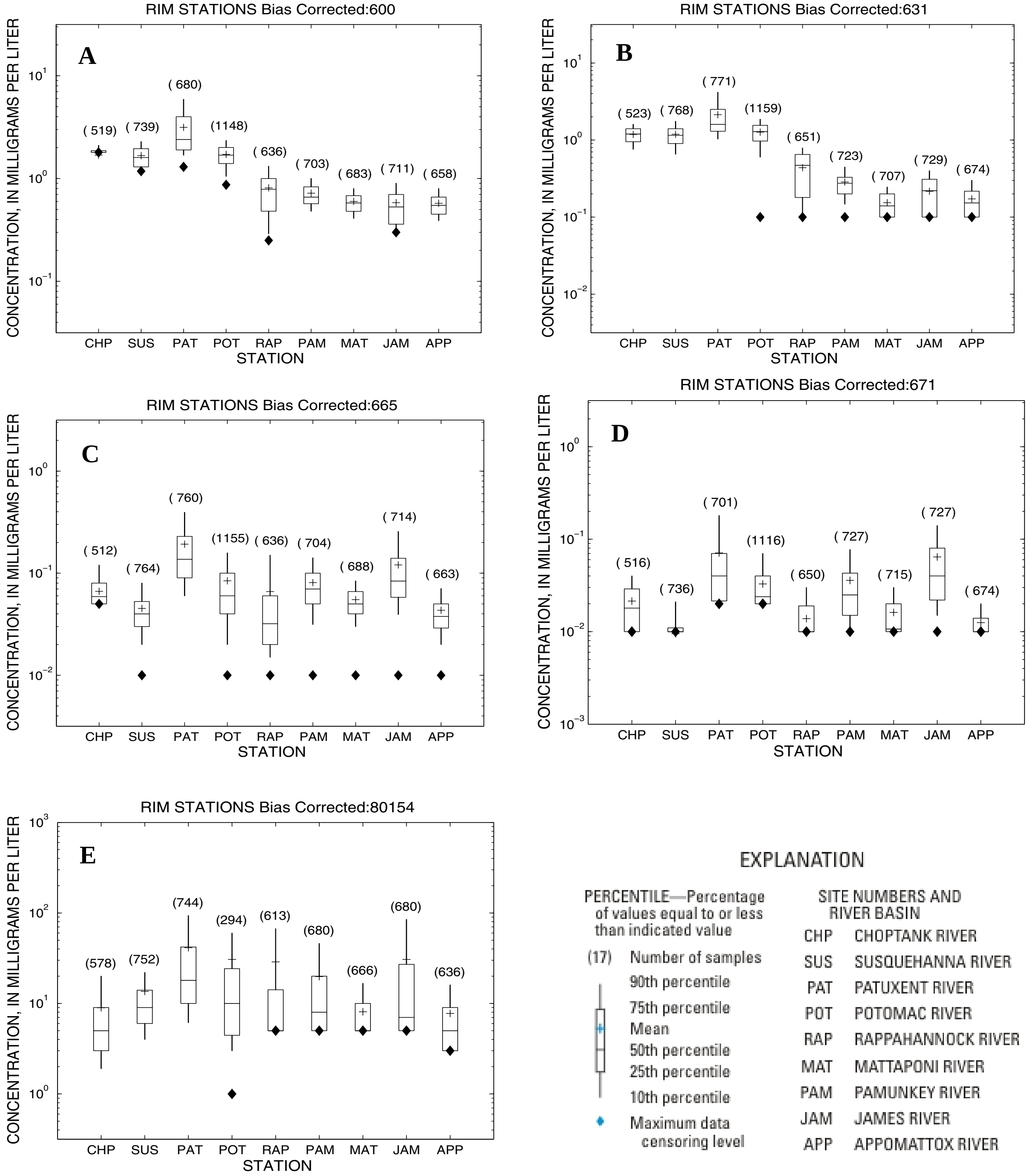


Figure 4. Bias-corrected distribution and mean of observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate (NOx), (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment for the nine River Input Monitoring Program (RIM) stations, Chesapeake Bay watershed, 1985-2006.

Annual Flow-Weighted Concentration

An approach to examine the changing relation between streamflow and load was by approximating the flow-weighted annual concentration (FWC). Changes over temporal scales can be illustrated within a basin and comparisons can be made among different basins by use of the FWC. The combined annual mean FWCs for TN, TP, and SED were calculated by summing the total load and dividing by the summed total flow from each of the nine RIM Program sites from 1990 to 2006, the time period for which all nine RIM Program sites were sampled. In contrast, FWC for the nine individual RIM Program sites use data back to 1985, where available.

Total nitrogen FWC indicates a downward tendency in the 1990s and an upward tendency since 2002 (fig. 5A), although the total variability in TN FWC was less than 1 mg/L. The combined mean FWC was 3.5 mg/L for 1990-2006. Downward tendencies in FWC are indicated for all 9 RIM sites for TN from 1985 to 1990, most notably at the Patuxent site (fig. 5B). FWCs for TN were higher and generally decreasing at the northern sites (Choptank, Susquehanna, Patuxent, and Potomac) and were lower and more constant at the southern sites (Rappahannock, Pamunkey, Mattaponi, James, and Appomattox). FWC for TN was higher in 2006 than in 2005 at the James River site (fig. 5B).

FWCs for TP and SED exhibited much more variability than the FWCs for TN because of different transport mechanisms. Most of the TN was transported in the dissolved phase as nitrate-nitrogen; most TP and all SED are transported in the particulate phase. A general decline in FWC for TP was reversed in 2003, when concentrations sharply increased and have since declined (fig. 6A). From 1990 through 2006, the combined FWC for TP averaged about 0.195 mg/L for the RIM Program sites and ranged from a high of 0.33 mg/L in 2003 to a low of 0.13 mg/L in 1999.

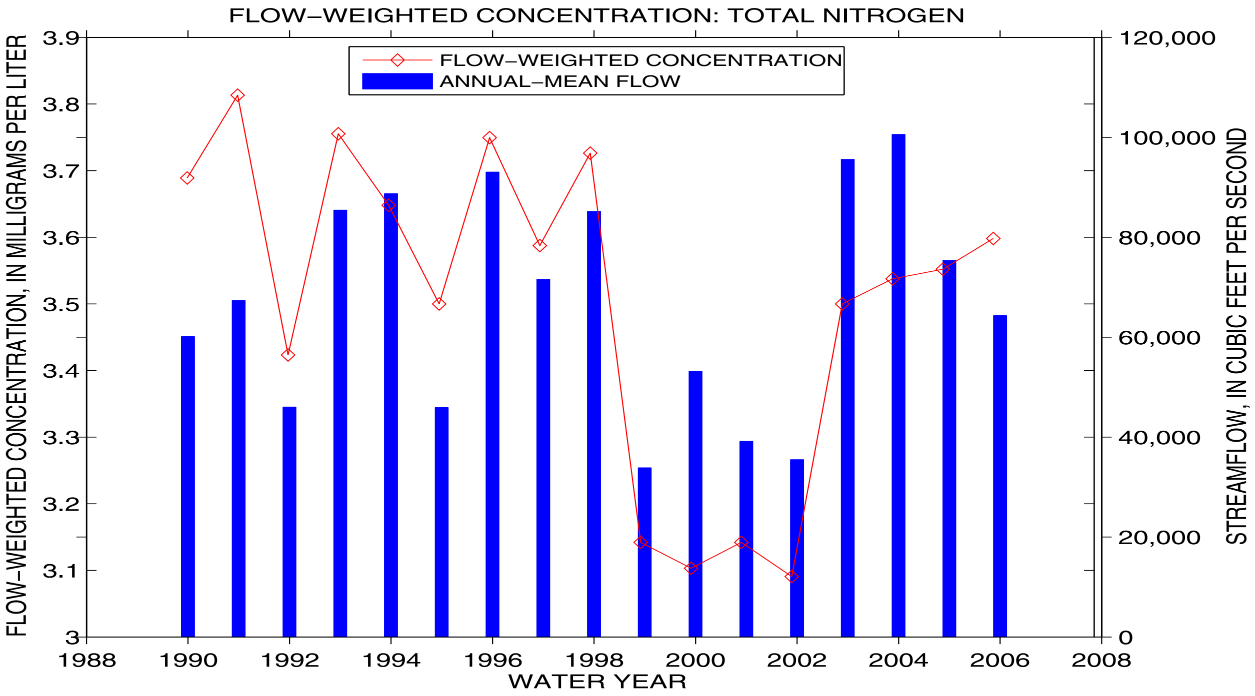


Figure 5A. Combined River Input Monitoring annual mean flow and total nitrogen flow-weighted concentration, 1990-2006.

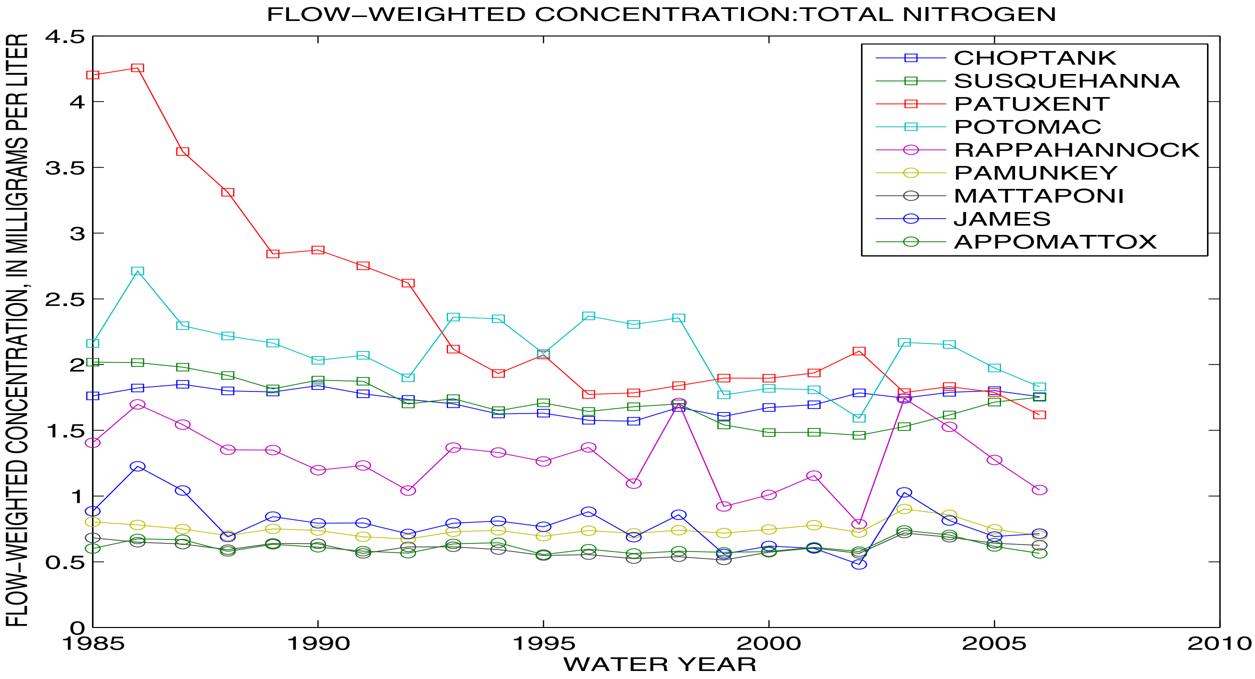


Figure 5B. Annual flow-weighted total nitrogen concentrations for the four northern (square) and five southern (circle) River Input Monitoring Program sites.

FWCs for TP indicated general decreases from 1985 through 1990 at two of the four northern RIM Program sites [Potomac and Patuxent (fig. 6B)]. The Patuxent RIM Program site exhibited a steady decrease, followed by a slight increase during the last few years of the study period, very similar to the results for TN. In the southern basins, FWCs for TP at the Rappahannock and James sites were relatively higher and more variable than those for TN, and the FWC for TP had been increasing steadily at the Pamunkey site. The highest annual mean FWC for TP (0.63 mg/L) was in the Rappahannock River in 1986 (fig. 6B); the Rappahannock River also had the highest long-term annual mean FWC for TP of 0.22 mg/L. Conversely, the lowest FWC for TP (0.03 mg/L) was in the Susquehanna River in 1995; TP also had the lowest long-term annual mean FWC in the Susquehanna River (0.05 mg/L). The lower values in the Susquehanna River are most likely because of the TP and SED being trapped behind three large reservoirs in the lower reaches of the river (Langland and Hainly, 1997). FWCs for TP generally have been decreasing since the high-flow years (2003-2004) for many of the RIM Program sites (fig. 6B). FWC for SED was higher in 2006 than in 2005 at the Patuxent and James River sites (fig. 6B).

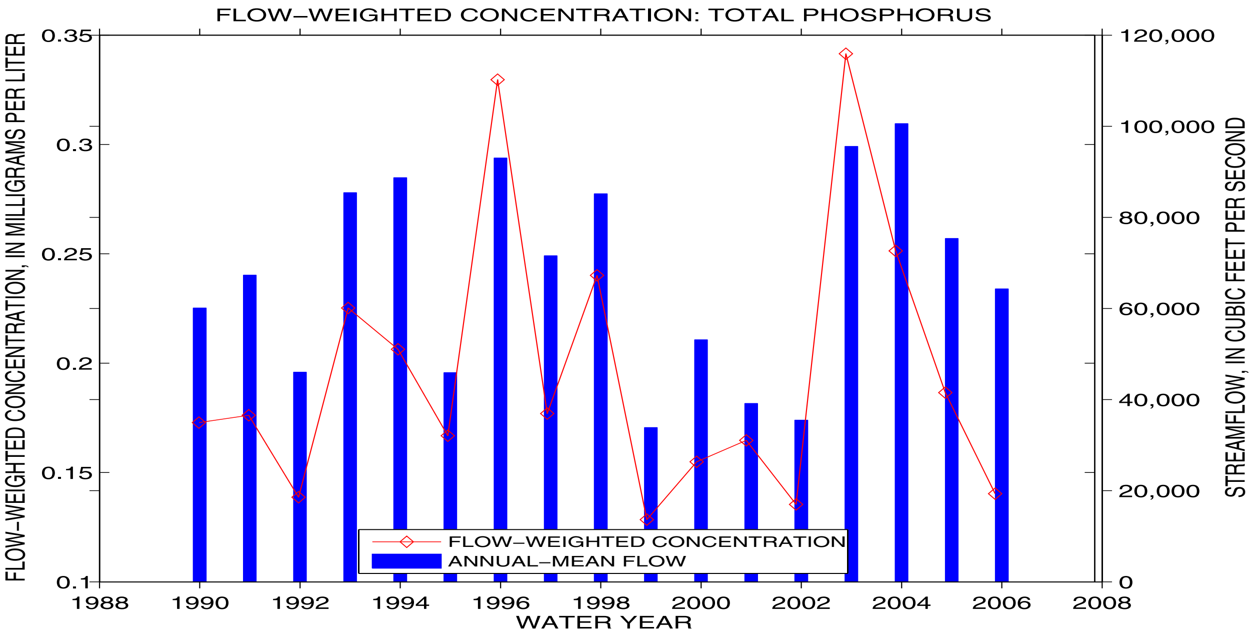


Figure 6A. Combined River Input Monitoring annual-mean flow and total phosphorus flow-weighted concentration,1990-2006

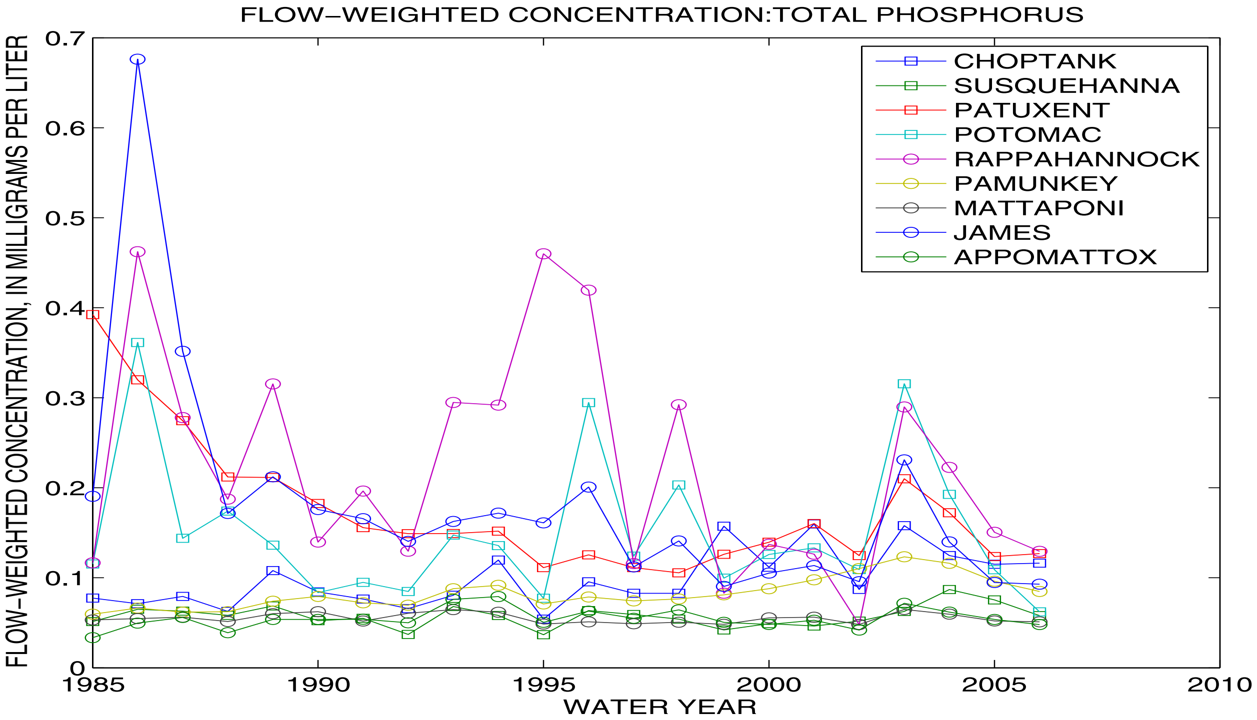


Figure 6B. Annual flow-weighted total phosphorus concentrations for the four northern (square) and five southern (circle) River Input Monitoring Program sites.

As previously mentioned, the highest and lowest combined flow from the RIM stations were for years were 2004 and 1999, respectively. The highest and lowest combined FWC for SED (294 mg/L in 1996 and 37 mg/L in 2002) did not correspond directly to the highest and lowest flow years (fig. 7A). The combined average mean FWC for SED during 1990-2006 was 116 mg/L as measured at the RIM Program sites. Similar to the FWCs for TN and TP, a more variable but downward tendency in FWC for SED was exhibited through the early 2000s, followed by a sharp increase the high flow years of 2003-04, and have since declined.

Prior to 1990, the highest annual mean FWC for SED was 704 mg/L in the Potomac River (fig. 7B). Similar to the FWC for TP, the FWC for SED was higher in the high flow years and lower in the low flow years. The highest mean annual FWC for SED during 1990-2005 was in the Rappahannock River (586 mg/L in 1995; fig. 7B), which also had the highest long-term annual mean (244 mg/L). The lowest annual mean FWC for SED was in the Choptank River (5.7 mg/L in 2002) and the lowest long-term mean FWC was in the Pamunkey River (9.7 mg/L). The variability in FWC was consistent among the RIM Program sites; the Rappahannock was the most variable and continuously since 1990 had the highest annual FWC for SED, with the exception of 2002. Similar to FWC for TP, FWC for SED was higher in 2006 than in 2005 at the Patuxent and James River sites (fig. 7B).

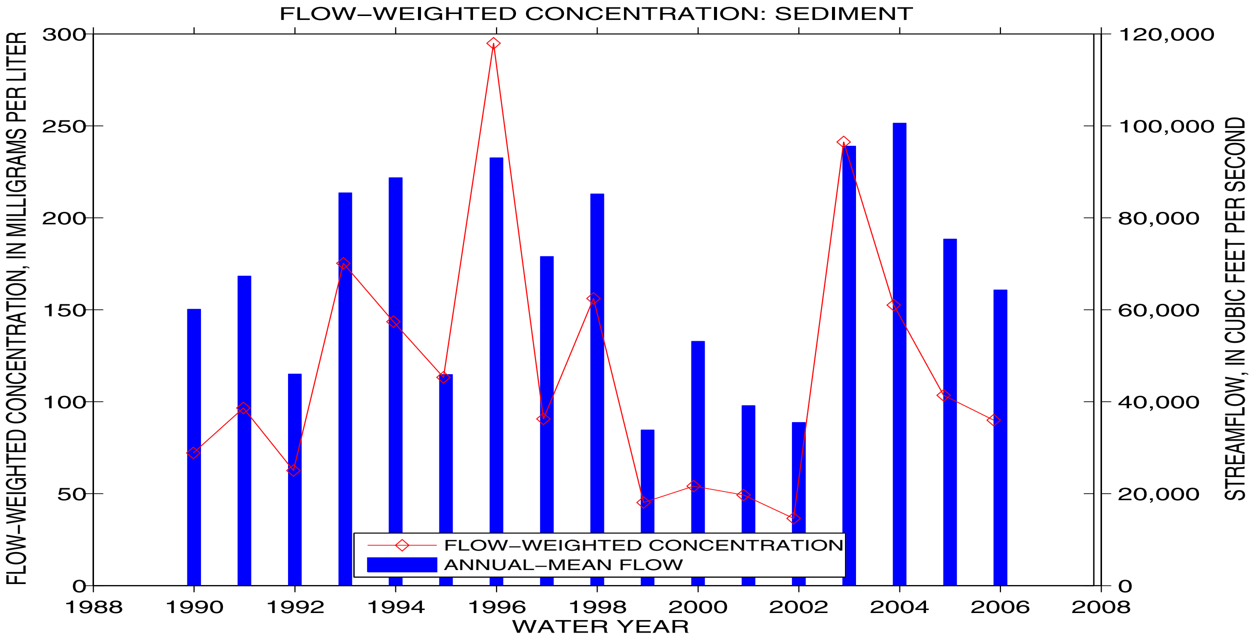


Figure 7A. Combined River Input Monitoring annual-mean flow and sediment flow-weighted concentration, 1990-2006.

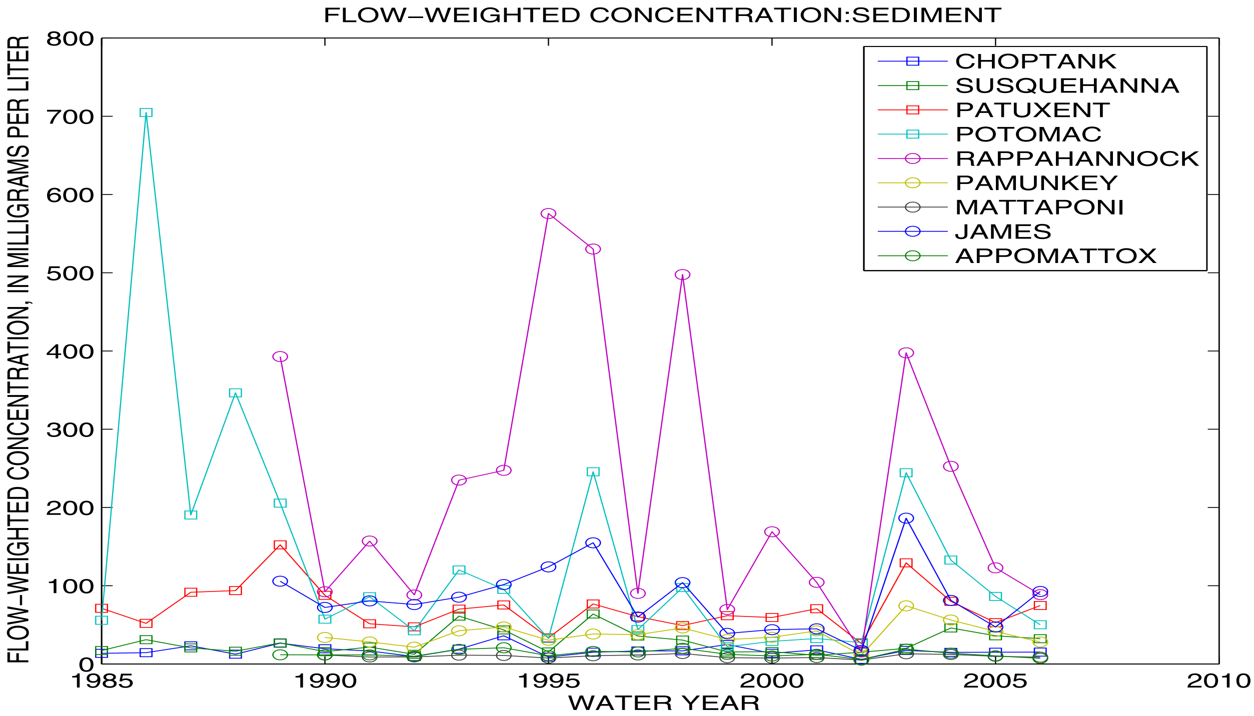


Figure 7B. Annual flow-weighted sediment concentrations for the four northern (square) and five southern (circle) River Input Monitoring Program sites.

Non-Flow-Adjusted Trends in Concentration and Load

Constituent concentrations and loads in streams vary through time in response to many factors, including changes in sources, processes that might modify concentration, human actions, and variations in climatology, notably precipitation. NFA trends allow for the examination of the overall response of the ecosystem to these changing factors and for the comparison to changes in the ecosystem downstream.

Non-flow-adjusted trends in concentration (NFAC) and load (NFAL) were estimated for the time period 1985 through 2006 (although some sites have shorter periods of analysis). The results for TN, TP, and TSS or SED through water year 2006 for the nine RIM Program sites are shown in fig. 8 (NFAC) and fig. 9 (NFAL). The complete results for all reported constituents and sites are provided in appendix 5 (non-flow-adjusted trend in concentration) and appendix 6 (non-flow-adjusted trend in load).

All RIM Program sites exhibited insignificant or downward non-flow-adjusted trends in TN concentration, except for the Pamunkey River, which exhibited an upward trend (fig. 8). For TP, the only significantly downward was in the Patuxent River; the Pamunkey and Choptank Rivers had statistically significant upward trends. Only the Patuxent River site had a statistically significant non-flow-adjusted trend (downward) in SED or TSS concentration. These results are very consistent with the results of the Spearman rho analysis (appendix 3).

For the 9 RIM and 25 Multi-Agency Nontidal Monitoring Program sites, 20 sites had statistically significant downward trends in TN; 2 sites had statistically significant upward trends. The largest decrease was at Patuxent River at Bowie (-60 percent), and the largest increase was at North Fork Shenandoah River (+27 percent) (appendix 5). Large statistically significant downward trends were estimated for concentration of TP at 19 sites, and 3 sites had statistically significant upward trends. The range in trend magnitude for TP was (-78) percent at James Creek near Bent Creek to (+83) percent for North Fork Shenandoah River. Statistically significant downward trends were estimated for SED or TSS at two sites (Conestoga at Conestoga and Patuxent River at Bowie).

Constituent loads are computed using streamflow and, therefore, exhibit variance that closely corresponds to variance in streamflow. Therefore, few, if any, statistically significant trends in load were expected because few statistically significant trends in streamflow were observed over the study period. Furthermore, the large variance in streamflow and load tend to produce very large confidence intervals in the estimated trend. For the nine RIM Program sites (fig. 9), only one statistically significant NFAL was estimated for TN – [(Patuxent River at Bowie - downward) and one for TP (Choptank River - upward)]. For the 25 Multi-Agency Nontidal Monitoring Program sites (appendix 6), very few yielded statistically significant non-flow-adjusted trends in TN, TP, or SED loads. No sites were significant for TN. For TP, only one site, North Fork Shenandoah River was significantly upward (+117 percent). No statistically significant non-flow-adjusted trends in load were estimated for SED.

In addition to providing an estimate of the trend over the study period, the non-flow-adjusted trend method provided continuous estimation of the non-flow-adjusted trends over time. An example 4-panel illustration used to present results for non-flow adjusted trends in concentration and load for all 34 sites in appendix 7 is shown in fig. 2.

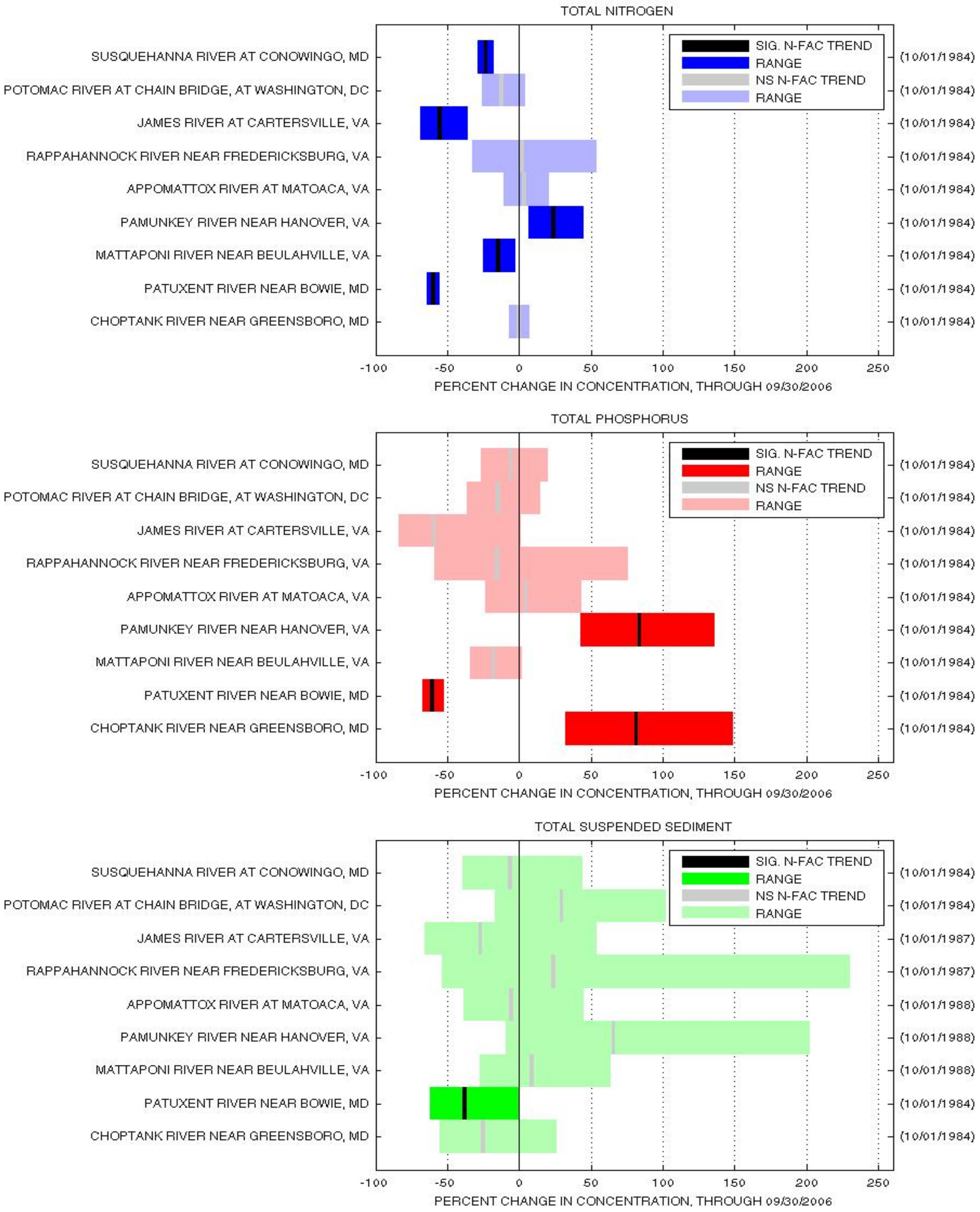
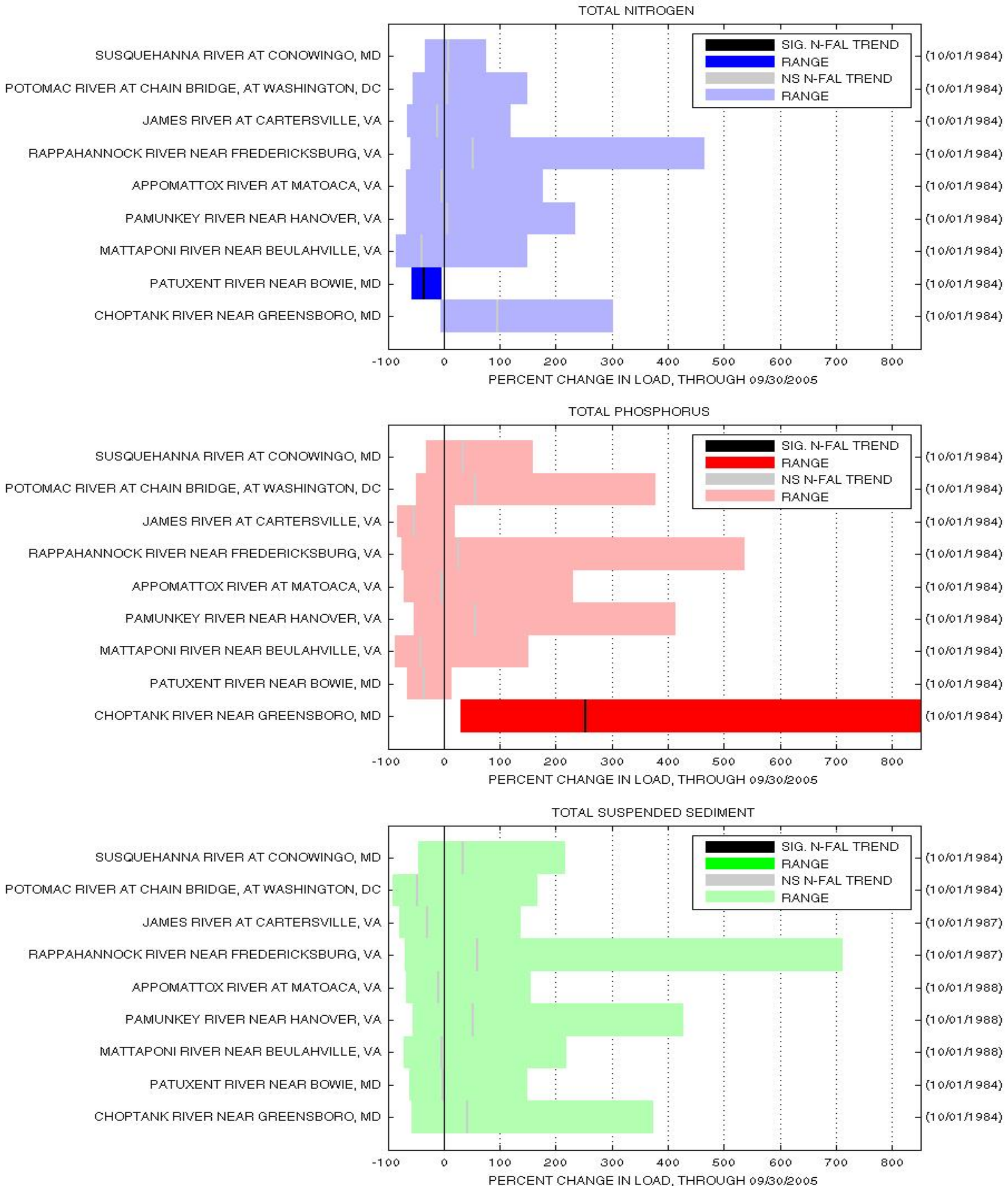


Figure 8. Estimated non-flow-adjusted trend in concentration (NFAC) and confidence interval for total nitrogen, total phosphorus, and sediment for the nine River Input Monitoring Program sites, 1985-2006.

[Sites are organized from largest (Susquehanna) to smallest (Choptank) in terms of mean annual streamflow. Dates on the right y-axis indicate the starting date, t_0, Significance, p-value less than 0.05.]



TOTAL NITROGEN

TOTAL PHOSPHORUS

TOTAL SUSPENDED SEDIMENT

Figure 9. Estimated non-flow-adjusted trend in load (NFAL) and confidence interval for total nitrogen, total phosphorus, and sediment for the nine River Input Monitoring Program sites, 1985-2006.

[Sites are organized from largest (Susquehanna) to smallest (Choptank) in terms of mean annual streamflow. Dates on the right y-axis indicate the starting date, t_0, Significance, p-value less than 0.05.]

Flow-Adjusted Trend in Concentration

Observed concentration and FAC are highly influenced by variability in streamflow. Therefore, the ESTIMATOR model (eq. 3) estimates a trend independent of the influence of streamflow to improve the understanding of water-quality changes that result (at least in part) from human influences. Model results are used to determine flow-adjusted trends. By partitioning variability in observed concentration due to season and streamflow, the coefficients from the "time" parameters can be used as an estimate of the amount of change over time.

The flow-adjusted trend does not necessarily represent all the water-quality changes that result from human influence and management actions; it only describes those separate from flow. A change in farming practices that reduces surface runoff but increases ground-water recharge or a change in atmospheric deposition may not be captured in the flow-adjusted trend. Therefore, while flow-adjusted trends are an indicator of human activities affecting water quality within a watershed, the relative magnitude of the trend must be considered in terms of the hydrologic variability.

Flow-adjusted trends in TN, TP, and SED or TSS for the nine RIM Program sites for the period 1985 through 2006 are shown in fig. 10. The four largest monitored rivers in terms of flow (Susquehanna, Potomac, James, and Rappahannock) in addition to the Mattaponi and Patuxent Rivers exhibit statistically significant downward trends in TN. Only the Pamunkey River exhibits a statistically significant upward trend in TN. A unique pattern exists for the nine RIM Program sites for TP FAC. Eight of the nine sites are significant, four sites each indicating downward or upward trends. Of the largest four monitored sites, only the Potomac River has a statistically significant upward trend. For TP, five RIM sites were significant for SED or TSS. The Pamunkey River exhibited the only statistically significant upward trend. Statistically significant downward trends in SED or TSS were observed for the Susquehanna, Potomac, Patuxent, and Choptank Rivers.

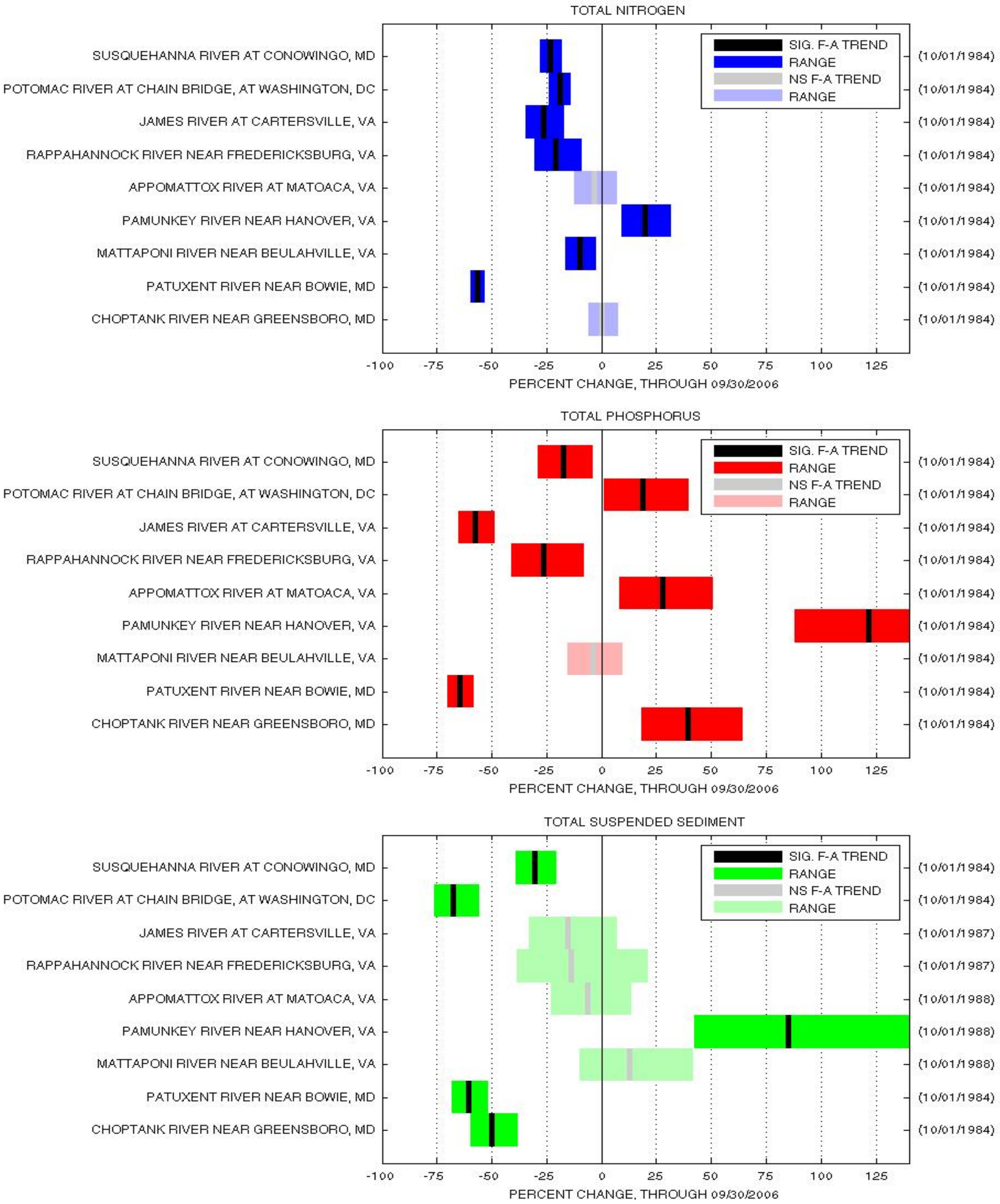


Figure 10. Estimated flow-adjusted trend in concentration (FAC) and confidence interval for total nitrogen, total phosphorus, and sediment for the nine River Input Monitoring Program sites, 1985-2006.

[Sites are organized from largest (Susquehanna) to smallest (Choptank) in terms of mean annual streamflow. Dates on the right y-axis indicate the starting date, t_0 , Significance, p-value less than 0.05.]

Complete results of the flow-adjusted trend estimation are provided in appendix 8; results are summarized for TN, TP, and SED or TSS in figures 11, 12, 13, respectively. FAC results for TN indicate downward trends at 25 of the 34 sites (74 percent) (fig. 11). All 8 sites in the Susquehanna River Basin, including the RIM Program site, had downward trends in TN over the study period. In the Potomac River Basin, 11 sites had downward flow-adjusted trends in TN and 1 site had an upward trend. Five sites in the lower Virginia basins indicated significantly downward flow-adjusted trends in TN, two sites indicated upward trends (both in the Pamunkey River Basin), and three sites indicated no statistically significant trend. One site (Patuxent River at Bowie) had downward TN flow-adjusted trends greater than 50 percent; no sites had upward trends greater than 50 percent.

Statistically significant downward flow-adjusted trends for TP were identified at 23 of the 34 sites (68 percent) (appendix 8, fig. 12) and upward trends at 6 sites. Six of the 34 sites had downward TP flow-adjusted trends greater than 50 percent, and 2 sites had upward trends greater than 50 percent. Trends were downward at 4 RIM Program sites, and downward flow-adjusted trends in TP were identified in 6 of the 10 major bay drainage basins. Upward flow-adjusted trends in TP were identified at six sites, four of which are RIM Program sites (Choptank, Potomac, Pamunkey, and Appotmattox). All eight sites in the Susquehanna River Basin had downward trends. The Potomac River Basin had eight sites with downward trends, two sites with upward trends, and two sites with no statistically significant trend. The Rappahannock, Pamunkey, Mattaponi, and James River Basins together had five sites with downward trends, three sites with upward trends, and three sites with no significant trends.

Significant downward flow-adjusted trends for SED were detected at 11 of the 34 sites (32 percent). Upward trends were reported at two sites (both in the Pamunkey River Basin) (appendix 8, fig. 13). The Maryland RIM Program sites had four downward trends (Choptank, Susquehanna, Patuxent, and Potomac); the Virginia RIM Program had two sites with downward trends, one site with an upward flow-adjusted trend, and four sites with no statistically significant trends in SED. In the Susquehanna River Basin, downward trends were estimated for six of eight sites. Results for the Potomac Basin indicate three sites with downward trends and nine sites with no statistically significant trend. In the lower Virginia river basins, no sites had downward trends; two sites had upward trends, and eight sites did not have statistically significant trends. In addition, three sites had downward SED flow-adjusted trends greater than 50 percent, and two sites had upward trends greater than 50 percent.

The flow-adjusted trend was estimated as a continuous function of time as a percent change relative to the starting time, t_0. The continuous trend line allows additional interpretation of management actions within a watershed. Continuous trend lines are presented for all 34 sites in appendix 9. As a final comparison of all the types of trends, streamflow, Spearman rho, non-flow-adjusted concentration, non-flow-adjusted load, and flow-adjusted concentrations, results for all 34 sites are shown in table 4.

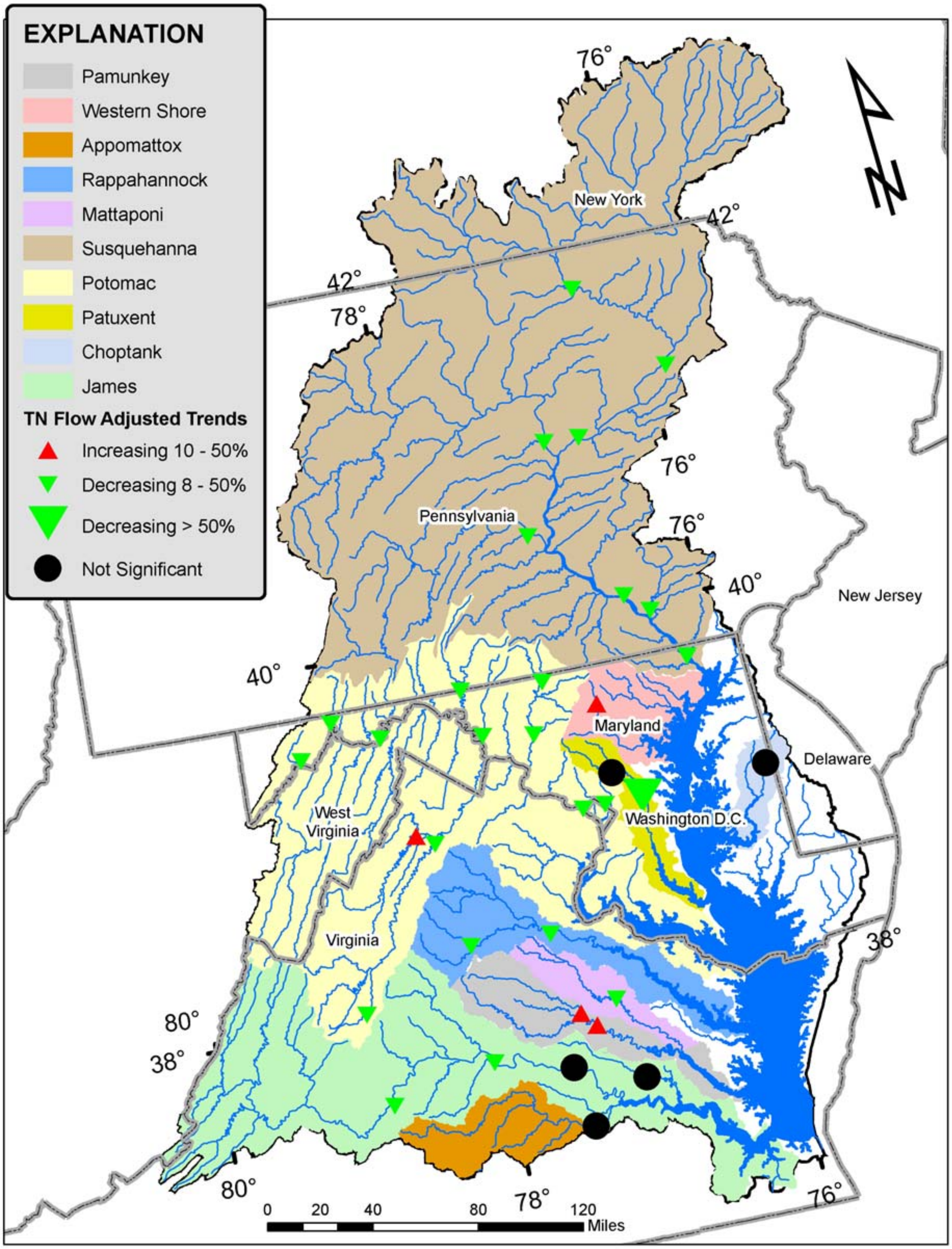


Figure 11. Flow-adjusted trend results for total nitrogen (TN) at the 34 study sites in the Chesapeake Bay watershed.

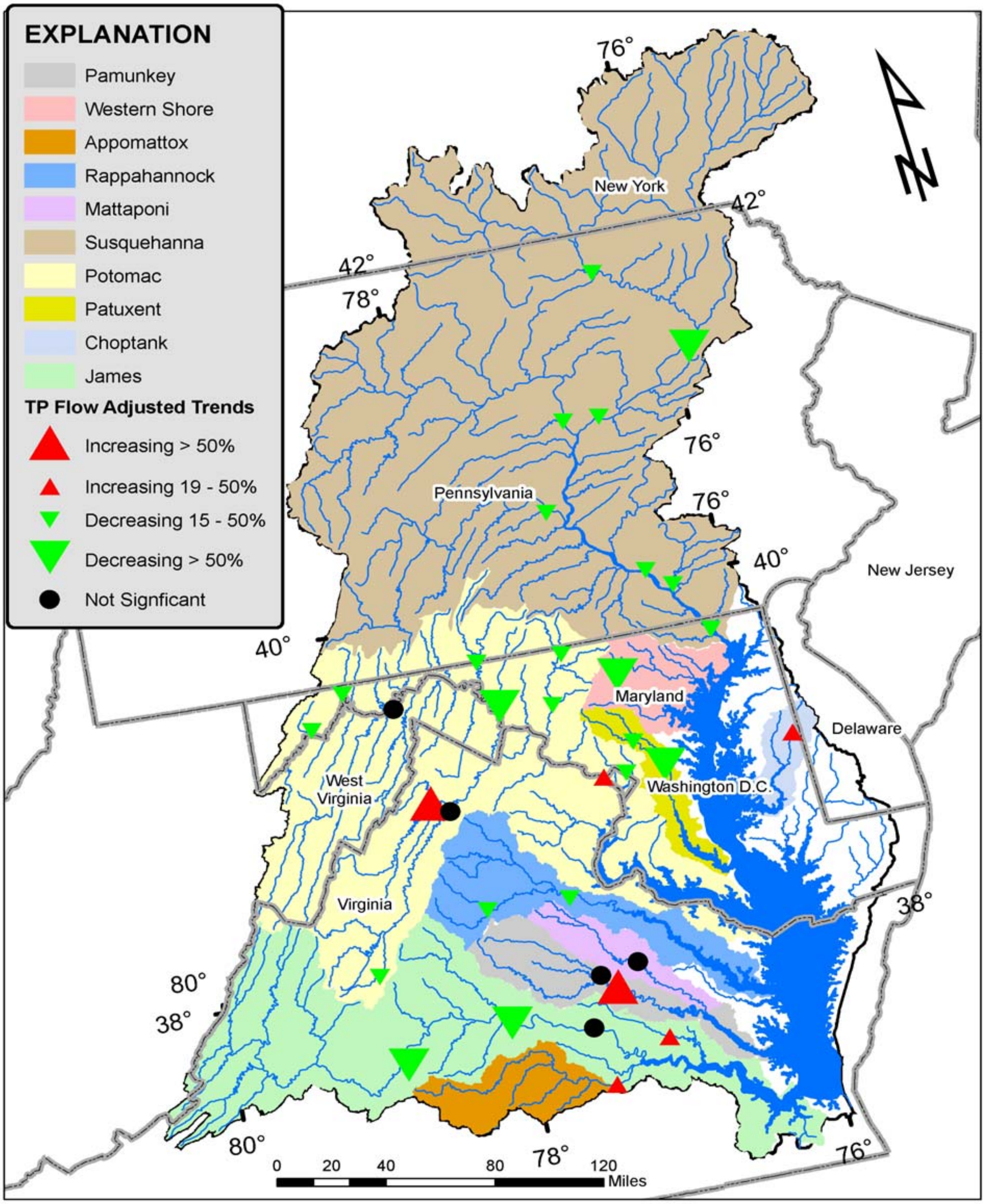


Figure 12. Flow-adjusted trend results for total phosphorus (TP) at the 34 study sites in the Chesapeake Bay watershed.

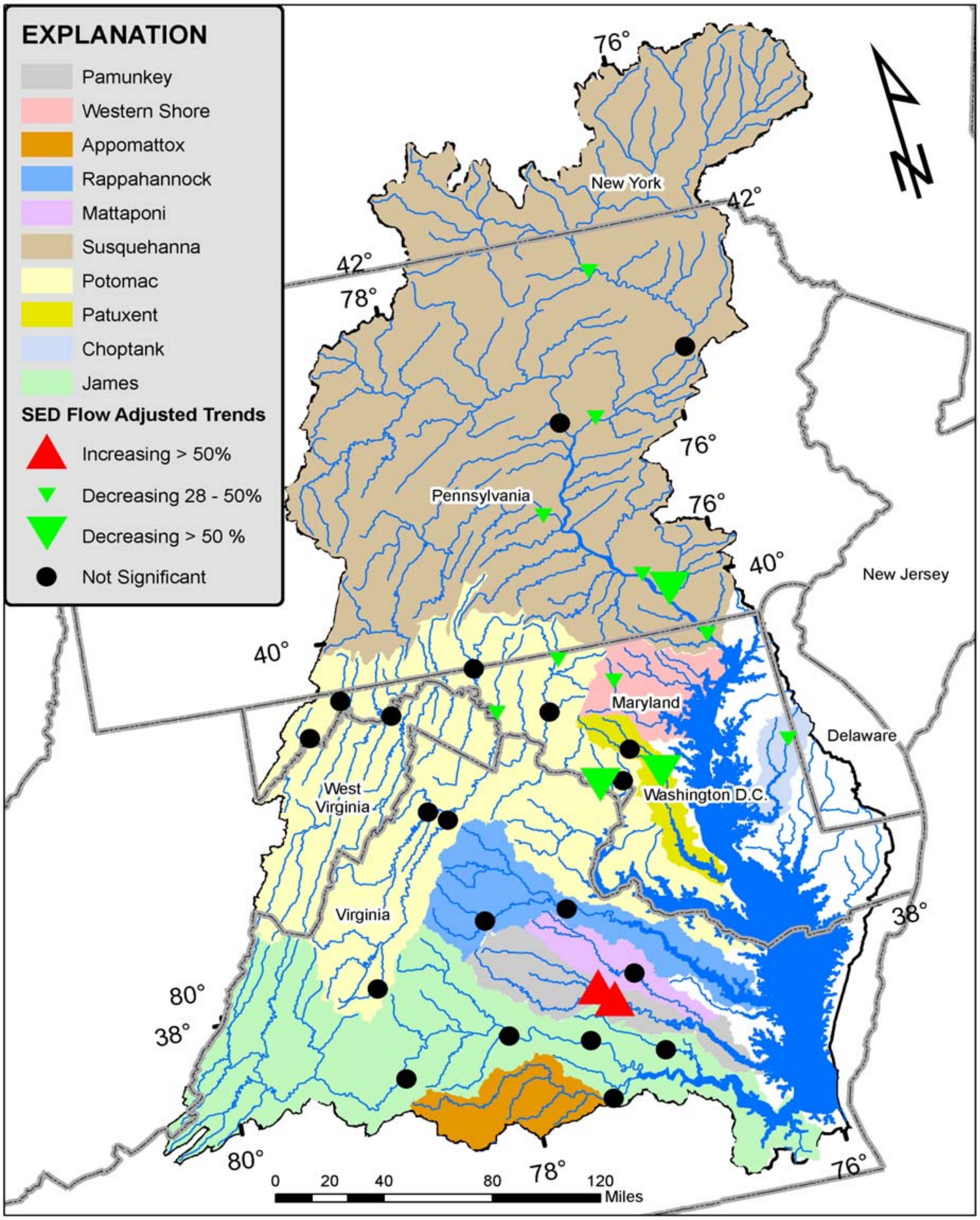


Figure 13. Flow-adjusted trend results for sediment (SED) at the 34 study sites in the Chesapeake Bay watershed.

Changes in Load

Nutrient and sediment loads have a large effect on the health of the Chesapeake Bay ecosystem and habitat in the rivers of the watershed. On the basis of the combined annual runoff from the RIM basins, annual flow was classified as “normal” in 2006 (fig. 3). However, all nine of the RIM Program sites experienced a decline in streamflow runoff in 2006 compared to 2005 (appendix 1). As a result, TN, TP, and SED loads for all constituents for the 9 RIM sites as well as the majority of the 25 basins were lower in 2006 than in 2005. Total estimated loads from all nine RIM sites for TN declined by nearly 34 Mlbs (million pounds) to 206 Mlbs (fig. 14A). Loads for TN are below the long-term average loads at eight of the nine RIM sites (appendix 10). The combined TP load from the 9 RIM sites was 8 Mlbs, a decrease of 4.5 Mlbs (fig. 14C), with 7 RIM sites below the long-term average load. The combined SED load was 5,000 Mlbs, a decrease of 2,100 Mlbs (fig. 5E) with 7 RIM sites below the long-term average load. Combined annual loads and streamflow also are presented for NOx (fig. 14B) and DIP (fig. 14D). The streamflow and loads at the RIM Program sites represent drainage from approximately 78 percent of the nontidal watershed.

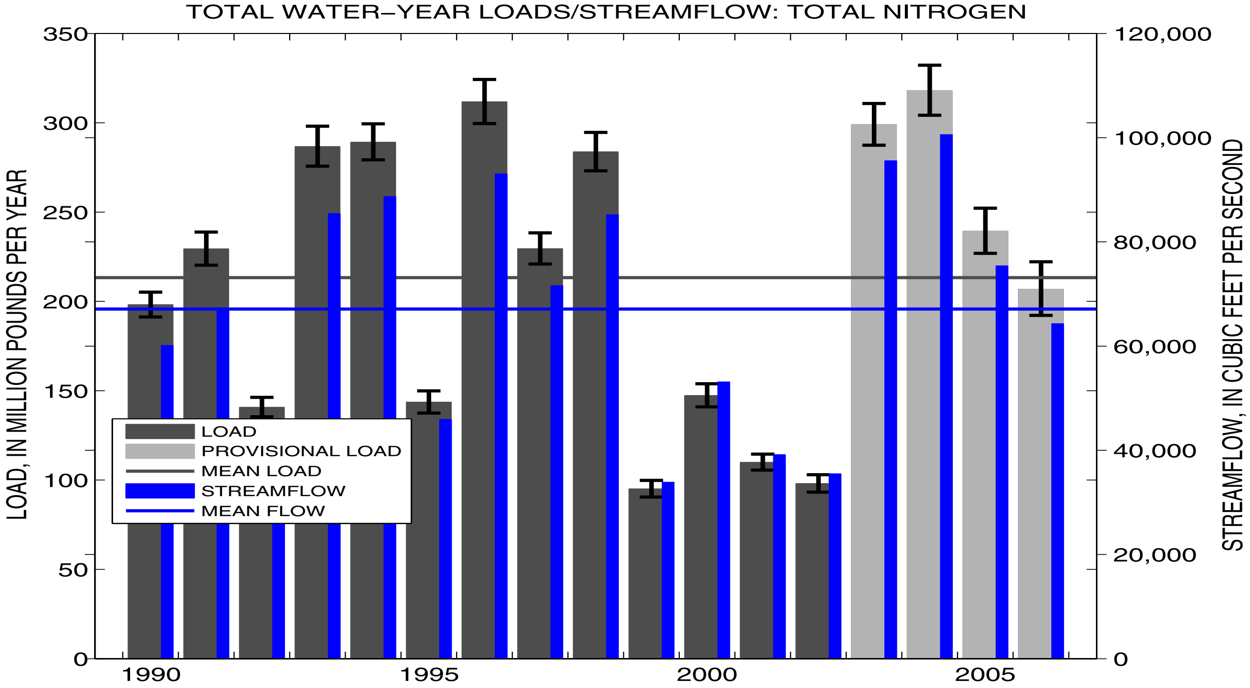


Figure 14A. Combined annual loads of total nitrogen with 95-percent confidence interval and streamflow for the nine River Input Monitoring Program sites, 1990-2006.

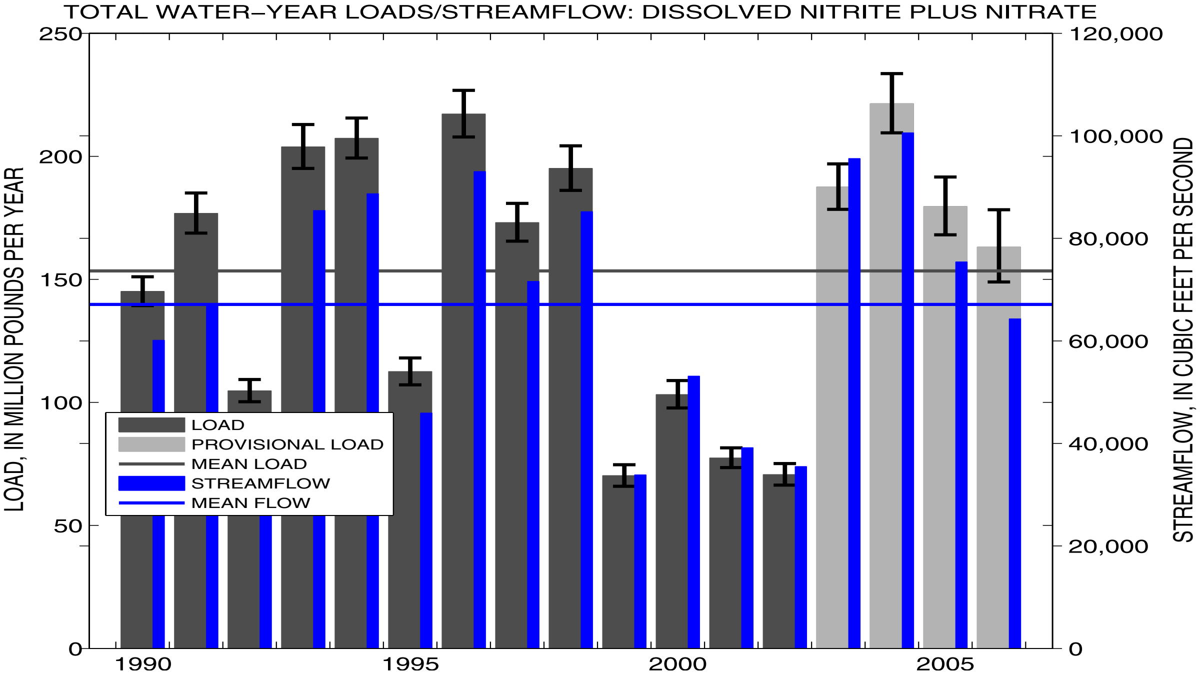


Figure 14B. Combined annual loads of total nitrate plus nitrate (NOx) with 95-percent confidence interval and streamflow for the nine River Input Monitoring Program sites, 1990-2006.

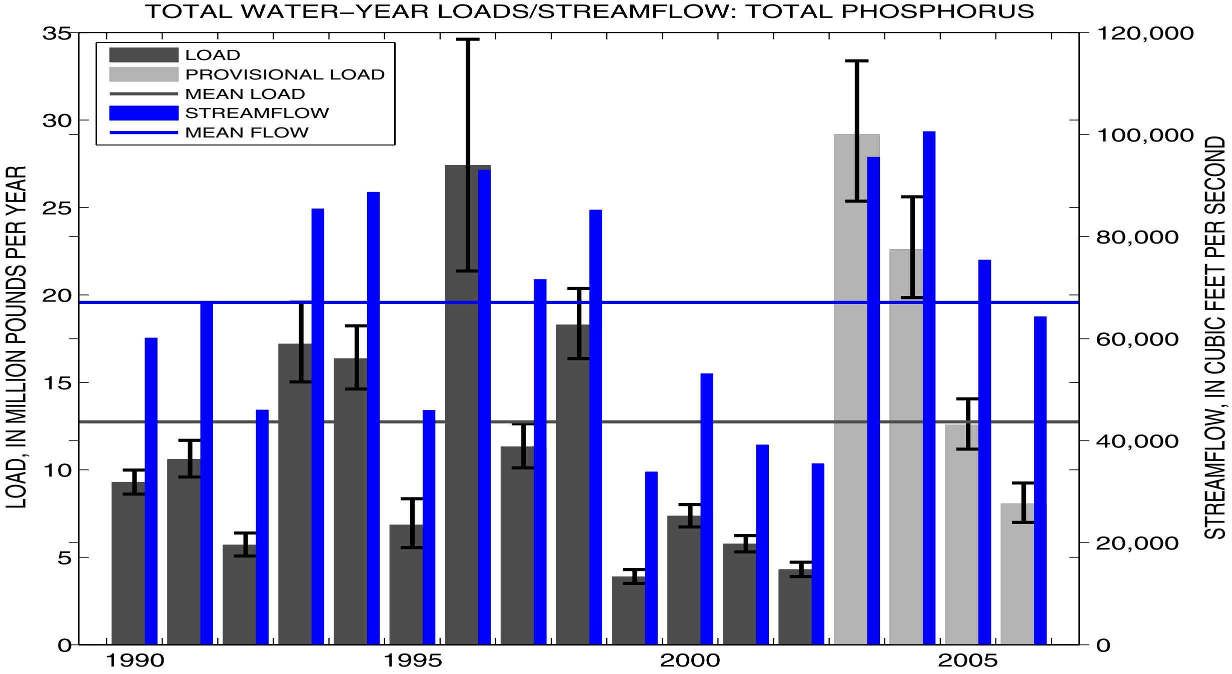


Figure 14C. Combined annual loads of total phosphorus with 95-percent confidence interval and streamflow for the nine River Input Monitoring Program sites, 1990-2006.

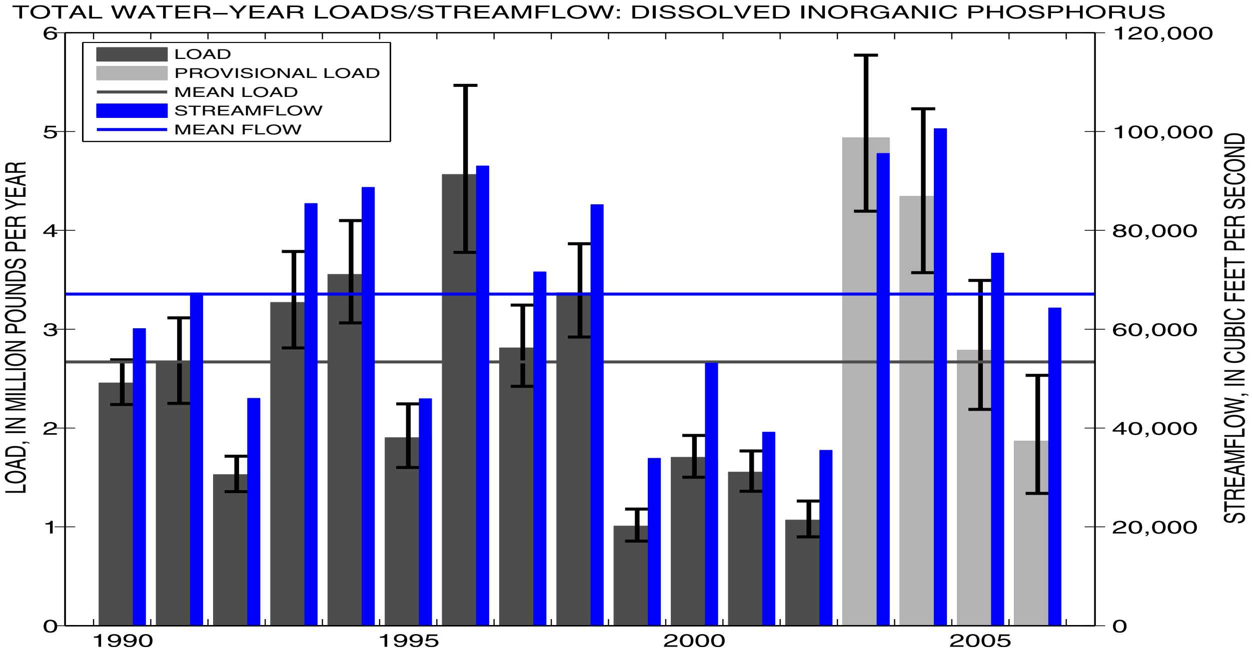


Figure 14D. Combined annual loads of dissolved inorganic phosphorus with 95-percent confidence interval and streamflow for the nine River Input Monitoring Program sites, 1990-2006.

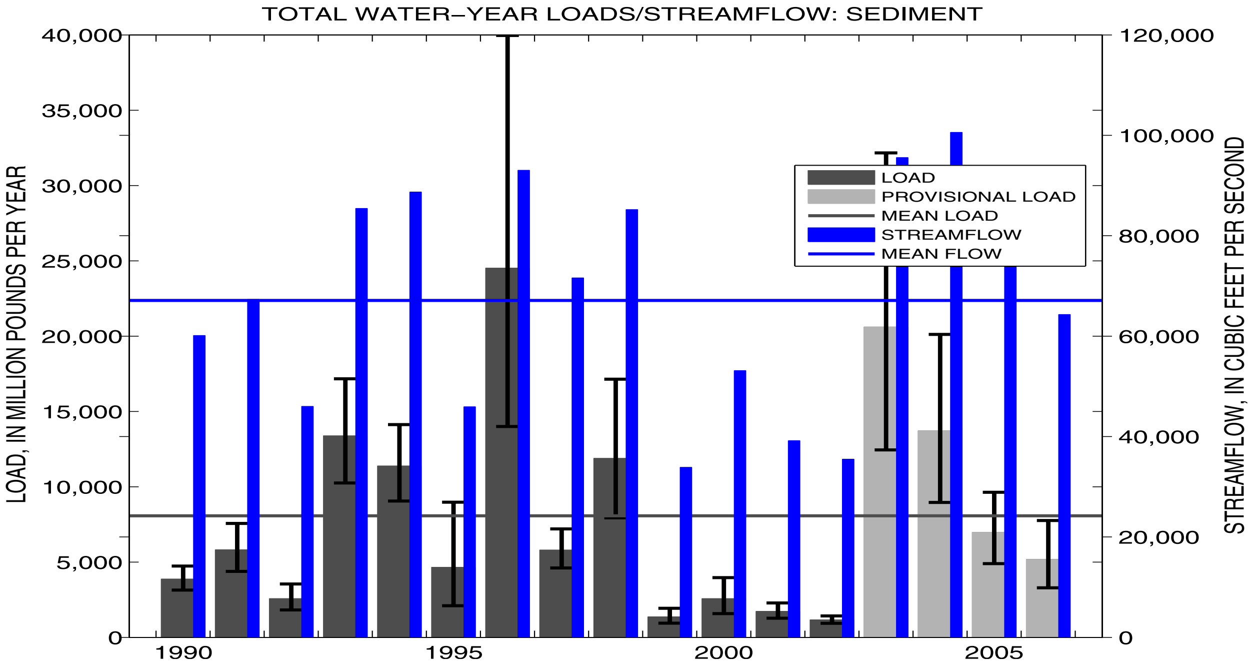


Figure 14E. Combined annual loads of sediment with 95-percent confidence interval and streamflow for the nine River Input Monitoring Program sites, 1990-2006.

Table 4. Summary results for flow, Spearman rho, non-flow-adjusted and flow-adjusted trend analysis for the 34 sites.

[Station number, USGS station identification number; Map ID, site number on Figure 1; Constituent Name, TN–total nitrogen; NOx–total or dissolved nitrite plus nitrate or nitrate TP–total phosphorus; DIP–dissolved inorganic phosphorus; SSC–suspended sediment; TSS–total suspended solids; NFA, non-flow-adjusted trend; FA, flow-adjusted trend; SIG-UP, significant upward trend; SIG-DOWN, significant downward trend; NS, no significant trend detected at the 0.05 significance level]

Station number	Station Name	Map ID	Constituent Name	Spearman rho	NFA trend in concentration	NFA trend in load	FA trend in concentration
01491000	Choptank River near Greensboro, Md.	9	TN	NS	NS	NS	NS
01491000	Choptank River near Greensboro, Md.	9	NOx	**SIG-UP**	NS	**SIG-UP**	**SIG-UP**
01491000	Choptank River near Greensboro, Md.	9	TP	NS	**SIG-UP**	**SIG-UP**	**SIG-UP**
01491000	Choptank River near Greensboro, Md.	9	DIP	NS	NS	**SIG-UP**	NS
01491000	Choptank River near Greensboro, Md.	9	SSC	NS	NS	NS	**SIG-DOWN**
01531500	SUSQUEHANNA RIVER AT TOWANDA, PA	1	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01531500	SUSQUEHANNA RIVER AT TOWANDA, PA	1	NOx	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01531500	SUSQUEHANNA RIVER AT TOWANDA, PA	1	TP	NS	NS	NS	**SIG-DOWN**
01531500	SUSQUEHANNA RIVER AT TOWANDA, PA	1	DIP	**SIG-UP**	**SIG-UP**	**SIG-UP**	**SIG-UP**
01531500	SUSQUEHANNA RIVER AT TOWANDA, PA	1	SSC	NS	NS	NS	**SIG-DOWN**
01536500	SUSQUEHANNA RIVER AT WILKES-BARRE, PA	2	TSS	NS	NS	NS	NS
01536500	SUSQUEHANNA RIVER AT WILKES-BARRE, PA	2	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01536500	SUSQUEHANNA RIVER AT WILKES-BARRE, PA	2	NOx	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01536500	SUSQUEHANNA RIVER AT WILKES-BARRE, PA	2	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01540500	SUSQUEHANNA RIVER AT DANVILLE, PA	3	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01540500	SUSQUEHANNA RIVER AT DANVILLE, PA	3	NOx	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01540500	SUSQUEHANNA RIVER AT DANVILLE, PA	3	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01540500	SUSQUEHANNA RIVER AT DANVILLE, PA	3	DIP	**SIG-UP**	**SIG-UP**	**SIG-UP**	**SIG-UP**
01540500	SUSQUEHANNA RIVER AT DANVILLE, PA	3	SSC	NS	NS	NS	**SIG-DOWN**
01553500	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	4	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01553500	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	4	NOx	NS	NS	NS	**SIG-DOWN**
01553500	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	4	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01553500	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	4	DIP	**SIG-UP**	**SIG-UP**	**SIG-UP**	**SIG-UP**
01553500	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	4	SSC	NS	NS	NS	NS
01567000	JUNIATA RIVER AT NEWPORT, PA	5	TN	NS	NS	NS	**SIG-DOWN**
01567000	JUNIATA RIVER AT NEWPORT, PA	5	NOx	NS	**SIG-UP**	NS	**SIG-UP**
01567000	JUNIATA RIVER AT NEWPORT, PA	5	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01567000	JUNIATA RIVER AT NEWPORT, PA	5	DIP	**SIG-UP**	**SIG-UP**	**SIG-UP**	**SIG-UP**
01567000	JUNIATA RIVER AT NEWPORT, PA	5	SSC	NS	NS	NS	**SIG-DOWN**
01576000	SUSQUEHANNA RIVER AT MARIETTA, PA	6	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01576000	SUSQUEHANNA RIVER AT MARIETTA, PA	6	NOx	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01576000	SUSQUEHANNA RIVER AT MARIETTA, PA	6	TP	NS	NS	NS	**SIG-DOWN**
01576000	SUSQUEHANNA RIVER AT MARIETTA, PA	6	DIP	**SIG-UP**	**SIG-UP**	**SIG-UP**	**SIG-UP**
01576000	SUSQUEHANNA RIVER AT MARIETTA, PA	6	SSC	NS	NS	NS	**SIG-DOWN**

01576754	CONESTOGA RIVER AT CONESTOGA, PA	7	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01576754	CONESTOGA RIVER AT CONESTOGA, PA	7	NOx	NS	NS	NS	NS
01576754	CONESTOGA RIVER AT CONESTOGA, PA	7	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01576754	CONESTOGA RIVER AT CONESTOGA, PA	7	DIP	NS	NS	NS	**SIG-DOWN**
01576754	CONESTOGA RIVER AT CONESTOGA, PA	7	SSC	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01578310	Susquehanna River at Conowingo, MD	8	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01578310	Susquehanna River at Conowingo, MD	8	NOx	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01578310	Susquehanna River at Conowingo, MD	8	TP	NS	NS	NS	**SIG-DOWN**
01578310	Susquehanna River at Conowingo, MD	8	DIP	NS	**SIG-UP**	**SIG-UP**	**SIG-UP**
01578310	Susquehanna River at Conowingo, MD	8	SSC	**SIG-DOWN**	NS	NS	**SIG-DOWN**
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	10	TSS	NS	NS	NS	**SIG-DOWN**
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	10	TN	NS	NS	NS	**SIG-UP**
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	10	NOX	NS	**SIG-UP**	NS	**SIG-UP**
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	10	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	10	DIP	NS	NS	NS	NS
01592500	PATUXENT RIVER NEAR LAUREL, MD	11	TSS	NS	NS	NS	NS
01592500	PATUXENT RIVER NEAR LAUREL, MD	11	TN	NS	NS	NS	NS
01592500	PATUXENT RIVER NEAR LAUREL, MD	11	NOX	NS	NS	NS	NS
01592500	PATUXENT RIVER NEAR LAUREL, MD	11	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01592500	PATUXENT RIVER NEAR LAUREL, MD	11	DIP	NS	NS	NS	NS
01594440	Patuxent River at Bowie, MD	12	TN	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01594440	Patuxent River at Bowie, MD	12	NOX	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01594440	Patuxent River at Bowie, MD	12	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01594440	Patuxent River at Bowie, MD	12	DIP	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01594440	Patuxent River at Bowie, MD	12	SSC	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01599000	GEORGES CREEK AT FRANKLIN, MD	13	TSS	NS	NS	NS	NS
01599000	GEORGES CREEK AT FRANKLIN, MD	13	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01599000	GEORGES CREEK AT FRANKLIN, MD	13	NOX	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01599000	GEORGES CREEK AT FRANKLIN, MD	13	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01599000	GEORGES CREEK AT FRANKLIN, MD	13	DIP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01601500	WILLS CREEK NEAR CUMBERLAND, MD	14	TSS	NS	NS	NS	NS
01601500	WILLS CREEK NEAR CUMBERLAND, MD	14	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01601500	WILLS CREEK NEAR CUMBERLAND, MD	14	NOX	NS	NS	NS	NS
01601500	WILLS CREEK NEAR CUMBERLAND, MD	14	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01601500	WILLS CREEK NEAR CUMBERLAND, MD	14	DIP	NS	**SIG-UP**	NS	**SIG-UP**
01610000	POTOMAC RIVER AT PAW PAW, WV	15	TSS	NS	NS	NS	NS
01610000	POTOMAC RIVER AT PAW PAW, WV	15	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01610000	POTOMAC RIVER AT PAW PAW, WV	15	NOX	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01610000	POTOMAC RIVER AT PAW PAW, WV	15	TP	NS	NS	NS	NS
01610000	POTOMAC RIVER AT PAW PAW, WV	15	DIP	NS	**SIG-UP**	NS	NS
01614500	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	16	TSS	NS	NS	NS	NS
01614500	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	16	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**

01614500	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	16	NOX	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01614500	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	16	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01614500	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	16	DIP	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	17	TSS	NS	NS	NS	**SIG-DOWN**
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	17	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	17	NOX	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	17	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	17	DIP	NS	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01626000	SOUTH RIVER NEAR WAYNESBORO, VA	18	TSS	NS	NS	NS	NS
01626000	SOUTH RIVER NEAR WAYNESBORO, VA	18	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01626000	SOUTH RIVER NEAR WAYNESBORO, VA	18	NOX	NS	NS	NS	NS
01626000	SOUTH RIVER NEAR WAYNESBORO, VA	18	TP	NS	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	19	TSS	NS	NS	NS	NS
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	19	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	19	NOX	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	19	TP	**SIG-DOWN**	NS	NS	NS
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	19	DIP	NS	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	20	TSS	NS	NS	NS	NS
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	20	TN	NS	**SIG-UP**	NS	**SIG-UP**
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	20	NOX	NS	**SIG-UP**	**SIG-UP**	**SIG-UP**
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	20	TP	NS	**SIG-UP**	**SIG-UP**	**SIG-UP**
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	20	DIP	NS	**SIG-UP**	**SIG-UP**	**SIG-UP**
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	21	TSS	NS	NS	NS	**SIG-DOWN**
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	21	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	21	TNO3	NS	NS	NS	NS
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	21	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	21	DIP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	22	TSS	NS	NS	NS	NS
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	22	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	22	TNO3	NS	NS	NS	NS
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	22	TP	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	22	DIP	NS	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01646580	Potomac River at Chain Bridge, MD	23	TN	NS	NS	NS	**SIG-DOWN**
01646580	Potomac River at Chain Bridge, MD	23	NOX	NS	NS	NS	**SIG-DOWN**
01646580	Potomac River at Chain Bridge, MD	23	TP	NS	NS	NS	**SIG-UP**
01646580	Potomac River at Chain Bridge, MD	23	DIP	NS	NS	NS	NS
01646580	Potomac River at Chain Bridge, MD	23	SSC	NS	NS	NS	**SIG-DOWN**
01651000	NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	24	TSS	NS	NS	NS	NS
01651000	NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	24	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01651000	NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	24	TNO3	NS	NS	NS	NS
01651000	NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	24	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
01651000	NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	24	DIP	NS	NS	NS	**SIG-DOWN**

01666500	ROBINSON RIVER NEAR LOCUST DALE, VA	25	TSS	NS	NS	NS	NS
01666500	ROBINSON RIVER NEAR LOCUST DALE, VA	25	TN	NS	NS	NS	**SIG-DOWN**
01666500	ROBINSON RIVER NEAR LOCUST DALE, VA	25	NOX	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01666500	ROBINSON RIVER NEAR LOCUST DALE, VA	25	TP	NS	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	26	TSS	NS	NS	NS	NS
01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	26	TN	NS	NS	NS	**SIG-DOWN**
01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	26	NOX	NS	NS	NS	**SIG-DOWN**
01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	26	TP	NS	NS	NS	**SIG-DOWN**
01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	26	DIP	NS	NS	NS	**SIG-DOWN**
01671020	NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	TSS	NS	NS	NS	**SIG-UP**
01671020	NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	TN	NS	NS	NS	**SIG-UP**
01671020	NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	TNO3	NS	NS	NS	NS
01671020	NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	TP	NS	NS	NS	NS
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	28	TSS	NS	NS	NS	**SIG-UP**
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	28	TN	NS	**SIG-UP**	NS	**SIG-UP**
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	28	NOX	**SIG-UP**	**SIG-UP**	NS	**SIG-UP**
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	28	TP	**SIG-UP**	**SIG-UP**	NS	**SIG-UP**
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	28	DIP	NS	**SIG-UP**	**SIG-UP**	**SIG-UP**
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	29	TSS	NS	NS	NS	NS
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	29	TN	NS	**SIG-DOWN**	NS	**SIG-DOWN**
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	29	NOX	NS	**SIG-DOWN**	NS	NS
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	29	TP	NS	NS	NS	NS
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	29	DIP	NS	NS	NS	**SIG-DOWN**
02026000	JAMES RIVER AT BENT CREEK, VA	30	TSS	NS	NS	NS	NS
02026000	JAMES RIVER AT BENT CREEK, VA	30	TN	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
02026000	JAMES RIVER AT BENT CREEK, VA	30	TNO3	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
02026000	JAMES RIVER AT BENT CREEK, VA	30	TP	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
02035000	JAMES RIVER AT CARTERSVILLE, VA	31	TSS	**SIG-DOWN**	NS	NS	NS
02035000	JAMES RIVER AT CARTERSVILLE, VA	31	TN	**SIG-DOWN**	NS	NS	**SIG-DOWN**
02035000	JAMES RIVER AT CARTERSVILLE, VA	31	NOX	NS	**SIG-DOWN**	NS	**SIG-DOWN**
02035000	JAMES RIVER AT CARTERSVILLE, VA	31	TP	**SIG-DOWN**	**SIG-DOWN**	NS	**SIG-DOWN**
02035000	JAMES RIVER AT CARTERSVILLE, VA	31	DIP	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**	**SIG-DOWN**
02037500	JAMES RIVER NEAR RICHMOND, VA	32	TSS	NS	NS	NS	NS
02037500	JAMES RIVER NEAR RICHMOND, VA	32	TN	NS	NS	NS	NS
02037500	JAMES RIVER NEAR RICHMOND, VA	32	TNO3	NS	NS	NS	NS
02037500	JAMES RIVER NEAR RICHMOND, VA	32	TP	NS	NS	NS	NS
02041650	APPOMATTOX RIVER AT MATOACA, VA	33	TSS	NS	NS	NS	NS
02041650	APPOMATTOX RIVER AT MATOACA, VA	33	TN	NS	NS	NS	NS
02041650	APPOMATTOX RIVER AT MATOACA, VA	33	NOX	NS	NS	NS	NS
02041650	APPOMATTOX RIVER AT MATOACA, VA	33	TP	NS	NS	NS	**SIG-UP**
02041650	APPOMATTOX RIVER AT MATOACA, VA	33	DIP	NS	NS	NS	NS
02042500	CHICHIMOMINY RIVER NEAR PROVIDENCE FORGE, VA	34	TSS	**SIG-DOWN**	NS	NS	NS

02042500	CHICHIMOMINY RIVER NEAR PROVIDENCE FORGE, VA	34	TN	**SIG-DOWN**	NS	NS	NS
02042500	CHICHIMOMINY RIVER NEAR PROVIDENCE FORGE, VA	34	TNO3	NS	NS	NS	NS
02042500	CHICHIMOMINY RIVER NEAR PROVIDENCE FORGE, VA	34	TP	NS	NS	NS	**SIG-UP**

Summary and Conclusions

Nutrient and sediment data from 34 sites in nontidal parts of selected streams in the Chesapeake Bay watershed were analyzed to document changes in streamflow and in concentrations and loads of nutrients and sediment from 1985 through 2006, as part of an annual update of water-quality conditions for the Chesapeake Bay Program. Changes in seasonal and annual flow, annual nutrient and sediment concentration and load, and flow-weighted concentration were evaluated. Concentration percentiles and mean concentration were corrected for bias due to targeted flow- sampling regimes. Flow-adjusted and non-flow-adjusted trends in concentration in addition to trends in loads were estimated by use of the U.S. Geological Survey ESTIMATOR model. Flow-adjusted trends were estimated to help assess changes that result from human activities and resource-management actions.

Estimated total freshwater flow to the bay in 2006 was approximately 78,650 ft^3/s or (18.5 trillion gallons). This is less than 1 percent greater than the long-term annual mean from 1937 to 2005 of 78,600 ft^3/s. Total freshwater flow entering the bay for the 2006 water year was below normal for the spring (April-May-June) season and above normal for the summer (July-August-September) season. Trend analyses for streamflow data for 1985 through 2006 revealed significant upward trends at 2 of the 34 sites.

For all 34 sites, higher ranges in concentrations of total nitrogen and total phosphorus were observed in the northern bay basins (Pennsylvania, Maryland, and northern Virginia) than in the southern bay basins (remainder of bay drainage in Virginia). Concentrations of total sediment were comparable across the watershed. The Conestoga River at Conestoga, Pa., exhibited the greatest concentrations of total nitrogen, nitrate, and sediment for all estimated percentiles (10th, 25th, 50th, 75th, and 90th). For all constituents, annual means for 2006 decreased from the means of the previous 3 years at nearly all River Input Monitoring Programs sites. Samples were collected during high-flow events in addition to scheduled monthly sampling. With this flow bias corrected, results from the Spearman rho analysis indicate that for the nine River Input Monitoring Program sites, downward trends in observed concentrations for total nitrogen, total phosphorus, and sediment were identified at three, two, and one sites, respectively, and one site showed an upward trend in total phosphorus.

Loads for nearly all constituents at all nine River Input Monitoring Program sites were lower in 2006 than in 2005. For the major nutrients and sediments of concern, the combined RIM estimated loads of total nitrogen declined by nearly 34 Mlbs (million pounds) to 206 Mlbs; total phosphorus load was 8 Mlbs, a decrease of 4.5 Mlbs; and sediment load was 5,000 Mlbs, a decrease of 2,100 Mlbs. On the basis of the annual runoff from the nine River Input Monitoring Program basins, annual flow was classified as "normal" in 2006 at all nine sites. The loads for total nitrogen to be below the long-term average loads at eight of the nine River Input Monitoring Program sites; for total phosphorus and sediment loads, seven sites were below the long-term average load.

Combined annual mean flow-weighted concentrations of total nitrogen from the nine River Input Monitoring Program sites were lower in 2006 than in 2005 and at eight of the nine basins, and were higher only in the James River Basin. The combined mean flow-weighted concentration was 3.5 mg/L for 1990-2006 (the time period for which all nine River Input Monitoring Program sites were sampled). Flow-weighted concentrations for total nitrogen were higher and generally decreasing at the northern bay basin sites and were lower and more constant at the southern sites (Rappahannock, Pamunkey, Mattaponi, James, and Appomattox). Flow-weighted concentrations for total nitrogen ranged from a high of 4.26 mg/L at the Patuxent site in 1988 to a low of 0.51 mg/L at the Mattaponi site in 1999. From 1990 through 2005, the combined flow-weighted concentration for total phosphorus averaged about 0.19 mg/L for the River Monitoring Program sites and ranged from a high of 0.33 mg/L in 2003 to a low of 0.13 mg/L in 1999. A general decline in flow-weighted concentrations for total phosphorus was reversed in 2003, when concentrations significantly increased, then declined in 2004 through 2006. The highest annual mean flow-weighted concentration for total phosphorus (0.45 mg/L) was in the Rappahannock River in 1995; total phosphorus also had the highest long-term annual mean flow-weighted concentration of 0.22 mg/L in this river. Conversely, the lowest flow-weighted concentration for total phosphorus (0.03 mg/L) was in the Susquehanna River in 1995; total phosphorus also had the lowest long-term annual mean flow-weighted concentration in this river (0.05 mg/L). The lower values in the Susquehanna River were most likely because of phosphorus and sediment trapped behind three large reservoirs in the lower reaches of the river. The highest and lowest combined flow-weighted concentration for sediment (294 mg/L and 37 mg/L) did not correspond to the high and low flow years. The combined average mean flow-weighted concentration for sediment during 1990-2006 was 115 mg/L as measured at the River Input Monitoring Program sites. The highest mean annual flow-weighted concentration for sediment during 1990-2005 was in the Rappahannock River (586 mg/L in 1995), which also had the highest long-term annual mean (244 mg/L). The lowest annual mean flow-weighted concentration was in the Choptank River (5.7 mg/L in 2002), and the lowest long-term mean flow-weighted concentration was in the Pamunkey River (9.7 mg/L).

When the influences of flow and seasonality are removed, results for trends adjusted for flow indicate improvement in water quality. Flow-adjusted concentration results for total nitrogen indicate downward trends at 25 of the 34 sites sampled (74 percent). Eight sites in the Susquehanna River Basins, 11 sites in the Potomac River Basins and five sites in the lower (southern) Virginia basins had significant downward trends in total nitrogen over the study period. One site had a downward trend greater than 50 percent; no sites had upward trends greater than 50 percent. Trends in total nitrogen were downward at five River Input Monitoring Program sites.

Flow-adjusted trends for total phosphorus were significant and downward at 23 of the 34 sites (68 percent) and upward at 6 sites. Trends in total phosphorus were downward at four River Input Monitoring Program sites, and downward flow-adjusted trends in total phosphorus were identified in six of the ten major bay drainage basins. Flow-adjusted trends in total phosphorus were upward at six sites, four of which are River Input Monitoring Program sites. Eight sites in the Susquehanna and Potomac River Basin and four sites in the lower Virginia basins had downward trends. Six sites had downward total phosphorus flow-adjusted trends greater than 50 percent, and 2 sites had an upward trend greater than 50 percent.

Significant downward flow-adjusted trends for sediment were identified at 11 of the 34 sites (32 percent). Upward trends were identified at two sites. The Maryland River Input Monitoring Program sites had four downward trends (Choptank, Susquehanna, Patuxent, and Potomac), and the Virginia River Input Monitoring Program sites had one upward flow-adjusted trend (Pamunkey) and four with no statistically significant trend in sediment. In the Susquehanna River Basin, downward trends were identified at six of eight sites. In the lower (southern) Virginia river basins, no sites had a downward trend; two sites had upward trends, and eight sites did not have statistically significant trends. In addition, three sites had downward sediment flow-adjusted trends greater than 50 percent, and two sites had upward trends greater than 50 percent.

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Appendixes

Appendix 1. Annual and seasonal flow variations for the River Input Monitoring and 25 Multi-Agency Nontidal Monitoring Program stations.

(see example in text, figure 3.)

Appendix 2. Observed concentrations for the 9 River Input Monitoring Program sites and the 25 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2006.

Appendix 3. Concentration percentiles and Spearman rho for the 9 River Input Monitoring Program sites and the 25 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2006.

Appendix 4. Bias-corrected distribution and mean of observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment for the 25 Multi-Agency Nontidal Monitoring Program sites, Chesapeake Bay watershed, 1985-2006.

(see example in text, figure 4.)

Appendix 5. Non-flow-adjusted trends in concentration for the 9 River Input Monitoring Program sites and 25 Multi-Agency Nontidal Monitoring Program sites, 1985-2006

Appendix 6. Non-flow-adjusted trends in load for the 9 River Input Monitoring Program Sites and 25 Multi-Agency Nontidal Monitoring Program sites, 1985-2006

Appendix 7. Four-panel plots used to display non-flow-adjusted trend results for 9 River Input Monitoring Program sites and the 25 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2006.

Upper left shows the "raw" sample concentration data, upper right shows annual and mean loads and streamflow lower left shows the continuous non-linear trend for non-flow adjusted concentrations, and lower right shows linear trend for non-flow-adjusted trend in load.

(see example in text, figure 2)

Appendix 8. Flow-adjusted trends in concentration for the 9 River Input Monitoring Program Sites and 25 Multi-Agency Nontidal Monitoring Program sites, 1985-2006

Appendix 9. Flow-adjusted trend plots for the 9 River Input Monitoring Program Sites and 25 Multi-Agency Nontidal Monitoring Program sites, 1985-2006.

(see example in text, figure 2.)

Appendix 10. Graphs showing annual loads, annual-mean streamflow, mean annual load, and annual-mean streamflow for the 9 River Input Monitoring Program sites and the 25 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2006.

(see example in text, figure 14)