Changes in Streamflow and Water Quality in Selected Nontidal Basins in the Chesapeake Bay Watershed, 1985-2004

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Conversion Factors

Multiply	By	To obtain
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
million pounds, avoirdupois (Mlbs)	0.4536	kilogram
ton per year (ton/yr)	0.9072	metric ton per year

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

Abbreviations and Acronyms

CBP	Chesapeake Bay Program
DIP	dissolved inorganic phosphorus
FWC	flow-weighted concentration
MD DNR	Maryland Department of Natural Resources
MWCOG	Metropolitan Washington Council of Governments
NO23	nitrite plus nitrate
NWIS	National Water Information System
PPCC	probability plot correlation coefficient
RIM	River Input Monitoring Program
SCR	serial correlation of residuals
SED	suspended sediment
SIG-DOWN	significantly downward trend
SIG-UP	significantly upward trend
SRBC	Susquehanna River Basin Commission
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
USGS	U.S. Geological Survey
VA DNR	Virginia Department of Natural Resources
<	less than
>	greater than

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Abstract

As part of an annual evaluation of water-quality conditions by the Chesapeake Bay Program, water-quality and streamflow data from 32 sites in nontidal parts of the Chesapeake Bay watershed were analyzed to document annual nutrient and sediment trends for 1985 through 2004. This study also formalized different trend tests and methodologies used in assessing the effectiveness of management actions in reducing nutrients and sediments to the Chesapeake Bay. Trends in streamflow were tested at multiple time scales (daily, seasonal, and annual), resulting in only one significant trend (annual-mean streamflow for the Choptank River near Greensboro, Md.). Total freshwater flow entering the bay for the July-August-September “summer” season 2004 was the highest ever estimated for that 3-month period (1937-2004). Observed (unbiased) concentration summaries indicate higher ranges in total-nitrogen concentrations in the northern major river basins, those in Pennsylvania, Maryland, and northern Virginia, compared to the more southern basins in Virginia. Almost half of the monitoring sites in the northern basins exhibited significant downward trends in total nitrogen with time. Comparisons with total phosphorus and sediment showed similar results to total nitrogen.

Monthly and annual loads were available for the River Input Monitoring Program sites from the U.S. Geological Survey. Although loads were significantly reduced from 2003, in 2004, the combined estimated total nitrogen loads were the third highest since 1990, whereas total phosphorus and sediment loads were the fifth highest. A flow-weighted concentration (FWC) is useful in evaluating changes through time. Combined annual mean total nitrogen FWC from the 9 River Input Monitoring Program sites indicated a downward tendency from 1985 through 1998 and an upward tendency since 2001. From 1990 to 2004, the mean concentrations of total nitrogen, total phosphorus, and sediment were 1.58, 0.085, and 51 milligrams per liter, respectively. Flow-weighted concentrations for phosphorus and sediment were lower in the Susquehanna River at Conowingo, Md., most likely due to the trapping efficiency of three large reservoirs upstream from the sampling point.

Trends in concentrations, not adjusted for flow, identified 10 statistically significant upward trends, and 50 statistically significant downward trends in concentration for the period 1985 through 2004. Trends in concentrations, when adjusted for flow, can be used as an indicator of human activity and management actions. The flow-adjusted trends indicated significant downward trends at approximately 72, 81, and 43 percent of the sites for total nitrogen, total phosphorus, and sediment, respectively. This indicates 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 of low dissolved-oxygen concentrations in the bay. Algal blooms and sediment block sunlight needed by underwater grasses. In the mid-1980s, the Chesapeake Bay Program (CBP), a partnership between 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 has developed water-quality criteria (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 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 first reported trends from the River Input Monitoring (RIM) Program sites using multivariate regression techniques developed by Cohn and others (1992), which are further explained in Darrell and others (1998). The trend technique attempts to adjust for the influences of streamflow and season (flow-adjusted trend) to help understand concentration trends related to management actions. Although this technique is useful in assessing the water-quality changes resulting primarily from management actions, results can not be appropriately compared to trends in the tidal waters, because those trends are not adjusted for flow and season. Therefore, the USGS developed additional trend approaches to aid in the comparison of tidal and nontidal data (Langland and others, 2000). These methods can be used to estimate trends in streamflow, load, and flow-weighted concentration.

The ongoing need to update trend estimates by use of these techniques has resulted in additional questions about the most appropriate techniques to use to (1) address changes in water quality that affect the ecosystem of the bay and its watershed, and (2) assess the influence of management actions to reduce nutrient and sediment concentrations. To evaluate the techniques needed to address these issues and to better explain the factors affecting the trends in the watershed, the USGS began a 3-year study in 2003 in partnership with the CBP, the Maryland Department of Natural Resources (MD DNR), and the Virginia Department of Environmental Quality (VA DEQ). One goal of the study is to evaluate and enhance existing trends techniques.

This report presents trends in streamflow, load, and observed concentrations, as well as flow-adjusted trends, of nutrients and sediment from 32 sites from 1985 to 2004. The report also presents the results of continued evaluation of techniques to describe changes in streamflow, concentrations, and loads in the Chesapeake Bay watershed. In addition, results from all current evaluations for all sites are presented in the appendixes at the end of the report.

Methods of Study

This section includes (1) a discussion of how data sets used to assess streamflow and water quality were constructed and (2) a description and evaluation of the methods used to analyze the data sets for streamflow and water quality. Additionally, the results of an evaluation of the trend techniques reported in Langland and others (2004) with additional new trends in observed concentration and load are presented. The trend methods, issues, and results of the evaluation are discussed in more detail and summarized at the end of this section.

Data-Set Construction

The USGS maintains and annually updates a “nontidal database” containing selected water-quality and biological data from approximately 1,320 sites in the Chesapeake Bay watershed. The database comprises water-quality and streamflow data from sites with a minimum of 3 consecutive years of sampling from 1972 through 2004. Although many sites are sampled on a routine (usually monthly) basis, many of these sites do not have a continuous streamflow record, which is necessary to compute annual loads. Water-quality data are updated annually at 30-35 sites, and are updated about every 3-4 years 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 have been organized 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 32 sites with long-term (15-20 years) water-quality and streamflow data are used to determine annual and seasonal changes in streamflow concentrations and to estimate long-term trends. As part of the RIM Program, water-quality and streamflow data at 9 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. Trend calculations were completed at 23 of these sites (fig. 1) by the USGS in cooperation with the MD DNR, VA DEQ, the Metropolitan Washington Council of Governments (MWCOG), and the Susquehanna River Basin Commission (SRBC). The 32 sites selected for analysis are slightly different from previous years. These sites are part of a nontidal water-quality monitoring network, designed by the Nontidal Workgroup, part of the Chesapeake Bay Program (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 32 sites analyzed as part of this study is listed in table 1.

A total of 42 physical, biological, and chemical water-quality constituents are stored in the nontidal database. These constituents include 14 nutrient species, suspended sediment (SED), and total suspended solids (TSS). 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 provided the input data files to estimate trends. Concentration data were quality-assured using a statistical program that identified suspect remark codes (such as less than detection), missing dates, and (or) missing times associated with the sample before they were added to the database. In addition, statistical tests and visual examination of the raw data and model residuals were made before and during their use in the various trend analysis programs.

The species (forms) of nitrogen, phosphorus, and sediment evaluated for trends are shown in table 2. Due to 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.

Records were missing for some water-quality constituents. Where possible, values for these 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. Missing constituent values were estimated only for the input data files used to estimate 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, then the estimate was reported as less than one-half the combined minimum reporting limit.

The optimum period for reporting trend results for this study began in January 1985 and ended in December 2004. 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. Trends were estimated on data sets for any period of 10 years or more starting between January 1985 and January 1989, and continuing through December 2004.

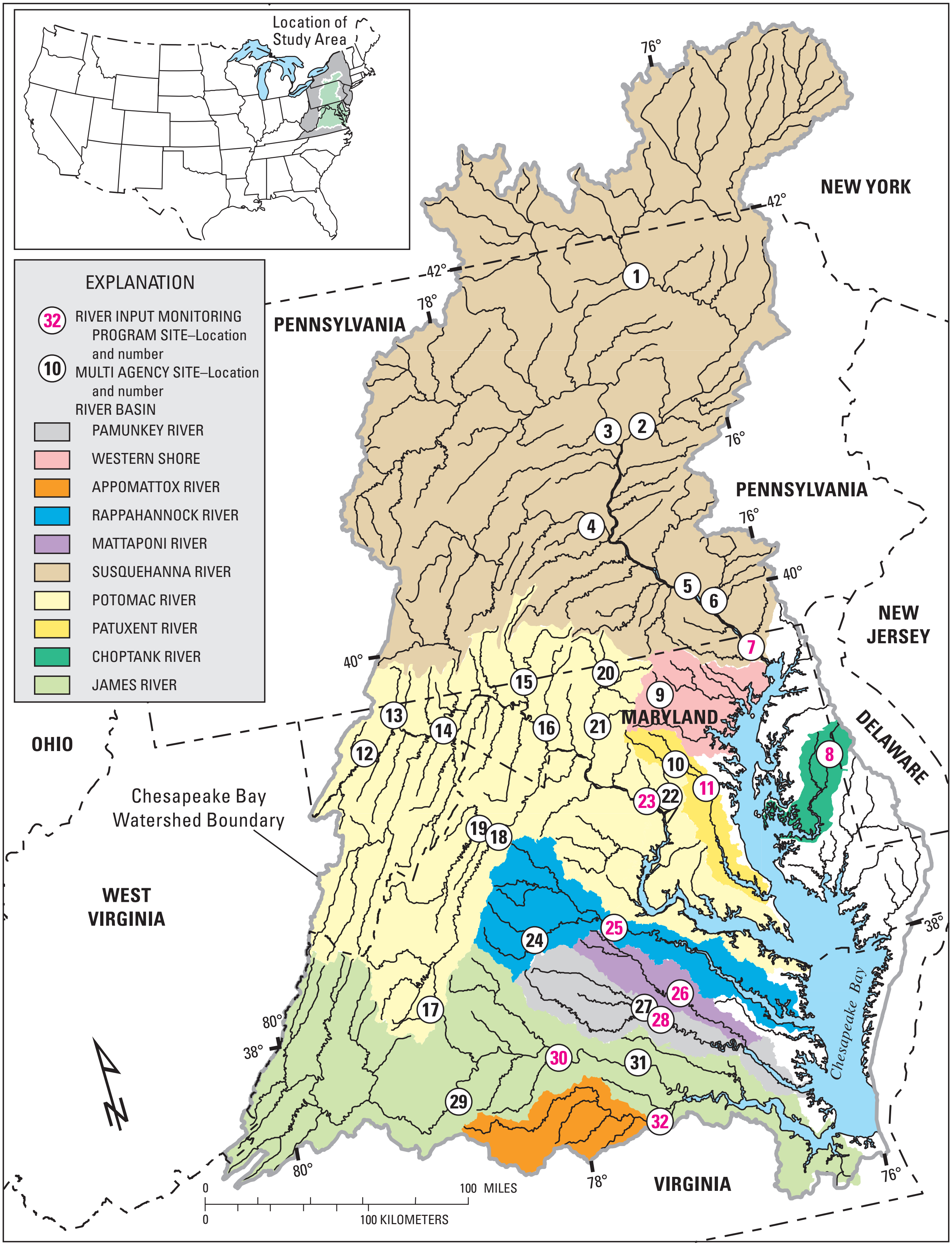

Figure 1A. Locations of the 32 sites in the Chesapeake Bay watershed used in the study. Numbers indicate site identification numbers; red numbers indicate the River Input Monitoring Program sites.

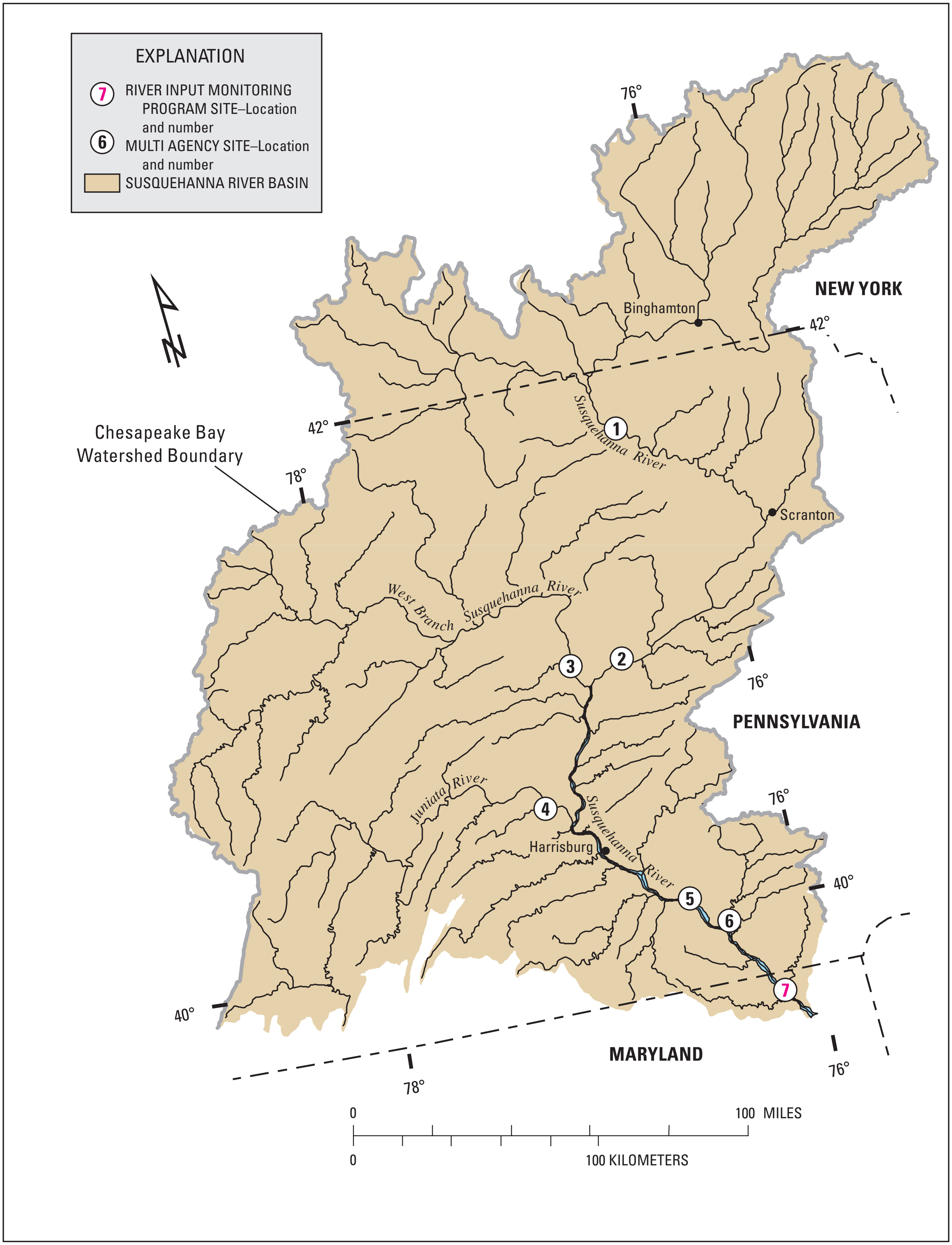

Figure 1B. Locations of the 32 sites in the Chesapeake Bay watershed used in the study. Numbers indicate site identification numbers; red numbers indicate the River Input Monitoring Program sites.

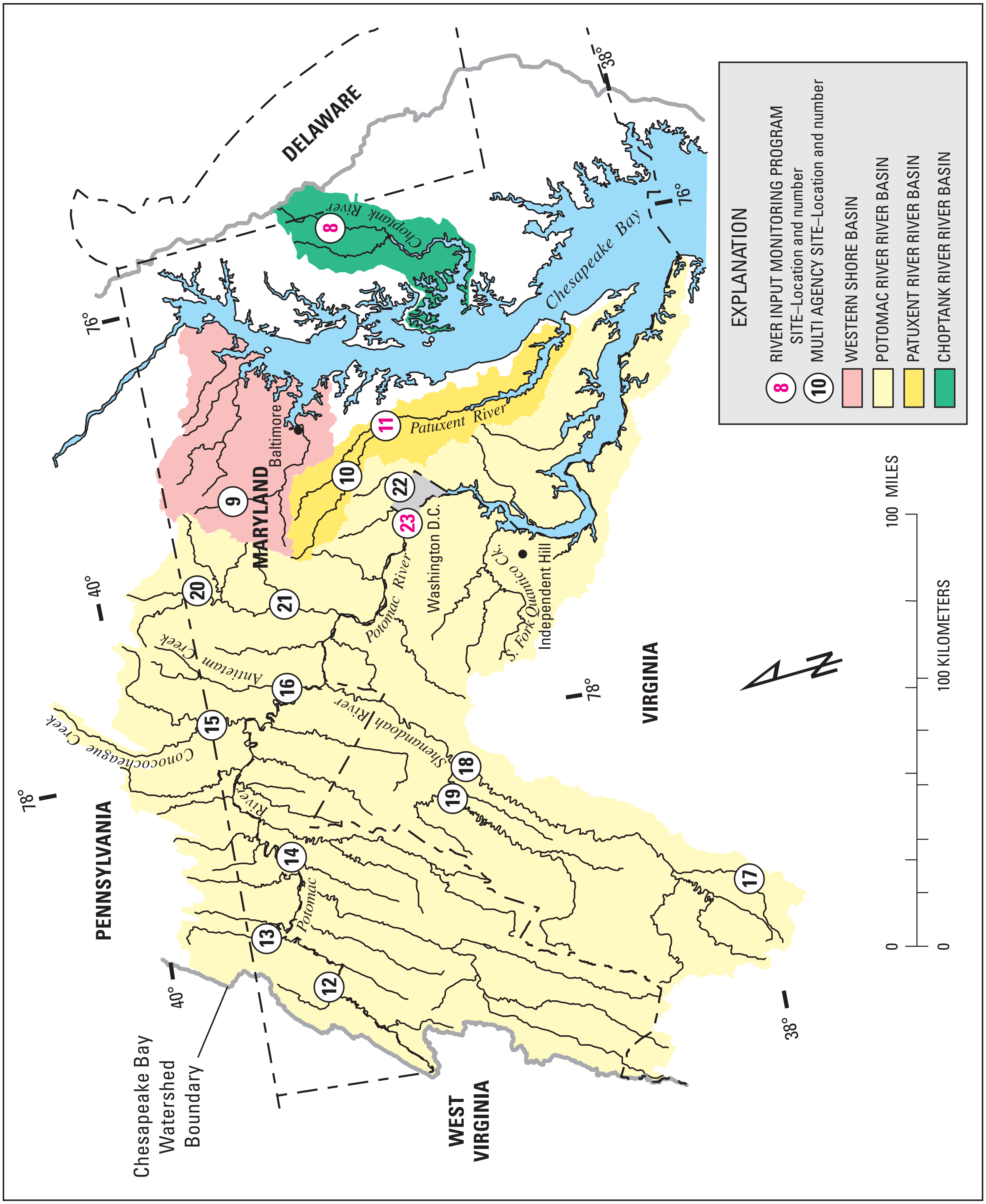

Figure 1C. Locations of the 32 sites in the Chesapeake Bay watershed used in the study. Numbers indicate site identification numbers; red numbers indicate the River Input Monitoring Program sites.

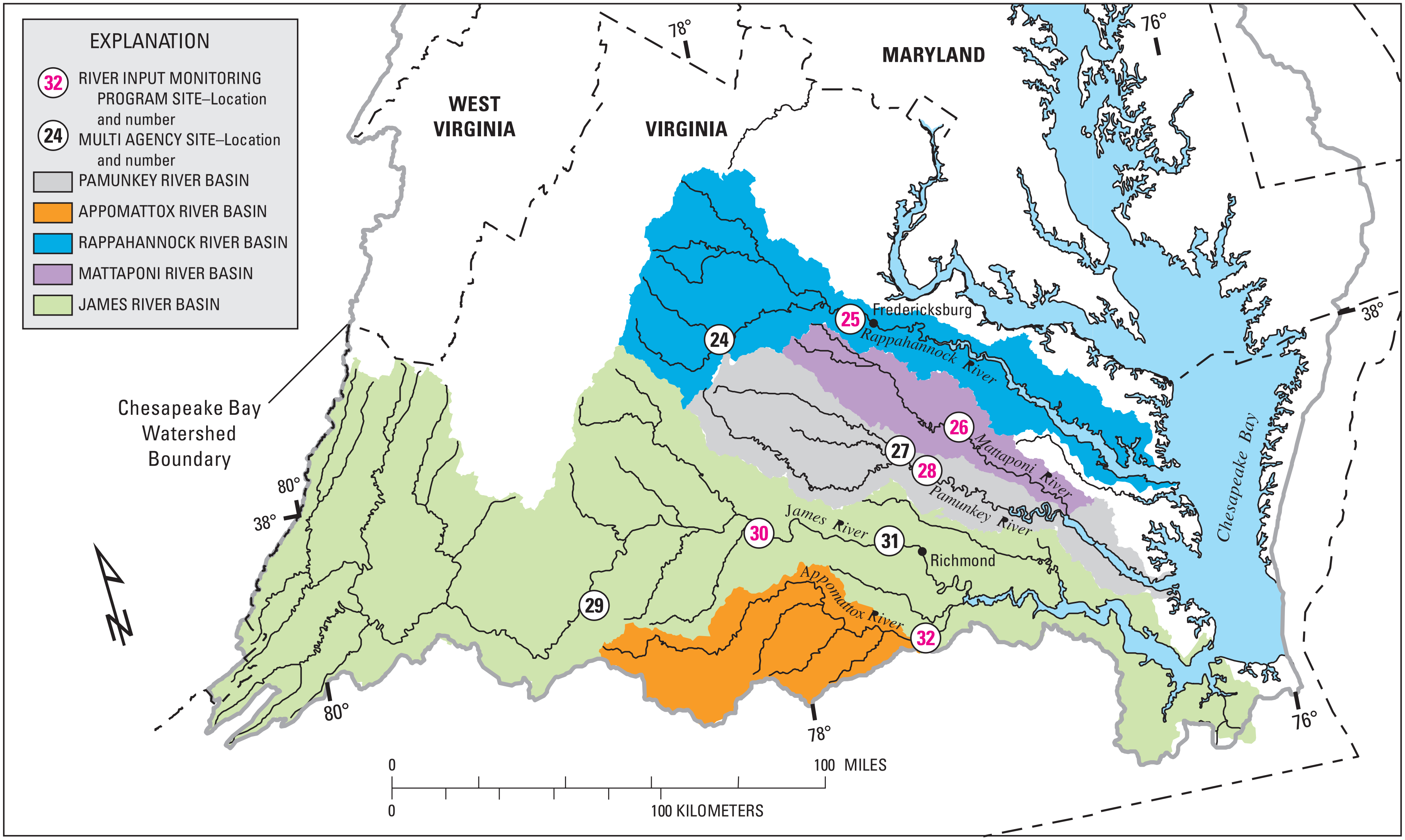

Figure 1D. Locations of the 32 sites in the Chesapeake Bay watershed used in the study. Numbers indicate site identification numbers; red numbers indicate the River Input Monitoring Program sites.

Table 1. Streamflow and water-quality site information for the 9 River Input Monitoring Program and 23 Multi-Agency Nontidal Monitoring Program sites.

[Map ID, Figure 1 identification number; mi^2, square miles]

Streamflow site	Water-quality site	Additional water-quality sites	latitude (DDMMSS)	Longitude (DDMMSS)	Map ID	Drainage area (mi^2)	Site name
River Input Monitoring Program Sites							
01491000	01491000	N/A	385950	754710	8	113	CHOPTANK RIVER NEAR GREENSBORO, MD
01578310	01578310	N/A	393928	761029	7	27,100	SUSQUEHANNA RIVER AT CONOWINGO, MD
01594440	01594440	N/A	385721	764136	11	348	PATUXENT RIVER NEAR BOWIE, MD
01646580	PR01	N/A	385546	770701	23	11,600	POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.
01668000	01668000	N/A	381920	773105	25	1,596	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA
01673000	01673000	N/A	374603	771957	28	1,081	PAMUNKEY RIVER NEAR HANOVER, VA
01674500	01674500	N/A	375316	770948	26	601	MATTAPONI RIVER NEAR BEULAHVILLE, VA
02035000	02035000	N/A	374015	780510	30	6,257	JAMES RIVER AT CARTERSVILLE, VA
02041650	02041650	N/A	371330	772832	32	1,344	APPOMATTOX RIVER AT MATOACA, VA
Multi-Agency Nontidal Monitoring Program Sites							
01531500	01531500	WQN0305	414555	762628	1	7,797	SUSQUEHANNA RIVER AT TOWANDA, PA
01540500	01540500	WQN0301	405729	763710	2	11,220	SUSQUEHANNA RIVER AT DANVILLE, PA
01553500	01553500	WQN0401	405803	765236	3	6,859	WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA
01567000	01567000	WQN0214	402842	770746	4	3,354	JUNIATA RIVER AT NEWPORT, PA
01576000	01576000	WQN0201	400316	763152	5	25,990	SUSQUEHANNA RIVER AT MARIETTA, PA
01576754	01576754	WQN0231	395647	762205	6	470	CONESTOGA RIVER AT CONESTOGA, PA
01586000	NPA0165	01586000	393000	765300	9	56.6	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD
01592500	PXT0809	01592500	390700	765231	10	132	PATUXENT RIVER NEAR LAUREL, MD
01599000	GEO0009	01599000	392936	790242	12	47	GEORGES CREEK AT FRANKLIN, MD
01601500	WIL0013	01601500, BDK0000	393941	784650	13	247	WILLS CREEK NEAR CUMBERLAND, MD
01610000	POT2766	01610000	393218	782717	14	3,109	POTOMAC RIVER AT PAW PAW, WV
01614500	CON0180	01614500	394256	774931	15	501	CONOCOCHEAGUE CREEK AT FAIRVIEW, MD
01619500	ANT0044	01619500	392701	774352	16	281	ANTIETAM CREEK NEAR SHARPSBURG, MD
01626000	1BSTH027.85	01626000	380326	785429	17	127	SOUTH RIVER NEAR WAYNESBORO, VA
01631000	1BSSF003.56	01631000	385449	781240	18	1,642	SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA
01634000	1BNFS010.34	01634000	385836	782011	19	768	NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA
01639000	MON0528	01639000	394043	771406	20	173	MONOCACY RIVER AT BRIDGEPORT, MD
01643000	MON0155	01643000, MON0167, 01643020	392313	772158	21	817	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD
01651000	ANA0082	01651000, A4	385708	765778	22	49.4	NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD
01666500	3-ROB001.90	01666500	381930	780545	24	179	ROBINSON RIVER NEAR LOCUST DALE, VA
01671020	8-NAR005.42	01671020	375100	772541	27	463	NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA
02026000	2-JMS229.14	02026000	373211	773250	29	3,680	JAMES RIVER AT BENT CREEK, VA
02037500	2-JMS127.35	02037500, 2-JMS127.50	373347	773250	31	6,758	JAMES RIVER NEAR RICHMOND, VA

Table 2. Nitrogen, phosphorus, and sediment species tested for trend.

[N, nitrogen; mg/L, milligrams per liter]

Constituent	Species (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) as N	mg/L	NO23
Phosphorus	Total phosphorus (00665)	mg/L	TP
	Dissolved inorganic phosphorus (00671)	mg/L	DIP
Sediments	Suspended sediment (80154)	mg/L	SED
	Total suspended solids (00530)	mg/L	TSS

Streamflow

Streamflow and streamflow variation have important consequences for water quality in the Chesapeake Bay and its watershed. The salinity levels, freshwater/saltwater interface location, and stratification of tidal water in the bay are all affected by the quantity of flow. Estimates of annual flow to the Chesapeake Bay from 1937 to 2004 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 they may help explain trends in water quality.

Trends in streamflow may indicate changes in climatological or hydrologic conditions over time. These changes can be caused by both natural and anthropogenic factors. Precipitation, evapotranspiration, and ground-water recharge, storage, and discharge are the primary natural factors affecting streamflow; land-use change and other anthropogenic factors (diversions) also affect streamflow.

A technique using linear regression to determine the trend in streamflow was presented in Langland and others (2000) and was evaluated for use in the present study. Linear regression (ordinary least squares) is a tool that can be used to describe the relation between a variable of interest and one or more other variables (Montgomery and Peck, 1982; Helsel and Hirsch, 1992). Application of the method is straightforward; a linear relation is obtained by regressing a response variable (such as streamflow) against one or more explanatory variables (such as time).

Evaluation of time series of daily-mean and monthly-mean streamflow for this study determined that the data residuals generally were autocorrelated; therefore, trend estimation can be difficult. Autocorrelation problems may be overcome using a number of possible approaches. One approach was to increase the averaging period. Time series of seasonal-mean streamflow were constructed based on four "seasons"—January-February-March, April-May-June, July-August-September, and October-November-December. Time series of annual-mean streamflow for each site, as well as for the total freshwater flow to the bay, also were constructed. The annual-mean streamflow time series provide a basis for evaluating inter-annual variability; the seasonal-mean time series allow the analysis of trends for a particular season.

The time series (using time-averaged data, either seasonal-mean or annual-mean streamflow) were modeled by regressing both streamflow and the natural logarithm of streamflow against time:

$$y = \hat{\alpha}_0 + \hat{\alpha}_1 t + \varepsilon$$
$$\ln(y) = \hat{\alpha}_0 + \hat{\alpha}_1 t + \varepsilon \quad (1)$$

where

- y is annual-mean streamflow or seasonal-mean streamflow for a particular season, in cubic feet per second;
- ln is the natural logarithm function;
- $\hat{\alpha}_0$ is a constant;
- $\hat{\alpha}_1$ is the coefficient on time and estimates the trend;
- t is time, in years; and
- ε is the unexplained noise or error in the data.

To evaluate trends, a null hypothesis of a zero coefficient on time ($\hat{\alpha}_1$) 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 log-linear trend over time exists. A *p*-value of 0.05 or less was considered significant for this study. 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 upward (SIG-UP) or downward (SIG-DOWN) if the confidence interval of the modeled value at the end of 2004 was entirely greater than or entirely less than the modeled starting value.

In evaluating the application of linear regression to trend estimation for streamflow, it was generally observed that very few statistically significant trends were found for seasonal-mean and annual-mean streamflow for the sites listed in table 1 over the study period. Graphical depiction of the data and summary statistics can provide insights into variations in streamflow in the Chesapeake Bay watershed, however. For each time series, the 25th, 50th (or median), and 75th percentiles of the data were calculated. The data were 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 interquartile range (between the 25th and 75th percentiles).

A second approach used to overcome autocorrelation problems involves the use of time-series models that include autoregressive (AR) and moving average (MA) terms, such as an autoregressive integrated moving average process model (ARIMA) or seasonal ARIMA (Box and Jenkins, 1976). 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:

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

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 ε_t is an independent, identically distributed error term.

As in application of linear regression modeling to the seasonal-mean and annual-mean streamflow time series, 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 was also used in conjunction with a 6-parameter water-quality model (described below) to estimate non-flow adjusted trends in concentration and load.

Water Quality

Data retrieved from the nontidal database are 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. Estimated annual loads, calculated using the USGS water-quality model ESTIMATOR and available from the USGS for the 9 RIM Program sites, were used to calculate a flow-weighted concentration. Output from the ESTIMATOR model are also used to estimate both flow-adjusted and non-flow adjusted trends.

Observed Concentrations

Observed concentrations of TN, nitrite plus nitrate (NO23), TP, dissolved inorganic phosphorus (DIP), and TSS are routinely monitored at 23 Multi-Agency Nontidal Monitoring Program sites and 9 RIM Program sites (table 1). Typically, water-quality samples are collected monthly at all 32 monitoring sites. Additionally, to improve load estimations, targeted water-quality sample collection occurs during high-flow periods at the 9 RIM Program sites and many of the 23 Multi-Agency Nontidal Monitoring Program sites. The period record for this report extends from 1985 through 2004.

The water-quality constituents monitored at the 32 sites can serve as indicators of water-quality conditions and input for data analyses such as trend estimation. At the 9 RIM Program sites and at many of the 23 Multi-Agency Nontidal Monitoring Program sites, one of the primary goals is to estimate total loading over a specific time period. The main strategy for minimizing error in the load estimate is to preferentially collect samples during high-flow events, in addition to the scheduled monthly sampling. This targeted high-flow event sampling produces a record of observations that does 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, then the estimates will be biased. In order to reliably estimate concentration statistics over time, an approach for removing the flow-bias must be applied. For this study, an algorithm that is robust with respect to censored observations was used to obtain an estimate of $c(p)$, the concentration corresponding to the p-th quartile, $0 < p < 1$, as well as the mean value of the concentration for the water-quality variable of interest.

To illustrate the utility of the unbiasing algorithm, SED data (USGS parameter code 80154) were retrieved from the National Water Information System: Web Interface (NWISWeb) for South Fork Quantico Creek near Independent Hill, Va. (USGS site 01658500) (table 3). This USGS site was selected because it is a daily sediment monitoring site and has at least one data value per day for SED. The data consist of 668 SED samples collected on 355 days in 1998. The second column of table 3 presents the raw quantiles derived from the 668 observations. As multiple samples tended to be collected on high-flow days, however, these quantile estimates are likely to be biased. An unbiased estimate was made by selecting only a single sample (based on the modulus of the day of the year) to represent a set of multiple samples for those days having multiple samples. The resulting unbiased estimates, based on 355 samples, are listed in the third column. Note that subselecting a single sample on multiple sample days lowers the quantile estimate, and the effect of correction is greatest for the higher quantiles.

Table 3. Empirical percentiles for raw and unbiased suspended-sediment concentrations from samples collected during 1998 at South Fork Quantico Creek near Independent Hill, Va. (USGS station number 01658500).

[n, number of samples]

Percentile	Suspended-sediment concentration (in milligrams per liter)			
	Raw n = 668	Unbiased n = 355	Raw n = 20	Unbiased n = 20
0.1	5	4	2	2
0.25	8.5	6	7	6
0.5	21	10	22	10
0.75	50	18	66	24
0.9	90	39	271	29

These data provide useful examples that demonstrate a second problem arising from sampling bias. At most sites, a rich data set of 355 values is not available; more commonly, data from a mix of 12 monthly sampled values and several storm-event samples are available. As the data include storm samples, the unadjusted quantiles based on the 20 samples will tend to over-represent high-flow events, leading to an upward bias in the quantile estimates. A correction method has been developed that weights the samples according to the flow quantile on days that samples are taken. By use of this approach, multiple samples collected at the higher flow quantiles are given less weight in determining a given quantile, resulting in an unbiased estimate.

The effect of weighting the quantiles is demonstrated in the fourth and fifth columns of table 3. A random sample of 20 samples is drawn from the 355 daily samples, with a bias towards storm events. The standard quantile estimates for the biased sample are given in the fourth column. Column five of table 3 shows the effect of weighting the samples to correct for the sampling bias, which is quite large for the higher quantiles.

Water-quality data collected at the 32 monitoring sites are shown mainly in tabular and graphical form. Bias-corrected concentrations are used when presenting descriptive statistics (mean, median, and other quantiles) for each water-quality constituent collected at each of the 32 sites. Boxplots of TN, NO23, TP, DIP, and SED or TSS collected from 1985 through 2004 provide information on the mean, median and other quantiles for each constituent and allow for the comparison of observed water-quality conditions between the 9 RIM Program sites. In addition, boxplots of annual TN, NO23, TP, DIP, and SED or TSS are presented for each of the 32 sites. These annual boxplots provide information on the mean, median, and other quantiles for each constituent and allow for the comparison of observed water-quality conditions from year to year. Trends in the annual boxplots with respect to time are often difficult to visually discern, however. One approach that is used to statistically test for significant trends in the quantiles of the bias-corrected boxplots is the calculation of the Spearman rank correlation coefficient.

The Spearman rank correlation coefficient (called rho) is a test of the independence between two random variables (Conover, 1999). This statistic was used to test whether the bias-corrected concentration values were independent of order of year of occurrence; that is, that there was no upward or downward trend in annual observed concentration values. The mean as well as the 10^{th}, 25^{th}, 50^{th} (median), 75^{th}, and 90^{th} quantile values were tested; because the distribution of these statistics is not necessarily known, a nonparametric test was chosen. Spearman rho values range between +1 and –1, where +1 (–1) indicates a strong consistent (opposite) relation between variables, hence an upward (downward) trend in the annual value of the water-quality concentration. This test was performed for each of five water-quality constituents, namely, TN, NO23, TP, DIP, and SED or TSS, at each of the 32 water-quality monitoring sites. Results are only reported if the test is significant at the $p < 0.05$ level. A positive (negative) value for rho indicates that the q-th quantile concentration has increased (decreased) at a statistically significant level over the period of record.

Water-Quality Models

A suite of water-quality models was developed to estimate non-flow adjusted and flow-adjusted trends in water quality. The models use multiple linear regression to relate observed concentration to predictor variables of streamflow and time. Models were developed for all 32 sites, for all constituents given in table 2, and for a period of record from 1985 through 2004, when possible. In some cases, data limitations (such as large breaks in the record, paucity of 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.

Estimates of constituent loading provide critical information on the amount and timing of material reaching downstream water bodies. A load is an integrated mass flux over some time interval $\{t_a, t_b\}$:

$$L = \int_{t_a}^{t_b} l(t)\,dt = \int_{t_a}^{t_b} kc(t)q(t)\,dt \,, \tag{3}$$

where

- L is the total load;
- l is the instantaneous load;
- k is a unit conversion factor;
- c is the instantaneous observed concentration; and
- q is the instantaneous streamflow.

The load represents the amount of a given constituent transported and delivered downstream of the point at which measurements of c and q are made.

The USGS log-linear regression model (ESTIMATOR) developed by Cohn and others (1989) is used by the USGS RIM Program to estimate loads of nutrients and SED. The program computes loads in two steps. First, a center-estimate linear model is fit to the logarithms of the concentration. The model uses the Minimum Variance Unbiased Estimator (MVUE) developed by Bradu and Mundlak (1970) to correct for retransformation bias arising when model results using the logarithm of c are transformed into “real” units. The Adjusted Maximum Likelihood Estimator (AMLE) (Cohn, 1988) is used to estimate the log-linear model for sites having censored observations, which are concentration values below a detectable limit. Coefficients estimated using AMLE are nearly unbiased, and the variance of the sums of loads is easy to compute. AMLE is identical to ordinary least squares for the cases where no observations are censored. A 7-parameter model is used to estimate loads for the RIM Program sites:

$$\ln(c) = \hat{\beta}_0 + \hat{\beta}_1 \ln(q/q_c) + \hat{\beta}_2 \left[\ln(q/q_c)\right]^2 + \hat{\beta}_3 (t - t_c) + \hat{\beta}_4 (t - t_c)^2 + \hat{\beta}_5 \sin(2\pi t) + \hat{\beta}_6 \cos(2\pi t) + \varepsilon \,, \tag{4}$$

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

ε is residual error, assumed to be normally distributed with zero mean and variance σ_ε^2.

Centering variables are defined such that time and time-squared (and flow and flow-squared) predictor variables are orthogonal (independent). Centering of variables simplifies numerical calculations but has no effect on load estimation. Defined in this way the model has flow and time terms as independent predictors. As estimates are conditioned on flow, the model automatically accounts for any bias in the sampling strategy. A sampling protocol that targets high and low flow conditions reduces the error in load estimates generated by the model due to the log-linear relation between concentration and flow.

After the model coefficients have been estimated, daily concentrations are computed. 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 standard errors are estimated using formulas in Gilroy and others (1990) and Cohn and others (1992).

For the 9 RIM Program sites, loads are estimated using this model (eq. 4) and a 9-year moving window (Yochum, 2000) and reported annually to USGS cooperators and the public on the RIM web site (*http:// va.water.usgs.gov/chesbay/RIMP/index.html*). The published values are also presented graphically in this report; values for the last 4 years (2001-2004) are shown in a different color or shade to indicate that they are provisional and will be updated in subsequent years. The 7-parameter water-quality model was also used to estimate flow-adjusted trends (Langland and others, 2004), for all 32 sites and all constituents.

Non-flow adjusted trends (described below) are estimated from a 6-parameter water-quality model of the form:

$$\ln(c) = \hat{\beta}_0 + \hat{\beta}_1 \ln(q/q_c) + \hat{\beta}_2 (t - t_c) + \hat{\beta}_3 (t - t_c)^2 + \hat{\beta}_4 \sin(2\pi t) + \hat{\beta}_5 \cos(2\pi t) + \varepsilon \qquad (5)$$

in conjunction with a streamflow model. This model does not include the streamflow-squared ($[\ln(q/q_c)]^2$) term. Future work will investigate inclusion of this term in the combined streamflow and water-quality model for non-flow adjusted trend.

Loads estimated using the 6-parameter model (eq. 5) for all 32 sites are presented graphically in this report (app. 4) for the sole purpose of visual comparison with the estimated non-flow adjusted trend in load.

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 that is not adjusted for flow, and may be useful in analyzing concentration trends 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. As 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. In previous reports (Langland and others, 2000), a monthly FWC was calculated by dividing the monthly load (from ESTIMATOR) by the monthly streamflow, and a trend in FWC was estimated. There are concerns about conducting trend analyses on estimated loads (from which FWCs are derived), however, because of the potential for biased and unreliable trend statistics. Therefore, trends in monthly FWC are not estimated or presented. Instead, annual FWC results are summarized and presented. The FWC data are useful in evaluating 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 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. A non-flow adjusted trend can be estimated by performing a Kendall-tau test on “raw” observations, or by regressing observations on time excluding a flow term. Non-flow adjusted trends estimated by use of these methods are not conditioned on flow and exhibit bias in cases in which the frequency with which event samples are taken has changed systematically with time. In this study (see previous section “Observed Concentrations”), a nonparametric method was used to assess monotonic change in concentration, not adjusted for flow, over time, using the Spearman rho.

For this study, a new parametric method for computing non-flow adjusted trend in concentration and load was developed to: (1) correct for event sample bias, (2) examine the correlative and explanatory variables that contribute to water-quality trend, and (3) not rely on sub-sampling data. A complete discussion of the differences between parametric and nonparametric methods, and their advantages and disadvantages, is presented in Helsel and Hirsch (1992). The parametric method and results presented here are intended to complement the Spearman rho results, and potentially provide additional insight through the inclusion of nonlinearity in trend. In addition, the method is used to estimate trend in load.

As discussed previously, trends as defined in this report are not an estimate of year-to-year change, but the overall change between the start date and the end date based on modeled concentration, flow, and time. Specifically, the time dependence in the water-quality trend model (eq. 5) is described using time and time-squared variables. Changes (trends) are considered significant if the confidence interval of the modeled value at the end of 2004 was entirely greater than (SIG-UP), or entirely less than (SIG-DOWN) the modeled starting value.

For non-flow adjusted trend in concentration, the method uses a 6-parameter water-quality model (eq. 5) in conjunction with a flow model (eq. 2). The time dependence in the water-quality model is described by the function:

$$g(t)=\hat{\beta}_2(t-t_c)+\hat{\beta}_3(t-t_c)^2=\begin{bmatrix}(t-t_c) & (t-t_c)^2\end{bmatrix}\begin{bmatrix}\hat{\beta}_2\\ \hat{\beta}_3\end{bmatrix}. \tag{6}$$

Between two times, a starting (or reference) time, t_0, and any subsequent time, t, the difference is:

$$g(t)-g(t_0)=\begin{bmatrix}(t-t_0) & (t-t_c)^2-(t_0-t_c)^2\end{bmatrix}\begin{bmatrix}\hat{\beta}_2\\ \hat{\beta}_3\end{bmatrix}, \tag{7}$$

or, defining the time function vector:

$$\vec{t}=\begin{bmatrix}(t-t_0) & (t-t_c)^2-(t_0-t_c)^2\end{bmatrix}, \tag{8}$$

equation (7) may be rewritten:

$$g(t)-g(t_0)=\vec{t}\begin{bmatrix}\hat{\beta}_2\\ \hat{\beta}_3\end{bmatrix}. \tag{9}$$

The time dependence in the flow model is described in the same manner as in the water-quality model (eq. 6), by the function:

$$h(t)=\hat{\alpha}_1(t-t_c)+\hat{\alpha}_2(t-t_c)^2=\begin{bmatrix}(t-t_c) & (t-t_c)^2\end{bmatrix}\begin{bmatrix}\hat{\alpha}_1\\ \hat{\alpha}_2\end{bmatrix}. \tag{10}$$

Between two times, a starting (or reference) time, t_0, and any subsequent time, t, the difference is:

$$h(t)-h(t_0)=\vec{t}\begin{bmatrix}\hat{\alpha}_1\\ \hat{\alpha}_2\end{bmatrix}. \tag{11}$$

The estimated non-flow adjusted trend, at any point in time *t*, and in percent difference relative to a starting (or reference) time, t_0, is given by:

$$\text{N-FA Trend} = 100\left(e^{\hat{\tau}} - 1\right), \quad (12)$$

where

$$\hat{\tau} = \vec{t}\begin{bmatrix}\hat{\alpha}_1 \\ \hat{\alpha}_2\end{bmatrix}\hat{\beta}_1 + \vec{t}\begin{bmatrix}\hat{\beta}_2 \\ \hat{\beta}_3\end{bmatrix}. \quad (13)$$

The approximate variance is given by:

$$\hat{A}'\hat{V}(\hat{\gamma})\hat{A}, \quad (14)$$

where

$$\hat{A}' = \begin{bmatrix}\hat{\beta}_1\vec{t} & \vec{t}\begin{bmatrix}\hat{\alpha}_1 \\ \hat{\alpha}_2\end{bmatrix} & \vec{t}\end{bmatrix}, \quad (15)$$

and the covariance matrix for the estimated coefficients $\hat{\gamma}$ is given by:

$$\hat{V}(\hat{\gamma}) = \begin{bmatrix} \hat{V}(\hat{\alpha}_1,\hat{\alpha}_1) & \hat{V}(\hat{\alpha}_1,\hat{\alpha}_2) & 0 & 0 & 0 \\ \hat{V}(\hat{\alpha}_2,\hat{\alpha}_1) & \hat{V}(\hat{\alpha}_2,\hat{\alpha}_2) & 0 & 0 & 0 \\ 0 & 0 & \hat{V}(\hat{\beta}_1,\hat{\beta}_1) & \hat{V}(\hat{\beta}_1,\hat{\beta}_2) & \hat{V}(\hat{\beta}_1,\hat{\beta}_3) \\ 0 & 0 & \hat{V}(\hat{\beta}_2,\hat{\beta}_1) & \hat{V}(\hat{\beta}_2,\hat{\beta}_2) & \hat{V}(\hat{\beta}_2,\hat{\beta}_3) \\ 0 & 0 & \hat{V}(\hat{\beta}_3,\hat{\beta}_1) & \hat{V}(\hat{\beta}_3,\hat{\beta}_2) & \hat{V}(\hat{\beta}_3,\hat{\beta}_3) \end{bmatrix}. \quad (16)$$

The confidence interval is given by:

$$\text{CI} = 100\left(e^{\hat{\tau} \pm 1.96SE} - 1\right), \quad (17)$$

where 1.96 is the value of the standard normal distribution corresponding to significance level 0.95 (in other words, assuming *n* is large enough to be approximated by infinity, such that the *t* value for $\alpha = 0.025$ and *n* = infinity is used and 1/*n* approaches zero). The standard error of $\hat{\tau}$ is:

$$SE = \sqrt{\hat{A}'\hat{V}(\hat{\gamma})\hat{A}}\,. \quad (18)$$

For the estimated total time trend at any value of time *t*, $\hat{\tau}$, the significance test is constructed as follows. A *t* statistic is calculated as:

$$t\ \text{statistic} = \frac{\hat{\tau}}{SE}, \quad (19)$$

where *SE* is the standard error of $\hat{\tau}$ (eq. 18). The *p*-value is then calculated from a two-tailed test as:

$$\text{p-value} = 2\left[1 - F\left(|t\ \text{statistic}, 0, 1|\right)\right], \quad (20)$$

where *F* is the value of the standard (mean of 0 and standard deviation of 1) normal cumulative distribution function for the calculated value of the *t* statistic.

The non-flow-adjusted trend in load is estimated in a similar manner. Concentration and load models are 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.

In this report, the following are presented for non-flow adjusted trend in concentration and load: the values of $\hat{\tau}$ with their *p*-values, the magnitude of the total trend for the end time with the confidence interval around this estimate, and a remark on whether the trend is significant and up, significant and down, or not statistically significant. Finally, a comment is reported if there is some question concerning the water-quality model residuals (if the serial correlation of the residuals, SCR, is greater than 0.5 or the probability plot correlation coefficient, PPCC, is less then 0.95).

Flow-Adjusted Trend

Concentrations of water-quality constituents commonly are correlated with streamflow and season. For analysis of trends, concentrations are often adjusted to remove the effects of streamflow. A common approach to estimating flow-adjusted trend 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 (Schertz 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).

For flow-adjusted trend[1], this study uses a 7-parameter water-quality model (eq. 4). The form of the model is identical to that used for load estimation for the RIM Program sites. The model for trend estimation is calibrated for a single time period (typically 1985-2004), however, rather than for a series of time intervals (the moving-window approach used for RIM Program site load estimation). The time dependence in the water-quality model is described by the function:

$$g(t) = \hat{\beta}_3 (t - t_c) + \hat{\beta}_4 (t - t_c)^2 . \tag{21}$$

Between two times, a starting (or reference) time, t_0, and any subsequent time, t, the difference is:

$$\hat{\tau}_{FA} = g(t) - g(t_0) = \hat{\beta}_3 (t - t_0) + \hat{\beta}_4 \left[(t - t_c)^2 - (t_0 - t_c)^2 \right], \tag{22}$$

or

$$\hat{\tau}_{FA} = g(t) - g(t_0) = \hat{\beta}_3 (t - t_0) + 2\hat{\beta}_4 (t - t_0)(\bar{t} - t_c), \tag{23}$$

where $\bar{t}$ is the midpoint between t and t_0 (or the average of the two values). The parameter $\hat{\tau}_{FA}$ is, therefore, an estimate for the flow-adjusted (i.e., independent of flow) change in ln(concentration) between t and t_0. The estimated trend as a function of time, in percent difference relative to a starting time, t_0, is given by:

$$\text{F-A Trend} = 100\left(e^{\hat{\tau}_{FA}} - 1\right). \tag{24}$$

The confidence interval is given by:

$$\text{CI} = 100\left(e^{\hat{\tau}_{FA} \pm z^{*} SE} - 1\right), \tag{25}$$

where z^* corresponds to either: the integral of the standard normal distribution between –2 and 2 standard deviations from the mean of zero (or 1.96), in the case where one or more observations is censored; or the integral of the Student's t distribution for degrees of freedom, df (= $N - P$, where N is the number of observations and P is the number of parameters in the model), in the case of no censored observations.

[1]A flow-adjusted trend estimated in the manner described is mathematically identical for concentration and load. Hence, the general-use term, "flow-adjusted trend."

The standard error of $\hat{\beta}_t$ is given by:

$$SE = \sqrt{\begin{bmatrix} (t-t_0) & (t-t_c)^2-(t_0-t_c)^2 \end{bmatrix} \begin{bmatrix} V(\hat{\beta}_3) & V(\hat{\beta}_3,\hat{\beta}_4) \\ V(\hat{\beta}_4,\hat{\beta}_3) & V(\hat{\beta}_4) \end{bmatrix} \begin{bmatrix} (t-t_0) \\ (t-t_c)^2-(t_0-t_c)^2 \end{bmatrix}}, \tag{26}$$

or

$$SE = \sqrt{V(\hat{\beta}_3)(t-t_0)^2 + 2V(\hat{\beta}_3,\hat{\beta}_4)\left\{(t-t_0)\left[(t-t_c)^2-(t_0-t_c)^2\right]\right\} + V(\hat{\beta}_4)\left[(t-t_c)^2-(t_0-t_c)^2\right]^2}. \tag{27}$$

For the time trend coefficient at any value of time *t*, $\hat{\tau}_{FA}$, the significance test is constructed as follows. A *t* statistic is calculated as:

$$t \text{ statistic} = \frac{\hat{\tau}_{FA}}{SE}, \tag{28}$$

where *SE* is the standard error of $\hat{\tau}_{FA}$ (eqs. 26, 27). In cases where no censored observations are used (ordinary least squares), the *p*-value is calculated from a two-tailed test using the Student's *t* distribution as:

$$\text{p-value} = 2\left[1 - F_t\left(\left|t \text{ statistic}, df\right|\right)\right], \tag{29}$$

where F_t is the value of Student's *t* cumulative distribution function for the calculated value of the *t* statistic and given degrees of freedom, *df* (= *N* – *P*, where *N* is the number of observations and *P* is the number of parameters in the model). In cases where censored observations are used (and hence AMLE is applied), the *p*-value is calculated as:

$$\text{p-value} = 2\left[1 - F\left(\left|t \text{ statistic}, 0, 1\right|\right)\right], \tag{30}$$

where *F* is the value of the standard (mean of 0 and standard deviation of 1) normal cumulative distribution function for the calculated value of the *t* statistic.

The following are presented in this report: the value of $\hat{\tau}_{FA}$ for the end time with its *p*-value, the magnitude of the flow-adjusted trend for the end time with the confidence interval around this estimate, and a remark on whether the trend is significant and up, significant and down, or not statistically significant. Finally, a comment is reported if there is some question concerning the model residuals (if the SCR is greater than 0.5 or the PPCC is less then 0.95).

Summary of Changes in Methods

In previous reports (Langland and others, 1998, 2000), tests for trend were reported for the following:

1. Monthly streamflow,
2. Monthly load,
3. Monthly FWC, and
4. A concentration adjusted for flow and season.

The evaluation of methods in 2003 and 2004 raised several concerns with (1) sample data sets used to represent concentrations in a river, and (2) the statistical tests used to estimate a trend. Water-quality-data sample collection can be classified into two groups, which are ambient and targeted sampling. Ambient sampling involves collection of a sample at approximately the same interval, usually monthly, whereas targeted sampling contains a combination of ambient and higher-flow storm samples. Although this targeting protocol is beneficial to compute loads using ESTIMATOR-type load models, a biased assessment could result when estimating a trend in observed concentration and loads. This potential bias is the result of the sample of water-quality observations, which may not be representative of the true variability in the concentrations that occur in the stream or river. In addition, changes in timing of sample collection (monthly to seasonally) or missing samples could also bias a data set.

To address these concerns, new and revised methods include:

1. Streamflow—annual, seasonal, and daily linear regression with auto-regressive techniques, for all 32 sites,
2. Observed concentration—procedure to "un-bias" targeted sampling to produce descriptive statistics and trends using non-parametric test (Spearman rho) for all 32 sites,
3. Flow-weighted concentration—no trend, annual FWC presented for the 9 RIM Program sites,
4. Non-flow adjusted trends, in concentration and load—computations by modification of the ESTIMATOR model using the linear and non-linear time coefficients and only the linear flow coefficient (6-parameter model), in conjunction with a flow model with trends reported for all 32 sites, and
5. Flow-adjusted trend—computation includes both the linear and non-linear time and flow coefficients (7-parameter model) and is presented as a "continuous" change over time for all 32 sites.

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 both 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 may 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 rivers.

Annual-Mean Flow

Estimated total freshwater flow entering the bay in 2004, 105,500 ft^3/s, was above normal (as defined by the interquartile range, between the 25th and 75th percentiles), as it was in 2003, when the total flow was 131,500 ft^3/s (fig. 2). For the period 1937 through 2004, the 25th, 50th, and 75th percentiles were 64,100, 75,700, and 89,000 ft^3/s, respectively.

Between 1940 and 1959, the annual total streamflow values in15 of the 20 years was within the interquartile range. A dry period occurred in the 1960s (6 of the 10 years were below the 25^{th} percentile), and wetter conditions occurred in the 1970s (5 of the 10 years were above the 75^{th} percentile). The 15 years between 1990 and 2004 were marked by high flow variability; only 3 years were within the interquartile range. The wetter conditions observed from 1970 to 2004 (12 of 35 years were above the 75^{th} 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 and that persist (Phillips, 2002).

Inter-basin variability in annual streamflow can be examined by dividing total annual streamflow by basin area. The resulting basin runoff for the 9 RIM Program sites (fig. 3) demonstrates the magnitude of variability from year to year and from basin to basin, with the range for most years and for all basins between approximately 5 and 35 inches, with 1996 and 2003 having higher runoffs. The highest runoff came from the Susquehanna River Basin in 7 of 20 years, with the Choptank River Basin having the highest runoff for 7 of 20 years. The Mattaponi River Basin had the lowest runoff for 10 of 20 years. Calculated runoffs decreased in 8 of the 9 RIM basins in 2004, with the exception of the Susquehanna River Basin. Calculated runoff for the Susquehanna River Basin in 2004 was well above that of the other 8 RIM Program basins, due to the fact that the Susquehanna River Basin produced very large flows following remnants of hurricanes in September 2004.

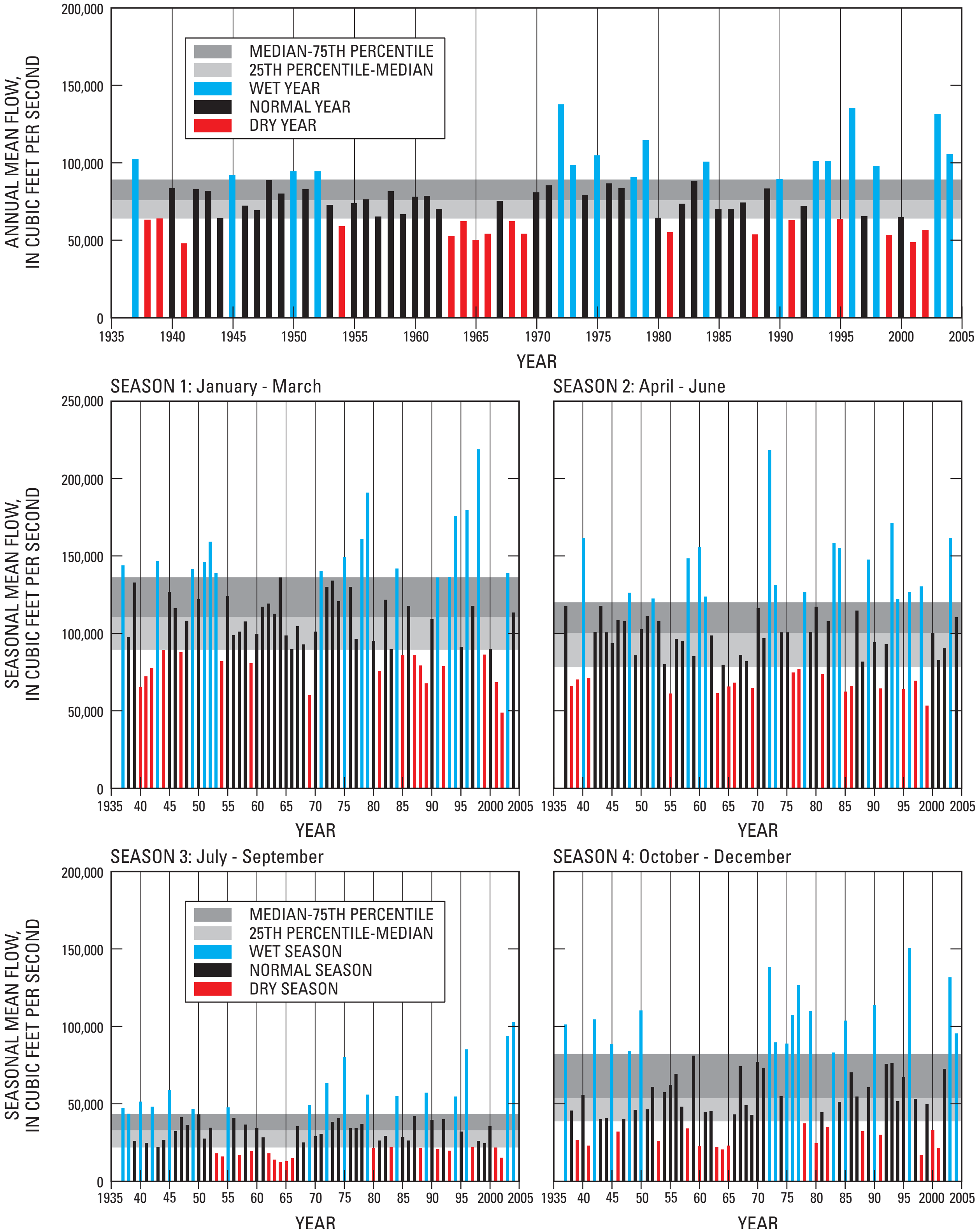

Figure 2. Estimated total annual and seasonal freshwater flow to Chesapeake Bay for the period 1937-2004 (using methods as described in Bue, 1968).

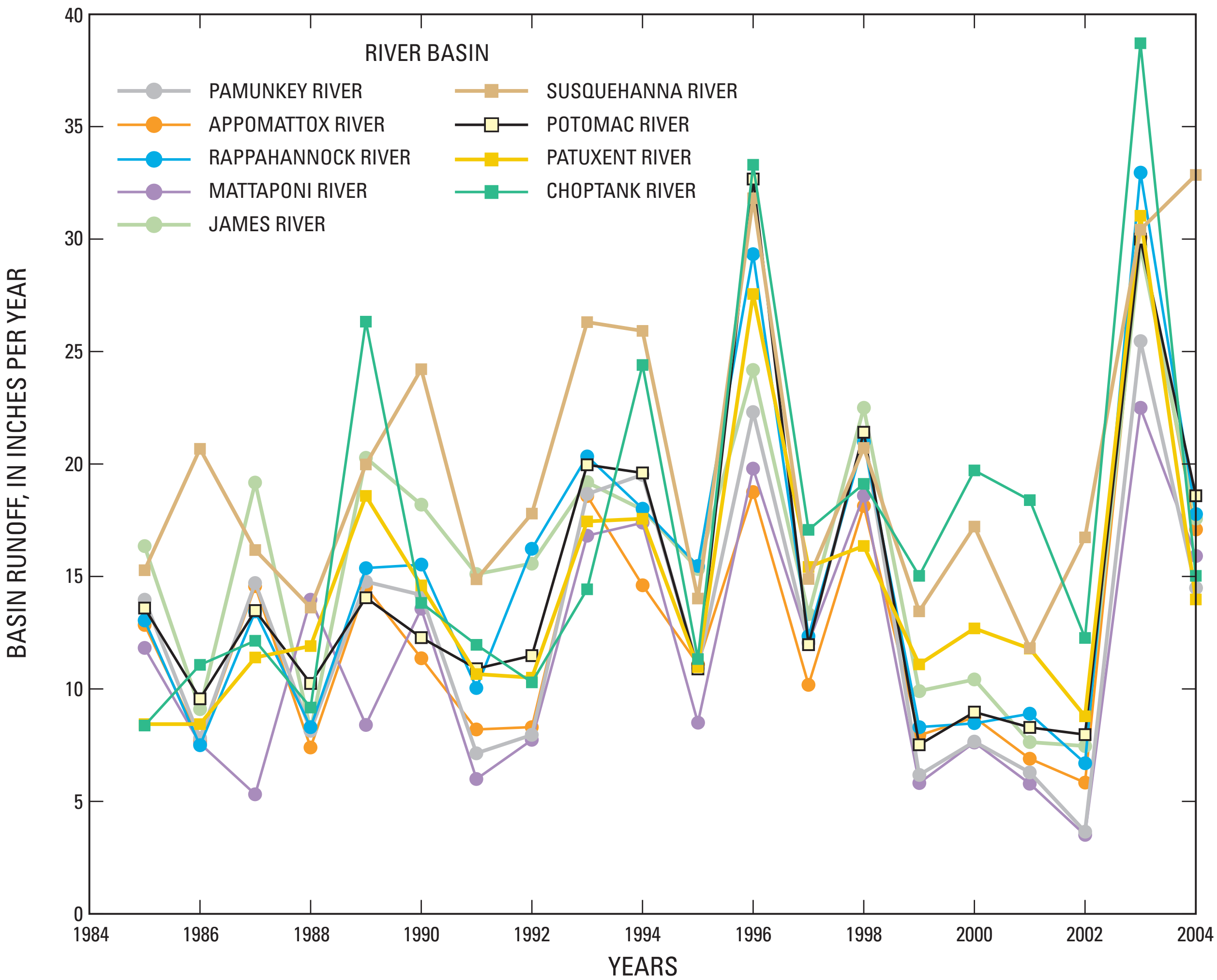

Figure 3. Annual basin runoff from the 9 River Input Monitoring Program basins, 1985-2004.

Linear regression models of annual-mean streamflow were developed for all 32 sites in this study. Only 1 site (Choptank River) yielded a statistically significant trend:

$$\ln(y) = -65 + 0.035t + \varepsilon \,, \qquad (31)$$

where

- ln is the natural logarithm function;
- y is annual-mean streamflow, in cubic feet per second;
- -65 is a constant;
- 0.035 is the coefficient on time and estimates the trend;
- t is time, in years; and
- ε is the unexplained noise or error in the data.

with $R^2 = 0.25$ and p-value = 0.02. This model indicates a statistically significant increase in annual-mean streamflow, estimated to be approximately 3.5 percent per year. The model explains only 25 percent of the year-to-year variability in streamflow, however. While the regression model indicates flow about doubled from 1985 to 2004 (fig. 4A), the flows were about the same in 1987 and 2002. Therefore, the model is more indicative of the long-term tendency than the inter-annual change.

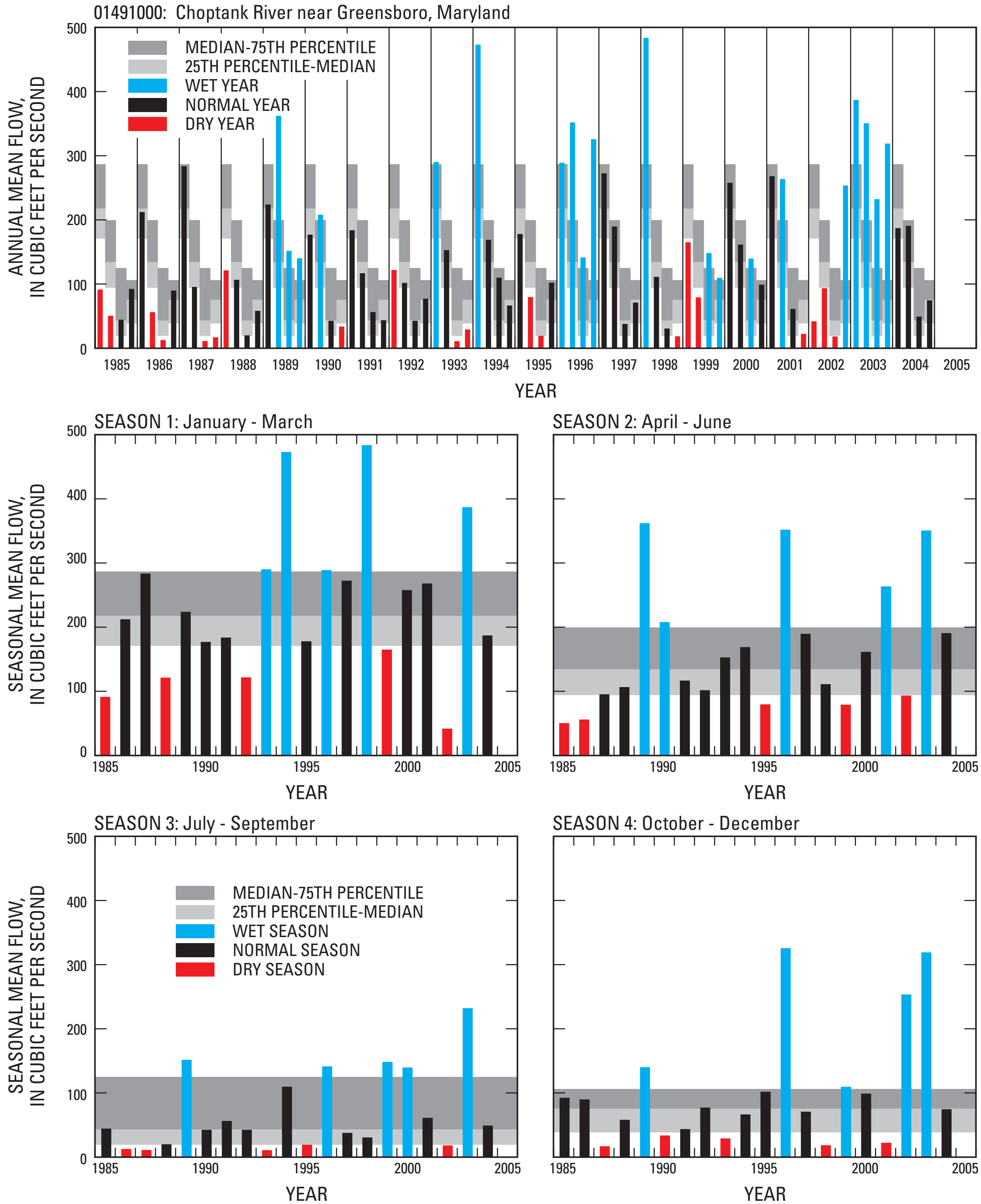

Figure 4A. Annual and seasonal flow variations for the Choptank River near Greensboro, Maryland.

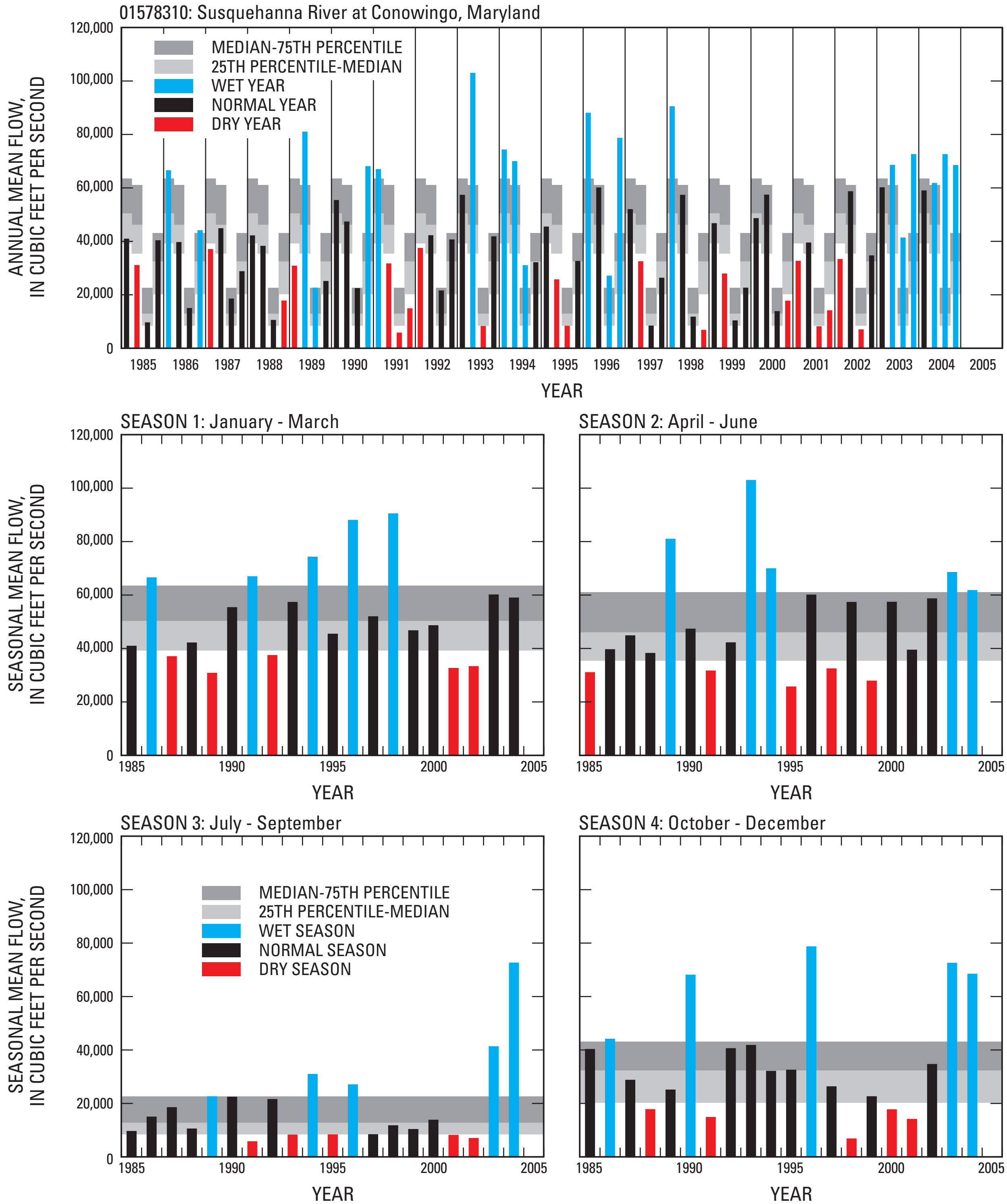

Figure 4B. (Continued) Annual and seasonal flow variations for the Susquehanna River at Conowingo, Maryland.

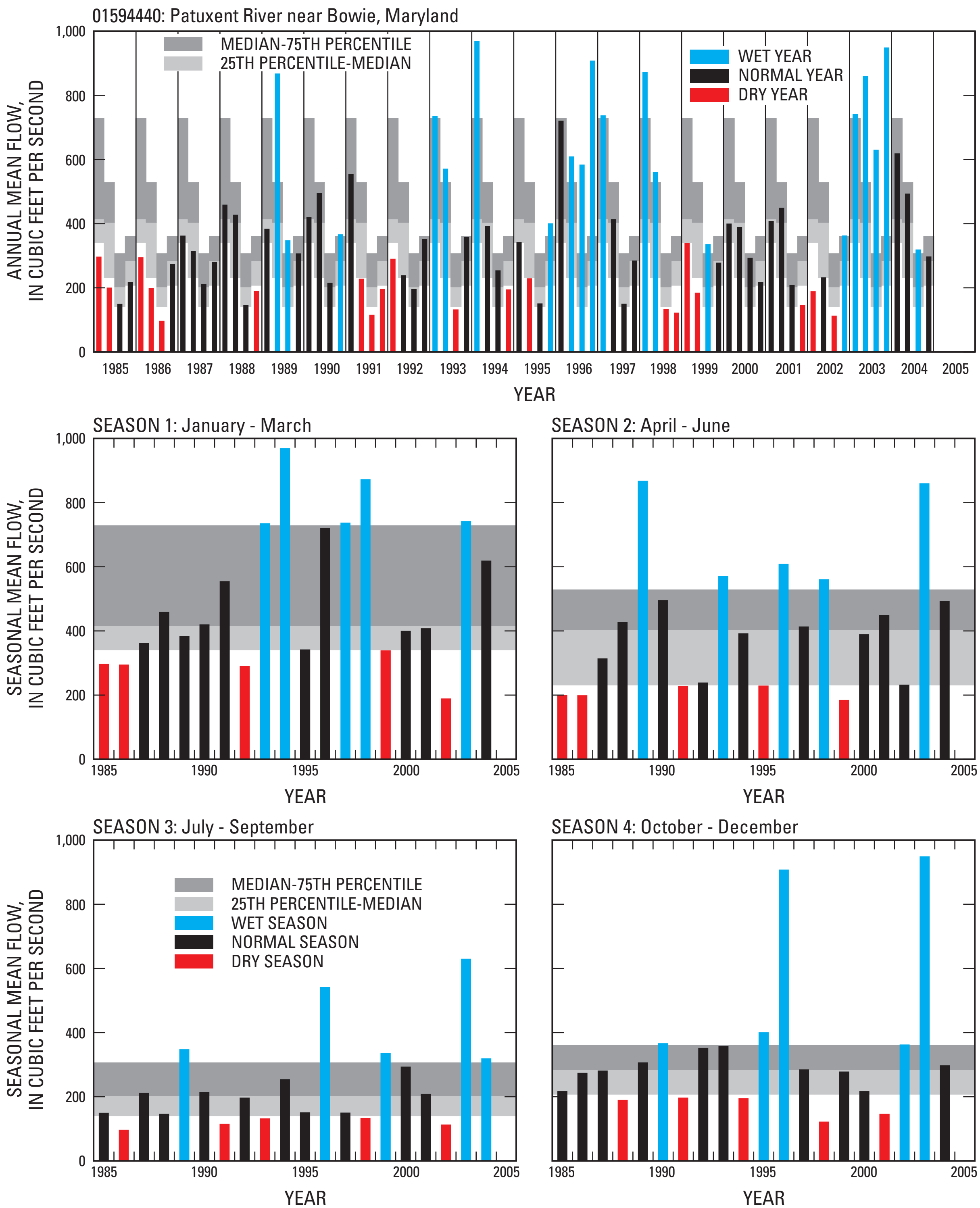

Figure 4C. (Continued) Annual and seasonal flow variations for the Patuxent River at Bowie, Maryland.

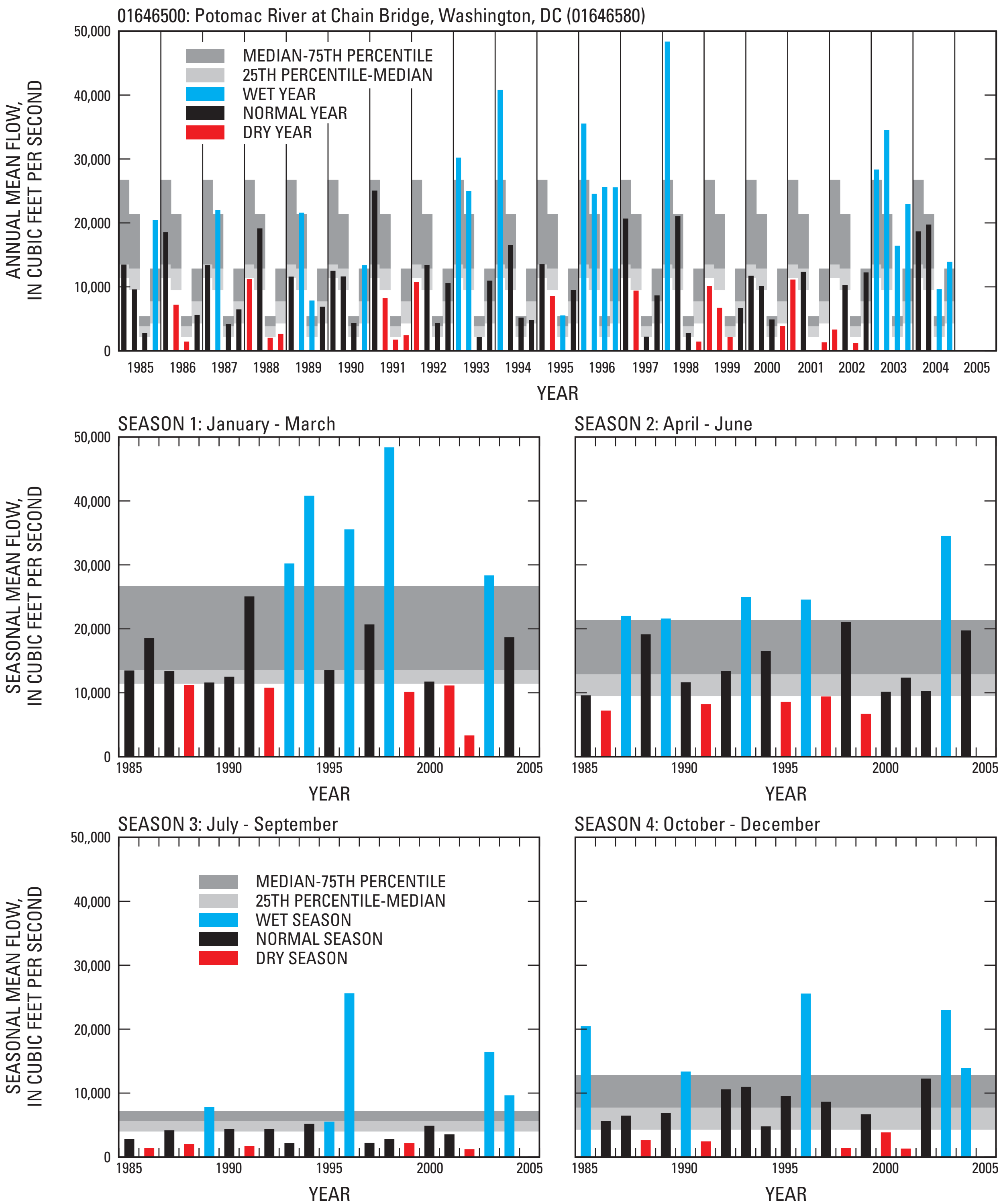

Figure 4D. (Continued) Annual and seasonal flow variations for the Potomac River at Chain Bridge, Washington, D.C.

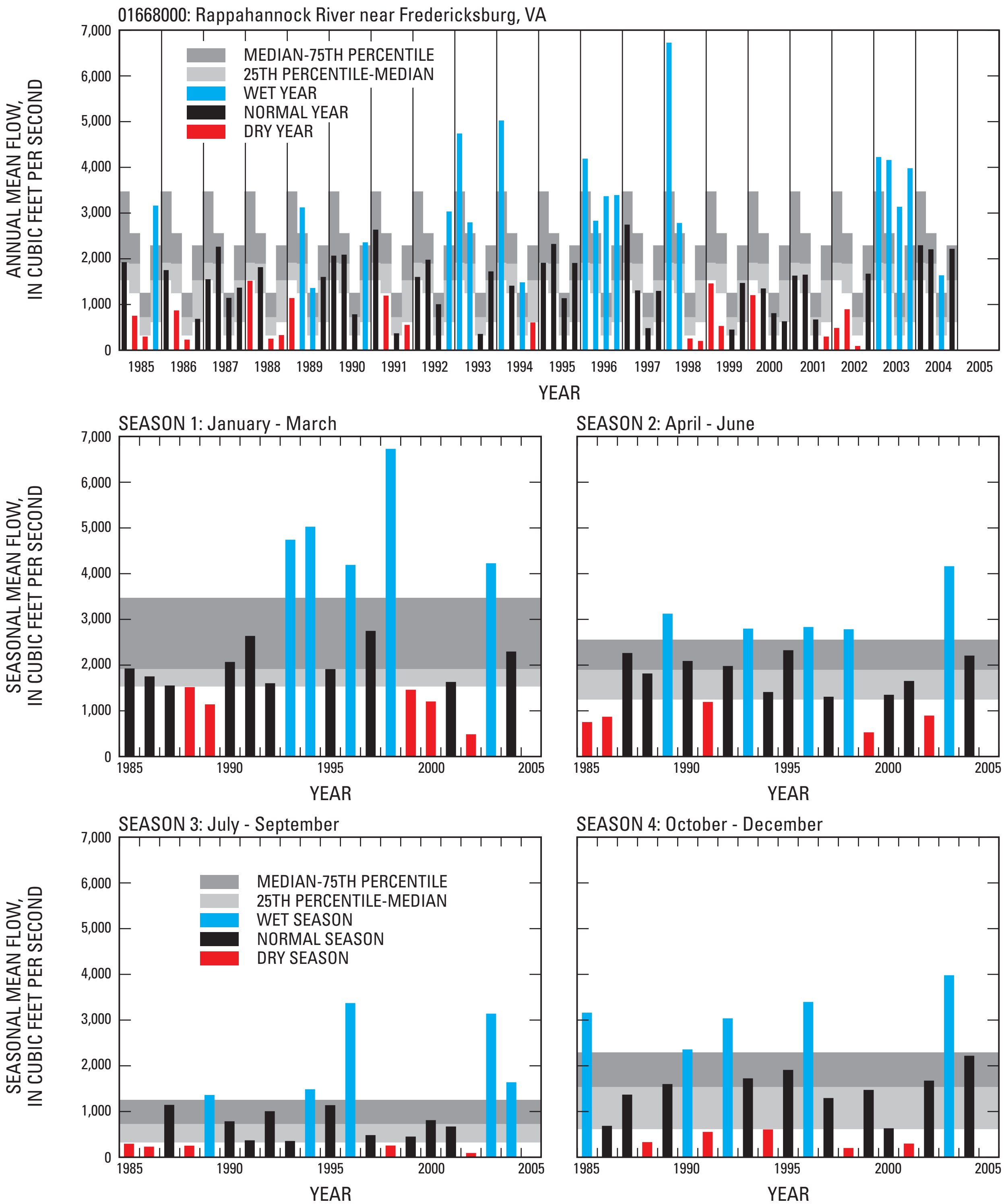

Figure 4E. (Continued) Annual and seasonal flow variations for the Rappahannock River near Fredericksburg, Virginia.

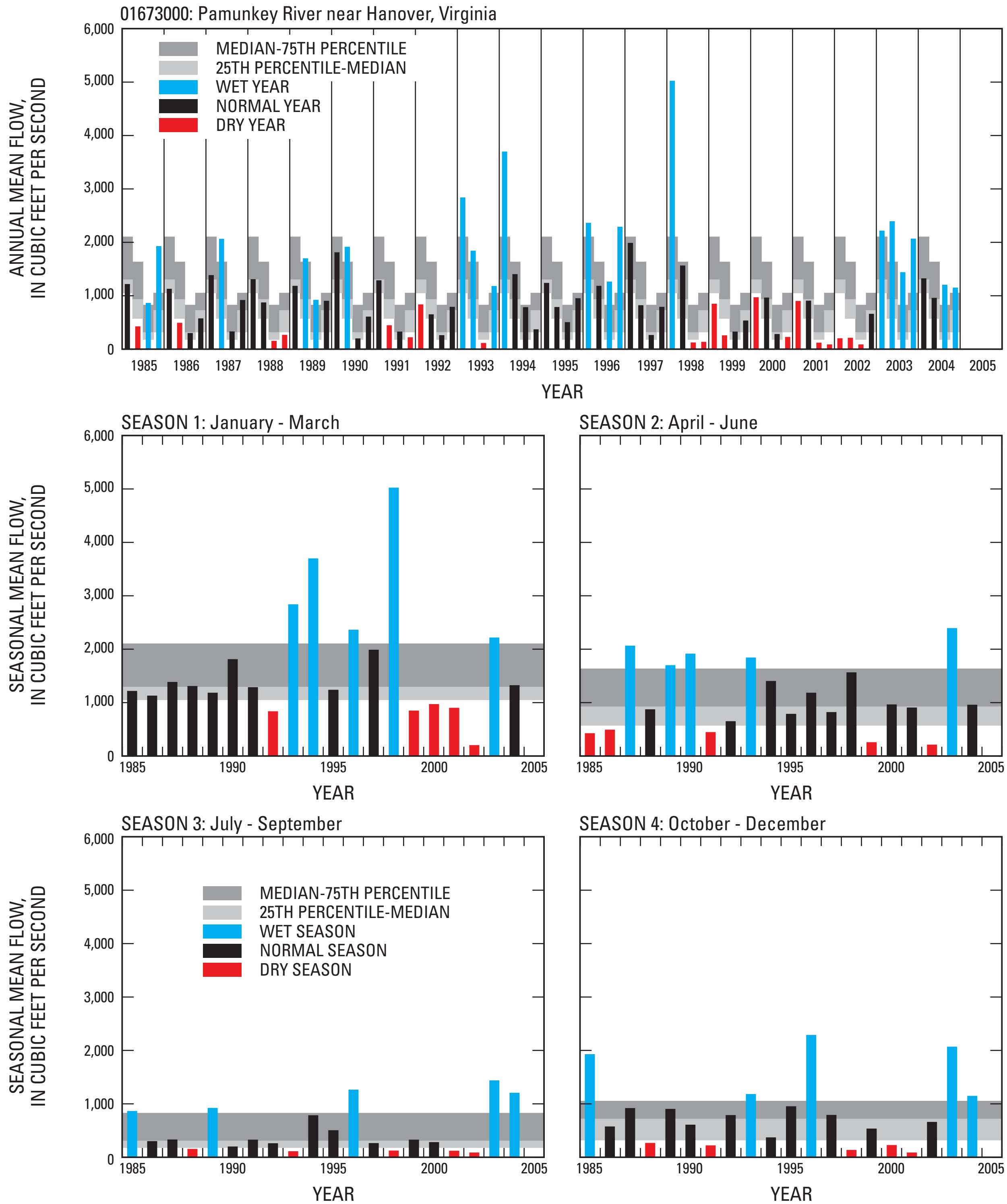

Figure 4F. (Continued) Annual and seasonal flow variations for the Pamunkey River near Hanover, Virginia.

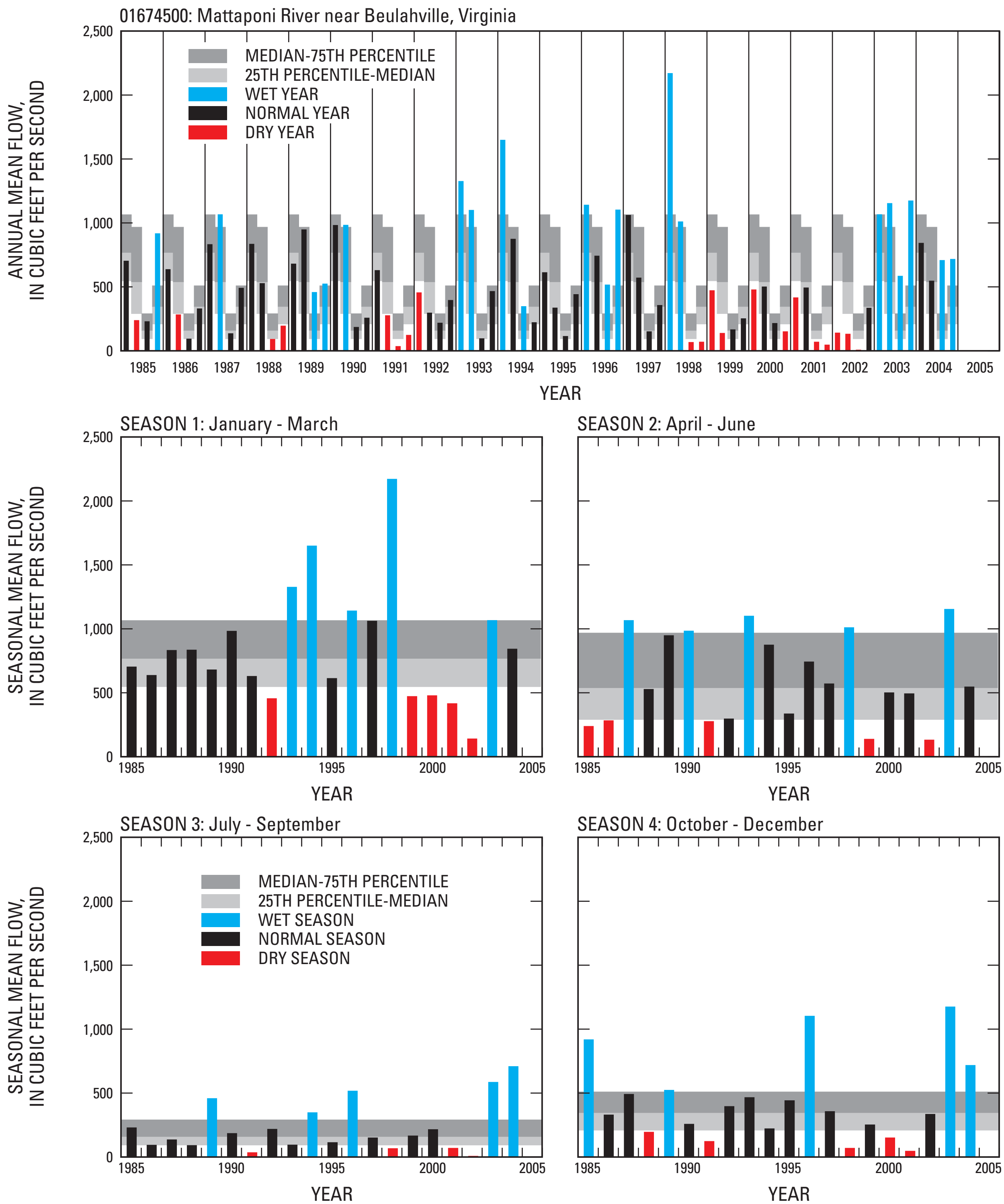

Figure 4G. (Continued) Annual and seasonal flow variations for the Mattaponi River near Beulahville, Virginia.

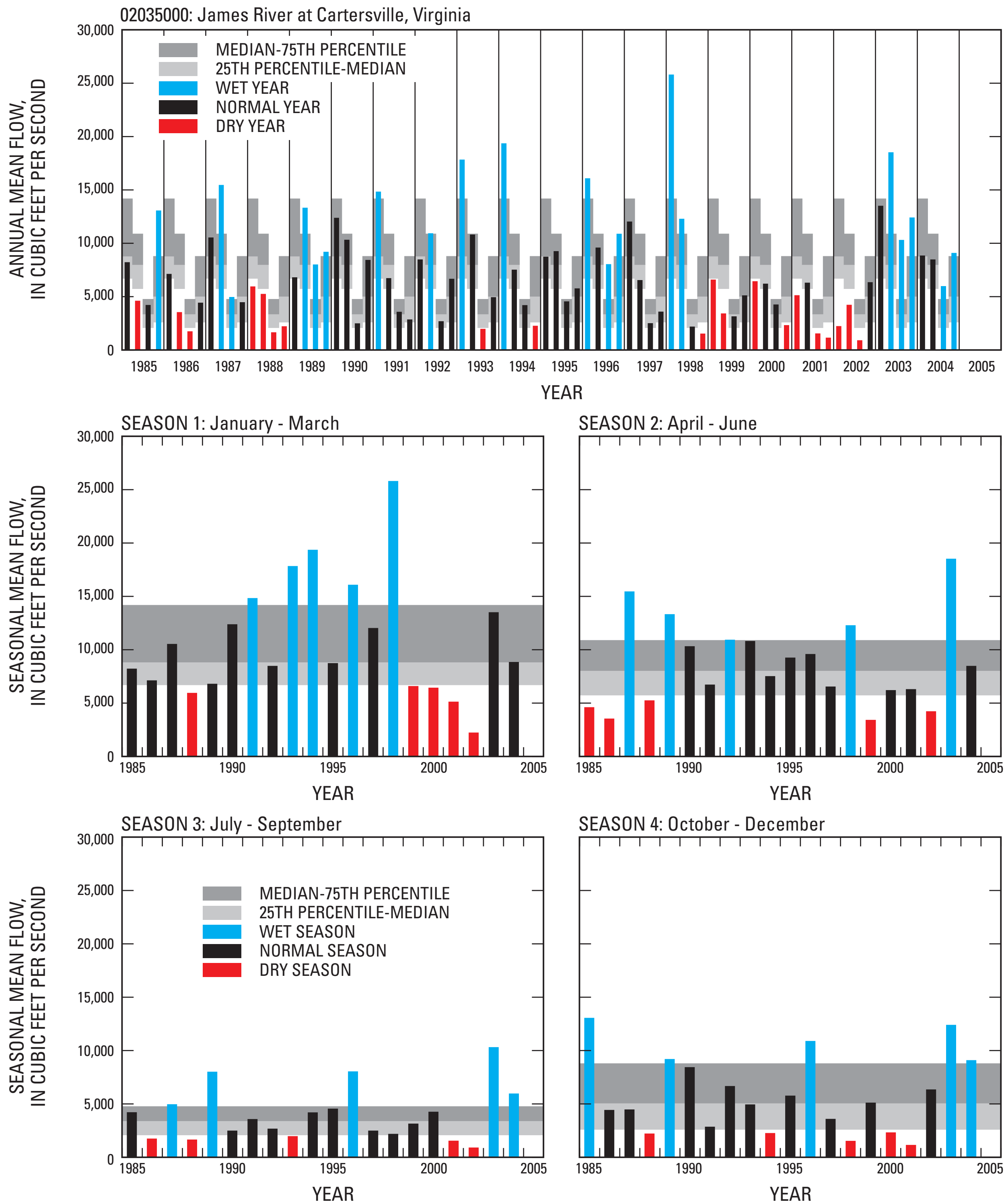

Figure 4H. (Continued) Annual and seasonal flow variations for the James River at Cartersville, Virginia.

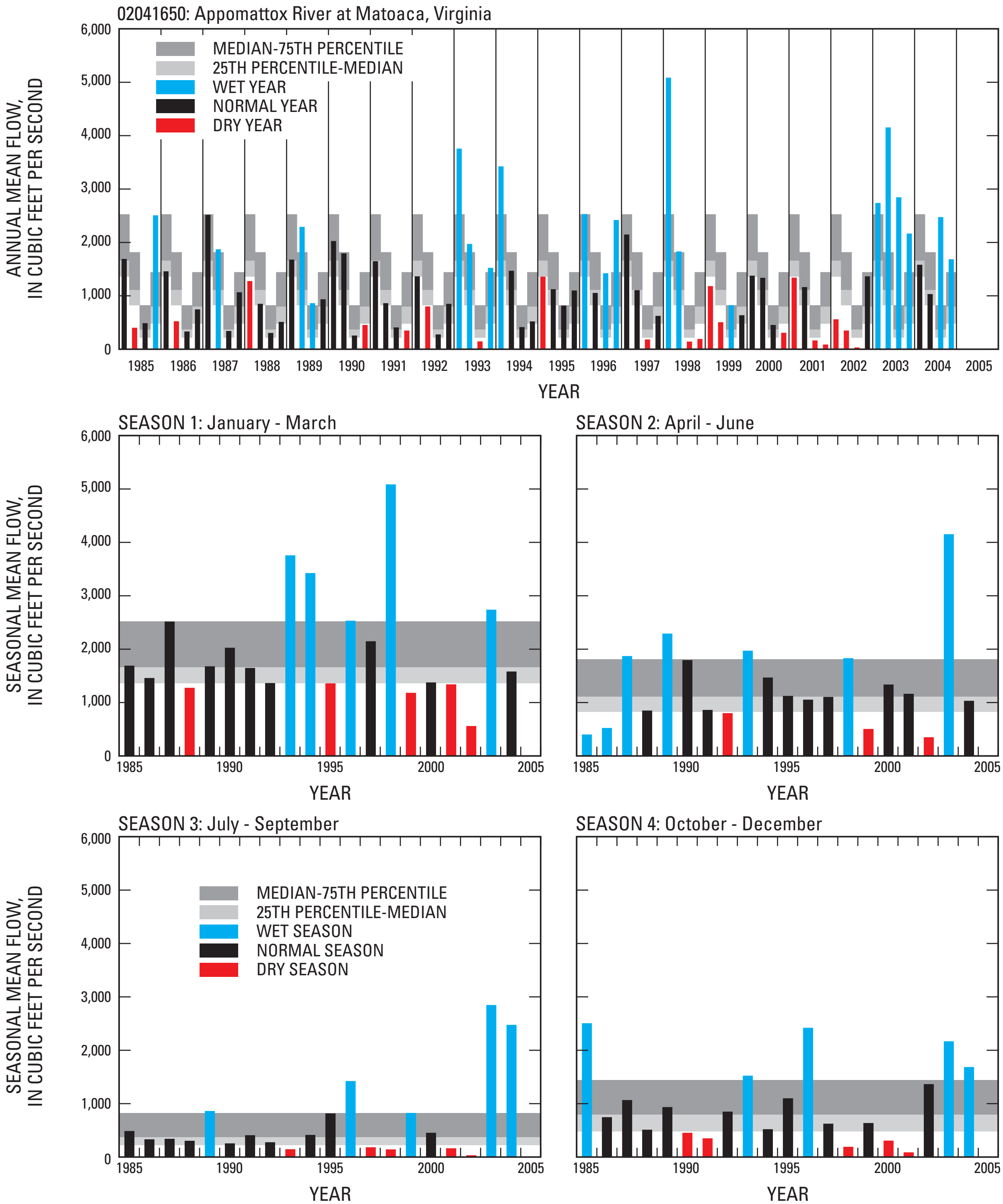

Figure 4I. (Continued) Annual and seasonal flow variations for the Appomattox River at Matoaca, Virginia.

Seasonal-Mean Flow

Variability in seasonal-mean streamflow can provide insight into climatological or hydrologic changes within a watershed for a particular season and help explain changes in the bay and tidal rivers. Total freshwater flow to the bay is estimated on a monthly basis (Bue, 1968), and results were averaged for four “seasons” (January-February-March, April-May-June, July-August-September, and October-November-December). In addition, linear regression models were developed for seasonal-mean streamflow for all 32 sites in this study.

Total freshwater flow entering the bay (fig. 2) for the summer (July-August-September) season 2004 was the highest ever estimated for that season from 1937-2004, due in large part to very large flows from the Susquehanna Basin following hurricanes in September 2004. The winter (January-February-March) and spring (April-May-June) flows were both normal (within the interquartile ranges for each season), in contrast to 2003, in which flows for all four seasons were above normal.

To investigate possible trends in seasonal-mean streamflow, linear regression models were developed for each site. As is the case for daily-mean and monthly-mean streamflow, autocorrelation within the seasonal-mean streamflow time series for each season makes trend estimation difficult. Graphical depiction of the seasonal data and some summary statistics can provide insights into variations in flow in the Chesapeake Bay watershed, however (fig. 4; app. 1).

A number of observations are common to all RIM Program sites. The drought of 1999-2002 is evident for all 9 RIM Program sites, as are the relatively wet years 2003 and 2004. For the three largest rivers (Susquehanna, Potomac, and James; fig. 4), all 12 quarters for 1999 through 2001 were normal (between the 25^{th} and 75^{th} percentiles) or dry (below the 25^{th} percentile). For all 9 RIM Program sites, all eight quarters of 2003 and 2004 exhibited normal or above-normal (above the 75^{th} percentile) flows. This is true for the 23 Multi-Agency Nontidal Monitoring Program sites in the study as well (app. 1).

Daily-Mean Flow

Regression models of daily-mean streamflow that included seasonal and 60-order autoregressive process terms were developed using data from all 32 sites. The results from these models indicated no significant trends in daily-mean streamflow for the 32 sites studied.

Changes in Water Quality

Changes in water quality shown by descriptive statistics for concentration, non-flow adjusted trends, and flow-adjusted trends for 1985-2004 are presented for all 32 of the study sites, although some sites have shorter data-collection and analysis periods. Not all trends tests previously reported (Langland and others, 2000) are presented based on the evaluation of trend procedures. The reasons for omitting specific trends tests are presented and discussed in the section “Study Methods.”

Observed Concentration

The most direct measure of change in water quality is observed-concentration data. The unbiased percentiles for the observed concentrations of TN, NO23, TP, DIP, and TSS or SED for the 32 water-quality monitoring sites are listed in table 4A-4E. TN concentrations were elevated in the northern river basins (including the Susquehanna, Choptank, Patapsco, Patuxent, and Potomac Rivers and their tributaries) compared to TN concentrations in the southern river basins (Rappahannock, Mattaponi, Pamunkey, James, and Appomattox Rivers and their tributaries).

Table 4. Unbiased percentiles for observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) suspended sediment or total suspended solids, and associated trend at the 9 River Input Monitoring Sites and the 23 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2004.

[Units given in milligrams per liter. NS, not significant; SIG-DOWN, significant downward trend; SIG-UP, significant upward trend]

(A) Nitrogen, as N

Site name	Map ID (fig. 1)	Site number	Percentile						Spearman's Rho p < 0.05
			10th	25th	50th	75th	90th	Mean	
River Input Monitoring Program Sites									
CHOPTANK RIVER NEAR GREENSBORO, MD	8	01491000	1.26	1.45	1.66	1.86	2.1	1.68	NS
SUSQUEHANNA RIVER AT CONOWINGO, MD	7	01578310	1.11	1.33	1.6	1.97	2.3	1.7	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	11	01594440	1.7	1.95	2.52	3.98	5.33	3.11	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	23	01646580	1.09	1.41	1.7	2.02	2.38	1.75	NS
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	25	01668000	0.28	0.48	0.78	1.01	1.38	0.81	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	26	01674500	0.41	0.48	0.57	0.68	0.8	0.59	NS
PAMUNKEY RIVER NEAR HANOVER, VA	28	01673000	0.48	0.56	0.66	0.83	0.97	0.71	SIG-UP
JAMES RIVER AT CARTERSVILLE, VA	30	02035000	0.29	0.36	0.52	0.69	0.9	0.58	SIG-DOWN
APPOMATTOX RIVER AT MATOACA, VA	32	02041650	0.39	0.46	0.55	0.66	0.8	0.58	NS
Multi-Agency Nontidal Monitoring Program Sites									
SUSQUEHANNA RIVER AT TOWANDA, PA	1	01531500	0.79	0.91	1.1	1.32	1.63	1.15	SIG-DOWN
SUSQUEHANNA RIVER AT DANVILLE, PA	2	01540500	0.77	0.92	1.12	1.43	1.8	1.24	SIG-DOWN
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	3	01553500	0.7	0.83	1	1.23	1.5	1.09	NS
JUNIATA RIVER AT NEWPORT, PA	4	01567000	0.95	1.38	1.68	1.92	2.38	1.67	NS
SUSQUEHANNA RIVER AT MARIETTA, PA	5	01576000	1.03	1.26	1.5	1.9	2.28	1.62	NS
CONESTOGA RIVER AT CONESTOGA, PA	6	01576754	5.8	6.86	8.13	9.49	10.62	8.18	NS
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	9	01586000	2.95	3.6	4.3	4.8	5.14	4.18	NS
PATUXENT RIVER NEAR LAUREL, MD	10	01592500	1.23	1.5	1.71	1.98	2.1	1.74	NS
GEORGES CREEK AT FRANKLIN, MD	12	01599000	0.94	1.17	1.54	1.89	2.25	1.55	SIG-DOWN
WILLS CREEK NEAR CUMBERLAND, MD	13	01601500	0.36	0.49	0.8	1.37	1.84	0.98	SIG-DOWN
POTOMAC RIVER AT PAW PAW, WV	14	01610000	0.69	0.89	1.05	1.23	1.52	1.08	SIG-DOWN
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	15	01614500	3.39	3.8	4.5	5.2	5.82	4.61	SIG-DOWN
ANTIETAM CREEK NEAR SHARPSBURG, MD	16	01619500	4.02	4.63	5.39	6.01	6.6	5.32	SIG-DOWN
SOUTH RIVER NEAR WAYNESBORO, VA	17	01626000	0.65	0.73	0.85	1.04	1.22	0.91	NS
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	18	01631000	0.64	1.03	1.35	1.71	2	1.38	NS
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	19	01634000	0.95	1.4	1.9	2.38	2.8	1.91	NS
MONOCACY RIVER AT BRIDGEPORT, MD	20	01639000	0.95	1.28	1.91	2.85	3.6	2.14	NS
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	21	01643000	2.66	3.05	3.57	4.06	4.65	3.58	NS
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	22	01651000	0.99	1.31	1.58	1.92	2.48	1.76	SIG-DOWN
ROBINSON RIVER NEAR LOCUST DALE, VA	24	01666500	0.57	0.65	0.76	0.96	1.14	0.83	NS
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	01671020	0.25	0.34	0.42	0.52	0.63	0.44	NS
JAMES RIVER AT BENT CREEK, VA	29	02026000	0.43	0.51	0.66	0.9	0.91	0.69	NS
JAMES RIVER NEAR RICHMOND, VA	31	02037500	0.34	0.44	0.53	0.6	0.7	0.54	NS

Table 4. (Continued) Unbiased percentiles for observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) suspended sediment or total suspended solids, and associated trend at the 9 River Input Monitoring Sites and the 23 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2004.

[Units given in milligrams per liter. NS, not significant; SIG-DOWN, significant downward trend; SIG-UP, significant upward trend]

(B) Nitrite plus Nitrate, as N

Site name	Map ID (fig. 1)	Site number	Percentile						Spearman's Rho p < 0.05
			10th	25th	50th	75th	90th	Mean	
River Input Monitoring Program Sites									
CHOPTANK RIVER NEAR GREENSBORO, MD	8	01491000	0.724	0.94	1.168	1.4	1.57	1.164	SIG-UP
SUSQUEHANNA RIVER AT CONOWINGO, MD	7	01578310	0.65	0.9	1.16	1.4	1.767	1.199	NS
PATUXENT RIVER NEAR BOWIE, MD	11	01594440	1.03	1.3	1.6	2.5	3.88	2.067	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	23	01646580	0.62	0.98	1.29	1.55	1.87	1.278	NS
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	25	01668000	<0.040	0.177	0.471	0.64	0.788	<0.439	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	26	01674500	0.07	0.1	0.14	0.196	0.237	0.152	NS
PAMUNKEY RIVER NEAR HANOVER, VA	28	01673000	0.148	0.2	0.275	0.327	0.446	0.287	SIG-UP
JAMES RIVER AT CARTERSVILLE, VA	30	02035000	<0.040	0.079	0.21	0.3	0.4	<0.214	NS
APPOMATTOX RIVER AT MATOACA, VA	32	02041650	0.06	0.1	0.152	0.218	0.292	0.17	NS
Multi-Agency Nontidal Monitoring Program Sites									
SUSQUEHANNA RIVER AT TOWANDA, PA	1	01531500	0.227	0.46	0.587	0.77	0.962	0.607	NS
SUSQUEHANNA RIVER AT DANVILLE, PA	2	01540500	0.237	0.44	0.639	0.85	1.1	0.657	SIG-DOWN
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	3	01553500	0.46	0.535	0.67	0.84	0.984	0.707	NS
JUNIATA RIVER AT NEWPORT, PA	4	01567000	0.563	1	1.28	1.543	1.76	1.253	NS
SUSQUEHANNA RIVER AT MARIETTA, PA	5	01576000	0.44	0.7	0.96	1.29	1.701	1.037	NS
CONESTOGA RIVER AT CONESTOGA, PA	6	01576754	4.389	5.67	6.83	8.048	9.293	6.836	NS
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	9	01586000	–	–	–	–	–	–	–
PATUXENT RIVER NEAR LAUREL, MD	10	01592500	–	–	–	–	–	–	–
GEORGES CREEK AT FRANKLIN, MD	12	01599000	–	–	–	–	–	–	–
WILLS CREEK NEAR CUMBERLAND, MD	13	01601500	–	–	–	–	–	–	–
POTOMAC RIVER AT PAW PAW, WV	14	01610000	–	–	–	–	–	–	–
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	15	01614500	2.9	3.291	3.889	4.6	5.1	3.962	NS
ANTIETAM CREEK NEAR SHARPSBURG, MD	16	01619500	–	–	–	–	–	–	–
SOUTH RIVER NEAR WAYNESBORO, VA	17	01626000	–	–	–	–	–	–	–
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	18	01631000	–	–	–	–	–	–	–
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	19	01634000	–	–	–	–	–	–	–
MONOCACY RIVER AT BRIDGEPORT, MD	20	01639000	–	–	–	–	–	–	–
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	21	01643000	–	–	–	–	–	–	–
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	22	01651000	–	–	–	–	–	–	–
ROBINSON RIVER NEAR LOCUST DALE, VA	24	01666500	–	–	–	–	–	–	–
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	01671020	–	–	–	–	–	–	–
JAMES RIVER AT BENT CREEK, VA	29	02026000	–	–	–	–	–	–	–
JAMES RIVER NEAR RICHMOND, VA	31	02037500	–	–	–	–	–	–	–

Table 4. (Continued) Unbiased percentiles for observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) suspended sediment or total suspended solids, and associated trend at the 9 River Input Monitoring Sites and the 23 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2004.

[Units given in milligrams per liter. NS, not significant; SIG-DOWN, significant downward trend; SIG-UP, significant upward trend]

(C) Total Phosphorus, as P

Site name	Map ID (fig. 1)	Site number	Percentile						Spearman's Rho p < 0.05
			10th	25th	50th	75th	90th	MEAN	
River Input Monitoring Program Sites									
CHOPTANK RIVER NEAR GREENSBORO, MD	8	01491000	0.02	0.039	0.052	0.08	0.11	0.063	NS
SUSQUEHANNA RIVER AT CONOWINGO, MD	7	01578310	0.02	0.03	0.04	0.054	0.08	0.046	NS
PATUXENT RIVER NEAR BOWIE, MD	11	01594440	0.06	0.09	0.14	0.229	0.391	0.193	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	23	01646580	0.02	0.04	0.06	0.1	0.15	0.085	NS
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	25	01668000	0.015	0.02	0.03	0.059	0.159	0.066	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	26	01674500	0.03	0.04	0.05	0.07	0.084	0.056	NS
PAMUNKEY RIVER NEAR HANOVER, VA	28	01673000	0.033	0.049	0.069	0.096	0.135	0.079	SIG-UP
JAMES RIVER AT CARTERSVILLE, VA	30	02035000	0.04	0.061	0.09	0.14	0.24	0.122	SIG-DOWN
APPOMATTOX RIVER AT MATOACA, VA	32	02041650	0.02	0.03	0.039	0.05	0.07	0.044	SIG-UP
Multi-Agency Nontidal Monitoring Program Sites									
SUSQUEHANNA RIVER AT TOWANDA, PA	1	01531500	0.03	0.04	0.06	0.09	0.13	0.073	SIG-DOWN
SUSQUEHANNA RIVER AT DANVILLE, PA	2	01540500	0.03	0.04	0.068	0.1	0.158	0.083	SIG-DOWN
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	3	01553500	<0.020	<0.020	0.035	0.06	0.12	<0.061	SIG-DOWN
JUNIATA RIVER AT NEWPORT, PA	4	01567000	0.021	0.04	0.064	0.1	0.14	0.084	NS
SUSQUEHANNA RIVER AT MARIETTA, PA	5	01576000	0.03	0.044	0.067	0.095	0.154	0.082	NS
CONESTOGA RIVER AT CONESTOGA, PA	6	01576754	0.11	0.16	0.241	0.4	0.609	0.335	SIG-DOWN
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	9	01586000	<0.010	0.014	0.023	0.05	0.092	<0.046	NS
PATUXENT RIVER NEAR LAUREL, MD	10	01592500	0.012	0.022	0.037	0.05	0.06	0.055	NS
GEORGES CREEK AT FRANKLIN, MD	12	01599000	0.018	0.025	0.048	0.101	0.184	0.084	SIG-DOWN
WILLS CREEK NEAR CUMBERLAND, MD	13	01601500	<0.01	<0.01	0.016	0.033	0.074	0.036	NS
POTOMAC RIVER AT PAW PAW, WV	14	01610000	0.013	0.023	0.038	0.056	0.09	0.051	NS
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	15	01614500	0.052	0.08	0.14	0.207	0.32	0.173	SIG-DOWN
ANTIETAM CREEK NEAR SHARPSBURG, MD	16	01619500	0.093	0.12	0.17	0.233	0.329	0.194	SIG-DOWN
SOUTH RIVER NEAR WAYNESBORO, VA	17	01626000	<0.100	<0.100	<0.100	<0.100	<0.100	<0.108	SIG-DOWN
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	18	01631000	<0.100	<0.100	<0.100	0.2	0.24	<0.148	NS
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	19	01634000	<0.100	<0.100	<0.100	0.2	0.33	<0.172	NS
MONOCACY RIVER AT BRIDGEPORT, MD	20	01639000	0.045	0.064	0.115	0.184	0.293	0.148	NS
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	21	01643000	0.082	0.11	0.191	0.298	0.436	0.226	NS
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	22	01651000	0.02	0.031	0.046	0.077	0.121	0.069	NS
ROBINSON RIVER NEAR LOCUST DALE, VA	24	01666500	<0.100	<0.100	<0.100	<0.100	<0.100	<0.115	SIG-DOWN
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	01671020	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	SIG-DOWN
JAMES RIVER AT BENT CREEK, VA	29	02026000	<0.100	<0.100	<0.100	0.2	0.3	<0.162	SIG-DOWN
JAMES RIVER NEAR RICHMOND, VA	31	02037500	<0.100	<0.100	<0.100	<0.100	0.2	<0.124	SIG-DOWN

Table 4. (Continued) Unbiased percentiles for observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) suspended sediment or total suspended solids, and associated trend at the 9 River Input Monitoring Sites and the 23 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2004.

[Units shown in milligrams per liter. NS, not significant; SIG-DOWN, significant downward trend; SIG-UP, significant upward trend]

(D) Dissolved Inorganic Phosphorus, as P

Site name	Map ID (fig. 1)	Site number	Percentile						Spearman's Rho p < 0.05
			10th	25th	50th	75th	90th	MEAN	
River Input Monitoring Program Sites									
CHOPTANK RIVER NEAR GREENSBORO, MD	8	01491000	<0.010	<0.010	0.018	0.03	0.04	<0.022	NS
SUSQUEHANNA RIVER AT CONOWINGO, MD	7	01578310	<0.010	<0.010	<0.010	0.011	0.022	<0.013	NS
PATUXENT RIVER NEAR BOWIE, MD	11	01594440	<0.020	0.024	0.042	0.07	0.15	<0.069	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	23	01646580	<0.020	<0.020	<0.020	0.04	0.07	<0.036	NS
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	25	01668000	<0.010	<0.010	<0.010	0.017	0.028	<0.015	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	26	01674500	<0.010	<0.010	0.011	0.02	0.03	<0.017	NS
PAMUNKEY RIVER NEAR HANOVER, VA	28	01673000	<0.010	0.015	0.025	0.043	0.074	<0.035	NS
JAMES RIVER AT CARTERSVILLE, VA	30	02035000	0.016	0.025	0.045	0.08	0.14	0.066	SIG-DOWN
APPOMATTOX RIVER AT MATOACA, VA	32	02041650	<0.010	<0.010	<0.010	0.014	0.02	<0.014	NS
Multi-Agency Nontidal Monitoring Program Sites									
SUSQUEHANNA RIVER AT TOWANDA, PA	1	01531500	–	–	–	–	–	–	–
SUSQUEHANNA RIVER AT DANVILLE, PA	2	01540500	–	–	–	–	–	–	–
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	3	01553500	–	–	–	–	–	–	–
JUNIATA RIVER AT NEWPORT, PA	4	01567000	–	–	–	–	–	–	–
SUSQUEHANNA RIVER AT MARIETTA, PA	5	01576000	–	–	–	–	–	–	–
CONESTOGA RIVER AT CONESTOGA, PA	6	01576754	–	–	–	–	–	–	–
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	9	01586000	–	–	–	–	–	–	–
PATUXENT RIVER NEAR LAUREL, MD	10	01592500	–	–	–	–	–	–	–
GEORGES CREEK AT FRANKLIN, MD	12	01599000	–	–	–	–	–	–	–
WILLS CREEK NEAR CUMBERLAND, MD	13	01601500	–	–	–	–	–	–	–
POTOMAC RIVER AT PAW PAW, WV	14	01610000	–	–	–	–	–	–	–
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	15	01614500	0.03	0.042	0.078	0.13	0.209	0.103	SIG–DOWN
ANTIETAM CREEK NEAR SHARPSBURG, MD	16	01619500	–	–	–	–	–	–	–
SOUTH RIVER NEAR WAYNESBORO, VA	17	01626000	–	–	–	–	–	–	–
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	18	01631000	0.037	0.052	0.1	0.148	0.18	0.106	NS
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	19	01634000	<0.020	0.04	0.1	0.17	0.247	<0.121	SIG–UP
MONOCACY RIVER AT BRIDGEPORT, MD	20	01639000	–	–	–	–	–	–	–
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	21	01643000	–	–	–	–	–	–	–
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	22	01651000	–	–	–	–	–	–	–
ROBINSON RIVER NEAR LOCUST DALE, VA	24	01666500	–	–	–	–	–	–	–
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	01671020	–	–	–	–	–	–	–
JAMES RIVER AT BENT CREEK, VA	29	02026000	–	–	–	–	–	–	–
JAMES RIVER NEAR RICHMOND, VA	31	02037500	–	–	–	–	–	–	–

Table 4. (Continued) Unbiased percentiles for observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) suspended sediment or total suspended solids, and associated trend at the 9 River Input Monitoring Sites and the 23 Multi-Agency Nontidal Monitoring Program sites in the Chesapeake Bay watershed, 1985-2004.

[Units shown in milligrams per liter. NS, not significant; SIG-DOWN, significant downward trend; SIG-UP, significant upward trend]

(E) Suspended Sediment Concentration or Total Suspended Solids

Site name	Map ID (fig. 1)	Site number	Percentile						Spearman's Rho p < 0.05
			10th	25th	50th	75th	90th	MEAN	
River Input Monitoring Program Sites									
CHOPTANK RIVER NEAR GREENSBORO, MD	8	01491000	2	3	5	9	20	9	NS
SUSQUEHANNA RIVER AT CONOWINGO, MD	7	01578310	4	6	9	14	22	14	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	11	01594440	6	11	19	46	100	44	NS
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	23	01646580	3	5	10	24	60	30	NS
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	25	01668000	<3	<3	4	14	70	<29	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	26	01674500	<5	<5	<5	10	17	<9	NS
PAMUNKEY RIVER NEAR HANOVER, VA	28	01673000	5	5	7	20	45	20	NS
JAMES RIVER AT CARTERSVILLE, VA	30	02035000	<3	<3	6	28	87	<32	NS
APPOMATTOX RIVER AT MATOACA, VA	32	02041650	<3	<3	5	9	17	<8	NS
Multi-Agency Nontidal Monitoring Program Sites									
SUSQUEHANNA RIVER AT TOWANDA, PA	1	01531500	2	5	10	27	70	35	NS
SUSQUEHANNA RIVER AT DANVILLE, PA	2	01540500	4	8	14	32	80	36	NS
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	3	01553500	2	3	6	15	42	24	NS
JUNIATA RIVER AT NEWPORT, PA	4	01567000	2	4	11	29	57	25	NS
SUSQUEHANNA RIVER AT MARIETTA, PA	5	01576000	4	7	16	39	83	38	NS
CONESTOGA RIVER AT CONESTOGA, PA	6	01576754	4	9	21	56	210	125	SIG-DOWN
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	9	01586000	<2	3	5	11	24	<14	NS
PATUXENT RIVER NEAR LAUREL, MD	10	01592500	3	4	6	9	15	8	NS
GEORGES CREEK AT FRANKLIN, MD	12	01599000	4	10	16	24	39	23	NS
WILLS CREEK NEAR CUMBERLAND, MD	13	01601500	<2	<2	6	12	22	<14	NS
POTOMAC RIVER AT PAW PAW, WV	14	01610000	<2	<2	6	14	24	<13	NS
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	15	01614500	<1	3	7	16	34	<19	NS
ANTIETAM CREEK NEAR SHARPSBURG, MD	16	01619500	<2	5	10	18	31	<14	NS
SOUTH RIVER NEAR WAYNESBORO, VA	17	01626000	<5	<5	<5	9	16	<8	NS
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	18	01631000	<5	<5	<5	8	20	<11	NS
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	19	01634000	<5	<5	<5	<5	10	<10	NS
MONOCACY RIVER AT BRIDGEPORT, MD	20	01639000	<2	5	9	18	33	<15	NS
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	21	01643000	<2	5	10	22	55	<23	NS
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	22	01651000	2	3	7	15	43	21	NS
ROBINSON RIVER NEAR LOCUST DALE, VA	24	01666500	<5	<5	<5	10	26	<14	NS
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	27	01671020	<5	<5	<5	<5	8	<7	NS
JAMES RIVER AT BENT CREEK, VA	29	02026000	<5	<5	<5	9	19	<12	NS
JAMES RIVER NEAR RICHMOND, VA	31	02037500	<5	<5	<5	9	25	<14	NS

The median (50th percentile) TN concentrations in the northern basins ranged from 0.80 to 8.13 mg/L (milligrams per liter), compared to the median TN concentrations in the southern basins that ranged from 0.42 to 0.93 mg/L (table 4A). Similarly, median concentrations of NO23 in the northern basins were elevated, ranging from 0.67 to 6.83 mg/L, compared to the range of median concentrations in the southern basins of 0.14 to 0.47 mg/L (table 4B). The Conestoga River at Conestoga, Pa. (site number 01576754) had the highest TN and NO23 concentrations for all percentiles (10th, 25th, 50th, 75th, and 90th) (table 4A-4B).

The Spearman rho analysis indicated that 43 percent of the monitoring sites in the northern basins exhibited significant downward trends in TN, based on the unbiased 50th percentiles (table 4A). In the Susquehanna River Basin, 2 mainstem sites, Susquehanna River at Towanda, Pa. (site number 01531500) and Susquehanna River at Danville, Pa (site number 01540500) and the RIM Program site, Susquehanna River at Conowingo (site number 01578310) had significant downward trends in TN. Two additional mainstem sites exhibited significant downward trends in the 50th percentile of TN. These sites are the Patuxent River near Bowie, Md. (site number 01574400) and the Potomac River at Paw Paw, W.Va. (site number 01610000). All other significant downward trends in the 50th percentile were observed in smaller tributary basins (table 4A). In the southern basins, the Spearman rho analysis showed that only 2 of the 9 basins had significant trends in the 50th percentile with time. The Pamunkey River RIM Program site (site number 01673000) had a significant upward trend and the James River RIM Program site (02035000) had a significant downward trend in TN. The significant coefficients for the Spearman rho analysis for TN and NO23 are listed in appendixes 2.1A and 2.1B.

Concentrations of TP were elevated in the northern river basins compared to TP concentrations in the southern river basins. The median TP concentrations in the northern basins ranged from 0.023 to 0.241 mg/L, compared to the median TP concentrations in the southern basins that ranged from approximately 0.030 to 0.090 mg/L (table 4C). Median concentrations of DIP in the northern basins were approximately double the median concentrations that were observed in the southern basins (table 4D). The range of median DIP concentrations in the northern and southern basins was 0.018 to 0.10 mg/L and approximately 0.010 to 0.045 mg/L, respectively.

The Spearman rho analysis identified that there was a significant downward trend in TP at 9 of the 23 monitoring sites in the northern basins (table 4C). In the Susquehanna River Basin, 2 mainstem sites (Susquehanna River at Towanda, Pa., and Susquehanna River at Danville, Pa.) and the West Branch River site at Lewisburg, Pa., had significant downward trends in TP. Additionally, a downward trend was detected for median TP concentrations at the Conestoga River at Conestoga, Pa. Five other water-quality monitoring sites also showed downward trends in median concentrations of TP—the Patuxent River near Bowie, Md.; Georges Creek near Franklin, Md.; Conococheague Creek at Fairview, Md.; Antietam Creek near Sharpsburg, Md.; and South River near Waynesboro, Va. (table 4C). In the southern basins, 7 of the 9 sites had significant trends over time for median TP concentrations. Of the 7 sites that had significant trends, 5 exhibited significant downward trends in TP—the Robinson River near Locust Dale, Va.; North Anna River at Hart Corner near Doswel, Va.; James River at Bent Creek, Va.; James River at Cartersville, Va.; and James River near Richmond, Va. (table 4C). Two sites in the southern river basins exhibited significant upward trends for median TP concentration over time. These sites are both RIM Program sites and are the Pamunkey River near Hanover, Va. (site number 01673000) and the Appomattox River at Matoaca, Va. (02041650). Significant coefficients for the Spearman rho analysis for TP and DIP are listed in appendix 2.1.

Geographic differences also were observed for median concentrations of total TSS or SED. In the northern basins, the range in median suspended-sediment concentration was <5 to 21 mg/L, with 10 of the 23 sites having median concentrations greater than or equal to 10 mg/L. In the southern basins, the range in median suspended-sediment concentration was <5 to 7 mg/L, with 7 of the 9 sites having median concentrations of 5 mg/L or less (table 4E). The 2 monitoring sites with the highest concentrations of SED for all unbiased percentiles (10th, 25th, 50th, 75th, and 90th) are the Conestoga River at Conestoga, Pa. (site number 01576754), with a range of 4 to 210 mg/L, and the Patuxent River near Bowie, Md. (site number 01594440), with a concentration range of 6 to 100 mg/L. The 2 sites with the lowest concentration of SED across all percentiles are the North Anna River at Hart Corner near Doswel, Va. (site number 01671020) with a concentration range of <3 to 8 mg/L, and the North Fork Shenandoah River near Strasburg, Va. (site number 01634000) with a concentration range of <5 to 10 mg/L. The Spearman rho analysis identified that there was a significant downward trend in median SED concentrations with respect to time at 2 of the 32 monitoring sites (table 4E). Both of these sites are in the Susquehanna River Basin—the Conestoga River at Conestoga, Pa. (site number 01576754), and the Susquehanna River at Conowingo, Md. (site number 01578310). An additional 9 sites also had significant downward trends in SED with time in the other percentiles. The significant coefficients for the Spearman rho analysis for SED are listed in appendix 2.1.

The unbiased percentiles (10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles) and unbiased mean for TN, NO23, TP, DIP, and SED collected at the 9 RIM Program sites during 1985-2004 are shown in figure 5A-5E. TN and NO23 concentrations generally were elevated at the Susquehanna, Potomac, Patuxent, and Choptank RIM Program sites, ranging from 0.3 to 10 mg/L, compared to the concentrations observed at the Rappahannock, Mattaponi, Pamunkey, James, and Appomattox RIM Program sites, ranging from 0.2 to 1.3 mg/L.

TP concentrations at each of the 9 RIM Program sites typically ranged from 0.02 to 0.20 mg/L whereas concentrations of DIP typically ranged from 0.01 to 0.08 mg/L (fig. 5). TP and DIP concentrations were highest at the Patuxent and James RIM Program sites. SED concentrations also were similar at each of the 9 RIM Program sites, and typically ranged from 3 to 100 mg/L with the highest concentrations reported at the Patuxent RIM Program site. Annual distribution of the unbiased percentiles and mean for TN, NO23, TP, DIP, and SED collected at each of the RIM Program sites are shown in figure 6A-6I. Annual distributions of TN, NO23, TP, DIP, and SED for each of 23 Multi-Agency Nontidal Monitoring Program sites are presented in appendix 2.2.

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. In 2004, combined estimated TN loads for the RIM Program sites were the third highest since 1990, while TP and SED loads were the fifth highest (fig. 7A-7C). For the major nutrients and sediments of concern, combined estimated TN loads for the RIM Program sites declined by nearly 50 Mlbs (million pounds) to 304 Mlbs as compared to 2003 (fig. 7A), TP load was 16 Mlbs, a decrease of 12 Mlbs compared to 2003 (fig. 7C), and SED load was 10,200 Mlbs, a decrease of 8,300 Mlbs compared to 2003 (fig. 7E). Loads for TN, TP, and SED, however, were still greater than the long-term annual mean load by 48, 15, and 25 percent, respectively. Annual loads and streamflow are also presented for NO23 (fig. 7B) and DIP (fig. 7D). The loads at the RIM Program sites represent drainage from approximately 78 percent of the watershed and do not include load information for the remaining 22 percent of the watershed.

In 2003, prolonged high-flow conditions and elevated concentrations of TN, TP, and sediment resulted in one of the greatest annual loads of nutrients and sediment delivered to the Chesapeake Bay since monitoring began in the late 1980s (Langland and others, 2004). In contrast, combined flows at the RIM Program sites in 2004 decreased by about 15 percent, with resulting load decreases of 15 percent in TN, and approximately 45 percent reductions in TP and sediment as compared to 2003. While nitrogen concentrations showed only slight changes at the RIM Program sites between the 2 years (fig. 6), there were more significant reductions in concentrations of TP and SED at most of the RIM Program sites.

A general north-south asymmetry in runoff from the RIM basins in 2004 resulted in the Susquehanna being the only basin with higher flows in 2004 than in 2003. All other basins experienced a decline in runoff from 2003 to 2004. As a result, loads for all constituents for the 8 RIM basins, excluding the Susquehanna, were lower in 2004 than in 2003 (app. 3). For the Susquehanna, estimated nutrient loads were lower in 2004 than in 2003 (although the confidence intervals overlapped), but sediment loads more than doubled from 2003 to 2004 (from 2,600 to 6,400 Mlbs).

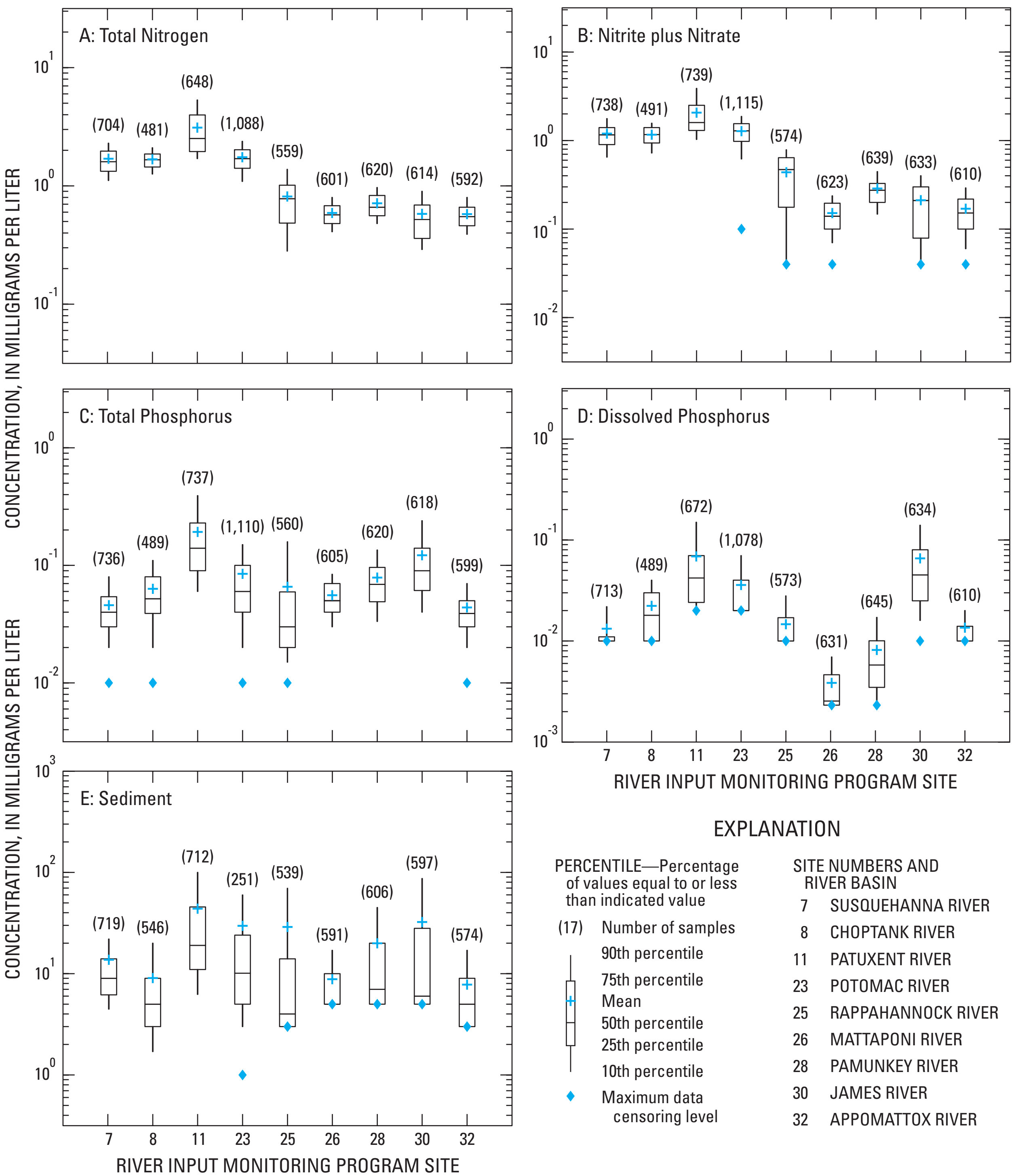

Figure 5. Unbiased distribution and mean of observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment for the 9 River Input Monitoring Program sites, Chesapeake Bay watershed, 1985-2004.

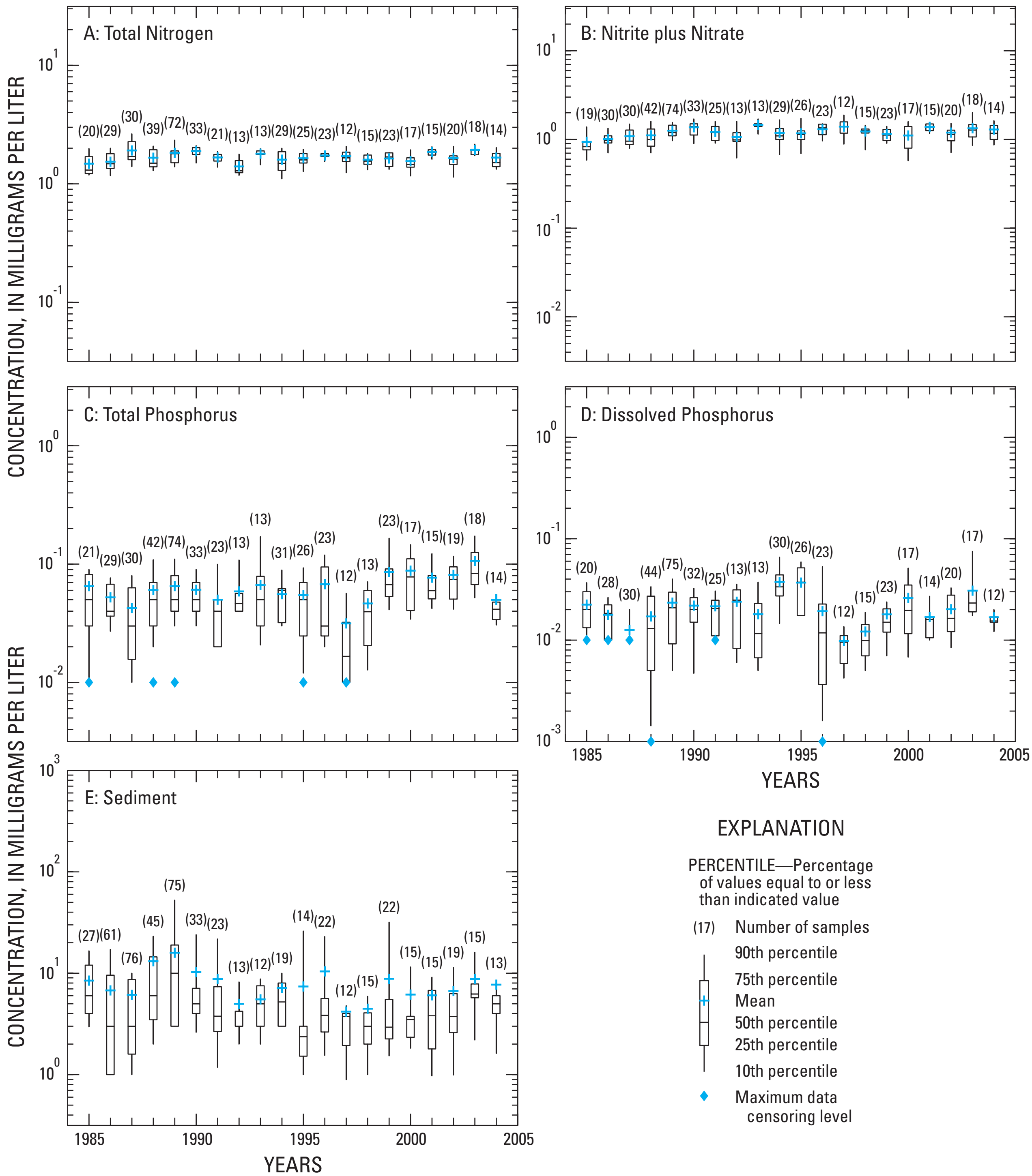

Figure 6A. Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Choptank River in the Chesapeake Bay watershed, 1985-2004.

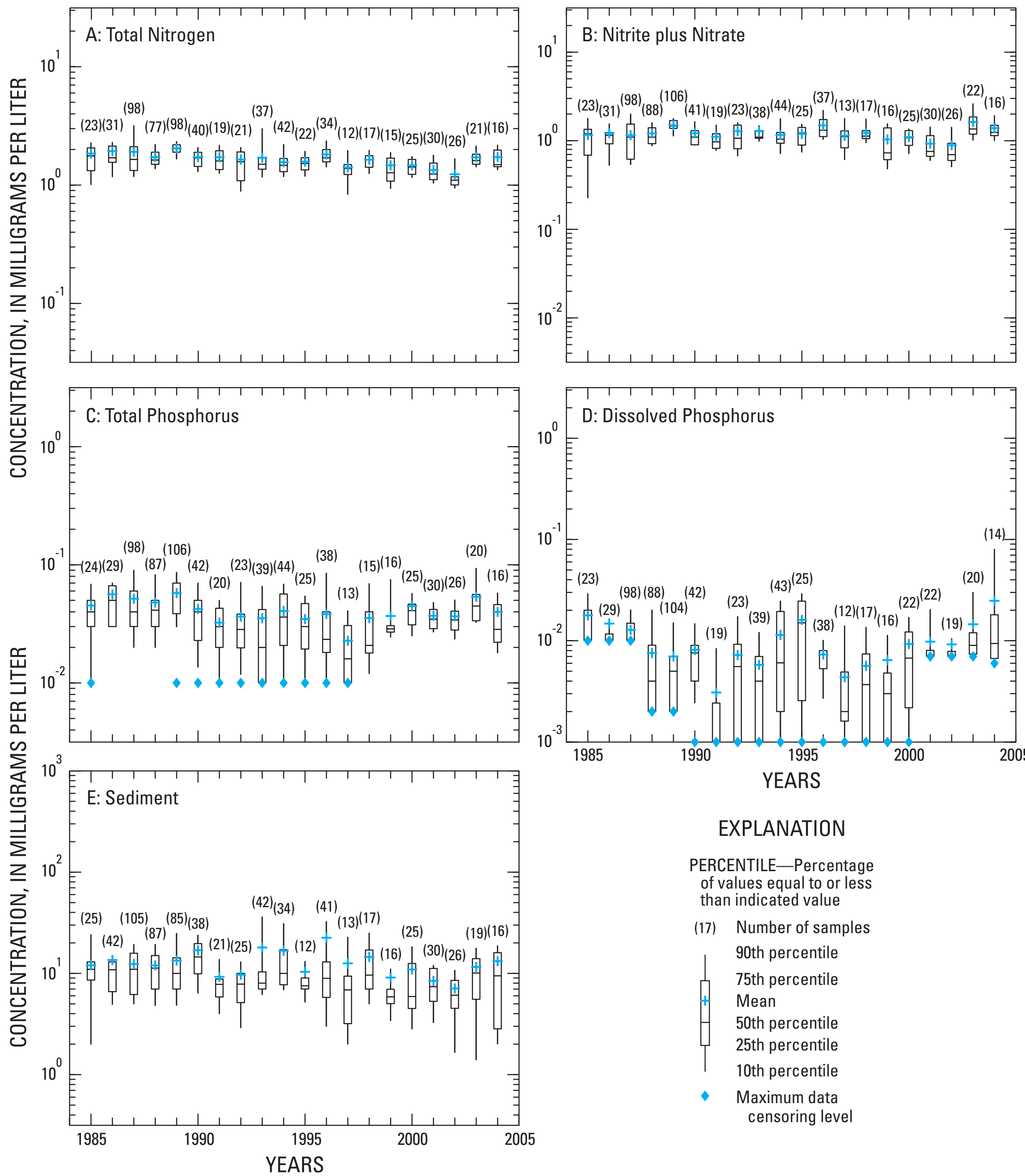

Figure 6B. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Susquehanna River in the Chesapeake Bay watershed, 1985-2004.

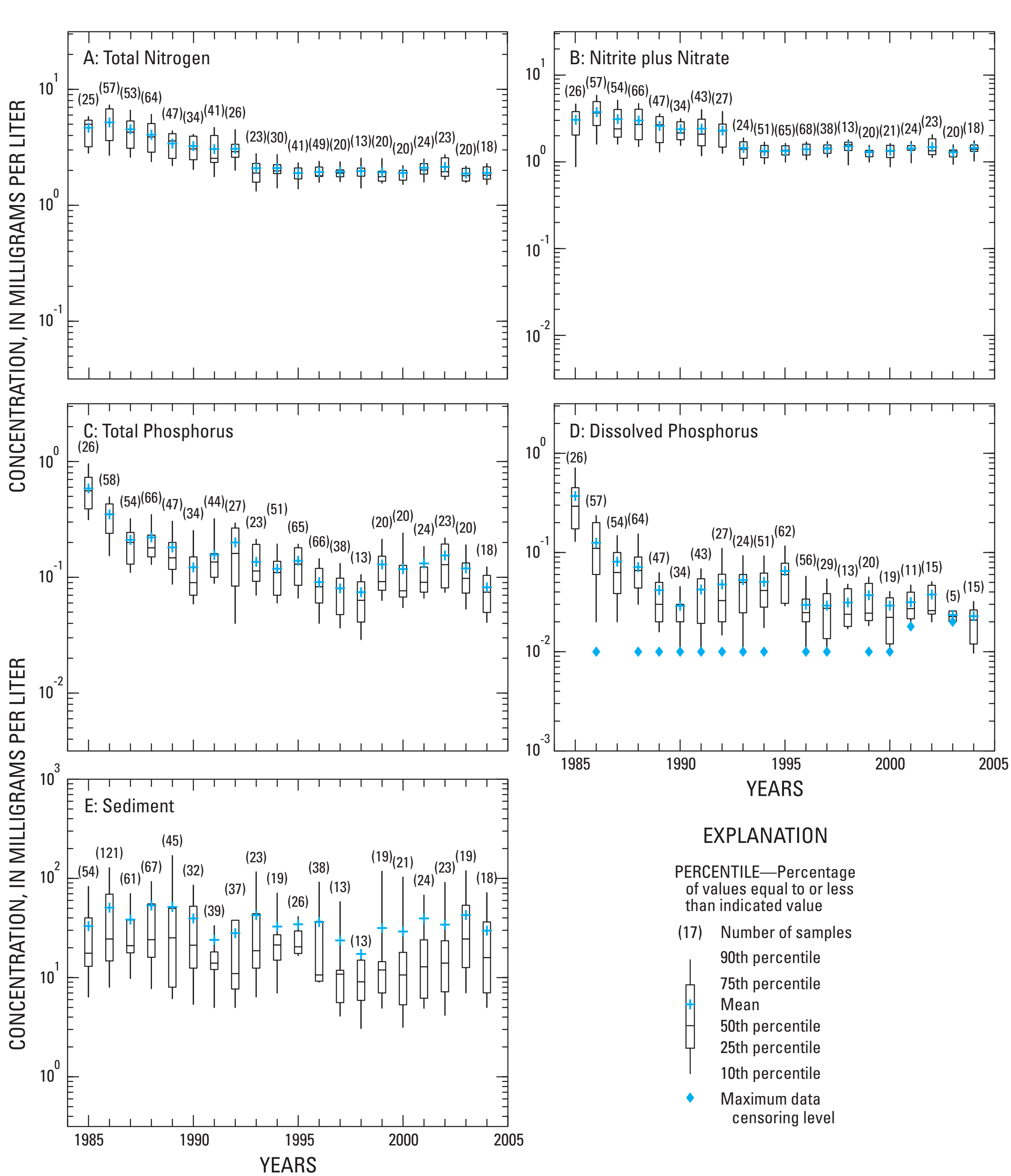

Figure 6C. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Patuxent River in the Chesapeake Bay watershed, 1985-2004.

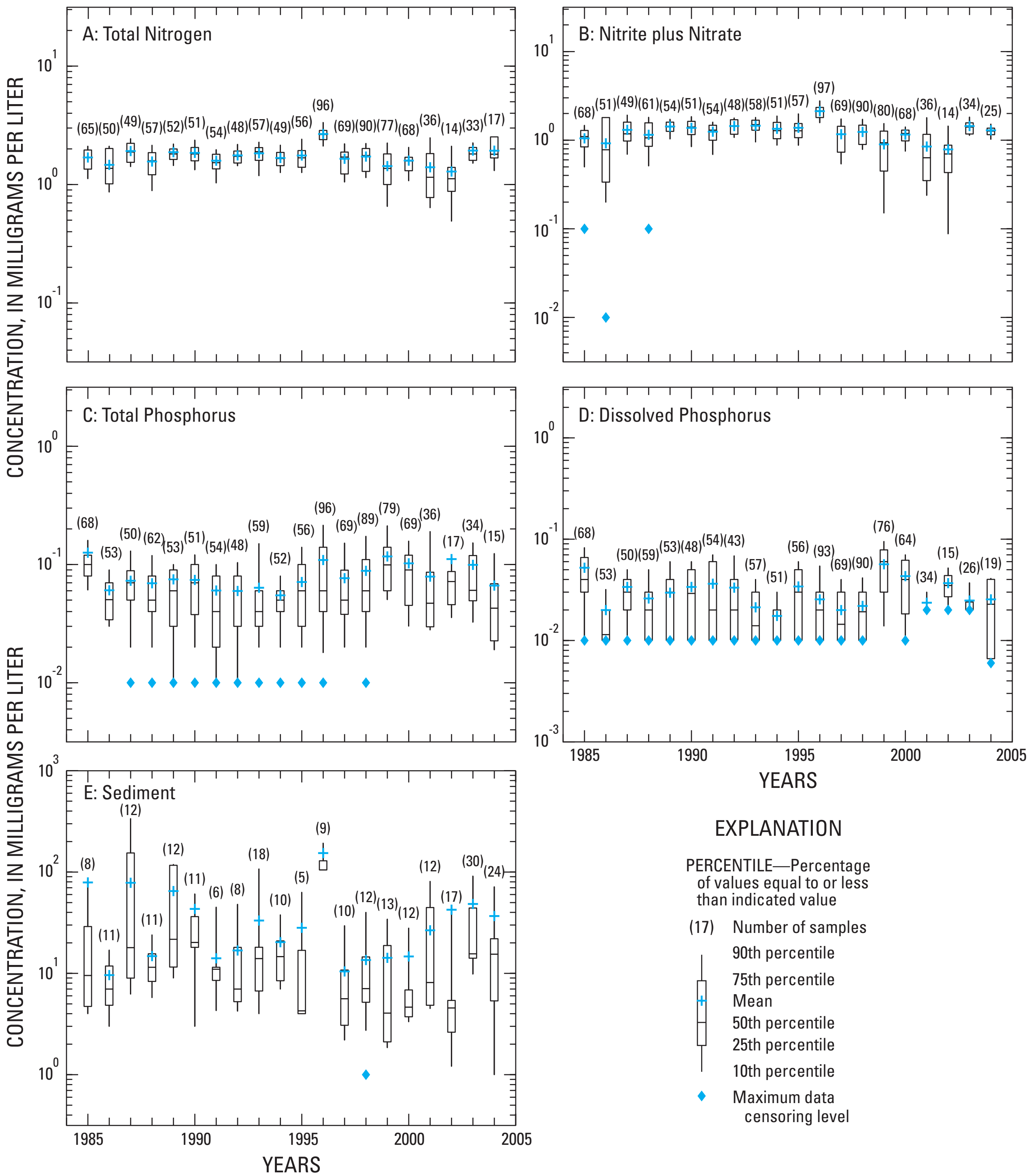

Figure 6D. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Potomac River in the Chesapeake Bay watershed, 1985-2004.

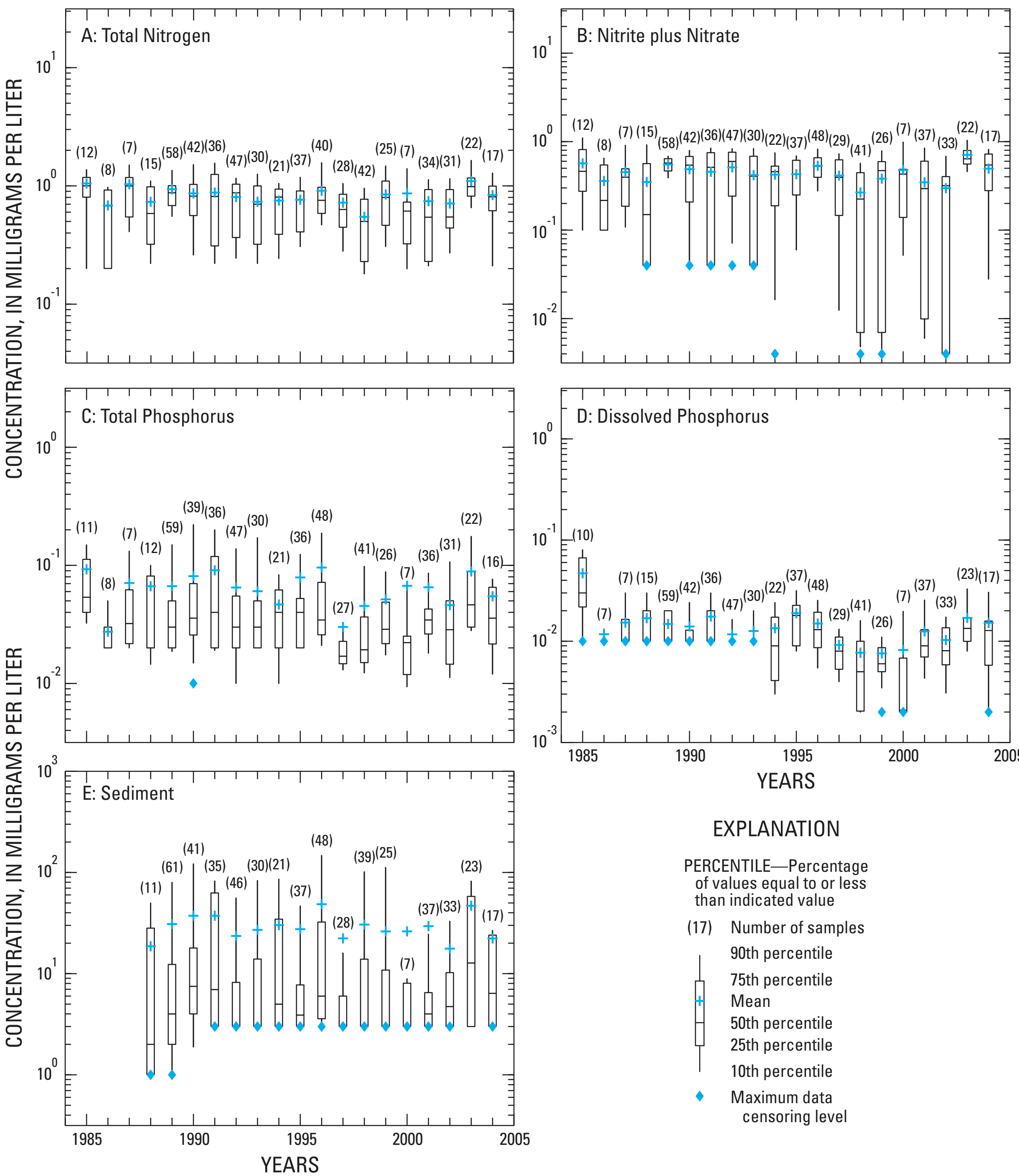

Figure 6E. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Rappahannock River in the Chesapeake Bay watershed, 1985-2004.

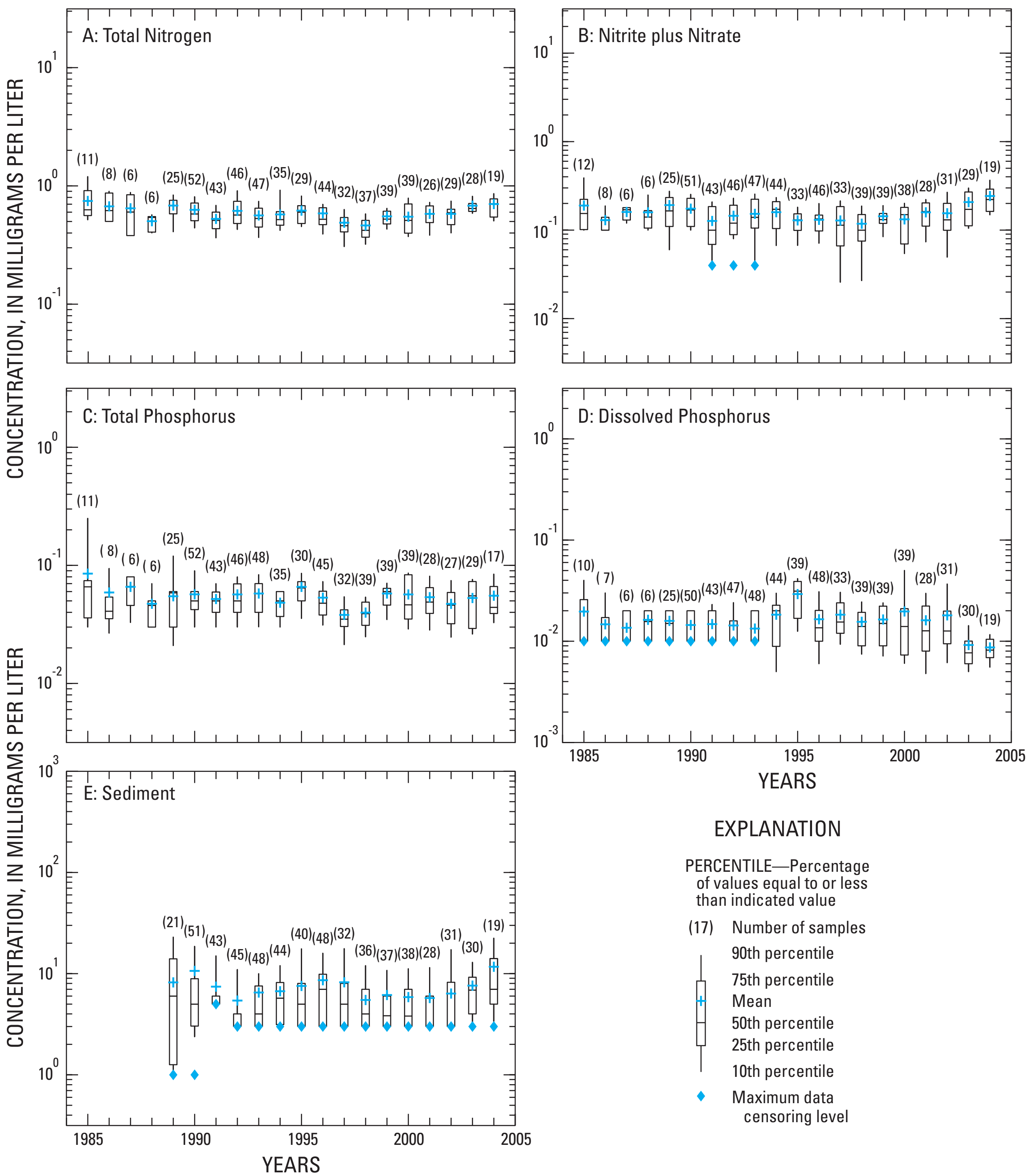

Figure 6F. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Mattaponi River in the Chesapeake Bay watershed, 1985-2004.

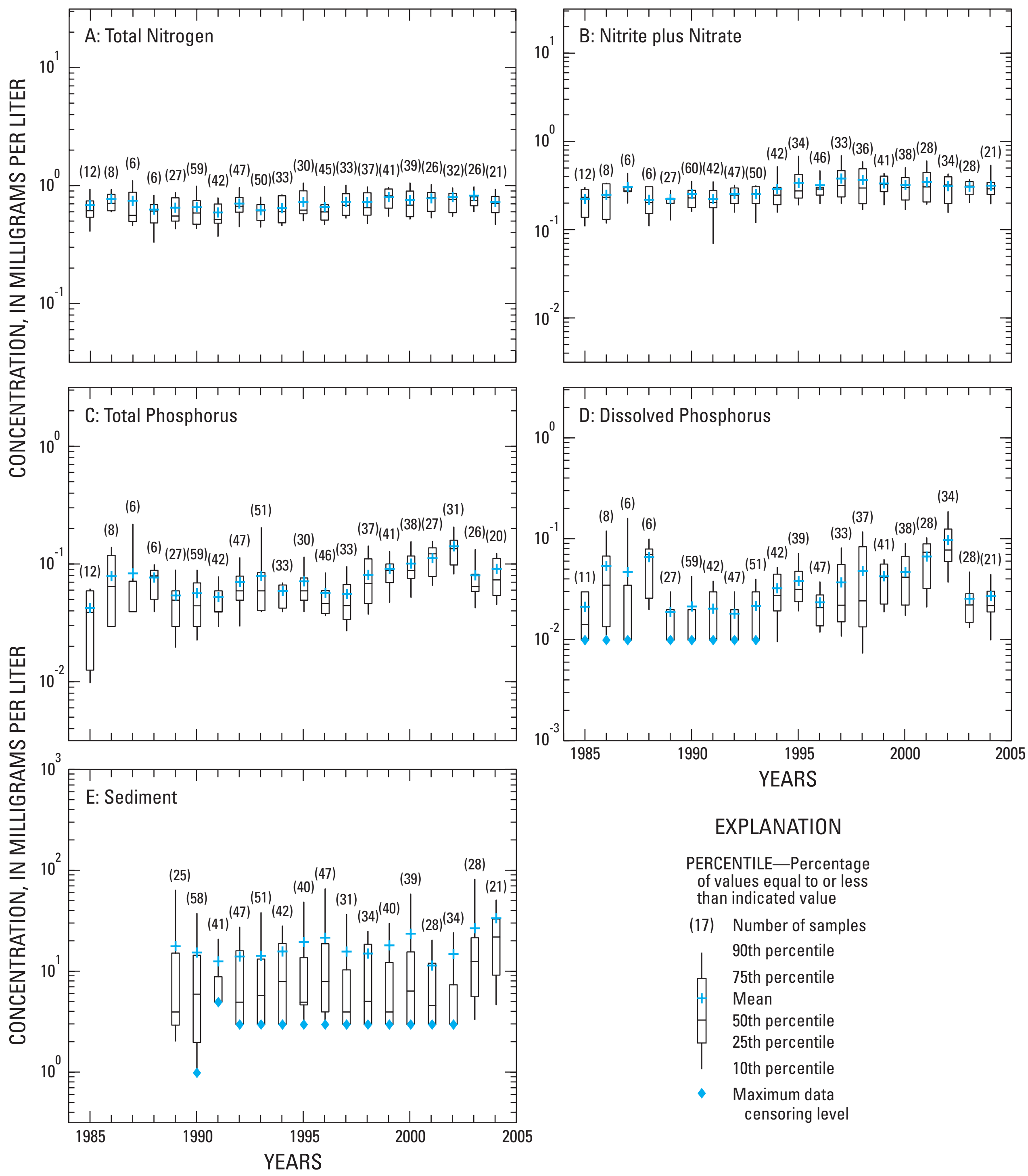

Figure 6G. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Pamunkey River in the Chesapeake Bay watershed, 1985-2004.

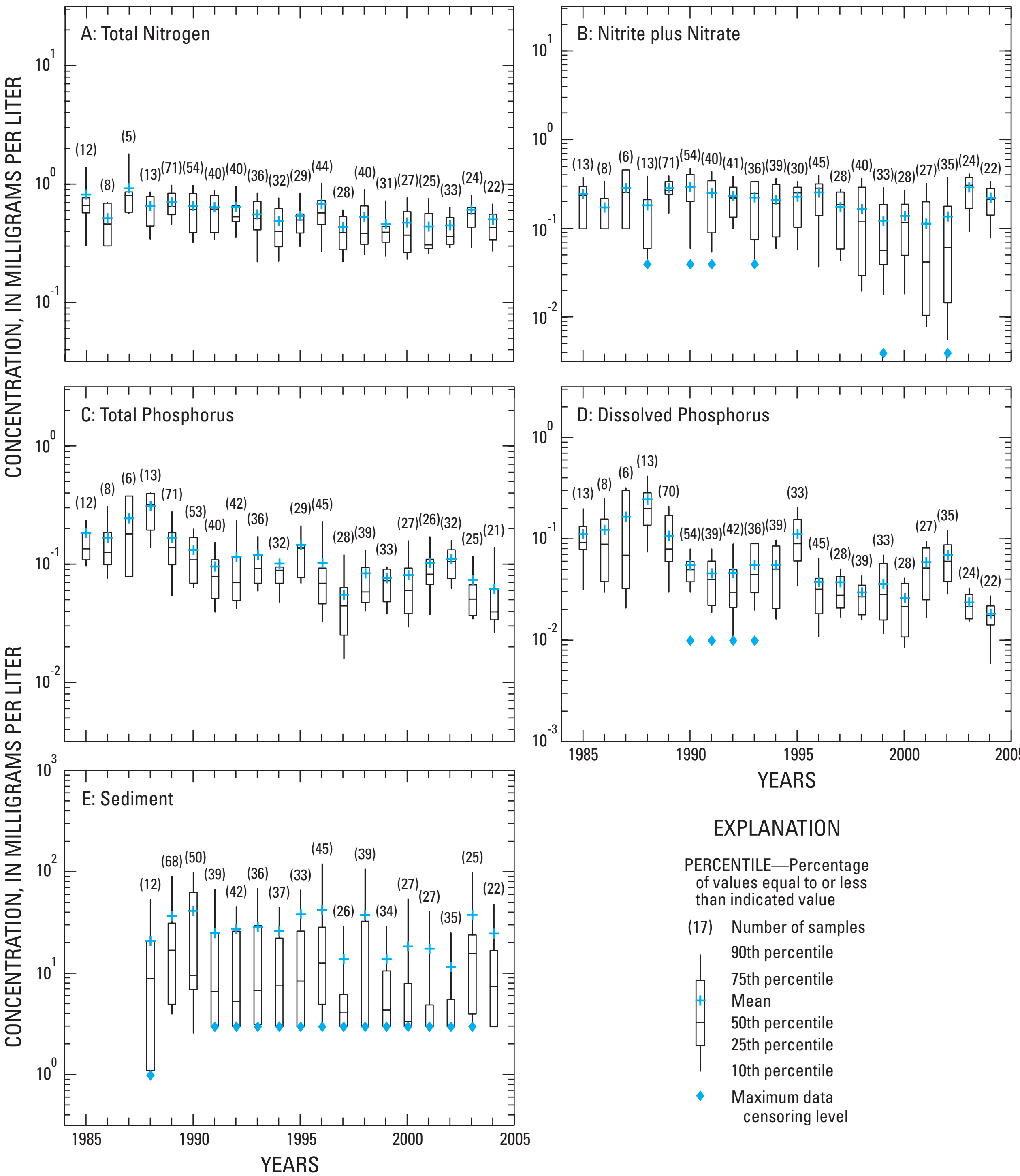

Figure 6H. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the James River in the Chesapeake Bay watershed, 1985-2004.

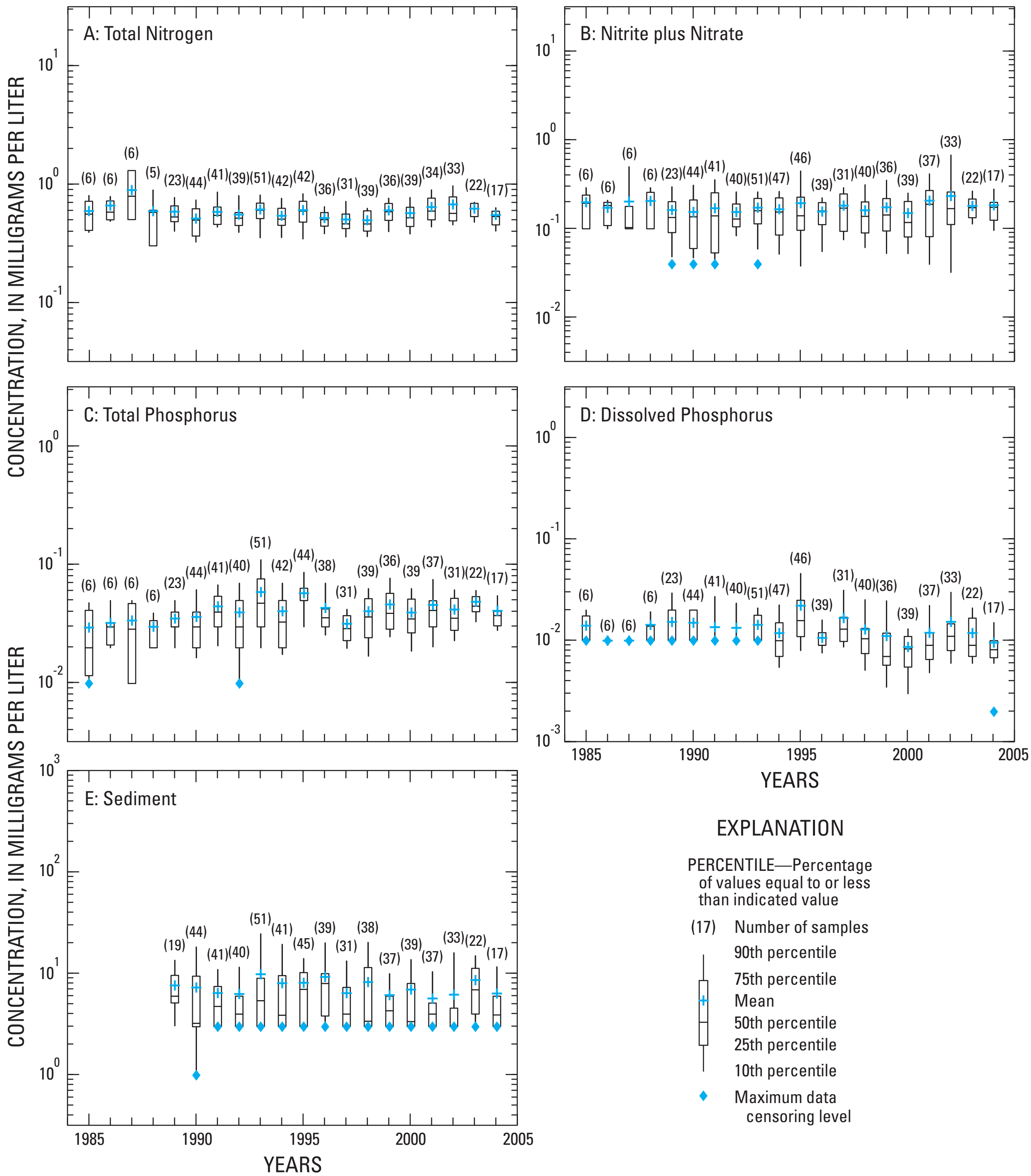

Figure 6I. (Continued) Unbiased distribution and mean of annual observed concentrations of (A) total nitrogen, (B) nitrite plus nitrate, (C) total phosphorus, (D) dissolved inorganic phosphorus, and (E) sediment collected at the River Input Monitoring Program site for the Appomattox River in the Chesapeake Bay watershed, 1985-2004.

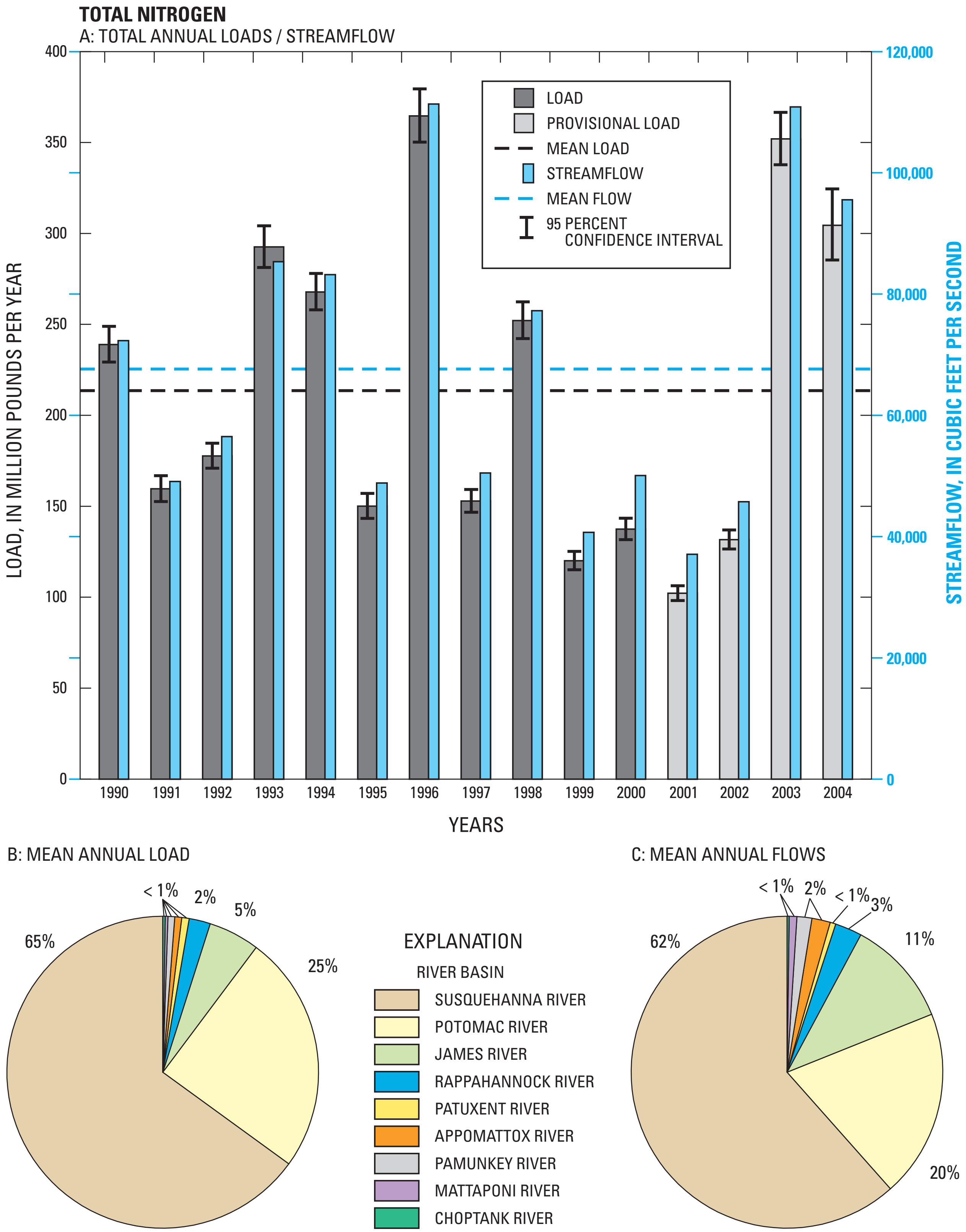

Figure 7A. (A) Combined annual total nitrogen loads (with 95 percent confidence interval) and streamflow for the 9 River Input Monitoring Program sites, (B) percentage of mean annual total nitrogen load by basin, and (C) percentage of annual-mean streamflow by basin, 1990-2004.

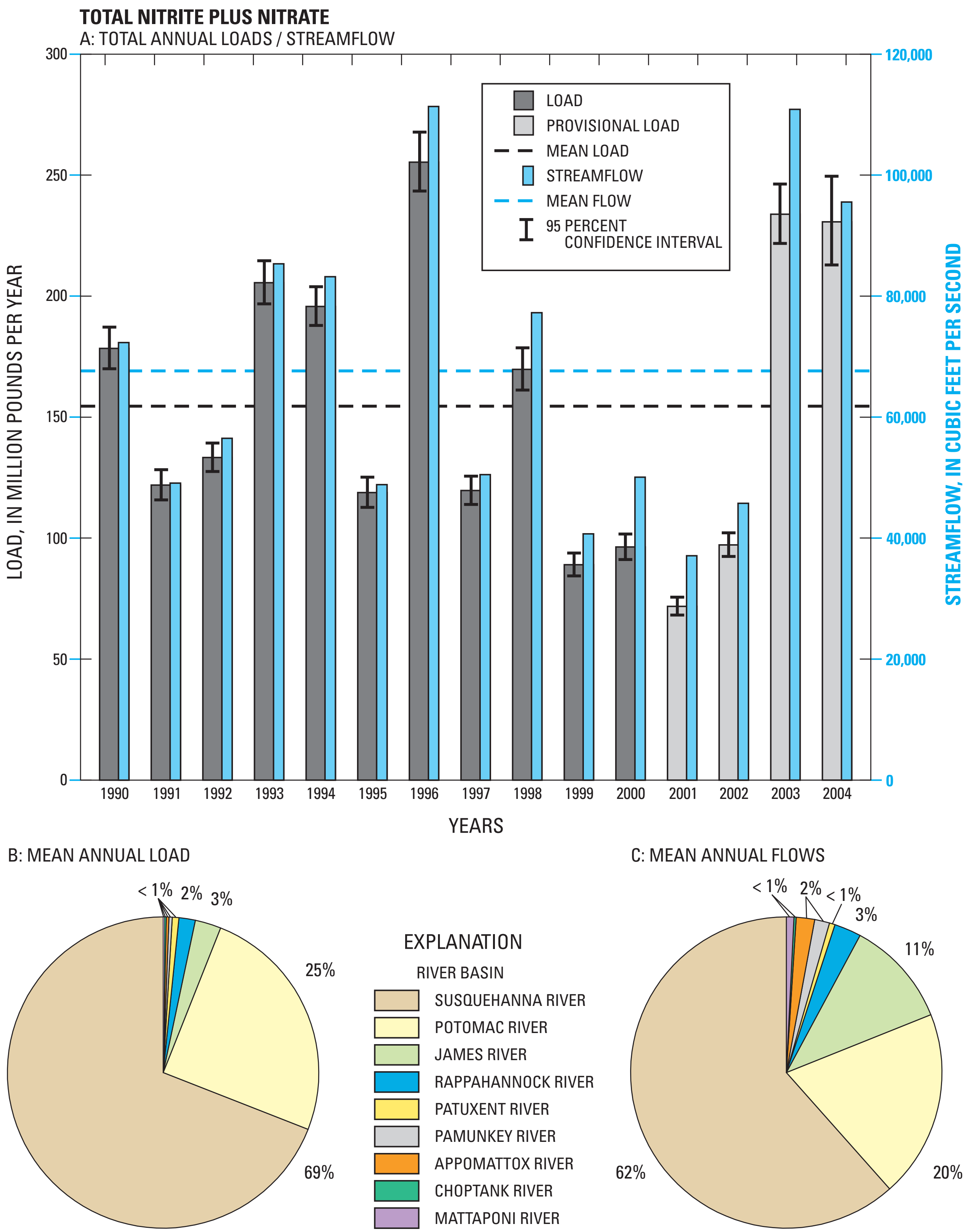

Figure 7B. (Continued) (A) Combined annual total phosphorus loads (with 95 percent confidence interval) and streamflow for the 9 River Input Monitoring Program sites, (B) percentage of mean annual total phosphorus load by basin, and (C) percentage of annual-mean streamflow by basin, 1990-2004.

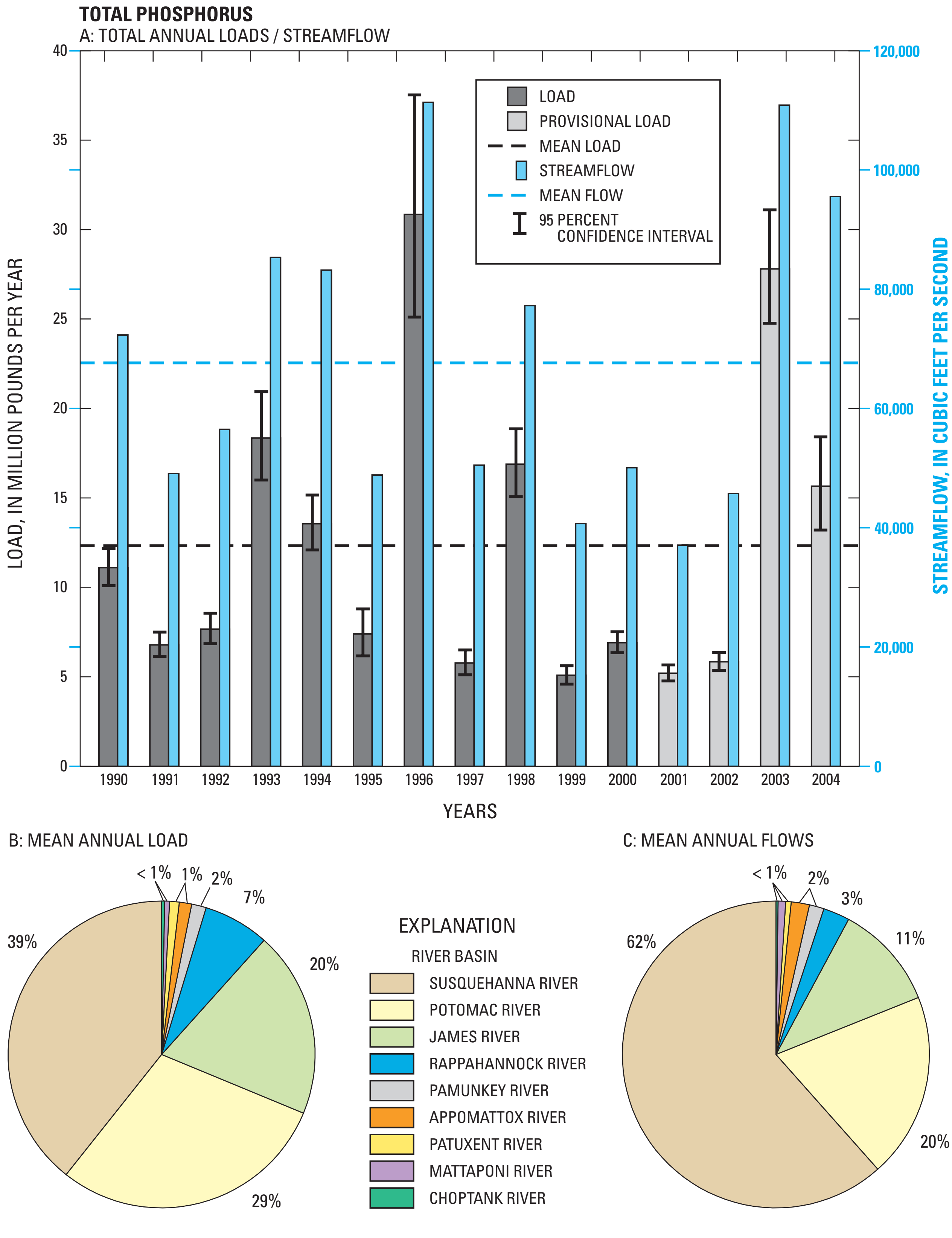

Figure 7C. (Continued) (A) Combined annual total phosphorus loads (with 95 percent confidence interval) and streamflow for the 9 River Input Monitoring Program sites, (B) percentage of mean annual total phosphorus load by basin, and (C) percentage of annual-mean streamflow by basin, 1990-2004.

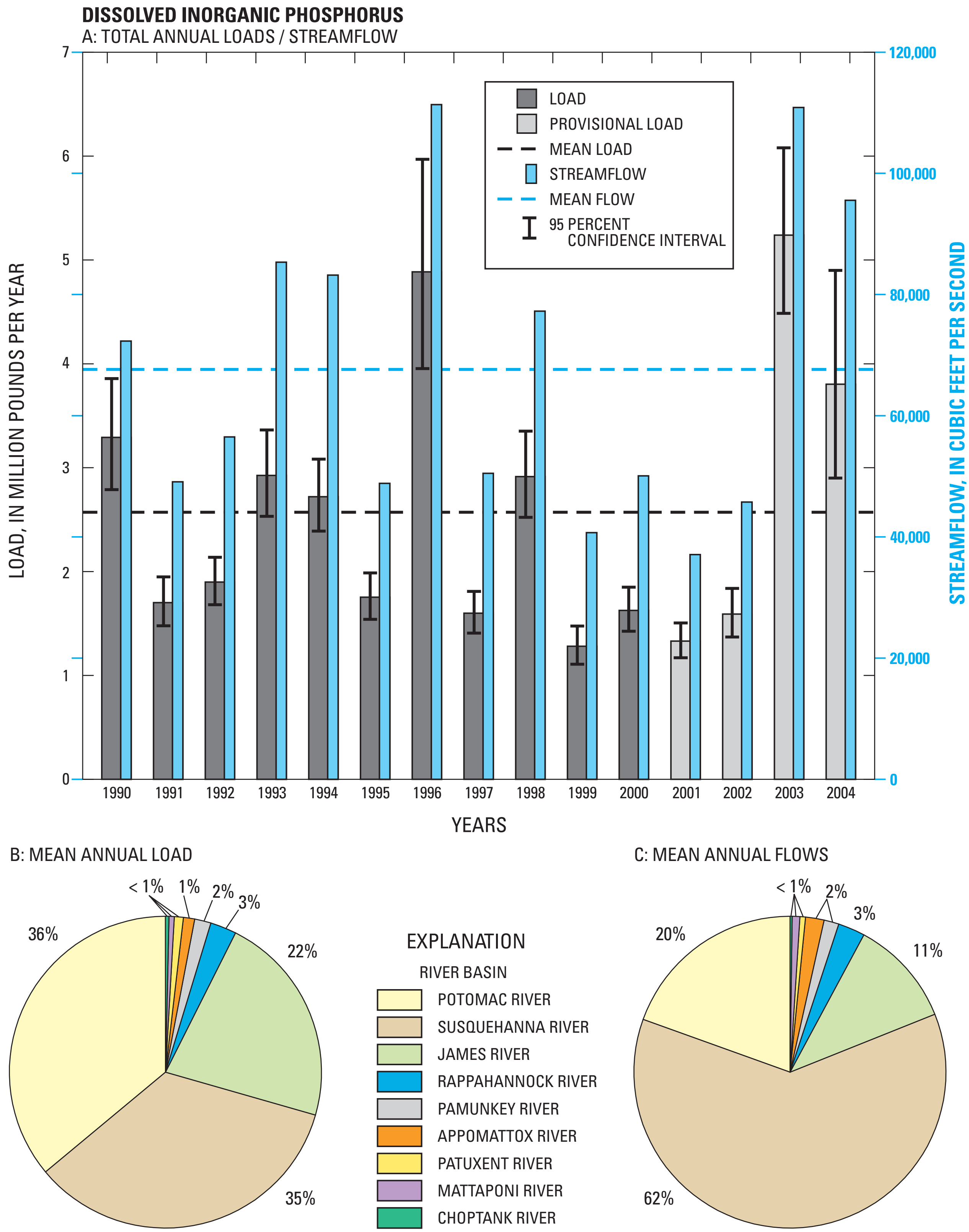

Figure 7D. (Continued) (A) Combined annual dissolved inorganic phosphorus loads (with 95 percent confidence interval) and streamflow for the 9 River Input Monitoring Program sites, (B) percentage of mean annual dissolved inorganic phosphorus load by basin, and (C) percentage of annual-mean streamflow by basin, 1990-2004.

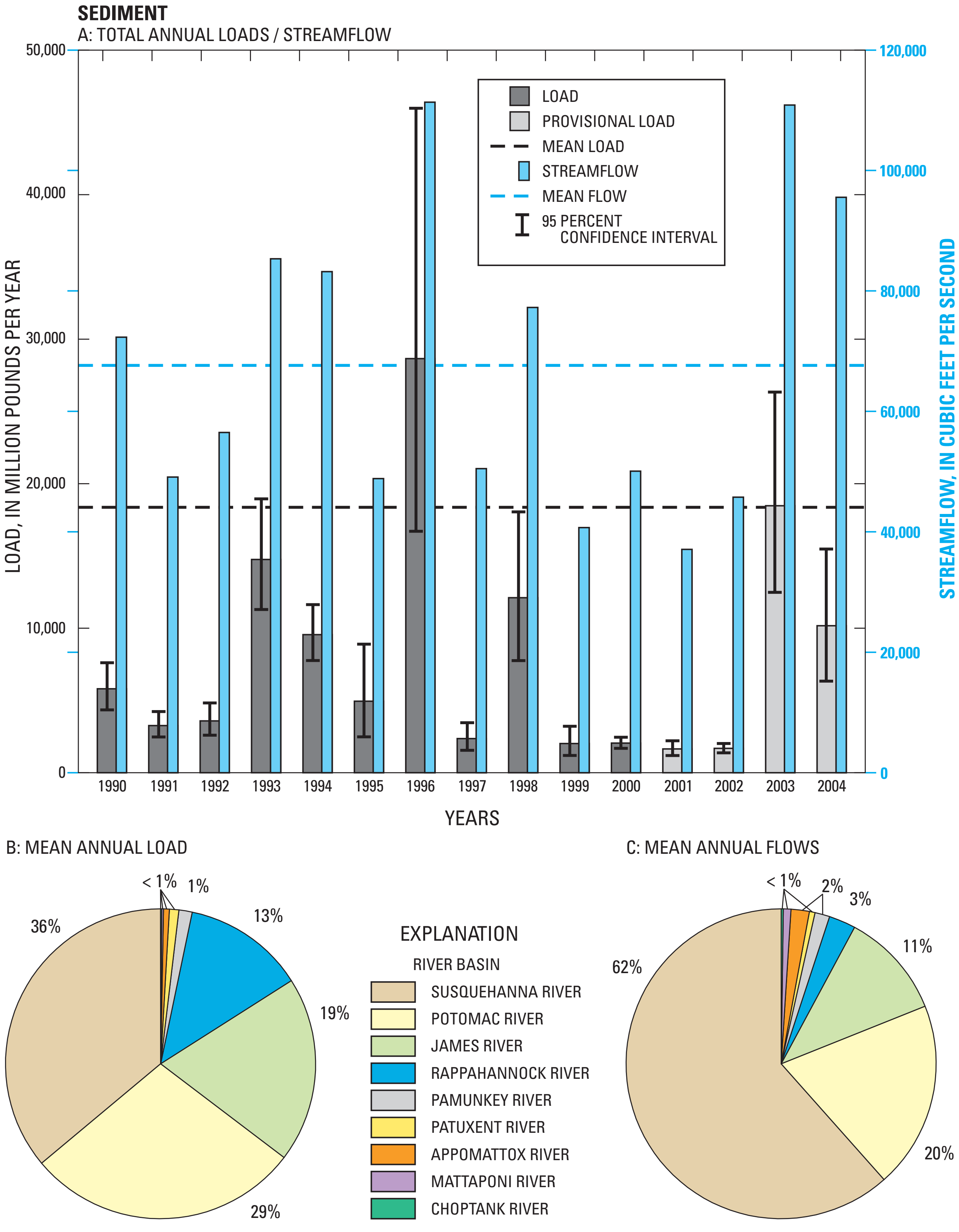

Figure 7E. (Continued) (A) Combined annual sediment loads (with 95 percent confidence interval) and streamflow for the 9 River Input Monitoring Program sites, (B) percentage of mean annual sediment load by basin, and (C) percentage of annual-mean streamflow by basin, 1990-2004.

Flow-Weighted Concentration

The FWC is an approach to evaluating the changing relation between streamflow and load by approximating the annual concentration. Changes over temporal scales can be illustrated within a basin and comparisons can be made among different basins by use of the FWC. Results for TN, TP, and SED for the RIM Program sites are presented and discussed below.

The combined annual mean FWC for TN calculated using the total load divided by total flow from each of the 9 RIM Program sites indicates a downward tendency in the 1990s and no change to a slightly upward tendency since 2000 (fig. 8A). The highest and lowest flow years, 1996 and 2001, respectively, did not correspond to the highest and lowest FWCs for TN. The highest combined FWC for TN occurred in 1993 (1.74 mg/L), whereas the lowest combined FWC for TN (1.38 mg/L) occurred in 2000. The combined mean FWC was 1.58 mg/L for 1990-2004 (the time period for which all 9 RIM Program sites were sampled).

Downward tendencies in FWC for TN occurred from 1985-90 at the northern RIM Program sites (Choptank, Susquehanna, Patuxent, and Potomac), most notably at the Patuxent site (fig. 8B). FWCs for TN were higher and generally decreasing at the northern sites, and were lower and more constant at the southern sites (Rappahannock, Pamunkey, Mattaponi, James, and Appomattox). FWCs for TN ranged from a high of 4.17 mg/L at the Patuxent site in 1985 to a low of 0.516 mg/L at the Mattaponi site in 1999. In addition, all FWCs for TN were lower in 2003 than 2004 for the southern basins, but higher in the northern basins in 2004 than 2003. As previously mentioned, the remnants of two hurricanes led to widespread flooding in the northern basins, especially in the Susquehanna.

FWCs for TP and SED exhibited much more variability than the FWCs for TN because of different transport mechanisms. Most of the TN is transported in the dissolved phase as nitrate-nitrogen; most TP and all SED are transported in the particulate phase. A general decline in combined FWC for TP was reversed in 2003 and 2004, when concentrations increased (fig. 8C). From 1990 through 2004, the combined FWC for TP averaged about 0.085 mg/L for the RIM Program sites and ranged from a high of 0.141 mg/L to a low of 0.058 mg/L in consecutive years, 1996 and 1997, respectively.

FWCs for TP indicated general decreases from 1985 through 1990 at 2 of the 4 northern RIM Program sites (Potomac and Patuxent, fig. 8D). The Patuxent RIM Program site exhibited a sharp 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 are relatively higher and more variable than those for TN, and FWC for TP has been increasing steadily at the Pamunkey site. The highest annual mean value of FWC for TP (0.41 mg/L) occurred in the Rappahannock River in 1995; TP also had the highest long-term annual mean FWC of 0.21 mg/L in the Rappahannock River (fig. 8D). Conversely, the lowest FWC for TP (0.03 mg/L) occurred in the Susquehanna River in 1997; 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 due to the TP and SED being trapped behind three large reservoirs in the lower reaches of the river (Langland and Hainly, 1997). An increase in FWC for TP during high flow years and through the drought period of 1999-2002 for many of the RIM Program sites is shown in figure 8D.

As previously mentioned, the highest and lowest flow years were 1996 and 2001. The high flow year did correspond to the highest combined FWC for SED (131 mg/L) while the lowest combined FWC for SED (24 mg/L) did not correspond to the lowest flow year, but occurred in 2002 (fig. 8E). The combined average mean FWC for SED during 1990-2004 was 51 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 during last 2 years of the study period.

Prior to 1990, the highest annual mean FWC for SED was 740 mg/L in the Potomac River (fig. 8F). Similar to the FWC for TP, the FWC for SED was highest in the high flow years and lowest in the low flow years. The highest mean annual FWC during 1990-2004 occurred in the Rappahannock River (558 mg/L in 1996; fig. 8F). The lowest annual mean FWC occurred in the Choptank River (8.8 mg/L in 1995) and the lowest long-term mean FWC occurred in the Pamunkey River (9.8 mg/L). The variability in FWC was consistent among the RIM Program sites, with the Rappahannock being the most variable and continuously having the highest annual FWC for SED, with the exception of 2002.

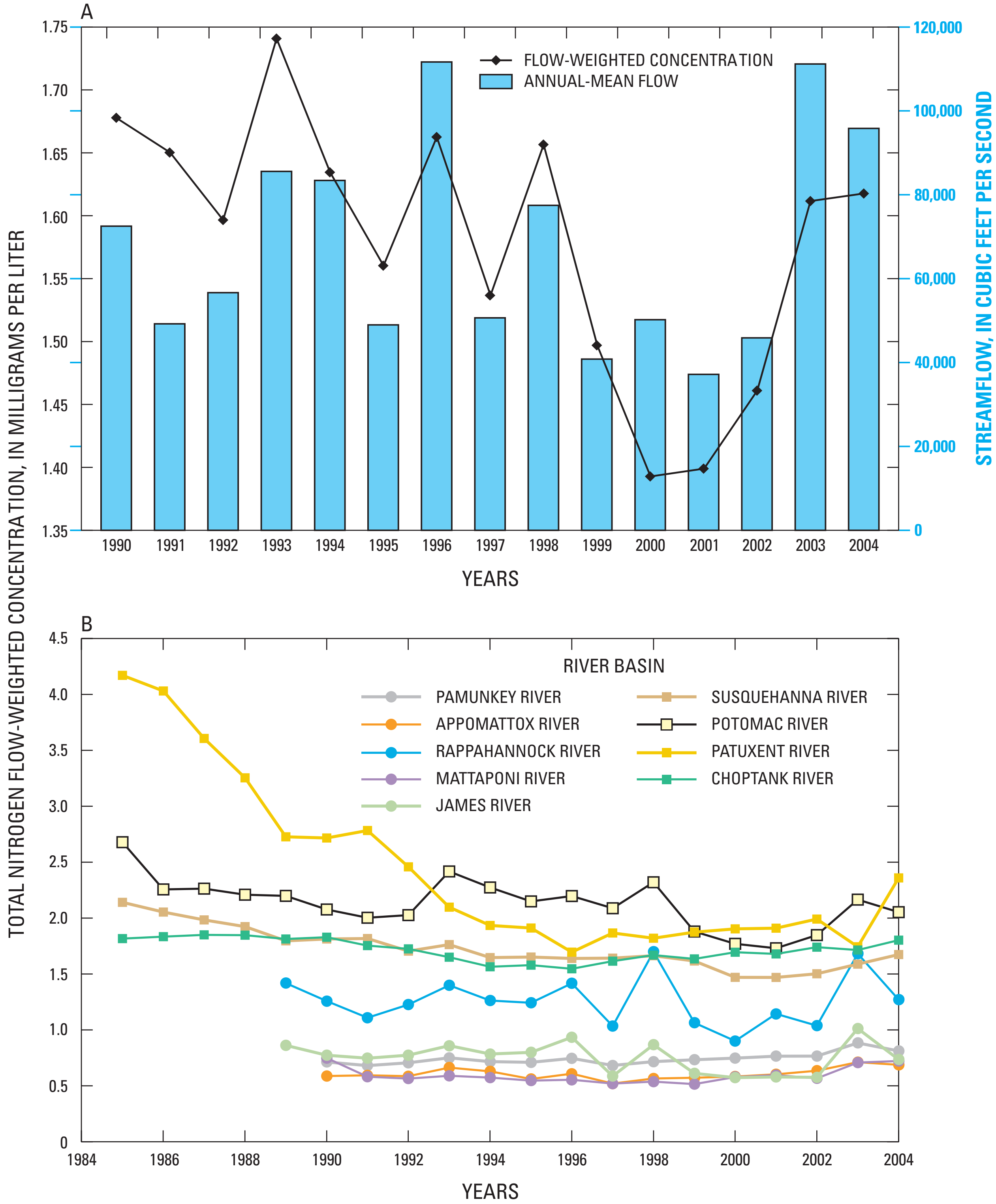

Figure 8. (A) Combined annual-mean flow, flow-weighted total nitrogen concentration, and (B) total nitrogen flow-weighted concentration for the 9 River Input Monitoring Program sites.

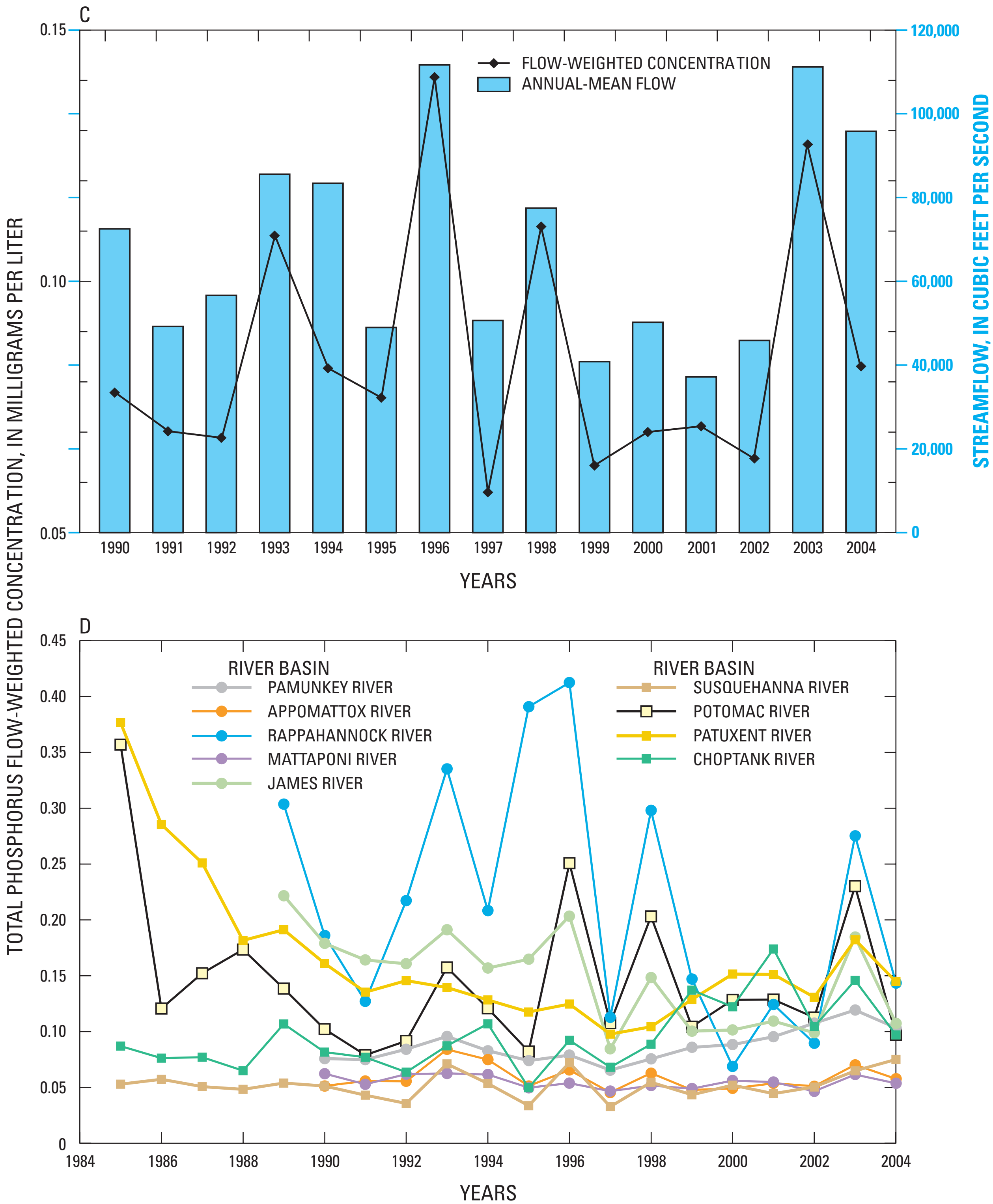

Figure 8. (C) Combined annual-mean flow, flow-weighted total phosphorus concentration, and (D) total phosphorus flow-weighted concentration for the 9 River Input Monitoring Program sites.

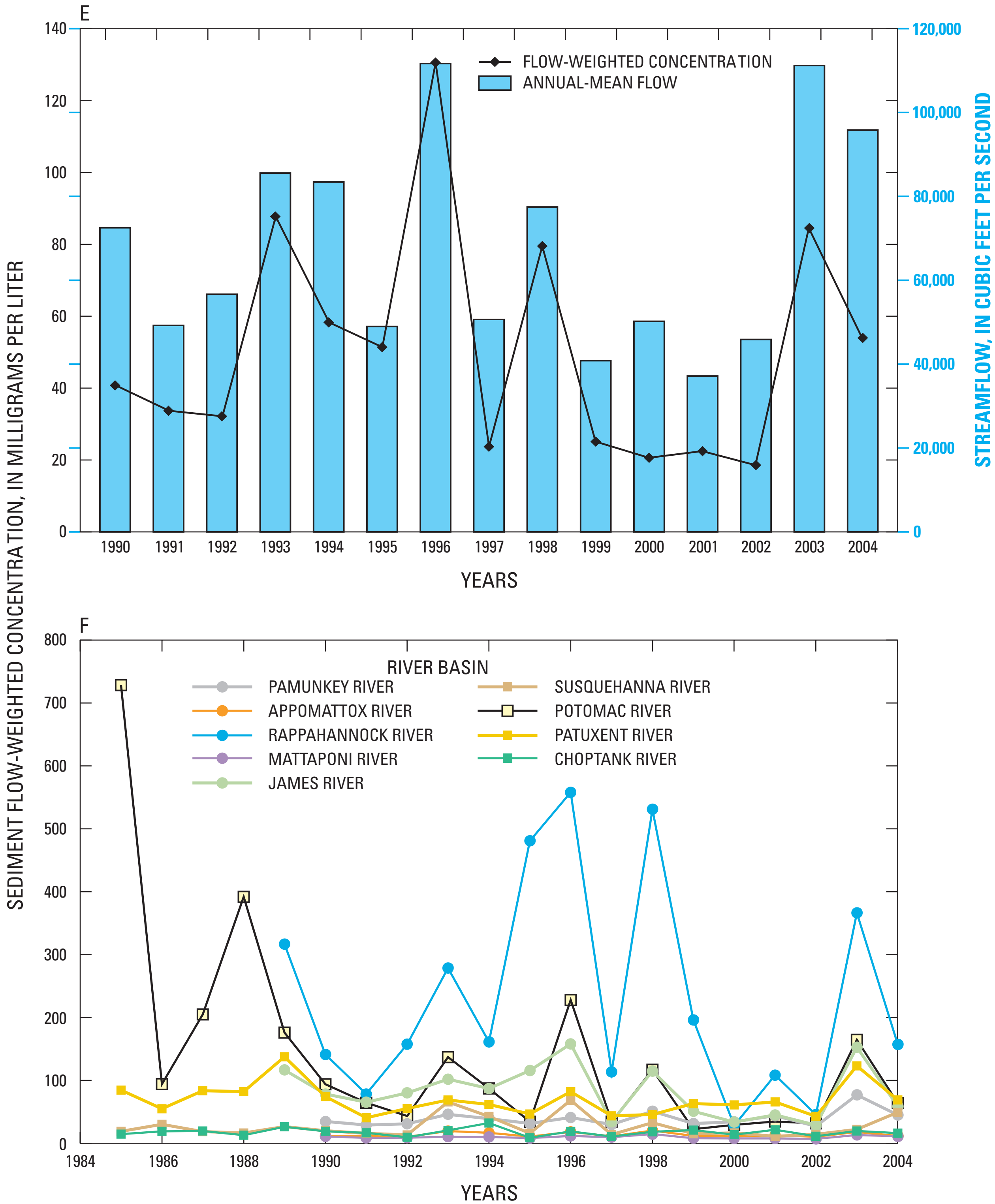

Figure 8. (E) Combined annual-mean flow, flow-weighted sediment concentration, and (F) sediment flow-weighted concentration for the 9 River Input Monitoring Program sites.

Non-Flow Adjusted Trend

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. Non-flow adjusted trends allow for the examination of the overall response of the ecosystem to these changing factors, and comparison to changes in the ecosystem downstream.

Non-flow adjusted trend computation produces estimates of non-flow adjusted trends in both concentration and load for the time period 1985 through 2004 (although some sites have shorter periods of analysis). The results for TN, TP, and TSS or SED for the end of 2004 for the 9 RIM Program stations are shown in figure 9 (non-flow adjusted trend in concentration) and figure 10 (non-flow adjusted trend in load). The complete results for all reported constituents and sites are provided in appendixes 4.1 and 4.2 (non-flow adjusted trend in concentration) and appendixes 5.1 and 5.2 (non-flow adjusted trend in load).

Except for the Pamunkey River, all RIM Program sites exhibited insignificant or downward non-flow adjusted trends in TN concentration. For TP, only the Pamunkey and Choptank Rivers had significant upward trends; the Susquehanna, James, and Patuxent Rivers had statistically significant downward trends. No sites had statistically significant non-flow adjusted trends in SED or TSS concentration. These results are very consistent with the Spearman rho analysis results (table 4).

For the 23 Multi-Agency Nontidal Monitoring Program sites, the largest statistically significant non-flow adjusted trends in TN concentration (apps. 4.1 and 4.2) were estimated for: North Fork of the Shenandoah River near Strasburg, Va. (+48 percent, 1985-2004); Georges Creek at Franklin, Md. (–42 percent, 1985-2004); and South Fork Shenandoah River at Front Royal, Va. (–40 percent, 1985-2004). Large statistically significant downward trends were estimated for TP concentration for North Anna River at Hart Corner near Doswell, Va. (–80 percent, 1985-2004), and for James River at Bent Creek, Va. (–79 percent, 1985-2004). Large statistically significant upward trends were estimated for TP concentration for North Fork of the Shenandoah River near Strasburg, Va. (+328 percent, 1985-2004).

Constituent loads are computed using streamflow and, therefore, exhibit variance that closely corresponds to variance in streamflow. Thus, statistically significant trends in load were not expected in most cases, 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 9 RIM Program sites (fig. 10), non-statistically significant non-flow adjusted trends in load were estimated for TN or SED/TSS; only TP for the Choptank River exhibited a statistically significant increase in load. Not coincidentally, the Choptank was the only site to show a mild upward trend in annual-mean flow.

For the 23 Multi-Agency Nontidal Monitoring Program sites (apps. 5.1 and 5.2), very few yielded statistically significant non-flow adjusted trends in load. The largest statistically significant trends were estimated for the North Fork of the Shenandoah River near Strasburg, Va. (TP, +541 percent, 1985-2004) and the North Anna River at Hart Corner near Doswell, Va. (TP, –84 percent, 1985-2004).

In addition to providing an estimate of the trend over the study period, the non-flow adjusted trend method provides continuous estimation of the non-flow adjusted trends through time. An example 4-panel illustration used to present results for all 32 sites in appendix 6 is shown in figure 11.

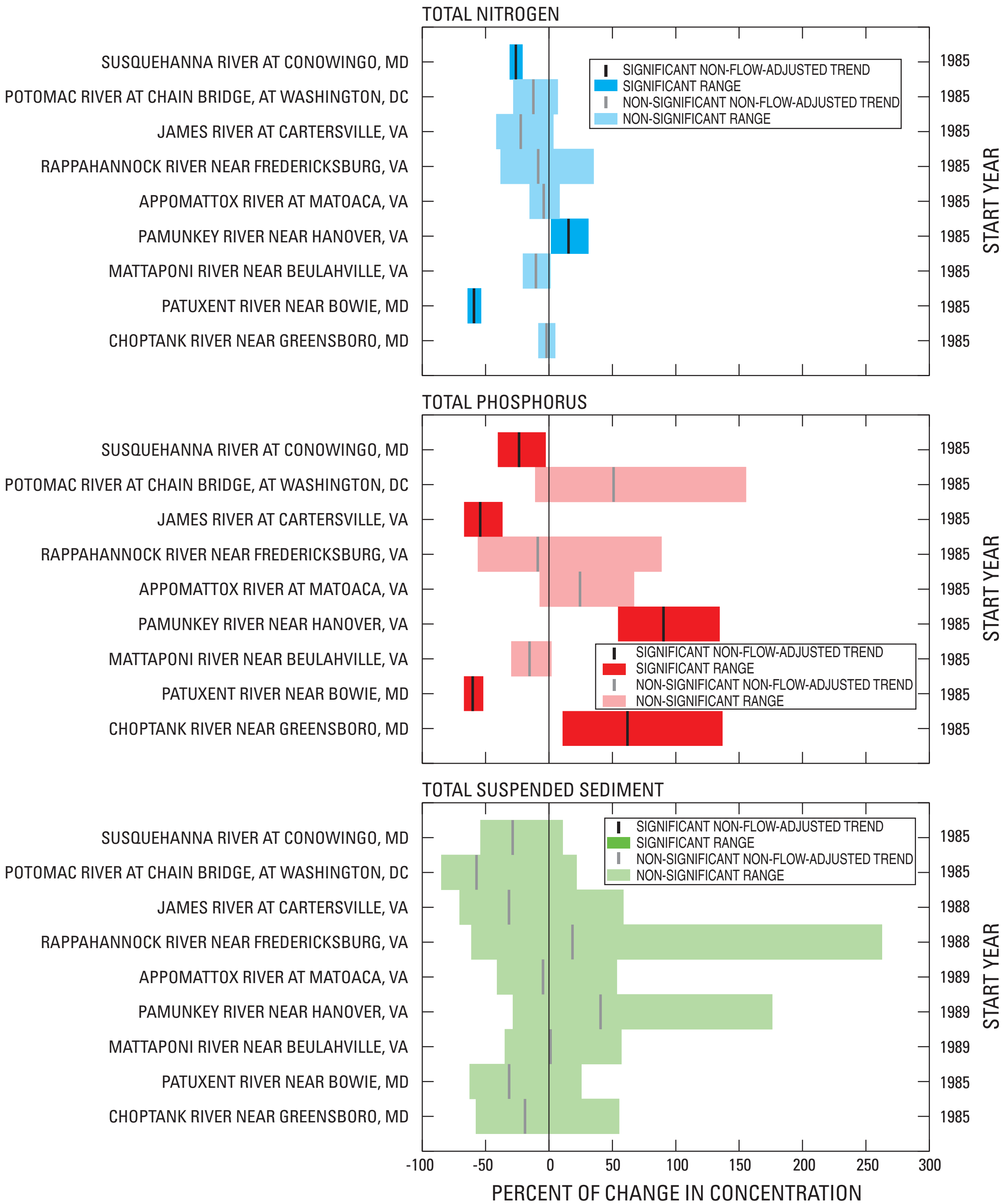

Figure 9. Estimated non-flow adjusted trend in concentration and confidence interval for total nitrogen, total phosphorus, and sediment for the 9 River Input Monitoring Program sites, 1985-2004. Sites are organized from largest (Susquehanna) to smallest (Choptank) in terms of mean annual streamflow. Dates on the right y-axis indicate the starting date, t_0.

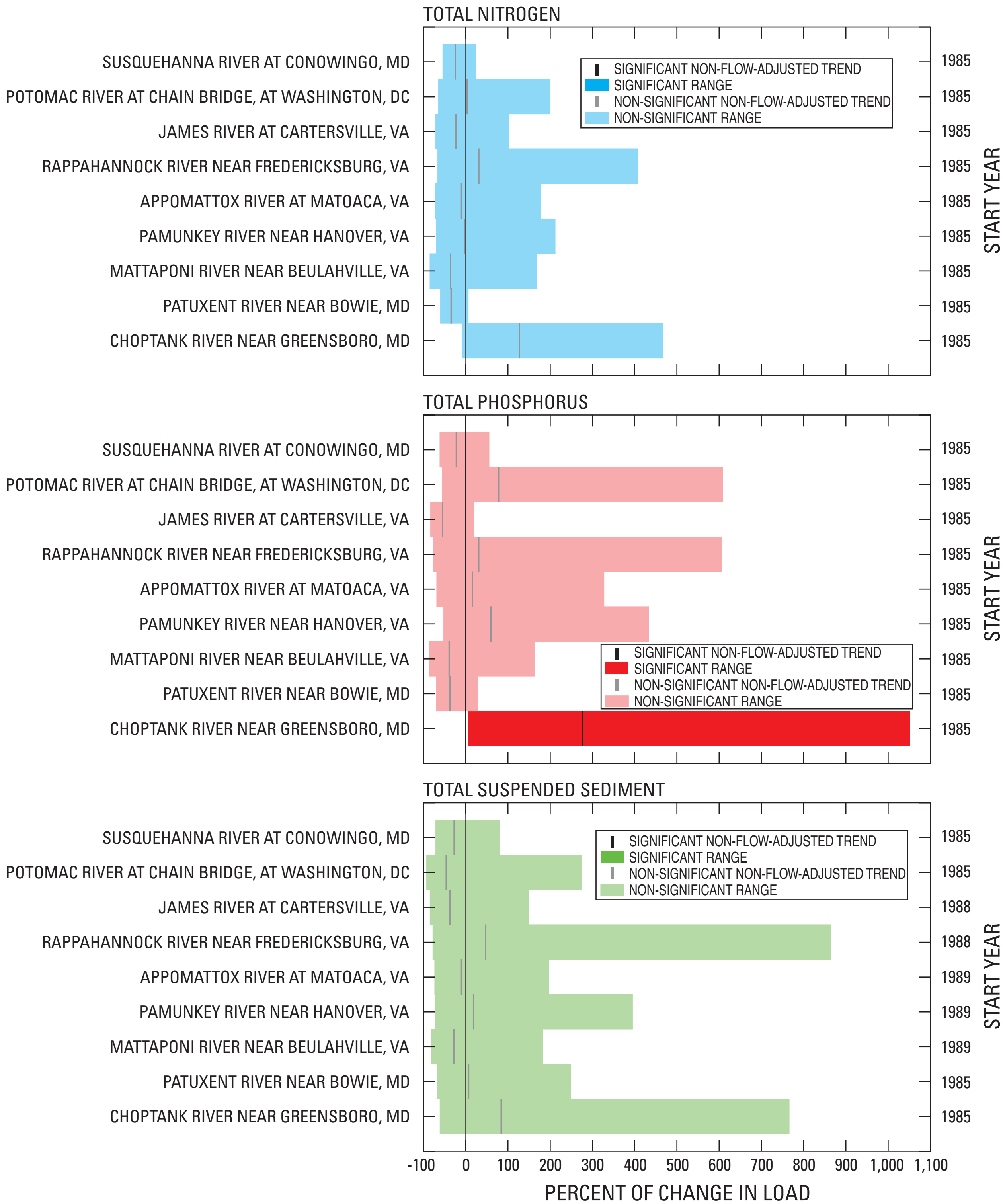

Figure 10. Estimated non-flow adjusted trend in load and confidence interval for total nitrogen, total phosphorus, and sediment for the 9 River Input Monitoring Program sites, 1985-2004. Sites are organized from largest (Susquehanna) to smallest (Choptank) in terms of mean annual streamflow. Dates on the right y-axis indicate the starting date, t_0.

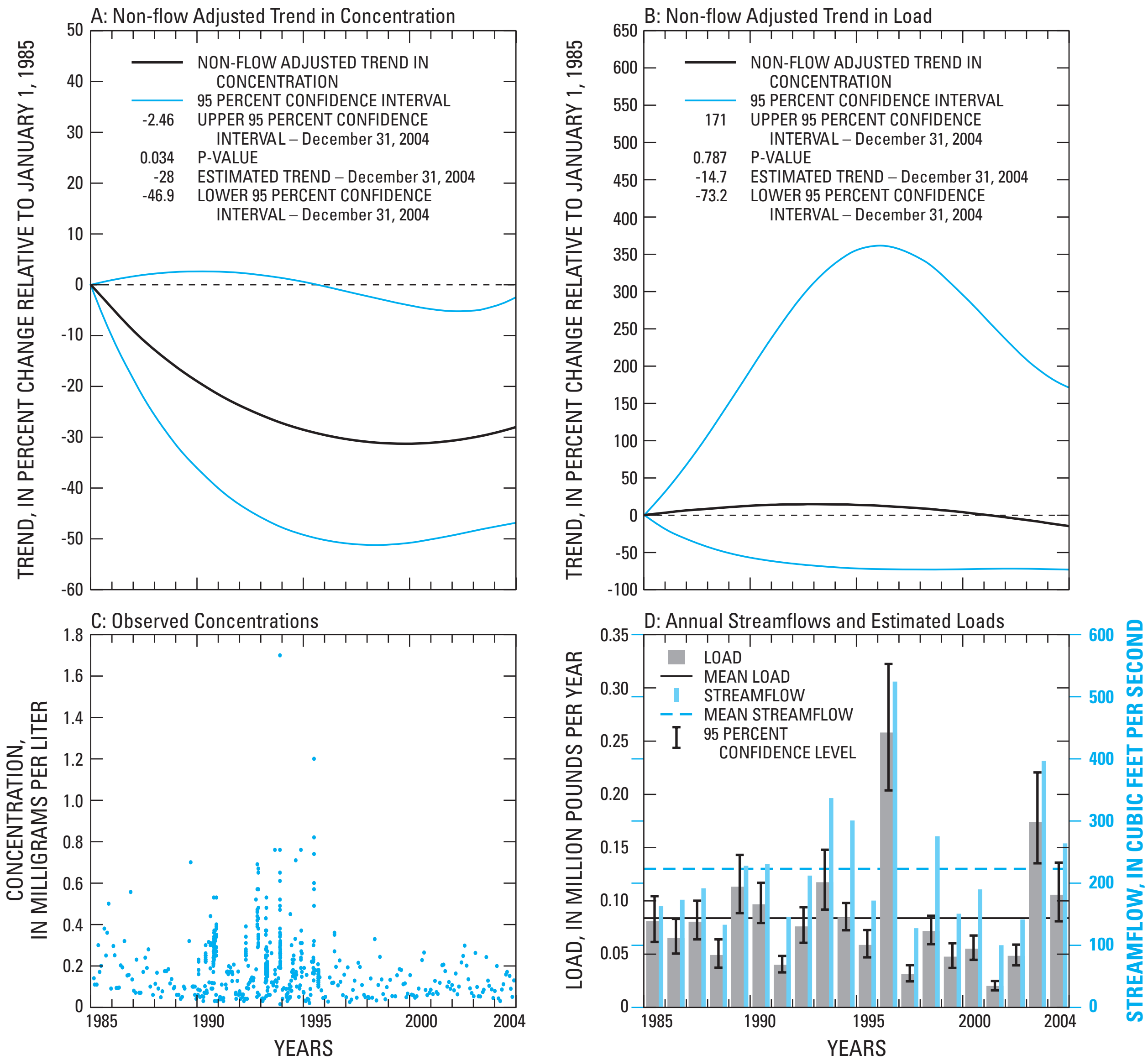

Figure 11. Example 4-panel plot used to display non-flow adjusted trend results for all 32 sites presented in appendix 6. Upper left (A) shows the continuous non-flow adjusted trend in concentration, upper right (B) shows the continuous non-flow adjusted trend in load, lower left (C) shows the “raw” sample concentration data, and lower right (D) shows annual and mean loads and streamflow from 1985-2004. Statistical results are presented in the top left of A and B and represent lower confidence range (lower blue line), actual trend (black line), significance, and upper confidence range (upper blue line), respectively, for the period t_0 through 2004.

Flow-Adjusted Trend

Observed concentration and FWC are highly influenced by variability in streamflow. Therefore, the water-quality model (eq. 4) 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, so that the coefficients from the "time" parameters are an estimate of the amount of change over time.

An important point is that 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 must be considered in terms of the hydrologic variability.

Flow-adjusted trends in TN, TP, and SED or TSS for the 9 RIM Program sites for the period 1985 through 2004 are shown in figure 12. The four largest monitored rivers (Susquehanna, Potomac, James, and Rappahannock) exhibit statistically significant downward trends in TN. Only the Pamunkey River exhibits a statistically significant upward trend in TN. For TP, the Potomac, Mattaponi, and Choptank Rivers have statistically significant upward trends, whereas the remaining river basins, with the exception of the Appomattox, have statistically significant downward trends. The Pamunkey River is the only site with a statistically significant upward trend in SED or TSS. Statistically significant downward trends in SED or TSS were observed for the Susquehanna, Potomac, Patuxent, and Choptank Rivers.

Complete results of the flow-adjusted trend estimation are provided in appendixes 7.1 and 7.2; results are summarized for TN, TP, and SED or TSS in figures 13-15, respectively. All 7 sites in the Susquehanna River Basin, including the RIM Program site, had downward trends in TN over the study period (fig. 13). In the Potomac River Basin, there were 11 downward flow-adjusted trends in TN, 2 upward trends, and 1 site with no statistically significant trend. Five sites in the lower Virginia basins indicated significantly downward flow-adjusted trends in TN, 2 sites indicated upward trends (both in the Pamunkey River) and 3 sites indicated no statistically significant trend.

Flow-adjusted trends for TP were significant and downward at 26 of the 32 sites (apps. 7.1 and 7.2, fig. 14) and upward at 4 sites. Trends were downward at 5 RIM Program sites with downward flow-adjusted trends in TP occurring in 7 of the 10 major bay drainage basins. Upward flow-adjusted trends in TP were identified at 4 sites, 3 of which are RIM Program sites (Choptank, Potomac, and Pamunkey). All 7 sites in the Susquehanna River Basin had downward trends. The Potomac River Basin has 7 sites with downward trends, 2 sites with upward trends, and 1 site with no statistically significant trend. The James River Basin had 3 sites with downward trends and 1 site with no significant trend. Ten sites had downward TP flow-adjusted trends greater than 50 percent, whereas 2 sites had upward trends greater than 50 percent.

Significant downward flow-adjusted trends for sediment were detected at 14 of the 32 sites. An upward trend was reported at 2 sites (sites 27 and 28) (apps. 7.1 and 7.2, fig. 15). The Maryland RIM Program sites had 4 downward trends (Choptank, Susquehanna, Patuxent, and Potomac), whereas the Virginia RIM Program sites had 1 upward flow-adjusted trend (Pamunkey) and 4 with no statistically significant trend in SED. In the Susquehanna River Basin, downward trends were estimated for all 7 sites. Results for the Potomac River Basin indicate an equal number of sites with downward trends (7) and sites with no statistically significant trend (also 7). In the lower Virginia river basins, there were no sites with downward trends, 2 sites with upward trends, and 8 sites that had no statistically significant trend. In addition, 6 sites had downward SED flow-adjusted trends greater than 50 percent, whereas 2 sites had upward trends greater than 50 percent.

The flow-adjusted trend is estimated as a continuous function of time as a percent change relative to the starting time, t_0. Three examples are shown in figure 16. The continuous trend line allows additional interpretation of management actions within a watershed.

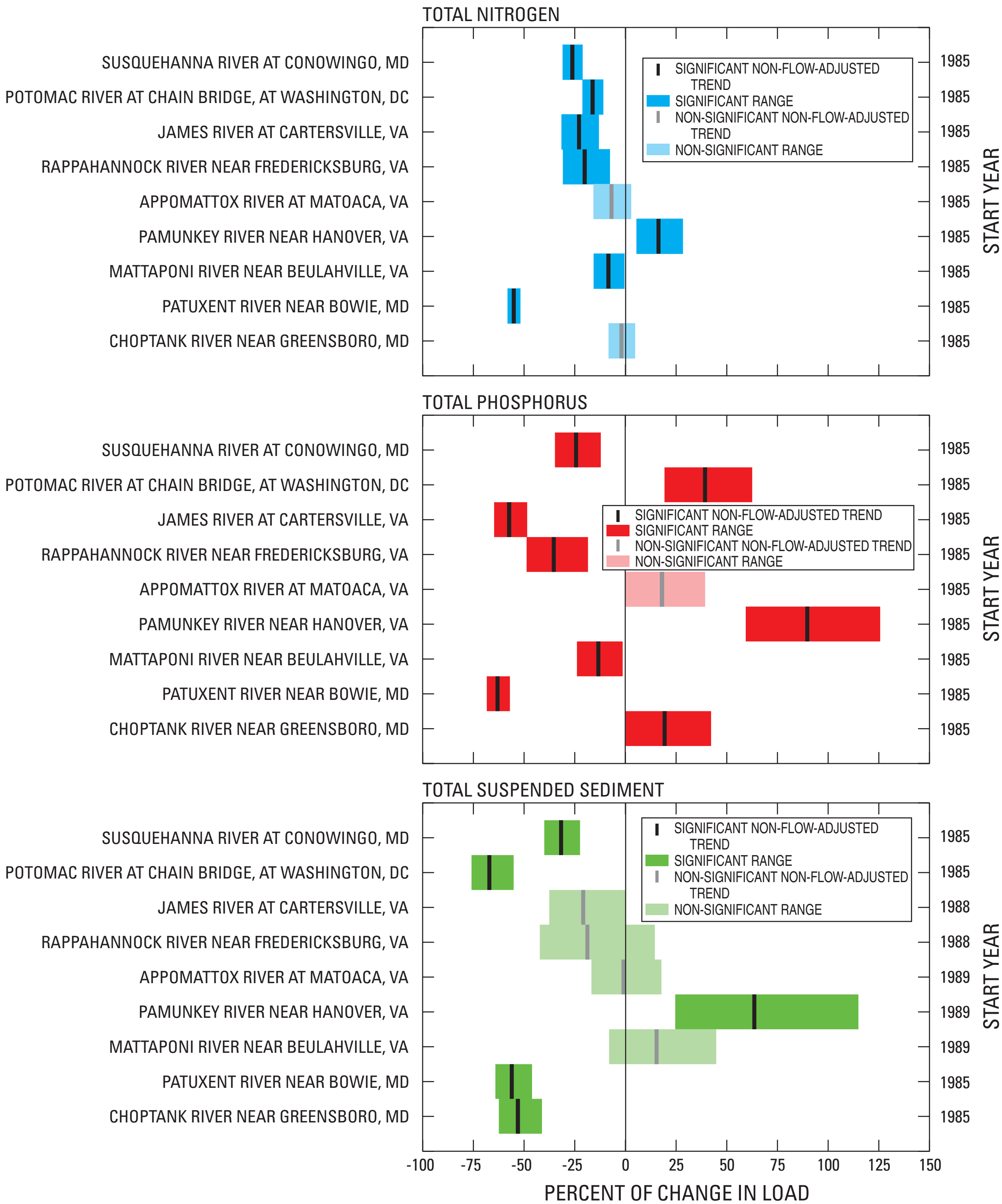

Figure 12. Estimated flow-adjusted trend and confidence interval for total nitrogen, total phosphorus, and sediment for the 9 River Input Monitoring Program sites, 1985-2004. Sites are organized from largest (Susquehanna) to smallest (Choptank) in terms of mean annual streamflow. Dates on the right y-axis indicate the starting date, t_0.

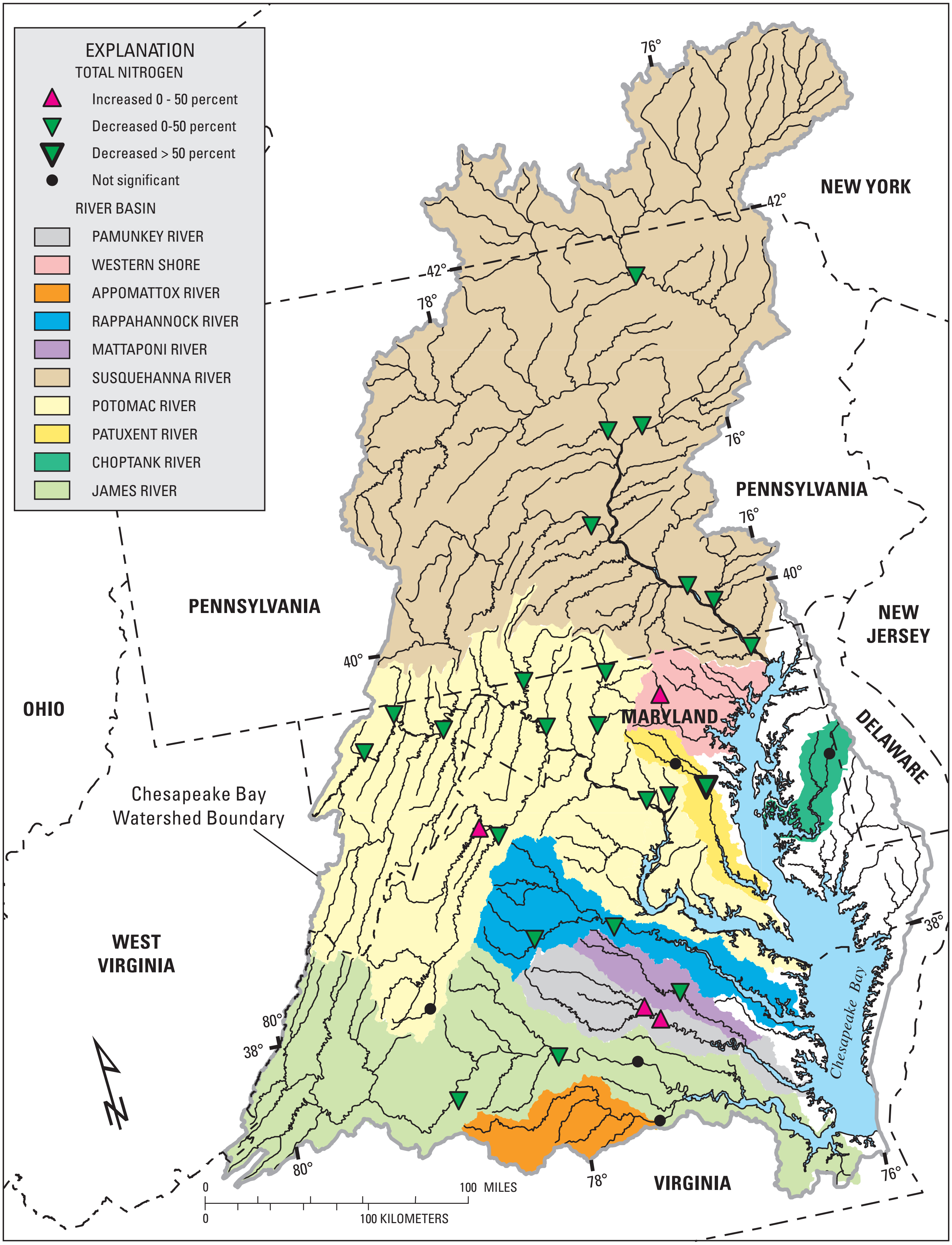

Figure 13. Flow-adjusted trend results for total nitrogen at the 32 study sites in the Chesapeake Bay watershed.

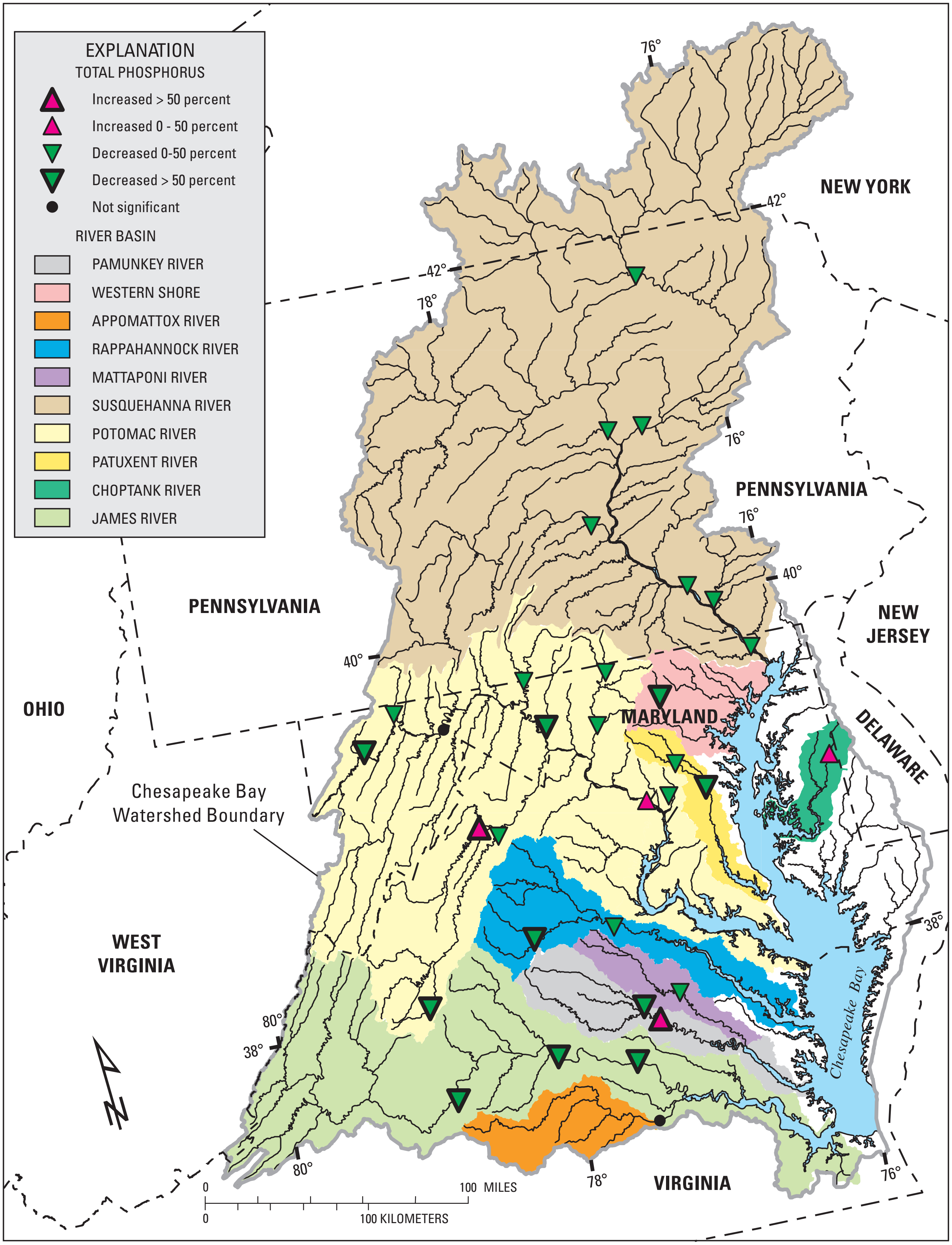

Figure 14. Flow-adjusted trend results for total phosphorus at the 32 study sites in the Chesapeake Bay watershed.

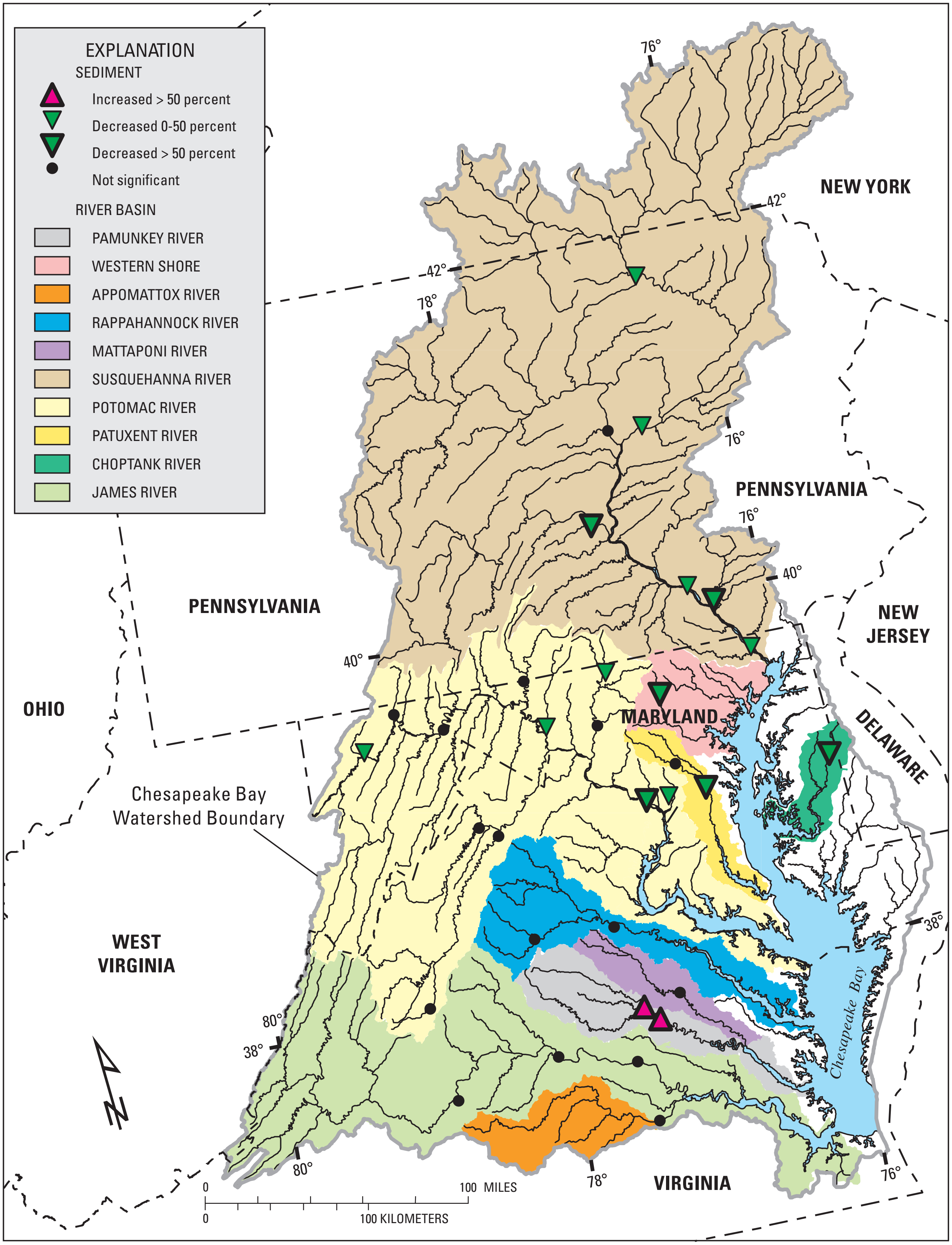

Figure 15. Flow-adjusted trend results for sediment at the 32 study sites in the Chesapeake Bay watershed.

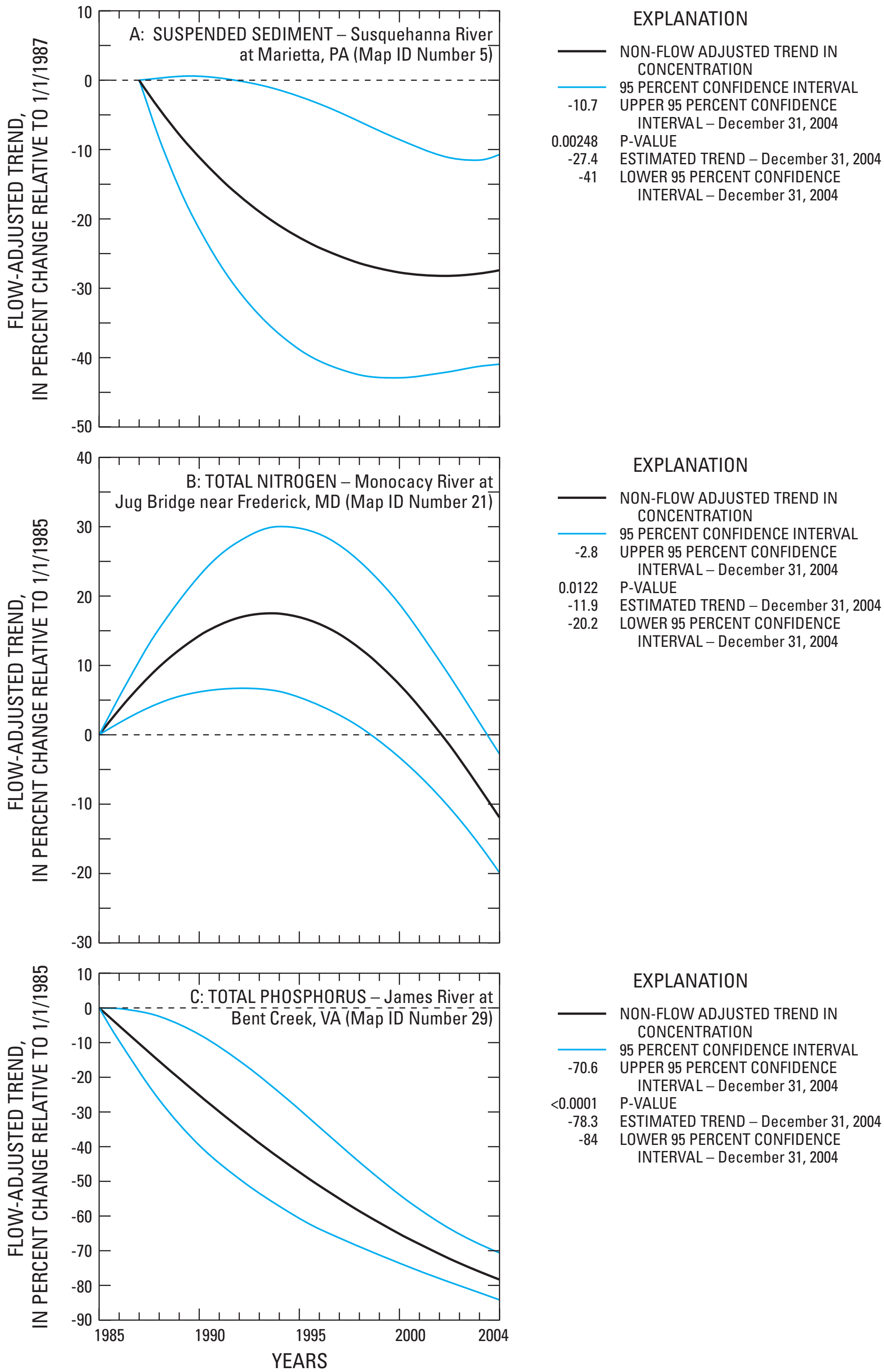

Figure 16. Examples of continuous flow-adjusted trend line plots used to display results for all 32 study sites. Statistical results are presented in appendix.

Summary and Conclusions

Nutrient and sediment data from 32 sites in nontidal parts of the streams in Chesapeake Bay watershed were analyzed to document changes in streamflow and in concentrations and loads of nutrients and sediment from 1985 through 2004, as part of an annual update of water-quality conditions for the Chesapeake Bay Program. Flow-adjusted trends were estimated by use of the U.S. Geological Survey ESTIMATOR model. Changes in seasonal and annual flow, annual nutrient and sediment concentration and load, and flow-weighted concentration were evaluated. Flow-adjusted trends were estimated to help assess changes that result from human activities and management actions. As part of this report, new trend techniques for observed concentration (non-flow adjusted) and loads were developed to improve statistical analysis to help address water-quality changes.

Estimated total freshwater flow to the bay in 2004 was more than double that in 2002, and was the third highest since 1937. Total freshwater flow entering the bay for the “summer” season (July-August-September) 2004 was the highest ever estimated for the period 1937-2004. Trend analyses for streamflow data for 1985 through 2003, however, revealed a significant increase in annual-mean flow for only 1 site, the Choptank River Input Monitoring Program site in Maryland.

Higher ranges in concentrations of total nitrogen and total phosphorus were observed in the northern basins (in Pennsylvania and Maryland) compared to those in the southern basins (in Virginia). Total sediment concentrations are comparable across the watershed. The Conestoga River at Conestoga, Pa., exhibited the greatest total nitrogen, nitrate, and sediment concentrations for all percentiles (10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th}). Median concentrations decreased at all 9 River Input Monitoring Program sites for total nitrogen, total phosphorus, and sediment in 2004 compared to 2003. Results from the Spearman rho analysis indicate that for the 9 RIM Program sites, downward trends in unbiased observed concentrations for total nitrogen, total phosphorus, and sediment, occurred at 3, 2, and 1 site, respectively.

In 2004, combined estimated total nitrogen loads for the River Input Monitoring Program sites were the third highest since 1990, whereas total phosphorus and sediment loads were the fifth highest. From 2003 to 2004, combined estimated total nitrogen loads for the River Input Monitoring Program sites declined nearly 50 Mlbs (million pounds), to 304 Mlbs; total phosphorus declined more than 12 Mlbs, to 15.6 Mlbs; and sediment declined 8,300 Mlbs, to 10,200 Mlbs. Loads for total nitrogen, total phosphorus, and sediment, however, were still greater than the long-term annual mean load by 48, 15, and 25 percent, respectively. The high loads of nutrients and sediment in 2004 likely contributed to observed low concentrations of dissolved oxygen and loss of submerged aquatic vegetation in the tidal waters of Chesapeake Bay.

Combined annual mean flow-weighted concentrations of total nitrogen from the 9 River Input Monitoring Program sites indicates a downward tendency in the 1990s and an upward tendency since 2001; the mean concentration was 1.58 mg/L (milligrams per liter) for 1990 through 2004. Total nitrogen concentrations ranged from a high of 2.78 mg/L in the Patuxent to a low of 0.516 mg/L in the Mattaponi River. Flow-weighted concentrations for total phosphorus and sediment exhibited much more variability than those for total nitrogen. From 1990 to 2004, the combined total phosphorus flow-weighted concentration averaged about 0.085 mg/L for the River Input Monitoring Program sites and ranged from a high of 0.141 mg/L in 1996 to a low of 0.058 mg/L in 1997. The highest annual mean and long-term annual mean concentrations of total phosphorus flow-weighted concentration (0.41 mg/L, 0.21 mg/L) occurred in the Rappahannock River. Conversely, the lowest annual and long-term mean flow-weighted concentration of total phosphorus (0.03 mg/L, 0.05 mg/L) occurred in the Susquehanna River. The lower values in the Susquehanna River were most likely due to phosphorus and sediment being trapped behind three large reservoirs in the lower reaches of the river. Total phosphorus flow-weighted concentrations tended to increase during high-flow years and through the drought period of 1999-2002 for many of the River Input Monitoring Program sites. The combined average mean sediment flow-weighted concentration from 1990 through 2004 was 51 mg/L as measured at the River Input Monitoring Program sites, ranging from 130 mg/L in 1996 to 18 mg/L in 2002. Prior to 1990, the highest annual mean sediment flow-weighted concentration was 740 mg/L in the Potomac River. The sediment flow-weighted concentration was highest in the high-flow years and lowest in the low-flow years. The highest mean annual flow-weighted concentration from 1990 through 2004 was at the Rappahannock River (558 mg/L in 1996).

The lowest annual mean flow-weighted concentration for sediment occurred at the Choptank River (8.8 mg/L in 1995) and lowest long-term mean concentration for sediment occurred at the Pamunkey site (9.8 mg/L).

The results of four different water-quality trend tests were presented (table 5):

1. The Spearman rank correlation coefficient, or rho, which tests for monotonic changes through time in unbiased observed concentration percentiles;
2. A non-flow-adjusted trend in concentration, which is a parametric trend test using linear regression and includes both time and time-squared terms as predictors;
3. A non-flow-adjusted trend in load, which is also a parametric trend test using linear regression and includes both time and time-squared terms as predictors; and
4. A flow-adjusted trend, which uses linear regression to model the changes in concentration independent of variations in streamflow, and includes both time and time-squared terms as predictors.

When the influences of flow and seasonality are removed, results for trends adjusted for flow indicate improvement in water quality. Results of analyses described herein indicate that about 72 percent of the sites (23 sites) had downward flow-adjusted trends for total nitrogen. Five sites indicated upward flow-adjusted trends, with no statistically significant trend at the remaining 4 sites. Trends were downward at 6 and upward at 2 of the 9 River Input Monitoring Program sites. All 7 sites in the Susquehanna River Basin had downward flow-adjusted trends in total nitrogen. In the Potomac River Basin, there were 11 downward trends, 2 upward trends, and 1 site with no statistically significant trend. Five sites in the lower Virginia basins indicated significant downward trends, 2 sites had upward trends (both in the Pamunkey River) and 3 had no statistically significant trend. Flow-adjusted trends in nitrate were downward at 15 sites in nearly all major Chesapeake Bay drainage basins and upward at 5 of the 32 sites. Downward trends for total nitrogen and nitrate were present at 8 of the sites; an upward trend occurred at 1 site.

Flow-adjusted trends for total phosphorus were downward at 26 of the 32 sites and upward at 4 sites; the remaining 2 sites did not have any statistically significant trend. Trends were downward at 5 River Input Monitoring Program sites with downward flow-adjusted trends in total phosphorus occurring in 7 of the 10 major bay drainage basins. Upward flow-adjusted trends in total phosphorus were identified at 4 sites, 3 of which are RIM Program sites (Choptank, Potomac, and Pamunkey).

Significant downward flow-adjusted trends for sediment were detected at 14 sites. An upward trend was reported at 2 sites. The Maryland River Input Monitoring Program sites had 4 downward trends (Choptank, Susquehanna, Patuxent, and Potomac), whereas the Virginia River Input Monitoring Program sites had 1 upward flow-adjusted trend (Pamunkey) and 4 had no statistically significant trend in sediment. The Susquehanna River Basin had downward trends at all 7 sites. The Potomac River Basin had an equal number of downward trends (seven) and sites with no statistically significant trend (also 7). In the lower Virginia river basins, there were no downward trends, 2 downward trends, and 8 sites had no statistically significant trend.

Table 5. Results of Spearman rho, non-flow adjusted (for concentrations and loads) and flow-adjusted trend analysis for the 32 sites.

[TN, total nitrogen; NO23, nitrite plus nitrate; TP, total phosphorus; DIP, dissolved inorganic phosphorus; SED, suspended sediment; TSS, total suspended solids; NS, not significant; SIG-UP, upward significant trend; SIG-DOWN, downward significant trend; all significant trends reported at 95 percent confidence level]

Site name	Site number	Map ID (fig. 1)	Beginning date	End date	Constituent	Spearman rho	Non-flow adjusted trend in concentration	Non-flow adjusted trend in load	Flow-adjusted trend
River Input Monitoring Program Sites									
CHOPTANK RIVER NEAR GREENSBORO, MD	01491000	8	1985	2004	TN	NS	NS	NS	NS
CHOPTANK RIVER NEAR GREENSBORO, MD	01491000	8	1985	2004	NO23	SIG-UP	NS	SIG-UP	SIG-UP
CHOPTANK RIVER NEAR GREENSBORO, MD	01491000	8	1985	2004	TP	NS	SIG-UP	SIG-UP	SIG-UP
CHOPTANK RIVER NEAR GREENSBORO, MD	01491000	8	1985	2004	DIP	NS	SIG-UP	SIG-UP	NS
CHOPTANK RIVER NEAR GREENSBORO, MD	01491000	8	1985	2004	SED	NS	NS	NS	SIG-DOWN
SUSQUEHANNA RIVER AT CONOWINGO, MD	01578310	7	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT CONOWINGO, MD	01578310	7	1985	2004	NO23	NS	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT CONOWINGO, MD	01578310	7	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT CONOWINGO, MD	01578310	7	1985	2004	DIP	NS	SIG-UP	NS	SIG-UP
SUSQUEHANNA RIVER AT CONOWINGO, MD	01578310	7	1985	2004	SED	SIG-DOWN	NS	NS	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	01594440	11	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	01594440	11	1985	2004	NO23	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	01594440	11	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	01594440	11	1985	2004	DIP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
PATUXENT RIVER NEAR BOWIE, MD	01594440	11	1985	2004	SED	NS	NS	NS	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	01646580	23	1985	2004	TN	NS	NS	NS	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	01646580	23	1985	2004	NO23	NS	NS	NS	SIG-DOWN
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	01646580	23	1985	2004	TP	NS	NS	NS	SIG-UP
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	01646580	23	1985	2004	DIP	NS	NS	NS	SIG-UP
POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, D.C.	01646580	23	1985	2004	SED	NS	NS	NS	SIG-DOWN
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	01668000	25	1988	2004	TSS	NS	NS	NS	NS
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	01668000	25	1985	2004	TN	NS	NS	NS	SIG-DOWN
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	01668000	25	1985	2004	NO23	NS	NS	NS	SIG-DOWN
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	01668000	25	1985	2004	TP	NS	NS	NS	SIG-DOWN
RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	01668000	25	1985	2004	DIP	NS	NS	NS	SIG-DOWN
PAMUNKEY RIVER NEAR HANOVER, VA	01673000	28	1989	2004	TSS	NS	NS	NS	SIG-UP
PAMUNKEY RIVER NEAR HANOVER, VA	01673000	28	1985	2004	TN	SIG-UP	SIG-UP	NS	SIG-UP
PAMUNKEY RIVER NEAR HANOVER, VA	01673000	28	1985	2004	NO23	SIG-UP	SIG-UP	NS	SIG-UP
PAMUNKEY RIVER NEAR HANOVER, VA	01673000	28	1985	2004	TP	SIG-UP	SIG-UP	NS	SIG-UP
PAMUNKEY RIVER NEAR HANOVER, VA	01673000	28	1985	2004	DIP	NS	SIG-UP	NS	SIG-UP
MATTAPONI RIVER NEAR BEULAHVILLE, VA	01674500	26	1989	2004	TSS	NS	NS	NS	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	01674500	26	1985	2004	TN	NS	NS	NS	SIG-DOWN

Table 5. (Continued) Results of Spearman rho, non-flow adjusted (for concentrations and loads) and flow-adjusted trend analysis for the 32 sites.

[TN, total nitrogen; NO23, nitrite plus nitrate; TP, total phosphorus; DIP, dissolved inorganic phosphorus; SED, suspended sediment; TSS, total suspended solids; NS, not significant; SIG-UP, upward significant trend; SIG-DOWN, downward significant trend; all significant trends reported at 95 percent confidence level]

Site name	Site number	Map ID (fig. 1)	Beginning date	End date	Constituent	Spearman rho	Non-flow adjusted trend in concentration	Non-flow adjusted trend in load	Flow-adjusted trend
MATTAPONI RIVER NEAR BEULAHVILLE, VA	01674500	26	1985	2004	NO23	NS	NS	NS	NS
MATTAPONI RIVER NEAR BEULAHVILLE, VA	01674500	26	1985	2004	TP	NS	NS	NS	SIG-DOWN
MATTAPONI RIVER NEAR BEULAHVILLE, VA	01674500	26	1985	2004	DIP	NS	NS	NS	NS
JAMES RIVER AT CARTERSVILLE, VA	02035000	30	1988	2004	TSS	NS	NS	NS	NS
JAMES RIVER AT CARTERSVILLE, VA	02035000	30	1985	2004	TN	SIG-DOWN	NS	NS	SIG-DOWN
JAMES RIVER AT CARTERSVILLE, VA	02035000	30	1985	2004	NO23	NS	SIG-DOWN	NS	SIG-DOWN
JAMES RIVER AT CARTERSVILLE, VA	02035000	30	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
JAMES RIVER AT CARTERSVILLE, VA	02035000	30	1985	2004	DIP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
APPOMATTOX RIVER AT MATOACA, VA	02041650	32	1989	2004	TSS	NS	NS	NS	NS
APPOMATTOX RIVER AT MATOACA, VA	02041650	32	1985	2004	TN	NS	NS	NS	NS
APPOMATTOX RIVER AT MATOACA, VA	02041650	32	1985	2004	NO23	NS	NS	NS	SIG-DOWN
APPOMATTOX RIVER AT MATOACA, VA	02041650	32	1985	2004	TP	SIG-UP	NS	NS	NS
APPOMATTOX RIVER AT MATOACA, VA	02041650	32	1985	2004	DIP	NS	NS	NS	NS
Multi-Agency Nontidal Monitoring Program Sites									
SUSQUEHANNA RIVER AT TOWANDA, PA	01531500	1	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT TOWANDA, PA	01531500	1	1991	2004	NO23	NS	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT TOWANDA, PA	01531500	1	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT TOWANDA, PA	01531500	1	1989	2004	SED	NS	NS	NS	SIG-DOWN
SUSQUEHANNA RIVER AT DANVILLE, PA	01540500	2	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT DANVILLE, PA	01540500	2	1985	2004	NO23	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT DANVILLE, PA	01540500	2	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT DANVILLE, PA	01540500	2	1985	2004	SED	NS	NS	NS	SIG-DOWN
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	01553500	3	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	01553500	3	1985	2004	NO23	NS	NS	NS	NS
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	01553500	3	1985	2004	TP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
WEST BRANCH SUSQUEHANNA RIVER AT LEWISBURG, PA	01553500	3	1985	2004	SED	NS	NS	NS	NS
JUNIATA RIVER AT NEWPORT, PA	01567000	4	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
JUNIATA RIVER AT NEWPORT, PA	01567000	4	1985	2004	NO23	NS	NS	NS	NS
JUNIATA RIVER AT NEWPORT, PA	01567000	4	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
JUNIATA RIVER AT NEWPORT, PA	01567000	4	1985	2004	SED	NS	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT MARIETTA, PA	01576000	5	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
SUSQUEHANNA RIVER AT MARIETTA, PA	01576000	5	1987	2004	NO23	NS	NS	NS	NS
SUSQUEHANNA RIVER AT MARIETTA, PA	01576000	5	1985	2004	TP	NS	NS	NS	SIG-DOWN

Table 5. (Continued) Results of Spearman rho, non-flow adjusted (for concentrations and loads) and flow-adjusted trend analysis for the 32 sites.

[TN, total nitrogen; NO23, nitrite plus nitrate; TP, total phosphorus; DIP, dissolved inorganic phosphorus; SED, suspended sediment; TSS, total suspended solids; NS, not significant; SIG-UP, upward significant trend; SIG-DOWN, downward significant trend; all significant trends reported at 95 percent confidence level]

Site name	Site number	Map ID (fig. 1)	Beginning date	End date	Constituent	Spearman rho	Non-flow adjusted trend in concentration	Non-flow adjusted trend in load	Flow-adjusted trend
SUSQUEHANNA RIVER AT MARIETTA, PA	01576000	5	1987	2004	SED	NS	NS	NS	SIG-DOWN
CONESTOGA RIVER AT CONESTOGA, PA	01576754	6	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
CONESTOGA RIVER AT CONESTOGA, PA	01576754	6	1986	2004	NO23	NS	NS	NS	SIG-UP
CONESTOGA RIVER AT CONESTOGA, PA	01576754	6	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
CONESTOGA RIVER AT CONESTOGA, PA	01576754	6	1985	2004	SED	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	01586000	9	1985	2004	TSS	NS	NS	NS	SIG-DOWN
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	01586000	9	1985	2004	TN	NS	NS	NS	SIG-UP
NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	01586000	9	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
PATUXENT RIVER NEAR LAUREL, MD	01592500	10	1985	2004	TSS	NS	NS	NS	NS
PATUXENT RIVER NEAR LAUREL, MD	01592500	10	1985	2004	TN	NS	NS	NS	NS
PATUXENT RIVER NEAR LAUREL, MD	01592500	10	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
GEORGES CREEK AT FRANKLIN, MD	01599000	12	1985	2004	TSS	NS	NS	NS	SIG-DOWN
GEORGES CREEK AT FRANKLIN, MD	01599000	12	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
GEORGES CREEK AT FRANKLIN, MD	01599000	12	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
WILLS CREEK NEAR CUMBERLAND, MD	01601500	13	1985	2004	TSS	NS	NS	NS	NS
WILLS CREEK NEAR CUMBERLAND, MD	01601500	13	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
WILLS CREEK NEAR CUMBERLAND, MD	01601500	13	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
POTOMAC RIVER AT PAW PAW, WV	01610000	14	1985	2004	TSS	NS	NS	NS	NS
POTOMAC RIVER AT PAW PAW, WV	01610000	14	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
POTOMAC RIVER AT PAW PAW, WV	01610000	14	1985	2004	TP	NS	NS	NS	NS
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	01614500	15	1985	2004	TSS	NS	NS	NS	NS
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	01614500	15	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	01614500	15	1985	2004	NO23	NS	SIG-DOWN	NS	SIG-DOWN
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	01614500	15	1985	2004	TP	SIG-DOWN	NS	NS	SIG-DOWN
CONOCOCHEAGUE CREEK AT FAIRVIEW, MD	01614500	15	1985	2004	DIP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
ANTIETAM CREEK NEAR SHARPSBURG, MD	01619500	16	1985	2004	TSS	NS	NS	NS	SIG-DOWN
ANTIETAM CREEK NEAR SHARPSBURG, MD	01619500	16	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
ANTIETAM CREEK NEAR SHARPSBURG, MD	01619500	16	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
SOUTH RIVER NEAR WAYNESBORO, VA	01626000	17	1985	2004	TSS	NS	NS	NS	NS
SOUTH RIVER NEAR WAYNESBORO, VA	01626000	17	1985	2004	TN	NS	NS	NS	NS
SOUTH RIVER NEAR WAYNESBORO, VA	01626000	17	1985	2004	TP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	01631000	18	1985	2004	TSS	NS	NS	NS	NS
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	01631000	18	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	01631000	18	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN

Table 5. (Continued) Results of Spearman rho, non-flow adjusted (for concentrations and loads) and flow-adjusted trend analysis for the 32 sites.

[TN, total nitrogen; NO23, nitrite plus nitrate; TP, total phosphorus; DIP, dissolved inorganic phosphorus; SED, suspended sediment; TSS, total suspended solids; NS, not significant; SIG-UP, upward significant trend; SIG-DOWN, downward significant trend; all significant trends reported at 95 percent confidence level]

Site name	Site number	Map ID (fig. 1)	Beginning date	End date	Constituent	Spearman rho	Non-flow adjusted trend in concentration	Non-flow adjusted trend in load	Flow-adjusted trend
SOUTH FORK SHENANDOAH RIVER AT FRONT ROYAL, VA	01631000	18	1985	2004	DIP	NS	NS	NS	NS
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	01634000	19	1985	2004	TSS	NS	NS	NS	NS
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	01634000	19	1985	2004	TN	NS	SIG-UP	NS	SIG-UP
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	01634000	19	1985	2004	TP	NS	SIG-UP	SIG-UP	SIG-UP
NORTH FORK SHENANDOAH RIVER NEAR STRASBURG, VA	01634000	19	1985	2004	DIP	SIG-UP	SIG-UP	SIG-UP	SIG-UP
MONOCACY RIVER AT BRIDGEPORT, MD	01639000	20	1985	2004	TSS	NS	NS	NS	SIG-DOWN
MONOCACY RIVER AT BRIDGEPORT, MD	01639000	20	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
MONOCACY RIVER AT BRIDGEPORT, MD	01639000	20	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	01643000	21	1985	2004	TSS	NS	NS	NS	NS
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	01643000	21	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	01643000	21	1985	2004	TP	NS	NS	NS	SIG-DOWN
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	01651000	22	1985	2004	TSS	NS	NS	NS	SIG-DOWN
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	01651000	22	1985	2004	TN	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
NW BRANCH ANACOSTIA RIVER NEAR HYATTSVILLE, MD	01651000	22	1985	2004	TP	NS	SIG-DOWN	NS	SIG-DOWN
ROBINSON RIVER NEAR LOCUST DALE, VA	01666500	24	1985	2004	TSS	NS	NS	NS	NS
ROBINSON RIVER NEAR LOCUST DALE, VA	01666500	24	1985	2004	TN	NS	NS	NS	SIG-DOWN
ROBINSON RIVER NEAR LOCUST DALE, VA	01666500	24	1985	2004	TP	SIG-DOWN	SIG-DOWN	NS	SIG-DOWN
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	01671020	27	1985	2004	TSS	NS	NS	NS	SIG-UP
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	01671020	27	1985	2004	TN	NS	NS	NS	SIG-UP
NORTH ANNA RIVER AT HART CORNER NEAR DOSWELL, VA	01671020	27	1985	2004	TP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
JAMES RIVER AT BENT CREEK, VA	02026000	29	1985	2004	TSS	NS	NS	NS	NS
JAMES RIVER AT BENT CREEK, VA	02026000	29	1985	2004	TN	NS	SIG-DOWN	NS	SIG-DOWN
JAMES RIVER AT BENT CREEK, VA	02026000	29	1985	2004	TP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN
JAMES RIVER NEAR RICHMOND, VA	02037500	31	1985	2004	TSS	NS	NS	NS	NS
JAMES RIVER NEAR RICHMOND, VA	02037500	31	1985	2004	TN	NS	NS	NS	NS
JAMES RIVER NEAR RICHMOND, VA	02037500	31	1985	2004	TP	SIG-DOWN	SIG-DOWN	SIG-DOWN	SIG-DOWN

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