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STATUS AND TRENDS IN WATER QUALITY AND LIVING RESOURCES IN THE VIRGINIA CHESAPEAKE BAY: RAPPAHANNOCK RIVER (1985-2002)

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Submitted to:

Chesapeake Bay Program Office
Virginia Department of Environmental Quality
629 East Main Street
Richmond, Virginia 23230

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Preface

This material in this report was produced for the Virginia Department of Environmental Quality 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 periodically 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.

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Summary

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. An overal summary of findings for the major VA Bay tributaries (i.e. James, Yourk and Rappahannock Rivers) is bulleted below while the remainder of this report focuses on the detailed results for the Rappahannock River. Overall 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 20% 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 13% for nitrogen, compared to the 1985 baseline loads.

- For phosphorus, there were improving trends above the fall-line at the river input stations of the James River, Appomattox River, Mattaponi River, and Rappahannock 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 18 years. Both improving trends many degrading trends in phosphorus were detected were detected in the Virginia tributaries . Overall, there were 10 areas with improving trends and 11 areas with degrading trends in this parameter within the Virginia tributaries. Nearly half of those areas with improving trends in phosphorus were located in the Elizabeth River.

- For nitrogen, there were improving trends above the fall-line at the river input stations of the James River, Appomattox River, Mattaponi River and Rappahannock River and a degrading trend in the Pamunkey River. Overall, there were nine areas showing improving trends but only two areas showing degrading trends for nitrogen. Nitrogen levels showed improving trends in nearly segments all of the Elizabeth River.

- Chlorophyll *a* levels are moderately high throughout much of the tidal waters. Degrading trends were widespread geographically and indicative of detrimentally high nutrient levels. Overall, six areas showed degrading trends in chlorophyll *a* and four showed an improving trend. Every tributary had at least one degrading trend in chlorophyll *a* except the Elizabeth River.

- Water clarity, a very important environmental parameter, was generally fair or poor throughout the tributaries and degrading trends were detected five areas in the tributaries. 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 five areas showing improving trends and six areas showing degrading trends in water clarity.

- Levels of dissolved oxygen are improving in geographically widespread areas of the tidal rivers. Overall, there were 11 areas showing improving trends and no areas showing degrading trends for dissolved oxygen conditions. Dissolved oxygen conditions were good in most of the segments in the Virginia tributaries.

- The Virginia tributaries continue to contain favorable diatom populations that are generally dominant among the other flora in their abundance and biomass. However, there are increasing population trends among the cyanobacteria and dinoflagellates that are degrading and represent a less favorable phytoplankton population for these rivers. If these trends continue they would directly impact the trophic status and balance within the plankton community. Any increased development of dinoflagellate blooms within these rivers is another concern.

- Degrading trends and poor status of microzooplankton communities were observed in all of Virginia tributaries except the Elizabeth River. Most of the degrading trends and poor status occurred in the lower portions of each of the three major tributaries. Improving trends in the microzooplankton were observed in the Upper and Middle James River. Degrading trends in the microzooplankton may be related to degrading trends in nutrients and water clarity indicators and/or the decreasing trends in salinity observed in these regions.

- 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) monitored by the Department of Conservation and Recreation. Values with a "*" were updated with the latest available point source data.

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)	21,813*	-74%	246,721*	+11%		
York (9)	84,618*	-59%	502,801*	-20%		
James (30)	607,670*	-62%	6,974,083*	-44%		
Coastal (8)	66,482	-56%	826,527	+40%		
Totals	1,031,801	-57%	13,886,177	-20%		
C. Total Loads. All river basins combined.						
Nonpoint Source	3,569,127	-7%	24,028,077	-9%	2,178,145	-10.8%
Point Source	1,031,801	-57%	13,886,177	-20%		
Combined Loads	4,600,928	-26%	37,914,254	-13%	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 18 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 2002. 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 2002. Water quality data have also been collected by the Virginia Department of Environmental Quality (DEQ) 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 Virginia DEQ at 27 sites in the James, York (including the Mattaponi and Pamunkey) and Rappahannock rivers (Figure 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). In August 1990, station LAF1 was dropped from the Elizabeth River Long Term Monitoring (ERLTM) Program.

The temporal sampling scheme for the water quality monitoring program changed several times over the 18 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 until 1996. Starting in 1996 Mainstem sampling cruises were conducted semi-monthly for July and August and monthly the rest of the year. 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 (Donat and Doughten, 2002).

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 (Donat and Doughten, 2002). 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 "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. Microzooplankton

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 2-3). 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).

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.

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 ºC and ashing at 550 ºC 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 time periods or "seasons" 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 2000 through December of 2002 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, 2000 through December, 2002. 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.

Water quality data were also assessed to determine if the SAV habitat requirements were met for the following parameters: chlorophyll *a* , total suspended solids, secchi depth, 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 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 secchi depth) 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.

Status for phytoplankton, and microzooplankton 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 copepod nauplii abundance and rotifer abundance.

Status of benthic communities at each station was characterized using the three-year mean value (2000 through 2002) 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.

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

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.

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. These changes resulted in step trends in these parameters. In order to compensate for the step trends, a "blocked" seasonal Kendall approach (Gilbert, 1987) was used to compare trends conducted between two separate time periods which in this case were the pre-method (1985 through 1993) and post-method change (1995 through 2002) time periods for these parameters. Note that 1994 was eliminated from the analyses because samples during this year were collected and processed by laboratory that was different than the DEQ. The "blocked" seasonal Kendall test was applied only to those segment/parameter combination for which a method change occurred. The statistical tests used for all other segment/parameter combinations were the seasonal Kendall test for monotonic trends and the Van Belle and Hughes tests for homogeneity of trends between stations, seasons, and station-season combinations (Gilbert, 1987).

A p value of 0.05 was chosen as the statistical test criterion for all water quality 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).

3. 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:

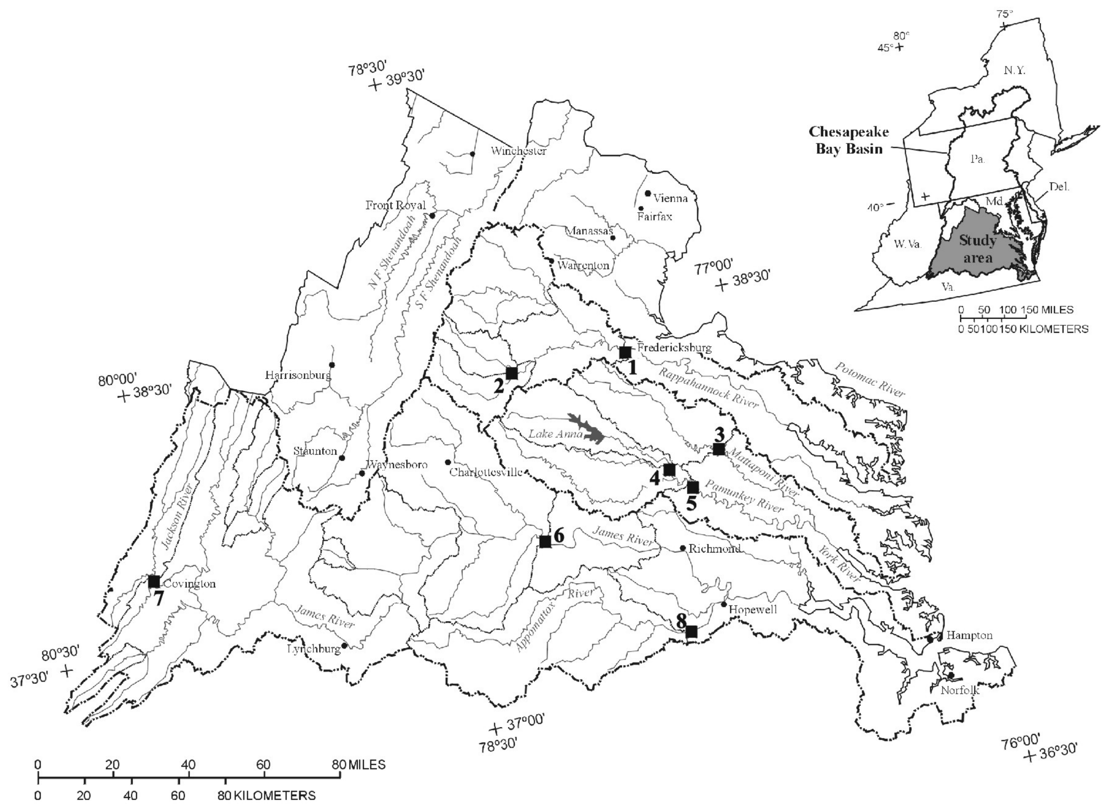
$$D = \frac{S - 1}{\log_2 N}$$

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

Trend analyses for microzooplankton communities were conducted by station using monthly medians of microzooplankton collected from the beginning of the monitoring program through December of 2002. 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.

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 17 year period of 1985-2002. 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.

The statistical tests used for the living resources bioinidcators were the seasonal Kendall test for monotonic trends and the Van Belle and Hughes tests for homogeneity of trends between seasons (Gilbert, 1987). Statistical test criterion for the phytoplankton and microzooplankton was a p value of 0.05 while the criterion for the benthic bioindicators was a p value of 0.10.



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.

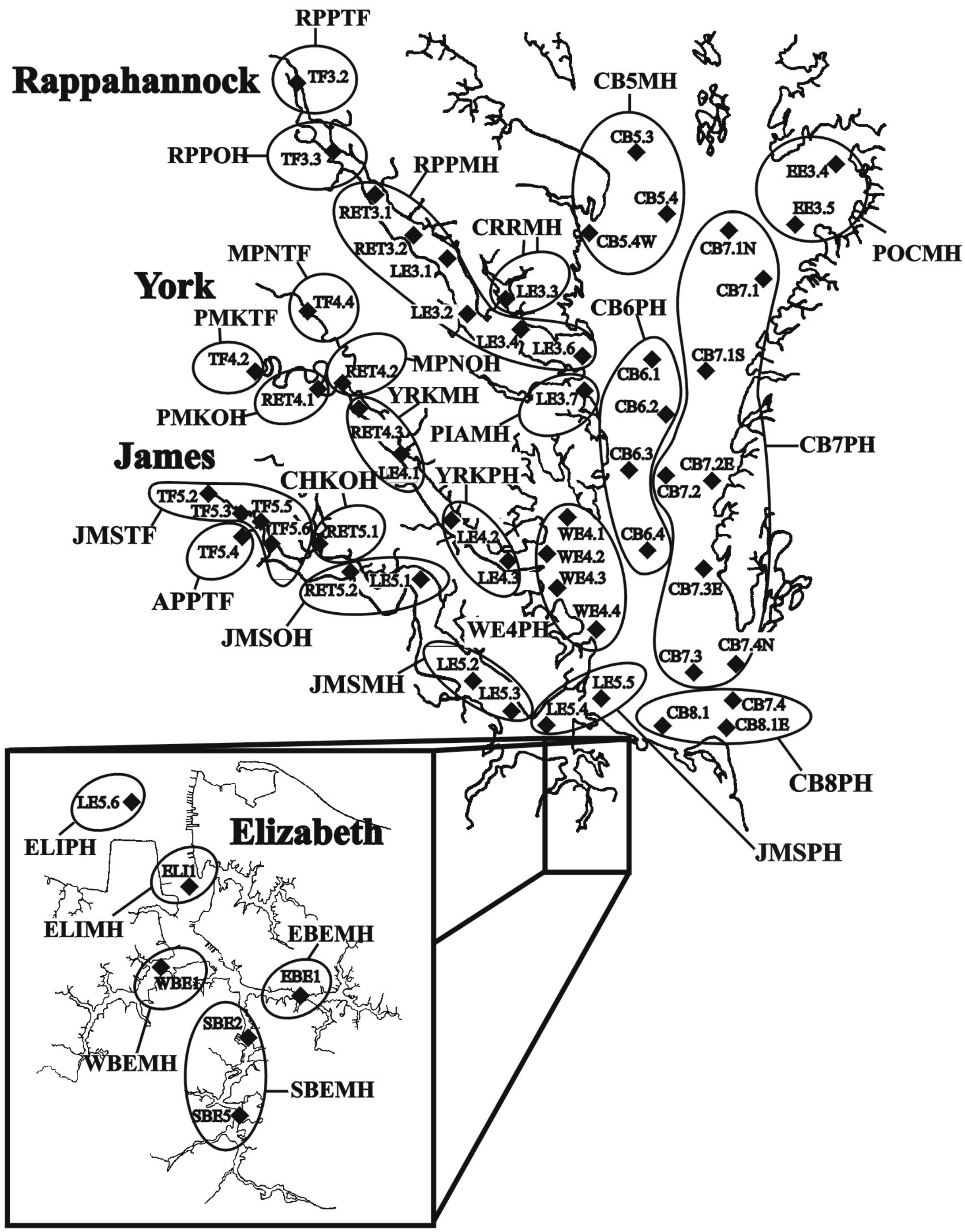


Figure 2-2. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem used in the statistical analyses. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

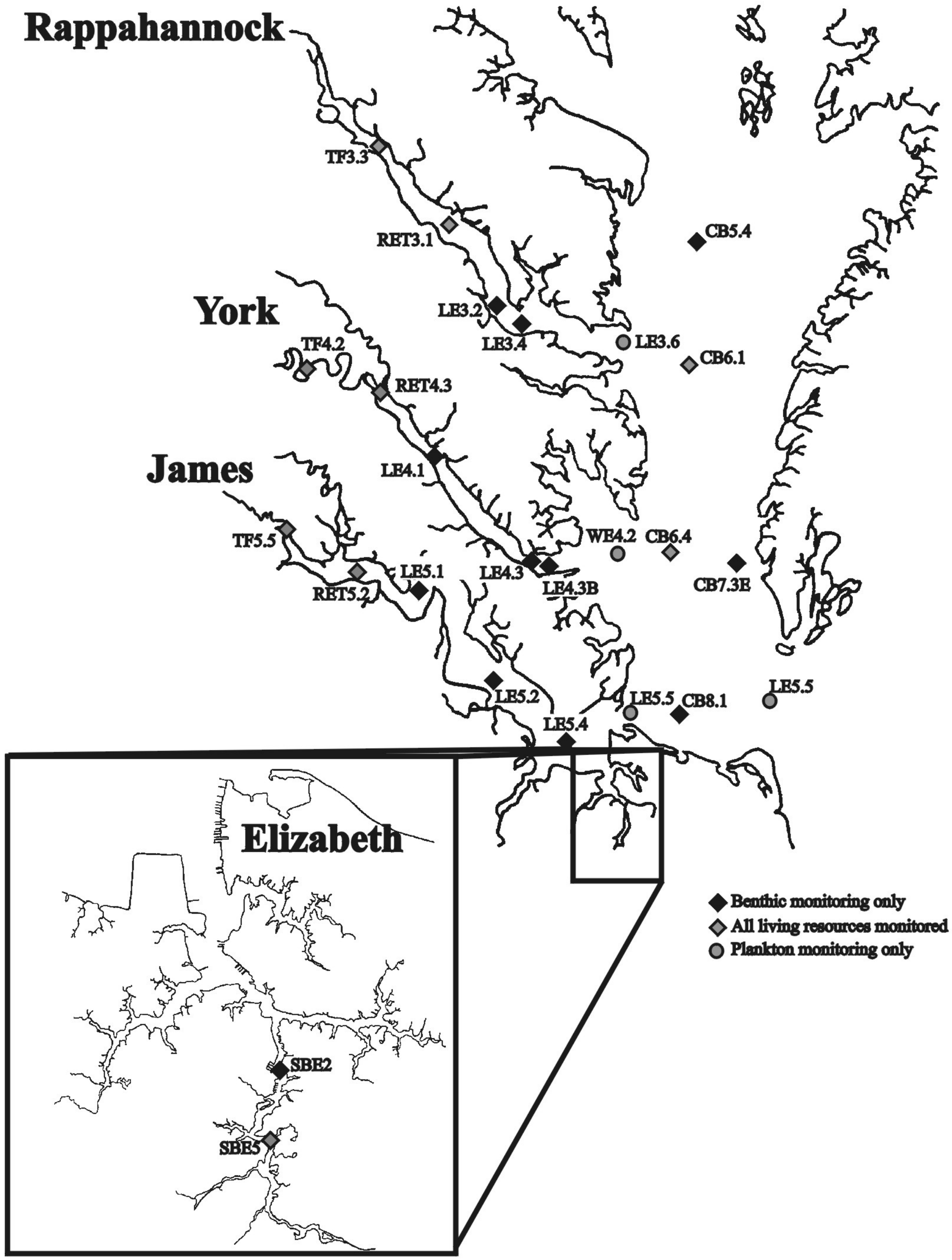


Figure 2-3. Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem.

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, Sep.-Nov.	<1.5	<15	<15	<0.15	<0.01

Chapter 3. 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. In 2001, point source loadings of total nitrogen and total phosphorus to the Rappahannock River were 246,721 kg/yr and 21,813 kg/yr, 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, 2002. Grand mean flow at the fall-line was 45.32 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 3-7 and 3-8 provide summaries of water quality status and trend analyses for the Rappahannock River. Relative status of nutrients and dissolved oxygen was good or fair for all parameter/segment combinations in the Rappahannock River main stem. Relative status for the surface chlorophyll *a* was poor or fair. For suspended solids the status ranged from poor to good. For surface total suspended solids, the Upper Rappahannock (RPPTF) status was poor while the Middle and Lower Rappahannock (RPPOH and RPPMH) status was good. The bottom total suspended solids status was fair for the Upper and Middle Rappahannock (RPPTF and RPPOH) and good for the Lower Rappahannock (RPPMH). The status of water clarity for the Upper Rappahannock (RPPTF) was poor, for the Middle Rappahannock (RPPOH) the status was fair, and for the Lower Rappahannock (RPPMH) the status was good. 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 did not met the SAV habitat requirements.

With respect to nutrients, only three long-term trends were statistically consistent between the pre- and post-method change periods: a degrading trend in surface total nitrogen in the Upper Rappahannock River (RPPTF), an improving trend in bottom dissolved inorganic phosphorus in the Middle Rappahannock River (RPPOH), and a degrading trend in bottom dissolved inorganic phosphorus in the Lower Rappahannock River (RPPMH). Numerous degrading trends in nutrient parameters were detected in the pre-method change period but none of these trends were detected in the post-method change data. In contrast, improving trends in either total nitrogen or dissolved inorganic nitrogen were detected during the post-method change period in all segments of the Rappahannock River except the Upper Rappahannock River (RPPTF). Improving trends in surface and bottom dissolved inorganic phosphorus were also detected during the post-method change period in the Upper Rappahannock River (RPPTF). Degrading trends were detected in surface chlorophyll *a* in both the Upper and Middle Rappahannock River (RPPTF and RPPOH). A degrading trend in secchi depth was detected in the Corrotoman River (CRRMH) while an improving trend was detected in summer bottom dissolved oxygen in the Middle Rappahannock River (RPPOH).

Figures 3-9 to 3-11 provide summaries of living resource status and trend analyses for the Rappahannock River. Improving trends for chlorophyte biomass were present for all sections of this river, with productivity improving moving from the upstream to downstream regions. 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. The total phytoplankton biomass and abundance are increasing in the river at the tidal freshwater and middle segments, with no trend downstream. A major relationship is future cyanobacteria development and to what degree the diatom dominance is affected. The more desirable flora throughout the tidal river segments are diatoms and chlorophytes, in contrast to cyanobacteria and dinoflagellates. These data indicate mixed trends in the dinoflagellates degrading upstream and downstream. These downstream regions are locations for seasonal dinoflagellate blooms that may include species toxic to local fauna. Status for copepod nauplii was good or fair throughout the Rappahannock River while status of rotifer abundance was poor at both stations in the Lower Rappahannock (RPPMH) and good in the Middle Rappahannock River (RPPOH). A degrading trend in rotifer abundance was 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).

With respect to phytoplankton communities, increased concentrations and abundance associated with the cyanobacteria and dinoflagellate components of the phytoplankton may threaten the dominance of the more favorable populations of diatoms and chlorophytes. Problems with the microzooplankton community appear to be localized in the lower portion of the Lower Rappahannock River (RPPMH) as indicated by the poor status and degrading trend in rotifer abundance. 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 stations monitored in the Lower Rappahannock River (RPPMH) ranged from marginal 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) was marginal with degrading trends in pollution indicative abundance and pollution sensitive biomass.

II. Management Recommendations

At present, water quality problems in the Rappahannock River appear to be localized in the upper two segments of this estuary (RPPTF and RPPOH) and are reflected primarily in chlorophyll *a* and water clarity. Status of chlorophyll *a* was poor in both segments and there were degrading trends in chlorophyll *a* in both of these segments for this parameter. In addition, the status of total suspended solids and secchi depth was generally fair or poor in these two segments. The relative status of all nutrient parameters was either good or fair in all segments and the SAV habitat requirements for nutrients were met in most segments. In addition, there were relatively few degrading trends in nutrients in this river. However, the degrading tremnds in chlorophyll suggest that nutrient concentrations remain above desirable levels.

There is no clear cause for chlorophyll *a* or water clarity issues in the Rappahannock River. It is likely the water clarity issues may be directly related to the high concentrations of phytoplankton in the water column as is indicated by the poor status of chlorophyll *a*, as well as, the increasing trends detected in this parameter within these segments. Additional evidence implicating phytoplankton as the source for the water clarity problem is the increasing trends in total phytoplankton abundance found in both the Upper and Middle Rappahannock River segments (RPPTF and RPPOH). Specific phytoplankton groups that showed increases in biomass at one or both stations were diatoms, cyanobacteria, chlorophytes, autotrophic picoplankton, and cryptophytes. The status of cyanobacteria and dinoflagellate trends of increased abundance and biomass should be closely watched, in addition to any increase in bloom development by species within these two categories.

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 decreasing trend in freshwater flow observed at the fall-line 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 suspended solids concentrations, freshwater flow and phytoplankton concentrations is recommended

Degrading trends in the microzooplankton indicators in the lower portion of the mesohaline Rappahannock River (RPPMH) may be related to the degrading trend in dissolved inorganic phosphorus. Patterns in the status of microzooplankton do not directly reflect patterns in water quality since both the degrading trend and poor status observed for rotifer abundance occurred in the Lower Rappahannock River (RPPMH). Perhaps the change in rotifer abundance is a reflection of the change in phytoplankton community composition as indicated by the increasing trends in cyanobacteria biomass and abundance.

The trends observed in benthic community conditions appear to more clearly reflect water quality trends. All of the degrading trends in benthic community parameters including the B-IBI were observed in the Upper and Middle Rappahannock River stations where degrading trends in chlorophyll *a* and , for the case of the Upper Rappahannock River, where a degrading trend in surface total nitrogen occurred.

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 3-1a). 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 3-1b).

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 3-2a-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 3-2a). 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 data from 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 3-3a-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 225,000 to 317,000 kg/yr over the last 17 years with no clear trend in the data (Figure 3-4a). Point source loadings of phosphorus declined substantially following the phosphate ban in 1989 and remained relatively stable between approximately 45,000 and 35,000 kg/yr through 1997 (Figure 3-4b). In 1998, point source loadings of total phosphorus decreased again to just under 30,000 kg/yr and continued to decline to a level of approximately 21,800 kg/yr in 2001 (Figure 3-4b). In 2001, both total nitrogen and total phosphorus loadings were highest in above the fall-line and in segment RPPTF (Figure 3-5a,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, 2002. Grand mean flow at the fall-line was 45.32 m^3/sec. There was a significant trend in freshwater flow at the Rappahannock River fall-line and annual peaks in monthly mean flow during the last four years appear to be much lower than during previous years (Figure 3-6a). In addition, annual mean flow was approximately 20% to 25% lower than the grand mean flow during the last three years (Figure 3-6b).

IV. Overview of Monitoring Results

Relative status of nutrients and dissolved oxygen was good or fair for all parameter/segment combinations in the Rappahannock River main stem. Relative status of all other parameter/segment combinations in this region ranged from good to poor, with the poor status mainly in the Upper Rappahannock improving to predominately good status as one moves downstream. 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 did not met the SAV habitat requirements.

There was a degrading trend in surface total nitrogen in the Upper Rappahannock River (RPPTF) that was consistent between the pre- and post-method change periods. A significant improving trend and a significant degrading trend in bottom dissolved inorganic phosphorus were detected in the Middle Rappahannock River (RPPOH) and Lower Rappahannock River (RPPMH). Both of these trends were not significantly different between the pre- and post-method change periods. Degrading trends were detected in surface chlorophyll *a* in the Upper and Middle Rappahannock River (RPPTF and RPPOH) and in secchi depth in the Corrotoman River (CRRMH). An improving trend in dissolved oxygen was detected in the Lower Rappahannock River (RPPMH). Increasing trends in surface and bottom salinity were detected in the Upper Rappahannock River (RPPTF) (Figures 3-7 and 3-8).

There were general trends of increased biomass and abundance of total phytoplankton produced by a variety of taxonomic groups including the less favorable dinoflagellates andcyanobacteria. In general, a favorable composite of phytoplankton, dominated by diatoms and chlorophytes is present within the river. However, concern is focused on increased concentrations of cyanobacteria and dinoflagellates. The reach of the river continued to be the site of common dinoflagellate bloom during the summer and early fall months. (Figure 3-9).

Status of copepod nauplii abundance was good in the Middle Rappahannock River (RPPOH) and station RET3.1 in the Lower Rappahannock River (RPPMH) fair at station LE3.6 in the Lower Rappahannock River (RPPMH). Status of rotifer abundance was good in the Middle Rappahannock River (RPPOH) and poor in the Lower Rappahannock River (RPPMH) (Figure 3-10).

Benthic community status ranged from marginal to severely degraded 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)with degrading trends in pollution indicative abundance and pollution sensitive biomass (Figure 3-11).

V. Detailed Overview of Status and Trends

A. Fall-Line

Only two trends were detected above the fall-line at Fredericksburg in the Rappahannock River: a decreasing trend in freshwater flow and an improving trend in loadings of dissolved inorganic phosphorus (Table 3-1).

B. Mesohaline Rappahannock River (RPPMH - Lower Rappahannock)

1. Water quality for living resources

a) Nutrient parameters

Status of all nitrogen parameters was good. Status of surface and bottom total phosphorus was fair while the status of surface and bottom dissolved inorganic phosphorus was good (Table 3-2). There were significant differences in trends detected between the pre- and post-method change periods for surface and bottom measurements of total nitrogen, dissolved inorganic nitrogen and total phosphorus. For surface and bottom total nitrogen and dissolved inorganic nitrogen, no trends were detected in the pre-method change period while significant improving trends were detected in the post-method change period. Although the seasonal Kendall slope estimate for both trends in dissolved inorganic nitrogen was equal to 0, an examination of scatterplots of the data revealed that values for this parameter have dropped to or below the detection limit for all observations collected after 1999 suggesting an improvement in water quality conditions with respect to this parameter.
A degrading trend in bottom dissolved inorganic phosphorus was detected that was statistically consistent between the pre- and post-method change periods. For surface and bottom total phosphorus, degrading trends were detected in the pre-method change period but no significant trends were detected in the post-method change period. A significant degrading trend in bottom dissolved inorganic phosphorus was detected that was consistent between the pre- and post-method change periods (Table 3-3).

b) Non-nutrient parameters

Status of surface chlorophyll *a* was fair while the status of all measures of water clarity was good. The status of dissolved oxygen was fair (Table 3-2). No significant trends were detected in this segment for the Non-nutrient parameters (Table 3-3).

2. Water quality for SAV

a) SAV habitat requirements

SAV habitat requirements were met for all parameters (Table 3-4).

b) Nutrient parameters

There were no significant trends in any nutrient parameters that were consistent between the pre- and post-method change periods. Although significantly different between periods, decreasing trends in surface dissolved inorganic nitrogen were detected in both the pre- and post-method change periods. Although a significant degrading trend in surface total phosphorus was detected in the pre-method change period, this trend was not significant in the post-method change period. A significant improving trend in surface dissolved inorganic phosphorus was detected in the post-method change period (Table 3-5).

c) Non-nutrient parameters

No significant trends in Non-nutrient parameters were detected in the SAV growing season (Table 3-5).

3. Living resources

At station LE3.6 there were no significant trends in total phytoplankton biomass, abundance, or diversity, with the status for total biomass being poor. Diatom biomass status was fair with no significant trends. This region is a common site for summer dinoflagellate blooms, and there is a trend for increased dinoflagellate biomass along with poor status for this group, in addition to poor status and degrading trends associated with cyanobacteria abundance and biomass. The chlorophytes possess favorable biomass status, along with a favorable trend for the group. No significant trends were associated with the prokaryote to eukaryote biomass ration with the biomass to abundance ratio showing no trend and poor status. The major concern at this station is the increased trends in both the dinoflagellates and cyanobacteria (Figure 3-9). At station LE3.6 in the lowermost portion of this segment, relative status was fair for copepod nauplii abundance and poor for rotifer abundance. A degrading trend in rotifer abundance was detected along with a decreasing trend in polychaeta larval abundance (Figure 3-10). In the lower portion of this segment (stations LE3.2 and LE3.4), benthic community status was degraded to severely degraded. Both stations are strongly impacted by low dissolved oxygen events (Figure 3-11).

Station RET3.1 possessed several favorable trends that include increased diatom, chlorophyte, and cryptophyte biomass. The dinoflagellates had fair status and no significant trends, with the total phytoplankton abundance and biomass was increasing. On the negative side, there were poor status and degrading trends of increased biomass and abundance of the cyanobacteria. The diversity status was good, with no significant trends. Trends were also absent, along with poor status for the biomass to abundance ration, and good status associated with the prokaryote to eukaryote ratio. The site remains generally healthy in reference to the phytoplankton composition, with diatoms remaining the dominant component. Concern remains with increasing cyanobacteria populations (Figure 3-9). At station RET3.1 in the upper portion of this segment, status for copepod nauplii abundance was good while status for rotifer abundance was poor. There were no significant trends in the microzooplankton parameters at this station (Figure 3-10). At station RET3.1 in the upper portion of this segment, benthic community status was marginal. There were degrading trends in the B-IBI and several metrics of the IBI (Figure 3-11).

C. Oligohaline Rappahannock River (RPPOH - Middle Rappahannock)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good in this segment (Table 3-6). A significant improving trend in bottom dissolved inorganic phosphorus was detected that was consistent between the pre- and post-method change periods. Significantly different trends were detected between the pre- and post-method change period for bottom total nitrogen, surface and bottom dissolved inorganic nitrogen, and surface and bottom dissolved inorganic phosphorus (Table 3-7).

b) Non-nutrient parameters

Status of surface chlorophyll *a* was poor. Status of surface and bottom total suspended solids was good and fair, respectively. Status of secchi depth was fair. Status of bottom dissolved oxygen was good (Table 3-6). A degrading trend in surface chlorophyll *a* was detected along with an improving trend in summer bottom dissolved oxygen (Table 3-7).

2. Water quality for SAV

a) SAV habitat requirements

Although the SAV requirement for surface dissolved inorganic phosphorus was met, the remaining parameters did not meet their respective SAV criteria (Table 3-8).

b) Nutrient parameters

No significant trends were detected that were consistent between the pre- and post-method change periods. A significant improving trend in surface dissolved inorganic nitrogen was detected in the post-method change period while a significant degrading trend in surface total phosphorus was detected in the pre-method change period (Table 3-9).

c) Non-nutrient parameters

A degrading trends in surface chlorophyll *a* was detected in this segment during the SAV growing season (Table 3-9).

3. Living resources

The total phytoplankton biomass and abundance show increasing trends along with increasing (favorable) trends in the biomass of the diatoms chlorophytes, and cryptophytes. There were no significant trends for productivity (poor status), or the prokaryote to eukaryote ratio (good status). However, the status of cyanobacteria abundance and biomass, and dinoflagellate biomass were poor, with degrading trends associated with cyanobacteria biomass and abundance and the dinoflagellate biomass. This continuing increase in the cyanobacteria and dinoflagellate flora represents a concern and a pattern that needs to be followed. Further increases in cyanobacteria may have a negative influence on the trophic status at this station. However, it is possible that this increase may represent only one phase of a cyclic pattern of development that would be followed by a period of reduced cyanobacteria abundance (Figure 3-9). Status for copepod nauplii and rotifer abundance was good and there were no significant annual trends in the microzooplankton parameters (Figure 3-10). Benthic community status was marginal. There were degrading trends in pollution sensitive species biomass and pollution indicative species abundance (Figure 3-11).

D. Tidal Freshwater Rappahannock (RPPTF - Upper Rappahannock)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good except for surface and bottom dissolved inorganic nitrogen for which the status was fair (Table 3-10). A significant degrading trend in surface total nitrogen was detected that was consistent between the pre- and post-method change periods. Significantly different trends in surface and bottom dissolved inorganic nitrogen, surface total phosphorus, and surface and bottom dissolved inorganic phosphorus were detected between the pre- and post-method change periods. Degrading trends in surface and bottom dissolved inorganic nitrogen and surface total phosphorus were detected in the pre-method change period but no significant trends were detected in the post-method change period. Although no significant trends in surface and bottom dissolved inorganic phosphorus were detected in the pre-method change period, significant improving trends in both of these parameter were detected in the pos-method change period (Table 3-11).

b) Non-nutrient parameters

Status of surface chlorophyll *a* and all measures of water clarity was either fair or poor. Status of bottom dissolved oxygen was good (Table 3-10). A degrading trend in surface chlorophyll *a* was detected along with increasing trends in surface and bottom water temperature and salinity (Table 3-11).

2. Water quality for SAV

a) SAV habitat requirements

Although the SAV requirement for surface dissolved inorganic phosphorus was met, the remaining parameters did not meet their respective SAV criteria (Table 3-12).

b) Nutrient parameters

A significant degrading trend in surface total nitrogen was detected that was consistent between the pre- and post-method change periods. Degrading trends were detected in the pre-method change period in surface dissolved inorganic nitrogen and surface total phosphorus. An improving trend in surface dissolved inorganic phosphorus was detected in the post-method change period (Table 3-13).

c) Non-nutrient parameters

An increasing trend in surface salinity was detected in this segment during the SAV growing season (Table 3-13).

3. Living resources

No living resources data are available for this segment.

E. Mesohaline Corrotoman River (CRRMH - Corrotoman River)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good (Table 3-14). Significantly different trends were detected between the pre- and post-method periods for bottom total nitrogen, surface and bottom dissolved inorganic nitrogen, and surface and bottom total phosphorus. For bottom total nitrogen, a significant improving trend in the post-method change period was detected although there was no trend in the pre-method change period. No significant trends in surface or bottom dissolved inorganic nitrogen parameters were detected in the pre-method change period but degrading trends for both parameters were detected in the post-method change period. Although significant degrading trends were detected in surface and bottom total phosphorus during the pre-method change period, no significant trends in these parameters were detected in the post-method change period (Table 3-15).

b) Non-nutrient parameters

Status of surface chlorophyll *a* and all measures of water clarity was good. Status of bottom dissolved oxygen was fair (Table 3-14). A degrading trend in secchi depth was detected in this segment (Table 3-15).

2. Water quality for SAV

a) SAV habitat requirements

SAV habitat requirements were met for all parameters (Table 3-16).

b) Nutrient parameters

There were no significant trends in any nutrient parameters that were consistent between the pre- and post-method change periods. Although significantly different between periods, decreasing trends in surface dissolved inorganic nitrogen were detected in both the pre- and post-method change periods. Although a significant degrading trend in surface total phosphorus was detected in the pre-method change period, this trend was not significant in the post-method change period (Table 3-17).

c) Non-nutrient parameters

Although there was a significant improving trends in surface total suspended solids, there was a significant degrading trend in secchi depth. An increasing in surface salinity was also detected in this segment (Table 3-17).

3. Living resources

No living resources data are available for this segment.

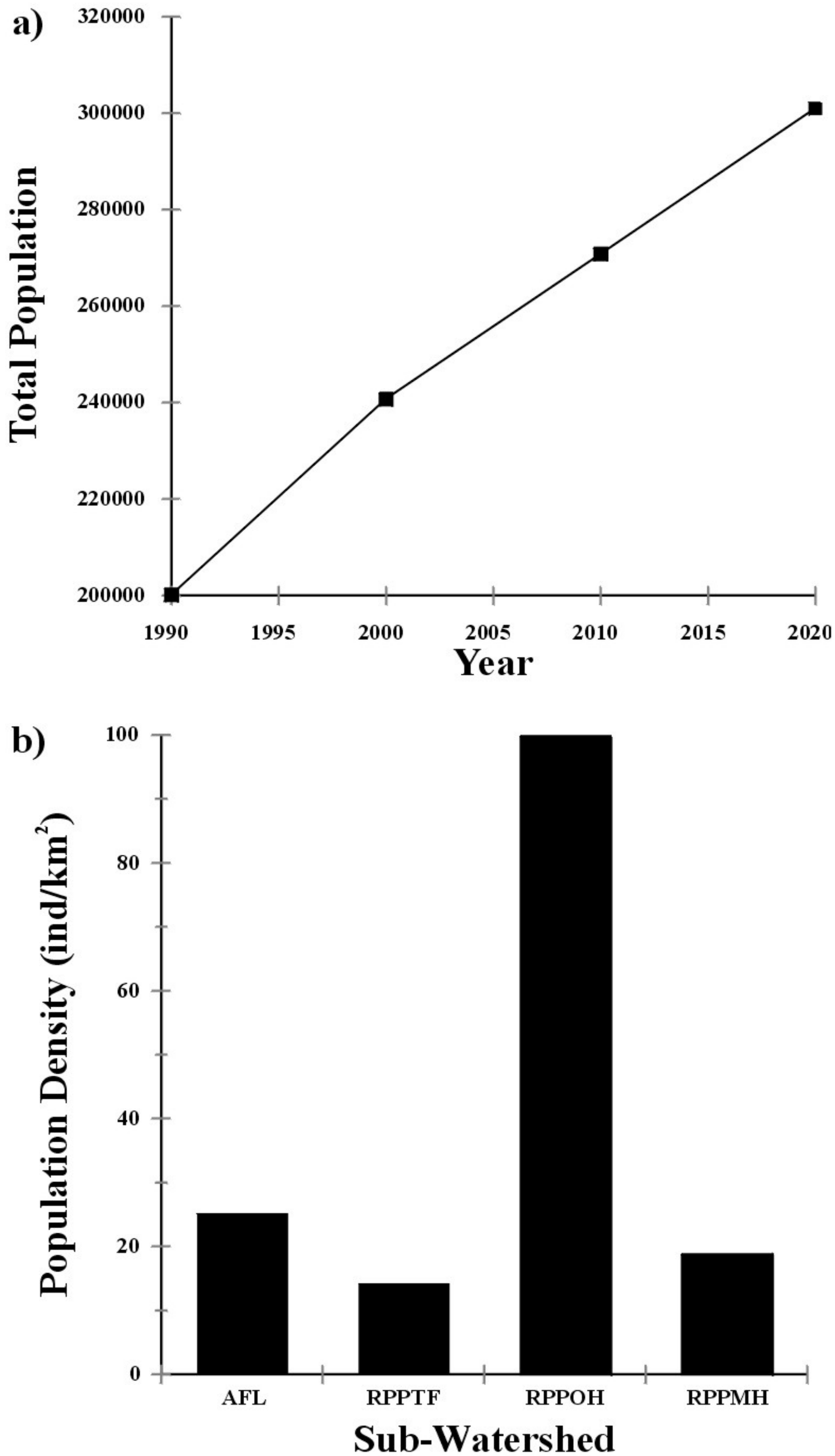


Figure 3-1. Patterns in a) total and projected total watershed population over time and b) population density between sub-watersheds within the Rappahannock River basin for the year 2000.

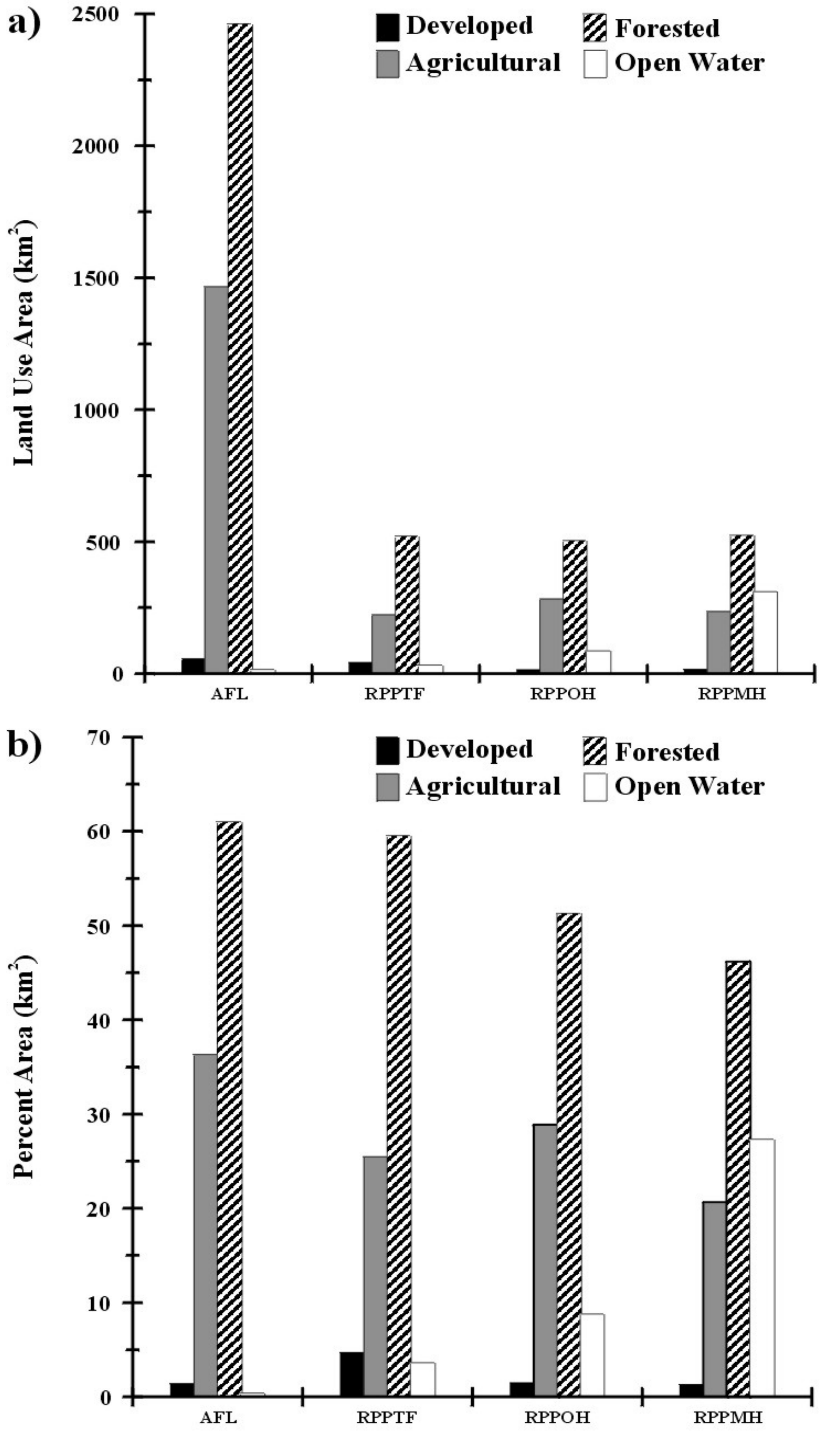


Figure 3-2. Differences in a) total area and b) percentages of land-use types between sub-watersheds of the Rappahannock River for 1999. Data presented were provided by the USEPA, Chesapeake Bay Program Office.

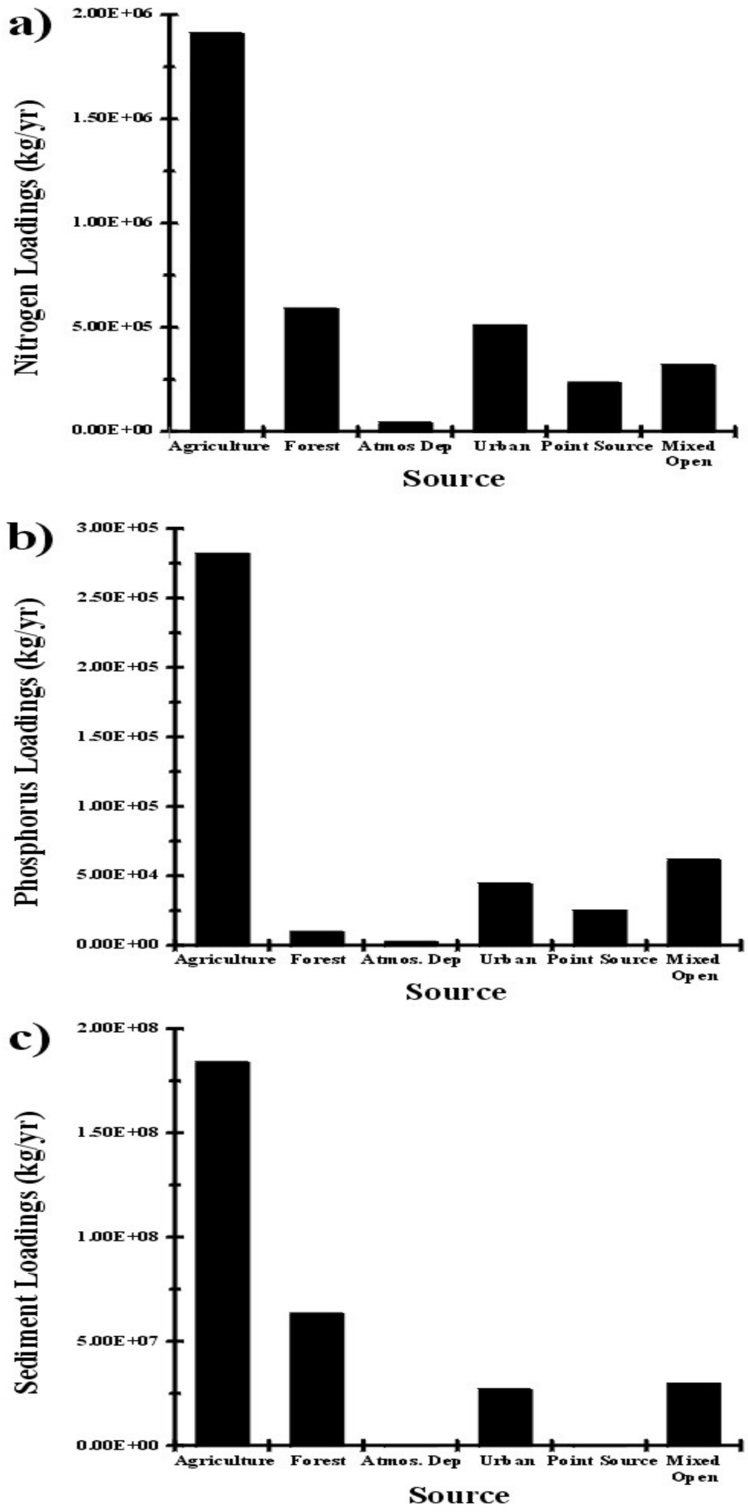
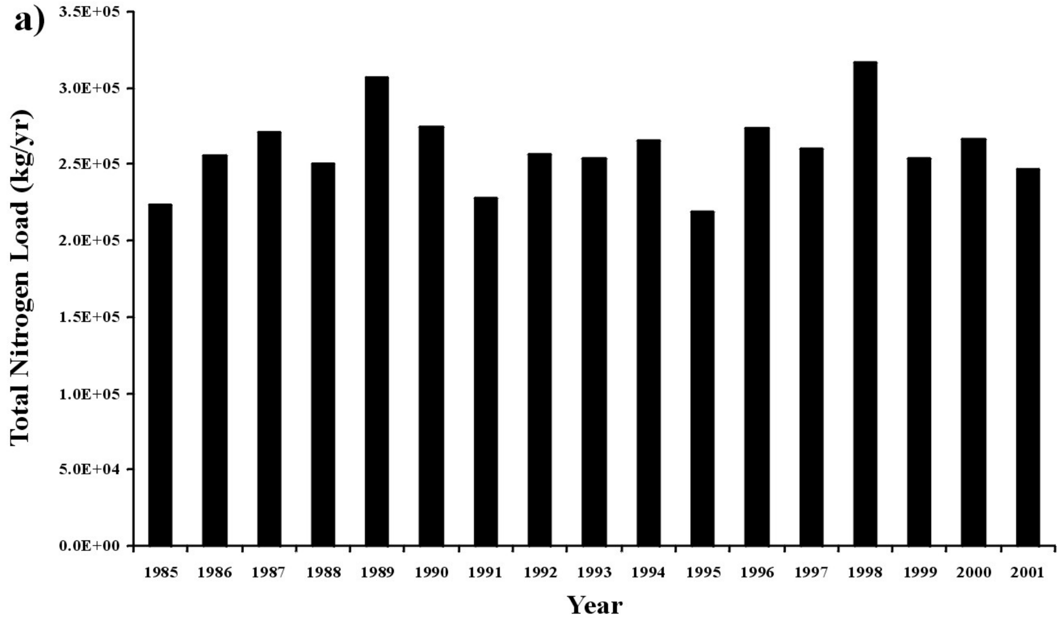


Figure 3-3. Non-point source loadings of a) total nitrogen, b) total phosphorus, and c) sediments by source for the Rappahannock River in 2000. Data generated using the USEPA Chesapeake Bay Watershed Model.

a)



b)

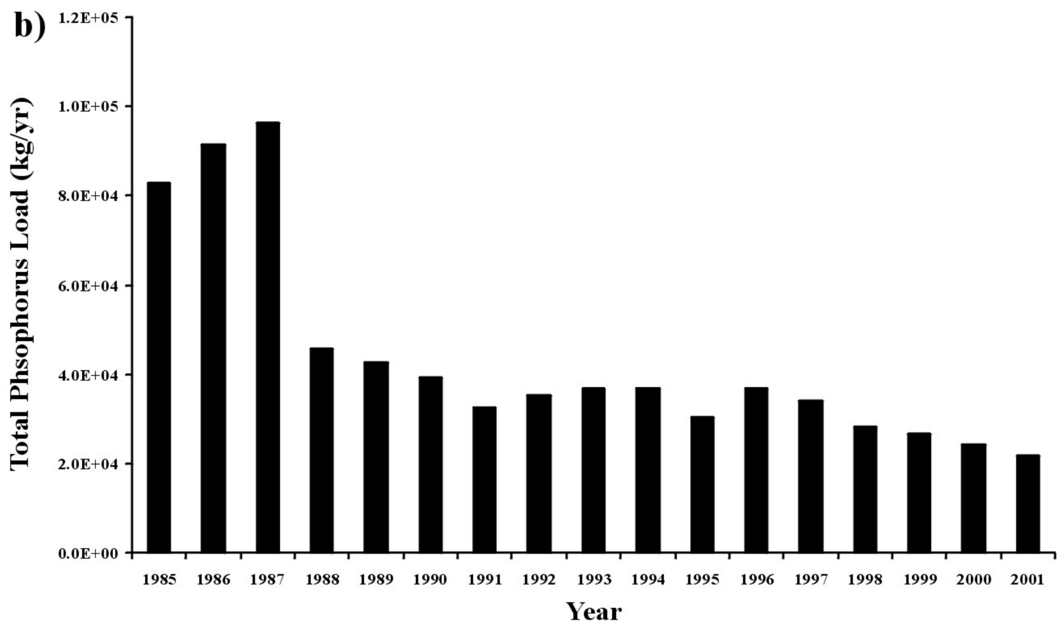


Figure 3-4. Long-term trends in point source a) total nitrogen loadings and b) total phosphorus loadings in the Rappahannock River for 1985 through 2001.

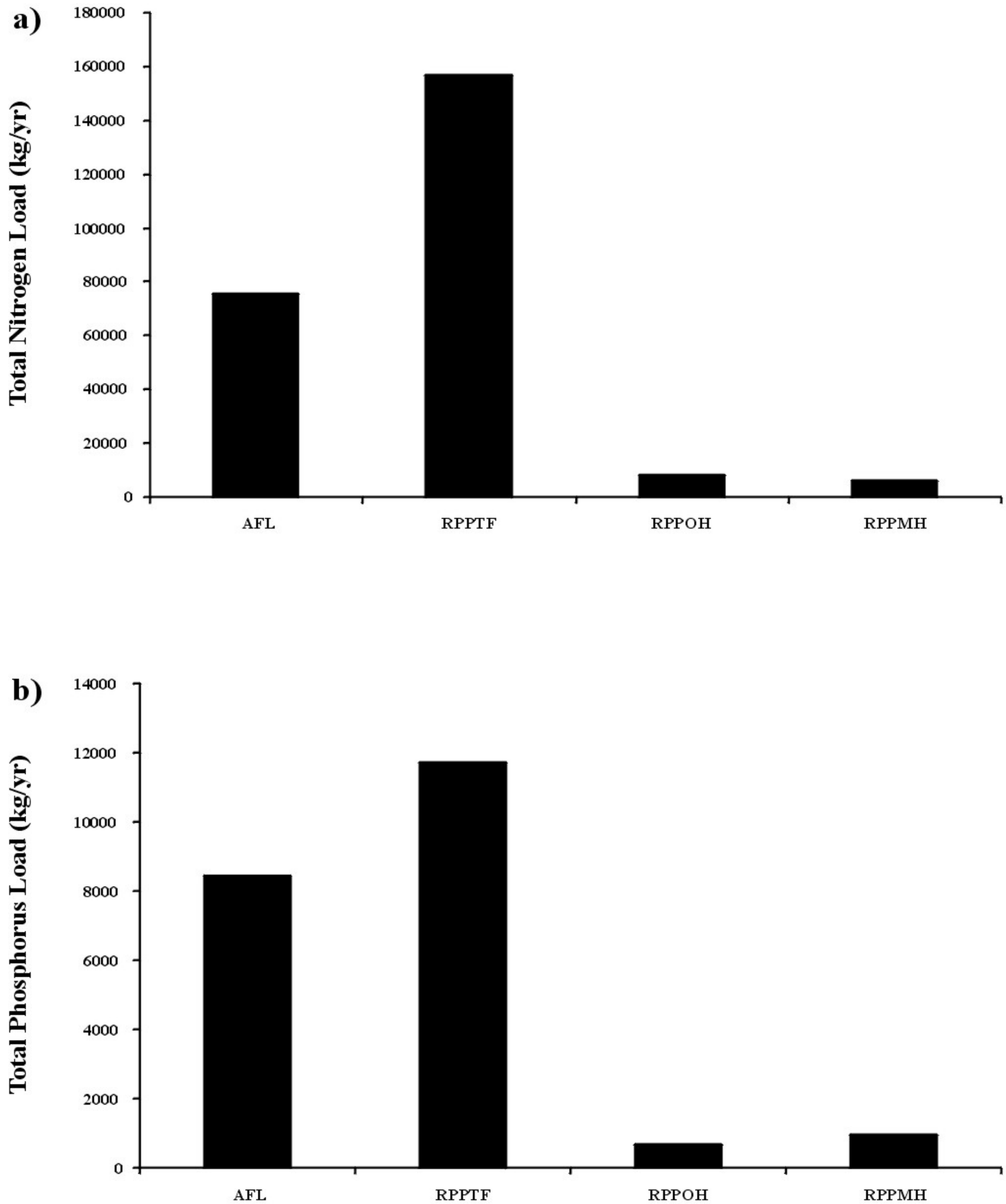


Figure 3-5. Spatial patterns in point source a) total nitrogen and b) total phosphorus loadings in the Rappahannock River for 2001.

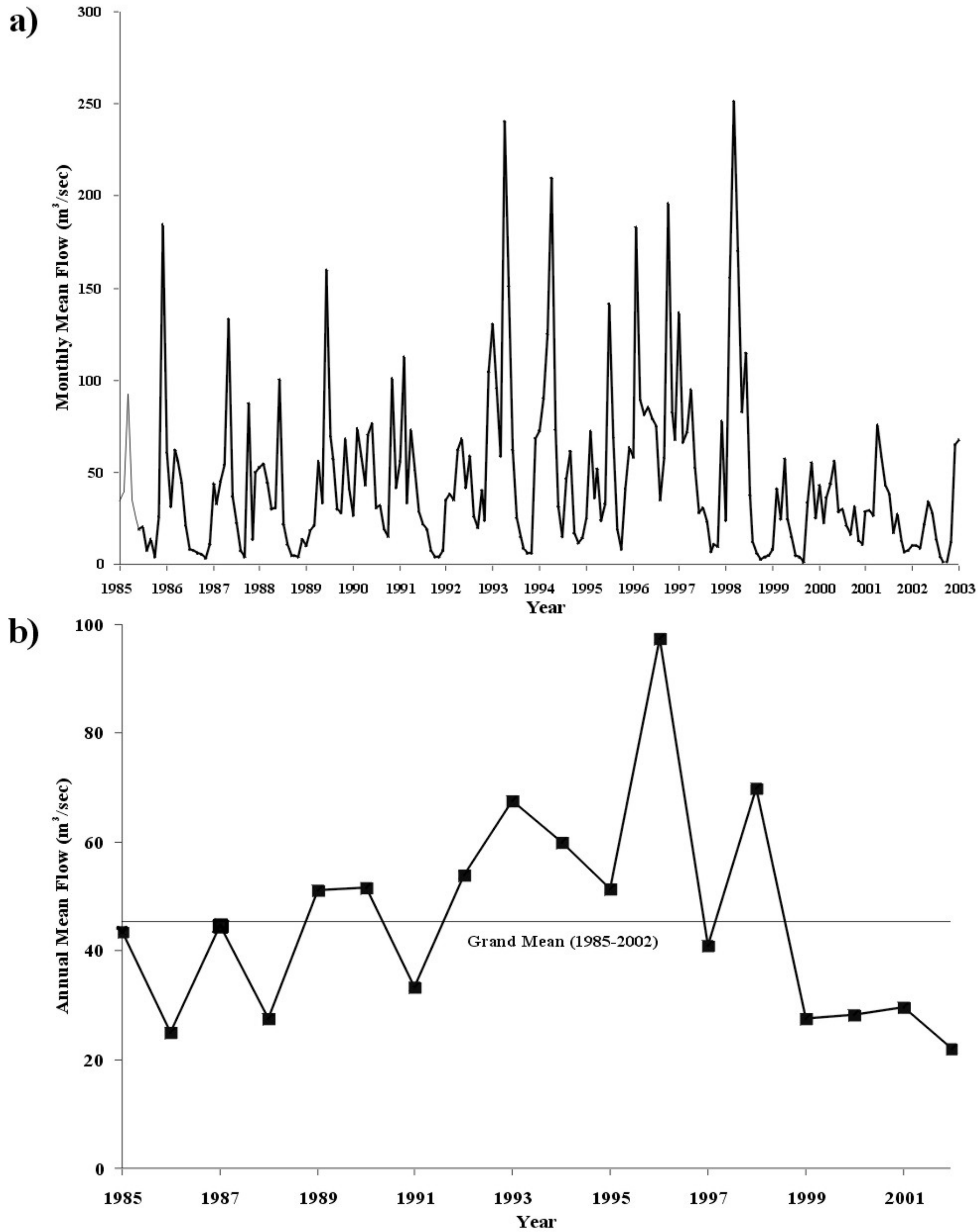
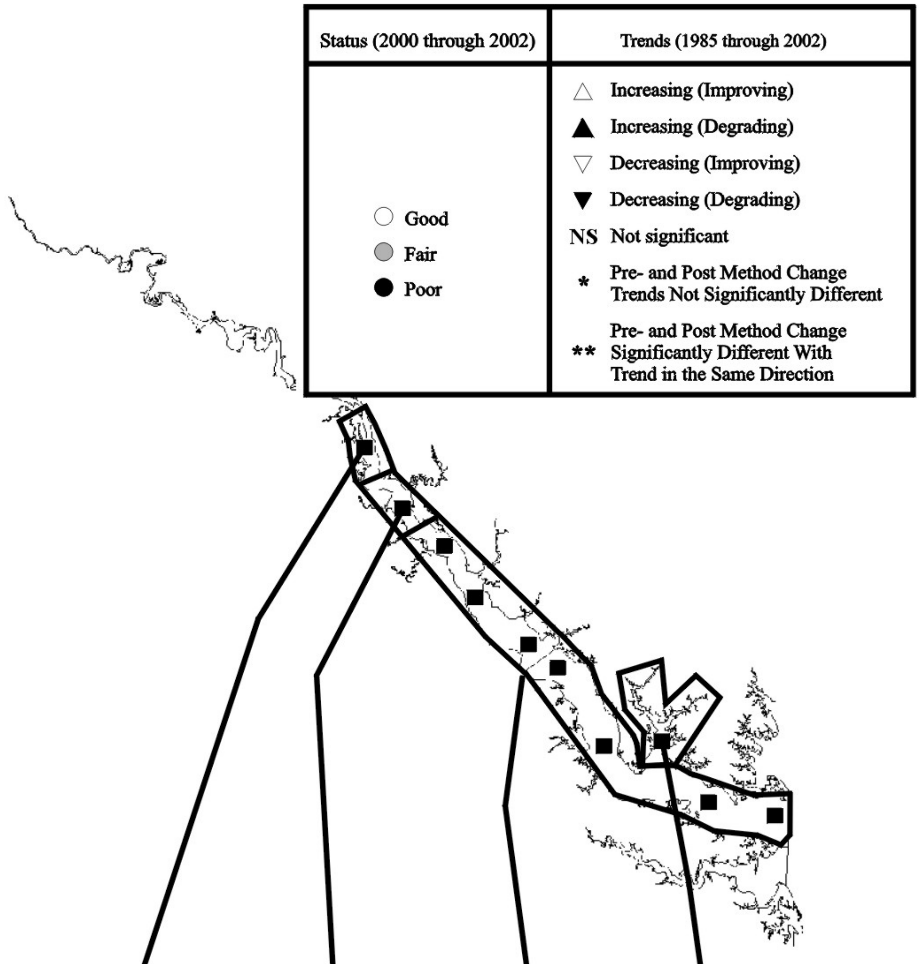


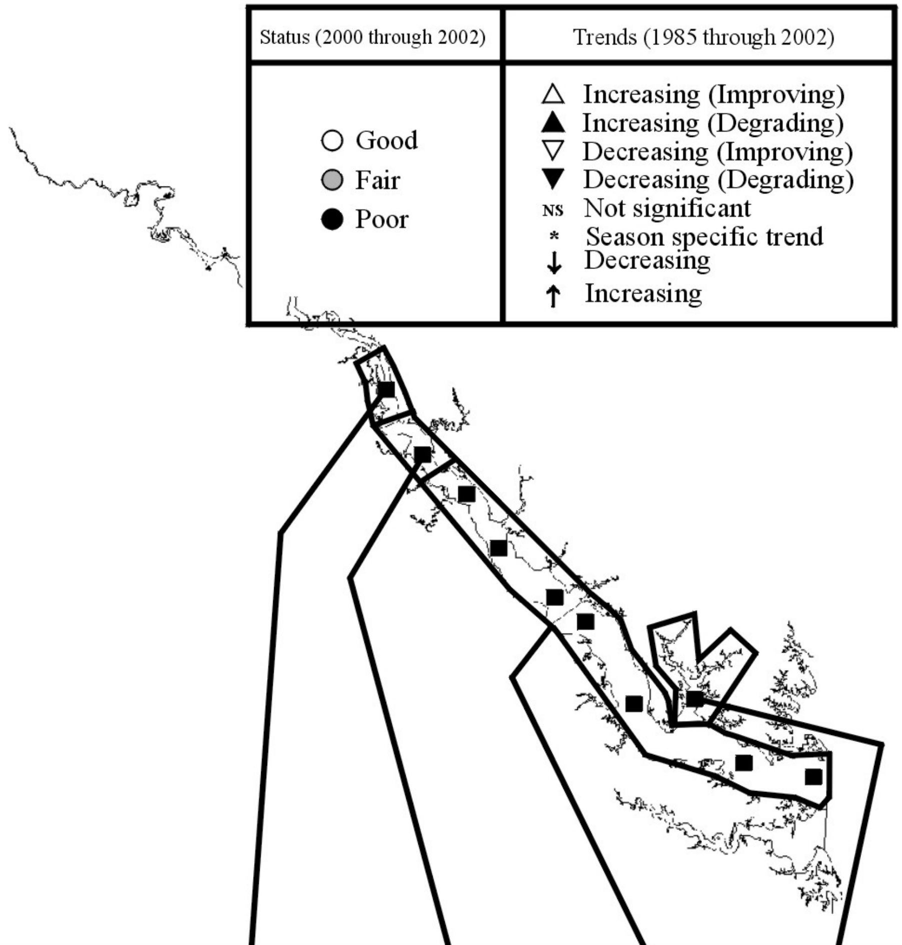
Figure 3-6. Plot of a) monthly mean and b) annual mean freshwater flow at the Rappahannock River fall-line for the period of 1985 through 2002.



Parameter	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corrotoman River
STN	Good ▲*	Good NS**	Good NS ▽	Good NS**
BTN	Good NS*	Good ▲ NS	Good NS ▽1	Good NS ▽1
SDIN	Fair ▲ NS	Good NS ▽	Good NS ▽1	Good NS ▽1
BDIN	Fair ▲ NS	Good NS ▽	Good NS ▽	Good NS ▽
STP	Good ▲ NS	Good ▲ NS	Fair ▲ NS	Good ▲ NS
BTP	Good NS*	Good ▲ NS	Fair ▲ NS	Good ▲ NS
SDIP	Good NS ▽	Good NS*	Good NS**	Good NS*
BDIP	Good NS ▽	Good ▽*	Good ▲*	Good NS*

1 = Slope of zero but appreciable pattern observed in scatterplot

Figure 3-7. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period 1985 through 2002. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The prefixes S and B refer to surfaceand bottom measurements, respectively. The presence of two trend symbols indicates a significant difference between pre- and post-method change trends. For such cases, the first symbol represents the pre-method change result while the second symbol is the post method change result.

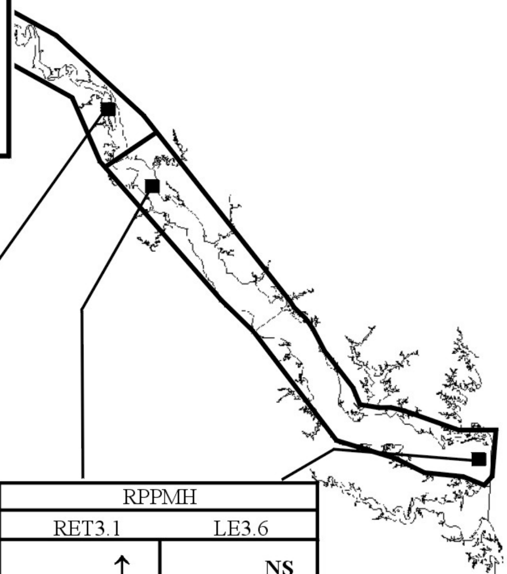


Parameter	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corrotoman River
SCHLA	● Poor ▲ Increasing (Degrading)	● Poor ▲ Increasing (Degrading)	Fair NS	○ Good NS
STSS	● Poor NS	○ Good NS	○ Good NS	○ Good NS
BTSS	Fair NS	Fair NS	○ Good NS	○ Good NS
SECCHI	● Poor NS	Fair NS	○ Good NS	○ Good ▼ Decreasing (Degrading)
BDO	○ Good NS	○ Good △ Increasing (Improving)	Fair NS	Fair NS
SWTEMP	↑	NS	NS	NS
BWTEMP	↑	NS	NS	NS
SSALIN	↑1	NS	NS	NS
BSALIN	↑1	NS	NS	NS

1 = Slope of zero but appreciable pattern observed in scatterplot

Figure 3-8. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period 1985 through 2002. 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.

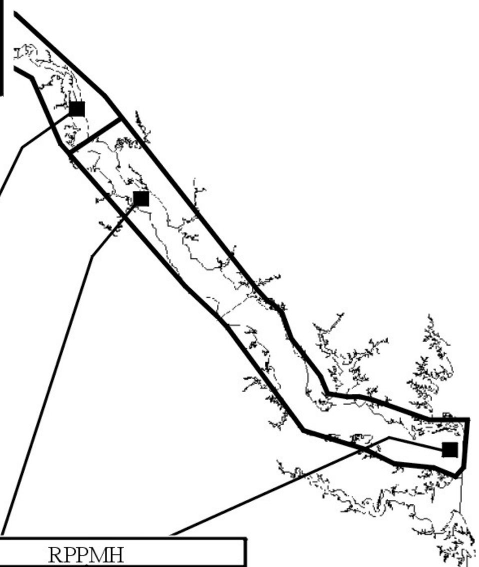
Status (2000 through 2002)	Trends (1985 through 2002)
○ Good ◍ Fair ● Poor	△ Increasing (Improving) ▲ Increasing (Degrading) ▽ Decreasing (Improving) ▼ Decreasing (Degrading) NS Not significant * Season specific trend ↓ Decreasing ↑ Increasing



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

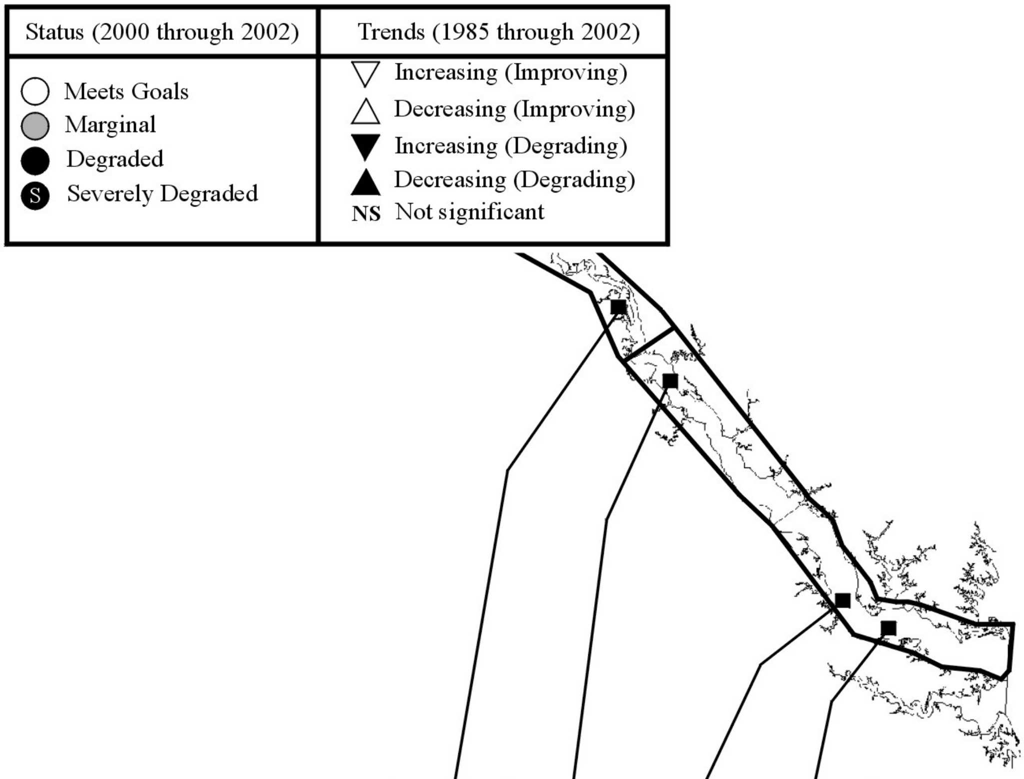
Figure 3-9. Map of the Rappahannock River basin showing summaries of the status and trend analyses for phytoplankton bioindicators for each segment for the period 1985 through 2002.

Status (2000 through 2002)	Trends (1993 through 2002)
○ Good ◍ Fair ● Poor	△ Increasing (Improving) ▲ Increasing (Degrading) ▽ Decreasing (Improving) ▼ Decreasing (Degrading) NS Not significant * Season specific trend ↑ Increasing ↓ Decreasing



	RPPOH	RPPMH	
	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	NS
Polychaeta Larvae Abundance	NS	NS	↓

Figure 3-10. Map of the Rappahannock River basin showing summaries of the status and trend analyses for microzooplankton bioindicators for each segment for the period 1985 through 2002.



	RPPOH	RPPMH		
	TF3.3	RET3.1	LE3.2	LE3.4
Benthic IBI	Marginal; NS	Marginal; Increasing (Degrading)	Degraded; NS	S (Severely Degraded); Decreasing (Improving)
Total Abundance	NS	NS	Decreasing (Improving)	Decreasing (Improving)
Total Biomass	NS	Increasing (Degrading)	NS	Decreasing (Improving)
Pollution Sensitive Species Abundance (%)	NS	Increasing (Degrading)	NS	NS
Pollution Indicative Species Abundance (%)	Decreasing (Degrading)	Decreasing (Degrading)	NS	NS
Pollution Sensitive Species Biomass (%)	Increasing (Degrading)	Increasing (Degrading)	NS	NS
Pollution Indicative Species Biomass (%)	NS	Decreasing (Degrading)	NS	NS
Shannon-Weiner Diversity Index	NS	NS	NS	NS

Figure 3-11. Map of the Rappahannock River basin showing summaries of the status and trend analyses for benthic bioindicators for each segment for the period of 1985 through 2002.

Table 3-1. Water quality trends at the Rappahannock River RIM station 1668000 (Rappahannock River at Fredericksburg) for the period of 1985 to 2002. All results presented are from statistical tests conducted on log-transformed data. In the Data Type column, FAC refers to flow adjusted concentrations, FWC refers to flow weighted concentrations, and LOAD refers to loadings.

Location	Station	Parameter	Season	Data Type	Slope	% BDL	pvalue	Direction
Rappahannock River at Fredericksburg	1668000	Flow	Annual	FLOW	-0.038	0	0.013	**Decreasing**
Rappahannock River at Fredericksburg	1668000	PO4F	Annual	LOAD	-0.051	0	0.018	**Improving**

Table 3-2. 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	0.4433	12.6	**Good**	0.4798	11.9	**Good**
RPPMH	TN	SPRING1	0.4250	10.7	**Good**	0.4995	10.4	**Good**
RPPMH	TN	SPRING2	0.4750	14.6	**Good**	0.5290	13.5	**Good**
RPPMH	TN	SUMMER1	0.4960	11.2	**Good**	0.5125	11.8	**Good**
RPPMH	TN	SUMMER2	0.5165	12.4	**Good**	0.5145	11.1	**Good**
RPPMH	DIN	ANNUAL	0.0145	1.8	**Good**	0.0218	2.6	**Good**
RPPMH	DIN	SPRING1	0.0151	1.5	**Good**	0.0215	2.4	**Good**
RPPMH	DIN	SPRING2	0.0150	1.8	**Good**	0.0180	2.1	**Good**
RPPMH	DIN	SUMMER1	0.0088	0.9	**Good**	0.0272	3.5	**Good**
RPPMH	DIN	SUMMER2	0.0095	1.3	**Good**	0.0286	7.4	**Good**
RPPMH	TP	ANNUAL	0.0385	39.9	**Fair**	0.0472	42.7	**Fair**
RPPMH	TP	SPRING1	0.0366	38.5	**Good**	0.0490	41.0	**Good**
RPPMH	TP	SPRING2	0.0453	47.8	**Fair**	0.0560	42.3	**Good**
RPPMH	TP	SUMMER1	0.0452	34.8	**Good**	0.0583	39.9	**Good**
RPPMH	TP	SUMMER2	0.0434	31.6	**Good**	0.0585	40.6	**Good**
RPPMH	PO4F	ANNUAL	0.0050	28.0	**Good**	0.0060	32.9	**Good**
RPPMH	PO4F	SPRING1	0.0050	40.3	**Good**	0.0060	39.0	**Good**
RPPMH	PO4F	SPRING2	0.0050	36.6	**Good**	0.0060	32.9	**Good**
RPPMH	PO4F	SUMMER1	0.0050	23.0	**Good**	0.0100	38.2	**Good**
RPPMH	PO4F	SUMMER2	0.0064	26.8	**Good**	0.0105	48.0	**Fair**
RPPMH	CHLA	ANNUAL	7.8875	48.8	**Fair**	-	-	-
RPPMH	CHLA	SPRING1	7.9700	37.2	**Good**	-	-	-
RPPMH	CHLA	SPRING2	7.9700	46.5	**Fair**	-	-	-
RPPMH	CHLA	SUMMER1	10.8000	63.5	**Poor**	-	-	-
RPPMH	CHLA	SUMMER2	10.8050	66.0	**Poor**	-	-	-
RPPMH	TSS	ANNUAL	8.0381	29.4	**Good**	14.4556	36.7	**Good**
RPPMH	TSS	SPRING1	8.6300	38.4	**Good**	18.0000	46.5	**Fair**
RPPMH	TSS	SPRING2	9.0000	41.2	**Good**	18.0000	37.8	**Good**
RPPMH	TSS	SUMMER1	8.5831	21.9	**Good**	14.3906	29.9	**Good**
RPPMH	TSS	SUMMER2	8.8600	18.3	**Good**	18.5000	43.5	**Good**
RPPMH	SECCHI	ANNUAL	1.2000	62.4	**Good**	-	-	-
RPPMH	SECCHI	SPRING1	1.1000	62.4	**Good**	-	-	-
RPPMH	SECCHI	SPRING2	1.1000	60.2	**Good**	-	-	-
RPPMH	SECCHI	SUMMER1	1.1250	67.5	**Good**	-	-	-
RPPMH	SECCHI	SUMMER2	1.1500	66.6	**Good**	-	-	-
RPPMH	DO	SPRING1	-	-	-	8.2600	-	**Good**
RPPMH	DO	SPRING2	-	-	-	6.5100	-	**Good**
RPPMH	DO	SUMMER1	-	-	-	4.3200	-	**Fair**
RPPMH	DO	SUMMER2	-	-	-	4.2200	-	**Fair**

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

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
RPPMH	S	TN	0.3461	0.0030	0.0002	-0.0159	0.0065	Sign. Dif.	0.0000	-
RPPMH	B	TN	0.4080	0.0025	0.0000	-0.0236	0.0004	Sign. Dif.	0.0000	-
RPPMH	S	DIN	0.0908	0.0000	0.0000	0.0000	0.0000	Sign. Dif.	0.0001	-
RPPMH	B	DIN	0.7851	0.0000	0.0000	-0.0055	0.0000	Sign. Dif.	0.0000	-
RPPMH	S	TP	0.0001	0.0020	0.1637	-0.0007	0.0000	Sign. Dif.	0.0238	-
RPPMH	B	TP	0.0391	0.0013	0.3528	-0.0007	0.0036	Sign. Dif.	0.2989	-
RPPMH	S	PO4F	0.8825	0.0000	0.0554	0.0000	0.0350	Sign. Dif.	0.0789	-
RPPMH	B	PO4F	0.4297	0.0000	0.1430	0.0000	0.3725	No Sign. Dif.	0.0375	**Degrading**

b) Non-nutrient parameters (no significant trends detected)

Table 3-4. 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	Season	Value	Score	Status	Habitat Requirement
RPPMH	DIN	SAV1	0.014	1.9	**Good**	**Meets**
RPPMH	PO4F	SAV1	0.0055	30.2	**Good**	**Meets**
RPPMH	CHLA	SAV1	9.8964	58.6	**Poor**	**Meets**
RPPMH	TSS	SAV1	8.86	25.2	**Good**	**Meets**
RPPMH	SECCHI	SAV1	1.1	63.3	**Good**	**Meets**

Table 3-5. SAV Season Water quality trends in segment RPPMH (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
RPPMH	S	TN	0.0843	0.0065	0.1228	-0.0052	0.0011	Sign. Dif.	0.9256	-
RPPMH	S	DIN	0.6905	0.0000	0.0005	0.0000	0.0041	Sign. Dif.	0.0002	-
RPPMH	S	TP	0.0018	0.0020	0.8884	-0.0001	0.0017	Sign. Dif.	0.0058	-
RPPMH	S	PO4F	0.7434	0.0000	0.0080	0.0000	0.0152	Sign. Dif.	0.0536	-

b) Non-nutrient parameters (no significant trends detected)

Table 3-6. 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	0.6625	13.2	Good	0.8080	23.5	Good
RPPOH	TN	SPRING1	0.9980	59.1	Poor	1.0280	45.5	Fair
RPPOH	TN	SPRING2	0.7925	34.5	Good	0.8195	22.3	Good
RPPOH	TN	SUMMER1	0.6070	10.1	Good	0.6920	15.3	Good
RPPOH	TN	SUMMER2	0.5860	7.5	Good	0.6820	16.5	Good
RPPOH	DIN	ANNUAL	0.0630	4.3	Good	0.0594	3.2	Good
RPPOH	DIN	SPRING1	0.1680	12.3	Good	0.1750	14.8	Good
RPPOH	DIN	SPRING2	0.1380	10.7	Good	0.1150	6.8	Good
RPPOH	DIN	SUMMER1	0.0085	0.1	Good	0.0145	0.2	Good
RPPOH	DIN	SUMMER2	0.0070	0.0	Good	0.0110	0.0	Good
RPPOH	TP	ANNUAL	0.0700	29.6	Good	0.0907	32.2	Good
RPPOH	TP	SPRING1	0.1048	50.8	Fair	0.1315	51.5	Fair
RPPOH	TP	SPRING2	0.1068	57.3	Fair	0.1190	42.6	Fair
RPPOH	TP	SUMMER1	0.0662	27.0	Good	0.1027	39.1	Good
RPPOH	TP	SUMMER2	0.0624	26.7	Good	0.1040	44.8	Fair
RPPOH	PO4F	ANNUAL	0.0080	14.4	Good	0.0080	13.2	Good
RPPOH	PO4F	SPRING1	0.0115	31.8	Good	0.0100	23.1	Good
RPPOH	PO4F	SPRING2	0.0120	32.4	Good	0.0110	26.8	Good
RPPOH	PO4F	SUMMER1	0.0075	13.9	Good	0.0095	19.1	Good
RPPOH	PO4F	SUMMER2	0.0090	22.4	Good	0.0110	27.0	Good
RPPOH	CHLA	ANNUAL	16.5350	87.0	Poor	-	-	-
RPPOH	CHLA	SPRING1	16.0900	84.0	Poor	-	-	-
RPPOH	CHLA	SPRING2	19.3700	90.7	Poor	-	-	-
RPPOH	CHLA	SUMMER1	17.3900	85.5	Poor	-	-	-
RPPOH	CHLA	SUMMER2	16.9800	81.8	Poor	-	-	-
RPPOH	TSS	ANNUAL	26.0000	38.3	Good	52.0000	51.5	Fair
RPPOH	TSS	SPRING1	41.0000	45.7	Fair	75.0000	57.5	Fair
RPPOH	TSS	SPRING2	41.0000	51.3	Fair	75.0000	60.6	Poor
RPPOH	TSS	SUMMER1	21.5000	33.5	Good	53.0000	49.8	Fair
RPPOH	TSS	SUMMER2	19.0000	32.9	Good	50.0000	48.9	Fair
RPPOH	SECCHI	ANNUAL	0.4000	46.6	Fair	-	-	-
RPPOH	SECCHI	SPRING1	0.3000	45.1	Fair	-	-	-
RPPOH	SECCHI	SPRING2	0.3000	30.3	Poor	-	-	-
RPPOH	SECCHI	SUMMER1	0.5000	51.7	Fair	-	-	-
RPPOH	SECCHI	SUMMER2	0.4500	27.4	Poor	-	-	-
RPPOH	DO	SPRING1	-	-	-	7.8200	.	Good
RPPOH	DO	SPRING2	-	-	-	6.9900	.	Good
RPPOH	DO	SUMMER1	-	-	-	6.4500	.	Good
RPPOH	DO	SUMMER2	-	-	-	6.4250	.	Good

Table 3-7. Water quality trends in segment RPPOH (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	‘93 Trend p value	‘93 Slope	‘02 Trend p value	‘02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
RPPOH	S	TN	0.1786	0.0100	0.1127	-0.0084	0.0031	Sign. Dif.	0.8515	-
RPPOH	B	TN	0.0014	0.0263	0.1570	-0.0105	0.0000	Sign. Dif.	0.0775	-
RPPOH	S	DIN	0.8740	0.0000	0.0006	-0.0043	0.0014	Sign. Dif.	0.0003	-
RPPOH	B	DIN	0.6779	0.0000	0.0015	-0.0058	0.0065	Sign. Dif.	0.0003	-
RPPOH	S	TP	0.0006	0.0060	0.1986	-0.0021	0.0000	Sign. Dif.	0.0262	-
RPPOH	B	TP	0.0001	0.0075	0.2164	-0.0032	0.0000	Sign. Dif.	0.0040	-
RPPOH	S	PO4F	0.0000	0.0000	0.1402	0.0000	0.1326	No Sign. Dif.	0.1542	NS
RPPOH	B	PO4F	0.4896	0.0000	0.1141	0.0000	0.2946	No Sign. Dif.	0.0397	**Improving**

b) Non-nutrient parameters

Segment	Parameter	Layer	Season	Baseline	Slope	% Change	% BDL	pValue	Direction
RPPOH	CHLA	S	Annual	4.65	0.3997	154.79	12.96	0.0000	**Degrading**
RPPOH	DO	B	Summer1	6.25	0.0364	10.47	0.00	0.0350	**Improving**

Table 3-8. 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	Season	Value	Score	Status	Habitat Requirement
RPPOH	DIN	SAV1	0.012	0.1	Good	-
RPPOH	PO4F	SAV1	0.0115	31.3	Good	Meets
RPPOH	CHLA	SAV1	17.48	85.7	Poor	Fails
RPPOH	TSS	SAV1	24	33.7	Good	Fails
RPPOH	SECCHI	SAV1	0.4	37	Poor	Fails

Table 3-9. SAV Season Water quality trends in segment RPPOH (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
RPPOH	S	TN	0.0529	0.0160	0.6739	-0.0023	0.0173	Sign. Dif.	0.1478	-
RPPOH	S	DIN	0.4982	0.0000	0.0129	0.0000	0.0037	Sign. Dif.	0.1266	-
RPPOH	S	TP	0.0010	0.0067	1.0000	0.0000	0.0006	Sign. Dif.	0.0006	-
RPPOH	S	PO4F	0.7610	0.0000	0.7202	0.0000	0.5444	No Sign. Dif.	0.9195	NS

b) Non-nutrient parameters

Segment	Layer	Season	Parameter	Baseline	Slope	% Change	p value	%BDL	Direction
RPPOH	S	SAV1	CHLA	9.33	0.5527	106.69	0.0000	6.02	Degrading

Table 3-10. 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	0.9540	41.1	**Good**	0.9905	34.1	**Good**
RPPTF	TN	SPRING1	0.8920	53.7	**Fair**	0.9905	41.4	**Good**
RPPTF	TN	SPRING2	0.8465	44.3	**Fair**	0.9590	30.2	**Good**
RPPTF	TN	SUMMER1	0.8890	35.3	**Good**	0.9180	23.9	**Good**
RPPTF	TN	SUMMER2	0.8340	30.8	**Good**	0.8920	20.5	**Good**
RPPTF	DIN	ANNUAL	0.4675	53.2	**Fair**	0.4496	48.0	**Fair**
RPPTF	DIN	SPRING1	0.4938	63.5	**Poor**	0.4860	56.2	**Fair**
RPPTF	DIN	SPRING2	0.4211	47.0	**Fair**	0.4401	41.5	**Good**
RPPTF	DIN	SUMMER1	0.2195	34.5	**Good**	0.2155	31.5	**Good**
RPPTF	DIN	SUMMER2	0.1845	13.2	**Good**	0.1905	12.5	**Good**
RPPTF	TP	ANNUAL	0.0760	24.1	**Good**	0.0815	22.1	**Good**
RPPTF	TP	SPRING1	0.0671	24.1	**Good**	0.0832	20.6	**Good**
RPPTF	TP	SPRING2	0.0814	31.2	**Good**	0.0941	27.8	**Good**
RPPTF	TP	SUMMER1	0.0789	22.1	**Good**	0.0834	20.5	**Good**
RPPTF	TP	SUMMER2	0.0767	20.6	**Good**	0.0828	19.5	**Good**
RPPTF	PO4F	ANNUAL	0.0074	9.0	**Good**	0.0070	9.7	**Good**
RPPTF	PO4F	SPRING1	0.0090	12.1	**Good**	0.0090	10.4	**Good**
RPPTF	PO4F	SPRING2	0.0070	7.8	**Good**	0.0070	9.3	**Good**
RPPTF	PO4F	SUMMER1	0.0063	5.7	**Good**	0.0063	7.2	**Good**
RPPTF	PO4F	SUMMER2	0.0068	7.0	**Good**	0.0070	7.4	**Good**
RPPTF	CHLA	ANNUAL	18.1825	82.5	**Poor**	-	-	-
RPPTF	CHLA	SPRING1	15.4625	81.6	**Poor**	-	-	-
RPPTF	CHLA	SPRING2	18.8500	80.6	**Poor**	-	-	-
RPPTF	CHLA	SUMMER1	30.7175	79.8	**Poor**	-	-	-
RPPTF	CHLA	SUMMER2	32.5600	80.0	**Poor**	-	-	-
RPPTF	TSS	ANNUAL	23.7500	68.6	**Poor**	34.8542	53.8	**Fair**
RPPTF	TSS	SPRING1	29.1250	61.6	**Poor**	50.5000	73.0	**Poor**
RPPTF	TSS	SPRING2	27.3750	70.6	**Poor**	50.5000	73.2	**Poor**
RPPTF	TSS	SUMMER1	22.7500	75.4	**Poor**	33.2500	54.6	**Fair**
RPPTF	TSS	SUMMER2	22.0000	75.8	**Poor**	33.0000	53.4	**Fair**
RPPTF	SECCHI	ANNUAL	0.4500	14.2	**Poor**	-	-	-
RPPTF	SECCHI	SPRING1	0.4500	13.8	**Poor**	-	-	-
RPPTF	SECCHI	SPRING2	0.4000	11.8	**Poor**	-	-	-
RPPTF	SECCHI	SUMMER1	0.4500	9.2	**Poor**	-	-	-
RPPTF	SECCHI	SUMMER2	0.4500	9.4	**Poor**	-	-	-
RPPTF	DO	SPRING1	-	-	-	9.0750	.	**Good**
RPPTF	DO	SPRING2	-	-	-	7.8700	.	**Good**
RPPTF	DO	SUMMER1	-	-	-	6.6450	.	**Good**
RPPTF	DO	SUMMER2	-	-	-	6.5475	.	**Good**

Table 3-11. Water quality trends in segment RPPTF (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
RPPTF	S	TN	0.3027	0.0100	0.1013	0.0093	0.5648	No Sign. Dif.	0.0078	**Degrading**
RPPTF	B	TN	0.4258	-0.0100	0.2971	0.0085	0.0646	No Sign. Dif.	0.7998	NS
RPPTF	S	DIN	0.0146	0.0180	0.1684	-0.0152	0.0002	Sign. Dif.	0.3253	-
RPPTF	B	DIN	0.0043	0.0213	0.1193	-0.0161	0.0000	Sign. Dif.	0.2582	-
RPPTF	S	TP	0.0202	0.0017	0.5922	-0.0005	0.0042	Sign. Dif.	0.0803	-
RPPTF	B	TP	0.1129	0.0017	0.9695	-0.0001	0.0949	No Sign. Dif.	0.1281	NS
RPPTF	S	PO4F	0.3893	0.0000	0.0000	-0.0010	0.0003	Sign. Dif.	0.0000	-
RPPTF	B	PO4F	0.9227	0.0000	0.0000	-0.0010	0.0000	Sign. Dif.	0.0000	-

b) Non-nutrient parameters

Segment	Parameter	Layer	Season	Baseline	Slope	% Change	% BDL	pValue	Direction
RPPTF	CHLA	S	Annual	12.39	0.0578	8.39	13.40	0.0396	**Degrading**
RPPTF	WTEMP	S	Annual	16.33	0.0571	6.30	0.00	0.0423	**Increasing**
RPPTF	WTEMP	B	Annual	17.75	0.0643	6.52	0.00	0.0338	**Increasing**
RPPTF	SALINITY	S	Annual	0.01	0.0000	0.00	0.00	0.0000	**Increasing**
RPPTF	SALINITY	B	Annual	0.01	0.0000	0.00	0.00	0.0000	**Increasing**

Table 3-12. 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	Season	Value	Score	Status	Habitat Requirement
RPPTF	DIN	SAV1	0.3355	40.5	**Good**	-
RPPTF	PO4F	SAV1	0.007	6.9	**Good**	**Meets**
RPPTF	CHLA	SAV1	24.775	81.3	**Poor**	**Fails**
RPPTF	TSS	SAV1	23.5	65.1	**Poor**	**Fails**
RPPTF	SECCHI	SAV1	0.45	11.8	**Poor**	**Fails**

Table 3-13. SAV Season Water quality trends in segment RPPTF (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
RPPTF	S	TN	0.0167	0.0241	0.1472	0.0104	0.3752	No Sign. Dif.	0.0001	**Degrading**
RPPTF	S	DIN	0.0005	0.0465	0.0919	-0.0180	0.0000	Sign. Dif.	0.0924	-
RPPTF	S	TP	0.0211	0.0025	0.7682	-0.0004	0.0069	Sign. Dif.	0.0442	-
RPPTF	S	PO4F	0.0643	0.0000	0.0093	-0.0002	0.0001	Sign. Dif.	0.3308	-

b) Non-nutrient parameters

Segment	Layer	Season	Parameter	Baseline	Slope	% Change	p value	%BDL	Direction
RPPTF	S	SAV1	SALINITY	0.01	0.0000	0.00	0.0000	0.00	**Increasing**

Table 3-14. 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	0.4320	8.0	**Good**	0.4730	10.2	**Good**
CRRMH	TN	SPRING1	0.4180	6.6	**Good**	0.4410	5.3	**Good**
CRRMH	TN	SPRING2	0.4675	11.8	**Good**	0.4895	10.3	**Good**
CRRMH	TN	SUMMER1	0.4825	8.3	**Good**	0.5270	13.0	**Good**
CRRMH	TN	SUMMER2	0.4985	7.6	**Good**	0.5270	11.8	**Good**
CRRMH	DIN	ANNUAL	0.0070	0.5	**Good**	0.0100	0.4	**Good**
CRRMH	DIN	SPRING1	0.0140	1.2	**Good**	0.0140	1.0	**Good**
CRRMH	DIN	SPRING2	0.0130	1.3	**Good**	0.0120	0.7	**Good**
CRRMH	DIN	SUMMER1	0.0060	0.4	**Good**	0.0085	0.2	**Good**
CRRMH	DIN	SUMMER2	0.0070	0.6	**Good**	0.0100	0.2	**Good**
CRRMH	TP	ANNUAL	0.0308	26.7	**Good**	0.0372	29.1	**Good**
CRRMH	TP	SPRING1	0.0259	19.6	**Good**	0.0298	20.8	**Good**
CRRMH	TP	SPRING2	0.0336	27.7	**Good**	0.0420	29.9	**Good**
CRRMH	TP	SUMMER1	0.0390	23.3	**Good**	0.0495	28.8	**Good**
CRRMH	TP	SUMMER2	0.0447	30.4	**Good**	0.0536	34.7	**Good**
CRRMH	PO4F	ANNUAL	0.0040	20.6	**Good**	0.0040	18.9	**Good**
CRRMH	PO4F	SPRING1	0.0055	35.9	**Good**	0.0065	43.3	**Fair**
CRRMH	PO4F	SPRING2	0.0045	24.5	**Good**	0.0040	17.0	**Good**
CRRMH	PO4F	SUMMER1	0.0035	13.3	**Good**	0.0050	17.4	**Good**
CRRMH	PO4F	SUMMER2	0.0050	21.2	**Good**	0.0080	31.0	**Good**
CRRMH	CHLA	ANNUAL	5.7200	25.4	**Good**	-	-	-
CRRMH	CHLA	SPRING1	5.0400	12.4	**Good**	-	-	-
CRRMH	CHLA	SPRING2	6.8000	24.1	**Good**	-	-	-
CRRMH	CHLA	SUMMER1	8.3850	43.0	**Fair**	-	-	-
CRRMH	CHLA	SUMMER2	9.6100	55.1	**Fair**	-	-	-
CRRMH	TSS	ANNUAL	4.0000	9.7	**Good**	7.0000	10.5	**Good**
CRRMH	TSS	SPRING1	4.0000	7.8	**Good**	7.0000	12.5	**Good**
CRRMH	TSS	SPRING2	4.0000	7.6	**Good**	10.0000	14.1	**Good**
CRRMH	TSS	SUMMER1	4.5000	6.9	**Good**	8.0000	8.4	**Good**
CRRMH	TSS	SUMMER2	5.0000	6.1	**Good**	8.0000	8.4	**Good**
CRRMH	SECCHI	ANNUAL	1.6000	78.8	**Good**	-	-	-
CRRMH	SECCHI	SPRING1	1.6000	82.1	**Good**	-	-	-
CRRMH	SECCHI	SPRING2	1.2000	70.8	**Good**	-	-	-
CRRMH	SECCHI	SUMMER1	1.3000	79.4	**Good**	-	-	-
CRRMH	SECCHI	SUMMER2	1.4000	83.8	**Good**	-	-	-
CRRMH	DO	SPRING1	-	-	-	8.7450	.	**Good**
CRRMH	DO	SPRING2	-	-	-	6.8650	.	**Good**
CRRMH	DO	SUMMER1	-	-	-	4.1000	.	**Fair**
CRRMH	DO	SUMMER2	-	-	-	3.9500	.	**Fair**

Table 3-15. Water quality trends in segment CRRMH (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
CRRMH	S	TN	0.8175	0.0000	0.0692	-0.0083	0.0375	Sign. Dif.	0.1259	-
CRRMH	B	TN	0.1297	0.0050	0.0001	-0.0218	0.0143	Sign. Dif.	0.0000	-
CRRMH	S	DIN	0.6073	0.0000	0.0000	0.0000	0.0000	Sign. Dif.	0.0002	-
CRRMH	B	DIN	0.7738	0.0000	0.0000	0.0000	0.0000	Sign. Dif.	0.0000	-
CRRMH	S	TP	0.0001	0.0013	0.5598	-0.0004	0.0000	Sign. Dif.	0.0006	-
CRRMH	B	TP	0.0001	0.0020	0.0860	-0.0013	0.0000	Sign. Dif.	0.0254	-
CRRMH	S	PO4F	0.9336	0.0000	0.6058	0.0000	0.6543	No Sign. Dif.	0.4816	NS
CRRMH	B	PO4F	0.1818	0.0000	0.8569	0.0000	0.3275	No Sign. Dif.	0.1499	NS

b) Non-nutrient parameters

Segment	Parameter	Layer	Season	Baseline	Slope	% Change	% BDL	pValue	Direction
CRRMH	SECCHI	S	Annual	1.95	-0.0146	-13.52	0.00	0.0022	**Degrading**

Table 3-16. 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	Season	Value	Score	Status	Habitat Requirement
CRRMH	DIN	SAV1	0.008	0.6	**Good**	**Meets**
CRRMH	PO4F	SAV1	0.005	23.9	**Good**	**Meets**
CRRMH	CHLA	SAV1	8.235	43	**Fair**	**Meets**
CRRMH	TSS	SAV1	4	5.8	**Good**	**Meets**
CRRMH	SECCHI	SAV1	1.3	74.2	**Good**	**Meets**

Table 3-17. SAV Season Water quality trends in segment CRRMH (only significant trends are displayed).

a) Nutrient parameters

Segment	Layer	Parameter	'93 Trend p value	'93 Slope	'02 Trend p value	'02 Slope	Trend Comparison p value	Trend Comparison	Combined Trend p value	Combined Trend Direction
CRRMH	S	TN	0.7718	0.0000	0.5894	-0.0031	0.8445	No Sign. Dif.	0.3774	NS
CRRMH	S	DIN	0.0000	0.0000	0.0001	0.0000	0.0006	Sign. Dif.	0.0003	-
CRRMH	S	TP	0.0030	0.0013	0.9589	-0.0003	0.0014	Sign. Dif.	0.0028	-
CRRMH	S	PO4F	0.8569	0.0000	0.8742	0.0000	0.6934	No Sign. Dif.	1.0000	NS

b) Non-nutrient parameters

Segment	Layer	Season	Parameter	Baseline	Slope	% Change	p value	%BDL	Direction
CRRMH	S	SAV1	TSS	8.00	0.0000	0.00	0.0242	49.32	**Improving**
CRRMH	S	SAV1	SECCHI	1.75	-0.0167	-17.14	0.0005	0.00	**Degrading**
CRRMH	S	SAV1	SALINITY	17.48	-0.1200	-12.36	0.0392	0.00	**Decreasing**

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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 minimum 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, a nd 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 5^{th} percentile and the 50^{th} percentile (median) of the distribution of values at reference sites. Samples with metric values less than the lower 5^{th} percentile are scored as a 1. Samples with values between the 5^{th} and 50^{th} metrics are scored as 3 and values greater than the 50^{th} percentile are scored as 5. For abundance and biomass, values below the 5^{th} and above the 95^{th} percentile are scored as 1, values between the 5^{th} and 25^{th} and the 75^{th} and 95^{th} percentiles are scored as 3 and values between the 25^{th} and 75^{th} 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.