In cooperation with the
Maryland Department of Natural Resources
Virginia Department of Environmental Quality
Pennsylvania Department of Environmental Protection

Nutrient and Sediment Concentrations, Loads, and Trends for Four Nontidal Tributaries in the Chesapeake Bay Watershed, 1997–2001

Scientific Investigations Report 2004-5125

U.S. Department of the Interior
U.S. Geological Survey

Cover. Chesterville Branch water-quality-monitoring station 01493112 at the MD State Route 291 (River Road) overpass near Crumpton, Maryland.

[Photograph by Michael P. Senus, U.S. Geological Survey]

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by Michael P. Senus, Michael J. Langland, and Douglas L. Moyer

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Conversion Factors, Datums, and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Flow Rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
ton per day per square mile [$(ton/d)/mi^2$]	0.3503	megagram per day per square kilometer
ton per year (ton/yr)	0.9072	metric ton per year
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Altitude, as used in this report, refers to distance above or below sea level.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88) and horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Water year: Defined as the period beginning October 1 and ending September 30, designated by the calendar year in which it ends. Thus, the water year beginning on October 1, 2000 and ending on September 30, 2001, is called the 2001 water year.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

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

Abbreviations and Acronyms

AMLE	Adjusted Maximum Likelihood Estimate
BMPs	Best Management Practices
BNR	biological nutrient reduction
CBP	Chesapeake Bay Program
DO	dissolved oxygen
EDI	equal-discharge increment
ETR	equal-transit rate
EWI	equal-width increment
GIS	geographic information system
HSPF	Hydrological Simulation Program- FORTRAN
MD DNR	Maryland Department of Natural Resources
MVUE	Minimum Variance Unbiased Estimate
MWCOG	Metropolitan Washington Council of Governments
NAWQA	National Water-Quality Assessment Program
NWIS	National Water Information System
NWQL	National Water-Quality Laboratory
PA DEP	Pennsylvania Department of Environmental Protection
pH	hydrogen potential
QA	quality assurance
QAPP	quality-assurance project plan
QC	quality control
RIM	River Input Monitoring
SEP	standard error of prediction
SPARROW	SPAtially Referenced Regressions On Watershed attributes
SRBC	Susquehanna River Basin Commission
TMDL	Total Maximum Daily Load
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VA DEQ	Virginia Department of Environmental Quality
WSM	Chesapeake Bay Watershed Model

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Abstract

Excess nutrient and sediment loads in the Chesapeake Bay can cause unbalanced water-quality conditions that reduce the amount of oxygen and sunlight available to aquatic plants and organisms. Nutrient and sediment loads and trends were analyzed at four nontidal tributaries in the Chesapeake Bay watershed to collect additional data for the ongoing (since 1985) U.S. Geological Survey Chesapeake Bay River Input Monitoring Program. These sites were Chesterville Branch in Maryland, Conodoguinet Creek in Pennsylvania, North Fork Shenandoah River in Virginia, and South Fork Shenandoah River in Virginia. Monthly base-flow and stormflow water-quality samples were collected at each site, with a total of 90–120 samples collected at each site during the study period (1997–2001). These data were used to compute annual and monthly loads for selected nutrient and suspended-sediment constituents using a mass-load estimating model, ESTIMATOR, developed by the U.S. Geological Survey. Each of the four study sites in this report was characterized on the basis of land use and water-quality data. Basins with high percentages of agricultural land use had higher nitrogen and phosphorus loads and yields than basins with higher percentages of forested land and less agricultural land. No relation between land use and suspended-sediment loads and yields was evident. Study results also indicate that suspended-sediment loads were higher in years of high mean annual streamflow at Conodoguinet Creek, North Fork Shenandoah River, and South Fork Shenandoah River. The highest total suspended-sediment loads and yields at Chesterville Branch were caused by Hurricane Floyd in 1999, which was not a year with the highest annual total streamflow. Results of this study indicate that a 5-year period of record is too short a timeframe to characterize factors affecting trends. Moreover, a combination of extreme variability in climate and lack of recent land-use data made characterizing basin nutrient and sediment relations problematic. Although the data and analysis established a baseline of water quality at the four tributaries, additional monitoring and tracking of loads would help identify long-term trends and factors affecting trends.

Introduction

The Chesapeake Bay has been degraded by water-quality problems, loss of habitat, and over-harvesting of living resources. Since the early 1980s, scientists have been studying the bay and its 64,000-mi^2 (square mile) watershed, which drains parts of Delaware, the District of Columbia, Maryland, New York, Pennsylvania, Virginia, and West Virginia (fig. 1). One important issue for bay resource managers is how the bay's tributaries support a complex aquatic food web that is vulnerable to changes in water quality. The amount of nutrients and sediment delivered to the bay's estuary affects water quality. Nutrients are needed to sustain life, but excess nutrient loads from human activities may cause unbalanced and unhealthy changes in water quality that are harmful to aquatic organisms. Nitrogen and phosphorus are two known nutrients of concern. Poor water quality caused by an abundance of these nutrients can stimulate the excessive growth of phytoplankton, promote algal blooms, reduce dissolved oxygen (DO) levels, and cause fish kills. Similarly, high sediment loads delivered to the bay degrade water quality. Sediment delivery from land surfaces to water bodies is a result of erosion. The erosion process also can be accelerated by certain land uses such as urban growth, or not using best management practices (BMPs) on agricultural land. If BMPs, such as conservation tillage and use of cover crops, planting buffer strips or grass waterways, establishing animal waste retention basins, or constructing streambank reinforcements are not utilized, then a greater load of excess nutrients and/or sediment is expected to be delivered to the bay. As a result, water clarity is reduced and sunlight needed to penetrate the water

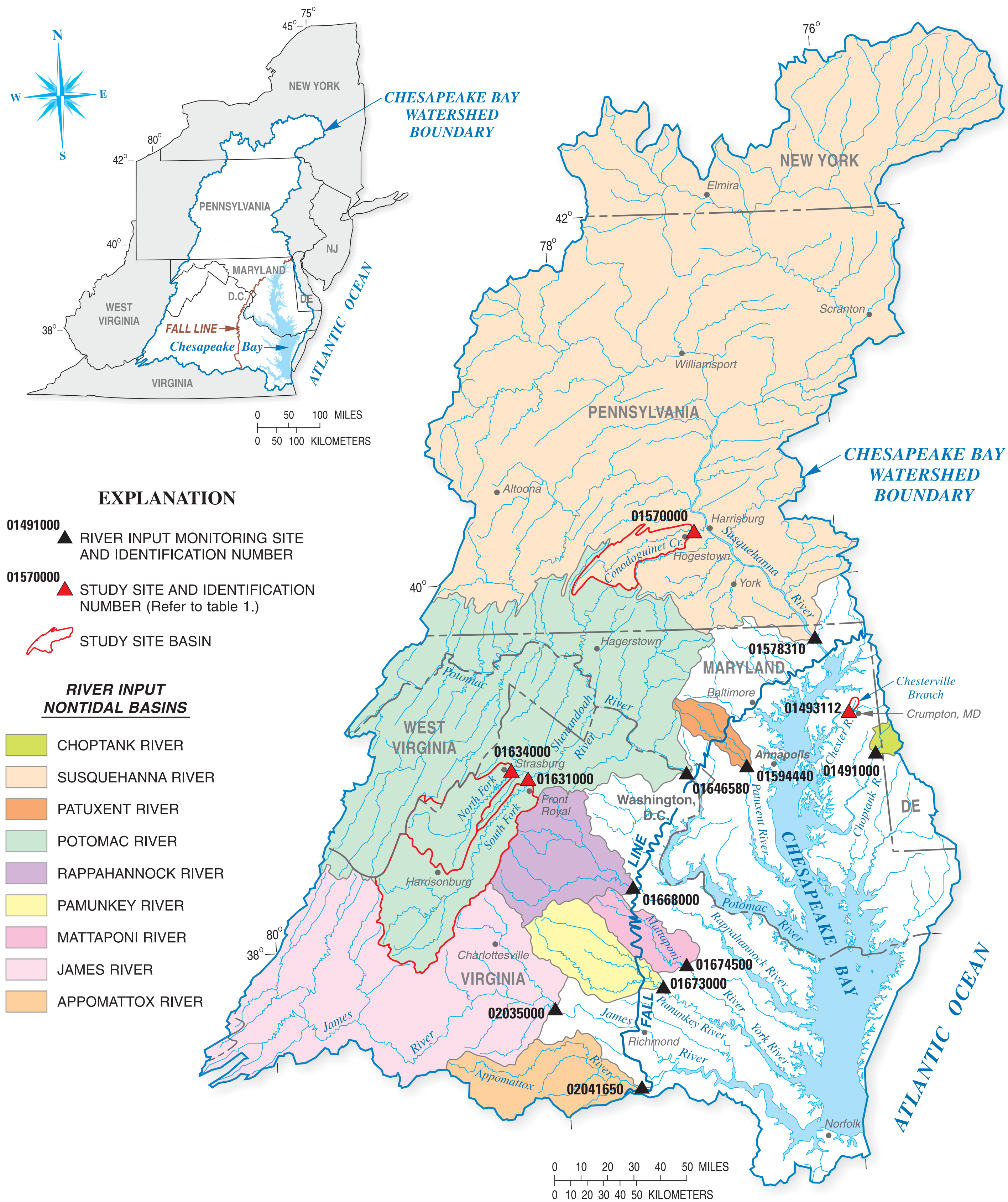

Figure 1. Location of Chesapeake Bay watershed study area, study site basins, and Chesapeake Bay River Input Monitoring Program site basins.

column for underwater bay grasses is diminished. Without sunlight, underwater plants die and remove life-supporting habitat and food for fish, shellfish, and other living resources. Hence, the Chesapeake Bay Program has determined that by reducing nutrient and sediment loads to the bay, water quality would improve by alleviating low DO conditions, reducing algal blooms, and improving water clarity (S.W. Phillips, U.S. Geological Survey, written commun., 2003; U.S. Environmental Protection Agency, 1988, 2000, 2003).

Background

Following a multi-year U.S. Geological Survey (USGS) study to assess water quality in the bay, the District of Columbia, Maryland, Pennsylvania, and Virginia signed a multi-jurisdictional agreement in 1983 with the U.S. Environmental Protection Agency (USEPA) to form the Chesapeake Bay Program (CBP). The CBP is a voluntary partnership that works with citizen advisory groups to improve the quality of the bay and its tributaries. In 1999, the bay was listed formally under the Clean Water Act as an impaired water body because of excess nutrients and sediment (Phillips, 2001). The "Chesapeake 2000" agreement states that if improvements in water-quality conditions in the bay are not made by 2010, strict regulatory actions may be implemented (S.W. Phillips, U.S. Geological Survey, written commun., 2003; U.S. Environmental Protection Agency, 1988, 2000, 2003).

To help facilitate evaluation of the bay's health on or before 2010, USGS monitoring, assessment, and prediction are used by the CBP to characterize past and present water-quality conditions. The Chesapeake Bay River Input Monitoring (RIM) Program provides long-term water-quality monitoring data and continuous streamflow data to quantify nutrient and sediment loads and trends in the nine major nontidal tributaries of the Chesapeake Bay watershed (fig. 1). In Maryland, the RIM Program was implemented in 1983 between the USGS, the Maryland Department of Natural Resources (MD DNR), and the Metropolitan Washington Council of Governments (MWCOG). In 1988, the USGS began the RIM Program in Virginia in cooperation with the Virginia Department of Environmental Quality (VA DEQ). The Conodoguinet Creek site in Pennsylvania was a cooperative effort between the USGS and the Pennsylvania Department of Environmental Protection (PA DEP). To further characterize the bay, watershed-process modelers utilize these monitoring data to establish connections between watershed conditions (land-use type, agricultural management practices, anthropogenic nutrient inputs, and sediment erosion), hydrologic conditions (size, geology, and slope), changes in climate, and water quality in the bay. The CBP Watershed Model (WSM)[1] and the USGS SPAtially Referenced Regressions On Watershed attributes (SPARROW) models help to identify factors affecting trends and are discussed further in Sprague and others (2000).

This study was undertaken in cooperation with the MD DNR, VA DEQ, and PA DEP, and is a supplement to the RIM studies that have been conducted since 1985. In the mid–1990s, the RIM Program was well established and studies were encouraged in order to advance scientific knowledge of the bay. To increase understanding of the nontidal part of the bay watershed, monitoring sites in addition to the RIM sites were needed to further describe the agricultural land-use part of the Eastern Shore, examine potential effects of emerging land-use changes in the lower Susquehanna River Basin, and focus study on two sub-basins of the Potomac River Basin. In 1996, four nontidal tributary sites within the Chesapeake Bay watershed were selected by the CBP Monitoring and Assessment subcommittee and associated workgroups for additional monitoring by the RIM Program. Balancing financial resources and the desire for greater understanding of the watershed, the subcommittee felt that four sites would meet this need (S.W. Phillips and J.P. Raffensperger, U.S. Geological Survey, oral commun., 2003). These sites were Chesterville Branch in Maryland, Conodoguinet Creek in Pennsylvania, North Fork Shenandoah River in Virginia, and South Fork Shenandoah River in Virginia. These "add-on" sites will be referred to as the "study" sites.

In this report, the Chesapeake Bay watershed is defined as the area bounded by physical barriers that cause water to drain to the bay's tributaries and estuary. Land area upstream of each USGS streamflow-gaging station is referred to as a "basin" for each study site. Collectively, these basins make up the bay watershed. Unless otherwise specified, the term "observed concentration" or "measured concentration" will be referred to simply as "concentration".

Purpose and Scope

This report presents the nutrient and sediment concentrations, loads, and trends at the four study sites within the bay watershed for 5 full calendar years, 1997 through 2001. The purpose of this report, determined by the CBP, is to:

1. Provide watershed modelers with additional water-quality data for the SPARROW models and additional calibration data for the WSM to fill in the models' spatial gaps;
2. Provide monthly and annual loads for nitrogen, phosphorus, and suspended sediment and relate them to various hydrogeomorphic regions in the watershed;
3. Provide information that can be used with other data to determine factors affecting trends in concentration and load; and

[1] Model utilizes Hydrological Simulation Program-FORTRAN (HSPF).

4. Provide information to resource managers formulating tributary strategies aimed at Total Maximum Daily Load (TMDL) development for nutrient and sediment control, and to the USEPA for nutrient- and sediment-reduction goals.

Criteria for selecting the new monitoring sites included limited capital costs, sites with a real-time streamflow gaging station already in operation, adequate site access under changing flow conditions, present and usable platforms for water-quality sampling near or at the streamflow-gaging station, and the need to further characterize specific basins because of land-use changes or data gaps.

Previous Studies

Initial studies in the Chesapeake Bay watershed focused on three major tributaries in Lang (1982). The RIM Program has over a decade of constituent and field parameter data for Virginia sites and almost two decades of data for the Maryland sites (James and others, 2003). Since 1994, reports on loads and trends for CBP RIM sites have been published periodically by the USGS in cooperation with the MD DNR and the VA DEQ. These data, values, and trends are available in publications and in electronic format through the USGS (Darrell and others, 1999; Lizarraga, 1999; Johnson and others, 1998; Langland and others, 1998, 2000, 2001). The regression model, ESTIMATOR, was developed by the USGS and is widely used for load estimation. The model is discussed in detail in Bradu and Mundlak (1970) and in Cohn and others (1989, 1992). Historical use of the ESTIMATOR model for Chesapeake Bay studies is described in Darrell and others (1999), and the revised load estimation procedure is described in Yochum (2000). Trends in nutrient and sediment delivery to the bay are discussed in Langland and others (2001) and Sprague and others (2000).

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Description of Study Sites

The four study sites were carefully selected to meet the goals and objectives set forth by the CBP Monitoring and Assessment subcommittee. This section describes each of the four sites, and lists any characteristics unique to each site and its basin. The Chesterville Branch, Conodoguinet Creek, North Fork Shenandoah River, and South Fork Shenandoah River study sites were monitored for water quality and flow well above the point of tidal effects of the bay. Most RIM monitoring sites are located close to a point downstream not affected by tides, also known as the “Fall Line” boundary (fig. 1). The Fall Line refers to a distinct change in slope generally along a southwest to northeast trending line through the bay watershed, representing the boundary between the Piedmont and Coastal Plain hydrogeomorphic regions. The study sites’ basins include a wide range of land cover (fig. 2, table 1), geographic, and geologic regions, draining such diverse areas as the forested, agricultural, and developed land of the Appalachian Plateau of New York and Pennsylvania, the Valley and Ridge of the Pennsylvania and West Virginia highlands, the Shenandoah Valley of Virginia, and the flat lowlands of Maryland’s Eastern Shore and Delaware.

Chesterville Branch near Crumpton, Maryland

Streamflow and water quality are monitored on Chesterville Branch at the MD State Route 291 (also known as River Road) overpass, near Crumpton, MD. Chesterville Branch is a small tributary of the Chester River in the central part of the Eastern Shore in Kent County. The gaging station is located and water-quality samples are collected from the downstream side of the Route 291 overpass.

The Chesterville Branch Basin is 6.12 mi^2, and is the smallest of the four study site basins and all nine RIM basins. Chesterville Branch originates in Kent County and flows south-southwest to the Chester River. The entire basin lies within the Atlantic Coastal Plain hydrogeomorphic region (fig. 3). Land use above the Chesterville gaging station is 3 percent forested, over 90 percent agricultural, and less than 1 percent developed (table 1). This basin is representative of a part of the Eastern Shore that is dominated by agricultural land use. The Chesterville gaging station is located in the Coastal Plain dissected upland hydrogeomorphic region (Brakebill and Kelley, 2000) that is underlain by permeable Tertiary sand and the marine glauconite Aquia Formation near land surface (Böhlke and Denver, 1995).

The Chesterville Branch near Crumpton, MD site was selected as a monitoring location in order to provide an additional Eastern Shore site in the Coastal Plain. The current (2004) RIM site on the Eastern Shore is at the Choptank River near Greensboro, MD (01491000). The Choptank River Basin is not entirely representative of the agriculturally dominated Eastern Shore (Sprague and others, 2000). Land use above the Choptank RIM site is approximately 30 percent forested whereas the Chesterville Branch near Crumpton site is approximately 3 percent forested as narrow wooded riparian zones (U.S. Geological Survey, 2000). Agricultural land use in the Choptank River Basin is 50 percent, and agricultural land use in the Chesterville Branch Basin is over 90 percent (U.S. Geological Survey, 2000). The high percentage of agricultural to forested land use has

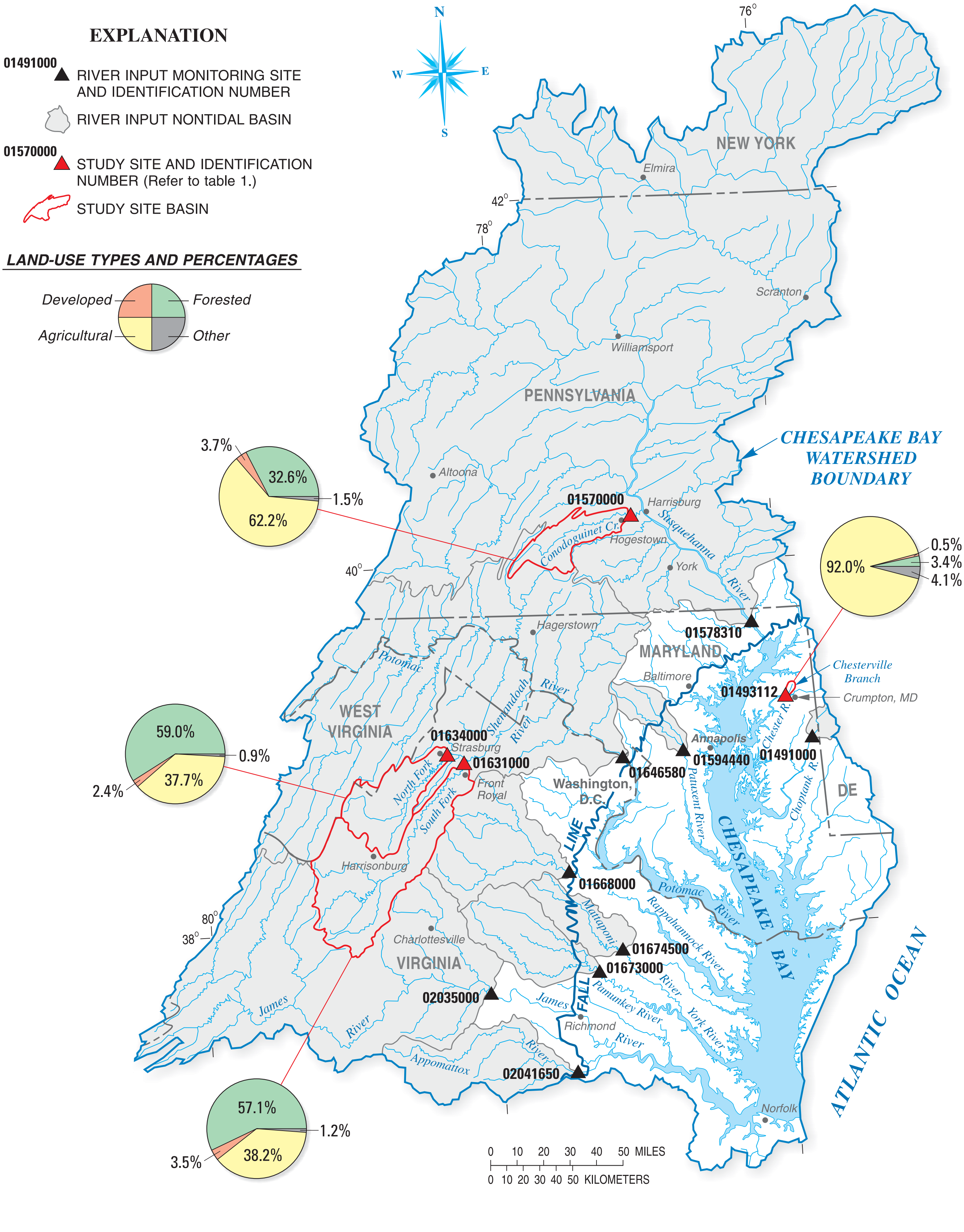

Figure 2. Location of Chesapeake Bay watershed study area showing land-use percentages of study site basins.

Table 1. *Study site locations and land-use characteristics in the study basins, Chesapeake Bay watershed*

[Modified from U.S. Geological Survey (USGS), 2000; ° , ' , " , degree, minute, second]

USGS station name	USGS station number	Latitude (° ' ")	Longitude (° ' ")	Drainage (square miles)	Percentage of Land Use			
					Forested	Developed	Agricultural	Other
Chesterville Branch near Crumpton, MD	01493112	39 15 00	75 53 00	6.12	3.4	0.5	92.0	4.1
Conodoguinet Creek near Hogestown, PA	01570000	40 15 08	77 01 17	470	32.6	3.7	62.2	1.5
North Fork Shenandoah River near Strasburg, VA	01634000	38 58 36	78 20 11	768	59.0	2.4	37.7	0.9
South Fork Shenandoah River at Front Royal, VA	01631000	38 54 50	78 12 40	1,642	57.1	3.5	38.2	1.2

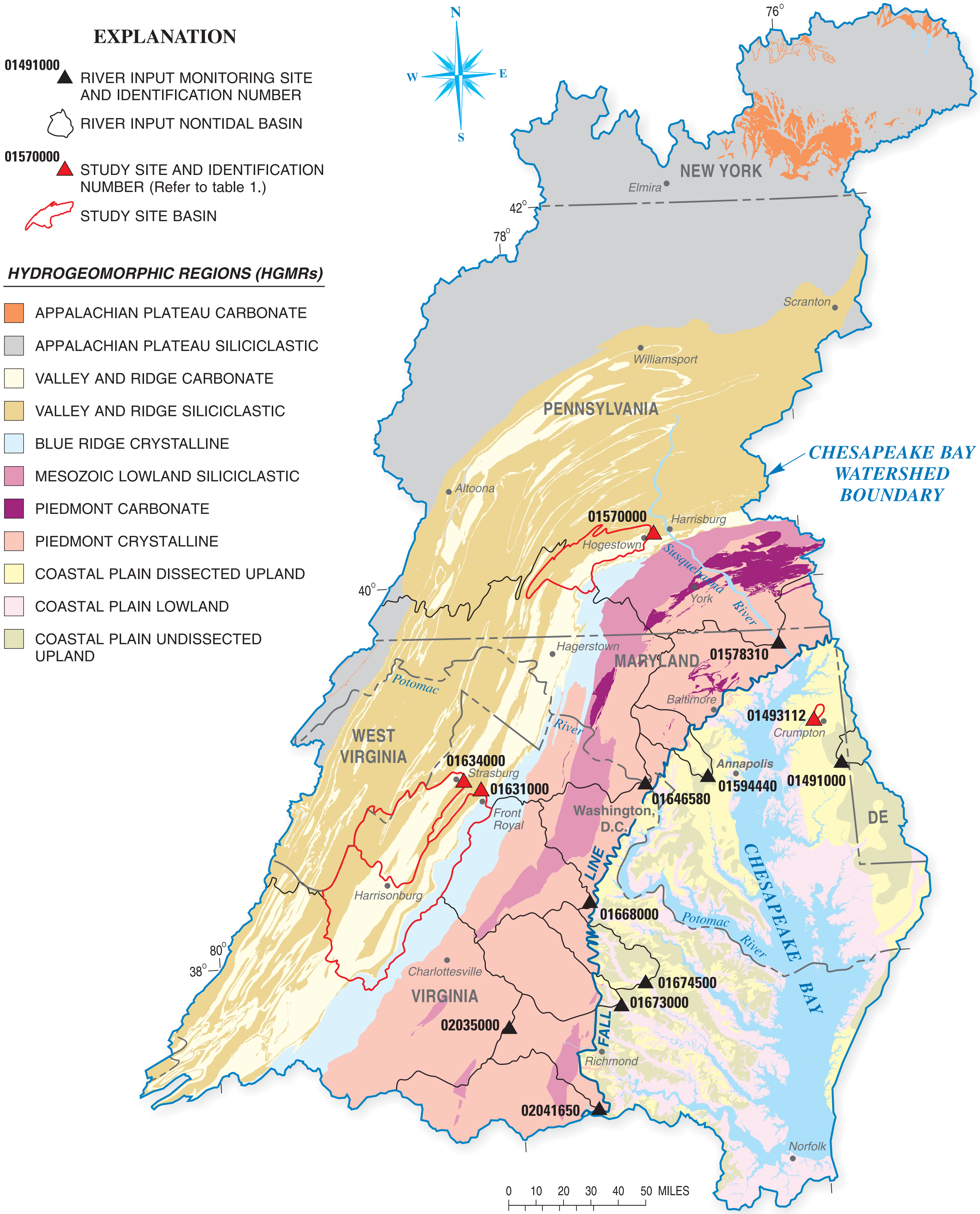

Figure 3. Hydrogeomorphic regions in the Chesapeake Bay watershed.

remained constant over the past 40–50 years (Böhlke and Denver, 1995). Much of the basin above the Choptank River gaging station has poorly drained soils and requires a network of ditches throughout the agricultural land. These ditches generally are devoid of vegetation to facilitate flow off the farmlands. Therefore, nutrient uptake by plants and denitrification are less likely to occur in comparison to other Eastern Shore basins.

Conodoguinet Creek near Hogestown, Pennsylvania

Streamflow and water quality are monitored on Conodoguinet Creek in Cumberland County, Pennsylvania. The Conodoguinet Creek Basin (470 mi^2) originates in Cumberland County and flows northeast to the Susquehanna River (fig. 1). The Conodoguinet Creek Basin lies mostly within the Valley and Ridge Physiographic Province. The basin is composed geologically of a mix of 3 percent Blue Ridge Crystalline, 37 percent Valley and Ridge Carbonate, and 60 percent Valley and Ridge Siliciclastic hydrogeomorphic regions (Brakebill and Kelley, 2000). In 1997, land use above the Conodoguinet gaging station was 33 percent forested, 62 percent agricultural, and 4 percent developed (U.S. Geological Survey, 2000; table 1).

The Conodoguinet Creek near Hogestown, PA site was selected with input from the PA DEP because of rapid land-use changes from agriculture to developed lands within the basin. Much of this growth was caused by the development of residential communities along the flood plain on the banks of Conodoguinet Creek. Most of the land-use change has occurred downstream of the Conodoguinet gaging station; however, suburban growth is increasing at a rapid pace and moving upstream within the basin near the gaging station. In addition to the increase in residential areas, there has been a change from private individual septic systems to recently controlled or expanded public sewage-treatment plants, which have the potential to increase the nitrogen and phosphorus loads into Conodoguinet Creek.

North Fork Shenandoah River near Strasburg, Virginia

Streamflow and water quality are monitored on the North Fork Shenandoah River gaging station at the State Route 55 bridge near Strasburg, VA. Streamflow has been measured continuously at this site since March 1925. A water-stage recorder (stilling well) is the recording device used at this gaging station. The North Fork Shenandoah River originates in Rockingham County, VA and flows northeast to the Shenandoah River. The 768-mi^2 North Fork Shenandoah River Basin is a sub-basin of the Potomac River watershed. The North Fork Shenandoah flows southwest to northeast through long valleys and ridges where it converges with the South Fork Shenandoah River and continues on northward to empty into the Potomac River.

Land use above the North Fork site is 59 percent forested, 38 percent agricultural, and less than 3 percent developed (table 1). The percentage of agricultural land use has increased in this basin in the past decade, and the intensity of the agricultural practices also has increased. This basin lies in the Appalachian Mountain range in the Valley and Ridge Physiographic Province. It is composed of a mix of over 30 percent carbonate and over 60 percent siliciclastic Paleozoic sedimentary rock (Johnson and Belval, 1998).

The North Fork Shenandoah River site was selected for two reasons. The first was to study the shift in the major source of agricultural nitrogen from synthetic fertilizer to manure. The increase in manure use on agricultural lands primarily resulted from the growth of the poultry industry near the site in Rockingham, Shenandoah, and Page Counties, Virginia (U.S. Department of Agriculture, National Agricultural Statistics Service, 1997). As a result, there has been a considerable increase in manure production and distribution in the basin. Second, this site was chosen in conjunction with the South Fork Shenandoah River site to monitor the combined load of these two tributaries so that the Potomac River Basin could be partitioned between waters from Virginia and waters from West Virginia and Maryland.

An in-depth study of 35 sites in 5 major river basins in Virginia, including the North Fork and South Fork Shenandoah Rivers, was conducted from 1985 to 1996. The study is described in Johnson and Belval (1998) and presents a discussion of spatial distribution and temporal changes in concentrations, loads, and trends. This report represents a continuation of that study for 2 of the 35 sites that were monitored.

South Fork Shenandoah River at Front Royal, Virginia

Streamflow and water quality are monitored on the South Fork Shenandoah River at Front Royal, VA. Streamflow at this site has been measured continuously since September 1930. The gaging station is located 0.7 mi (mile) downstream of the State Route 619 bridge at Front Royal, VA. Water-quality samples are collected from the bridge. The South Fork Shenandoah River Basin (1,642 mi^2) is the largest of the four study sites. The South Fork Shenandoah River originates in Augusta County, VA and flows northeast to the Shenandoah River. The South Fork Shenandoah River Basin is a sub-basin of the Potomac River watershed. The South Fork Shenandoah River flows southwest-northeast through long valleys and ridges where it converges with the North Fork Shenandoah River and continues until it reaches the Potomac River.

Land use above the South Fork gaging station is 57 percent forested, 38 percent agricultural, and less than 4 percent developed (table 1). This sub-basin recently has been losing agricultural and forested land to increased urbanization and development in the area. The South Fork Basin is mainly in the Appalachian Mountain range, in the Valley and Ridge Physiographic Province, and is composed of a mix of over 35 percent carbonate Paleozoic sedimentary rock, over 40 percent Paleozoic sedimentary rock, and approximately 20 percent Blue Ridge Crystalline region, metamorphic-igneous rock (Johnson and Belval, 1998).

This site was chosen in conjunction with the North Fork Shenandoah River site to monitor the combined nutrient and sediment load of these two tributaries, and provide a separation between Virginia's contribution and the contributions of West Virginia and Maryland in the Potomac River Basin.

Methods of Study

As discussed earlier, this study was conducted to:

1. Collect water samples and continuously monitor water-quality parameters at four USGS gaging stations on a monthly basis under base-flow and stormflow conditions from 1997 through 2001;
2. Estimate monthly and annual loads for nitrogen, phosphorus, and suspended sediment from water-quality data; and
3. Utilize estimated loads to determine trends.

Concentrations were used to measure in-stream conditions at monitoring sites and are reported in mg/L (milligrams per liter). Loads were estimated as unit mass of nutrient or sediment transported by streamflow over unit time and are reported in tons/yr (tons per year). To compare loads between study basins, loads were normalized by calculating yields, load per unit area, and are reported in tons/yr/mi^2 (tons per year per square mile). Temporal trends were determined by using either linear regression or by a non-parametric Kendall-Theil test (Langland and others, 2001).

Data Collection

Streamflow and water-quality data were used in the estimation of annual loads and trends (Langland and others, 2001). Daily streamflow was calculated and water-quality concentrations were checked visually and statistically for accuracy. Both data sets then were stored and entered into the USGS National Water Information System (NWIS) data base. As of 2002, water-quality and discharge monitoring was discontinued at Chesterville Branch. Conodoguinet Creek water-quality monitoring was discontinued, but the USGS still measures flow. VA DEQ conducts water-quality sampling at North Fork Shenandoah River and South Fork Shenandoah River every other month, and discharge is monitored daily by the USGS.

Measurement of Streamflow

Discharge measurements at each of the study sites were made using standard USGS streamflow-gaging procedures (Buchanan and Somers, 1982). Streamflow is the rate at which a volume of water passes a cross section in a stream channel per unit of time, such as ft^3/s (cubic feet per second) (James and others, 2003). The relation between continuous gage-height measurements (stage) and periodic instantaneous discharge measurements, referred to as the "rating," was used for calculation of either instantaneous or mean daily discharge (James and others, 2003). Monthly measurements were made at each gaging station to verify or adjust the rating at that gaging station (Carter and Davidian, 1968).

Water-Quality Samples

Both base-flow and stormflow water-quality samples were collected at each of the four study sites for a targeted list of constituents (table 2). How each constituent is reported and the parameter numbers used in the USGS NWIS water-quality data base and, subsequently, in the load computation process are also described in table 2.

Three of these monitored constituents are of primary concern to the CBP and are discussed in detail: total nitrogen, total phosphorus, and suspended sediment. In addition, field parameters, such as air and water temperature, hydrogen potential (pH), barometric pressure, specific conductance, alkalinity, and DO, were measured when water-quality samples were taken in order to ensure that the data obtained represent the *in-situ* quality of water (James and others, 2003) (table 2). Water-quality samples were collected, processed, and transported to their respective laboratories in accordance with USGS guidelines and protocol (Wilde and others, 1998) on the day of collection.

At least one water-quality base-flow sample and as many as three stormflow samples were collected monthly. Storm-event sampling was emphasized because a major portion of runoff and associated nutrients and suspended-sediment loads is carried by storms (Johnson and Belval, 1998). Sampling began in June 1996 and ended in July 2002, however, the ESTIMATOR program traditionally has based its calculations on the calendar year (January 1 through December 31); therefore, concentrations, loads, and trends are presented in this report for a period of record beginning on January 1, 1997 and ending on December 31, 2001.

Collection Technique and Equipment Depth-integrated monthly samples were collected at this site using the equal-width increment (EWI) method, or equal-transit rate (ETR) method, during low-flow and stormflow conditions at up to five sections along the sampling platform. This technique requires that the sampler(s) collect sample volumes proportional to the amount of flow at each of the approximately 6 to 10 spaced verticals along the tributary's cross section (Darrell and others, 1999).

The collection technique is determined by specific site characteristics and stage of water at the site. Water-quality samples were collected either as a composite sample at equal-width increments across a cross section of the tributary when possible, or collected as a discrete sample at a fixed point if depth and width of the tributary channel were too low under base-flow conditions (Maryland Department of Natural Resources, 2001). The platform above Chesterville Branch and the stream's short cross-sectional distance did not allow for an operator to move freely across the width of the tributary above the water, so only a grab sample at the center of flow was collected.

A high flow or storm event at each of the monitoring sites is defined as a measurable increase in discharge based on the antecedent precipitation, the magnitude of discharge, and the season of the year. Efforts were made to sample a representative range of storm types and sizes throughout the year. Storms were selected for sampling on the basis of the

Table 2. *Constituents and field parameters monitored at study sites in the Chesapeake Bay watershed, 1997–2001*

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; n/a, not applicable; °C, degrees Celsius; mm Hg, millimeters of mercury; µS/cm, microsiemens per centimeter at 25 °Celsius]

Constituent	USGS parameter number	Reported in	Reported as
Total nitrogen (TN)	P00600	mg/L	Nitrogen (N)
Dissolved ammonia (NH_3)	P00608	mg/L	Nitrogen (N)
Dissolved nitrite (NO_2)	P00613	mg/L	Nitrogen (N)
Dissolved kjeldahl nitrogen (dissKN)	P00623	mg/L	Nitrogen (N)
Total kjeldahl nitrogen (TKN)	P00625	mg/L	Nitrogen (N)
Dissolved nitrite + nitrate (NO_2+NO_3)	P00631	mg/L	Nitrogen (N)
Total phosphorus (TP)	P00665	mg/L	Phosphorus (P)
Dissolved phosphorus (diss P)	P00666	mg/L	Phosphorus (P)
Orthophosphate (*o*-PO_4)	P00671	mg/L	Phosphorus (P)
Total organic carbon (TOC)	P00680	mg/L	Carbon (C)
Dissolved silica (SiO_2)	P00955	mg/L	Silicon dioxide (SiO_2)
Suspended-sediment concentration (SSC)	P80154	mg/L	n/a

Field parameters	USGS parameter number	Reported in
Water temperature	P00010	°C
Air temperature	P00020	°C
Barometric pressure	P00025	mm Hg
Gage height	P00065	feet
Specific conductance	P00095	µS/cm
Dissolved oxygen (DO)	P00300	mg/L
pH	P00400	standard units
Alkalinity	P39086	mg/L as calcium carbonate

previous storm sampling history, such as frequency, size, and duration.

Various sample-collection devices, or samplers, used at the study sites are discussed in Wilde and others (1998). Geometry of the tributary's cross section, access and sampling platform above the water, high- or low-flow conditions, and velocity of streamflow were factors in sampler selection. Selection of the type of sampler used was made at the discretion of the field personnel who assessed site and stream conditions in order to collect water-quality samples that are representative of tributary conditions at the time of sampling.

USGS field personnel used both isokinetic and non-isokinetic samplers to manually collect water samples (fig. 4). Isokinetic samplers are designed to accumulate representative, continuous, and depth-integrated water samples with ambient flow changes in actual stream velocities. Isokinetic samplers (fig. 5) with nozzles require a minimum stream velocity of 1.5 ft/s (feet per second) to function properly. The DH-95, D-96, and the D-95[2] samplers commonly were used during this study. These samplers are designed so that they are heavy enough to maintain a horizontal position under the water as they are lowered down to the streambed or riverbed and back up to the surface. They are designed to allow sample water to enter the sampler nozzle at the same velocity as the stream, allow the sampler nozzle to get as close to the streambed as possible without disturbing the bottom sediment, and minimize disturbance to the flow pattern of the stream (Guy and Norman, 1970).

For stream velocities less than 1.5 ft/s, non-isokinetic open-mouthed samplers were used at study sites. An operator raised and lowered these suspended samplers by using a hand reel and a polyethylene rope. Either a 1-L (liter) stainless-steel weighted-bottle sampler (fig. 4) or a WBH-96 was used.

The Isco 6700SR refrigerated autosampler (automatic sampler) was used at Chesterville Branch beginning in 2000. Because of the small size of this basin, the stream reacts quickly (within hours) to rainfall events, or is "flashy," making the installation of a refrigerated automatic sampler a necessity. The sampler automatically drew a sample once a specific stage was reached. High-flow and stormflow samples were collected either by the automatic sampler or, if the storm duration was long enough, by a 1-L stainless-steel weighted-bottle sampler or the isokinetic DH-59 sampler. Using the larger sampling devices, such as the DH-95 or D-95, was not practical considering the small size of the Chesterville Branch cross-sectional width. Every effort was made to sample large stormflow events.

Sample Processing and Analysis Water-quality samples collected for this study were composited in a polypropylene churn splitter. When the churn splitter was used, the sample was composited into the pre-cleaned plastic vessel and subsamples for whole-water analysis were drawn while churning at a standard rate. The churn splitter was used to allow for subsamples to be drawn while maintaining a uniform distribution of suspended material in the composite sample (Darrell and others, 1999). The remaining samples were filtered on site for dissolved analysis using a 0.45-micrometer (average pore size, polycarbonate) capsule filter. After acid was added to the appropriate samples for preservation, the nutrient samples were placed immediately on ice and shipped within 24 hours to either the USGS National Water-Quality Laboratory in Denver, CO or to the Virginia Division of Consolidated Laboratory Services (VDCLS) in Richmond, VA. Samples collected on weekends or holidays were refrigerated and held until the next possible shipping day. Suspended-sediment samples, collected concurrently with the water-quality samples, were shipped to the USGS Sediment Laboratory in Louisville, KY for analysis. Chain-of-custody procedures followed recommended USGS water-quality laboratory procedures.

Quality-Assurance Program Quality-assurance methods were documented in an annual Quality-Assurance Project Plan (QAPP) (Maryland Department of Natural Resources, 2001). The monitoring for this study was consistent with previous RIM Program monitoring because the same personnel using the same equipment, procedures, and sampling techniques were involved. The quality-assurance effort included documentation of concentration variability within the cross section, sediment-transport analysis, sample-collection techniques and field personnel, and the variability within and among the analyzing laboratories. Discrete and composite samples, or samples collected by automatic sampler, were quality assured using a statistical program that identified suspect remark codes, missing dates, and/or missing times associated with the sample before they were added to the USGS data base (Langland and others, 2000). Quality-assurance results can be obtained from the USGS MD-DE-DC, VA, and PA District offices. Laboratory quality control is discussed in detail in the USGS National Water-Quality Laboratory Quality Control manual (Pritt and Raese, 1992).

Blanks and duplicates were collected to evaluate bias and variability because of field sampling, processing, transportation, and analysis of environmental water-quality samples. Field blanks, trip blanks, and split-replicate samples were collected at each of the four study sites at a rate of no less than 1 quality-assurance sample per every 15 environmental samples, or greater than 5 percent. In addition, USGS personnel performed comparability studies between samples collected from an autosampler and those collected manually.

Blank water samples were collected using laboratory-grade inorganic-free deionized water. Trip blanks were collected as a solution that is processed with the same type of bottle used for an environmental sample and kept with the

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2. D- indicates "depth-integrated," DH- indicates "depth-integrated, hand-held," and WBH- indicates "weighted-bottle holder, hand-held."

Figure 4. Stainless-steel weighted-bottle sampler and hand-reel with polyethylene rope. *(Photograph by Michael P. Senus, U.S. Geological Survey)*

Figure 5. DH-95 isokinetic sampler with 1-liter Teflon bottle. *(Photograph by Michael P. Senus, U.S. Geological Survey)*

set of sample bottles before and after environmental-sample collection, then transported to the analyzing laboratory with the environmental samples. Field-blank solutions were subjected to all aspects of sample collection, field-processing, preservation, transportation, and laboratory handling as environmental samples. These also were submitted to the analyzing laboratory along with the environmental samples.

Duplicate samples were collected to help evaluate laboratory precision. These split-replicate samples were processed from the same churn splitter as those processed as environmental samples. Results of the quality-assurance study showed that statistically similar nutrient-concentration data were repeated over a range of values reported by the laboratories.

Data Analysis

A brief description of the methods used to estimate loads and calculate trends is presented in the following section. The data-analysis approach and methods used for the four study sites were similar to those used for the RIM Program.

Estimation of Loads Load is the concentration of chemical constituents, such as nutrients and suspended sediment, in water multiplied by instantaneous volumetric discharge of water. Loads for nitrogen, phosphorus, and suspended sediment were estimated in a two-step process by using concentration values and calculated daily streamflow data and the USGS seven-parameter log-linear regression model ESTIMATOR.

In the first step, the relations among the variables of flow, concentration, and time are quantified in ESTIMATOR; therefore, concentrations are predicted for the days in the period of record in which discharge was measured but raw water-quality concentrations were not (Helsel and Hirsch, 1992). In the second step, the model-predicted daily concentrations are multiplied by daily mean discharge values to estimate daily load values. These daily load values are summed to obtain both monthly and annual loads for each of the four study sites. An explanation of how streamflow, time, and seasonal terms are used in model simulation to predict daily constituent concentrations is presented in Cohn and others (1989).

To correct for a log-transformed bias associated with log-linear regression, a Minimum Variance Unbiased Estimator (MVUE) is used in ESTIMATOR—it is documented in Bradu and Mundlak (1970) and discussed in Gilroy and others (1990). The ESTIMATOR model incorporates a MVUE for correcting the bias when transforming data from "log space" to "real space." An Adjusted Maximum Likelihood Estimator (AMLE) is used in the model to assign concentration values to censored data values—data below a detectable limit. The AMLE is discussed further in Cohn (1988) and Cohn and others (1992).

The size of the basin is the primary factor in determining the volume of captured precipitation in that basin. The amount of rainfall and snowmelt directly affects surface-water runoff and ground-water recharge, and, subsequently, streamflow. As a result, increased discharge increases loads, and therefore affects water quality. In addition to visual comparison of loads between basins, annual loads were "normalized" by using basin area to calculate yields, which can be used to make meaningful comparisons among basins of different sizes. Taking the mean-annual discharge or annual load and dividing by the drainage area of the study site basin determined annual yields.

Annual nutrient and sediment loads were calculated based on a calendar year. The quality of the data set greatly affects the accuracy of the regression produced by the ESTIMATOR model. If the regression is not performed on different flow conditions, the slope of the regression line will adversely affect the extrapolation of concentration values. In other words, the relation developed between concentration and flow will not be representative of the undersampled flow conditions. The model simulates actual conditions with at least 21 observations above detectable limits for at least each of the 2 consecutive years (Baire and others, 2000). Every effort was made to meet this guideline at each study site. Monthly base-flow and stormflow water-quality samples were collected for each site, totaling 90–120 samples at each site during the study period of 5 calendar years, from 1997 through 2001.

A standard error of prediction (SEP) within a 95-percent confidence interval is used in ESTIMATOR to calculate loads. A SEP is generated to indicate how well the estimated regression model fits a "true" regression model (Darrell and others, 1999). SEP is a function of the variability between the estimated and predicted loads on the days of measurement. SEPs are presented along with their respective study site loads in appendix A.

Calculation of Trends Trends are the statistically significant, measurable tendencies for streamflow, concentration, or load to change over time. Trends can be used to quantify improving, degrading, or unchanged water-quality conditions over time. For this study, trends in (1) streamflow, (2) load, (3) flow-weighted concentration, and (4) flow-adjusted concentration were calculated for the four study sites. Each trend analysis was used to characterize changes within the study basins during the 5-year study period.

Trends were calculated for each of the three selected constituents for which loads were determined. These trends are expressed as a percent change during the period of record. A positive percent change, or upward trend, indicates a degrading trend in concentration or load. A negative percent change, or downward trend, indicates an improving trend either in concentration or load. The probability that a computed trend is real and not caused by random variations in the data is measured by the probability value (p-value) of the time coefficient (Johnson and Belval, 1998). A lower p-value indicates greater confidence in a trend. For this study, a p-value that was less than 0.05 was considered significant. In other words, a trend with a p-value of 0.05 has a 95-percent chance that the computed trend truly is present in the data, and is not a result of random variation.

Trend in streamflow (also referred to as flow or discharge) helps to indicate natural hydrologic changes. Natural fluctuations in flow affect water-quality concentrations, loads, and trends. Trend in flow was calculated using parametric log regression with time. Trend in load represents the temporal change of a particular water-quality constituent delivered downstream to a particular point—in this case, the point of sample collection.

Flow-weighted concentration was calculated by dividing the average monthly load by the average monthly streamflow (Langland and others, 2001). The resulting flow-weighted concentration provides a more representative, or truer, monthly concentration than is represented by a point in time (sample value). This trend in flow-weighted concentration is not adjusted for flow, and therefore may be useful in comparing trends in nontidal areas to those in the tidal estuaries.

Concentrations and loads can fluctuate over time as flow conditions change. This fluctuation makes the characterization of trends by use of only time-series plots of raw concentration data difficult. Additionally, the effectiveness of BMPs are difficult to assess. To characterize trends over time under uniform flow conditions for the period of record, trend in flow-adjusted concentration was used. Trend in flow-adjusted concentration was calculated by predicting daily concentration values using only season and streamflow terms (not time) in the ESTIMATOR model. A non-parametric Kendall-Theil test (Helsel and Hirsch, 1992) was used on residual concentrations, the difference between predicted and observed concentrations, thereby removing the effect of flow. When flow is removed, other factors, such as land use and BMPs within the basin, may become apparent.

Concentrations, Loads, and Trends at Study Sites

Concentrations of Nutrients and Suspended Sediment

The distribution of selected water-quality constituents for each of the four study sites is shown in boxplots of the data (fig. 6). Concentrations are presented in time-series plots (figs. 7–10), and summary statistics for the concentrations measured from January 1, 1997 through December 31, 2001, are shown in table 3. These data provide the basis for analysis of loads and yields for this study. Concentrations for phosphorus and suspended sediment increased with increased streamflow at all four sites, and the rate of increase in concentration was amplified during extreme high-flow conditions.

The representation of targeted storm samples at the four study sites results in a bias in the distribution of each year's data. As a result, the mean and the median presented in the table and boxplots are not representative of the true mean and median for the population of total nitrogen, total phosphorus, and suspended-sediment concentrations. Percentiles for total nitrogen, total phosphorus, and suspended-sediment concentrations presented in this report do accurately represent the sample mean and sample median, however.

Chesterville Branch Streamflow and total nitrogen, phosphorus, and suspended-sediment concentrations (fig. 7) were measured at the Chesterville Branch gaging station from 1997 through 2001. Total nitrogen concentrations ranged from 1.20 to 8.70 mg/L, with a median of 6.1 mg/L (table 3). Total nitrogen concentrations were correlated poorly with discharge. Total phosphorus and suspended-sediment concentrations were correlated positively with discharge. Total phosphorus and suspended-sediment concentrations were at their highest levels during Hurricane Floyd (September 1999) and other high-flow events (fig. 7). Total phosphorus concentrations ranged from less than (<) 0.001 to 1.280 mg/L, with a median of 0.076 mg/L. Suspended-sediment concentrations ranged from 3.1 to 608 mg/L, with a median of 15.0 mg/L.

Conodoguinet Creek Streamflow was measured and water samples were collected and analyzed for total nitrogen, total phosphorus, and suspended-sediment concentration at the Conodoguinet Creek gaging station from 1997 through 2001 (fig. 8). Total nitrogen concentrations ranged from 2.4 to 5.1 mg/L, with a median of 3.8 mg/L. Total nitrogen concentrations were correlated poorly with discharge. Total phosphorus concentrations ranged from <0.005 to 0.50 mg/L, with a median of 0.03 mg/L. Total phosphorus concentrations were correlated poorly with discharge. Suspended-sediment concentrations ranged from 1.0 to 490 mg/L, with a median of 8.0 mg/L. Suspended-sediment concentrations were correlated positively with discharge.

North Fork Shenandoah River Streamflow and total nitrogen, phosphorus, and suspended-sediment concentrations were measured at the North Fork Shenandoah River gaging station from 1997 through 2001 (fig. 9). Total nitrogen concentrations ranged from 0.59 to 4.10 mg/L, with a median of 2.10 mg/L, and concentrations were correlated poorly with discharge. Total phosphorus concentrations ranged from <0.01 to 0.94 mg/L, with a median of 0.193 mg/L, and concentrations were correlated poorly with discharge. Suspended-sediment concentrations ranged from 0.5 to 652 mg/L, with a median of 8.1 mg/L, and concentrations were correlated positively with discharge.

South Fork Shenandoah River Streamflow and total nitrogen, phosphorus, and suspended-sediment concentrations were measured at the South Fork Shenandoah River from 1997 through 2001 (fig. 10). Total nitrogen concentrations ranged from 0.40 to 3.40 mg/L, with a median of 1.40 mg/L, and were correlated poorly with discharge. Total phosphorus concentrations ranged from <0.01 to 0.77 mg/L, with a median of 0.131 mg/L, and were correlated poorly with discharge. Suspended-sediment concentrations ranged from 0.3 to 755 mg/L, with a median of 7.3 mg/L, and were correlated positively with discharge.

Loads of Nutrients and Suspended Sediment

Selected loads for each of the four study sites are tabulated by site, parameter, and year in appendix A. Annual load estimates are discussed in the following respective site

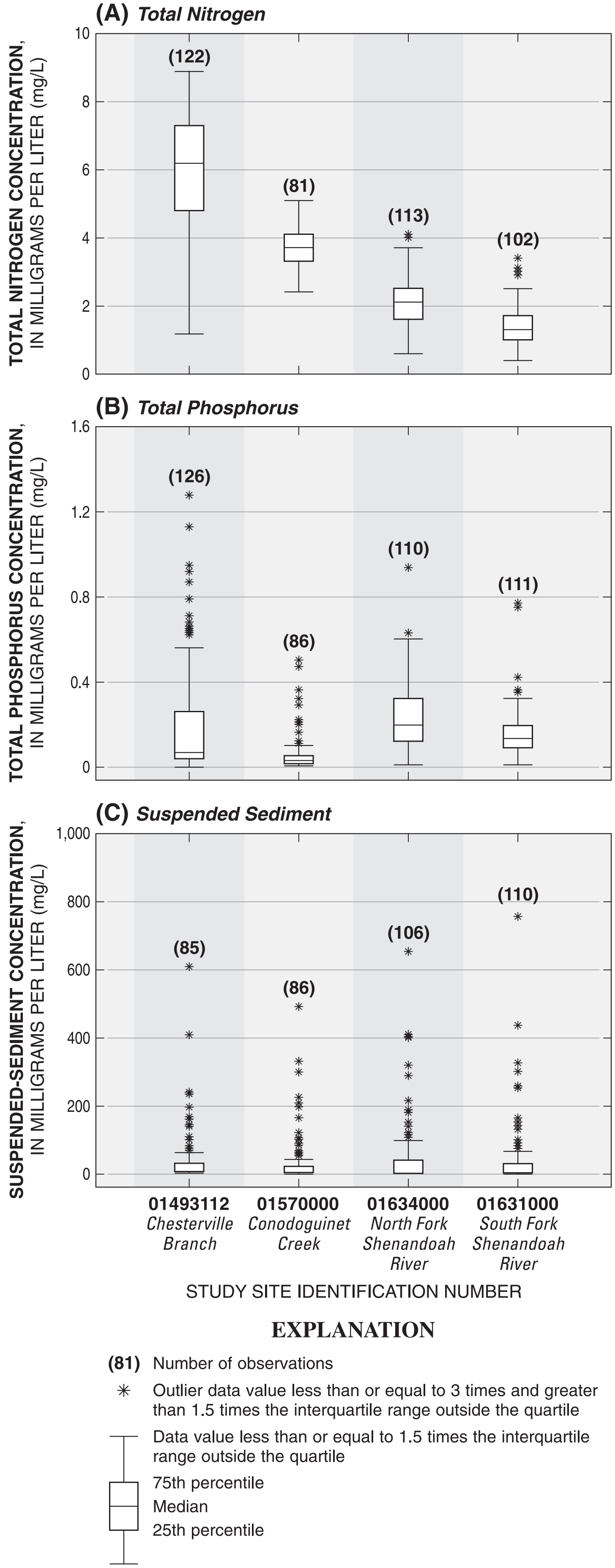

Figure 6. Range of concentrations of **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment at study sites.

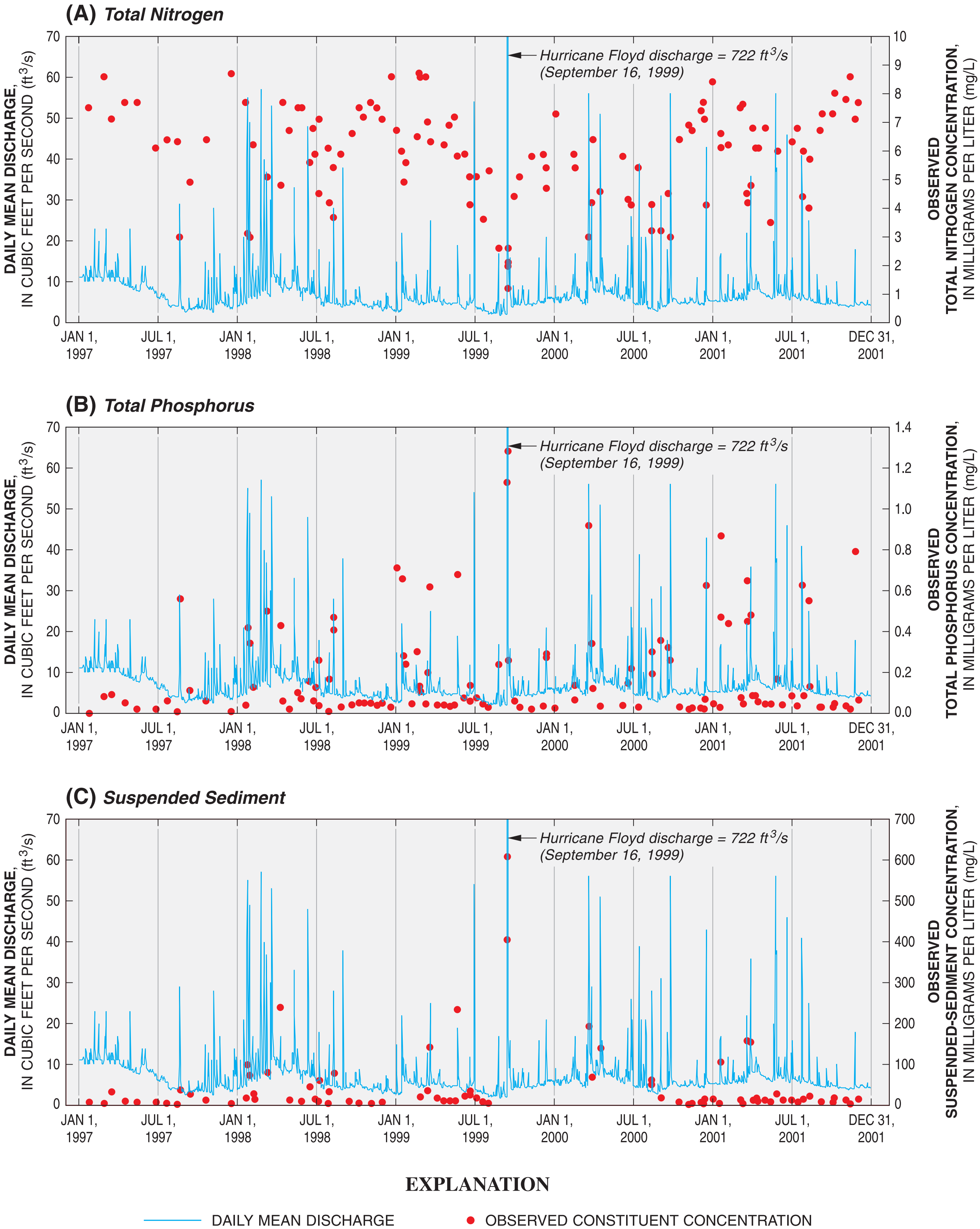

Figure 7. Daily mean discharge and observed concentrations for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment at Chesterville Branch near Crumpton, Maryland, January 1997 through December 2001.

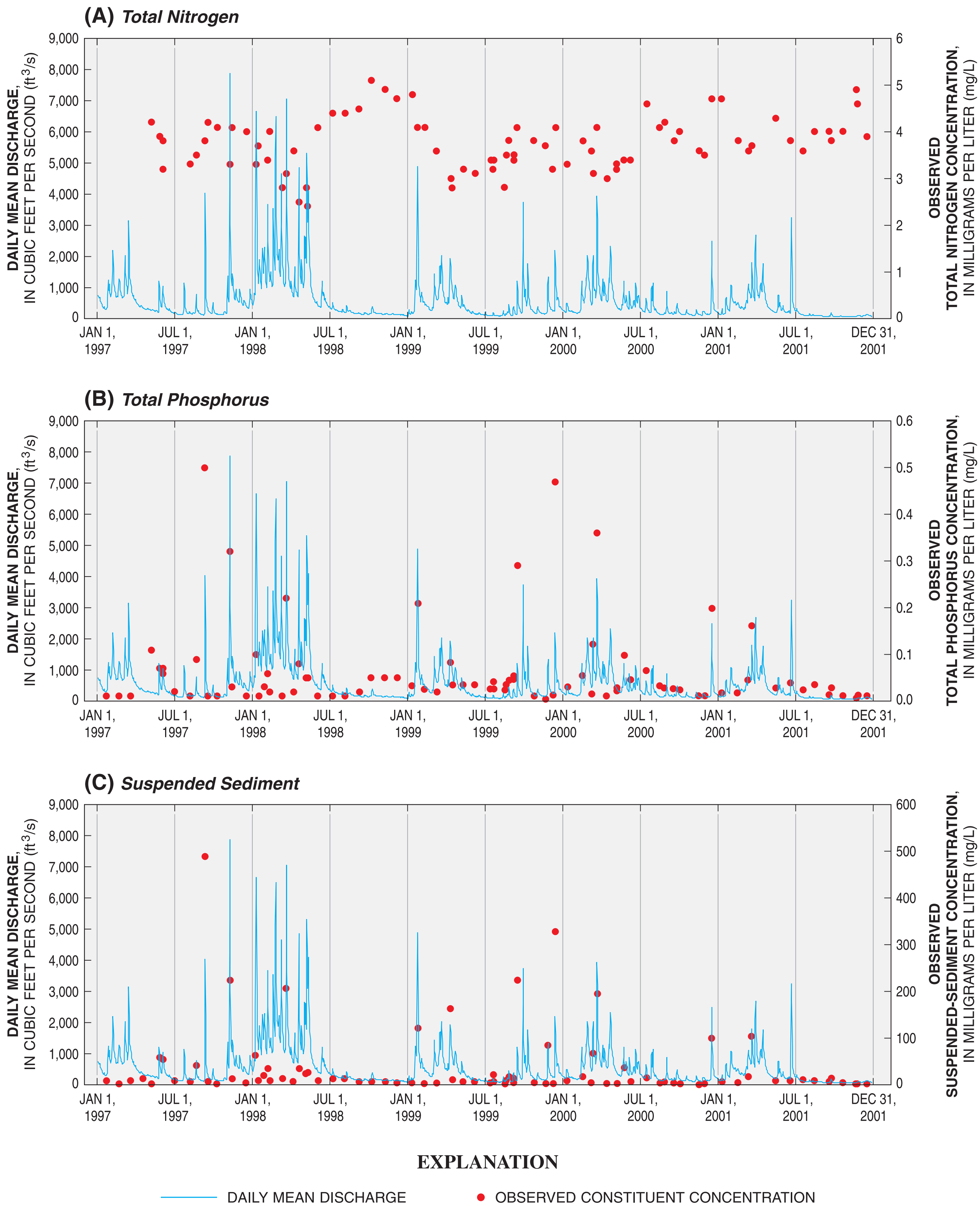

Figure 8. Daily mean discharge and observed concentrations for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment at Conodoguinet Creek near Hogestown, Pennsylvania, January 1997 through December 2001.

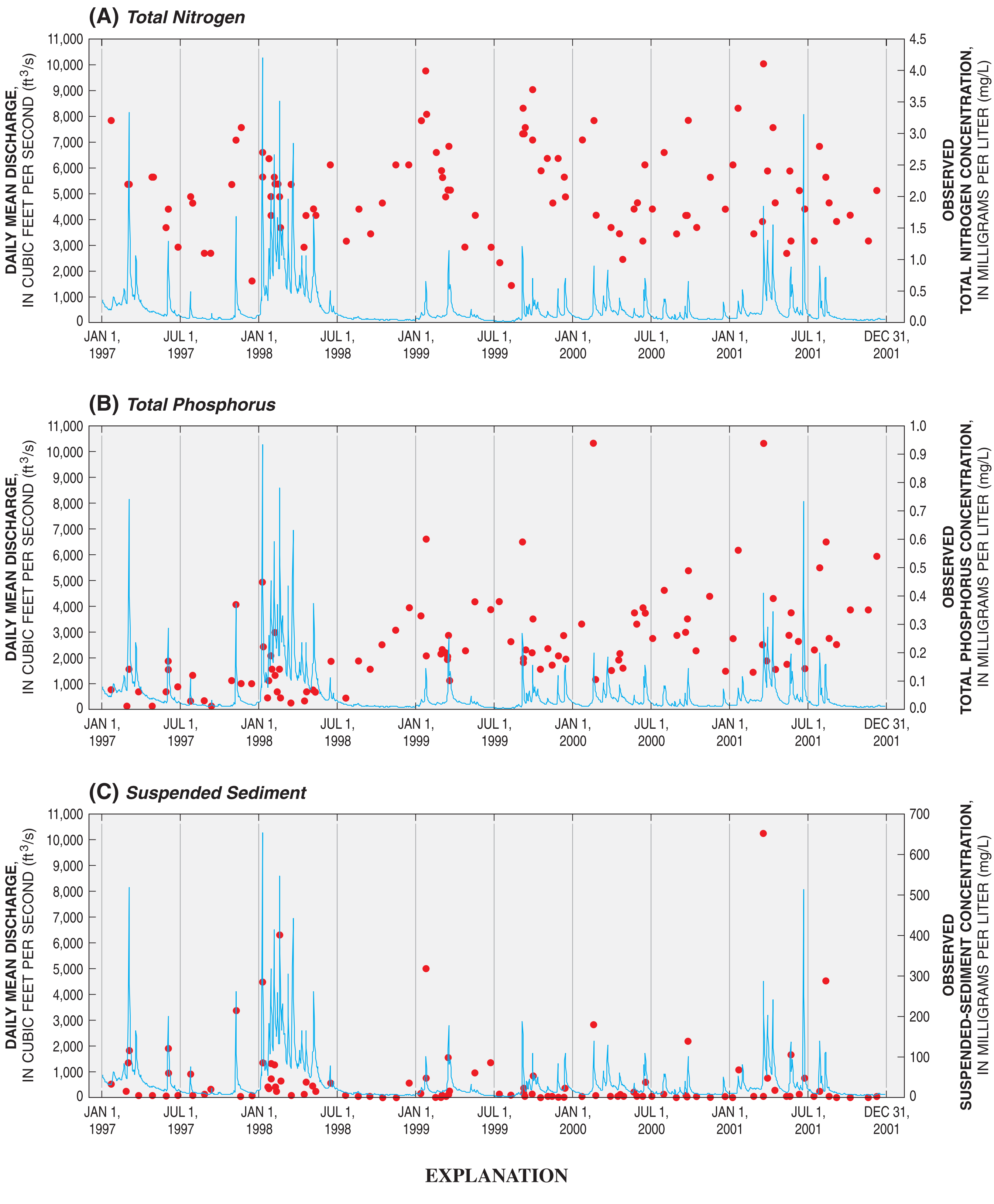

Figure 9. Daily mean discharge and observed concentrations for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment at North Fork Shenandoah River near Strasburg, Virginia, January 1997 through December 2001.

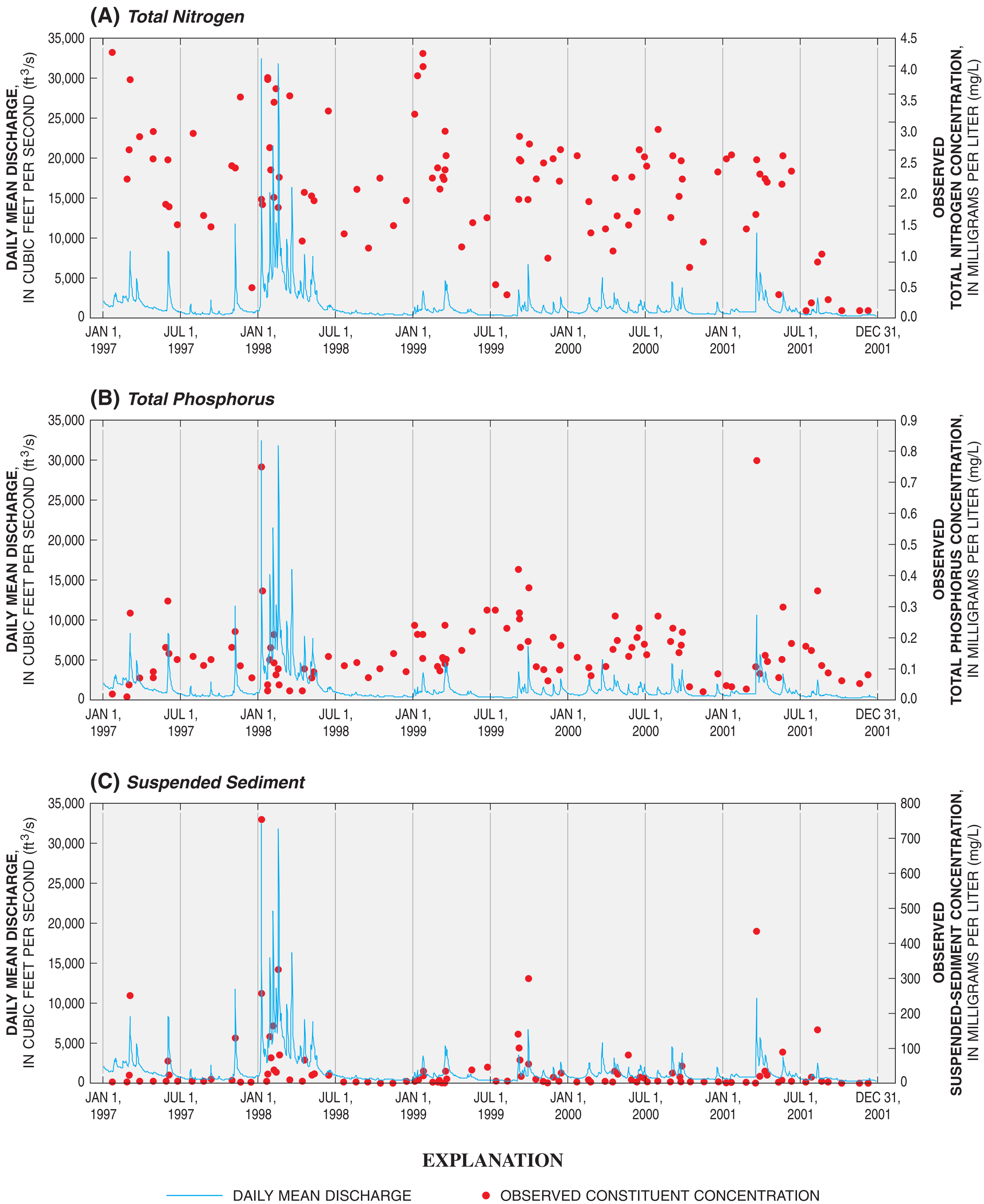

Figure 10. Daily mean discharge and observed concentrations for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment at South Fork Shenandoah River at Front Royal, Virginia, January 1997 through December 2001.

Table 3. *Summary statistics for selected water-quality constituents monitored at the study sites in the Chesapeake Bay watershed, 1997–2001*

[All values are in milligrams per liter; <, less than; mean was calculated with all values less than the reporting limit set at the reporting limit, possibly giving a slight positive bias to the estimate of the mean]

Statistic	Total nitrogen	Total phosphorus	Suspended sediment
Chesterville Branch near Crumpton, MD			
Number of observations	122	126	85
Minimum	1.20	<0.001	3.1
Mean	5.89	0.203	45.9
Median	6.10	0.076	15.0
Maximum	8.70	1.28	608
Conodoguinet Creek near Hogestown, PA			
Number of observations	81	86	86
Minimum	2.40	<0.005	1.0
Mean	3.74	0.0622	36.7
Median	3.80	0.03	8.0
Maximum	5.10	0.50	490
North Fork Shenandoah River near Strasburg, VA			
Number of observations	113	110	106
Minimum	0.59	<0.01	0.5
Mean	2.12	0.228	44.4
Median	2.10	0.193	8.1
Maximum	4.10	0.94	652
South Fork Shenandoah River at Front Royal, VA			
Number of observations	102	111	110
Minimum	0.40	<0.01	0.3
Mean	1.45	0.157	42.9
Median	1.40	0.131	7.3
Maximum	3.40	0.77	755

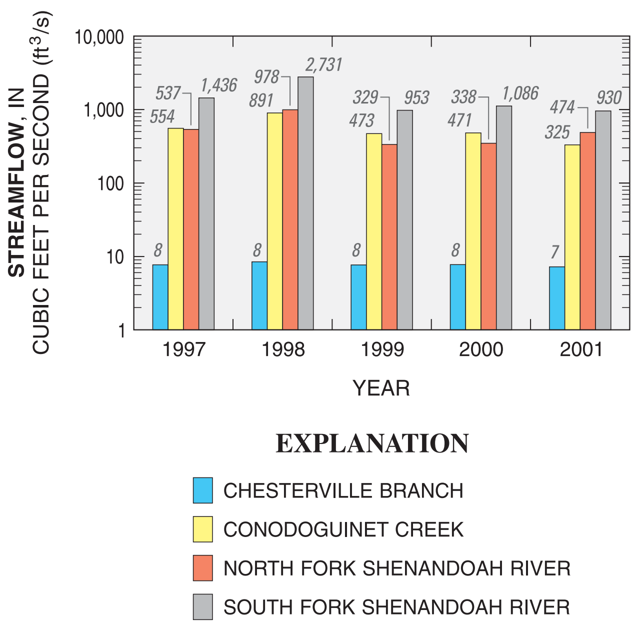

Figure 11. Mean annual streamflow at study sites, 1997-2001.

sections. These estimates provide the basis for analysis of yields and trends for this study.

Chesterville Branch The annual loads of total nitrogen entering the Chesapeake Bay from Chesterville Branch measured near Crumpton, MD ranged from 38 tons/yr in 1999 to 56 tons/yr in 1997 (appendix A). The annual load of total phosphorus ranged from 0.6 tons/yr in 1997 to 3.4 tons/yr in 1999, and the annual load for suspended sediment ranged from 220 tons/yr in 2001 to 1,349 tons/yr in 1999. Total annual loads for total phosphorus and suspended sediment were much higher in 1999 than during the other 4 years of the study period. Outlier data may be attributed to Hurricane Floyd and could have positively biased phosphorus and suspended-sediment load estimates for the month of September 1999 as well as the annual loads for 1999. The SEP is especially high for phosphorus (79 percent) and suspended sediment (71 percent) for 1999, while for other years, the SEP was below 25 percent (appendix A). The SEP affected the yield calculations for those two constituents (discussed later in the Comparison of Study Sites section), where mean annual discharge showed that 1999 was not apparently a distinctly wet year during the study period (fig. 11). During Hurricane Floyd, a total of over 12 inches of rainfall fell between September 15–17, 1999, and peak (instantaneous) discharge[3] was recorded at 3,220 ft^3/s (Tallman and Fisher, 2001). The flood recurrence interval on Chesterville Branch was not computed because the streamflow-gaging station had not been in operation long enough to provide the data needed to produce meaningful statistics (Tallman and Fisher, 2001). However, the estimated recurrence intervals for flooding from Hurricane Floyd in the nearby Morgan Creek and Unicorn Branch sub-basins in the Chester River Basin were 85 and 200 years, respectively (Doheny and Dillow, 2002).

Conodoguinet Creek The annual load of total nitrogen entering the Chesapeake Bay from Conodoguinet Creek measured near Hogestown, PA ranged from 1,189 tons/yr in 2001 to 3,029 tons/yr in 1998. The annual load for total phosphorus ranged from 27 tons/yr in 2001 to 90 tons/yr in 1998, and the annual load for suspended sediment ranged from 12,950 tons/yr in 2001 to 71,353 tons/yr in 1998. Total annual loads for all three constituents were higher in 1998 than during the other 4 years in the study period, because 1998 was a relatively wet year compared to other recent years. There was no apparent effect on annual loads from Hurricane Floyd in 1999, a relatively dry year.

North Fork Shenandoah River The annual load of total nitrogen entering the Chesapeake Bay from the North Fork Shenandoah River measured near Strasburg, VA ranged from 714 tons/yr in 2000 to 2,205 tons/yr in 1998. The annual load for total phosphorus ranged from 32 tons/yr in 1997 to 181 tons/yr in 2001, and the annual load for suspended sediment ranged from 4,828 tons/yr in 2000 to 174,536 tons/yr in 1998. Total annual loads for all three constituents at the North Fork Shenandoah River gaging station were significantly higher during 1998 than during the other 4 years in the study period (with the exception of 2001, during which relatively high phosphorus loads also occurred). These high loads can be attributed to 1998 having been a wet year.

The SEP is high (greater than 16 percent) at all study sites for suspended-sediment loads, but is highest for the North Fork Shenandoah River Basin (29–98 percent). This high SEP indicates that there is a lower confidence level in the corresponding load values. Further analysis of the relation between larger basin size and higher SEP may be helpful in explaining this SEP.

South Fork Shenandoah River The annual load of total nitrogen entering the Chesapeake Bay from the South Fork Shenandoah River measured at Front Royal, VA ranged from 1,136 tons/yr in 2001 to 4,813 tons/yr in 1998. The annual load for total phosphorus ranged from 121 in 1997 to 471 tons/yr in 1998, and the annual load for suspended sediment ranged from 17,051 tons/yr in 1999 to 347,315 tons/yr in 1998. As with the North Fork Shenandoah River Basin, the total annual loads for all three constituents at the South Fork Shenandoah River were significantly higher during 1998 than during the other 4 years in the study period (appendix A). This result can be attributed to 1998 being a wet year.

Trends of Nutrients and Suspended Sediment

Selected trends for each of the four study sites are tabulated by site, parameter, and type of trend in appendix B. Trend results are discussed in the following sections on study sites.

[3] Mean daily discharge for September 16, 1999, was 722 ft^3/s.

Chesterville Branch A significant upward (degrading) trend in flow-adjusted concentration and flow-weighted concentration for total phosphorus during the study period was evident, but no significant trends in load and flow-weighted concentration were observed for total nitrogen or suspended sediment (appendix B).

Factors affecting trends or relations between streamflow and constituent loading at Chesterville Branch are difficult to assess because of the small size of the basin and the flashy response to precipitation, runoff, and snowmelt. In addition, there was no significant trend in flow during the study period (appendix B), so determining whether BMPs had any effect is problematic. This basin would have been ideal to study the effects of BMPs because there historically has not been any large change in land use for tens of years.

Conodoguinet Creek There was a downward trend in flow during the study period. There was a significant downward (improving) trend in load for total nitrogen, and a significant upward (degrading) trend in flow-adjusted concentration for total phosphorus and suspended sediment during the study period (appendix B).

North Fork Shenandoah River Phosphorus and sediment generally are transported by runoff (Brooks and others, 1991). As a result, there usually is a corresponding upward trend in phosphorus and suspended-sediment concentrations if there is an upward trend in flow. Although there was an upward trend in load, in flow-adjusted concentration, and in flow-weighted concentration for phosphorus (appendix B) at the North Fork Shenandoah River, there was no corresponding trend in flow or suspended sediment as might be expected. Further evaluation at this site would help determine why runoff apparently was not a factor in the increase of phosphorus concentration.

Although there was an upward trend in flow-adjusted concentration for nitrogen during a 1985–96 study (Johnson and Belval, 1998), there was no significant trend either in load, flow-adjusted concentration, or flow-weighted concentration for total nitrogen during the current study. The reason for this result is not known at this time.

South Fork Shenandoah River There was a downward trend in flow during the study period. There was a significant downward (improving) trend in load and flow-weighted concentration for total nitrogen, and there was a significant upward (degrading) trend in flow-adjusted concentration for total phosphorus (appendix B).

A downward trend in flow-adjusted concentration for phosphorus was documented in a 1985–96 study and discussed in Johnson and Belval (1998). The reason for the change in trend direction is not known at this time.

Comparison of Study Sites

Part of this study included analysis of the basins encompassing the study sites to provide information to resource managers formulating tributary strategies aimed at TMDLs. To highlight individual basin characteristics, all four study basins were compared by yields to each other and to the nine RIM site basins. Annual loads were normalized by using basin area to calculate yields, which can be used to make meaningful comparisons between annual and/or monthly loads and basins of different sizes (fig. 12). As discussed in the Data Analysis section, annual yield was determined by taking the mean-annual discharge or annual load and dividing by the drainage area of the study site basin. The results of this analysis showed higher nitrogen yields in basins with higher percentages of agricultural land, whereas lower values of nitrogen loads and yields were indicated for areas with higher percentages of forested land and less agriculture. There was no apparent relation between land use and phosphorus or suspended-sediment yields.

Hurricane Floyd positively biased monthly (September 1999) and annual load estimates (1999) for Chesterville Branch. This bias subsequently affected the yield calculations, especially for phosphorus and suspended sediment, where mean annual discharge in 1999 was not unusually high during the study period (fig. 11).

High annual yields for total nitrogen, total phosphorus, and suspended sediment (figs. 12 a–c) at Conodoguinet Creek were positively associated with higher annual streamflow. Annual yields for all three constituents had the highest values in 1998, the year with the highest streamflow.

High annual yields for total nitrogen and suspended sediment (figs. 12a and 12c) at North Fork Shenandoah River were positively associated with higher annual streamflow (appendix A). Annual yields for nitrogen and suspended sediment were highest in 1998, the year with the highest mean annual streamflow. Annual yields for phosphorus also were high in 1998 and 2001.

High annual yields for total nitrogen, total phosphorus, and suspended sediment (figs. 12a–c) at the South Fork Shenandoah River were associated with higher annual streamflow. Annual yields for all three constituents had the highest values in 1998, the year with the highest streamflow.

The South Fork Shenandoah River Basin (1,642 mi^2) is more than twice the size of the North Fork Shenandoah River Basin (768 mi^2). Both basins have nearly identical mean annual yields (appendix A) of nitrogen and nearly identical percentages of primary land-use types (fig. 2), with the exception of yield in 2001. Similar observations were noted during the 1985–96 study described in Johnson and Belval (1998).

Study site yields in relation to percentages of agricultural, forested, and developed land use are shown in figures 13–15. The three land uses are used for comparison because they show the greatest differences from other common land-use types.

A series of linear regressions was performed for the four study sites, as well as the nine RIM sites to compare the relation between nutrient and suspended-sediment yields and land-use type (figs. 13–15). The RIM sites were used for additional data points for comparison and regression analysis. Mean annual yields of nitrogen, phosphorus, and

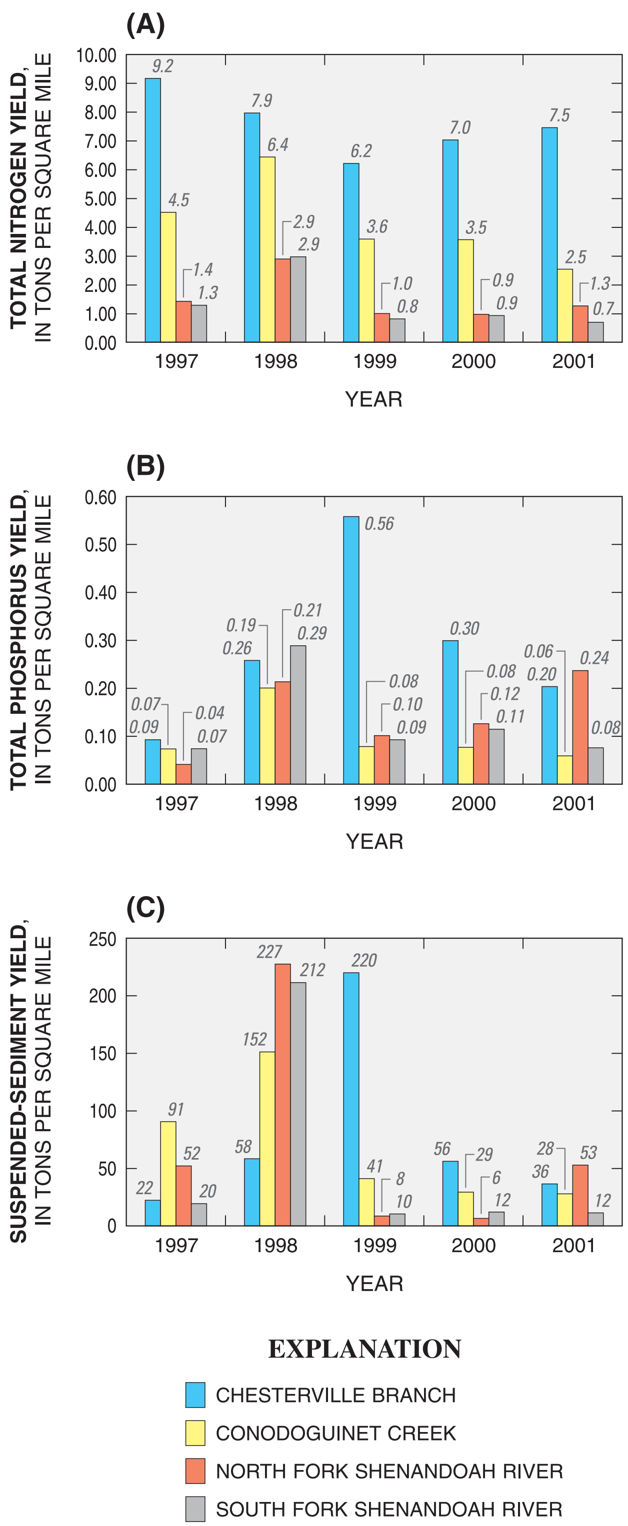

Figure 12. Calculated yields for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment at study sites, 1997-2001.

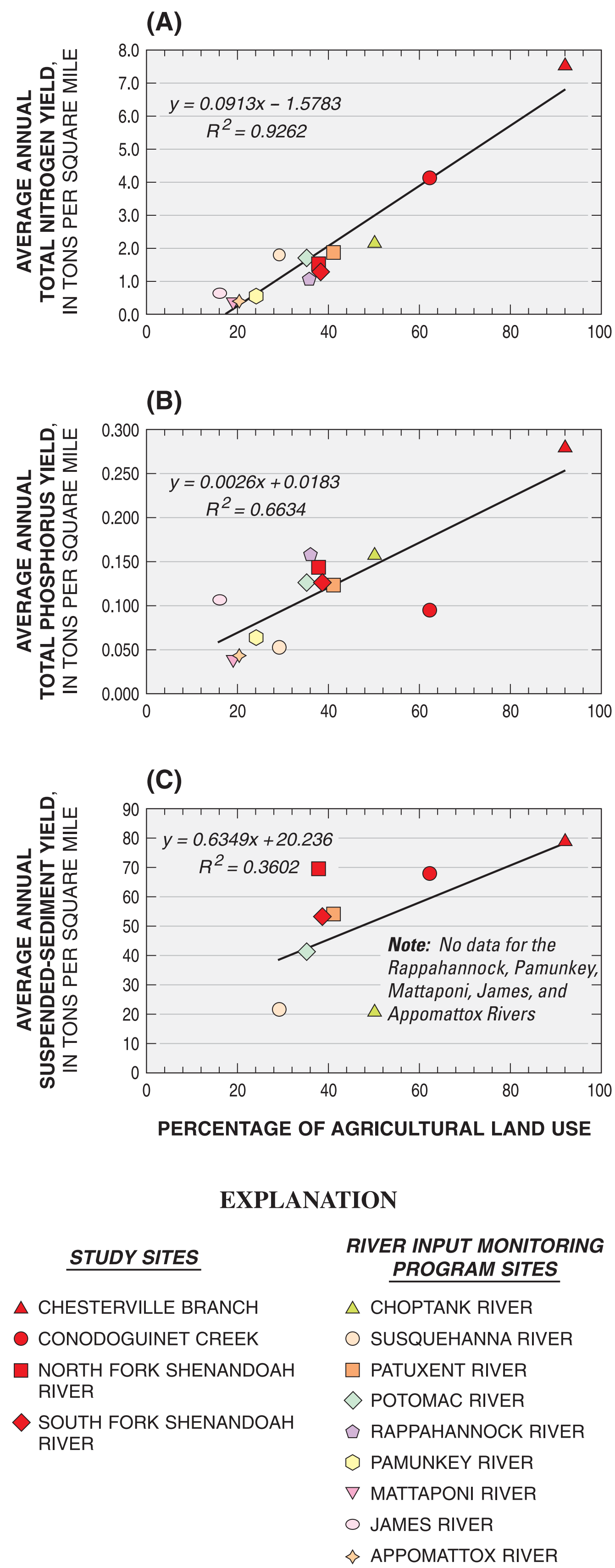

Figure 13. Comparison of average annual yields for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment and percentage of agricultural land use at the study sites and River Input Monitoring Program sites, 1997-2001.

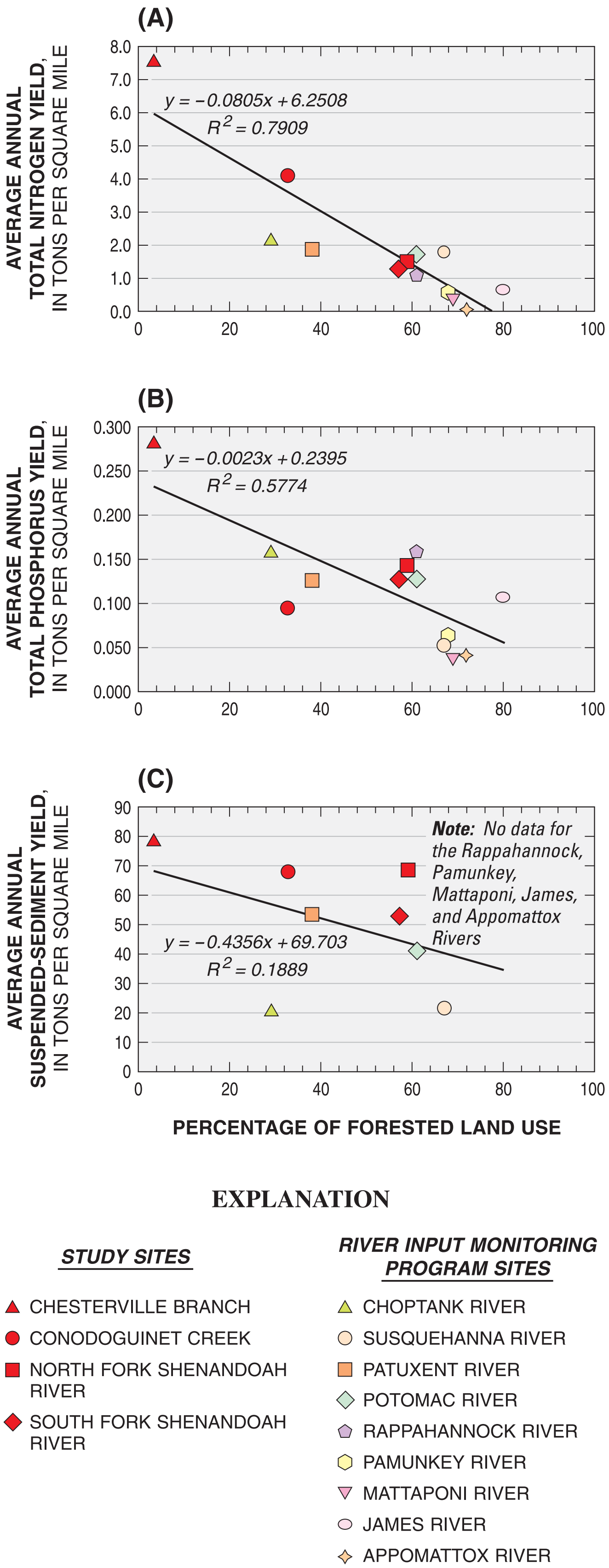

Figure 14. Comparison of average annual yields for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment and percentage of forested land use at the study sites and River Input Monitoring Program sites, 1997-2001.

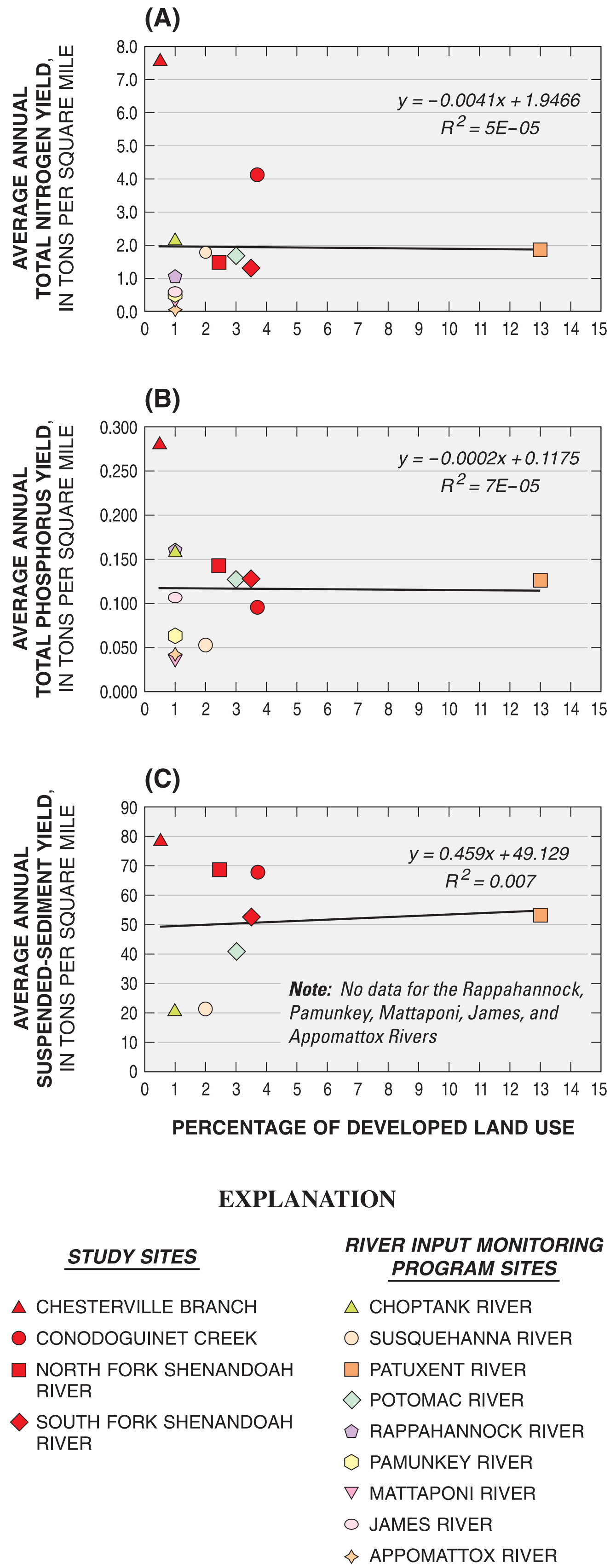

Figure 15. Comparison of average annual yields for **(A)** total nitrogen, **(B)** total phosphorus, and **(C)** suspended sediment and percentage of developed land use at the study sites and River Input Monitoring Program sites, 1997-2001.

suspended sediment were plotted and regressed against percentages of three major land uses in the Chesapeake Bay watershed: agricultural, forested, and developed lands. Plots showed a strong, positive linear correlation (positive slope) between the percentage of agricultural land within a basin and the nitrogen yield. This sub-plot (fig. 13a) had the largest coefficient of determination (R^2= 0.93) of any of the relations indicating that this is the best relation of those presented. Phosphorus yields (fig. 13b) showed the same relation to the percentage of agricultural land as that of nitrogen, but contained more outliers and had a lower R^2 value (0.66). There was a strong, negative linear correlation (R^2= 0.79) between nitrogen and forested land (fig. 14a). This correlation indicated that yields of nitrogen decrease with an increasing percentage of forested lands in a basin. A lower negative correlation (R^2= 0.58) was calculated between phosphorus yield and the percentage of forested lands (fig. 14b). There was no significant correlation between suspended sediment and any of the three major land uses (figs. 13c, 14c, and 15c). There was no apparent relation between nitrogen, phosphorus, and suspended-sediment yields and percentage of developed land (figs. 15 a–c).

Summary and Conclusions

The Chesapeake Bay Program has determined that excess nitrogen, phosphorus, and suspended sediment can trigger unbalanced algae growth and poor water-quality conditions that deprive living resources of oxygen and sunlight. By reducing nutrient and sediment loads to the bay, scientists predict water quality would improve by relieving low dissolved-oxygen conditions, reducing algal blooms, and improving water clarity. Since 1985, the River Input Monitoring Program has estimated the load of nutrient and sediment constituents in the nine major tributaries draining the Chesapeake Bay watershed.

This report presents the results of a study in cooperation with the Maryland Department of Natural Resources, the Virginia Department of Environmental Quality, and the Pennsylvania Department of Environmental Protection that was conducted in four basins of the Chesapeake Bay watershed. The watershed drains 64,000 square miles in Delaware, the District of Columbia, Maryland, New York, Pennsylvania, Virginia, and West Virginia. The study included (1) base-flow and stormflow water-quality sampling on a monthly basis from 1997 through 2001, (2) estimation of monthly and annual nutrient and sediment loads using the U.S. Geological Survey ESTIMATOR model, and (3) calculation of trends in streamflow, load, flow-adjusted concentration, and flow-weighted concentration. This study provided supplemental information to the River Input Monitoring Program by presenting short-term water-quality data and estimated loads at four sites from 1997 through 2001.

The four study sites (Chesterville Branch, Conodoguinet Creek, North Fork Shenandoah River, and South Fork Shenandoah River) were selected to meet the goals and objectives set forth by the Chesapeake Bay Program Monitoring and Assessment subcommittee. The basins encompassing the study sites include a wide range of land use, geographic, and geologic regions, draining such diverse areas as the forested, agricultural, and developed land of the Appalachian Plateau of New York and Pennsylvania, the Valley and Ridge of the Pennsylvania and West Virginia highlands, the Shenandoah Valley of Virginia, and the flat lowlands of Maryland's Eastern Shore and Delaware.

The Chesterville Branch Basin is the smallest (6.12 square miles) of the four study site basins, and is located in a predominantly agricultural region of Maryland's Eastern Shore. The site was chosen to supplement the River Input Monitoring Program location on the Choptank River, which is more forested and developed than the Chesterville Branch. The Conodoguinet Creek Basin lies mostly within the Valley and Ridge Physiographic Province in Pennsylvania. This site was selected because land use is changing rapidly from agriculture to developed lands within the basin.

The North Fork Shenandoah River in Virginia was chosen for study because of recent increases in agricultural intensity and a shift in nitrogen source from fertilizer to poultry manure. This site was monitored in conjunction with the South Fork Shenandoah River in Virginia to allow the separation of Virginia's contribution and the contributions of West Virginia and Maryland to nutrient and sediment loads in the Potomac River Basin. The South Fork Shenandoah River is the largest of the study basins, and recently has been losing agricultural and forested land to increased urbanization and development.

The results of the study showed higher nitrogen and phosphorus loads and yields in basins with higher percentages of agricultural land, whereas lower values of nitrogen loads and yields were indicated for areas with higher percentages of forested land and less agriculture. There was no apparent relation between land use and suspended-sediment loads or yields.

Land-use characteristics are important in the determination of factors affecting trends. Basins that predominantly are agricultural tend to have applied a proportionally greater amount of fertilizers than forested or developed areas. In this study, determining relations between nutrient loads and factors, such as fertilizers sales, fertilizer application rates, manure loads, or animal densities within basins, was problematic because of the lack of agricultural census data that corresponded with the study period (1997–2001). The connection between nutrient loads and land development also could not be established. The period of record, which included 2 drought years (1997 and 2001) and Hurricane Floyd (1999), was probably too short to differentiate the effect of increased development from climatic variability in any of the study basins and draw meaningful conclusions.

Both Conodoguinet Creek and South Fork Shenandoah River had the highest nitrogen, phosphorus, and suspended-sediment loads and yields in the years of highest annual total streamflow. Similarly, loads and yields of total nitrogen and suspended sediment were related to annual total streamflow in the North Fork Shenandoah River. Total phosphorus, however, did not show the same pattern. Chesterville Branch had the highest phosphorus and suspended-sediment loads and yields as a result of Hurricane Floyd in 1999, which was not the year with the highest annual total streamflow.

Chesterville Branch, Conodoguinet Creek, and the North and South Fork Shenandoah River Basins represent various and unique land-use, geologic, hydrologic, and hydrogeomorphic characteristics. Activities within a basin, such as the use of combined sewer overflows, may affect water quality. The Chesapeake Bay Program may benefit from additional studies that consider specific basin characteristics and how they affect nutrient and sediment loads and yields. Although the data and analysis from this study established a baseline of water quality at these four sites, additional monitoring and tracking of loads in selected basins would help identify long-term trends and factors affecting those trends.

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Appendix A. *Annual load estimates and yield calculations for study sites: Chesterville Branch near Crumpton, Maryland; Conodoguinet Creek near Hogestown, Pennsylvania; North Fork Shenandoah River near Strasburg, Virginia; and South Fork Shenandoah River at Front Royal, Virginia*

[mi^2, square mile; kg/yr, kilogram per year; kg/mi^2/yr, kilogram per square mile per year; ton/yr, ton per year; ton/mi^2/yr, ton per square mile per year. The standard errors of prediction also are provided. The standard error of prediction is a measure of the expected difference between an individual estimate and the estimated daily load. **Station:** U.S. Geological Survey streamflow-gaging and water-quality station number. **Parameters:** TN, total nitrogen; TP, total phosphorus; and SSC, suspended-sediment concentration]

Station number	Basin area (mi^2)	USGS parameter code	Parameter	Year	Annual Load (kg/yr)	Standard Error of Prediction + / - (kg/yr)	Standard Error of Prediction + / - (Percent)	Annual Yield (kg/mi^2/yr)	Annual Load (ton/yr)	Standard Error of Prediction + / - (ton/yr)	Standard Error of Prediction + / - (Percent)	Annual Yield (ton/mi^2/yr)
Chesterville Branch near Crumpton, MD												
01493112	6.12	P00600	TN	1997	50,882	2,629	5	8,314	56.1	2.9	5	9.16
01493112	6.12	P00600	TN	1998	44,124	1,234	3	7,210	48.6	1.4	3	7.95
01493112	6.12	P00600	TN	1999	34,433	1,222	4	5,626	38.0	1.3	4	6.20
01493112	6.12	P00600	TN	2000	39,044	1,029	3	6,380	43.0	1.1	3	7.03
01493112	6.12	P00600	TN	2001	41,376	1,465	4	6,761	45.6	1.6	4	7.45
01493112	6.12	P00665	TP	1997	504	118	23	82	0.6	0.1	23	0.09
01493112	6.12	P00665	TP	1998	1,423	288	20	233	1.6	0.3	20	0.26
01493112	6.12	P00665	TP	1999	3,091	2,447	79	505	3.4	2.7	79	0.56
01493112	6.12	P00665	TP	2000	1,658	343	21	271	1.8	0.4	21	0.30
01493112	6.12	P00665	TP	2001	1,121	266	24	183	1.2	0.3	24	0.20
01493112	6.12	P80154	SSC	1997	123,372	22,382	18	20,159	136.0	24.7	18	22.22
01493112	6.12	P80154	SSC	1998	323,534	52,834	16	52,865	356.6	58.2	16	58.27
01493112	6.12	P80154	SSC	1999	1,224,140	871,692	71	200,023	1,349.4	960.9	71	220.48
01493112	6.12	P80154	SSC	2000	313,667	54,374	17	51,253	345.8	59.9	17	56.50
01493112	6.12	P80154	SSC	2001	199,932	37,680	19	32,669	220.4	41.5	19	36.01
Conodoguinet Creek near Hogestown, PA												
01570000	470	P00600	TN	1997	1,930,059	75,992	4	4,107	2,127.5	83.8	4	4.53
01570000	470	P00600	TN	1998	2,747,494	72,431	3	5,846	3,028.5	79.8	3	6.44
01570000	470	P00600	TN	1999	1,531,903	35,378	2	3,259	1,688.6	39.0	2	3.59
01570000	470	P00600	TN	2000	1,512,403	35,946	2	3,218	1,667.1	39.6	2	3.55
01570000	470	P00600	TN	2001	1,079,020	35,814	3	2,296	1,189.4	39.5	3	2.53
01570000	470	P00665	TP	1997	31,019	12,144	39	66	34.2	13.4	39	0.07
01570000	470	P00665	TP	1998	81,697	18,980	23	174	90.1	20.9	23	0.19
01570000	470	P00665	TP	1999	33,207	7,633	23	71	36.6	8.4	23	0.08
01570000	470	P00665	TP	2000	32,584	5,667	17	69	35.9	6.2	17	0.08
01570000	470	P00665	TP	2001	24,841	7,729	31	53	27.4	8.5	31	0.06
01570000	470	P80154	SSC	1997	38,611,053	19,428,930	50	82,151	42,560.7	21,416.4	50	90.55
01570000	470	P80154	SSC	1998	64,731,394	18,118,683	28	137,726	71,352.9	19,972.1	28	151.81
01570000	470	P80154	SSC	1999	17,330,905	5,197,019	30	36,874	19,103.7	5,728.6	30	40.65
01570000	470	P80154	SSC	2000	12,455,660	2,526,287	20	26,501	13,729.8	2,784.7	20	29.21
01570000	470	P80154	SSC	2001	11,748,262	4,413,563	38	24,996	12,950.0	4,865.0	38	27.55

Appendix A. *Annual load estimates and yield calculations for study sites: Chesterville Branch near Crumpton, Maryland; Conodoguinet Creek near Hogestown, Pennsylvania; North Fork Shenandoah River near Strasburg, Virginia; and South Fork Shenandoah River at Front Royal, Virginia*—Continued

						Standard Error of Prediction				Standard Error of Prediction		
Station number	Basin area (mi^2)	USGS parameter code	Parameter	Year	Annual Load (kg/yr)	+ / - (kg/yr)	+ / - (Percent)	Annual Yield ($kg/mi^2/yr$)	Annual Load (ton/yr)	+ / - (ton/yr)	+ / - (Percent)	Annual Yield ($ton/mi^2/yr$)
North Fork Shenandoah River near Strasburg, VA												
01634000	768	P00600	TN	1997	986,641	74,478	8	1,285	1,087.6	82.1	8	1.42
01634000	768	P00600	TN	1998	2,000,322	105,482	5	2,605	2,204.9	116.3	5	2.87
01634000	768	P00600	TN	1999	696,065	34,968	5	906	767.3	38.5	5	1.00
01634000	768	P00600	TN	2000	647,467	28,822	4	843	713.7	31.8	4	0.93
01634000	768	P00600	TN	2001	881,471	54,762	6	1,148	971.6	60.4	6	1.27
01634000	768	P00665	TP	1997	28,574	4,461	16	37	31.5	4.9	16	0.04
01634000	768	P00665	TP	1998	148,257	21,086	14	193	163.4	23.2	14	0.21
01634000	768	P00665	TP	1999	70,406	7,618	11	92	77.6	8.4	11	0.10
01634000	768	P00665	TP	2000	86,963	8,073	9	113	95.9	8.9	9	0.12
01634000	768	P00665	TP	2001	164,420	27,818	17	214	181.2	30.7	17	0.24
01634000	768	P80154	SSC	1997	36,179,427	29,886,661	83	47,109	39,880.3	32,943.9	83	51.93
01634000	768	P80154	SSC	1998	158,339,439	82,095,939	52	206,171	174,536.4	90,493.8	52	227.26
01634000	768	P80154	SSC	1999	5,743,956	2,494,897	43	7,479	6,331.5	2,750.1	43	8.24
01634000	768	P80154	SSC	2000	4,379,962	1,265,568	29	5,703	4,828.0	1,395.0	29	6.29
01634000	768	P80154	SSC	2001	36,602,503	35,789,211	98	47,660	40,346.7	3,9450.2	98	52.53
South Fork Shenandoah River at Front Royal, VA												
01631000	1,642	P00600	TN	1997	1,912,439	172,132	9	1,165	2,108.1	189.7	9	1.28
01631000	1.642	P00600	TN	1998	4,366,077	260,124	6	2,659	4,812.7	286.7	6	2.93
01631000	1.642	P00600	TN	1999	1,218,784	61,886	5	742	1,343.5	68.2	5	0.82
01631000	1,642	P00600	TN	2000	1,349,342	62,126	5	822	1,487.4	68.5	5	0.91
01631000	1,642	P00600	TN	2001	1,030,299	76,383	7	627	1,135.7	84.2	7	0.69
01631000	1,642	P00665	TP	1997	109,464	14,500	13	67	120.7	16.0	13	0.07
01631000	1,642	P00665	TP	1998	427,365	53,288	12	260	471.1	58.7	12	0.29
01631000	1,642	P00665	TP	1999	137,239	12,730	9	84	151.3	14.0	9	0.09
01631000	1,642	P00665	TP	2000	170,210	14,655	9	104	187.6	16.2	9	0.11
01631000	1,642	P00665	TP	2001	112,337	14,110	13	68	123.8	15.6	13	0.08
01631000	1,642	P80154	SSC	1997	29,054,829	9,784,497	34	17,695	32,026.9	10,785.4	34	19.50
01631000	1,642	P80154	SSC	1998	315,084,158	122,424,059	39	191,890	347,315.0	134,947.2	39	211.52
01631000	1,642	P80154	SSC	1999	15,468,601	4,185,743	27	9,421	17,050.9	4,613.9	27	10.38
01631000	1,642	P80154	SSC	2000	18,043,287	3,414,841	19	10,989	19,889.0	3,764.2	19	12.11
01631000	1,642	P80154	SSC	2001	17,245,857	5,777,642	34	10,503	19,010.0	6,368.7	34	11.58

Appendix B. *Trends in streamflow, load, flow-weighted concentration, and flow-adjusted concentration data for study sites: Chesterville Branch near Crumpton, Maryland; Conodoguinet Creek near Hogestown, Pennsylvania; North Fork Shenandoah River near Strasburg, Virginia; and South Fork Shenandoah River at Front Royal, Virginia*

[**Station:** U.S. Geological Survey streamflow-gaging and water-quality station number. **Trend:** Q, streamflow; FWC, flow-weighted concentration; FAC, flow-adjusted concentration; **Parameters:** Q, streamflow; TN, total nitrogen; TP, total phosphorus; and SSC, suspended-sediment concentration. **Statistics:** test, regression (Reg), Kendall Theil (KT); *p*-value, measure of significance of regressor at 0.05; trend direction, upward (up), downward (down), **bold "**up**"** or **"**down**"** are significant at 95-percent confidence level, residuals are not significant (ns); **Magnitude:** minimum, and maximum percentage change in trend indicated for period of record; --, not applicable or insufficient data]

				Statistics								
										Magnitude		
Station number	Period of record	Trend	Parameter	Test	Log transform	Regression slope	*p*-value	Normality	Trend direction	Trend	Minimum	Maximum
Chesterville Branch near Crumpton, Maryland												
01493112	1997–2001	Q	Q	Reg	yes	-0.02637	0.4143	0.86819	ns	-10.0115	-29.979	15.649
01493112	1997–2001	load	TN	Reg	yes	-0.03759	0.1144	0.96027	ns	-13.9595	-28.381	3.366
01493112	1997–2001	FWC	TN	Reg	yes	-0.0112	0.4102	0.8349	ns	-4	-14	6
01493112	1997–2001	FAC	TN	KT	yes	-0.0018	0.8914	--	ns	-1	-13	13
01493112	1997–2001	load	TP	Reg	yes	0.131593	0.1335	0.92352	ns	69.278	-14.016	233.258
01493112	1997–2001	FWC	TP	Reg	yes	0.1580	0.0106	0.9622	**up**	88	18	200
01493112	1997–2001	FAC	TP	KT	yes	0.1237	0.0244	--	**up**	85	7	221
01493112	1997–2001	load	SSC	Reg	yes	0.05422	0.5463	0.85642	ns	24.2195	-38.321	150.175
01493112	1997–2001	FWC	SSC	Reg	yes	0.0806	0.1987	0.8868	ns	38	-15	124
01493112	1997–2001	FAC	SSC	KT	yes	0.0547	0.2303	--	ns	31	-17	109

Appendix B. *Trends in streamflow, load, flow-weighted concentration, and flow-adjusted concentration data for study sites: Chesterville Branch near Crumpton, Maryland; Conodoguinet Creek near Hogestown, Pennsylvania; North Fork Shenandoah River near Strasburg, Virginia; and South Fork Shenandoah River at Front Royal, Virginia*—Continued

				Statistics								
										Magnitude		
Station number	Period of record	Trend	Parameter	Test	Log transform	Regression slope	*p*-value	Normality	Trend direction	Trend	Minimum	Maximum
Conodoguinet Creek near Hogestown, Pennsylvania												
01570000	1997–2001	Q	Q	Reg	yes	-0.18118	0.0014	0.98247	**down**	-51.5532	-68.275	-26.0177
01570000	1997–2001	load	TN	Reg	yes	-0.17787	0.0011	0.98526	**down**	-50.9081	-67.2676	-26.3722
01570000	1997–2001	FWC	TN	Reg	yes	0.0033	0.3845	0.9722	ns	1	-2	4
01570000	1997–2001	FAC	TN	KT	yes	0.0050	0.6892	--	ns	3	-10	17
01570000	1997–2001	load	TP	Reg	yes	-0.09046	0.4871	0.96683	ns	-30.3612	-74.73	91.911
01570000	1997–2001	FWC	TP	Reg	yes	0.0907	0.2438	0.9521	ns	44	-21	163
01570000	1997–2001	FAC	TP	KT	yes	0.2760	0.0000	--	**up**	296	103	675
01570000	1997–2001	load	SSC	Reg	yes	-0.29324	0.0611	0.96713	ns	-69.0549	-90.704	3.015
01570000	1997–2001	FWC	SSC	Reg	yes	-0.1121	0.2760	0.9510	ns	-36	-71	42
01570000	1997–2001	FAC	SSC	KT	yes	0.1435	0.0205	--	**up**	105	10	281

Appendix B. *Trends in streamflow, load, flow-weighted concentration, and flow-adjusted concentration data for study sites: Chesterville Branch near Crumpton, Maryland; Conodoguinet Creek near Hogestown, Pennsylvania; North Fork Shenandoah River near Strasburg, Virginia; and South Fork Shenandoah River at Front Royal, Virginia*—Continued

				Statistics								
										Magnitude		
Station number	Period of record	Trend	Parameter	Test	Log transform	Regression slope	*p*-value	Normality	Trend direction	Trend	Minimum	Maximum
North Fork Shenandoah River near Strasburg, Virginia												
01634000	1997–2001	Q	Q	Reg	yes	-0.07965	0.2394	0.97231	ns	-27.284	-56.963	22.862
01634000	1997–2001	load	TN	Reg	yes	-0.06508	0.4193	0.97249	ns	-22.92	-58.8	44.209
01634000	1997–2001	FWC	TN	Reg	yes	0.0146	0.3294	0.9757	ns	6	-6	19
01634000	1997–2001	FAC	TN	KT	yes	0.0223	0.2769	--	ns	12	-9	37
01634000	1997–2001	load	TP	Reg	yes	0.349258	0.0001	0.93501	**up**	304.318	124.221	629.07
01634000	1997–2001	FWC	TP	Reg	yes	0.4289	0.0001	0.9758	**up**	456	339	605
01634000	1997–2001	FAC	TP	KT	yes	0.4477	0.0000	--	**up**	834	514	1,321
01634000	1997–2001	load	SSC	Reg	yes	-0.21732	0.1924	0.93435	ns	-58.075	-88.474	52.494
01634000	1997–2001	FWC	SSC	Reg	yes	-0.1377	0.1824	0.9032	ns	-42	-74	28
01634000	1997–2001	FAC	SSC	KT	yes	-0.0845	0.2788	--	ns	-34	-70	44

Appendix B. *Trends in streamflow, load, flow-weighted concentration, and flow-adjusted concentration data for study sites: Chesterville Branh near Crumpton, Maryland; Conodoguinet Creek near Hogestown, Pennsylvania; North Fork Shenandoah River near Strasburg, Virginia; and South Fork Shenandoah River at Front Royal, Virginia*—Continued

				Statistics								
										Magnitude		
Station number	Period of record	Trend	Parameter	Test	Log transform	Regression slope	*p*-value	Normality	Trend direction	Trend	Minimum	Maximum
South Fork Shenandoah River at Front Royal, Virginia												
01631000	1997–2001	Q	Q	Reg	yes	-0.13965	0.0132	0.95862	**down**	-42.7986	-62.689	-12.3056
01631000	1997–2001	load	TN	Reg	yes	-0.20862	0.0064	0.96462	**down**	-56.5895	-75.622	-22.6975
01631000	1997–2001	FWC	TN	Reg	yes	-0.0690	0.0020	0.9827	**down**	-24	-36	-10
01631000	1997–2001	FAC	TN	KT	yes	-0.0215	0.3924	--	ns	-10	-30	16
01631000	1997–2001	load	TP	Reg	yes	-0.08366	0.2703	0.93641	ns	-28.4393	-60.284	28.9378
01631000	1997–2001	FWC	TP	Reg	yes	0.0560	0.0708	0.9621	ns	25	-1	59
01631000	1997–2001	FAC	TP	KT	yes	0.1058	0.0095	--	**up**	70	13	154
01631000	1997–2001	load	SSC	Reg	yes	-0.29182	0.0649	0.92159	ns	-68.8783	-90.76	4.8281
01631000	1997–2001	FWC	SSC	Reg	yes	-0.1522	0.1442	0.9140	ns	-46	-76	22
01631000	1997–2001	FAC	SSC	KT	yes	0.0697	0.2567	--	ns	42	-24	163