Relation of Stream Quality to Streamflow, and Estimated Loads of Selected Water-Quality Constituents in the James and Rappahannock Rivers Near the Fall Line of Virginia, July 1988 through June 1990

By D.L. Belval, M.D. Woodside, and J.P. Campbell

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
ounce, fluid (oz)	0.02957	liter (L)
liter (L)	33.82	ounce, fluid
pound avoirdupois (lb)	0.4536	kilogram (kg)
kilogram (kg)	2.205	pound avoirdupois
pound avoirdupois per day (lb/d)	0.4536	kilogram per day (kg/d)
kilogram per day (kg/d)	2.205	pound avoirdupois per day

Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 18\ (°C) + 32$$

Abbreviated water-quality units: Chemical concentrations, air and water temperature, and specific conductance in this report are reported in metric units. Chemical concentration is reported in milligrams per liter (mg/L). Air and water temperature are reported in degrees Celsius (°C). Specific conductance of water is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm). Barometric pressure in this report is reported in millimeters of mercury (mmHg).

Relation of Stream Quality to Streamflow, and Estimated Loads of Selected Water-Quality Constituents in the James and Rappahannock Rivers Near the Fall Line of Virginia, July 1988 through June 1990

By Donna L. Belval, Michael D. Woodside, *and* Jean P. Campbell

ABSTRACT

This report presents the results of a study by the U.S. Geological Survey, funded by the Virginia Department of Environmental Quality–Division of Intergovernmental Coordination, to monitor and estimate loads of selected nutrients and suspended solids discharged to Chesapeake Bay from two major tributaries in Virginia. Monitoring was conducted previously from 1984 through 1988. The emphasis was on scheduled monitoring during that period and, therefore, most samples were collected at base-flow conditions. Because some constituent concentrations change during stormflow conditions, and because the increased river discharge affects the total loads of all constituents, the monitoring program was revised in 1988 to include stormflow sampling. The revised sampling scheme, including base-flow and stormflow sampling, increased precision in load estimation.

From July 1988 through June 1990, monitoring consisted of collecting depth-integrated, cross-sectional samples from the James and Rappahannock Rivers in Virginia during stormflow and at scheduled intervals, which were sometimes during stormflow but were usually base-flow conditions. Water-quality constituents that were monitored for which loads were estimated included total suspended solids (residue, total at 105 °Celsius), dissolved nitrite-plus-nitrate nitrogen, dissolved ammonia nitrogen, total Kjeldahl nitrogen (ammonia plus organic), total nitrogen, total phosphorus, dissolved orthophosphorus, total organic carbon, and dissolved silica. Other selected constituents also were monitored for which loads were not calculated. Daily mean load estimates of each constituent were computed by month using a seven-parameter log-linear-regression model that used variables of time, discharge, and seasonality.

Water-quality data and constituent-load estimates are included in the report in tabular and graphic form. Illustrations of load estimates overlain by hydrographs for the same period, showing the magnitude of the increase in loads that occurs during stormflow events, also are included in the report. Water-quality data are included in tabular form in the appendixes.

Wide ranges in estimated loads of constituents were observed for both rivers. Monthly loads of total suspended solids ranged from 257,000 to 339,000,000 kg in the James River and from 22,800 to 184,000,000 kg in the Rappahannock River. Estimated monthly loads of total nitrogen ranged from 72,600 to 1,840,000 kg in the James River and from 3,968 to 750,200 kg in the Rappahannock River. Total phosphorus loads ranged from 35,700 to 469,000 kg in the James River and from 558 to 221,030 kg in the Rappahannock River. The greatest monthly load for all constituents monitored was observed at both rivers in May 1989, when a series of storms resulted in 2 to 3 weeks of above-normal streamflow. During that month, the estimated load of suspended solids was more than 30 percent of the total load for the entire 2-year data-collection period at the James River, and more than 50 percent of the total load for the Rappahannock River.

Quality-assurance data comparing the results between the Virginia Division of Consolidated Laboratory Services to the National Water Quality Laboratory of the U.S. Geological Survey indicate that there are consistent

differences between the laboratories for several constituents. The water-quality data and load estimates provided in this report will be used to calibrate the computer-modeling efforts of the Chesapeake Bay region, to evaluate the water quality of the Bay and the major affects on the water quality, and to assess the results of best-management practices in Virginia.

INTRODUCTION

The Chesapeake Bay is the largest estuary on the eastern seaboard of the United States, extending nearly 200 mi from the mouth of the Susquehanna River in Maryland to where it discharges into the Atlantic Ocean, along the southeastern coast of Virginia. The watershed contains parts of Delaware, Pennsylvania, Maryland, New York, Virginia, West Virginia, and the District of Columbia and is approximately 64,000 mi^2 in area (fig. 1). The Bay contains areas of freshwater and saltwater, tidal and nontidal wetlands, and open and protected waters that provide wildlife habitats. The various habitats support an extensive commercial fishing and recreation industry, and provide jobs directly and indirectly to thousands of people in the watershed area.

Development in the Chesapeake Bay region has adversely affected the water quality of the Bay. Beginning in 1978, the Chesapeake Bay Program identified three critical areas of concern for intensive investigation: (1) nutrient enrichment, (2) toxic substances, and (3) the decline of submerged aquatic vegetation (U.S. Environmental Protection Agency, 1982). The changes in the quality of water in the Bay have resulted in the decline of important commercial fish and oyster industries and a reduction in the number of acres populated by aquatic vegetation that provides food and habitat for fish and shellfish. The sources of nutrients and toxic substances entering the Bay, which also can affect the aquatic vegetation population, include nonpoint sources and point sources, such as agriculture, industrial and urban runoff, and industrial and septic waste-water discharges, among others.

The Chesapeake Bay Agreement, which was signed in 1987 by the Governors of Virginia, Maryland, and Pennsylvania, the Mayor of Washington, D.C., the Administrator of the U.S. Environmental Protection Agency (USEPA), and representatives of the Chesapeake Bay Commission, commits Federal, State, and other agencies to work toward improving the quality of water in the Bay by reducing toxin input and by continuing to monitor water, plant, and animal resources. The agreement set a goal to reduce controllable nutrient input into the Bay by 40 percent by the year 2000.

In order to assess the effects of nutrient and suspended-solid loads on the ecosystems of the Chesapeake Bay, it is necessary to quantify the loads of these constituents into the Bay and to evaluate the trends of these loads. The load estimates will be used to assess nonpoint-source control practices in the Chesapeake Bay watershed and will be used to calibrate and validate the computer-modeling efforts of the Chesapeake Bay Program.

Nutrient and suspended-solid monitoring began in Virginia in 1984 by the U.S. Geological Survey (USGS), in cooperation with the Virginia Department of Environmental Quality—Division of Intergovernmental Coordination (DEQ) (formerly, the Virginia Water Control Board), to quantify loads of nutrients and solids entering into the Bay. The initial monitoring program consisted of collecting water-quality data on a semimonthly scheduled basis at sites near the Fall Line on four tributaries to the Bay—the James, Rappahannock, Pamunkey, and Mattaponi Rivers. The Fall Line is the point farthest downstream that is unaffected by tides, and that could, therefore, be measured as a single-point source of loads to the Chesapeake Bay. Because loads of nutrients and suspended solids are greatest during high-flow or stormflow conditions, a comprehensive program was established in 1988 by the USGS, funded by the Virginia DEQ, to collect water-quality data during stormflow conditions at the two major tributaries to the Chesapeake Bay, the James and Rappahannock Rivers.

A seven-parameter log-linear-regression model, which included variables of discharge, seasonality, and time, was used to estimate concentrations of selected constituents for those days when no concentration data were available. The product of the estimated concentrations and the daily mean discharge gave daily mean load estimates, which were then totaled to provide monthly mean loads.

A nutrient-monitoring program conducted by the USGS at Maryland tributaries parallels the Virginia program and has been in place since 1982, and is the source for the seven-parameter log-linear-regression model. The extensive data base developed since 1982 was used to evaluate different methods of estimating nutrient and suspended-sediment loads. The study concluded that

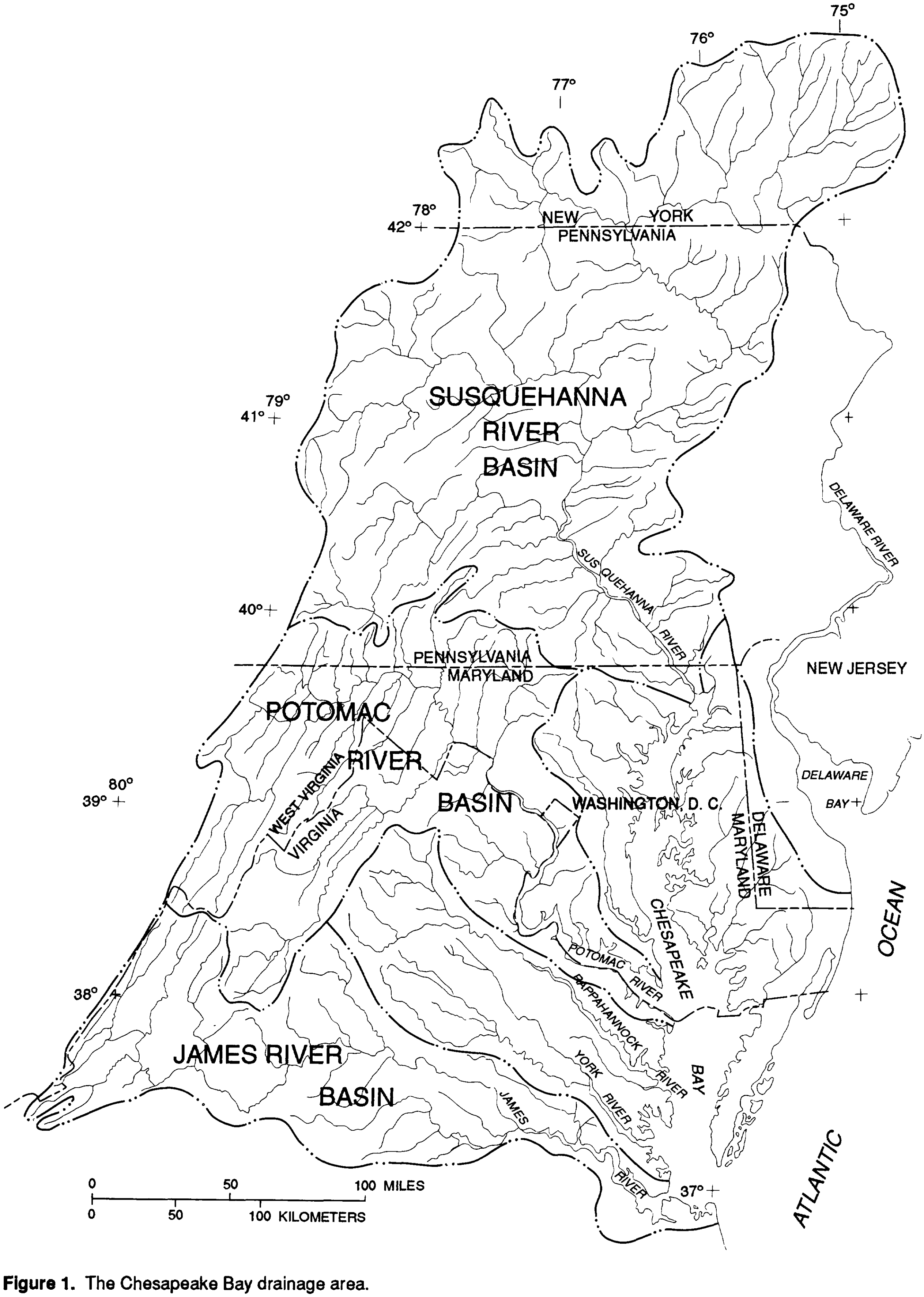

Figure 1. The Chesapeake Bay drainage area.

the use of a seven-parameter log-linear-regression model, using the minimum variance unbiased estimator (MVUE) of Bradu and Mundlak (1970), resulted in low-variance, nearly unbiased load estimates (Cohn and others, 1989; Gilroy and others, 1990). This method has also been used successfully in other ongoing studies in the Chesapeake Bay watershed, including by Cohn and others (1992); by L.D. Zynjuk and others (unpublished data on file in the Towson, Md., Office of the U.S. Geological Survey); and by Fishel and others (1991).

Purpose and Scope

This report presents water-quality data and monthly load estimates of nutrients and suspended solids near the Fall Line of two major tributaries to the Chesapeake Bay in Virginia, the James and Rappahannock Rivers. Data and estimated loads are included in the report for the following constituents—total suspended solids, dissolved nitrite-plus-nitrate nitrogen, dissolved ammonia nitrogen, total Kjeldahl nitrogen (also identified as ammonia-plus-organic nitrogen), total nitrogen, total phosphorus, dissolved orthophosphorus, total organic carbon, and dissolved silica.

Water-quality samples were collected on a scheduled bimonthly basis at each station and during stormflow conditions from July 1, 1988, through June 30, 1990. Stormflow conditions were defined by use of the flow-duration statistics generated from the historical hydrologic record at each station. Sample-collection records from other rivers indicated that approximately 40 stormflow samples were needed during precipitation events at each station to estimate loads. During a stormflow event three to five samples were normally collected, with a goal of collecting samples during the rise, peak, and fall of the stormflow hydrograph.

Description of Study Area

The James and Rappahannock River basins represent more than 50 percent of the Chesapeake Bay drainage area in Virginia, and about 20 percent of the total Chesapeake Bay drainage area. The locations of the James and Rappahannock River Basins and the Fall Line monitoring stations are shown in figure 2.

The James River basin encompasses a land area of approximately 10,206 mi^2, which constitutes about one-fourth of the State of Virginia. The river is the third largest source of freshwater to the Chesapeake Bay, after the Susquehanna and Potomac Rivers. The James River basin extends from the eastern part of West Virginia through four physiographic provinces: (1) Valley and Ridge, (2) Blue Ridge, (3) Piedmont, and (4) Coastal Plain. Approximately 65 percent of the basin is forested, 12 percent is cropland, 12 percent is hay and pasture, 8 percent is urban areas, including residential, commercial, public, and industrial, and about 3 percent is water (Virginia Water Control Board, 1991).

A study published by the USEPA (1982) indicates that the highest loading rates for nutrients and sediment generally were in agricultural (cropland) areas, the lowest loading rates were in forested areas, and intermediate rates were in pastoral and residential areas. In the James River Basin specifically, nonpoint sources of elevated nutrients and sediment can include agricultural runoff and erosion of cropland. Additionally, discharge from industrial plants and sewage-treatment facilities, as well as urban runoff contributes nutrients to the river (Virginia Department of Conservation and Recreation, 1989). The major cities in the James River basin are Richmond, Lynchburg, Petersburg, Charlottesville, Williamsburg, Hopewell, and parts of Norfolk and Newport News.

The water-quality monitoring station on the James River near Cartersville, Va. (USGS station 02035000 and VDEQ station TF5.1), represents a contributing area of 6,257 mi^2 to the Chesapeake Bay from Virginia near the Fall Line, or about 60 percent of the James River Basin drainage area. This station is about 40 mi upstream of the Fall Line, but was selected because of the well-documented long-term flow record, and because there are no major streams contributing to the flow between this station and the Fall Line at Richmond. In addition, this station is part of the National Stream Quality Accounting Network (NASQAN), a nationwide long-term water-quality sampling network; therefore, historical water-quality data are available for this site. The average discharge at this site, computed during a period of 91 years, is 7,062 ft^3/s (Prugh and others, 1989). The location of this monitoring site is lat 37°40'15", long 78°05'10", and is located at State Highway 45 at the Goochland/Cumberland County line, Va.

The Rappahannock River flows from the eastern edge of the Blue Ridge Province through the rolling hills of the Piedmont and Coastal Plain Provinces to the

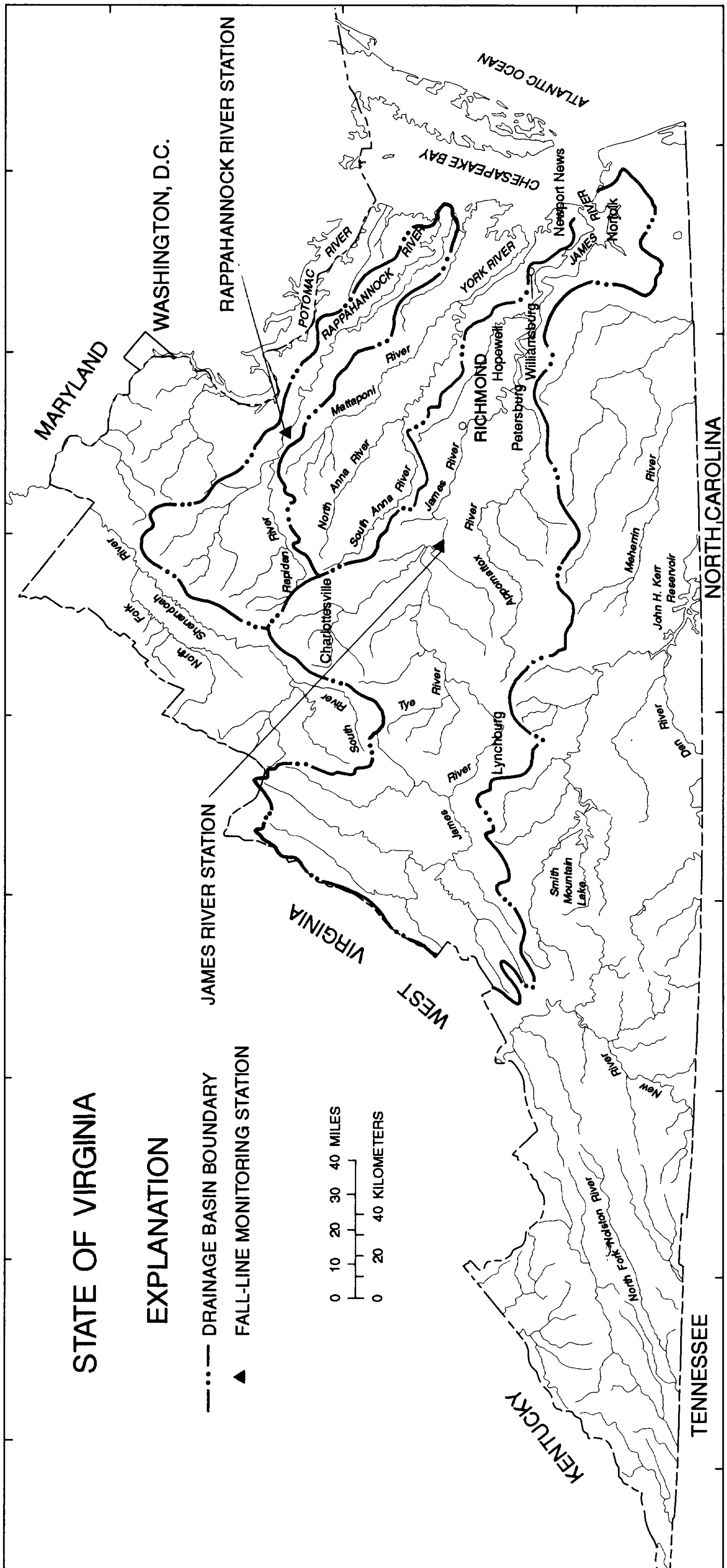

Figure 2. Location of Fall Line monitoring stations in the James and Rappahannock River basins.

Chesapeake Bay, and is the second largest contributor of flow toward the Chesapeake Bay from Virginia. About 55 percent of the Rappahannock River Basin is forestland, 16 percent is cropland, 10 percent is hay and pasture, 6 percent is urban, and about 13 percent is water (Virginia Water Control Board, 1991). Expansion of the Washington, D.C., suburbs is increasingly affecting the water quality of the river, which is one reason why the basin was selected for monitoring. Increased construction may cause elevated sediment concentrations in runoff, and an increase in concentrations of nutrients associated with the sediment, such as phosphorus.

The Rappahannock River monitoring station (USGS station 01668000 and VDEQ station TF3.1) is located near Fredericksburg and also is a NASQAN station. Upstream from the station, most of the basin is in the uplands of the Piedmont Province, and because of the high relief, the river produces rapid, or "flashy," streamflow peaks as a result of precipitation. The river, therefore, carries large loads of suspended solids and other constituents, relative to the size of the basin. The average discharge at this station is 1,652 ft^3/s, computed during a period of 82 years (Prugh and others, 1989). The area of the drainage basin upstream from the sampling station is approximately 1,596 mi^2, which is about 57 percent of the entire 2,848 mi^2 basin. The location of the site in Spotsylvania County, Va., is lat 38°19'20", long 77°31'05".

Previous Studies

Previous investigations contained information about constituent monitoring in the Chesapeake Bay Basin and load-computation methods. Lang and Grason (1980) provide water-quality monitoring data for the Susquehanna, Potomac, and James Rivers—three major tributaries to the Chesapeake Bay. Lang (1982) computed loads of nutrients and metals from the same three rivers, using a bivariate linear-regression-equation method. Cohn and others (1992) demonstrated the use of a seven-parameter log-linear-regression equation method to estimate nutrient loads using data from the Susquehanna, Patuxent, Choptank, and Potomac Rivers in Maryland. Ott and others (1990) and Fishel and others (1991) used this seven-parameter log-linear-regression model to compute nutrient and sediment loads to the Chesapeake Bay from tributaries in Pennsylvania. L.D. Zynjuk (unpublished data on file in the Towson, Md., Office of the U.S. Geological Survey) also computed nutrient and sediment loads from several Maryland tributaries, using the seven-parameter log-linear-regression model.

Acknowledgments

The authors gratefully acknowledge Frederick Hoffman and Donald McCall of the Virginia Department of Environmental Quality—Division of Intergovernmental Coordination, Chesapeake Bay Office, for their assistance and guidance of the program. Most analyses for this project were performed by the Virginia Division of Consolidated Laboratories Bureau of Chemistry—specifically the Nutrients Laboratory and the Non-Metals Laboratory; we thank these people for their work.

METHODS OF STUDY

In order to document methods of study for this project clearly, procedures were divided into the following categories: (1) field data collection, (2) sample preparation and analysis, (3) quality assurance and quality control, and (4) load estimation. The details of these study methods follow.

Field Data Collection

Water-quality samples were collected at each station during the period July 1, 1988, through June 30, 1990, on a bimonthly basis and also during stormflow conditions. Approximately 30 to 40 stormflow samples per year were needed to estimate loads accurately by use of the log-linear regression-equation model selected for this study. Stormflow-sampling criteria were established by determining a gage height that is reached at each river about 40 times per year. At progressively higher gage heights, the water level would be reached on a lower number of days. In order to sample the range of gage heights, an emphasis was placed on sampling on days of higher flow.

The specific sampling criteria are listed in tables 1 and 2. These criteria were used as guidelines for sample collection, and were not strict criteria. During extreme low-flow or high-flow periods, the sampling criteria could be modified in an attempt to obtain the target number of samples. Whenever possible, and as permitted by flow conditions, water samples were collected near the rise, peak, and fall of the stormflow hydrograph.

Table 1. Criteria for stormflow sampling at the James River station

[>, greater than; <, less than; ft^3/s, cubic foot per second; ft, foot; %, percent]

Gage height (ft)	Daily mean flow (ft^3/s)	Flow duration (% of time discharge was equaled/exceeded)	Sampling frequency (%)
>12	>32,000	<2	100
9-12	21,000-32,000	2- 5	[a]>90
6- 9	12,000-21,000	5- 14	[b]50-100
<6	<12,000	14-100	[c]13

[a]Attempt to sample >90 percent of days with streamflows in excess of 21,000 ft^3/s.

[b]The percentage will differ depending on weather conditions. During dry periods, attempts were made on all days when streamflow was in this range; during wet periods, attempts were made to sample on at least half the days when streamflow was in this range.

[c]The percentage is based on the 24 base-flow samples scheduled per year (by the U.S. Geological Survey and the Department of Environmental Quality). During extreme dry periods, however, this sampling frequency could be increased to include small precipitation events to estimate loads more accurately.

Table 2. Criteria for stormflow sampling at the Rappahannock River station

[>, greater than; <, less than; ft^3/s, cubic foot per second; ft, foot; %, percent]

Gage height (ft)	Daily mean flow (ft^3/s)	Flow duration (% of time discharge was equaled/exceeded)	Sampling frequency (%)
>6.5	>9,000	<2	[a]100
5.2-6.5	5,000-9,000	2- 5	[b]>90
4.2-5.2	2,700-5,000	5- 14	[c]50-100
<4.2	<2,700	14-100	[d]13

[a]Sample from the Interstate-95 bridge when the gage height exceeds 12 feet.

[b]Attempts were made to sample on >90 percent of days when streamflow was in excess of 5,000 ft^3/s at the Fredericksburg gage (or 3,800 ft^3/s combined flow of gages on Rappahannock River at Remington, Va., and Rapidan River near Culpeper, Va.).

[c]The percentage will differ depending on weather conditions. During dry periods, attempts were made to sample on all days when streamflow was in this range; during wet periods, attempts were made to sample on at least half the days when streamflow was in this range.

[d]The percentage is based on the 24 base-flow samples scheduled per year (by the U.S. Geological Survey). During extreme dry periods, however, this sampling frequency could be increased to include small precipitation events to estimate loads more accurately.

Streamflow gages upstream of the monitoring stations were outfitted with telemetry equipment, so that water levels that changed as a result of precipitation could be monitored. Because of the remoteness of the Rappahannock River station, telemetry equipment could not be installed; therefore, decisions about sampling criteria were based on the flow conditions at the two telemetry stations upstream—the Rappahannock River near Remington and the Rapidan River near Culpeper (table 2). The Rappahannock River station above Fredericksburg was inaccessible during extreme high-flow events; therefore, at those times stormflow samples were collected from the Interstate–95 (I-95) bridge above the Rappahannock River about 1 mile downstream of the sampling station. There are no major contributions of flow to the river between the two sites.

In addition to stormflow sampling, median-flow or base-flow samples were collected on a scheduled basis. These base-flow samples were collected once each month by VDEQ personnel and once each month by USGS personnel at the James River at Cartersville, and twice each month by USGS personnel at the Rappahannock River near Fredericksburg.

The VDEQ sampling procedure differed slightly from that of the USGS for samples collected during high flow; therefore, only data from samples collected at high flow using USGS methods were used in this study. The majority of samples collected were analyzed by the Virginia Division of Consolidated Laboratories (VDCLS) in Richmond, Va. The quality-assurance samples were analyzed by the National Water Quality Laboratory (NWQL) of the USGS in Arvada, Colo.

Water-quality samples were collected using an equal-discharge increment (EDI) method or an equal-width increment (EWI) method, so that water samples were representative of stream conditions at the time of collection. The EDI method, in which samples are obtained at the centroids of equal discharge increments of flow, is normally used in streams with stable channels where discharge ratings change very little during the year. The EWI method, in which samples are collected at centroids of equal-width increments of the stream, is used most often in shallow or sandbed streams where the distribution of water discharge in the cross-section is not stable, or in streams where the distribution of discharge in the cross-section is unknown. Samples were collected using a depth-integrating sampler when average streamflow velocities exceeded 1.5 ft/s, or a weighted sample bottle at lower velocities when depth-integrating samplers were not effective. A depth-integrating sampler is designed to sample the vertical water column of the river proportionally to the velocity at each depth. These methods are documented by Edwards and Glysson (1988) and by Ward and Harr (1990). All samples at the Rappahannock River station were collected by USGS personnel using the EDI method, except samples collected from the I-95 bridge during extreme high flow, when an EWI method was used. All samples collected at the James River station by USGS personnel also were collected by the EDI method. Monthly scheduled samples collected by the VDEQ at the James River station were collected using a non-depth-integrating, or point sampler, at approximately equal-width increments across the river. The VDEQ did not have access to a depth-integrating sampler; therefore, only those VDEQ samples collected when flow velocities were less than 1.5 ft/s, when point samplers would be effective, were used in this study. The criteria for equipment use based on the flow at each site are listed in tables 3 and 4.

Table 3. Criteria for equipment use during stormflow and base-flow sampling at the James River station
[NA, not applicable]

Gage height (foot)	Sampler	Nozzle (inch)	Bottle (liter)
0 - 2.5	Weighted bottle	NA	2
2.5-12	D-74AL	3/16	1
12 -20	D-74	1/8	1
above 20	D-74 + 50 pounds	1/8	1

Table 4. Criteria for equipment use during stormflow and base-flow sampling at the Rappahannock River station
[above a gage height of 12 feet, the cableway is unsafe to operate, and sampling is done from the I-95 bridge. Five equally-spaced depth-integrated samples will be collected. NA, not applicable]

Gage height (foot)	Sampler	Nozzle (inch)	Bottle (liter)
0- 5	Weighted bottle	NA	2
5- 9	D-74AL	3/16	1
9-12	D-74	3/16	1
above 12	D-74	1/8	1

Field measurements of water temperature, pH, specific conductance, dissolved oxygen, barometric pressure, and air temperature were made routinely on days when nutrient and suspended-solids samples were collected.

Sample Preparation and Analysis

Collected water samples were packed in ice and transported to VDCLS. Samples were filtered and analyzed by VDCLS under procedures established by Clesceri, Greenberg, and Trussell (1989) and the USEPA Environmental Monitoring and Support Laboratory (1983). Requirements set by the USEPA for regulatory laboratories state that nutrient samples be filtered within 24 hours and suspended-solid determinations be performed within 7 days. Samples collected on weekends were chilled to 4 °C and held until they could be accepted by VDCLS on Monday. Approximately one of every ten samples was sent to both VDCLS and NWQL in Arvada, Colo., as a quality assurance check of the analytical results. Samples sent to NWQL were filtered and preserved in the field, then shipped by express mail to the laboratory. The analyses were performed within 7 days after receipt at the laboratory. Analytical methods used at NWQL were documented by Fishman and Friedman (1989).

Quality Assurance and Quality Control

Three general quality-assurance objectives were established to ensure the quality of data collected, including: (1) comparability of results; (2) assessment of data accuracy, precision, and completeness; and (3) representativeness of sample sites and samples. The following is a description of these objectives and how they were achieved.

Objective 1.—The data collected should be comparable and reproducible; therefore, sampling methods and sample analyses must be as uniform as possible and consistent among the agencies and personnel collecting and analyzing the data. The quality-assurance efforts that addressed comparability for this project included:

(a) Documentation of depth-integrated, cross-sectional water-quality variability. To ensure the collection of representative samples, an analysis of historic cross-sectional variability of conductance, water temperature, dissolved oxygen, pH, and suspended sediment was used to determine that the sampling points across each river adequately represented the vertical and horizontal water-quality conditions in the cross section.

(b) Quality assurance of sampling by field personnel. Verification of proper sample-collection techniques was conducted through in-house tests of procedures and through comparisons of field and laboratory-analyzed constituent results.

(c) Documentation of the analytical differences between laboratories. Differences in analytical results between the laboratories were qualified by collecting laboratory-duplicate (or split) samples, then assessing the differences between the analyses.

Objective 2.—Assessment of data precision and accuracy for the Virginia Fall-Line Monitoring Program consisted of collecting and analyzing duplicate, laboratory-split, and standard-reference samples. The purpose of these quality-assurance practices is to evaluate precision, comparability between laboratories, and accuracy. Completeness is determined by comparing the number of samples scheduled to be collected and analyzed to the final number of samples collected and analyzed.

Objective 3.—Representative samples are collected using USGS-approved guidelines, which ensure that the samples represent water-quality conditions of the river as closely as possible. In addition, stormflow-sampling guidelines ensure that base flow and storms are adequately sampled in accordance with the project purpose. This study was designed for sampling to occur during a variety of flow conditions to develop as complete and representative a set of data as possible.

The quality-assurance data provided an ongoing check to indicate any differences that could have occurred because of any errors. Quality-control procedures included the collection of quality-assurance samples as follows:

1. Approximately 10 percent of the samples collected at each monitoring site were collected as duplicate samples. Two duplicate samples were sent to VDCLS as a quality-control check for analytical precision.

2. Approximately 10 percent of the samples collected at each monitoring site were collected as "laboratory-split" samples. A subsample of the full sample volume collected was sent to NWQL and another subsample to VDCLS to compare results between the two laboratories.

3. Standard-reference material samples (or "standard reference samples") were submitted to VDCLS and NWQL to compare analytical results and to check these results against a known standard. A reference material is a substance for which one or more properties are established sufficiently well to validate a measurement process (Taylor, 1987). Sources for reference samples include the USEPA and commercial laboratories.

Quality-assurance samples were collected at the Rappahannock and James Rivers throughout the period of study and included laboratory-split, standard-reference, and duplicate samples. All data were reviewed for transcription errors and corrected. A nonparametric test, the Wilcoxon signed-rank test, was used to analyze the data for the laboratory-split and the standard-reference samples because of the small number of quality-assurance analyses (fewer than 30) for each constituent. The Wilcoxon signed-rank test is used to determine whether the difference between medians of paired observations equals zero. Concentrations below the reporting limit (or "censored") were considered to be equal to the reporting limit in order to be used in the computation of the median for each group of data. The Wilcoxon signed-rank test was used to compute the difference between pairs of data, rank the absolute difference, and compute statistics on the rank-transformed data for the laboratory-split sample pairs and the standard-reference laboratory-sample pairs.

Load Estimation

Several statistical methods are available to estimate constituent concentrations and loads of nutrients and suspended solids. Cohn and others (1989) provides a review of these methods, and determined that the minimum variance unbiased estimator (MVUE) of Bradu and Mundlak (1970) using a seven-parameter log-linear-regression equation best estimated the concentrations of nutrients and suspended sediment that entered the Chesapeake Bay from four Maryland rivers sampled for that study (Cohn and others, 1992; Gilroy, Hirsch, and Cohn (1990). Because the four Maryland rivers represented a variety of flow conditions, land use, and basin sizes, the method also could be applicable to other rivers in the Chesapeake Bay Basin. The regression-equation method was used to estimate constituent concentrations in tributaries to the Chesapeake Bay from Pennsylvania (Fishel, Langland, and Truhlar, 1991).

For this study, the same methods were used to compute loads, to be consistent with other studies within the Chesapeake Bay watershed. The method also will be used to estimate loads to the Chesapeake Bay from other Virginia tributaries.

Constituent loads were estimated in two steps: (1) daily constituent concentrations were estimated by use of a multivariate log-linear model; and (2) daily constituent loads were computed as the product of discharge and the estimated constituent concentration. The regression equation used to estimate constituent concentrations is as follows:

$$ln[C] = \beta_0 + \beta_1 (ln[Q/\tilde{Q}]) + \beta_2 (ln[Q/\tilde{Q}])^2 + \beta_3 [T - \tilde{T}] + \beta_4 [T - \tilde{T}]^2 + \beta_5 \sin[2\pi T] + \beta_6 \cos[2\pi T] + \varepsilon \text{ , and} \quad (1)$$

where: $ln[\,]$ = the natural logarithm function,
C = the concentration (in mg/L),
Q = the instantaneous discharge (in ft^3/s),
T = time (in years),
sin = the sine function,
cos = the cosine function,
π = 3.14169,
β = coefficient of the regression model,
ε = model errors, and
$\tilde{Q}$ and $\tilde{T}$ = centering variables (see Cohn and others, 1992).

Coefficients β_0 through β_6 are the parameters of the regression model that were computed from the concentration data collected. The model errors (ε) are assumed to be independent and normally distributed with zero mean and variance (σ^2). "Centering variables" simplify the numerical work and have no effect on the load estimates. They are defined so that the predictor variables, β, corresponding to each centering variable are statistically independent. This equation results in an estimate of daily logarithmic constituent concentration.

Daily estimates of constituent concentrations are then multiplied by daily mean discharge to produce a daily mean load, using the following equation:

$$ln[L_i] = Q_i \times ln[C_i] \times K \ . \quad (2)$$

where for any interval i:
ln = the natural logarithm function,
L_i = the daily mean load (in kg/d),
Q_i = the daily mean discharge for that interval (in ft^3/s),
C_i = the mean concentration (in mg/L), and
K = 2.447, the correction factor for unit conversion.

In the transformation of data from logarithmic space to real space a bias is introduced. This bias can lead to an underestimation of the loads by as much as 50 percent (Ferguson, 1986; Koch and Smillie, 1986; Cohn and others, 1992). Several methods are available to correct for the transformation bias associated with log-linear models. Cohn and others (1989) identified the MVUE of Bradu and Mundlak (1970) to have minimum variance and negligible bias in the estimation of tributary nutrient loadings. The MVUE was employed in the load-computation program that estimated nutrient and suspended-solids loads for the James and Rappahannock Rivers.

RELATION OF STREAM QUALITY TO STREAMFLOW

Because characteristics that affect stream quality, including elevation, geology, and land use, are unique to each basin, the relation between stream quality and streamflow also is unique. In order to provide information on that relation for the James and Rappahannock River Basins, an overview of the streamflow conditions for the period is provided below, followed by a brief explanation of how the relation between streamflow and stream quality is addressed in this report. Also provided is an assessment of the quality of the analytical data.

Streamflow

Flow conditions in Virginia differed during the data-collection period. During the first year of data collection, from July 1, 1988, through June 30, 1989, the average discharge at the James River station was 16 percent below the average yearly discharge and the average discharge at the Rappahannock River station was 27 percent below the average. There was a short (2 to 3 week) period of above-normal streamflow in May 1989; however, prevailing low-flow conditions during the rest of that year kept the yearly average low.

During the second year, from July 1, 1989, through June 30, 1990, the average yearly discharge was 41 percent above normal at the James River station, and 8 percent above normal at the Rappahannock River station. The average monthly flows, overlain by the hydrograph for the two rivers during the sampling period, are shown in figure 3.

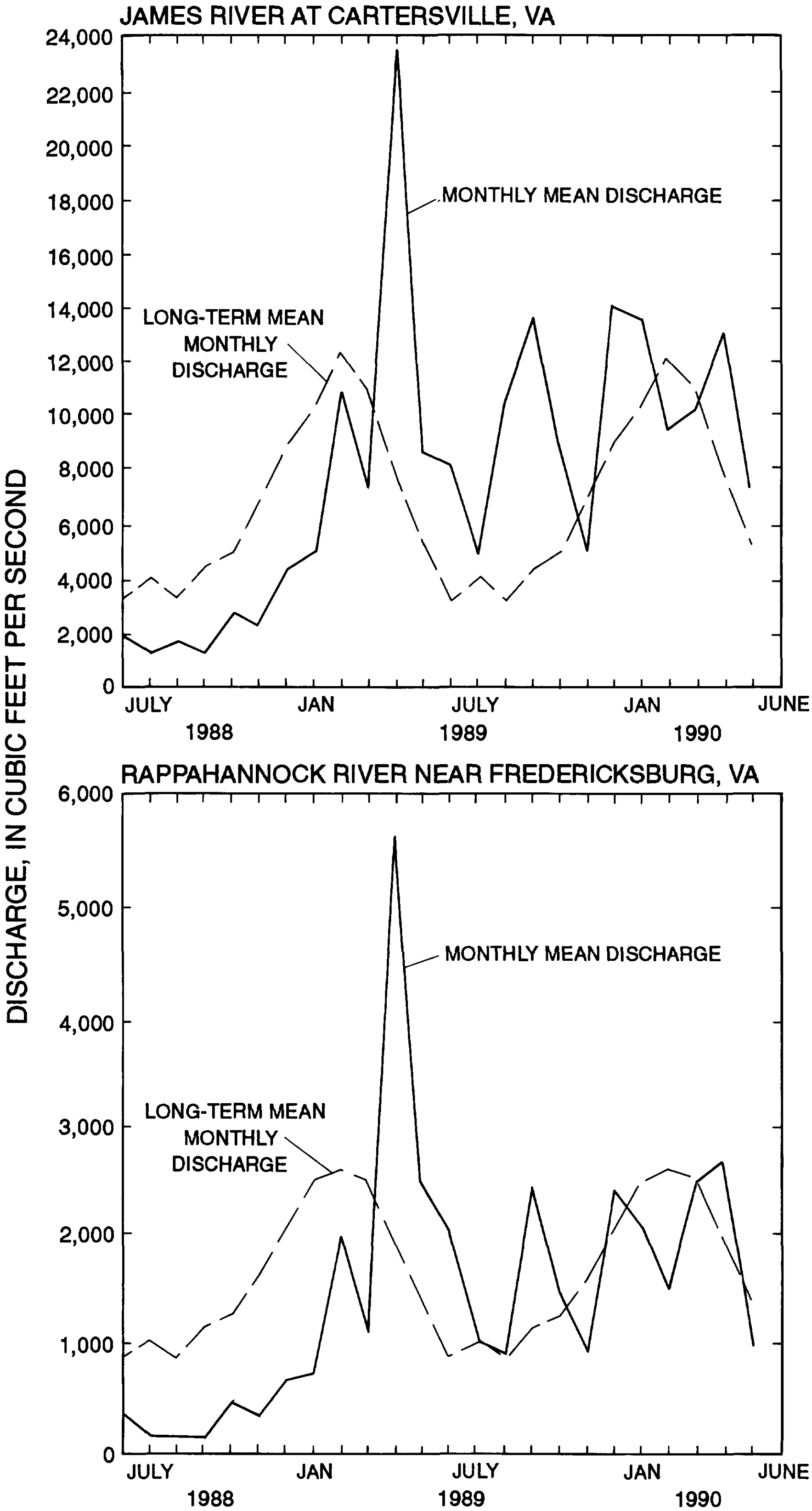

Figure 3. Hydrograph showing monthly mean and long-term mean monthly discharge for the two Fall Line stations.

Stream Quality and the Relation to Streamflow

During the 2-year sampling period, approximately 110 samples were collected at the James River station and 90 at the Rappahannock River station. The water-quality data collected during this sampling period that were used to estimate loads are given in appendixes 1 and 2. These appendixes also include some additional analytical data for which loads were not calculated, but which could be useful for future water-quality investigations. The relation of concentration to discharge for selected constituents is shown in figures 4 through 12 (at end of report). These figures show the ranges of concentrations and how the concentrations change during different flow conditions.

In some instances, the analytical method for certain constituents can differ for the total constituent and the constituent in dissolved form. For each analytical method, there is a range in which the actual concentration is expected, so that it is possible for the total concentration of a particular constituent to be lower than that of the concentration for that constituent in dissolved form.

Quality Assurance

Results of laboratory accuracy, as found from the analysis of duplicates, is ongoing and will not be addressed in this report. Comparisons of quality-assurance samples analyzed by VDCLS and NWQL, and results from VDCLS for standard reference samples are presented below.

For laboratory-split samples, the null hypothesis associated with the Wilcoxon signed-rank test states that for a given constituent the median concentration reported by VDCLS is equal to the median concentration reported by NWQL. Probability (*p*) is the significance level that was reached by the test. If p is ≤ 0.05, the null hypothesis is rejected. Two-sided probability tests are used when evidence in either direction from the null hypothesis would cause the null hypothesis to be rejected, as may occur when assessing differences between the two laboratories. Results of the Wilcoxon signed-rank test between the laboratory splits for each constituent, including the two-sided probability value and the number of valid cases, are listed in table 5.

Table 5. Results of Wilcoxon signed-rank test comparing constituent concentrations analyzed by the Virginia Division of Consolidated Laboratory Services with concentrations analyzed by the National Water Quality Laboratory

[---, no value determined]

Constituent	Two-sided probability value	Number of valid cases
Solids, total suspended	0.581	22
Nitrogen, ammonia dissolved	---	25
Nitrogen, ammonia + organic total	.019	25
Nitrogen, nitrite + nitrate dissolved	.339	24
Phosphorus, total	.108	25
Phosphorus, ortho dissolved	.053	25
Carbon, organic total	.000	30
Silica, dissolved	.026	25

A statistically significant difference ($p \leq 0.05$) was observed between the values reported by the laboratories for the following constituents: total Kjeldahl nitrogen, total organic carbon, and dissolved silica. These statistics do not specify the source of the differences, but only that a difference exists between the analytical method and (or) the environment of each laboratory. Scatterplots were used to show the relation of selected constituents analyzed by VDCLS to constituents analyzed by the NWQL (figs. 13–18; at end of report). A fixed line (x=y) was drawn on each graph to assist in analyzing the symmetry of the data around the ideal case in which the concentrations reported by each laboratory for the sample are equal. Figure 13 demonstrates a symmetric pattern about the fixed line for total suspended solids. The distribution of total phosphorus is shown in figure 14 as an example of a constituent for which analyses were generally higher for VDCLS, and is therefore not symmetric. However, there is not a statistically significant difference between the two laboratories for this constituent.

The VDCLS reported consistently higher concentrations for dissolved ammonia nitrogen than were reported by NWQL. Concentrations reported by NWQL were consistently higher than concentrations reported by VDCLS for the following constituents: total Kjeldahl nitrogen, total organic carbon, and dissolved silica.

The difference observed between concentrations reported by VDCLS and NWQL for dissolved ammonia nitrogen is shown in figure 15. The minimum reporting limit for dissolved nitrogen was 0.04 mg/L at VDCLS, whereas the minimum reporting limit for dissolved ammonia nitrogen was 0.01 mg/L at NWQL, so the data were not comparable. The Wilcoxon signed-rank test could not be used to test the difference between the two laboratories because 64 percent of the concentrations reported by VDCLS were censored data. By definition, the Wilcoxon test is valid only if fewer than 50 percent of the data are censored. In addition, the preservation technique required by each of the two laboratories for nutrient samples differs. Samples sent to VDCLS were preserved by chilling at 4°C and were usually analyzed within a 24-hour period; exceptions to this were samples that were collected during a weekend or holiday, in which case the samples were held until the next working day. Samples sent to NWQL were immediately preserved with mercuric chloride, chilled in a darkened bottle, and shipped to the laboratory in Arvada, Colo. The samples were usually analyzed within 1 week, although mercuric chloride preservation is thought to be able to stabilize the sample for as long as 1 month. The difference between laboratories in values for total Kjeldahl nitrogen (fig. 16) could also be due to this difference in preservation technique. Estimated loads based on data from VDCLS for dissolved ammonia nitrogen could be larger, and for total Kjeldahl nitrogen could be smaller than if USGS data were used to estimate loads.

A statistically significant difference also was observed between values reported by VDCLS and NWQL for total organic carbon (fig. 17). The differences that were observed were discussed by representatives from the laboratories. Specifically, the possible reasons that the analyses differ are that two different field collection protocols were used based on the requirements of each laboratory, and that the samples were analyzed differently. The sample sent to NWQL was collected at the center of flow in the river and mailed in a baked-glass bottle; the sample sent to the VDCLS was collected as a cross-sectional composite and sent to the laboratory in a plastic bottle. In addition, VDCLS used an analytical method that permitted particles in the sample to settle. The procedure followed by VDCLS to analyze total organic carbon did not require mixing the sample before withdrawing an aliquot for analysis. Total organic carbon in samples collected during stormflow, therefore, would be underestimated by the VDCLS analytical technique. The results of the standard reference samples for total organic carbon analyzed by VDCLS for the period of study were within acceptable limits; however, reference samples are not produced from an ambient-water matrix and, therefore, contain no sediment. The negative bias of the concentrations reported by VDCLS for total organic carbon is shown in figure 17. This problem was corrected by VDCLS and samples analyzed after March 1, 1992 will reflect the change in technique (Robert Potts, Virginia Division of Consolidated Laboratory Services, oral commun., 1993). The estimates for total organic carbon loads before March 1, 1992, however, will be lower than if an analytical method more appropriate for large sediment concentrations had been used.

The concentrations reported for dissolved silica also indicated a statistically significant difference between laboratories. Although the NWQL indicated a slight positive bias for dissolved silica, most values are within two standard deviations of the median (Maloney and others, 1992). The bias is consistent enough to cause the median concentrations of the two laboratories to be significantly different, despite the presence of a strong positive relation between the x and y values. The bias evident in the NWQL samples in the midrange values for dissolved silica is shown in figure 18. A line could be drawn parallel to the x,y line, indicating a consistent positive bias for NWQL. Estimated loads for silica could therefore be slightly lower using the VDCLS data than they would have been if NWQL performed the analyses.

The USEPA-approved standard reference samples were sent to VDCLS for analysis to check for consistent bias in the analytical procedures at VDCLS. The Wilcoxon signed-rank test indicated a significant bias for dissolved nitrite plus nitrate (table 6).

Table 6. Results of Wilcoxon signed-rank test comparing constituent concentrations analyzed by the Virginia Division of Consolidated Laboratory Services to standard-reference samples approved by the U.S. Environmental Protection Agency

Constituent	Two-sided probability value	Number of valid cases
Solids, total suspended	0.441	9
Nitrogen, ammonia dissolved	.120	11
Nitrogen, ammonia + organic total	.753	11
Nitrogen, nitrite + nitrate dissolved	.021	11
Phosphorus, total	.838	11
Phosphorus, ortho dissolved	.610	11
Carbon, organic total	.314	9
Silica, dissolved[1]	---	---

[1]Dissolved silica was unavailable in a standard-reference sample.

A negative bias was observed for the VDCLS nitrite-plus-nitrate analysis in comparison to standard-reference samples. Eleven samples were analyzed during the period of study. Three of the 11 samples available for analysis were greater than 2 standard deviations from the median. The data were checked for transcription errors, but none were found, although two of the outlying values were possible laboratory transcription errors. If the two possible errors are disregarded there would not be a significant difference from the expected value for nitrite plus nitrate.

ESTIMATED LOADS OF SELECTED WATER-QUALITY CONSTITUENTS

Regression summaries for concentrations are listed in tables 7 and 8. Data used as input to the log-linear regression model are concentrations shown in appendixes 1 and 2, with the exception of the values for total nitrogen, which were obtained by summing the values for nitrite-plus-nitrate nitrogen and total Kjeldahl nitrogen. A censored concentration (any concentration below the detection limit) was entered in the data base at the detection limit. For example, an ammonia concentration less than 0.04 mg/L was entered into the data base as 0.04.

The regression summaries include the variance *s* and the coefficient of determination r^2 for each constituent, and the model variables, the coefficients used to determine the concentration for each variable, the standard deviation of each coefficient, and the T value that is a measure of the significance of the coefficient in the seven-parameter model. A model variable whose absolute T value is greater than 2 is considered to be significant, with the exception of the sine and cosine variables. Because these variables together indicate seasonality, if either variable is significant, the other is also considered significant. Any significant variable indicates a relation to constituent concentration. Because the data sets used to develop these equations are only for a 2-year period, the equations have a relatively high variance. As the data set is updated, the equations also will be updated and re-evaluated. Error associated with predicted concentrations will decrease as the number of samples that are collected increases.

The r^2, or coefficient of determination, is the percentage of the variation explained by the regression equation. For example, an r^2 of 0.74 indicates that approximately 74 percent of the variation in the actual data is explained by the equation.

Tables 9 through 26 (at end of report) report the estimated daily mean constituent load rate, or constituent discharge, in kilograms per day for each month of the study, their associated standard errors, the standard error of prediction, and the total monthly load in kilograms. The monthly loads are shown overlain with the hydrograph for the period for each river in figures 19 through 36 (at end of report).

Table 7. Regression summary for the seven-parameter log-linear model used to estimate concentrations at the James River station

[*s*, variance; r^2, coefficient of determination; β_0, constant; β_1, natural logarithm of streamflow; β_2, natural logarithm of streamflow, squared; β_3, time; β_4, time squared; β_5, sine (time); β_6, cosine (time); underline shows significant coefficient value]

s	r^2	Variable	Coefficient	Standard deviation	T value
			Total suspended solids		
0.7432	75	β_0	3.1104	0.1374	22.63
		β_1	1.6043	.1184	13.55
		β_2	-.2792	.0778	-3.59
		β_3	-.7239	.1873	-3.86
		β_4	1.4333	.3718	3.85
		β_5	-.2652	.1186	-2.24
		β_6	-.2068	.1159	-1.78
			Dissolved nitrite plus nitrate nitrogen		
.2774	64	β_0	-1.1868	.0508	-23.36
		β_1	.1827	.0430	4.25
		β_2	-.1215	.0290	-4.19
		β_3	.3151	.0684	4.60
		β_4	-.2517	.1437	-1.75
		β_5	.0042	.0425	.10
		β_6	.0516	.0428	1.20

Table 7.—Continued

s	r^2	Variable	Coefficient	Standard deviation	T value
			Dissolved ammonia nitrogen		
.3974	25	β_0	-3.0826	.0733	-42.06
		β_1	.1289	.0632	2.04
		β_2	-.0240	.0420	-.57
		β_3	-.3960	.0984	-4.03
		β_4	.5948	.2086	2.85
		β_5	-.0618	.0620	-1.00
		β_6	.1755	.0616	2.85
			Total Kjeldahl nitrogen		
.5429	25	β_0	-1.1627	.0994	-11.69
		β_1	.2985	.0841	3.55
		β_2	.1343	.0568	2.37
		β_3	-.2668	.1339	-1.99
		β_4	.4249	.2812	1.51
		β_5	-.0600	.0831	-.72
		β_6	.0033	.0838	.04
			Total nitrogen		
.3427	27	β_0	-.4759	.0628	-7.58
		β_1	.2356	.0531	4.44
		β_2	.0550	.0358	1.53
		β_3	-.0488	.0845	-.58
		β_4	.2507	.1775	1.41
		β_5	-.0416	.0525	-.79
		$\beta 6$	.0045	.0529	.09
			Total phosphorus		
.5263	33	β_0	-2.2769	.0964	-23.62
		β_1	.3033	.0815	3.72
		β_2	.1229	.0550	2.23
		β_3	-.3972	.1298	-3.06
		β_4	1.1706	.2726	4.29
		β_5	-.0965	.0806	-1.20
		β_6	.0950	.0813	1.17
			Dissolved orthophosphate		
.4737	67	β_0	-2.7469	.0869	-31.61
		β_1	-.2982	.0738	-4.04
		β_2	-.0630	.0496	-1.27
		β_3	-.7374	.1168	-6.31
		β_4	.4893	.2454	1.99
		β_5	-.1636	.0731	-2.24
		β_6	.1717	.0740	2.32
			Total organic carbon		
.3178	30	β_0	1.2022	.0587	20.50
		β_1	.1566	.0499	3.14
		β_2	.0239	.0334	.71
		β_3	-.2455	.0810	-3.03
		β_4	.2877	.1663	1.73
		β_5	-.2518	.0496	-5.08
		β_6	-.0314	.0500	-.63
			Dissolved silica		
.1941	31	β_0	1.9475	.0356	54.78
		β_1	.1117	.0301	3.72
		β_2	-.0763	.0203	-3.76
		β_3	-.0267	.0479	-.56
		β_4	.2377	.1005	2.36
		β_5	-.1545	.0297	-5.20
		β_6	-.0766	.0300	-2.55

Table 8. Regression summary for the seven-parameter log-linear model used to estimate concentrations at the Rappahannock River station

[s, variance; r^2, coefficient of determination; β_0, constant; β_1, natural logarithm of streamflow; β_2, natural logarithm of streamflow, squared; β_3, time; β_4, time squared; β_5, sine (time); β_6, cosine (time); underline shows significant coefficient value]

s	r^2	Variable	Coefficient	Standard deviation	T value
		Total suspended solids			
.7811	85	β_0	2.8322	.1324	21.39
		β_1	1.9024	.1033	18.41
		β_2	-.2239	.0480	-4.66
		β_3	-1.0627	.2013	-5.28
		β_4	2.6492	.4580	5.78
		β_5	-.5239	.1379	-3.80
		β_6	-.1095	.1321	-0.83
		Dissolved nitrite plus nitrate nitrogen			
.3997	74	β_0	-.4360	.0701	-6.22
		β_1	.2094	.0536	3.91
		β_2	-.1403	.0246	-5.69
		β_3	.2901	.1033	2.81
		β_4	-.6916	.2382	-2.90
		β_5	.2271	.0713	3.18
		β_6	.1948	.0687	2.84
		Dissolved ammonia nitrogen			
.4132	41	β_0	-2.9678	.0724	-40.97
		β_1	.3493	.0554	6.30
		β_2	-.0349	.0255	-1.37
		β_3	-.4135	.1068	-3.87
		β_4	.7501	.2462	3.05
		β_5	-.0666	.0738	-.90
		β_6	.2455	.0710	3.46
		Total Kjeldahl nitrogen			
.4371	71	β_0	-.8972	.0766	-11.71
		β_1	.7502	.0586	12.79
		β_2	-.0474	.0270	-1.76
		β_3	-.4170	.1130	-3.69
		β_4	1.1998	.2605	4.61
		β_5	-.3161	.0780	-4.05
		β_6	.1170	.0751	1.56
		Total nitrogen			
.2936	76	β_0	.0715	.0515	1.39
		β_1	.4786	.0394	12.15
		β_2	-.0685	.0181	-3.78
		β_3	-.1085	.0759	-1.43
		β_4	.3414	.1749	1.95
		β_5	-.0790	.0524	-1.51
		β_6	.1356	.0504	2.69
		Total phosphorus			
.6345	70	β_0	-2.7534	.1103	-24.97
		β_1	1.0336	.0851	12.15
		β_2	-.0458	.0391	-1.17
		β_3	-.7571	.1639	-4.62
		β_4	1.8875	.3779	4.99
		β_5	-.4752	.1124	-4.23
		β_6	-.1228	.1081	-1.14

Table 8.—Continued

s	r^2	Variable	Coefficient	Standard deviation	T value
			Dissolved orthophosphate		
.4423	30	β_0	-4.0682	.0769	-52.93
		β_1	.2331	.0593	3.93
		β_2	-.0349	.0272	-1.28
		β_3	-.0673	.1142	-0.59
		β_4	.0695	.2634	.26
		β_5	-.3891	.0783	-4.97
		β_6	.0757	.0753	1.01
			Total organic carbon		
.3422	58	β_0	1.2946	.0583	22.22
		β_1	.4302	.0452	9.51
		β_2	-.0267	.0211	-1.26
		β_3	-.2666	.0892	-2.99
		β_4	.6262	.2008	3.12
		β_5	-.2468	.0608	-4.06
		β_6	.0300	.0582	.52
			Dissolved silica		
.1862	53	β_0	2.3462	.0324	72.52
		β_1	-.0427	.0250	-1.71
		β_2	-.0769	.0115	-6.71
		β_3	.0476	.0481	.99
		β_4	-.1474	.1109	-1.33
		β_5	-.0227	.0330	-.69
		β_6	-.0522	.0317	-1.65

SUMMARY

This report presents the results of a study by the U.S. Geological Survey, in cooperation with the Virginia Department of Environmental Quality—Division of Intergovernmental Coordination, to monitor and estimate loads of selected nutrients and suspended solids discharged to Chesapeake Bay from two major tributaries in Virginia. Monitoring was conducted previously from 1984 through 1988. The emphasis was on scheduled monitoring during that period and, therefore, most samples were collected at base-flow conditions. Because some constituent concentrations can change during stormflow conditions, and because the increased river discharge affects the total loads of all constituents, the monitoring program was revised in 1988 to include stormflow sampling. This sampling scheme, including base-flow and stormflow sampling, increased precision in load estimation from earlier estimations.

From July 1988 through June 1990, monitoring consisted of collecting depth-integrated, cross-sectional samples from the James and Rappahannock Rivers in Virginia, during stormflow and at scheduled intervals, which were sometimes during stormflow, but were usually base-flow conditions. Approximately 110 samples were collected at the James River and approximately 90 samples at the Rappahannock during the 2-year sampling period. Water-quality constituents that were monitored for which loads were computed included total suspended solids (residue, total at 105 °C), dissolved nitrite-plus-nitrate nitrogen, dissolved ammonia nitrogen, total Kjeldahl nitrogen (ammonia plus organic), total nitrogen, total phosphorus, dissolved orthophosphorus, total organic carbon, and dissolved silica. Other selected constituents were monitored, but loads were not calculated for them.

Water-quality data and constituent-load estimates are presented in the report in tabular and graphic form. Constituent concentrations were plotted against discharge to show the range of concentrations and the relation between discharge and concentration. Total monthly load estimates of each constituent were computed by use of a seven-parameter log-linear-regression model that used variables of time, discharge, and seasonality. Also included are illustrations of load estimates overlain by hydrographs for the same period, showing the magnitude of the increase in loads that occurs following precipitation. Raw water-quality data are included in tabular form in the appendixes.

Wide ranges in estimated loads of constituents were observed for both rivers. Monthly loads of total suspended solids ranged from 257,000 to 339,000,000 kg in the James River and from 22,800 to 184,000,000 kg in the Rappahannock River. Estimated monthly loads of total nitrogen ranged from 72,600 to 1,840,000 kg in the James River and from 3,968 to 750,200 kg in the Rappahannock River. Dissolved nitrite-plus-nitrate nitrogen loads ranged from 8,120 to 477,000 kg in the James River and 682 to 237,000 kg in the Rappahannock River. Dissolved ammonia nitrogen loads ranged from 7,720 to 99,200 kg in the James River and 589 to 36,270 kg in the Rappahannock River, and total Kjeldahl nitrogen loads ranged from 57,500 to 1,460,000 kg in the James River and 2,697 to 564,200 kg in the Rappahannock River. Total phosphorus loads ranged from 35,700 to 469,000 kg in the James River, and from 558 to 221,030 kg in the Rappahannock River. Estimated monthly loads of total organic carbon ranged from 506,000 to 7,390,000 kg in the James River and 31,310 to 2,852,000 kg in the Rappahannock River. Monthly loads of dissolved silica ranged from 551,800 to 11,811,000 kg in the James River and 73,160 to 3,317,000 kg in the Rappahannock River. The greatest monthly load for all constituents monitored was observed at both rivers in May 1989, when a series of storms resulted in 2 to 3 weeks of above-normal streamflow. During that month, the estimated load of suspended solids was more than 30 percent of the total load for the entire 2-year data-collection period at the James River, and more than 50 percent of the total load for the Rappahannock River.

Quality-assurance data comparing the analytical results between VDCLS and NWQL indicate that there are consistent differences between laboratories for several constituents, including dissolved ammonia nitrogen, total Kjeldahl nitrogen, total organic carbon, and dissolved silica. A Wilcoxon signed-rank test was used to test the significance of the differences between the two laboratories. Quality-assurance data were used to compare the analytical results between VDCLS and standard reference samples, indicating that there are statistically significant differences between the laboratory and the reference samples for dissolved nitrite-plus-nitrate nitrogen. The differences between the laboratories and between VDCLS samples and the standard reference samples were evaluated with respect to the loads, and possible reasons for the differences are given.

The water-quality data and load estimates provided in this report will be used to calibrate computer-modeling efforts of the Chesapeake Bay region, to evaluate the water quality of the Bay and the major effects on the water quality, and to assess the results of best-management practices in Virginia.

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FIGURES AND TABLES

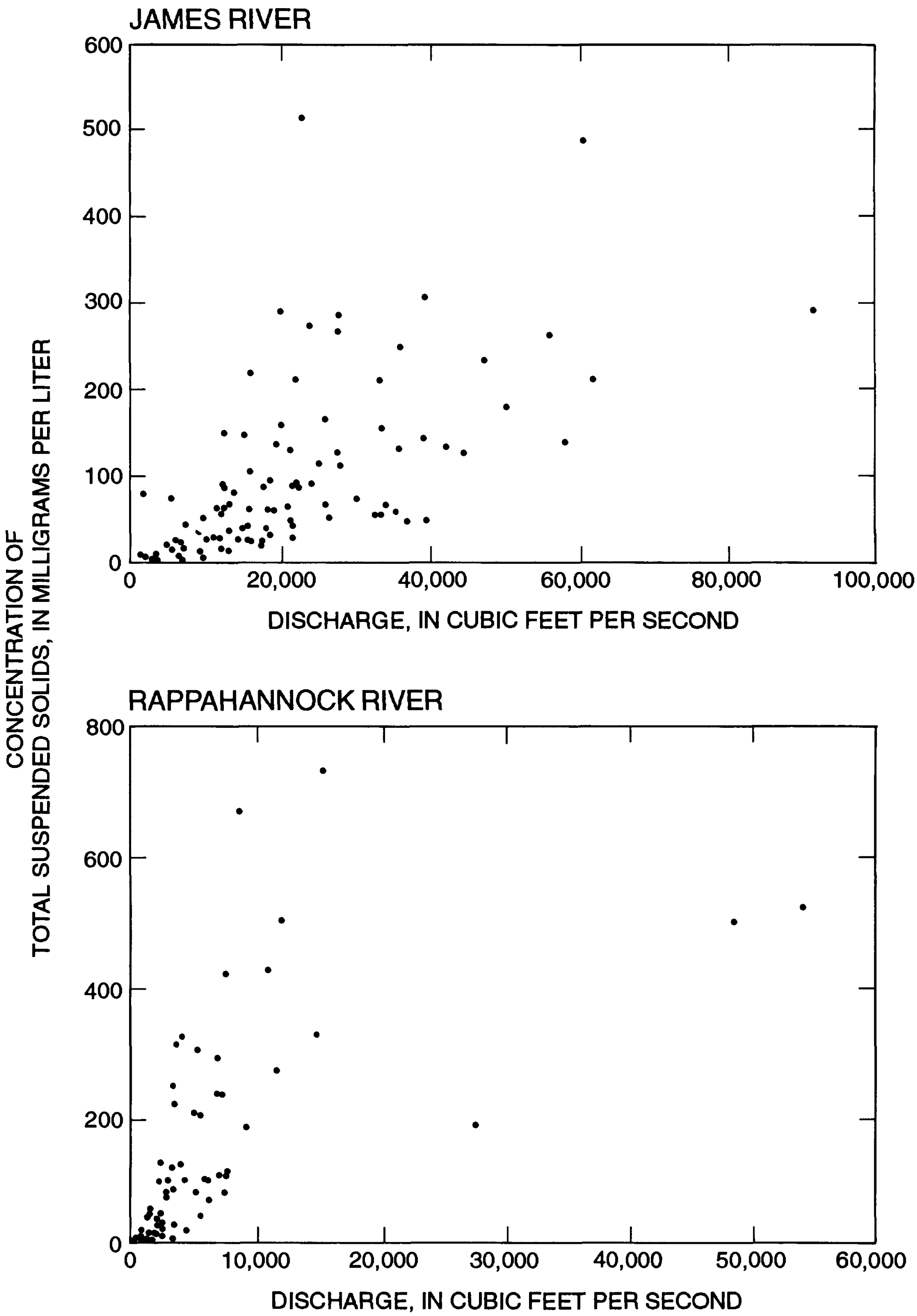

Figure 4. Total suspended solids to discharge for the James River station and the Rappahannock River station.

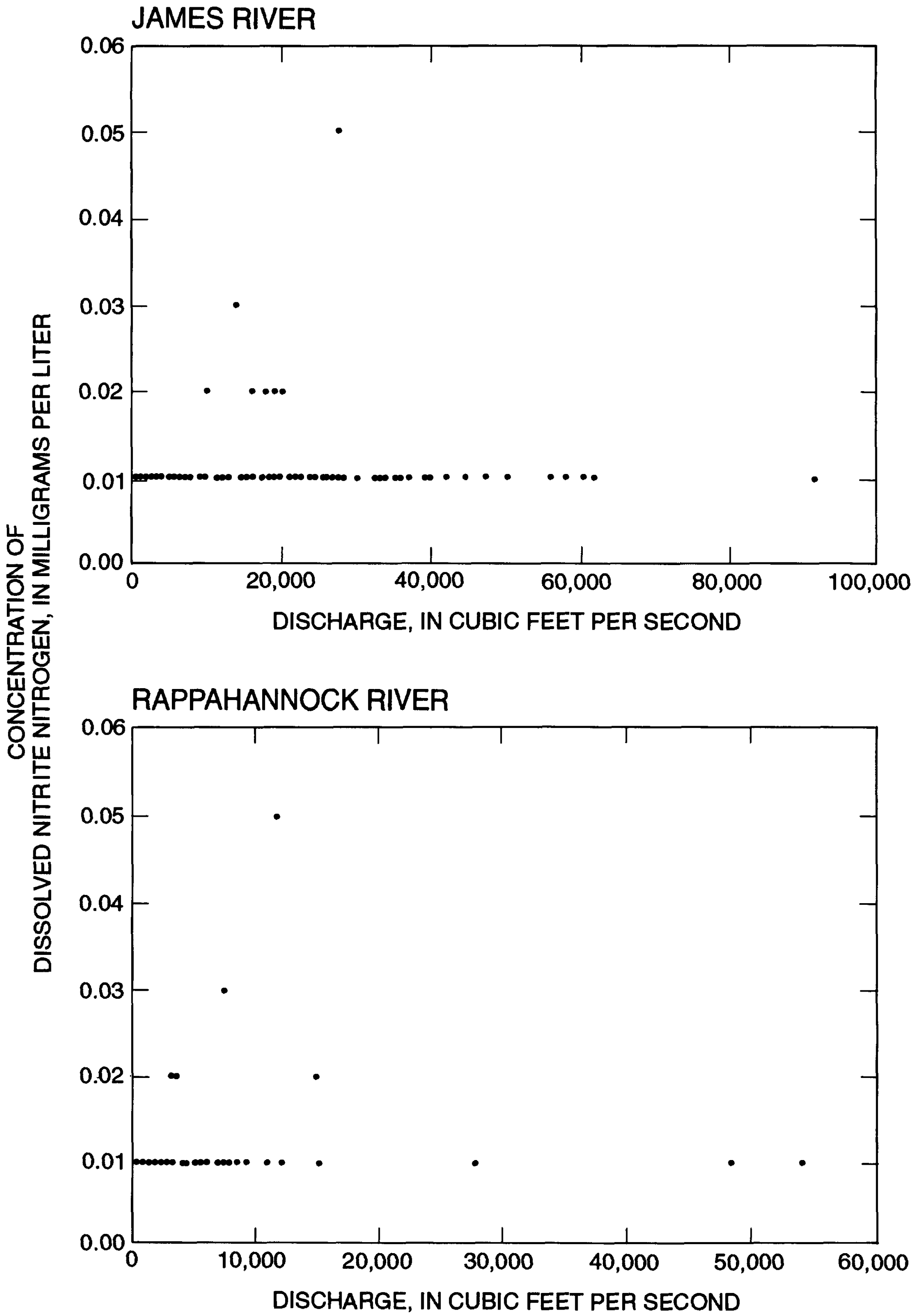

Figure 5. Dissolved nitrite nitrogen to discharge for the James River station and the Rappahannock River station.

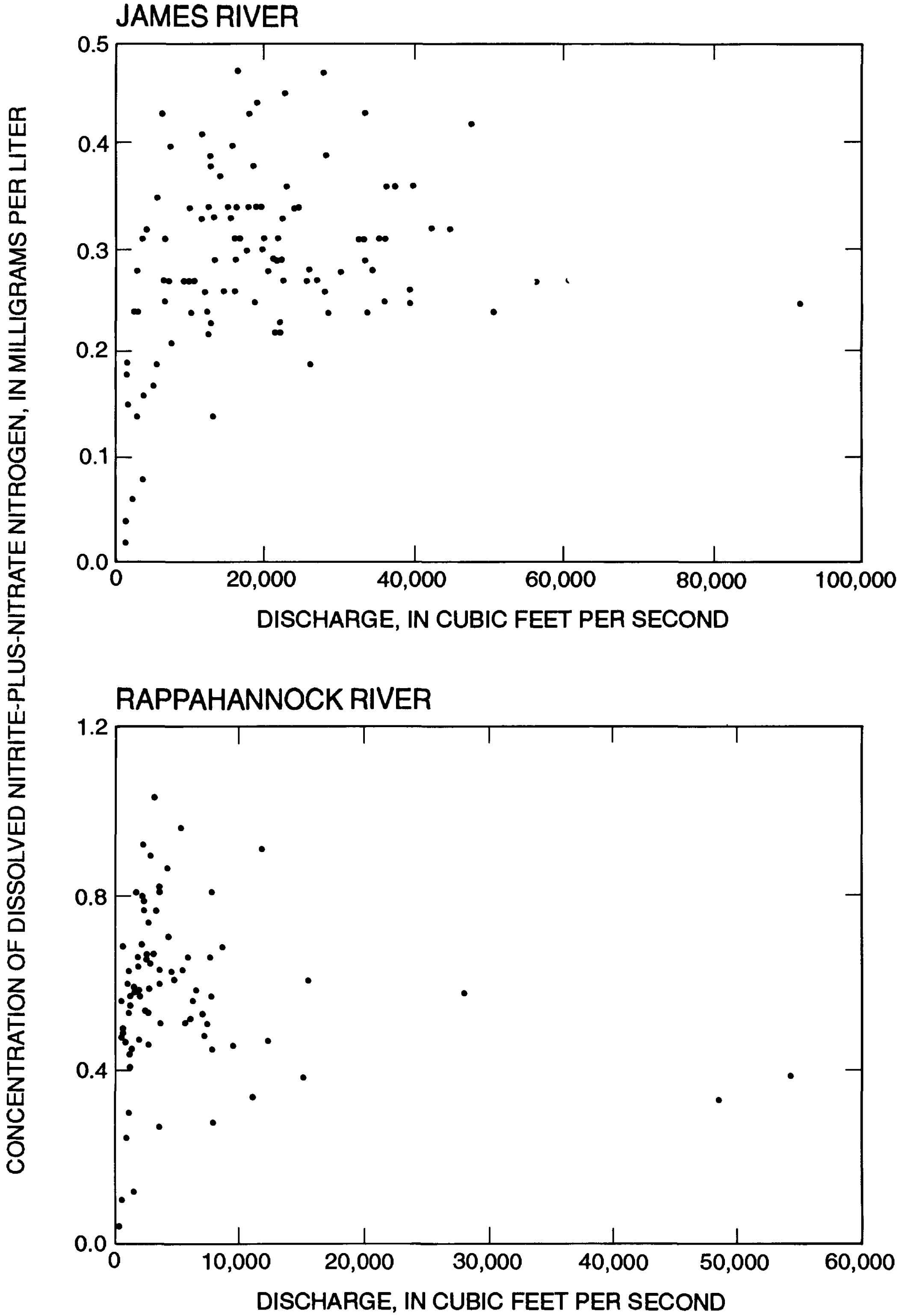

Figure 6. Dissolved nitrite-plus-nitrate nitrogen to discharge for the James River station and the Rappahannock River station.

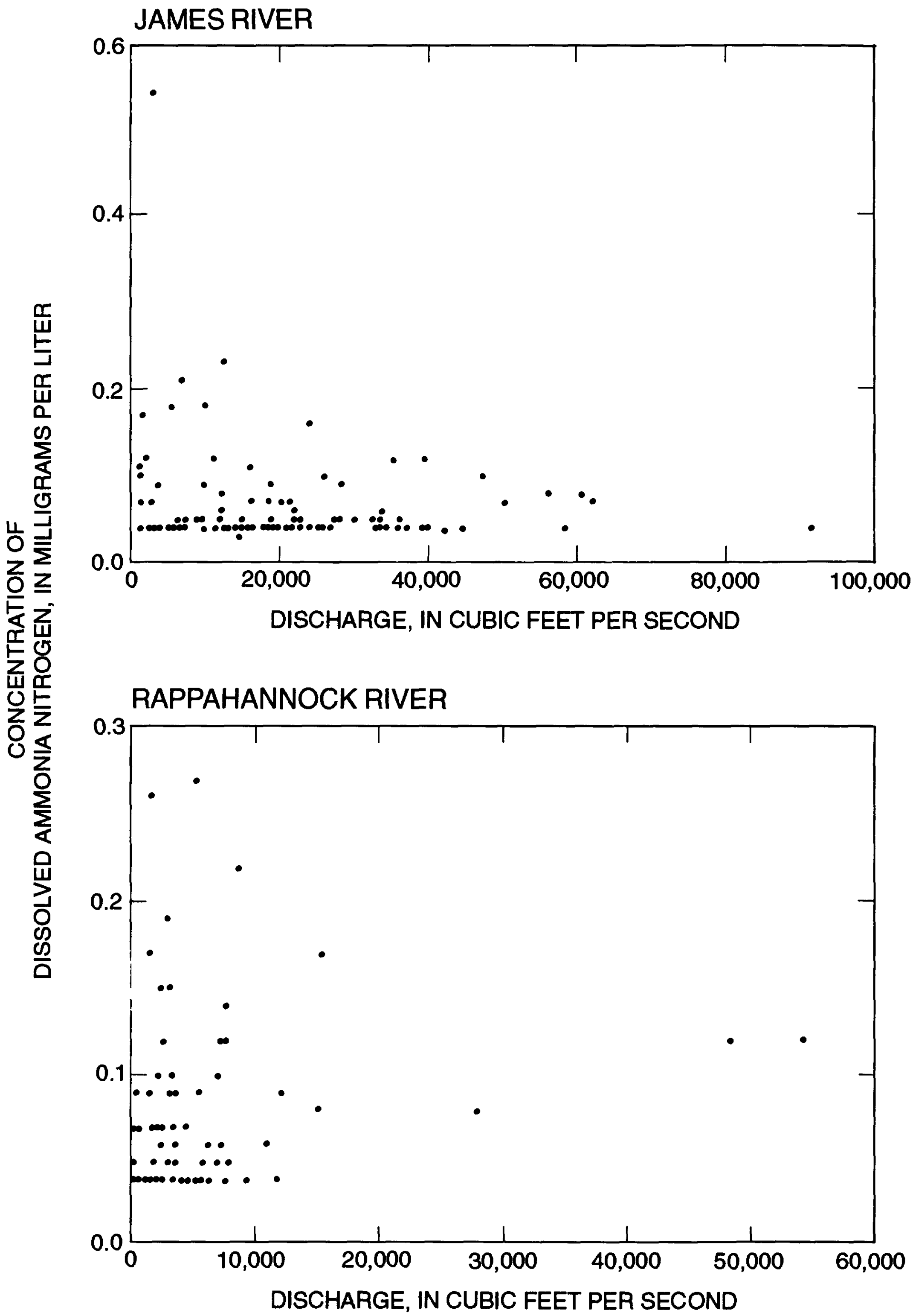

Figure 7. Dissolved ammonia nitrogen to discharge for the James River station and the Rappahannock River station.

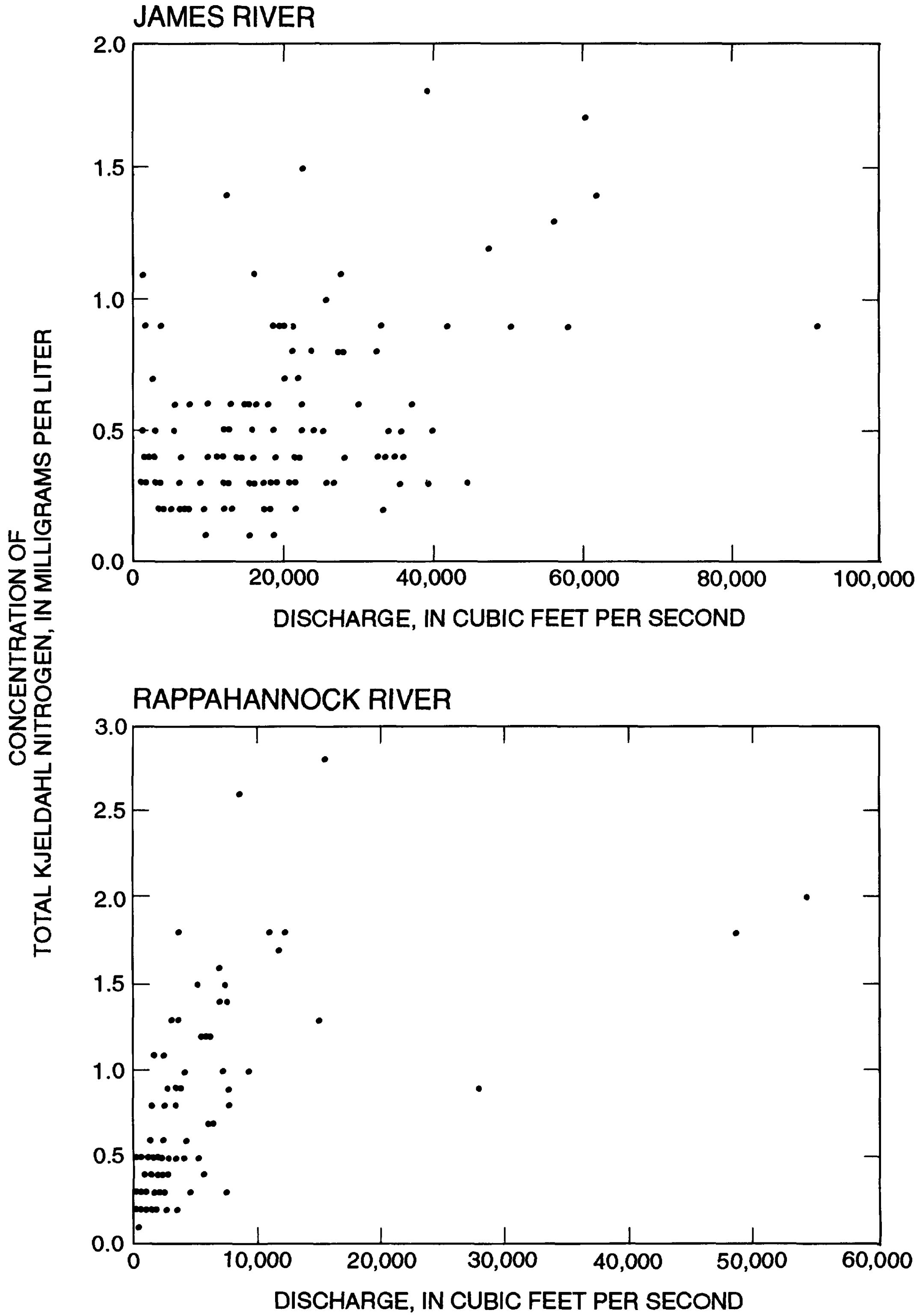

Figure 8. Total Kjeldahl nitrogen to discharge for the James River station and the Rappahannock River station.

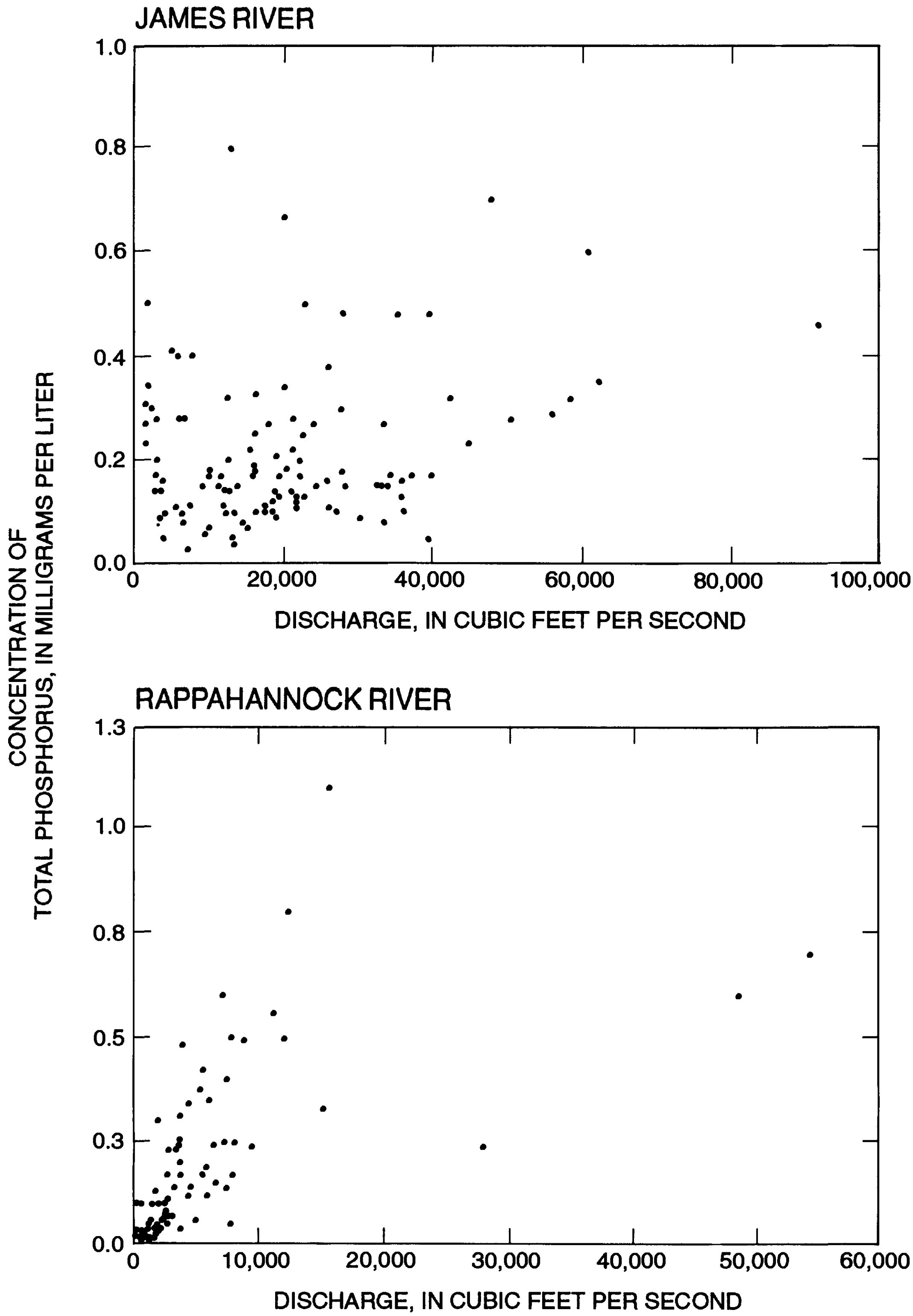

Figure 9. Total phosphorus to discharge for the James River station and the Rappahannock River station.

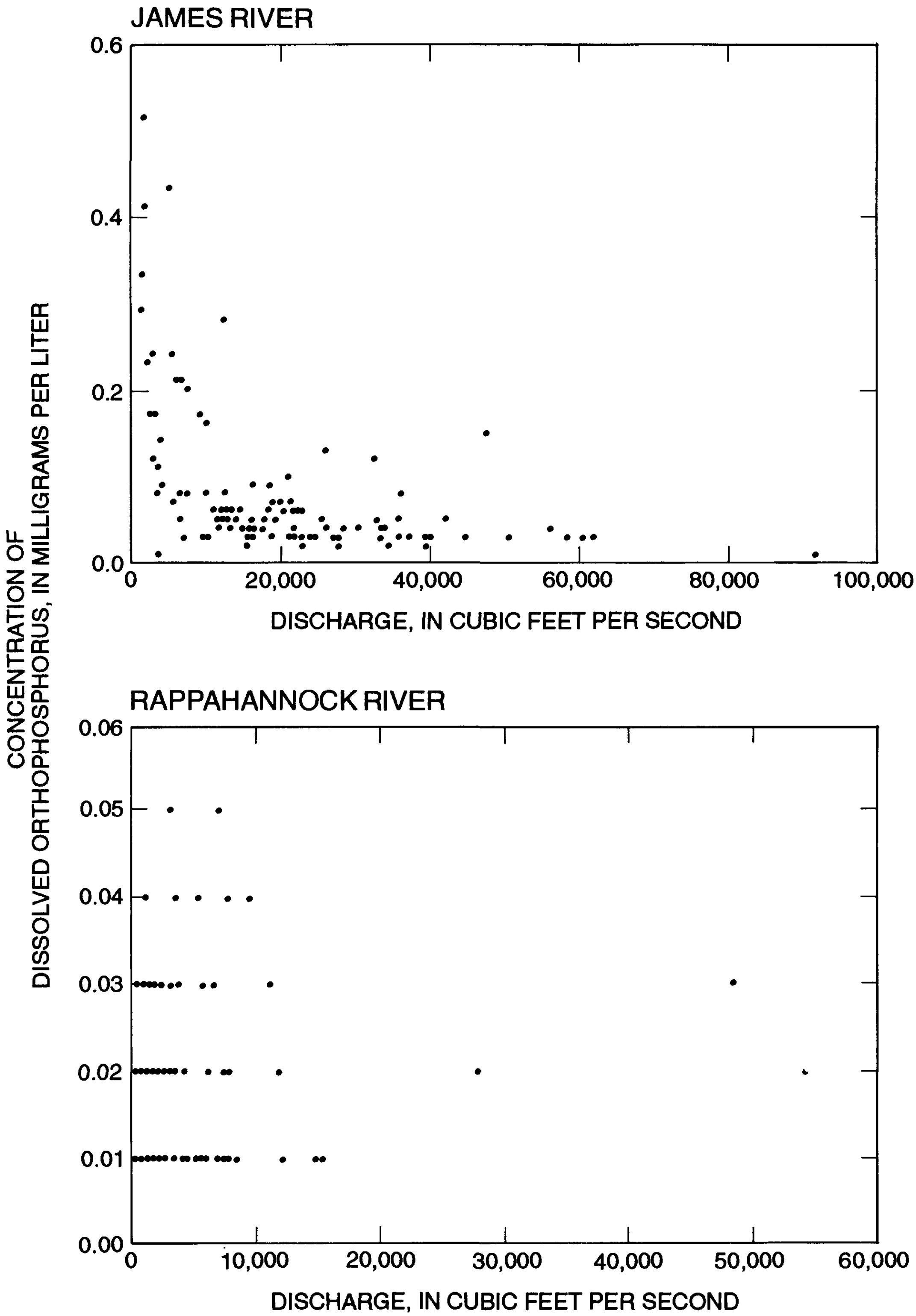

Figure 10. Dissolved orthophosphorus to discharge for the James River station and the Rappahannock River station.

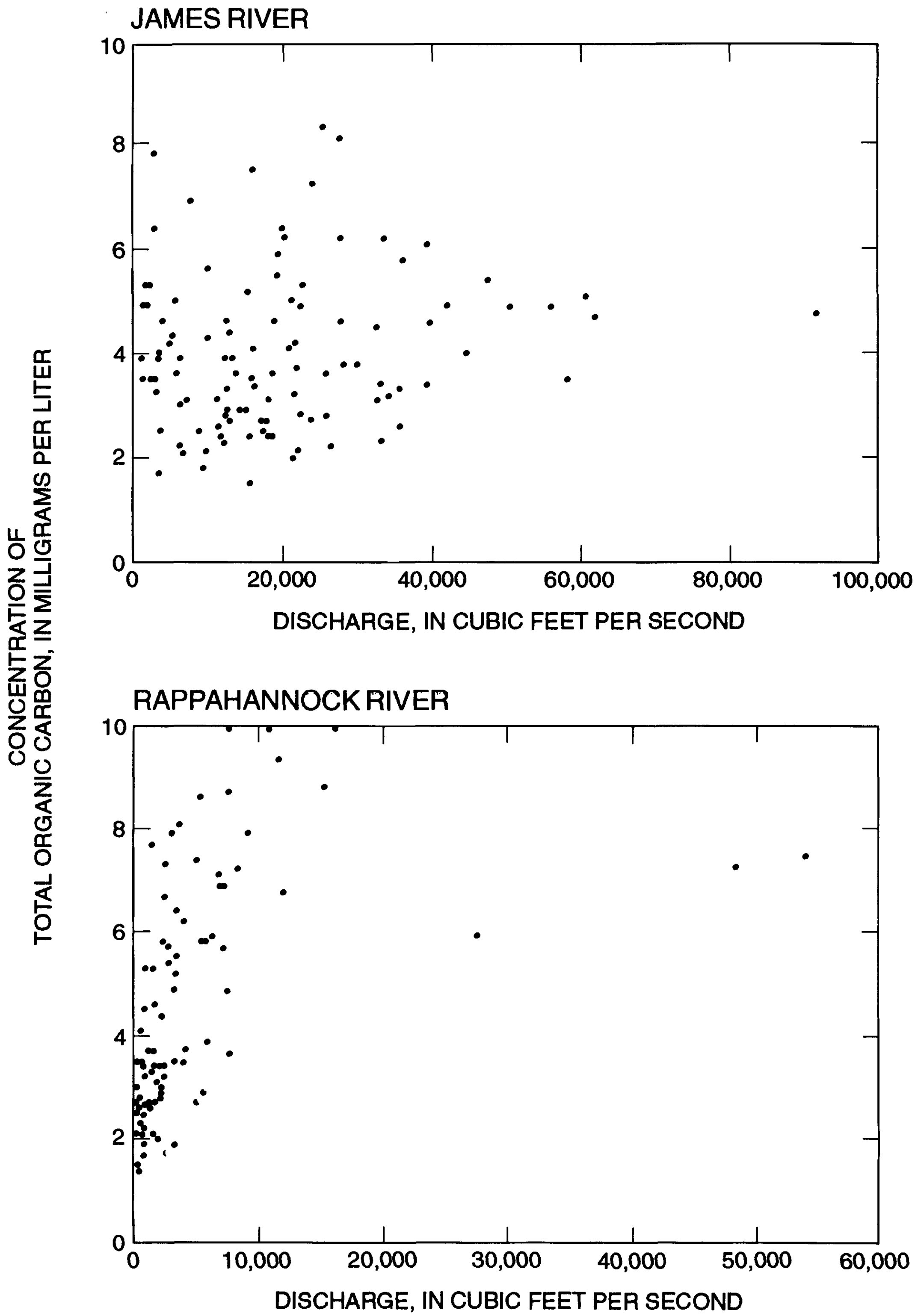

Figure 11. Total organic carbon to discharge for the James River station and the Rappahannock River station.

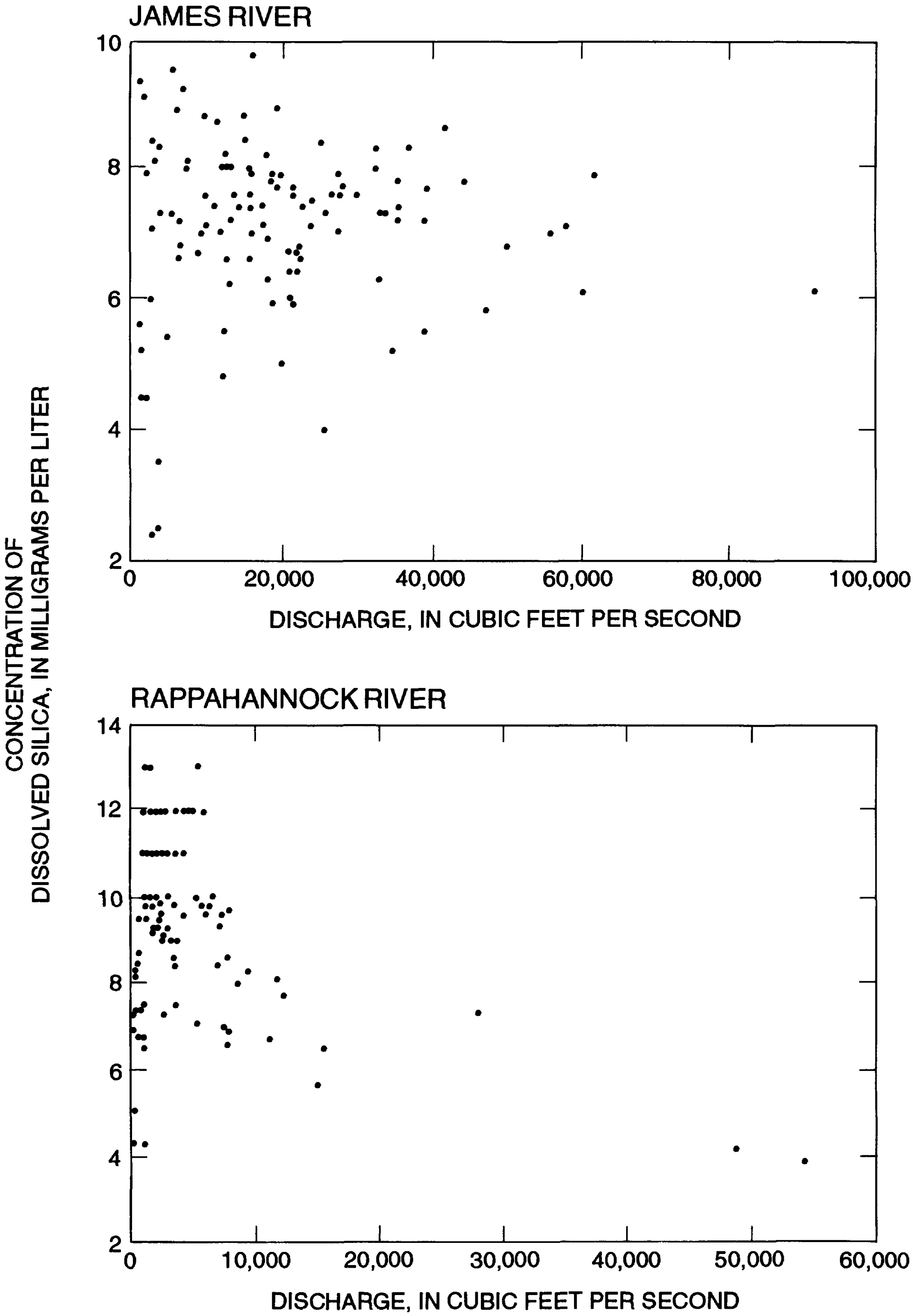

Figure 12. Dissolved silica to discharge for the James River station and the Rappahannock River station.

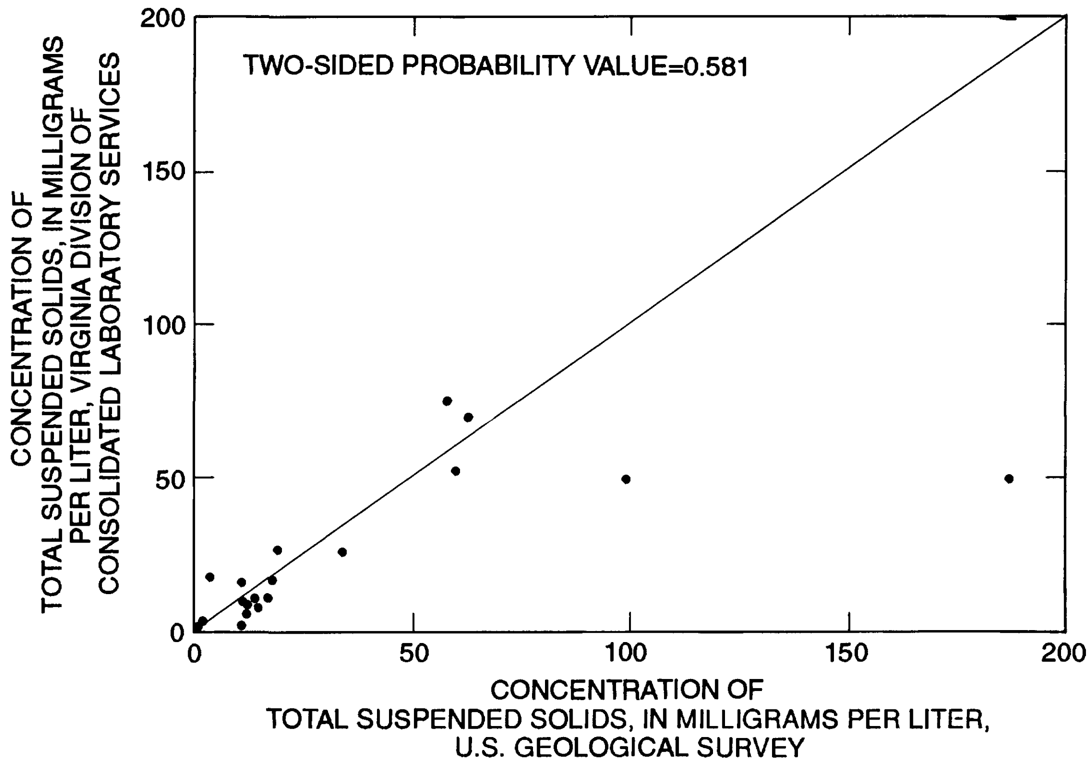

Figure 13. Total suspended-solids concentrations measured by the Virginia Division of Consolidated Laboratory Services to concentrations measured by the National Water Quality Laboratory.

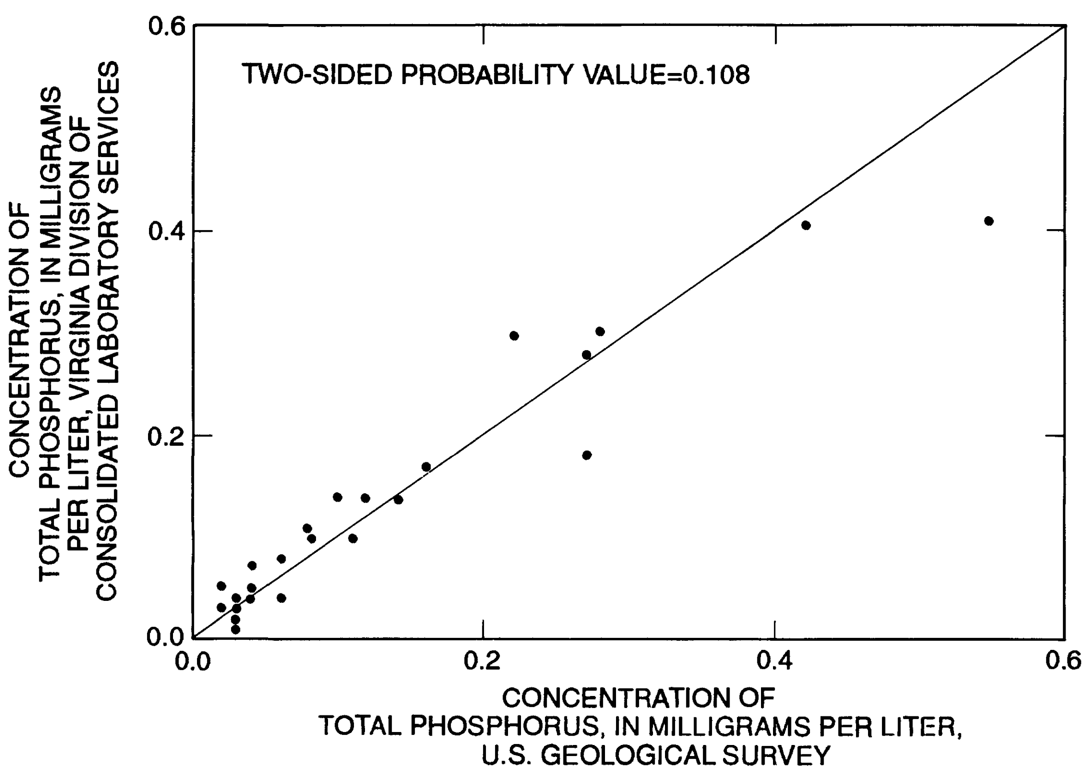

Figure 14. Total phosphorus concentrations measured by the Virginia Division of Consolidated Laboratory Services to concentrations measured by the National Water Quality Laboratory.

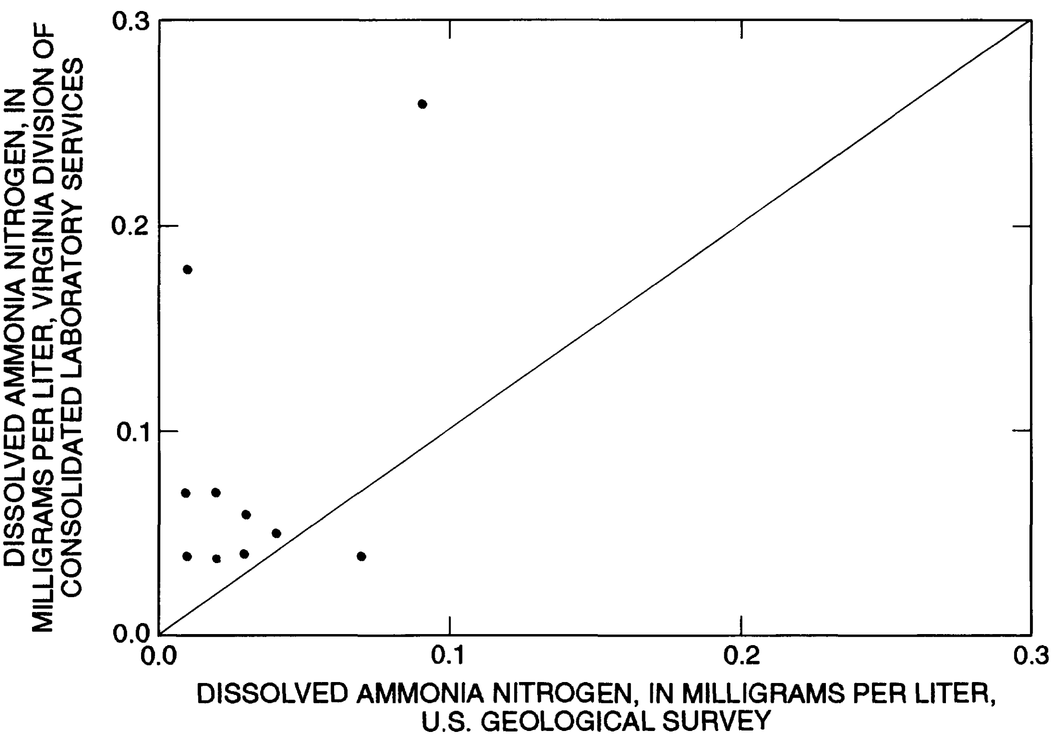

Figure 15. Dissolved ammonia nitrogen concentrations measured by the Virginia Division of Consolidated Laboratory Services to concentrations measured by the National Water Quality Laboratory.

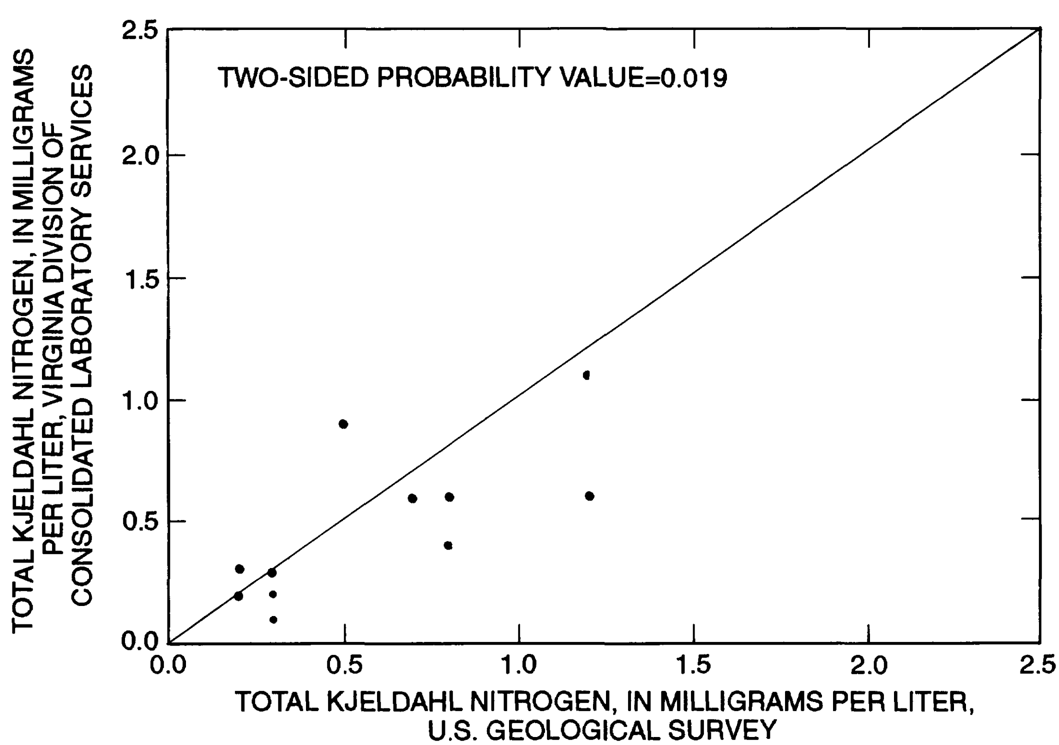

Figure 16. Total Kjeldahl nitrogen concentrations measured by the Virginia Division of Consolidated Laboratory Services to concentrations measured by the National Water Quality Laboratory.

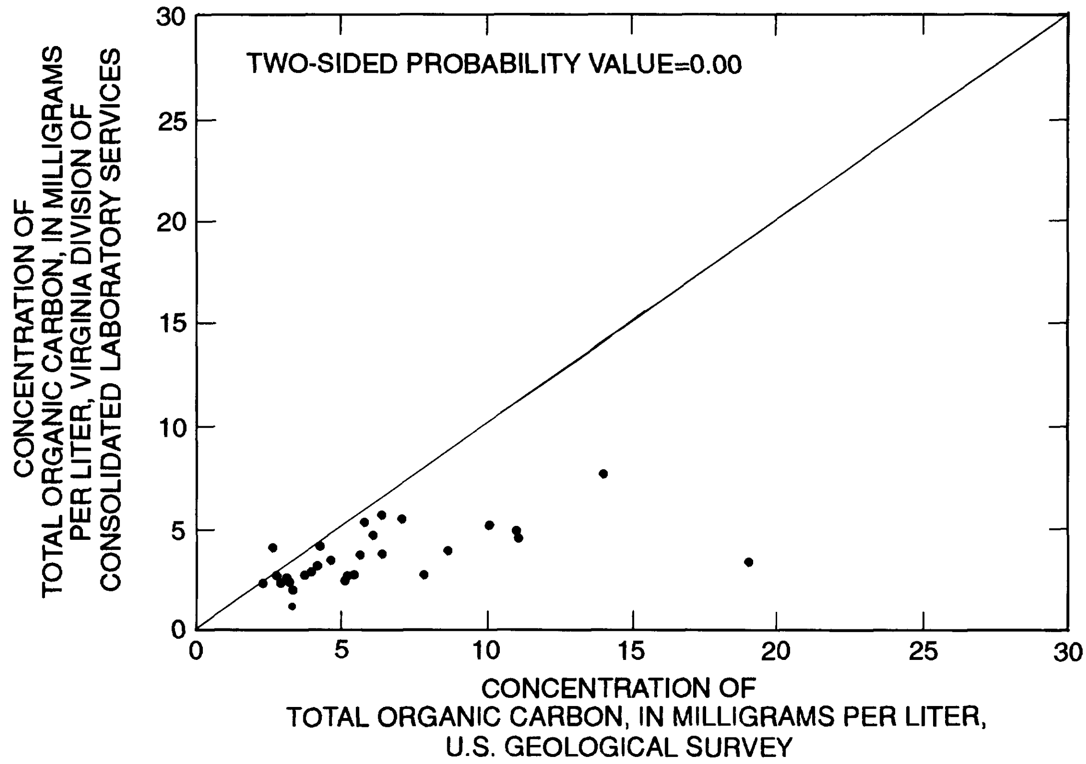

Figure 17. Total organic carbon concentrations measured by the Virginia Division of Consolidated Laboratory Services to concentrations measured by the National Water Quality Laboratory.

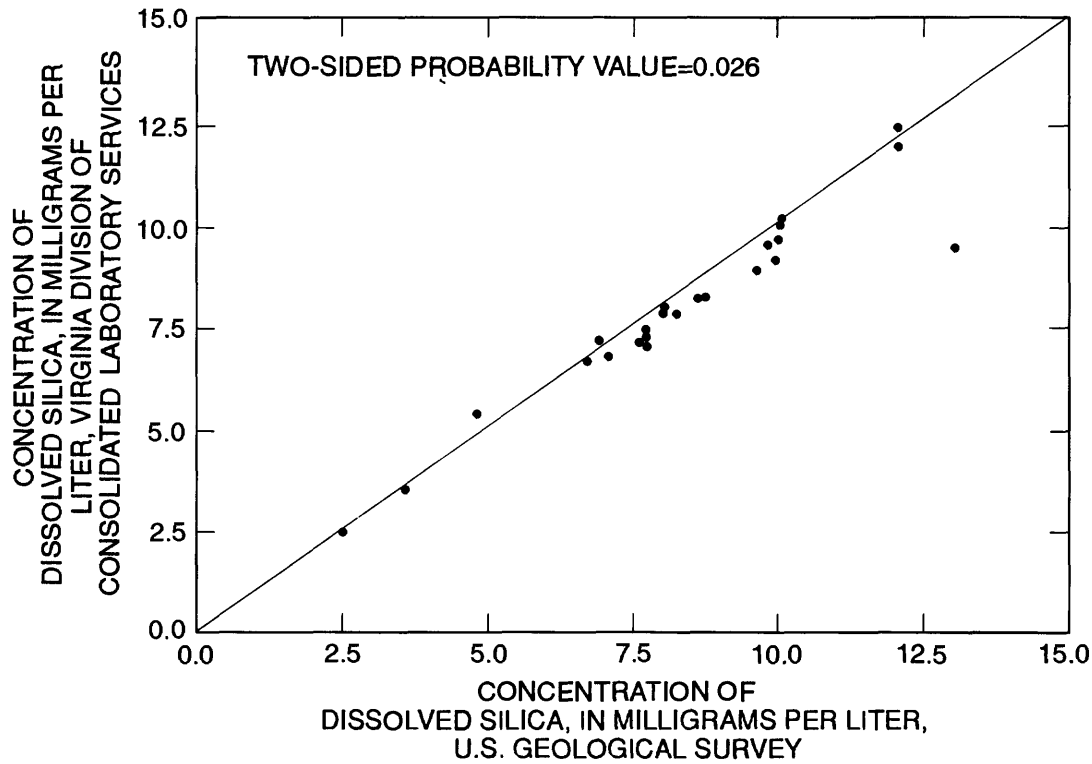

Figure 18. Dissolved silica concentrations measured by the Virginia Division of Consolidated Laboratory Services to concentrations measured by the National Water Quality Laboratory.

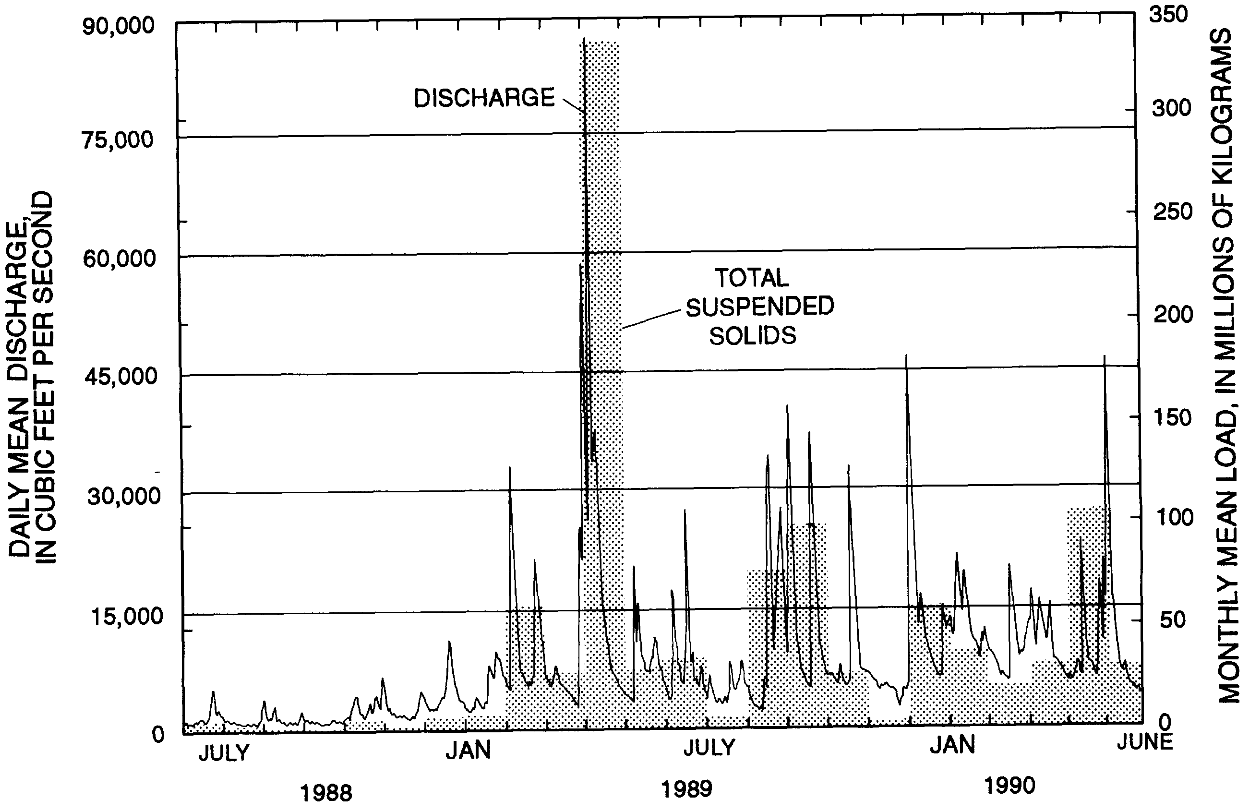

Figure 19. Total suspended solids at James River station.

Table 9. Estimated daily mean discharge of total suspended solids, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	184,000	80,300	108,000	5,690,000
08-88	39,500	12,4000	22,700	1,230,000
09-88	58,000	16,7000	25,100	1,740,000
10-88	8,290	2,160	2,680	257,000
11-88	154,000	33,900	54,100	4,620,000
12-88	50,100	8,610	15,000	1,550,000
01-89	261,000	45,700	96,400	8,080,000
02-89	286,000	45,300	85,200	8,000,000
03-89	1,990,000	276,000	639,000	61,500,000
04-89	954,000	131,000	377,000	28,600,000
05-89	10,900,000	2,090,000	3,640,000	339,000,000
06-89	958,000	174,000	289,000	28,700,000
07-89	1,100,00	193,000	413,000	34,000,000
08-89	216,000	44,900	63,800	6,680,000
09-89	2,550,00	460,000	890,000	76,600,000
10-89	3,210,000	590,000	1,080,000	99,500,000
11-89	912,000	157,000	371,000	27,400,000
12-89	112,000	23,200	30,200	3,460,000
01-90	1,940,000	360,000	666,000	60,200,000
02-90	1,360,000	232,000	347,000	38,000,000
03-90	668,000	118,000	185,000	20,700,000
04-90	1,040,000	179,000	265,000	31,200,000
05-90	3,420,000	658,000	1,320,000	106,000,000
06-90	969,000	192,000	379,000	29,100,000

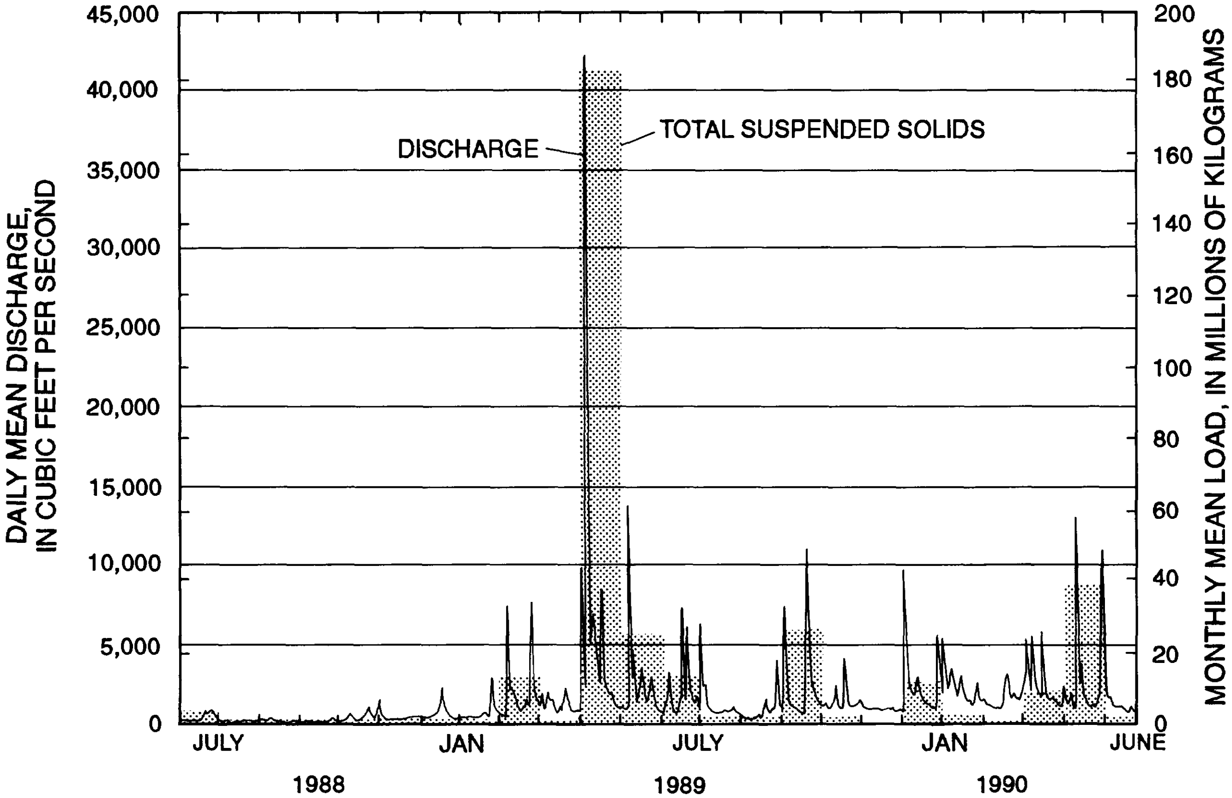

Figure 20. Total suspended solids at Rappahannock River station.

Table 10. Estimated daily mean discharge of total suspended solids, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	119,000	75,400	87,200	3,689,000
08-88	2,130	794	997	66,030
09-88	1,840	594	860	55,200
10-88	736	178	407	22,816
11-88	42,100	12,200	22,500	1,263,000
12-88	2,710	530	885	84,010
01-89	35,600	7,400	19,900	1,103,600
02-89	36,300	6,290	21,300	1,052,700
03-89	439,000	73,300	213,000	13,609,000
04-89	34,700	6,180	11,200	1,041,000
05-89	5,940,000	1,850,000	3,820,000	184,140,000
06-89	835,000	142,000	504,000	25,050,000
07-89	439,000	82,200	196,000	13,609,000
08-89	61,400	11,900	35,200	1,903,400
09-89	69,600	15,100	38,100	2,088,000
10-89	863,000	221,000	437,000	26,753,000
11-89	68,600	15,000	28,000	2,058,000
12-89	9,350	2,200	2,720	289,850
01-90	385,000	89,700	184,000	11,935,000
02-90	101,000	19,800	31,200	2,929,000
03-90	48,300	9,050	16,000	1,497,300
04-90	273,000	50,500	95,200	8,190,000
05-90	1,270,000	329,000	693,000	39,370,000
06-90	57,000	14,300	23,400	1,710,000

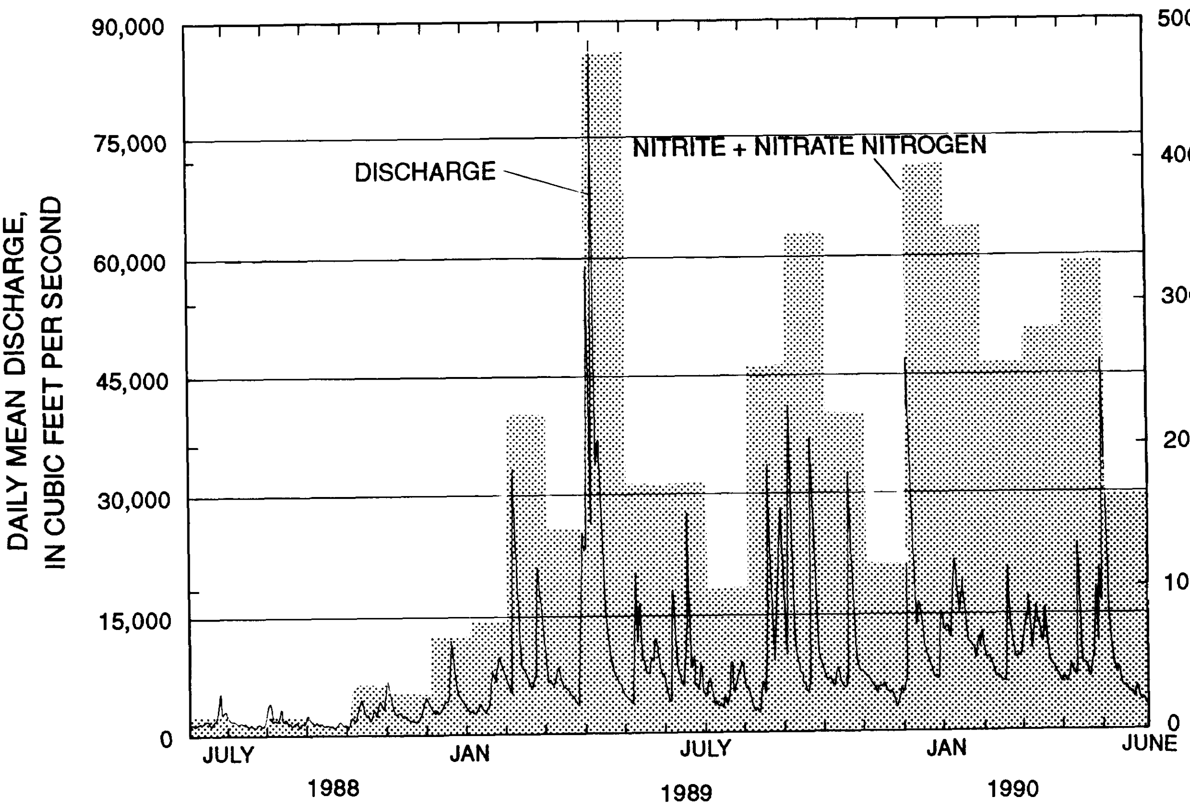

Figure 21. Nitrite-plus-nitrate nitrogen at James River station.

Table 11. Estimated daily mean discharge of dissolved nitrite-plus-nitrate nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	431	58	66	13,400
08-88	262	29	34	8,120
09-88	412	40	47	12,400
10-88	267	27	30	8,280
11-88	1,180	87	114	35,300
12-88	930	60	81	28,800
01-89	2,210	128	189	68,600
02-89	2,840	158	241	79,600
03-89	7,190	350	564	223,000
04-89	4,800	263	422	144,000
05-89	15,400	829	1,310	477,000
06-89	5,800	392	517	174,000
07-89	5,660	386	520	175,000
08-89	3,230	248	306	100,000
09-89	8,520	509	787	256,000
10-89	11,300	662	974	349,000
11-89	7,390	444	644	222,000
12-89	3,790	289	350	117,000
01-90	12,800	782	1,090	398,000
02-90	12,600	759	1,030	354,000
03-90	8,270	524	690	256,000
04-90	9,370	566	764	281,000
05-90	10,600	669	954	330,000
06-90	5,500	406	546	165,000

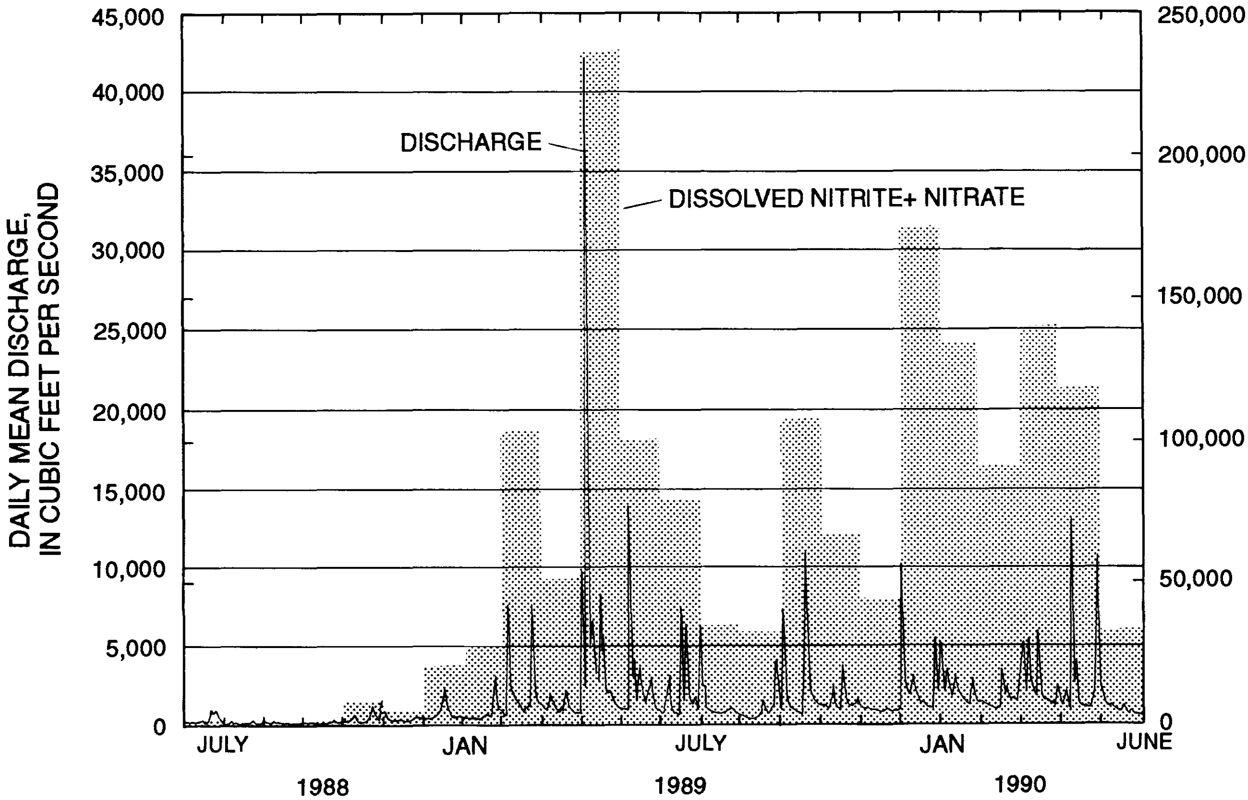

Figure 22. Nitrite-plus-nitrate nitrogen at Rappahannock River station.

Table 12. Estimated daily mean discharge of dissolved nitrite-plus-nitrate nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	88	23	25	2,728
08-88	22	4	4	682
09-88	26	4	5	780
10-88	27	4	5	837
11-88	278	33	47	8,340
12-88	182	18	23	5,642
01-89	667	59	93	20,677
02-89	922	79	140	26,738
03-89	3,350	257	435	103,850
04-89	1,720	161	218	51,600
05-89	7,640	612	1,020	236,840
06-89	3,350	279	470	100,500
07-89	2,540	243	359	78,740
08-89	1,110	119	164	34,410
09-89	1,090	117	173	32,700
10-89	3,460	389	545	107,260
11-89	2,230	240	307	66,900
12-89	1,420	166	198	44,020
01-90	5,650	586	792	175,150
02-90	4,610	445	591	133,690
03-90	2,930	282	371	90,830
04-90	4,660	423	590	139,800
05-90	3,800	410	578	117,800
06-90	1,100	137	172	33,000

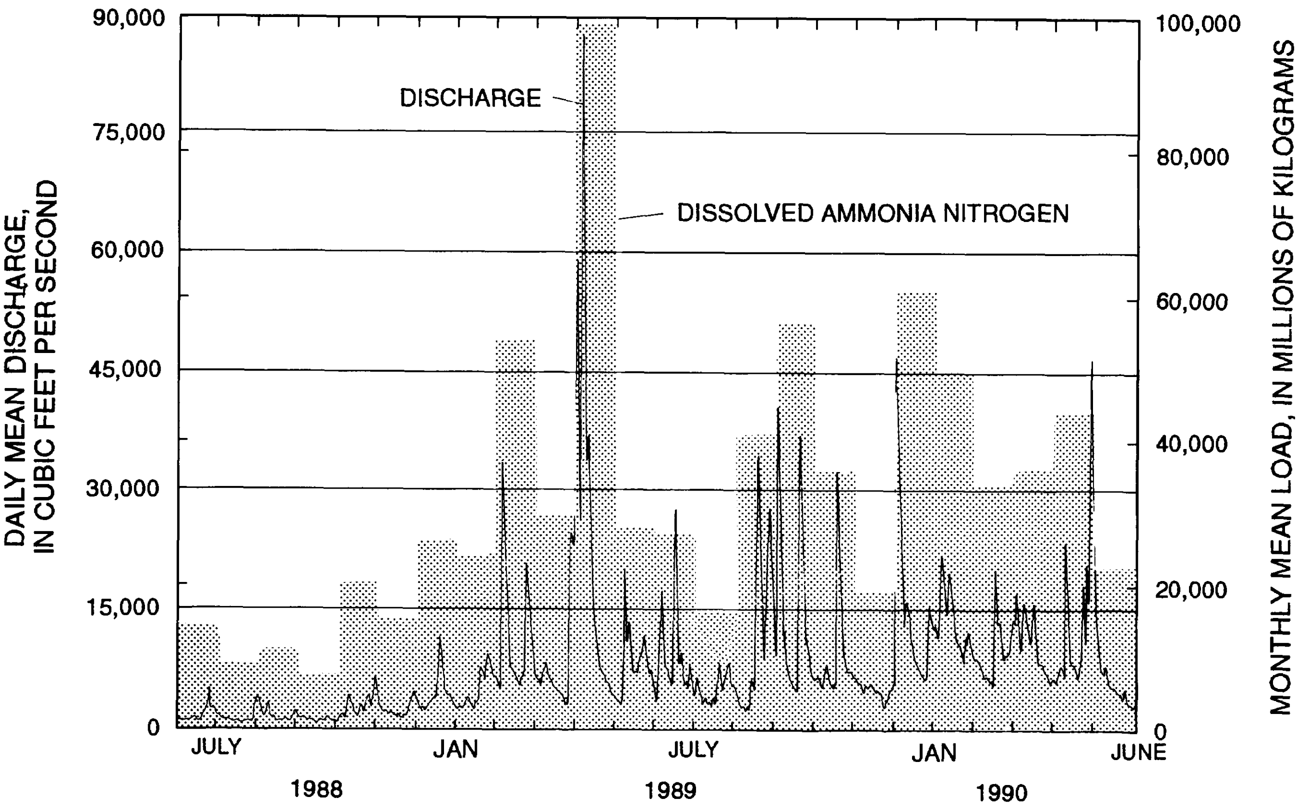

Figure 23. Dissolved ammonia nitrogen at James River station.

Table 13. Estimated daily mean discharge of dissolved ammonia nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	473	91	100	14,700
08-88	291	47	53	9,020
09-88	377	52	61	11,300
10-88	249	37	42	7,720
11-88	682	71	92	20,500
12-88	494	48	63	15,300
01-89	854	72	104	26,500
02-89	863	72	105	24,200
03-89	1,780	126	205	55,000
04-89	996	81	126	29,900
05-89	3,200	262	422	99,100
06-89	936	91	121	28,100
07-89	883	87	118	27,400
08-89	521	58	71	16,200
09-89	1,370	118	185	41,200
10-89	1,840	157	234	57,100
11-89	1,200	104	153	36,000
12-89	630	71	86	19,500
01-90	1,980	176	250	61,300
02-90	1,790	156	214	50,000
03-90	1,110	103	135	34,300
04-90	1,210	106	143	36,200
05-90	1,430	130	191	44,400
06-90	759	81	108	22,800

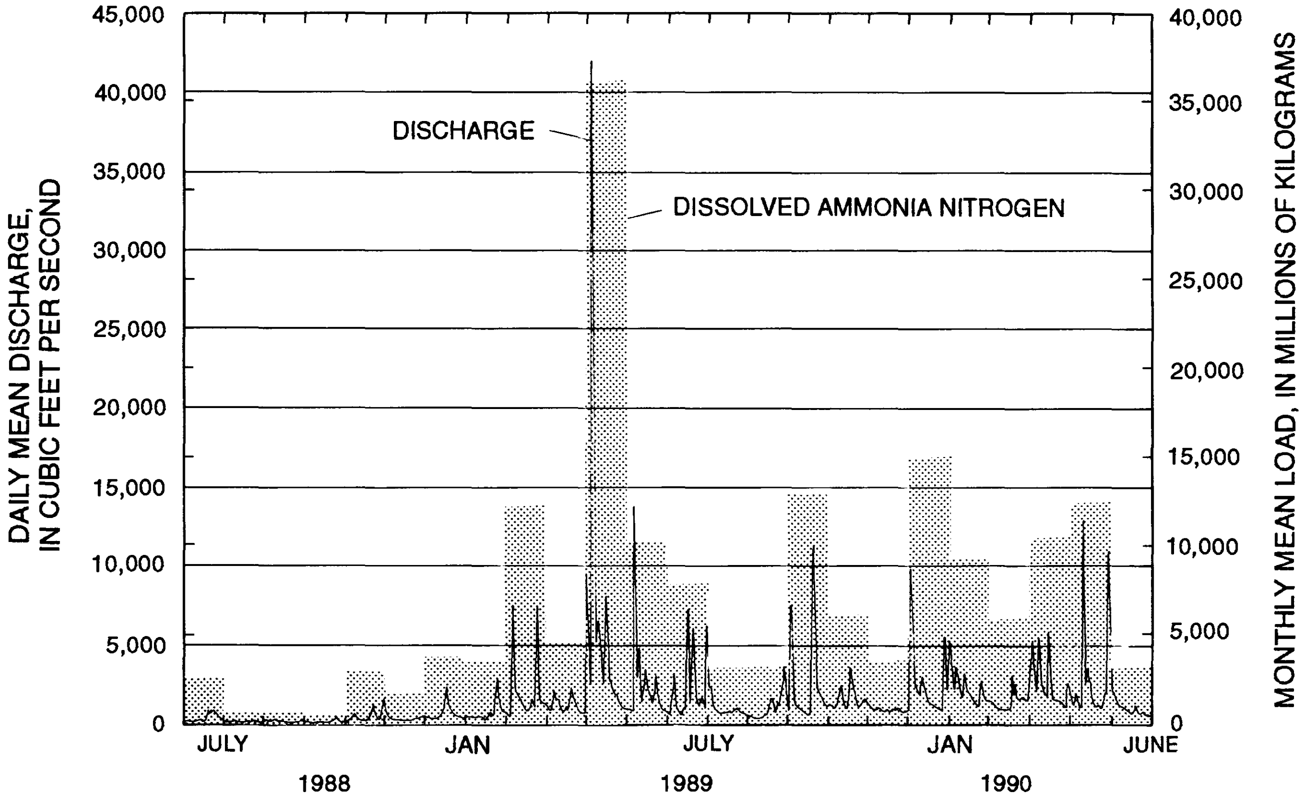

Figure 24. Dissolved ammonia nitrogen at Rappahannock River station.

Table 14. Estimated daily mean discharge of dissolved ammonia nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Mean monthly load (kg)
07-88	86	22	24	2,666
08-88	24	4	5	744
09-88	23	4	4	690
10-88	19	3	3	589
11-88	103	12	17	3,090
12-88	55	6	7	1,705
01-89	126	12	18	3,906
02-89	122	11	19	3,538
03-89	398	32	58	12,338
04-89	150	14	20	4,500
05-89	1,170	127	236	36,270
06-89	343	29	58	10,290
07-89	253	25	39	7,843
08-89	104	12	16	3,224
09-89	111	12	19	3,330
10-89	422	50	75	13,082
11-89	206	23	30	6,180
12-89	115	14	16	3,565
01-90	486	53	75	15,066
02-90	321	32	43	9,309
03-90	192	19	25	5,952
04-90	351	33	47	10,530
05-90	403	47	72	12,493
06-90	109	14	18	3,270

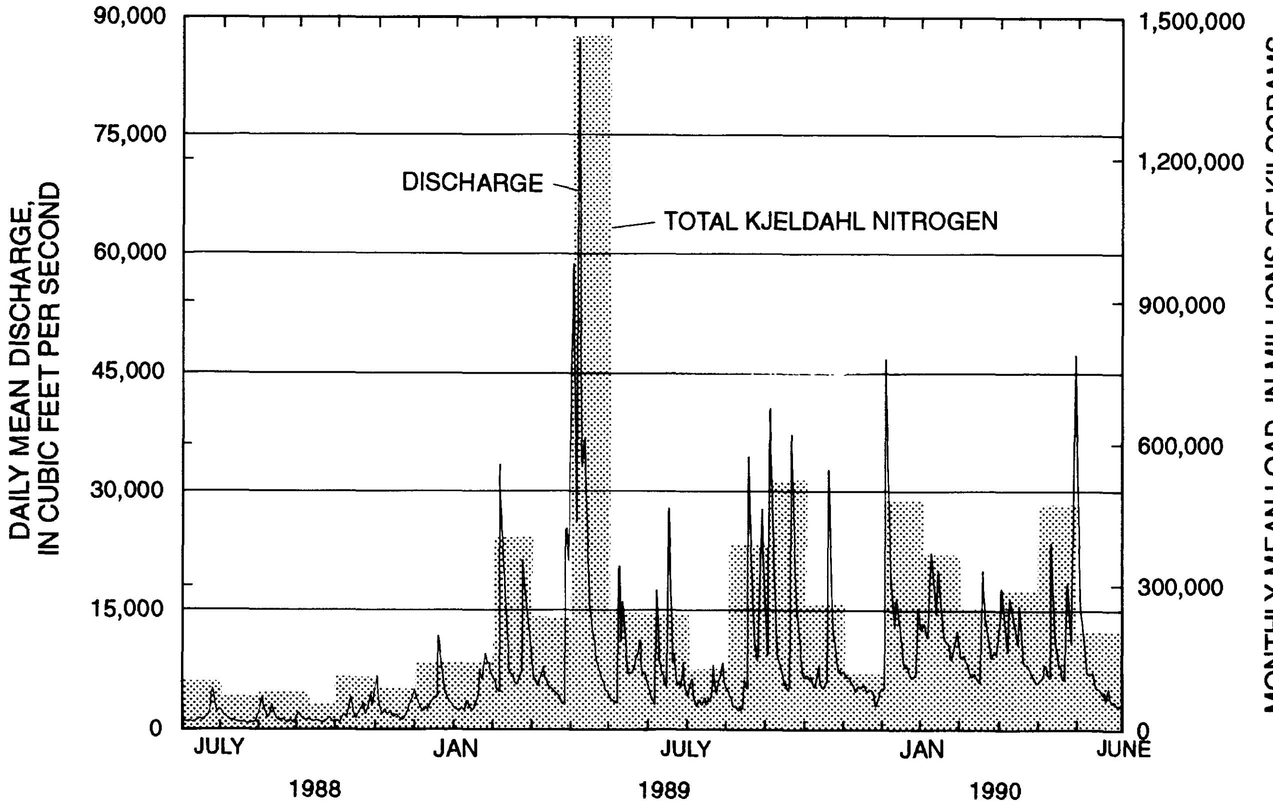

Figure 25. Total Kjeldahl nitrogen at James River station.

Table 15. Estimated daily mean discharge of total Kjeldahl nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	3,260	868	948	101,000
08-88	2,280	515	575	70,700
09-88	2,600	499	580	78,000
10-88	1,860	383	430	57,500
11-88	3,700	529	684	111,000
12-88	2,750	369	480	85,400
01-89	4,600	529	779	143,000
02-89	5,000	560	844	140,000
03-89	13,100	1,260	2,270	405,000
04-89	7,810	833	1,480	234,000
05-89	46,900	6,150	10,500	1,460,000
06-89	8,060	1,080	1,470	242,000
07-89	7,970	1,060	1,550	247,000
08-89	4,130	637	788	128,000
09-89	13,000	1,550	2,620	391,000
10-89	17,000	2,020	3,310	526,000
11-89	8,630	1,020	1,680	259,000
12-89	3,830	584	715	119,000
01-90	15,600	1,930	3,050	485,000
02-90	13,100	1,560	2,200	366,000
03-90	8,090	1,020	1,380	251,000
04-90	9,710	1,170	1,610	291,000
05-90	15,400	1,960	3,260	476,000
06-90	6,810	997	1,410	204,000

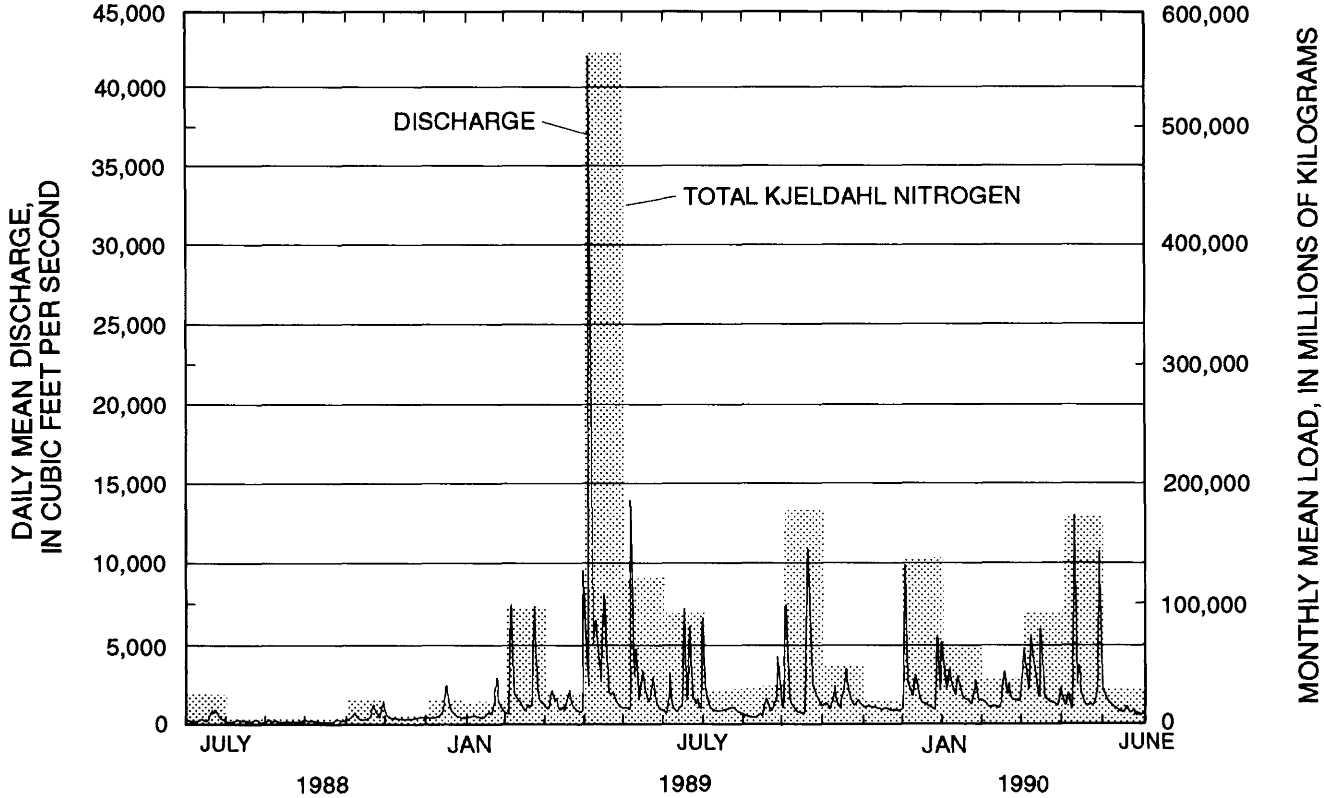

Figure 26. Total Kjeldahl nitrogen at Rappahannock River station.

Table 16. Estimated daily mean discharge of total Kjeldahl nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	809	233	256	25,079
08-88	140	27	30	4,340
09-88	132	22	26	3,960
10-88	87	13	16	2,697
11-88	723	98	143	21,690
12-88	242	26	35	7,502
01-89	708	70	127	21,948
02-89	661	60	129	19,169
03-89	3,170	271	575	98,270
04-89	845	85	121	25,350
05-89	18,200	2,540	4,920	564,200
06-89	4,060	358	894	121,800
07-89	3,000	312	550	93,000
08-89	927	106	174	28,737
09-89	1,070	125	217	32,100
10-89	5,790	759	1,240	179,490
11-89	1,670	197	271	50,100
12-89	652	83	100	20,212
01-90	4,470	527	830	138,570
02-90	2,270	240	331	65,830
03-90	1,250	130	180	38,750
04-90	3,150	313	472	94,500
05-90	5,570	718	1,250	172,670
06-90	992	135	175	29,760

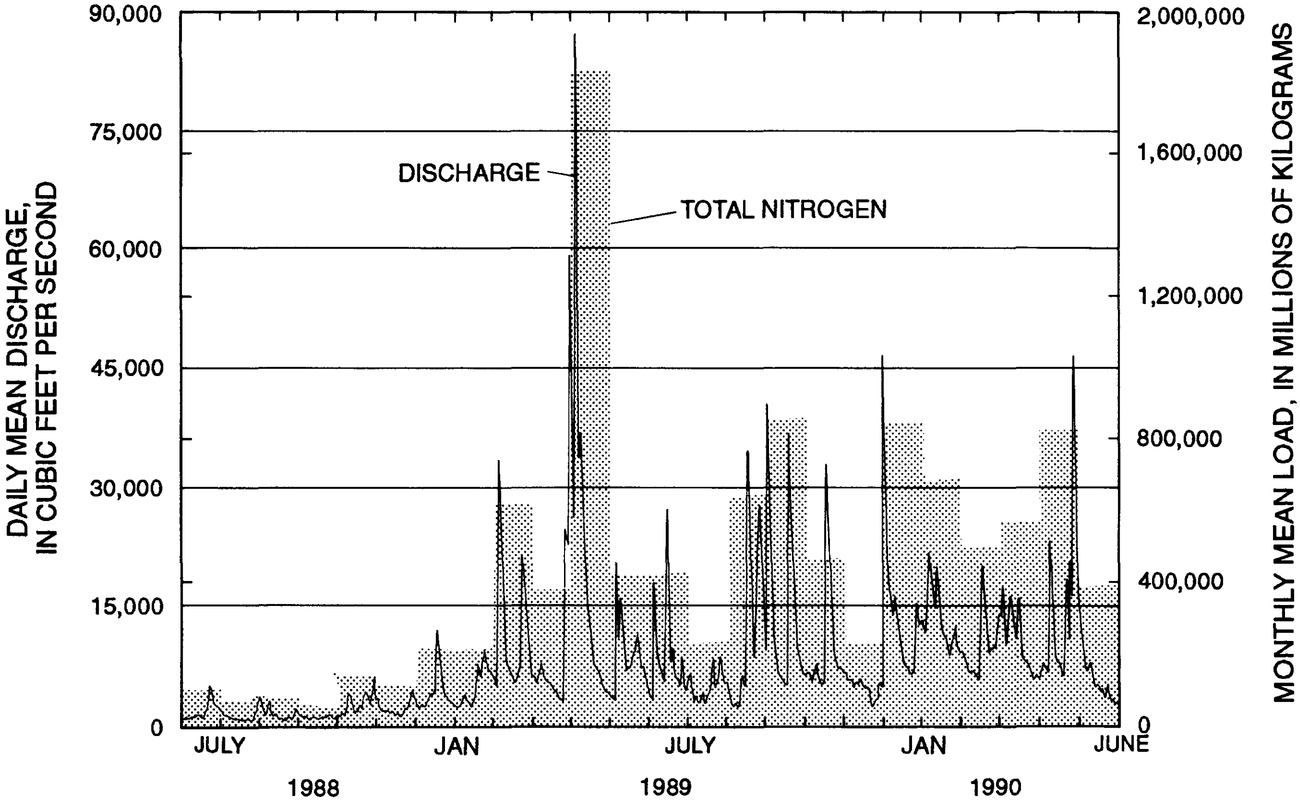

Figure 27. Total nitrogen at James River station.

Table 17. Estimated daily mean discharge of total nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	3,490	572	627	108,000
08-88	2,340	323	362	72,600
09-88	2,920	347	403	87,500
10-88	2,030	257	288	62,900
11-88	4,960	444	571	149,000
12-88	3,770	311	404	117,000
01-89	6,910	494	718	214,000
02-89	7,900	549	819	221,000
03-89	20,000	1,200	2,040	621,000
04-89	12,600	847	1,420	379,000
05-89	59,300	4,490	7,370	1,840,000
06-89	13,900	1,160	1,550	418,000
07-89	13,700	1,150	1,600	425,000
08-89	7,460	715	877	231,000
09-89	21,400	1,580	2,550	643,000
10-89	27,800	2,040	3,170	862,000
11-89	15,500	1,150	1,770	466,000
12-89	7,410	702	851	230,000
01-90	27,400	2,090	3,100	851,000
02-90	24,700	1,840	2,530	692,000
03-90	15,900	1,250	1,660	493,000
04-90	18,900	1,410	1,920	567,000
05-90	26,800	2,110	3,260	831,000
06-90	12,900	1,180	1,610	388,000

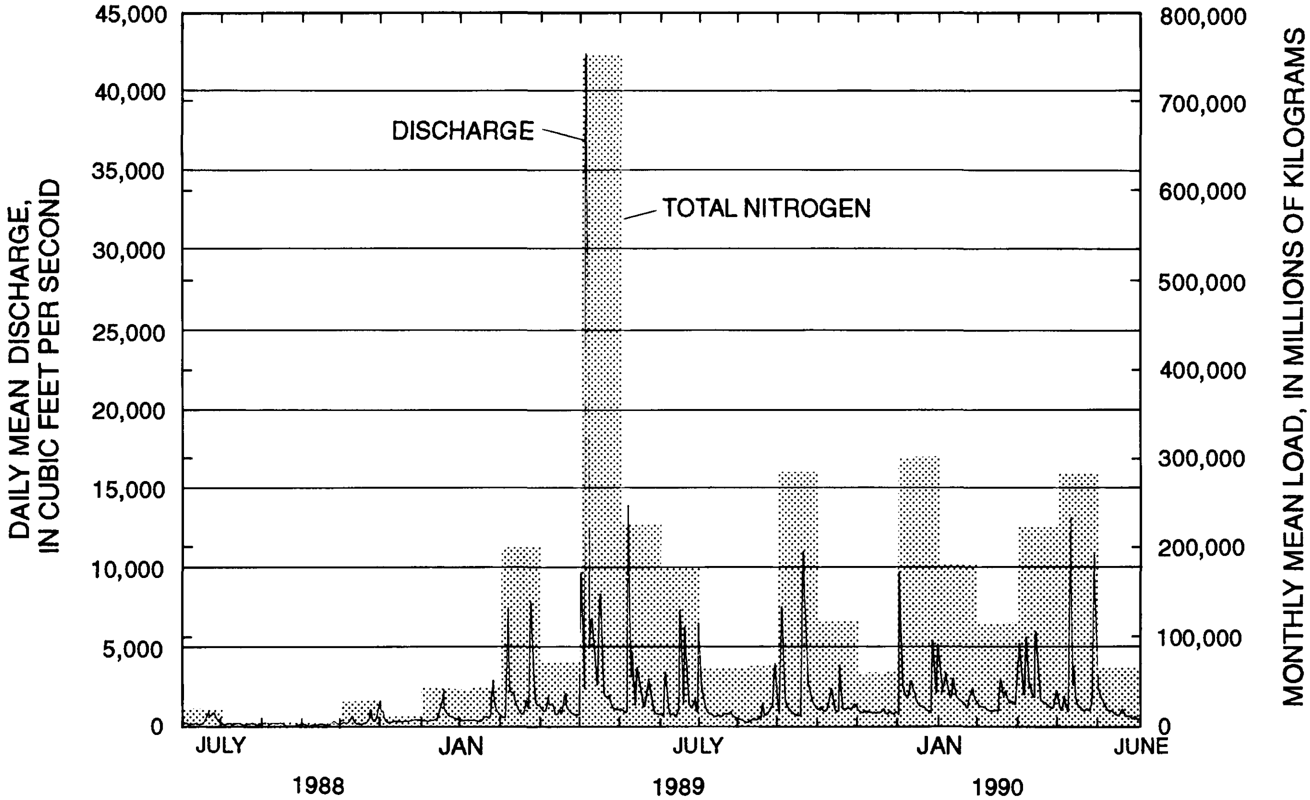

Figure 28. Total nitrogen at Rappahannock River station.

Table 18. Estimated daily mean discharge of total nitrogen, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	684	126	138	21,204
08-88	155	20	22	4,805
09-88	159	17	20	4,770
10-88	128	13	16	3,968
11-88	1,020	89	126	30,600
12-88	482	35	45	14,942
01-89	1,440	93	155	44,640
02-89	1,590	98	185	46,110
03-89	6,460	362	684	200,260
04-89	2,420	164	225	72,600
05-89	24,200	1,850	3,410	750,200
06-89	7,490	439	914	224,700
07-89	5,690	394	633	176,390
08-89	2,120	164	241	65,720
09-89	2,240	175	276	67,200
10-89	9,200	778	1,180	285,200
11-89	3,890	305	400	116,700
12-89	1,940	165	196	60,140
01-90	9,730	749	1,080	301,630
02-90	6,230	439	588	180,670
03-90	3,710	259	346	115,010
04-90	7,510	497	714	225,300
05-90	9,210	757	1,190	285,510
06-90	2,180	198	250	65,400

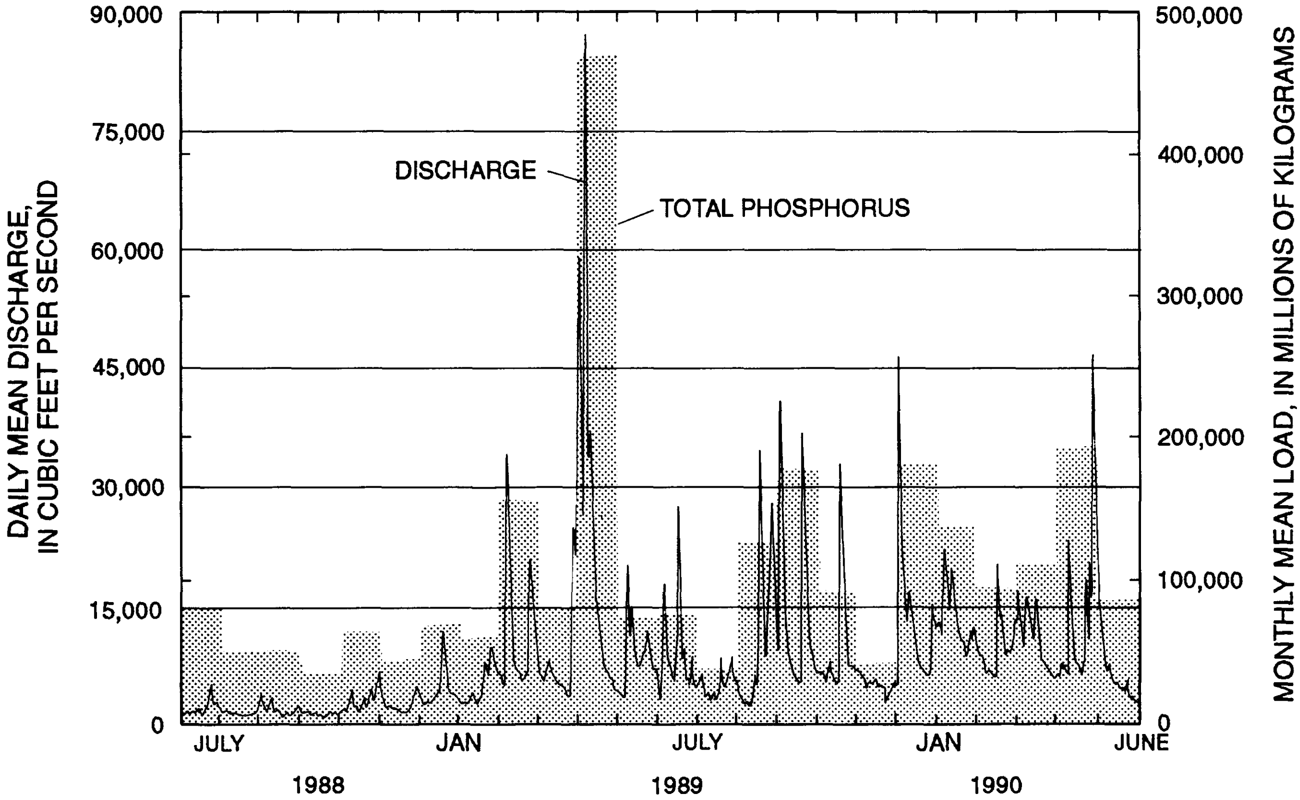

Figure 29. Total phosphorus at James River station.

Table 19. Estimated daily mean discharge of total phosphorus, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	2,650	681	743	82,100
08-88	1,660	362	404	51,400
09-88	1,770	329	383	53,000
10-88	1,150	229	258	35,700
11-88	2,180	302	390	65,300
12-88	1,480	191	248	45,800
01-89	2,240	249	367	69,400
02-89	2,150	234	350	60,200
03-89	5,110	476	861	158,000
04-89	2,700	281	489	81,100
05-89	15,100	1,910	3,250	469,000
06-89	2,490	322	439	74,700
07-89	2,440	315	458	75,500
08-89	1,290	192	238	39,900
09-89	4,270	492	829	128,000
10-89	5,780	665	1,080	179,000
11-89	3,100	356	582	93,100
12-89	1,410	209	255	43,800
01-90	5,860	700	1,100	182,000
02-90	4,970	574	805	139,000
03-90	3,090	376	510	95,700
04-90	3,760	438	604	113,000
05-90	6,270	775	1,290	194,000
06-90	2,920	415	580	87,600

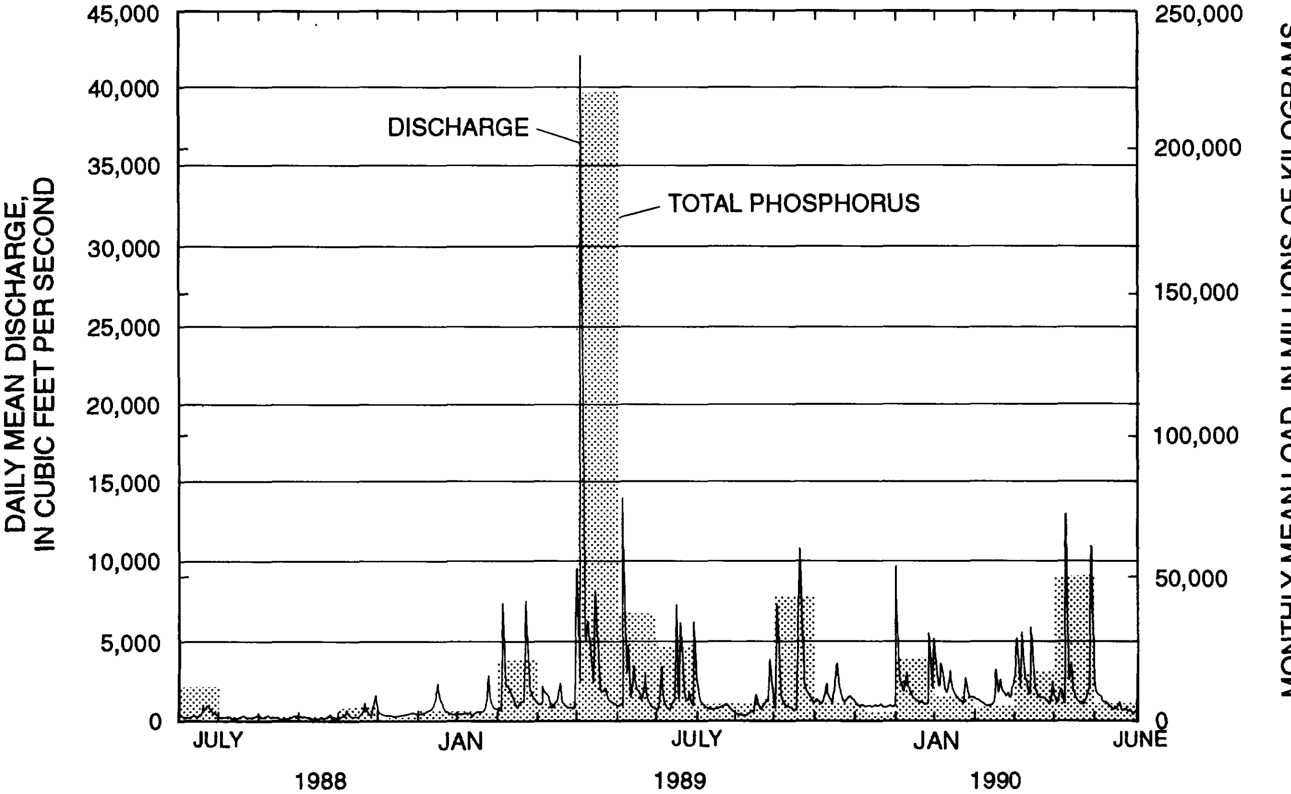

Figure 30. Total phosphorus at Rappahannock River station.

Table 20. Estimated daily mean discharge of total phosphorus, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	400	181	201	12,400
08-88	46	13	15	1,426
09-88	37	9	11	1,110
10-88	18	4	5	558
11-88	163	34	52	4,890
12-88	37	6	8	1,147
01-89	120	18	37	3,720
02-89	109	15	36	3,161
03-89	694	89	214	21,514
04-89	143	21	32	4,290
05-89	7,130	1,660	3,360	221,030
06-89	1,250	163	483	37,500
07-89	847	127	254	26,257
08-89	204	33	65	6,324
09-89	214	37	72	6,420
10-89	1,410	278	491	43,710
11-89	250	43	64	7,500
12-89	72	14	16	2,232
01-90	722	129	224	22,382
02-90	305	48	68	8,845
03-90	174	26	39	5,394
04-90	590	87	140	17,700
05-90	1,660	329	623	51,460
06-90	213	43	58	6,390

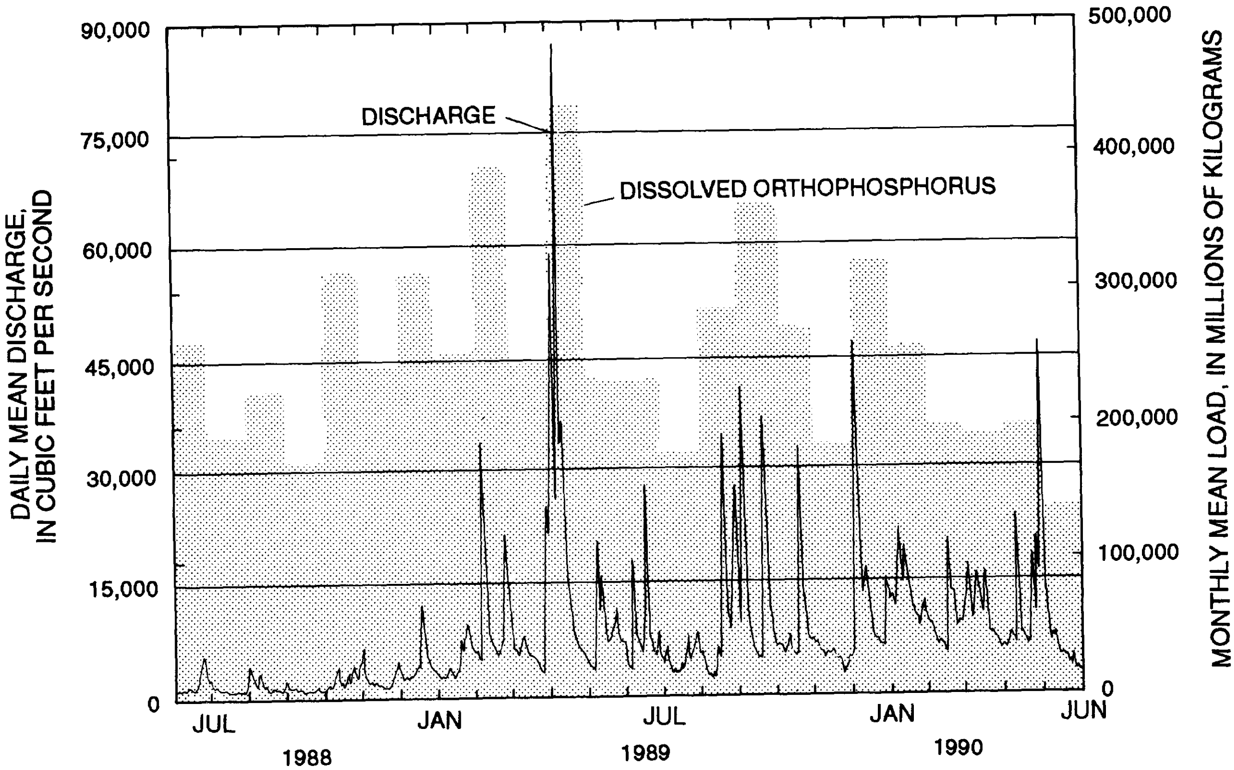

Figure 31. Dissolved orthophosphorus at James River station.

Table 21. Estimated daily mean discharge of dissolved orthophosphorus, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	1,540	353	384	47,700
08-88	1,100	214	239	34,200
09-88	1,360	225	261	40,700
10-88	985	175	197	30,500
11-88	1,920	237	301	57,500
12-88	1,420	166	213	43,900
01-89	1,840	184	255	56,900
02-89	1,640	164	232	46,000
03-89	2,320	200	301	72,000
04-89	1,480	153	212	44,400
05-89	2,600	226	352	80,500
06-89	1,400	168	215	42,000
07-89	1,350	165	211	42,000
08-89	1,020	138	168	31,700
09-89	1,730	180	258	51,800
10-89	2,150	222	307	66,700
11-89	1,640	177	238	49,300
12-89	1,050	141	171	32,700
01-90	1,880	201	270	58,200
02-90	1,660	174	236	46,500
03-90	1,130	126	163	34,900
04-90	1,120	118	158	33,500
05-90	1,130	124	166	35,000
06-90	782	103	129	23,500

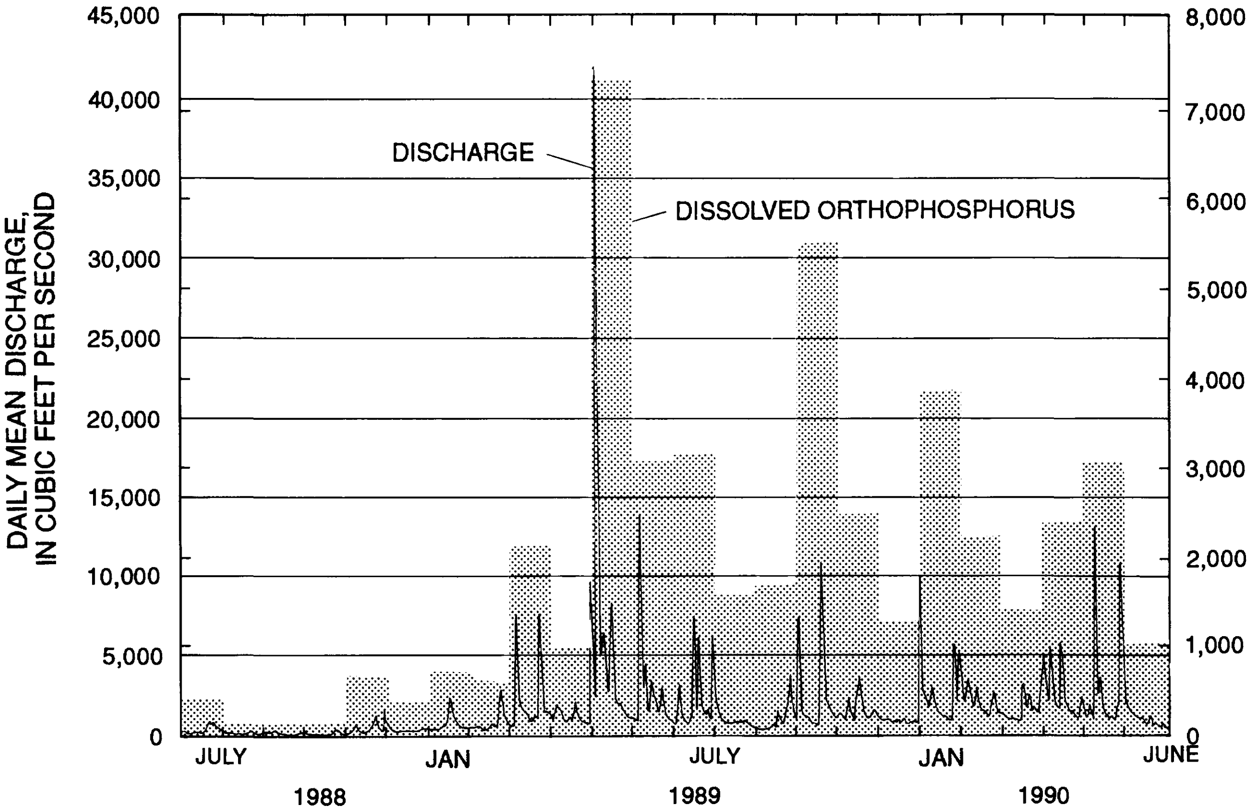

Figure 32. Dissolved orthophosphorus at Rappahannock River station.

Table 22. Estimated daily mean discharge of dissolved orthophosphorus, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	14	4	4	434
08-88	5	1	1	155
09-88	6	1	1	180
10-88	5	1	1	155
11-88	23	3	4	690
12-88	12	1	2	372
01-89	24	2	4	744
02-89	22	2	4	638
03-89	69	6	10	2,139
04-89	33	3	5	990
05-89	237	25	46	7,347
06-89	103	9	17	3,090
07-89	102	11	16	3,162
08-89	51	6	8	1,581
09-89	56	7	10	1,680
10-89	178	22	32	5,518
11-89	83	10	13	2,490
12-89	41	5	6	1,271
01-90	125	15	20	3,875
02-90	77	8	11	2,233
03-90	45	5	6	1,395
04-90	80	8	11	2,400
05-90	99	12	18	3,069
06-90	34	5	6	1,020

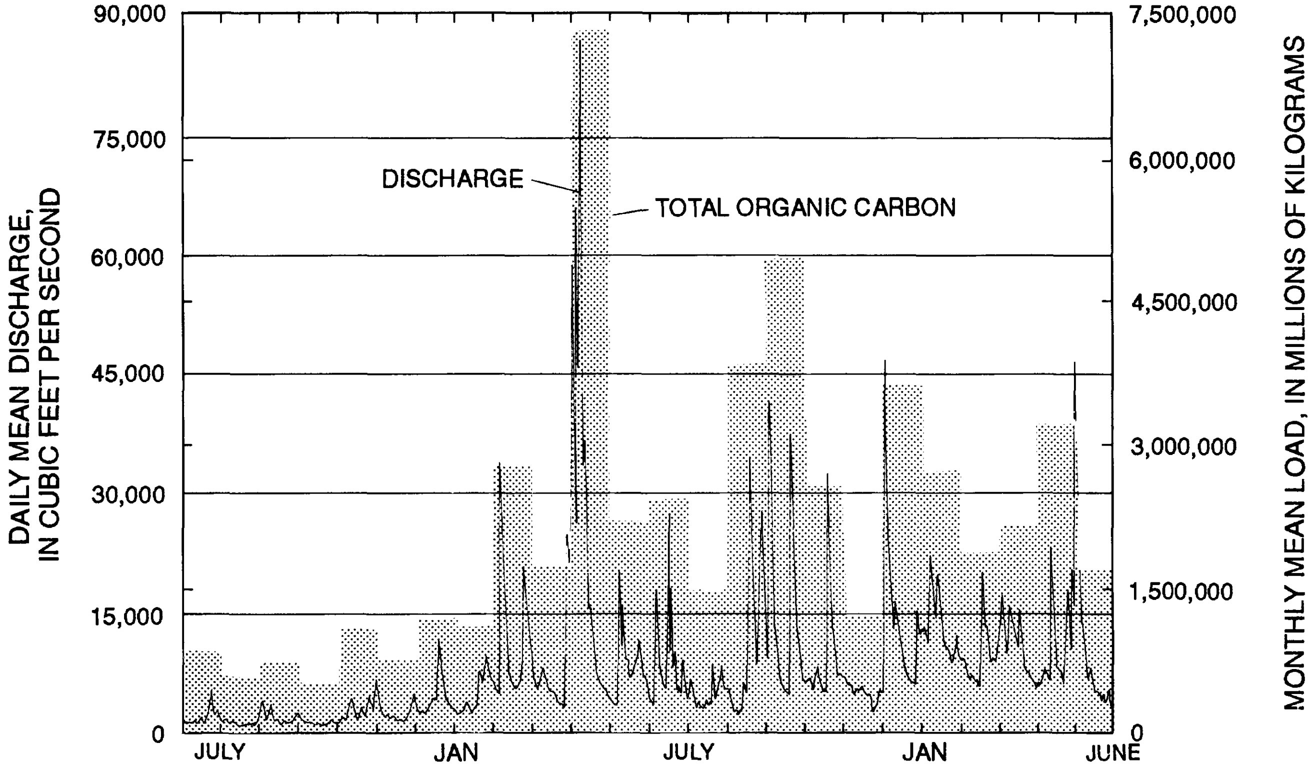

Figure 33. Total organic carbon at James River station.

Table 23. Estimated daily mean discharge of total organic carbon, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	27,400	4,200	4,600	850,000
08-88	19,300	2,470	2,770	597,000
09-88	24,600	2,720	3,160	738,000
10-88	16,300	1,910	2,140	506,000
11-88	36,400	3,020	3,860	1,090,000
12-88	24,700	1,900	2,450	766,000
01-89	39,100	2,610	3,740	1,210,000
02-89	39,900	2,610	3,820	1,120,000
03-89	90,200	5,060	8,330	2,800,000
04-89	58,400	3,720	5,970	1,750,000
05-89	238,000	16,000	25,900	7,390,000
06-89	74,300	5,820	7,640	2,230,000
07-89	79,400	6,240	8,470	2,460,000
08-89	48,700	4,350	5,310	1,510,000
09-89	129,000	8,930	14,000	3,870,000
10-89	161,000	11,100	16,700	4,990,000
11-89	86,700	6,100	8,950	2,600,000
12-89	39,500	3,520	4,240	1,220,000
01-90	117,000	8,600	12,300	3,640,000
02-90	97,900	7,030	9,460	2,740,000
03-90	61,400	4,660	6,040	1,900,000
04-90	72,400	5,260	6,950	2,170,000
05-90	104,000	7,940	11,600	3,230,000
06-90	57,200	5,030	6,590	1,710,000

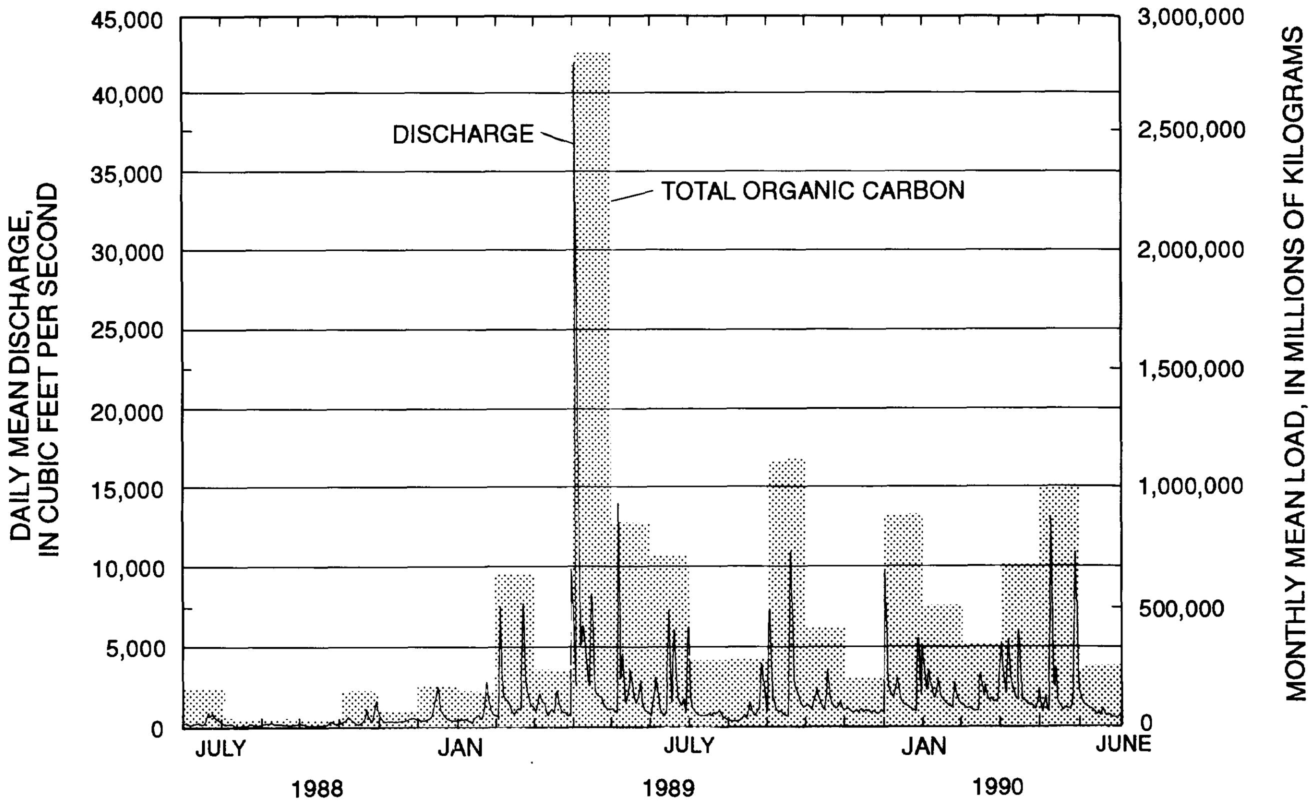

Figure 34. Total organic carbon at Rappahannock River station.

Table 24. Estimated daily mean discharge of total organic carbon, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	5,210	1,110	1,210	161,510
08-88	1,430	214	237	44,330
09-88	1,390	177	205	41,700
10-88	1,010	119	143	31,310
11-88	5,280	529	729	158,400
12-88	2,460	210	268	76,260
01-89	5,610	428	684	173,910
02-89	5,540	409	731	160,660
03-89	20,900	1,400	2,600	647,900
04-89	8,190	662	895	245,700
05-89	92,000	8,700	16,300	2,852,000
06-89	28,500	1,920	4,090	855,000
07-89	23,200	1,800	2,970	719,200
08-89	9,170	792	1,170	284,270
09-89	9,460	827	1,310	283,800
10-89	36,100	3,510	5,370	1,119,100
11-89	14,000	1,270	1,670	420,000
12-89	6,610	653	778	204,910
01-90	28,800	2,600	3,780	892,800
02-90	17,600	1,450	1,950	510,400
03-90	10,900	885	1,180	337,900
04-90	22,700	1,760	2,520	681,000
05-90	32,600	3,140	5,000	1,010,600
06-90	8,640	919	1,140	259,200

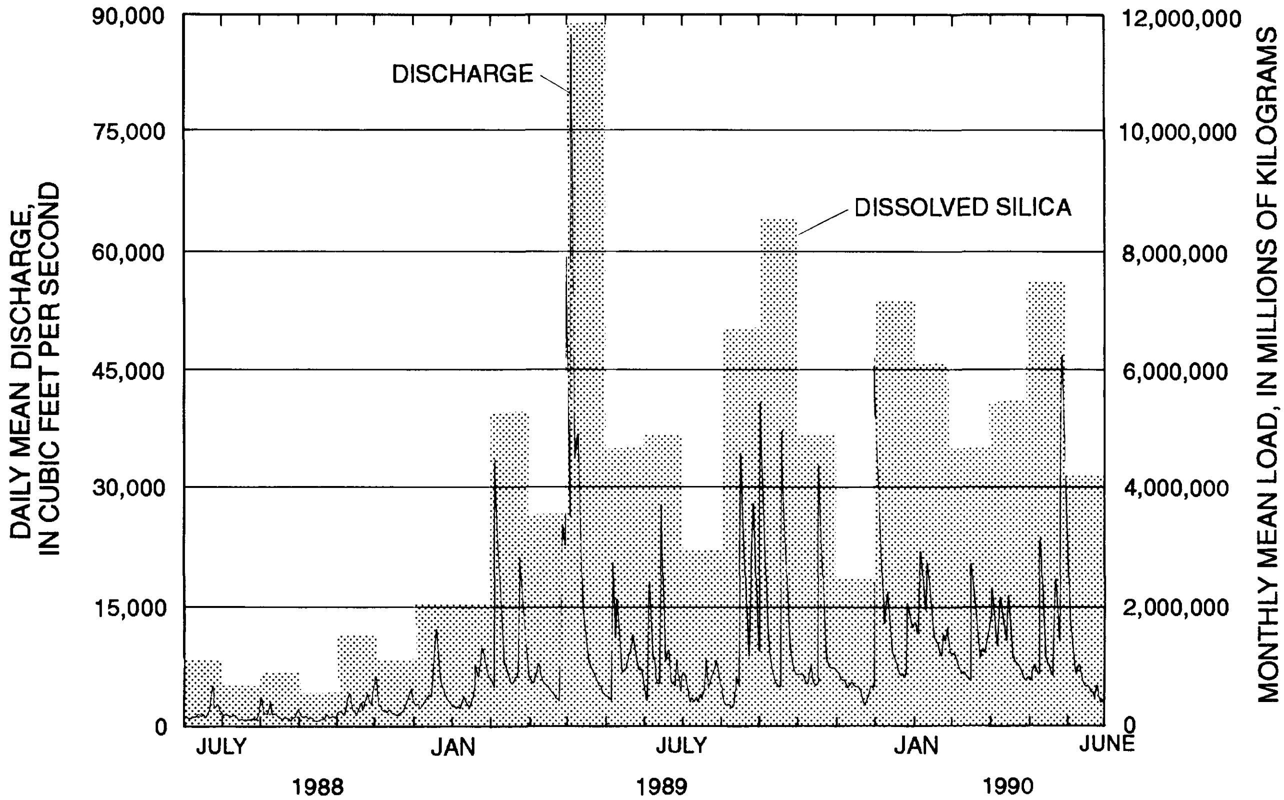

Figure 35. Dissolved silica at James River station.

Table 25. Estimated daily mean discharge of dissolved silica, standard error of the discharge, standard error of prediction, and total monthly load at the James River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	36,100	3,350	3,720	1,119,100
08-88	22,200	1,690	1,940	688,200
09-88	29,800	2,000	2,350	894,000
10-88	17,800	1,250	1,410	551,800
11-88	51,600	2,620	3,370	1,548,000
12-88	35,600	1,630	2,140	1,103,600
01-89	65,700	2,640	3,810	2,036,700
02-89	73,800	2,880	4,280	2,066,400
03-89	170,000	5,770	9,210	5,270,000
04-89	117,000	4,510	7,060	3,510,000
05-89	381,000	14,400	22,700	11,811,000
06-89	154,000	7,280	9,500	4,620,000
07-89	157,000	7,510	10,000	4,867,000
08-89	94,400	5,080	6,210	2,926,400
09-89	223,000	9,270	14,200	6,690,000
10-89	274,000	11,200	16,500	8,494,000
11-89	162,000	6,810	9,740	4,860,000
12-89	79,300	4,210	5,100	2,458,300
01-90	231,000	9,820	13,700	7,161,000
02-90	218,000	9,130	12,400	6,104,000
03-90	150,000	6,630	8,680	4,650,000
04-90	181,000	7,660	10,200	5,430,000
05-90	241,000	10,600	15,200	7,471,000
06-90	140,000	7,280	9,540	4,200,000

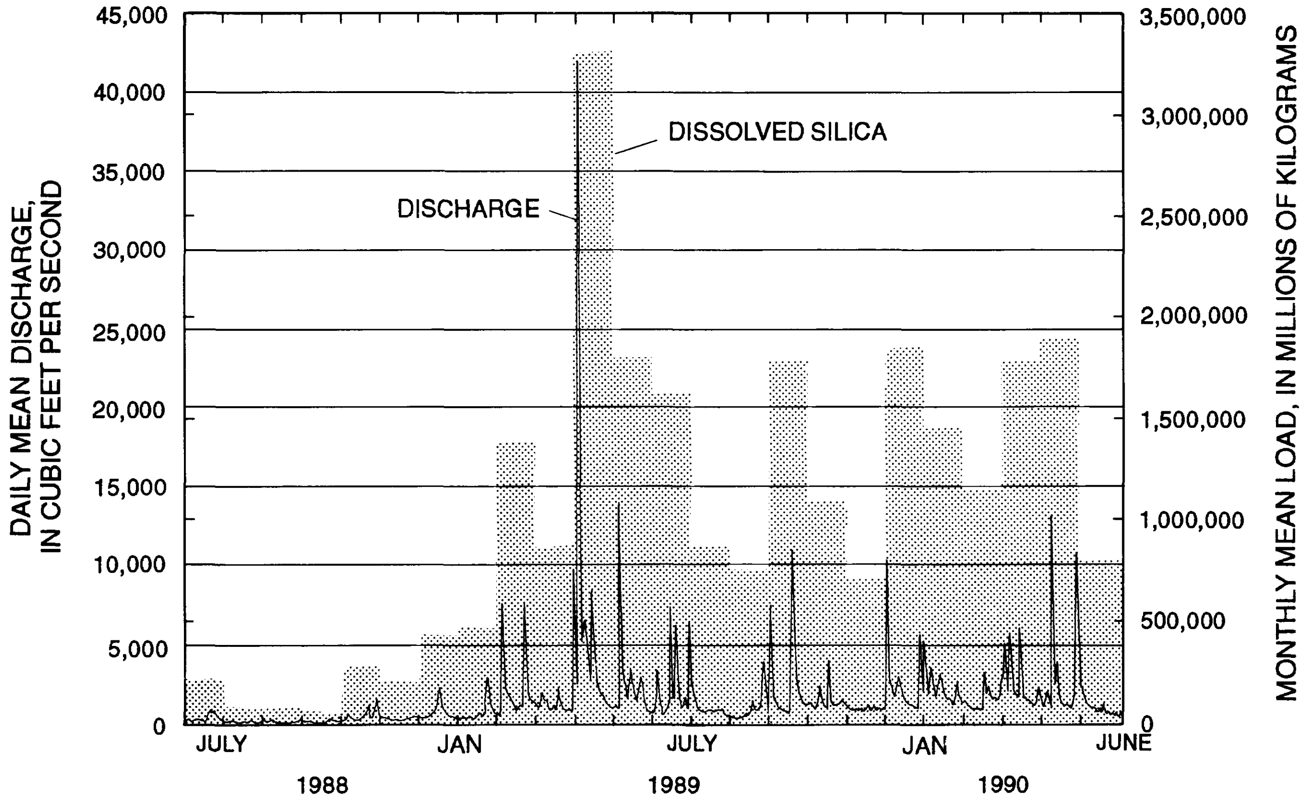

Figure 36. Dissolved silica at Rappahannock River station.

Table 26. Estimated daily mean discharge of dissolved silica, standard error of the discharge, standard error of prediction, and total monthly load at the Rappahannock River station
[kg/d, kilograms per day; kg, kilogram]

Date	Daily mean constituent discharge (kg/d)	Standard error (kg/d)	Standard error of prediction (kg/d)	Total monthly load (kg)
07-88	7,450	829	888	230,950
08-88	2,820	227	249	87,420
09-88	2,850	196	224	85,500
10-88	2,360	153	179	73,160
11-88	9,840	510	671	295,200
12-88	6,680	310	388	207,080
01-89	14,100	571	820	437,100
02-89	16,200	663	1,010	469,800
03-89	45,000	1,600	2,490	1,395,000
04-89	29,200	1,280	1,670	876,000
05-89	107,000	3,810	6,210	3,317,000
06-89	59,900	2,310	3,550	1,797,000
07-89	52,500	2,280	3,190	1,627,500
08-89	28,200	1,410	1,810	874,200
09-89	25,300	1,260	1,690	759,000
10-89	57,800	2,910	3,900	1,791,800
11-89	36,500	1,810	2,250	1,095,000
12-89	23,000	1,240	1,460	713,000
01-90	59,700	2,830	3,700	1,850,700
02-90	50,200	2,230	2,910	1,455,800
03-90	37,400	1,660	2,130	1,159,400
04-90	59,700	2,500	3,360	1,791,000
05-90	61,300	3,020	4,050	1,900,300
06-90	26,900	1,550	1,870	807,000

APPENDIXES

Appendix 1. Selected chemical and physical water-quality characteristics of the James River at Cartersville, Virginia, station number 0203500

[All samples were collected by the U.S. Geological Survey, except where noted, and analyzed by the Virginia Division of Consolidated Laboratories; °C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft³/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft³/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C suspended (mg/L) (00530)
07-21-88[a]	30.0	--	--	1,640	315	6.8	8.6	<1
07-22-88	30.0	--	--	1,770	298	--	--	80
08-08-88[a]	27.5	--	--	1,230	255	8.0	8.9	10
08-30-88	22.0	26.5	755	2,060	295	8.0	8.1	6
09-15-88	18.5	17.5	761	1,240	280	7.5	8.3	<1
10-12-88	10.0	13.0	753	1,430	345	9.2	7.9	<1
10-25-88[a]	10.0	--	--	1,270	185	11.3	8.3	<1
11-22-88[a]	8.0	--	--	2,800	95	10.5	7.5	5
11-28-88	4.0	9.0	748	5,490	198	12.0	6.6	75
11-29-88	9.0	12.5	757	7,470	182	10.3	7.4	45
12-19-88[a]	0.0	--	--	1,420	110	16.9	6.5	10
12-28-88	2.0	18.0	744	4,860	315	13.2	6.7	21
01-05-89[a]	5.0	--	--	2,560	110	14.2	7.5	2
01-16-89	4.5	--	752	6,380	232	13.4	7.5	26
01-17-89	7.0	--	758	12,600	196	11.5	7.0	150
01-18-89	6.0	4.0	755	12,300	208	11.4	7.2	90
01-19-89	6.5	7.0	753	8,920	185	12.2	7.2	36
01-25-89	5.0	16.0	760	3,840	137	12.7	7.9	5
02-14-89[a]	5.0	--	--	2,690	155	14.2	8.7	5
02-22-89	8.5	9.5	747	9,910	200	11.3	7.5	53
02-23-89	8.5	1.5	751	9,880	125	11.0	7.1	28
03-07-89	4.0	0.0	761	39,300	170	12.8	7.9	308
03-08-89	3.0	-3.0	768	23,900	120	12.8	7.4	274
03-09-89	4.5	4.0	768	1,880	160	12.9	7.1	95
03-10-89	5.0	4.5	764	15,900	160	11.8	7.0	62
03-11-89	6.0	9.5	761	11,200	118	11.8	7.7	30
03-23-89	9.5	5.0	770	6,440	134	10.7	7.7	--
03-24-89	8.0	5.0	767	13,100	114	11.2	7.7	39
03-25-89	7.5	8.5	767	21,600	101	11.2	7.8	47
03-26-89	9.0	7.5	770	21,000	123	11.1	7.8	66

[a] Sample collected by the Virginia Division of Consolidated Laboratories.

Appendix 1.—Continued

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
07-21-88[a]	<1	<1	0.14	0.01	0.15	0.17	0.9	0.34	0.41	5.3	9.1
07-22-88	12	68	--	--	--	--	--	--	--	--	--
08-08-88[a]	8	2	.04	<.01	.04	.11	1.1	.27	.20	4.9	9.3
08-30-88	1	5	.06	<.01	.06	.12	.4	.30	.23	5.3	7.9
09-15-88	<1	<1	.04	<.01	.04	.10	.3	.40	.29	3.9	5.6
10-12-88	<1	<1	.18	<.01	.18	<.04	.3	.50	.51	4.9	5.2
10-25-88[a]	<1	<1	.00	.02	<.04	.07	.5	.31	.33	3.5	4.5
11-22-88[a]	3	2	.24	<.01	.24	<.04	.5	.20	.17	7.8	7.1
11-28-88	45	30	.19	<.01	.19	.18	.6	.40	.24	5.0	7.3
11-29-88	10	35	.21	<.01	.21	.05	.6	.40	.20	6.9	8.1
12-19-88[a]	10	0	.19	<.01	.19	<.04	.4	.23	.20	4.9	4.5
12-28-88	9	12	.17	<.01	.17	<.04	.2	.41	.43	4.2	5.4
01-05-89[a]	2	0	.24	<.01	.24	.07	.4	.17	.17	3.5	6.0
01-16-89	2	24	.25	<.01	.25	.05	.4	.28	.21	3.9	6.6
01-17-89	30	120	.23	<.01	.23	.23	1.4	.80	.08	2.9	6.6
01-18-89	20	70	.22	<.01	.22	.08	.3	.32	.28	2.8	5.5
01-19-89	10	26	.27	<.01	.27	.05	.3	.15	.17	2.5	6.7
01-25-89	2	3	.32	<.01	.32	.04	.2	.10	.09	2.5	7.3
02-14-89[a]	3	2	.11	.03	.14	--	.7	.28	.24	6.4	2.4
02-22-89	9	44	.22	.02	.24	.18	.6	.18	.16	5.6	7.1
02-23-89	2	26	.27	<.01	.27	.09	.4	.17	.08	4.3	7.6
03-07-89	56	252	.26	<.01	.26	.12	1.8	.48	.02	6.1	5.5
03-08-89	30	244	.34	<.01	.34	.16	.8	.27	.03	7.2	7.1
03-09-89	12	83	.34	<.01	.34	.09	.5	.21	.07	3.6	5.9
03-10-89	11	51	.31	<.01	.31	.11	.4	.17	.09	3.5	6.6
03-11-89	4	26	.32	.01	.33	.12	.4	.15	.06	3.1	7.4
03-23-89	--	--	.27	<.01	.27	.04	.4	.10	.08	3.0	6.8
03-24-89	10	29	.14	<.01	.14	<.04	.6	.04	.04	3.9	6.2
03-25-89	11	36	.21	.01	.22	.04	.3	.11	.06	4.2	5.9
03-26-89	14	52	.28	.01	.29	<.04	.3	.14	.10	4.1	6.7

Appendix 1. Selected chemical and physical water-quality characteristics of the James River at Cartersville, Virginia, station number 02035000—Continued

[°C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C, suspended (mg/L) (00530)
03-27-89	10.5	9.0	755	18,400	120	10.4	7.8	62
03-28-89	13.0	19.0	761	14,400	108	9.7	7.8	28
03-29-89	15.5	21.0	755	11,800	105	9.3	7.8	29
04-25-89	18.5	25.0	750	3,410	165	9.1	7.9	9
04-27-89	19.5	27.0	752	12,200	111	8.0	7.4	57
04-28-89	18.5	16.0	753	25,900	190	7.9	7.5	166
04-29-89	17.5	14.5	755	21,200	102	8.5	7.4	130
04-30-89	17.0	16.0	757	22,000	101	8.8	7.5	91
05-01-89	17.0	21.5	754	22,400	119	8.9	7.5	92
05-02-89	16.5	17.0	750	50,400	95	8.6	7.4	180
05-03-89	15.5	12.0	759	61,900	105	8.2	7.5	212
05-03-89	16.0	19.5	758	56,100	107	8.6	7.6	264
05-04-89	15.5	22.0	763	39,300	98	9.2	7.6	143
05-04-89	15.5	25.0	767	35,800	95	9.0	7.5	132
05-05-89	15.5	18.5	749	25,900	115	9.7	7.6	69
05-06-89	15.0	16.0	747	60,500	173	9.3	7.6	488
05-07-89	15.0	6.5	748	91,500	85	9.5	7.4	292
05-08-89	14.0	14.5	751	58,200	102	9.6	7.8	139
05-09-89	13.5	17.0	752	34,200	106	10.2	7.5	68
05-10-89	12.5	26.0	748	32,800	120	10.5	7.2	57
05-11-89	13.5	16.0	746	35,700	115	9.9	7.1	59
05-12-89	13.5	21.5	753	33,400	100	10.0	7.2	57
05-13-89	12.0	8.5	756	26,800	93	10.3	7.3	52
05-14-89	13.5	14.5	757	21,600	90	10.0	7.4	30
05-15-89	12.5	14.0	756	15,800	85	10.4	7.3	27
06-08-89	22.5	22.5	751	20,200	130	8.7	6.5	158
06-28-89	28.5	33.0	753	7,170	151	7.0	7.8	17
07-06-89	24.0	29.0	757	19,800	107	7.2	7.1	290
07-07-89	23.5	29.5	756	15,900	100	7.5	7.0	218
07-17-89	22.5	22.5	751	33,600	88	9.8	7.1	156

Appendix 1.—Continued

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
03-27-89	12	50	0.24	0.01	0.25	<0.04	0.2	0.12	0.09	3.1	6.3
03-28-89	4	24	.25	.01	.26	.03	.4	.08	.06	2.9	7.4
03-29-89	4	25	.25	.01	.26	.05	.4	.11	.05	2.4	7.0
04-25-89	4	5	.08	<.01	.08	<.04	.2	.14	.11	1.7	2.5
04-27-89	9	48	.24	<.01	.24	.06	.5	.14	.05	3.9	4.8
04-28-89	25	141	.18	.01	.19	.10	1.0	.38	.13	3.6	4.0
04-29-89	19	111	.28	.01	.29	.07	.8	.28	.07	5.0	6.4
04-30-89	14	77	.28	.01	.29	.06	.7	.17	.06	3.7	6.7
05-01-89	14	78	.27	<.01	.27	.05	.6	.25	.06	2.8	6.8
05-02-89	25	155	.24	<.01	.24	.07	.9	.28	.03	4.9	6.8
05-03-89	28	184	.27	.01	.28	.07	1.4	.35	.03	4.7	7.9
05-03-89	32	232	.26	.01	.27	.08	1.3	.29	.04	4.9	7.0
05-04-89	19	124	.24	.01	.25	.04	.3	.05	.03	3.4	7.2
05-04-89	16	116	.24	.01	.25	.04	.5	.13	.03	3.3	7.2
05-05-89	8	61	.28	<.01	.28	.04	.3	.11	.04	2.8	7.3
05-06-89	30	458	.27	<.01	.27	.08	1.7	.60	.03	5.1	6.1
05-07-89	36	256	.25	<.01	.25	.04	.9	.46	.01	4.8	6.1
05-08-89	17	122	.25	<.01	.25	.04	.9	.32	.03	3.5	7.1
05-09-89	10	58	.28	<.01	.28	<.04	.5	.17	.02	3.2	7.3
05-10-89	10	47	.31	<.01	.31	<.04	.4	.15	.05	3.1	8.0
05-11-89	5	54	.31	<.01	.31	<.04	.3	.16	.05	2.6	7.8
05-12-89	8	49	.29	<.01	.29	<.04	.2	.08	.04	2.3	7.3
05-13-89	7	45	.27	<.01	.27	<.04	.3	.10	.03	2.2	7.6
05-14-89	5	25	.31	<.01	.31	<.04	.2	.12	.04	2.0	7.6
05-15-89	4	23	.34	<.01	.34	.04	.3	.19	.04	1.5	7.4
06-08-89	20	138	.26	.02	.28	.07	.7	.18	.06	6.2	5.0
06-28-89	3	14	.40	<.01	.40	<.04	.2	.11	.08	3.1	8.0
07-06-89	44	246	.30	.01	.31	<.04	.9	.34	.07	6.4	7.9
07-07-89	33	185	.25	.01	.26	.04	.5	.18	.05	7.5	7.6
07-17-89	22	134	.24	<.01	.24	.06	.4	.15	.04	6.2	7.3

Appendix 1. Selected chemical and physical water-quality characteristics of the James River at Cartersville, Virginia, station number 0203500—Continued

[°C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C, suspended (mg/L) (00530)
07-18-89	22.0	21.0	755	12,500	100	10.0	7.4	87
07-26-89	27.5	31.0	763	5,410	109	7.2	7.3	17
08-08-89[a]	26.5	--	--	3,730	190	7.2	8.5	4
08-29-89	25.0	29.5	748	5,990	178	7.3	7.8	27
09-06-89[a]	23.0	--	--	2,720	149	8.3	8.7	4
09-17-89	22.0	30.0	756	27,500	80	7.3	7.0	268
09-18-89	22.0	22.0	758	36,000	180	7.3	7.0	250
09-19-89	20.5	19.0	758	19,400	122	8.2	7.4	136
09-20-89	20.0	23.0	759	12,900	110	9.0	6.8	68
09-26-89	17.0	19.0	756	25,400	87	8.8	7.0	116
09-27-89	16.0	13.0	760	27,700	74	8.7	7.1	128
09-28-89	16.0	19.5	768	19,200	93	8.7	7.0	61
10-02-89	17.0	22.0	752	16,000	118	7.6	7.7	26
10-03-89	18.0	23.0	753	42,100	100	8.5	6.4	134
10-04-89	17.0	19.0	756	32,500	140	7.8	7.5	--
10-06-89	17.5	21.0	757	15,000	120	7.9	7.7	41
10-19-89	14.0	9.5	749	28,200	200	9.7	7.7	112
10-21-89	13.0	16.5	748	30,100	125	10.9	7.0	75
10-22-89	13.5	6.5	757	21,700	115	9.5	6.8	45
10-26-89	11.5	16.5	760	9,750	124	10.2	7.3	6
11-18-89	11.0	10.5	760	35,100	166	10.0	7.8	--
11-28-89	7.0	18.0	742	6,770	130	11.9	7.4	5
12-26-89	1.0	6.5	750	3,290	92	14.3	7.8	1
01-02-90	2.5	1.5	760	47,500	200	14.3	7.0	234
01-03-90	2.5	1.0	760	33,200	119	13.4	6.1	210
01-04-90	4.5	5.0	755	22,500	100	14.5	7.1	88
01-05-90	4.0	13.0	758	18,700	--	15.5	6.7	32
01-30-90	5.5	13.0	751	12,200	175	11.9	7.5	16
02-05-90	7.0	4.0	758	17,500	128	10.5	6.7	27
02-06-90	7.5	13.0	757	22,100	163	10.1	6.5	212

[a] Sample collected by the Virginia Division of Consolidated Laboratories.

Appendix 1.—Continued

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
07-18-89	10	77	0.39	<0.01	0.39	<0.04	0.3	0.14	0.06	4.6	8.2
07-26-89	5	12	.35	<.01	.35	<.04	.5	.11	.07	4.3	9.5
08-08-89[a]	1	3	.16	<.01	.16	.09	.9	.16	.14	4.6	8.3
08-29-89	3	24	.42	.01	.43	<.04	.3	.28	.21	3.6	8.9
09-06-89[a]	4	0	.28	<.01	.28	.04	.3	.14	.12	3.5	8.4
09-17-89	30	238	.46	.01	.47	.05	.8	.30	.03	8.1	7.0
09-18-89	36	214	.35	.01	.36	.05	.4	.10	.08	5.8	7.4
09-19-89	20	116	.30	<.01	.30	<.04	.9	.17	.05	5.9	7.7
09-20-89	10	58	.32	.01	.33	.04	.2	.05	.05	4.4	8.0
09-26-89	18	98	.26	.01	.27	.04	.5	.16	.05	8.3	8.4
09-27-89	16	112	.25	.01	.26	.05	.8	.18	.02	6.2	7.9
09-28-89	8	53	.32	.02	.34	.04	.4	.13	.05	5.5	8.9
10-02-89	5	21	.29	<.01	.29	.04	.3	.10	.05	4.1	9.7
10-03-89	14	120	.32	<.01	.32	.04	.9	.32	.05	4.9	8.6
10-04-89	--	--	.30	.01	.31	.05	.8	.15	.12	4.5	8.3
10-06-89	7	34	.33	.01	.34	.05	.6	.07	.04	2.9	8.8
10-19-89	16	96	.24	<.01	.24	.09	.4	.15	<.04	3.8	7.7
10-21-89	9	66	.28	<.01	.28	.05	.6	.09	.04	3.8	7.6
10-22-89	6	39	.23	<.01	.23	<.04	.4	.13	.03	3.2	7.7
10-26-89	1	5	.34	<.01	.34	<.04	.1	.07	.03	2.1	8.8
11-18-89	--	--	.31	<.01	.31	.12	.4	.48	--	--	5.2
11-28-89	1	4	.27	<.01	.27	.21	.2	.03	.03	2.1	9.2
12-26-89	<1	1	.31	<.01	.31	<.04	.3	.09	.08	3.9	8.1
01-02-90	23	211	.42	<.01	.42	.10	1.2	.70	.15	5.4	5.8
01-03-90	18	192	.43	<.01	.43	.05	.9	.27	.03	3.4	6.3
01-04-90	6	82	.45	<.01	.45	.05	.5	.13	.03	4.9	6.6
01-05-90	3	29	.44	<.01	.44	.05	.3	.09	.03	4.6	7.9
01-30-90	1	15	.33	.01	.34	.06	.2	.10	.06	2.3	8.0
02-05-90	5	22	.30	<.01	.30	.04	.3	.11	.04	2.7	7.4
02-06-90	31	181	.33	<.01	.33	.05	.4	.20	.06	2.1	6.4

Appendix 1. Selected chemical and physical water-quality characteristics of the James River at Cartersville, Virginia, station number 02035000—Continued

[°C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C, suspended (mg/L) (00530)
02-07-90	9.5	12.0	751	18,300	143	10.7	6.8	41
02-13-90	9.0	21.0	764	17,500	116	10.5	7.4	20
02-26-90	5.0	-3.0	772	13,100	131	12.5	7.3	14
03-18-90	17.0	23.5	752	21,200	82	7.2	7.2	--
03-19-90	14.5	19.0	750	16,100	110	9.1	7.1	--
03-28-90	10.0	9.0	761	9,350	132	10.8	7.2	13
04-25-90	19.0	21.5	752	6,390	129	8.7	7.7	8
05-11-90	18.0	18.5	755	27,800	65	7.9	7.0	288
05-12-90	17.5	9.0	758	16,100	120	8.6	7.0	106
05-13-90	17.0	22.0	745	11,400	110	8.9	7.4	64
05-23-90	18.5	17.0	751	12,500	128	8.4	7.1	64
05-24-90	18.5	22.5	750	17,800	165	8.4	7.5	90
05-25-90	18.0	21.0	765	13,800	220	7.0	7.6	82
05-27-90	19.0	20.0	752	22,700	98	9.3	7.2	512
05-28-90	18.0	18.0	760	15,300	97	9.3	7.4	148
05-29-90	16.5	18.0	746	37,100	86	9.6	7.4	50
05-30-90	17.0	23.0	747	44,700	105	9.2	7.0	127
05-31-90	17.0	19.0	757	39,700	127	9.1	7.2	50
06-01-90	17.5	20.5	757	24,100	123	9.4	6.8	92
06-02-90	18.5	20.0	757	18,800	108	9.5	7.0	62
06-03-90	19.5	20.5	752	15,600	115	8.9	6.9	44
06-27-90	26.0	30.0	760	3,620	162	7.9	8.2	11

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3 dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
02-07-90	6	35	0.37	0.01	0.38	0.07	0.3	0.10	0.06	2.4	6.9
02-13-90	<1	20	.34	<.01	.34	<.04	.2	.10	.05	2.5	7.1
02-26-90	1	13	.29	<.01	.29	<.04	.2	.10	.06	2.7	7.2
03-18-90	--	--	.22	<.01	.22	.04	.9	.22	.03	--	6.0
03-19-90	--	--	.31	<.01	.31	.07	1.1	.33	.03	--	7.0
03-28-90	5	8	.27	<.01	.27	.05	.2	.06	.03	1.8	7.0
04-25-90	6	2	.31	<.01	.31	<.04	.2	.08	.05	2.2	7.2
05-11-90	40	248	.34	.05	.39	.05	1.1	.48	.03	4.6	7.6
05-12-90	16	90	.45	.02	.47	.04	.6	.25	.04	3.4	7.9
05-13-90	8	56	.41	<.01	.41	.04	.4	.17	.04	2.6	8.7
05-23-90	13	51	.38	<.01	.38	<.04	.5	.20	.05	3.3	8.0
05-24-90	15	75	.41	.02	.43	<.04	.6	.27	.05	2.7	8.2
05-25-90	10	72	.34	.03	.37	<.04	.4	.15	.05	3.6	7.6
05-27-90	48	464	.36	<.01	.36	<.04	1.5	.50	.02	5.3	7.4
05-28-90	16	132	.33	<.01	.33	<.04	.6	.22	.02	5.2	8.4
05-29-90	10	40	.36	<.01	.36	<.04	.6	.17	.03	--	8.3
05-30-90	24	103	.32	<.01	.32	<.04	.3	.23	.03	4.0	7.8
05-31-90	12	38	.36	<.01	.36	<.04	.5	.17	.03	4.6	7.7
06-01-90	16	76	.34	<.01	.34	<.04	.5	.15	.03	2.7	7.5
06-02-90	15	47	.34	<.01	.34	<.04	.1	.14	.03	2.4	7.8
06-03-90	13	31	.40	<.01	.40	<.04	<.1	.17	.03	2.4	8.0
06-27-90	6	5	.16	<.01	.16	<.04	.3	.05	.01	4.0	3.5

Appendix 2. Selected chemical and physical water-quality characteristics of the Rappahannock River near Fredericksburg, Virginia, station number 01668000

[All samples were collected by the U.S. Geological Survey and analyzed by the Virginia Division of Consolidated Laboratories; °C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C, suspended (mg/L) (00530)
08-16-88	29.5	26.0	760	179	73	6.7	6.9	2
08-31-88	19.0	--	764	432	98	8.2	7.1	7
09-16-88	20.5	18.0	771	125	81	8.5	6.7	<1
09-28-88	15.0	18.5	764	270	90	8.7	7.4	4
10-11-88	10.0	19.0	753	121	83	10.1	6.6	<1
10-27-88	10.5	13.0	765	179	135	9.6	7.2	1
11-15-88	9.5	14.0	766	225	86	11.0	7.3	2
11-21-88	8.5	21.0	757	1,400	84	11.1	7.0	42
11-29-88	1.5	5.0	768	1,600	90	12.1	6.5	50
12-14-88	0.5	--	760	330	92	14.8	7.7	2
12-29-88	2.0	6.0	767	399	90	13.4	7.2	1
01-10-89	4.0	10.5	772	605	92	13.9	7.7	2
01-15-89	4.5	--	750	1,590	96	13.4	7.8	16
01-16-89	4.0	10.5	752	2,460	97	13.2	7.5	125
01-17-89	3.5	7.5	761	1,440	91	13.6	7.7	38
01-26-89	4.0	7.5	761	501	84	13.3	7.8	<1
02-21-89	6.0	7.0	752	540	88	13.2	7.9	5
02-23-89	6.5	3.0	759	3,030	94	12.1	8.1	95
03-06-89	5.5	1.0	768	1,950	80	12.7	7.7	19
03-07-89	3.0	-3.0	768	8,510	79	12.7	7.4	660
03-08-89	2.5	-4.0	768	3,390	74	13.8	7.7	242
03-09-89	2.0	1.5	772	2,180	75	14.1	7.6	37
03-10-89	3.0	6.5	768	2,650	76	13.9	7.7	20
03-22-89	7.5	7.0	767	1,800	89	11.9	7.6	17
03-24-89	6.0	--	765	7,570	75	11.6	7.8	78
03-25-89	6.0	11.0	763	7,340	80	11.7	7.0	228
03-26-89	8.0	20.0	766	3,370	81	10.6	7.6	119
03-27-89	12.0	20.5	762	2,230	85	10.3	7.6	26
04-04-89	14.0	22.0	752	1,010	77	9.2	6.4	4
04-20-89	15.0	14.0	765	2,490	87	9.4	7.4	46

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
08-16-88	2	0	<0.040	0.010	<0.040	<0.040	0.30	0.040	0.020	2.7	8.3
08-31-88	2	5	.100	<.010	.100	.090	.50	.100	.020	3.5	7.4
09-16-88	<1	<1	<.040	<.010	<.040	.070	.30	.100	<.010	2.5	6.9
09-28-88	1	3	<.040	<.010	<.040	<.040	.20	<.100	<.010	2.1	5.1
10-11-88	<1	<1	<.040	<.010	<.040	<.040	.18	<.100	<.010	3.0	4.3
10-27-88	<1	<1	<.040	.010	<.040	.050	.30	<.100	<.010	4.0	7.3
11-15-88	1	1	<.040	<.010	<.040	<.040	.20	.020	<.010	3.5	8.2
11-21-88	7	35	.120	<.010	.120	.090	.60	.100	.010	3.7	8.0
11-29-88	10	40	.570	.010	.580	.260	1.10	.300	.030	7.7	9.2
12-14-88	2	0	.560	<.010	.560	<.040	.20	.020	.010	3.0	8.5
12-29-88	1	0	.480	<.010	.480	<.040	.10	.010	.030	2.6	6.8
01-10-89	2	0	.470	<.010	.470	<.040	.50	.030	.010	4.1	7.4
01-15-89	2	14	.660	<.010	.660	.040	.50	.050	.010	3.7	9.8
01-16-89	10	115	.740	<.010	.740	.150	1.10	.230	.030	6.7	9.1
01-17-89	4	34	.810	<.010	.810	.170	.80	.130	.020	5.3	10.0
01-26-89	<1	<1	.680	.010	.690	<.040	.30	.030	.010	1.5	8.7
02-21-89	2	3	.490	<.010	.490	.070	.20	.030	<.010	1.4	6.8
02-23-89	10	85	.770	<.010	.770	.150	1.30	.230	.030	7.9	9.0
03-06-89	4	15	.680	.010	.690	.070	.40	.060	<.010	3.1	9.3
03-07-89	68	592	.680	.010	.690	.220	2.6	.490	<.010	7.2	8.0
03-08-89	30	212	.810	.010	.820	.100	.90	.250	<.010	5.5	8.4
03-09-89	7	30	.920	<.010	.920	.100	.50	.100	.020	3.4	9.5
03-10-89	4	16	.900	<.010	.900	.120	.40	.070	.020	--	11.0
03-22-89	4	13	.570	<.010	.570	<.040	.50	<.100	.020	3.4	9.3
03-24-89	11	67	.440	.010	.450	<.040	.30	.050	.010	4.9	8.6
03-25-89	36	192	.650	.010	.660	.120	1.50	.400	.020	6.9	7.0
03-26-89	29	90	.800	.010	.810	.090	.80	.200	.020	4.9	8.6
03-27-89	6	20	.760	.010	.770	.070	.40	.080	.020	2.9	9.6
04-04-89	1	3	.530	<.010	.530	<.040	.20	.020	<.010	5.3	9.8
04-20-89	7	39	.450	.010	.460	.060	.80	.170	.010	5.8	7.3

Appendix 2. Selected chemical and physical water-quality characteristics of the Rappahannock River near Fredericksburg, Virginia, station number 01668000—Continued

[All samples were collected by the U.S. Geological Survey and analyzed by the Virginia Division of Consolidated Laboratories; °C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft³/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft³/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C, suspended (mg/L) (00530)
04-24-89	15.5	19.5	757	915	81	9.6	7.8	3
05-02-89	17.5	21.0	748	12,100	80	7.2	7.4	494
05-03-89	16.0	14.5	756	6,960	63	8.5	7.6	230
05-03-89	17.0	21.0	755	5,540	65	8.8	7.4	197
05-04-89	16.0	18.0	761	3,390	63	9.2	7.4	83
05-06-89	16.0	26.0	753	48,400	46	9.8	7.0	496
05-06-89	16.0	24.0	753	54,100	51	--	7.3	514
05-07-89	14.5	8.5	757	27,800	57	8.6	7.0	184
05-08-89	12.5	16.5	759	7,760	64	10.7	7.2	109
05-09-89	12.0	18.5	760	5,220	69	9.5	6.9	79
05-10-89	14.0	17.0	747	5,670	70	9.5	7.4	43
05-11-89	13.0	15.0	755	6,120	64	10.2	6.8	100
05-12-89	14.0	13.5	751	4,570	72	9.4	6.4	23
05-13-89	15.0	23.5	754	3,490	65	10.0	6.7	29
05-15-89	14.0	15.5	755	2,650	64	8.8	6.7	26
05-17-89	15.0	25.0	755	7,180	83	9.5	6.7	105
06-07-89	20.5	23.0	758	14,900	59	8.0	7.2	318
06-08-89	20.5	23.0	760	7,630	68	8.0	7.0	106
06-23-89	24.5	31.5	762	2,360	77	8.3	7.4	45
06-28-89	27.5	29.0	758	934	81	6.9	7.2	10
07-05-89	25.5	--	763	1,800	76	8.0	7.5	3
07-16-89	24.5	29.5	758	1,110	76	8.1	7.3	2
07-17-89	21.5	21.0	761	7,500	55	7.6	6.7	414
07-18-89	21.5	23.0	764	2,430	70	8.1	7.3	95
07-21-89	23.5	27.5	762	5,270	76	7.7	7.0	297
07-25-89	26.5	28.0	768	1,440	65	7.7	7.1	11
07-31-89	22.0	25.0	762	10,900	60	7.6	6.8	420
08-01-89	22.0	26.5	764	3,540	60	8.2	7.3	304
08-07-89	27.5	29.0	754	992	80	7.8	7.3	1
08-22-89	24.0	23.0	765	817	138	7.6	7.6	2

Appendix 2.—Continued

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
04-24-89	1	2	0.230	0.010	0.240	<0.040	0.30	0.040	0.010	3.4	7.5
05-02-89	58	436	.460	.010	.470	.090	1.8	.800	<.010	6.8	7.7
05-03-89	30	200	.470	.010	.480	.100	1.4	.250	.010	6.9	9.3
05-03-89	26	171	.500	.010	.510	.090	1.2	.190	.010	5.8	9.8
05-04-89	13	70	.500	.010	.510	.050	.50	.170	.010	3.5	11
05-06-89	56	440	.320	.010	.330	.120	1.8	.600	.030	7.3	4.1
05-06-89	54	460	.380	.010	.390	.120	2.0	.700	.020	7.5	3.8
05-07-89	18	166	.570	.010	.580	.080	.90	.240	.020	5.9	7.3
05-08-89	11	98	.280	<.010	.280	.050	.80	.250	.010	3.7	9.7
05-09-89	11	68	.630	<.010	.630	<.040	.50	.170	<.010	2.7	10
05-10-89	7	36	.660	<.010	.660	<.040	.40	.120	.030	2.9	12
05-11-89	12	88	.560	<.010	.560	.060	.70	.240	.020	3.9	9.8
05-12-89	4	19	.610	<.010	.610	<.040	.30	.060	<.010	--	12
05-13-89	5	24	.630	<.010	.630	<.040	.20	.040	.010	1.9	12
05-15-89	5	21	.650	<.010	.650	<.040	.20	.070	.010	1.7	12
05-17-89	15	90	.500	.010	.510	.060	1.0	.140	.010	5.7	9.6
06-07-89	30	288	.370	.020	.390	.080	1.3	.330	.010	10	5.6
06-08-89	14	92	.780	.030	.810	.140	.90	.170	.040	9.9	6.9
06-23-89	7	38	.650	.010	.660	<.040	.50	.080	.010	4.4	12
06-28-89	2	8	.630	<.010	.630	<.040	.20	.050	.030	1.9	12
07-05-89	2	1	.470	<.010	.470	.050	.20	.030	.010	2.7	11
07-16-89	2	0	.570	<.010	.570	<.040	.30	.060	<.010	4.5	11
07-17-89	56	358	.560	.010	.570	.120	1.4	.500	.020	8.7	6.6
07-18-89	13	82	.670	<.010	.670	.060	.60	.110	.020	7.3	9.0
07-21-89	39	258	--	--	--	--	--	.420	.010	8.6	13
07-25-89	1	10	.580	<.010	.580	<.040	.20	.040	.020	2.7	13
07-31-89	40	380	.340	<.010	.340	.060	1.8	.560	.030	9.9	6.7
08-01-89	36	268	.270	<.010	.270	.090	1.3	.480	<.030	8.1	7.5
08-07-89	<1	1	.620	.010	.630	.040	.40	.060	.040	3.2	12
08-22-89	1	1	--	--	--	--	--	--	--	2.3	--

Appendix 2. Selected chemical and physical water-quality characteristics of the Rappahannock River near Fredericksburg, Virginia, station number 01668000—Continued

[All samples were collected by the U.S. Geological Survey and analyzed by the Virginia Division of Consolidated Laboratories; °C, degrees Celsius; 00027, parameter code; mmHg, millimeter of mercury; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; <, less than; --, no data available]

Date	Temperature, water (°C) (00010)	Temperature, air (°C) (00020)	Barometric pressure (mmHg) (00025)	Discharge (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	Oxygen, dissolved (mg/L) (00300)	pH (00400)	Residue, total at 105°C, suspended (mg/L) (00530)
09-27-89	15.5	18.0	773	3,470	79	9.5	7.1	212
10-02-89	18.0	27.0	756	2,280	70	9.2	7.0	13
10-03-89	18.0	26.0	759	6,840	70	8.6	6.9	284
10-04-89	17.5	13.0	762	2,900	78	9.2	7.2	70
10-13-89	14.0	21.5	762	792	80	9.2	7.2	6
10-20-89	13.0	14.5	755	9,230	65	7.6	7.1	180
10-21-89	12.5	20.0	758	6,330	73	9.8	7.4	66
11-06-89	10.0	18.0	761	1,040	82	11.1	7.4	4
11-28-89	7.5	19.0	761	1,520	102	12.5	7.2	7
12-07-89	4.0	3.0	767	925	77	14.2	7.9	1
12-18-89	.0	2.0	767	834	80	13.5	--	1
01-02-90	1.0	11.0	772	5,140	77	14.5	7.5	200
01-03-90	1.0	17.0	770	2,880	77	14.4	7.3	74
01-29-90	5.0	3.0	765	2,160	83	12.7	7.7	12
02-08-90	8.0	7.0	763	2,010	83	11.4	7.4	4
02-20-90	9.0	4.5	767	1,390	83	11.6	7.0	6
03-13-90	14.5	23.0	760	1,040	75	9.9	7.6	3
03-23-90	13.5	18.0	759	1,780	83	11.1	7.1	16
04-03-90	13.5	8.0	750	5,840	81	10.1	7.3	98
04-04-90	11.5	13.0	748	3,350	74	10.2	7.2	8
04-05-90	12.5	18.5	749	2,540	68	10.4	7.2	30
04-23-90	15.0	23.0	757	1,650	78	9.9	7.6	7
05-09-90	19.5	25.0	760	1,070	83	10.1	7.3	4
05-11-90	16.5	23.5	760	15,300	55	8.1	6.8	724
05-12-90	15.5	14.0	768	4,110	62	10.0	7.1	316
05-14-90	16.5	21.0	764	4,300	67	10.0	7.1	94
05-25-90	18.5	24.5	764	1,020	70	9.9	6.9	6
05-27-90	18.0	23.0	756	2,490	50	8.7	6.6	11
05-30-90	16.0	17.5	763	11,700	68	8.6	7.1	264
05-31-90	15.5	21.0	770	4,090	71	9.0	7.3	120
06-14-90	22.0	25.0	755	843	75	7.9	8.4	18
06-26-90	21.0	23.0	758	579	73	8.9	7.3	2

Date	Residue, volatile, suspended (mg/L) (00535)	Residue, fixed nonfilterable (mg/L) (00540)	Nitrogen, nitrate, dissolved (mg/L, as N) (00618)	Nitrogen, nitrite, dissolved (mg/L, as N) (00613)	Nitrogen, NO_2+NO_3, dissolved (mg/L, as N) (00631)	Nitrogen, ammonia, dissolved (mg/L, as N) (00608)	Nitrogen, ammonia + organic (mg/L, as N) (00625)	Phosphorus, total (mg/L, as P) (00665)	Phosphorus, ortho, dissolved (mg/L, as P) (00671)	Carbon, organic, total (mg/L, as C) (00680)	Silica, dissolved (mg/L, as SiO_2) (00955)
09-27-89	32	180	0.610	0.020	0.630	0.060	1.8	0.310	0.040	6.4	9.0
10-02-89	3	10	.540	<.010	.540	<.040	.30	.070	.030	3.0	11
10-03-89	32	252	.520	.010	.530	.050	1.6	.600	.050	7.1	8.4
10-04-89	10	60	.670	<.010	.670	.050	.90	.140	.050	5.4	10
10-13-89	2	4	.600	<.010	.600	<.040	.30	.020	.020	2.1	12
10-20-89	20	160	.450	.010	.460	<.040	1.0	.240	.040	7.9	8.3
10-21-89	9	57	.590	<.010	.590	<.040	.70	.150	.030	5.9	10
11-06-89	1	3	.410	<.010	.410	<.040	.20	.020	.010	1.9	13
11-28-89	2	5	.640	<.010	.640	.070	.40	.030	.010	2.6	12
12-07-89	1	0	.440	<.010	.440	<.040	.20	.010	<.010	2.5	10
12-18-89	1	0	.240	<.010	.240	<.040	.20	.020	.010	3.2	11
01-02-90	20	180	.950	.010	.960	.270	1.5	.370	.040	7.4	7.1
01-03-90	8	66	1.02	.010	1.03	.190	.50	.140	.020	5.7	9.3
01-29-90	1	11	.790	<.010	.790	.070	.40	.070	.020	2.8	12
02-08-90	2	2	.800	<.010	.800	<.040	.30	.040	.010	2.0	12
02-20-90	1	5	.590	<.010	.590	<.040	.20	.020	<.010	2.6	10
03-13-90	3	0	.300	<.010	.300	.040	.20	.010	<.010	1.7	4.3
03-23-90	3	13	.570	<.010	.570	<.040	.30	.040	.030	4.6	10
04-03-90	14	84	.520	<.010	.520	.050	1.2	.350	.010	5.8	9.6
04-04-90	6	2	.580	.020	.600	.070	.90	.240	.020	5.2	9.8
04-05-90	17	13	.590	<.010	.590	.040	.40	.110	.010	3.4	11
04-23-90	1	6	.590	<.010	.590	.040	.30	<.040	.010	2.1	11
05-09-90	1	3	.450	<.010	.450	<.040	.30	.020	<.010	2.7	9.5
05-11-90	84	640	.600	.010	.610	.170	2.8	1.10	.010	8.8	6.5
05-12-90	40	276	.710	<.010	.710	.070	1.0	.340	.020	6.2	9.6
05-14-90	12	82	.630	<.010	.630	<.040	.60	.140	.010	3.7	12
05-25-90	6	0	.550	<.010	.550	<.040	.20	.020	.010	2.2	11
05-27-90	2	9	.530	<.010	.530	<.040	.30	.050	<.010	3.2	11
05-30-90	30	234	.860	.050	.910	<.040	1.7	>.500	.020	9.3	8.1
05-31-90	13	107	.870	<.010	.870	<.040	.50	.120	.020	3.5	11
06-14-90	4	14	.240	<.010	.240	.040	.20	.040	<.010	2.5	6.5
06-26-90	2	<1	.500	<.010	.500	<.040	.20	.030	.010	2.8	9.5

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