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STATUS AND TRENDS IN WATER QUALITY AND LIVING RESOURCES IN THE VIRGINIA CHESAPEAKE BAY: RAPPAHANNOCK RIVER (1985-2003)

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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 preiodically updated and they were intended for an audience already knowledgeable of the history and rationale of the program; design of the program; field and laboratory methods; specialized parameters, e.g. the Benthic Index of Biotic Integrity; status and trends analytical methods, etc.

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

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

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Summary of Status and Trends for the Chesapeake Bay and the James York and Rappahannock Rivers

The Virginia Chesapeake Bay and its tidal tributaries continue to show some environmental trends indicating progress toward restoration of a more balanced and healthy ecosystem. However, the Bay system remains degraded and some areas and indicators show continuing degradation. Progress in reducing nutrient inputs has made demonstrable improvements and we expect that continued progress toward nutrient reduction goals, along with appropriate fisheries management and chemical contaminant controls, will result in additional improvements to the Bay. Findings from the last 18 years of the monitoring programs are highlighted below.

In 1995, the Virginia DEQ instituted changes to its analytical techniques for determining nutrient concentrations in the tidal waters of Virginia. These changes resulted in step trends in the data for both the nitrogen and phosphorus parameters for which status and long-term trends were assessed. An appropriate statistical technique was employed to determine long-term trends for the entire period of record (1985-2003) and for trends that occurred during the pre-method change and post-method change periods. For the tidal waters of Virginia, all information presented in this summary concerning long-term trends in nutrient parameters refers only to trends detected for the entire period of record and focuses only on the James, Elizabeth, York and Rappahannock rivers.

- Nonpoint source loads (estimates of controllable and uncontrollable) of phosphorus, nitrogen, and sediment as calculated by the Bay Program Watershed Model, decreased by 13%,11%, and 12%, respectively, compared to the 1985 baseline loads (Table 1).

- Point source nutrient loads were reduced by 53% for phosphorus and 30% for nitrogen, compared to the 1985 baseline loads. This decrease in discharge may be partly due to ongoing drought conditions in Virginia (Table 1).

- Combined nutrient loads were reduced by 28% for phosphorus and 18% for nitrogen, compared to the 1985 baseline loads (Table 1).

- For nitrogen, there were improving trends at the river input stations of the James River, and the Rappahannock River along with a degrading trend in the Pamunkey River. For most segments, status of nitrogen parameters was either good or fair. Overall, there were four segments showing improving trends and six segments showing degrading trends. Five of the six degrading segment trends were in the York River. Three of the four improving segment trends were in the Elizabeth River and the James River and Rappahannock River.

- For phosphorus, there were improving trends in flow adjusted concentrations above the fall-line at the river input stations of the James River, Appomattox River, and Rapphannock River with a degrading trend in the Pamunkey River. Status in phosphorus parameters was typically poor in most segments except the tidal freshwater segments. Overall, there were nine improving segment trends and nine degrading segment trends in total phosphorus in the Virginia tributaries. All seven segments of the York River showed degrading phosphorus trends. Improving trends in phosphorus parameters were detected in nearly of the segments in the Elizabeth River.

- Chlorophyll *a* levels were high in just under half of the segments sampled but there was only one segment with a degrading trend in chlorophyll *a* and three showed an improving trend.

- Water clarity, a very important environmental parameter, was generally fair or poor in most segments throughout the tributaries. This is probably related to high and scattered increasing levels of suspended solids. These degrading conditions are a major impediment to restoration of submerged aquatic vegetation (SAV). No segments showed improving trends and seven segments showed degrading trends in water clarity.

- Levels of dissolved oxygen were good in the majority of areas in the tributaries and improving trends were detected in three segments.

- Phytoplankton populations are a major food source and oxygen producer in these waters, and represent a major indicator to the health status of these tributaries. Although dominated by favorable concentrations and long-term trends among the diatoms and chlorophytes within segments of these rivers, there are disturbing signs of increased concentrations of cyanobacteria throughout these estuaries, and blooms of dinoflagellates occur seasonally. These trends were enhanced at several locations by increased concentrations becoming more common since 1999. Among these taxa are species known to be toxin producers. Future attention will continue to be directed to any increased presence of these less favorable algal categories, and the environmental conditions that would favor their development over diatoms and chlorophytes.

- Benthic community patterns differed greatly between the rivers. In the James River there were 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, community status was good in the down stream segments where communities continued to improve. In the Rappahannock River status was poor in the downstream segments of the river and degrading trends were detected at the middle station.

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 2003 data to 1985 data. Nonpoint source loads are results based on the Year 2003 Progress Run of the Chesapeake Bay Watershed Model and calculated reductions for calendar year 2001 Best Management Practices (BMPs) as monitored by the Department of Conservation and Recreation. Values with a "*" were updated with the latest available point source data.

Non Point Source Loads						
Tributary Basin	2003 Phosphorus Load (kg/yr)	% Change in Phosphorus	2003 Nitrogen Load(kg/yr)	% Change in Nitrogen	2003 Sediment Load (mtu/yr)	% Change in Sediment
Potomac	708,138	-15%	6,554,972	-6%	647,340	-14%
Rappahannock	396,540	-19%	3,263,308	-22%	301,575	-21%
York	273,596	-17%	2,914,234	-16%	114,097	-20%
James	1,864,703	-10%	9,934,493	-7%	1,058,367	-8%
Coastal	88,092	-14%	882,602	-11%	19,885	-6%
Totals	3,331,069	-13%	23,549,610	-11%	2,141,255	-12%

Point Source Loads and in parentheses the number of point sources				
Tributary Basin	2003 Phosphorus Load (kg/yr)	% Change in Phosphorus	2003 Nitrogen Load (kg/yr)	% Change in Nitrogen
Potomac (39)	236,924	-32%	3,309,286	-33%
Rappahannock (18)	32,092	-63%	312,415	24%
York (10)	78,015	-62%	525,344	-17%
James (37)	782,495	-55%	7,731,942	-30%
Coastal Bays (5)	3,486	-81%	106,272	-18%
Totals	1,133,012	-53%	11,985,258	-30%

Total Loads						
Tributary Basin	2003 Phosphorus Load	% Change in Phosphorus	2003 Nitrogen Load	% Change in Nitrogen	2003 Sediment Load (mtu/yr)	% Change in Sediment
Non Point Source	3,331,069	-13%	23,549,610	-11%	2,141,255	-12%
Point Source	1,133,012	-53%	11,985,258	-30%		
Combined	4,464,081	28%	35,534,868	18%	2,141,255	-12%

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 19 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, 2003, 2004a, 2004b; 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 2003. 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 and updates past basin summary reports (Dauer et al., 2003a, 2003b, 2003c).

Chapter 2. Chesapeake Bay 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 2003. 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 19 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. 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. Physical and chemical measurements were also made at the random locations.

C. Laboratory Sample Processing

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

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

IV. 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 stations from the January 2001 through December of 2003 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, 2001 through December, 2003. 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, 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 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.

Status of benthic communities at each station was characterized using the three-year mean value (2001 through 2003) 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.

Status of benthic communities was also quantified by using the probability-based sampling to estimate the bottom area populated by benthos meeting the Chesapeake Bay Benthic Community Restoration Goals (Ranasinghe et al. 1994; Weisberg et al. 1997). This approach produces an estimate of the spatial extent and distribution of degraded benthic communities in Chesapeake Bay (Dauer and Llansó 2003; Llansó et al. 2003). To estimate the amount of area in the entire Bay that failed to meet the Chesapeake Bay Benthic Restoration Goals (P), we defined for every site *i* in stratum *h* a variable y_{hi} that had a value of 1 if the benthic community met the goals, and 0 otherwise. For each stratum, the estimated proportion of area meeting the goals, $p_{h,}$ and its variance were calculated as the mean of the y_{hi}'s as follows:

$$p_h = \bar{y}_h = \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h},$$

Variance for this estimate was calculated as:

$$\text{var}\ (p_h) = s_h^2 = \sum_{i=1}^{n_h} \frac{(y_{hi} - \bar{y}_h)^2}{n_h - 1}.$$

Estimates for strata were combined to achieve a statewide estimate as:

$$\hat{P}_{ps} = \bar{y}_{ps} = \sum_{h=1}^{10} W_h \bar{y}_h,$$

were the weighting factors, W_h, = A_h/A and A_h were the total area of the *h*th stratum. The variance of (3) was estimated as:

$$\text{var}\ (\hat{P}_{ps}) = V(\bar{y}_{ps}) = \sum_{h=1}^{10} W_h s_h^2 / n_h.$$

For combined strata, the 95% confidence intervals were estimated as the proportion plus or minus twice the standard error. For individual strata, the exact confidence interval was determined from tables.

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.

2. Tidal water quality

Trend analyses were conducted on the same suite of water quality parameters used for the status assessments, as well as, 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 laboratory 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 2003) time periods for these parameters. Note that 1994 was eliminated from the analyses because samples during this year were collected and processed by a laboratory that was different than the VADCLS. The “blocked” seasonal Kendall test was applied only to those segment/parameter combinations 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 0.01 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. A statistical test criterion for phytoplankton metrics was a *P* value of 0.05.

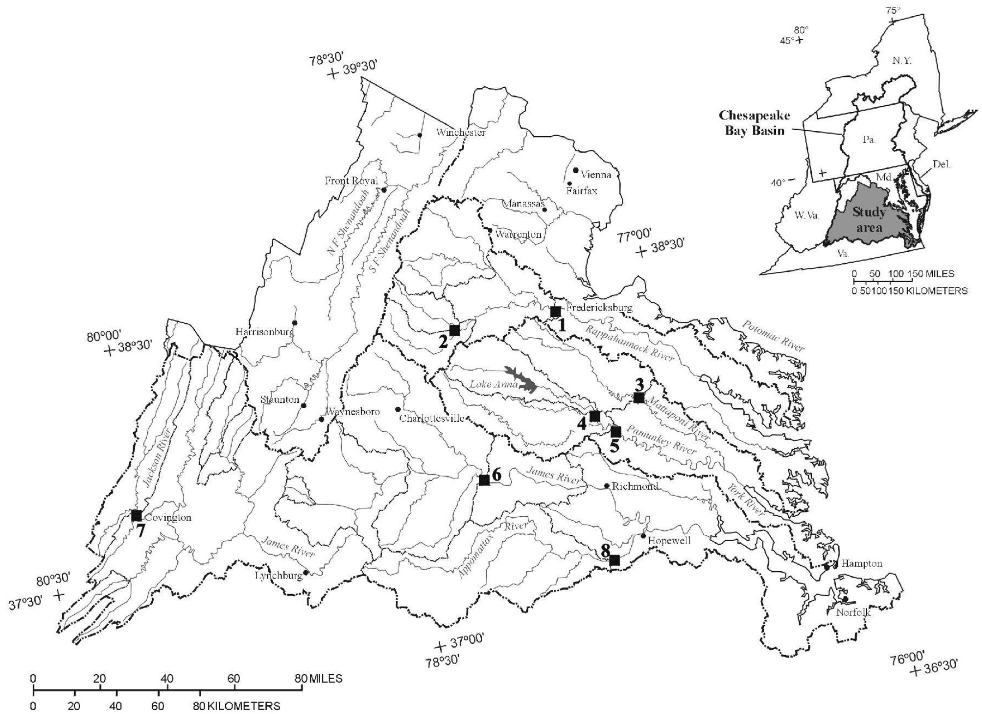
The Margalef species diversity index was calculated as follows:

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

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

Trend analyses for 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 19 year period of 1985-2003. 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). The statistical test 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.

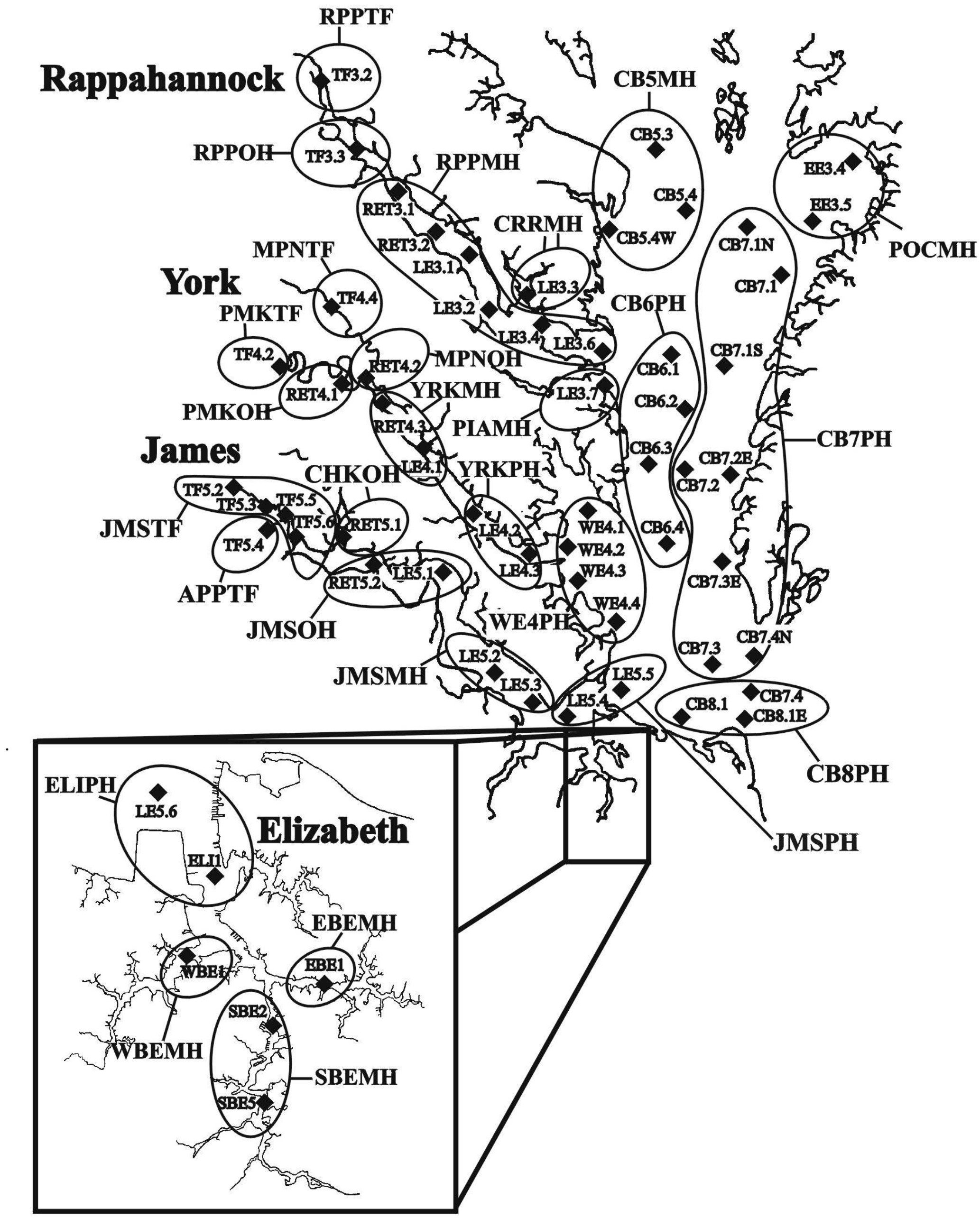


Figure 2-2. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem used in the statistical analyses. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

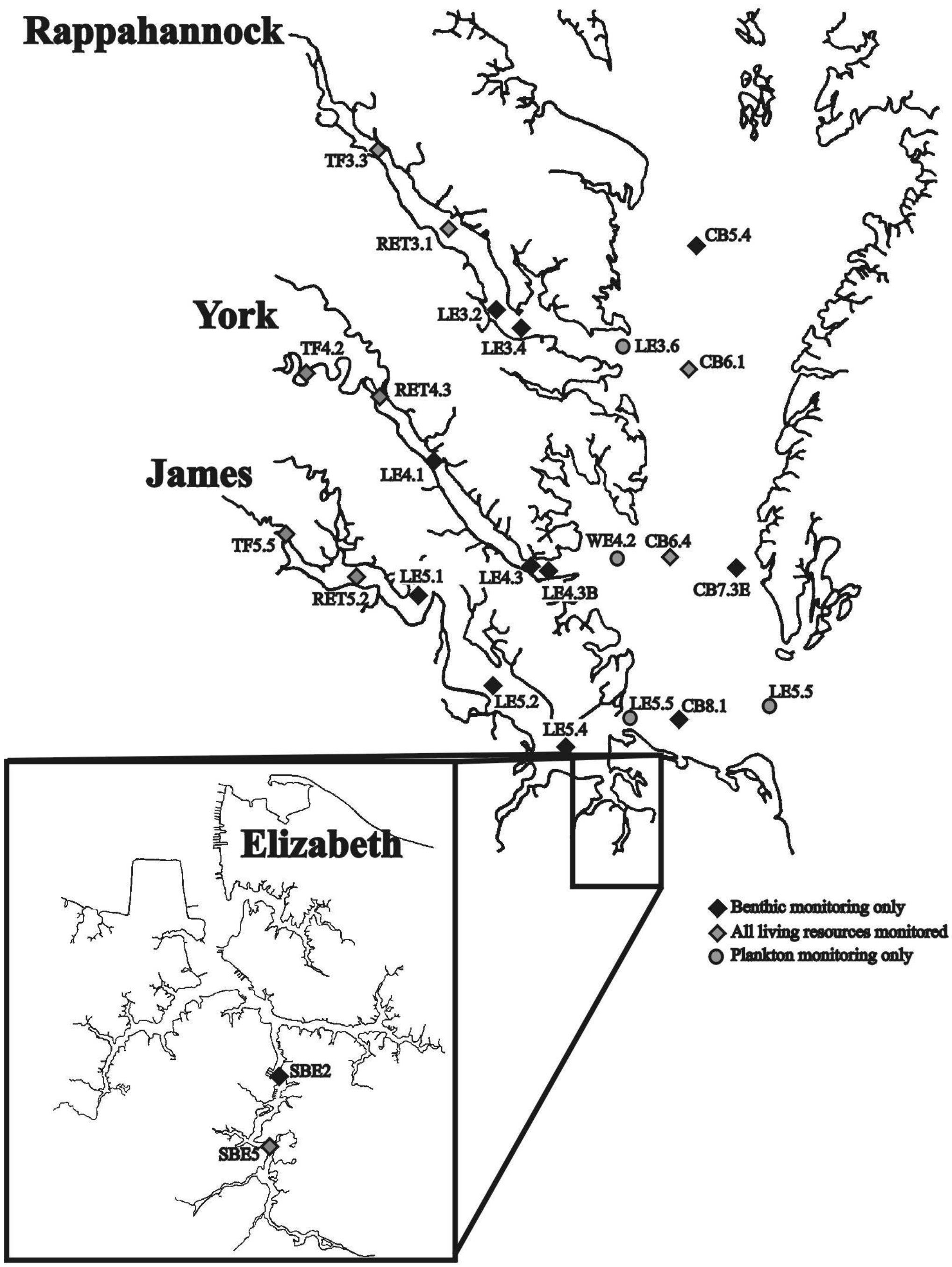


Figure 2-3. Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem.

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 Batiuk 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 have 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 3-1 to 3-6 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. The terms *good*, *fair*, and *poor* used in conjunction with water quality conditions are statistically determined classifications for comparison among areas of similar salinity within the Chesapeake Bay system. Though useful in comparing current conditions among different areas of the Chesapeake Bay system, these terms are not absolute evaluations but only appraisals relative to other areas of a generally degraded system. Several major scientific studies have shown that the Chesapeake Bay system is currently nutrient enriched and has excessive and detrimental levels of nutrient and sediment pollution (USEPA, 1982; USEPA, 1983; Boynton et al., 1995; Harding and Perry, 1997; Bricker et al., 1999; USEPA 2001; Hagy et al., 2004). Given this, it is likely that an absolute evaluation in relation to ideal conditions would indicate that most water quality parameters are currently poor throughout the whole Bay system.

Relative status of nutrients and dissolved oxygen was good or fair for all segments in the Rappahannock River while the status of surface chlorophyll *a*, total suspended solids and secchi depth was poor in the Upper Rappahannock River (RPPTF) and Middle Rappahannock River (RPPOH), while status of these parameters was generally fair or good in the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). SAV habitat requirements were not met for most parameters in the Upper Rappahannock River (RPPTF) and Middle Rappahannock River (RPPOH), but were met for most parameters in the Lower Rappahannock River (RPPMH) and Corrotoman River (CRRMH).

The only long-term trends in nutrient parameters detected were improving trends in surface dissolved inorganic nitrogen in the Corrotoman River for both the Annual and SAV growing seasons. Degrading trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and in secchi depth in the Corrotoman River (CRRMH). An improving trend in Summer1 dissolved oxygen was detected in the Middle Rappahannock River (RPPOH), and an increasing trend in salinity was detected in the Corrotoman River (CRRMH). Degrading trends in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and secchi depth in the Corrotoman River (CRRMH) were detected during the SAV growing season. Decreasing trends in salinity were also detected in the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH) during the SAV growing season.

Figures 3-9 to 3-11 provide summaries of living resource status and trend analyses for the Rappahannock River. Status of phytoplankton community metrics was poor at many stations in the Rappahannock River, as was primary productivity at station TF3.3 in the Middle Rappahannock River (RPPOH). Status of diatoms and chlorophyte biomass was good throughout the Rappahannock River. Status of primary productivity improved from poor at station TF3.3 in the Middle Rappahannock River (RPPOH) to fair at station RET3.1 and good at station LE3.6 in the Lower Rappahannock River (RPPMH). Improving trends in diatom and chlorophyte biomass were detected at all stations in the Rappahannock River. Improving trends in the biomass to abundance ratio and cryptophyte biomass were detected at station TF3.3 in the Middle Rappahannock River (RPPOH) and station RET3.1 in the Lower Rappahannock River (RPPMH). Degrading trends in cyanophyte abundance and biomass were detected at all stations in this river. In addition, degrading trends in picoplankton biomass were detected in both stations of the Middle Rappahannock River (RPPOH). Finally, degrading trends in dinoflagellate biomass were detected at station TF3.3 in the Middle Rappahannock River (RPPOH) and at station LE3.6 in the Lower Rappahannock River.

Status of the B-IBI ranged from marginal to severely degraded in this tributary. A degrading trend in the B-IBI and several of its component metrics was detected at station RET3.1 in the upper portion of the Lower Rappahannock River (RPPMH).

C. Summary of Major Issues in the Basin

Results suggest that the primary concerns for water quality in the Rappahannock River are chlorophyll *a*, total suspended solids, and water clarity primarily in the Upper and Middle portions of the river. 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 status was good for each of these parameters except secchi depth for which it was fair. 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). A degrading trend was also detected for secchi depth in the Corrotoman River (CRRMH).

The major concerns within the phytoplankton community are increasing long-term trends in abundance and biomass among the cyanobacteria. These taxa are a less favorable food and oxygen source within the water column, are associated with degrading water conditions, and also contain several potential bloom and toxin producers. An additional concern is the increased trends of dinoflagellate biomass in the middle and lower regions of the Rappahannock River.

Benthic community status was severely degraded at both stations in the Lower Rappahannock River (RPPMH) as a result of a high frequency of low dissolved oxygen events caused by naturally occurring summer pycnoclines in a deep trench located near these stations. Benthic community status within the Middle Rappahannock River (RPPOH) was marginal at both stations, with a degrading trend in the B-IBI and nearly all of its component metrics at station RET3.1. Status and trends in benthic communities of the Middle Rappahannock River (RPPOH) may be related to the problems in water quality conditions described.

II. Management Recommendations

Water quality problems in the Rappahannock River appear to be especially pronounced in the upper two segments of this estuary (RPPTF and RPPOH), and are related primarily to chlorophyll *a,* total suspended solids and water clarity. Status of each of these parameters was poor in these two segments and with respect to SAV habitat requirements, these parameters were either borderline or failed to meet the SAV criteria in both 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 all segments. In addition, there were no long-term degrading trends in nutrients although several pre-method degrading trends in nutrients were detected.

The chlorophyll *a* and water clarity problems in the Rappahannock River may be related to the high concentrations of phytoplankton in the water column as is indicated by: (1) the poor status of chlorophyll *a*, (2) the increasing trend detected in this parameter within the Middle Rappahannock River (RPPOH) and (3) the increasing trends in many phytoplankton community metrics within both the Middle Rappahannock River (RPPOH) and the Lower Rappahannock River (RPPMH) including total abundance and biomass, and diatom, chlorophyte, cryptophyte and cyanophyte biomass.

While non-point source loadings are the major source of nutrients and sediment throughout the Rappahannock River, point source loadings for both total nitrogen and total phosphorus are highest near the fall-line and decrease moving downstream, suggesting a potential link between water clarity and point source nutrient loadings in the upper segments of the Rappahannock River. It is possible that 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 exacerbate anthropogenic effects. These low flows could contribute to the poor status of water clarity by reducing downstream flushing and the export of suspended solids, nutrients, and/or phytoplankton in the water column. The reduced flushing also likely increases residence time in the river which may allow for increased phytoplankton biomass accumulation.

No direct link between any of these factors and water clarity can be made with the analyses performed for this report. A more thorough investigation of existing data sets may help to identify potential sources of the water clarity problems. Trend analysis of 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.

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 densities 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). A detailed examination of relationships between these sources of anthropogenic stress and water quality conditions is beyond the scope of this report. 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

Figures 3-7 and 3-8 provide a summary of status and trend analysis results for water quality parameters. Relative status of nutrients and dissolved oxygen was good or fair for all segments in the Rappahannock River and the Corrotoman River (CRRMH). Relative status of surface chlorophyll *a*, and surface and bottom total suspended solids was poor in the Upper Rappahannock River (RPPTF) and the Middle Rappahannock River (RPPOH) but fair in the Lower Rappahannock River (RPPMH) and good in the Corrotoman River (CRRMH). Secchi depth status was poor in all segments of the Rappahannock except the Corrotoman River (CRRMH) where status of this parameter was fair.

The SAV habitat criteria were met for surface dissolved inorganic nitrogen and phosphorus in all applicable segments. Surface chlorophyll *a* failed to meet the SAV habitat requirement in the Upper Rappahannock River (RPPTF), was borderline in the Middle Rappahannock River (RPPOH) but met the criterion in the Lower Rappahannock River (RPPMH) and Corrotoman River (CRRMH). Surface total suspended solids and secchi depth failed to meet the SAV habitat requirements in the Upper Rappahannock River (RPPTF) and Middle Rappahannock River (RPPOH) but met the criteria or were borderline in the Lower Rappahannock River (RPPMH) and Corrotoman River (CRRMH).

The only long-term trend in nutrients observed was an improving trend in bottom dissolved inorganic nitrogen in the Corrotoman River (CRRMH); however, improving trends in surface and bottom dissolved inorganic phosphorus were detected during the post-method change period. Degrading trends in surface total phosphorus were detected during the pre-method change period in all segments except the Upper Rappahanock River (RPPTF) and also for bottom total phosphorus for the Middle Rappahannock River (RPPOH) and the Corrotoman River (CRRMH). A pre-method change degrading trend was also detected in the Lower Rappahannock River (RPPMH) for bottom total nitrogen. Degrading trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and secchi depth in the Corrotoman River (CRRMH). An improving trend in Summer1 bottom dissolved oxygen was detected in the Middle Rappahannock River (RPPOH). During the SAV growing season, a significant long-term improving trend in surface dissolved inorganic nitrogen was detected in the Corrotoman River (CRRMH). Degrading long-term trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and in secchi depth in the Corrotoman River (CRRMH) during the SAV growing season. Decreasing trends in surface salinity were detected in the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). In general, water quality issues in the Rappahannock River appear limited primarily to surface chlorophyll *a* , surface and bottom total suspended solids and secchi depth in the two upper segments of the river.

Figures 3-9 and 3-10 summarize the results of the living resources status and trend analyses for the Rappahannock River. Status of diatom and chlorophyte biomass was good while status of cyanobacteria abundance was poor throughout the Rappahannock River. Status of many phytoplankton metrics improved moving from station TF3.3 in the Middle Rappahannock River to the downstream station LE3.6 in the Lower Rappahannock River. Status of the Margalef Diversity Index improved from fair at stations TF3.3 and RET3.1 to good at station LE3.6. Status of cyanophyte and picoplankton biomass improved from poor at stations TF3.3 and RET3.1 to good at station LE3.6. Status of primary productivity improved from poor at station TF3.3 to fair at station RET3.1 to good at station LE3.6. Improving trends in diatom biomass and chlorophyte biomass were detected at all stations in the Rappahannock River, as were degrading trends in cyanobacteria abundance. Improving trends in the biomass to abundance ratio were detected at station TF3.3 in the Middle Rappahannock River (RPPOH) and RET3.1 in the Lower Rappahannock River (RPPMH), but not at station LE3.6 in the Lower Rappahannock River (RPPMH). Improving trends in picoplankton biomass and primary productivity were detected at station LE3.6 in the Lower Rappahannock River (RPPMH), but not in the upstream stations in the Rappahannock River. In general, phytoplankton communities in the Rappahannock River are more impacted at the upstream stations than at station LE3.6 in the Lower Rappahannock River, but conditions are generally improving throughout this tributary. This pattern appears to reflect the patterns observed in water quality.

The phytoplankton trends and status provide a mixed representation of the flora in the Rappahannock River. There exists a favorable status and dominance of diatoms and chlorophytes throughout the river segments, in addition to favorable trends among the cryptophytes. These populations show increasing trends that will provide food and an oxygen source within the water column. However, there exists degrading trends in abundance and biomass among the cyanobacteria and picoplankton biomass within these waters. Productivity status within the river segments tend to indicate a greater degrading impact is associated with the upstream stations than those downstream.

Benthic community status ranged from marginal in the Middle Rappahannock River (RPPOH) to severely degraded in the Lower Rappahannock River (RPPMH). Severely degraded status at the stations in the Lower Rappahannock River (RPPMH) is related to the frequency of low dissolved oxygen events that occur in this segment. Status of both stations in the Middle Rappahannock River (RPPOH) was marginal. A degrading trend in the B-IBI was detected at station RET3.1 in the Lower Rappahannock River (RPPOH). Marginal status throughout the Middle Rappahannock River (RPPOH) and the degrading trend at station RET3.1 may reflect the poor status of many water quality parameters in this segment.

V. Detailed Overview of Status and Trends

A. Fall-Line

Above the fall-line, a degrading trend in flow adjusted concentrations of total Kjeldahl nitrogen was detected in Robinson Creek near Locustdale along with improving trends in flow adjusted concentrations of surface nitrates-nitrites and surface total phosporus. An improving trend was detected at the fall-line in flow adjusted concentrations of surface total phosphorus the Rappahannock River near Fredricksburg (Table 3-1).

B. 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 (Figure 3-7;Table 3-2). No significant trends in nutrients were detected that were consistent between the pre- and post-method change periods; however, significant improving trends in surface and bottom dissolved inorganic phosphorus were detected during the post-method change period.(Figure 3-7; Table 3-3).

b) Non-nutrient parameters

Status of all non-nutrient parameters was poor except for Summer1 bottom dissolved oxygen for which the status was good (Figure 3-8;Table 3-2). No trends in non-nutrient parameters were detected in this segment (Figure 3-8;Table 3-4).

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 3-5).

b) Nutrient parameters

No significant trends in nutrients were detected that were consistent between the pre- and post-method change periods; however, an improving trend in surface dissolved inorganic phosphorus was detected in the post-method change period for the SAV growing season (Table 3-6).

c) Non-nutrient parameters

No significant trends were detected for any of the non-nutrient parameters in this segment during the SAV growing season (Table 3-7).

3. Living resources

Living resource monitoring is not conducted in this segment.

C. Oligohaline Rappahannock River (RPPOH - Middle Rappahannock)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good or fair in this segment (Figure 3-7;Table 3-2). No significant trends in nutrients were detected that were consistent between the pre- and post-method change periods. However, degrading trends in surface and bottom total phosphorus were detected during the pre-method change period (Figure 3-7; Table 3-3).

b) Non-nutrient parameters

Status of all non-nutrient parameters was poor except for Summer1 bottom dissolved oxygen for which the status was good (Figure 3-8;Table 3-2). A degrading trend in surface chlorophyll *a* was detected along with an improving trend in Summer1 bottom dissolved oxygen (Figure 3-8;Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

Although the SAV habitat requirement for surface dissolved inorganic phosphorus was met, the surface chlorophyll a was borderline and surface total suspended solids and secchi depth failed to met their respective SAV criteria (Table 3-5).

b) Nutrient parameters

No significant trends were detected that were consistent between the pre- and post-method change periods; however, a significant degrading trend in surface total phosphorus was detected during the pre-method change period.(Table 3-6).

c) Non-nutrient parameters

A degrading trend in surface chlorophyll *a* was detected in this segment during the SAV growing season (Table 3-7).

3. Living resources

The total phytoplankton abundance and biomass had increasing trends at this site (TF3.3), with good biomass status. However, there was poor status associated with the biomass to abundance ratio, productivity, and the biomass for dinoflagellates, cyanobacteria, and picoplankton. There were degrading trends of increased biomass for dinoflagellates and picoplankton as well as degrading trends in biomass and abundance of cyanobacteria (Figure 3-9, Appendix F). Several potentially toxic cyanobacteria were among these taxa. In contrast, the diatoms and chlorophytes showed good status and favorable increasing biomass. This was generally an impacted area for the phytoplankton.

Status of the B-IBI was marginal at station TF3.3 and, although there was no trend in the B-IBI, a degrading trend in pollution sensitive species biomass was detected (Figure 3-10). Although they occasionally exceed it, values of the B-IBI generally remain below the B-IBI goal at this station (Appendix L).

D. Mesohaline Rappahannock River (RPPMH - Lower Rappahannock)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good except for surface and bottom total phosphorus for which the status was fair (Figure 3-7;Table 3-2). There were no significant trends detected in nutrients that were consistent between the pre- and post-method change periods. However, degrading trends in bottom total nitrogen and surface total phosphorus were detected in the pre-method change period (Figure 3-7;Table 3-3).

b) Non-nutrient parameters

Status of all non-nutrient parameters was fair except for secchi depth for which the status was poor. The status of dissolved oxygen was fair (Figure 3-8;Table 3-2). No significant trends were detected in this segment for the non-nutrient parameters (Figure 3-8;Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

SAV habitat requirements were met for all parameters except for secchi depth which was borderline (Table 3-5).

b) Nutrient parameters

There were no significant trends in any nutrient parameters that were consistent between the pre- and post-method change periods. Degrading trends in surface total nitrogen and surface total phosphorus were detected during the pre-method change period along with an improving trend in surface dissolved inorganic nitrogen (Table 3-6).

c) Non-nutrient parameters

A significant decreasing trend in salinity was detected in this segment during the SAV growing season (Table 3-7).

3. Living resources

There was some improvement in the phytoplankton status comparing station RET3.1 with the upstream station TF3.3. Status was mixed among the parameters from good to poor; however there continued increased trends in total phytoplankton abundance and biomass, with no significant trends in species diversity or productivity. Diatoms and chlorophytes continued to have good status with increasing biomass trends. The dinoflagellates improved to a fair status showing an improving trend. However, poor status remained for the cyanobacteria biomass and abundance, and picoplankton biomass with degrading trends for each of these categories (Figure 3-9, Appendix F).

There were increasing long-term trends in total phytoplankton abundance and biomass at station LE3.6 that was associated increased biomass trends among the diatoms, dinoflagellates, chlorophytes, and cyanobacteria. Of concern is the increased biomass patterns associated with bloom forming dinoflagellates and cyanobacteria. However, productivity status was good with an improving trend, with a good status for species diversity (Figure 3-9;Appendix F). Several of the phytoplankton status parameters have improved moving downstream to this site (species diversity, productivity, cyanobacteria and picoplankton biomass); however, the persistence of the dinoflagellate trends and those associated with the cyanobacteria represent concern if these trends continue.

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 3-10). Values of the B-IBI show a definite decline beginning around 1990 but the B-IBI may be beginning to increase again (Appendix L).

Status of benthic communities at both stations LE3.2 and LE3.4 was severely degraded and there were no trends in the B-IBI (Figure 3-10). Both stations are strongly impacted by low dissolved oxygen events and values of the B-IBI rarely approach the B-IBI goal (Appendix L).

E. Mesohaline Corrotoman River (CRRMH - Corrotoman River)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good except for surface total phosphorus for which the status was fair (Figure 3-7;Table 3-2). A significant improving trend in surface dissolved inorganic nitrogen was detected that was consistent between pre- and post-method change periods. Significant degrading trends were detected during the pre-method change period but were not consistent with results for the post-method change period which were not significant (Figure 3-7;Table 3-3).

b) Non-nutrient parameters

Status of surface chlorophyll *a* and surface and bottom total suspended solids was good while the status of secchi depth and dissolved oxygen was fair (Figure 3-8;Table 3-2). A degrading trend in secchi depth was detected in this segment along with an increasing trend in surface salinity (Figure 3-8;Table 3-4).

<u>2. Water quality for SAV</u>

a) SAV habitat requirements

SAV habitat requirements were met for all parameters (Table 3-5).

b) Nutrient parameters

A significant trend in surface dissolved inorganic nitrogen that was consistent between the pre- and post-method change periods was detected in this segment. No other trends in nutrient parameters were detected in this segment during the SAV growing season (Table 3-6).

c) Non-nutrient parameters

There was a significant degrading trend in secchi depth coupled with a decreasing in surface salinity in this segment (Table 3-17).

<u>3. Living resources</u>

No living resources monitoring is conducted in this segment.

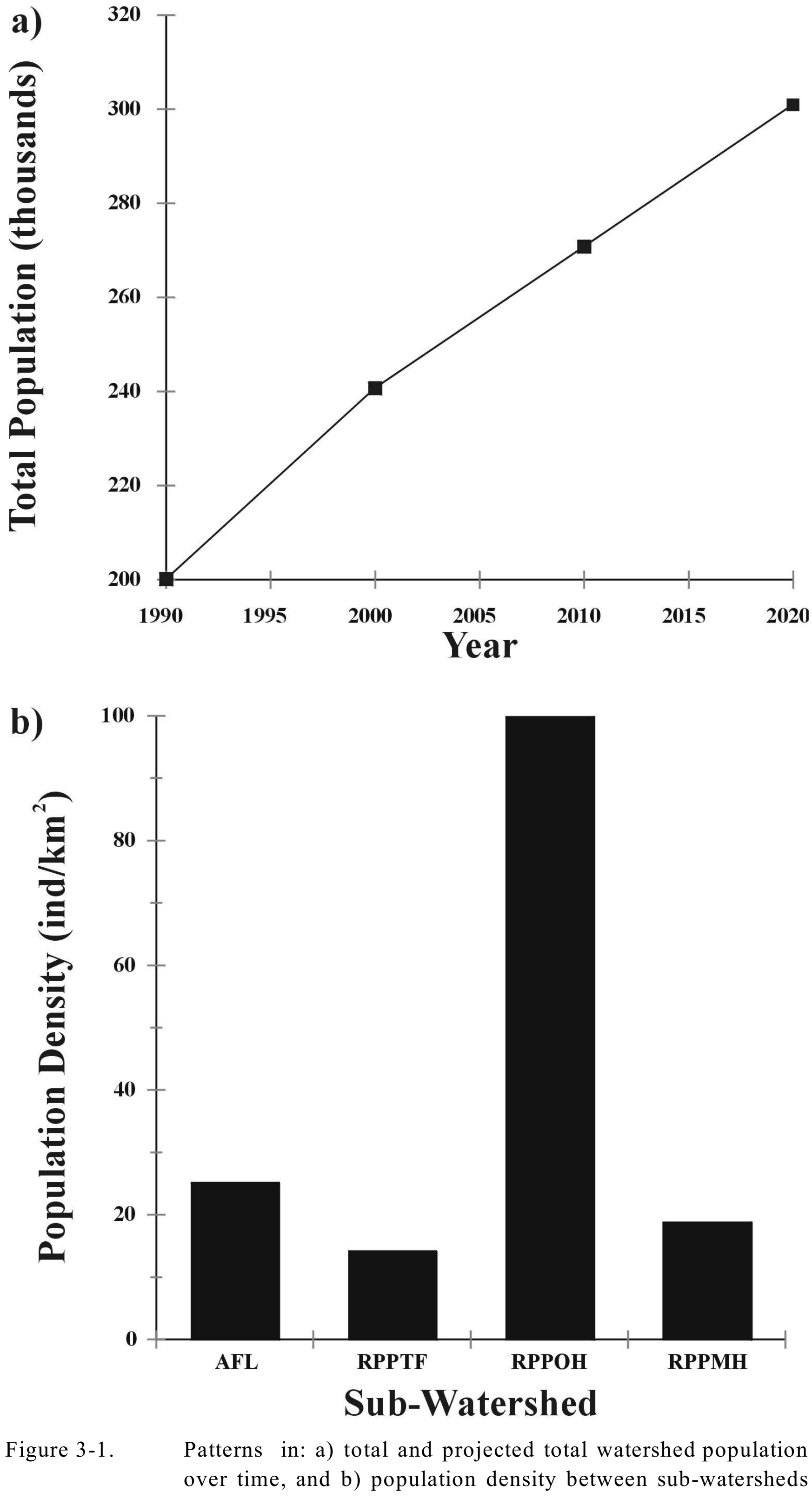


Figure 3-1. Patterns in: a) total and projected total watershed population over time, and b) population density between sub-watersheds within the Rappahannock River basin for the year 2000.

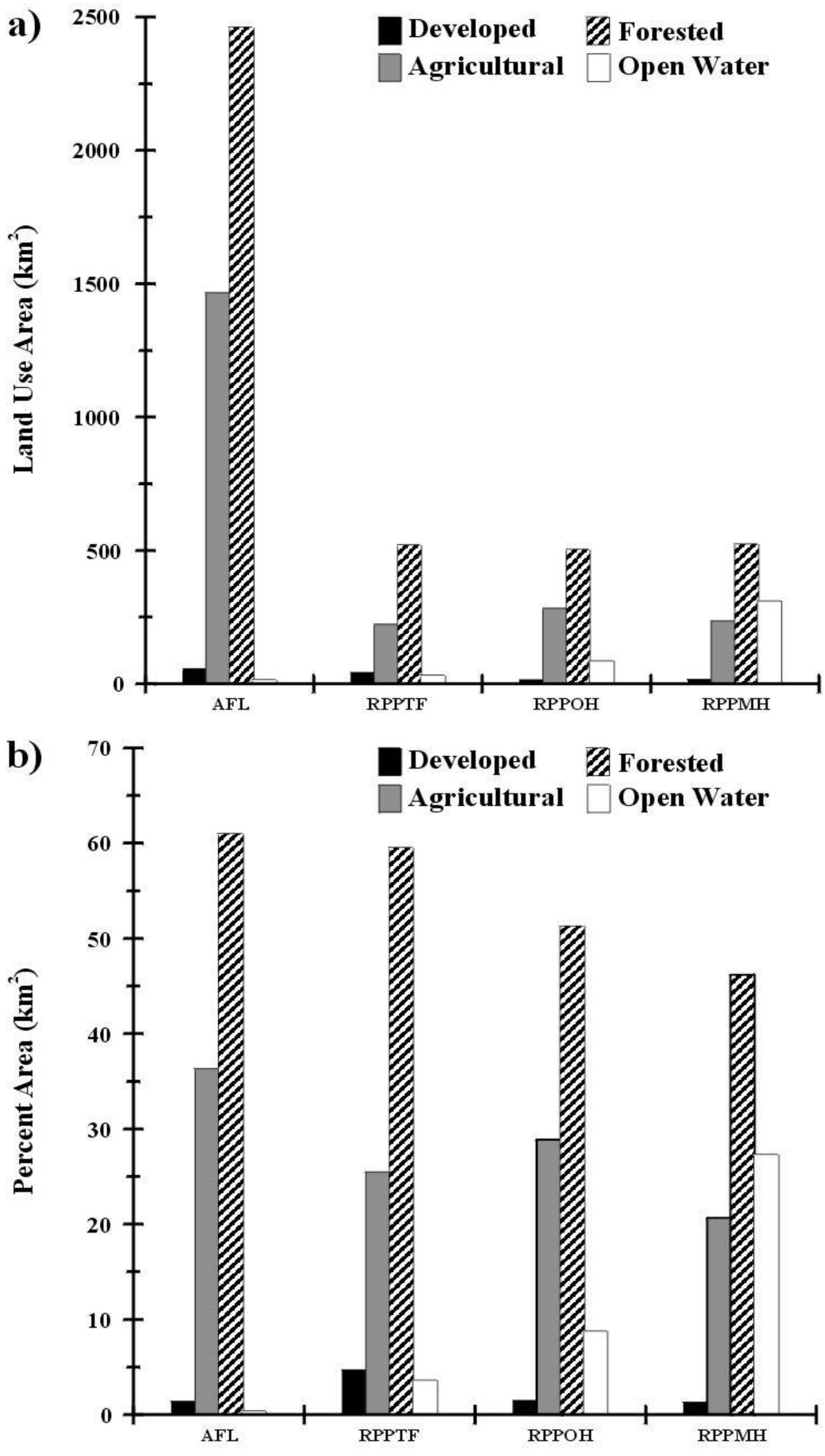


Figure 3-2. Differences in: a) total area, and b) percentages of land-use types between sub-watersheds of the Rappahannock River for 1999. Data presented were provided by the USEPA, Chesapeake Bay Program Office.

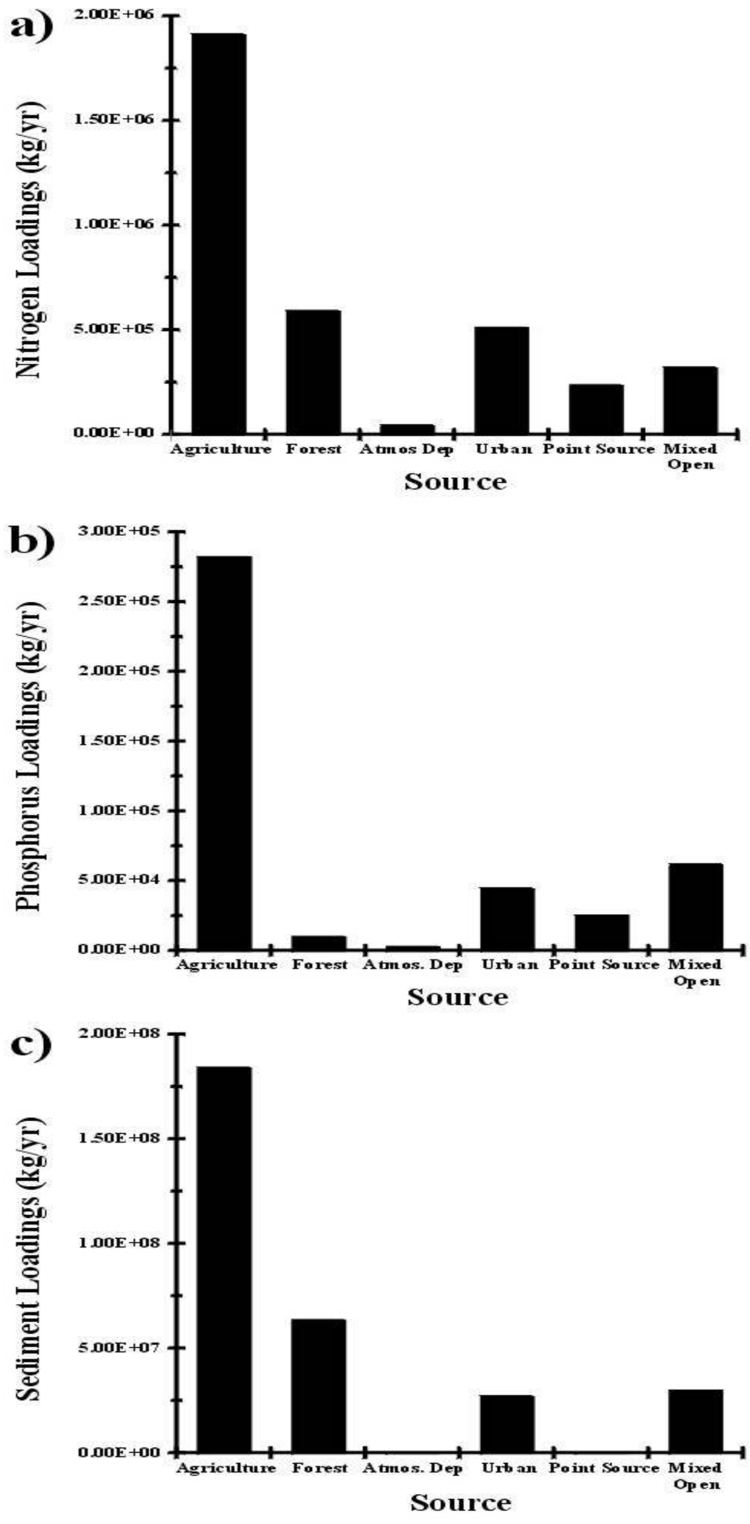


Figure 3-3. Non-point source loadings of: a) total nitrogen, b) total phosphorus, and c) sediments by source for the Rappahannock River in 2000. Data generated using the USEPA Chesapeake Bay Watershed Model.

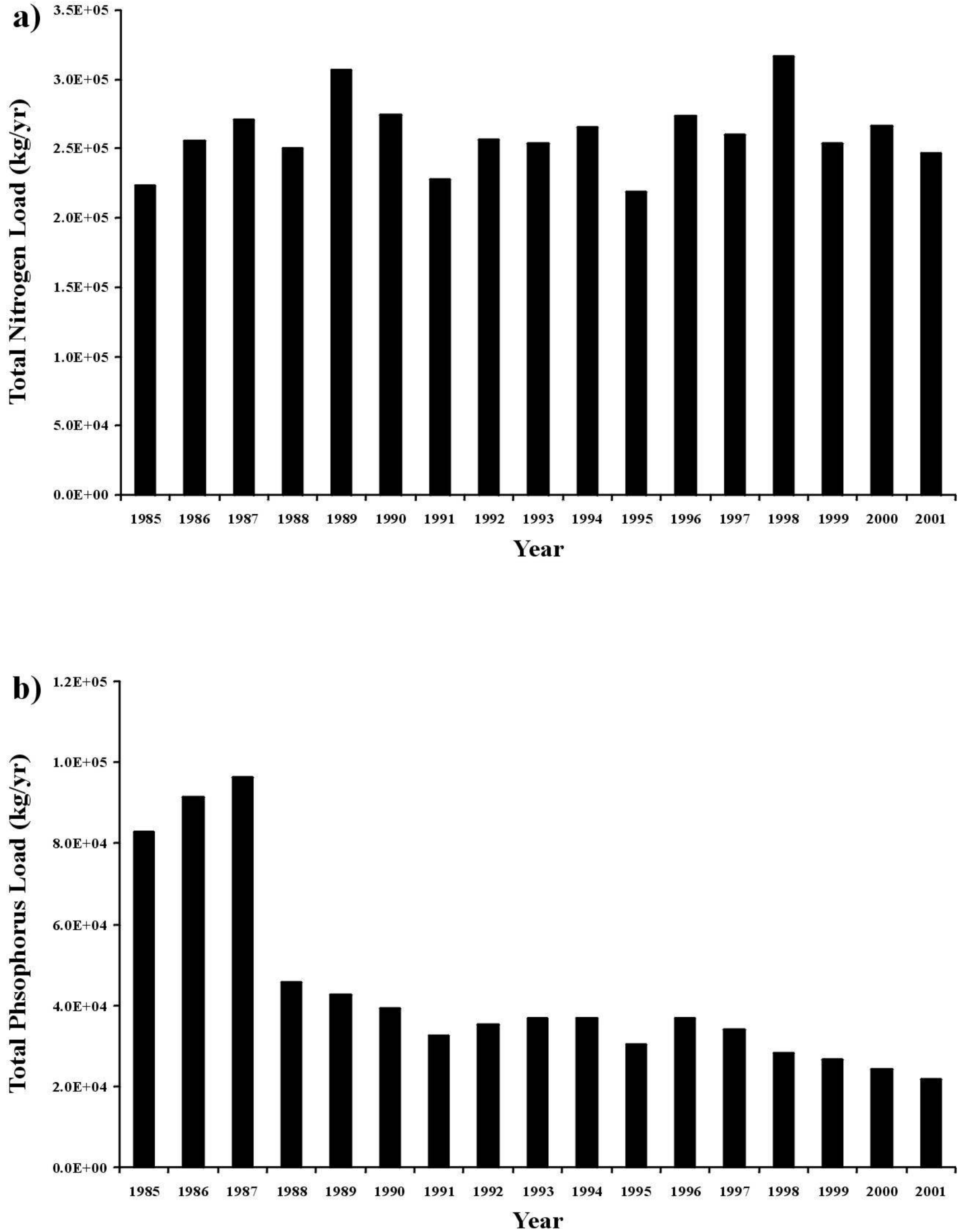
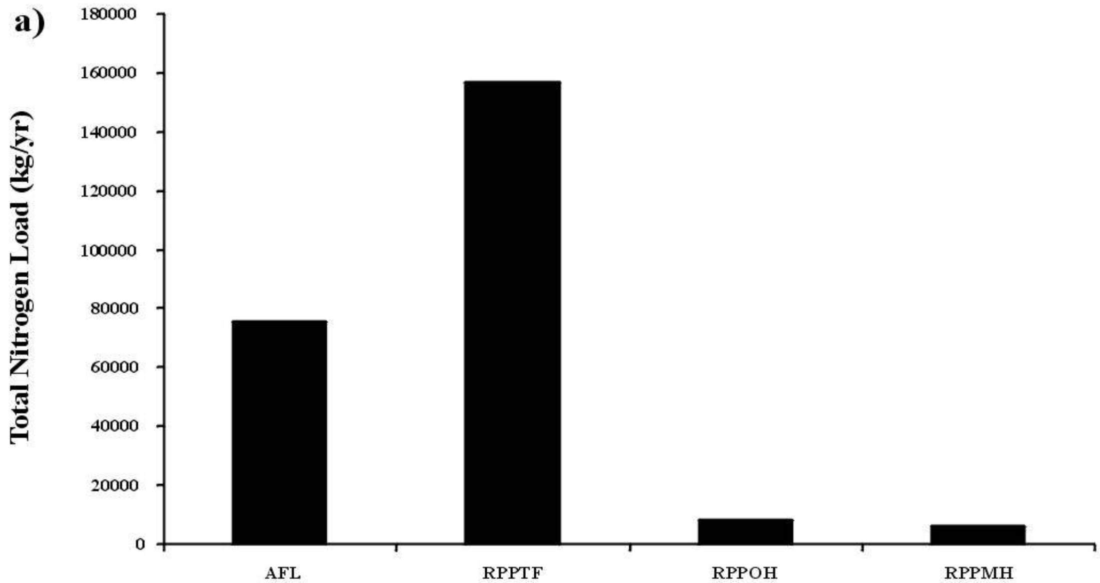


Figure 3-4. Long-term trends in point source: a) total nitrogen loadings, and b) total phosphorus loadings in the Rappahannock River for 1985 through 2001.



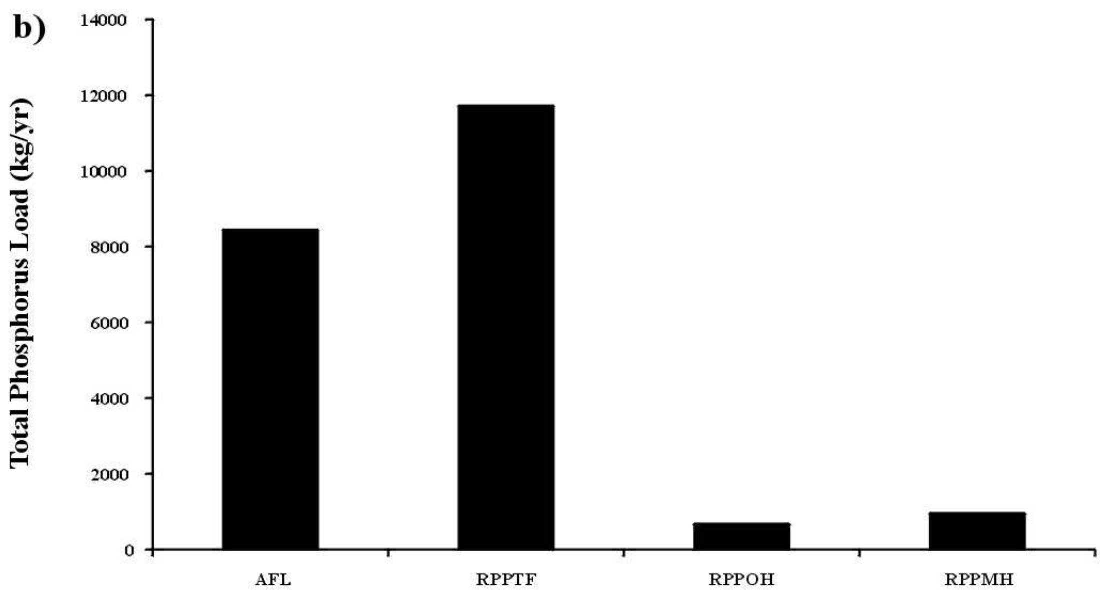


Figure 3-5. Spatial patterns in point source: a) total nitrogen, and b) total phosphorus loadings in the Rappahannock River for 2001.

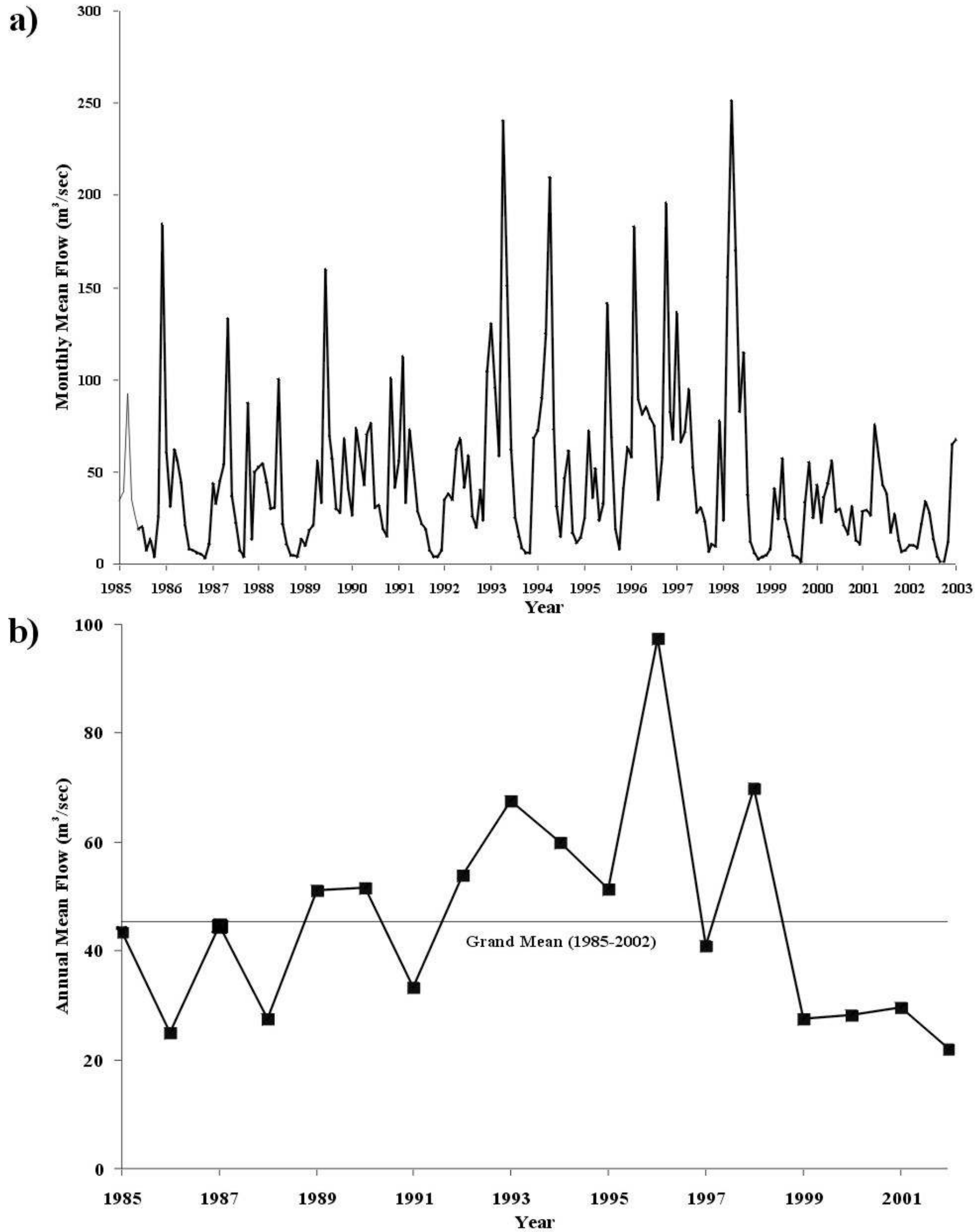
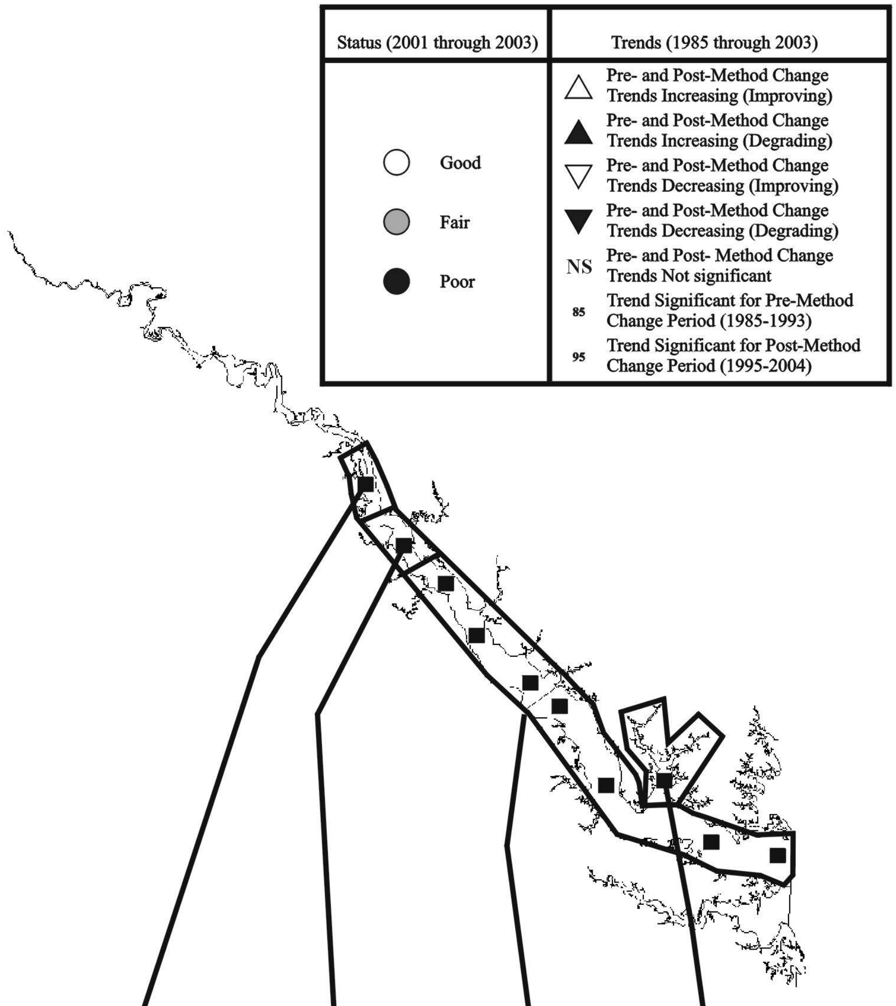
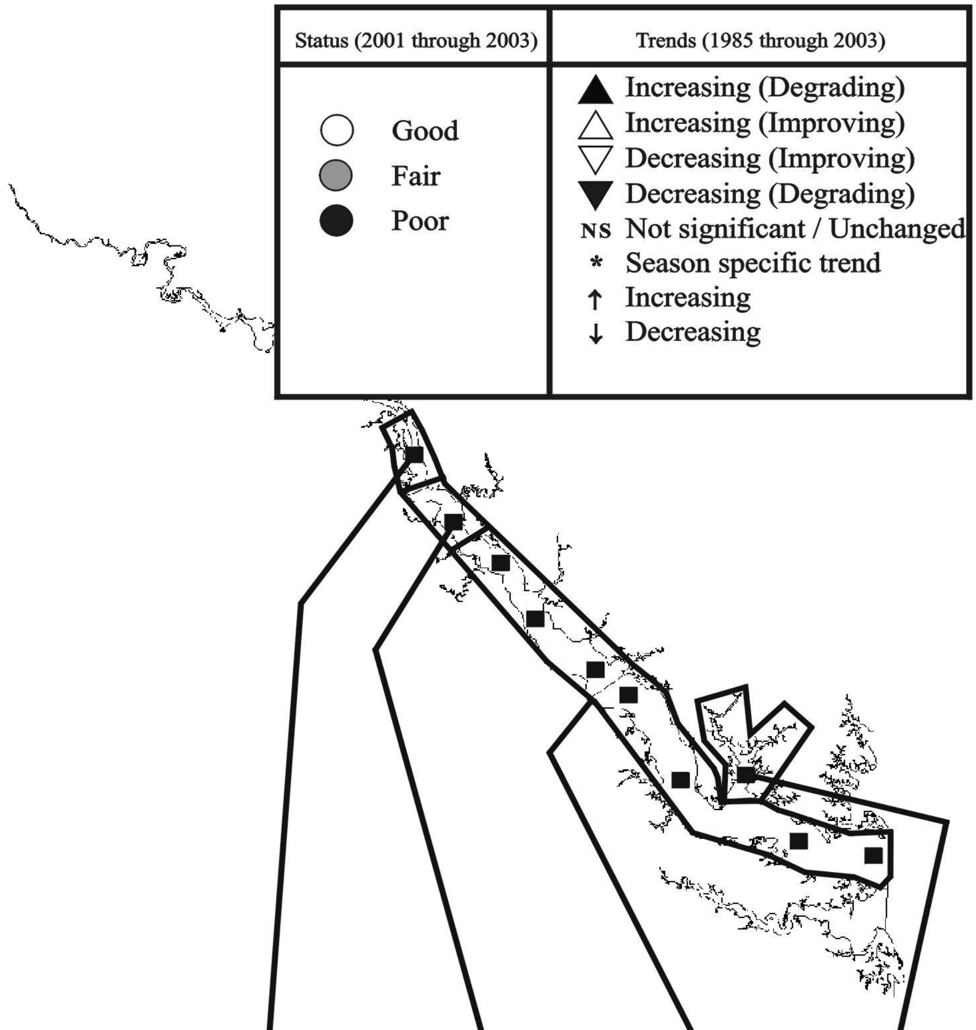


Figure 3-6. Plot of: a) monthly mean, and b) annual mean freshwater flow at the Rappahannock River fall-line for the period of 1985 through 2002.



Parameter	Upper Rappahannock (status)	Upper Rappahannock (trend)	Middle Rappahannock (status)	Middle Rappahannock (trend)	Lower Rappahannock (status)	Lower Rappahannock (trend)	Corottoman River (status)	Corottoman River (trend)
STN	○	NS	○	NS	○	NS	○	NS
BTN	○	NS	Fair (gray)	NS	○	▲85	○	NS
SDIN	Fair (gray)	NS	○	NS	○	NS	○	▽
BDIN	Fair (gray)	NS	○	NS	○	NS	○	NS
STP	○	NS	Fair (gray)	▲85	Fair (gray)	▲85	Fair (gray)	▲85
BTP	○	NS	Fair (gray)	▲85	Fair (gray)	NS	○	▲85
SDIP	○	▽95	○	NS	○	NS	○	NS
BDIP	○	▽95	○	NS	○	NS	○	NS

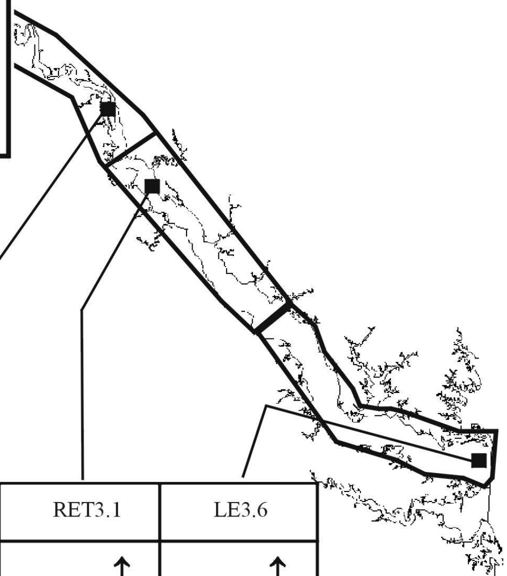
Figure 3-7. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period 1985 through 2003. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The 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		Corottoman River	
SCHLA	● (Poor)	NS	● (Poor)	▲	◍ (Fair)	NS	○ (Good)	NS
STSS	● (Poor)	NS	● (Poor)	NS	◍ (Fair)	NS	○ (Good)	NS
BTSS	● (Poor)	NS	● (Poor)	NS	◍ (Fair)	NS	○ (Good)	NS
SECCHI	● (Poor)	NS	● (Poor)	NS	● (Poor)	NS	◍ (Fair)	▼
BDO	○ (Good)	NS	○ (Good)	△	◍ (Fair)	NS	◍ (Fair)	NS
SSALIN		NS		NS		NS		↓
BSALIN		NS		NS		NS		NS
SWTEMP		NS		NS		NS		NS
BWTEMP		NS		NS		NS		NS

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 2003. 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.

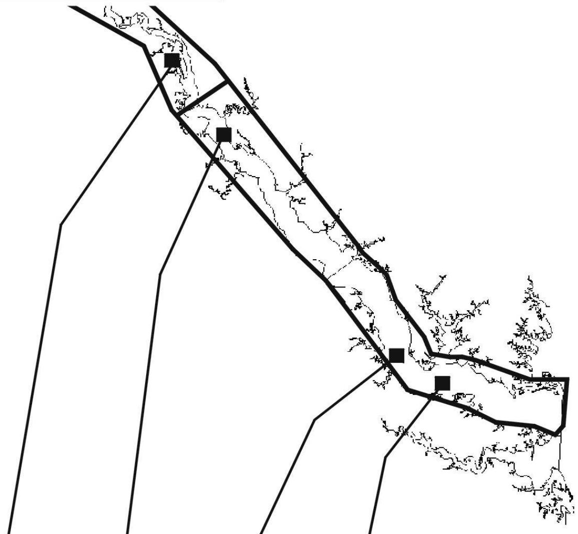
Status (2001 through 2003)	Trends (1985 through 2003)
○ Good ◍ Fair ● Poor	△ Increasing (Improving) ▲ Increasing (Degrading) ▽ Decreasing (Improving) ▼ Decreasing (Degrading) NS Not significant * Season specific trend ↓ Decreasing ↑ Increasing



	TF3.3		RET3.1		LE3.6	
Total Abundance		↑		↑		↑
Total Biomass	○	↑	◍	↑	●	↑
Biomass to Abundance	●	△	●	△	●	NS
Margalef Diversity Index	◍	NS	◍	NS	○	NS
Productivity	●	NS	◍	NS	○	▽
Diatom Biomass	○	△	○	△	○	△
Dinoflagellate Biomass	●	▲	◍	▽	●	▲
Cyanophyte Biomass	●	▲	●	▲	◍	▲
Chlorophyte Biomass	○	△	○	△	○	△
Picoplankton Biomass	●	▲	●	▲	◍	▽
Cryptophyte Biomass		△		△		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 2003.

Status (2001 through 2003)	Trends (1985 through 2003)
○ Meets Goals	▽ Increasing (Improving)
◍ Marginal	△ Decreasing (Improving)
● Degraded	▼ Increasing (Degrading)
Ⓢ Severely Degraded	▲ Decreasing (Degrading)
	NS Not significant



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

Figure 3-10. 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 2003.

Table 3-1. Trends in flow adjusted concentrations (FAC) of water quality parameters at the Rappahannock River watershed RIM stations located in Robinson Creek near Locustdale, and the Rappahannock River at Fredricksburg for the period 1985 through 2003.

Station	Data Type	Parameter	t-stat	p-value	slope	Direction
Robinson Creek near Locustdale	FAC	TN	0.1025	0.9209	0.0007	No Trend
Robinson Creek near Locustdale	FAC	TKN	3.2014	0.0126	0.0249	Degrading
Robinson Creek near Locustdale	FAC	NH4	-0.3048	0.7683	-0.0143	No Trend
Robinson Creek near Locustdale	FAC	NO23	-3.6547	0.0065	-0.0348	Improving
Robinson Creek near Locustdale	FAC	TP	-4.3174	0.0026	-0.0419	Improving
Robinson Creek near Locustdale	FAC	TSS	0.8960	0.3964	0.0133	No Trend
Rappahannock River at Fredricksburg	FAC	TN	0.1213	0.9064	-0.0004	No Trend
Rappahannock River at Fredricksburg	FAC	NO23	-0.7924	0.4510	-0.0069	No Trend
Rappahannock River at Fredricksburg	FAC	TP	-2.3400	0.0474	-0.0174	Improving
Rappahannock River at Fredricksburg	FAC	DIP	0.2339	0.8209	0.0011	No Trend
Rappahannock River at Fredricksburg	FAC	TSS	-0.5881	0.5727	-0.0077	No Trend

Table 3-2. Annual season water quality status in the Rappahannock River for the period 2001 through 2003 (values presented are median concentrations with secchi depth in meters, chlorophyll *a* in µg/l, all other parameters in mg/l).

Segment	Parameter	Surface Median	Surface Score	Surface Status	Bottom Median	Bottom Score	Bottom Status
RPPTF	TN	0.9680	37.57	Good	1.0610	32.39	Good
RPPTF	DIN	0.5385	47.65	Fair	0.5495	40.51	Fair
RPPTF	TP	0.0752	29.78	Good	0.0794	28.84	Good
RPPTF	PO4F	0.0080	26.77	Good	0.0080	29.45	Good
RPPTF	CHLA	15.46	67.36	Poor	-	-	-
RPPTF	TSS	28.50	83.73	Poor	37.88	67.32	Poor
RPPTF	SECCHI	0.40	12.80	Poor	-	-	-
RPPOH	TN	0.8273	34.20	Good	0.8565	40.40	Fair
RPPOH	DIN	0.1380	18.45	Good	0.1150	12.76	Good
RPPOH	TP	0.0737	51.73	Fair	0.0882	51.50	Fair
RPPOH	PO4F	0.0120	31.50	Good	0.0100	30.13	Good
RPPOH	CHLA	14.34	77.08	Poor	-	-	-
RPPOH	TSS	26.00	85.11	Poor	55.00	81.50	Poor
RPPOH	SECCHI	0.40	6.83	Poor	-	-	-
RPPMH	TN	0.4850	22.57	Good	0.5212	39.58	Good
RPPMH	DIN	0.0201	16.23	Good	0.0307	17.30	Good
RPPMH	TP	0.0385	52.28	Fair	0.0461	47.01	Fair
RPPMH	PO4F	0.0056	35.20	Good	0.0060	27.37	Good
RPPMH	CHLA	9.95	53.38	Fair	-	-	-
RPPMH	TSS	8.42	46.40	Fair	14.79	46.20	Fair
RPPMH	SECCHI	1.13	27.92	Poor	-	-	-
CRRMH	TN	0.4610	18.15	Good	0.5140	33.33	Good
CRRMH	DIN	0.0110	17.42	Good	0.0190	12.75	Good
CRRMH	TP	0.0304	36.20	Fair	0.0400	37.82	Good
CRRMH	PO4F	0.0050	33.18	Good	0.0050	26.75	Good
CRRMH	CHLA	6.91	35.72	Good	-	-	-
CRRMH	TSS	4.00	19.40	Good	6.25	10.16	Good
CRRMH	SECCHI	1.50	46.34	Fair	-	-	-

Table 3-3. Trends in nutrient parameters in the Rappahannock River for the Annual season for the period 1985 through 2003.

Segment	Parameter	'93 Trend P value	'93 Slope	'93 Trend Direction	'03 Trend P value	'03 Slope	'03 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
RPPTF	STN	0.3813	-0.0089	No Trend	0.0115	0.0120	No Trend	0.0155	Same	0.2572	No Trend
RPPTF	BTN	0.0187	-0.0215	No Trend	0.0372	0.0128	No Trend	0.0016	Different	0.8924	-
RPPTF	SDIN	0.1096	0.0113	No Trend	0.6884	0.0010	No Trend	0.4157	Same	0.1528	No Trend
RPPTF	BDIN	0.0489	0.0100	No Trend	0.9507	-0.0007	No Trend	0.1530	Same	0.1953	No Trend
RPPTF	STP	0.0808	0.0007	No Trend	0.3303	-0.0007	No Trend	0.0515	Same	0.5983	No Trend
RPPTF	BTP	0.3526	0.0007	No Trend	0.6493	-0.0006	No Trend	0.3154	Same	0.7494	No Trend
RPPTF	SPO4F	0.6364	0.0000	High BDLs	0.0000	-0.0008	Improving	0.0000	Different	0.0004	-
RPPTF	BPO4F	0.7403	0.0000	High BDLs	0.0000	-0.0008	Improving	0.0003	Different	0.0001	-
RPPOH	STN	0.2225	0.0133	No Trend	0.6515	0.0070	No Trend	0.5899	Same	0.2253	No Trend
RPPOH	BTN	0.0064	0.0275	Degrading	0.7436	0.0023	No Trend	0.0925	Same	0.0286	No Trend
RPPOH	SDIN	0.0211	-0.0086	No Trend	0.7753	0.0000	No Trend	0.1586	Same	0.0632	No Trend
RPPOH	BDIN	0.0046	-0.0100	Improving	0.6060	-0.0004	No Trend	0.1120	Same	0.0177	No Trend
RPPOH	STP	0.0001	0.0050	Degrading	0.1185	-0.0020	No Trend	0.0001	Different	0.0820	-
RPPOH	BTP	0.0000	0.0070	Degrading	0.1249	-0.0040	No Trend	0.0000	Different	0.0221	-
RPPOH	SPO4F	0.4892	0.0000	High BDLs	0.2289	-0.0002	No Trend	0.5138	Same	0.1571	No Trend
RPPOH	BPO4F	0.1177	0.0000	High BDLs	0.1988	-0.0003	No Trend	0.8284	Same	0.0510	No Trend
RPPMH	STN	0.0235	0.0100	No Trend	0.3206	-0.0023	No Trend	0.0205	Same	0.3906	No Trend
RPPMH	BTN	0.0009	0.0149	Degrading	0.0979	-0.0095	No Trend	0.0004	Different	0.2498	-
RPPMH	SDIN	0.0037	-0.0050	Improving	0.9759	0.0000	No Trend	0.0495	Same	0.0402	No Trend
RPPMH	BDIN	0.2307	-0.0008	No Trend	0.1756	-0.0027	No Trend	0.9144	Same	0.0676	No Trend
RPPMH	STP	0.0000	0.0020	Degrading	0.2919	-0.0005	No Trend	0.0000	Different	0.0093	-
RPPMH	BTP	0.0045	0.0015	Degrading	0.5274	-0.0006	No Trend	0.0140	Same	0.1314	No Trend
RPPMH	SPO4F	0.8505	0.0000	High BDLs	0.6906	0.0000	No Trend	0.6399	Same	0.8044	No Trend
RPPMH	BPO4F	0.1538	0.0000	High BDLs	0.7836	0.0000	No Trend	0.6696	Same	0.3370	No Trend
CRRMH	STN	0.0776	0.0121	No Trend	0.9726	-0.0001	No Trend	0.2144	Same	0.2542	No Trend
CRRMH	BTN	0.0109	0.0200	No Trend	0.1234	-0.0078	No Trend	0.0045	Different	0.6631	-
CRRMH	SDIN	0.0007	-0.0050	High BDLs	0.0976	-0.0006	No Trend	0.1308	Same	0.0002	Improving
CRRMH	BDIN	0.0496	-0.0017	High BDLs	0.2842	-0.0007	No Trend	0.5956	Same	0.0315	No Trend
CRRMH	STP	0.0000	0.0013	Degrading	0.4793	-0.0003	No Trend	0.0001	Different	0.0048	-
CRRMH	BTP	0.0000	0.0017	Degrading	0.1792	-0.0010	No Trend	0.0001	Different	0.0395	-
CRRMH	SPO4F	0.6865	0.0000	High BDLs	0.4599	0.0000	No Trend	0.3826	Same	0.6624	No Trend
CRRMH	BPO4F	0.2846	0.0000	High BDLs	0.6592	0.0000	No Trend	0.3375	Same	0.8845	No Trend

Table 3-4. Trends in non-nutrient parameters in Rappahannock River for the Annual season for the period 1985 through 2003.

Segment	Season	Layer	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
RPPTF	Annual	S	SCHLA	31.53	0.6242	0.0000	12.39	0.00	No Trend
RPPTF	Annual	S	STSS	2.12	0.1644	0.1667	24.75	10.77	No Trend
RPPTF	Annual	B	BTSS	2.47	0.8081	0.0590	36.75	2.57	No Trend
RPPTF	Annual	S	SECCHI	0.00	0.2619	0.0000	0.50	0.00	No Trend
RPPTF	Summer1	B	BDO	0.00	0.7753	-0.0053	7.38	-1.35	No Trend
RPPTF	Annual	S	SSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
RPPTF	Annual	B	BSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
RPPTF	Annual	B	BWTEMP	0.00	0.1533	0.0400	17.75	4.28	No Trend
RPPTF	Annual	S	SWTEMP	0.00	0.1883	0.0377	16.33	4.39	No Trend
RPPOH	Annual	S	SCHLA	22.52	0.0000	0.2664	5.04	0.00	Degrading
RPPOH	Annual	S	STSS	0.86	0.3034	-0.2113	31.00	-10.91	No Trend
RPPOH	Annual	B	BTSS	0.43	0.2749	0.4000	39.00	16.41	No Trend
RPPOH	Annual	S	SECCHI	0.00	0.3215	0.0000	0.40	0.00	No Trend
RPPOH	Summer1	B	BDO	0.00	0.0078	0.0500	6.25	15.20	Improving
RPPOH	Annual	S	SSALINITY	0.00	0.3310	0.0000	2.17	0.00	No Trend
RPPOH	Annual	B	BSALINITY	0.00	0.5807	0.0000	2.59	0.00	No Trend
RPPOH	Annual	B	BWTEMP	0.00	0.4392	0.0175	16.40	2.03	No Trend
RPPOH	Annual	S	SWTEMP	0.00	0.1715	0.0335	16.00	3.97	No Trend
RPPMH	Annual	S	SCHLA	12.21	0.0537	0.0742	8.33	16.92	No Trend
RPPMH	Annual	S	STSS	22.66	0.4066	-0.0500	6.75	0.00	No Trend
RPPMH	Annual	B	BTSS	9.08	0.2489	0.1250	10.75	22.09	No Trend
RPPMH	Annual	S	SECCHI	0.00	0.4285	0.0000	1.28	0.00	No Trend
RPPMH	Summer1	B	BDO	0.00	0.1668	-0.0309	5.38	-10.94	No Trend
RPPMH	Annual	S	SSALINITY	0.00	0.0126	-0.1000	15.30	-12.42	No Trend
RPPMH	Annual	B	BSALINITY	0.00	0.0996	-0.0525	17.02	-5.87	No Trend
RPPMH	Annual	B	BWTEMP	0.00	0.4546	-0.0131	16.23	-1.54	No Trend
RPPMH	Annual	S	SWTEMP	0.00	0.9758	0.0000	17.90	0.00	No Trend
CRRMH	Annual	S	SCHLA	18.99	0.6936	0.0000	7.33	0.00	No Trend
CRRMH	Annual	S	STSS	58.80	0.0000	0.0000	5.00	0.00	High BDLs
CRRMH	Annual	B	BTSS	37.44	0.0204	0.0000	13.50	0.00	High BDLs
CRRMH	Annual	S	SECCHI	0.00	0.0002	-0.0167	1.95	-16.24	Degrading
CRRMH	Summer1	B	BDO	0.00	0.0101	-0.0967	4.95	-37.10	No Trend
CRRMH	Annual	S	SSALINITY	0.00	0.0075	-0.1104	16.51	-12.71	Decreasing
CRRMH	Annual	B	BSALINITY	0.00	0.0805	-0.0700	16.84	-7.90	No Trend
CRRMH	Annual	B	BWTEMP	0.00	0.1905	-0.0265	17.83	-2.83	No Trend
CRRMH	Annual	S	SWTEMP	0.00	0.7236	0.0083	18.50	0.86	No Trend

Table 3-5. SAV season water quality status in in the Rappahannock River for the period 2001 through 2003 (values presented are median concentration with secchi depth in meters, chlorophyll *a* in µg/l, all other parameters in mg/l).

Segment	Parameter	Season	Layer	Median	Score	Status	Habitat Requirement
RPPTF	STN	SAV1	S	0.9540	37.82	Good	-
RPPTF	SDIN	SAV1	S	0.4770	48.35	Fair	-
RPPTF	STP	SAV1	S	0.0707	30.01	Good	-
RPPTF	SPO4F	SAV1	S	0.0090	29.74	Good	Pass
RPPTF	SCHLA	SAV1	S	17.63	67.61	Poor	Fail
RPPTF	STSS	SAV1	S	31.50	83.14	Poor	Fail
RPPTF	SECCHI	SAV1	S	0.40	12.08	Poor	Fail
RPPOH	STN	SAV1	S	0.8780	34.87	Good	-
RPPOH	SDIN	SAV1	S	0.1350	14.53	Good	-
RPPOH	STP	SAV1	S	0.0789	63.42	Poor	-
RPPOH	SPO4F	SAV1	S	0.0120	32.65	Good	Pass
RPPOH	SCHLA	SAV1	S	16.70	85.99	Poor	Borderline
RPPOH	STSS	SAV1	S	26.00	84.76	Poor	Fail
RPPOH	SECCHI	SAV1	S	0.40	7.18	Poor	Fail
RPPMH	STN	SAV1	S	0.4713	23.63	Good	-
RPPMH	SDIN	SAV1	S	0.0233	14.55	Good	Pass
RPPMH	STP	SAV1	S	0.0398	54.82	Fair	-
RPPMH	SPO4F	SAV1	S	0.0060	36.53	Good	Pass
RPPMH	SCHLA	SAV1	S	9.20	52.77	Fair	Pass
RPPMH	STSS	SAV1	S	9.00	46.91	Fair	Pass
RPPMH	SECCHI	SAV1	S	1.18	25.68	Poor	Borderline
CRRMH	STN	SAV1	S	0.5260	18.53	Good	-
CRRMH	SDIN	SAV1	S	0.0120	16.01	Good	Pass
CRRMH	STP	SAV1	S	0.0319	40.47	Fair	-
CRRMH	SPO4F	SAV1	S	0.0050	34.85	Good	Pass
CRRMH	SCHLA	SAV1	S	7.18	42.32	Good	Pass
CRRMH	STSS	SAV1	S	4.00	19.58	Good	Pass
CRRMH	SECCHI	SAV1	S	1.50	47.15	Fair	Pass

Table 3-6. Trends in nutrient parameters in the Rappahannock River for the SAV season for the period 1985 through 2003.

Segment	Parameter	'93 Trend P value	'93 Slope	'93 Trend Direction	'03 Trend P value	'03 Slope	'03 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
RPPTF	STN	0.4778	0.0090	No Trend	0.0247	0.0115	No Trend	0.2895	Same	0.0341	No Trend
RPPTF	SDIN	0.0126	0.0213	No Trend	0.6647	-0.0086	No Trend	0.0362	Same	0.1543	No Trend
RPPTF	STP	0.0884	0.0010	No Trend	0.1086	-0.0019	No Trend	0.0178	Same	0.9539	No Trend
RPPTF	SPO4F	0.2040	0.0000	High BDLs	0.0025	-0.0005	Improving	0.0013	Different	0.1050	-
RPPOH	STN	0.0264	0.0273	No Trend	0.6085	0.0070	No Trend	0.2405	Same	0.0504	No Trend
RPPOH	SDIN	0.2774	-0.0050	No Trend	0.8719	0.0000	No Trend	0.3621	Same	0.5310	No Trend
RPPOH	STP	0.0005	0.0050	Degrading	0.0905	-0.0022	No Trend	0.0002	Different	0.1883	-
RPPOH	SPO4F	0.8404	0.0000	High BDLs	0.9045	0.0000	No Trend	1.0000	Same	0.8099	No Trend
RPPMH	STN	0.0025	0.0175	Degrading	0.9059	0.0004	No Trend	0.0440	Same	0.0252	No Trend
RPPMH	SDIN	0.0059	-0.0048	Improving	0.3220	0.0005	No Trend	0.0083	Different	0.2508	-
RPPMH	STP	0.0001	0.0020	Degrading	0.8438	-0.0001	No Trend	0.0034	Different	0.0096	-
RPPMH	SPO4F	1.0000	0.0000	High BDLs	0.3363	0.0001	No Trend	0.3807	Same	0.3807	No Trend
CRRMH	STN	0.1932	0.0150	No Trend	0.4343	0.0052	No Trend	0.8053	Same	0.1392	No Trend
CRRMH	SDIN	0.0001	-0.0060	High BDLs	0.1895	-0.0007	No Trend	0.0397	Same	0.0001	Improving
CRRMH	STP	0.0011	0.0013	Degrading	0.8975	-0.0002	No Trend	0.0135	Same	0.0256	No Trend
CRRMH	SPO4F	0.3893	0.0000	High BDLs	0.3592	0.0000	No Trend	0.2048	Same	0.7654	No Trend

Table 3-7. Trends in non-nutrient parameters in the Rappahannock River for the SAV season for the period 1985 through 2003.

Segment	Season	Layer	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
RPPTF	SAV1	S	SCHLA	32.44	0.9784	0.0000	25.14	0.00	No Trend
RPPTF	SAV1	S	STSS	1.36	0.4847	0.1000	24.75	6.46	No Trend
RPPTF	SAV1	S	SECCHI	0.00	1.0000	0.0000	0.40	0.00	No Trend
RPPTF	SAV1	S	SSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
RPPTF	SAV1	S	SWTEMP	0.00	0.5785	0.0179	23.63	1.44	No Trend
RPPOH	SAV1	S	SCHLA	16.18	0.0000	0.5155	9.33	0.00	Degrading
RPPOH	SAV1	S	STSS	0.83	0.2082	-0.3000	29.00	-16.55	No Trend
RPPOH	SAV1	S	SECCHI	0.00	0.0338	0.0000	0.58	0.00	No Trend
RPPOH	SAV1	S	SSALINITY	0.00	0.0730	-0.0100	3.99	-4.76	No Trend
RPPOH	SAV1	S	SWTEMP	0.00	0.2836	0.0275	24.08	2.17	No Trend
RPPMH	SAV1	S	SCHLA	11.89	0.0150	0.1200	8.49	26.86	No Trend
RPPMH	SAV1	S	STSS	21.33	0.4424	-0.0588	6.75	0.00	No Trend
RPPMH	SAV1	S	SECCHI	0.00	0.2105	-0.0045	1.20	-7.20	No Trend
RPPMH	SAV1	S	SSALINITY	0.00	0.0050	-0.1342	16.06	-15.88	Decreasing
RPPMH	SAV1	S	SWTEMP	0.00	0.2959	-0.0250	23.10	-2.06	No Trend
CRRMH	SAV1	S	SCHLA	18.64	0.7354	0.0133	11.24	0.00	No Trend
CRRMH	SAV1	S	STSS	53.33	0.0005	-0.1667	8.00	0.00	High BDLs
CRRMH	SAV1	S	SECCHI	0.00	0.0001	-0.0179	1.75	-19.39	Degrading
CRRMH	SAV1	S	SSALINITY	0.00	0.0013	-0.1643	17.48	-17.86	Decreasing
CRRMH	SAV1	S	SWTEMP	0.00	0.8324	-0.0063	23.80	-0.50	No Trend

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Glossary of Important Terms

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

Anthropogenic - resulting from or generated by human activities.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Threshold - a value of a metric that determines the B-IBI scoring. For all metrics except abundance and biomass, two thresholds are used - the lower 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.