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STATUS AND TRENDS IN WATER QUALITY AND LIVING RESOURCES IN THE VIRGINIA CHESAPEAKE BAY: RAPPAHANNOCK RIVER (1985-2001)

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Principal Investigators:

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Submitted to:

Mr. Frederick J. Hoffman
Virginia Department of Environmental Quality
629 East Main Street
Richmond, Virginia 23230

February 24, 2003

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Notice

During the mid-1990's the Chesapeake Bay Program's (CBP) Analytical Methods and Quality Assurance Workgroup recommended that the CBP adopt new and more accurate analytical methods for measuring total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus. An recent examination of scatterplots of these parameters suggested that the adoption of these news methods in 1994 may have resulted in step trends in concentrations of these parameters. Since the presence of a step trend in the data would adversely affect the ability to detect long-term trends, the CBP's Tidal Monitoring and Assessment Workgroup (TMAW) recommended a statistical protocol that could be used to identify and correct step trends caused by the method changes in these parameters. This procedure would serve as a "stop-gap" protocol until more robust statistical techniques could be developed and adopted for general use by the CBP for long term-trend detection in such cases.

This report presents long-term trend results on nutrient data using TMAW's "stop-gap" protocol (see in Chapter III). Subsequent examinations of the results of these analyses by the TMAW indicate that, in some cases, the method correction protocols may not have performed with the desired validity. As a result, caution should be used in interpreting the long-term water quality trends conducted on the method-corrected nutrient data provided in this report.

Results for dissolved inorganic nitrogen in tidal fresh and oligohaline segments indicated there were no method change effects (see Table 3-1:Chapter III) and, as a result, long-term trend analyses performed on these parameters within these salinity regimes should be valid. In addition, all long term trends (1985 to 2001) presented for chlorophyll *a*, total suspended solids, secchi depth, dissolved oxygen, salinity and temperature were not subjected to method correction protocols and can be considered valid. All trends presented on data collected from 1995 through 2001 are valid. A new method for assessing long term trends on data subjected to analytical method changes will be used in all subsequent reports.

Preface

This material in this report was produced for the Virginia Department of Environmental Qaulity in order to summarize patterns of status and trends in water quality, phytoplankton, primary productivity, zooplankton and benthos collected as part of the Virginia Chesapeake Bay Program. There are three reports, referred to as basin summaries, one each for the James River, the York River and the Rappahannock River. These basin summaries are intended to be electronic reports that will be preiodically updated and they were intended for an audience already knowledgeable of the history and rationale of the program; design of the program; field and laboratory methods; specialized parameters, e.g. the Benthic Index of Biotic Integrity; status and trends analytical methods, etc.

In order to create a record of past patterns in status and trends and to make these data more widely available, a printed version of each basin summary was produced. To make the information more interpretable we have added an introduction and a methods section. However, this report is a data report and is not a comprehensive, interpretive report. Therefore, there is no discussion section to this report.

All three basin summaries and appendices are available at the Old Dominion University Chesapeake Bay Program website <www.chesapeakebay.odu.edu> under "Reports." The James River Report includes the Elizabeth River, the Chickahominy River and the Appomattox River. The York River Report includes the tidal Pamunkey River and Mattaponi River. The Rappahannock River Report includes the Corrotoman River. Also available at this website are appendices that include (1) tables of status for all parameters measured at all stations sampled by each program, (2) tables of all parameters and metrics for which there was a significant trend, and (3) scatter plots of all parameters over time. There are five appendices: water quality, phytoplankton, primary productivity, zooplankton and benthos.

Table of Contents

List of Appendices (on attached CD-ROM)

Summary

This summary includes materials provided by Rick Hoffman of the Chesapeake Bay Program of the Virginia Department of Environmental Quality. Environmental information regarding other important conditions in Chesapeake Bay (e.g. submerged aquatic vegetation, fisheries, chemical contaminants) has been reported previously (*Chesapeake Bay and its Tributaries: Results of Monitoring Programs And Status of Resources; 2002 Biennial Report of the Secretary of Natural Resources to The Virginia General Assembly*).

The Virginia Chesapeake Bay and its tidal tributaries continue to show some environmental trends indicating progress toward restoration of a more balanced and healthy ecosystem. However, the Bay system remains degraded and some areas and indicators show continuing degradation. Progress in reducing nutrient inputs has made demonstrable improvements and we expect that continued progress toward nutrient reduction goals, along with appropriate fisheries management and chemical contaminant controls, will result in additional improvements to the Bay. Findings from the last 17 years of the monitoring programs are highlighted below. Patterns of nutrient and sediment loads are summarized in Table 1.

- Nonpoint source loads (estimates of controllable and uncontrollable) of phosphorus, nitrogen, and sediment as calculated by the Bay Program Watershed Model, decreased by 7%, 9%, and 11%, respectively, compared to the 1985 baseline loads.

- Point source nutrient loads were reduced by 57% for phosphorus and 25% for nitrogen, compared to the 1985 baseline loads. This decrease in discharge may be partly due to ongoing drought conditions in Virginia.

- Combined nutrient loads were reduced by 26% for phosphorus and 15% for nitrogen, compared to the 1985 baseline loads.

- For phosphorus, there were improving trends at the river input stations of the James River, Mattaponi River and Rapphannock River with a degrading trend in the Pamunkey River. The improving trends are indicative of both point and nonpoint source nutrient reductions over the last 17 years. Although some improving trends were detected in tidal waters, many degrading trends in phosphorus were detected. Overall, there were 12 areas with improving trends and 19 areas with degrading trends in this parameter.

- For nitrogen, there were improving trends in the Mattaponi River and the Potomac River and a degrading trend in the Pamunkey River. Nitrogen levels showed improving trends in much of the tidal Potomac River and Elizabeth River. Degrading trends occurred in much of the tidal York River and lower James River. Overall, there were 9 areas showing improving trends and 10 areas showing degrading trends for nitrogen.

- Because of improvements made in analytical techniques instituted in 1995, a second set of trend analyses on data from 1995 through the present were preformed in order to use the most consistent data record. Both phosphorus and nitrogen show many improving conditions throughout the Virginia Chesapeake Bay when these most recent seven years are examined. These improvements are probably related to the management actions to reduce nutrient inputs as well as the generally decreased river flow that has occurred in recent years.

- Chlorophyll levels are moderately high throughout much of the tidal waters. Degrading trends were widespread geographically and indicative of detrimentally high nutrient levels. Overall, nine areas showed degrading trends in chlorophyll *a* while only one area showed an improving trend.

- Levels of dissolved oxygen are improving in geographically widespread areas of the tidal rivers. However, conditions for dissolved oxygen still remain only fair in much of the Virginia Chesapeake Bay and a few of the river segments near the Bay. The Corrotoman River and Tangier Sound are the only areas with degrading trends in dissolved oxygen. Overall, there were 13 areas showing improving trends and two areas showing degrading trends for dissolved oxygen conditions.

- Water clarity, a very important environmental parameter, was generally poor and degrading trends were detected in many areas near and in the Virginia Chesapeake Bay. This is probably related to high and scattered increasing levels of suspended solids. These degrading conditions in the Virginia Chesapeake Bay may result in degradation of zooplankton populations and are a major impediment to restoration of submerged aquatic vegetation (SAV). Overall, there were no areas showing improving trends and 13 areas showing degrading trends in water clarity.

- With regard to algal levels, there are widespread increases in cyanobacterial abundance and biomass and also concern about the poor status of dinoflagellates. However, there are widespread improvements in rates of primary productivity.

- Zooplankton community diversity showed generally improving trends in upstream regions but degrading trends at the mouths of all three rivers. These degrading trends are possibly related to degrading trends in nitrogen, phosphorus, and water clarity indicators, and a decreasing trend in salinity.

- Benthic community patterns differed greatly between the rivers. In the James River there strong improving trends upstream and continued good status down stream. In the Elizabeth River there was a strong improving trend although the status of the benthic communities remains poor. In the York River and the Rappahannock River there are degrading trends in the middle reaches.

Table 1. Nutrient and Sediment Loads for Virginia (2001). Modified from data provided by the Virginia Department of Environmental Quality. Phosphorous and nitrogen loads are in kg/year and sediment loads are metric tons/year. Percent change compares 2001 data to 1985 data. Nonpoint source loads are results based on the Year 2000 Progress Run of Phase 4.3 of the Chesapeake Bay Watershed Model and calculated reductions for calendar year 2001 Best Management Practices (BMPs) as monitored by the Department of Conservation and Recreation.

River Basin	2001 Phosphorus Load	Percent Change in Phosphorus	2001 Nitrogen Load	Percent Change in Nitrogen	2001 Sediment Load	Percent Change in Sediment
A. Nonpoint Loads						
Potomac	749,527	-10.5%	6,305,959	-10.1%	650,655	-13.4%
Rappahannock	396,532	-19.5%	3,372,686	-19.9%	297,812	-21.4%
York	297,250	-13.4%	3,089,427	-13.3%	126,172	-12.2%
James	2,037,523	- 0.8%	10,316,677	- 2.7%	1,085,925	- 5.4%
Coastal	88,295	-14.2%	943,327	- 5.0%	17,581	-17.2%
Totals	3,569,127	- 7%	24,028,077	- 9%	2,178,145	-11%
B. Point Source Loads. In parentheses is the number of significant point source discharges.						
Potomac (40)	251,218	-28%	5,336,045	+8%		
Rappahannock (14)	21,850	-74%	247,132	+11%		
York (9)	83,000	-59%	501,573	-20%		
James (30)	619,655	-62%	6,138,200	-44%		
Coastal (8)	66,482	-56%	826,527	+40%		
Totals	1,042,205	-57%	13,049,477	-25%		
C. Total Loads. All river basins combined.						
Nonpoint Source	3,569,127	-7%	24,028,077	-9%	2,178,145	-10.8%
Point Source	1,042,205	-57%	13,049,477	-25%		
Combined Loads	4,611,332	-26%	37,077,555	-15%	2,178,145	-10.8%

Chapter 1. Introduction

A marked decline in the water quality of the Chesapeake Bay has occurred over the past several decades. The disappearance of submerged aquatic vegetation in certain regions of the Bay, declines in the abundance of some commercially and recreationally important species, increases in the incidence of low dissolved oxygen events, changes in the Bay's food web, and other ecological problems have been related to the deteriorating water quality. The results of concentrated research efforts in the late 1970s and early 1980s stimulated the establishment of Federal and state directives to better manage the Chesapeake Bay watershed. By way of the Chesapeake Bay Agreements of 1983, the State of Maryland, the Commonwealths of Virginia and Pennsylvania, and the District of Columbia, agreed to share the responsibility for improving environmental conditions in the Chesapeake Bay. As part of this agreement, a long-term monitoring program in the Chesapeake Bay was established in order to: 1) track long-term trends in water quality and living resource conditions over time, 2) assess current water quality and living resource conditions, and 3) establish linkages between water quality and living resources communities. By tracking long-term trends in water quality and living resources, managers may be able to determine if changes in water quality and living resource conditions have occurred over time and if those changes are a reflection of management actions. Assessments of current status may allow managers to identify regions of concern that could benefit from the implementation of pollution abatement or management strategies. By identifying linkages between water quality and living resources it may be possible for managers to determine the impact of water quality management practices on living resource communities.

Water quality and living resource monitoring in the Virginia Mainstem and tributaries began in 1985 and has continued for 16 years. Detailed assessments of the status and long-term trends in water quality and living resources in Chesapeake Bay and its tributaries have been previously conducted (Alden et al., 1991,1992; Carpenter and Lane, 1998; Dauer, 1997; Dauer et al., 1998a,1998b, 2002; Lane et al.,1998; Marshall, 1994,1996; Marshall and Burchardt, 1998; Marshall et al., 1998). An attempt was made to determine if there was concordance in current conditions of, and long-term changes, in water quality and living resources. The purpose of this project was to reassess the results of these studies by re-conducting the analyses after adding data collected during 2001. This report describes the status of water quality and living resource conditions for the Virginia Mainstem and tributaries, summarizes major long-term trends in water quality and measures of living resource community health.

Chapter 2. Monitoring Program Descriptions

I. Water Quality

A. Sampling Locations and Procedures

As part of the U. S. Geological Survey's River Input Program, water quality data have been collected at five stations near the fall line and three stations above the fall line in Virginia. Samples were taken at base-flow twice a month and during high flows whenever possible between 1988 and 2001. Water quality data have also been collected by the Virginia Department of Environmental Quality at three additional stations upstream of these River Input sites (Figure 2-1). These stations had a minimum of three consecutive years of samples taken between 1985 and 1996 with sampling occurring on at least a monthly basis.

Water quality conditions were regularly monitored at 28 sites in the Bay Mainstem beginning in July, 1985. From 1985 until 1995 eight stations were sampled by Old Dominion University (ODU) and 20 stations were sampled by the Virginia Institute of Marine Science (VIMS). From 1995 through the present, Mainstem water quality monitoring was conducted by ODU. Tributary water quality monitoring was conducted by the Department of Environmental Quality at 28 sites in the James, York (including Mattaponi and Pamunkey) and Rappahannock rivers (Figure 2-2). In addition, six permanent water quality monitoring sites were established in the Elizabeth River/Hampton Roads Harbor by ODU in February, 1989 (Figure 2-2).

The temporal sampling scheme for the water quality monitoring program changed several times over the 14 year period (varying from 20 to 12 sampling events per year) as a result of changes in the monitoring program budget. In general, Mainstem sampling cruises were conducted semi-monthly from March through October and monthly from November through February. Tributary sampling by the Virginia Department of Environmental Quality was generally conducted 20 times per year. The Elizabeth River stations were sampled monthly. Field sampling procedures used for ODU and VIMS water quality collections are described in detail by Alden et al., 1992a. Field sampling procedures for DEQ water quality collections are described in detail in DEQ's Quality Assurance Project Plan for the Chesapeake Bay Program (Applied Marine Research Laboratory, 1998).

B. Laboratory sample processing

Descriptions of laboratory sample processing and standard operating procedures for all water quality parameters are found in the Chesapeake Bay Program Quality Assurance Project Plans (QAPjPs) prepared by each of the participating laboratories (Applied Marine Research Laboratory, 1998). Copies of the QAPjPs can be obtained by contacting EPA's Chesapeake Bay Program Quality Assurance Officer.

II. Phytoplankton

A. Sampling Locations and Procedures

Seven stations were established in Chesapeake Bay in July 1985. These were CB6.1, CB6.4, CB7.3E, CB7.4, LE5.5, WE4.2, and LE3.6(Figure 2-3). From July, 1985 through September, 1990, phytoplankton collections were taken from these stations twice a month from March through October, and monthly November through February. From October, 1990, monthly samples were taken at all Bay stations. Monthly sample collections and analysis in the James (TF5.5, RET5.2),
York (RET4.1, RET4.3), and Rappahannock (TF3.3, RET3.1) rivers began in March, 1986. In March, 1987, station RET4.1 in the Pamunkey River was replaced by station TF4.2, and in February, 1989, monthly collections began at two stations (SBE2, SBE5) in the Elizabeth River. Picoplankton analysis was included at several trial stations in January, 1989, and was expanded to include all stations in July, 1989. Primary production analysis was added to all Bay and tributary stations in July 1989.

At each station, two vertical sets of three liter water samples were taken at five equidistant depths above the pycnocline and placed in two separate carboys. The process was repeated at five depths below the pycnocline. The water in each carboy was carefully mixed and replicate 500 ml sub-samples were removed from each carboy, and fixed with Lugol's solution. A second set of 125 ml sub-samples were also taken above and below the pycnocline, preserved with glutaraldehyde and placed in a cooler. These samples were taken to determine the concentrations of the autotrophic picoplankton population. An additional replicate set was also taken from the same carboy set taken above the pycnocline for primary productivity measurements.

B. Laboratory Sample Processing

Samples for phytoplankton analyses were passed through a series of settling and siphoning steps to produce a concentrate (or fraction of the concentrate) that was examined using a modified Utermöhl method with an inverted plankton microscope (Marshall and Alden, 1990). The analysis procedure attained an estimated precision of 85% (Venrick, 1978). The autotrophic picoplankton were processed through a protocol that included their collection on a 0.2 µ nucleopore filter, with subsequent analysis using an epifluorescent microscope, under oil at 1000x magnification, with a "green" and “blue” filter sets (Marshall, 1995). Supplemental analysis with a scanning electron microscope was used in several of the species identifications. Methodology for the productivity measurements is given in Marshall and Nesius (1996). Appropriate quality assurance/quality control practices in sample collection, analysis, and data entry were employed throughout this period.

III. Zooplankton

A. Sampling Locations and Procedures

Microzooplankton communities were monitored monthly at seven sites in the Mainstem and six sites in the Virginia tributaries beginning in January, 1993 (Figure 3-3). Whole water samples were collected at all stations. Before sampling, 10 ml of modified Lugol's solution was placed into two liter (L) bottles designated for each station. The water was sampled through the use of a battery powered pump attached to a hose. Two composite water samples, each totaling 15 L, were taken from five equidistant depths above the pycnocline and collected in two carboys. Each carboy was thoroughly mixed and 1 L taken from each (Samples A and B for each station).

Mesozooplankton communities were monitored monthly at seven sites in the Mainstem beginning in July, 1985 (Figure 3-3). Monthly mesozooplankton monitoring was conducted at six sites in the major Virginia tributaries (Rappahannock, York/Pamunkey, and James rivers) beginning in March, 1986 (one site on the Pamunkey was originally sampled at RET4.1 but relocated to TF4.2 in February, 1987). In 1986 a new sampling regime began that increased frequency to two samples per month during April, May, July, and August at all the tidal freshwater stations (TF3.3, TF4.2, TF5.5). At the same time, sampling frequency was increased to twice per month for July and August also at stations RET3.1, RET4.3, RET5.2, LE5.5, and SBE5 in order to allow better characterization of zooplankton communities during spawning periods of commercially important fish species in these areas.

Single mesozooplankton tows were conducted at each site using a bongo apparatus with 202 µ mesh nets. The nets were towed obliquely from the surface to 1 m above the bottom and back to the surface over a period of approximately five minutes. A calibrated flowmeter was attached to each net and flowmeter readings were recorded just prior to net deployment and immediately upon net retrieval. Once onboard the research vessel, the nets were "washed down" and the contents of the cod-ends were decanted into pre-labeled one liter sample containers and preserved with 7% buffered formalin. All sample numbers were recorded on a sample chain-of-custody form before departing the site.

B. Laboratory Sample Processing

The whole water samples taken for microzooplankton (<200µ) analysis were processed through a screen, plus a series of settling and siphoning procedures (Park and Marshall, 1993). These steps removed the larger zooplankters and debris to provide 3 sub-sets based on size to be analyzed. This method insured the collection and analysis of the small non-loricated ciliates to be included in the count.

The mesozooplankton samples were processed according to the coefficient of variation stabilizing (CVS) method described by Alden et al. (1982). This method has numerous advantages over other zooplankton enumeration techniques. The CVS method provides abundance estimates with equitable coefficients of variation for species of interest in zooplankton subsamples. It is particularly useful in increasing the precision of the estimates of numbers of large species of relatively low abundance that may be important due to their biomass, their trophic position, or their economic significance. The investigator can be quite confident that the precision of the abundance estimates is at least at the pre-determined level for all species processed by the CVS method. The method also has the advantage of allowing the investigator to set a level of precision that is consistent with cost, manpower, or time constraints. Finally, the size class data produced by the CVS method may provide information of intrinsic ecological significance.

Briefly, the CVS method involves the sieve fractionation of the samples into size classes of 2000µ, 850µ, 650µ, 300µ , and 200µ. This series was found useful for Bay mesozooplankton communities. An additional sieve size fraction between 200µ and 63µ was collected and analyzed beginning in 1998. This fraction was added to allow greater comparability with the mesozooplankton data collected in Maryland. However, these data are incomplete and the results from this additional sieve-size fraction will be reported beginning with the 1999 data set. The size classes appropriate for whole counts were transferred to labeled vials containing 7% buffered formalin and temporarily stored until counted. The size class aliquots in which the organisms were too numerous to count in their entirety were split with a Folsom plankton splitter until an appropriate sample size was achieved for statistically valid counts of the dominant species. A level of sampling error of 30% requires that each species of interest be counted to achieve a range of between 30 and 56 organisms counted in any given split. During the splitting process, reserve splits were labeled, preserved in formalin and retained until the counting procedure was completed. Those species observed in the final split were counted in the reserved splits until all had achieved the range for the 30% error level (see Alden et al., 1982 for details of CVS methodology). However, if commercially important species (e.g., blue crab zoea) were encountered, they were counted to achieve the 30% error level for the statistical models. The samples were counted under a dissecting microscope in custom-designed counting trays (60 mm tissue culture dishes). Taxonomic identifications were made under compound or inverted microscopes and reference collections and/or photographs were maintained for each taxon for documentation and QA/QC purposes.

IV. Benthos

A. Fixed Location Sampling

Sixteen stations in the lower Chesapeake Bay were sampled quarterly (March, June, September, December) from March 1985 through December 1995 as part of the Benthic Biological Monitoring Program of the Chesapeake Bay Program. Beginning in 1996 sampling at the fixed stations occurred only in June and September and a stratified random sampling element was added to the program. Power and robustness analyses indicated that sampling during June and September would be sufficient for detecting long-term trends at the fixed locations while at the same time, allow funding resources to be reallocated to the probability-based random sampling regime (Alden et al., 1997). Stations were located within the mainstem of the bay and the major tributaries -the James, York and Rappahannock rivers(Figure 2-3). In the tributaries, stations were located within the tidal freshwater zone (TF5.5, TF4.2, TF3.3), turbidity maximum (transitional) zone (RET5.2, RET4.3, RET3.1), lower estuarine mesohaline muds (LE5.2, LE4.1,

LE3.2) and lower estuarine polyhaline silty-sands (LE5.4, LE4.3). The tidal freshwater station within the York River estuary was located in the Pamunkey River. In the Mainstem of the Bay three stations were located off the mouths of the major tributaries (CB8.1, CB6.4, CB6.1) and two stations in the deeper channels near the bay mouth (CB7.3E) and above the Rappahannock River near the Virginia-Maryland border (CB5.4).
In 1989, five additional stations were added to the program: two stations in the Southern Branch of the Elizabeth River (SBE2, SBE5) in regions exposed to contaminated sediments, a station in the transitional region of the James River (LE5.1), a station in the lower York River exposed to low dissolved oxygen events (LE4.3B), and a station in the lower Rappahannock River exposed to low dissolved oxygen events (LE3.4).

For the fixed point stations three replicate box core samples were collected for benthic community analysis. Each replicate had a surface area of 184 cm^2, a minimum depth of penetration to 25 cm within the sediment, was sieved on a 0.5 mm screen, relaxed in dilute isopropyl alcohol and preserved with a buffered formalin-rose bengal solution.

At each station on each collection date a 50g subsample of the surface sediment was taken for sediment analysis. Salinity and temperature were measured using a Beckman RS5-3 conductive salinometer and bottom dissolved oxygen was measured using a YSI Model 57 oxygen meter. For the original 16 stations see Dauer et al. (1992) for a summary of the pattern of bottom oxygen values, Dauer et al. (1993) for a summary of the distribution of contaminants in the sediments and Dauer (1993) for a summary of salinity, water depth, and sedimentary parameters.

B. Probability-based Sampling

In 1996 a probability-based sampling program was added to estimate the area of the Virginia Chesapeake Bay and its tributaries that met the Benthic Restoration Goals as indicated by the B-IBI (Ranasinghe et al., 1994; Weisberg et al., 1997; Alden et al., 2002). Four strata were defined and each stratum was sampled by 25 randomly allocated sites. The four strata were: 1) the James River; 2) the York River (including the Pamunkey and Mattaponi rivers); 3) the Rappahannock River; and 4) the Mainstem of the Chesapeake Bay. Each year a new set of 25 random sites was selected for each stratum.

Probability-based sampling within strata supplements data collected at fixed-point stations. Sampling design and methods for probability-based sampling are based upon those developed by EPA's Environmental Monitoring and Assessment Program (EMAP, Weisberg et al., 1993) and allow unbiased comparisons of conditions between strata (e.g., tributaries) of the Chesapeake Bay within the same collection year and within tributaries for between different years. The consistency of sampling design and methodologies for probability-based sampling between the Virginia and Maryland benthic monitoring programs allows bay-wide characterizations of the condition of the benthos for the Chesapeake Bay (Dauer 1999; Dauer and Rodi 1998a, 1998b, 1999, 2001, 2002).

Within each probability-based stratum, 25 random locations were sampled using a 0.04 m^2 Young grab. At each station one grab sample was taken for macrobenthic community analysis and a second grab sample for sediment particle size analysis and the determination of total volatile solids. All sampling processing for probability-based sampling stations were identical to those for the fixed stations. Physico-chemical measurements were also made at the random locations.

C. Laboratory Sample Processing

In the laboratory, each replicate was sorted and all the individuals identified to the lowest possible taxon and enumerated. Biomass was estimated for each taxon as ash-free dry weight (AFDW) by drying to constant weight at 60 °C and ashing at 550 °C for four hours. Biomass was expressed as the difference between the dry and ashed weight.

The sand fraction of each sediment sample was dry sieved and the silt-clay fraction was quantified by a pipette analysis using the techniques of Folk (1974). Total volatile solids for each sediment sample was determined as the AFDW weight of the sediment divided by the dry weight of the sediment, expressed as a percentage.

V. Statistical Analyses

In order to ensure that long-term trends in water quality and living resource data are correctly interpreted, a unified approach for conducting the statistical analyses and interpreting their results was developed. Statistical analytical procedures used in this study were based on guidelines developed by the CBP Monitoring Subcommittee's Tidal Monitoring and Assessment Workgroup.
For both status and trend analyses, the stations were grouped into segments based on the segmentation scheme developed by the Data Analysis Workgroup (Figure 2-2). Status and trend analyses were conducted for different seasonal time periods as defined for each monitoring component in Table 2-1.

A. Status Assessments

For the tidal water quality stations, status analyses were conducted using surface and bottom water quality measurements for six parameters: total nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved inorganic phosphorus, chlorophyll *a*, and total suspended solids. Status analyses were also performed on secchi depth and bottom dissolved oxygen. All analyses were conducted using water quality data collected from all of the Chesapeake Bay Mainstem and tributary collection stations from the January 1999 through December of 2001 except for bottom dissolved oxygen for which analyses were conducted using data collected only during the summer months of June through September.

The relative status of each station and segment was determined by comparison to a benchmark data set comprised of all data collected from 1985 to 1990 by both the Virginia and Maryland monitoring programs. Each station was rated as poor, fair, or good relative to the benchmark data. The ratings are obtained for data collected within each salinity zone with salinity zones being assigned using the Venice classification system (Symposium on the Classification of Brackish Waters, 1958). For each parameter in the benchmark data set, a transformation was chosen that yields a distribution that was symmetric and approximated by the logistic cumulative distribution function (CDF). In most cases, the logarithmic transformation was selected. A logistic CDF based on the mean and variance of each parameter of the benchmark data set was used to perform a probability integral transform on all data collected during the period of January, 1998 through December, 2001. This resulted in data in the interval (0,1) that follow a uniform distribution. The three year median of these transformed data was computed as an indicator of status for the period specified. The median of n observations taken from a uniform distribution follows a Beta distribution with parameters (m,m) where:

$$m = (n+1)/2$$

and n is the number of observations.

The transformed three year medians were compared to the Beta density distribution and status was determined by the placement of the transformed medians along the distribution. If the median was in the upper third of the distribution (where upper is chosen as the end of the distribution that is ecologically desirable) then the status rating is good, while a median in the middle third was rated fair, and a median in the lower third was rated poor. In most cases, serial dependence of the raw data resulted in greater than expected variance in the Beta density of the medians. To adjust for this, the variance of the Beta density was increased by a function of the ratio of among station variance to within station variance.

Because sampling regimes between monitoring programs varied with respect to the number of collection events within a given month and the number of replicate samples collected at each station varied, a uniform calculation protocol was adopted for use by both states to insure that the calculations were not inadvertently biased by these discrepancies. First, replicate values were combined by calculating a median for each station date and layer combination. Median values for each station month and year combination were calculated to combine separate cruises per month. Finally, station specific or segment specific median scores were calculated that were compared to the benchmark scale.

Status for phytoplankton, microzooplankton and mesozooplankton involved the calculation of relative status using the same technique as described for water quality relative status assessments.
For phytoplankton communities the following indicators were assessed: total phytoplankton community abundance, total phytoplankton community biomass, diatom abundance, dinoflagellate abundance, cyanobacteria abundance, picoplankton abundance, and primary productivity (carbon fixation). Benchmarks for picoplankton abundance were made using data collected only in Virginia since sampling protocols for the Maryland program did not include counts of epifluorescent picoplankton. Microzooplankton parameters assessed included total microzooplankton abundance, copepod nauplii abundance and rotifer abundance. Mesozooplankton parameters assessed included the Margalef diversity index, the Shannon-Weiner diversity index, and total mesozooplankton abundance. Note that the

benchmarks for mesozooplankton data were made using data collected only in Virginia since the sampling protocols for the Maryland program does not include counts of epifluorescent picoplankton. A change in laboratory sample processing for the mesozooplankton
program occurred in 2000 and as a result only data collected through 1999 were used in both status and trend analyses for the mesozooplankton.

Status of benthic communities at each station was characterized using the three-year mean value (1999-2001) of the B-IBI (Weisberg et al., 1997). The B-IBI indicates whether the macrobenthic community meets the restoration goals developed for benthic habitats of the Chesapeake Bay. An index value that exceeds or equals 3.0 indicates that the macrobenthic community meets or exceeds the restoration goals developed for that habitat type while a value below 3.0 indicates that the macrobenthic community does not meet the restoration goals. Status of the benthic community was classified into four levels based on the B-IBI. Values less than or equal to 2 were classified as severely degraded, values from 2.0 to 2.6 were classified as degraded, values greater than 2.6 but less than 3.0 were classified as marginal, and values of 3.0 or more were classified as meeting goals.

Water quality data were assessed to determine if the SAV habitat requirements were met for the following parameters: light attenuation (KD), percentage of required light at the leaf surface (PLL) (0.5 and 1.0 m), total suspended solids, chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus. Three year medians for the SAV growing season were compared to the SAV habitat requirement values (see Table 2-2) using a Mann-Whitney U-test. If the median values were significantly higher (lower for PLL) than the habitat requirement for that parameter then the parameter was considered to have failed to met the SAV habitat requirements and if the values were significantly lower (higher for PLL) than the habitat requirement then the parameter was to considered to have met the SAV habitat requirement. If there was no significant difference between the habitat requirements or there were insufficient data to conduct the analysis, the parameter was considered borderline.

B. Long-term Trend Analyses

1. Non-tidal water quality

Trend analyses were conducted on data collected at nine stations at and above the fall-line in the Virginia tributaries. Concentrations of water-quality constituents are often correlated with streamflow. Removal of natural flow variability allows examination of changes in water quality resulting from human activities. Flow-adjusted concentration trends were determined with a non-parametric Kendall-Theil analysis. The trend slope was the overall median of the pairwise slopes of residuals from a log-linear-regression model incorporating flow and season terms. For data sets with greater than five percent censored data, a range in slope and magnitude was defined by twice computing the median slope - first, with censored data equal to zero and second, with censored data equal to the maximum detection limit. For data sets with greater than twenty percent censored data, no results were reported. A p-value of 0.05 or less was considered significant for this analysis.

When considering the health of living resources, it is necessary to examine trends in concentrations that may be both flow- and human-induced. These concentrations were weighted, but not adjusted, for flow. The flow-weighting resulted in a more representative monthly concentration than the one point per month typical of many observed data sets. The volume of flow occurring between these infrequent sample dates is likely to have a pronounced effect on average concentrations in the tidal estuaries and other mixed receiving areas. Therefore trends in flow-weighted concentrations may correlate better with trends in estuarine concentrations. The linear trend in flow-weighted concentration was estimated by regressing flow-weighted concentrations with time. In most cases, the data was log-transformed in order to meet the assumptions of normality, constant variance, and linearity. A p-value of 0.01 or less was considered significant for this analysis.

2. Tidal water quality

The statistical tests used for the trend analyses were the Seasonal Kendall test for monotonic trends and the Van Belle and Hughes (Gilbert, 1987) tests for homogeneity of trends between stations, seasons, and station-season combinations. A p value of 0.05 was chosen as the statistical test criterion for all trend analyses. Recent studies on representative data sets from the Chesapeake Bay monitoring program have indicated that these tests are very powerful and robust, even when data violate most of the assumptions of parametric statistics (Alden et al., 1991; Alden et al., 1992b; Alden et al., 1994; Alden and Lane, 1996).

Trend analyses were conducted on the same suite of water quality parameters used for the status assessments and salinity and water temperature. Prior to the trend analyses, data were reduced to a single observation for each station month and layer combination by first calculating the median of all replicates for each layer by station and date and then calculating the median between all dates for a given station within each month. For all applicable water quality parameters, any values less then the highest detection limit were set to one half of the highest detection limit. For calculated parameters, each constituent parameter that was below the detection limit was set to one half of the detection limit and the parameter was then calculated.

Increasing trends in total nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved inorganic phosphorus, chlorophyll *a* and total suspended solids should indicate increased eutrophication and as a result positive slopes in these parameters indicate degrading conditions while negative slopes indicate improving water quality conditions. Increasing trends in secchi depth and bottom dissolved oxygen indicate increasing water clarity and reduced eutrophication, respectively and, as a result, indicate improving water quality conditions. Decreasing trends in these two parameters indicate degrading conditions.

3. Tidal water quality method corrections

In 1994, changes in analytical methods for estimating concentrations of total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus were implemented by the Department of Environmental Quality in order to improve the accuracy of concentration estimates. Procedural changes involved the implementation of automated sample processing on a Scalar auto-analyzer for nitrites (NO2F), nitrates-nitrites (NO23F), ammonia (NH4F) and orthophosphate (PO4F). In addition, particulate nitrogen(PN), total dissolved nitrogen (TDN), particulate phosphorus (PHOSP) and total dissolved phosphorus (TDP) were added to the suite of parameters measured via auto-analyzer while total Kjeldahl nitrogen (fixed and whole) and direct measurements of total phosphorus (TP) were discontinued. These changes resulted in step trends in the data for these parameters that must be accounted for prior to conducting trend analyses.

Data were corrected for method changes by conducting a multiple regression analysis on log transformed water quality data with the following terms: 1) a linear trend term (Time); 2) a non-linear trend term ($Time^2$); 3) a month term to control for the effect of seasonal cycles; 4) a station term to control for the effect of differences due to station location and; 5) a dummy variable term that accounts for the effect of any changes in methods (0=prior to method change, 1=after method change). Analyses were conducted by salinity regime. For parameter/salinity regime combinations with a significant method change effect ($p. < 0.05$), coefficients for this model term were used as correction factors that were applied to the original data. The resulting "method corrected" data were analyzed for long-term trends using the seasonal Kendall trend test. A comparison was made between the method corrected trends and trends conducted on the original data to assess the effect of the method correction analysis on trend analysis results. For the Elizabeth River all segments except the Elizabeth River Mouth segment used the newer analytical methods from the inception of this program in 1989. Therefore, method corrections were only applied to the Elizabeth River Mouth segment.

4. Living resources

Trend analyses for phytoplankton communities were conducted on the following phytoplankton community indices: the phytoplankton IBI, total phytoplankton abundance (excluding picoplankton); total phytoplankton biomass (excluding picoplankton); the Margalef species diversity index, and C^{14} productivity. In addition, trend analyses were conducted on abundance and biomass values for the following taxonomic groups: diatoms; dinoflagellates; cyanobacteria; cryptomonads; chlorophytes; bloom producing species; and toxic bloom producing species.

The Margalef species diversity index was calculated as follows:

$$D = \frac{S - 1}{\log_2 N}$$

where S is the number of taxa in the sample and N is the number of individuals (Margalef, 1958).

Trend analyses were conducted by station using monthly medians of microzooplankton and mesozooplankton data collected from the beginning of the respective monitoring programs through

December of 2001 and December of 1999 for microzooplankton and mesozooplankton, respectively. Microzooplankton bioindicators used for the trend analyses included: total microzooplankton abundance; rotifer abundance; copepod nauplii abundance; oligotrich abundance; tintinnid abundance; sarcodinia abundance; and microzooplankton cladoceran abundance. Mesozooplankton bioindicators used for these analyses were: total mesozooplankton abundance (excluding copepod nauplii); holoplankton abundance; meroplankton abundance; indices of mesozooplankton community species diversity (including the total number of species collected, the Shannon-Weiner index, the Margalef diversity index, and Pielou's evenness); calanoid copepod abundance; cladoceran abundance; cyclopoid copepod abundance; *Acartia tonsa* abundance; *Bosmina longirostris* abundance; *Eurytemora spp.* abundance; and crab zoea abundance.

The Shannon Weiner diversity index (H') was calculated as follows:

$$H' = -\sum_{i=1}^{s} p_i \log_2 p_i$$

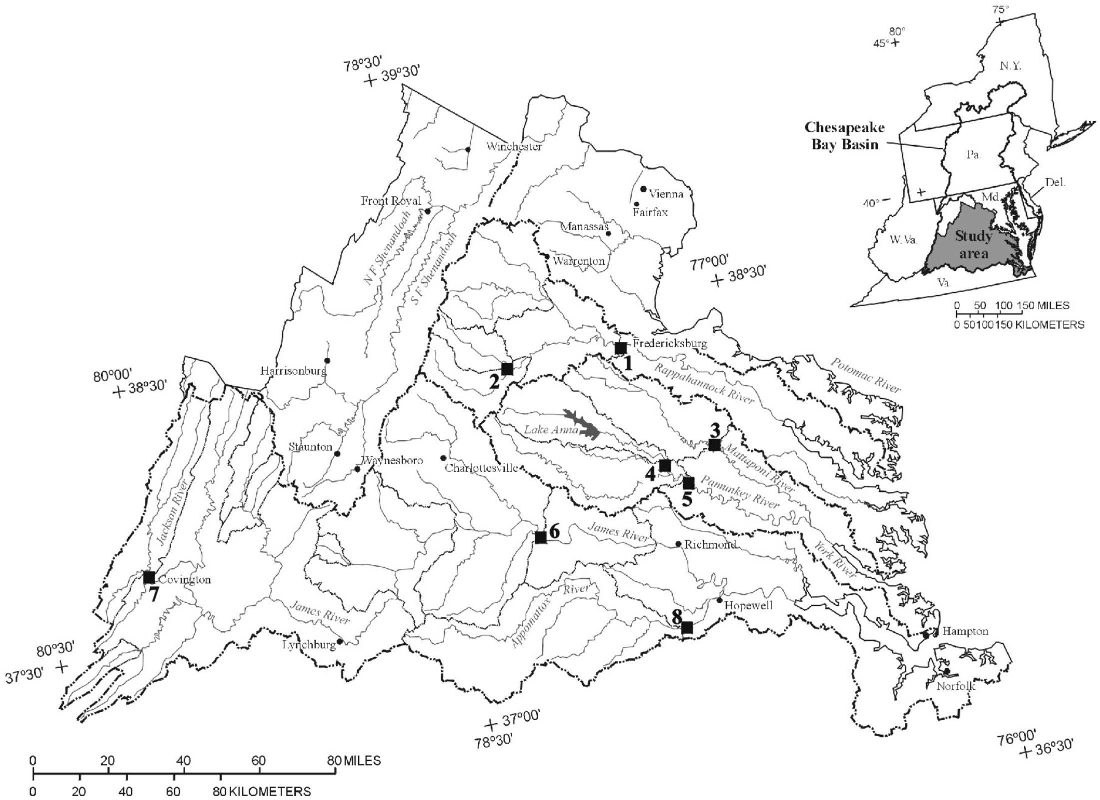
where p_i is the proportion of the ith species and S is the number of species.

Pielou's evenness index (J) was calculated using the equation:

$$J = \frac{H'}{\log_2 S}$$

where H' is the diversity index and S is the total number of species collected. Increasing trends in mesozooplankton abundance, holoplankton abundance, merozooplankton abundance and measures of species diversity indicate improving conditions while negative slopes indicate degrading conditions.

Trend analyses for benthic communities were conducted using the B-IBI (Ranasinghe et al., 1994; Weisberg et al., 1997) and on selected metrics of the B-IBI. Benthic restoration goals were developed for benthic habitats of the Chesapeake Bay based upon reference sites that were minimally impacted by low dissolved oxygen events and sediment contaminants. Goals were developed based upon data from an index period of July 15 through September 30. Therefore trends in the value of the B-IBI were based upon September cruise values for the 14 year period of 1985-1998. Selected benthic metrics were species diversity (H'), community abundance, community biomass, pollution-indicative species abundance, pollution-indicative species biomass, pollution-sensitive species abundance, and pollution-sensitive species biomass. See Weisberg et al. (1997) for a list of pollution-indicative and pollution-sensitive taxa.



1 Station 01668000 - Rappahannock River near Fredericksburg
2 Station 01666500 - Robinson River
3 Station 01674500 - Mattaponi River near Beulahville
4 Station 01671020 - North Anna River near Doswell
5 Station 01673000 - Pamunkey River near Hanover
6 Station 02035000 - James River at Cartersville
7 Station 02013100 - Jackson River at Covington
8 Station 02041650 - Appomattox River

Figure 2-1. Locations of the USGS sampling stations at and above the fall-line in each of the Virginia tributaries.

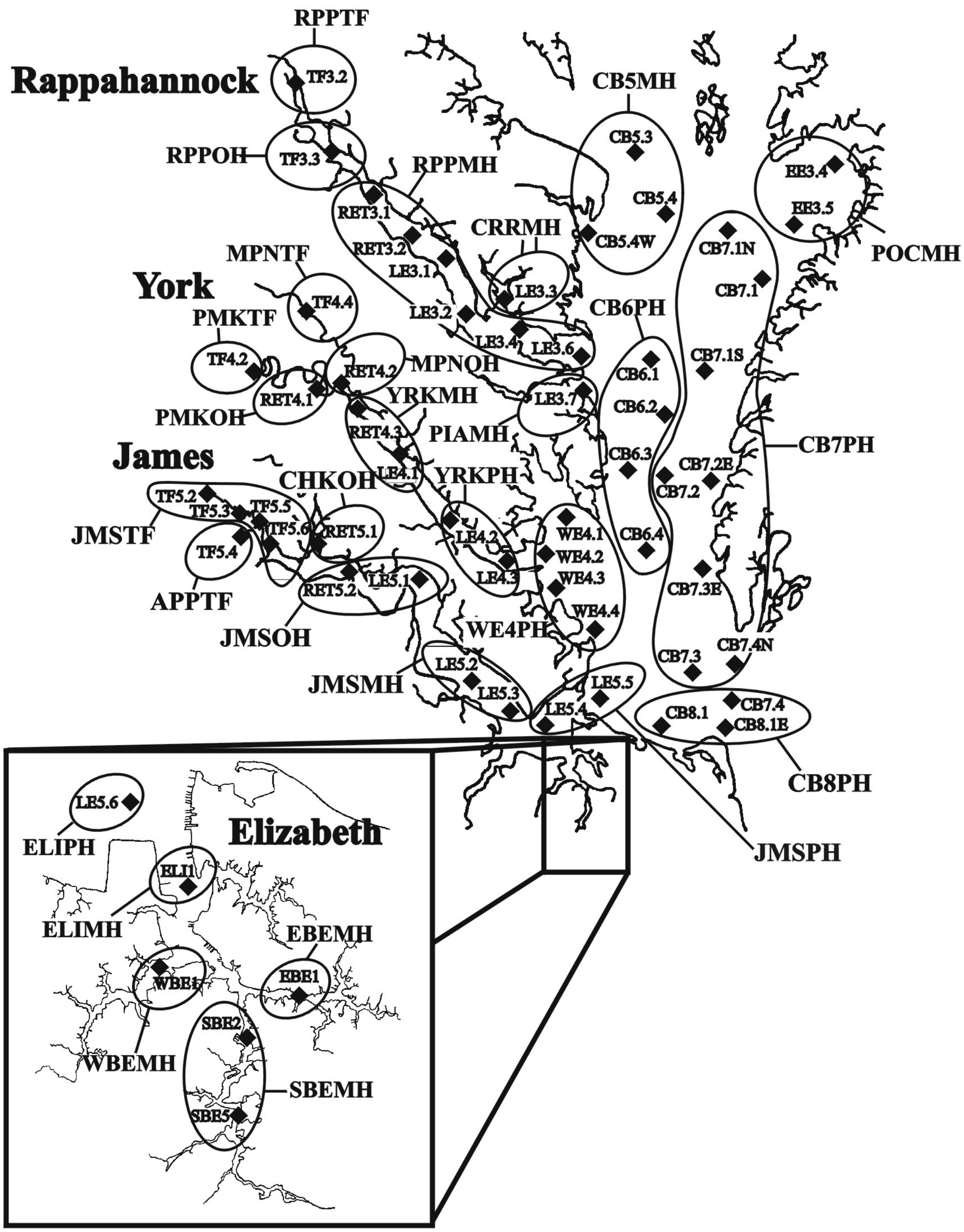


Figure 2-2. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem used in the statistical analyses. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

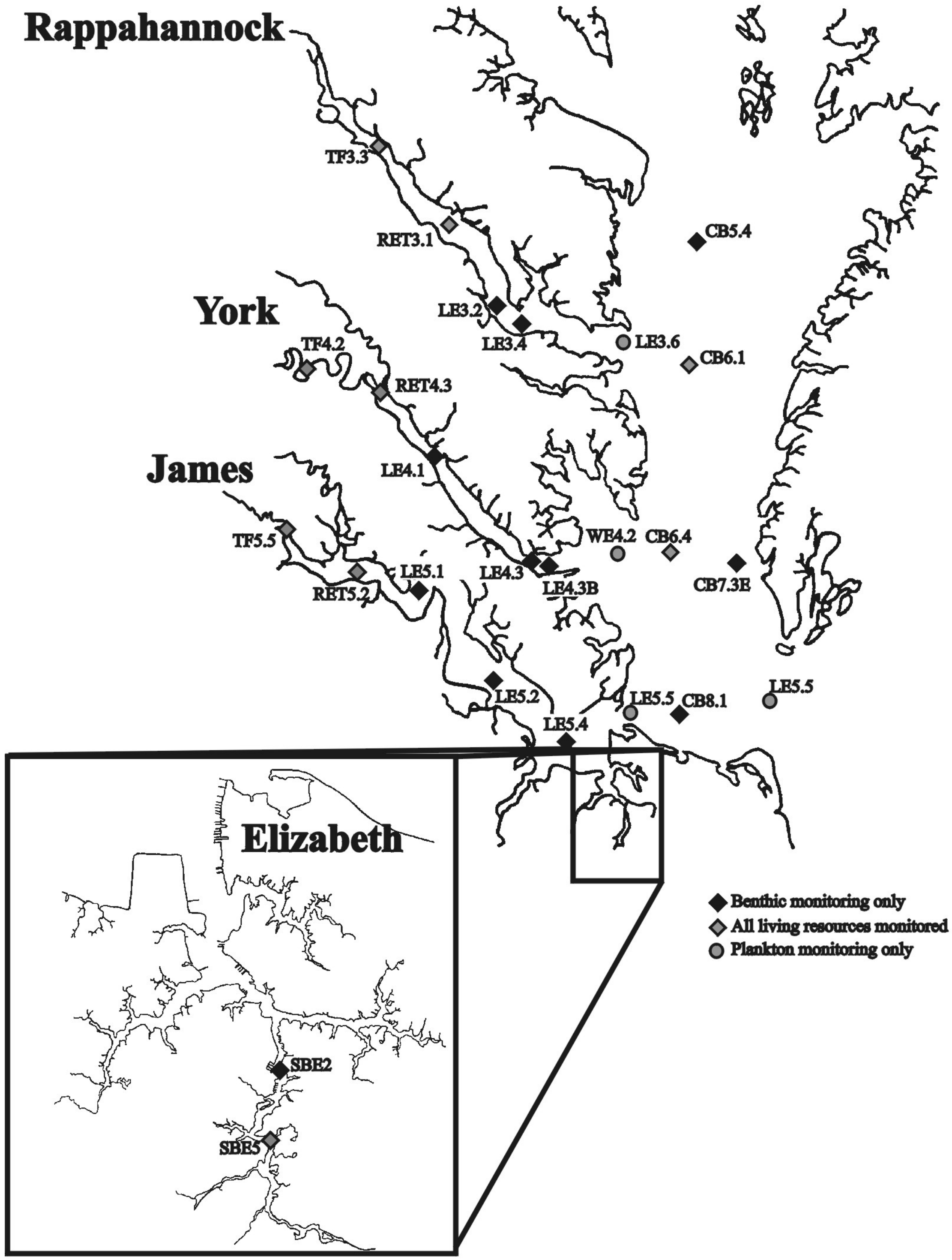


Figure 2-3. Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem.

Table 2-1. Definitions of seasonal time periods for status and trend analyses conducted for of the tidal monitoring programs. A "x" indicates the analysis was conducted for the season and parameter group combination while a "-" indicates that no analysis was conducted. Benthic status and trend analyses were conducted on data collected from July 15 through September 30*.

		Water Quality			Plankton		Benthos	
Season	Definition	Status	Trend	SAV Goals	Status	Trend	Status	Trend
Annual	Entire year	x	x	-	x	x	-	-
SAV1	March through May and September through November	x	x	x	x	x	-	-
SAV2	April through October	x	x	-	x	x	-	-
Summer1	June through September	x	x	-	x	x	x*	x*
Summer2	July through September	x	x	-	x	x	-	-
Spring1	March through May	x	x	-	x	x	-	-
Spring2	April through June	x	x	-	x	x	-	-
Fall	October through December	-	x	-	x	x	-	-
Winter	January and February	-	x	-	x	x	-	-

Table 2-2. Habitat requirements for growth and survival of SAV (from Batuik et al., 1992; 2000).

Salinity Regime	SAV Growth Season	Percent Light at Leaf	Total Suspended Solids (mg/l)	Chlorophyll *a* (µg/l)	Dissolved Inorganic Nitrogen (mg/l)	Dissolved Inorganic Phosphorus (mg/l)
Tidal Freshwater	Apr.-Oct.	<2	<15	<15	none	<0.02
Oligohaline	Apr.- Oct.	<2	<15	<15	none	<0.02
Mesohaline	Apr.-Oct.	<1.5	<15	<15	<0.15	<0.01
Polyhaline	Mar.-May,	<1.5	<15	<15	<0.15	<0.01

Chapter 3. Water Quality Method Correction Analyses

I. Method Change Effects

This chapter summarizes the effects of the changes in analytical methods for estimating concentrations of total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus implemented by the Department of Environmental Quality in 1994. Significant method effects were detected for both total nitrogen and total phosphorus in all salinity regimes. Correction factors for total nitrogen and total phosphorus indicate that the changes in analytical methods for these two parameters resulted in data that were lower in all salinity regimes after 1994. Significant method change effects were detected for dissolved inorganic nitrogen in the mesohaline (an increase in concentration after 1994) and the polyhaline (a decrease after 1994) salinity regimes. Significant method change effects were detected for dissolved inorganic phosphorus in all salinity regimes. Correction factors for this parameter indicate that the changes in analytical methods resulted in data that were lower in the tidal freshwater and oligohaline salinity regimes and higher in the mesohaline and polyhaline salinity regimes after 1994 (Table 3-1).

II. Trend Analysis Comparison

A. James River

Previous investigations using data collected through 2000 indicated widespread decreasing trends throughout the James River. However, addition of data collected in 2001 and application of method corrections for this parameter resulted in either the disappearance or reversal of the majority of these trends. The only improving trends which persisted in the corrected data set were detected in the Upper James River (JMSTF, surface and bottom) and the Chickahominy River (CHKOH, surface only) (Table 3-2).

In contrast to total nitrogen, trends in dissolved inorganic nitrogen for the "corrected" data were similar to those previously detected with the exception of the disappearance of two improving trends in the Lower James River (JMSMH) (Table 3-2).

Nearly all of the previously detected improving trends in total phosphorus disappeared or were reversed after application of the method corrections and addition of the data collected in 2001. In addition, degrading trends in "corrected" total phosphorus were detected in the Middle James River (JMSOH) and the Chickahominy River (CHKOH). The improving trends in both surface and bottom total phosphorus persisted in the Upper James River (JMSTF) despite the method correction and addition of the data collected in 2001 (Table 3-3).

The direction or absence of trends in dissolved inorganic phosphorus persisted within all tidal freshwater and oligohaline segments. However, in the Lower James River (JMSMH) and James River Mouth (JMSPH) previously detected improving trends reversed and disappeared, respectively, as a result of additional data from 2001 and application of the method corrections (Table 3-2).

B. Elizabeth River

For the majority of segments, no method corrections were applied and as a result few changes in pattern were observed. However, in the Elizabeth River Mouth previously detected improving trends reversed or disappeared (Table 3-3).

C. York River

As a result of the method corrections and addition of data collected in 2001, most of the previously detected improving trends in total nitrogen in the York River either reversed or disappeared. In addition, degrading trends in both surface and bottom total nitrogen appeared in the Lower Pamunkey River (segment PMKOH) and the Lower Mattaponi River (segment MPNOH) while degrading trends in bottom total nitrogen appeared in the Middle York River (segment YRKPH) and Lower York River (segment YRKPH) (Table 3-4).

Few trends in dissolved inorganic nitrogen were detected in the York River through 2000. This pattern persisted despite the addition of data for 2001 and the application of the method corrections.
Two improving trends in dissolved inorganic nitrogen were previously detected but both disappeared in the method "corrected" data (Table 3-4).

As a result of the addition of data collected in 2001 and the application of the method corrections, degrading trends in total phosphorus appeared in nearly all segments of the York River and a previously detected improving trend in the Lower York River was reversed (Table 3-4).

In contrast, previously detected degrading trends in dissolved inorganic phosphorus in the Pamunkey and Mattaponi Rivers disappeared as a result of the addition of data collected in 2001 and the application of the method corrections. Two degrading trends in dissolved inorganic phosphorus appeared in the Middle York River (segment JMSOH) (Table 3-4).

D. Rappahannock River

As a result of the addition of the data collected in 2001 and the application of the method corrections, nearly all improving trends in total nitrogen in the Rappahannock River either disappeared or were reversed. In addition, two degrading trends in bottom total nitrogen appeared in the Middle Rappahannock River (segment RPPOH) and the Corrotoman River (CRRMH) (Table 3-5).

Previously detected improving trends in dissolved inorganic nitrogen in the Middle Rappahannock River (segment RPPOH) disappeared after addition of the data collected in 2001 and the application of the method corrections. A degrading trend in bottom dissolved inorganic nitrogen appeared in the Upper

Rappahannock River (segment JMSTF) (Table 3-5).

Although few trends in total phosphorus were detected in the data collected through 2000, the addition of the data collected in 2001 and the application of the method corrections resulted in the appearance of widespread degrading trends in both surface and bottom total phosphorus (Table 3-5).

There were no changes in trend analysis results for dissolved inorganic phosphorus as a result of the addition of the data collected in 2001 and the application of the method corrections (Table 3-5).

Table 3-1. Method change correction factors for each salinity regime. An "ns" indicates the method change effect was not significant (p>0.05). A "-" indicates that no method change analysis was performed for the parameter indicated. In the salinity regime column, an TF =Tidal freshwater, O =Oligohaline, M=Mesohaline, and P=Polyhaline.

Salinity Zone	Total Nitrogen	Dissolved Inorganic Nitrogen	Dissolved Inorganic Phosphorus	Total Phosphorus
TF	0.8894	ns	1.3748	0.8000
O	0.7999	ns	1.0661	0.7821
M	0.8231	1.1003	0.8131	0.8424
P	0.7342	0.8209	0.6004	0.7115

Table 3-2. Changes in the pattern of water quality trends between 2001 and 2000 analyses for the James River. Dark shading indicates a previously improving trend that changes to a degrading trend. Light shading indicates either (1) a previous improving trend that changes to no trend (Disappearance Improving), (2) or a previous no trend changing to a degrading trend (Appearance Degrading).

	Appomattox	Upper James	Chickahominy	Middle James	Lower James	River Mouth
STN	Disappearance Improving	Same Improving	Same Improving	Disappearance Improving	Reversal Degrading	Reversal Degrading
BTN	Disappearance Improving	Same Improving	Disappearance Improving	Reversal Degrading	Reversal Degrading	Appearance Degrading
SDIN	Same NS	Same Improving	Same NS	Same Improving	Disappearance Improving	Same NS
BDIN	Same NS	Same Improving	Same NS	Same Improving	Disappearance Improving	Same NS
STP	Disappearance Improving	Same Improving	Appearance Degrading	Appearance Degrading	Reversal Degrading	Disappearance Improving
BTP	Reversal Degrading	Same Improving	Appearance Degrading	Appearance Degrading	Appearance Degrading	Disappearance Improving
SDIP	Same Improving	Same Improving	Same NS	Same NS	Reversal Degrading	Disappearance Improving
BDIP	Same Improving	Same Improving	Same NS	Same NS	Reversal Degrading	Disappearance Improving

Table 3-3. **Changes in the pattern of water quality trends between 2001 and 2000 analyses for the Elizabeth River. See Table III-2 for shading explanation.**

	Western Branch	Southern Branch	Eastern Branch	Elizabeth River Mainstem NStem	Elizabeth River Mouth
STN	Same Improving	Same Improving	Same Improving	Appearance Improving	Reversal Degrading
BTN	Same Improving	Appearance Improving	Same Improving	Appearance Improving	Reversal Degrading
SDIN	Same Improving	Same Improving	Same Improving	Same Improving	Disappearance Improving
BDIN	Same Improving	Same Improving	Same Improving	Same Improving	Disappearance Improving
STP	Same Improving	Same Improving	Same Improving	Same Improving	Reversal Degrading
BTP	Same Improving	Same Improving	Same Improving	Same Improving	Reversal Degrading
SDIP	Same Improving	Same Improving	Same Improving	Same Improving	Disappearance Improving
BDIP	Same Improving	Same Improving	Same Improving	Same Improving	Disappearance Improving

Table 3-4. **Changes in the pattern of water quality trends between 2001 and 2000 analyses for the York River. See Table III-2 for shading explanation.**

	Upper Pamunkey	Lower Pamunkey	Upper Mattaponi	Lower Mattaponi	Middle York	Lower York	Mobjack Bay
STN	Disappearance Improving	Appearance Degrading	Disappearance Improving	Appearance Degrading	Reversal Degrading	Reversal Degrading	Disappearance Improving
BTN	Disappearance Improving	Appearance Degrading	Same Improving	Appearance Degrading	Appearance Degrading	Appearance Degrading	Reversal Degrading
SDIN	Same NS	Same NS	Same NS	Same NS	Disappearance Improving	Same NS	Same NS
BDIN	Same NS	Same NS	Same NS	Same NS	Same NS	Same NS	Disappearance Improving
STP	Appearance Degrading	Appearance Degrading	Appearance Degrading	Appearance Degrading	Appearance Degrading	Appearance Degrading	Appearance Degrading
BTP	Appearance Degrading	Appearance Degrading	Appearance Degrading	Appearance Degrading	Same Degrading	Reversal Degrading	Same NS
SDIP	Disappearance Degrading	Disappearance Degrading	Disappearance Degrading	Disappearance Degrading	Appearance Degrading	Same NS	Same NS
BDIP	Disappearance Degrading	Same NS	Disappearance Degrading	Disappearance Degrading	Appearance Degrading	Same NS	Same NS

Table 3-5. Changes in the pattern of water quality trends between 2001 and 2000 analyses for the Rappahannock River. See Table III-2 for shading explanation.

	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corrotoman
STN	Disappearance Improving	Disappearance Improving	Disappearance Improving	Reversal Degrading
BTN	Same Improving	Appearance Degrading	Disappearance Improving	Appearance Degrading
SDIN	Same NS	Disappearance Improving	Same NS	Same NS
BDIN	Appearance Degrading	Disappearance Improving	Same NS	Same NS
STP	Same NS	Appearance Degrading	Appearance Degrading	Appearance Degrading
BTP	Disappearance Improving	Appearance Degrading	Appearance Degrading	Same Degrading
SDIP	Same NS	Same NS	Same NS	Same NS
BDIP	Same NS	Same NS	Same NS	Same NS

Chapter 4. Rappahannock River Basin

I. Executive Summary

A. Summary of Basin Characteristics

The Rappahannock River, the second largest tributary to Chesapeake Bay in Virginia, has a watershed of 7,368 km^2 that accounts for seven percent of the area of the state of Virginia. The Rappahannock River begins in the Blue Ridge physiographic region and extends through the Piedmont and Coastal Plain physiographic regions where it empties into Chesapeake Bay. Approximately 56% of the Rappahannock River watershed is located above the fall-line at Fredericksburg. Over 56% of the total area or approximately 4,200 km^2 of the watershed consists of primarily deciduous or mixed deciduous and evergreen forests while 31% (2279 $km^{2)}$ is agricultural cropland. All other land use types account for only 14% of the total area of the watershed. Less than 150 km^2 was urban, most of which was low intensity residential land. Approximately 7,200 km of the over 11,000 km of streambanks and shoreline within the watershed has a 30 m minimum riparian forest buffer. Human population in the watershed was 240,754 in the year 2000 with a population density of 32.7 individuals per km^2. Most of the population is distributed in rural areas within watershed and the largest population center is Fredericksburg, VA. Other towns in the watershed include Culpeper, Falmouth, Orange and Tappahannock.

Total point and non-point source loadings of nitrogen were estimated to be 3,620,000 kg/yr in 2000. Total point and non-point source loadings of phosphorus and sediments were approximately 427,000 kg/yr and 304,814 metric tons/yr, respectively in 2000. Point source loadings of total nitrogen and total phosphorus to the Rappahannock River were 253,752 kg/yr and 26,769 kg/yr in 1999, respectively. Daily freshwater flow at the fall-line ranged from a minimum of 0.25 m^3/sec to a maximum of 1,546 m^3/sec for the period of January 1, 1985 through December 31, 2001. Grand mean flow at the fall-line was 46.63 m^3/sec. Figures 4-1 to 4-6 provide summary information of basin characteristics of the Rappahannock River.

B. Summary of Status and Long Term Trends

Figures 4-7 to 4-10 provide summaries of water quality status and trend analyses for the Rappahannock River. Relative status of nutrients and dissolved oxygen was good for nearly all parameter/segment combinations in the Rappahannock River main stem. Relative status of all other parameter/segment combinations in this region was either fair or poor. Relative status was good for all parameters in the Corrotoman River except for bottom dissolved oxygen for which the status was fair. SAV habitat requirements were met for all parameters in both the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). All parameters except dissolved inorganic phosphorus in the Upper and Middle Rappahannock River either did not met the SAV habitat requirements or were borderline. Degrading trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and in secchi depth and bottom dissolved oxygen in the Lower Rappahannock River (RPPMH). With respect to the method corrected nutrient data, degrading trends in surface and bottom total nitrogen were detected in the Corrotoman River (CRRMH), as well as degrading trends in bottom total nitrogen in the Lower Rappahannock River (RPPMH) and bottom dissolved inorganic nitrogen in the Upper Rappahannock River. Degrading trends were detected in method corrected surface and bottom total phosphorus in all segments except the Upper Rappahannock River.

For data collected after the method correction (1995-2001), improving trends were detected in surface and bottom measurements of total nitrogen in the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). Improving trends in surface and bottom dissolved inorganic nitrogen were detected in the Lower Rappahannock River (RPPMH). Degrading trends in surface chlorophyll *a* were detected in the Upper and Middle Rappahannock River (RPPTF and RPPOH). Degrading trends in secchi depth were detected in the Upper Rappahannock River and Corrotoman River (RPPTF and CRRMH). A degrading trend in dissolved oxygen was detected in the Upper Rappahannock River (RPPTF). Increasing trends in surface and bottom temperature were detected in both the Upper and Middle Rappahannock River (RPPTF and RPPOH). Increasing trends in surface and bottom salinity were detected in all segments except the Upper Rappahannock River (RPPTF).

Figures 4-11 to 4-14 provide summaries of living resource status and trend analyses for the York River. Improving trends for chlorophyte biomass, and the autotrophic picoplankton biomass were present in all segments of the river. The diatom and cryptophyte biomass trends were favorable at both station TF3.3 and RET3.1, with no significant trends at the downstream station. In contrast, there were degrading trends in all river segments for cyanobacteria abundance and biomass. In general total phytoplankton biomass and abundance are increasing in the river at the tidal freshwater and middle segments, with no trend in the lower segment. A major relationship to follow is the future cyanobacteria development, and to what degree the diatom dominance is affected. The more desirable flora throughout the tidal river segments are the diatoms and chlorophytes, in contrast to cyanobacteria and dinoflagellates. These data indicate mixed trends in the dinoflagellates, degrading downstream. These downstream regions are locations for seasonal dinoflagellate blooms that may include species toxic to local fauna.

A degrading trend in rotifer abundance was detected in the lower portion of the mesohaline Rappahannock River (RPPMH) and status for this microzooplankton indicator was poor for both the mesohaline and oligohaline segments of the river. There were no trends in copepod nauplii abundance and status for this parameter was either good in the upper segments and poor in the mesohaline segment.

Although changes in sample processing methods precluded performing status and trend analyses on mesozooplankton bioindicators, results of analyses conducted on data collected through 1999 indicate improving trends in mesozooplankton diversity in the oligohaline Rappahannock River (RPPOH) and the upper portion of the mesohaline Rappahannock River (RPPMH). Degrading trends in mesozooplankton diversity and several other indicators were detected in the lower portion of the mesohaline Rappahannock River (RPPMH).

A degrading trend in the B-IBI and several of its component metrics was detected in the upper portion of the mesohaline Rappahannock River (RPPMH) and status of the B-IBI ranged from marginal to severely degraded. Although benthic community status within the oligohaline Rappahannock River (RPPOH) was only marginal, there were degrading trends in pollution sensitive species biomass and pollution indicative abundance.

C. Summary of Major Issues in the Basin

Results suggest that the primary concern for water quality in the Rappahannock River is water clarity. Status of surface chlorophyll *a*, secchi depth and total suspended solids was poor or fair in all segments in the Rappahannock River except for the Corrotoman River (CRRMH) where it was good. SAV habitat requirements were either not met or were borderline for all parameters except dissolved inorganic phosphorus in both the Upper and Middle Rappahannock River (RPPTF and RPPOH). Degrading trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and in secchi depth and bottom dissolved oxygen in the Upper Rappahannock River (RPPTF).

Degrading trends in the "method corrected" data were detected in both surface and bottom total nitrogen and total phosphorus in several segments within the Rappahannock River; however, these trends were not detected in the data collected after the method change occurred. This coupled with an examination of scatterplots of these parameters indicate that the possibility that the trends observed in the "method corrected" data were an artifact of the method correction process cannot be eliminated.

Degrading trends in cyanobacterial abundances throughout the river are of particular concern. Degrading trends in microzooplankton and mesozooplankton indicators were detected in the lower portion of the Lower Rappahannock River (RPPMH). Further consideration should be given to the ecological implications of these trends specifically as it might affect stocks of planktivorous feeding fish. Benthic community status at all stations monitored in the Lower Rappahannock River (RPPMH) ranged from degraded to severely degraded and there were degrading trends in the B-IBI and nearly all of its component metrics at station RET3.1 in this segment. Benthic community status within the Middle Rappahannock River (RPPOH) met the Benthic Restoration goals although there was a degrading trend in pollution sensitive species biomass.

II. Management Recommendations

It is unclear whether or not there are significant problems in nutrient concentrations in this tributary. Although degrading trends in both method corrected total nitrogen and total phosphorus were detected in several segments, these trends were not detected in data collected after the method change. Status of nutrients was good and SAV habitat requirements for nutrients were met in most segments. At present, the primary concern for water quality in the main stem of Rappahannock River appears to be water clarity. The status of water clarity (secchi depth) was fair in most segments in this tributary and in half the segments the SAV habitat requirements for water clarity measurements such as light attenuation and the percent light at the leaf surface were either not met or borderline.

There is no clear cause for water clarity problems in the Rappahannock River. However, the water clarity issues may be caused by high concentrations of phytoplankton and/or total suspended solids as is indicated by the fact that status for chlorophyll *a* and total suspended solids ranged from fair to poor in those segments with fair water clarity status. Additional evidence implicating phytoplankton as the source for the water clarity problem is the increasing trends in total phytoplankton abundance found in the Upper and Middle Rappahannock River segments. Specific phytoplankton groups which showed increases in biomass at one or more stations were diatoms, cyanobacteria, and cryptophytes. Increasing trends in cyanobacterial, autotrophic picoplankton, and chlorophyte abundance were detected at all stations.

Water quality problems in the Rappahannock River appear to be localized in the upper segments of the river. Poor relative status values and SAV habitat requirement violations were for the most part restricted to these two segments. Point source loadings for both total nitrogen and total phosphorus are highest above the fall-line and decrease moving downstream suggesting a potential link between water clarity and point source nutrient loadings. It is possible the higher upstream loadings of nutrients result in higher phytoplankton densities which in turn result in poor water clarity. Alternatively, water clarity may be low because non-point source suspended solid loads from agricultural land are high. Agricultural non-point sources account for over 60% of the total sediment loads to the Rappahannock River and most of agricultural land in the basin is found above the fall-line and in sub-watersheds surrounding the Upper and Middle Rappahannock River segments. This also suggests a potential link between agricultural run-off and poor water clarity in the upper reaches of the Rappahannock River. The low freshwater flows observed during the last three years, may confound or amplify any potential anthropogenic effects. These low flows could contribute to the poor status of water clarity by reducing the export of suspended solids, nutrients, and/or phytoplankton in the water column.

No direct link between any of these factors and water clarity can be made; however, a more thorough investigation of existing data sets may help to identify potential sources of the water clarity problems. An analysis of trends in both the fixed and volatile components of total suspended solids along with a statistical analysis of potential relationships between secchi depth and various environmental factors such as suspend solids concentrations, freshwater flow and phytoplankton concentrations is recommended. Without additional information, specific management recommendations for solving this problem cannot be made but both additional point and non-point source controls may be required.

Degrading trends in the microzooplankton and mesozooplankton indicators in the lower portion of the mesohaline Rappahannock River (RPPMH) may be related to the degrading trend in total phosphorus. Poor status in rotifer abundance may be related to poor status in total suspended solids and chlorophyll *a*.

III. Overview of Basin Characteristics

The Rappahannock River, the second largest tributary to Chesapeake Bay in Virginia, has a watershed of 7,368 km^2 that accounts for seven percent of the area of the state of Virginia. The Rappahannock River begins in the Blue Ridge physiographic region and extends for 296 km through the Piedmont and Coastal Plain physiographic regions where it empties into Chesapeake Bay. Major tributaries to the Rappahannock River include the Rapidan, Robinson, and Corrotoman rivers. Approximately 56% of the Rappahannock River watershed is located above the fall-line at Fredericksburg.

The human population in the watershed has increased from just over 200,000 in 1990 to over 240,000 in 2000 and is projected to exceed 300,000 by the year 2010 (Figure 4-1a). Most of the population is distributed in rural areas within watershed and the largest population center is Fredericksburg, VA. Other towns in the watershed include Culpeper, Falmouth, Orange and Tappahannock. Population ranges from approximately14.1 individuals per km^2 in the Upper Rappahannock River sub-watershed to just under 100 individuals per km^2 in the Middle Rappahannock River sub-watershed (RPPOH) (Figure 4-1b).

Nearly 57% or approximately 4,200 km^2 of the watershed consists of primarily deciduous or mixed deciduous and evergreen forests, In general, the percentage of forested land within sub-watersheds of the Rappahannock River decreases steadily from over 60% above the fall-line to approximately 46% in the Lower Rappahannock River (RPPMH) sub-watershed (Figure 4-2a-b). Approximately 7,200 km of the over 11,000 km (approximately 65%) of streambanks and shoreline within the watershed have a 30 m minimum riparian forest buffer. Approximately 31% (2,279 km^2) of the watershed is agricultural cropland. This land-use type comprises over 25% of the area in all sub-watersheds within the Rappahannock River basin; however, in terms of actual area, most agricultural land is located above the fall-line (Figure 4-2a). All other land use types account for only 14% of the total area of the watershed. Less than 150 km^2 was urban, most of which was low intensity residential land.

Based on calculations using the Chesapeake Bay Program water quality model, total point and non-point source loadings of nitrogen are estimated to be 3,620,000 kg/yr. Total point and non-point source loadings of phosphorus and sediments are approximately 427,000 kg/yr and 304,814 metric tons/yr, respectively. Both nutrient and sediment loadings to the Rappahannock River are primarily from agricultural non-point sources (Figure 4-3a-c). More detailed information concerning the distribution of non-point source loadings of nutrients and sediments is required in order to examine potential relationships between these sources of anthropogenic stress and water quality conditions.

Point source loadings of nitrogen have fluctuated from approximately 220,000 to 300,000 kg/yr over the last decade with no clear trend in the data (Figure 4-4a). Point source loadings of phosphorus declined substantially following the phosphate ban in 1989 and have remained relatively stable at less than 40,000 kg/yr (Figure 4-4b). Both total nitrogen and total phosphorus loadings were highest above the fall-line and decreased steadily downstream (Figure 4-5a-b).

Daily freshwater flow at the fall-line ranged from a minimum of 0.25 m^3/sec to a maximum of 1,546 m^3/sec for the period of January 1, 1985 through December 31, 2001. Grand mean flow at the fall-line was 46.63 m^3/sec. Although there was no significant trend in freshwater flow at the Rappahannock River fall-line, the annual peaks in monthly mean flow during the last three years appear to be much lower than during previous years and annual mean flow was approximately 20% to 25% lower than the grand mean flow during the last three years (Figure 4-6).

IV. Overview of Monitoring Results

Relative status of nutrients and dissolved oxygen was good for nearly all parameter/segment combinations in the Rappahannock River main stem. Relative status of all other parameter/segment combinations in this region was either fair or poor. Relative status was good for all parameters in the Corrotoman River except for bottom dissolved oxygen for which the status was fair. SAV habitat requirements were met for all parameters in both the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). All parameters except dissolved inorganic phosphorus in the Upper and Middle Rappahannock River either did not met the SAV habitat requirements or were borderline. Degrading trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and in secchi depth and bottom dissolved oxygen in the Lower Rappahannock River (RPPMH) (Figures 4-7 and 4-8).

Degrading trends in surface chlorophyll *a* were detected in the Upper and Middle Rappahannock River (RPPTF and RPPOH). Degrading trends in secchi depth were detected in the Upper Rappahannock River and Corrotoman River (RPPTF and CRRMH). A degrading trend in dissolved oxygen was detected in the Upper Rappahannock River (RPPTF). Increasing trends in surface and bottom temperature were detected in both the Upper and Middle Rappahannock River (RPPTF and RPPOH). Increasing trends in surface and bottom salinity were detected in all segments except the Upper Rappahannock River (RPPTF). With respect to the method corrected nutrient data, degrading trends in surface and bottom total nitrogen were detected in the Corrotoman River (CRRMH), as well as degrading trends in bottom total nitrogen in the Lower Rappahannock River (RPPMH) and bottom dissolved inorganic nitrogen in the Upper Rappahannock River. Degrading trends were detected in method corrected surface and bottom total phosphorus in all segments except the Upper Rappahannock River (Figures 4-7 and 4-8).

For data collected after the method correction (1995-2001), improving trends were detected in surface and bottom measurements of total nitrogen in the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). Improving trends in surface and bottom dissolved inorganic nitrogen were detected in the Lower Rappahannock River (RPPMH) (Figures 4-9 and 4-10).

There was a general trend of increased biomass and abundance for the total phytoplankton which was associated with a pattern of increased diatoms as the dominant floral component, and the chlorophytes, cyanophytes, picoplankton, and cryptophytes as prominent background categories. Areas of floral concern within this river system would be the increasing abundance and biomass of the cyanobacteria with additional increases associated with dinoflagellates. There was no significant trends in the procaryote:eukaryote ratio, and only a few significant trends associated with species diversity and productivity. Downstream flora changed from fresh water species to dominant estuarine species, with the diatoms still the dominant flora, with dinoflagellates increasing in abundance. The lower reach of this river was also the site for increased dinoflagellate blooms from late spring through early fall (Figure 4-11).

Zooplankton parameters continue the same degrading trend with respect to rotifer abundance at the mouth with poor status for this parameter in all segments monitored except the tidal fresh. Copepod nauplii abundance was good in the upper regions of the bay and poor at the mouth (Figure 4-12). A change in methodology prevents a critical review of the status and trends in the mesozooplankton monitoring results. However, plots of raw data indicate that relative abundances and numbers of species of mesozooplankton are mostly unchanged from 1999. The related water quality trends of the adjacent mainstem (secchi depth and salinity) have not changed substantially from last year and therefore, it is likely that the general mesozooplankton status and trends have not changed much from 1999. Mesozooplankton diversity continues to decline at the mouth of the river which is associated with generally poor clarity trends in the mainstem and declining salinity. Figure 4-13 summarizes status and trends in mesozooplankton indicators through 1999.

Benthic community status was severely degraded at all stations in the Lower Rappahannock River (RPPMH). The status observed at these stations is related to the frequency of low dissolved oxygen events that occur in this segment. A degrading trend in the B-IBI was detected at station RET3.1 in the upper portion of this segment. Benthic community status was marginal in the Middle Rappahannock (RPPOH) but degrading trends in pollution sensitive species biomass and pollution indicative species abundance were detected in this segment (Figure 4-14).

V. Detailed Overview of Status and Trends

A. Fall-Line

In the Rappahannock River at Fredricksburg, improving trends in flow adjusted concentrations of nitrates-nitrites (fixed) and total phosphorus (Table 4-1). A degrading trend in total suspended solids was detected at this station. In the Robinson River at Locust Dale, improving trends in flow adjusted and flow weighted concentrations of total nitrogen were detected. The trends in total nitrogen were related to reductions in the dissolved inorganic nitrogen species and not organic nitrogen compounds as is indicated by the improving trends in flow adjusted concentrations, flow weighted concentrations and loadings of ammonia, nitrate-nitrites (whole) and nitrates (whole) and by the degrading trend in flow weighted concentration of total Kjeldahl nitrogen detected at this station.

B. Mesohaline Rappahannock River (RPPMH - Lower Rappahannock)

1. Water quality for living resources

Status was fair to good for all water quality parameters in the Lower Rappahannock segment (Table 4-2). Status was good for surface and bottom total nitrogen, surface and bottom dissolved inorganic nitrogen, and bottom dissolved inorganic phosphorus, and status was fair for surface and bottom total phosphorus, surface dissolved inorganic phosphorus, surface chlorophyll *a* , surface and bottom total suspended solids, secchi depth and bottom dissolved oxygen. There were no significant overall trends for most parameters (Table 4-3), but surface and bottom total phosphorus showed degrading trends. No parameters showed improving trends.

2. Water quality for SAV

Relative status of most parameters was fair except for surface total nitrogen and dissolved inorganic nitrogen for which relative status was good. SAV habitat requirements were met for all parameters (Table 4-4). Degrading trends in surface total nitrogen, total phosphorus and the percentage of light at the leaf surface at both 0.5 and 1.0 meters were detected in this segment (Table 4-5).

3. Water quality trends for 1995-2001

Improving trends were detected in surface and bottom measurements of both total and dissolved inorganic nitrogen. Increasing trends in surface and bottom salinity were also detected (Figure 4-9 and 4-10).

4. Living resources

There were no significant trends in total phytoplankton biomass, abundance, or diversity at station LE3.6. Yet, the status for total biomass and diversity was poor. Diatom biomass status was fair, with no significant trends for change. This region is a common site for summer dinoflagellate blooms, and there is a trend for increased dinoflagellate biomass present, along with poor status for these flora. Another degrading trend at this site is for increased biomass and abundance for cyanobacteria. The chlorophytes and autotrophic picoplankton possess favorable biomass status, along with favorable trends. No significant trends were associated with the prokaryote to eukaryote biomass ratio with the biomass to abundance ratio showing a positive trend (Figure 4-11). The major concern at this station is the increased trends in both cyanobacteria and dinoflagellates.

Several favorable trends were established at station RET3.1. These included increased diatom, chlorophyte, and cryptophyte biomass, and reduced biomass for the dinoflagellates and autotrophic picoplankton. In general, the total phytoplankton abundance and biomass was increasing. On the negative side, there were degrading trends of increased biomass and abundance of the cyanobacteria. The status of diversity remained poor, with no significant trends. Trends were also absent for the poor status of biomass to abundance ratio, and the prokaryote to eukaryote ratio (Figure 4-11). The site remains healthy in reference to the phytoplankton composition, with diatoms remaining the dominant flora component.

At station RET3.1 in the upper portion of this segment, there were no significant annual trends in the microzooplankton parameters. Status for copepod nauplii abundance was good while status for rotifer abundance was poor (Figure 4-11). This mixed status is associated with the mixed status of water quality parameters that are good or fair for nutrients but poor to fair for water clarity and chlorophyll *a*.

At station LE3.6 at the lowermost portion of this segment at the mouth of the river, a degrading trend in micozooplankton was detected as seen in an increase in rotifer abundance (Figure 4-12). This is the same degrading trend detected last year and is associated with generally degrading trends in water quality in the mainstem and declining salinity. The water quality at this station is probably best judged by adjacent mainstem results since this station is averaged in with the other mesohaline stations of this segment. Copepod nauplii abundance status changed from fair last year to poor this year while rotifer abundance status was poor indicating continued poor water quality.

At station RET3.1 in the upper portion of this segment, benthic community status was degraded. There were degrading trends in the B-IBI and several metrics of the IBI. In the lower portion of this segment (stations LE3.2 and LE3.4), benthic community status was severely degraded. Both stations are strongly impacted by low dissolved oxygen events (Figure 4-14).

C. Oligohaline Rappahannock River (RPPOH - Middle Rappahannock)

1. Water quality for living resources

Status was fair to good for most of the water quality parameters in the Middle Rappahannock segment (Table 4-6): surface and bottom total nitrogen and total phosphorus, surface and bottom dissolved inorganic nitrogen and dissolved inorganic phosphorus, and bottom dissolved oxygen. Status was fair for surface total suspended solids and secchi depth, and poor for surface chlorophyll *a*, and bottom total suspended solids. There were no significant trends for most parameters (Table 4-7), but there were degrading trends for bottom total nitrogen, surface and bottom total phosphorus, and surface chlorophyll *a*. Bottom dissolved oxygen showed an improving trend.

2. Water quality for SAV

Relative status for most parameters was good or fair except for surface chlorophyll *a* for which the relative status was poor. Most parameters either did not meet the SAV habitat requirements or were borderline with the exception of dissolved inorganic phosphorus which met the SAV habitat requirement (Table 4-8). Degrading trends in surface total nitrogen, total phosphorus and chlorophyll *a* were detected in this segment (Table 4-9).

3. Water quality trends for 1995-2001

A degrading trend in surface chlorophyll *a* was detected along with increasing trends in surface and bottom water temperature and salinity (Figure 4-9 and 4-10).

4. Living resources

The total phytoplankton biomass and abundance show increasing trends at this site, along with increasing (favorable) trends of biomass associated with the diatoms, chlorophytes, and cryptophytes. There were no significant trends for productivity or the prokaryote to eukaryote ratio. However, the status of cyanobacteria and dinoflagellate biomass was poor, with degrading trends associated with cyanobacteria biomass and abundance but dinoflagellate biomass had a decreasing trend. This continuing increase in the presence of cyanobacteria represents a concern and a pattern that needs to be followed. Further increases in cyanobacteria may influence the trophic status at this station. This may represent a cyclic pattern, where reduced concentrations may subsequently occur (Figure 4-11).

There were no significant annual trends in the microzooplankton parameters. Status for copepod nauplii abundance was good while status for rotifer abundance changed from poor last year to good this year was poor (Figure 4-12). This mixed status is associated with the mixed status of water quality parameters that are good for nutrients but poor to fair for water clarity and chlorophyl *a* parameters.

Benthic community status was marginal. There were degrading trends in pollution sensitive species biomass and pollution indicative species abundance (Figure 4-14).

D. Tidal Freshwater Rappahannock (RPPTF - Upper Rappahannock)

1. Water quality for living resources

Status of surface and bottom total nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved inorganic phosphorus and bottom dissolved oxygen was good. Status of bottom total suspended solids and water clarity was fair. Status of surface chlorophyll *a* and surface total suspended solids was poor (Table 4-10). Improving trends were detected in surface and bottom total nitrogen, bottom total phosphorus, and secchi depth. No degrading trends were detected (Table 4-11).

2. Water quality for SAV

Although relative status of all surface nutrients was good, relative status for surface chlorophyll *a*, total suspended solids and secchi depth was poor. Most parameters either met the SAV habitat requirements or were borderline with the exception of dissolved inorganic phosphorus which did not meet the SAV habitat requirement (Table 4-12). Improving trends in the percentage of light at the leaf surface at both 0.5 and 1.0 meters were detected in this segment while a degrading trend is surface dissolved inorganic nitrogen was also detected (Table 4-13).

3. Water quality trends for 1995-2001

Improving trends in surface and bottom dissolved inorganic phosphorus were detected; however, degrading trends in surface chlorophyll *a*, secchi depth and bottom dissolved oxygen were also detected (Figure 4-9 and 4-10).

4. Living resources

No living resources data are available for this segment.

E. Mesohaline Corrotoman River (CRRMH - Corrotoman River)

1. Water quality for living resources

Status of all parameters was good except for surface total phosphorus and bottom dissolved oxygen for which the status was fair (Table 4-14). An improving season specific trend in surface total nitrogen was detected. Degrading trends in bottom total phosphorus and secchi depth were also detected. Decreasing trends in surface and bottom salinity were detected in this segment (Table 4-15).

2. Water quality for SAV

Relative status of all parameters was good and all parameters met the SAV habitat requirements (Table 4-16). Degrading trends in surface total phosphorus secchi depth and the percentage of light at the leaf surface at 1.0 meters were detected in this segment (Table 4-17).

3. Water quality trends for 1995-2001

Improving trends in surface and bottom total nitrogen were detected in this segment; however, a degrading trend in secchi depth was detected. Increasing trends in surface and bottom salinity were also detected (Figure 4-9 and 4-10).

4. Living resources

No living resources data are available for this segment.

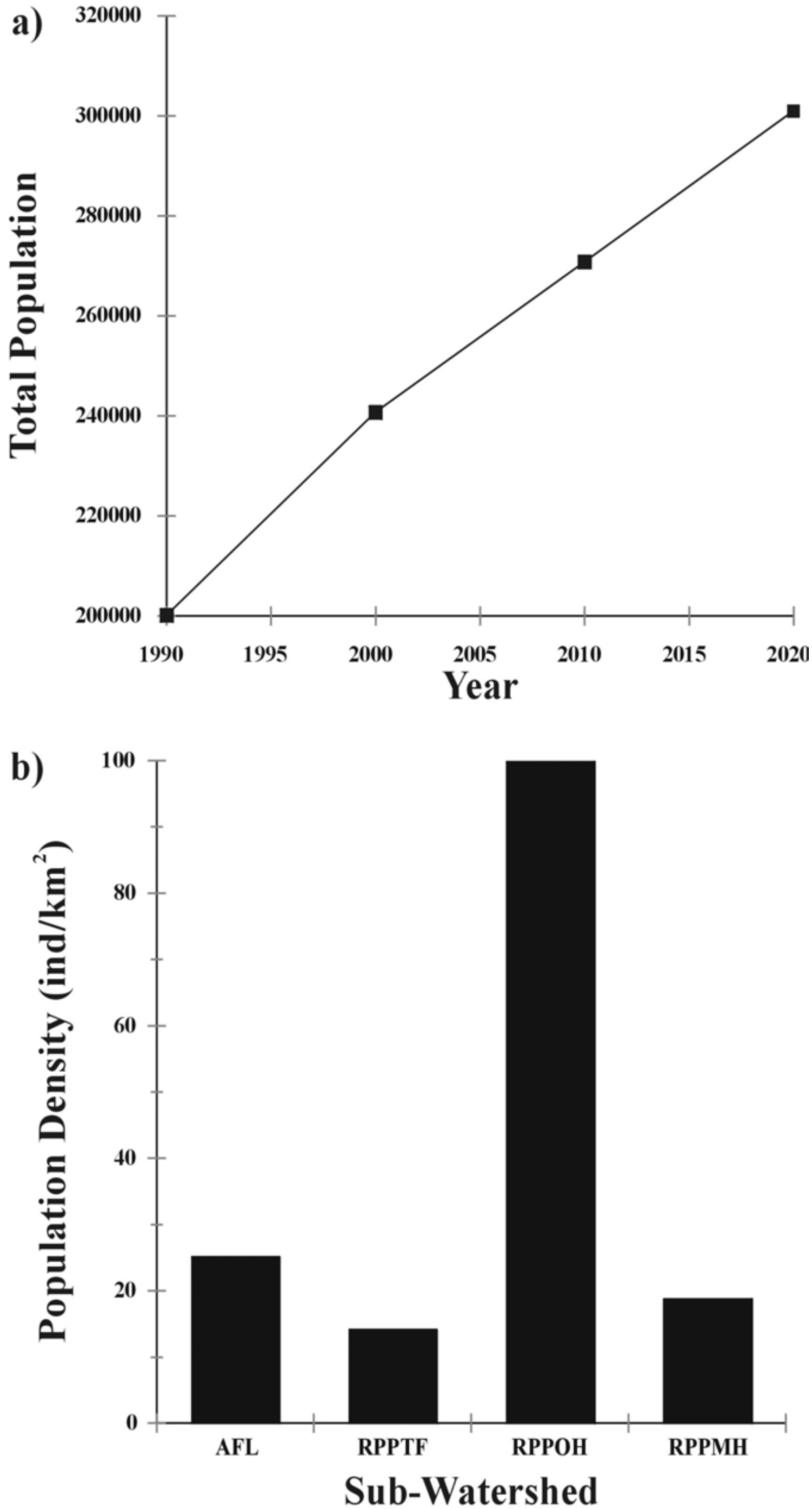


Figure 4-1. Patterns in a) total and projected total watershed population over time and b) population density between sub-watersheds within the Rappahannock River basin for the year 2000.

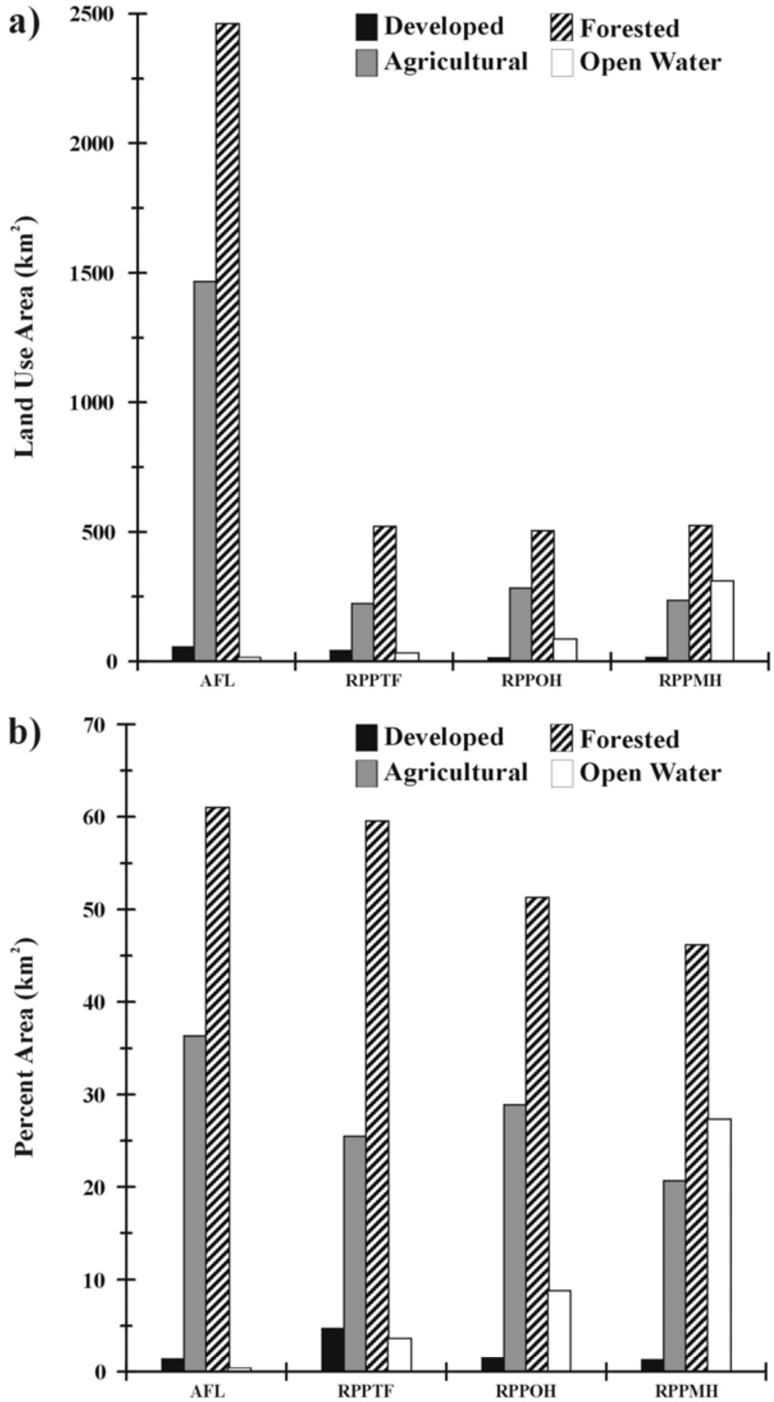


Figure 4-2. Differences in a) total area and b) percentages of land-use types between sub-watersheds of the Rappahannock River for 1999. Data presented were provided by the USEPA, Chesapeake Bay Program Office.

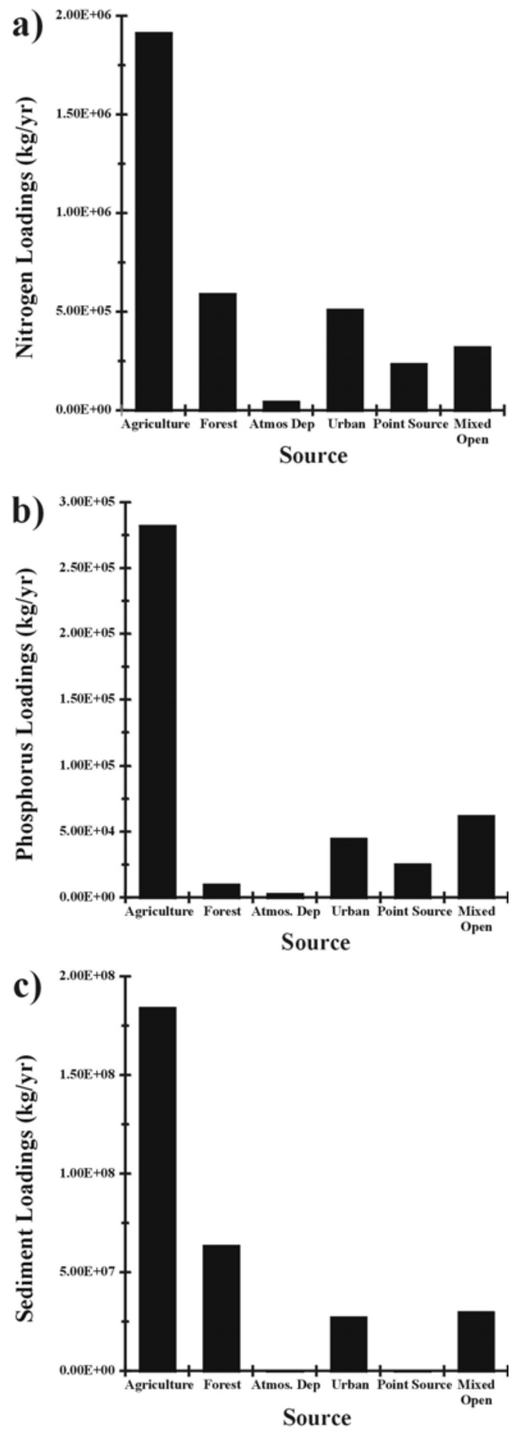


Figure 4-3. Non-point source loadings of a) nitrogen, b) phosphorus, and c) sediments by source for the Rappahannock River in 2000. Data generated using the USEPA Chesapeake Bay Watershed Model.

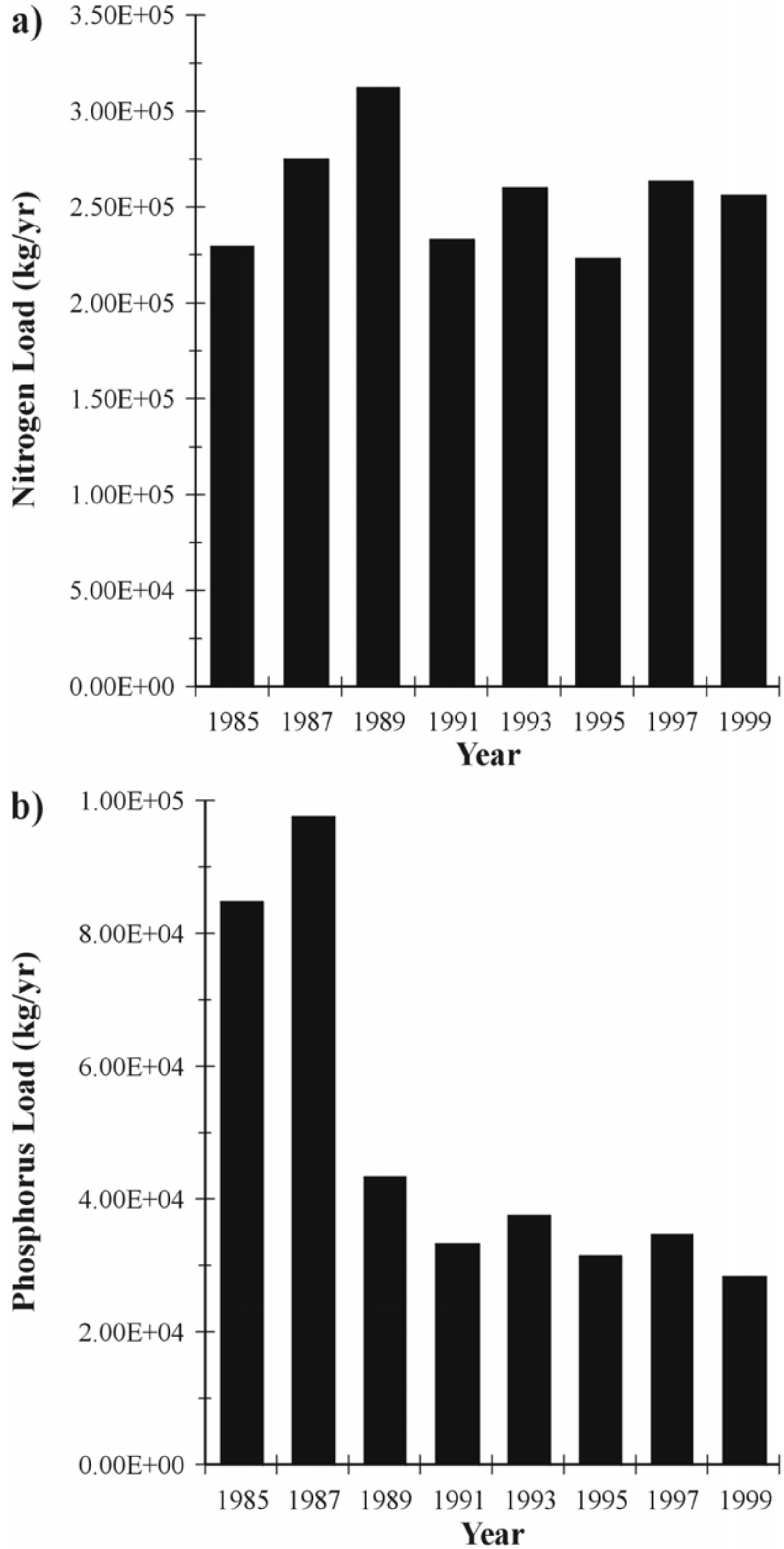
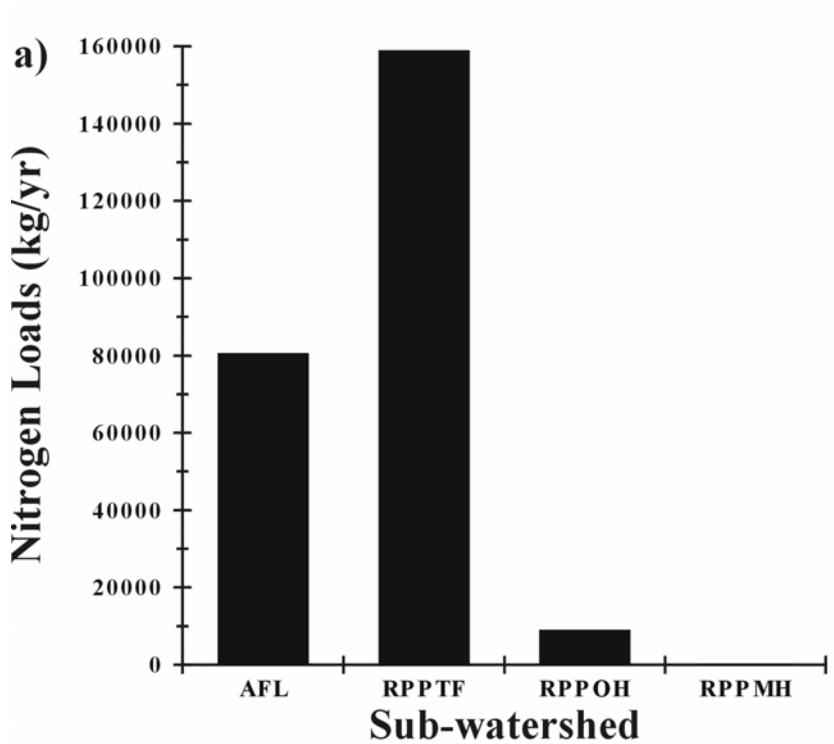


Figure 4-4. Long-term trends in point source a) nitrogen loadings and b) phosphorus loadings in the Rappahannock River.



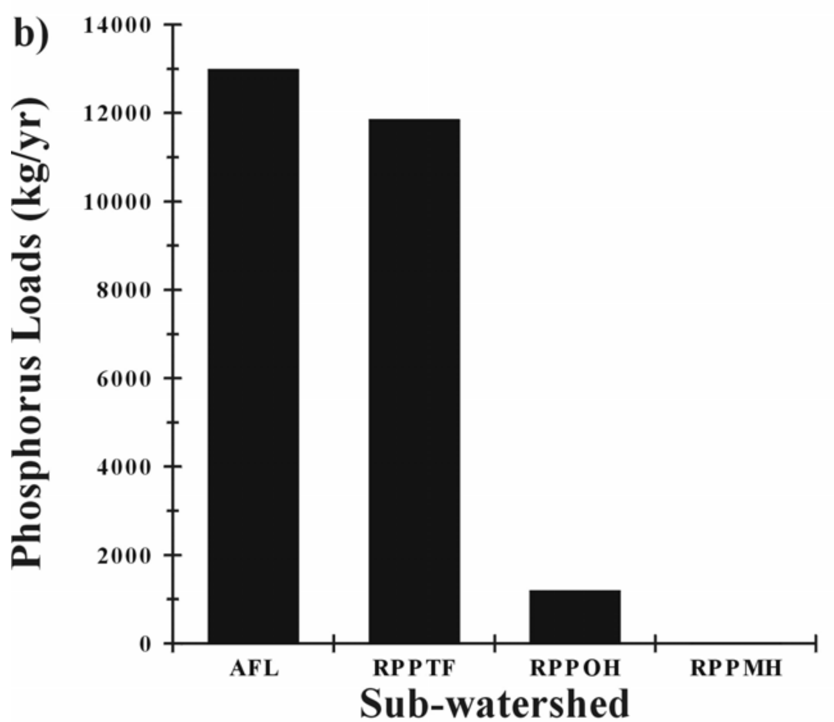


Figure 4-5. Spatial patterns in point source a) nitrogen and b) phosphorus loadings in the Rappahannock River for 1999.

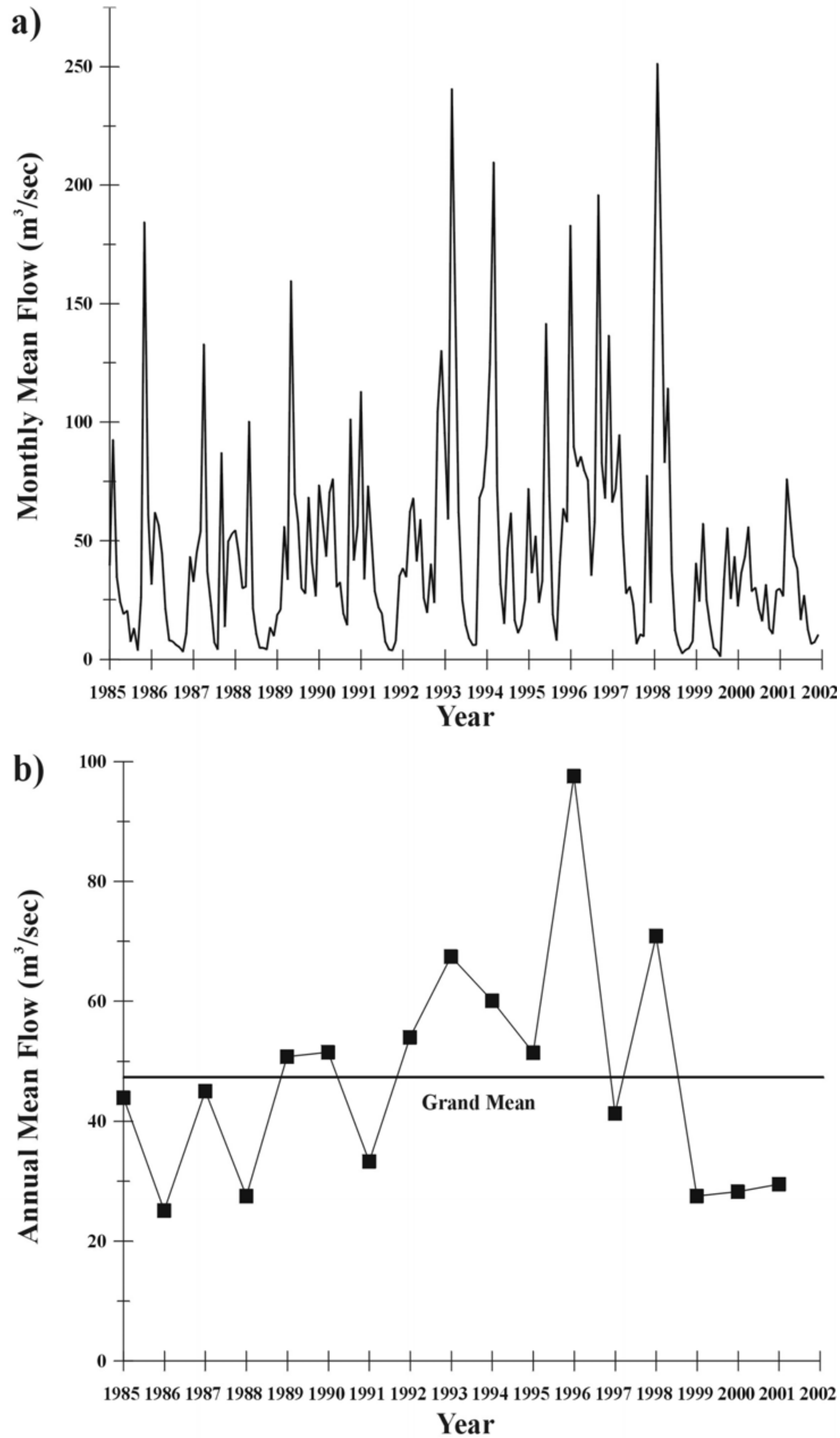
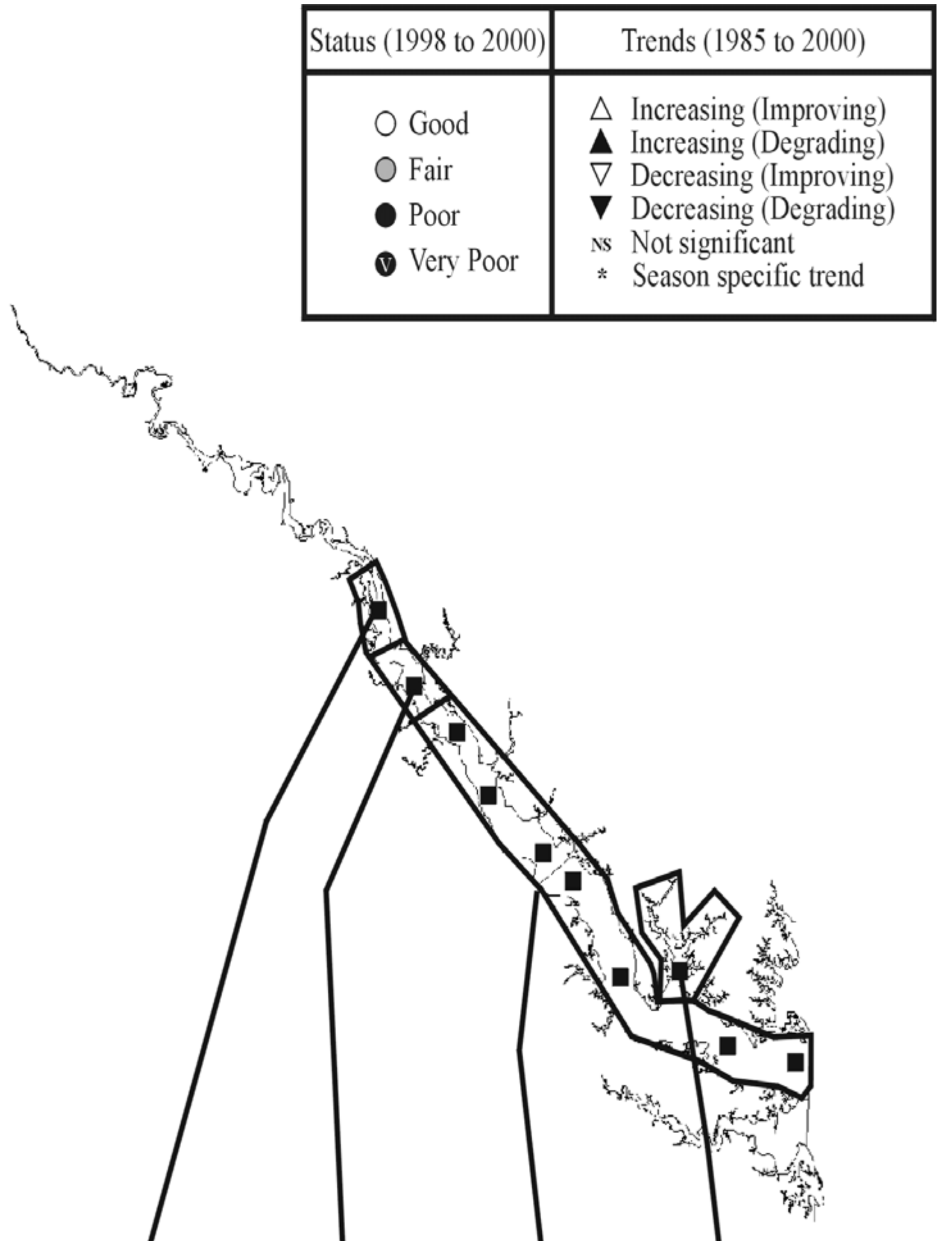
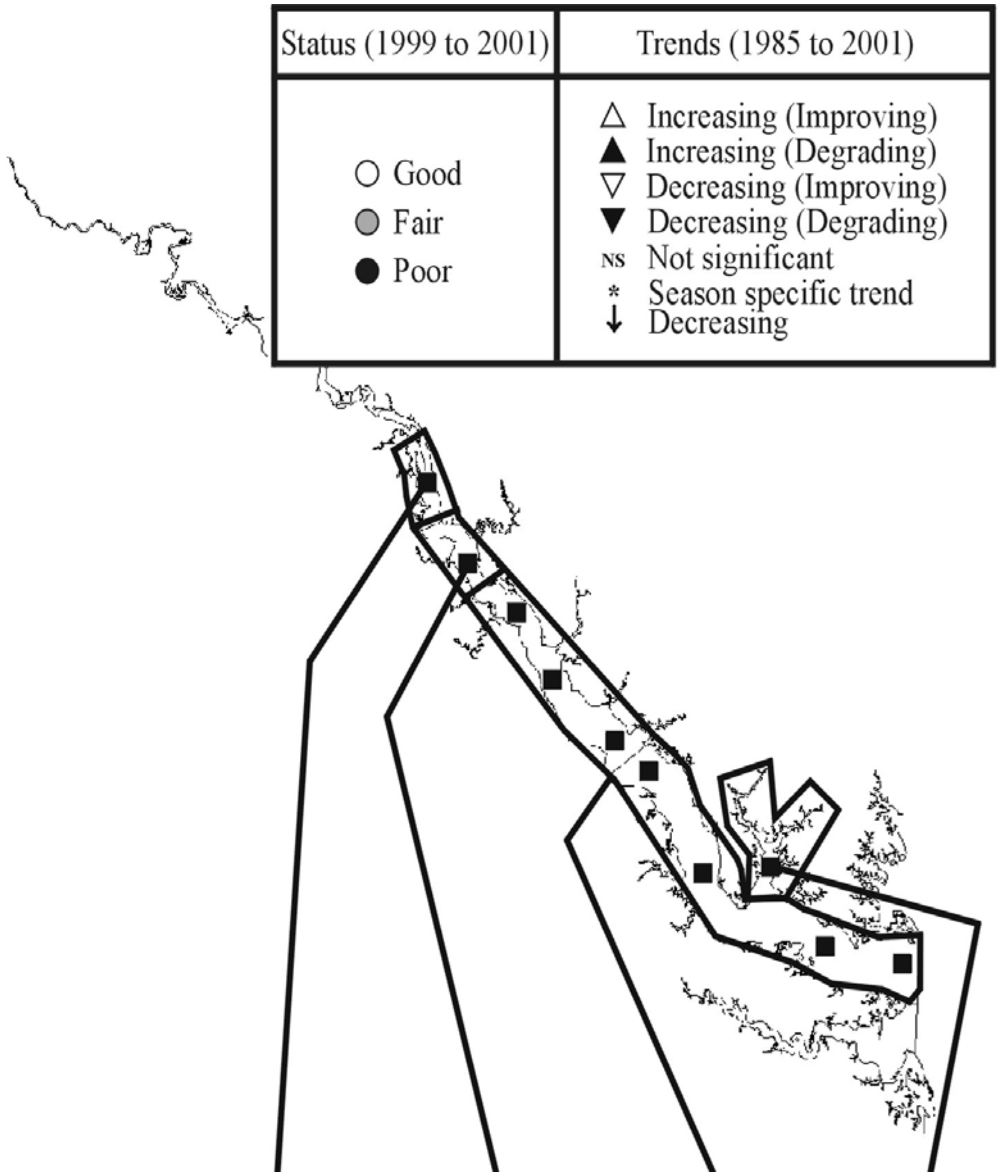


Figure 4-6. Plot of a) monthly mean and b) annual mean freshwater flow at the Rappahannock River fall-line for the period of 1985 to 2001.



Parameter	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corrotoman River
STN	○ NS	○ NS	○ NS	○ ▲
BTN	○ ▽	○ ▲	○ NS	○ ▲
SDIN	○ NS	○ NS	○ NS	○ NS
BDIN	○ ▲	○ NS	○ NS	○ NS
STP	○ NS	○ ▲	◍ ▲	○ ▲
BTP	○ NS	○ ▲	◍ ▲	○ ▲
SDIP	○ NS	○ NS	◍ NS	○ NS
BDIP	○ NS	○ NS	○ NS	○ NS

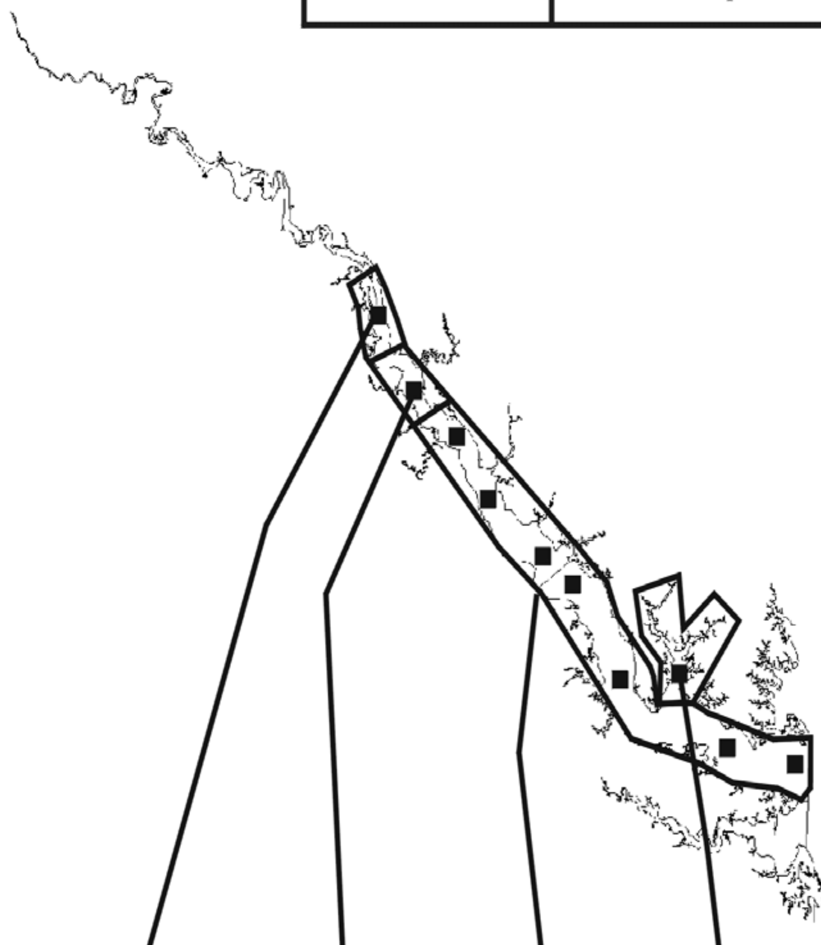
Figure 4-7. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment. Abbreviations for each parameter are: TN= total nitrogen: DIN=dissolved inorganic nitrogen; TP=total phosphorus; DIP= dissolved inorganic nitrogen. The prefixes S and B refer to surface and bottom measurements, respectively. All parameters shown were corrected for potential method effects associated with changes to analytical techniques that occurred in 1994.



Parameter	Upper Rappahannock (Status)	Upper Rappahannock (Trend)	Middle Rappahannock (Status)	Middle Rappahannock (Trend)	Lower Rappahannock (Status)	Lower Rappahannock (Trend)	Corrotoman River (Status)	Corrotoman River (Trend)
SCHLA	● Poor	NS	● Poor	▲	Fair	NS	○ Good	NS
STSS	● Poor	NS	Fair	NS	Fair	NS	○ Good	NS
BTSS	Fair	NS	● Poor	NS	Fair	NS	○ Good	NS
SECCHI	Fair	NS	Fair	NS	Fair	NS	○ Good	▼
BDO	○ Good	NS	○ Good	△	Fair	NS	Fair	▼
SWTEMP		NS		NS		NS		NS
BWTEMP		NS		NS		NS		NS
SSALIN		NS		NS		↓		↓
BSALIN		NS		NS		↓		↓

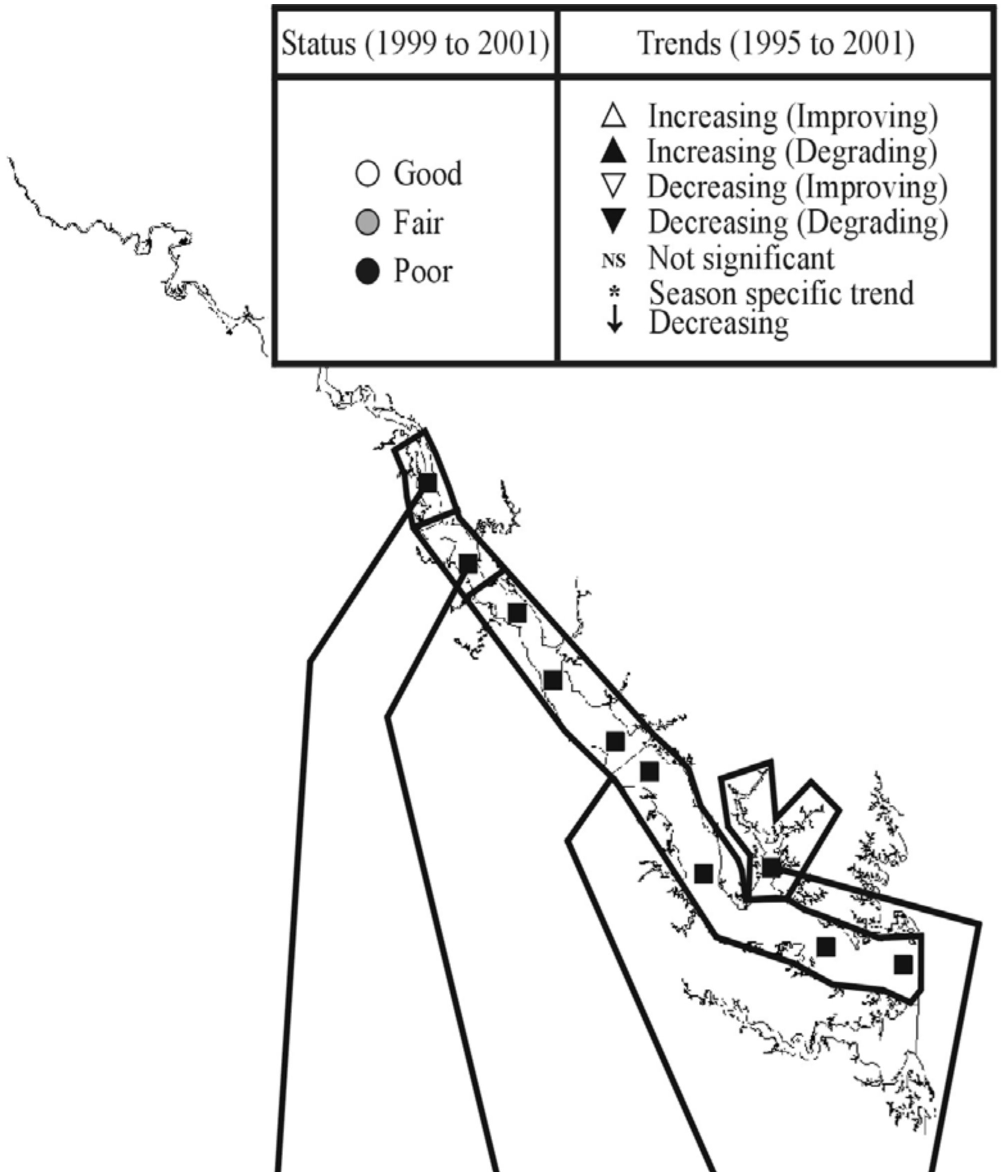
Figure 4-8. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment. Abbreviations for each parameter are: CHLA=chlorophyll a: TSS=total suspended solids; SECCHI=secchi depth; DO=dissolved oxygen; WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

Status (1999 to 2001)	Trends (1995 to 2001)
○ Good ◍ Fair ● Poor ⓥ Very Poor	△ Increasing (Improving) ▲ Increasing (Degrading) ▽ Decreasing (Improving) ▼ Decreasing (Degrading) NS Not significant * Season specific trend



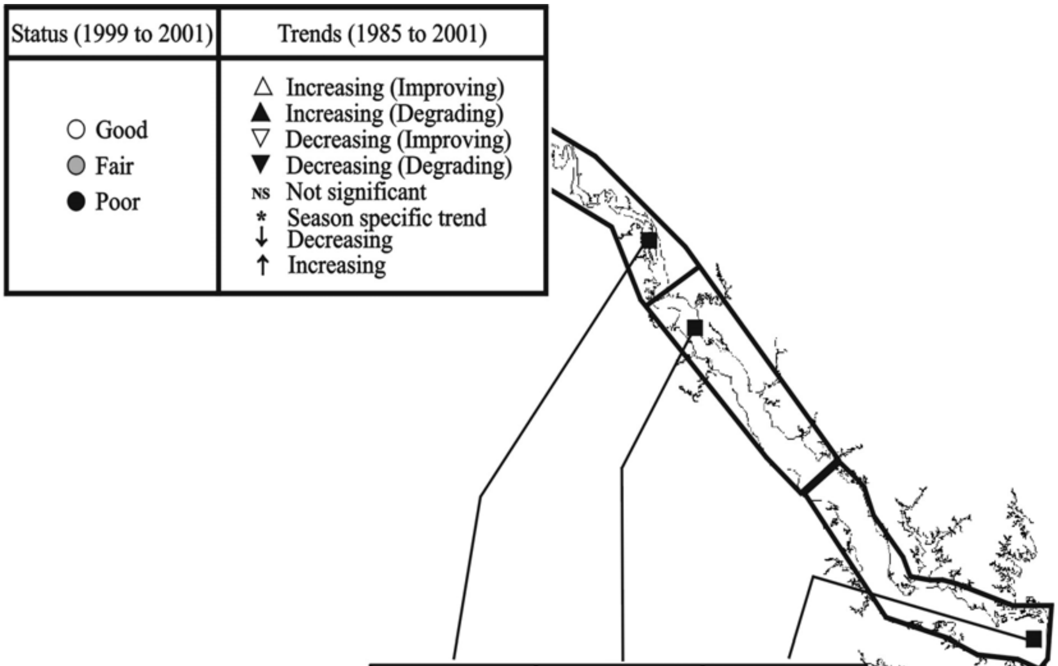
Parameter	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corrotoman River
STN	○ NS	○ NS	○ ▽	○ ▽
BTN	○ NS	○ NS	○ ▽	○ ▽
SDIN	○ NS	○ NS	○ ▽	○ NS
BDIN	○ NS	○ NS	○ ▽	○ NS
STP	○ NS	○ NS	◍ NS	○ NS
BTP	○ NS	○ NS	◍ NS	○ NS
SDIP	○ ▽	○ NS	◍ NS	○ NS
BDIP	○ ▽	○ NS	○ NS	○ NS

Figure 4-9. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period after the method corrections were initiated (1995-2001). Abbreviations for each parameter are: TN= total nitrogen: DIN=dissolved inorganic nitrogen; TP=total phosphorus; DIP= dissolved inorganic nitrogen. The prefixes S and B refer to surface and bottom measurements, respectively.



Parameter	Upper Rappahannock		Middle Rappahannock		Lower Rappahannock		Corrotoman River	
SCHLA	●	▲	●	▲	◍	NS	○	NS
STSS	●	NS	◍	NS	◍	NS	○	NS
BTSS	◍	NS	●	NS	◍	NS	○	NS
SECCHI	◍	▼	◍	NS	◍	NS	○	▼
BDO	○	▼	○	NS	◍	NS	◍	NS
SWTEMP		↑		↑		NS		NS
BWTEMP		↑		↑		NS		NS
SSALIN		NS		↑		↑		↑
BSALIN		NS		↑		↑		↑

Figure 4-10. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period after the method corrections were initiated (1995-2001). Abbreviations for each parameter are: CHLA=chlorophyll a: TSS=total suspended solids; SECCHI=secchi depth; DO= dissolved oxygen; WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.



	TF3.3		RET3.1		LE3.6	
Total Abundance		↑		↑		NS
Total Biomass	◍	↑	●	↑	●	NS
Biomass to Abundance	●	△	●	NS	●	NS
Margalef Diversity Index	●	△	●	NS	●	NS
Productivity	◍	NS	◍	NS	○	▽
Diatom Biomass	○	△	○	△	◍	NS
Dinoflagellate Biomass	●	NS	◍	▽	●	▲
Cyanophyte Biomass	●	▲	●	▲	◍	▲
Chlorophyte Biomass	○	△	○	△	○	△
Picoplankton Biomass	○	▽	○	▽	○	▽
Cryptophyte Biomass		△		△		NS
Procaryote to Eucaryote Biomass	○	NS	○	NS	○	NS
Cyanophyte Abundance		▲		▲		▲

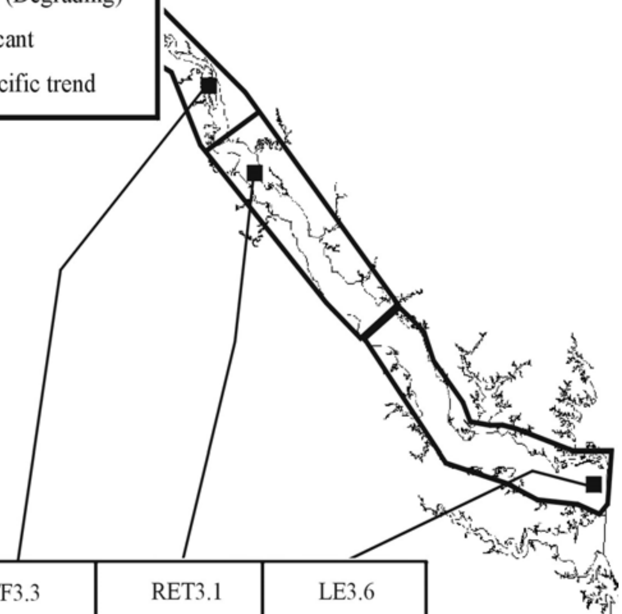
Figure 4-11. Map of the Rappahannock River basin showing summaries of the status and trend analyses for phytoplankton bioindicators for each segment.

Status (1999 to 2001)	Trends (1993 to 2001)
○ Good ◉ Fair ● Poor	△ Increasing (Improving) ▲ Increasing (Degrading) ▽ Decreasing (Improving) ▼ Decreasing (Degrading) NS Not significant * Season specific trend ↑ Increasing ↓ Decreasing

	TF3.3	RET3.1	LE3.6
Total Abundance	NS	NS	NS
Total Biomass	NS	NS	NS
Copepod Nauplii Abundance	○ NS	○ NS	● NS
Rotifer Abundance	○ NS	● NS	● ▲
Oligotrich Abundance	NS	NS	NS
Cladoceran Abundance	↓	NS	NS
Tintinnid Abundance	NS	NS	↓
Polychaeta Larvae Abundance	NS	NS	↓

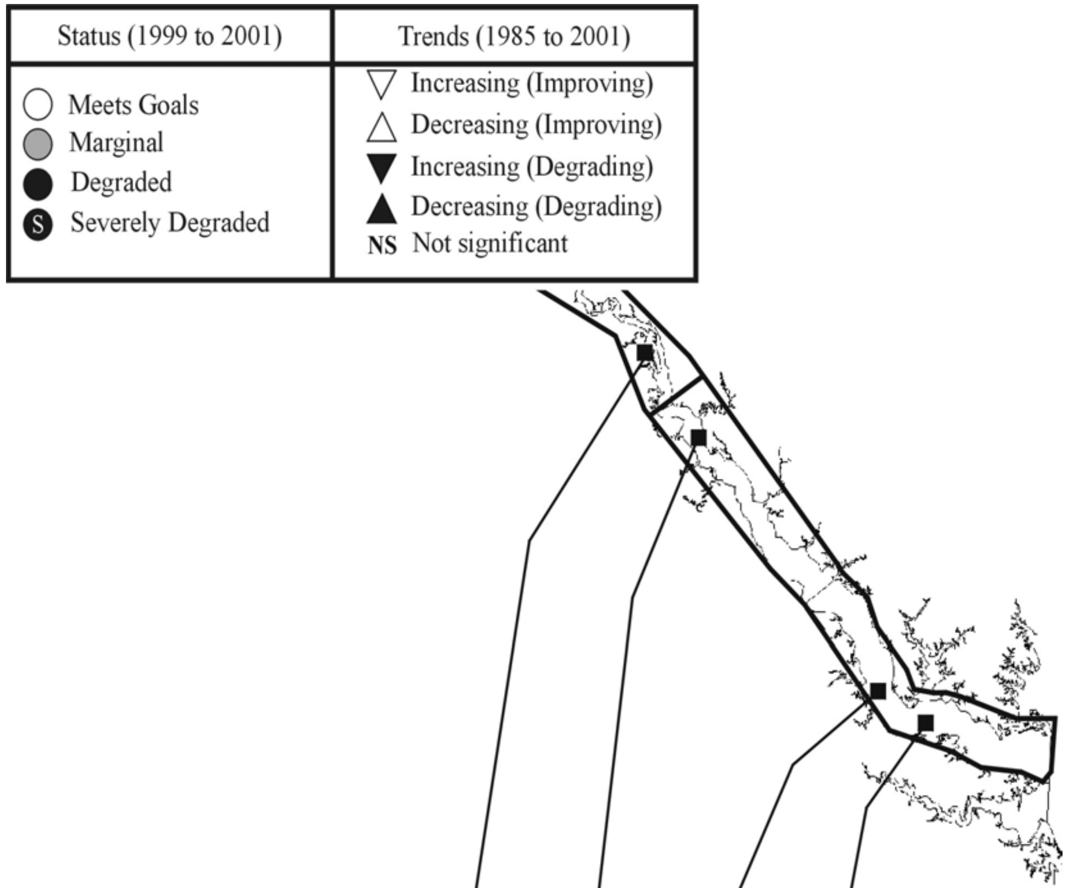
Figure 4-12. Map of the Rappahannock River basin showing summaries of the status and trend analyses for microzooplankton bioindicators for each segment.

Status (1997 to 1999)	Trends (1985 to 1999)
○ Good	△ Increasing (Improving)
◍ Fair	▼ Decreasing (Degrading)
● Poor	NS Not significant
	* Season specific trend



	TF3.3		RET3.1		LE3.6	
Total Abundance	○	NS	●	NS	●	▼
Margalef Diversity Index	○	△	○	△	◍	NS
Shannon Wiener Index	○	△	○	△	◍	▼
Holoplankton Abundance		NS		NS		▼
Meroplankton Abundance		NS		△		NS
Calanoid Abundance		NS		NS		▼
Cyclopoid Abundance		△		NS		NS
Cladoceran Abundance		NS		△		▼
Crab Zoea Abundance		NS		△		NS
Acartia tonsa		▼		NS		▼
Eurytemora spp.		NS		NS		NS
Bosmina longirostis		NS		NS		NS

Figure 4-13. Map of the Rappahannock River basin showing summaries of the status and trend analyses for mesozooplankton bioindicators for each segment.



	TF3.3	RET3.1	LE3.2	LE3.4
Benthic IBI	○ NS	● ▼	● NS	● NS
Total Abundance	NS	NS	△	△
Total Biomass	NS	▼	NS	△
Pollution Sensitive Species Abundance (%)	NS	▼	NS	△
Pollution Indicative Species Abundance (%)	▲	NS	NS	NS
Pollution Sensitive Species Biomass (%)	▼	▼	NS	△
Pollution Indicative Species Biomass (%)	NS	▲	NS	NS
Shannon-Weiner Diversity Index	NS	▼	NS	△

Figure 4-14. Map of the Rappahannock River basin showing summaries of the status and trend analyses for benthic bioindicators for each segment.

Table 4-1. Water quality trends at Rappahannock River RIM stations 1668000 (Fredericksburg) and 1666500 (Robinson River at Locust Dale).

River	Station	Parameter	Data Type	Status	Slope	pValue	Direction
Rappahannock River at Fredericksburg	1668000	NO23F	FAC	--	-0.0256	0.0118	IMPROVING
Rappahannock River at Fredericksburg	1668000	TP	FAC	--	-0.0201	0.0145	IMPROVING
Rappahannock River at Fredericksburg	1668000	TSSED	FAC	--	0.2111	0.0004	DEGRADING
Robinson River at Locust Dale	1666500	TN	FAC	--	-0.0142	0.0015	IMPROVING
Robinson River at Locust Dale	1666500	TN	FWC	0.63001	-0.0140	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	TNH4	FAC	--	-0.0321	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	TNH4	FWC	0.03281	-0.0320	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	TNH4	LOAD	0.11814	-0.0356	0.0094	IMPROVING
Robinson River at Locust Dale	1666500	TKN	FAC	--	0.0280	0.0034	DEGRADING
Robinson River at Locust Dale	1666500	TKN	FWC	0.35933	0.0251	0.0001	DEGRADING
Robinson River at Locust Dale	1666500	NO23W	FAC	--	-0.0473	0.0000	IMPROVING
Robinson River at Locust Dale	1666500	NO23W	FWC	0.24793	-0.0482	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	NO23W	LOAD	0.99401	-0.0518	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	NO3W	FAC	--	-0.0513	0.0000	IMPROVING
Robinson River at Locust Dale	1666500	NO3W	FWC	0.23391	-0.0522	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	NO3W	LOAD	0.93003	-0.0558	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	TP	FAC	--	-0.0264	0.0007	IMPROVING
Robinson River at Locust Dale	1666500	TP	FWC	0.04525	-0.0266	0.0001	IMPROVING
Robinson River at Locust Dale	1666500	TP	LOAD	0.17120	-0.0301	0.0482	IMPROVING

Table 4-2. Water quality status in segment RPPMH (value is the median concentration, secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Season	SValue	SScore	SStatus	BValue	BScore	BStatus
RPPMH	TN	Annual	0.464	10.8	GOOD	0.519	13.9	GOOD
RPPMH	TN	Spring1	0.463	6.4	GOOD	0.528	10.6	GOOD
RPPMH	TN	Spring2	0.466	8.8	GOOD	0.528	11.0	GOOD
RPPMH	TN	Summer1	0.511	14.9	GOOD	0.513	13.4	GOOD
RPPMH	TN	Summer2	0.517	15.5	GOOD	0.501	14.6	GOOD
RPPMH	DIN	Annual	0.012	1.5	GOOD	0.023	1.5	GOOD
RPPMH	DIN	Spring1	0.014	0.5	GOOD	0.023	1.5	GOOD
RPPMH	DIN	Spring2	0.013	1.3	GOOD	0.018	1.5	GOOD
RPPMH	DIN	Summer1	0.009	2.1	GOOD	0.023	2.1	GOOD
RPPMH	DIN	Summer2	0.009	2.2	GOOD	0.027	2.5	GOOD
RPPMH	TP	Annual	0.038	46.2	FAIR	0.048	48.2	FAIR
RPPMH	TP	Spring1	0.038	57.5	FAIR	0.049	52.2	FAIR
RPPMH	TP	Spring2	0.044	60.8	POOR	0.056	57.9	POOR
RPPMH	TP	Summer1	0.045	34.6	GOOD	0.059	47.1	FAIR
RPPMH	TP	Summer2	0.043	29.8	GOOD	0.059	38.1	GOOD
RPPMH	DIP	Annual	0.005	39.4	FAIR	0.006	37.9	GOOD
RPPMH	DIP	Spring1	0.005	62.0	POOR	0.006	58.5	POOR
RPPMH	DIP	Spring2	0.005	44.4	FAIR	0.006	47.5	FAIR
RPPMH	DIP	Summer1	0.005	38.0	GOOD	0.009	30.2	GOOD
RPPMH	DIP	Summer2	0.006	35.4	GOOD	0.010	32.7	GOOD
RPPMH	CHLA	Annual	8.722	48.7	FAIR	-	-	-
RPPMH	CHLA	Spring1	9.896	52.1	FAIR	-	-	-
RPPMH	CHLA	Spring2	10.290	50.0	FAIR	-	-	-
RPPMH	CHLA	Summer1	11.866	49.3	FAIR	-	-	-
RPPMH	CHLA	Summer2	11.547	47.8	FAIR	-	-	-
RPPMH	TSS	Annual	7.770	44.1	FAIR	15.040	51.2	FAIR
RPPMH	TSS	Spring1	8.310	59.7	POOR	18.500	65.9	POOR
RPPMH	TSS	Spring2	13.375	67.4	POOR	18.500	73.2	POOR
RPPMH	TSS	Summer1	8.738	42.5	GOOD	16.456	61.6	POOR
RPPMH	TSS	Summer2	7.540	36.0	GOOD	18.500	59.8	POOR
RPPMH	SECCHI	Annual	1.175	47.3	FAIR	-	-	-
RPPMH	SECCHI	Spring1	1.100	39.3	POOR	-	-	-
RPPMH	SECCHI	Spring2	1.100	38.2	POOR	-	-	-
RPPMH	SECCHI	Summer1	1.125	54.7	FAIR	-	-	-
RPPMH	SECCHI	Summer2	1.150	55.7	FAIR	-	-	-
RPPMH	DO	Spring1	-	-	-	8.905	-	GOOD
RPPMH	DO	Spring2	-	-	-	6.740	-	GOOD
RPPMH	DO	Summer1	-	-	-	4.320	-	FAIR
RPPMH	DO	Summer2	-	-	-	4.220	-	FAIR

Table 4-3. Water quality trends in segment RPPMH (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
RPPMH	TN*	Summer1	S	0.545	0.0170	51.48	0.00	0.0054	DEGRADING
RPPMH	TN*	Spring2	S	0.566	0.0200	60.36	0.00	0.0296	DEGRADING
RPPMH	TN*	Summer1	B	0.577	0.0250	73.11	0.00	0.0026	DEGRADING
RPPMH	TN*	Spring2	B	0.606	0.0280	78.49	0.00	0.0390	DEGRADING
RPPMH	TP*	Annual	S	0.035	0.0020	81.96	0.93	<0.0001	DEGRADING
RPPMH	TP*	Summer1	S	0.038	0.0010	63.45	0.00	0.0003	DEGRADING
RPPMH	TP*	Fall	S	0.027	0.0020	132.79	0.00	0.0073	DEGRADING
RPPMH	TP*	Summer2	S	0.037	0.0020	83.29	0.00	0.0021	DEGRADING
RPPMH	TP*	Annual	B	0.052	0.0010	39.06	0.00	0.0020	DEGRADING
RPPMH	TP*	Winter	B	0.032	0.0020	120.95	0.00	0.0299	DEGRADING
RPPMH	CHLA*	Summer1	S	8.50	0.169	33.86	0.00	0.0170	DEGRADING
RPPMH	CHLA*	Summer2	S	9.00	0.180	34.00	0.00	0.0170	DEGRADING
RPPMH	TSS	Summer2	S	9.70	-0.375	-65.72	0.00	0.0200	IMPROVING
RPPMH	TSS	Spring1	B	8.10	0.879	184.40	0.00	0.0100	DEGRADING
RPPMH	TSS	Spring2	B	7.70	0.923	203.69	0.00	0.0170	DEGRADING
RPPMH	SALIN	Annual	S	14.96	-0.13	-14.99	0.00	0.0020	DECREASING
RPPMH	SALIN	Summer1	S	17.16	-0.17	-16.96	0.00	0.0030	DECREASING
RPPMH	SALIN	Summer2	S	17.53	-0.18	-17.11	0.00	0.0030	DECREASING
RPPMH	SALIN	Annual	B	16.60	-0.07	-6.81	0.00	0.0480	DECREASING
RPPMH	WTEMP	Summer1	B	25.00	-0.06	-4.03	0.00	0.0130	DECREASING
RPPMH	WTEMP	Spring2	B	18.86	-0.10	-8.99	0.00	0.0130	DECREASING
RPPMH	PLL05	Annual	S	0.40	-0.004	-17.85	0.00	0.0260	DEGRADING
RPPMH	PLL05	Spring1	S	0.40	-0.011	-44.63	0.00	0.0100	DEGRADING
RPPMH	PLL05	Spring2	S	0.50	-0.011	-38.42	0.00	0.0010	DEGRADING
RPPMH	PLL10	Annual	S	0.30	-0.004	-21.53	0.00	0.0040	DEGRADING
RPPMH	PLL10	Spring1	S	0.30	-0.009	-49.87	0.00	0.0080	DEGRADING
RPPMH	PLL10	Spring2	S	0.30	-0.009	-51.57	0.00	0.0010	DEGRADING

Table 4-4. SAV season water quality status in segment RPPMH (value is the median concentration; secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Value	Score	Status	SAV Goal Value	Habitat Requirement
RPPMH	TN	0.485	12.1	Good	-	-
RPPMH	DIN	0.010	2.2	Good	0.0107	Pass
RPPMH	TP	0.043	46.5	Fair	-	-
RPPMH	DIP	0.005	43.7	Fair	0.0050	Pass
RPPMH	CHLA	11.17	50.8	Fair	11.2	Pass
RPPMH	TSS	8.31	42.6	Fair	8.4	Pass
RPPMH	SECCHI	1.15	47.6	Fair	-	-
RPPMH	KD	-	-	-	1.30	Pass
RPPMH	PLL05	-	-	-	0.348	Pass
RPPMH	PLL10	-	-	-	0.181	Pass

Table 4-5. SAV Season Water quality trends in segment RPPMH (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
RPPMH	TN*	SAV1	S	0.570	0.0110	34.02	0.00	0.0099	DEGRADING
RPPMH	TP*	SAV1	S	0.038	0.0010	62.65	0.00	0.0001	DEGRADING
RPPMH	TP*	SAV2	S	0.036	0.0010	66.27	0.00	0.0045	DEGRADING
RPPMH	SALIN	SAV1	S	16.03	-0.16	-17.23	0.00	0.0010	DECREASING
RPPMH	PLL05	SAV1	S	0.40	-0.006	-25.07	0.00	0.0040	DEGRADING
RPPMH	PLL10	SAV1	S	0.30	-0.005	-29.47	0.00	0.0010	DEGRADING

Table 4-6. Water quality status in segment RPPOH (value is the median concentration, secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Season	SValue	SScore	SStatus	BValue	BScore	BStatus
RPPOH	TN	Annual	0.745	10.2	GOOD	0.816	11.7	GOOD
RPPOH	TN	Spring1	1.036	17.0	GOOD	1.172	19.4	GOOD
RPPOH	TN	Spring2	0.811	11.6	GOOD	0.823	9.9	GOOD
RPPOH	TN	Summer1	0.627	9.3	GOOD	0.669	9.7	GOOD
RPPOH	TN	Summer2	0.584	8.1	GOOD	0.656	10.1	GOOD
RPPOH	DIN	Annual	0.135	13.5	GOOD	0.175	17.4	GOOD
RPPOH	DIN	Spring1	0.512	28.1	GOOD	0.453	23.5	GOOD
RPPOH	DIN	Spring2	0.186	12.9	GOOD	0.185	12.2	GOOD
RPPOH	DIN	Summer1	0.008	1.1	GOOD	0.010	1.2	GOOD
RPPOH	DIN	Summer2	0.004	0.6	GOOD	0.009	1.4	GOOD
RPPOH	TP	Annual	0.077	36.4	GOOD	0.092	34.2	GOOD
RPPOH	TP	Spring1	0.103	52.7	FAIR	0.144	57.7	FAIR
RPPOH	TP	Spring2	0.103	50.6	FAIR	0.119	41.1	FAIR
RPPOH	TP	Summer1	0.069	23.6	GOOD	0.101	32.9	GOOD
RPPOH	TP	Summer2	0.064	19.9	GOOD	0.105	36.5	GOOD
RPPOH	DIP	Annual	0.008	32.2	GOOD	0.008	32.4	GOOD
RPPOH	DIP	Spring1	0.012	55.3	FAIR	0.011	50.5	FAIR
RPPOH	DIP	Spring2	0.012	49.7	FAIR	0.011	45.2	FAIR
RPPOH	DIP	Summer1	0.009	34.6	GOOD	0.009	32.0	GOOD
RPPOH	DIP	Summer2	0.009	35.9	GOOD	0.010	36.3	GOOD
RPPOH	CHLA	Annual	16.840	67.2	POOR	-	-	-
RPPOH	CHLA	Spring1	8.955	40.1	GOOD	-	-	-
RPPOH	CHLA	Spring2	17.960	67.2	POOR	-	-	-
RPPOH	CHLA	Summer1	18.695	59.7	POOR	-	-	-
RPPOH	CHLA	Summer2	18.260	54.9	FAIR	-	-	-
RPPOH	TSS	Annual	26.000	57.0	FAIR	50.000	65.8	POOR
RPPOH	TSS	Spring1	41.000	70.9	POOR	79.000	78.0	POOR
RPPOH	TSS	Spring2	36.000	65.6	POOR	79.000	78.0	POOR
RPPOH	TSS	Summer1	22.500	49.1	FAIR	42.500	52.4	FAIR
RPPOH	TSS	Summer2	19.000	41.3	FAIR	31.000	36.7	GOOD
RPPOH	SECCHI	Annual	0.400	44.7	FAIR	-	-	-
RPPOH	SECCHI	Spring1	0.300	35.6	POOR	-	-	-
RPPOH	SECCHI	Spring2	0.300	29.3	POOR	-	-	-
RPPOH	SECCHI	Summer1	0.475	53.9	FAIR	-	-	-
RPPOH	SECCHI	Summer2	0.438	41.3	FAIR	-	-	-
RPPOH	DO	Spring1	-	-	-	9.270	-	GOOD
RPPOH	DO	Spring2	-	-	-	7.420	-	GOOD
RPPOH	DO	Summer1	-	-	-	6.635	-	GOOD
RPPOH	DO	Summer2	-	-	-	6.560	-	GOOD

Table 4-7. Water quality trends in segment RPPOH (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
RPPOH	TN*	Summer1	S	0.479	0.0280	99.28	0.00	0.0027	DEGRADING
RPPOH	TN*	Spring2	S	0.592	0.0310	87.93	0.00	0.0302	DEGRADING
RPPOH	TN*	Summer2	S	0.527	0.0240	77.48	0.00	0.0239	DEGRADING
RPPOH	TN*	Annual	B	0.698	0.0240	57.20	0.00	0.0010	DEGRADING
RPPOH	TN*	Summer1	B	0.490	0.0420	144.43	0.00	0.0002	DEGRADING
RPPOH	TN*	Summer2	B	0.531	0.0400	128.13	0.00	0.0009	DEGRADING
RPPOH	DIN*	Winter	S	0.915	-0.0400	-74.32	0.00	0.0348	IMPROVING
RPPOH	TP*	Annual	S	0.058	0.0040	114.83	0.95	0.0001	DEGRADING
RPPOH	TP*	Summer1	S	0.047	0.0040	141.29	0.00	0.0116	DEGRADING
RPPOH	TP*	Fall	S	0.051	0.0050	152.16	0.00	0.0212	DEGRADING
RPPOH	TP*	Winter	S	0.047	0.0040	141.29	6.67	0.0253	DEGRADING
RPPOH	TP*	Summer2	S	0.042	0.0040	144.47	0.00	0.0385	DEGRADING
RPPOH	TP*	Annual	B	0.071	0.0060	132.38	0.00	<0.0001	DEGRADING
RPPOH	TP*	Summer1	B	0.069	0.0070	159.52	0.00	0.0020	DEGRADING
RPPOH	TP*	Fall	B	0.053	0.0050	165.42	0.00	0.0290	DEGRADING
RPPOH	TP*	Winter	B	0.043	0.0080	308.28	0.00	0.0140	DEGRADING
RPPOH	TP*	Summer2	B	0.059	0.0070	205.78	0.00	0.0015	DEGRADING
RPPOH	CHLA*	Annual	S	4.60	0.461	170.26	0.18	<0.0001	DEGRADING
RPPOH	CHLA*	Spring1	S	2.90	0.412	241.46	0.12	0.0070	DEGRADING
RPPOH	CHLA*	Summer1	S	9.60	0.623	110.27	0.02	<0.0001	DEGRADING
RPPOH	CHLA*	Spring2	S	3.70	0.618	283.72	0.06	0.0040	DEGRADING
RPPOH	CHLA*	Summer2	S	9.90	0.617	105.86	0.02	0.0030	DEGRADING
RPPOH	SECCHI	Summer2	S	0.70	-0.01	-17.97	0.00	0.0460	DEGRADING
RPPOH	DO	Summer1	B	6.30	0.06	15.43	0.00	0.0030	IMPROVING

Table 4-8. SAV season water quality status in segment RPPOH (value is the median concentration; secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Value	Score	Status	SAV Goal Value	Habitat Requirement
RPPOH	TN	0.657	9.1	Good	-	-
RPPOH	DIN	0.012	1.1	Good	0.0120	-
RPPOH	TP	0.079	33.3	Good	-	-
RPPOH	DIP	0.009	36.2	Good	0.0090	Pass
RPPOH	CHLA	18.03	60.5	Poor	18.1	Borderline
RPPOH	TSS	26.00	55.6	Fair	26.0	Fails
RPPOH	SECCHI	0.40	42.6	Fair	-	-
RPPOH	KD	-	-	-	3.60	Fails
RPPOH	PLL05	-	-	-	0.058	Borderline
RPPOH	PLL10	-	-	-	0.010	Fails

Table 4-9. SAV Season Water quality trends in segment RPPOH (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
RPPOH	TN*	SAV1	S	0.558	0.0220	65.77	0.00	0.0043	DEGRADING
RPPOH	TP*	SAV1	S	0.047	0.0040	140.81	0.00	0.0005	DEGRADING
RPPOH	TP*	SAV2	S	0.062	0.0040	107.54	0.00	0.0289	DEGRADING
RPPOH	CHLA*	SAV1	S	9.30	0.620	113.41	0.03	<0.0001	DEGRADING
RPPOH	SALIN	SAV1	S	3.99	-0.03	-14.19	0.00	0.0160	DECREASING

Table 4-10. Water quality status in segment RPPTF (value is the median concentration, secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Season	SValue	SScore	SStatus	BValue	BScore	BStatus
RPPTF	TN	Annual	0.923	16.8	GOOD	0.933	13.4	GOOD
RPPTF	TN	Spring1	0.891	14.6	GOOD	0.925	14.5	GOOD
RPPTF	TN	Spring2	0.923	13.0	GOOD	0.857	11.0	GOOD
RPPTF	TN	Summer1	0.938	16.4	GOOD	0.991	14.1	GOOD
RPPTF	TN	Summer2	0.932	15.4	GOOD	0.983	14.1	GOOD
RPPTF	DIN	Annual	0.482	30.8	GOOD	0.475	29.7	GOOD
RPPTF	DIN	Spring1	0.530	24.1	GOOD	0.517	24.3	GOOD
RPPTF	DIN	Spring2	0.424	20.6	GOOD	0.446	18.8	GOOD
RPPTF	DIN	Summer1	0.260	21.8	GOOD	0.251	23.5	GOOD
RPPTF	DIN	Summer2	0.185	12.5	GOOD	0.191	15.7	GOOD
RPPTF	TP	Annual	0.074	32.5	GOOD	0.082	30.7	GOOD
RPPTF	TP	Spring1	0.075	32.8	GOOD	0.080	30.4	GOOD
RPPTF	TP	Spring2	0.073	33.4	GOOD	0.091	32.6	GOOD
RPPTF	TP	Summer1	0.077	27.2	GOOD	0.089	32.6	GOOD
RPPTF	TP	Summer2	0.078	25.3	GOOD	0.089	31.9	GOOD
RPPTF	DIP	Annual	0.008	14.4	GOOD	0.007	21.0	GOOD
RPPTF	DIP	Spring1	0.009	16.3	GOOD	0.009	24.0	GOOD
RPPTF	DIP	Spring2	0.007	9.6	GOOD	0.007	16.6	GOOD
RPPTF	DIP	Summer1	0.006	9.7	GOOD	0.006	12.8	GOOD
RPPTF	DIP	Summer2	0.006	10.3	GOOD	0.006	13.4	GOOD
RPPTF	CHLA	Annual	16.026	76.9	POOR	-	-	-
RPPTF	CHLA	Spring1	12.615	73.8	POOR	-	-	-
RPPTF	CHLA	Spring2	19.260	81.7	POOR	-	-	-
RPPTF	CHLA	Summer1	28.198	79.9	POOR	-	-	-
RPPTF	CHLA	Summer2	28.875	80.8	POOR	-	-	-
RPPTF	TSS	Annual	22.000	66.4	POOR	32.500	48.0	FAIR
RPPTF	TSS	Spring1	27.500	64.3	POOR	37.500	62.5	POOR
RPPTF	TSS	Spring2	23.500	66.8	POOR	39.000	64.1	POOR
RPPTF	TSS	Summer1	21.250	70.1	POOR	32.500	47.1	FAIR
RPPTF	TSS	Summer2	22.000	71.1	POOR	33.500	47.4	FAIR
RPPTF	SECCHI	Annual	0.500	44.1	FAIR	-	-	-
RPPTF	SECCHI	Spring1	0.500	25.7	POOR	-	-	-
RPPTF	SECCHI	Spring2	0.500	24.3	POOR	-	-	-
RPPTF	SECCHI	Summer1	0.500	40.8	FAIR	-	-	-
RPPTF	SECCHI	Summer2	0.500	40.3	POOR	-	-	-
RPPTF	DO	Spring1	-	-	-	9.200	-	GOOD
RPPTF	DO	Spring2	-	-	-	8.300	-	GOOD
RPPTF	DO	Summer1	-	-	-	6.905	-	GOOD
RPPTF	DO	Summer2	-	-	-	6.855	-	GOOD

Table 4-11. Water quality trends in segment RPPTF (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
RPPTF	TN*	Annual	B	0.947	-0.0170	-29.62	0.00	0.0308	IMPROVING
RPPTF	TN*	Winter	B	1.561	-0.0860	-93.99	0.00	0.0023	IMPROVING
RPPTF	DIN*	Summer1	S	0.198	0.0260	221.14	19.44	0.0448	DEGRADING
RPPTF	DIN*	Summer2	S	0.120	0.0380	539.12	25.93	0.0200	DEGRADING
RPPTF	DIN*	Annual	B	0.435	0.0130	50.46	7.69	0.0303	DEGRADING
RPPTF	DIN*	Spring1	B	0.563	0.0190	55.83	0.00	0.0492	DEGRADING
RPPTF	DIN*	Summer1	B	0.216	0.0260	207.26	16.67	0.0206	DEGRADING
RPPTF	DIN*	Summer2	B	0.120	0.0340	474.58	22.22	0.0148	DEGRADING
RPPTF	TP*	Winter	B	0.096	-0.0080	-141.66	0.00	0.0234	IMPROVING
RPPTF	SECCHI	Summer1	S	0.40	0.01	21.25	0.00	0.0200	IMPROVING
RPPTF	DO	Spring1	B	8.70	0.07	12.90	0.00	0.0150	IMPROVING
RPPTF	PLL05	Summer1	S	0.00	0.002	0.00	0.00	0.0160	IMPROVING
RPPTF	PLL10	Annual	S	0.00	0.001	0.00	0.00	0.0280	IMPROVING
RPPTF	PLL10	Summer1	S	0.00	0.001	0.00	0.00	0.0070	IMPROVING

Table 4-12. SAV season water quality status in segment RPPTF (value is the median concentration; secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Value	Score	Status	SAV Goal Value	Habitat Requirement
RPPTF	TN	0.932	16.6	Good	-	-
RPPTF	DIN	0.336	26.2	Good	0.4575	-
RPPTF	TP	0.074	28.6	Good	-	-
RPPTF	DIP	0.007	11.5	Good	0.0070	Pass
RPPTF	CHLA	23.90	81.7	Poor	19.6	Borderline
RPPTF	TSS	22.00	69.7	Poor	17.0	Borderline
RPPTF	SECCHI	0.50	23.1	Poor	-	-
RPPTF	KD	-	-	-	2.90	Fails
RPPTF	PLL05	-	-	-	0.070	Borderline
RPPTF	PLL10	-	-	-	0.019	Fails

Table 4-13. SAV Season Water quality trends in segment RPPTF (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
RPPTF	DIN*	SAV1	S	0.258	0.0220	146.85	14.29	0.0069	DEGRADING
RPPTF	PLL05	SAV1	S	0.00	0.002	0.00	0.00	0.0370	IMPROVING
RPPTF	PLL10	SAV1	S	0.00	0.001	0.00	0.00	0.0110	IMPROVING

Table 4-14. Water quality status in segment CRRMH (value is the median concentration, secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Season	SValue	SScore	SStatus	BValue	BScore	BStatus
CRRMH	TN	Annual	0.468	10.1	GOOD	0.477	11.0	GOOD
CRRMH	TN	Spring1	0.403	2.9	GOOD	0.421	3.4	GOOD
CRRMH	TN	Spring2	0.472	7.2	GOOD	0.502	7.9	GOOD
CRRMH	TN	Summer1	0.498	12.5	GOOD	0.517	14.3	GOOD
CRRMH	TN	Summer2	0.513	14.1	GOOD	0.496	13.2	GOOD
CRRMH	DIN	Annual	0.007	0.7	GOOD	0.009	0.2	GOOD
CRRMH	DIN	Spring1	0.007	0.1	GOOD	0.008	0.1	GOOD
CRRMH	DIN	Spring2	0.007	0.5	GOOD	0.013	0.5	GOOD
CRRMH	DIN	Summer1	0.006	1.0	GOOD	0.013	0.6	GOOD
CRRMH	DIN	Summer2	0.007	1.4	GOOD	0.034	4.2	GOOD
CRRMH	TP	Annual	0.029	29.1	GOOD	0.037	33.4	GOOD
CRRMH	TP	Spring1	0.026	35.7	GOOD	0.034	37.1	GOOD
CRRMH	TP	Spring2	0.032	39.0	GOOD	0.042	47.3	FAIR
CRRMH	TP	Summer1	0.039	26.0	GOOD	0.054	41.5	FAIR
CRRMH	TP	Summer2	0.042	26.3	GOOD	0.054	34.2	GOOD
CRRMH	DIP	Annual	0.003	32.2	GOOD	0.004	29.6	GOOD
CRRMH	DIP	Spring1	0.004	48.4	FAIR	0.004	44.8	FAIR
CRRMH	DIP	Spring2	0.005	50.2	FAIR	0.004	36.1	GOOD
CRRMH	DIP	Summer1	0.004	29.1	GOOD	0.006	22.7	GOOD
CRRMH	DIP	Summer2	0.004	27.2	GOOD	0.006	20.4	GOOD
CRRMH	CHLA	Annual	6.020	25.5	GOOD	-	-	-
CRRMH	CHLA	Spring1	4.300	13.5	GOOD	-	-	-
CRRMH	CHLA	Spring2	8.350	35.6	GOOD	-	-	-
CRRMH	CHLA	Summer1	8.465	29.0	GOOD	-	-	-
CRRMH	CHLA	Summer2	8.510	28.1	GOOD	-	-	-
CRRMH	TSS	Annual	4.000	14.4	GOOD	8.000	21.9	GOOD
CRRMH	TSS	Spring1	4.000	13.3	GOOD	6.000	11.4	GOOD
CRRMH	TSS	Spring2	10.000	54.2	FAIR	12.000	41.6	GOOD
CRRMH	TSS	Summer1	4.500	12.5	GOOD	9.500	32.9	GOOD
CRRMH	TSS	Summer2	4.000	8.5	GOOD	8.000	23.6	GOOD
CRRMH	SECCHI	Annual	1.600	69.8	GOOD	-	-	-
CRRMH	SECCHI	Spring1	1.700	73.0	GOOD	-	-	-
CRRMH	SECCHI	Spring2	1.200	52.6	FAIR	-	-	-
CRRMH	SECCHI	Summer1	1.350	72.8	GOOD	-	-	-
CRRMH	SECCHI	Summer2	1.400	76.6	GOOD	-	-	-
CRRMH	DO	Spring1	-	-	-	8.820	-	GOOD
CRRMH	DO	Spring2	-	-	-	6.750	-	GOOD
CRRMH	DO	Summer1	-	-	-	3.925	-	FAIR
CRRMH	DO	Summer2	-	-	-	3.900	-	FAIR

Table 4-15. Water quality trends in segment CRRMH (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
CRRMH	TN*	Annual	S	0.509	0.0060	20.69	0.00	0.0172	DEGRADING
CRRMH	TN*	Winter	S	0.326	0.0260	135.90	0.00	0.0056	DEGRADING
CRRMH	TN*	Spring2	S	0.466	0.0180	64.91	0.00	0.0283	DEGRADING
CRRMH	TN*	Annual	B	0.472	0.0170	59.41	0.94	0.0007	DEGRADING
CRRMH	TN*	Summer1	B	0.517	0.0210	67.73	0.00	0.0317	DEGRADING
CRRMH	TP*	Annual	S	0.026	0.0010	71.43	5.66	<0.0001	DEGRADING
CRRMH	TP*	Spring1	S	0.028	0.0010	54.35	3.70	0.0380	DEGRADING
CRRMH	TP*	Summer1	S	0.031	0.0010	60.20	0.00	0.0096	DEGRADING
CRRMH	TP*	Fall	S	0.017	0.0010	107.30	3.70	0.0034	DEGRADING
CRRMH	TP*	Summer2	S	0.030	0.0010	78.84	0.00	0.0048	DEGRADING
CRRMH	TP*	Annual	B	0.027	0.0010	87.44	0.94	<0.0001	DEGRADING
CRRMH	TP*	Summer1	B	0.032	0.0020	111.94	0.00	0.0037	DEGRADING
CRRMH	TP*	Fall	B	0.020	0.0010	118.96	0.00	0.0060	DEGRADING
CRRMH	TP*	Winter	B	0.017	0.0020	191.71	6.25	0.0310	DEGRADING
CRRMH	TP*	Summer2	B	0.031	0.0020	114.53	0.00	0.0059	DEGRADING
CRRMH	TSS	Summer1	S	7.50	-0.150	-34.00	0.32	0.0160	IMPROVING
CRRMH	TSS	Summer2	S	9.00	-0.375	-70.83	0.35	<0.0001	IMPROVING
CRRMH	TSS	Summer2	B	16.00	-0.500	-53.13	0.22	0.0230	IMPROVING
CRRMH	SECCHI	Annual	S	2.00	-0.01	-11.31	0.00	0.0090	DEGRADING
CRRMH	SECCHI	Spring2	S	1.90	-0.02	-17.89	0.00	0.0020	DEGRADING
CRRMH	DO	Summer1	B	5.00	-0.12	-39.17	0.00	0.0060	DEGRADING
CRRMH	SALIN	Annual	S	16.51	-0.15	-15.45	0.00	0.0010	DECREASING
CRRMH	SALIN	Summer1	S	18.17	-0.23	-21.19	0.00	<0.0001	DECREASING
CRRMH	SALIN	Summer2	S	18.77	-0.24	-21.50	0.00	0.0010	DECREASING
CRRMH	SALIN	Annual	B	16.84	-0.09	-9.41	0.00	0.0200	DECREASING
CRRMH	SALIN	Summer1	B	18.24	-0.14	-13.26	0.00	0.0110	DECREASING
CRRMH	SALIN	Summer2	B	19.03	-0.14	-12.58	0.00	0.0210	DECREASING
CRRMH	WTEMP	Summer1	B	25.50	-0.11	-7.11	0.00	0.0020	DECREASING
CRRMH	WTEMP	Spring2	B	20.20	-0.11	-9.64	0.00	0.0020	DECREASING
CRRMH	PLL05	Annual	S	0.50	-0.002	-7.82	0.00	0.0360	DEGRADING
CRRMH	PLL05	Spring2	S	0.50	-0.006	-21.42	0.00	0.0140	DEGRADING
CRRMH	PLL10	Annual	S	0.40	-0.003	-12.75	0.00	0.0250	DEGRADING
CRRMH	PLL10	Spring2	S	0.40	-0.006	-26.35	0.00	0.0120	DEGRADING

Table 4-16. SAV season water quality status in segment CRRMH (value is the median concentration; secchi in meters, chlorophyll *a* in µg/l all other parameters in mg/l).

Segment	Parameter	Value	Score	Status	SAV Goal Value	Habitat Requirement
CRRMH	TN	0.478	10.3	Good	-	-
CRRMH	DIN	0.008	1.2	Good	0.0075	Pass
CRRMH	TP	0.035	31.5	Good	-	-
CRRMH	DIP	0.004	34.2	Good	0.0040	Pass
CRRMH	CHLA	8.42	34.1	Good	8.4	Pass
CRRMH	TSS	4.00	10.9	Good	4.0	Pass
CRRMH	SECCHI	1.40	68.1	Good	-	-
CRRMH	KD	-	-	-	1.00	Pass
CRRMH	PLL05	-	-	-	0.465	Pass
CRRMH	PLL10	-	-	-	0.277	Pass

Table 4-17. SAV Season Water quality trends in segment CRRMH (only significant trends are displayed).

Segment	Parameter	Season	Layer	Baseline	Slope	%Change	%BDL	pValue	Direction
CRRMH	TP*	SAV1	S	0.030	0.0010	62.72	0.00	0.0010	DEGRADING
CRRMH	TP*	SAV2	S	0.025	0.0010	81.15	3.70	0.0011	DEGRADING
CRRMH	SECCHI	SAV1	S	1.80	-0.01	-12.56	0.00	0.0070	DEGRADING
CRRMH	SALIN	SAV1	S	17.48	-0.20	-19.45	0.00	<0.0001	DECREASING
CRRMH	PLL10	SAV1	S	0.30	-0.003	-15.87	0.00	0.0360	DEGRADING

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Glossary of Important Terms

Anoxic - condition in which the water column is characterized by a complete absence of oxygen. Anoxic conditions typically result from excessive decomposition of organic material by bacteria, high respiration by phytoplankton, stratification of the water column due to salinity or temperature effects or a combination of these factors. Anoxic conditions can result in fish kills or localized extinction of benthic communities.

Anthropogenic - resulting from or generated by human activities.

Benthos - refers to organisms that dwell on or within the bottom. Includes both hard substratum habitats (e.g. oyster reefs) and sedimentary habitats (sand and mud bottoms).

B-IBI - the benthic index of biotic integrity of Weisberg et al. (1997). The B-IBI is a multi-metric index that compares the condition of a benthic community to reference conditions.

Biological Nutrient Removal (BNR) - A temperature dependent process in which the ammonia nitrogen present in wastewater is converted by bacteria first to nitrate nitrogen and then to nitrogen gas. This technique is used to reduce the concentration of nitrogen in sewage treatment plant effluents.

Biomass - a quantitative estimate of the total mass of organisms for a particular population or community within a given area at a given time. Biomass for phytoplankton is measured as the total carbon within a liter of water. Biomass for the benthos is measured as the total ash-free dry weight per square meter of sediment habitat.

Chlorophyll *a* - a green pigment found in plant cells that functions as the receptor for energy in the form of sunlight. This energy is used in the production of cellular materials for growth and reproduction in plants. Chlorophyll *a* concentrations are measured in µg/L and are used as estimate of the total biomass of phytoplankton cells in the water column. In general, high levels of chlorophyll *a* concentrations are believed to be indicative of excessive growth of phytoplankton resulting from excess nutrients such as nitrogen and phosphorus in the water column.

Calanoid copepod - crustaceans of the subclass Copepoda and order Calanoida that are the dominant group of the mesozooplankton in marine systems. Copepods in this group (e.g. *Acartia tonsa*) are one of the most important consumers of phytoplankton in estuarine systems.

Chlorophytes - algae belonging to the division Chlorophyta often referred to as true "green algae." Chlorophytes occur in unicellular, colonial and filamentous forms and are generally more common in tidal freshwater and oligohaline portions of estuaries.

Cladocerans - crustaceans of the class Branchipoda and class Cladocera commonly referred to as "water fleas." Although cladocerans are primarily found in tidal freshwater areas in estuaries, blooms of marine cladocerans periodically occur in higher salinity areas. Some smaller species such as *Bosmina longirostris* are believed to be indicators of poor water quality conditions.

Cryptomonads -algae belonging to the division Cryptophyta that have accessory pigments in addition to chlorophyll *a* which give these small flagellated cells a red, brown or yellow color.

Cyanobacteria - algae belonging to the division Cyanophycea that are procaryotic and that occur in single-celled , filamentous and colonial forms. In general, high concentrations of cyanobacteria are considered to be indicative of poor water quality.

Cyclopoid copepod - crustaceans of the subclass Copepoda and order Cyclopoida that are the dominant group of the mesozooplankton in marine systems. Copepods in this group (e.g. *Mesocyclops edax*) are one of the most important consumers of phytoplankton in estuarine systems.

Diatoms - algae belonging to the division Bacillariophyta that have a cell wall that is composed primarily of silica and that consists of two separate halves. Most diatoms are single-celled but some are colonial and filamentous forms. Diatoms are generally considered to be indicative of good water quality and are considered to be appropriate food for many zooplankton.

Dinoflagellates - biflagellated, predominately unicellular protists which are capable of performing photosynthesis. Many dinoflagellates are covered with cellulose plates or with a series of membranes. Some dinoflagellates periodically reproduce in large numbers causing blooms that are often referred to as "red tides." Certain species produce toxins and blooms of these forms have been implicated in fish kills. High concentrations of dinoflagellates are generally considered to be indicative of poor water quality.

Dissolved oxygen (DO) - the concentration of oxygen in solution in the water column, measured in mg/L. Most organisms rely on oxygen for cellular metabolism and as a result low levels of dissolved oxygen adversely affect important living resources such as fish and the benthos. In general, dissolved oxygen levels decrease with increasing pollution.

Dissolved inorganic nitrogen (DIN) - the concentration of inorganic nitrogen compounds including ammonia (NH_4), nitrates (NO_3) and nitrites (NO_2) in the water column measured in mg/L. These dissolved inorganic forms of nitrogen are directly available for uptake by phytoplankton by diffusion without first undergoing the process of decomposition. High concentrations of dissolved inorganic nitrogen can result in excessive growth of phytoplankton which in turn can adversely effect other living resources.

Dissolved inorganic phosphorus (PO4F) - the concentration of inorganic phosphorus compounds consisting primarily of orthophosphates (PO_4), The dissolved inorganic forms of phosphorus are directly available for uptake by phytoplankton by diffusion without first undergoing the process of decomposition. High concentrations of dissolved inorganic phosphorus can result in excessive growth of phytoplankton which in turn can adversely effect other living resources.

Estuary - A semi-enclosed body of water that has a free connection with the open sea and within which seawater is diluted measurably with freshwater derived from land drainage.

Eucaryote - organisms the cells of which have discrete organelles and a nucleus separated from the cytoplasm by a membrane.

Fall-line - location of the maximum upstream extent of tidal influence in an estuary typically characterized by a waterfall.

Fixed Point Stations - stations for long-term trend analysis whose location is unchanged over time.

Flow adjusted concentration (FAC) - concentration value which has been recalculated to remove the variation caused by freshwater flow into a stream. By removing variation caused by flow, the effects of other factors such as nutrient management strategies can be assessed.

Holoplankton - zooplankton such as copepods or cladocerans that spend their entire life cycle within the water column.

Habitat - a local environment that has a community distinct from other such habitat types. For the B-IBI of Chesapeake Bay seven habitat types were defined as combinations of salinity and sedimentary types - tidal freshwater, oligohaline, low mesohaline, high mesohaline sand, high mesohaline mud, polyhaline sand and polyhaline mud.

Hypoxic - condition in which the water column is characterized by dissolved oxygen concentrations less than 2 mg/L but greater than 0 mg/L. Hypoxic conditions typically result from excessive decomposition of organic material by bacteria, high respiration by phytoplankton, stratification of the water column due to salinity or temperature effects or a combination of these factors. Hypoxic conditions can result in fish kills or localized extinction of benthic communities.

Light attenuation (KD) - Absorption, scattering, or reflection of light by dissolved or suspended material in the water column expressed as the change in light extinction per meter of depth. Light attenuation reduces the amount of light available to submerged aquatic vegetation.

Loading - the total mass of contaminant or nutrient added to a stream or river generally expressed in lbs/yr.

Macrobenthos - a size category of benthic organisms that are retained on a mesh of 0.5 mm.

Meroplankton - temporary zooplankton consisting of the larval stages of organisms whose adult stages are not planktonic.

Mesohaline - refers to waters with salinity values ranging between 0.5 and 18.0 ppt.

Mesozooplankton - zooplankton with a maximum dimension ranging between 63 µm and 2000 µm. This size category consists primarily of adults stages of copepods, cladocerans, mysid shrimp, and chaetognaths, as well as, the larval stages of a variety of invertebrates and fish.

Metric - a parameter or measurement of community structure (e.g., abundance, biomass, species diversity).

Microzooplankton - zooplankton with a maximum dimension ranging between 2 µm and 63 µm. This size category consists primarily of single-celled protozoans, rotifers and the larval stages of copepods, cladocerans and other invertebrates.

Nauplii - earliest crustacean larval stage characterized by a single simple eye and three pairs of appendages.

Non-point source - a source of pollution that is distributed widely across the landscape surrounding a water body instead of being at a fixed location (e.g. run-off from residential and agricultural land).

Oligohaline - refers to waters with salinity values ranging between 0.5 and 5.0 ppt.

Oligotrich - protists of the phylum Ciliophora and order Oligotricha. These ciliates are important predators of small phytoplankton in marine systems.

Percent of light at the leaf surface (PLL) - the percentage of light at the surface of the water column that reaches the surface of the leaves of submerged aquatic vegetation generally estimated for depths of 0.5 m and 1.0 m. Without sufficient light at the leaf surface, submerged aquatic plants cannot perform photosynthesis and hence cannot grow or reproduce.

Phytoplankton - that portion of the plankton capable of producing its own food by photosynthesis. Typical members of the phytoplankton include diatoms, dinoflagellates and chlorophytes.

Picoplankton - phytoplankton with a diameter between 0.2 and 2.0 µm in diameter. Picoplankton consists primarily of cyanobacteria and high concentrations of picoplankton are generally considered to be indicative of poor water quality conditions.

Pielou's evenness - an estimate of the distribution of proportional abundances of individual species within a community. Evenness (J) is calculated as follows: $J=H'/\ln S$ where H' is the Shannon - Weiner diversity index and S is the number of species.

Plankton - aquatic organisms that drift within and that are incapable of movement against water currents. Some plankton have limited locomotor ability that allows them to change their vertical position in the water column.

Point source - a source of pollution that is concentrated at a specific location such as the outfall of a sewage treatment plant or factory.

Polyhaline - refers to waters with salinity values ranging between 18.0 and 30 ppt.

Primary productivity - the rate of production of living material through the process of photosynthesis that for phytoplankton is typically expressed in grams of carbon per liter of water per hour. High rates of primary productivity are generally considered to be related to excessive concentrations of nutrients such as nitrogen and phosphorus in the water column.

Probability based sampling - all locations within a stratum have an equal chance of being sampled. Allows estimation of the percent of the stratum meeting or failing the benthic restoration goals.

Procaryote - organisms the cells of which do not have discrete organelles or a nucleus (e.g. Cyanobacteria).

Pycnocline - a rapid change in salinity in the water column indicating stratification of water with depth resulting from either changes in salinity or water temperature.

Random Station - a station selected randomly within a stratum. In every succeeding sampling event new random locations are selected.

Recruitment - The successful dispersal settlement and development of larval forms of plants or animal to a reproducing adult.

Reference condition - the structure of benthic communities at reference sites.

Reference sites - sites determined to be minimally impacted by anthropogenic stress. Conditions at theses sites are considered to represent goals for restoration of impacted benthic communities. Reference sites were selected by Weisberg et al. (1997) as those outside highly developed watersheds, distant from any point-source discharge, with no sediment contaminant effect, with no low dissolved oxygen effect and with a low level of organic matter in the sediment.

Restoration Goal - refers to obtaining an average B-IBI value of 3.0 for a benthic community indicating that values for metrics approximate the reference condition.

Riparian Buffer - An area of trees and shrubs a minium of 100 feet wide located up gradient, adjacent, and parallel to the edge of a water feature which serves to: 1) reduce excess amounts of sediment, organic matter, nutrients, and other pollutants in surface runoff, 2) reduce soluble pollutants in shallow ground water flow, 3) create shade along water bodies to lower aquatic temperatures, 4) provide a source of detritus and large woody debris aquatic organisms, 5) provide riparian habitat and corridors for wildlife, and 6) reduce erosion of streambanks and shorelines.

Rotifer - small multicellular planktonic animal of phylum Rotifera. These organisms are a major component of the microzooplankton and are major consumers of phytoplankton. High densities of rotifers are believed to be indicative of high densities of small phytoplankton such as cyanobacteria and as such are believed to be indicative of poor water quality.

Salinity - the concentration of dissolved salts in the water column measured in mg/L, ppt or psu. The composition and distribution of plant and animal communities is directly affected by salinity in estuarine systems. The effects of salinity on living resources must be taken into consideration when interpreting the potential effects of human activities on living resources.

Sarcodinians - single celled protists of the subphylum Sarcodina which includes amoeba and similar forms, characterized by possession of pseudopodia. Planktonic forms of sarcodinians typically have a external shell or test constructed of detrital or sedimentary particles and are important consumers of phytoplankton.

Secchi depth - the depth of light penetration expressed in meters as measured using a secchi disk. Light penetration depth directly affects the growth and recruitment of submerge aquatic vegetation.

Shannon Weiner diversity index - a measure of the number of species within a community and the relative abundances of each species. The Shannon Weiner index is calculated as follows:

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i$$

where p_i is the proportion of the *i*th species and *S* is the number of species.

Stratum - a geographic region of unique ecological condition or managerial interest.

Submerged aquatic vegetation (SAV) - rooted vascular plants (e.g. eelgrass, widgeon grass, sago pondweed) that grow in shallow water areas . SAV are important in marine environments because they serve as major food source, provide refuge for juvenile crabs and fish, stabilize sediments preventing shoreline erosion and excessive suspended materials in the water column, and produce oxygen in the water column.

Threshold - a value of a metric that determines the B-IBI scoring. For all metrics except abundance and biomass, two thresholds are used - the lower 5th percentile and the 50th percentile (median) of the distribution of values at reference sites. Samples with metric values less than the lower 5th percentile are scored as a 1. Samples with values between the 5th and 50th metrics are scored as 3 and values greater than the 50th percentile are scored as 5. For abundance and biomass, values below the 5th and above the 95th percentile are scored as 1, values between the 5th and 25th and the 75th and 95th percentiles are scored as 3 and values between the 25th and 75th percentiles are scored as 5.

Tidal freshwater - refers to waters with salinity values ranging between 0 and 0.5 ppt which are located in the upper reaches of the estuary at or just below the maximum upstream extent of tidal influence.

Tintinnid - protists of phylum Ciliophora and order Oligotricha. These ciliates are important predators of small phytoplankton in marine systems. Tintinnids are distinguished from other members of this group because they create an exoskeleton or test made of foreign particles that have been cemented together.

Total nitrogen (TN) - the concentration of both inorganic and organic compounds in the water column which contain nitrogen measured in mg/L. Nitrogen is a required nutrient for protein synthesis. Inorganic forms of nitrogen are directly available for uptake by phytoplankton while organic compounds must first be decomposed by bacteria prior to being available for use for other organisms. High levels of total nitrogen are considered to be detrimental to living resources either as a source of nutrients for excessive phytoplankton growth or as a source of excessive bacterial decomposition that can increase the incidence and extent of anoxic or hypoxic events.

Total phosphorus (TP) - the concentration of both inorganic and organic compounds in the water column which contain phosphorus measured in mg/L. Phosphorus is a required nutrient for cellular metabolism and for the production of cell membranes. Inorganic forms of phosphorus are directly available for uptake by phytoplankton while organic compounds must first be decomposed by bacteria prior to being available for use for other organisms. High levels of total nitrogen are considered to be detrimental to living resources either as a source of nutrients for excessive phytoplankton growth or as a source of excessive bacterial decomposition that can increase the incidence and extent of anoxic or hypoxic events.

Total suspended solids (TSS) - the concentration of suspended particles in the water column, measured in mg/L. The composition of total suspended solids includes both inorganic (fixed) and organic (volatile) compounds. The fixed suspended solids component is comprised of sediment particles while the volatile suspended solids component is comprised of detrital particles and planktonic organisms. The concentration of total suspended solids directly affects water clarity which in turn affects the development and growth of submerged aquatic vegetation.

Zoea - last planktonic larval stage of crustaceans such as crabs and shrimp. Numbers of crab zoea may reflect the recruitment success of adult crabs.

Zooplankton - the animal component of the plankton which typically includes copepods, cladocerans, jellyfish and many other forms.