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STATUS AND TRENDS IN WATER QUALITY AND LIVING RESOURCES IN THE VIRGINIA CHESAPEAKE BAY: RAPPAHANNOCK RIVER (1985-2004)

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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.

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 four sets of appendices: water quality, phytoplankton, primary productivity, and benthos.

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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 main stem and tributaries began in 1985 and has continued for 20 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, 2002b; 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 2004. This report describes the status of water quality and living resource conditions for the Virginia main stem 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 2004. 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 main stem 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, main stem 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 20 year period (varying from 20 to 12 sampling events per year) as a result of changes in the monitoring program budget. In general, main stem sampling cruises were conducted semi-monthly from March through October and monthly from November through February until 1996. Starting in 1996 main stem 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 until 1996 after which sample were conducted monthly. 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, 2003). Field sampling procedures for DEQ water quality collections are described in detail in DEQ's Quality Assurance Project Plan for the Chesapeake Bay Program (available from DEQ). QA Project plans and methodologies are also available on the internet (http://www.chesapeakebay.net/qatidal.htm).

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, 2003). 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. If no pycnocline is present, the composite series of samples are taken from the upper third and lower third regions of depth at the station. 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). Each sample is examined with specific protocols at 3 magnifications (125X, 300X, 600X) to determine species composition and abundance. 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). In 2004 the June cruise to fixed point stations was eliminated to support a special benthic study (Dauer and Lane 2005b) and to allow additional random benthic sampling in support of the National Coastal Assessment Program. Stations were located within the main stem 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 main stem 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 25 random sites were allocated to each stratum with a new set of 25 selected for each stratum for each year. 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 main stem of the Chesapeake Bay.

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 et al. 2005a, 2005b, 2005c; Dauer and Lane 2005a).

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. 303(d) Assessment Methods

To meet the requirements of the Clean Water Act, the States of Maryland and Virginia are using benthic biological criteria for reporting overall condition and identification of impaired waters in Chesapeake Bay. The Chesapeake Bay benthic index of biotic integrity (B-IBI) is the basis for these biological criteria. Previous work conducted by Versar and Old Dominion University had two objectives: to develop a methodology for the assessment of benthic community status for 303(d) impairment decisions and to produce an assessment for each of the Chesapeake Bay segments and sub-segments containing benthic community data. A statistical procedure was developed that tests whether the distribution of B-IBI scores from probability-based samples collected from a Bay segment is significantly different from the distribution of reference site scores (Llansó et al. 2003). This procedure, a stratified Wilcoxon rank sum test, was evaluated and applied to the 2003 assessment data. The assessment resulted in 26 segments considered impaired based upon benthic community condition. The Wilcoxon approach, however, was sensitive to small shifts in B-IBI scores relative to the reference condition and did not allow estimation of the magnitude of shift. It was recommended that alternative methods be evaluated, especially those that take into account magnitude of departure from reference conditions and whether this magnitude is above specific thresholds of protection that the States may wish to implement. For the 2006 303(d) report, a new method that quantifies magnitude of degradation (Llansó et al. 2005).

In addition, a benthic diagnostic tool has been developed that can be used to identify potential sources of stress affecting benthic community condition in the Chesapeake Bay (Dauer et al. 2002a, 2005d). The tool can distinguish stress due to contaminants versus stress due to other factors (e.g., low dissolved oxygen, or unknown). This screening tool was used to identify which impaired segments have a high probability of sediment contamination. These segments could then be targeted for additional sampling or evaluation. The B-IBI metric scores for abundance and biomass were also used to identify (1) insufficient abundance patterns consistent with a low dissolved oxygen effect and (2) excessive abundance patterns consistent with eutrophication effects.

D. Laboratory Sample Processing

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

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

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 main stem and tributary stations from the January 2001 through December of 2004 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, 2004. 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.

The terms good, fair, and poor used in conjunction with water quality relative status are statistically determined classifications for comparison between 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 which have led to large areas of hypoxia as well as reductions in submerged aquatic vegetation and other effects on living resources. Given this, an absolute evaluation in relation to ideal conditions would indicate that most water quality parameters are currently poor throughout the whole Bay system. The Monitoring Subcommittee of the Federal-Interstate Chesapeake Bay Program continues to develop additional methodologies for absolute water quality status evaluations, which in the future will be used in conjunction with, or possibly in replacement of, the current methods.

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 (2002 through 2004) 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:

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

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

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

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:

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

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 for some parameters at some stations. 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 2004) 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 20 year period of 1985-2004. 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.

C. 303(d) Assessment Methods

The assessment data for the 2006 303(d) report consisted of random samples collected from 2000 to 2004 throughout the Chesapeake Bay. A total of 1,430 samples (single replicates) were used, including 750 samples collected by the Maryland Chesapeake Bay benthic monitoring program, 500 samples collected by the Virginia Chesapeake Bay benthic monitoring program, 150 samples collected by the Elizabeth River benthic biological monitoring program, and 10 samples collected for a gear comparison study in each of Mobjack Bay, the tidal fresh Mattaponi River, and the Nansemond River. All assessment samples were collected with a Young grab (440 cm^2 surface area, 0.5-mm screen).

Assessments were produced for each of 85 Chesapeake Bay Program segments and sub-segments containing benthic data. Segments (TMAW, 1999) are Chesapeake Bay regions having similar salinity and hydrographic characteristics. In Virginia, segments were sub-divided into smaller units by the Virginia Department of Environmental Quality. Sub-segments were produced for each of the main stems of rivers and bays (e.g., James River mesohaline) and for some of the smaller systems opening into the main stem (e.g., Pagan River). Assessment samples were assigned to segments and sub-segments using GIS software. Existing hydrographic data for each sample were used to assign each sample to one of seven habitat classes used in the calculation of the B-IBI. These are the same habitat classes used in the reference data set.

1. Bootstrap Method

The Bootstrap Method developed for the 2006 assessment was based on the confidence limit and bootstrap simulation concepts described in Alden et al. (2002). Specifically, bootstrap simulation (Efron and Tibshirani, 1998) was applied to incorporate uncertainty in reference conditions. Simulations were used because the reference data (by habitat) are based on a small number of samples and the B-IBI score corresponding to a particular percentile in the distribution is likely to vary if a different set of reference sites were sampled. Reference data are assumed to be representative sample from a "super population" of reference sites.

For each habitat, a threshold based on the 5th percentile B-IBI score of the reference data set for the good sites (or the maximum B-IBI score observed for the degraded sites, see below), was determined. This threshold was not intended to serve as a criterion for classifying individual B-IBI scores, rather it was used to categorize the segment as impaired or not based on the proportion of sites below the threshold and the variance associated with this estimate. The variance in the estimates of proportions for each segment was estimated by the simulations.

The B-IBI scores for the reference good and degraded sites had degrees of overlap that ranged from quite high in the tidal freshwater and oligohaline habitats to moderately low in the mesohaline and polyhaline habitats. An assessment sample is more likely to come from an impaired benthic community if the B-IBI score for this sample is within the range of scores observed for sites known to be degraded. Therefore, two criteria were established for determining the threshold: its score had to be within the lower bound of the good reference distribution (i.e., 5th percentile), and it had to be within the upper range of observed scores for known degraded sites (i.e., the reference degraded sites). If the 5th percentile score for a simulation run was not within the range of scores for the reference degraded sites, then the maximum B-IBI score for the reference degraded sites was selected as the threshold. Thus, in this study, sites with low B-IBI scores below thresholds were unlikely to have good sediment quality and were likely to be impaired.

In each simulation run, a subset of the reference good sites for each habitat was selected at random, and the B-IBI threshold for this subset was determined (i.e., the B-IBI score at the 5th percentile, or the maximum score for the reference degraded samples). The assessment B-IBI data for each habitat was then compared to the threshold to estimate the proportion of sites below the threshold. By repeating this process over and over again (5,000 runs) we were able to estimate the variance in the proportion of sites below the threshold from the bootstrap estimates. This variance reflects variability in the thresholds as well as sampling variability.

In the final step of the method, segments were declared impaired if the proportion of sites below the threshold was significantly higher than expected under the null hypothesis. Under the null hypothesis, a small number of sites (defined as 5% of the sites) would be expected to have low IBI scores even if all sites in a segment were in good condition (i.e., no low dissolved oxygen, contaminant, or nutrient enrichment problems). This is because of natural variability in the benthic communities, the effects of natural stressors, and sampling and methodological error. For a segment to be declared as impaired, the lower bound of the 95% confidence interval of the estimate had to higher than 5% (the expected proportion under the null hypothesis), with a minimum sample size of 10.

2. Wilcoxon Test

A stratified Wilcoxon rank sum test was applied as described in Llansó et al. (2003) using Proc-StatXact 5 software (ytel Software Corporation 2002). B-IBI scores were grouped into three ordered condition categories (1.0-2.0, 2.1-2.9, 3.0-5.0) and the distribution of scores within a segment was compared for each habitat to the distribution of scores for the reference condition. Under the null hypothesis (H_o) of no impairment, the two populations (segment and reference) were considered to have the same underlying multinomial distributions of samples among the ordered categories. The assessment of impairment was based on a one-sided exact test of H_o against the alternative hypothesis that the segment had a distribution shifted towards lower B-IBI scores than for the reference condition. The ranking was done separately by habitat, and then combined across habitats. Segments with a minimum of 10 samples for which the test was significant at the 1% alpha level and 90% power, were considered impaired under this method.

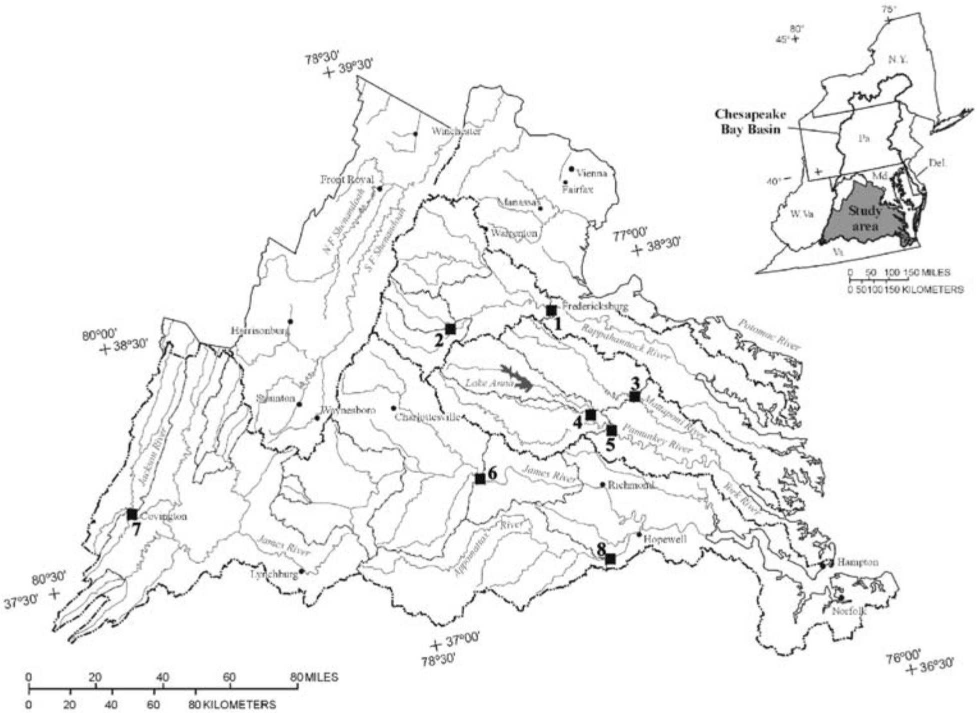
3. Benthic Diagnostic Tool

The benthic diagnostic tool allows environmental managers to identify potential sources of anthropogenic stress to benthic communities within Chesapeake Bay. The development and application of the tool was described in detail in Dauer et al. (2002a, 2005). The benthic diagnostic tool is based on a linear discriminant function that classifies sites in Chesapeake Bay identified as having degraded benthic communities into categories distinguished by the type of stress experienced by those communities. Presently, the function is capable of discriminating contaminated sites from sites affected by all other potential sources of stress in any of the seven benthic habitat types of Chesapeake Bay. The function was developed using a variety of metrics of benthic community structure, diversity, and function.

For this assessment, sites with B-IBI scores < 2.7 were defined as “degraded” for benthic diagnostic tool application purposes. This cutoff value may differ from the threshold used by the bootstrap method to determine proportion of sites with degraded benthic communities, but it should be very close to that threshold. Because cutoff values differ, diagnostic tool percentages should only be used as a general guide for identifying potential causes of degradation. For each “degraded” site, benthic metric values were submitted to the function and posterior probabilities of group membership calculated. Posterior probabilities for impaired segments were then used to identify the most likely source of stress affecting benthic communities in these segments.

4. Insufficient and Excess Abundance/Biomass Criteria

Insufficient and excess abundance or biomass was determined from the abundance and biomass metrics scores. In the B-IBI, a score of 1 is assigned to total species abundance and total biomass if the value of these metrics for the site being evaluated is below the 5th percentile or Below the 95th percentile of corresponding reference values. A score of 1 is assigned for both insufficient and excess abundance or biomass because abundance and biomass of organisms respond bimodally to pollution. An increase in abundance or biomass is expected at polluted sites when stress from pollution is moderate, such as at sites where there is organic enrichment of the sediment. Excess abundance and excess biomass are phenomena usually associated with eutrophic conditions. A decrease in abundance and biomass is expected at sites with high degrees of stress from pollution; for example, sites affected by low dissolved oxygen or toxic contamination. The insufficient and excess abundance or biomass criteria can then be used to determine the likelihood of contaminant or low dissolved oxygen problems versus eutrophic conditions for each of the Chesapeake Bay segments evaluated.



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.

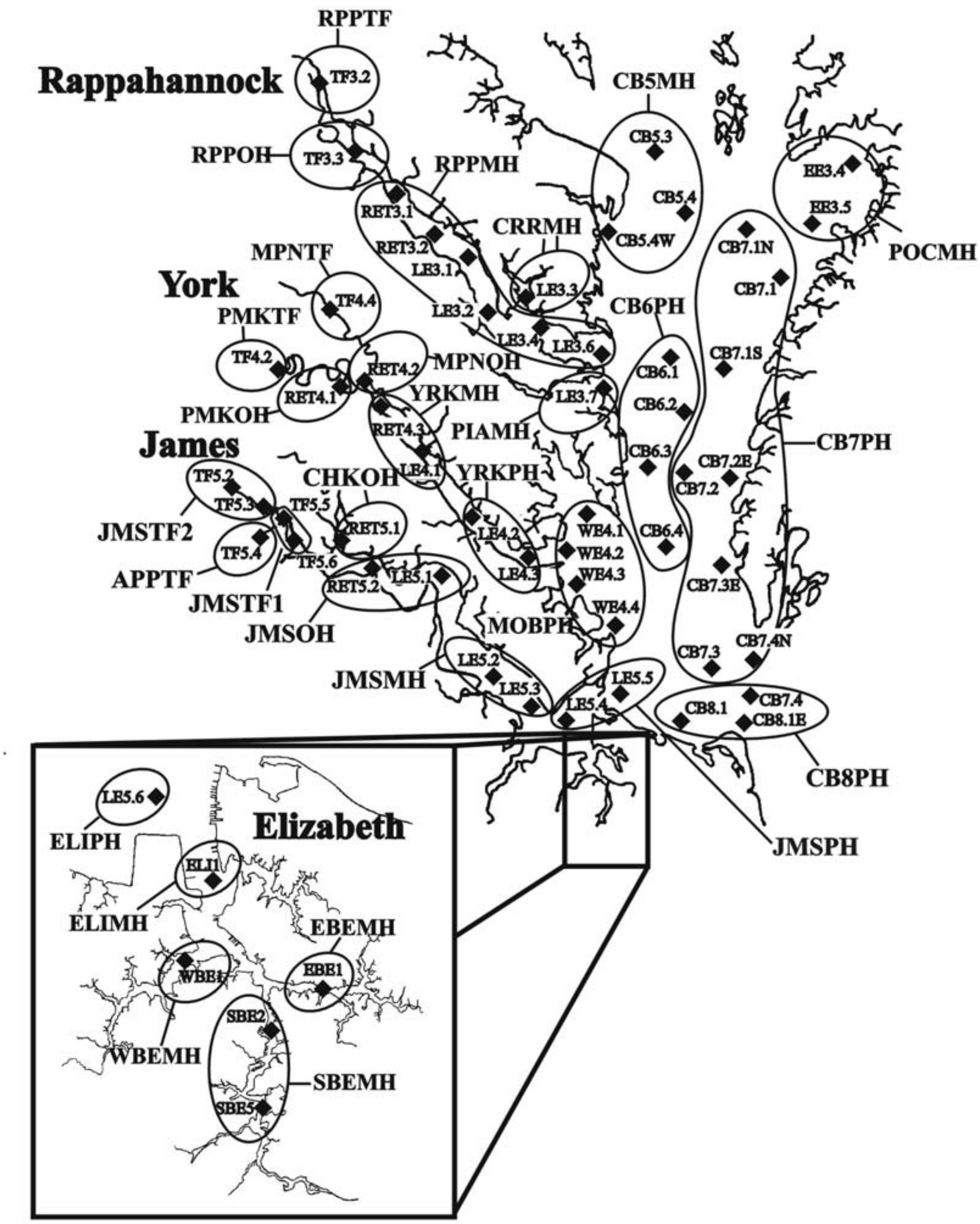


Figure 2-2. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay main stem used in the statistical analyses. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

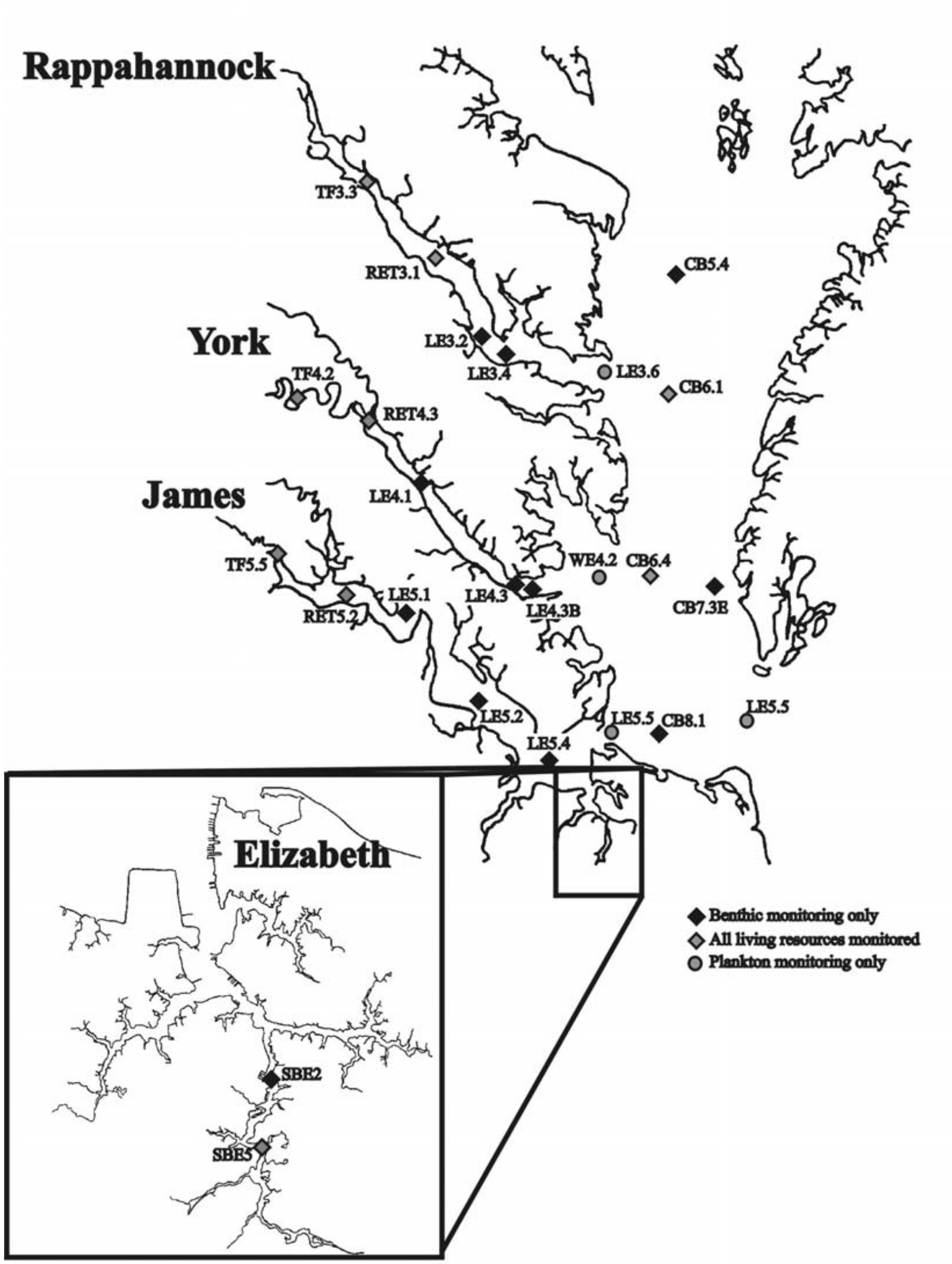


Figure 2-3. Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay main stem.

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. Basin Characteristics

- The Rappahannock River is predominantly rural with lowest overall population density and percentage of developed land of all three Virginia tributaries coupled with high percentages of agricultural and forest land use types. It has the second highest area of agricultural cropland of all three of the Virginia tributaries.

- Sub-watershed specific percentages of agricultural land were generally near or greater than 20% and decreased moving downstream from above the fall-line while percentages of forest land were above 40% and also decreased moving downstream. The percentage of shoreline with a riparian buffer was 35.6% overall in the basin and decreased moving downstream from the Upper Tidal portion of the river.

- Non-point sources accounted for nearly 57% of the 3,387,000 kg/yr of nitrogen loads and almost 70% of the 411,000 kg/yr of phosphorus loads entering the Rappahannock River in 2004. Overall BMPs have resulted in over 20% reductions in both nitrogen and phosphorus non-point sources loads and a 67% reduction in phosphorus loads to the Rappahannock from 1985 to 2004 but point source loads of total nitrogen increased slightly (2%) during the same period.

- Point source loadings of nitrogen were generally higher below the fall-line than above. AFL point source loadings of nitrogen typically ranged between 160,000 kg/yr to 200,000 kg/yr and peaked at 312,000 kg/yr and 283,000 kg/yr in 1996 and 2003, respectively. BFL point source loadings of nitrogen increased initially from 330,000 kg/yr in 1985 to 470,000 kg/yr in 1989, declined to levels near or below 300,000 during the next eight years, peaked at 491,000 kg/yr in 1998 and generally declined during the next six years.

- Annual BFL point source loadings of phosphorus were typically higher than AFL values for the period of 1985 through 1995 but have become comparable during the last eight years following substantial and generally steady declines in both regions that began in 1989 following the phosphate ban.

- No significant trends in freshwater flow at the Rappahannock River fall-line were detected but peaks in monthly mean flow have risen above 100 m^3/sec and annual mean flow was higher than the grand mean during the last two years.

B. Water Quality

- Improving trends in flow adjusted concentrations of total nitrogen and total phosphorus were detected in both the Rappannock River and the Robinson River above the fall-line. Improving trends in nitrate-nitrites and dissolved inorganic phosphorus were also detected in the Rappahannock River above the fall line.

- Relative status of nutrients was good in nearly all segments in the Rappahannock River and fair in all others.

- SAV habitat requirements for nutrients were met in all applicable segments.

- Degrading long-term trends were detected in bottom total nitrogen and surface dissolved inorganic nitrogen in the middle river (RPPMH) and the upper river (RPPTF), respectively while an improving trend in bottom dissolved inorganic phosphorus was detected in the upper river (RPPTF). A degrading and improving post-1994 trends were detected in surface total nitrogen and dissolved inorganic phosphorus, respectively, in the upper river (RPPTF).

- During the SAV growing season, a degrading long-trend in surface total nitrogen was detected in the middle river (RPPOH) while an improving trend in surface dissolved inorganic nitrogen was detected in the Corottoman River (CRRMH).

- Relative status of most non-nutrient parameters was fair or good with the exception of surface and bottom total suspended solids and secchi depth at station TF3.3 in the middle river (RPPOH) to station LE3.6 in the lower river (RPPMH) where it was primarily poor.

- SAV habitat requirements for chlorophyll *a* , total suspended solids and secchi depth were not met or borderline in the upper and middle river (RPPTF and RPPOH) but were typically met at the downstream segments.

- During the SAV growing season, degrading trends in chlorophyll *a* were detected in the middle and lower river (RPPOH anad RPPMH) and for Secchi depth in the Corottoman River (CRRMH). An improving trend in total suspended solids was also detected in the Corottoman River (CRRMH).

C. Living Resources

- Although the status of diatom, chlorophyte and cryptophyte biomass was good and status of the biomass to abundance ratio was poor throughout the Rappahannock River, status of most parameters appears to improve moving downstream from station TF3.3 in the middle river (RPPOH) in the lower river (RPPMH).

- Most improving trends in phytoplankton parameters occurred at stations TF3.3 (segment RPPOH) and RET3.1 (segment RPPMH). Degrading trends were detected in cyanophyte biomass and abundance throughout the Rappahannock River.

- Benthic community status met the restoration goals only at station TF3.3 in the middle river (RPPOH) and in general became more degraded moving downstream.

- A degrading trend in the B-IBI was detected at station RET3.1 in the middle river (RPPMH).

- Probability-based benthic monitoring results indicated that 7% and 37% of samples collected were classified as impaired in the upper river (RPPTF) and the lower river (RPPMH) while all other segments in the river had insufficient sample size to conduct an assessment.

- Benthic degradation in the upper river (RPPTF) appears to be the result of anthropogenic contamination while degradation in the lower river may be the result of a combination of contamination and low dissolved oxygen effects.

D. Management Issues

- Water quality problems appear to be more severe in the upper segments of the Rappahannock River and include poor status and violations of SAV habitat criteria for both suspended solids and secchi depth along with increasing trends in either total or dissolved nitrogen concentrations.

- Issues with phytoplankton communities include poor status and degrading trends in cyanobacteria abundance and biomass throughout the basin, as well as, poor status and degrading trends in dinoflagellate abundance in the lower river.

- Status of benthic communities for fixed point monitoring stations was degraded at stations in the Lower Rappahannock River probably as a result of low dissolved oxygen. Degrading trends were detected in B-IBI and or its component metrics in segment RPPOH and uppermost station of segment RPPMH.

- Probability-based monitoring results indicated that the upper river (RPPTF) was classified as unimpaired while the lower river (RPPMH) was classified as impaired. Predominant sources of stress to the benthos in this river potentially included both contaminants and low dissolved oxygen.

II. Overview of Monitoring Results

A. Basin Characteristics

1. General

The Rappahannock River is the first major drainage basin south of the Potomac River. It is the largest free-flowing river in the Chesapeake Bay watershed and the entire portion of the river above the fall-line is classified as a State Scenic River. The Rappahannock River begins in the Blue Ridge physiographic region and extends for 296 km through the Piedmont and Coastal Plain physiographic regions becoming an estuary below the fall line at Fredericksburg and eventually entering into Chesapeake Bay approximately 35 km south of the Potomac River. Major tributaries to the Rappahannock River include the Rapidan River, Robinson River, and Corrotoman River. It is the smallest of the three major watersheds exclusive to Virginia with a total watershed area of 7,029 km^2 that accounts for seven percent of the area of the state of Virginia and 4% of the entire Chesapeake Bay watershed (Table 3-1A).

Below the fall-line fluvial terraces surrounding the river basin are characterized by an overlying 0.5 to 1.5 m cap of sandy to clayey silt while the underlying fluvial sediments from Fredericksburg to Port Royal are primarily sand and fine gravel that grade into estuarine sands moving downstream (Colman, 1983). Above the fall-line, the river is typically clear, swift, and dominant substrates are bedrock, boulder and cobble while below the fall-line the river flow slows down becoming more turbid and the substrate is dominated by sand and silt (Odenkirk, 2004).

Predominant industries in the basin are agriculture, diary farming, lumber and chemical production. Commercial fisheries are also important in the basin. The tidal portion of the Rappahannock River is a significant nursery and spawning area for anadromous fish including the alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) (O'Connell and Angermeier, 1997), and the striped bass (*Morone saxatilis*) (Olney et al., 1991). The non-tidal portion of the Rappahannock is an important recreational fishery, particularly for smallmouth bass (Odenkirk, 2004). Historically, the Rappahannock River had the most productive oyster (*Crassotrea virginica*) grounds of all the tributaries of Chesapeake Bay (Whitcomb and Haven, 1989).

2. Land Use and Human Populations

Although the Rappahannock River basin has the smallest population density, the smallest area (>150 km^2) and percentages of developed land and the smallest percentage of area with an impervious surface of all three Virginia tributaries, it has both the second highest total area and the largest percentage of agricultural land (31.4%) (3-1A). Approximately 4,200 km^2 or nearly 57% of the watershed consists of primarily deciduous or mixed deciduous forests making it the basin with both the smallest total area and percentage of total watershed area of all the Virginia's tributaries for this land use type (Table 3-1A). The Rappahannock River has the lowest percentage of wetlands and the lowest percentage of shoreline with a riparian buffer of all the Virginia tributaries (Table 3-1A). Percentages of the total area in developed land was less than 5% in all of the sub-watersheds of the

Rappahannock River and the percentages of impervious surfaces within sub-watersheds was typically less than 3% (Table 3-1B). With the exception of the Rappahannock River mouth sub-watershed, percentages of total area designated as agricultural land were higher than 20% in all of the Rappahannock River sub-watersheds although the total area of agricultural land decreases moving downstream. In general, the total area of forest land and the percentage of the total area in forest land in a given sub-watershed decreases steadily moving downstream from above the fall-line to the mouth of the Rappahannock River (portions of segment RPPMH) sub-watershed (Table 3-1B).

Approximately 3,670 km of the 10,320 km (35.6%) of shoreline within the watershed have a 30 m minimum riparian forest buffer (Table 3-1A). The percentage of shoreline with a riparian buffer was highest in the Upper Tidal Rappahannock and generally decreased moving downstream to a miniumum of 32.0% at the mouth of the Rapphannock (Table 3-1B). Percentage of shoreline with a riparian buffer was also low (32.2%) above the fall-line relative to other sub-watersheds in the basin, probably as a result of the high percentage of agricultural land use in this region.

The human population in the Rappahannock River was approximately 241,000 in 2000. U.S. Census estimates project populations to increase to over 300,000 individuals by 2010. Of the three major tributaries exclusively in Virginia, the watershed of the Rappahannock River has both the lowest total population and the lowest population density (Table 3-1A). Most of this population is distributed in rural areas located above the fall-line and within the tidal freshwater portion of the watershed (Table 3-1B). The largest population center in the basin is Fredericksburg and other cities the watershed include Culpeper, Falmouth, Orange and Tappahannock.

3. Nutrient and Sediment Loadings

Based on estimates provided by the Virginia DEQ, total point and non-point source loadings of nitrogen to the Rappahannock River are approximately 3,387,000 kg/yr with non-point loadings accounting for nearly 57% of the total nitrogen loads to this watershed. Application of best management practices (BMPs) are estimated to have resulted in a 25% reduction of non-point source loadings of total nitrogen to the watershed from 1985 to 2004 while point source loadings have increased approximately 2% during the same period (Table 3-2). Total point and non-point source loadings of phosphorus were approximately 411,000 kg/yr in 2004 with non-point source loadings accounting for almost 70% of the total load. From 1985 through 2004, BMPs reduced non-point source loads by an estimated 22% while point source loads dropped by 67%, probably as a result of the phosphate ban (Table 3-2). Approximately 291,000 metric tons/yr enter the Rappahannock River due to non-point source runoff. Application of BMPs resulted in a 23% reduction in sediments from 1985 to 2004 (Table 3-2).

Annual point source loadings of nitrogen were higher below the fall-line (BFL) than above the fall-line (AFL) from 1985 through 2003 except during 1996. Annual AFL point source loadings of total nitrogen were typically ranged between 160,000 to 200,000 kg/yr during most years from1985 through 2003 and reached peak levels of approximately 312,000 kg/yr and 283,000 kg/yr in 1996 and 2003, respectively. Annual BFL loadings of total nitrogen steadily increased from approximately 330,000 kg/yr in 1985 to nearly 470,000 in 1989 and then declined to levels near or below 300,000 kg/yr during the next eight years. Annual BFL total nitrogen loads peaked at nearly 491,000 kg/yr in 1996 but then declined again to levels between 338,000 kg/yr and 413,000 kg/yr during the period from 1997 through 2003 (Figure 3-1A).

Annual AFL point source loadings of phosphorus were typically higher than BFL values for the period of 1985 through 1995 but since then have been at comparable levels ranging between 20,000 kg/yr to 40,000 kg/yr. Annual point sources loadings both above and below the fall-line dropped substantially beginning in 1988 from levels of approximately 66,300 kg/yr to less than 40,000 in 1991 above the fall-line and from 143,000 kg/yr to less than less than 60,000 kg/yr below the fall-line. Annual AFL point source loadings experienced a slight and relatively steady increase for the period from 1991 through 1995 but generally declined thereafter reaching a minimum of over 18,600 kg/yr in 2001 but increased during the next two years reaching over 36,000 kg/yr in 2003. (Figure 3-1B).

4. Freshwater Flow

Daily freshwater flow at the fall-line ranged from a minimum of 0.23 m^3/sec to a maximum of 1,546 m^3/sec for the period of January 1, 1985 through December 31, 2004. There was no significant trends in freshwater flow at the Rappahannock River fall-line. Annual peaks in monthly mean flow were typically near or above 100 m^3/sec from 1985 through 1998. From 1999 through 2002 peaks in monthly mean flow dropped to at or below 80 m^3/sec but have risen again to above 100 m^3/sec during the last two years (Figure 3-2A). Grand mean flow at the fall-line was 49.76 m^3/sec. Annual mean flows in the Rappahannock River were highly variable with values typically near or below the grand mean from 1985 through 1992 and at or above the grand mean from 1993 through 1996. In 1999, annual mean flow fell to approximately 27m^3/sec and remained consistently below 30 m^3/sec for the next three years. Annual mean flow peaked in 2003 at over twice the grand mean value but declined again to just under 10 m^3/sec higher than the grand mean in 2004 (Figure 3-2B). Subtidal currents at the mouth of the Rappahannock River show continuous inflow near the river bottom which in combination with reductions in surface flows downstream from the fall-line result in vertical mixing characteristic of a partially mixed estuary (Kuo et al., 1991). Salt water intrusion into the Rappahannock River ranges from approximately 120 km to 70 km upstream from the mouth during periods of high and low flow, respectively (Kuo et al., 1996).

B. Water Quality

1. Non-tidal

Improving trends in flow adjusted concentrations in total nitrogen, nitrate-nitrites, total phosphorus, and dissolved inorganic phosphorus were detected above the fall-line in the Rappahannock River near Fredricksburg. No trend was detected in total suspended solids at this station (Table 3-3). Improving trends in total nitrogen and total phosphorus were also detected in the Robinson River at Locust Dale (Table 3-3).

2. Tidal

Relative status of nutrients was good in nearly all segments in the Rappahannock River and fair in all others (Figure 3-3; Table 3-4). Relative status of surface chlorophyll *a* was fair in all segments of the Rappahannock River except the Upper Rappahannock River (RPPTF) were it was good. Relative status of surface and bottom total suspended solids was poor or fair in all segments but the Corrotoman River (CRRMH) where it was good. Secchi depth status was poor in Upper Rappahannock River (RPPTF) and the Middle Rappahannock River (RPPOH) and fair in the Lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH). Status of Summer bottom dissolved oxygen was good or fair in all segments (Figure 3-4; Table 3-4).

Degrading long-term trends were detected in bottom total nitrogen and surface dissolved inorganic nitrogen in the Middle Rappahannock River (RPPMH) and the Upper Rappahannock River (RPPTF), respectively. An improving trend in bottom dissolved inorganic phosphorus was detected in the Upper Rappahannock River (RPPTF). A degrading post-1994 change trend in surface total nitrogen was detected in the Upper Rappahannock River (RPPTF) while an improving post-1994 change trend in surface dissolved inorganic phosphorus was detected in the same segment. Degrading trends in surface and bottom total phosphorus were detected during the pre-method change period in all segments except the Upper Rappahanock River (RPPTF) (Figure 3-3; Table 3-5). Degrading trends were detected in surface chlorophyll *a* in the Middle Rappahannock River (RPPOH) and Lower Rappahannock River (RPPMH) and in secchi depth in the Corrotoman River (CRRMH). An improving trend in Summer bottom dissolved oxygen was detected in the Middle Rappahannock River (RPPOH). Decreasing trends in surface and bottom salinity were detected in the Lower Rappahannock River (RPPMH) and Corrottoman River (CRRMH) (Figures 3-4;Table 3-6).

The SAV habitat criteria were met for surface dissolved inorganic nitrogen and phosphorus in all applicable segments. Relative status of all nutrients during the SAV growing season was fair or good in all segments. Surface chlorophyll *a* was borderline with respect to the SAV habitat requirement in the Upper Rappahannock River (RPPTF) and the Middle Rappahannock River (RPPOH) but met the criterion in the Lower Rappahannock River (RPPMH) and Corrotoman River (CRRMH). Relative status of chlorophyll *a* during the SAV growing season was fair or poor in all segments except the Upper Rappahannock River (RPPTF). 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). Relative status of these two parameters was fair or poor in all segments except for surface total suspended solids in the Corrotoman River where it was good (Figure 3-5; Table 3-7).

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) (Figures 3-5; Table 3-8).

C. Phytoplankton

Status of the biomass for the diatom, cryptophyte and chlorophyte categories was good while status of cyanobacteria abundance and biomass was generally poor or fair throughout the Rappahannock River. Status of many phytoplankton metrics improved moving from station TF3.3 in the Middle Rappahannock River (RPPOH) to the downstream station LE3.6 in the Lower Rappahannock River (RPPMH). Status of the Margalef Diversity Index improved from fair at stations TF3.3 and RET3.1 to good at station LE3.6. Status of picoplankton biomass improved from poor at stations TF3.3 and RET3.1 to fair at station LE3.6 while status of primary productivity improved from poor at stations TF3.3 and RET3.1 to fair at station LE3.6. Improving trends in diatom, cryptophyte, and chlorophyte biomass were detected at all stations in the river. Improving trends in the biomass to abundance ratio were detected at stations TF3.3 in the Middle Rappahannock River (RPPOH) and RET3.1 in the Lower Rappahannock River (RPPMH), but not at station LE3.6. Improving trends in picoplankton biomass were detected at station LE3.6 in the Lower Rappahannock River (RPPMH), but not in the upstream stations (Figure 3-6;Table 3-9). 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 only concern at this time is the increasing trends in cyanobacterial abundance and biomass common within this river. Also of note is an increasing trend in the dinoflagellate biomass in the lower river station and its poor status here and at the up river location.

Phytoplankton composition within the tidal freshwater region of the Rappahannock River is discussed in detail by Marshall and Burchardt (2004b) identifying the seasonally dominant flora and showing the monthly range of development over the monitoring period. Previous discussion regarding long term trends of phytoplankton components and water quality in this river were given by Marshall et al. (1998) and Marshall and Burchardt (2004a). Additional information regarding the phytoplankton composition within tributaries of the Chesapeake Bay estuarine complex is given in Marshall et al. (2005). These reports identify a diverse phytoplankton population within the Bay tributaries, primarily dominated by a diatom flora with a diverse complement of species coming from both freshwater and neritic coastal sources. Many of these taxa deserve continued monitoring in light of their potential deteriorating impact on the environmental status of these tributaries. Potentially harmful taxa are presented in Marshall et al. 2005.

D. Benthos

1. Fixed Point Monitoring

Benthic community status met the restoration goals at station TF3.3 in the Middle Rappahannock River (RPPOH); however, degrading trends were observed for several benthic community metrics including total biomass, pollution indicative species abundance and pollution indicative species biomass. In the Lower Rappahannock River (RPPMH), status of the benthos was marginal at station RET3.1, severely degraded at station LE3.4 and degraded at station LE3.4. A degrading trend in the B-IBI was detected at station RET3.1 resulting from degrading trends in four of the seven component metrics of the B-IBI (Figure 3-7; Tables 3-10 and 3-11). The status observed in the downstream stations of segment RPPMH are probably related to the frequency of low dissolved oxygen events that occur in this area. Marginal status and a degrading trend in the B-IBI were observed at station RET3.1 may reflect the poor water quality status of some parameters observed in the segment.

2. Probability-Based Monitoring

Only 7% of samples collected in the upper Rappahannock River (RPPTFa) were classified as below the threshold resulting in segment being classified as unimpaired overall and the average B-IBI for the segment was 3.5. The lower Rappahannock River (RPPMHa) was classified as impaired with 37% of samples classified as below the threshold. Only five samples and eight samples were collected in the middle Rappahannock River (RPPOH) and Corrotoman River (CRRMHa), respectively, making assessments of benthic community impairment unreliable. Of the samples collected in these two segments, 6% and 23% were classified below the B-IBI threshold. Average B-IBI values in these two segments were 3.5 and 2.4, respectively (Table 3-12).

In the Upper Rappahannock (RPPTF), 100% of degraded samples were classified as contaminated using the Contaminant Discriminant Tool (CDT). In the Lower Rappahannock River (RPPMH), 67% of the degraded samples were classified as contaminated, with an average contaminant group posterior probability of 0.67. The remaining degraded samples that were not classified into the contaminant group had insufficient abundance/biomass indicating low dissolved oxygen as an additional source of stress (Table 3-13).

In summary, degradation in the upper Rappahannock River (RPPTFa) appears to be the result of anthropogenic contamination while degradation in the lower Rappahannock River may be the result of a combination of contamination and low dissolved oxygen effects. The small number of samples collected makes assessments of overall benthic community condition in the middle Rappahannock River (RPPOHa) and Corrotoman River (CRRMHa) difficult but, the degradation observed appears to be from a variety of sources in both segments.

III. Management Issues

In general, water quality above the fall-line appears to be improving as indicated by decreasing trends observed for both nitrogen and phosphorus parameters at the fall-line and in the Rapidan River. Reductions in flow corrected concentrations of nutrients at these stations could be related to reductions in non-point and/or point source loadings that occurred in the non-tidal portions of the Rappahannock River watershed.

Tidal water quality problems in the tidal portion of the Rappahannock River appear to occur primarily in the upper two segments of this estuary (RPPTF and RPPOH). In this region the status of total suspended solids and secchi depth was generally poor and the SAV habitat requirements were not. Although the relative status of all nutrient parameters was either good or fair the degrading long-term trends in water quality parameters occurred in these two segments including long-term degrading trends in surface dissolved inorganic nitrogen in segment RPPTF and bottom total nitrogen in segment RPPOH along with a post-1994 change degrading trend in surface total nitrogen in segment RPPTF.

Suspended solids 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 the increasing trends detected in trends in many phytoplankton community metrics within both the Upper Rappahannock River. Alternatively, the recent high spring freshets during the last two years, which were preceded by several dry years, may have resulted in an increase in suspended solids concentrations from agricultural runoff resulting in decreased water clarity.

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 source of the increasing trends in nitrogen parameters is unclear. Although point source loadings of total nitrogen increased overall, non-point source loadings decreased substantially. A potential alternative source of increased nitrogen in the Rappahannock River might be atmospheric deposition. Atmospheric deposition may account for 60% of total nitrogen inputs to this tributary (Rowan et al., 2000). Although atmospheric deposition could significantly affect water column concentrations of total nitrogen, temporal trends in atmospheric deposition to individual tributaries within the Chesapeake Bay watershed have yet to be examined and their effects on long-term trends in water quality quantified.

Diatoms represent the dominant component within this river that resulted in the increasing trend in total phytoplankton biomass. Other contributors to this biomass are chlorophytes, cryptophytes, dinoflagellates, and cyanobacteria. Seasonal expressions of abundance appear with the diatom spring bloom and increasing concentrations of dinoflagellates and cyanobacteria during summer and fall. Noteworthy are the increasing trends in cyanobacterial abundance and biomass, which come from mainly colonial and filamentous taxa. Among these taxa is a diverse floral representation, some capable of toxin production (Marshall and Burchardt, 2004). In addition, dinoflagellate biomass in the Lower Rappahannock was also increasing and had poor status. Further attention will be focused on these two categories in the future. For instance, this region is generally where summer blooms of the potentially harmful dinoflagellate *Cochlodinium polykrikoides* begin annually (Marshall, 1995).

The status of benthic communities monitored at the fixed point monitoring stations in the Lower Rappahannock River reflects stress due to the episodic low dissolved oxygen events that occur at these locations every summer. The influence of these phenomena on the structure of benthic communities in lower Rappahannock River is well documented (Dauer et al., 1992; Llanso et al. 1992; Smith and Dauer, 1994; Dauer and Alden, 1995). The trends observed in the B-IBI and its component metrics in the Upper Rappahannock River and for some component metrics in the Middle Rappahannock River may be related to degrading water quality trends including increased trends in nitrogen parameters and/or chlorophyll *a*.

The areal extent of benthic community degradation observed in the Rappahannock River using our probability based sampling results was comparable to estimates obtained using different assessment techniques. Diaz et al. (2003) estimated the areal extent of benthic community degradation of the Rappahannock River to be approximately 26% using an organism-sediment index (OSI). Paul et al., (1999) estimated the areal extent of impacted benthos in the Rappahannock River as 44% of the total area using the EMAP-Virginian Province Benthic Index.

Low dissolved oxygen appears to be a predominant source of stress in the Rappahannock River as nearly 33% of degraded sites had insufficient benthic community abundance and/or biomass. As mentioned above, this particular source of stress has been previously identified as an important factor that influences community structure in the lower Rappahannock River. Previous estimates of the areal extent of benthos degraded due to low dissolved oxygen were lower than the present study (i.e. 15%) but these estimates were based on a much smaller data set (Paul et al., 1999). The spatial extent of low dissolved oxygen events in this region have been demonstrated to be directly effected by physical factors such as spring tide mixing and residual current velocity which effect stratification (Kuo and Neilson, 1987; Kuo et al., 1991). More recently modeling studies indicate that both sediment and water column oxygen demand are important factors that affect the spatial extent of low dissolved oxygen (Park et al., 1996). As such, both non-point and point source nutrient loadings, which influence primary production rates, might play a role in the spatial extent of hypoxia in the lower Rappahannock River. As such, management policies designed to reduce point and non-point nutrient loads could reduce hypoxia effects in the lower Rappahannock River.

Anthropogenic contaminant was not previously believed to be a widespread important environmental problem in the Rappahannock River (USEPA, 1999). However, the current study indicates that sediment contamination may be more extensive than previously believed. All samples classified as degraded in the Upper Rappahannock River (RPPTF) were also classified as contaminated using the CDT and anthropogenic contamination was identified as a likely source of stress for 67% of degraded samples in the Lower Rappahannock River (RPPMH). This characterization is not entirely without precedence. Bioassays performed on sediments collected at ten sites located throughout portions of the Rappahannock River indicated that survival for specimens of the amphipod *Leptocheirus plumulosus* and the polychaete *Streblospio benedicti* was significantly different from that found in control sediments for one site and eight sites, respectively (Winfield, 2000). Associated chemical analyses revealed that concentrations of the heavy metal nickel were greater than Effects Range-Low benchmark concentrations at eight of the ten sites indicating that metals contaminants might be a potential source of stress to benthic communities in the Rappahannock River. Paul et al. (1999) also found toxicity (<80% survival) in bioassays performed on *Ampelisca abdita* in 9% of samples collected in the Rappahannock River. They also found that ERL concentrations of a least one contaminant (metal or organic) were exceeded in all samples collected in Rappahannock River and that 22% of samples had concentrations of PAHs in excess of 200 µg per gram of sediment organic carbon.

Examination of the spatial distribution of contaminated sites and isopleth mapping of contaminant group posterior probabilities may provide insight as to location, potential source(s) and possible identity of sediment contaminants in the Rappahannock River. However, direct measurements of sediment contaminant concentrations will be required to verify their presence and identify the type, source and spatial extent in the Rappahannock River.

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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.

Delivered load -the amount of point or non-point source nutrient loadings, expressed as a annual rate, that reaches the tidal portion of the estuary. In general, both point and non-point source nutrient loadings decrease as a result of the natural ability of a water body to assimilate and remove nutrients as they pass through it. Note that when calculating delivered loads to an estuary, both non-tidal point and non-point source nutrient loadings are adjusted for in-stream removal while point source loadings below the fall-line are given as discharged loads with no in-stream removal adjustment.

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.

Discharged load - the amount of point source nutrient loadings, expressed as a annual rate in kg/yr, that are directly input to a waterbody.

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.

Figures

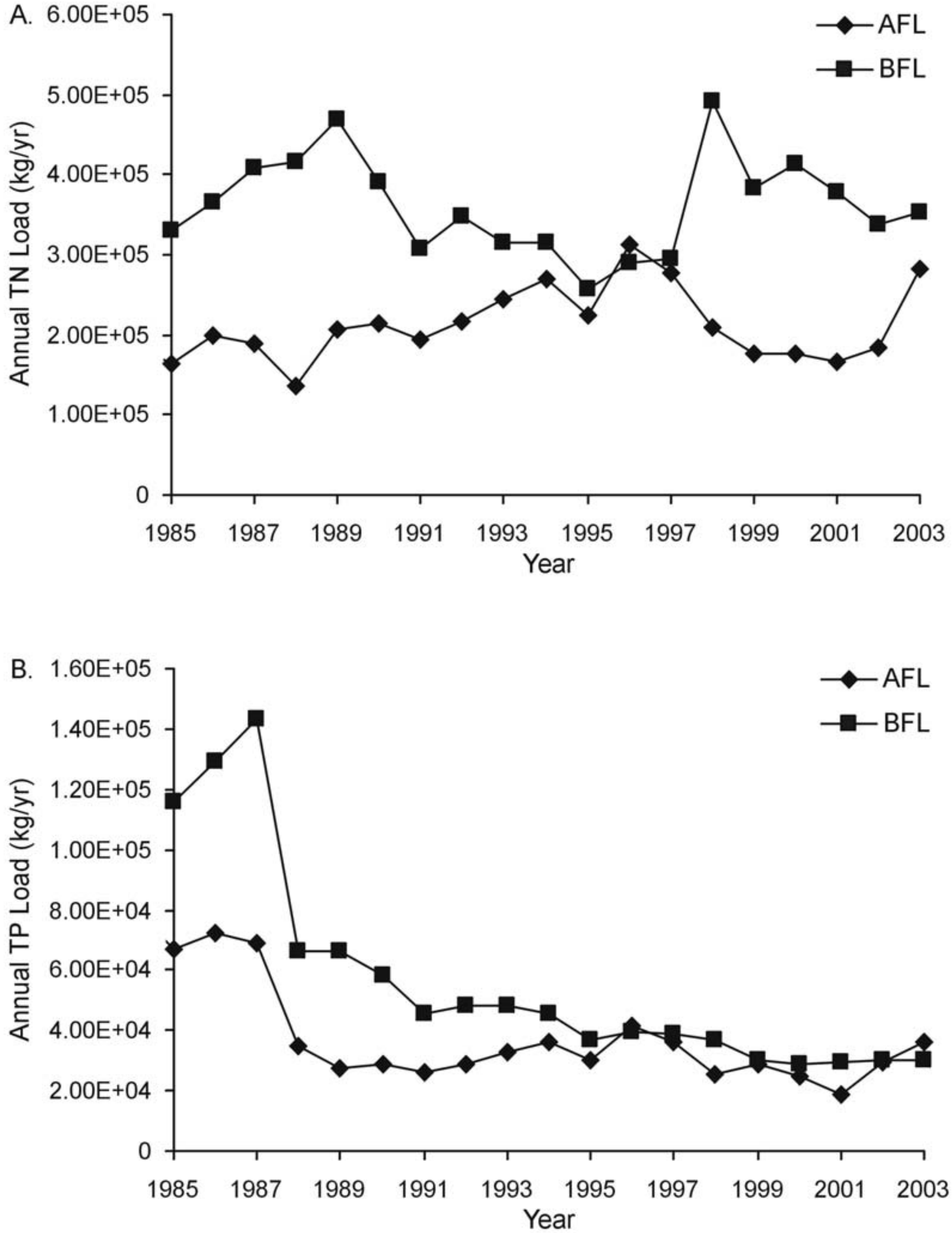


Figure 3-1. Long-term changes in above fall-line (AFL) and below fall-line (BFL) discharged point source A. Total Nitrogen Loadings, and B. Total Phosphorus Loadings in the Rappahannock River for 1985 through 2004.

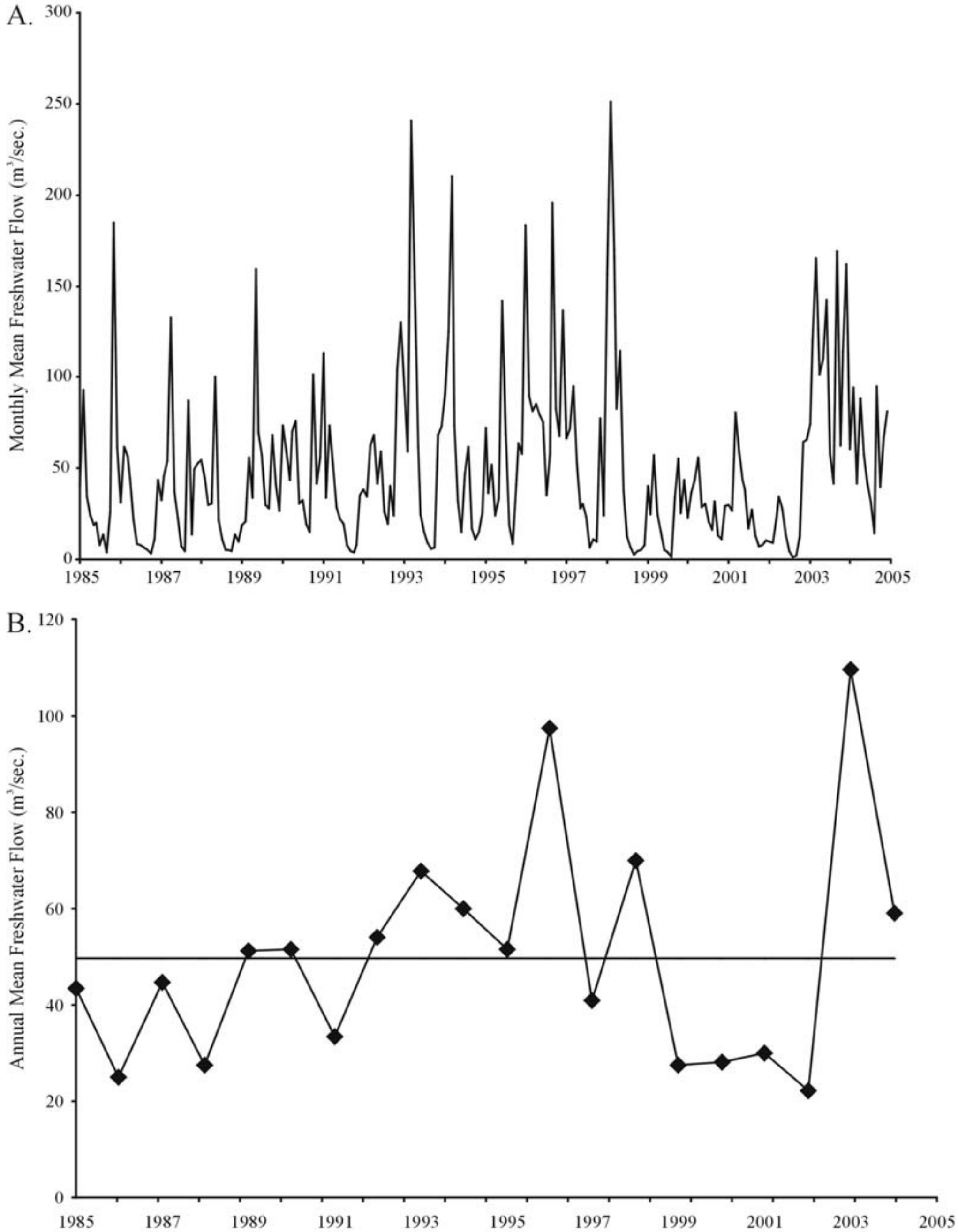
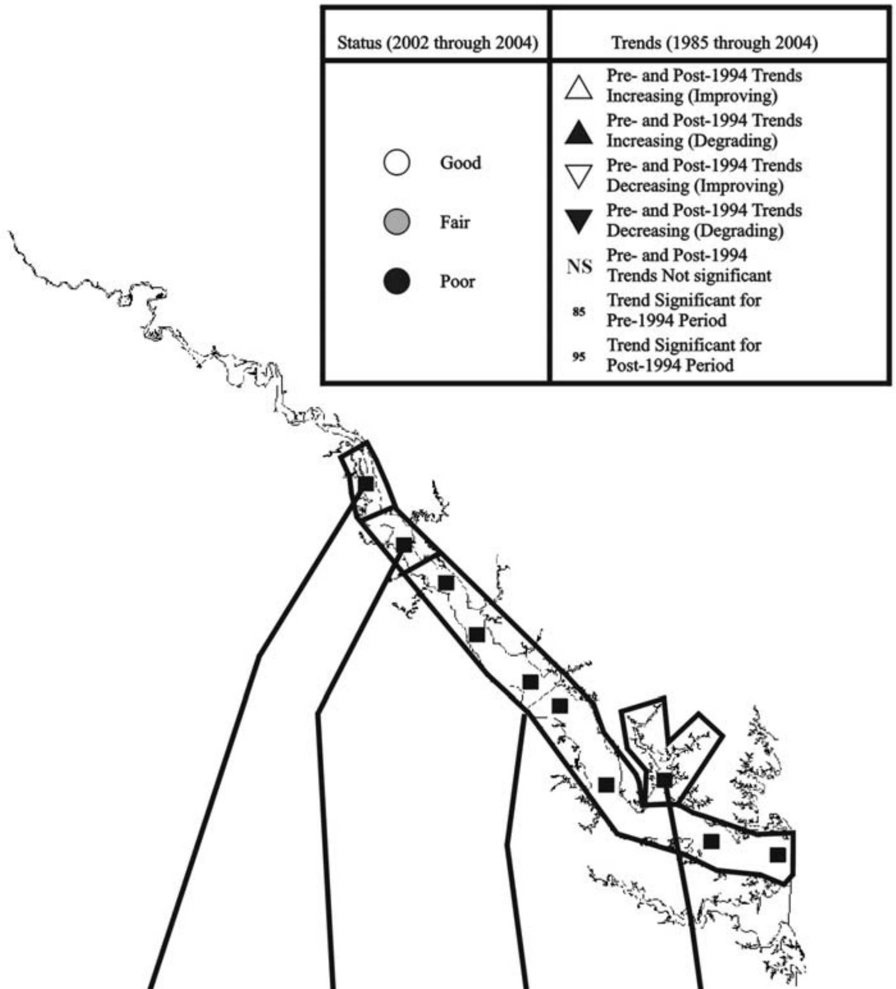
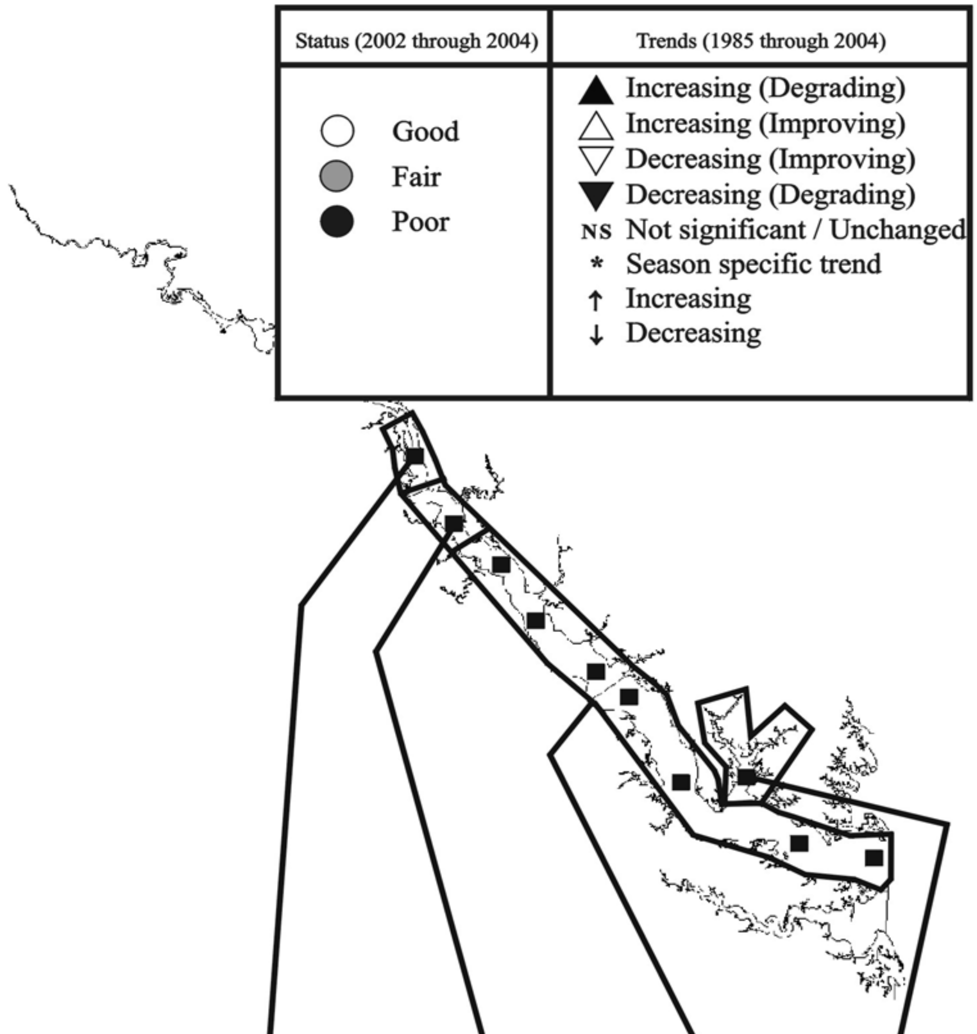


Figure 3-2. Plot of: A. monthly mean, and B. annual mean freshwater flow at the Rappahannock River fall-line for the period of 1985 through 2004.



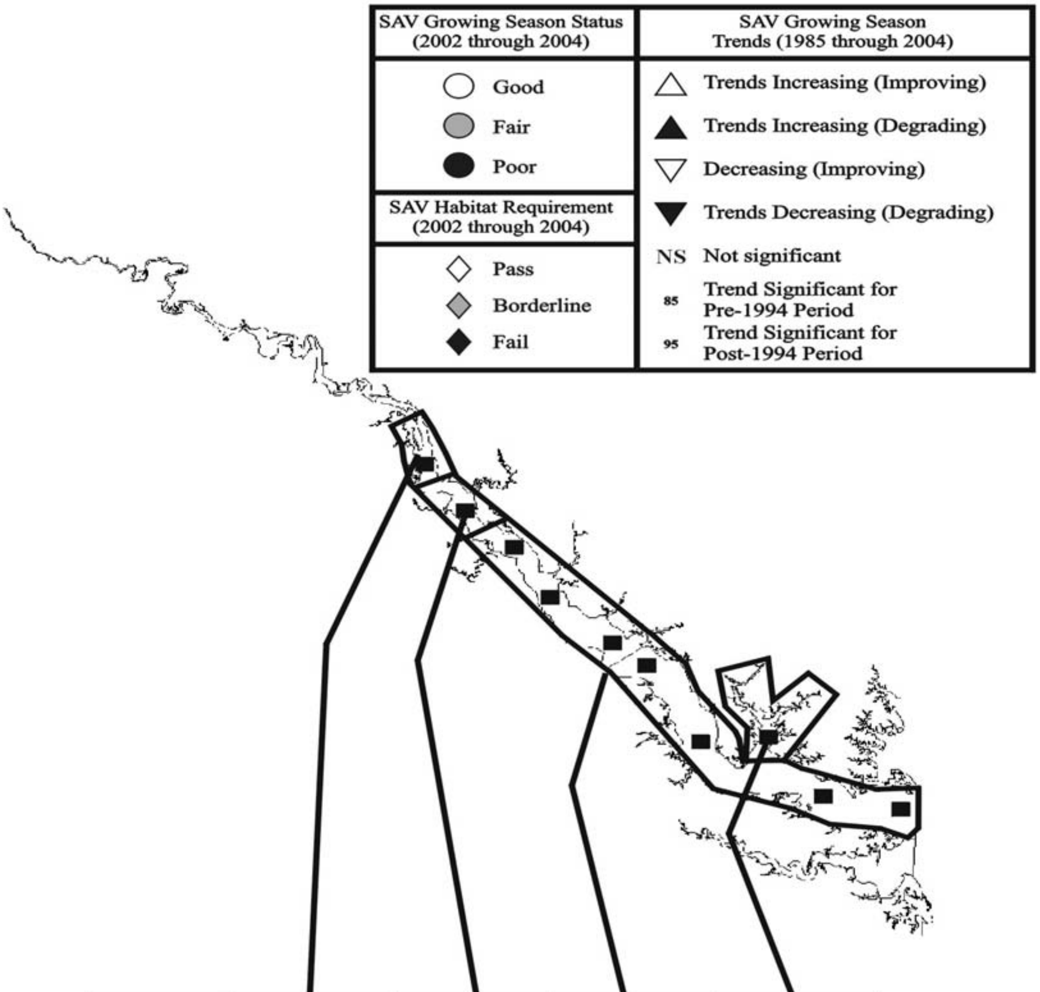
Parameter	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corottoman River
STN	○ ▲95	○ NS	○ NS	○ NS
BTN	○ NS	○ ▲	◍ NS	○ NS
SDIN	○ ▲	○ NS	○ NS	○ NS
BDIN	○ NS	○ NS	○ NS	○ NS
STP	○ NS	◍ ▲85	◍ ▲85	○ ▲85
BTP	○ NS	◍ ▲85	○ ▲85	○ ▲85
SDIP	○ ▽95	○ NS	○ NS	○ NS
BDIP	○ ▽	○ NS	○ NS	○ NS

Figure 3-3. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period 1985 through 2004. 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-1994 change trends. For such cases, the first symbol represents the pre-method change result while the second symbol is the post-1994 change result.



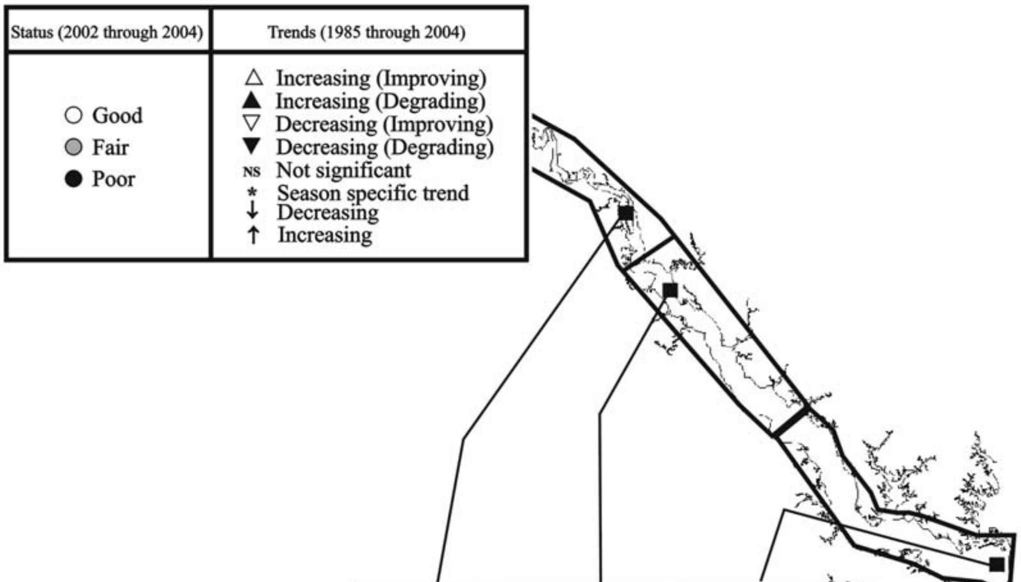
Parameter	Upper Rappahannock		Middle Rappahannock		Lower Rappahannock		Corottoman River	
SCHLA	○	NS	◍	▲	◍	▲	◍	NS
STSS	●	NS	●	NS	◍	NS	○	NS
BTSS	◍	NS	●	NS	◍	NS	○	NS
SECCHI	●	NS	●	NS	◍	NS	◍	▼
BDO	○	NS	○	△	◍	NS	◍	NS
SSALIN		NS		NS		↓		↓
BSALIN		NS		NS		↓		↓
SWTEMP		NS		NS		NS		NS
BWTEMP		NS		NS		NS		NS

Figure 3-4. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period 1985 through 2004. 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.



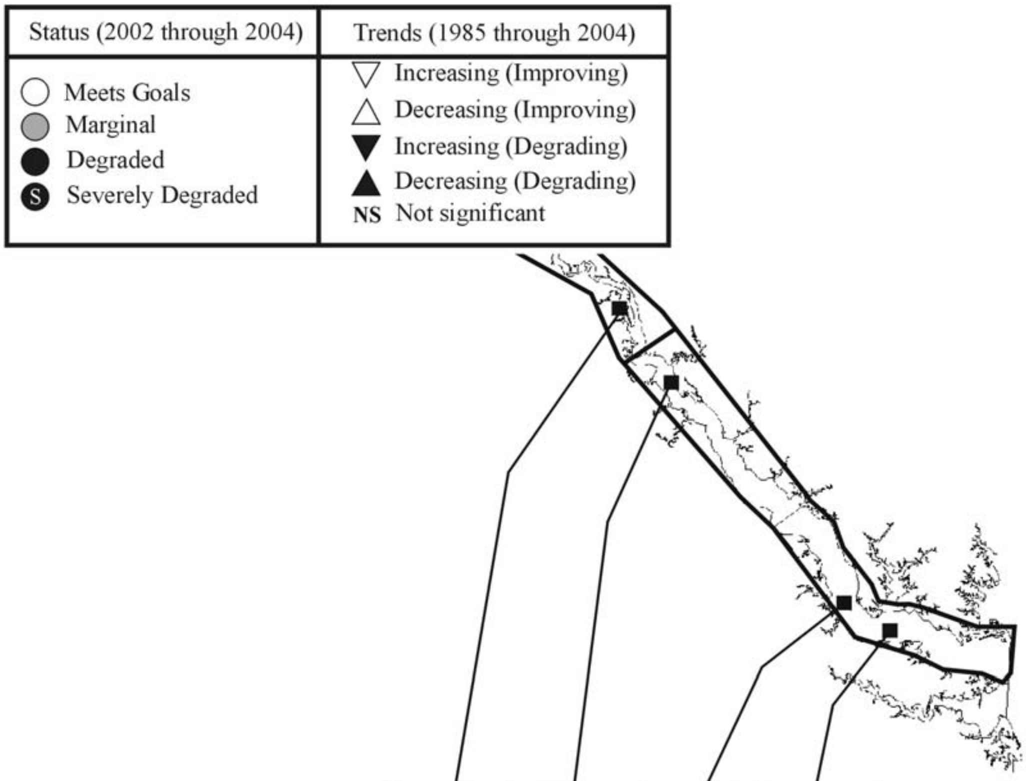
Parameter	Upper Rappahannock	Middle Rappahannock	Lower Rappahannock	Corottoman River
STN	Good; NS	Good; Increasing (Degrading)	Good; NS	Good; NS
SDIN	Good; NS	Good; NS	Good, Pass; Decreasing (Improving) 85	Good, Pass; Decreasing (Improving)
STP	Good; NS	Fair; NS	Fair; Increasing (Degrading) 85	Good; NS
SDIP	Good, Pass; NS	Good, Pass; NS	Good, Pass; NS	Good, Pass; NS
SCHLA	Good, Borderline; NS	Poor, Borderline; Increasing (Degrading)	Fair, Pass; Increasing (Degrading)	Fair, Pass; NS
STSS	Poor, Fail; NS	Poor, Fail; NS	Fair, Pass; NS	Good, Pass; Decreasing (Improving)
SECCHI	Poor, Fail; NS	Poor, Fail; NS	Poor, Borderline; NS	Fair, Pass; Increasing (Degrading)
BDO	Good; NS	Good; NS	Good; NS	Good; NS

Figure 3-5. Map of the Rappahannock River basin showing summaries of the status and trend analyses for each segment for the period of 1985 through 2004 for the SAV growing season. Abbreviations for each parameter are: TN=total nitrogen, SDIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus, CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=Secchi depth, DO=dissolved oxygen. 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-1994 trends. For such cases, the first symbol represents the pre-method change result while the second symbol is the post-1994 change result.



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

Figure 3-6. 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 2004.



	TF3.3	RET3.1	LE3.2	LE3.4
Benthic IBI	○ (Meets Goals) NS	◍ (Marginal) ▼	Ⓢ (Severely Degraded) NS	● (Degraded) NS
Total Abundance	NS	NS	NS	NS
Total Biomass	▼	▼	NS	NS
Pollution Sensitive Species Abundance (%)	NS	▼	NS	NS
Pollution Indicative Species Abundance (%)	▲	NS	NS	NS
Pollution Sensitive Species Biomass (%)	▼	▼	NS	NS
Pollution Indicative Species Biomass (%)	NS	NS	NS	NS
Shannon-Weiner Diversity Index	NS	▲	NS	NS

Figure 3-7. 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 2004.

Tables

Table 3-1. Land use and population patterns in the Rappahannock River watershed in comparison to A. Watersheds of the Virginia portion of Chesapeake Bay, and within B. Sub-watersheds of the Rappahannock River. Land use values are expressed as the total area in km2 within each watershed or sub-watershed and in parentheses as percentages of the total area within the watershed or sub-watershed. Note that Impervious Surfaces are a portion of the Developed land use type. Riparian buffers are measured in km of shoreline with a 30 m riparian buffer. Population values are provided as both total number per watershed or sub-watershed and densities expressed in the number of individuals per km^2. All land use and population data presented were provided by and/or modified from data available from the USEPA's Chesapeake Bay Program Watershed Profiles website: http://www.chesapeakebay.net/wspv31/.

A. Watersheds of the Virginia portion of Chesapeake Bay

	Land Use Area in km^2 (percent of Watershed total)									
Watershed	**Total Area**	**Developed**	**Agriculture**	**Forested**	**Open Water**	**Wetland**	**Barren**	**Impervious Surfaces**	**Riparian Buffers (%)**	**Pop. Number/ Density(#/km^2)**
Entire Chesapeake Bay	171,944	6,239(3.6)	48,938(28.5)	103,343(60.1)	7,415(4.3)	4,421(2.6)	1,551(0.9)	3,026(1.8)	110,134 (36.9)	15,594,241(91)
James River	27,019	1,222(4.5)	4,605(17.0)	19,119(70.8)	989(3.7)	704(2.6)	365(1.4)	511(1.9)	16,636(37.6)	2,522,583(93)
York River	8,469	192(2.3)	1,761(20.8)	5,159(60.9)	647(7.6)	575(6.8)	135(1.6)	81(1.0)	6,062(37.6)	372,488(44)
Rappahannock River	7,029	124(1.8)	2,207(31.4)	4,009(57.0)	443(6.3)	171(2.4)	75(1.1)	46(0.7)	3,672(35.6)	240,754(34)

B. Sub-watersheds of the Rappahannock River

	Land Use Area in km^2 (percent of Sub-watershed total)									
Sub-Watershed	**Total Area**	**Developed**	**Agriculture**	**Forested**	**Open Water**	**Wetland**	**Barren**	**Impervious Surfaces**	**Riparian Buffers (%)**	**Pop. Number/ Density(#/km^2)**
AFL Rappahannock	4035	57(1.4)	1466(36.3)	2463(61.0)	16(0.4)	10(0.3)	28(0.7)	15(0.4)	1470(32.2)	101306(25)
Upper Tidal Rappahannock	878	41(4.7)	223(25.4)	521(59.3)	31(3.5)	47(5.3)	16(1.8)	21(2.4)	682(41.3)	97960(112)
Middle/Lower Rappahannock	982	16(1.6)	282(28.8)	502(51.2)	85(8.7)	80(8.2)	16(1.6)	5(0.5)	825(38.7)	12373(13)
Lower Rappahannock	694	8(1.1)	155(22.4)	339(48.9)	155(22.4)	28(4.1)	13(1.9)	3(0.4)	449(37.2)	10480(15)
Mouth of Rappahannock	440	8(1.8)	80(18.2)	184(41.8)	155(35.3)	8(1.8)	5(1.2)	2(0.5)	244(32.0)	10786(24)

Table 3-2. Nutrient and Sediment A. Non-point Source and B. Point Source and C Total Loadings for Virginia tributaries for 2004, modified from data provided by the Virginia Department of Environmental Quality. Phosphorous and nitrogen loads are in kg/yr and sediment loads are metric tonnes per year (t/yr). Percent changes compare 2004 data to 1985 data. Non-point source loads are results based on the Year 2005 Progress Run of the Chesapeake Bay Watershed Model and calculated reductions for calendar year 2005 Best Management Practices (BMPs) as monitored by the Department of Conservation and Recreation and are expressed as delivered loads. Point source loadings are expressed as delivered loads. Number of major point sources for each watershed are provided in parentheses to the right of the watershed name.

A. Non-point Source

Tributary	2004 Phosphorus Load (kg/yr)	% Change in Phosphorus	2004 Nitrogen Load (kg/yr)	% Change in Nitrogen	2004 Sediment Load (t/yr)	% Change in Sediment
James	1,752,035	-0.15	9,676,183	-0.09	1,014,036	-0.12
York	268,239	-0.19	2,841,566	-0.18	112,347	-0.21
Rappahannock	383,145	-0.22	3,155,383	-0.25	290,692	-0.23
Potomac	696,186	-0.17	6,661,144	-0.05	623,163	-0.17
Coastal	86,828	-0.15	871,116	-0.12	19,722	-0.08
Totals	3,187,342	-0.17	23,206,301	-0.12	2,061,532	-0.16

B. Point Source

Tributary	2004 Phosphorus Load (kg/yr)	% Change in Phosphorus	2004 Nitrogen Load (kg/yr)	% Change in Nitrogen
James (37)	769,391	-0.61	7,426,636	-0.31
York (10)	71,424	-0.63	604,317	0.01
Rappahannock (18)	27,862	-0.67	231,831	0.02
Potomac (39)	120,817	-0.51	2,186,824	-0.46
Coastal Bays (5)	3,040	-0.84	87,379	-0.34
Totals	989,494	-0.6	10,449,608	-0.33

C. Total Loads

Tributary	2004 Phosphorus Load (kg/yr)	2004 Nitrogen Load (kg/yr)	2004 Sediment Load (t/yr)
James	2,521,426	17,102,819	1,014,036
York	339,663	3,445,883	112,347
Rappahannock	411,007	3,387,214	290,692
Potomac	817,003	8,847,968	623,163
Coastal Bays	89,868	958,495	19,722
Totals	4,176,836	33,655,909	2,061,532

Table 3-3. 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 2004.

Station Name	Parameter	Beta-T	p-value	% Change	Direction
Robinson River near Locust Dale	TSS	0.0845	0.7258	8.8	No trend
Robinson River near Locust Dale	TN	-0.1800	0.0341	-16.5	Improving
Robinson River near Locust Dale	TP	-0.8820	<0.0001	-58.6	Improving
Rappahannock River near Fredericksburg	TN	-0.2243	0.0023	-20.1	Improving
Rappahannock River near Fredericksburg	DNO23	-0.5645	<0.0001	-43.1	Improving
Rappahannock River near Fredericksburg	TP	-0.4371	0.0002	-35.4	Improving
Rappahannock River near Fredericksburg	DIP	-0.2302	0.0328	-20.6	Improving
Rappahannock River near Fredericksburg	TSS	-0.2065	0.237	-18.7	No trend

Table 3-4. Annual and Summer (DO only) season water quality status in the Rappahannock River and Corrotoman River for the period of 2002 through 2004 (presented are median values with Secchi depth in meters, chlorophyll *a* in µg/l, and all other parameters in mg/l).

Segment	Parameter	Season	Surface Median	Surface Score	Surface Status	Bottom Median	Bottom Score	Bottom Status
RPPTF	TN	Annual	0.97	18.48	Good	1.00	16.30	Good
RPPTF	DIN	Annual	0.61	33.24	Good	0.62	32.70	Good
RPPTF	STP	Annual	0.07	25.54	Good	0.08	24.23	Good
RPPTF	PO4F	Annual	0.01	26.77	Good	0.01	31.77	Good
RPPTF	CHLA	Annual	6.11	36.47	Good	-	-	-
RPPTF	TSS	Annual	27.50	76.29	Poor	37.88	60.57	Fair
RPPTF	SECCHI	Annual	0.40	21.12	Poor	-	-	-
RPPTF	DO	Summer1	-	-	-	6.86	-	Good
RPPMH	TN	Annual	0.57	24.03	Good	0.58	35.14	Fair
RPPMH	DIN	Annual	0.06	22.76	Good	0.10	23.83	Good
RPPMH	STP	Annual	0.04	34.72	Fair	0.04	35.25	Good
RPPMH	PO4F	Annual	0.01	32.54	Good	0.01	28.00	Good
RPPMH	CHLA	Annual	10.00	48.35	Fair	-	-	-
RPPMH	TSS	Annual	8.93	39.57	Fair	16.76	47.07	Fair
RPPMH	SECCHI	Annual	1.08	36.07	Fair	-	-	-
RPPMH	DO	Summer1	-	-	-	4.28	-	Fair
RPPOH	TN	Annual	1.00	24.96	Good	1.03	29.06	Good
RPPOH	DIN	Annual	0.41	22.82	Good	0.39	19.00	Good
RPPOH	STP	Annual	0.08	35.81	Fair	0.11	49.02	Fair
RPPOH	PO4F	Annual	0.01	29.18	Good	0.01	31.30	Good
RPPOH	CHLA	Annual	11.80	54.90	Fair	-	-	-
RPPOH	TSS	Annual	32.00	86.89	Poor	63.00	82.75	Poor
RPPOH	SECCHI	Annual	0.30	10.18	Poor	-	-	-
RPPOH	DO	Summer1	-	-	-	6.68	-	Good
CRRMH	TN	Annual	0.53	22.79	Good	0.55	30.78	Good
CRRMH	DIN	Annual	0.02	19.78	Good	0.03	15.38	Good
CRRMH	STP	Annual	0.03	27.28	Good	0.04	28.12	Good
CRRMH	PO4F	Annual	0.00	32.17	Good	0.01	28.00	Good
CRRMH	CHLA	Annual	9.74	49.87	Fair	-	-	-
CRRMH	TSS	Annual	5.00	18.01	Good	7.00	13.35	Good
CRRMH	SECCHI	Annual	1.30	54.74	Fair	-	-	-
CRRMH	DO	Summer1	-	-	-	4.31	-	Fair

Table 3-5. Annual season trends in nutrient parameters in the Rappahannock River and Corrotoman River for the period of 1985 through 2004.

Segment	Parameter	'93 Trend P value	'93 Slope	'93 Trend Direction	'04 Trend P value	'04 Slope	'04 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
RPPTF	STN	0.3813	-0.009	No Trend	0.0076	0.011	Degrading	0.0089	Different	0.1528	-
RPPTF	BTN	0.0187	-0.022	No Trend	0.0458	0.010	No Trend	0.0022	Different	1.0000	-
RPPTF	SDIN	0.1096	0.011	No Trend	0.0448	0.011	No Trend	0.6278	Same	0.0097	Degrading
RPPTF	BDIN	0.0489	0.010	No Trend	0.0958	0.009	No Trend	0.9837	Same	0.0106	No Trend
RPPTF	STP	0.0808	0.001	No Trend	0.2686	-0.001	No Trend	0.0459	Same	0.7526	No Trend
RPPTF	BTP	0.3526	0.001	No Trend	0.9559	0.000	No Trend	0.5575	Same	0.5026	No Trend
RPPTF	SPO4F	0.6364	0.000	High BDLs	0.0008	-0.001	Improving	0.0018	Different	0.0100	-
RPPTF	BPO4F	0.7403	0.000	High BDLs	0.0038	-0.001	Improving	0.0253	Same	0.0083	Improving
RPPMH	STN	0.0235	0.010	No Trend	0.9588	0.000	No Trend	0.1286	Same	0.1496	No Trend
RPPMH	BTN	0.0009	0.015	Degrading	0.6606	-0.002	No Trend	0.0120	Same	0.0651	No Trend
RPPMH	SDIN	0.0037	-0.005	Improving	0.4376	0.000	No Trend	0.0138	Same	0.2073	No Trend
RPPMH	BDIN	0.2307	-0.001	No Trend	1.0000	0.000	No Trend	0.4291	Same	0.4291	No Trend
RPPMH	STP	<0.0001	0.002	Degrading	0.3658	0.000	No Trend	0.0001	Different	0.0152	-
RPPMH	BTP	0.0045	0.001	Degrading	0.2349	-0.001	No Trend	0.0059	Different	0.3519	-
RPPMH	SPO4F	0.8505	0.000	High BDLs	0.7725	0.000	No Trend	0.7161	Same	0.8652	No Trend
RPPMH	BPO4F	0.1538	0.000	High BDLs	0.8959	0.000	No Trend	0.4499	Same	0.6034	No Trend
RPPOH	STN	0.2225	0.013	No Trend	0.0737	0.016	No Trend	0.6055	Same	0.0301	No Trend
RPPOH	BTN	0.0064	0.028	Degrading	0.0745	0.016	No Trend	0.6570	Same	0.0016	Degrading
RPPOH	SDIN	0.0211	-0.009	No Trend	0.4820	0.000	No Trend	0.0400	Same	0.3241	No Trend
RPPOH	BDIN	0.0046	-0.010	Improving	0.8908	0.000	No Trend	0.0523	Same	0.0837	No Trend
RPPOH	STP	0.0001	0.005	Degrading	0.7189	0.000	No Trend	0.0036	Different	0.0179	-
RPPOH	BTP	<0.0001	0.007	Degrading	0.9079	0.000	No Trend	0.0014	Different	0.0025	-
RPPOH	SPO4F	0.4892	0.000	High BDLs	0.1440	0.000	No Trend	0.3347	Same	0.1010	No Trend
RPPOH	BPO4F	0.1177	0.000	High BDLs	0.0897	0.000	No Trend	0.4704	Same	0.0237	No Trend
CRRMH	STN	0.0776	0.012	No Trend	0.3294	0.003	No Trend	0.7276	Same	0.0600	No Trend
CRRMH	BTN	0.0109	0.020	No Trend	0.5445	-0.003	No Trend	0.0445	Same	0.3040	No Trend
CRRMH	SDIN	0.0007	-0.005	Improving	1.0000	0.000	No Trend	0.0154	Same	0.0154	No Trend
CRRMH	BDIN	0.0496	-0.002	No Trend	0.8705	0.000	No Trend	0.2619	Same	0.1685	No Trend
CRRMH	STP	<0.0001	0.001	Degrading	0.5641	0.000	No Trend	0.0004	Different	0.0074	-
CRRMH	BTP	<0.0001	0.002	Degrading	0.0506	-0.001	No Trend	<0.0001	Different	0.1771	-
CRRMH	SPO4F	0.6865	0.000	High BDLs	0.4313	0.000	No Trend	0.3623	Same	0.5999	No Trend
CRRMH	BPO4F	0.2846	0.000	High BDLs	0.8610	0.000	No Trend	0.7167	Same	0.5004	No Trend

Table 3-6. Annual and Summer (BDO only) season trends in non-nutrient parameters in the Rappahannock River and Corrotoman River for the period of 1985 through 2003.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
RPPTF	Annual	SCHLA	11.75	0.1703	-0.002	12.390	-0.35	No trend
RPPTF	Annual	STSS	1.17	0.1425	0.167	24.750	11.45	No trend
RPPTF	Annual	BTSS	1.46	0.5878	0.083	36.750	3.85	No trend
RPPTF	Annual	SECCHI	0.00	0.1013	0.000	0.500	0.00	No trend
RPPTF	Summer1	BDO	0.00	0.5629	-0.008	7.375	-2.26	No trend
RPPTF	Annual	BDO	0.00	0.7693	0.002	8.600	0.50	No trend
RPPTF	Annual	SSALIN	0.00	<0.0001	0.000	0.010	0.00	No trend
RPPTF	Annual	BSALIN	0.00	<0.0001	0.000	0.010	0.00	No trend
RPPTF	Annual	BWTEMP	0.00	0.2972	0.026	17.750	2.90	No trend
RPPTF	Annual	SWTEMP	0.00	0.3722	0.026	16.325	3.18	No trend
RPPMH	Annual	SCHLA	6.52	0.0064	0.097	8.328	23.22	Degrading
RPPMH	Annual	STSS	12.45	0.2018	-0.067	6.750	-19.86	No trend
RPPMH	Annual	BTSS	4.18	0.3934	0.078	10.750	14.56	No trend
RPPMH	Annual	SECCHI	0.00	0.2140	-0.004	1.275	-6.83	No trend
RPPMH	Summer1	BDO	0.00	0.2114	-0.026	5.375	-9.72	No trend
RPPMH	Annual	BDO	0.00	0.3534	-0.007	7.025	-2.04	No trend
RPPMH	Annual	SSALIN	0.00	0.0003	-0.144	15.295	-18.80	Decreasing
RPPMH	Annual	BSALIN	0.00	0.0048	-0.094	17.018	-11.05	Decreasing
RPPMH	Annual	BWTEMP	0.00	0.5119	-0.010	16.225	-1.23	No trend
RPPMH	Annual	SWTEMP	0.00	0.8587	-0.005	17.900	-0.61	No trend
RPPOH	Annual	SCHLA	11.66	<0.0001	0.251	5.035	99.75	Degrading
RPPOH	Annual	STSS	0.43	0.4602	-0.115	31.000	-6.33	No trend
RPPOH	Annual	BTSS	0.43	0.0505	0.577	39.000	25.15	No trend
RPPOH	Annual	SECCHI	0.00	0.0831	0.000	0.400	0.00	No trend
RPPOH	Annual	BDO	0.00	0.0602	0.020	8.650	4.62	No trend
RPPOH	Summer1	BDO	0.00	0.0090	0.042	6.250	13.33	Improving
RPPOH	Annual	SSALIN	0.00	0.0328	0.000	2.165	0.00	No trend
RPPOH	Annual	BSALIN	0.00	0.0883	0.000	2.588	0.00	No trend
RPPOH	Annual	BWTEMP	0.00	0.3660	0.020	16.400	2.44	No trend
RPPOH	Annual	SWTEMP	0.00	0.1335	0.033	16.000	4.18	No trend
CRRMH	Annual	SCHLA	9.72	0.3960	0.012	7.325	3.36	No trend
CRRMH	Annual	STSS	31.72	0.0003	0.000	5.000	-	No trend
CRRMH	Annual	BTSS	22.37	0.0349	0.000	13.500	-	No trend
CRRMH	Annual	SECCHI	0.00	<0.0001	-0.018	1.950	-18.32	Degrading
CRRMH	Summer1	BDO	0.00	0.0203	-0.073	4.950	-29.41	No trend
CRRMH	Annual	BDO	0.00	0.0499	-0.027	7.325	-7.41	No trend
CRRMH	Annual	SSALIN	0.00	0.0001	-0.150	16.510	-18.17	Decreasing
CRRMH	Annual	BSALIN	0.00	0.0016	-0.100	16.840	-11.88	Decreasing
CRRMH	Annual	BWTEMP	0.00	0.1185	-0.028	17.825	-3.18	No trend
CRRMH	Annual	SWTEMP	0.00	0.9309	0.000	18.500	0.00	No trend

Table 3-7. SAV season water quality status in the Rappahannock River and Corrotoman River for the period of 2002 through 2004 (presented are median values with Secchi depth in meters, chlorophyll *a* in µg/l, and all other parameters in mg/l).

Segment	Parameter	Season	Layer	Median	Score	Status	Habitat Requirement
RPPTF	STN	SAV1	S	0.894	18.25	Good	-
RPPTF	SDIN	SAV1	S	0.602	31.73	Good	-
RPPTF	STP	SAV1	S	0.066	23.21	Good	-
RPPTF	SPO4F	SAV1	S	0.011	28.90	Good	Pass
RPPTF	SCHLA	SAV1	S	5.230	29.40	Good	Borderline
RPPTF	STSS	SAV1	S	30.500	76.69	Poor	Fail
RPPTF	SECCHI	SAV1	S	0.425	20.31	Poor	Fail
RPPOH	STN	SAV1	S	0.998	23.81	Good	-
RPPOH	SDIN	SAV1	S	0.406	19.02	Good	-
RPPOH	STP	SAV1	S	0.082	46.98	Fair	-
RPPOH	SPO4F	SAV1	S	0.010	30.20	Good	Pass
RPPOH	SCHLA	SAV1	S	14.535	70.69	Poor	Borderline
RPPOH	STSS	SAV1	S	34.000	87.81	Poor	Fail
RPPOH	SECCHI	SAV1	S	0.300	10.40	Poor	Fail
RPPMH	STN	SAV1	S	0.523	21.28	Good	-
RPPMH	SDIN	SAV1	S	0.071	19.03	Good	Pass
RPPMH	STP	SAV1	S	0.041	36.64	Fair	-
RPPMH	SPO4F	SAV1	S	0.006	33.46	Good	Pass
RPPMH	SCHLA	SAV1	S	9.420	48.75	Fair	Pass
RPPMH	STSS	SAV1	S	9.500	42.85	Fair	Pass
RPPMH	SECCHI	SAV1	S	1.150	34.69	Poor	Borderline
CRRMH	STN	SAV1	S	0.542	22.03	Good	-
CRRMH	SDIN	SAV1	S	0.022	16.99	Good	Pass
CRRMH	STP	SAV1	S	0.032	30.07	Good	-
CRRMH	SPO4F	SAV1	S	0.004	33.46	Good	Pass
CRRMH	SCHLA	SAV1	S	10.345	54.57	Fair	Pass
CRRMH	STSS	SAV1	S	5.000	18.40	Good	Pass
CRRMH	SECCHI	SAV1	S	1.400	52.04	Fair	Pass

Table 3-8. SAV growing season trends in nutrient parameters in the Rappahannock River and Corrotoman River for the period of 1985 through 2004.

Segment	Season	Parameter	‘93 Trend P value	‘93 Slope	‘93 Trend Direction	‘04 Trend P value	‘04 Slope	‘04 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
RPPTF	SAV1	STN	0.4778	0.0090	No Trend	0.0112	0.0120	No Trend	0.1506	Same	0.0158	No Trend
RPPTF	SAV1	BTN	0.4778	-0.0102	No Trend	0.3102	0.0072	No Trend	0.2084	Same	0.7776	No Trend
RPPTF	SAV1	SDIN	0.0126	0.0213	No Trend	0.2646	0.0046	No Trend	0.4255	Same	0.0126	No Trend
RPPTF	SAV1	BDIN	0.0071	0.0200	Degrading	0.4561	0.0043	No Trend	0.2264	Same	0.0192	No Trend
RPPTF	SAV1	STP	0.0884	0.0010	No Trend	0.1216	-0.0013	No Trend	0.0208	Same	0.9788	No Trend
RPPTF	SAV1	BTP	0.0795	0.0021	No Trend	0.3598	-0.0009	No Trend	0.0610	Same	0.6161	No Trend
RPPTF	SAV1	SPO4F	0.2040	<0.0001	No Trend	0.0658	-0.0003	No Trend	0.0236	Same	0.4061	No Trend
RPPTF	SAV1	BPO4F	0.5681	<0.0001	No Trend	0.0614	-0.0004	No Trend	0.0566	Same	0.2212	No Trend
RPPOH	SAV1	STN	0.0264	0.0273	No Trend	0.0976	0.0162	No Trend	0.8370	Same	0.0064	Degrading
RPPOH	SAV1	BTN	0.0003	0.0360	Degrading	0.1129	0.0165	No Trend	0.2386	Same	0.0003	Degrading
RPPOH	SAV1	SDIN	0.2774	-0.0050	No Trend	0.6053	<0.0001	No Trend	0.2605	Same	0.7337	No Trend
RPPOH	SAV1	BDIN	0.0481	-0.0075	No Trend	0.8045	<0.0001	No Trend	0.2598	Same	0.1330	No Trend
RPPOH	SAV1	STP	0.0005	0.0050	Degrading	0.8051	-0.0003	No Trend	0.0114	Same	0.0308	No Trend
RPPOH	SAV1	BTP	0.0001	0.0067	Degrading	0.9407	0.0003	No Trend	0.0093	Different	0.0068	-
RPPOH	SAV1	SPO4F	0.8404	<0.0001	No Trend	0.5596	<0.0001	No Trend	0.6912	Same	0.5211	No Trend
RPPOH	SAV1	BPO4F	0.6073	<0.0001	No Trend	0.5078	-0.0001	No Trend	0.7593	Same	0.3910	No Trend
RPPMH	SAV1	STN	0.0025	0.0175	Degrading	0.7609	0.0008	No Trend	0.0800	Same	0.0268	No Trend
RPPMH	SAV1	BTN	<0.0001	0.0258	Degrading	0.6848	0.0015	No Trend	0.0156	Same	0.0024	Degrading
RPPMH	SAV1	SDIN	0.0059	-0.0048	Improving	0.2628	0.0005	No Trend	0.0085	Different	0.3709	-
RPPMH	SAV1	BDIN	0.3325	<0.0001	No Trend	0.9192	-0.0002	No Trend	0.5685	Same	0.4680	No Trend
RPPMH	SAV1	STP	0.0001	0.0020	Degrading	0.7100	-0.0002	No Trend	0.0044	Different	0.0230	-
RPPMH	SAV1	BTP	0.0204	0.0017	No Trend	0.4777	-0.0006	No Trend	0.0400	Same	0.3360	No Trend
RPPMH	SAV1	SPO4F	1.0000	<0.0001	No Trend	0.5129	<0.0001	No Trend	0.5418	Same	0.5418	No Trend
RPPMH	SAV1	BPO4F	0.1059	<0.0001	No Trend	0.6070	<0.0001	No Trend	0.2465	Same	0.8265	No Trend
CRRMH	SAV1	STN	0.1932	0.0150	No Trend	0.2359	0.0052	No Trend	0.9095	Same	0.0781	No Trend
CRRMH	SAV1	BTN	0.0436	0.0200	No Trend	0.2185	-0.0050	No Trend	0.0269	Same	0.8204	No Trend
CRRMH	SAV1	SDIN	0.0001	-0.0060	Improving	0.6304	<0.0001	No Trend	0.0158	Same	0.0020	Improving
CRRMH	SAV1	BDIN	0.0431	-0.0025	No Trend	0.1716	-0.0013	No Trend	0.8031	Same	0.0179	No Trend
CRRMH	SAV1	STP	0.0011	0.0013	Degrading	0.8225	-0.0002	No Trend	0.0171	Same	0.0403	No Trend
CRRMH	SAV1	BTP	0.0012	0.0020	Degrading	0.1077	-0.0010	No Trend	0.0007	Different	0.3149	-
CRRMH	SAV1	SPO4F	0.3893	<0.0001	No Trend	0.2111	<0.0001	No Trend	0.1232	Same	0.5028	No Trend
CRRMH	SAV1	BPO4F	0.6626	<0.0001	No Trend	0.2287	-0.0002	No Trend	0.4313	Same	0.1968	No Trend

Table 3-9. SAV growing season trends in non-nutrient parameters in the Rappahannock River and Corrotoman River for the period of 1985 through 2004.

Segment	Season	Layer	Parameter	% BDL	P value	Slope	Baseline	% Change	Direction
RPPTF	SAV1	S	SCHLA	12.85	0.5231	-0.097	25.135	-7.71	No trend
RPPTF	SAV1	S	STSS	0.81	0.3912	0.125	24.750	8.59	No trend
RPPTF	SAV1	B	BTSS	1.09	0.8031	0.059	35.750	2.81	No trend
RPPTF	SAV1	S	SECCHI	0.00	0.8156	0.000	0.400	0.00	No trend
RPPTF	SAV1	B	BDO	0.00	0.6611	-0.005	7.875	-1.27	No trend
RPPTF	SAV1	S	SSALINITY	0.00	<0.0001	0.000	0.010	0.00	Unchanged
RPPTF	SAV1	B	BSALINITY	0.00	<0.0001	0.000	0.010	0.00	Unchanged
RPPTF	SAV1	B	BWTEMP	0.00	0.5808	0.011	24.000	0.95	No trend
RPPTF	SAV1	S	SWTEMP	0.00	0.7967	0.008	23.625	0.71	No trend
RPPOH	SAV1	S	SCHLA	9.52	<0.0001	0.520	9.325	111.57	Degrading
RPPOH	SAV1	S	STSS	0.00	0.3220	-0.204	29.000	-11.97	No trend
RPPOH	SAV1	B	BTSS	0.00	0.1198	0.500	41.000	20.73	No trend
RPPOH	SAV1	S	SECCHI	0.00	0.0112	-0.004	0.575	-12.42	No trend
RPPOH	SAV1	B	BDO	0.00	0.0464	0.025	6.575	7.60	No trend
RPPOH	SAV1	S	SSALINITY	0.00	0.0062	-0.024	3.990	-11.82	Decreasing
RPPOH	SAV1	B	BSALINITY	0.00	0.0237	-0.018	4.340	-8.06	No trend
RPPOH	SAV1	B	BWTEMP	0.00	0.5189	0.015	24.650	1.19	No trend
RPPOH	SAV1	S	SWTEMP	0.00	0.3026	0.025	24.075	2.08	No trend
RPPMH	SAV1	S	SCHLA	7.63	0.0031	0.141	8.488	33.26	Degrading
RPPMH	SAV1	S	STSS	11.41	0.2483	-0.086	6.750	-25.35	No trend
RPPMH	SAV1	B	BTSS	3.13	0.1542	0.179	9.250	38.61	No trend
RPPMH	SAV1	S	SECCHI	0.00	0.0859	-0.006	1.200	-10.42	No trend
RPPMH	SAV1	B	BDO	0.00	0.1891	-0.017	5.950	-5.64	No trend
RPPMH	SAV1	S	SSALINITY	0.00	0.0006	-0.156	16.060	-19.38	Decreasing
RPPMH	SAV1	B	BSALINITY	0.00	0.0162	-0.100	17.018	-11.79	No trend
RPPMH	SAV1	B	BWTEMP	0.00	0.0976	-0.030	22.975	-2.61	No trend
RPPMH	SAV1	S	SWTEMP	0.00	0.2488	-0.027	23.100	-2.37	No trend
CRRMH	SAV1	S	SCHLA	10.53	0.2105	0.070	11.240	12.46	No trend
CRRMH	SAV1	S	STSS	25.36	0.0026	-0.143	8.000	-35.71	Improving
CRRMH	SAV1	B	BTSS	20.66	0.0182	-0.273	10.750	-48.20	No trend
CRRMH	SAV1	S	SECCHI	0.00	<0.0001	-0.017	1.750	-19.05	Degrading
CRRMH	SAV1	B	BDO	0.00	0.0136	-0.053	6.425	-16.38	No trend
CRRMH	SAV1	S	SSALINITY	0.00	0.0001	-0.175	17.480	-20.02	Decreasing
CRRMH	SAV1	B	BSALINITY	0.00	0.0010	-0.127	17.585	-14.44	Decreasing
CRRMH	SAV1	B	BWTEMP	0.00	0.0156	-0.050	23.675	-4.22	No trend
CRRMH	SAV1	S	SWTEMP	0.00	0.6150	-0.013	23.800	-1.09	No trend

Table 3-10. Annual season status in phytoplankton bioindicators in the Rappahannock Riverfor the period of 2002 through 2004.

Station	Season	Parameter	Above Pycnocline Median	Above Pycnocline Score	Above Pycnocline Score
TF3.3	Annual	Total Biomass	1.66E+09	64.48	Good
TF3.3	Annual	Biomass to Abundance Ratio	42.60	33.06	Poor
TF3.3	Annual	Margalef Diversity Index	1.94	53.95	Fair
TF3.3	Annual	Diatom Biomass	9.21E+08	68.56	Good
TF3.3	Annual	Dinoflagellate Biomass	3.72E+07	80.66	Poor
TF3.3	Annual	Cyanobacteria Biomass	6.77E+07	68.52	Poor
TF3.3	Annual	Chlorophyte Biomass	2.14E+08	77.71	Good
TF3.3	Annual	Primary Productivity	219.30	89.48	Poor
TF3.3	Annual	Cryphtophyte Biomass	3.34E+07	85.24	Good
TF3.3	Annual	Cyanobacteria Abundance	1.17E+07	75.24	Poor
RET3.1	Annual	Total Biomass	1.11E+09	43.78	Fair
RET3.1	Annual	Biomass to Abundance Ratio	41.88	16.07	Poor
RET3.1	Annual	Margalef Diversity Index	1.71	47.96	Fair
RET3.1	Annual	Diatom Biomass	6.96E+08	62.92	Good
RET3.1	Annual	Dinoflagellate Biomass	1.20E+07	48.06	Fair
RET3.1	Annual	Cyanobacteria Biomass	3.29E+07	66.24	Poor
RET3.1	Annual	Chlorophyte Biomass	4.89E+07	91.28	Good
RET3.1	Annual	Primary Productivity	105.30	84.07	Poor
RET3.1	Annual	Cryphtophyte Biomass	4.71E+07	98.96	Good
RET3.1	Annual	Cyanobacteria Abundance	6.68E+06	77.31	Poor
LE3.6	Annual	Total Biomass	6.08E+08	30.11	Poor
LE3.6	Annual	Biomass to Abundance Ratio	62.24	24.96	Poor
LE3.6	Annual	Margalef Diversity Index	2.05	77.21	Good
LE3.6	Annual	Diatom Biomass	4.00E+08	58.03	Good
LE3.6	Annual	Dinoflagellate Biomass	8.82E+07	70.34	Poor
LE3.6	Annual	Cyanobacteria Biomass	3.08E+06	53.59	Fair
LE3.6	Annual	Chlorophyte Biomass	1.06E+06	80.03	Good
LE3.6	Annual	Primary Productivity	45.62	55.56	Fair
LE3.6	Annual	Cryphtophyte Biomass	3.70E+07	98.89	Good
LE3.6	Annual	Cyanobacteria Abundance	5.40E+05	56.76	Fair

Table 3-11. Annual season trends in phytoplankton bioindicators in the Rappahannock River for the period of 1985 through 2004. "N.E." in the Percent Change column indicates "No Estimate" was made for the percent change due to a zero value for the parameter baseline.

Station	Season	Layer	Parameter	P value	Slope	Baseline	Percent Change	Direction	Homogeneity test P value
TF3.3	Annual	AP	Total Abundance	<0.0001	1.40E+06	4.89E+06	542.49	Increasing	0.6660
TF3.3	Annual	AP	Total Biomass	<0.0001	5.30E+07	9.43E+07	1068.15	Increasing	0.3411
TF3.3	Annual	AP	Biomass to Abundance Ratio	<0.0001	0.992	22.37	84.23	Improving	0.2397
TF3.3	Annual	AP	Margalef Diversity Index	0.2513	0.007	1.54	8.84	No Trend	0.9925
TF3.3	Annual	AP	Diatom Biomass	<0.0001	3.24E+07	7.24E+07	849.07	Improving	0.2801
TF3.3	Annual	AP	Dinoflagellate Biomass	0.0065	2.18E+04	8.81E+05	47.04	Degrading	0.3775
TF3.3	Annual	AP	Cyanobacteria Biomass	<0.0001	1.47E+06	1.36E+06	2049.64	Degrading	0.5126
TF3.3	Annual	AP	Chlorophyte Biomass	<0.0001	5.94E+06	1.75E+06	6445.24	Improving	0.7069
TF3.3	Annual	AP	Primary Productivity	0.0640	0.98	51.88	15.66	30.19	0.9411
TF3.3	Annual	AP	Cryptophyte Biomass	<0.0001	1.11E+06	1.24E+07	169.37	Increasing	0.9141
TF3.3	Annual	AP	Cyanobacteria Abundance	<0.0001	3.73E+05	1.71E+05	4137.35	Degrading	0.8530
RET3.1	Annual	AP	Total Abundance	<0.0001	1.00E+06	6.64E+06	286.07	Increasing	0.1808
RET3.1	Annual	AP	Total Biomass	<0.0001	3.42E+07	2.01E+08	322.59	Increasing	0.0400
RET3.1	Annual	AP	Biomass to Abundance Ratio	0.0877	0.327	29.08	21.37	No Trend	0.9833
RET3.1	Annual	AP	Margalef Diversity Index	0.4903	-0.004	1.77	-4.14	No Trend	0.7773
RET3.1	Annual	AP	Diatom Biomass	<0.0001	1.91E+07	1.18E+08	308.50	Improving	0.2354
RET3.1	Annual	AP	Dinoflagellate Biomass	0.0482	-1.67E+05	2.08E+07	-15.24	No Trend	0.9587
RET3.1	Annual	AP	Cyanobacteria Biomass	<0.0001	1.07E+06	1.94E+06	1047.32	Degrading	0.0931
RET3.1	Annual	AP	Chlorophyte Biomass	<0.0001	1.37E+06	1.49E+06	1747.33	Improving	0.7660
RET3.1	Annual	AP	Primary Productivity	0.0356	1.46	65.84	23.28	35.36	0.9277
RET3.1	Annual	AP	Cryptophyte Biomass	<0.0001	1.57E+06	2.14E+07	139.78	Increasing	0.0777
RET3.1	Annual	AP	Cyanobacteria Abundance	<0.0001	2.16E+05	1.69E+05	2422.23	Degrading	0.5997
LE3.6	Annual	AP	Total Abundance	0.0027	1.62E+05	5.06E+06	64.16	Increasing	0.7184
LE3.6	Annual	AP	Total Biomass	0.0152	9.84E+06	3.78E+08	52.10	No Trend	0.2537
LE3.6	Annual	AP	Biomass to Abundance Ratio	0.8779	0.074	59.35	2.50	No Trend	0.3201
LE3.6	Annual	AP	Margalef Diversity Index	0.5456	-0.004	2.23	-3.83	No Trend	0.5115
LE3.6	Annual	AP	Diatom Biomass	0.0144	5.41E+06	2.25E+08	48.08	No Trend	0.1389
LE3.6	Annual	AP	Dinoflagellate Biomass	0.0001	2.26E+06	2.32E+07	194.87	Degrading	0.6258
LE3.6	Annual	AP	Cyanobacteria Biomass	<0.0001	7.85E+04	6.43E+02	244189.96	Degrading	0.4579
LE3.6	Annual	AP	Chlorophyte Biomass	0.0002	1.41E+04	1.87E+05	150.65	Improving	0.8119
LE3.6	Annual	AP	Primary Productivity	0.7775	-0.14	34.88	-2.28	-6.54	0.3063
LE3.6	Annual	AP	Cryptophyte Biomass	0.4546	1.50E+05	2.72E+07	11.02	No Trend	0.4830
LE3.6	Annual	AP	Cyanobacteria Abundance	<0.0001	1.42E+04	2.56E+02	111000.00	Degrading	0.8632

Table 3-12. Annual season status in benthic community condition based on the B-IBI in the Rappahannock River for the period of 2002 through 2004.

Station	Score	Status
TF3.3	3.7	Meets Goals
RET3.1	2.8	Marginal
LE3.2	1.7	Severely degraded
LE3.4	2.0	Degraded

Table 3-13. Annual season trends in the benthic IBI and its component metrics in the Rappahannock River for the period of 1985 through 2004.

Station	Parameter	P value	Slope	Baseline	% Change	Direction
TF3.3	Benthic Index of Biotic Integrity	0.5951	0.02	3.40	11.44	No Trend
TF3.3	Total Abundance per square meter	0.7049	-14.91	1001.70	-29.76	No Trend
TF3.3	Total Biomass per square meter	0.0582	-2.27	93.92	-48.29	Degrading
TF3.3	Shannon-Weiner Diversity Index	0.7049	0.00	1.95	-4.43	No Trend
TF3.3	Pollution Sensitive Species Abundance	0.4047	-0.61	32.36	-37.77	No Trend
TF3.3	Pollution Indicative Species Abundance	0.0486	0.71	0.00	N .E.	Degrading
TF3.3	Pollution Sensitive Species Biomass	0.0124	-2.24	80.17	-55.89	Degrading
TF3.3	Pollution Indicative Species Biomass	0.1525	0.27	0.00	N .E.	No Trend
RET3.1	Benthic Index of Biotic Integrity	0.0150	-0.07	3.57	-37.38	Degrading
RET3.1	Total Abundance per square meter	0.4040	42.42	1001.70	84.70	No Trend
RET3.1	Total Biomass per square meter	0.0080	-0.44	9.02	-98.31	Degrading
RET3.1	Shannon-Weiner Diversity Index	0.0956	-0.03	2.40	-22.62	Degrading
RET3.1	Pollution Sensitive Species Abundance	0.0064	-1.60	33.99	-93.97	Degrading
RET3.1	Pollution Indicative Species Abundance	0.6215	0.11	1.88	122.31	No Trend
RET3.1	Pollution Sensitive Species Biomass	0.0080	-4.20	71.23	-117.85	Degrading
RET3.1	Pollution Indicative Species Biomass	0.4251	0.03	1.57	41.69	No Trend
LE3.2	Benthic Index of Biotic Integrity	0.7904	-0.01	2.00	-6.20	No Trend
LE3.2	Total Abundance per square meter	0.1292	19.08	429.30	88.89	No Trend
LE3.2	Total Biomass per square meter	0.4481	0.01	0.27	52.38	No Trend
LE3.2	Shannon-Weiner Diversity Index	0.9698	0.00	1.21	-0.32	No Trend
LE3.2	Pollution Sensitive Species Abundance	0.8788	0.00	41.28	0.00	No Trend
LE3.2	Pollution Indicative Species Abundance	0.6222	0.17	50.26	6.94	No Trend
LE3.2	Pollution Sensitive Species Biomass	1.0000	0.00	46.51	0.00	No Trend
LE3.2	Pollution Indicative Species Biomass	0.4260	0.92	36.27	50.54	No Trend
LE3.4	Benthic Index of Biotic Integrity	0.3214	0.03	2.40	25.00	No Trend
LE3.4	Total Abundance per square meter	1.0000	0.00	791.82	0.00	No Trend
LE3.4	Total Biomass per square meter	0.9641	0.00	1.17	-1.83	No Trend
LE3.4	Shannon-Weiner Diversity Index	0.9282	-0.01	1.56	-7.76	No Trend
LE3.4	Pollution Sensitive Species Abundance	0.8203	0.00	16.74	0.00	No Trend
LE3.4	Pollution Indicative Species Abundance	0.3444	-1.21	68.60	-31.66	No Trend
LE3.4	Pollution Sensitive Species Biomass	0.7505	-0.36	51.66	-12.57	No Trend
LE3.4	Pollution Indicative Species Biomass	0.6204	-1.02	38.94	-47.04	No Trend

Table 3-14. Bootstrap and Wilcoxon rank sum test results for 85 Chesapeake Bay segments and sub-segments for the period 2000-2004. Shown is sample size, proportion of sites in segment below threshold (P), proportion of sites below threshold under the null hypothesis (P_o), difference between P and P_o, lower 95% confidence limit bound for the difference (CL-L), upper 95% confidence limit bound for the difference (CL-U), power and p-values for the Wilcoxon test, impaired segments by the bootstrap method (lower 95% confidence bound for the difference > 0), impaired segments for the Wilcoxon test (reference and segment B-IBI score distributions differ, with lower scores in segment than in reference), mean B-IBI value, number of sites in segment with B-IBI scores equal to or greater than 2.7, number of sites in segment with B-IBI scores equal to or greater than 3.0, percent of sites in segment with B-IBI scores equal to or grater than 2.7, and percent of sites in segment with B-IBI scores equal to or greater than 3.0. $P-P_o$ confidence limits for segments with small sample size (<10) were not calculated. Segment RPPMHm refers to Totuskey Creek.

		Bootstrap Results					Wilcoxon Results		Impaired						
Segment	Sample Size	P	Po	P-Po	CL- L (P-Po)	CL-U (P-Po)	Power	p-value	Bootstrap	Wilcoxon	mean B-IBI	N >=2.7	N >=3.0	% >=2.7	% >=3.0
RPPTF	11	0.07	0.05	0.02	-0.20	0.24	1.00	0.2356	No	No	3.5	9	9	82	82
RPPOH	5	0.06	0.05	0.01	-	-	1.00	0.3063	-	-	3.5	3	3	60	60
RPPMH	98	0.37	0.05	0.32	0.18	0.45	1.00	<0.0001	Yes	Yes	2.6	49	43	50	44
RPPMHm	2	0.50	0.05	0.45	-	-	0.85	0.3929	-	-	3.1	1	1	50	50
CRRMH	8	0.23	0.05	0.18	-	-	1.00	0.0074	-	-	2.4	5	4	63	50

Table 3-15. Diagnostic assessment of benthic community degradation for random sites sampled within Chesapeake Bay segments and sub-segments for the period 2000-2004. Presented is the mean B-IBI score in each segment, the total number of samples collected, the mean posterior probability of membership in the Contaminant group (Cont. Post. Prob.), and the total number, percentage of degraded, and percentage of the total samples for the following: (1) samples with posterior probability of contaminant group membership >=0.50, (2) degraded samples with excessive abundance or biomass, and (3) degraded samples with insufficient abundance or biomass. w/o Cont. = Percentage of samples (of degraded or total) not classified in the contaminant group. Segments in bold were classified as impaired by the bootstrap analysis. Segment RPPMHd refers to Robinson Creek while RPPMHm refers to Totuskey Creek.

				Samples with Contaminant Posterior Prob. >=0.50			Degraded Samples with Excessive Abundance/Biomass				Degraded Samples with Insufficient Abundance/Biomass			
Segment	B-IBI	# of Samples	Cont. Post. Prob.	Total #	% of Degraded	% of Total	Total #	% of Degraded	% of Degraded w/o Cont.	% of Total w/o Cont.	Total #	% of Degraded	% of Degraded w/o Cont.	% of Total w/o Cont.
RPPTF	3.5	11	0.9873	2	100.00	18.18	0	0.00	0.00	0.00	0	0.00	0.00	0.00
RPPOH	3.5	5	0.5421	1	50.00	20.00	1	50.00	50.00	20.00	0	0.00	0.00	0.00
RPPMH	2.6	98	0.6720	33	67.35	33.67	8	16.33	0.00	0.00	35	71.43	32.65	16.33
RPPMHd	1.7	1	0.5447	1	100.00	100.00	0	0.00	0.00	0.00	1	100.00	0.00	0.00
RPPMHm	3.1	2	0.9911	1	100.00	50.00	1	100.00	0.00	0.00	0	0.00	0.00	0.00
CRRMH	2.4	8	0.2693	1	33.33	12.50	0	0.00	0.00	0.00	2	66.67	33.33	12.50