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

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Preface

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

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

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

List of Appendices (on attached CD-ROM)

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 1. Nutrient and Sediment Loads for Virginia (2001). Modified from data provided by the Virginia Department of Environmental Quality. Phosphorous and nitrogen loads are in kg/year and sediment loads are metric tons/year. Percent change compares 2003 data to 1985 data. Nonpoint source loads are results based on the Year 2003 Progress Run of the Chesapeake Bay Watershed Model and calculated reductions for calendar year 2001 Best Management Practices (BMPs) as monitored by the Department of Conservation and Recreation. Values with a "*" were updated with the latest available point source data.

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

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

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

Chapter 1. Introduction

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

Water quality and living resource monitoring in the Virginia Mainstem and tributaries began in 1985 and has continued for 19 years. Detailed assessments of the status and long-term trends in water quality and living resources in Chesapeake Bay and its tributaries have been previously conducted (Alden et al., 1991,1992; Carpenter and Lane, 1998; Dauer, 1997; Dauer et al., 1998a,1998b, 2002; Lane et al.,1998; Marshall, 1994,1996; Marshall and Burchardt, 1998, 2003, 2004a, 2004b; Marshall et al., 1998). An attempt was made to determine if there was concordance in current conditions of, and long-term changes, in water quality and living resources. The purpose of this project was to reassess the results of these studies by re-conducting the analyses after adding data collected during 2003. This report describes the status of water quality and living resource conditions for the Virginia Mainstem and tributaries, summarizes major long-term trends in water quality and measures of living resource community health and updating past basin summary reports (Dauer et al 2003a, 2003b, 2003c).

Chapter 2. Chesapeake Bay Monitoring Program Descriptions

I. Water Quality

A. Sampling Locations and Procedures

As part of the U. S. Geological Survey's River Input Program, water quality data have been collected at five stations near the fall line and three stations above the fall line in Virginia. Samples were taken at base-flow twice a month and during high flows whenever possible between 1988 and 2003. Water quality data have also been collected by the Virginia Department of Environmental Quality (DEQ) at three additional stations upstream of these River Input sites (Figure 2-1). These stations had a minimum of three consecutive years of samples taken between 1985 and 1996 with sampling occurring on at least a monthly basis.

Water quality conditions were regularly monitored at 28 sites in the Bay Mainstem beginning in July, 1985. From 1985 until 1995 eight stations were sampled by Old Dominion University (ODU) and 20 stations were sampled by the Virginia Institute of Marine Science (VIMS). From 1995 through the present, Mainstem water quality monitoring was conducted by ODU. Tributary water quality monitoring was conducted by the Virginia DEQ at 27 sites in the James, York (including the Mattaponi and Pamunkey) and Rappahannock rivers (Figure 2). In addition, six permanent water quality monitoring sites were established in the Elizabeth River/Hampton Roads Harbor by ODU in February, 1989 (Figure 2-2). In August 1990, station LAF1 was dropped from the Elizabeth River Long Term Monitoring (ERLTM) Program.

The temporal sampling scheme for the water quality monitoring program changed several times over the 19 year period (varying from 20 to 12 sampling events per year) as a result of changes in the monitoring program budget. In general, Mainstem sampling cruises were conducted semi-monthly from March through October and monthly from November through February until 1996. Starting in 1996 Mainstem sampling cruises were conducted semi-monthly for July and August and monthly the rest of the year. Tributary sampling by the Virginia Department of Environmental Quality was conducted 20 times per year until 1994 when sampling was reduced to 12 times per year. The Elizabeth River stations were sampled monthly. Field sampling procedures used for ODU and VIMS water quality collections are described in detail by Alden et al. (1992a). Field sampling procedures for DEQ water quality collections are described in detail in DEQ's Quality Assurance Project Plan for the Chesapeake Bay Program (Donat and Doughten, 2002).

B. Laboratory sample processing

Descriptions of laboratory sample processing and standard operating procedures for all water quality parameters are found in the Chesapeake Bay Program Quality Assurance Project Plans (QAPjPs) prepared by each of the participating laboratories (Donat and Doughten, 2002). Copies of the QAPjPs can be obtained by contacting EPA's Chesapeake Bay Program Quality Assurance Officer.

II. Phytoplankton

A. Sampling Locations and Procedures

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

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

B. Laboratory Sample Processing

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

III. Benthos

A. Fixed Location Sampling

Sixteen stations in the lower Chesapeake Bay were sampled quarterly (March, June, September, December) from March 1985 through December 1995 as part of the Benthic Biological Monitoring Program of the Chesapeake Bay Program. Beginning in 1996 sampling at the fixed stations occurred only in June and September and a stratified random sampling element was added to the program. Power and robustness analyses indicated that sampling during June and September would be sufficient for detecting long-term trends at the fixed locations while at the same time, allow funding resources to be reallocated to the probability-based random sampling regime (Alden et al., 1997). Stations were located within the mainstem of the bay and the major tributaries - the James, York and Rappahannock rivers (Figure 2-3). In the tributaries, stations were located within the tidal freshwater zone (TF5.5, TF4.2, TF3.3), turbidity maximum (transitional) zone (RET5.2, RET4.3, RET3.1), lower estuarine mesohaline muds (LE5.2, LE4.1, LE3.2) and lower estuarine polyhaline silty-sands (LE5.4, LE4.3). The tidal freshwater station within the York River estuary was located in the Pamunkey River. In the Mainstem of the Bay three stations were located off the mouths of the major tributaries (CB8.1, CB6.4, CB6.1) and two stations in the deeper channels near the bay mouth (CB7.3E) and above the Rappahannock River near the Virginia-Maryland border (CB5.4).

In 1989, five additional stations were added to the program: two stations in the Southern Branch of the Elizabeth River (SBE2, SBE5) in regions exposed to contaminated sediments, a station in the transitional region of the James River (LE5.1), a station in the lower York River exposed to low dissolved oxygen events (LE4.3B), and a station in the lower Rappahannock River exposed to low dissolved oxygen events (LE3.4).

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

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

B. Probability-Based Sampling

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

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

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

C. Laboratory Sample Processing

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

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

IV. Statistical Analyses

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

A. Status Assessments

For the tidal water quality stations, status analyses were conducted using surface and bottom water quality measurements for six parameters: total nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved inorganic phosphorus, chlorophyll *a*, and total suspended solids. Status analyses were also performed on secchi depth and bottom dissolved oxygen. All analyses were conducted using water quality data collected from all of the Chesapeake Bay Mainstem and tributary stations from the January 2001 through December of 2003 except for bottom dissolved oxygen for which analyses were conducted using data collected only during the summer months of June through September.

The relative status of each station and segment was determined by comparison to a benchmark data set comprised of all data collected from 1985 through 1990 by both the Virginia and Maryland monitoring programs. Each station was rated as poor, fair, or good relative to the benchmark data. The ratings are obtained for data collected within each salinity zone with salinity zones being assigned using the Venice classification system (Symposium on the Classification of Brackish Waters, 1958). For each parameter in the benchmark data set, a transformation was chosen that yields a distribution that was symmetric and approximated by the logistic cumulative distribution function (CDF). In most cases, the logarithmic transformation was selected. A logistic CDF based on the mean and variance of each parameter of the benchmark data set was used to perform a probability integral transform on all data collected during the period of January, 2001 through December, 2003. This resulted in data in the interval (0,1) that follow a uniform distribution. The three year median of these transformed data was computed as an indicator of status for the period specified. The median of n observations taken from a uniform distribution follows a Beta distribution with parameters (m,m) where:

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

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

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

Finally, median scores were calculated that were compared to the benchmark scale.

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

Status for phytoplankton involved the calculation of relative status using the same technique as described for water quality relative status assessments. For phytoplankton communities the following indicators were assessed: total phytoplankton community abundance, total phytoplankton community biomass, diatom abundance, dinoflagellate abundance, cyanobacteria abundance, picoplankton abundance, and primary productivity (carbon fixation). Benchmarks for picoplankton abundance were made using data collected only in Virginia since sampling protocols for the Maryland program did not include counts of epifluorescent picoplankton.

Status of benthic communities at each fixed station was characterized using the three-year mean value (2001 through 2003) of the B-IBI (Weisberg et al., 1997). The B-IBI indicates whether the macrobenthic community meets the restoration goals developed for benthic habitats of the Chesapeake Bay. An index value that exceeds or equals 3.0 indicates that the macrobenthic community meets or exceeds the restoration goals developed for that habitat type while a value below 3.0 indicates that the macrobenthic community does not meet the restoration goals. Status of the benthic community was classified into four levels based on the B-IBI. Values less than or equal to 2 were classified as severely degraded, values from 2.0 to 2.6 were classified as degraded, values greater than 2.6 but less than 3.0 were classified as marginal, and values of 3.0 or more were classified as meeting goals.

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

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

Variance for this estimate was calculated as:

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

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

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

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

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

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

B. Long-term Trend Analyses

1. Non-tidal water quality

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

2. Tidal water quality

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

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

In 1994, changes in laboratory analytical methods for estimating concentrations of total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus were implemented by the Department of Environmental Quality in order to improve the accuracy of concentration estimates. These changes resulted in step trends in these parameters. In order to compensate for the step trends, a "blocked" seasonal Kendall approach (Gilbert, 1987) was used to compare trends conducted between two separate time periods which in this case were the pre-method (1985 through 1993) and post-method change (1995 through 2003) time periods for these parameters. Note that 1994 was eliminated from the analyses because samples during this year were collected and processed by a laboratory that was different than the VADCLS. The "blocked" seasonal Kendall test was applied only to those segment/parameter combinations for which a method change occurred. The statistical tests used for all other segment/parameter combinations were the seasonal Kendall test for monotonic trends and the Van Belle and Hughes tests for homogeneity of trends between stations, seasons, and station-season combinations (Gilbert, 1987).

A P value of 0.01 was chosen as the statistical test criterion for all water quality trend analyses. Recent studies on representative data sets from the Chesapeake Bay monitoring program have indicated that these tests are very powerful and robust, even when data violate most of the assumptions of parametric statistics (Alden et al., 1991; Alden et al., 1992b; Alden et al., 1994; Alden and Lane, 1996).

3. Living resources

Trend analyses for phytoplankton communities were conducted on the following phytoplankton community indices: the phytoplankton IBI, total phytoplankton abundance (excluding picoplankton); total phytoplankton biomass (excluding picoplankton); the Margalef species diversity index, and C^{14} productivity. In addition, trend analyses were conducted on abundance and biomass values for the following taxonomic groups: diatoms; dinoflagellates; cyanobacteria; cryptomonads; chlorophytes; bloom producing species; and toxic bloom producing species. A statistical test criterion for phytoplankton metrics was a P value of 0.05.

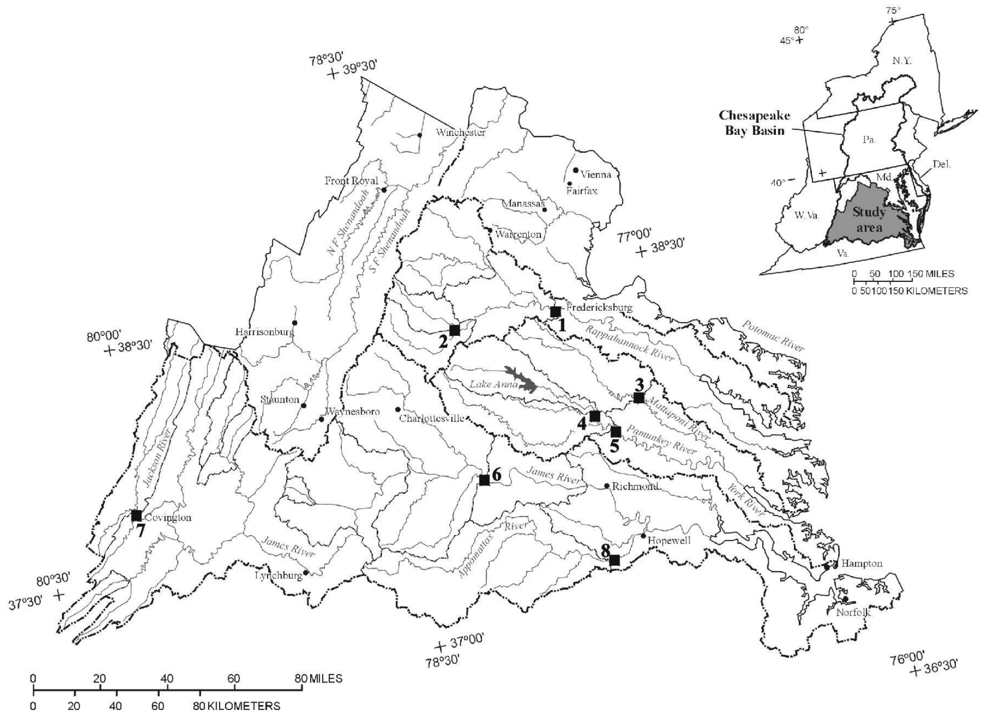
The Margalef species diversity index was calculated as follows:

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

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

Trend analyses for benthic communities were conducted using the B-IBI (Ranasinghe et al., 1994; Weisberg et al., 1997) and on selected metrics of the B-IBI. Benthic restoration goals were developed for benthic habitats of the Chesapeake Bay based upon reference sites that were minimally impacted by low dissolved oxygen events and sediment contaminants. Goals were developed based upon data from an index period of July 15 through September 30. Therefore trends in the value of the B-IBI were based upon September cruise values for the 19 year period of 1985-2003. Selected benthic metrics were species diversity (H'), community abundance, community biomass, pollution-indicative species abundance, pollution-indicative species biomass, pollution-sensitive species abundance, and pollution-sensitive species biomass. See Weisberg et al. (1997) for a list of pollution-indicative and pollution-sensitive taxa.

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



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

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

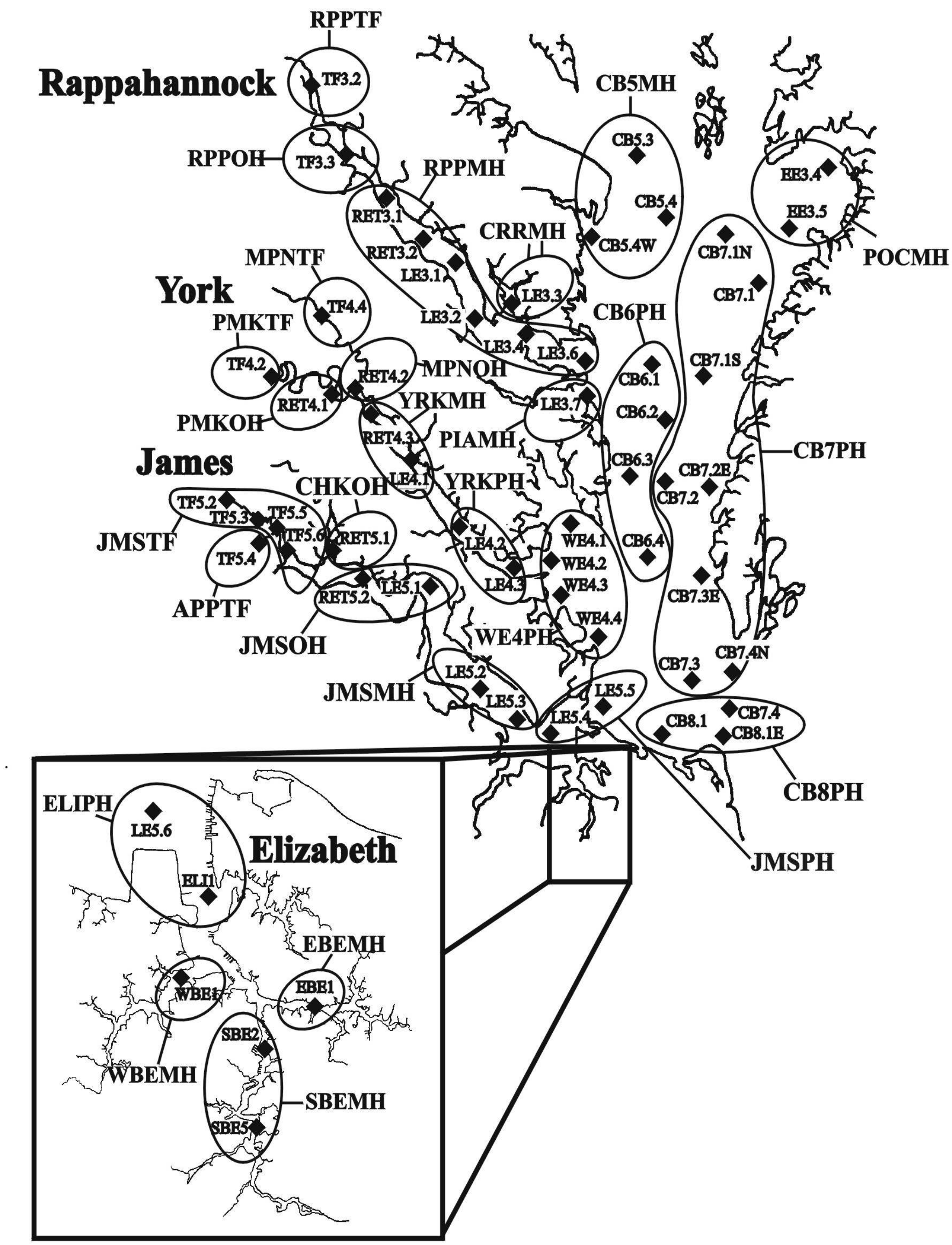


Figure 2-2. Map showing the locations of the water quality monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem used in the statistical analyses. Also shown are ellipses that delineate the Chesapeake Bay Program segmentation scheme.

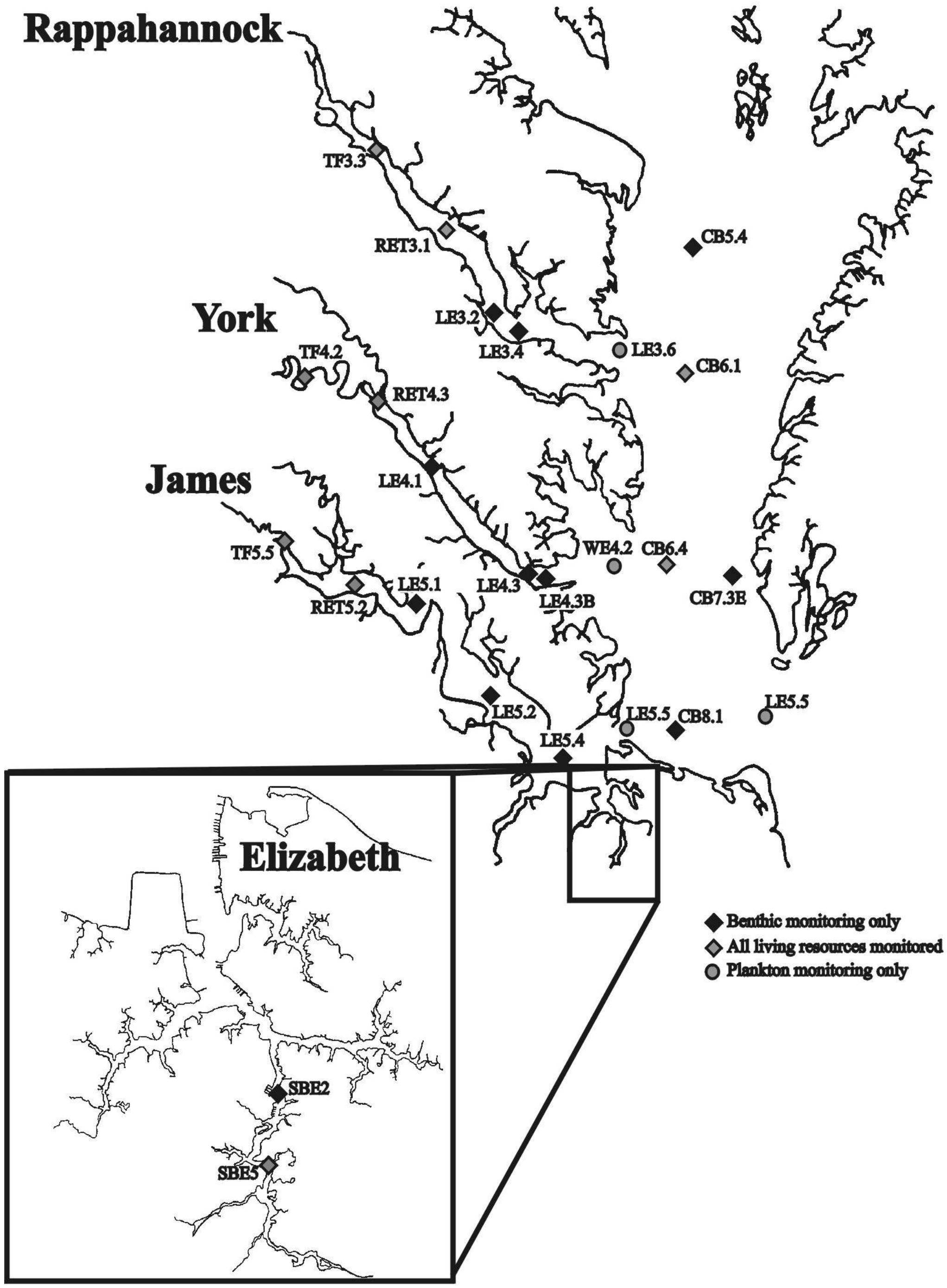


Figure 2-3. Location of living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem.

Table 2-1. **Definitions of seasonal time periods for status and trend analyses conducted for of the tidal monitoring programs. A "x" indicates the analysis was conducted for the season and parameter group combination while a "-" indicates that no analysis was conducted. *Note that benthic status and trend analyses were conducted on data collected from June 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**	**Light Attenuation Coefficient (Kd)**	**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	>9	<15	<15	none	<0.02
Oligohaline	Apr.- Oct.	<2	>9	<15	<15	none	<0.02
Mesohaline	Apr.-Oct.	<1.5	>15	<15	<15	<0.15	<0.01
Polyhaline	Mar.- May,	<1.5	>15	<15	<15	<0.15	<0.01

Chapter 3. James River Basin

I. Executive Summary

A. Summary of Basin Characteristics

The James River basin is the largest river basin in Virginia covering 26,422 km^2 or nearly 25% of the Commonwealth's total area. The James River begins in the Allegheny Mountains where it is formed by the confluence of the Jackson and Cowpasture rivers. From its sources, the James River flows 547 km in a southeasterly direction to the fall-line near Richmond and for an additional 180 km to Hampton Roads where it enters Chesapeake Bay. Approximately 71% of the entire basin is forested and an additional 17% of the watershed is covered by agricultural land. All other land use types account for just over 12% of the basin. Approximately 16,600 km of the 44,290 km (38%) of streambanks and shoreline within the watershed have a 30 m minimum riparian forest buffer. The population in the James River basin for 2000 was 2,522,583 people with a population density of 93.4 individuals per km^2. Most of the basin's population is concentrated in approximately 5% of the watershed which consists of residential and industrial land found in the urban areas of Tidewater, Richmond, Petersburg, Lynchburg and Charlottesville.

Total point and non-point source loadings of nitrogen were estimated to be 16,132,907 kg/yr in 2000. Total point and non-point source loadings of phosphorus and sediments were approximately 2,587,742 kg/yr and 1,096,793 metric tons/yr with point sources accounting, respectively in 2000. In 2001, point source loads for total nitrogen and total phosphorus in the James River watershed were approximately 6,974,100 kg/yr and 607,670 kg/yr, respectively. Daily freshwater flow at the 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, 2002. Grand mean flow at the fall-line was 193.30 m^3/sec. Figures 3-1 to 3-7 provide summary information of basin characteristics of the James River.

B. Summary of Status and Long Term Trends

Figures 3-8 to 3-11 provide summaries of water quality status and trend analyses for the James and Elizabeth rivers. The terms *good*, *fair*, and *poor* used in conjunction with water quality conditions are statistically determined classifications for comparison among areas of similar salinity within the Chesapeake Bay system. Though useful in comparing current conditions among different areas of the Chesapeake Bay system, these terms are not absolute evaluations but only appraisals relative to other areas of a generally degraded system. Several major scientific studies have shown that the Chesapeake Bay system is currently nutrient enriched and has excessive and detrimental levels of nutrient and sediment pollution (USEPA, 1982; USEPA, 1983; Boynton et al., 1995; Harding and Perry, 1997; Bricker et al., 1999; USEPA 2001; Hagy et al., 2004). Given this, it is likely that an absolute evaluation in relation to ideal conditions would indicate that most water quality parameters are currently poor throughout the whole Bay system.

Status of nitrogen parameters was either good or fair in all segments of the James River. Relative status of total phosphorus and dissolved inorganic phosphorus was good and fair in the upper segments of the James River (JMSTF, APPTF, and CHKOH) and poor or fair in the lower segments (JMSOH, JMSMH, JMSPH). Status of all nutrients was poor for all segments in the Elizabeth River. Status of surface chlorophyll *a* was good in all James River main stem segments except the James River Mouth (JMSPH) where it was fair. Status of surface chlorophyll *a* was poor in the Appomattox River (APPTF) and Chickahominy River (CHKOH). Status of surface chlorophyll *a* was poor in the Western Branch (WBEMH) and Elizabeth River Mainstem (ELIPH), fair in the Eastern Branch (EBEMH) and good in the Southern Branch. Status of surface and bottom total suspended solids and secchi depth was poor in nearly all segment of the James River. Status of surface total suspended solids was poor in the Western Branch (WBEMH) and Elizabeth River Mainstem (ELIPH), and fair in the Southern Branch and Eastern Branch. Status of bottom total suspended solids was poor in the Western Branch (WBEMH) and Elizabeth River Mainstem (ELIPH), and good in the Southern Branch and Eastern Branch. Status of secchi depth was poor in all segments of the Elizabeth River. Status of bottom dissolved oxygen was good throughout the James River and either fair or good in all segments of the Elizabeth River.

Most parameters in the James River either did not meet the SAV habitat requirements or were borderline with the exceptions of surface dissolved inorganic phosphorus in the Chickahominy River (CHKOH), surface chlorophyll *a* in the Middle James River (JMSOH), the Lower James River (JMSMH) and the James River Mouth (JMSPH). Most parameters in the Elizabeth River either did not meet the SAV habitat requirements or were borderline except for secchi depth in the Southern Branch and surface chlorophyll *a* and surface total suspended solids in all segments but the Western Branch (WBEMH).

There were no improving trends in total nitrogen or dissolved inorganic nitrogen and a single degrading trend in bottom total nitrogen in the Lower James River (JMSMH). Improving trends in surface and bottom dissolved inorganic phosphorus were detected in the Appomattox River (APPTF) and for bottom dissolved inorganic phosphorus in the Upper James River (JMSTF). Degrading trends for surface and bottom dissolved inorganic phosphorus were detected in the Middle James River (JMSOH) and the Lower James River (JMSMH). An improving trend in surface chlorophyll *a* was detected in the Chickahominy River (CHKOH). Degrading trends in bottom total suspended solids were detected in the Upper James River (JMSTF), the Chickahominy River (CHKOH), and the Lower James River (JMSMH). Degrading trends in secchi depth were detected in the Upper James River (JMSTF), the Chickahominy River (CHKOH), and the James River Mouth (JMSPH). Improving trends were detected in the Upper James River (JMSTF) and the James River Mouth (JMSPH). Improving trends in surface total nitrogen were detected in the Western Branch (WBEMH) and Southern Branch (SBEMH) while an improving trend in bottom total nitrogen was detected in the Eastern Branch (EBEMH) of the Elizabeth River. Improving trends in surface and bottom dissolved inorganic nitrogen were detected in the Southern Branch (SBEMH) and in the Eastern Branch (EBEMH) of the Elizabeth River, respectively. Improving trends in surface and bottom total phosphorus were detected in all segments in the Elizabeth River except the Elizabeth River Mouth (ELIPH). An improving trend in surface chlorophyll *a* was detected in the Western

Branch (WBEMH) along with improving trends in surface and bottom total suspended solids in the Eastern Branch (EBEMH) and the Southern Branch (SBEMH). A degrading trend in secchi depth was detected in the Elizabeth River Mouth segment (ELIPH).

Figures 3-12 and 3-13 provide summaries of living resources status and trend analyses for the James River. 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). Status of most parameters at station SBE5 was poor or fair while status for the Margalef diversity index, chlorophyte biomass, picoplankton biomass and primary productivity was good. Improving trends in diatom and chlorophyte biomass were detected at all stations in the James River and at station SBE5 in the Southern Branch of the Elizabeth River. Improving 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). An improving trend in this parameter was also detected at station SBE5 in the Southern Branch (SBEMH) of the Elizabeth River. 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 and at station SBE5 in the Southern Branch of the Elizabeth River (SBEMH).

Improving trends in the benthic IBI (B-IBI) were detected at station TF5.5 in the Upper James River (JMSTF), 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 all stations 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 in the Elizabeth River was degraded.

C. Summary of Major Issues in the Basin

Two major water quality issues are evident in the main stem of the James River. The first is the apparent widespread problem in water clarity. Relative status of secchi depth was poor in all segments of the James River while status of surface and bottom total suspended solids was poor in all segments except the James River Mouth (JMSPH). The SAV habitat requirements for secchi depth and surface total suspended solids were not met in any segments in the James River except the James River Mouth (JMSPH). In addition, degrading trends in secchi depth and bottom total suspended solids occurred in half of the segments in the James River.

In addition to water clarity, phosphorus appear to also be problematic in this tributary although the phenomenon appears to be localized primarily in the Middle James River (JMSOH) and Lower

James River (JMSMH). Relative status of surface and bottom total and dissolved inorganic phosphorus was poor in the Middle James River (JMSOH) and the Lower James River (JMSMH). Also the SAV habitat requirement for surface dissolved inorganic phosphorus was not met in either of these two segments. Finally, degrading trends in surface and bottom dissolved inorganic phosphorus were detected in both of these segments that were consistent between the pre- and post-method periods in both the Middle James River (JMSOH) and the Lower James River (JMSMH).

The major concerns within the phytoplankton community are increasing long-term trends in abundance and biomass among the cyanobacteria and poor status of these indicators. These taxa are a less favorable food source within the water column, are associated with degrading water conditions, and also contain several potential bloom and toxin producers. An additional concern is the poor status of dinoflagellate biomass in the upper and mid-regions of the river, and increased trends of dinoflagellate biomass in the lower regions of the James. These concerns, as well as those mentioned in the section above, support the need for the adoption for the numeric chlorophyll *a* criteria in the James River described by VADEQ (2005). The primary area of concern with respect to the benthos is the Upper James River (JMSTF) at station TF5.5 where status of the B-IBI is degraded.

In the Elizabeth River, water quality problems are more widespread and primarily due to excessive nutrient concentrations as is evidenced by the poor status of nutrients in all segments and by the fact that surface dissolved inorganic nitrogen and surface dissolved inorganic phosphorus either failed to meet their respective SAV habitat requirements or were borderline in all segments. Water clarity is also a problem in the Elizabeth River as indicated by the poor relative status of this parameter in all segments and the fact that the SAV habitat criterion was met only in the Southern Branch (SBEMH). Despite these problems, conditions in the Elizabeth River appear to be improving as was indicated by the improving trends of some nutrient parameters in all segments except the Elizabeth River Mainstem (ELIPH).

Phytoplankton communities in the Southern Branch of the Elizabeth River (SBEMH) are impacted as indicated by the fair to poor status of the majority of community metrics, as well as, the degrading trends in cyanophyte abundance and biomass at station SBE5. Despite a significant improving trend in the B-IBI at one station, the status of the B-IBI within the Southern Branch of the Elizabeth River remains degraded.

II. Management Recommendations

Problems both with respect to water quality and living resources are still evident in the James River, despite improvements in point source nutrient loadings. Problems with nutrients appear to be evident especially in the mesohaline and polyhaline segments of the James River and in the Elizabeth River. These segments are located in or near the largest concentration of urban land in the state of Virginia. This suggests that the environmental problems in these areas may be the result of their proximity to the point sources and urban non-point sources in this population center. Additional point source and non-point source controls will help alleviate these problems. If nutrient concentrations are not limiting in these areas, water clarity may be reduced by a high concentration of total suspended solids and/or high phytoplankton concentrations caused by existing nutrient levels. Additional point and non-point nutrient controls could also ameliorate water clarity problems within these segments. Problems with water clarity are more widespread in both James and the Elizabeth suggesting that a combination of factors such as non-point and point source sediment loadings, or high phytoplankton concentrations may be adversely effecting water clarity. Problems with SAV habitat requirements tended to be widespread, as most segments had at least one parameter which failed to meet the SAV habitat requirements. Within the lower portions of the James River and the segments located in the Elizabeth River, water quality problems are most likely caused by nutrient loadings from point source loadings and urban run-off.

Problems with phytoplankton communities also tended to be widespread 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 and Elizabeth River. These problems should be addressed through adoption of numeric water quality standards for chlorophyll *a.*

The cause of water quality and living resource problems in the upper segments of the James River and the Appomattox and Chickahominy rivers is unclear. A more concerted effort should be placed on designing studies that can determine the cause of the water quality and living resource problems in these segments.

III. Overview of Monitoring Results

Figures 3-8 and 3-9 summarize the annual status and trend results for water quality in the James River. Status of all nitrogen parameters was good in the Upper and Middle James River, as well as the Appomattox and Chickahominy rivers (segments JMSTF, JMSOH, APPTF, and CHKOH). In the Lower James River (JMSMH) and the James River Mouth (JMSPH), status of nitrogen parameters was either good or fair. Relative status of total and dissolved inorganic phosphorus was fair in the Upper James River (JMSTF), good in the Appomattox River (APPTF) and Chickahominy River (CHKOH), and poor in the Middle and Lower James River (segments JMSOH and JMSMH). Status of these parameters in the James River Mouth (JMSPH) was fair for all but surface total phosphorus for which the status was poor. Status of surface chlorophyll *a* was good for the Upper, Middle, and Lower James River (segments JMSTF, JMSOH, and JMSMH). Status of surface and bottom total suspended solids and secchi depth was poor in all segments of the James River except the James River Mouth (ELIPH) where only secchi depth had a poor status. Status of bottom dissolved oxygen was good throughout all segments of the James River.

With the exception of surface dissolved inorganic phosphorus in the Chickahominy River, SAV habitat requirements for nutrients, where applicable, were either borderline or not met (Table 3-5). Surface chlorophyll *a* failed the SAV habitat criterion in the Appomattox River (APPTF), was borderline in the Upper James (JMSTF) and Chickahominy River (CHKOH) but met the habitat requirement in all other segments downstream. Surface total suspended solids was either borderline or failed to meet the SAV requirement in all segments except the James River Mouth (JMSPH) where the criterion was met. Secchi depth failed to met the SAV habitat requirement in all segments except the James River Mouth (JMSPH) where it met the criterion.

With respect to nutrients, improving trends that were consistent between the pre- and post-method change periods were limited to surface and bottom dissolved inorganic phosphorus in the Appomattox River (APPTF) and bottom dissolved inorganic phosphorus in the Upper James River (JMSTF). Degrading trends consistent between pre- and post-method change periods include surface and bottom dissolved inorganic phosphorus in the Middle James River (JMSOH) and Lower James River (JMSMH) and bottom total nitrogen in the Lower James River (JMSMH). Improving trends were detected for surface chlorophyll *a* in the Chickahominy River (CHKOH) and bottom dissolved oxygen in the Upper James River (JSMTF) and the James River Mouth (JMSPH). No other trends for the entire period of record were observed. With the exception of degrading trends in surface dissolved inorganic phosphorus in segments the Middle James River (JMSOH) and Lower James River (JMSMH), no significant trends in nutrients were consistent between the pre- and post-method change periods during the SAV growing season (Table 3-6). An improving trend in surface chlorophyll *a* was detected in the Chickahominy River (CHKOH) and degrading trends in secchi depth were detected in the Upper James River (JMSTF) and the Chickahominy River (CHKOH) during the SAV growing season (Table 3-7).

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.

The James River phytoplankton parameters showed both positive and negative characterizations and trends. Specifically the total phytoplankton abundance and biomass indicated long-term increasing trends. Throughout the river the diatoms continued to show increasing biomass trends, with the negative conditions of increasing trends of cyanobacterial abundance and biomass.

Benthic community status was good in most segments of the James River except for station TF5.5 in the Upper James River where status was degraded and at station LE5.2 in the Lower James River (JMSMH) where the status was marginal. Improving trends in the B-IBI were detected at station TF5.5 in the Upper James River (JMSTF) and station RET5.2 in the Middle James River (JMSOH).

Figures 3-10 and 3-11 summarize the annual status and trend results for water quality in the Elizabeth River. Status of all nutrient parameters was poor in all segments of the Elizabeth River. Status of surface chlorophyll *a* was poor in the Western Branch (WBEMH) and the Elizabeth River Mainstem (ELIPH) but good in the Southern Branch (SBEMH) and fair in the Eastern Branch (EBEMH). Status of surface and bottom total suspended solids was generally fair or poor except for bottom total suspended solids in the Southern Branch (SBEMH) and Eastern Branch (EBEMH) where status was good for this parameter. Status of secchi depth was poor throughout the Elizabeth River while the status of bottom dissolved oxygen was either fair or good.

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 Western Branch (WBEMH) where surface chlorophyll *a* was borderline and surface total suspended solids failed the criterion. Secchi depth failed to meet the criterion in the Western Branch (WBEMH), was borderline in the Eastern Branch (EBEMH) and Elizabeth River Mainstem (ELIPH), and met the criterion in the Southern Branch (SBEMH).

Improving trends in either surface or bottom total nitrogen were found in all segments of the Elizabeth River except the Elizabeth River Mainstem (ELIPH). Improving trends in surface and bottom total phosphorus were detected in all segments of the Elizabeth River except the Elizabeth River Mainstem (ELIPH). In addition, an improving trend in surface dissolved inorganic nitrogen and an improving trend in bottom dissolved inorganic nitrogen were detected in the Southern Branch (SBEMH) and the Eastern Branch (EBEMH), respectively. In addition to the improving trends in nutrients, improving trends were detected in surface chlorophyll *a* in the Western Branch (WBEMH), bottom total suspended solids in the Southern Branch, and surface total suspended solids in the Eastern Branch (EBEMH). The only degrading trend detected in the Elizabeth River was for secchi depth in the Elizabeth River Mainstem (ELIPH). During the SAV growing season, improving trends were detected in surface total and dissolved inorganic phosphorus in the Eastern Branch (EBEMH). A degrading trend in secchi depth was detected in the Elizabeth River Mainstem (ELIPH) during this season. No other significant trends were detected during the SAV growing season (Tables 3-12,3-13).

Results of the relative status assessments and SAV habitat criteria indicate that water quality conditions within the Elizabeth River are heavily degraded. Trend results for both the Annual and and SAV growing season indicate that water quality is improving.

In general, status and trend results for the phytoplankton in the Southern Branch (SBEMH) reflect the results for the water quality. With respect to phytoplankton communities, many metrics showed only fair or poor status but improving trends were detected for diatom, chlorophyte and cryptophyte biomass. In addition, an improving trend in primary productivity was also detected. Despite the signs of improvement, phytoplankton populations remain under stress as indicated by the degrading trends observed for cyanophyte abundance and biomass.

Benthic community status in the Southern Branch (SBEMH) also reflected water quality conditions. Status of the B-IBI was poor at both station SBE5 and station SBE2 but an improving trend in the B-IBI, coupled with improving trends in several community composition metrics, was detected at station SBE5. Although no trend in B-IBI was detected, conditions at SBE2 may also be improving as was indicated in the improving trends observed for pollution indicative and pollution sensitive species biomass and abundance.

IV. Overview of Basin Characteristics

The James River basin is the largest river basin in Virginia covering 26,422 km^2 or nearly 25% of the Commonwealth's total area. The James River begins in the Allegheny Mountains where it is formed by the confluence of the Jackson and Cowpasture rivers. From its sources, the James River flows 547 km in a southeasterly direction to the fall-line near Richmond and for an additional 180 km to Hampton Roads where it enters Chesapeake Bay.

The population in the James River basin grew from 2,288,366 individuals in 1990 to 2,522,583 individuals in 2000 (Figure 3-1a) with a basin-wide population density of 93.4 individuals per km^2. Most of the basin's population is concentrated in approximately 5% of the watershed which consists of residential and industrial land found in the urban areas of Tidewater, Richmond, Petersburg, Lynchburg and Charlottesville. Population density in the James River Basin ranges from 108.45 individuals per km^2 in the Middle James River (JMSOH) to 894.53 individuals per km^2 in at the James River Mouth in the vicinity of Hampton Roads (Figure 3-1b).

Approximately 71% of the entire basin is forested and an additional 17% of the watershed is covered by agricultural land. All other land use types account for just over 12% of the basin. Approximately 16,600 km of the 44,290 km (38%) of streambanks and shoreline within the watershed has a 30 m minimum riparian forest buffer. In terms of total area, both forested and agricultural land use types were highest in the region around the Upper James River segment (Figure 3-2a), and accounted for 723.5 km^2 and 262.34 km^2 of land, respectively. The percentage of forested land within sub-watersheds of the James River remained relatively stable at 45% or more of the total sub-watershed from the Middle James River to the Appomattox River. However the percentage of forested land decreased to just under 35% in the Lower James River and to less than 10% at the James River Mouth (Figure 3-2b).

Total point and non-point source loadings of nitrogen were estimated to be 16,132,907 kg/yr in 2000. Total point and non-point source loadings of phosphorus and sediments were approximately 2,587,742 kg/yr and 1,096,793 metric tons/yr, respectively in 2000. Point sources account for approximately 6,173,000 kg/yr (38%) of the total nitrogen loadings and 715,768 kg/yr (nearly 28%) of the total phosphorus loadings (Figure 3-3a-b). Agricultural and forested land accounted for 494,418,550 kg/yr (45%) and 390,099,890 (36%) of the total suspended sediment loadings (Figure 3-3c).

Point source loadings of total nitrogen decreased from 11,231,184 kg/yr in 1985 to 6,974,083 kg/yr in 2001 (Figure 3-4a). Point source phosphorus showed a similar improving trend, decreasing from 1,653,887 kg/yr in 1985 to 607,670 kg/yr in 2001 (Figure 3-4b). Point source discharges for both total nitrogen and total phosphorus appear to be concentrated above the fall-line in James River (AFL-JR) and the James River Mouth (JMSPH) (Figure 3-5a-b).

The ratio of impacted (agricultural and urban) to forested land use peaks in the region around the James River Mouth (Figure 3-6). This suggests that the area around this segment would be more likely than other regions in the basin to experience high non-point source loadings of both nutrients and sediments from agricultural and urban land.

Daily freshwater flow at the 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, 2002. Grand mean flow at the fall-line was 193.30 m^3/sec. There was a significant decreasing trend in freshwater flow at the James River fall-line and annual peaks in monthly mean flow during the last four years appear to be much lower than during previous years (Figure 3-7a). Annual mean flow ranged from approximately 40% to 50% lower than the grand mean flow during the last four years (Figure 3-7b).

V. Detailed Overview of Status and Trends

A. Fall Line

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 3-1). 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 3-1).

A. Tidal Fresh Appomattox (APPTF - Appomattox)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good except for surface total phosphorus for which the status was fair (Figure 3-8; Table 3-2). Significant improving trends in surface and bottom dissolved inorganic phosphorus were detected that were consistent between the pre- and post-method change periods (Figure 3-8; Table 3-3). No other trends were detected in this segment

b) Non-nutrient parameters

Status of all non-nutrient parameters was poor except for bottom dissolved oxygen for which the status was good (Figure 3-9; Table 3-3). There were no trends in any of the non-nutrient parameters in this segment (Figure 3-9; Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

All parameters except surface dissolved inorganic phosphorus failed to meet the SAV habitat requirements (Table 3-5).

b) Nutrient parameters

There were no trends in nutrient parameters during the SAV growing season in this segment (Table 3-6).

c) Non-nutrient parameters

There were no trends in non-nutrient parameters during the SAV growing season in this segment (Table 3-6).

3. Living resources

Living resource monitoring is not conducted within this segment.

C. Tidal Fresh James River (JMSTF - Upper James)

1. Water quality for living resources

a) Nutrient parameters

Status of all nitrogen parameters in this segment was good while status of all phosphorus parameters was fair (Figure 3-8;Table 3-2). There were significant differences in trends between the pre- and post-method periods for surface and bottom total nitrogen, surface and bottom dissolved inorganic nitrogen, and surface dissolved inorganic phosphorus. For all of these parameters, a significant improving trend was detected in the pre-method change period which was not significant in the post-method change period. A improving significant trend in bottom dissolved inorganic phosphorus was detected which was consistent between the pre- and post-method change periods (Figure 3-8;Table 3-3).

b) Non-nutrient parameters

Status of surface and bottom total suspended solids and secchi depth was poor, however, status of surface chlorophyll *a*, bottom dissolved oxygen was good (Figure 3-9;Table 3-2). Degrading trends in surface bottom total suspended solids, and secchi depth were detected while an improving trend in Summer1 bottom dissolved oxygen was detected (Figure 3-9;Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

All parameters either failed to meet the SAV habitat requirement or were borderline (Table 3-5).

b) Nutrient parameters

Although there were significant improving trends in surface total nitrogen, surface dissolved inorganic nitrogen, and surface dissolved inorganic phosphorus during the pre-method change period, none were consistent with data collected during the post-method change periods. (Table 3-6).

c) Non-nutrient parameters

A degrading trend in secchi depth was detected in this segment (Table 3-17).

3. Living resources

The total phytoplankton populations increased in both abundance and biomass, including a favorable increase in the biomass to abundance ratio. There were no significant trends in productivity or species diversity. The diatoms, chlorophytes, and cryptophytes exhibited favorable increasing trends in biomass, with degrading trends of biomass and abundance associated with the cyanobacteria. Although the dinoflagellate biomass status was poor, there were no significant trends associated here, or with the picoplankton biomass. Overall, the floral component was mixed with status generally unfavorable and improvements required.

Benthic community status was degraded at station TF5.5; however, an improving trend in the B-IBI was detected due to increasing trends in pollution sensitive species abundance and biomass (Figure 3-13). Values of the B-IBI showed a fairly steady increase from around 2.0 (degraded) in 1985 to around 4.5 (above the B-IBI Goal) in 1999 but dropped precipitously during the last 4 years to degraded conditions in 2003 (Appendix L).

D. Oligohaline Chickahominy River (CHKOH - Chickahominy)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was good except for surface and bottom total phosphorus for which the status was poor (Figure 3-8;Table 3-2). No significant trends were detected for any of the nutrient parameters (Figure 3-8;Table 3-3).

b) Non-nutrient parameters

Status of all non-nutrient parameters was poor except for Summer1 bottom dissolved oxygen for which the status was good (Figure 3-9;Table 3-2). Degrading trends in bottom total suspended solids and secchi depth were detected along with an improving trend in surface chlorophyll *a* (Figure 3-9; Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

Surface dissolved inorganic phosphorus met its respective SAV habitat requirements while surface total suspended solids and secchi depth failed to met the requirements and surface chlorophyll *a* was borderline (Table 3-5).

b) Nutrient parameters

There were no trends in nutrient parameters during the SAV growing season in this segment (Table 3-6).

c) Non-nutrient parameters

An improving trend was detected in surface chlorophyll a while a degrading trend was detected in secchi depth (Table 3-7).

3. Living resources

Living resource monitoring is not conducted within this segment.

E. Oligohaline James River (JMSOH - Middle James)

1. Water quality for living resources

a) Nutrient parameters

Status of all nitrogen parameters was good while the status of all phosphorus parameters was poor (Figure 3-8;Table 3-2). No significant trends were detected for surface and bottom total nitrogen in either the pre- or post-method change periods. There were significant differences between pre- and post-method change periods for surface and bottom dissolved inorganic nitrogen. For both parameters the pre-method change trends were improving but the post-method change trends were not significant. There were significant differences in trends between the pre- and post-method change periods for surface and bottom total phosphorus. For surface total phosphorus, the pre-method change trend was degrading, but the post-method change trend was not significant. For bottom total phosphorus, the pre-method change trend was degrading but the post-method change trend was improving. (Figure 3-8;Table 3-3).

b) Non-nutrient parameters

Status of surface chlorophyll a and bottom dissolved oxygen was good while the status of all other parameters was poor (Figure 3-9;Table 3-2). Increasing trends in surface and bottom salinity were detected in this segment but no other trends were detected (Figure 3-9;Table 3-4).

2. Water quality for SAV

a) SAV habitat criteria

Although the SAV habitat requirement for surface chlorophyll *a* was met, all other parameters failed to meet their respective criteria (Table 3-5).

b) Nutrient parameter trends

Although a significant improving trend in surface dissolved inorganic nitrogen and a significant degrading trend in surface total phosphorus were detected during the pre-method change period, neither of these trends were significant during the post-method change period. A significant degrading trend in surface dissolved inorganic phosphorus was detected that was consistent between the pre- and post-method change periods (Table 3-6).

c) Non-nutrient parameter trends

There were no trends in the non-nutrient parameters in this segment during the SAV growing season (Table 3-7).

3. Living resources

There were mixed patterns at this station. However, the majority of status ratings for the phytoplankton parameters were poor (biomass to abundance ratio, species diversity, plus the biomass of dinoflagellates, cyanobacteria, and picoplankton, and cyanobacteria abundance). Good status occurred with productivity, and the biomass of diatoms and chlorophytes. Improving trends were then associated with diatom biomass, productivity, and the biomass of both cryptophytes and chlorophytes (Figure 3-12, Appendix F). These indices show a mixed pattern of prevailing and favorable populations under duress but still dominant with other less favorable algal categories increasing.

Benthic community status was good at both stations LE5.1 and RET5.2 and an improving trend in the B-IBI was detected at station RET5.2 due to increases in total abundance, pollution sensitive species abundance, pollution sensitive species biomass, and species diversity (Figure 3-13). Values of the B-IBI generally fluctuated around the B-IBI Goal at station LE5.1 while showing a slight but relatively consistent increase at station RET5.2 (Appendix L).

F. Mesohaline James River (JMSMH - Lower James)

1. Water quality for living resources

a) Nutrients parameters

Status of all nitrogen parameters was fair except surface total nitrogen for which the status was good while the status of all phosphorus parameters was poor (Figure 3-8; Table 3-2). Significant degrading trends in bottom total nitrogen and surface and bottom dissolved inorganic phosphorus were detected that were consistent between pre- and post-method change periods. Significant differences in trends between the pre- and post-method change periods for surface and bottom total phosphorus were detected. For both parameters, the pre-method change trend was degrading while the post-method change trends were not significant (Figure 3-8;Table 3-3).

b) Non-nutrient parameters

Although the status of surface chlorophyll *a* and Summer1 bottom dissolved oxygen was good, the status of surface and bottom total suspended solids and secchi depth was poor (Figure 3-9;Table Table 3-2). An degrading trend in secchi depth was detected (Figure 3-9; Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

Only surface chlorophyll *a* met its respective SAV habitat requirement. Both surface dissolved inorganic phosphorus and secchi depth failed their requirements and the remaining parameters were borderline (Table 3-5).

b) Nutrient parameter trends

Significant degrading trends were detected in surface total nitrogen and surface dissolved inorganic phosphorus which were consistent between the pre- and post-method change periods. A significant difference in trends was detected between the pre- and post-method change periods for surface total phosphorus. The degrading trend in the pre-method change data for this parameter was not detected in the post-method change period (Table 3-6).

c) Non-nutrient parameter trends

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

3. Living resources

Phytoplankton monitoring is not conducted within this segment.

Benthic community status at station LE5.2 was marginal and, although there was no trend in the B-IBI, there was an improving trend in total abundance (Figure 3-13). Values for the B-IBI varied substantially at this site ranging periodically from below 2.5 (degraded) to values approaching 5.0 (Meets Goals) since 1985 (Appendix L).

G. Polyhaline James River (JMSPH - River Mouth)

1. Water quality for living resources

a) Nutrient parameters

Status of nitrogen parameters was good except for bottom total nitrogen for which the status was fair. Status of all phosphorus parameters was fair except for surface total phosphorus for which the status was poor (Figure 3-8;Table 3-2). No significant trends were detected for any of the nutrient parameters in this segment (Figure 3-8;Table 3-3).

b) Non-nutrient parameters

Status of surface chlorophyll *a* and surface total suspended solids was fair. Status of bottom total suspended solids and Summer1 bottom dissolved oxygen was good while the status of secchi depth was poor (Figure 3-9;Table 3-2). A degrading trend was detected in secchi depth while an improving trend was detected in Summer1 bottom dissolved oxygen. An increasing trend in bottom salinity and a decreasing trend in bottom water temperature were detected in this segment (Figure 3-9;Table 3-4).

2. Water quality for SAV

a) SAV habitat requirements

Surface dissolved inorganic nitrogen and phosphorus failed to meet the SAV habitat requirements while the criteria were met for all parameters in this segment (Table 3-5).

b) Nutrient parameter trends

Although a significant degrading trend in surface total phosphorus was detected for the pre-method change period, it was not consistent with the post-method change trend which was not significant. No other trends were detected for any of the nutrients in this segment (Table 3-6).

c) Non-nutrient parameter trends

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

3. Living resources

There were increased long-term trends in total phytoplankton abundance and biomass, with poor status represented for total biomass and the biomass to abundance ratio. The majority of phytoplankton categories had a status rating of fair or poor, including a poor status for productivity. There were positive increased biomass trends among the diatoms and chlorophytes, and in the biomass to abundance ratio, but poor status and degrading trends of increased biomass and abundance indicated for the cyanobacteria, plus increasing trends in dinoflagellate biomass. (Figure 3-12, Appendix F). This is a region is also associated with sporadic and common dinoflagellate blooms.

Benthic community status was good with no trend in the B-IBI at station LE5.4. Improving trends in total biomass and pollution indicative species abundance were detected at this station but a degrading trend in pollution sensitive species biomass was also detected (Figure 3-13). A plot of the B-IBI indicates the benthic community has remained relatively stable ranging between values of 3.0 to above 4.0 nearly every year since 1985 (Appendix L).

H. Western Branch of the Elizabeth River (WBEMH - Western Branch)

1. Water quality for living resources

a) Nutrient parameters

Status for all nutrient parameters was poor (Figure 3-10;Table 3-8). Improving trends were detected in surface total nitrogen and surface and bottom total phosphorus in this segment (Figure 3-10; Table 3-9).

b) Non-nutrient parameters

Status of surface chlorophyll a, surface and bottom total suspended solids, and secchi depth was poor while status of bottom dissolved oxygen was good (Figure 3-11;Table 3-8). An improving trend was detected in surface chlorophyll *a* but no other trends were detected in this segment (Figure 3-11; Table 3-10).

2. Water quality for SAV

a) SAV habitat requirements

Surface dissolved inorganic phosphorus, surface total suspended solids, and secchi depth failed to meet the SAV habitat requirements, while surface dissolved inorganic phosphorus and surface chlorophyll *a* were borderline (Table 3-11).

b) Nutrient parameters

Improving trends were detected in surface total phosphorus and surface dissolved inorganic phosphorus during the SAV growing season in this segment (Table 3-12).

c) Non-nutrient parameters

No trends in non-nutrient parameters were detected (Table 3-13).

3. Living resources

Phytoplankton and zooplankton monitoring is not conducted within this segment.

I. Southern Branch of the Elizabeth River (SBEMH - Southern Branch)

1. Water quality for living resources

a) Nutrient parameters

Status of all nutrient parameters was poor (Figure 3-10;Table 3-8). Improving trends were detected in surface total nitrogen, surface dissolved inorganic nitrogen and surface and bottom total phosphorus (Figure 3-10;Table 3-9).

b) Non-nutrient parameters

Status of surface chlorophyll *a* and bottom total suspended solids was good while status of surface total suspended solids and bottom dissolved oxygen was fair. Status of secchi depth was poor (Figure 3-11;Table 3-8). An improving trend were detected in bottom total suspended solids and increasing trends were detected in surface and bottom water temperature (Figure 3-11;Table 3-10).

2. Water quality for SAV

a) SAV habitat requirements

SAV habitat requirements were not met for surface chlorophyll *a*, surface total suspended solids and secchi depth; however, both surface dissolved inorganic nitrogen and surface of dissolved inorganic phosphorus did meet their respective criteria (Table 3-11).

b) Nutrient parameters

No significant trends were detected in any of the nutrients during the SAV growing season in this segment (Table 3-12).

c) Non-nutrient parameters

No significant trends were detected in the non-nutrient parameters in this segment during the SAV growing season (Table 3-13).

3. Living resources

The Elizabeth River is recognized as one of the most polluted rivers in Virginia. Its algal populations to a great extent are similar to those in the lower Chesapeake Bay, with a few representative species entering the southern branch from the Dismal Swamp Canal. The algal parameters have status ratings of good (species diversity, productivity, chlorophyte and picoplankton biomass), fair (biomass of diatoms, dinoflagellates, and cyanobacteria), and poor (total phytoplankton biomass, phytoplankton biomass to abundance ratio). Favorable trends are present in total productivity, and the biomass among diatoms, chlorophytes, and cryptophytes (Figure 3-12, Appendix F). Although there are signs of improvement within this community, the algal component remains under stress.

Although benthic community status was degraded at both SBE5 and SBE2, an improving trend in the B-IBI was detected at station SBE5 and improving trends in several community metrics were detected at SBE2. The improving trend in the B-IBI at station SBE5 was the result of trends in nearly all metrics of benthic community health (Figure 3-13). Values of the B-IBI showed a generally steady increase from 1989 through 2003 at station SBE5 while the B-IBI was fairly stable and below the B-IBI goal at station SBE2 (Appendix L).

J. Eastern Branch of the Elizabeth River (EBEMH - Eastern Branch)

1. Water quality for living resources

a) Nutrient parameters

Status of all nitrogen and phosphorus parameters was poor (Figure 3-10;Table 3-8). Improving trends were detected in bottom total nitrogen and dissolved inorganic phosphorus, as well as, surface and bottom total phosphorus (Figure 3-10; Table 3-9).

b) Non-nutrient parameters

Status of surface chlorophyll *a*, surface total suspended solids, and Summer1 bottom dissolved oxygen was fair, while the status of bottom total suspended solids was good. Secchi depth status was poor. An improving trend in surface total suspended solids was detected (Figure 3-11;Table 3-10).

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

a) SAV habitat requirements

Although surface dissolved inorganic nitrogen and phosphorus failed to meet the SAV habitat requirements, surface chlorophyll *a*, and surface total suspended solids met their respective requirements. Secchi depth was borderline (Table 3-11).

b) Nutrient parameters

No trends were detected in any of the nutrient parameters during the SAV growing season in this segment (Table 3-12).

c) Non-nutrient parameters

No significant trends were collected for any of the non-nutrient parameters in this segment (Table 3-13).

<u>3. Living resources</u>

Phytoplankton and zooplankton monitoring is not conducted within this segment.

K. Elizabeth River Mainstem (ELIPH - Mainstem)

<u>1. Water quality for living resources</u>

a) Nutrient parameters

Status of all nutrient parameters in this segment was poor and no significant trends in nutrients were detected (Figure 3-10;Tables 3-8, 3-9).

b) Non-nutrient parameters

Status in surface chlorophyll *a*, surface total suspended solids and secchi depth was poor while the status of bottom total suspended solids and Summer1 bottom dissolved oxygen were fair and good, respectively (Figure 3-11; Table 3-8). A degrading trend in secchi depth was detected but no other trends were detected in the non-nutrient parameters (Figure 3-11;Table 3-10).

2. Water quality for SAV

a) SAV habitat requirements

Although surface chlorophyll *a* and surface total suspended solids met the SAV habitat requirements, surface dissolved inorganic nitrogen failed to meet its criteria and surface dissolved inorganic phosphorus and secchi depth were borderline (Table 3-11).

b) Nutrient parameters

No significant degrading trends in nutrients were detected during the SAV growing season in this segment (Table 3-12).

c) Non-nutrient parameters

A degrading trend in secchi depth was detected during the SAV growing season in this segment (Table 3-13).

3. Living resources

Living resource monitoring is not conducted within this segment.

Further information about the benthos of the Elizabeth River can be found in Dauer (2004).

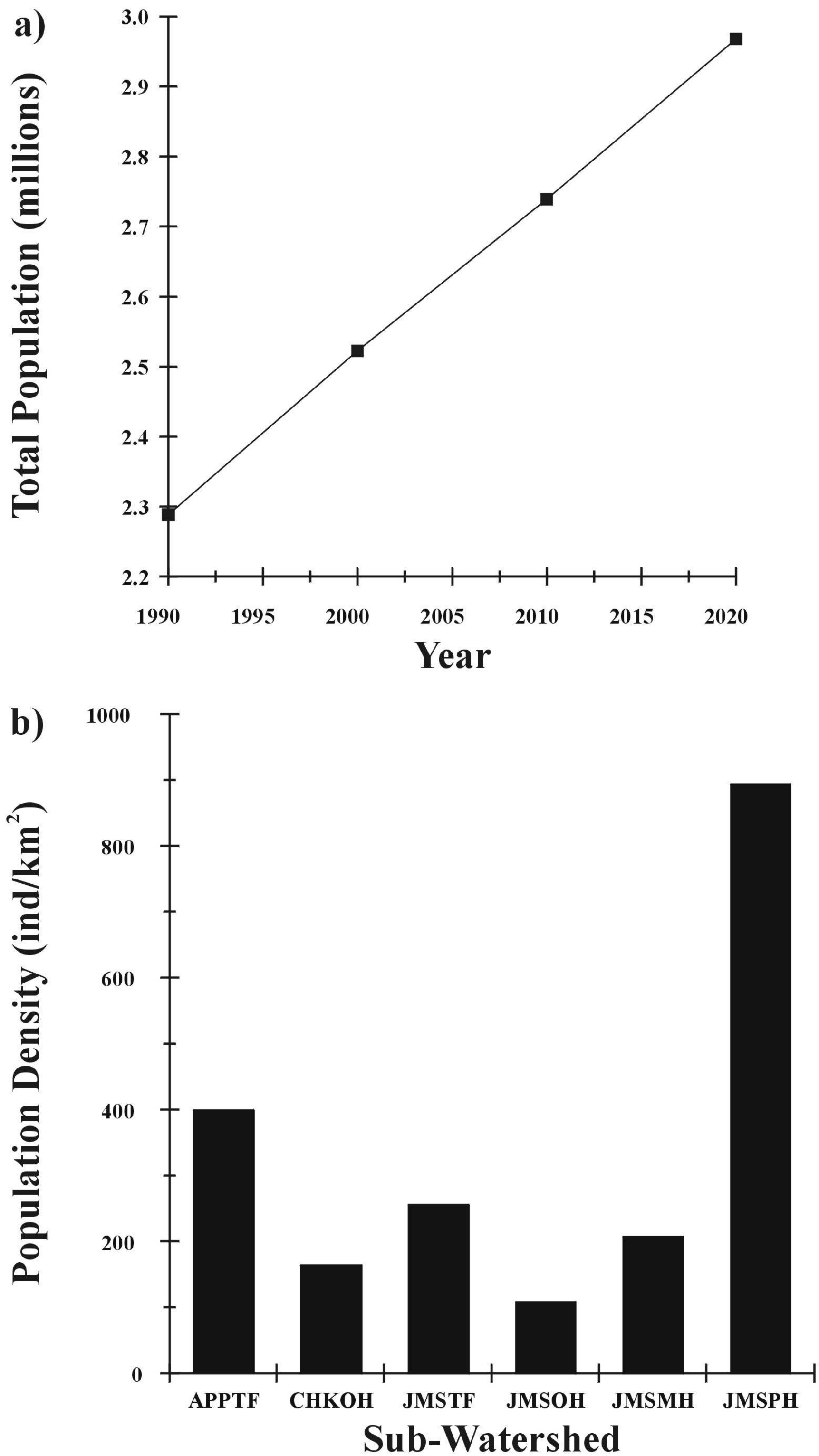


Figure 3-1. Patterns in: a) total and projected total watershed population over time, and b) population density between sub-watersheds within the James River basin for the year 2000.

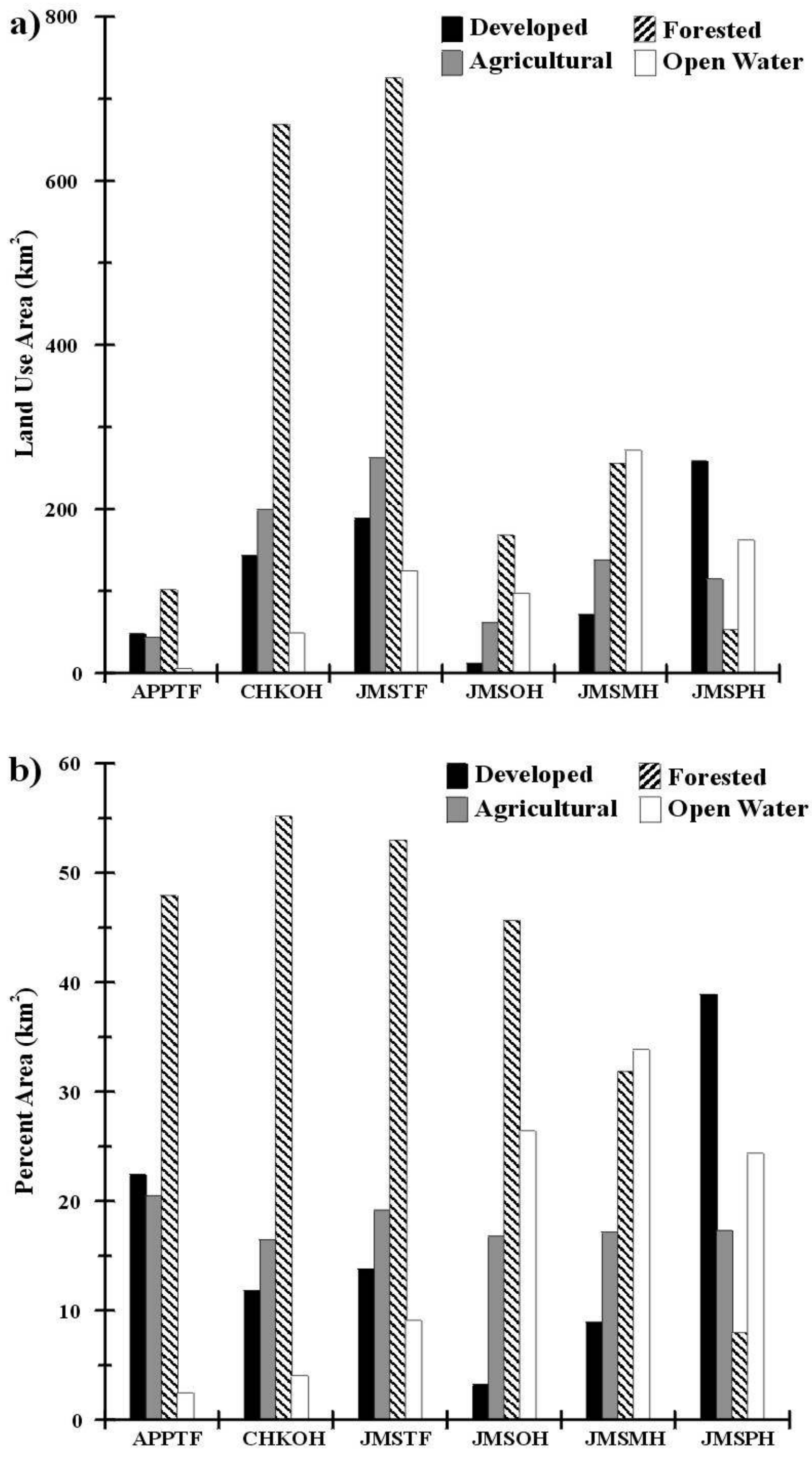


Figure 3-2. Differences in: a) total area, and b) percentages of land-use types between sub-watersheds of the James River for 1999. Data presented were provided by the USEPA, Chesapeake Bay Program Office.

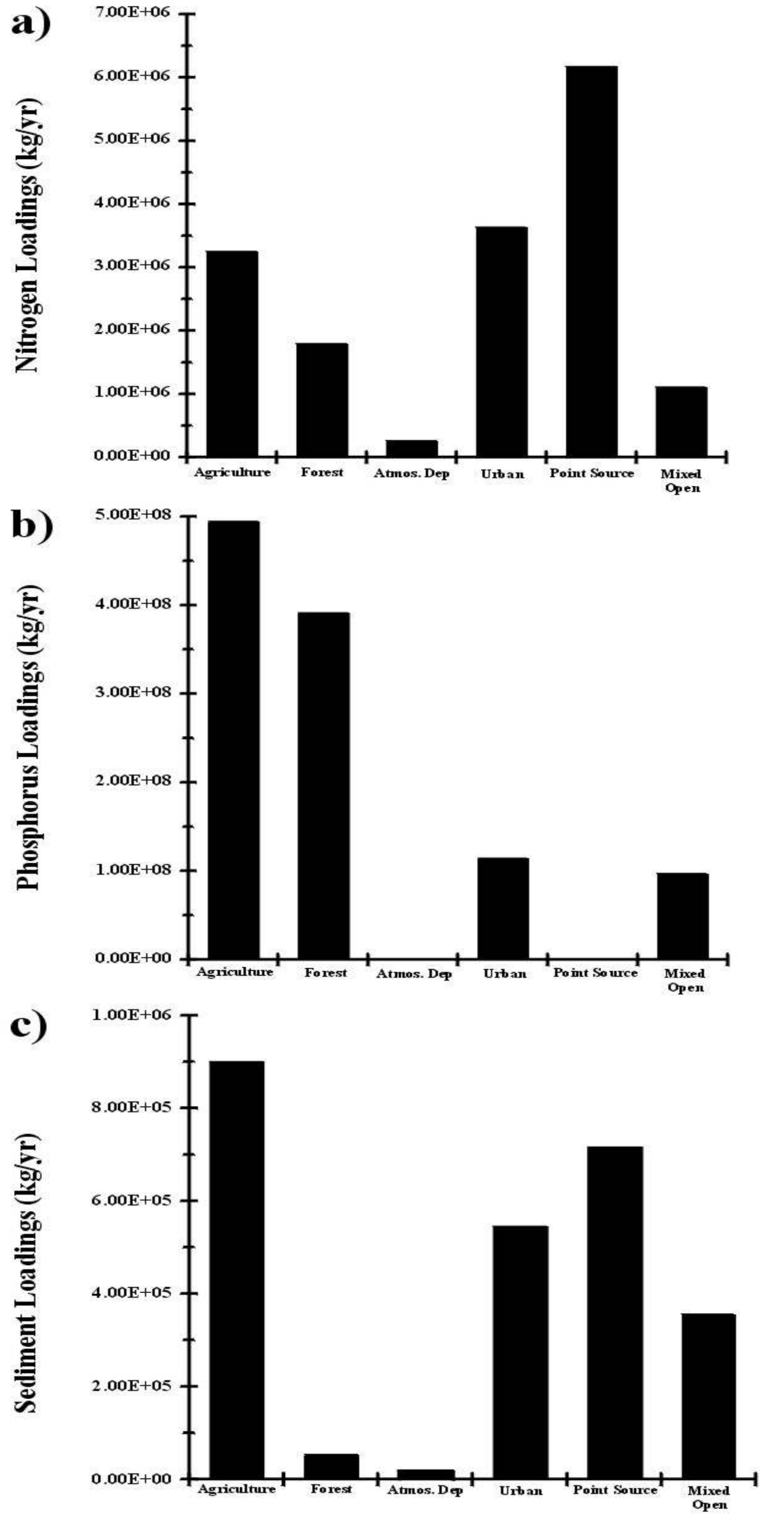


Figure 3-3. Non-point source loadings of: a) total nitrogen, b) total phosphorus, and c) sediments by source for the James River watershed in 2000. Data generated using the USEPA Chesapeake Bay Watershed Model.

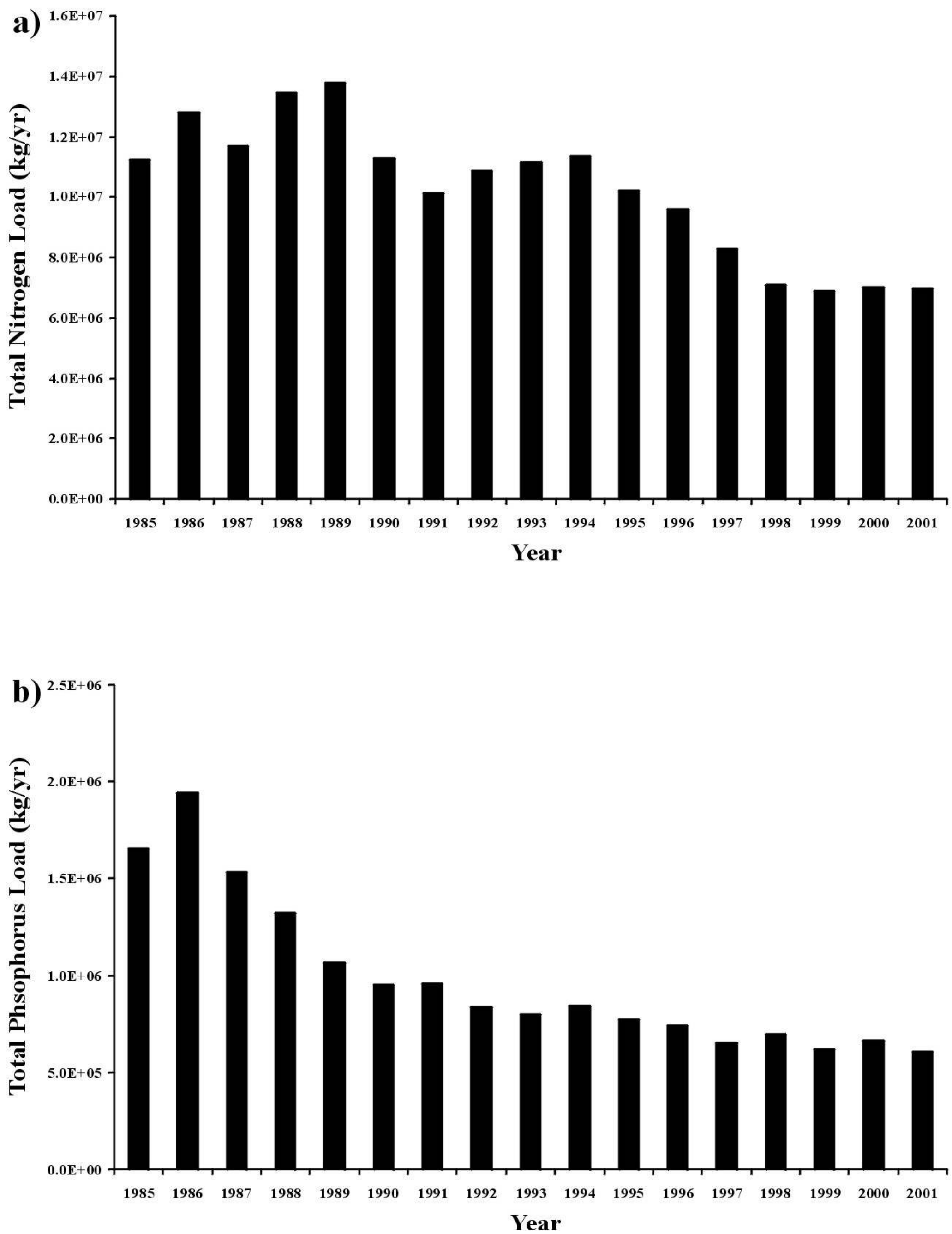


Figure 3-4. Long-term trends in point source: a) total nitrogen loadings, and b) total phosphorus loadings in the James River for 1985 through 2001.

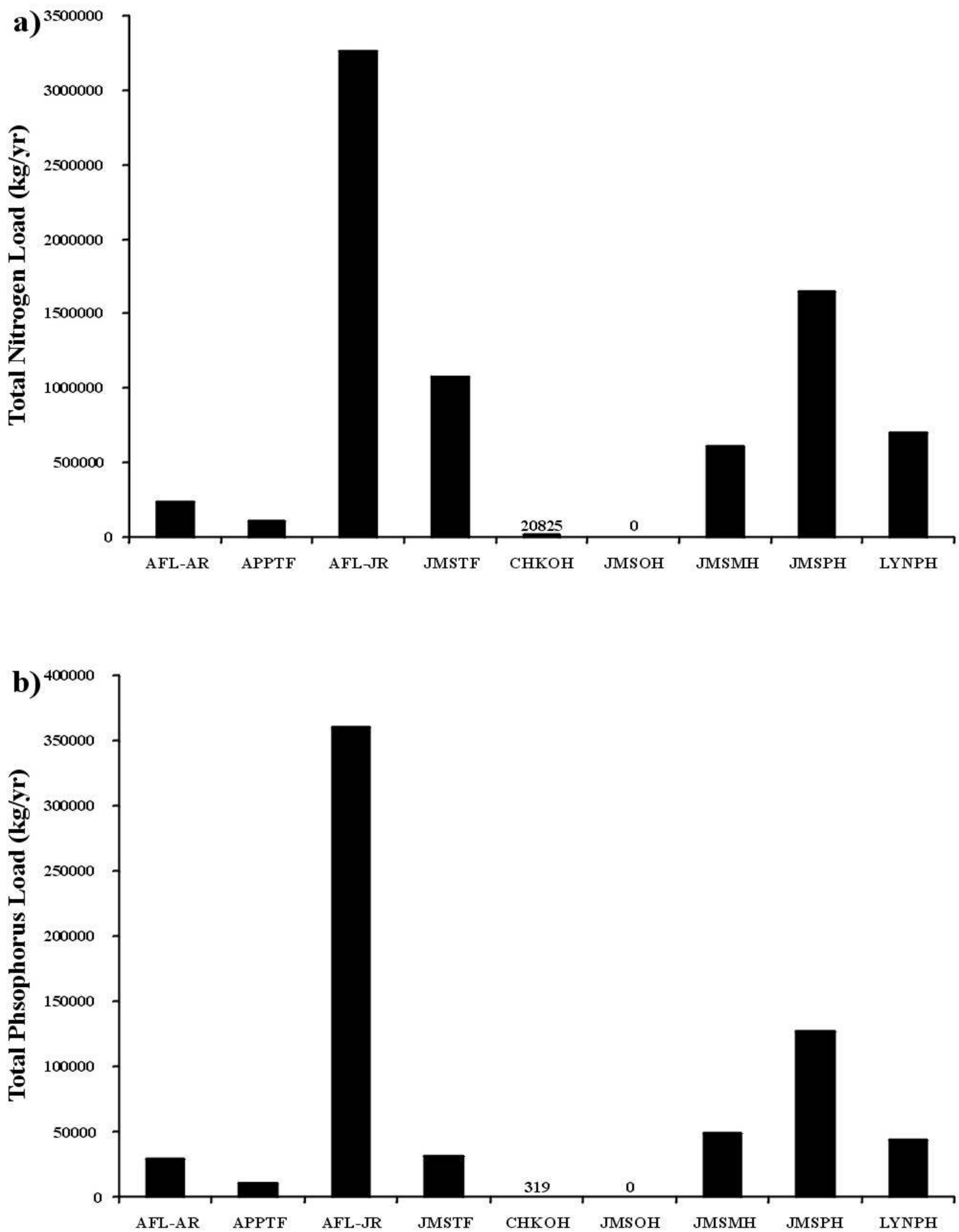


Figure 3-5. Spatial patterns in point source: a) total nitrogen and b) total phosphorus loadings in the James River by sub-watershed for 2001. Additional segments are as follows: AFL-AR=Above the Fall-line in the Appomattox River, APPTF=Appomattox River, AFL-JR=Above the Fall-line in the James River, LYNPH=Lynnhaven Bay.

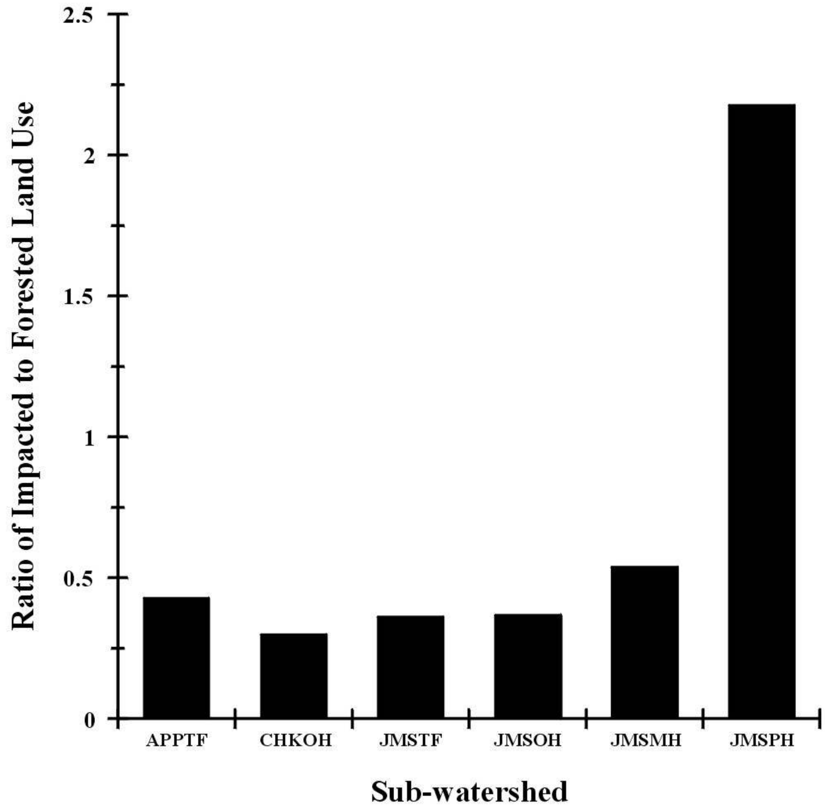


Figure 3-6. Spatial patterns in the ratio of impacted (agricultural and urban land) use to forested land use between sub-watersheds of the James River basin in 2000.

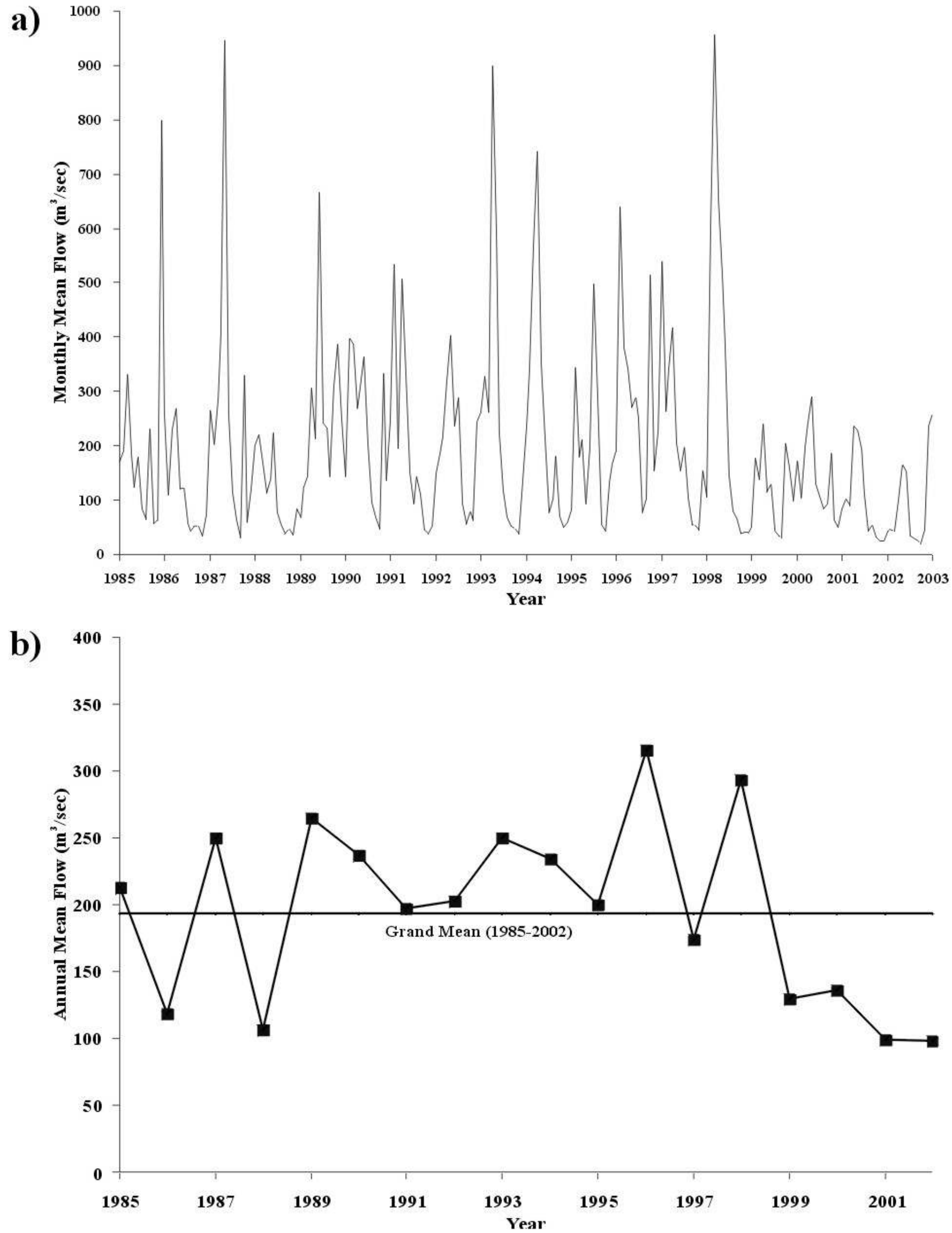
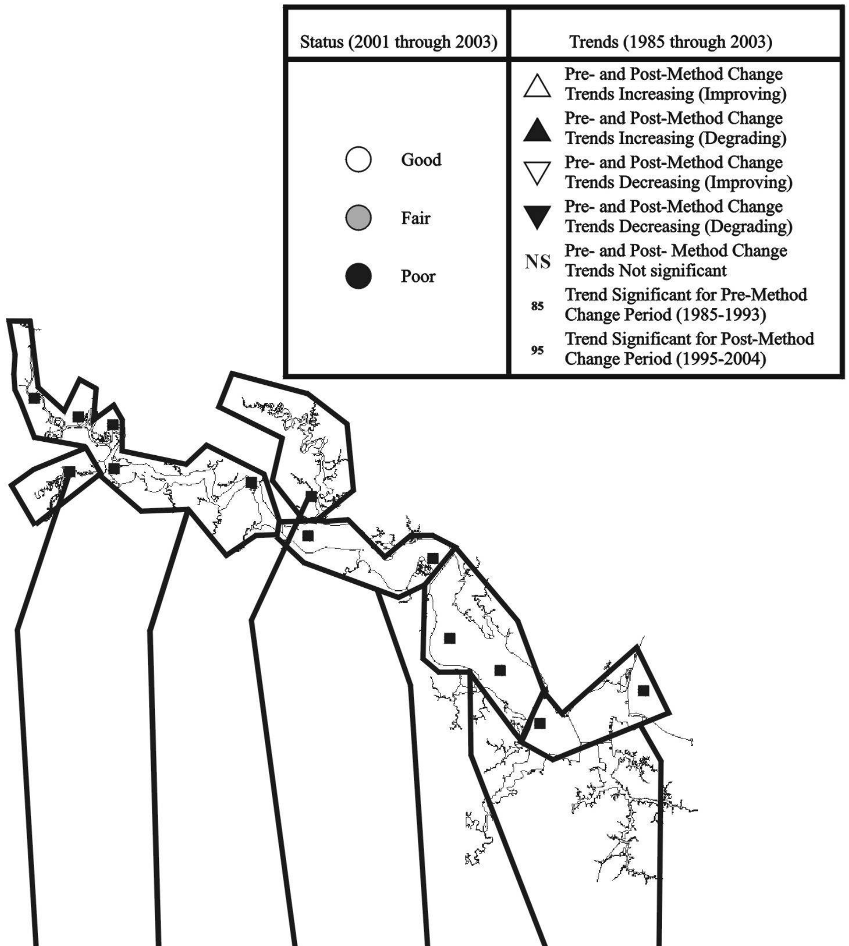
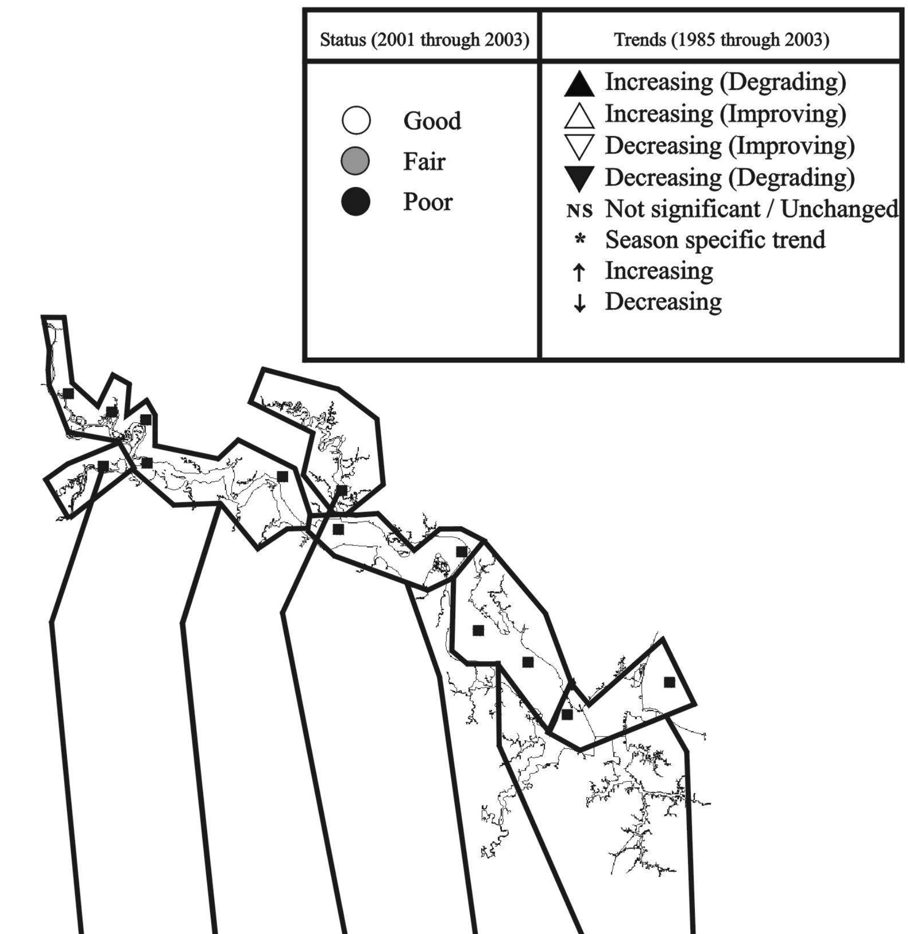


Figure 3-7. Plots of: a) monthly mean and b) annual mean freshwater flow at the James River fall-line for the period of 1985 through 2002.



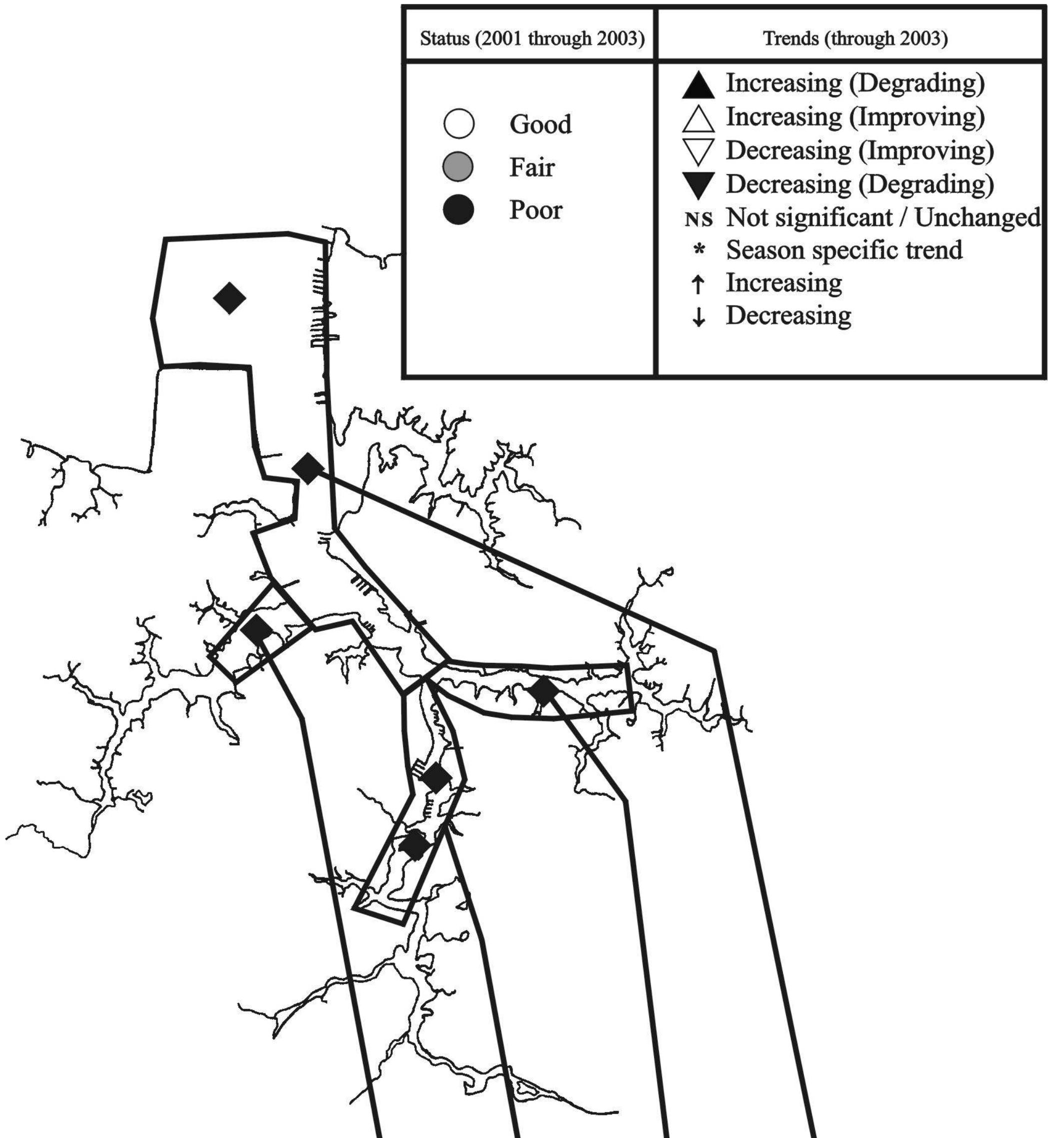
Parameter	Appomattox	Upper James	Chickahominy	Middle James	Lower James	River Mouth
STN	○ Good NS	○ Good ▽ 85	○ Good NS	○ Good NS	○ Good NS	○ Good NS
BTN	○ Good NS	○ Good ▽ 85	○ Good NS	○ Good NS	Fair ▲	Fair NS
SDIN	○ Good NS	○ Good ▽ 85	○ Good NS	○ Good ▽ 85	Fair NS	○ Good NS
BDIN	○ Good NS	○ Good ▽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

Figure 3-8. Map of the James River basin showing summaries of the status and trend analyses for each segment for the period of 1985 through 2003. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The prefixes S and B refer to surface and 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.



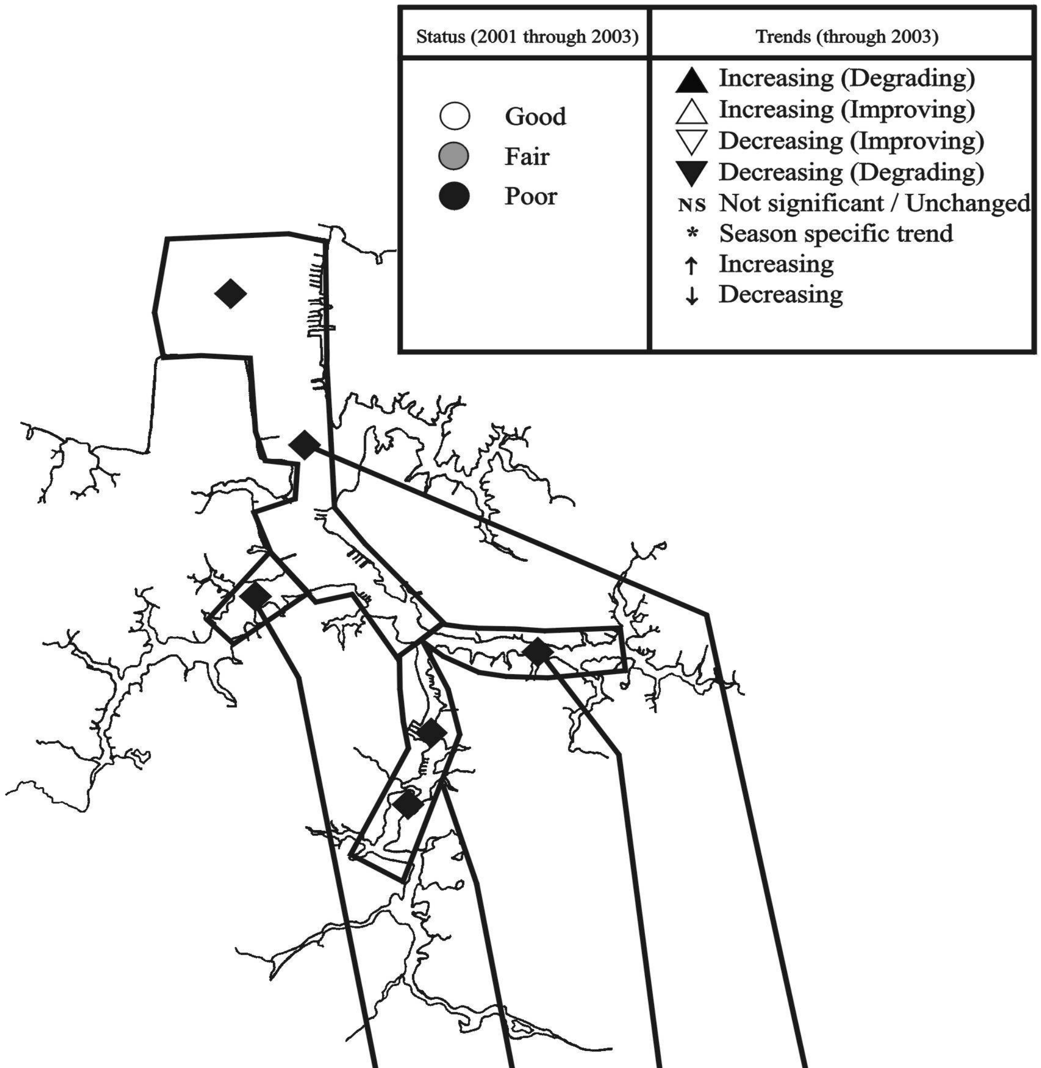
Parameter	Appomattox	Upper James	Chickahominy	Middle James	Lower James	River Mouth
SCHLA	● NS	○ NS	● ▽	○ NS	○ NS	◍ NS
STSS	● NS	● NS	● NS	● NS	● NS	◍ NS
BTSS	● NS	● ▲	● ▲	● NS	● ▲	○ NS
SECCHI	● NS	● ▼	● ▼	● NS	● NS	● ▼
BDO	○ NS	○ △	○ NS	○ NS	○ NS	○ △
SSALIN	NS	NS	NS	↑	NS	NS
BSALIN	NS	NS	NS	↑	NS	↓
SWTEMP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

Figure 3-9. Map of the James River basin showing summaries of the status and trend analyses for each segment for the period of 1985 through 2003. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.



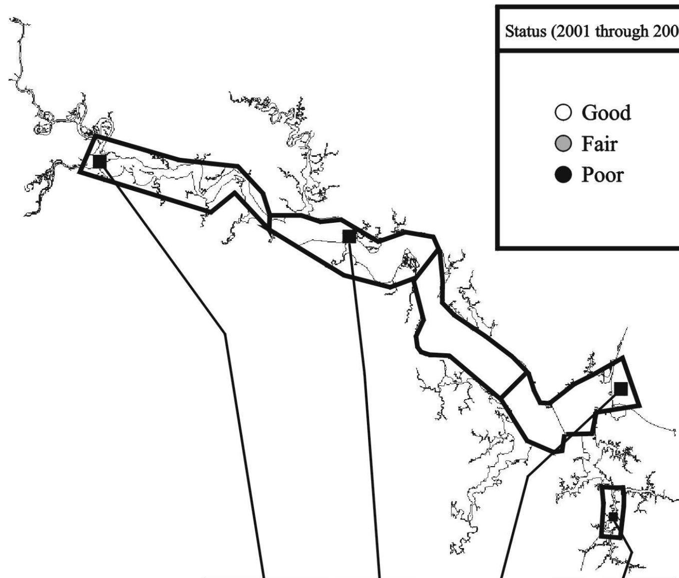
Parameter	Western Branch	Southern Branch	Eastern Branch	Elizabeth River Mainstem
STN	● ▽	● ▽	● NS	● NS
BTN	● NS	● NS	● ▽	● NS
SDIN	● NS	● ▽	● NS	● NS
BDIN	● NS	● NS	● ▽	● NS
STP	● ▽	● ▽	● ▽	● NS
BTP	● ▽	● ▽	● ▽	● NS
SDIP	● NS	● NS	● NS	● NS
BDIP	● NS	● NS	● NS	● NS

Figure 3-10. Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment from the start of monitoring through 2003. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP= dissolved inorganic phosphorus. The prefixes S and B refer to surface and bottom measurements, respectively.



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

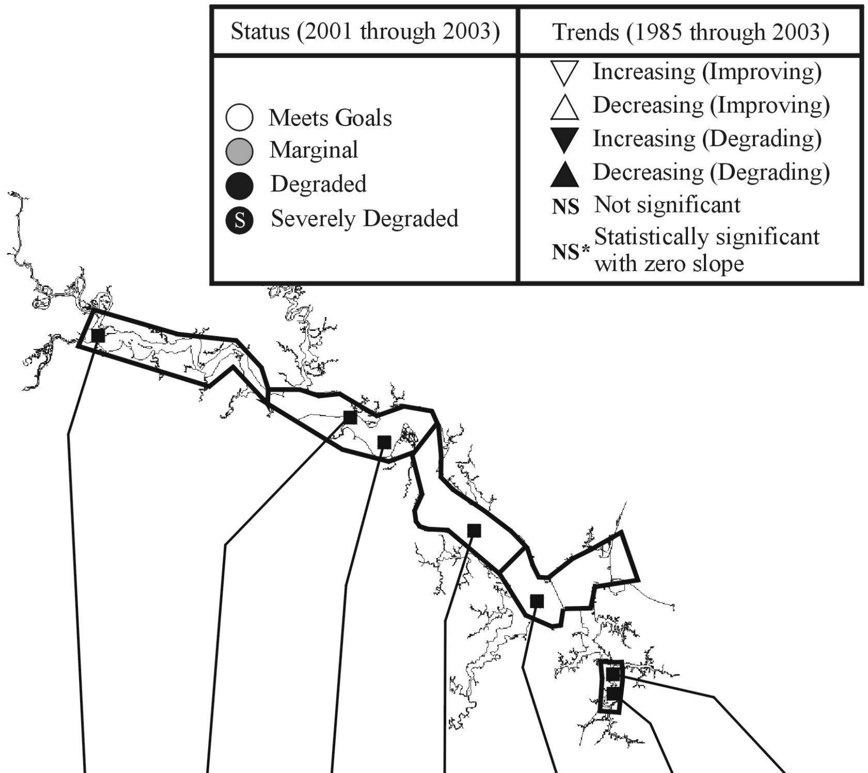
Figure 3-11. Map of the Elizabeth River basin showing summaries of the status and trend analyses for each segment from the start of monitoring through 2003. Abbreviations for each parameter are: CHLA=chlorophyll a, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.



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

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

Figure 3-12. Map of the James River basin showing summaries of the status and trend analyses for phytoplankton bioindicators for each segment for the period 1985 through 2003.



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

Figure 3-13. Map of the James River basin showing summaries of the status and trend analyses for benthic bioindicators for each segment for the period 1985 through 2003.

Table 3-1. 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 2003.

Station	Data Type	Parameter	T-statistic	P value	slope	Direction
Jackson River at Covington	FAC	TN	0.4353	0.6748	0.0026	No Trend
Jackson River at Covington	FAC	TKN	-0.6184	0.5535	-0.0007	No Trend
Jackson River at Covington	FAC	NH4	-3.0981	0.0147	-0.0346	Improving
Jackson River at Covington	FAC	NO23	-1.6638	0.1347	-0.0111	No Trend
Jackson River at Covington	FAC	TP	-14.2633	0.0000	-0.1419	Improving
Jackson River at Covington	FAC	TSS	-2.0570	0.0737	-0.0137	No Trend
James River at Bent Creek	FAC	TN	-1.1930	0.2671	-0.0031	No Trend
James River at Bent Creek	FAC	TKN	3.4340	0.0089	0.0225	Degrading
James River at Bent Creek	FAC	NH4	-3.2629	0.0115	-0.0375	Improving
James River at Bent Creek	FAC	NO23	-4.6114	0.0017	-0.0560	Improving
James River at Bent Creek	FAC	TP	-8.6212	0.0000	-0.0756	Improving
James River at Bent Creek	FAC	TSS	0.6613	0.5270	0.0181	No Trend
James River at Scottsville	FAC	TN	0.9845	0.3537	0.0082	No Trend
James River at Scottsville	FAC	TKN	0.7397	0.4806	0.0069	No Trend
James River at Scottsville	FAC	NH4	-5.2049	0.0008	-0.0532	Improving
James River at Scottsville	FAC	NO23	-1.3007	0.2296	-0.0263	No Trend
James River at Scottsville	FAC	TP	-7.0269	0.0001	-0.0569	Improving
James River at Scottsville	FAC	TSS	1.4781	0.1776	0.0182	No Trend
James River at Cartersville	FAC	TN	-1.9175	0.0915	-0.0077	No Trend
James River at Cartersville	FAC	NO23	-4.5689	0.0018	-0.0262	Improving
James River at Cartersville	FAC	TP	-5.8521	0.0004	-0.0346	Improving
James River at Cartersville	FAC	DIP	-9.0764	0.0000	-0.0578	Improving
James River at Cartersville	FAC	TSS	-1.6902	0.1295	-0.0135	No Trend
Appomattox River at Matoaca	FAC	TN	0.4489	0.6654	0.0036	No Trend
Appomattox River at Matoaca	FAC	NO23	-1.9599	0.0857	-0.0127	No Trend
Appomattox River at Matoaca	FAC	TP	-0.0909	0.9298	-0.0008	No Trend
Appomattox River at Matoaca	FAC	DIP	-2.6323	0.0301	-0.0185	Improving
Appomattox River at Matoaca	FAC	TSS	1.0946	0.3056	0.0048	No Trend

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

Segment	Parameter	Surface Median	Surface Score	Surface Status	Bottom Median	Bottom Score	Bottom Status
APPTF	TN	0.8990	29.82	Good	0.9130	23.96	**Good**
APPTF	DIN	0.3020	18.12	**Good**	0.3250	16.16	Good
APPTF	TP	0.0922	47.24	Fair	0.0932	37.03	Good
APPTF	PO4F	0.0185	33.60	Good	0.0180	36.66	Good
APPTF	CHLA	15.63	77.39	Poor	-	-	-
APPTF	TSS	23.50	77.45	Poor	31.50	66.41	Poor
APPTF	SECCHI	0.50	23.16	Poor	-	-	-
JMSTF	TN	0.8928	24.95	Good	1.0815	32.19	Good
JMSTF	DIN	0.3648	26.41	Good	0.4010	27.45	Good
JMSTF	TP	0.0844	39.83	Fair	0.1200	43.62	Fair
JMSTF	PO4F	0.0258	37.81	Fair	0.0235	40.50	Fair
JMSTF	CHLA	7.66	41.05	Good	-	-	-
JMSTF	TSS	16.25	71.63	Poor	51.00	75.77	Poor
JMSTF	SECCHI	0.40	23.16	Poor	-	-	-
CHKOH	TN	0.7365	17.74	Good	0.7830	19.10	Good
CHKOH	DIN	0.1465	11.41	**Good**	0.1395	8.22	Good
CHKOH	TP	0.0739	36.17	**Fair**	0.0902	38.92	Fair
CHKOH	PO4F	0.0125	30.90	**Good**	0.0130	33.32	Good
CHKOH	CHLA	13.22	77.30	Poor	-	-	-
CHKOH	TSS	22.00	75.36	**Poor**	38.50	64.70	Poor
CHKOH	SECCHI	0.50	12.80	**Poor**	**-**	**-**	**-**
JMSOH	TN	0.7250	24.39	**Good**	0.8385	30.82	Good
JMSOH	DIN	0.3190	33.63	**Good**	0.2960	36.35	**Good**
JMSOH	TP	0.0809	65.66	**Poor**	0.1131	75.78	**Poor**
JMSOH	PO4F	0.0260	81.02	**Poor**	0.0275	75.88	**Poor**
JMSOH	CHLA	6.44	30.83	**Good**	**-**	**-**	**-**
JMSOH	TSS	21.50	85.11	**Poor**	53.00	90.06	**Poor**
JMSOH	SECCHI	0.48	12.80	**Poor**	**-**	**-**	**-**
JMSMH	TN	0.5300	22.18	**Good**	0.5828	43.11	**Fair**
JMSMH	DIN	0.1400	39.12	**Fair**	0.1325	48.55	**Fair**
JMSMH	TP	0.0588	71.22	**Poor**	0.0762	80.86	**Poor**
JMSMH	PO4F	0.0265	92.54	**Poor**	0.0265	86.36	Poor
JMSMH	CHLA	6.60	27.40	Good	-	-	-
JMSMH	TSS	13.00	67.33	**Poor**	27.50	76.64	Poor
JMSMH	SECCHI	0.85	16.26	**Poor**	**-**	**-**	**-**
JMSPH	TN	0.4565	31.63	**Good**	0.4532	40.51	**Fair**
JMSPH	DIN	0.0566	32.86	**Good**	0.0555	30.99	Good
JMSPH	TP	0.0391	65.26	**Poor**	0.0432	47.01	**Fair**
JMSPH	PO4F	0.0097	63.15	**Fair**	0.0098	46.92	Fair
JMSPH	CHLA	7.57	48.30	Fair	-	-	-
JMSPH	TSS	9.95	59.43	Fair	15.39	38.59	Good
JMSPH	SECCHI	1.15	17.55	Poor	-	-	-

Table 3-3. Trends in nutrient parameters in the James, Apppomattox, and Chickahominy rivers for the Annual season for the period 1985 through 2003.

Segment	Parameter	'93 Trend P value	'93 Slope	'93 Trend Direction	'03 Trend P value	'03 Slope	'03 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
APPTF	STN	0.0114	-0.0238	No Trend	0.0239	0.0155	No Trend	0.0006	Different	0.7627	-
APPTF	BTN	0.1008	-0.0175	No Trend	0.3047	0.0081	No Trend	0.0546	Same	0.6392	No Trend
APPTF	SDIN	0.2946	-0.0050	No Trend	0.2044	-0.0078	No Trend	0.9266	Same	0.0975	No Trend
APPTF	BDIN	0.1003	-0.0067	No Trend	0.1326	-0.0093	No Trend	0.9077	Same	0.0244	No Trend
APPTF	STP	0.7501	0.0000	No Trend	0.7951	0.0003	No Trend	0.9819	Same	0.6658	No Trend
APPTF	BTP	0.0346	0.0025	No Trend	0.9216	0.0003	No Trend	0.1554	Same	0.1087	No Trend
APPTF	SPO4F	0.0005	-0.0013	Improving	0.2785	-0.0004	No Trend	0.1157	Same	0.0014	Improving
APPTF	BPO4F	0.0001	-0.0017	Improving	0.1725	-0.0004	No Trend	0.0850	Same	0.0002	Improving
JMSTF	STN	0.0001	-0.0483	Improving	0.3862	0.0058	No Trend	0.0007	Different	0.0336	-
JMSTF	BTN	0.0002	-0.0533	Improving	0.4604	0.0070	No Trend	0.0016	Different	0.0386	-
JMSTF	SDIN	0.0000	-0.0310	Improving	0.5748	-0.0025	No Trend	0.0051	Different	0.0003	-
JMSTF	BDIN	0.0000	-0.0392	Improving	0.2235	-0.0050	No Trend	0.0093	Different	0.0000	-
JMSTF	STP	0.0028	-0.0050	Improving	0.9005	0.0001	No Trend	0.0265	Same	0.0458	No Trend
JMSTF	BTP	0.0235	-0.0033	No Trend	0.8757	-0.0004	No Trend	0.1464	Same	0.0853	No Trend
JMSTF	SPO4F	0.0000	-0.0057	Improving	0.2852	-0.0005	No Trend	0.0007	Different	0.0000	-
JMSTF	BPO4F	0.0000	-0.0033	Improving	0.5388	-0.0002	No Trend	0.0102	Same	0.0005	Improving
CHKOH	STN	0.0290	-0.0367	No Trend	0.6496	-0.0034	No Trend	0.5158	Same	0.1343	No Trend
CHKOH	BTN	0.2880	-0.0283	No Trend	0.4170	-0.0090	No Trend	0.8645	Same	0.2107	No Trend
CHKOH	SDIN	0.0576	0.0000	High BDLs	0.4779	0.0005	No Trend	0.1277	Same	0.8406	No Trend
CHKOH	BDIN	0.0381	-0.0090	High BDLs	0.8486	0.0000	No Trend	0.4605	Same	0.2562	No Trend
CHKOH	STP	0.0311	0.0025	No Trend	0.0374	-0.0023	No Trend	0.0040	Different	0.4292	-
CHKOH	BTP	0.0315	0.0050	No Trend	0.0634	-0.0032	No Trend	0.0071	Different	0.5750	-
CHKOH	SPO4F	0.1546	0.0000	High BDLs	0.8514	0.0000	No Trend	0.4981	Same	0.7909	No Trend
CHKOH	BPO4F	0.0335	0.0000	High BDLs	0.6853	0.0000	No Trend	0.2348	Same	0.7064	No Trend
JMSOH	STN	0.0943	-0.0119	No Trend	1.0000	-0.0004	No Trend	0.2457	Same	0.2280	No Trend
JMSOH	BTN	0.1169	0.0195	No Trend	0.3274	-0.0116	No Trend	0.0686	Same	0.7023	No Trend
JMSOH	SDIN	0.0001	-0.0200	Improving	0.6275	0.0024	No Trend	0.0018	Different	0.0165	-
JMSOH	BDIN	0.0001	-0.0200	Improving	1.0000	0.0001	No Trend	0.0041	Different	0.0048	-
JMSOH	STP	0.0000	0.0050	Degrading	0.4357	-0.0005	No Trend	0.0005	Different	0.0194	-
JMSOH	BTP	0.0000	0.0117	Degrading	0.0041	-0.0071	Improving	0.0000	Different	0.0877	-
JMSOH	SPO4F	0.1452	0.0000	No Trend	0.0155	0.0009	No Trend	0.4550	Same	0.0054	Degrading
JMSOH	BPO4F	0.4470	0.0000	No Trend	0.0048	0.0010	Degrading	0.1298	Same	0.0093	Degrading
JMSMH	STN	0.0808	0.0125	No Trend	0.9490	0.0002	No Trend	0.2618	Same	0.2068	No Trend
JMSMH	BTN	0.0033	0.0188	Degrading	0.2493	0.0078	No Trend	0.2830	Same	0.0045	Degrading
JMSMH	SDIN	0.5830	-0.0017	No Trend	0.4807	0.0030	No Trend	0.3618	Same	0.9235	No Trend
JMSMH	BDIN	0.6912	0.0000	No Trend	0.4061	0.0030	No Trend	0.3656	Same	0.7506	No Trend
JMSMH	STP	0.0000	0.0036	Degrading	1.0000	0.0000	No Trend	0.0011	Different	0.0011	-
JMSMH	BTP	0.0000	0.0033	Degrading	0.6851	0.0003	No Trend	0.0057	Different	0.0007	-
JMSMH	SPO4F	0.0020	0.0013	Degrading	0.0306	0.0010	No Trend	0.6479	Same	0.0002	Degrading
JMSMH	BPO4F	0.0009	0.0006	Degrading	0.0010	0.0009	Degrading	0.8164	Same	0.0000	Degrading
JMSPH	STN	0.7406	0.0014	No Trend	0.7864	-0.0009	No Trend	0.6549	Same	0.9830	No Trend
JMSPH	BTN	0.2523	0.0070	No Trend	0.8073	0.0009	No Trend	0.5344	Same	0.3139	No Trend
JMSPH	SDIN	0.5421	0.0000	High BDLs	0.2655	0.0019	No Trend	0.2142	Same	0.7319	No Trend
JMSPH	BDIN	0.6873	0.0000	High BDLs	0.2922	0.0017	No Trend	0.6504	Same	0.2903	No Trend
JMSPH	STP	0.5062	0.0002	No Trend	0.2525	-0.0004	No Trend	0.1932	Same	0.7490	No Trend
JMSPH	BTP	0.4686	0.0005	No Trend	0.0188	-0.0010	No Trend	0.0281	Same	0.2584	No Trend
JMSPH	SPO4F	0.2896	0.0000	No Trend	0.8799	0.0000	No Trend	0.3855	Same	0.5436	No Trend
JMSPH	BPO4F	0.6633	0.0000	No Trend	0.7627	-0.0001	No Trend	0.9482	Same	0.5881	No Trend

Table 3-4. Trends in non-nutrient parameters in the James, Apppomattox, and Chickahominy rivers for the Annual season for the period 1985 through 2003.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
APPTF	Annual	SCHLA	21.43	0.2261	-0.0470	30.94	0.00	No Trend
APPTF	Annual	STSS	0.00	0.6607	0.0000	19.50	0.00	No Trend
APPTF	Annual	BTSS	0.00	0.9092	0.0000	27.25	0.00	No Trend
APPTF	Annual	SECCHI	0.00	0.0171	0.0000	0.50	0.00	No Trend
APPTF	Summer1	BDO	0.00	0.0414	0.0441	8.20	10.22	No Trend
APPTF	Annual	SSALINITY	0.00	0.0002	0.0000	0.01	0.00	Unchanged
APPTF	Annual	BSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
APPTF	Annual	BWTEMP	0.00	0.0398	0.0682	19.00	6.82	No Trend
APPTF	Annual	SWTEMP	0.00	0.0288	0.0627	19.68	6.05	No Trend
JMSTF	Annual	SCHLA	42.26	0.5318	0.0000	6.67	0.00	High BDLs
JMSTF	Annual	STSS	15.72	0.2574	0.0833	14.75	0.00	No Trend
JMSTF	Annual	BTSS	3.05	0.0051	1.0000	172.00	11.05	Degrading
JMSTF	Annual	SECCHI	0.00	0.0000	-0.0067	0.70	-18.10	Degrading
JMSTF	Summer1	BDO	0.00	0.0020	0.0409	6.35	12.25	Improving
JMSTF	Annual	SSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
JMSTF	Annual	BSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
JMSTF	Annual	BWTEMP	0.00	0.2484	0.0325	18.48	3.34	No Trend
JMSTF	Annual	SWTEMP	0.00	0.2141	0.0303	17.88	3.22	No Trend
CHKOH	Annual	SCHLA	7.75	0.0052	-0.4009	22.35	-28.71	Improving
CHKOH	Annual	STSS	0.00	0.0652	0.2500	17.50	22.86	No Trend
CHKOH	Annual	BTSS	0.00	0.0010	1.0000	27.00	59.26	Degrading
CHKOH	Annual	SECCHI	0.00	0.0000	-0.0091	0.60	-24.24	Degrading
CHKOH	Summer1	BDO	0.00	0.2786	0.0250	5.75	6.96	No Trend
CHKOH	Annual	SSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
CHKOH	Annual	BSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
CHKOH	Annual	BWTEMP	0.00	0.4274	0.0162	15.60	1.67	No Trend
CHKOH	Annual	SWTEMP	0.00	0.5471	0.0187	16.00	1.87	No Trend
JMSOH	Annual	SCHLA	18.32	0.1169	-0.0810	7.22	0.00	No Trend
JMSOH	Annual	STSS	2.43	0.0235	-0.4354	662.00	-1.25	No Trend
JMSOH	Annual	BTSS	0.44	0.7409	-0.2308	290.00	-1.51	No Trend
JMSOH	Annual	SECCHI	0.00	0.1581	0.0000	0.53	0.00	No Trend
JMSOH	Summer1	BDO	0.00	0.3814	-0.0090	6.88	-2.50	No Trend
JMSOH	Annual	SSALINITY	0.00	0.0092	0.0458	2.72	32.05	Increasing
JMSOH	Annual	BSALINITY	0.00	0.0037	0.0795	3.47	43.53	Increasing
JMSOH	Annual	BWTEMP	0.00	0.6057	0.0148	18.48	1.52	No Trend
JMSOH	Annual	SWTEMP	0.00	0.4608	0.0200	18.30	2.08	No Trend
JMSMH	Annual	SCHLA	28.21	0.6059	-0.0080	4.47	0.00	No Trend
JMSMH	Annual	STSS	8.83	0.4570	-0.0670	15.00	-8.48	No Trend
JMSMH	Annual	BTSS	3.96	0.0009	0.7500	142.00	10.04	Degrading
JMSMH	Annual	SECCHI	0.00	0.6075	0.0000	0.95	0.00	No Trend
JMSMH	Summer1	BDO	0.00	0.8865	0.0000	6.20	0.00	No Trend
JMSMH	Annual	SSALINITY	0.00	0.1200	0.0995	14.96	12.64	No Trend
JMSMH	Annual	BSALINITY	0.00	0.2237	0.0500	18.35	5.18	No Trend
JMSMH	Annual	BWTEMP	0.00	0.5177	0.0127	19.90	1.21	No Trend
JMSMH	Annual	SWTEMP	0.00	0.8313	0.0053	20.13	0.50	No Trend
JMSPH	Annual	SCHLA	16.43	0.2888	0.0318	8.19	0.00	No Trend
JMSPH	Annual	STSS	7.74	0.1821	0.0708	8.25	16.29	No Trend
JMSPH	Annual	BTSS	2.06	0.5512	-0.0686	18.45	-7.07	No Trend
JMSPH	Annual	SECCHI	0.00	0.0007	-0.0111	1.30	-16.24	Degrading
JMSPH	Summer1	BDO	0.00	0.0000	0.0500	5.95	15.97	Improving
JMSPH	Annual	SSALINITY	0.00	0.2982	-0.0417	21.56	-3.67	No Trend
JMSPH	Annual	BSALINITY	0.00	0.0000	-0.1418	24.64	-10.94	Decreasing
JMSPH	Annual	BWTEMP	0.00	0.0032	0.0623	16.95	6.99	Increasing
JMSPH	Annual	SWTEMP	0.00	0.9355	0.0000	17.40	0.00	No Trend

Table 3-5. SAV season water quality status in in the James, Appomattox, and Chickahominy rivers for the period 2001 through 2003 (values presented are median concentrations 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	SAV	S	0.8813	31.71	Good	-
APPTF	SDIN	SAV	S	0.2865	17.20	Good	-
APPTF	STP	SAV	S	0.0883	41.09	Fair	-
APPTF	SPO4F	SAV	S	0.0155	32.95	Good	Borderline
APPTF	SCHLA	SAV	S	11.25	66.84	Poor	Fail
APPTF	STSS	SAV	S	23.00	68.52	Poor	Fail
APPTF	SECCHI	SAV	S	0.40	22.00	Poor	Fail
JMSTF	STN	SAV	S	0.9010	27.69	Good	-
JMSTF	SDIN	SAV	S	0.3715	26.03	Good	-
JMSTF	STP	SAV	S	0.0814	36.75	Good	-
JMSTF	SPO4F	SAV	S	0.0250	38.82	Fair	Fail
JMSTF	SCHLA	SAV	S	6.15	20.38	Good	Borderline
JMSTF	STSS	SAV	S	20.00	70.11	Poor	Borderline
JMSTF	SECCHI	SAV	S	0.40	22.00	Poor	Fail
CHKOH	STN	SAV	S	0.7500	20.63	Good	-
CHKOH	SDIN	SAV	S	0.1435	10.61	Good	-
CHKOH	STP	SAV	S	0.0790	40.24	Fair	-
CHKOH	SPO4F	SAV	S	0.0125	32.42	Good	Pass
CHKOH	SCHLA	SAV	S	15.58	83.40	Poor	Borderline
CHKOH	STSS	SAV	S	23.50	75.78	Poor	Fail
CHKOH	SECCHI	SAV	S	0.40	12.08	Poor	Fail
JMSOH	STN	SAV	S	0.8108	31.91	Good	-
JMSOH	SDIN	SAV	S	0.3243	40.79	Fair	-
JMSOH	STP	SAV	S	0.0811	63.82	Poor	-
JMSOH	SPO4F	SAV	S	0.0270	78.91	Poor	Fail
JMSOH	SCHLA	SAV	S	5.88	28.26	Good	Pass
JMSOH	STSS	SAV	S	23.00	83.57	Poor	Fail
JMSOH	SECCHI	SAV	S	0.45	10.00	Poor	Fail
JMSMH	STN	SAV	S	0.6455	35.04	Good	-
JMSMH	SDIN	SAV	S	0.2973	55.34	Fair	Borderline
JMSMH	STP	SAV	S	0.0650	78.84	Poor	-
JMSMH	SPO4F	SAV	S	0.0308	92.57	Poor	Fail
JMSMH	SCHLA	SAV	S	4.28	18.21	Good	Pass
JMSMH	STSS	SAV	S	13.50	69.47	Poor	Borderline
JMSMH	SECCHI	SAV	S	0.83	13.55	Poor	Fail
JMSPH	STN	SAV	S	0.5022	38.91	Good	-
JMSPH	SDIN	SAV	S	0.0852	53.64	Fair	Borderline
JMSPH	STP	SAV	S	0.0470	73.06	Poor	-
JMSPH	SPO4F	SAV	S	0.0200	79.16	Poor	Borderline
JMSPH	SCHLA	SAV	S	7.67	51.55	Fair	Pass
JMSPH	STSS	SAV	S	11.72	69.35	Poor	Pass
JMSPH	SECCHI	SAV	S	1.05	13.49	Poor	Pass

Table 3-6. Trends in nutrient parameters in the James, Apppomattox, and Chickahominy rivers for the SAV season for the period 1985 through 2003.

Segment	Parameter	'93 Trend P value	'93 Slope	'93 Trend Direction	'03 Trend P value	'03 Slope	'03 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
APPTF	STN	0.0098	-0.0340	Improving	0.3933	0.0136	No Trend	0.0117	Same	0.1865	No Trend
APPTF	SDIN	0.6861	-0.0024	No Trend	0.0238	-0.0142	No Trend	0.2401	Same	0.0661	No Trend
APPTF	STP	0.1941	-0.0020	No Trend	0.8369	-0.0005	No Trend	0.4524	Same	0.2721	No Trend
APPTF	SPO4F	0.0413	-0.0007	High BDLs	0.6188	-0.0002	No Trend	0.3080	Same	0.0720	No Trend
JMSTF	STN	0.0000	-0.0513	Improving	0.9672	0.0015	No Trend	0.0025	Different	0.0037	-
JMSTF	SDIN	0.0000	-0.0358	Improving	0.2515	-0.0058	No Trend	0.0089	Different	0.0000	-
JMSTF	STP	0.0020	-0.0050	Improving	0.6933	-0.0006	No Trend	0.0636	Same	0.0134	No Trend
JMSTF	SPO4F	0.0000	-0.0050	Improving	0.7823	0.0001	No Trend	0.0006	Different	0.0029	-
CHKOH	STN	0.0546	-0.0375	No Trend	0.7733	-0.0030	No Trend	0.4985	Same	0.2125	No Trend
CHKOH	BTN	0.7753	-0.0150	No Trend	0.8048	-0.0029	No Trend	0.9715	Same	0.6948	No Trend
CHKOH	SDIN	0.4664	0.0000	High BDLs	0.0174	0.0017	No Trend	0.0131	Same	0.0836	No Trend
CHKOH	BDIN	0.4344	0.0000	High BDLs	0.1843	0.0010	No Trend	0.1151	Same	0.4416	No Trend
CHKOH	STP	0.1175	0.0020	No Trend	0.0639	-0.0027	No Trend	0.0160	Same	0.3951	No Trend
CHKOH	BTP	0.0622	0.0063	No Trend	0.1165	-0.0037	No Trend	0.0205	Same	0.6736	No Trend
CHKOH	SPO4F	0.3681	0.0000	High BDLs	0.2015	0.0004	No Trend	0.1230	Same	0.3869	No Trend
CHKOH	BPO4F	0.0599	0.0000	High BDLs	0.0609	0.0003	No Trend	0.0132	Same	0.3179	No Trend
JMSOH	STN	0.4530	-0.0050	No Trend	0.3143	0.0059	No Trend	0.2046	Same	0.8879	No Trend
JMSOH	BTN	0.0535	0.0221	No Trend	0.7473	0.0063	No Trend	0.2599	Same	0.1023	No Trend
JMSOH	SDIN	0.0020	-0.0173	Improving	0.0150	0.0123	No Trend	0.0001	Different	0.5611	-
JMSOH	STP	0.0001	0.0050	Degrading	0.8130	-0.0003	No Trend	0.0040	Different	0.0128	-
JMSOH	SPO4F	0.0083	0.0007	Degrading	0.0001	0.0015	Degrading	0.2744	Same	0.0000	Degrading
JMSMH	STN	0.0285	0.0167	No Trend	0.0641	0.0104	No Trend	0.8819	Same	0.0039	Degrading
JMSMH	SDIN	0.9656	0.0000	No Trend	0.0598	0.0101	No Trend	0.2081	Same	0.1671	No Trend
JMSMH	STP	0.0000	0.0050	Degrading	0.2874	0.0016	No Trend	0.0098	Different	0.0000	-
JMSMH	SPO4F	0.0054	0.0017	Degrading	0.0129	0.0014	No Trend	0.9096	Same	0.0002	Degrading
JMSPH	STN	0.1055	0.0113	No Trend	0.9661	0.0001	No Trend	0.2784	Same	0.2284	No Trend
JMSPH	SDIN	0.6665	-0.0001	High BDLs	0.2505	0.0054	No Trend	0.2498	Same	0.6280	No Trend
JMSPH	STP	0.0009	0.0015	Degrading	0.7012	-0.0004	No Trend	0.0088	Different	0.0442	-
JMSPH	SPO4F	1.0000	0.0000	No Trend	0.1298	0.0002	No Trend	0.2405	Same	0.2676	No Trend

Table 3-7. Trends in nutrient parameters in the James, Apppomattox, and Chickahominy rivers for the SAV season for the period 1985 through 2003.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
APPTF	SAV	SCHLA	17.24	0.0297	-0.8000	43.51	0.00	No Trend
APPTF	SAV	STSS	0.00	0.7686	0.0000	23.75	0.00	No Trend
APPTF	SAV	SECCHI	0.00	0.0395	0.0000	0.50	0.00	No Trend
APPTF	SAV	SSALINITY	0.00	0.0015	0.0000	0.01	0.00	Unchanged
APPTF	SAV	SWTEMP	0.00	0.0694	0.0723	22.75	6.04	No Trend
JMSTF	SAV	SCHLA	41.01	0.8925	0.0100	11.19	0.00	High BDLs
JMSTF	SAV	STSS	16.99	0.5394	0.0528	16.25	0.00	No Trend
JMSTF	SAV	SECCHI	0.00	0.0000	-0.0083	0.70	-22.62	Degrading
JMSTF	SAV	SSALINITY	0.00	0.0000	0.0000	0.01	0.00	Unchanged
JMSTF	SAV	SWTEMP	0.00	0.1350	0.0423	23.78	3.38	No Trend
CHKOH	SAV	SCHLA	5.37	0.0032	-0.5218	23.93	-34.89	Improving
CHKOH	SAV	STSS	0.00	0.0283	0.3333	17.50	30.48	No Trend
CHKOH	SAV	SECCHI	0.00	0.0000	-0.0111	0.60	-29.63	Degrading
CHKOH	SAV	SSALINITY	0.00	0.0001	0.0000	0.01	0.00	Unchanged
CHKOH	SAV	SWTEMP	0.00	0.1732	0.0591	22.58	4.19	No Trend
JMSOH	SAV	SCHLA	14.45	0.0604	-0.1335	7.69	-32.99	No Trend
JMSOH	SAV	STSS	2.54	0.1419	-0.3500	26.25	-21.33	No Trend
JMSOH	SAV	SECCHI	0.00	0.7034	0.0000	0.63	0.00	No Trend
JMSOH	SAV	SSALINITY	0.00	0.2033	0.0250	3.85	12.34	No Trend
JMSOH	SAV	SWTEMP	0.00	0.8531	0.0064	23.90	0.51	No Trend
JMSMH	SAV	SCHLA	33.43	0.9673	0.0000	4.67	0.00	No Trend
JMSMH	SAV	STSS	7.82	0.4612	-0.0833	19.00	-8.33	No Trend
JMSMH	SAV	SECCHI	0.00	0.6853	0.0000	1.08	0.00	No Trend
JMSMH	SAV	SSALINITY	0.00	0.7383	0.0353	15.82	4.24	No Trend
JMSMH	SAV	SWTEMP	0.00	1.0000	0.0000	23.73	0.00	No Trend
JMSPH	SAV	SCHLA	14.55	0.4072	-0.0353	8.24	-8.13	No Trend
JMSPH	SAV	STSS	4.48	0.5764	0.0310	10.00	5.89	No Trend
JMSPH	SAV	SECCHI	0.00	0.0728	-0.0056	1.00	-10.56	No Trend
JMSPH	SAV	SSALINITY	0.00	0.6272	-0.0417	18.06	-4.38	No Trend
JMSPH	SAV	SWTEMP	0.00	0.3604	0.0250	17.13	2.77	No Trend

Table 3-8. Annual season water quality status in the Eliazbeth River for the period 2001 through 2003 (values presented are median concentrations with secchi depth in meters, chlorophyll *a* in µg/l, and all other parameters in mg/l).

Segment	Parameter	Surface Median	Surface Score	Surface Status	Bottom Median	Bottom Score	Bottom Status
EBEMH	TN	0.8293	88.29	Poor	0.7285	82.93	Poor
EBEMH	DIN	0.3786	89.51	Poor	0.3079	97.84	Poor
EBEMH	TP	0.0536	80.15	Poor	0.0532	62.09	Poor
EBEMH	PO4F	0.0372	98.85	Poor	0.0579	99.62	Poor
EBEMH	CHLA	7.16	47.28	Fair	-	-	-
EBEMH	TSS	8.83	57.32	Fair	12.30	37.43	Good
EBEMH	SECCHI	1.10	17.55	Poor	-	-	-
WBEMH	TN	0.6982	63.12	Poor	0.6976	75.94	Poor
WBEMH	DIN	0.2510	72.64	Poor	0.2017	79.02	Poor
WBEMH	TP	0.0637	89.16	Poor	0.0608	69.45	Poor
WBEMH	PO4F	0.0452	99.68	Poor	0.0476	99.16	Poor
WBEMH	CHLA	11.75	66.98	Poor	-	-	-
WBEMH	TSS	19.00	88.26	Poor	20.68	67.20	Poor
WBEMH	SECCHI	0.70	6.08	Poor	-	-	-
SBEMH	TN	1.0335	98.38	Poor	0.9648	97.29	Poor
SBEMH	DIN	0.5375	98.97	Poor	0.4967	99.82	Poor
SBEMH	TP	0.0615	85.55	Poor	0.0624	75.81	Poor
SBEMH	PO4F	0.0357	98.91	Poor	0.0548	99.29	Poor
SBEMH	CHLA	4.18	16.56	Good	-	-	-
SBEMH	TSS	8.60	45.25	Fair	10.03	26.16	Good
SBEMH	SECCHI	1.13	17.55	Poor	-	-	-
ELIPH	TN	0.6556	70.13	Poor	0.6000	74.53	Poor
ELIPH	DIN	0.2143	77.21	Poor	0.2147	86.67	Poor
ELIPH	TP	0.0554	84.71	Poor	0.0710	79.00	Poor
ELIPH	PO4F	0.0414	98.64	Poor	0.0366	94.13	Poor
ELIPH	CHLA	10.20	62.98	Poor	-	-	-
ELIPH	TSS	10.41	61.81	Poor	17.74	49.54	Fair
ELIPH	SECCHI	1.03	13.04	Poor	-	-	-

Table 3-9. Trends in nutrient parameters in the Elizabeth River for the Annual season for the period 1985 through 2003.

a) Seasonal Kendall results

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
EBEMH	Annual	STN	0.00	0.0177	-0.0099	1.040	-14.28	No Trend
EBEMH	Annual	BTN	0.00	0.0007	-0.0094	0.855	-16.45	Improving
EBEMH	Annual	SDIN	0.00	0.0290	-0.0077	0.507	-22.93	No Trend
EBEMH	Annual	BDIN	0.00	0.0003	-0.0100	0.490	-30.47	Improving
EBEMH	Annual	STP	0.00	0.0000	-0.0014	0.075	-27.25	Improving
EBEMH	Annual	BTP	0.00	0.0000	-0.0013	0.074	-27.31	Improving
EBEMH	Annual	SPO4F	6.90	0.1132	0.0006	0.018	29.64	No Trend
EBEMH	Annual	BPO4F	8.57	0.1097	0.0006	0.022	25.12	No Trend
WBEMH	Annual	STN	0.00	0.0006	-0.0094	0.800	-17.69	Improving
WBEMH	Annual	BTN	0.00	0.0137	-0.0069	0.791	-13.12	No Trend
WBEMH	Annual	SDIN	6.18	0.2220	-0.0012	0.198	-8.93	No Trend
WBEMH	Annual	BDIN	2.81	0.1867	-0.0022	0.257	-12.68	No Trend
WBEMH	Annual	STP	0.00	0.0000	-0.0019	0.083	-33.68	Improving
WBEMH	Annual	BTP	0.00	0.0000	-0.0017	0.080	-31.20	Improving
WBEMH	Annual	SPO4F	14.69	0.5195	0.0000	0.008	0.00	No Trend
WBEMH	Annual	BPO4F	13.48	0.8750	0.0000	0.013	0.00	No Trend
SBEMH	Annual	STN	0.00	0.0018	-0.0148	1.333	-16.66	Improving
SBEMH	Annual	BTN	0.00	0.3509	-0.0032	1.070	-4.46	No Trend
SBEMH	Annual	SDIN	0.00	0.0001	-0.0145	0.738	-29.44	Improving
SBEMH	Annual	BDIN	0.00	0.1401	-0.0044	0.586	-11.14	No Trend
SBEMH	Annual	STP	0.00	0.0000	-0.0011	0.074	-23.21	Improving
SBEMH	Annual	BTP	0.00	0.0000	-0.0015	0.079	-28.57	Improving
SBEMH	Annual	SPO4F	2.52	0.0999	0.0008	0.033	22.82	No Trend
SBEMH	Annual	BPO4F	5.32	0.4642	0.0005	0.037	11.59	No Trend

b) Blocked seasonal Kendal results

Segment	Parameter	‘93 Trend P value	‘93 Slope	‘93 Trend Direction	‘03 Trend P value	‘03 Slope	‘03 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
ELIPH	STN	1.0000	0.0000	No Trend	0.0938	0.0102	No Trend	0.1928	Same	0.2091	No Trend
ELIPH	BTN	1.0000	0.0000	No Trend	0.1156	0.0066	No Trend	0.2234	Same	0.2234	No Trend
ELIPH	SDIN	0.9426	0.0002	No Trend	0.0326	0.0083	No Trend	0.1165	Same	0.0876	No Trend
ELIPH	BDIN	0.8504	0.0000	No Trend	0.4888	0.0020	No Trend	0.6892	Same	0.4951	No Trend
ELIPH	STP	0.8184	0.0000	No Trend	0.8564	0.0000	No Trend	1.0000	Same	0.7560	No Trend
ELIPH	BTP	0.1060	0.0013	No Trend	0.6089	-0.0005	No Trend	0.1342	Same	0.4809	No Trend
ELIPH	SPO4F	0.7632	0.0000	No Trend	0.4146	0.0003	No Trend	0.7030	Same	0.4066	No Trend
ELIPH	BPO4F	0.5036	0.0000	No Trend	0.3200	0.0003	No Trend	0.7882	Same	0.2267	No Trend

Table 3-10. Trends in non-nutrient parameters in the Elizabeth River for the Annual season for the period 1985 through 2003.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
ELIPH	Annual	SCHLA	16.54	0.5834	0.0180	8.63	0.00	No Trend
ELIPH	Annual	STSS	8.09	0.0153	-0.2000	8.00	-47.50	No Trend
ELIPH	Annual	BTSS	2.22	0.1449	-0.2833	16.00	-33.65	No Trend
ELIPH	Annual	SECCHI	0.00	0.0017	-0.0088	1.10	-15.24	Degrading
ELIPH	Summer1	BDO	0.00	0.2408	0.0244	5.25	8.85	No Trend
ELIPH	Annual	SSALINITY	0.00	0.1644	-0.0781	21.01	-7.06	No Trend
ELIPH	Annual	BSALINITY	0.00	0.0765	-0.0600	24.08	-4.73	No Trend
ELIPH	Annual	BWTEMP	0.00	0.2994	0.0287	17.90	3.04	No Trend
ELIPH	Annual	SWTEMP	0.00	0.1336	0.0328	20.00	3.12	No Trend
EBEMH	Annual	SCHLA	1.15	0.3586	-0.0750	6.600	-17.05	No Trend
EBEMH	Annual	STSS	0.57	0.0086	-0.2040	9.950	-30.75	Improving
EBEMH	Annual	BTSS	0.00	0.0375	-0.2650	12.150	-32.72	No Trend
EBEMH	Annual	SECCHI	0.00	0.0743	0.0000	1.000	0.00	No Trend
EBEMH	Summer1	BDO	0.00	0.0420	0.0760	3.250	35.08	No Trend
EBEMH	Annual	SSALINITY	0.00	0.0257	0.1150	16.850	10.24	No Trend
EBEMH	Annual	BSALINITY	0.00	0.6109	0.0329	18.400	2.68	No Trend
EBEMH	Annual	BWTEMP	0.00	0.0125	0.0921	15.900	8.69	No Trend
EBEMH	Annual	SWTEMP	0.00	0.1204	0.0486	17.000	4.29	No Trend
WBEMH	Annual	SCHLA	0.00	0.0083	-0.3733	23.000	-24.34	Improving
WBEMH	Annual	STSS	0.00	0.0160	-0.3233	20.600	-23.54	No Trend
WBEMH	Annual	BTSS	0.00	0.0367	-0.4380	20.500	-32.05	No Trend
WBEMH	Annual	SECCHI	0.00	0.0156	0.0000	0.600	0.00	No Trend
WBEMH	Summer1	BDO	0.00	0.0243	0.1057	4.400	36.04	No Trend
WBEMH	Annual	SSALINITY	0.00	0.0191	0.1500	15.900	14.15	No Trend
WBEMH	Annual	BSALINITY	0.00	0.0801	0.1060	16.700	9.52	No Trend
WBEMH	Annual	BWTEMP	0.00	0.2048	0.0448	16.150	4.16	No Trend
WBEMH	Annual	SWTEMP	0.00	0.1486	0.0560	17.000	4.94	No Trend
SBEMH	Annual	SCHLA	1.99	0.0723	-0.1080	4.050	-40.01	No Trend
SBEMH	Annual	STSS	0.85	0.0118	-0.2000	8.575	-34.99	No Trend
SBEMH	Annual	BTSS	0.29	0.0000	-0.4903	13.075	-56.24	Improving
SBEMH	Annual	SECCHI	0.00	0.1156	0.0083	0.750	16.67	No Trend
SBEMH	Summer1	BDO	0.00	0.0227	0.0909	2.650	51.46	No Trend
SBEMH	Annual	SSALINITY	0.00	0.0163	0.1691	14.750	17.20	No Trend
SBEMH	Annual	BSALINITY	0.00	0.4877	-0.0440	18.450	-3.57	No Trend
SBEMH	Annual	BWTEMP	0.00	0.0000	0.2100	17.100	18.42	Increasing
SBEMH	Annual	SWTEMP	0.00	0.0028	0.1142	18.200	9.41	Increasing

Table 3-11. SAV season water quality status in in the Elizabeth River for the period 2001 through 2003 (values presented are median concentrations 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
EBEMH	STN	SAV	S	0.8632	91.63	Poor	-
EBEMH	SDIN	SAV	S	0.4212	88.82	Poor	Fail
EBEMH	STP	SAV	S	0.0536	80.89	Poor	-
EBEMH	SPO4F	SAV	S	0.0330	98.12	Poor	Fail
EBEMH	SCHLA	SAV	S	6.41	45.75	Fair	Pass
EBEMH	STSS	SAV	S	8.12	54.01	Fair	Pass
EBEMH	SECCHI	SAV	S	1.10	20.16	Poor	Borderline
WBEMH	STN	SAV	S	0.7487	72.75	Poor	-
WBEMH	SDIN	SAV	S	0.2878	74.06	Poor	Borderline
WBEMH	STP	SAV	S	0.0637	92.37	Poor	-
WBEMH	SPO4F	SAV	S	0.0469	99.62	Poor	Fail
WBEMH	SCHLA	SAV	S	9.40	65.31	Poor	Borderline
WBEMH	STSS	SAV	S	16.82	85.90	Poor	Fail
WBEMH	SECCHI	SAV	S	0.75	5.91	Poor	Fail
SBEMH	STN	SAV	S	1.0266	98.15	Poor	-
SBEMH	SDIN	SAV	S	0.5686	98.29	Poor	Fail
SBEMH	STP	SAV	S	0.0578	84.80	Poor	-
SBEMH	SPO4F	SAV	S	0.0344	97.50	Poor	Fail
SBEMH	SCHLA	SAV	S	2.65	4.76	Good	Pass
SBEMH	STSS	SAV	S	7.63	44.29	Fair	Pass
SBEMH	SECCHI	SAV	S	1.23	21.85	Poor	Pass
ELIPH	STN	SAV	S	0.7167	80.09	Poor	-
ELIPH	SDIN	SAV	S	0.2819	88.67	Poor	Fail
ELIPH	STP	SAV	S	0.0709	92.42	Poor	-
ELIPH	SPO4F	SAV	S	0.0375	98.35	Poor	Borderline
ELIPH	SCHLA	SAV	S	9.35	57.97	Poor	Pass
ELIPH	STSS	SAV	S	11.69	67.19	Poor	Pass
ELIPH	SECCHI	SAV	S	0.90	9.80	Poor	Borderline

Table 3-12. Trends in nutrient parameters in the Elizabeth River for the SAV season for the period 1985 through 2003. Note collections of data in all segments except ELIPH begin in 1989.

a) Seasonal Kendall results

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
EBEMH	SAV	STN	0.00	0.2710	-0.0060	1.049	-8.58	No Trend
EBEMH	SAV	SDIN	0.00	0.0736	-0.0077	0.530	-21.88	No Trend
EBEMH	SAV	STP	0.00	0.0541	-0.0009	0.086	-14.91	No Trend
EBEMH	SAV	BTP	0.00	0.0006	-0.0013	0.099	-19.85	Improving
EBEMH	SAV	SPO4F	5.95	0.2225	-0.0006	0.066	-13.07	No Trend
WBEMH	SAV	STN	0.00	0.0112	-0.0088	0.813	-16.15	No Trend
WBEMH	SAV	SDIN	2.27	0.6815	-0.0005	0.246	-2.85	No Trend
WBEMH	SAV	STP	0.00	0.0000	-0.0022	0.110	-30.46	Improving
WBEMH	SAV	SPO4F	11.49	0.0001	-0.0010	0.051	-30.23	Improving
SBEMH	SAV	STN	0.00	0.0555	-0.0098	1.266	-11.57	No Trend
SBEMH	SAV	SDIN	0.00	0.0218	-0.0118	0.702	-25.21	No Trend
SBEMH	SAV	STP	0.00	0.0163	-0.0009	0.100	-14.20	No Trend
SBEMH	SAV	SPO4F	3.43	0.0604	-0.0008	0.067	-17.07	No Trend

b) Blocked seasonal Kendall results

Segment	Parameter	‘93 Trend P value	‘93 Slope	‘93 Trend Direction	‘03 Trend P value	‘03 Slope	‘03 Trend Direction	Trend Comparison P value	Trend Comparison	Combined Trend P value	Combined Trend Direction
ELIPH	STN	0.1387	0.0123	No Trend	0.0370	0.0130	No Trend	0.6432	Same	0.0104	No Trend
ELIPH	SDIN	1.0000	0.0000	No Trend	0.1601	0.0072	No Trend	0.3079	Same	0.3079	No Trend
ELIPH	STP	0.0048	0.0014	Degrading	0.8641	0.0000	No Trend	0.0700	Same	0.0341	No Trend
ELIPH	SPO4F	0.8412	0.0000	No Trend	0.0516	0.0003	No Trend	0.1904	Same	0.1016	No Trend

Table 3-13. Trends in non-nutrient parameters in the Elizabeth River for the SAV season for the period 1985 through 2003. Note collections of data in all segments except ELIPH begin in 1989.

Segment	Season	Parameter	% BDLs	P value	Slope	Baseline	% Change	Direction
EBEMH	SAV	SCHLA	1.20	0.7671	0.0208	3.550	8.78	No Trend
EBEMH	SAV	STSS	1.16	0.1440	-0.1219	9.950	-18.38	No Trend
EBEMH	SAV	SECCHI	0.00	0.0633	0.0077	0.950	12.15	No Trend
EBEMH	SAV	SSALINITY	0.00	0.0667	0.1150	17.950	9.61	No Trend
EBEMH	SAV	SWTEMP	0.00	0.2071	0.0433	23.950	2.71	No Trend
WBEMH	SAV	SCHLA	0.00	0.0517	-0.3560	19.250	-27.74	No Trend
WBEMH	SAV	STSS	0.00	0.6643	-0.1102	26.300	-6.28	No Trend
WBEMH	SAV	SECCHI	0.00	0.0491	0.0000	0.550	0.00	No Trend
WBEMH	SAV	SSALINITY	0.00	0.0945	0.1171	17.150	10.25	No Trend
WBEMH	SAV	SWTEMP	0.00	0.3173	0.0382	24.200	2.37	No Trend
SBEMH	SAV	SCHLA	2.33	0.0880	-0.1631	3.725	-65.67	No Trend
SBEMH	SAV	STSS	0.56	0.1242	-0.1500	8.575	-26.24	No Trend
SBEMH	SAV	SECCHI	0.00	0.0585	0.0125	0.750	25.00	No Trend
SBEMH	SAV	BDO	0.00	0.0006	0.0886	4.200	31.63	Improving
SBEMH	SAV	SSALINITY	0.00	0.0299	0.1788	16.700	16.06	No Trend
SBEMH	SAV	SWTEMP	0.00	0.0132	0.1143	25.200	6.80	No Trend
ELIPH	SAV	SCHLA	15.22	0.8820	0.0049	7.70	0.00	No Trend
ELIPH	SAV	STSS	3.54	0.9472	0.0000	8.70	0.00	No Trend
ELIPH	SAV	SECCHI	0.00	0.0045	-0.0090	0.95	-17.91	Degrading
ELIPH	SAV	SSALINITY	0.00	0.7069	-0.0357	17.84	-3.80	No Trend
ELIPH	SAV	SWTEMP	0.00	0.0613	0.0625	17.18	6.91	No Trend

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Glossary of Important Terms

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

Anthropogenic - resulting from or generated by human activities.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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