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STATUS AND TRENDS IN WATER QUALITY AND LIVING RESOURCES IN THE VIRGINIA CHESAPEAKE BAY: JAMES 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, and benthos collected as part of the Virginia Chesapeake Bay Program. There are three reports, referred to as basin summaries, one each for the James River, the York River and the Rappahannock River. These basin summaries are intended to be electronic reports that will be periodically updated and they were intended for an audience already knowledgeable of the history and rationale of the program; design of the program; field and laboratory methods; specialized parameters, e.g. the Benthic Index of Biotic Integrity; status and trends analytical methods, etc.

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

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:

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

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:

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

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.

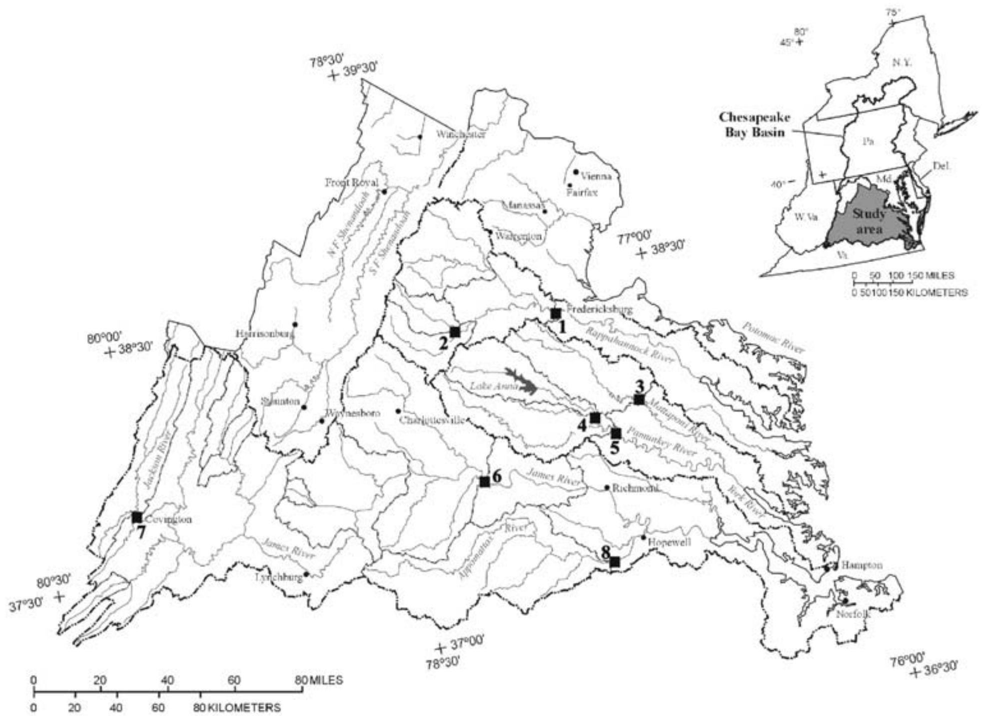
3. Benthic Diagnostic Tool

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.

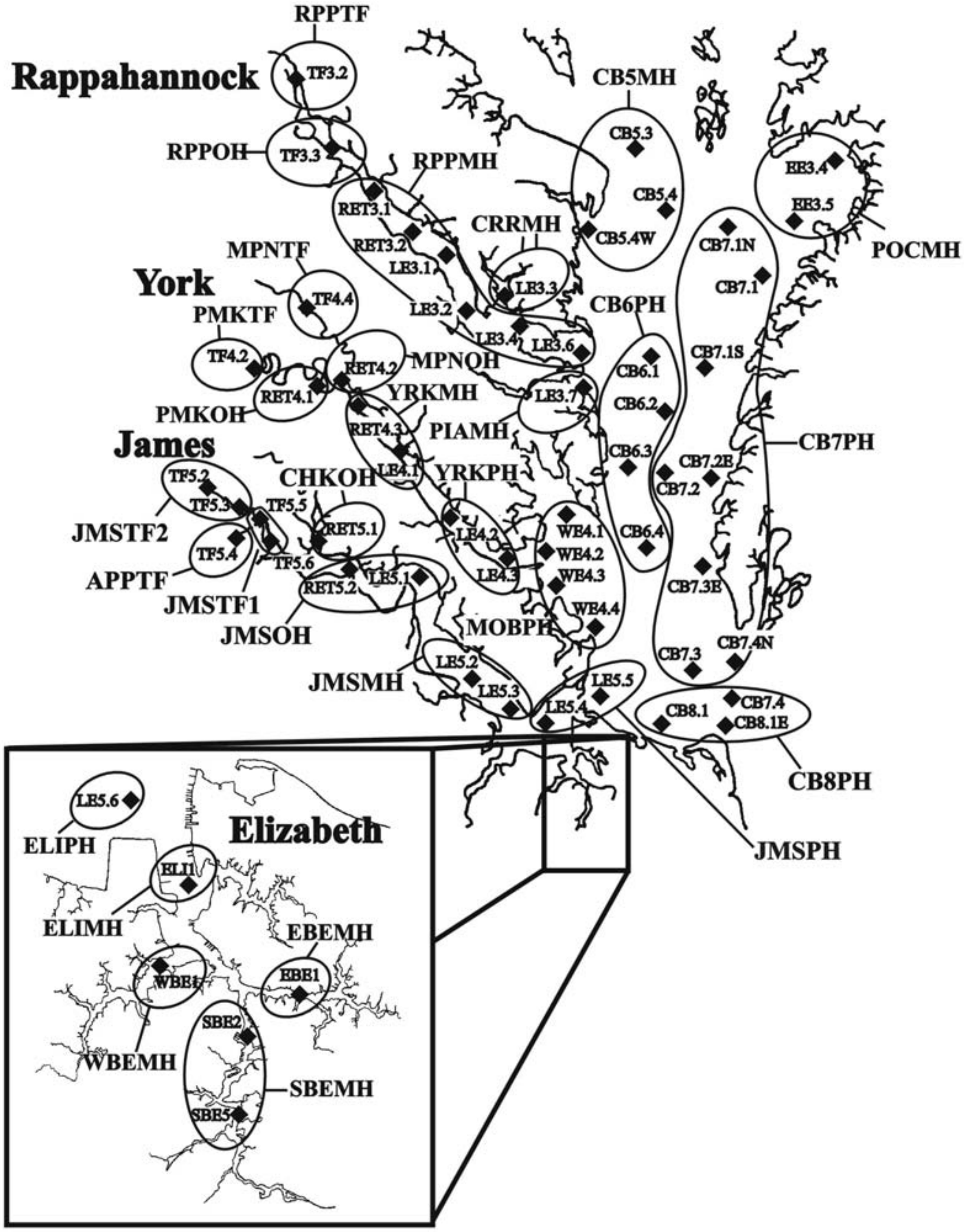


Figure 2-2. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay main stem used in the statistical analyses. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

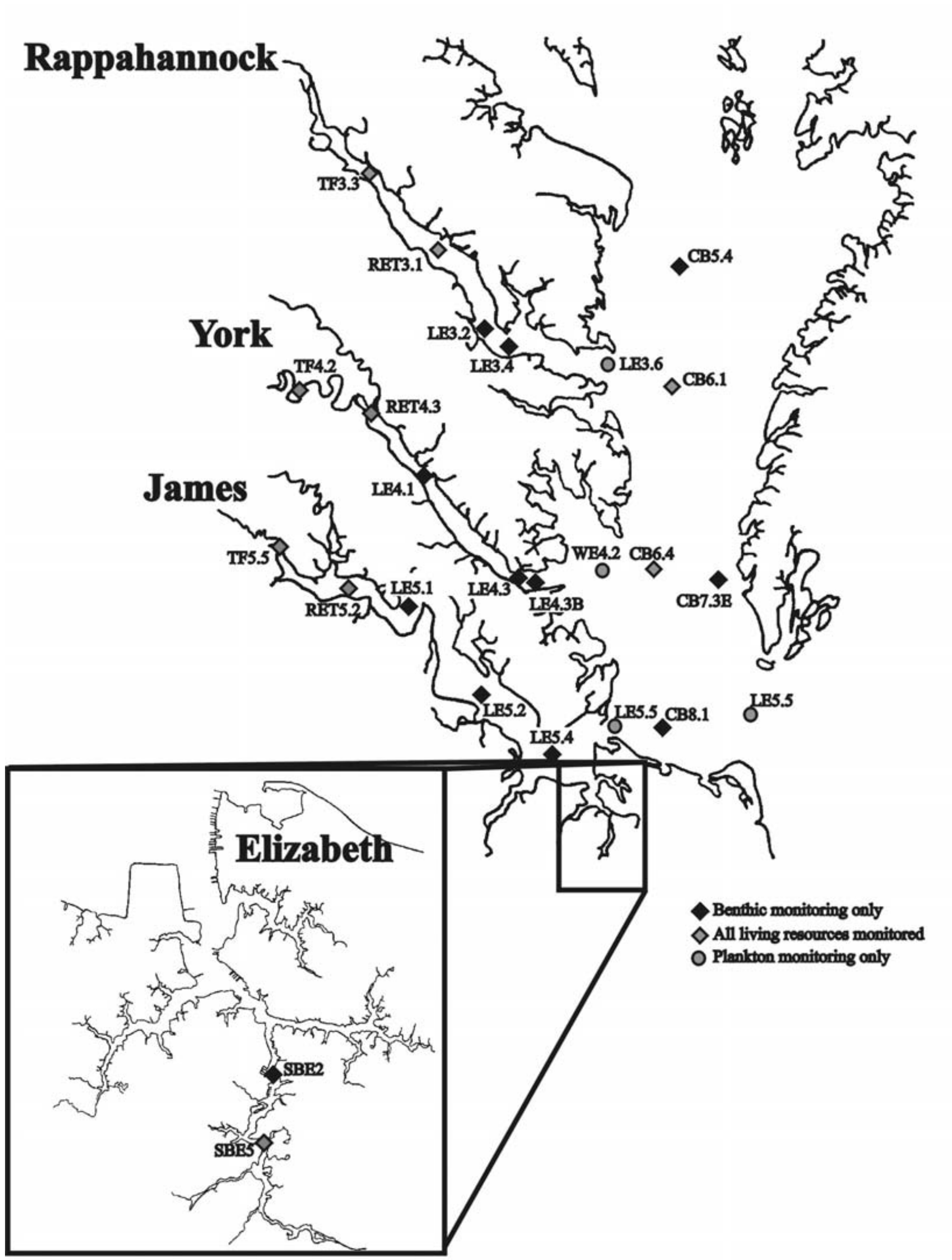


Figure 2-3. Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay main stem.

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. James River Basin

I. Executive Summary

A. Basin Characteristics

- The James River basin has the largest population, the highest population density, the largest percentage of developed land, and the largest percentage of land with impervious surfaces of the three Virginia tributaries while at the same time having the highest total area and percentage of forested land, and the lowest percentage of agricultural land.

- Above the fall-line, the James River is predominantly rural with the dominant land use type being forest coupled with some agricultural lands. The tidal portion of the river is characterized by two large urbanized regions (Richmond and Hampton Roads) with high population densities, higher percentages of impervious surfaces, relatively lower forest cover and fewer riparian buffer miles separated by large areas of predominantly forest land and open water with some agricultural land.

- Non-point sources accounted for nearly 57% of the 17,102,819 kg/yr of nitrogen loads and almost 70% of the 2,521,426 kg/yr of phosphorus loads entering the James River in 2004. Overall, BMPs have resulted in 9% and 15% reductions in nitrogen and phosphorus non-point sources loads, respectively and 31% and 61% reductions in total nitrogen and total phosphorus point source loads, respectively for the period from 1985 to 2004.

- Annual point source loadings of nitrogen were from five to eleven times higher below the fall-line (BFL) than above the fall-line (AFL). Annual AFL point source loadings of total nitrogen ranged between approximately 2,000,000 to 3,000,000 kg/yr from 1985 through 2003 with values prior to 1998 being generally 200,000 to 400,000 kg/yr higher. Following an initial increase from 22,140,000 kg/yr in 1985 to nearly 27,100,000 kg/yr in 1989, annual BFL loadings of total nitrogen declined steadily to approximately 12,300,000 kg/yr in 1999. During the next four years, BFL total nitrogen loadings have shown a slight but steady increase reaching approximately 14,600,000 kg/yr in 2003.

- Annual point source loadings of phosphorus were generally two to eight times higher below the fall-line (BFL) than above the fall-line (AFL). AFL total phosphorus loadings were near or above 500,000 kg/yr prior to 1988, declined sharply during the next two years to nearly 330,000 kg/yr in 1989 but have risen steadily since then to nearly 600,000 kg/yr in 2003. Following a peak at just over 4,070,000 kg/yr in 1986, BFL total phosphorus loadings declined sharply and have generally continued to steadily decline reaching approximately 1,050,000 kg/yr in 2003.

- No significant trends in freshwater flow in the James River at the fall-line were detected but peaks in monthly mean flow have risen above 300 m^3/sec and annual mean flow was higher than the grand mean during the last two years following a period of comparatively dry years from 1999 through 2002.

- No significant trends in freshwater flow were detected in the Appomattox River and a similar pattern in both monthly mean and annual mean flows were observed.

B. Water Quality

- In general, water quality above the fall-line in the James River and Appomattox River appear to be improving as indicated by the decreasing trends in both nitrogen and phosphorus.

- Relative status of most nutrients in the tidal James River was good or fair except in the lower river (JMSMH) where status of surface and bottom dissolved inorganic phosphorus was poor.

- While the relative status of surface chlorophyll *a* and bottom dissolved oxygen was good throughout most of the James River, status of total suspended solids and secchi was fair or poor throughout the river.

- SAV habitat requirements for nutrients, where applicable, were borderline or not met for most segments except in the Chickahominy River (CHKOH) where surface dissolved inorganic phosphorus pass the SAV requirements.

- SAV habitat requirements where met in most segments for surface chlorophyll *a* but either borderline or not met in most segments for surface total suspended solids and secchi depth.

- Most long term trends and all post-1994 trends in nutrients observed indicated improving water quality conditions except in the lower river (JMSMH), where degrading long-term trends where detected in bottom total nitrogen and surface and bottom dissolved inorganic phosphorus.

- Long-term trends during the SAV growing season were degrading for surface total nitrogen and dissolved inorganic phosphorus in the lower river (JMSMH) but improving for surface total nitrogen in the upper river (segment JMSTF1 only).

- The long term annual and SAV growing season trends observed for surface chlorophyll *a* and bottom dissolved oxygen were improving while all trends observed for total suspended solids and secchi depth were degrading.

- Status of all nutrients was either fair or poor in all segment of the Elizabeth River.

- Status of chlorophyll a and bottom dissolved oxygen was good or fair throughout the Elizabeth River and good or fair for surface total suspended solids in all segments except the Western Branch (WBEMH). Status of secchi depth was poor throughout the Elizabeth River.

- SAV habitat requirements for nutrients were not met in most segments of the Elizabeth River.

- SAV habitat requirements for chlorophyll *a* and total suspended solids were met in most segments of the Elizabeth River while the SAV habitat requirement was borderline or not met in most segments for secchi depth.

- With the exception of the Elizabeth River main stem (ELIPH), improving trends were detected for nutrients in most segments during both the annual and SAV growing seasons.

- Improving long term trends in surface and bottom total suspended solids were observed in nearly all segments for the Annual season and in surface total suspended solids in the Eastern Branch during the SAV growing season. An improving trend in surface chlorophyll *a* was detected in the Western Branch (WBEMH) during the annual season.

C. Living Resources

- Phytoplankton was dominated by diatoms throughout the year, producing a spring bloom in each salinity region. Major long term trends in biomass were present in both total phytoplankton biomass and abundance. Diatoms, cryptophytes, and chlorophytes also showed increased biomass trends, which are considered favorable trends. In contrast, there were modest, but long term trends in cyanobacteria abundance and biomass at all plankton stations, along with poor status ratings. The lower river station LE5.5 showed an increasing trend in dinoflagellates. Dinoflagellate status was considered poor upstream, but with no significant increasing trends.

- The B-IBI met restoration goals at most stations in the main stem of James River except station TF5.5 in the upper river (JMSTF1), and station LE5.2 in the lower river (JMSMH) where the status was marginal and degraded, respectively. Status of the B-IBI at both stations in the Elizabeth River was degraded.

- Improving trends in the B-IBI were detected at station RET5.2 in the middle river (JMSOH) and at station SBE5 in the Southern Branch (SBEMH) of the Elizabeth River.

- Results of the probability-based benthic monitoring indicate that most degraded communities in the James River main stem are located in the middle portions of the river and that contaminants may account for much of the degradation in these segments.

- Probability-based benthic monitoring indicated that five out of six segments in the Elizabeth River were impaired and that the predominant source of stress to benthic communities in the Elizabeth River is anthropogenic contamination but both eutrophication and low dissolved oxygen appear to be an additional source of stress within the Southern Branch (SBEMH) and upper main stem (ELIMH).

D. Management Issues

- A water quality issue in the James River is water clarity which is poor throughout the tidal waters. Nutrients, while not as elevated as other areas of the Chesapeake Bay system, also remain above desirable levels. In addition, some degradation in nutrient concentrations is indicated in the lower segments of the estuary.

- Phytoplankton communities throughout the James River exhibited long-term degrading trends in cyanobacteria abundance and biomass, fair or poor relative status for dinoflagellates and cyanobacteria biomass and poor relative status for the biomass-to-abundance ratio.

- With respect to the benthos, three of the five segments with sufficient sample size were impaired with anthropogenic contamination being the most probable source of stress.

- Intense urbanization resulting in high non-point source runoff into the Elizabeth River coupled with high point source nutrient loadings result in poor water quality in this tributary. Recent BMPs and reductions in point source loadings may be ameliorating these problems as indicated by improving trends in both nutrient concentrations and living resource conditions and expansion of these practices should result in further improvements.

- Increasing trends in cyanobacteria biomass and abundance in the Elizabeth River are an important concern but phytoplankton communities appear to be improving possibly in response to improving water quality.

- With respect to benthic communities, all but one segment of the Elizabeth River were impaired and the primary source of stress to these communities appears to be anthropogenic contaminants. These contaminants are the result of historical contamination, municipal and industrial point sources, non-point source storm water run-off, and automobile emissions.

II. Overview of Monitoring Results

A. Basin Characteristics

1. General

The James River basin is the largest river basin exclusive to Virginia covering over 27,000 km^2 or nearly 25% of the Commonwealth's total area (Table 3-1A) and draining nearly one-half of Virginia's portion of the Chesapeake Bay watershed (Kershner, 2004). The James River begins in the Allegheny Mountains where it is formed by the confluence of the Jackson and Cowpasture rivers. It flows through all of the major physiographic zones in the state where maximum elevations range from over 1200 m in the Blue Ridge to 150m and 70 m in the Piedmont and Coastal Plain, respectively (Kershner, 2004). From its sources, the James River flows 563 km in a southeasterly direction through Richmond and continuing to Hampton Roads where it enters Chesapeake Bay. The James River is roughly 70 m wide at its source, broadens gradually to 300 m at Richmond, and reaches its maximum width of nearly 8 km at its mouth at Hampton Roads (Pleasants, 1971). The tidal portion of the river extends from the mouth of the river approximately 250 km upstream to the fall-line in Richmond. Major tributaries include the Appomattox, Chickahominy, Warwick, Pagan, Nansemond and Elizabeth rivers.

2. Land Use

The James River has the largest population, the highest population density, the largest percentage of developed land, and the largest percentage of land with an impervious surface of the three Virginia tributaries. In contrast, this watershed also has the highest percentage of forested land (71%) overall and the lowest percentage of agricultural land (17%) of all three of the Virginia tributaries (Table 3-1A). The James River has the second highest percentage of shoreline with a riparian buffer of all the Virginia tributaries (Table 3-1A). Total population in the James River basin in 2000 was over 2,500,000 with a basin-wide population density of 93 individuals per km^2 (Table 3-1A).

In terms of total area, developed lands and impervious surfaces were concentrated in those sub-watersheds located in the vicinity of the Richmond and Hampton Roads (Table 3-1B). Population densities range from a minimum of 15 individuals/km^2 in the Piedmont sub-watershed to as high as 890 individuals/km^2 in the Elizabeth River/Hampton Roads sub-watershed with the highest numbers and percentages concentrated in areas around Richmond and Hampton Roads. (Table 3-1B).

Most agricultural land was found in sub-watersheds above the fall-line. Agricultural land accounted for at least 12% of the total area in all sub-watersheds of the James River but percentages of agricultural land were typically between 17% and 20% in most areas. The Nansemond River sub-watershed had the highest percentage of area in this land use category, as well as, the third highest total area of agricultural land (Table 3-1B).

Most of the forested land in the watershed is located above the fall-line. Within the non-tidal portion of the James River, the percentage of forested land generally decreases moving from the Upper James to those sub-watersheds in the vicinity of Richmond. Within the tidal portion of the James River, percentages of forest land decrease moving from the Upper Tidal James to the Elizabeth River/Hampton Roads sub-watershed although the actual area of forested land was slightly higher in the Lower Tidal James than in the Middle Tidal James (Table 3-1B). The percentages of coastline with a riparian buffer was at or above 32% in most of the James River sub-watersheds with the highest percentages occurring in above the fall-line, sub-watersheds upstream of Richmond and the lowest percentages occurring in the Lower Tidal James, Elizabeth River/Hampton Roads and Nansemond River sub-watersheds (Table 3-1B).

In general, most of the impacted land within the James River watershed is clustered around its two large population centers, Richmond and Hampton Roads. These areas had higher population densities, higher percentages of impervious surfaces, lower forest cover and fewer riparian buffer miles per mile of coastline and in comparison with other sub-watersheds slightly higher percentages of agricultural land.

3. Nutrient and Sediment Loadings

Based on estimates provided by the Virginia DEQ, total point and non-point source loadings of nitrogen to the James River are approximately 17,103,000 kg/yr with non-point loadings accounting for nearly 57% (Table 3-2). Application of best management practices (BMPs) are estimated to have resulted in a 9% reduction of non-point source loadings and a 31% reduction in point source loadings of total nitrogen from 1985 to 2004 (Table 3-2A,B). Total point and non-point source loadings of phosphorus were approximately 2,251,000 kg/yr in 2004 with non-point sources accounting for almost 70% of the total load (Table 3-2C). From 1985 through 2004, BMPs reduced non-point source loads by an estimated 15% while point source loads dropped by 61%, probably as a result of the phosphate ban (Table 3-2A,B). Approximately 1,014,000 metric tons/yr of sediment enter the tidal James River due to non-point source runoff. Application of BMPs resulted in a 12% reduction in sediments from 1985 to 2004 (Table 3-2A).

Annual point source loadings of nitrogen were from five to eleven times higher below the fall-line (BFL) than above the fall-line (AFL). Annual AFL point source loadings of total nitrogen ranged from approximately 2,000,000 kg/yr to just under 3,000,000 kg/yr from1985 through 2003 with values prior to 1998 being generally 200,000 kg/yr to 400,000 kg/yr higher (Figure 3-1A). Annual BFL loadings of total nitrogen increased from approximately 22,140,000 kg/yr in 1985 to nearly 27,100,000 in 1989. Thereafter, BFL total nitrogen loadings declined steadily to approximately 12,300,000 in 1999. During the next four years, BFL total nitrogen loadings have shown a slight but steady increase reaching approximately 14,600,000 kg/yr in 2003 (Figure 3-1B).

Annual point source loadings of phosphorus were generally two to eight time higher below the fall-line (BFL) than above the fall-line (AFL). Prior to 1988, AFL total phosphorus loadings were near or above 500,000 kg/yr. These values declined sharply during the next two years to nearly 330,000 kg/yr in 1989. However, since that time AFL total phosphorus loadings have risen steadily to nearly

600,000 kg/yr in 2003 (Figure 3-2A). Following a peak at just over 4,070,000 kg/yr in 1986, BFL total phosphorus loadings declined sharply following the phosphate ban and have generally continued to steadily decline reaching approximately 1,050,000 in 2003 (Figure 3-2B).

4. Freshwater Flow

Daily freshwater flow at the James River fall-line ranged from a minimum of 12.66 m^3/sec to a maximum of 5,635 m^3/sec for the period of January 1, 1985 through December 31, 2004. Daily freshwater flow at the Appomattox River fall-line ranged from a minimum of 0.52 m^3/sec to a maximum daily rate of 598.93 m^3/sec for the same time period. Grand mean flow in the James River and Appomattox River was 206.77 and 35.43 m^3/sec, respectively. From 1985 through 1998, mean monthly flows in the James River were characterized by large freshets with values in excess of 300 m^3/sec at least once but usually twice per year except during 1988 with the largest peaks in occurred in spring of 1998. This was followed by a four year dry period from 1999 through 2002 with flows returning to more typical levels during subsequent years (Figure 3-3A). With the exception of three years, annual mean flows from 1985 through 1998 for the James River were typically near or above the grand mean flow value (Figure 3-3B). From 1999 through 2002, the James River experienced a dry period when flows ranged from 71 to 110 m^3/sec lower than the grand mean value, after which annual mean flows peaked in 2003 and remained above the grand mean thereafter. Patterns in monthly mean and annual mean flows in the Appomattox River essentially paralleled those of the James River although magnitudes of both were substantially smaller (Figure 3-4A and B). There were no significant long-trends in freshwater flow in either the James River or Appomattox River.

B. Water Quality

1. Non-tidal

In general, water quality conditions above and at the fall-line in the James River appear to be improving. Improving trends in flow adjusted concentrations of ammonia were detected in the Jackson River at Covington, in the James River at Bent Creek, and in the James River at Scottsville. Improving trends in flow adjusted concentrations of nitrates-nitrites were detected in the James River at Scottsville and at Cartersville. Improving trends in flow adjusted concentrations of total phosphorus were detected at all stations at and above the fall-line in the James River. An improving trend in flow adjusted dissolved inorganic phosphorus was detected in the James River at Cartersville (Table 3-3). Water quality conditions above the fall-line in the Appomattox River also improved, as indicated by the improving trend in dissolved inorganic phosphorus at Mataoca (Table 3-3).

2. Tidal

Relative status of nitrogen parameters was good in all segments of the James River except the Lower James River (JMSMH) and the James River Mouth where status of nitrogen parameters was either good or fair. Relative status of surface and bottom total phosphorus was good or fair in all segments of the James with most segments characterized as fair being downstream. Status of surface and bottom dissolved inorganic phosphorus was fair in most segments except for the Chickahominy River (CHKOH) were status of both was good and in the Lower James River (JMSMH) where both were poor (Figure 3-5; Table 3-4).

Relative status of surface chlorophyll *a* was good in all segments except the Chickahominy River (CHKOH) and the James River Mouth (JMSPH) where it was fair. Status of surface and bottom total suspended solids and secchi depth were fair or poor in most segments except for the Upper James River (JMSTF2 only) where status of all these parameters was good. Status of bottom dissolved oxygen was good in all segments of the James River (Figure 3-6; Table3-4).

Improving trends that were consistent between the pre and post 1994 periods were limited for most nitrogen parameters to the Upper James River (segment JMSTF2 only). Improving long term trends were detected in surface and/or bottom dissolved inorganic phosphorus in the Appomattox River (APPTF) and both Upper James River segments (JMSTF1 and JMSTF2). Degrading long term trends were detected in surface and bottom dissolved inorganic phosphorus in the Lower James River (JMSMH). Improving trends were detected in bottom dissolved inorganic phosphorus in both the Middle James River (JMSOH) and the James River Mouth (JMSPH) for the post 1994. Improving trends were detected for surface chlorophyll *a* in the Chickahominy River (CHKOH) and bottom dissolved oxygen in both Upper James River segments (JSMTF1 and JMSTF2) and the James River Mouth (JMSPH). Degrading trends were detected in surface and/or bottom suspended solids in the Upper James River (JMSTF1 only), the Chickahominy River (CHKOH) and the Lower James River (JMSMH). Degrading long term trends were detected in secchi depth in the Upper James River (JMSTF1 only), the Chickahominy River (CHKOH) and the James River Mouth (JMSPH) (Figures 3-5 and 3-6; Tables 3-5 and 3-6).

SAV habitat requirements for nutrients, where applicable, were either borderline or not met with the exception of surface dissolved inorganic phosphorus in the Chickahominy River (CHKOH). Surface chlorophyll *a* passed the SAV habitat criterion in all segments except the Appomattox River (APPTF) where it was borderline. Surface total suspended solids status was either borderline or failed to meet the SAV requirement in all segments except the Upper James River and James River Mouth (JMSTF2 and JMSPH) where the criterion was met. Secchi depth either failed to meet the SAV habitat requirement or was borderline in all segments (Figure 3-7; Table3-7).

No long term trends in nutrients were detected during the SAV growing season except for an improving trend in surface total nitrogen in the Upper James River (JMSTF1 only), a degrading trend in surface total nitrogen in the Lower James River (JMSMH), and degrading trends in surface dissolved inorganic phosphorus in the Middle and Lower James River (JMSOH and JMSMH). Improving trends in surface chlorophyll *a* were detected in the Appomattox and Chickahominy

Rivers (APPTF and CHKOH) during the SAV growing season and degrading trends in secchi depth were detected in the Upper James River (JMSTF1 only) and the Chickahominy River (CHKOH) during the SAV growing season. Improving trends in bottom dissolved oxygen were detected in the Upper James River (JMSTF2 only) and James River Mouth (JMSPH) for the SAV growing season (Figure 3-7; Tables 3-8).

Status of all nutrient parameters was fair or poor in all segments of the Elizabeth River. Status of surface chlorophyll *a* was fair in the Western Branch (WBEMH) and the Elizabeth River main stem (ELIPH) but good in the Southern and Eastern Branches (SBEMH and EBEMH). Status of surface and bottom total suspended solids was fair or poor except in the Southern Branch (SBEMH) and Eastern Branch (EBEMH) where status was good for one or both of these parameters. Status of secchi depth was poor throughout the Elizabeth River while the status of bottom dissolved oxygen was either fair or good (Figures 3-8 and 3-9; Table 3-10).

Improving trends in both nitrogen and phosphorus parameters were detected in all segments of the Elizabeth River except the Elizabeth River main stem (ELIMH) were no nutrient trends were detected. Although only the Western Branch (WBEMH) showed an improving trend in surface chlorophyll *a*, improving trends were detected in bottom and/or surface total suspended solids for all segments. A degrading trend in secchi depth was detected in the Elizabeth River main stem (ELIPH) but no other trends in this parameter were detected (Figures 3-8 and 3-9; Table 3-11 and 3-12).

Surface dissolved inorganic nitrogen and surface dissolved inorganic phosphorus either failed to meet their respective SAV habitat requirements or were borderline in all Elizabeth River segments. Surface chlorophyll *a* and surface total suspended solids met their respective SAV habitat criteria in all Elizabeth River segments except the Eastern Branch (EBEMH) where surface chlorophyll *a* was borderline and surface total suspended solids failed the criterion. Secchi depth failed to meet the criterion in the Eastern Branch (EBEMH), was borderline in the Western and Southern Branches (WBEMH and SBEMH), and met the criterion in the Elizabeth River main stem (ELIPH) (Figure 3-10; Table 3-13).

During the SAV growing season, the Western Branch (WBEMH) showed improvement in surface total nitrogen while the Elizabeth River main stem (ELIPH) showed a degrading trend. Improving trends were detected in surface total phosphorus in the Western, Southern, and Eastern Branches (WBEMH, SBEMH, and EBEMH) and dissolved inorganic phosphorus in the Western and Southern Branches (WBEMH and SBEMH). Degrading trends in surface total phosphorus and secchi depth were also detected in the Elizabeth River main stem (ELIPH) during this season. Bottom dissolved oxygen showed improvement within two segments, the Southern and Eastern Branches (SBEMH and EBEMH). No other significant trends were detected during the SAV growing season (Figure 3-10; Table 3-14, 3-15).

With respect to water quality, nutrient conditions appear to be best in the upper segments of the James River particularly with respect to phosphorus and problems with nutrients are localized primarily in the Middle James River and Lower James River. Water clarity as measured by both total suspended solids and secchi depth was poor throughout most of the James River and no improvements were observed. Dissolved oxygen was good throughout the James River. Results of the relative status assessments and SAV habitat criteria indicate that water quality conditions within the Elizabeth River are degraded, but some trend results for both the Annual and Summer SAV growing season indicate that water quality is improving.

C. Phytoplankton

Although phytoplankton composition in the James River is represented by favorable dominance and abundance levels of diatoms, chlorophytes, and cryptophytes, there are significant signs of degradation. Status of most phytoplankton metrics was either poor or fair in the James River while status of primary productivity was poor at station TF5.5 in the Upper James River (JMSTF), good at station RET5.2 in the Middle James River (JMSOH) and fair at station LE5.5 in the James River Mouth segment (JMSPH). Improving trends in diatom and chlorophyte biomass were detected at all stations in the James River. Increasing trends in the biomass to abundance ratio were detected in all segments of the James River. Improving trends in cryptophyte biomass were detected at station TF5.5 in the Upper James River and station RET5.2 in the Middle James River (JMSOH). An improving trend in picoplankton abundance was detected at station RET5.2 in the Middle James River (JMSOH). Improving trends in primary productivity were detected at station RET5.2 in the Middle James River (JMSOH) and station LE5.5 in the James River Mouth (JMSPH) segment. Major status conditions and trends of concern are associated with the dinoflagellates (increasing trend at LE5.5), and specifically the cyanobacteria, which had poor status and unfavorable trends at all but one station in the river. These concerns are significant enough that the DEQ developed chlorophyll *a* criteria for the James River tidal waters. The composition and abundance of these populations will be monitored closely in the coming year regarding these trends and any presence of toxic species (Figure 3-11; Tables 3-16, 3-17).

Phytoplankton composition within the tidal freshwater region of the James River is discussed in detail by Marshall and Burchardt (2003) identifying the seasonally dominant flora during the monitoring period. Previous discussion regarding long term trends regarding 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 species are presented in Marshall et al. (2005).

D. Benthos

1. Fixed Point Monitoring

Improving trends in the benthic IBI (B-IBI) were detected at station RET5.2 in the Middle James River (JMSOH) and at station SBE5 in the Southern Branch (SBEMH) of the Elizabeth River. The B-IBI met goals at most stations in the main stem of James River except LE5.2 in the Lower James River (JMSMH) and at station TF5.5 in the Upper James River (JMSTF) where the status was marginal and degraded, respectively. Status of the B-IBI at both stations in the Elizabeth River was degraded (Figure 3-12; Table 3-18, 3-19).

2. Probability-Based Monitoring

In the main steam of the James River, the percentage of degraded sites increased from 2% in the upper James River (JMSTFa) to 37% in the lower James River (JMSMHa) but decreased to 12% at the James River mouth (JMSPHa) with segments JMSOHa, JMSMHa, being declared impaired (Table 3-20). The percentages of degraded samples with a contaminant effect ranged from 67% in the upper James River to 78% in the middle James River (JMSOHa) with average contaminant group posterior probabilities ranging from 0.64 to 0.79 (Table 3-21). In the Nansemond River, (sub-segment JMSMHb), 45% of all samples collected were degraded and 90% of these degraded samples were classified as contaminated with an average contaminant group posterior probability of 0.87 with 80% of degraded samples having posterior probabilities of at least 0.90 (Tables 3-20 and 3-21). All of these segments had either no samples or only small percentages of samples with excessive or insufficient abundance and/or biomass. All other segments in the James River could not be assessed for impairment due to insufficient sample size.

All segments in the Elizabeth River were classified as impaired except for the Lafayette River (LAFMH). In all of the impaired segments, the proportion of sites below the threshold ranged from 39% in the lower Elizabeth River main stem (ELIPH) to 70% in the Southern Branch (SBEMH) (Table 3-20). Percentages of degraded samples that were contaminated ranged from 50.0% in the lower Elizabeth River main stem (ELIPHa) to nearly 91% in the Eastern Branch (EBEMHa). At least 80% of all samples were classified as contaminated in both the Southern Branch (SBEMHa) and the Lafayette River (LAFMHa) and 68.4% were classified as contaminated in the upper Elizabeth River main stem (ELIMHa) (Table 3-21). Of the remaining degraded samples without a contaminant effect, excessive abundance/biomass was found in 9.1%, 12.5%, and 5.3% in the Western Branch (WBEMHa), Southern Branch (SBEMHa) and upper Elizabeth River main stem (ELIMH), respectively, indicating the potential of stress due to eutrophication (Table 3-21). Only one of uncontaminated degraded samples had excessive abundance in the lower Elizabeth River main stem (ELIPHa), despite the high percentage value observed. Insufficient abundance/biomass was found in 12.5%, 5.9%, and 15.8% of the remaining uncontaminated degraded samples in the Southern Branch (SBEMHa), the Lafayette River (LAFMHa) and the upper Elizabeth River (ELIMHa), respectively, indicating low dissolved oxygen as an additional source of stress to benthic communities in these segments.

Results indicate that most degraded communities in the James River main stem are located in the upper portions of the river and that contaminants may account for a large portion of the degradation in these segments (JMSTFa, JMSOHa and JMSMHa) . No degraded or contaminated communities were found at the James River mouth (JMSPHa). The primary source of degradation in the Nansemond River (JMSMHb) appears to be anthropogenic contamination. Although sampling was not sufficient for a reliable assessment, contaminated samples were collected in the Chucktuck/Pagan River segment (JMSMHc) and the Warwick River (JMSMHd). The predominant source of stress to benthic communities within the Elizabeth River is anthropogenic contamination. Both eutrophication and low dissolved oxygen appear to be an additional source of stress within the Southern Branch (SBEMHa) and upper Elizabeth River main stem (ELIMHa).

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 in both the James River and the Appomattox River. Reductions in flow corrected concentrations of nutrients at these stations is most likely related to reductions in non-point source loadings since above fall-line point source loading for nitrogen have remained relatively stable and point source loadings of phosphorus have increased overall since 1985. However, unless the increasing trend in point source loadings of total phosphorus is reversed the phosphorus concentrations observed might increase and eliminate improvements observed in this parameter.

Reduced water clarity is apparently a widespread problem in the main stem of the James River. Relative status of both secchi depth and total suspended solids was poor in most segments of the river. The SAV habitat requirements for secchi depth and surface total suspended solids were not met in most segments in the James River. In addition, degrading trends in secchi depth and surface and bottom total suspended solids occurred in several segments. Nutrient levels appear to be problematic in the lower segments of the James River (JMSOH, JMSMH, JMSPH) as indicated by the following: 1) relative status of nutrients was generally worse in these segments than those upstream, 2) nutrients in these segments either did not meet the habitat values or were borderline with respect to the criteria, and 3) degrading trends in both nitrogen and phosphorus parameters were observed.

The water clarity problems identified for the James River in this study have been described previously. A recent survey of water quality and living resource conditions in US Mid-Atlantic estuaries indicated that the SAV habitat requirements for secchi depth used as criteria by our study were not met in 68% of the tidal portion of the James River (Kiddon et al., 2003). The widespread distribution of the water clarity problems in the James River makes identification of a source(s) difficult. Water clarity can be related to sediment loadings from non-point source runoff, shoreline erosion and/or marsh erosion, phytoplankton densities, sediment resuspension, concentrations of dissolved organic matter or a combination of these factors. Each of these factors could be influenced directly or indirect by point and non-point source run-off of nutrients and/or sediments (Gallegos et al., 2005.). Additional BMPs for erosion control could help to reduce sediment loadings to the James River while reductions in point source nutrients could help to reduce phytoplankton concentrations in the James River. Estimation of non-point source loadings of sediments at finer spatial and temporal scales, measurements of dissolved organic matter and the addition of phytoplankton monitoring stations in areas not currently sampled could help to identify the source(s) of water clarity problem. Elevated concentrations, violations of nutrient SAV criteria, and degrading trends in nutrients were localized to those segments in the lower tidal portions of the estuary. The most likely explanation for these problems is the large point source inputs of nutrients in these segments.

Water quality conditions within the Elizabeth River are degraded as evidenced by: 1) the poor status of nitrogen and phosphorus parameters in all segments of the river, 2) the poor status of secchi depth in all segments of the river, and 3) the failure of SAV habitat criteria for surface dissolved inorganic nitrogen in most segments and for surface dissolved inorganic phosphorus in all segments. The source of water quality problems in the Elizabeth River is a combination of high point source and non-point source input of nutrients and sediments due to intense urbanization of the region around this river. The region has several significant point source facilities that contribute nutrient loadings to the river. In addition, this area has the highest population density, the highest concentration of developed land, and the highest percentage of impervious surfaces of all of the sub-watersheds of the James River. These factors coupled with relatively little forested land and few riparian buffers contribute to increased non-point source run-off to the Elizabeth River. Improving trends in nutrient concentrations observed are probably the result of a combination of factors which includes: 1) the phosphate ban, 2) the implementation of biological nutrient removal in local sewage treatment plants, 3) increases in the use of improved storm water runoff practices, 4) and the implementation of wetlands restoration (Alden et al., 1997; Elizabeth River Project, 2001).

Problems with phytoplankton communities also tended to be widespread throughout the tidal James River as exhibited by: 1) the occurrence of long-term degrading trends in cyanobacteria abundance and biomass at most stations, 2) the fair to poor status of dinoflagellates and cyanobacteria biomass, and 3) the poor status of the biomass-to-abundance ratio at all stations in the James River. The presence of a diverse cyanobacteria flora has been recorded from the tidal freshwater and oligohaline waters of the James (Marshall and Burchardt, 1998). A common toxin producer in this assemblage is *Microcystis aeruginosa*, a colonial cyanobacteria that is a bloom producer. Another concern is the increasing trend of dinoflagellates at station LE5.5. Many of these taxa are common bloom producers, some toxin producer (Marshall , 2003; Marshall et al., 2005). These widespread phytoplankton community problems supported the development of regulatory chlorophyll criteria in the James. The primary concern for phytoplankton in the Elizabeth River, are the degrading trends in cyanobacteria biomass and abundance. Improving trends observed in this tributary may reflect improvements in water quality.

Fixed point monitoring indicated the primary area of concern with respect to the benthos in the main stem of the James River is the Upper James River (JMSTF) at station TF5.5 where status of the B-IBI is degraded. Status of the benthos at the remaining fixed point stations either met the restoration goals or was marginal and improving trends in the B-IBI and some component metrics were detected at several stations. Poor status of the B-IBI at station TF5.5 may reflect the long-term impacts of point sources located upstream of this station and the improving trends in B-IBI component metrics may be correlated with reductions in both nitrogen and phosphorus loadings that have occurred at the Hopewell sewage treatment plant.

In the Elizabeth River, fixed point monitoring indicated that Southern Branch of the Elizabeth River remains degraded despite significant improving trends in B-IBI at one station and/or its component metrics at both stations. Poor status at these stations undoubtably reflects the poor water quality conditions reflected in poor relative status and violations of SAV criteria coupled with long term sediment contamination problems. Improvements in the B-IBI at these stations may reflect improvements in water quality conditions indicated by the improving trends in nutrients and total suspended solids.

Results of the probability-based monitoring program indicated that of the five segments with a sample size large enough to conduct a diagnostic assessment three (JMSOH, JMSMHa, and the Nansemond River- segment JMSMHb) were classified as impaired with from 28% to 45% of the total area of these segments being degraded. Previous estimates of the areal extent of benthic community degradation in the James River are similar to these results (Paul et al., 1999; Kiddon et al., 2003). For each of the impaired segments anthropogenic contaminants are identified as the predominant source of stress to the benthos while eutrophication and low dissolved oxygen do not appear to be a substantial problem. Sediment toxicity effects associated with chemical contaminants have been previously observed at a limited number of sites in the James River (Hall et al., 2002) but the areal extent of toxic sediments as measured by bioassay tests is generally small (<10%) (Paul et al., 1999; Kiddon et al., 2003). Results from other probability based monitoring programs provide evidence of potential contaminant problems but the concentration levels in sediments did not typically exceed the Long et al. (1995) Effects Range - Median (ER-M) levels typically associated with toxic effects. Still, estimates of the percent area of the James River with at least one contaminant in excess of the Long et al. (1995) Effect Range - Low range from 26% (Paul et al., 1999) to as high as 64% (Kiddon et al., 2003). In addition, dissolved oxygen does not appear to be factor that adversely impacts benthic communities in the James River. Our results indicate that either no stations or only a small percentage of stations in the impaired segments were affected by low dissolved oxygen. These results agree with other probability based monitoring programs which indicated that only from between 0% (Paul et al., 1999) to 5% (Kiddon et al., 2003) of the total area of the James River was subject to low dissolved oxygen levels.

USEPA (1999) has indicated the middle and lower portions of the James River as an area with potential adverse effects due to contaminants. These results appear to justify that classification. However, without direct measurements of sediment contaminant concentrations the source and spatial extent of contaminant problems in the James River cannot be verified. GIS mapping of the distribution of samples identified as potentially contaminated may assist with future studies of direct measurement of contaminants in the James River.

Within the Elizabeth River, five out of six segments monitored were classified as impaired with from 39% of samples at the Elizabeth River Mouth (ELIPHa) to 70% of samples in the Southern Branch (SBEMH) being declared degraded. The predominant source of stress to benthic communities appears to be anthropogenic contamination. Our results agree with previous studies conducted in the Elizabeth River which indicated significant sediment toxicity associated with organic and/or metals contaminants. At one site in the Southern Branch of the Elizabeth River sediment concentrations of four metals, nine organic contaminants and two pesticides exceeded the Long et al. (1995) Effects Range Median (ER-M) values and sediment toxicity was observed. Sediment concentrations of mercury and six PAHs exceeded ER-M values in the Elizabeth River main stem and sediment Effects Range Low values were also exceeded for organic and/or metals contaminants and significant sediment toxicity was observed at sites in Southern, Eastern and Western branches (see review by Hall et al., 2002). Contamination in the Elizabeth River is probably the result of a combination of factors that include historical contamination, municipal and industrial point sources, non-point source storm water run-off, and automobile emissions.

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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

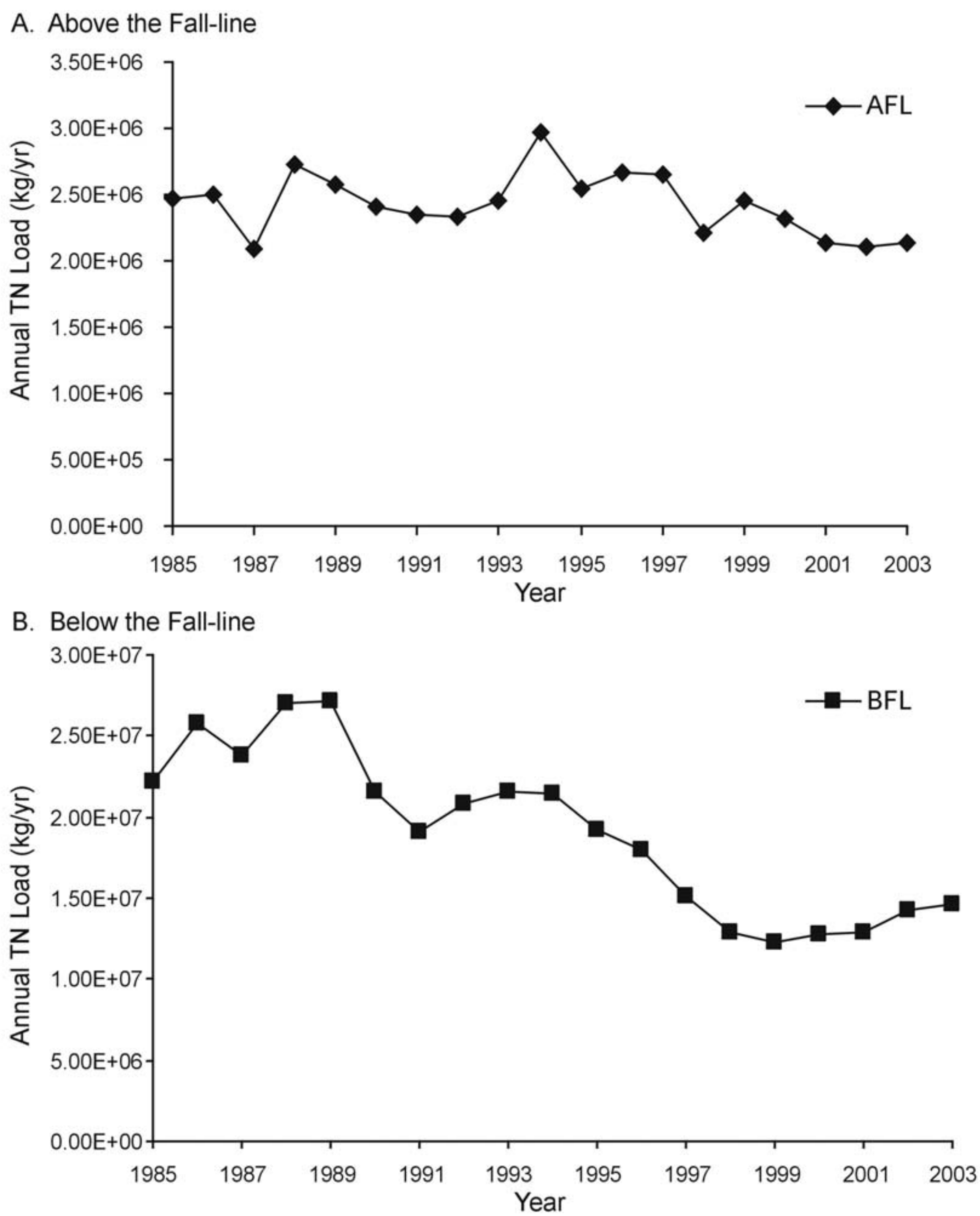


Figure 3-1. Long-term changes in above fall-line (AFL) and below fall-line (BFL) discharged point source Total Nitrogen Loadings A. Above the Fall-line, and B. Below the Fall-line in the James River for 1985 through 2004.

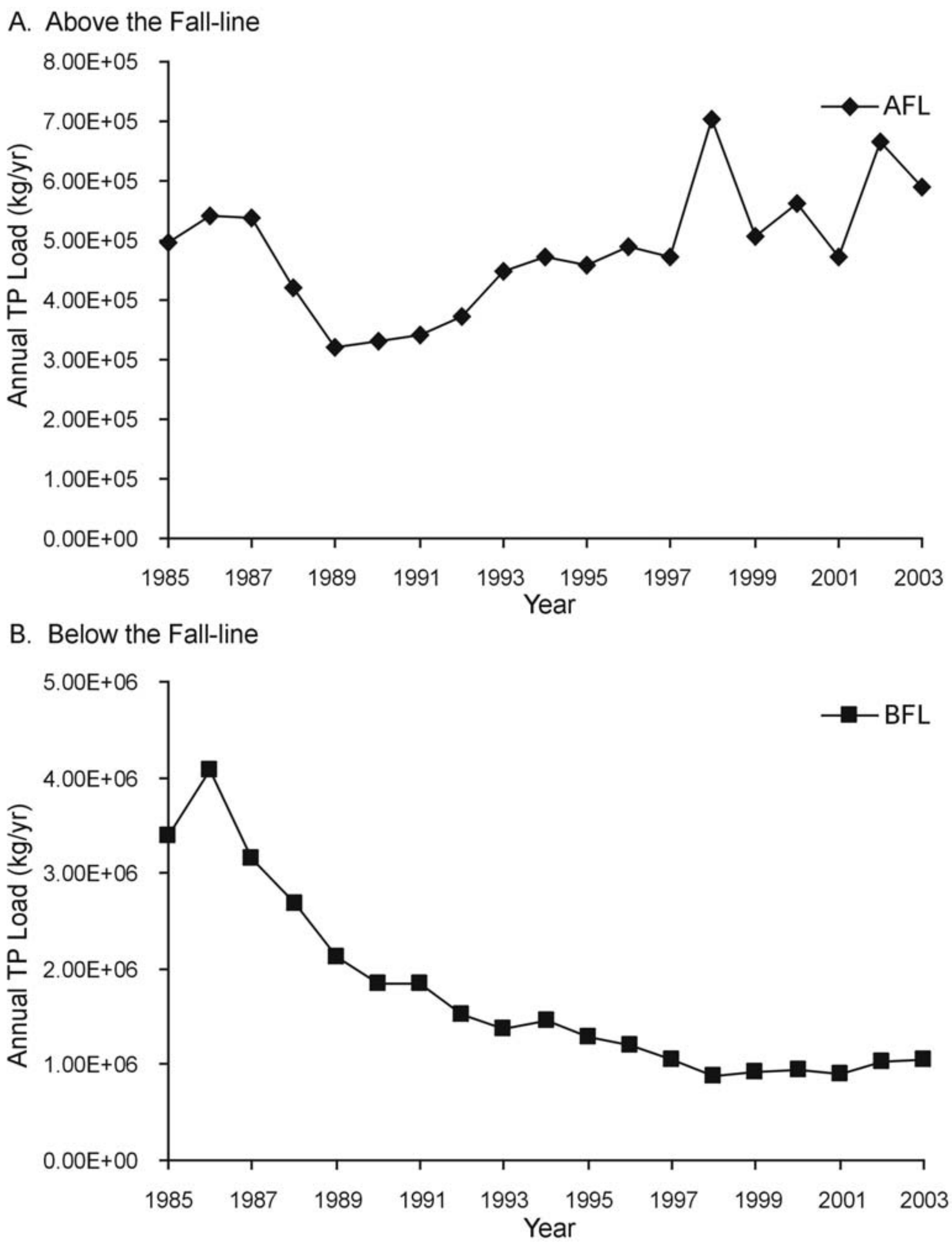


Figure 3-2. Long-term changes in above fall-line (AFL) and below fall-line (BFL) discharged point source Total Phosphorus Loadings A. Above the Fall-line, and B. Below the Fall-line in the James River for 1985 through 2004.

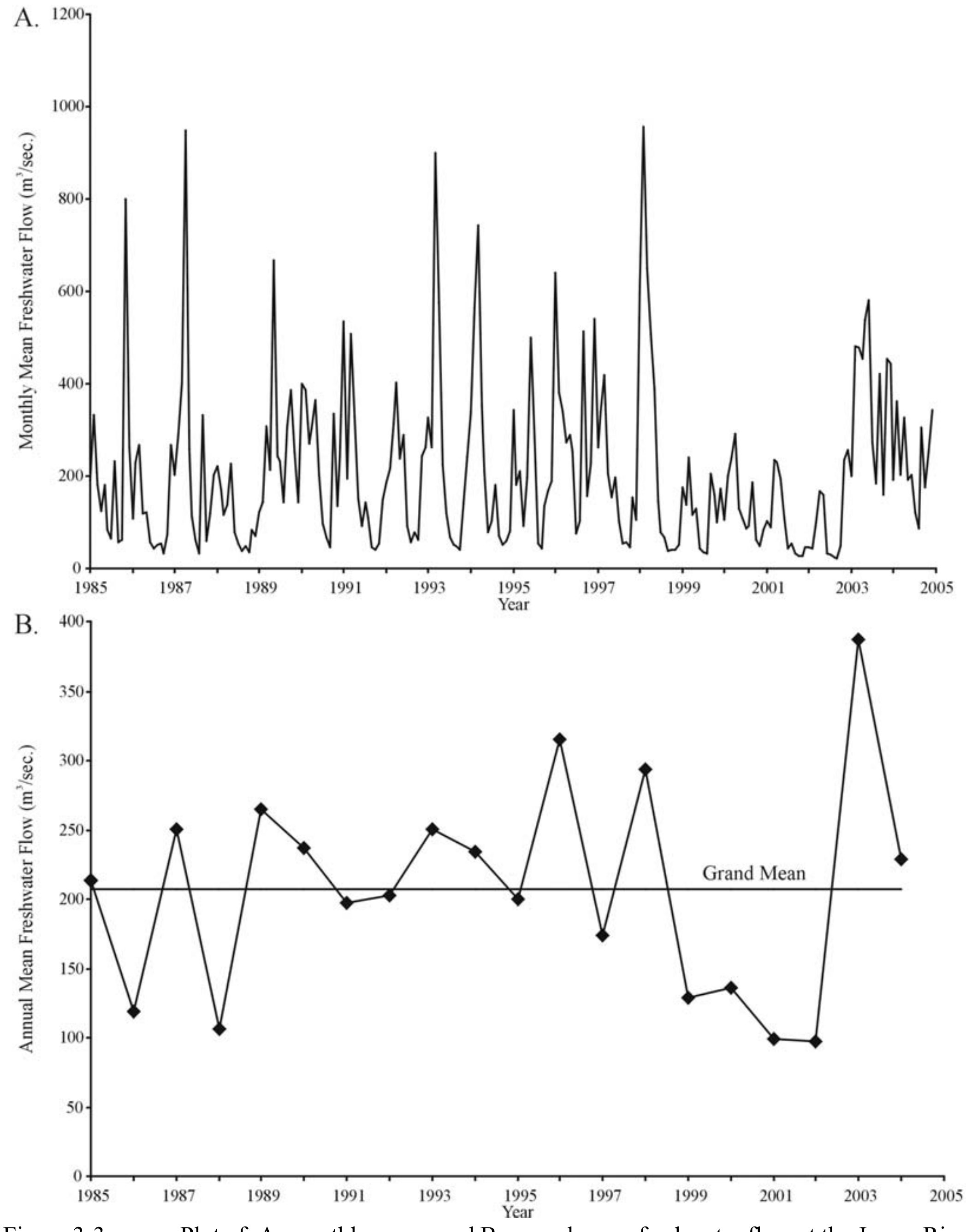
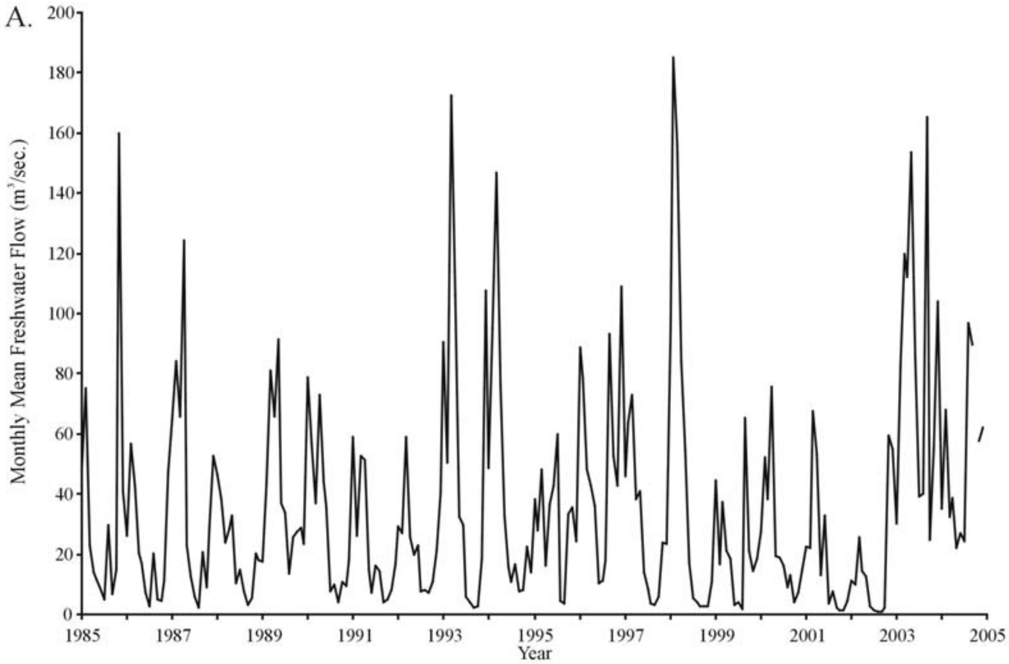


Figure 3-3. Plot of: A. monthly mean, and B. annual mean freshwater flow at the James River fall-line for the period of 1985 through 2004.



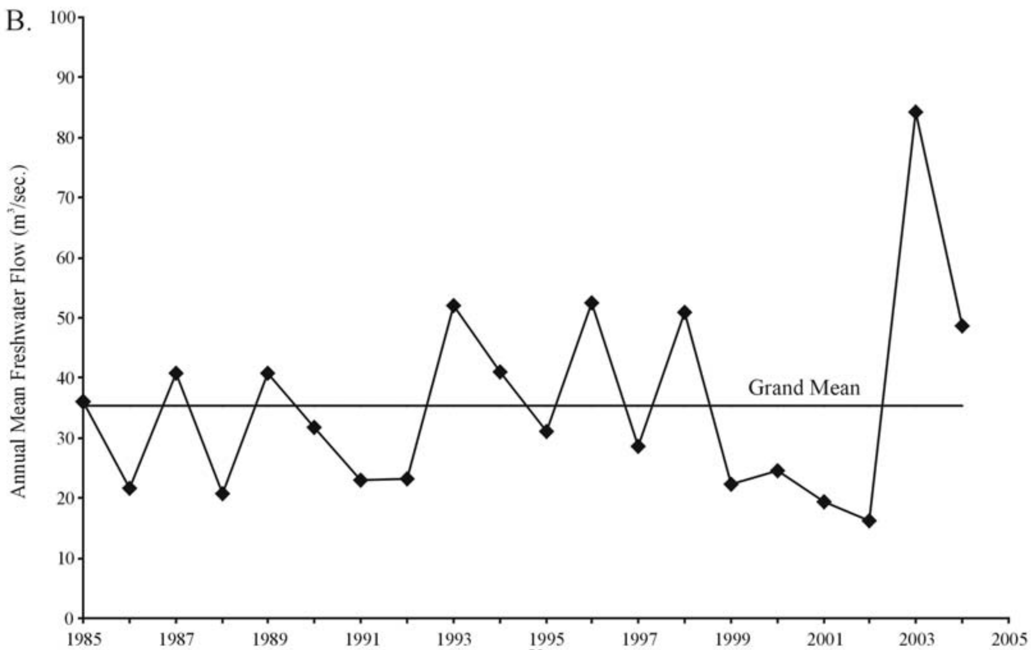
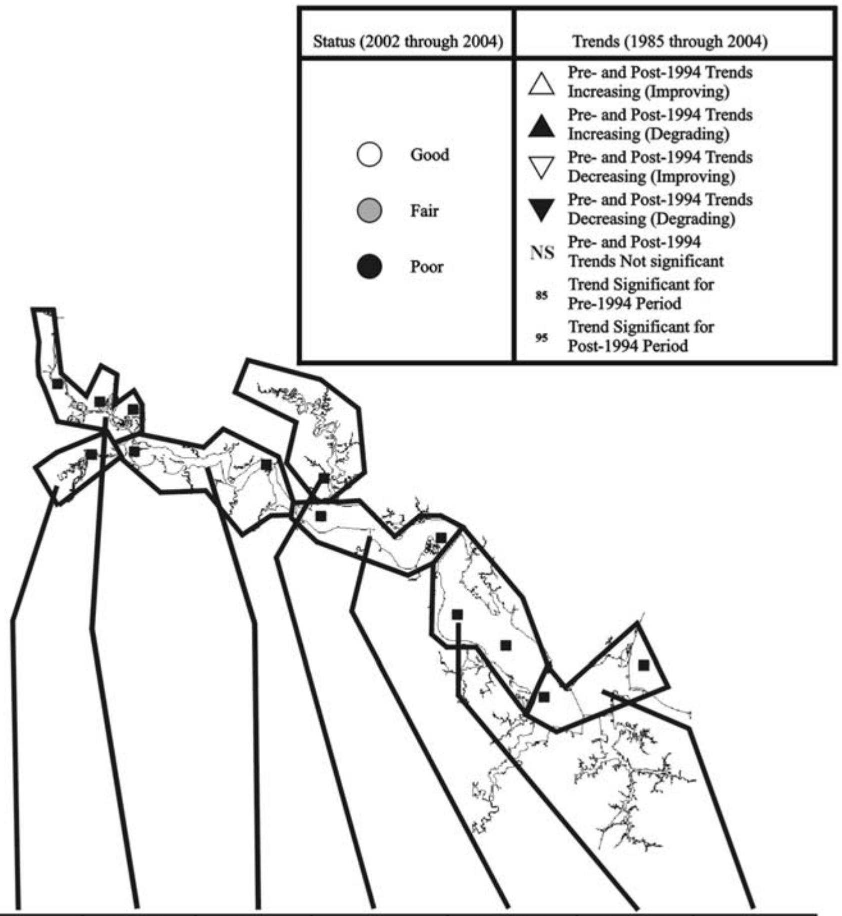
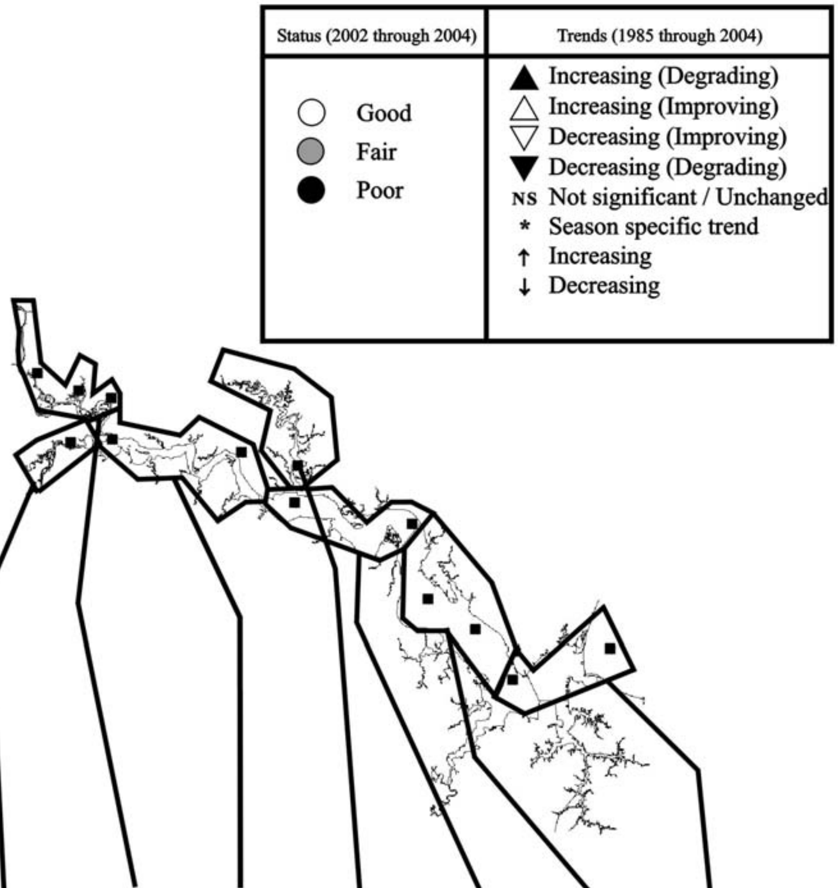


Figure 3-4. Plot of: A. monthly mean, and B. annual mean freshwater flow at the Appomattox River fall-line for the period of 1985 through 2004.



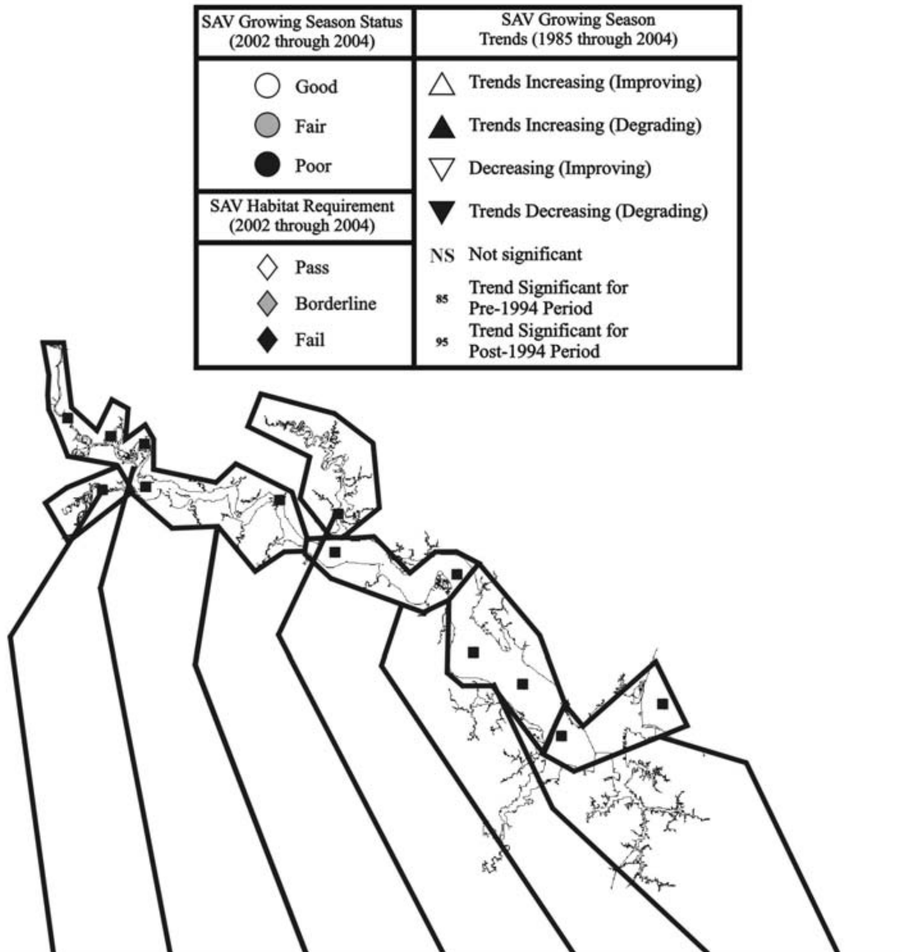
Parameter	Appomattox	Upper James 2	Upper James 1	Chickahominy	Middle James	Lower James	River Mouth
STN	○ NS	○ ▽85	○ ▽	○ NS	○ NS	○ NS	○ NS
BTN	○ NS	○ ▽85	○ ▽	○ NS	○ NS	◍ ▲	◍ NS
SDIN	○ NS	○ ▽85	○ NS	○ NS	○ ▽85	◍ NS	◍ NS
BDIN	○ NS	○ ▽85	○ ▽	○ NS	○ ▽85	◍ NS	◍ NS
STP	◍ NS	○ ▽85	○ NS	○ NS	○ ▲85	◍ ▲85	◍ NS
BTP	○ NS	○ ▽85	◍ ▽85	○ NS	◍ ▲85 ▽95	◍ ▲85	◍ ▽95
SDIP	○ ▽	◍ ▽85	◍ ▽	○ NS	◍ NS	● ▲	◍ NS
BDIP	◍ ▽	◍ ▽	◍ ▽	○ NS	◍ NS	● ▲	○ NS

Figure 3-5. Map of the James River basin showing summaries of the status and trend analyses for each segment for the period of 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-method change trends. For such cases, the first symbol represents the pre-method change result while the second symbol is the post method change result.



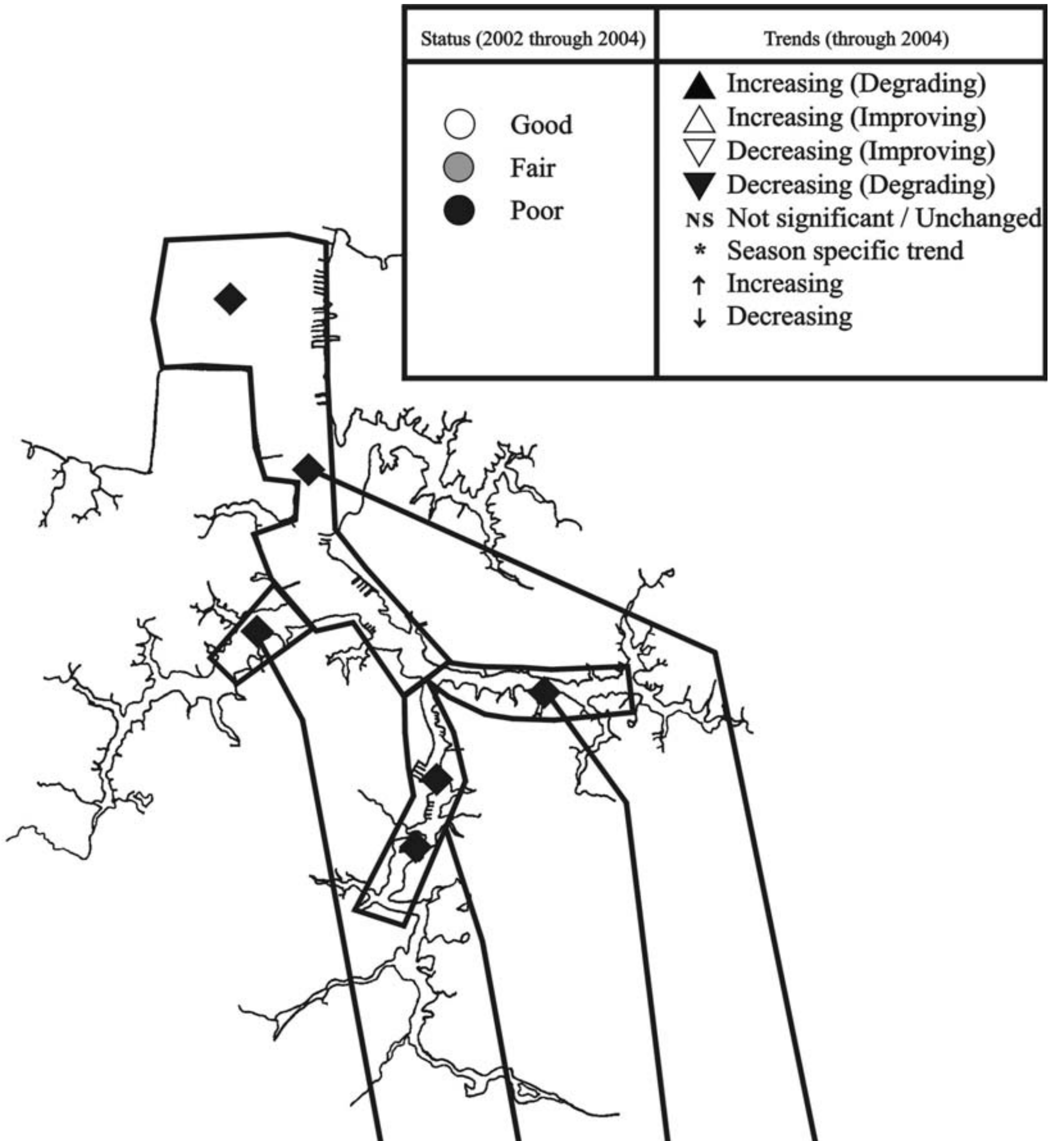
Parameter	Appomattox	Upper James 2	Upper James 1	Chickahominy	Middle James	Lower James	River Mouth
SCHLA	○ NS	○ NS	○ NS	◍ ▽	○ NS	○ NS	◍ NS
STSS	● NS	○ NS	● ▲	◍ NS	● NS	◍ NS	◍ NS
BTSS	◍ NS	○ NS	● ▲	◍ ▲	● NS	● ▲	◍ NS
SECCHI	◍ NS	○ NS	● ▼	◍ ▼	● NS	● NS	● ▼
BDO	○ NS	○ △	○ △	○ NS	○ NS	○ NS	○ △
SSALIN	NS	NS	NS	NS	NS	NS	NS
BSALIN	NS	NS	NS	NS	NS	NS	↓
SWTEMP	NS	NS	NS	NS	NS	NS	NS
BWTEMP	NS	NS	NS	NS	NS	NS	↑

Figure 3-6. Map of the James River basin showing summaries of the status and trend analyses for each segment for the period of 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.



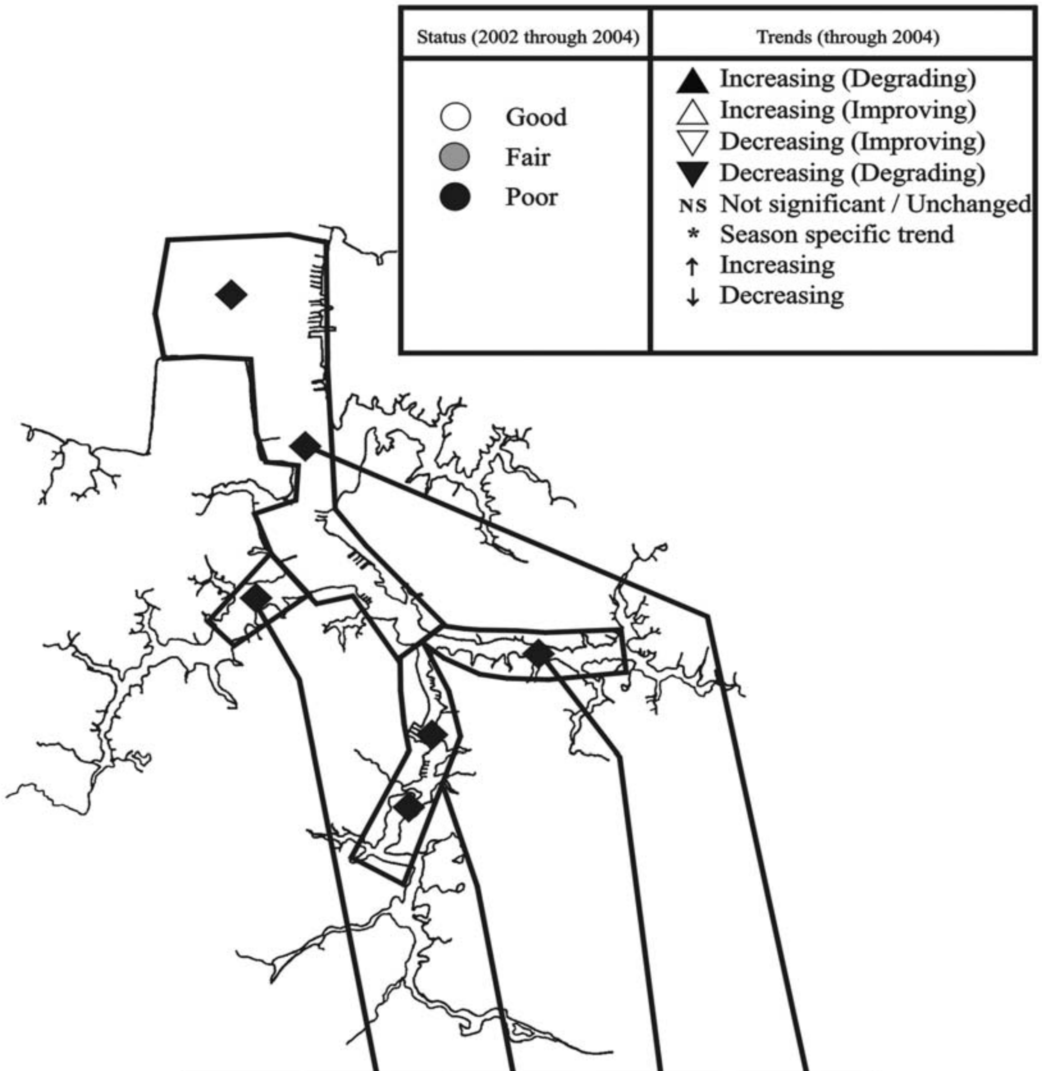
Parameter	Appomattox	Upper James 2	Upper James 1	Chickahominy	Middle James	Lower James	River Mouth
STN	Good, NS	Good, ▽ 85	Good, ▽	Good, NS	Good, NS	Good, ▲	Fair, NS
SDIN	Good, NS	Good, ▽ 85	Good, NS	Good, NS	Good, ▽ 85 / ▲ 95	Fair, Borderline, NS	Fair, Borderline, NS
STP	Good, NS	Good, ▽ 85	Good, NS	Good, NS	Good, ▲ 85	Fair, ▲ 85	Fair, ▲ 85
SDIP	Good, Borderline, NS	Fair, Fail, ▽ 85	Fair, Borderline, NS	Good, Pass, NS	Fair, Fail, ▲	Poor, Fail, ▲	Poor, Borderline, NS
SCHLA	Good, Borderline, ▽	Good, Pass, NS	Good, Pass, NS	Fair, Pass, ▽	Good, Pass, NS	Good, Pass, NS	Fair, Pass, NS
STSS	Fair, Fail, NS	Good, Pass, NS	Poor, Fail, ▲	Fair, Borderline, NS	Poor, Fail, NS	Fair, Borderline, NS	Fair, Pass, NS
SECCHI	Poor, Fail, NS	Good, Borderline, NS	Poor, Fail, ▼	Poor, Fail, ▼	Poor, Fail, NS	Poor, Fail, NS	Poor, Borderline, NS
BDO	Good, NS	Good, △	Good, NS	Good, NS	Good, NS	Good, NS	Good, △

Figure 3-7. Map of the James 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-method change trends. For such cases, the first symbol represents the pre-method change result while the second symbol is the post method change result.



Parameter	Western Branch	Southern Branch	Eastern Branch	Elizabeth River Mainstem
STN	Fair ▽	Poor ▽	Poor NS	Fair NS
BTN	Poor ▽	Poor NS	Poor ▽	Fair NS
SDIN	Fair NS	Poor ▽	Poor NS	Poor NS
BDIN	Poor NS	Poor NS	Poor ▽	Poor NS
STP	Poor ▽	Fair ▽	Poor ▽	Fair NS
BTP	Fair ▽	Poor ▽	Fair ▽	Poor NS
SDIP	Poor ▽	Poor ▽	Poor ▽	Poor NS
BDIP	Poor ▽	Poor ▽	Poor ▽	Poor NS

Figure 3-8. Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment for the period of 1989 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 surface and bottom measurements, respectively.



Parameter	Western Branch		Southern Branch		Eastern Branch		Elizabeth River Mainstem	
SCHLA	Fair	▽	Good	NS	Good	NS	Fair	NS
STSS	Poor	▽	Good	▽	Fair	▽	Fair	▽
BTSS	Poor	▽	Good	▽	Good	▽	Fair	NS
SECCHI	Poor	NS	Poor	NS	Poor	NS	Poor	▼
BDO	Good	NS	Fair	NS	Fair	NS	Fair	NS
SSALIN		NS		NS		NS		NS
BSALIN		NS		NS		NS		↓
SWTEMP		NS		↑		NS		NS
BWTEMP		NS		↑		NS		NS

Figure 3-9. Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment for the period of 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.

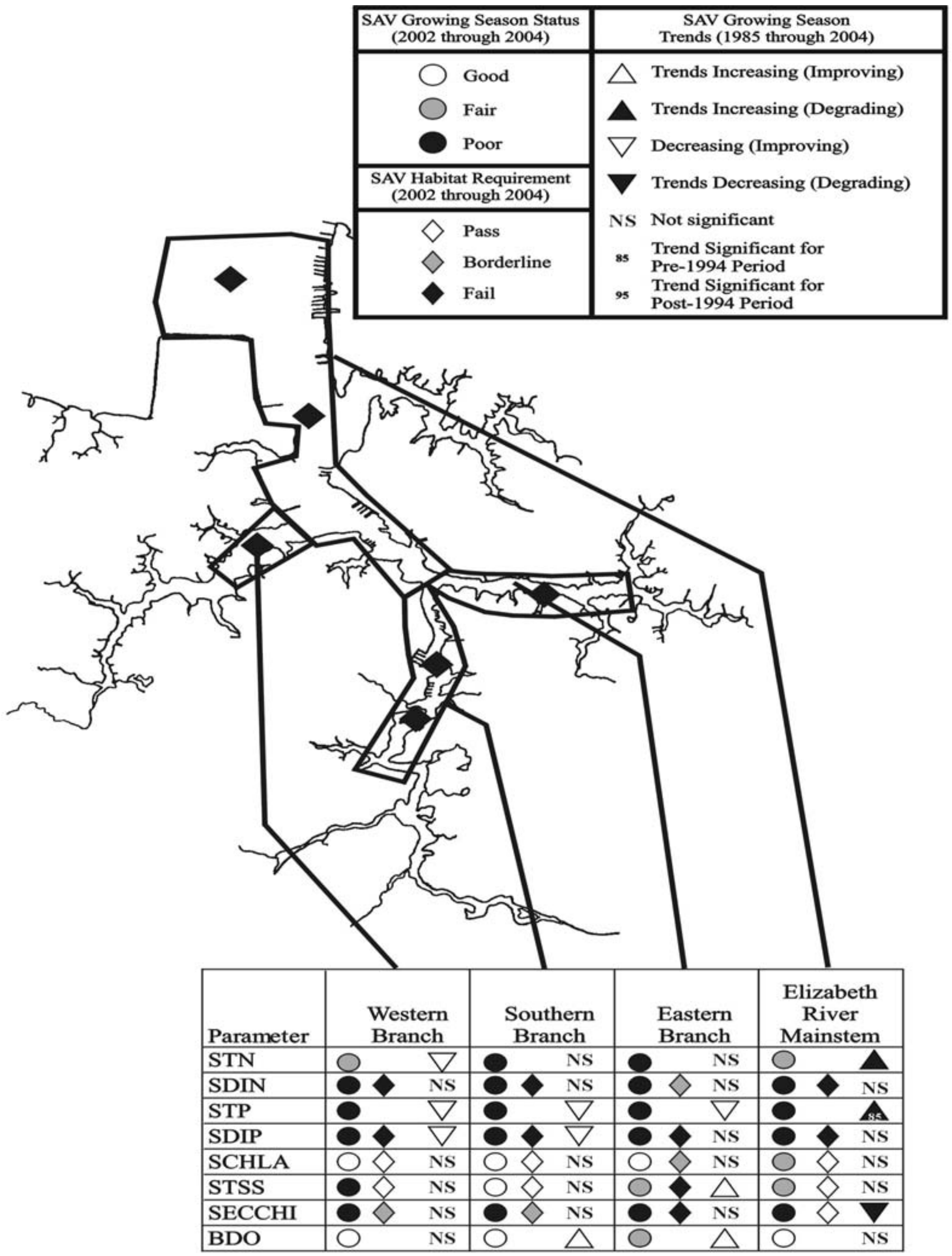
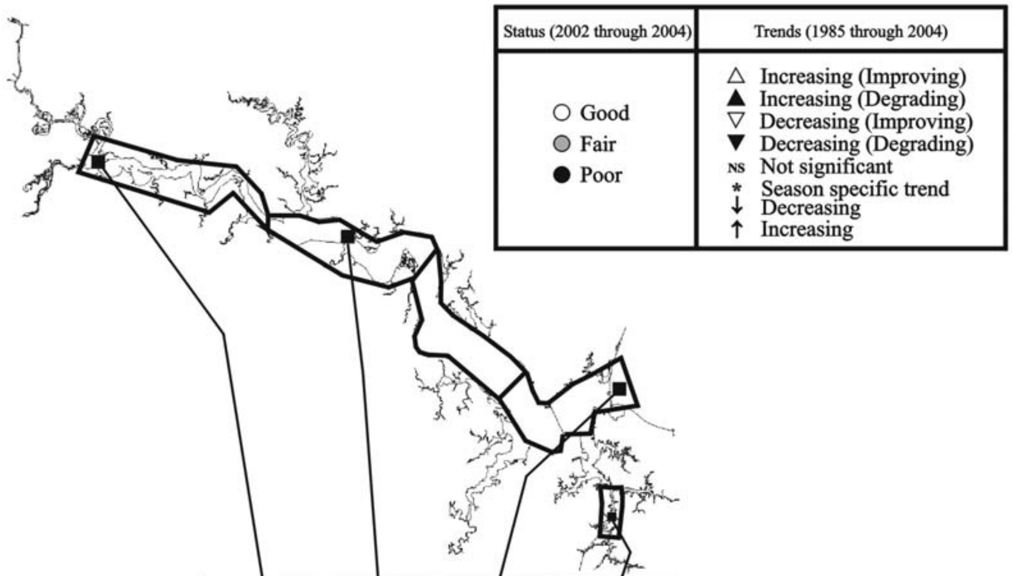
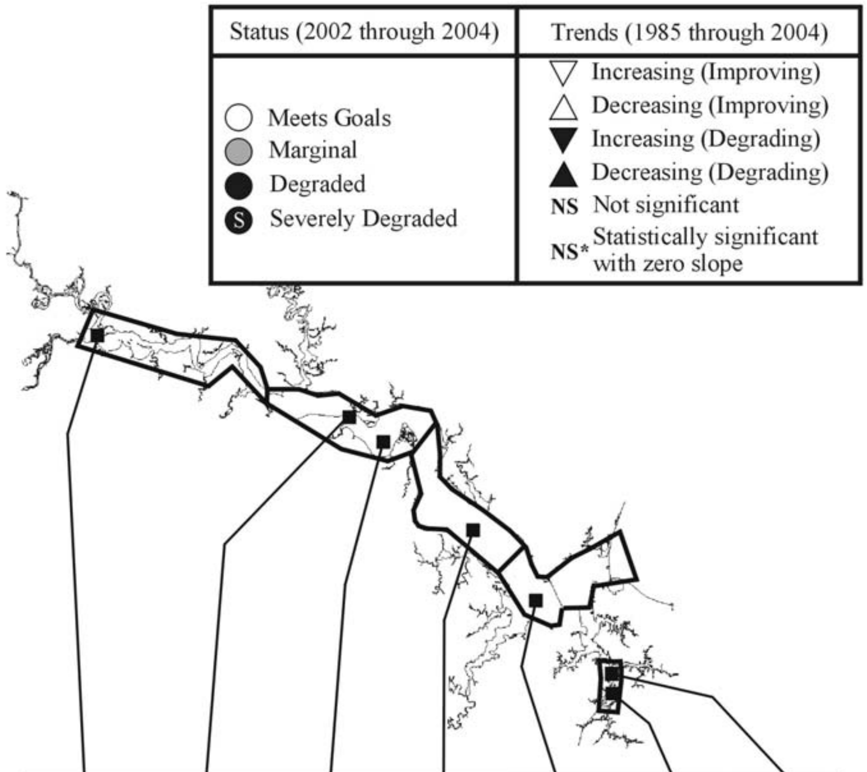


Figure 3-10. Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment for the period of 1985 through 2004 for the SAV growing season. Abbreviations for each parameter are: TN=total nitrogen, SDIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved 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-method change trends. For such cases, the first symbol represents the pre-method change result while the second symbol is the post method change result.



	TF5.5	RET5.2	LE5.5	SBE5
Total Abundance	↑	NS	↑	↑
Total Biomass	Fair ↑	Fair ↑	Poor ↑	Poor ↑
Biomass to Abundance	Poor △	Poor △	Poor NS	Poor NS
Margalef Diversity Index	Good NS	Poor ▼	Poor NS	Good NS
Productivity	Poor NS	Fair ▽	Poor NS	Good ▽
Diatom Biomass	Good △	Good △	Good △	Fair △
Dinoflagellate Biomass	Poor NS	Poor NS	Fair ▲	Fair NS
Cyanophyte Biomass	Poor ▲	Poor NS	Poor ▲	Fair ▲
Chlorophyte Biomass	Good △	Good △	Good △	Good △
Picoplankton Biomass	Poor ▽	Poor ▽	Fair NS	Good NS
Cryptophyte Biomass	Good △	Good △	Good NS	Good △
Cyanophyte Abundance	Poor ▲	Poor NS	Poor ▲	Fair ▲

Figure 3-11. Map of the James River basin showing summaries of the status and trend analyses for phytoplankton bioindicators for each segment for the period of 1985 through 2004.



	TF5.5	RET5.2	LE5.1	LE5.2	LE5.4	SBE5	SBE2
Benthic IBI	● NS	○ △	○ NS	◍ NS	○ NS	● △	● NS
Total Abundance	NS	NS	NS	△	NS	NS	△
Total Biomass	NS	NS	NS	NS	▼	NS	NS
Pollution Sensitive Species Abundance (%)	△	△	NS	△	NS	△	△
Pollution Indicative Species Abundance (%)	NS	NS	NS	NS	NS	▽	▽
Pollution Sensitive Species Biomass (%)	△	△	NS	NS	▼	△	△
Pollution Indicative Species Biomass (%)	NS	NS	NS	NS	NS	▽	NS
Shannon-Weiner Diversity Index	NS	△	NS	NS	▼	NS	NS

Figure 3-12. Map of the James 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 James River watershed in comparison to A. Watersheds of the Virginia portion of Chesapeake Bay, and within B. Sub-watersheds of the James 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 total)									
Watershed	Total Area	Developed	Agriculture	Forested	Open Water	Wetland	Barren	Impervious Surfaces	Riparian Buffers (%)	Pop. Number/ Density(#/km^2)
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 (58.5)	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(60.2)	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(60.3)	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 James River

	Land Use Area in km^2 (percent of total)									
Subwatershed	Total Area	Developed	Agriculture	Forested	Open Water	Wetland	Barren	Impervious Surfaces	Riparian Buffers (%)	Pop. Number/ Density(#/km^2)
AFL Upper James	7,938	67(0.8)	1158(14.6)	6630(83.5)	44(0.6)	10(0.1)	26(0.3)	140(0.3)	4427(40)	313780(40)
AFL North of Hopewell	642	171(26.6)	127(19.8)	280(43.5)	31(4.8)	18(2.8)	16(2.4)	11(10.6)	359(33)	367126(572)
AFL Piedmont	12,362	184(1.5)	2173(17.6)	9438(76.3)	114(0.9)	212(1.7)	243(2.0)	218(0.4)	8061(40)	186360(15)
AFL Richmond	790	91(11.5)	179(22.6)	461(58.4)	23(3.0)	28(3.6)	8(1.0)	14(3.8)	478(37)	60550(77)
AFL Swift Creek	471	21(4.4)	60(12.6)	376(79.7)	8(1.6)	3(0.5)	5(1.1)	8(2.1)	346(43)	188746(400)
AFL Upper Chickahominy	787	137(17.4)	148(18.8)	394(50.0)	10(1.3)	91(11.5)	8(1.0)	14(6.3)	739(32)	85669(109)
Appomattox	212	47(22.0)	44(20.7)	101(47.6)	5(2.4)	8(2.7)	8(3.7)	4(9.0)	121(32)	84765(399)
Lower Chickahominy	430	5(1.2)	52(12.0)	277(64.5)	39(9.0)	52(12.0)	5(1.2)	8(0.4)	537(34)	10343(24)
Upper Tidal James	730	18(2.5)	135(18.4)	445(61.0)	93(12.8)	31(4.3)	5(0.7)	13(1.2)	419(34)	36769(50)
Middle Tidal James	368	13(3.5)	62(16.9)	168(45.8)	96(26.1)	28(7.7)	3(0.7)	6(1.9)	311(35)	39886(108)
Lower Tidal James	803	73(9.0)	137(17.1)	256(31.9)	272(33.9)	62(7.7)	5(0.6)	14(3.8)	371(26)	166367(207)
Nansemond	559	28(5.1)	181(32.4)	197(35.2)	60(10.6)	85(15.3)	10(1.9)	10(2.5)	248(22)	49578(89)
Elizabeth River/Hampton Roads	668	259(38.8)	114(17.1)	52(7.8)	163(24.4)	67(10.1)	13(1.9)	12(21.1)	74(9)	594760(890)

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	-15	9,676,183	-9	1,014,036	-12
York	268,239	-19	2,841,566	-18	112,347	-21
Rappahannock	383,145	-22	3,155,383	-25	290,692	-23
Potomac	696,186	-17	6,661,144	-5	623,163	-17
Coastal	86,828	-15	871,116	-12	19,722	-8
Totals	3,187,342	-17	23,206,301	-12	2,061,532	-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	-61	7,426,636	-31
York (10)	71,424	-63	604,317	1
Rappahannock (18)	27,862	-67	231,831	-2
Potomac (39)	120,817	-51	2,186,824	-46
Coastal Bays (5)	3,040	-84	87,379	-34
Totals	989,494	-6	10,449,608	-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 James River watershed RIM stations located in the Jackson River at Covington, the James River at Cartersville, the James River at Scottsville, and the Appomattox River at Matoaca for the period 1985 through 2004.

Station Name	Parameter	Beta-T	p-value	% Change	Direction
James River at Bent Creek	TN	-0.2776	0.0031	-24.2	Improving
James River at Bent Creek	TP	-1.5287	<0.0001	-78.3	Improving
James River at Bent Creek	TSS	0.0872	0.7161	9.1	No trend
James River at Cartersville	TN	-0.2602	<0.0001	-22.9	Improving
James River at Cartersville	DNO23	-0.6167	<0.0001	-46	Improving
James River at Cartersville	TP	-0.8544	<0.0001	-57.4	Improving
James River at Cartersville	DIP	-1.357	<0.0001	-74.3	Improving
James River at Cartersville	TSS	-0.2337	0.0523	-20.8	No trend
James River near Richmond	TN	-0.1514	0.1006	-14.1	No trend
James River near Richmond	TP	-1.1887	<0.0001	-69.5	Improving
James River near Richmond	TSS	0.0541	0.7839	5.6	No trend
Appomattox River at Matoaca	TN	-0.0714	0.1591	-6.9	No trend
Appomattox River at Matoaca	DNO23	-0.2888	0.0177	-25.1	Improving
Appomattox River at Matoaca	TP	0.1644	0.0526	17.9	No trend
Appomattox River at Matoaca	DIP	-0.0822	0.4404	-7.9	No trend
Appomattox River at Matoaca	TSS	-0.0094	0.9154	-0.9	No trend
South River near Waynesboro	TN	-0.0637	0.395	-6.2	No trend
South River near Waynesboro	TP	-1.137	<0.0001	-67.9	Improving
South River near Waynesboro	TSS	-0.3459	0.0735	-29.2	No trend

Table 3-4. Annual and Summer (DO only) season water quality status in the James River, Appomattox River, and Chickahominy 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
APPTF	TN	Annual	0.81	13.37	Good	0.83	10.23	Good
APPTF	DIN	Annual	0.31	15.30	Good	0.33	14.96	Good
APPTF	STP	Annual	0.09	34.68	Fair	0.09	29.60	Good
APPTF	PO4F	Annual	0.02	33.25	Good	0.02	38.09	Fair
APPTF	CHLA	Annual	6.64	35.94	Good	-	-	-
APPTF	TSS	Annual	21.00	64.51	Poor	29.00	48.20	Fair
APPTF	SECCHI	Annual	0.40	36.37	Fair	-	-	-
APPTF	DO	Summer1	-	-	-	7.43	-	Good
JMSTF1	TN	Annual	0.92	16.31	Good	1.05	18.75	Good
JMSTF1	DIN	Annual	0.46	23.80	Good	0.45	23.26	Good
JMSTF1	STP	Annual	0.08	31.25	Good	0.11	39.91	Fair
JMSTF1	PO4F	Annual	0.02	35.84	Fair	0.02	40.30	Fair
JMSTF1	CHLA	Annual	5.60	32.61	Good	-	-	-
JMSTF1	TSS	Annual	29.00	77.17	Poor	58.00	79.02	Poor
JMSTF1	SECCHI	Annual	0.40	21.12	Poor	-	-	-
JMSTF1	DO	Summer1	-	-	-	6.78	-	Good
JMSTF2	TN	Annual	0.73	9.41	Good	0.79	9.01	Good
JMSTF2	DIN	Annual	0.38	18.74	Good	0.44	20.20	Good
JMSTF2	STP	Annual	0.06	23.82	Good	0.08	23.23	Good
JMSTF2	PO4F	Annual	0.03	42.20	Fair	0.03	48.45	Fair
JMSTF2	CHLA	Annual	1.34	5.56	Good	-	-	-
JMSTF2	TSS	Annual	7.00	20.01	Good	21.00	25.09	Good
JMSTF2	SECCHI	Annual	0.85	88.49	Good	-	-	-
JMSTF2	DO	Summer1	-	-	-	7.57	-	Good
CHKOH	TN	Annual	0.71	10.60	Good	0.71	11.39	Good
CHKOH	DIN	Annual	0.15	10.52	Good	0.13	9.69	Good
CHKOH	STP	Annual	0.07	28.96	Good	0.08	25.75	Good
CHKOH	PO4F	Annual	0.01	29.91	Good	0.01	34.24	Good
CHKOH	CHLA	Annual	11.62	52.42	Fair	-	-	-
CHKOH	TSS	Annual	17.00	54.62	Fair	33.00	52.41	Fair
CHKOH	SECCHI	Annual	0.50	36.37	Fair	-	-	-
CHKOH	DO	Summer1	-	-	-	6.09	-	Good
JMSOH	TN	Annual	0.81	14.98	Good	0.85	16.41	Good
JMSOH	DIN	Annual	0.38	25.11	Good	0.35	28.21	Good
JMSOH	STP	Annual	0.07	32.83	Good	0.10	46.26	Fair
JMSOH	PO4F	Annual	0.03	49.17	Fair	0.03	54.96	Fair
JMSOH	CHLA	Annual	6.41	26.66	Good	-	-	-
JMSOH	TSS	Annual	22.25	71.21	Poor	50.50	73.61	Poor
JMSOH	SECCHI	Annual	0.45	21.12	Poor	-	-	-
JMSOH	DO	Summer1	-	-	-	6.27	-	Good
JMSMH	TN	Annual	0.65	21.39	Good	0.64	41.76	Fair
JMSMH	DIN	Annual	0.25	38.91	Fair	0.20	50.05	Fair
JMSMH	STP	Annual	0.06	45.12	Fair	0.07	62.54	Fair
JMSMH	PO4F	Annual	0.03	83.14	Poor	0.03	82.81	Poor
JMSMH	CHLA	Annual	6.58	24.66	Good	-	-	-
JMSMH	TSS	Annual	13.25	54.31	Fair	30.50	78.18	Poor
JMSMH	SECCHI	Annual	0.80	25.33	Poor	-	-	-
JMSMH	DO	Summer1	-	-	-	5.76	-	Good
JMSPH	TN	Annual	0.51	30.06	Good	0.48	46.72	Fair
JMSPH	DIN	Annual	0.10	39.94	Fair	0.09	47.88	Fair
JMSPH	STP	Annual	0.04	50.21	Fair	0.04	38.86	Fair
JMSPH	PO4F	Annual	0.01	60.54	Fair	0.01	34.72	Good
JMSPH	CHLA	Annual	8.82	52.66	Fair	-	-	-
JMSPH	TSS	Annual	10.01	57.30	Fair	14.83	42.47	Fair
JMSPH	SECCHI	Annual	1.05	19.14	Poor	-	-	-
JMSPH	DO	Summer1	-	-	-	6.69	-	Good

Table 3-5. Annual season trends in nutrient parameters in the James River, Apppomattox River, and Chickahominy 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
APPTF	STN	0.0114	-0.024	No Trend	0.5773	0.005	No Trend	0.0315	Same	0.1823	No Trend
APPTF	BTN	0.1008	-0.018	No Trend	0.5984	-0.003	No Trend	0.4617	Same	0.1297	No Trend
APPTF	SDIN	0.2946	-0.005	No Trend	0.1859	-0.007	No Trend	0.7981	Same	0.0881	No Trend
APPTF	BDIN	0.1003	-0.007	No Trend	0.1144	-0.008	No Trend	0.9487	Same	0.0218	No Trend
APPTF	STP	0.7501	0.000	No Trend	0.6931	0.000	No Trend	0.5977	Same	0.9495	No Trend
APPTF	BTP	0.0346	0.003	No Trend	0.4432	-0.001	No Trend	0.0458	Same	0.3954	No Trend
APPTF	SPO4F	0.0005	-0.001	Improving	0.3213	0.000	No Trend	0.1473	Same	0.0029	Improving
APPTF	BPO4F	0.0001	-0.002	Improving	0.2517	0.000	No Trend	0.0990	Same	0.0007	Improving
JMSTF1	STN	0.0808	-0.023	No Trend	0.0539	-0.013	No Trend	0.8029	Same	0.0088	Improving
JMSTF1	BTN	0.1387	-0.029	No Trend	0.0066	-0.022	Improving	0.2977	Same	0.0024	Improving
JMSTF1	SDIN	0.0022	-0.026	Improving	0.8270	-0.001	No Trend	0.0615	Same	0.0279	No Trend
JMSTF1	BDIN	0.0003	-0.028	Improving	0.5850	-0.002	No Trend	0.0504	Same	0.0053	Improving
JMSTF1	STP	0.1733	0.001	No Trend	0.1309	-0.001	No Trend	0.0400	Same	0.8195	No Trend
JMSTF1	BTP	0.0008	0.005	Degrading	0.0210	-0.004	No Trend	0.0001	Different	0.6327	-
JMSTF1	SPO4F	0.0000	-0.003	Improving	0.3309	0.000	No Trend	0.0408	Same	0.0004	Improving
JMSTF1	BPO4F	0.0000	-0.002	Improving	0.0801	0.000	No Trend	0.1686	Same	0.0000	Improving
JMSTF2	STN	0.0001	-0.044	Improving	0.0200	0.013	No Trend	0.0000	Different	0.3455	-
JMSTF2	BTN	0.0000	-0.110	Improving	0.0205	0.016	No Trend	0.0000	Different	0.0060	-
JMSTF2	SDIN	0.0003	-0.020	Improving	0.2351	0.005	No Trend	0.0010	Different	0.1395	-
JMSTF2	BDIN	0.0000	-0.055	Improving	0.1363	0.008	No Trend	0.0000	Different	0.0109	-
JMSTF2	STP	0.0000	-0.013	Improving	0.8917	0.000	No Trend	0.0004	Different	0.0002	-
JMSTF2	BTP	0.0000	-0.019	Improving	0.8880	0.000	No Trend	0.0000	Different	0.0000	-
JMSTF2	SPO4F	0.0000	-0.011	Improving	0.1769	-0.001	No Trend	0.0040	Different	0.0000	-
JMSTF2	BPO4F	0.0000	-0.015	Improving	0.0349	-0.001	No Trend	0.0193	Same	0.0000	Improving
CHKOH	STN	0.0290	-0.037	No Trend	0.2633	-0.006	No Trend	1.0000	Same	0.0453	No Trend
CHKOH	BTN	0.2880	-0.028	No Trend	0.0579	-0.020	No Trend	0.2205	Same	0.0281	No Trend
CHKOH	SDIN	0.0576	0.000	No Trend	0.7782	0.000	No Trend	0.2913	Same	0.5889	No Trend
CHKOH	BDIN	0.0381	-0.009	No Trend	0.4416	-0.001	No Trend	0.8799	Same	0.1185	No Trend
CHKOH	STP	0.0311	0.003	No Trend	0.0857	-0.001	No Trend	0.0125	Same	0.5406	No Trend
CHKOH	BTP	0.0315	0.005	No Trend	0.0281	-0.003	No Trend	0.0033	Different	0.3038	-
CHKOH	SPO4F	0.1546	0.000	High BDLs	0.8695	0.000	No Trend	0.5474	Same	0.7735	No Trend
CHKOH	BPO4F	0.0335	0.000	High BDLs	0.8290	0.000	No Trend	0.6096	Same	0.3580	No Trend
JMSOH	STN	0.0943	-0.012	No Trend	0.6010	0.003	No Trend	0.1300	Same	0.4678	No Trend
JMSOH	BTN	0.1169	0.020	No Trend	0.2769	-0.009	No Trend	0.0614	Same	0.8171	No Trend
JMSOH	SDIN	0.0001	-0.020	Improving	0.1636	0.005	No Trend	0.0003	Different	0.1270	-
JMSOH	BDIN	0.0001	-0.020	Improving	0.3969	0.003	No Trend	0.0010	Different	0.0420	-
JMSOH	STP	0.0000	0.005	Degrading	0.4157	0.000	No Trend	0.0008	Different	0.0353	-
JMSOH	BTP	0.0000	0.012	Degrading	0.0012	-0.006	Improving	0.0000	Different	0.2722	-
JMSOH	SPO4F	0.1452	0.000	No Trend	0.3088	0.000	No Trend	0.8841	Same	0.0839	No Trend
JMSOH	BPO4F	0.4470	0.000	No Trend	0.1511	0.000	No Trend	0.5434	Same	0.1067	No Trend
JMSMH	STN	0.0808	0.013	No Trend	0.4248	0.003	No Trend	0.6218	Same	0.0823	No Trend
JMSMH	BTN	0.0033	0.019	Degrading	0.2649	0.006	No Trend	0.3443	Same	0.0068	Degrading
JMSMH	SDIN	0.5830	-0.002	No Trend	0.1760	0.005	No Trend	0.1581	Same	0.5082	No Trend
JMSMH	BDIN	0.6912	0.000	No Trend	0.1949	0.004	No Trend	0.1993	Same	0.4574	No Trend
JMSMH	STP	0.0000	0.004	Degrading	0.6642	0.000	No Trend	0.0007	Different	0.0068	-
JMSMH	BTP	0.0000	0.003	Degrading	0.8475	0.000	No Trend	0.0024	Different	0.0061	-
JMSMH	SPO4F	0.0020	0.001	Degrading	0.0876	0.001	No Trend	0.5571	Same	0.0011	Degrading
JMSMH	BPO4F	0.0009	0.001	Degrading	0.0284	0.001	No Trend	0.7479	Same	0.0001	Degrading
JMSPH	STN	0.7406	0.001	No Trend	0.5699	0.002	No Trend	0.8446	Same	0.5051	No Trend
JMSPH	BTN	0.2523	0.007	No Trend	0.1298	0.004	No Trend	0.7077	Same	0.0556	No Trend
JMSPH	SDIN	0.5421	0.000	No Trend	0.0560	0.003	No Trend	0.0613	Same	0.2964	No Trend
JMSPH	BDIN	0.6873	0.000	No Trend	0.0231	0.003	No Trend	0.1423	Same	0.0431	No Trend
JMSPH	STP	0.5062	0.000	No Trend	0.1037	0.000	No Trend	0.0913	Same	0.4322	No Trend
JMSPH	BTP	0.4686	0.001	No Trend	0.0012	-0.001	Improving	0.0032	Different	0.0497	-
JMSPH	SPO4F	0.2896	0.000	No Trend	0.2541	0.000	No Trend	0.8577	Same	0.1155	No Trend
JMSPH	BPO4F	0.6633	0.000	No Trend	0.0296	0.000	No Trend	0.1696	Same	0.0488	No Trend

Table 3-6. Annual and Summer (DO only) season trends in non-nutrient parameters in the James River, Apppomattox River, and Chickahominy River for the period of 1985 through 2004.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
APPTF	Annual	SCHLA	8.36	0.0321	-0.130	30.940	-8.40	No trend
APPTF	Annual	STSS	0.00	0.6756	0.000	19.500	0.00	No trend
APPTF	Annual	BTSS	0.00	0.4569	-0.182	27.250	-11.34	No trend
APPTF	Annual	SECCHI	0.00	0.0068	0.000	0.500	0.00	No trend
APPTF	Annual	BDO	0.00	0.0041	0.032	8.950	7.15	Improving
APPTF	Summer1	BDO	0.00	0.0321	0.042	8.200	10.16	No trend
APPTF	Annual	SSALIN	0.00	0.0018	0.000	0.010	0.00	No trend
APPTF	Annual	BSALIN	0.00	0.0005	0.000	0.010	0.00	No trend
APPTF	Annual	BWTEMP	0.00	0.1363	0.049	19.000	5.16	No trend
APPTF	Annual	SWTEMP	0.00	0.0639	0.050	19.675	5.08	No trend
JMSTF1	Annual	SCHLA	7.63	0.4838	0.000	16.560	0.00	No trend
JMSTF1	Annual	STSS	0.28	0.0029	0.346	19.750	29.80	Degrading
JMSTF1	Annual	BTSS	0.56	0.0073	1.125	172.000	13.08	Degrading
JMSTF1	Annual	SECCHI	0.00	0.0000	-0.008	0.600	-27.78	Degrading
JMSTF1	Annual	BDO	0.00	0.0004	0.033	7.825	8.52	Improving
JMSTF1	Summer1	BDO	0.00	0.0064	0.046	6.400	14.23	Improving
JMSTF1	Annual	SSALIN	0.00	0.0001	0.000	0.010	0.00	No trend
JMSTF1	Annual	BSALIN	0.00	0.0007	0.000	0.010	0.00	No trend
JMSTF1	Annual	BWTEMP	0.00	0.6095	0.016	18.350	1.71	No trend
JMSTF1	Annual	SWTEMP	0.00	0.4378	0.020	18.500	2.16	No trend
JMSTF2	Annual	SCHLA	37.09	0.0003	0.000	3.795	-	No trend
JMSTF2	Annual	STSS	18.23	0.6651	0.000	9.000	-	No trend
JMSTF2	Annual	BTSS	3.90	0.2636	0.136	16.250	14.27	No trend
JMSTF2	Annual	SECCHI	0.00	0.6372	0.000	1.000	0.00	No trend
JMSTF2	Annual	BDO	0.00	0.0040	0.033	7.750	8.57	Improving
JMSTF2	Summer1	BDO	0.00	0.0002	0.050	6.200	16.13	Improving
JMSTF2	Annual	SSALIN	0.00	0.0009	0.000	0.010	0.00	No trend
JMSTF2	Annual	BSALIN	0.00	0.0001	0.000	0.010	0.00	No trend
JMSTF2	Annual	BWTEMP	0.00	0.4427	0.023	19.000	2.42	No trend
JMSTF2	Annual	SWTEMP	0.00	0.9382	0.003	18.775	0.33	No trend
CHKOH	Annual	SCHLA	1.27	0.0002	-0.467	22.345	-35.49	Improving
CHKOH	Annual	STSS	0.00	0.4969	0.070	17.500	6.77	No trend
CHKOH	Annual	BTSS	0.00	0.0061	0.772	27.000	48.62	Degrading
CHKOH	Annual	SECCHI	0.00	0.0000	-0.007	0.600	-20.24	Degrading
CHKOH	Annual	BDO	0.00	0.9699	0.000	8.875	0.00	No trend
CHKOH	Summer1	BDO	0.00	0.7361	0.012	5.750	3.44	No trend
CHKOH	Annual	SSALIN	0.00	0.0016	0.000	0.010	0.00	No trend
CHKOH	Annual	BSALIN	0.00	0.0013	0.000	0.010	0.00	No trend
CHKOH	Annual	BWTEMP	0.00	0.7326	0.006	15.600	0.64	No trend
CHKOH	Annual	SWTEMP	0.00	0.8893	0.002	16.000	0.19	No trend
JMSOH	Annual	SCHLA	6.84	0.1172	-0.078	7.215	-21.66	No trend
JMSOH	Annual	STSS	1.08	0.0427	-0.357	662.000	-1.08	No trend
JMSOH	Annual	BTSS	0.00	0.3329	-0.567	290.000	-3.91	No trend
JMSOH	Annual	SECCHI	0.00	0.4995	0.000	0.525	0.00	No trend
JMSOH	Annual	BDO	0.00	0.2969	-0.010	8.075	-2.48	No trend
JMSOH	Summer1	BDO	0.00	0.5295	-0.006	6.875	-1.62	No trend
JMSOH	Annual	SSALIN	0.00	0.1665	0.015	2.718	10.67	No trend
JMSOH	Annual	BSALIN	0.00	0.0857	0.028	3.470	15.89	No trend
JMSOH	Annual	SWTEMP	0.00	0.6452	0.012	18.300	1.34	No trend
JMSOH	Annual	BWTEMP	0.00	0.8141	0.007	18.475	0.73	No trend
JMSMH	Annual	SCHLA	15.56	0.7598	-0.002	4.465	-	No trend
JMSMH	Annual	STSS	2.04	0.3526	-0.071	15.000	-9.52	No trend
JMSMH	Annual	BTSS	1.30	0.0014	0.667	142.000	9.39	Degrading
JMSMH	Annual	SECCHI	0.00	0.5846	0.000	0.950	0.00	No trend
JMSMH	Annual	BDO	0.00	0.7492	-0.003	7.500	-0.80	No trend
JMSMH	Summer1	BDO	0.00	0.9341	0.000	6.200	0.00	No trend
JMSMH	Annual	SSALIN	0.00	0.7957	0.020	14.958	2.67	No trend
JMSMH	Annual	BSALIN	0.00	0.9604	0.000	18.345	0.00	No trend

Table 3-6. Continued.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
JMSMH	Annual	BWTEMP	0.00	0.6861	0.006	19.900	0.60	No trend
JMSMH	Annual	SWTEMP	0.00	0.9526	0.000	20.125	0.00	No trend
JMSPH	Annual	SCHLA	9.59	0.0420	0.082	8.188	19.96	No trend
JMSPH	Annual	STSS	3.29	0.2231	0.056	8.250	13.61	No trend
JMSPH	Annual	BTSS	0.73	0.2649	-0.115	18.450	-12.46	No trend
JMSPH	Annual	SECCHI	0.00	0.0000	-0.013	1.300	-19.23	Degrading
JMSPH	Annual	BDO	0.00	0.0000	0.052	7.625	13.57	Improving
JMSPH	Summer1	BDO	0.00	0.0000	0.054	5.950	18.30	Improving
JMSPH	Annual	SSALIN	0.00	0.0367	-0.073	21.560	-6.81	No trend
JMSPH	Annual	BSALIN	0.00	0.0000	-0.188	24.640	-15.24	Decreasing
JMSPH	Annual	BWTEMP	0.00	0.0023	0.060	16.950	7.08	Increasing
JMSPH	Annual	SWTEMP	0.00	0.9104	0.000	17.400	0.00	No trend

Table 3-7. SAV season water quality status in the James River, Appomattox River and Chickahominy 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
APPTF	STN	SAV1	S	0.788	14.40	Good	-
APPTF	SDIN	SAV1	S	0.284	13.31	Good	-
APPTF	STP	SAV1	S	0.078	32.69	Good	-
APPTF	SPO4F	SAV1	S	0.018	34.31	Good	Borderline
APPTF	SCHLA	SAV1	S	3.435	19.88	Good	Borderline
APPTF	STSS	SAV1	S	18.000	55.25	Fair	Fail
APPTF	SECCHI	SAV1	S	0.450	34.63	Poor	Fail
JMSTF1	STN	SAV1	S	0.880	17.42	Good	-
JMSTF1	SDIN	SAV1	S	0.473	22.38	Good	-
JMSTF1	STP	SAV1	S	0.079	29.60	Good	-
JMSTF1	SPO4F	SAV1	S	0.019	37.59	Fair	Borderline
JMSTF1	SCHLA	SAV1	S	4.075	25.43	Good	Pass
JMSTF1	STSS	SAV1	S	25.000	72.70	Poor	Fail
JMSTF1	SECCHI	SAV1	S	0.400	20.31	Poor	Fail
JMSTF2	STN	SAV1	S	0.728	10.89	Good	-
JMSTF2	SDIN	SAV1	S	0.360	16.74	Good	-
JMSTF2	STP	SAV1	S	0.066	27.24	Good	-
JMSTF2	SPO4F	SAV1	S	0.026	40.97	Fair	Fail
JMSTF2	SCHLA	SAV1	S	1.520	7.36	Good	Pass
JMSTF2	STSS	SAV1	S	7.500	20.92	Good	Pass
JMSTF2	SECCHI	SAV1	S	0.850	86.67	Good	Borderline
CHKOH	STN	SAV1	S	0.750	13.27	Good	-
CHKOH	SDIN	SAV1	S	0.150	10.17	Good	-
CHKOH	STP	SAV1	S	0.080	34.11	Good	-
CHKOH	SPO4F	SAV1	S	0.014	31.93	Good	Pass
CHKOH	SCHLA	SAV1	S	11.525	56.67	Fair	Pass
CHKOH	STSS	SAV1	S	19.125	57.35	Fair	Borderline
CHKOH	SECCHI	SAV1	S	0.450	22.96	Poor	Fail
JMSOH	STN	SAV1	S	0.830	18.74	Good	-
JMSOH	SDIN	SAV1	S	0.422	31.13	Good	-
JMSOH	STP	SAV1	S	0.070	34.38	Good	-
JMSOH	SPO4F	SAV1	S	0.026	45.83	Fair	Fail
JMSOH	SCHLA	SAV1	S	5.440	27.51	Good	Pass
JMSOH	STSS	SAV1	S	22.250	69.47	Poor	Fail
JMSOH	SECCHI	SAV1	S	0.450	20.31	Poor	Fail
JMSMH	STN	SAV1	S	0.692	25.78	Good	-
JMSMH	SDIN	SAV1	S	0.333	44.77	Fair	Borderline
JMSMH	STP	SAV1	S	0.059	47.49	Fair	-
JMSMH	SPO4F	SAV1	S	0.035	90.88	Poor	Fail
JMSMH	SCHLA	SAV1	S	3.885	14.80	Good	Pass
JMSMH	STSS	SAV1	S	13.750	57.82	Fair	Borderline
JMSMH	SECCHI	SAV1	S	0.750	21.92	Poor	Fail
JMSPH	STN	SAV2	S	0.514	36.68	Fair	-
JMSPH	SDIN	SAV2	S	0.100	54.52	Fair	Borderline
JMSPH	STP	SAV2	S	0.046	54.61	Fair	-
JMSPH	SPO4F	SAV2	S	0.020	75.32	Poor	Borderline
JMSPH	SCHLA	SAV2	S	8.556	53.53	Fair	Pass
JMSPH	STSS	SAV2	S	11.575	61.05	Fair	Pass
JMSPH	SECCHI	SAV2	S	1.000	19.27	Poor	Borderline

Table 3-8. SAV growing season trends in nutrient parameters in the James River, Apppomattox River, and Chickahominy 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
APPTF	SAV1	STN	0.0098	-0.0340	Improving	0.7898	-0.0065	No Trend	0.1082	Same	0.0462	No Trend
APPTF	SAV1	BTN	0.0401	-0.0242	No Trend	0.2176	-0.0103	No Trend	0.6029	Same	0.0199	No Trend
APPTF	SAV1	SDIN	0.6861	-0.0024	No Trend	0.0785	-0.0103	No Trend	0.3309	Same	0.1133	No Trend
APPTF	SAV1	BDIN	0.4441	-0.0046	No Trend	0.0668	-0.0124	No Trend	0.4266	Same	0.0586	No Trend
APPTF	SAV1	STP	0.1941	-0.0020	No Trend	0.2755	-0.0013	No Trend	0.9576	Same	0.0889	No Trend
APPTF	SAV1	BTP	0.4609	0.0009	No Trend	0.2758	-0.0021	No Trend	0.1822	Same	0.7489	No Trend
APPTF	SAV1	SPO4F	0.0413	-0.0007	No Trend	0.7233	0.0000	No Trend	0.2972	Same	0.1116	No Trend
APPTF	SAV1	BPO4F	0.0053	-0.0013	Improving	0.9433	0.0000	No Trend	0.0797	Same	0.0626	No Trend
JMSTF1	SAV1	STN	0.1240	-0.0166	No Trend	0.0185	-0.0148	No Trend	0.4786	Same	0.0050	Improving
JMSTF1	SAV1	BTN	0.1259	-0.0271	No Trend	0.0020	-0.0276	Improving	0.2078	Same	0.0008	Improving
JMSTF1	SAV1	SDIN	0.0018	-0.0273	Improving	0.7793	0.0022	No Trend	0.0212	Same	0.0593	No Trend
JMSTF1	SAV1	BDIN	0.0006	-0.0300	Improving	0.6743	-0.0025	No Trend	0.0506	Same	0.0096	Improving
JMSTF1	SAV1	STP	0.0773	0.0025	No Trend	0.1760	-0.0013	No Trend	0.0279	Same	0.8971	No Trend
JMSTF1	SAV1	BTP	0.0002	0.0050	Degrading	0.0045	-0.0059	Improving	0.0000	Different	0.7952	-
JMSTF1	SAV1	SPO4F	0.0276	-0.0011	No Trend	0.3549	0.0002	No Trend	0.0314	Same	0.4626	No Trend
JMSTF1	SAV1	BPO4F	0.0456	-0.0003	No Trend	0.6575	0.0000	No Trend	0.1046	Same	0.3517	No Trend
JMSTF2	SAV1	STN	0.0000	-0.0567	Improving	0.0480	0.0145	No Trend	0.0000	Different	0.1137	-
JMSTF2	SAV1	BTN	0.0000	-0.1255	Improving	0.1081	0.0158	No Trend	0.0000	Different	0.0017	-
JMSTF2	SAV1	SDIN	0.0002	-0.0278	Improving	0.0928	0.0066	No Trend	0.0002	Different	0.2242	-
JMSTF2	SAV1	BDIN	0.0000	-0.0667	Improving	0.1424	0.0092	No Trend	0.0000	Different	0.0141	-
JMSTF2	SAV1	STP	0.0000	-0.0150	Improving	0.9730	0.0002	No Trend	0.0004	Different	0.0005	-
JMSTF2	SAV1	BTP	0.0000	-0.0225	Improving	1.0000	0.0000	No Trend	0.0000	Different	0.0000	-
JMSTF2	SAV1	SPO4F	0.0000	-0.0125	Improving	0.6599	-0.0003	No Trend	0.0024	Different	0.0002	-
JMSTF2	SAV1	BPO4F	0.0000	-0.0180	Improving	0.1775	-0.0008	No Trend	0.0081	Different	0.0000	-
CHKOH	SAV1	STN	0.0546	-0.0375	No Trend	0.7413	-0.0027	No Trend	0.5355	Same	0.2276	No Trend
CHKOH	SAV1	BTN	0.7753	-0.0150	No Trend	0.3692	-0.0091	No Trend	0.5211	Same	0.3358	No Trend
CHKOH	SAV1	SDIN	0.4664	0.0000	No Trend	0.0650	0.0014	No Trend	0.0439	Same	0.1792	No Trend
CHKOH	SAV1	BDIN	0.4344	0.0000	No Trend	0.5243	0.0003	No Trend	0.3500	Same	0.8215	No Trend
CHKOH	SAV1	STP	0.1175	0.0020	No Trend	0.1216	-0.0016	No Trend	0.0358	Same	0.4840	No Trend
CHKOH	SAV1	BTP	0.0622	0.0063	No Trend	0.0387	-0.0042	No Trend	0.0069	Different	0.3053	-
CHKOH	SAV1	SPO4F	0.3681	0.0000	No Trend	0.2085	0.0003	No Trend	0.1333	Same	0.3677	No Trend
CHKOH	SAV1	BPO4F	0.0599	0.0000	No Trend	0.3382	0.0002	No Trend	0.1207	Same	0.7959	No Trend
JMSOH	SAV1	STN	0.4530	-0.0050	No Trend	0.1136	0.0100	No Trend	0.0878	Same	0.5115	No Trend
JMSOH	SAV1	BTN	0.0535	0.0221	No Trend	0.7784	0.0028	No Trend	0.2704	Same	0.1280	No Trend
JMSOH	SAV1	SDIN	0.0020	-0.0173	Improving	0.0012	0.0135	Degrading	0.0000	Different	0.7886	-
JMSOH	SAV1	BDIN	0.0031	-0.0154	Improving	0.0071	0.0123	Degrading	0.0001	Different	0.9573	-
JMSOH	SAV1	STP	0.0001	0.0050	Degrading	0.7867	-0.0002	No Trend	0.0069	Different	0.0219	-
JMSOH	SAV1	BTP	0.0000	0.0104	Degrading	0.0332	-0.0047	No Trend	0.0000	Different	0.2081	-
JMSOH	SAV1	SPO4F	0.0083	0.0007	Degrading	0.0385	0.0010	No Trend	0.9370	Same	0.0010	Degrading
JMSOH	SAV1	BPO4F	0.1579	0.0000	No Trend	0.0835	0.0008	No Trend	0.6741	Same	0.0238	No Trend
JMSMH	SAV1	STN	0.0285	0.0167	No Trend	0.0320	0.0092	No Trend	0.8066	Same	0.0021	Degrading
JMSMH	SAV1	BTN	0.0004	0.0250	Degrading	0.0223	0.0122	No Trend	0.6245	Same	0.0001	Degrading
JMSMH	SAV1	SDIN	0.9656	0.0000	No Trend	0.0576	0.0089	No Trend	0.1676	Same	0.1355	No Trend
JMSMH	SAV1	BDIN	0.8283	0.0000	No Trend	0.0737	0.0053	No Trend	0.2246	Same	0.1222	No Trend
JMSMH	SAV1	STP	0.0000	0.0050	Degrading	0.9192	0.0001	No Trend	0.0023	Different	0.0014	-
JMSMH	SAV1	BTP	0.0000	0.0050	Degrading	0.4568	0.0009	No Trend	0.0068	Different	0.0001	-
JMSMH	SAV1	SPO4F	0.0054	0.0017	Degrading	0.1456	0.0008	No Trend	0.4979	Same	0.0035	Degrading
JMSMH	SAV1	BPO4F	0.0018	0.0014	Degrading	0.0782	0.0007	No Trend	0.5286	Same	0.0008	Degrading
JMSPH	SAV2	STN	0.1055	0.0113	No Trend	0.4652	0.0030	No Trend	0.5984	Same	0.1019	No Trend
JMSPH	SAV2	BTN	0.0297	0.0149	No Trend	0.0797	0.0072	No Trend	0.9117	Same	0.0055	Degrading
JMSPH	SAV2	SDIN	0.6665	-0.0001	No Trend	0.0486	0.0063	No Trend	0.0702	Same	0.2309	No Trend
JMSPH	SAV2	BDIN	0.9296	0.0000	No Trend	0.0130	0.0060	No Trend	0.0457	Same	0.0674	No Trend
JMSPH	SAV2	STP	0.0009	0.0015	Degrading	0.0528	-0.0008	No Trend	0.0003	Different	0.5016	-
JMSPH	SAV2	BTP	0.0017	0.0020	Degrading	0.4875	-0.0003	No Trend	0.0099	Different	0.1301	-
JMSPH	SAV2	SPO4F	1.0000	0.0000	No Trend	0.7410	0.0000	No Trend	0.8134	Same	0.7679	No Trend
JMSPH	SAV2	BPO4F	0.8821	0.0000	No Trend	0.5568	-0.0001	No Trend	0.7235	Same	0.5555	No Trend

Table 3-9. SAV growing season trends in non-nutrient parameters in the James River, Apppomattox River, and Chickahominy River for the period of 1985 through 2004.

Segment	Season	Layer	Parameter	% BDL	P value	Slope	Baseline	% Change	Direction
APPTF	SAV1	S	SCHLA	6.00	0.0024	-0.956	43.508	-43.97	Improving
APPTF	SAV1	S	STSS	0.00	0.6633	-0.071	23.750	-5.11	No trend
APPTF	SAV1	B	BTSS	0.00	0.9068	0.000	30.250	0.00	No trend
APPTF	SAV1	S	SECCHI	0.00	0.0125	0.000	0.500	0.00	No trend
APPTF	SAV1	B	BDO	0.00	0.1861	0.020	8.200	4.88	No trend
APPTF	SAV1	S	SSALINITY	0.00	0.0079	0.000	0.010	0.00	Unchanged
APPTF	SAV1	B	BSALINITY	0.00	0.0057	0.000	0.010	0.00	Unchanged
APPTF	SAV1	B	BWTEMP	0.00	0.3461	0.047	22.500	4.22	No trend
APPTF	SAV1	S	SWTEMP	0.00	0.1512	0.051	22.750	4.51	No trend
JMSTF1	SAV1	S	SCHLA	4.91	0.2017	-0.322	24.303	-26.49	No trend
JMSTF1	SAV1	S	STSS	0.27	0.0018	0.375	20.500	31.10	Degrading
JMSTF1	SAV1	B	BTSS	0.55	0.0506	1.211	37.250	55.27	No trend
JMSTF1	SAV1	S	SECCHI	0.00	0.0000	-0.011	0.650	-32.97	Degrading
JMSTF1	SAV1	B	BDO	0.00	0.0161	0.033	6.725	9.85	No trend
JMSTF1	SAV1	S	SSALINITY	0.00	0.0034	0.000	0.010	0.00	Unchanged
JMSTF1	SAV1	B	BSALINITY	0.00	0.0131	0.000	0.010	0.00	No trend
JMSTF1	SAV1	B	BWTEMP	0.00	0.7807	0.011	22.875	0.97	No trend
JMSTF1	SAV1	S	SWTEMP	0.00	0.5355	0.016	23.100	1.39	No trend
JMSTF2	SAV1	S	SCHLA	40.91	0.0491	0.000	4.868	0.00	No trend
JMSTF2	SAV1	S	STSS	19.51	0.4357	0.000	10.000	0.00	No trend
JMSTF2	SAV1	B	BTSS	3.32	0.2193	0.179	17.500	17.35	No trend
JMSTF2	SAV1	S	SECCHI	0.00	0.3859	-0.005	1.000	-10.00	No trend
JMSTF2	SAV1	B	BDO	0.00	0.0026	0.039	6.550	11.93	Improving
JMSTF2	SAV1	S	SSALINITY	0.00	0.0194	0.000	0.010	0.00	No trend
JMSTF2	SAV1	B	BSALINITY	0.00	0.0072	0.000	0.010	0.00	Unchanged
JMSTF2	SAV1	B	BWTEMP	0.00	0.5267	0.031	21.875	2.80	No trend
JMSTF2	SAV1	S	SWTEMP	0.00	0.7009	0.013	24.025	1.07	No trend
CHKOH	SAV1	S	SCHLA	1.61	0.0002	-0.601	23.933	-42.67	Improving
CHKOH	SAV1	S	STSS	0.00	0.3935	0.100	17.500	9.71	No trend
CHKOH	SAV1	B	BTSS	0.00	0.0032	1.333	32.500	69.74	Degrading
CHKOH	SAV1	S	SECCHI	0.00	0.0000	-0.009	0.600	-25.76	Degrading
CHKOH	SAV1	B	BDO	0.00	0.4379	-0.010	6.400	-2.66	No trend
CHKOH	SAV1	S	SSALINITY	0.00	0.0077	0.000	0.010	0.00	Unchanged
CHKOH	SAV1	B	BSALINITY	0.00	0.0063	0.000	0.010	0.00	Unchanged
CHKOH	SAV1	B	BWTEMP	0.00	0.2377	0.032	22.450	2.40	No trend
CHKOH	SAV1	S	SWTEMP	0.00	0.3548	0.041	22.575	3.07	No trend
JMSOH	SAV1	S	SCHLA	6.56	0.0841	-0.118	7.688	-30.68	No trend
JMSOH	SAV1	S	STSS	1.26	0.1967	-0.286	26.250	-18.50	No trend
JMSOH	SAV1	B	BTSS	0.00	0.8973	-0.125	57.500	-3.70	No trend
JMSOH	SAV1	S	SECCHI	0.00	0.7245	0.000	0.625	0.00	No trend
JMSOH	SAV1	B	BDO	0.00	0.2436	-0.012	7.000	-3.33	No trend
JMSOH	SAV1	S	SSALINITY	0.00	0.7282	0.002	3.850	1.30	No trend
JMSOH	SAV1	B	BSALINITY	0.00	0.7191	0.005	4.355	2.30	No trend
JMSOH	SAV1	B	BWTEMP	0.00	0.8062	-0.006	23.750	-0.54	No trend
JMSOH	SAV1	S	SWTEMP	0.00	0.9511	-0.001	23.900	-0.10	No trend
JMSMH	SAV1	S	SCHLA	18.89	0.7516	0.007	4.670	3.15	No trend
JMSMH	SAV1	S	STSS	2.35	0.2196	-0.125	19.000	-13.16	No trend
JMSMH	SAV1	B	BTSS	1.66	0.0004	1.033	24.750	70.98	Degrading
JMSMH	SAV1	S	SECCHI	0.00	0.9103	0.000	1.075	0.00	No trend
JMSMH	SAV1	B	BDO	0.00	0.9501	0.000	6.475	0.00	No trend
JMSMH	SAV1	S	SSALINITY	0.00	0.4801	-0.058	15.820	-7.31	No trend
JMSMH	SAV1	B	BSALINITY	0.00	0.2542	-0.047	19.313	-4.89	No trend
JMSMH	SAV1	B	BWTEMP	0.00	0.9316	0.000	23.450	0.04	No trend
JMSMH	SAV1	S	SWTEMP	0.00	0.7778	-0.008	23.725	-0.72	No trend

Table 3-9. SAV growing season trends in non-nutrient parameters in the James River, Apppomattox River, and Chickahominy River for the period of 1985 through 2004.

Segment	Season	Layer	Parameter	% BDL	P value	Slope	Baseline	% Change	Direction
JMSPH	SAV2	S	SCHLA	9.49	0.7809	0.009	7.060	2.44	No trend
JMSPH	SAV2	S	STSS	1.63	0.8114	-0.008	10.000	-1.58	No trend
JMSPH	SAV2	B	BTSS	0.27	0.3745	0.100	12.350	16.19	No trend
JMSPH	SAV2	S	SECCHI	0.00	0.0280	-0.008	1.300	-12.33	No trend
JMSPH	SAV2	B	BDO	0.00	0.0026	0.029	7.800	7.35	Improving
JMSPH	SAV2	S	SSALINITY	0.00	0.0716	-0.079	20.395	-7.75	No trend
JMSPH	SAV2	B	BSALINITY	0.00	0.0003	-0.134	21.685	-12.34	Decreasing
JMSPH	SAV2	B	BWTEMP	0.00	0.1896	0.040	16.825	4.75	No trend
JMSPH	SAV2	S	SWTEMP	0.00	0.7808	0.011	17.350	1.31	No trend

Table 3-10. Annual and Summer (DO only) season water quality status in the Elizabeth 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
EBEMH	TN	Annual	0.85	80.49	Poor	0.77	76.00	Pooru
EBEMH	DIN	Annual	0.40	88.40	Poor	0.35	93.81	Poor
EBEMH	STP	Annual	0.05	72.33	Poor	0.05	52.63	Fair
EBEMH	PO4F	Annual	0.02	84.69	Poor	0.03	84.20	Poor
EBEMH	CHLA	Annual	6.09	29.20	Good	-	-	-
EBEMH	TSS	Annual	8.31	42.55	Fair	11.36	29.17	Good
EBEMH	SECCHI	Annual	1.00	25.33	Poor	-	-	-
EBEMH	DO	Summer1	-	-	-	4.58	-	Fair
WBEMH	TN	Annual	0.70	57.35	Fair	0.69	68.05	Poor
WBEMH	DIN	Annual	0.20	59.41	Fair	0.21	68.77	Poor
WBEMH	STP	Annual	0.06	70.02	Poor	0.06	54.28	Fair
WBEMH	PO4F	Annual	0.02	74.85	Poor	0.02	63.50	Poor
WBEMH	CHLA	Annual	11.64	56.83	Fair	-	-	-
WBEMH	TSS	Annual	15.93	79.15	Poor	20.21	65.06	Poor
WBEMH	SECCHI	Annual	0.70	9.75	Poor	-	-	-
WBEMH	DO	Summer1	-	-	-	5.69	-	Good
SBEMH	TN	Annual	1.11	95.56	Poor	0.99	91.59	Poor
SBEMH	DIN	Annual	0.58	96.14	Poor	0.50	98.22	Poor
SBEMH	STP	Annual	0.06	64.96	Fair	0.06	64.65	Poor
SBEMH	PO4F	Annual	0.03	96.25	Poor	0.03	92.43	Poor
SBEMH	CHLA	Annual	3.62	7.90	Good	-	-	-
SBEMH	TSS	Annual	7.75	35.60	Good	9.28	24.32	Good
SBEMH	SECCHI	Annual	0.90	15.96	Poor	-	-	-
SBEMH	DO	Summer1	-	-	-	3.73	-	Fair
ELIPH	TN	Annual	0.65	55.20	Fair	0.60	63.99	Fair
ELIPH	DIN	Annual	0.28	72.58	Poor	0.23	87.54	Poor
ELIPH	STP	Annual	0.05	59.16	Fair	0.06	72.57	Poor
ELIPH	PO4F	Annual	0.02	85.24	Poor	0.02	77.09	Poor
ELIPH	CHLA	Annual	10.23	58.42	Fair	-	-	-
ELIPH	TSS	Annual	10.31	54.29	Fair	18.02	47.95	Fair
ELIPH	SECCHI	Annual	0.95	19.14	Poor	-	-	-
ELIPH	DO	Summer1	-	-	-	4.99	-	Fair

Table 3-11. Annual season trends in nutrient parameters in the Elizabeth River for the period of 1985 through 2004.

A) Seasonal Kendall

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
EBEMH	Annual	STN	0.00	0.0115	-0.008	1.040	-12.82	No trend
EBEMH	Annual	BTN	0.00	0.0012	-0.009	0.855	-16.04	Improving
EBEMH	Annual	SDIN	0.00	0.0777	-0.006	0.507	-19.16	No trend
EBEMH	Annual	BDIN	0.00	0.0033	-0.007	0.490	-24.24	Improving
EBEMH	Annual	STP	0.00	0.0000	-0.002	0.075	-33.29	Improving
EBEMH	Annual	BTP	0.00	0.0000	-0.002	0.074	-34.95	Improving
EBEMH	Annual	SPO4F	6.52	0.0001	-0.001	0.044	-22.07	Improving
EBEMH	Annual	BPO4F	8.11	0.0000	-0.001	0.046	-24.09	Improving
WBEMH	Annual	STN	0.00	0.0007	-0.009	0.800	-17.94	Improving
WBEMH	Annual	BTN	0.00	0.0071	-0.007	0.791	-13.21	Improving
WBEMH	Annual	SDIN	6.38	0.6562	0.000	0.198	-3.86	No trend
WBEMH	Annual	BDIN	2.66	0.3390	-0.001	0.257	-8.01	No trend
WBEMH	Annual	STP	0.00	0.0000	-0.002	0.083	-36.20	Improving
WBEMH	Annual	BTP	0.00	0.0000	-0.002	0.080	-36.23	Improving
WBEMH	Annual	SPO4F	14.44	0.0000	-0.001	0.035	-26.50	Improving
WBEMH	Annual	BPO4F	13.30	0.0000	-0.001	0.033	-32.32	Improving
SBEMH	Annual	STN	0.00	0.0017	-0.012	1.333	-14.69	Improving
SBEMH	Annual	BTN	0.00	0.3183	-0.003	1.070	-4.11	No trend
SBEMH	Annual	SDIN	0.00	0.0001	-0.014	0.738	-29.76	Improving
SBEMH	Annual	BDIN	0.00	0.2121	-0.003	0.586	-8.91	No trend
SBEMH	Annual	STP	0.00	0.0000	-0.001	0.074	-29.75	Improving
SBEMH	Annual	BTP	0.00	0.0000	-0.002	0.079	-36.57	Improving
SBEMH	Annual	SPO4F	2.39	0.0001	-0.001	0.048	-25.73	Improving
SBEMH	Annual	BPO4F	5.04	0.0000	-0.001	0.048	-33.84	Improving

B) Blocked Seasonal Kendall

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
ELIPH	STN	1.0000	0.000	No Trend	0.1000	0.006	No Trend	0.1761	Same	0.1900	No Trend
ELIPH	BTN	1.0000	0.000	No Trend	0.0201	0.007	No Trend	0.0570	Same	0.0570	No Trend
ELIPH	SDIN	0.9426	0.000	No Trend	0.0072	0.009	Degrading	0.0341	Same	0.0248	No Trend
ELIPH	BDIN	0.8504	0.000	No Trend	0.0389	0.005	No Trend	0.1149	Same	0.0669	No Trend
ELIPH	STP	0.8184	0.000	No Trend	0.0663	-0.001	No Trend	0.1087	Same	0.2008	No Trend
ELIPH	BTP	0.1060	0.001	No Trend	0.0707	-0.001	No Trend	0.0146	Same	0.7015	No Trend
ELIPH	SPO4F	0.7632	0.000	No Trend	0.8765	0.000	No Trend	0.7431	Same	0.9347	No Trend
ELIPH	BPO4F	0.5036	0.000	No Trend	0.7564	0.000	No Trend	0.8540	Same	0.4998	No Trend

Table 3-12. Annual and Summer (DO only) season trends in non-nutrient parameters in the Elizabeth River for the period of 1985 through 2004.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
EBEMH	Annual	SCHLA	1.09	0.3181	-0.079	6.600	-19.24	No trend
EBEMH	Annual	STSS	0.54	0.0002	-0.260	9.950	-41.81	Improving
EBEMH	Annual	BTSS	0.00	0.0012	-0.389	12.150	-51.21	Improving
EBEMH	Annual	SECCHI	0.00	0.0790	0.000	1.000	0.00	No trend
EBEMH	Summer1	BDO	0.00	0.0443	0.062	3.250	30.49	No trend
EBEMH	Annual	BDO	0.00	0.0001	0.072	6.100	18.97	Improving
EBEMH	Annual	SSALIN	0.00	0.1847	0.063	16.850	6.01	No trend
EBEMH	Annual	BSALIN	0.00	0.6250	-0.017	18.400	-1.47	No trend
EBEMH	Annual	BWTEMP	0.00	0.0237	0.078	15.900	7.84	No trend
EBEMH	Annual	SWTEMP	0.00	0.0953	0.047	17.000	4.41	No trend
WBEMH	Annual	SCHLA	0.00	0.0050	-0.340	23.000	-23.67	Improving
WBEMH	Annual	STSS	0.00	0.0013	-0.346	20.600	-26.86	Improving
WBEMH	Annual	BTSS	0.00	0.0018	-0.534	20.500	-41.69	Improving
WBEMH	Annual	SECCHI	0.00	0.0386	0.000	0.600	0.00	No trend
WBEMH	Annual	BDO	0.00	0.0050	0.058	6.900	13.49	Improving
WBEMH	Summer1	BDO	0.00	0.0634	0.068	4.400	24.73	No trend
WBEMH	Annual	SSALIN	0.00	0.2036	0.078	15.900	7.80	No trend
WBEMH	Annual	BSALIN	0.00	0.5027	0.035	16.700	3.35	No trend
WBEMH	Annual	BWTEMP	0.00	0.2128	0.038	16.150	3.76	No trend
WBEMH	Annual	SWTEMP	0.00	0.1988	0.045	17.000	4.28	No trend
SBEMH	Annual	SCHLA	1.89	0.0575	-0.075	4.050	-29.63	No trend
SBEMH	Annual	STSS	0.81	0.0007	-0.221	8.575	-41.19	Improving
SBEMH	Annual	BTSS	0.27	0.0000	-0.567	13.075	-69.44	Improving
SBEMH	Annual	SECCHI	0.00	0.2975	0.005	0.750	9.70	No trend
SBEMH	Annual	BDO	0.00	0.0002	0.070	5.250	21.33	Improving
SBEMH	Summer1	BDO	0.00	0.0541	0.070	2.650	42.26	No trend
SBEMH	Annual	SSALIN	0.00	0.0998	0.089	14.750	9.65	No trend
SBEMH	Annual	BSALIN	0.00	0.0823	-0.097	18.450	-8.41	No trend
SBEMH	Annual	BWTEMP	0.00	0.0000	0.196	17.100	18.38	Increasing
SBEMH	Annual	SWTEMP	0.00	0.0013	0.108	18.200	9.52	Increasing
ELIPH	Annual	SCHLA	9.57	0.4440	0.030	8.630	6.95	No trend
ELIPH	Annual	STSS	3.36	0.0074	-0.188	8.000	-47.08	Improving
ELIPH	Annual	BTSS	0.24	0.0367	-0.333	16.000	-41.67	No trend
ELIPH	Annual	SECCHI	0.00	0.0010	-0.008	1.100	-15.15	Degrading
ELIPH	Summer1	BDO	0.00	0.4263	0.013	5.250	4.76	No trend
ELIPH	Annual	BDO	0.00	0.0174	0.022	6.700	6.49	No trend
ELIPH	Annual	SSALIN	0.00	0.0231	-0.113	21.013	-10.79	No trend
ELIPH	Annual	BSALIN	0.00	0.0068	-0.085	24.080	-7.08	Decreasing
ELIPH	Annual	BWTEMP	0.00	0.5032	0.019	17.900	2.16	No trend
ELIPH	Annual	SWTEMP	0.00	0.1996	0.025	20.000	2.50	No trend

Table 3-13. SAV season water quality status in the Elizabeth River for the 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	Median	Score	Status	Habitat Requirement
EBEMH	STN	SAV1	0.867	82.62	Poor	-
EBEMH	SDIN	SAV1	0.436	82.67	Poor	Borderline
EBEMH	STP	SAV1	0.056	76.53	Poor	-
EBEMH	SPO4F	SAV1	0.034	97.39	Poor	Fail
EBEMH	SCHLA	SAV1	5.340	19.78	Good	Borderline
EBEMH	STSS	SAV1	8.018	40.09	Fair	Fail
EBEMH	SECCHI	SAV1	1.100	28.02	Poor	Fail
WBEMH	STN	SAV1	0.749	60.64	Fair	-
WBEMH	SDIN	SAV1	0.321	65.91	Poor	Fail
WBEMH	STP	SAV1	0.059	79.93	Poor	-
WBEMH	SPO4F	SAV1	0.018	78.70	Poor	Fail
WBEMH	SCHLA	SAV1	8.744	47.70	Fair	Pass
WBEMH	STSS	SAV1	15.060	77.07	Poor	Pass
WBEMH	SECCHI	SAV1	0.700	10.37	Poor	Borderline
SBEMH	STN	SAV1	1.290	93.60	Poor	-
SBEMH	SDIN	SAV1	0.584	91.94	Poor	Fail
SBEMH	STP	SAV1	0.057	69.67	Poor	-
SBEMH	SPO4F	SAV1	0.033	96.92	Poor	Fail
SBEMH	SCHLA	SAV1	2.044	4.08	Good	Pass
SBEMH	STSS	SAV1	6.805	31.65	Good	Pass
SBEMH	SECCHI	SAV1	0.850	16.60	Poor	Borderline
ELIPH	STN	SAV2	0.717	63.11	Fair	-
ELIPH	SDIN	SAV2	0.282	80.30	Poor	Fail
ELIPH	STP	SAV2	0.065	70.40	Poor	-
ELIPH	SPO4F	SAV2	0.037	97.58	Poor	Fail
ELIPH	SCHLA	SAV2	10.193	52.12	Fair	Pass
ELIPH	STSS	SAV2	11.325	59.31	Fair	Pass
ELIPH	SECCHI	SAV2	0.900	14.68	Poor	Pass

Table 3-14. SAV growing season trends in nutrient parameters in the Elizabeth River for the period of 1985 through 2004.

A) Seasonal Kendall

Segment	Season	Layer	Parameter	% BDL	P value	Slope	Baseline	% Change	Direction
EBEMH	SAV1	S	STN	0.00	0.3019	-0.005	1.049	-7.24	No trend
EBEMH	SAV1	B	BTN	0.00	0.0509	-0.006	0.861	-10.55	No trend
EBEMH	SAV1	S	SDIN	0.00	0.1797	-0.006	0.530	-18.00	No trend
EBEMH	SAV1	B	BDIN	0.00	0.1283	-0.005	0.511	-16.19	No trend
EBEMH	SAV1	S	STP	0.00	0.0014	-0.001	0.086	-24.11	Improving
EBEMH	SAV1	B	BTP	0.00	0.0000	-0.002	0.099	-27.88	Improving
EBEMH	SAV1	S	SPO4F	5.56	0.1325	-0.001	0.066	-14.85	No trend
EBEMH	SAV1	B	BPO4F	4.44	0.0106	-0.001	0.068	-21.98	No trend
WBEMH	SAV1	S	STN	0.00	0.0096	-0.008	0.813	-16.04	Improving
WBEMH	SAV1	B	BTN	0.00	0.0374	-0.008	0.891	-13.72	No trend
WBEMH	SAV1	S	SDIN	2.13	0.8457	0.000	0.246	0.70	No trend
WBEMH	SAV1	B	BDIN	2.15	0.5601	-0.001	0.292	-4.91	No trend
WBEMH	SAV1	S	STP	0.00	0.0000	-0.002	0.110	-33.90	Improving
WBEMH	SAV1	B	BTP	0.00	0.0000	-0.003	0.116	-37.29	Improving
WBEMH	SAV1	S	SPO4F	11.83	0.0002	-0.001	0.051	-28.24	Improving
WBEMH	SAV1	B	BPO4F	10.64	0.0001	-0.001	0.054	-29.63	Improving
SBEMH	SAV1	S	STN	0.00	0.0962	-0.008	1.266	-9.89	No trend
SBEMH	SAV1	B	BTN	0.00	0.6693	-0.001	0.978	-1.64	No trend
SBEMH	SAV1	S	SDIN	0.00	0.0515	-0.010	0.702	-22.00	No trend
SBEMH	SAV1	B	BDIN	0.00	0.8768	-0.001	0.561	-1.52	No trend
SBEMH	SAV1	S	STP	0.00	0.0002	-0.001	0.100	-21.47	Improving
SBEMH	SAV1	B	BTP	0.00	0.0000	-0.002	0.099	-36.37	Improving
SBEMH	SAV1	S	SPO4F	3.21	0.0075	-0.001	0.067	-21.41	Improving
SBEMH	SAV1	B	BPO4F	3.72	0.0003	-0.001	0.069	-27.83	Improving

B) Blocked Seasonal Kendall

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
ELIPH	SAV2	STN	0.1387	0.0123	No Trend	0.0236	0.0072	No Trend	0.4278	Same	0.0065	Degrading
ELIPH	SAV2	BTN	0.3222	0.0075	No Trend	0.0342	0.0072	No Trend	0.2987	Same	0.0209	No Trend
ELIPH	SAV2	SDIN	1.0000	0.0000	No Trend	0.0486	0.0066	No Trend	0.1260	Same	0.1260	No Trend
ELIPH	SAV2	BDIN	0.6703	-0.0025	No Trend	0.0576	0.0065	No Trend	0.0731	Same	0.2248	No Trend
ELIPH	SAV2	STP	0.0048	0.0014	Degrading	0.0670	-0.0007	No Trend	0.0012	Different	0.6725	-
ELIPH	SAV2	BTP	0.0001	0.0032	Degrading	0.1541	-0.0007	No Trend	0.0004	Different	0.1742	-
ELIPH	SAV2	SPO4F	0.8412	0.0000	No Trend	0.6864	0.0000	No Trend	0.8590	Same	0.6357	No Trend
ELIPH	SAV2	BPO4F	0.2683	0.0000	No Trend	0.6604	0.0000	No Trend	0.3001	Same	0.7447	No Trend

Table 3-15. SAV growing season trends in non-nutrient parameters in the Elizabeth River for the period of 1985 through 2004.

Segment	Season	Layer	Parameter	% BDL	P value	Slope	Baseline	% Change	Direction
EBEMH	SAV1	S	SCHLA	1.12	0.7337	0.024	3.550	10.62	No trend
EBEMH	SAV1	S	STSS	1.09	0.0049	-0.225	9.950	-36.18	Improving
EBEMH	SAV1	B	BTSS	0.00	0.0157	-0.413	12.600	-52.49	No trend
EBEMH	SAV1	S	SECCHI	0.00	0.0202	0.009	0.950	15.31	No trend
EBEMH	SAV1	B	BDO	0.00	0.0031	0.061	4.800	20.32	Improving
EBEMH	SAV1	S	SSALINITY	0.00	0.1980	0.072	17.950	6.39	No trend
EBEMH	SAV1	B	BSALINITY	0.00	0.5880	-0.033	18.650	-2.86	No trend
EBEMH	SAV1	B	BWTEMP	0.00	0.0084	0.105	23.000	7.30	Increasing
EBEMH	SAV1	S	SWTEMP	0.00	0.0558	0.054	23.950	3.63	No trend
WBEMH	SAV1	S	SCHLA	0.00	0.0320	-0.340	19.250	-28.28	No trend
WBEMH	SAV1	S	STSS	0.00	0.1915	-0.260	26.300	-15.79	No trend
WBEMH	SAV1	B	BTSS	0.00	0.0304	-0.759	37.100	-32.73	No trend
WBEMH	SAV1	S	SECCHI	0.00	0.0350	0.000	0.550	0.00	No trend
WBEMH	SAV1	B	BDO	0.00	0.0201	0.053	6.250	13.44	No trend
WBEMH	SAV1	S	SSALINITY	0.00	0.2639	0.068	17.150	6.38	No trend
WBEMH	SAV1	B	BSALINITY	0.00	0.4691	0.039	17.100	3.62	No trend
WBEMH	SAV1	B	BWTEMP	0.00	0.2363	0.045	23.800	3.04	No trend
WBEMH	SAV1	S	SWTEMP	0.00	0.1786	0.054	24.200	3.59	No trend
SBEMH	SAV1	S	SCHLA	2.17	0.0437	-0.148	3.725	-63.71	No trend
SBEMH	SAV1	S	STSS	0.53	0.0168	-0.192	8.575	-35.82	No trend
SBEMH	SAV1	B	BTSS	0.53	0.0000	-0.656	14.600	-71.89	Improving
SBEMH	SAV1	S	SECCHI	0.00	0.0736	0.010	0.750	21.33	No trend
SBEMH	SAV1	B	BDO	0.00	0.0040	0.070	4.200	26.67	Improving
SBEMH	SAV1	S	SSALINITY	0.00	0.0938	0.108	16.700	10.34	No trend
SBEMH	SAV1	B	BSALINITY	0.00	0.1974	-0.096	18.450	-8.32	No trend
SBEMH	SAV1	B	BWTEMP	0.00	0.0000	0.225	23.925	15.05	Increasing
SBEMH	SAV1	S	SWTEMP	0.00	0.0024	0.117	25.200	7.41	Increasing
ELIPH	SAV2	S	SCHLA	10.03	0.3363	0.029	5.138	11.28	No trend
ELIPH	SAV2	S	STSS	1.93	0.2939	-0.129	9.688	-26.67	No trend
ELIPH	SAV2	B	BTSS	0.00	0.4747	-0.110	9.688	-22.75	No trend
ELIPH	SAV2	S	SECCHI	0.00	0.0019	-0.011	1.250	-17.78	Degrading
ELIPH	SAV2	B	BDO	0.00	0.0286	0.017	7.425	4.68	No trend
ELIPH	SAV2	S	SSALINITY	0.00	0.1048	-0.078	20.050	-7.78	No trend
ELIPH	SAV2	B	BSALINITY	0.00	0.0235	-0.086	21.005	-8.19	No trend
ELIPH	SAV2	B	BWTEMP	0.00	0.2716	0.042	16.950	4.94	No trend
ELIPH	SAV2	S	SWTEMP	0.00	0.1378	0.048	17.875	5.38	No trend

Table 3-16. Annual season status in phytoplankton bioindicators in the James River and Elizabeth River for the period of 2002 through 2004.

Station	Season	Parameter	Above Pycnocline Median	Above Pycnocline Score	Above Pycnocline Score
TF5.5	Annual	Total Biomass	1.74E+09	58.90	Fair
TF5.5	Annual	Biomass to Abundance Ratio	48.15	25.75	Poor
TF5.5	Annual	Margalef Diversity Index	2.35	72.17	Good
TF5.5	Annual	Diatom Biomass	1.27E+09	64.16	Good
TF5.5	Annual	Dinoflagellate Biomass	2.61E+06	85.90	Poor
TF5.5	Annual	Cyanobacteria Biomass	4.47E+07	65.39	Poor
TF5.5	Annual	Chlorophyte Biomass	4.25E+08	79.37	Good
TF5.5	Annual	Primary Productivity	151.05	87.03	Poor
TF5.5	Annual	Cryphtophyte Biomass	2.73E+07	91.30	Good
TF5.5	Annual	Cyanobacteria Abundance	9.21E+06	73.84	Poor
RET5.2	Annual	Total Biomass	9.56E+08	51.68	Fair
RET5.2	Annual	Biomass to Abundance Ratio	52.38	39.56	Poor
RET5.2	Annual	Margalef Diversity Index	1.51	20.52	Poor
RET5.2	Annual	Diatom Biomass	4.85E+08	60.70	Good
RET5.2	Annual	Dinoflagellate Biomass	1.12E+06	64.37	Poor
RET5.2	Annual	Cyanobacteria Biomass	1.89E+07	60.17	Poor
RET5.2	Annual	Chlorophyte Biomass	1.35E+08	75.27	Good
RET5.2	Annual	Primary Productivity	60.03	60.05	Fair
RET5.2	Annual	Cryphtophyte Biomass	3.50E+07	85.41	Good
RET5.2	Annual	Cyanobacteria Abundance	2.45E+06	59.33	Poor
LE5.5	Annual	Total Biomass	4.80E+08	41.00	Poor
LE5.5	Annual	Biomass to Abundance Ratio	64.88	21.51	Poor
LE5.5	Annual	Margalef Diversity Index	2.38	39.63	Poor
LE5.5	Annual	Diatom Biomass	3.04E+08	57.66	Good
LE5.5	Annual	Dinoflagellate Biomass	6.88E+07	56.79	Fair
LE5.5	Annual	Cyanobacteria Biomass	1.30E+06	78.50	Poor
LE5.5	Annual	Chlorophyte Biomass	7.79E+04	78.80	Good
LE5.5	Annual	Primary Productivity	73.02	89.03	Poor
LE5.5	Annual	Cryphtophyte Biomass	2.52E+07	70.15	Good
LE5.5	Annual	Cyanobacteria Abundance	1.81E+05	80.84	Poor
SBE5	Annual	Total Biomass	2.14E+08	13.41	Poor
SBE5	Annual	Biomass to Abundance Ratio	41.01	15.68	Poor
SBE5	Annual	Margalef Diversity Index	1.92	67.42	Good
SBE5	Annual	Diatom Biomass	1.33E+08	47.21	Fair
SBE5	Annual	Dinoflagellate Biomass	1.23E+07	49.82	Fair
SBE5	Annual	Cyanobacteria Biomass	2.39E+06	52.89	Fair
SBE5	Annual	Chlorophyte Biomass	1.18E+06	82.02	Good
SBE5	Annual	Primary Productivity	24.88	25.76	Good
SBE5	Annual	Cryphtophyte Biomass	2.89E+07	98.80	Good
SBE5	Annual	Cyanobacteria Abundance	2.84E+05	53.17	Fair

Table 3-17. Annual season trends in phytoplankton bioindicators in the James River and Elizabeth River for the Annual season during the period of 1985 through 2004. "N.E." in the Percent Change column indicates "No Estimate" made due to a zero baseline value.

Station	Season	Layer	Parameter	P value	Slope	Baseline	Percent Change	Direction	Homogeneity test P value
TF5.5	Annual	AP	Total Abundance	0.0029	7.69E+05	2.12E+07	68.76	Increasing	0.0991
TF5.5	Annual	AP	Total Biomass	0.0000	8.00E+07	5.09E+08	298.68	Increasing	0.8890
TF5.5	Annual	AP	Biomass to Abundance Ratio	0.0000	2.114	28.27	142.09	Improving	0.7365
TF5.5	Annual	AP	Margalef Diversity Index	0.3740	0.005	2.39	3.99	No Trend	0.9479
TF5.5	Annual	AP	Diatom Biomass	0.0000	3.99E+07	3.44E+08	220.53	Improving	0.9533
TF5.5	Annual	AP	Dinoflagellate Biomass	0.2617	0	7.00E+05	0.00	No Trend	0.5075
TF5.5	Annual	AP	Cyanobacteria Biomass	0.0000	1.01E+06	1.62E+07	118.13	Degrading	0.6918
TF5.5	Annual	AP	Chlorophyte Biomass	0.0000	2.37E+07	1.37E+07	3293.34	Improving	0.9804
TF5.5	Annual	AP	Primary Productivity	0.2634	0.50	32.33	8.06	24.92	0.4219
TF5.5	Annual	AP	Cryptophyte Biomass	0.0000	1.38E+06	1.03E+07	254.89	Increasing	0.7966
TF5.5	Annual	AP	Cyanobacteria Abundance	0.0000	2.10E+05	4.51E+06	88.52	Degrading	0.3952
RET5.2	Annual	AP	Total Abundance	0.0739	3.37E+05	7.43E+06	86.06	No Trend	0.0752
RET5.2	Annual	AP	Total Biomass	0.0000	3.23E+07	1.68E+08	365.77	Increasing	0.0275
RET5.2	Annual	AP	Biomass to Abundance Ratio	0.0000	1.572	19.27	154.97	Improving	0.8757
RET5.2	Annual	AP	Margalef Diversity Index	0.0077	-0.020	1.65	-22.65	Degrading	0.7923
RET5.2	Annual	AP	Diatom Biomass	0.0000	1.77E+07	1.18E+08	286.55	Improving	0.0843
RET5.2	Annual	AP	Dinoflagellate Biomass	0.8223	0	4.79E+05	0.00	No Trend	0.5332
RET5.2	Annual	AP	Cyanobacteria Biomass	0.0268	4.26E+05	3.58E+06	226.01	No Trend	0.5313
RET5.2	Annual	AP	Chlorophyte Biomass	0.0000	6.30E+06	1.76E+06	6788.26	Improving	0.2111
RET5.2	Annual	AP	Primary Productivity	0.0000	-3.31	125.14	-52.95	-42.32	0.0485
RET5.2	Annual	AP	Cryptophyte Biomass	0.0000	1.51E+06	1.44E+07	200.07	Increasing	0.5877
RET5.2	Annual	AP	Cyanobacteria Abundance	0.0815	5.21E+04	7.15E+05	138.57	No Trend	0.2773
LE5.5	Annual	AP	Total Abundance	0.0009	1.32E+05	5.07E+06	52.24	Increasing	0.0743
LE5.5	Annual	AP	Total Biomass	0.0001	1.11E+07	2.35E+08	94.52	Increasing	0.0121
LE5.5	Annual	AP	Biomass to Abundance Ratio	0.0172	0.812	47.31	34.34	No Trend	0.0985
LE5.5	Annual	AP	Margalef Diversity Index	0.5866	-0.005	2.50	-4.12	No Trend	0.2721
LE5.5	Annual	AP	Diatom Biomass	0.0000	8.43E+06	1.61E+08	104.41	Improving	0.0208
LE5.5	Annual	AP	Dinoflagellate Biomass	0.0083	1.24E+06	2.08E+07	119.58	Degrading	0.4772
LE5.5	Annual	AP	Cyanobacteria Biomass	0.0000	3.92E+04	5.08E+02	154365.02	Degrading	0.9177
LE5.5	Annual	AP	Chlorophyte Biomass	0.0001	2.46E+04	5.83E+03	8434.73	Improving	0.8031
LE5.5	Annual	AP	Primary Productivity	0.1929	-0.85	62.05	-13.52	-21.80	0.1757
LE5.5	Annual	AP	Cryptophyte Biomass	0.2020	2.07E+05	2.02E+07	20.49	No Trend	0.0877
LE5.5	Annual	AP	Cyanobacteria Abundance	0.0000	6.40E+03	1.43E+04	895.84	Degrading	0.9968
SBE5	Annual	AP	Total Abundance	0.0008	1.38E+05	2.55E+06	86.18	Increasing	0.0737
SBE5	Annual	AP	Total Biomass	0.0046	5.33E+06	7.63E+07	111.79	Increasing	0.0021
SBE5	Annual	AP	Biomass to Abundance Ratio	0.1510	0.482	25.78	29.88	No Trend	0.0096
SBE5	Annual	AP	Margalef Diversity Index	0.1297	-0.013	2.40	-8.36	No Trend	0.0302
SBE5	Annual	AP	Diatom Biomass	0.0012	3.73E+06	4.44E+07	134.33	Improving	0.0024
SBE5	Annual	AP	Dinoflagellate Biomass	0.8228	-2.12E+04	8.66E+06	-3.92	No Trend	0.5706
SBE5	Annual	AP	Cyanobacteria Biomass	0.0000	1.18E+05	1.03E+05	1823.01	Degrading	0.9437
SBE5	Annual	AP	Chlorophyte Biomass	0.0077	4.40E+04	2.76E+05	255.27	Improving	0.1619
SBE5	Annual	AP	Primary Productivity	0.0069	-1.20	57.37	-16.81	-29.30	0.8914
SBE5	Annual	AP	Cryptophyte Biomass	0.0001	8.09E+05	1.37E+07	94.19	Increasing	0.3428
SBE5	Annual	AP	Cyanobacteria Abundance	0.0000	1.53E+04	7.87E+03	3111.59	Degrading	0.8842

Table 3-18. Annual season status in benthic community condition based on the B-IBI in the James River and Elizabeth River for the period of 2002 through 2004.

Station	Score	Status
TF5.5	2.3	Degraded
RET5.2	3.2	Meets Goals
LE5.1	3.8	Meets Goals
LE5.2	2.9	Marginal
LE5.4	3.4	Meets Goals
SBE2	2.3	Degraded
SBE5	2.3	Degraded

Table 3-19. Annual season term trends in the benthic IBI and its component metrics in the James River and Elizabeth River for the period of 1985 through 2004.

Station	Parameter	P value	Slope	Baseline	% Change	Direction
TF5.5	Benthic Index of Biotic Integrity	0.1598	0.04	2.13	40.06	No Trend
TF5.5	Total Abundance per square meter	0.1534	208.69	1335.60	312.50	No Trend
TF5.5	Total Biomass per square meter	0.4168	0.03	0.34	159.61	No Trend
TF5.5	Shannon-Weiner Diversity Index	0.8457	0.00	1.18	7.66	No Trend
TF5.5	Pollution Sensitive Species Abundance	0.0042	1.33	0.00	N .E.	Improving
TF5.5	Pollution Indicative Species Abundance	0.3636	-0.46	20.14	-45.27	No Trend
TF5.5	Pollution Sensitive Species Biomass	0.0042	3.01	0.00	N .E.	Improving
TF5.5	Pollution Indicative Species Biomass	0.2992	-1.38	43.89	-63.00	No Trend
RET5.2	Benthic Index of Biotic Integrity	0.0013	0.06	1.92	63.24	Improving
RET5.2	Total Abundance per square meter	0.2055	27.30	610.56	89.41	No Trend
RET5.2	Total Biomass per square meter	0.7208	-0.01	7.34	-1.84	No Trend
RET5.2	Shannon-Weiner Diversity Index	0.0137	0.05	1.66	56.55	Improving
RET5.2	Pollution Sensitive Species Abundance	0.0012	1.58	10.42	304.13	Improving
RET5.2	Pollution Indicative Species Abundance	0.8419	0.00	16.67	0.00	No Trend
RET5.2	Pollution Sensitive Species Biomass	0.0137	2.23	28.04	158.94	Improving
RET5.2	Pollution Indicative Species Biomass	0.3352	-0.01	8.42	-1.67	No Trend
LE5.1	Benthic Index of Biotic Integrity	0.3866	0.02	3.02	12.52	No Trend
LE5.1	Total Abundance per square meter	0.8691	6.13	524.70	19.87	No Trend
LE5.1	Total Biomass per square meter	0.3648	-0.03	5.71	-10.01	No Trend
LE5.1	Shannon-Weiner Diversity Index	0.8048	0.01	2.06	5.08	No Trend
LE5.1	Pollution Sensitive Species Abundance	0.5641	-0.29	32.16	-15.32	No Trend
LE5.1	Pollution Indicative Species Abundance	0.1554	0.28	7.13	66.00	No Trend
LE5.1	Pollution Sensitive Species Biomass	0.8691	-0.22	74.24	-4.96	No Trend
LE5.1	Pollution Indicative Species Biomass	0.1554	0.12	4.82	42.11	No Trend
LE5.2	Benthic Index of Biotic Integrity	0.5811	-0.02	3.33	-10.94	No Trend
LE5.2	Total Abundance per square meter	0.0976	41.62	1221.12	68.17	Improving
LE5.2	Total Biomass per square meter	0.3978	-0.12	4.58	-54.17	No Trend
LE5.2	Shannon-Weiner Diversity Index	0.2992	-0.03	2.55	-21.36	No Trend
LE5.2	Pollution Sensitive Species Abundance	0.0443	2.07	34.48	119.99	Improving
LE5.2	Pollution Indicative Species Abundance	0.9483	-0.07	17.25	-8.48	No Trend
LE5.2	Pollution Sensitive Species Biomass	0.7952	0.66	40.78	32.52	No Trend
LE5.2	Pollution Indicative Species Biomass	0.1194	0.38	8.76	87.02	No Trend
LE5.4	Benthic Index of Biotic Integrity	0.8704	0.00	3.73	0.00	No Trend
LE5.4	Total Abundance per square meter	0.5164	19.95	2528.10	15.78	No Trend
LE5.4	Total Biomass per square meter	0.0023	-1.54	22.86	-134.39	Degrading
LE5.4	Shannon-Weiner Diversity Index	0.0798	-0.02	3.69	-12.86	Degrading
LE5.4	Pollution Sensitive Species Abundance	0.2176	-0.71	50.52	-27.97	No Trend
LE5.4	Pollution Indicative Species Abundance	0.1214	-0.07	1.99	-71.06	No Trend
LE5.4	Pollution Sensitive Species Biomass	0.0231	-1.72	60.10	-57.39	Degrading
LE5.4	Pollution Indicative Species Biomass	0.9737	0.00	0.51	0.00	No Trend
SBE2	Benthic Index of Biotic Integrity	0.2403	0.02	2.00	19.37	No Trend
SBE2	Total Abundance per square meter	0.0271	186.12	1659.96	179.39	Improving
SBE2	Total Biomass per square meter	0.3214	0.03	0.92	49.07	No Trend
SBE2	Shannon-Weiner Diversity Index	0.4713	0.02	1.67	20.62	No Trend
SBE2	Pollution Sensitive Species Abundance	0.0003	4.77	4.62	1649.97	Improving
SBE2	Pollution Indicative Species Abundance	0.0192	-3.12	72.25	-69.19	Improving
SBE2	Pollution Sensitive Species Biomass	0.0272	2.16	8.41	411.33	Improving
SBE2	Pollution Indicative Species Biomass	0.8571	-0.15	44.94	-5.17	No Trend
SBE5	Benthic Index of Biotic Integrity	0.0050	0.07	1.25	95.59	Improving
SBE5	Total Abundance per square meter	0.7187	50.56	3806.46	21.25	No Trend
SBE5	Total Biomass per square meter	0.1612	0.05	0.58	131.15	No Trend
SBE5	Shannon-Weiner Diversity Index	0.5890	0.02	0.99	36.55	No Trend
SBE5	Pollution Sensitive Species Abundance	0.0000	4.01	0.31	20503.15	Improving
SBE5	Pollution Indicative Species Abundance	0.0012	-5.13	85.43	-96.15	Improving
SBE5	Pollution Sensitive Species Biomass	0.0060	2.79	2.15	2072.05	Improving
SBE5	Pollution Indicative Species Biomass	0.0717	-3.16	77.83	-65.06	Improving

Table 3-20. Bootstrap and Wilcoxon rank sum test results for James River 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. Additional segments listed are as follows: JMSMHb= Nansemond River, JMSMHc=Chuckatuck River and Pagan River, JMSMHd= Warwick River, and JMSPHd=Willoughby Bay.

		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
JMSTF	14	0.02	0.05	-0.03	-0.20	0.15	1.00	0.1250	No	No	3.2	8	7	57	50
JMSOH	22	0.28	0.05	0.23	0.01	0.45	1.00	0.0030	Yes	Yes	2.9	13	11	59	50
CHKOH	5	0.00	0.05	-0.05	-	-	1.00	0.2488	-	-	3.7	5	5	100	100
JMSMH	46	0.37	0.05	0.32	0.14	0.51	1.00	<0.0001	Yes	Yes	2.7	21	19	46	41
JMSMHb	16	0.45	0.05	0.40	0.11	0.70	1.00	<0.0001	Yes	Yes	2.4	6	6	38	38
JMSMHc	3	0.33	0.05	0.28	-	-	0.80	0.3049	-	-	3.1	2	2	67	67
JMSMHd	3	0.34	0.05	0.29	-	-	0.91	0.0287	-	-	2.8	2	1	67	33
JMSPH	10	0.12	0.05	0.07	-0.36	0.49	0.97	0.4675	No	No	3.4	10	9	100	90
JMSPHd	3	0.91	0.05	0.86	-	-	0.86	0.0004	-	-	1.7	0	0	0	0
ELIPH	17	0.39	0.05	0.34	0.05	0.63	1.00	0.0017	Yes	Yes	2.8	11	10	65	59
ELIMH	37	0.48	0.05	0.43	0.23	0.64	1.00	<0.0001	Yes	Yes	2.5	18	12	49	32
EBEMH	15	0.57	0.05	0.52	0.22	0.82	1.00	<0.0001	Yes	Yes	2.2	4	1	27	7
WBEMH	19	0.36	0.05	0.31	0.04	0.59	1.00	<0.0001	Yes	Yes	2.4	8	4	42	21
LAFMH	27	0.31	0.05	0.26	-0.06	0.57	1.00	<0.0001	No	Yes	2.4	10	5	37	19
SBEMH	47	0.70	0.05	0.65	0.49	0.80	1.00	<0.0001	Yes	Yes	2.0	7	2	15	4

Table 3-21. Diagnostic assessment of benthic community degradation for random sites sampled within James River 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. Additional segments listed are as follows: JMSMHb=Nansemond River, JMSMHc=Chuckatuck River and Pagan River, JMSMHd=Warwick River, and JMSPHd=Willoughby Bay.

				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.
APPTF	3.0	1	-	0	-	0.00	0	-	-	0.00	0	-	-	0.00
CHKOH	3.7	5	-	0	-	0.00	0	-	-	0.00	0	-	-	0.00
JMSTF	3.2	14	0.7190	4	66.67	28.57	1	16.67	0.00	0.00	0	0.00	0.00	0.00
JMSOH	2.9	22	0.7892	7	77.78	31.82	1	11.11	0.00	0.00	6	66.67	11.11	4.55
JMSMH	2.7	46	0.6422	18	72.00	39.13	6	24.00	4.00	2.17	10	40.00	4.00	2.17
JMSMHb	2.4	16	0.8690	9	90.00	56.25	7	70.00	0.00	0.00	4	40.00	0.00	0.00
JMSMHc	3.1	3	0.9855	1	100.00	33.33	1	100.00	0.00	0.00	1	100.00	0.00	0.00
JMSMHd	2.8	3	0.9547	1	100.00	33.33	1	100.00	0.00	0.00	0	0.00	0.00	0.00
JMSPH	3.4	10	-	0	-	0.00	0	-	-	0.00	0	-	-	0.00
JMSPHd	1.7	3	0.8388	3	100.00	100.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
WBEMH	2.4	19	0.7383	8	72.73	42.11	7	63.64	9.09	5.26	3	27.27	0.00	0.00
LAFMH	2.4	27	0.8793	15	88.24	55.56	11	64.71	0.00	0.00	3	17.65	5.88	3.70
SBEMH	2.0	47	0.7986	32	80.00	68.09	26	65.00	12.50	10.64	10	25.00	12.50	10.64
EBEMH	2.2	15	0.8904	10	90.91	66.67	7	63.64	0.00	0.00	1	9.09	0.00	0.00
ELIMH	2.5	37	0.6758	13	68.42	35.14	5	26.32	5.26	2.70	7	36.84	15.79	8.11
ELIPH	2.8	17	0.4849	3	50.00	17.65	1	16.67	16.67	5.88	2	33.33	16.67	5.88