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CURRENT STATUS AND LONG-TERM TRENDS IN WATER QUALITY AND LIVING RESOURCES IN THE VIRGINIA TRIBUTARIES AND CHESAPEAKE BAY MAINSTEM FROM 1985 THROUGH 2011

Prepared by

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I. Introduction

The period prior to the implementation of the Chesapeake Bay Monitoring Program was characterized by a marked decline in the water quality of the Chesapeake Bay. 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 (e.g. USEPA, 1982,1983;Officer et al.,1984; Orth and Moore, 1984). 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, 1987 and 2000, 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 these agreements, a long-term monitoring program of the Chesapeake Bay was established and maintained 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 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 on living resource communities.

Water quality and living resource monitoring in the Virginia Mainstem and tributaries began in 1985 and has continued for 24 years itill present. Detailed assessments of the status and long-term trends in water quality and living resources in Chesapeake Bay and its tributaries have been previously conducted (Alden et al., 1991,1992; Carpenter and Lane, 1998; Dauer, 1997; Dauer et al., 1998a,1998b, 2002b; Lane et al.,1998; Marshall, 1994,1996, 2009; Marshall and Burchardt, 1998, 2003, 2004a, 2004b, 2005; Marshall and Egerton 2009a;2009b; Marshall et al., 2005a;2005b;2006;2008a; 2008b; Nesius et al. 2007). This report summarizes the status of and long-term trends in water quality and living resource conditions for the Virginia tributaries through 2009 and updates the previous reports (Alden et al. 1992, 1996; Dauer et al., 1998a, 1998b; 1999; 2002; 2003a, 2003b, 2003c, 2003d, 20003e, 2003f; 2005a, 2005b, 2005c; 2007a, 2007b; 2008;2009; 2010;2011).

II. Methods and Materials

A. Monitoring Program Descriptions

Non-tidal water quality samples were collected from 1985 through 2010 at six stations at or near the fall-line in each of the major tributaries as part of the U.S. Geological Survey's (USGS) and the Virginia Department of Environmental Quality's (DEQ) River Input Monitoring Program and at an additional four stations above the fall-line (Figure 1). Although stations have been periodically added or removed from the monitoring program over time, tidal water quality has been regularly monitored at 22 sites in Mainstem segments of Chesapeake Bay and at 30 sites in segments of the James, York and Rappahannock rivers (Figure 2) beginning in July, 1985 and continuing through 2011. Six permanent water quality monitoring sites are located in the Elizabeth River five of which were established in 1989 (Figure 2). Current sample collection and processing protocols are available online at: http://www.chesapeakebay.net/qatidal.htm. Details of changes in the monitoring program sampling regime are provided elsewhere (Dauer et al., 2005a, 2005b, 2005c).

Phytoplankton monitoring was conducted at seven stations in the Chesapeake Bay Mainstem beginning in 1985 and at six sites in the major tributaries beginning in 1986 (Figure 3). Two phytoplankton monitoring programs stations (SBE5 and SBE2) were added in the Elizabeth River in 1989 although SBE2 was eventually discontinued. Epi-fluorescent autotrophic picoplankton were added to all stations in 1989. Details of changes in the monitoring program, field sampling and laboratory procedures are described by Dauer et al. (2005a, 2005b, 2005c).

Benthic monitoring was conducted at sixteen fixed point stations in the lower Chesapeake Bay Mainstem and its tributaries beginning in 1985. Sampling at five additional stations, two in the Elizabeth River and one in each of the three other tributaries, began in 1989 (Figure 3). Details of, and changes to, the fixed point monitoring program sampling regime and laboratory procedures are described by Dauer et al. (2005a, 2005b, 2005c).

In 1996, the benthic monitoring program was modified to add a probability-based sampling regime to supplement data collected at fixed-point stations and estimate the area of Chesapeake Bay and its tributaries that met restoration goals as indicated by the B-IBI (Ranasinghe et al., 1994; Weisberg et al., 1997; Alden et al., 2002). Data are collected at 25 randomly allocated stations in each of four separate strata in Virginia: 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 (Figure 3). An additional set of 25 random locations were collected in the Elizabeth River as a part of DEQ's Elizabeth River Monitoring Program beginning in 1999; however, this portion of the program was discontinued in 2007. Probability-based monitoring data are used to assess biological impairment in Chesapeake Bay at different spatial scales on an annual basis. Details of the sampling, laboratory and assessment protocols are provided in Dauer et al. (2005a,2005b,2005c) and Llansó et al. (2005).

B. Statistical Analysis

1. Basin Characteristics

Tabular summaries of land-use coverages were taken from estimates generated for the 2009 Progress Run scenario of the Chesapeake Bay Program Watershed Model (Phase 4.3). Current estimates for this progress run were developed using the Chesapeake Bay Program Land Use (CBPLU) database. This database was developed using coverage categories and areal estimates based on data from the U.S. Agricultural Census and EPA's LANSAT-derived GIS database for the year 1990 enhanced with USGS Geographic Information Retrieval and Analysis System and NOAA Coastal Change Assessment Program land-use/cover databases. The CBPLU database contains a total of 10 separate land-use coverages including: 1) agricultural coverages such as conventional tillage, conservation tillage, hay, pasture and manure acres; 2) pervious and impervious urban acres; 3) forest; 4) mixed open; and 5) non-tidal surface water. For this study, the developed land-use coverage was calculated as the summation of pervious and impervious urban coverages while the agricultural category is the summation of all agricultural coverages. Procedures used to create areal estimates for specific land-use categories are described in (Palace et al., 1998;USEPA, 2002).

Monthly total load estimates were produced by the US Geological Survey using concentration and freshwater flow measurements collected as part of their River Input Monitoring Program (RIMP). Direct measurements of point source nutrient loads were obtained by the Virginia DEQ from all dischargers located on each of the major Virginia tributaries in the state as part of the USEPA's voluntary National Pollutant

Discharge Elimination System (NPDES). Point source loads above and below the fall-line to each tributary were estimated by summing the total load from all dischargers for nitrogen and phosphorus on a monthly and an annual basis.

2. Status of Water Quality and Living Resources

Status of tidal water quality for each Chesapeake Bay program segment was determined using the Water Quality Index (WQI) of Williams et al. (2009). The WQI combines the percentages of observations violating established thresholds for three water quality parameters (dissolved oxygen, chlorophyll *a,* and secchi depth) into a multimetric index of water quality that is highly correlated with land-use patterns (Wlliams et al., 2009). The percentage of observations that exceed or are less than the thresholds is calculated on a station-by-station basis and then averaged first by station and then for each segment. Status characterizations are assigned to the WQI based on a grading system such that movement along a categorical scale from A to E indicates successively degrading water quality. Equally divided ranges of WQI values were assigned grades as follows: (1) values from 0 to 20% are E or Very Poor; (2) values from 21 to 40% are D or Poor; (3) values from 41 to 60% are C or Marginal; (4) values from 61 to 80% are B or Good; and (5) values from 81 to 100% are A or Very Good. All other methodological details for calculating the WQI can be found in Williams et al., (2009). Values for this index were provided by the University of Maryland Center for Environmental Science. Status using the WQI was based on water quality measurements collected during 2011.

Status characterizations for phytoplankton communities were determined using the Phytoplankton Index of Biotic Integrity or P-IBI (Buchanan et al., 2005; Lacouture et al., 2006). Status was assessed using station means of the P-IBI using all values from the spring and summer index periods for data collected during the period 2009 through 2011. Phytoplankton communities were classified as follows: (1) Poor for P-IBI values less than or equal to 2.00; (2) Fair-Poor for values greater than 2.00 and less than or equal to 2.67; (3) Fair for values greater then 2.67 and less than or equal to 3.00; (4) Fair-Good for values greater than 3.00 and less than or equal to 4.00; and (5) Good for values greater than 4.00. P-IBI values used in this study were generated and provided by the Chesapeake Bay Program Office of the USEPA and are available at http://www.chesapeakebay.net/data_plankton.aspx.

Status of benthic communities at each fixed point station was characterized using the three-year mean value (2009 through 2011) of the B-IBI (Weisberg et al., 1997). Status of benthic communities was classified as follows: (1) values less than or equal to 2 were classified as Severely Degraded; (2) values greater than 2.0 to 2.6 were classified as Degraded; (3) values greater than 2.6 but less than 3.0 were classified as Marginal; and (4) 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 of all strata classified as impaired using the B-IBI (Llansó et al., 2007).

3. Long-term Trend Analyses

Trend analysis for non-tidal water quality parameters was conducted using a seven parameter regression model that took into account the effects of flow, time, seasonal effects and other predictors conducted on flow-adjusted concentrations (Langland et al., 2006). Trends reported for non-tidal areas are considered to be those that were observed after natural effects such as flow have been removed from data set and that represent remaining positive or negative anthropogenic effects i.e management actions or increased pollution. Trend analyses of fall-line freshwater flow, non-point and point source loads, most tidal water quality parameters, and tidal living resource parameters were conducted using the seasonal Kendall test for monotonic trends using Sen's slope as an indicator of incremental change, and the Van Belle and Hughes tests for homogeneity of trends between stations, seasons (months), and station-season(month) combinations (Gilbert, 1987). A "blocked" seasonal Kendall approach (Gilbert, 1987) was used for water quality parameters for which an observed or suspected step trend occurred in association with known methodological or other institutional changes at various times during the monitoring program. For the blocked seasonal Kendall approach, separate trend analyses are conducted on the pre- and post-method change "blocks" of data using the seasonal Kendall approach. Trends for the two periods are statistically compared to determine if the direction is the same for both periods. If the trends for the two periods are not significantly different with respect to direction, then a trend for the entire period of record was reported (referred to in this report as long-term trends). If the trends are significantly different, only trends from the post-method change period were reported (referred to as post-method change trends).

Method changes for nutrient parameters occurred at different times depending on the institution responsible for sample processing. Samples collected in most segments of the James, York and Rappahannock rivers as well as a portion of the Elizabeth River (one station in segment ELIPH) were collected by the Virginia DEQ and processed by Virginia state laboratories which changed nutrient methodologies after 1993. During 1994, samples from these areas were processed using the new methods but processing was carried out by the Virginia Institute of Marine Science (VIMS). After instituting the new methodologies, the Virginia state laboratories resumed sample processing in 1995. In order to account for the method change and to eliminate any effects due to the brief change in laboratories, the pre-method change period for these data was designated as 1985 through 1993 while the post-method change data period was 1995 through 2011. All data from 1994 were dropped from the trend analyses for these parameters. An additional step trend was observed for total suspended solids that occurred when ODU took over sampling and laboratory processing in the entire Mainstem from VIMS in 1996. As such, the pre- and post-method change periods were prior to 1996 and from 1996 to the present, respectively.

Nutrient determinations in the Chesapeake Bay Mainstem, Mobjack Bay, Pocomoke Sound, the Piankatank River and portions of the Elizabeth River were conducted either exclusively by Old Dominion University (ODU) or by VIMS until 1996 and solely by ODU thereafter. Method changes for both institutions occurred at the beginning of 1988 and there were no apparent step changes in the nutrient data associated with the change in laboratories that occurred in 1996. Since the pre-method change period was only three years it was decided to eliminate this initial set of data from the nutrient trend analysis for the Mainstem and conduct a standard seasonal Kendall trend analysis on these parameters using data from 1988 through 2011 to reduce complexity of interpretation and potential Type I and Type II errors.

III. Results and Discussion

A. James River Basin

1. Basin Characteristics

The James River basin has the largest percentage of developed land, and the largest percentage of land with impervious surfaces of the three Virginia tributaries while at the same time having the highest total area, the second highest percentage of forested land and a relatively low percentage of agricultural land (Table

1A). Above the fall-line, the James River is predominantly rural with the dominant land use type being forest (66%) coupled with about 16% agricultural lands (Table 1B). The tidal portion of the river is characterized by higher percentages of developed land (38%) with over 15% being impervious surfaces. In addition, the tidal James River is characterized by relatively low forest coverage in comparison with other basins as well as a smaller percentage of agricultural land (Table 1B).

USGS estimates of total nitrogen, total phosphorus and total suspended solids non-point source loads at the fall-line in the James River have fluctuated substantially but overall appear to be decreasing (Figures 4A,5A and 6A) and long-term trends were detected for each of these parameters. No such improvements were observed in total loads for any of these parameters at the fall-line of the Appomattox River (Table 2) and, in fact, plots of annual total loads for total phosphorus appear to show a slight increase (Figure 6B). Long-term improvements in total NPS loads of nutrients and suspended solids are probably related to the long-term decreasing trend in freshwater flow to the James River (Table 3).

Significant improving long term trends in monthly point source loads of total nitrogen and total phosphorus were detected above the fall-line in the James River with an approximate reduction in loads of 30.4% and 27.5%, respectively (Table 4). Significant trends in monthly point source loads of total nitrogen and total phosphorus were also detected below the fall-line although reductions there were substantially higher at 60.8% and 62.7%, respectively (Table 4). Plots of annual total loads both above and below the fall line tend to confirm the results of the trend analyses (Figure 7).

2. Non-tidal Water Quality

Overall, water quality conditions at the fall line in the James River appears are improving as indicated by improving (decreasing) trends in flow adjusted concentrations of total nitrogen and total phosphorus (Table 5; Station 3 in Figures 8-9) as well as improving trends in flow adjusted nitrates and dissolved inorganic phosphates (Table 5). Trends above the fall-line in the Appomattox River were mixed that included an improving trend in dissolved inorganic phosphorus (Table 5) coupled with degrading trends in total phosphorus and total suspended solids (Table 5; Station 1 in Figures 9-10).

3. Tidal Water Quality

For all segments in the James River with the exception of JMSTF1, water quality status as measured using the WQI was classified as either Poor or Very Poor (Figure 11). With respect to nitrogen, improving trends were limited primarily to the tidal freshwater segments of the James River main stem (JMSTF1 and JMSTF2) and to the Chickahominy River (Figure 11). Improving long term or post method change trends in surface and/or bottom total phosphorus were detected in all of the segments of the James River except for the Chickahominy River (Figure 11). Improving trends in surface and bottom dissolved inorganic phosphorus were also detected but limited primarily to the tidal freshwater segments JMSTF1, JMSTF2, and APPTF (Figure 11).

Improving trends in surface chlorophyll *a* were restricted to the middle segments of James River (JMSTF1 and JMSOH) and to the Chickahominy River (CHKOH) while a degrading trend in chlorophyll *a* was detected at the entrance to James River in segment JMSPH (Figure 12). A degrading trends in bottom total suspended solids were detected in segment CHKOH while degrading trends in water clarity as measured by Secchi depth were detected in segments JMSTF2, CHKOH, and JMSPH (Figure 12). Summer bottom dissolved oxygen concentrations were unchanged for most segments except at segment JMSOH where a degrading trend was observed (Figure 12).

Water quality status based on the WQI was Very Poor in all segments of the Elizabeth River (Figure 13). Despite generally degraded water quality, conditions in the Elizabeth River appear to be improving in most segments. Improving trends in surface and bottom total nitrogen and total phosphorus were observed in all segments of the Elizabeth River except for the Mainstem (ELIPH) where only post method change trends in surface and bottom total phosphorus were observed (Figure 13). Additionally, improving trends in surface and bottom total suspended solids were observed in all segments of the Elizabeth River (Figure 14). The only degrading trend observed was a decreasing trend in Secchi depth in the Elizabeth River Mainstem ELIPH (Figure 14).

4. Phytoplankton Communities

In general, phytoplankton communities in the James River appear to be degraded as indicated by the Poor or Fair to Poor status of the P-IBI observed at all stations in this tributary. No trends in the P-IBI were observed at any of the stations (Figure 15). No improving trends in any phytoplankton community indicators were detected at any stations in the James River except chlorophyte biomass at station TF5.5 and picoplankton biomass at stations TF5.5 and RET5.2 (Appendix C - Section A). Several degrading trends were also detected including declining trends in Margalef species diversity at station RET5.2 and diatom biomass at station SBE5 and increasing trends cyanophyte biomass at station TF5.5 and LE5.5 (Appendix C - Section A).

There is a transition in phytoplankton composition moving downstream from the tidal freshwater station into the more saline waters where the dominant freshwater taxa are replaced by estuarine species. In the upstream waters freshwater diatoms (e.g. *Aulacosiera* spp., *Skeletonema potamos*), plus a variety of cyanobacteria and chlorophytes are the dominant algal flora. Whereas, downstream the major constituents are composed of estuarine diatoms (e.g. *Skeletonema costatum*, *Cerataulina pelagica*), cryptomonads, and a diverse assemblage of dinoflagellates. These taxa are similar to the algal composition in the lower Chesapeake Bay waters.

Seasonal blooms continue to be a common phenomenon in the James River and its tributaries. These begin with the spring diatom bloom beginning in late winter and continuing into early spring, and are common within each of the river's salinity regions. Dinoflagellate blooms begin in spring and continue into late autumn. These blooms are most common in the downstream regions of the river. Several of these blooms are designated as a HAB (harmful algal bloom), while others are not placed in this category. Taxa producing these non-harmful blooms include the common dinoflagellates *Heterocapsa triquetra*, *Heterocapsa rotundata*, *Akashiwo sanguinea*, *Scrippsiella trochoidea*, plus several *Gymnodinium* spp. Other common algal flora that are present, but not harmful include a variety of pennate and centric diatoms, chlorophytes, cryptomonads, cyanobacteria, euglenoids, and others throughout the seasons.

The harmful bloom producing algae include *Prorocentrum minimum* common from spring through autumn. Associated with this species are periods of low oxygen levels that may occur resulting in stress conditions or mortality among fish and shellfish present under this condition. Another spring dinoflagellate bloomer is the ichthyotoxic *Karlodinium veneficum* which has been more common in the Potomac River and its tributaries and inlets appears to becoming more common in the tidewater tributaries to Chesapeake Bay.

The major bloom producing dinoflagellate in this river is *Cochlodinium polykrikoides*, which becomes most dominant during summer and early autumn. Blooms of this species typically first occur in the Lafayette River, then spreads into the Elizabeth River, then into the James River. Other tributaries to the James follow a similar pattern of development and cell dispersal (e.g. Warrick River). These blooms are generally extensive in scope, long lasting, and are often associated with an accompanying odor. As this bloom moves down the river, it will enter the Lower Chesapeake Bay, and at times pass out of the Bay and progress along the coastline southward. Another toxin producer present in the upper James tidal freshwater region is the cyanobacterium *Microcystis aeruginosa*. This species is a frequent bloom producer in fresh water habitats, and its blooms in the river are common. Other potentially harmful and toxin producing species that have been noted in downstream locations, but less frequently is the raphidophyte *Chattonella subsalsa* and the dinoflagellate *Alexandrium monilatum*.

5. Benthic Communities

The B-IBI met restoration goals at only one station in the main stem of James River: station LE5.4 in segment JMSPH while status at all other stations was degraded while status of the B-IBI at stations in the Southern Branch of the Elizabeth River was degraded or severely degraded (Figure 16). An improving trend in the B-IBI was detected at station RET5.2 in segment JMSOH (Figure 16). No other trends in the B-IBI were detected at any fixed point stations. Results of the probability-based benthic monitoring indicate that over 80% of the total area of the James River failed to meet restoration goals (Figure 17) and that there was a significant increasing trend in the percentage of area failing the goal since 1996 (Figure 18). Previous studies suggest that anthropogenic contaminants may account for much of the degradation in the James River (Dauer et al., 2005a; Llansó et al.,2005).

6. Management Issues

Trends at the fall-line indicate that in general water quality is improving in the non-tidal portions of the James River basin with respect to nutrient concentrations although no change in suspended solids was observed. Water quality status in the tidal portions of the James River was Poor throughout nearly the entire basin with all other regions having Marginal status. Improving trends in nutrients, primarily total and dissolved inorganic phosphorus, were generally restricted to the tidal freshwater and oligohaline segments of the James River. The trends in phosphorus observed are probably directly related to decreasing trends in NPS and/or PS total phosphorus loads for this parameter both above and below the fall-line. It is unclear why similar reductions in NPS and PS nitrogen loads have not resulted in more a widespread response in nitrogen concentrations in James River. Few changes in chlorophyll *a*, suspended solids or dissolved oxygen were observed although degrading trends in Secchi depth were observed in multiple segments. A closer examination of the geographical distribution and relative contribution of NPS and PS loads to nutrient concentrations and their potential effects on phytoplankton concentrations in various regions of the James River basin may provide more insight into direct causes of the decreasing trends observed. Alternatively, studies designed to identify of sources of colored dissolved organic matter may be required answer this question.

Overall living resources conditions in the James River are degraded. Phytoplankton communities throughout the James River were characterized as Fair-Poor to Poor at all stations. Algal bloom development can be a major concern in reference to degrading the water quality, producing stress conditions and even mortality among fish and shellfish, plus human health concerns. Appropriate human health alerts, and restrictions directed at specific water based recreational activities may need to be considered in specific and intense bloom development. Presently the main species of concern regarding bloom conditions is *Cochlodinium polykrikoides*. It produces foul odors upon decomposition and its blooms are generally extensive, long lasting, and a concern to the various state agencies as producing potential toxins and anoxic conditions in the water column, and possible health risks to recreational users. Although no significant health problems have been associated with these blooms to date, its presence has often curtailed public recreational activities. Several of the other toxin producers (*Prorocentrum minimum*, *Karlodinium veneficum*, *Chattonells subsalsa*) are also of concern due to any economic, health, or recreational impact their contamination or mortality may produce in the local fisheries (fish and shellfish). These potentially harmful species are to be monitored throughout the year to appraise management of their status. These blooms are supported by nutrients entering the river and its tributaries so managerial efforts to reduce this input should be considered.

Status of the benthos at most fixed-point stations in the James Rivers was Degraded or Severely Degraded and probability-based benthic monitoring indicated that 80% of the total area of the river did not meet restoration goals. Only one improving trend in benthic community conditions based on the B-IBI was observed at all of the fixed point stations monitored and trend analysis of probability-based sampling data indicates a long term increase in the percentage of area failing to meet restoration goals for the basin as a whole. Living resource conditions in the James River are the result of a variety of anthropogenic effects including low dissolved oxygen related to nutrient input and degradation coupled with anthropogenic contamination.

In the Elizabeth River, water quality status was Poor but improvements in nutrients and total suspended solids were observed throughout this tributary. Intense urbanization resulting in high NPS runoff into the Elizabeth River coupled with high PS nutrient loads result in the poor water quality status observed in this tributary. The improving trends in nutrients observed are probably the result of improvements in PS loads of nutrients. Reductions in total suspended solids concentrations are probably due to the reductions in NPS loads below the fall-line.

Living resources in the Elizabeth River are also degraded as indicated by the Poor value for the P-IBI at station SBE5 and by Degraded B-IBI values observed at both fixed point stations. No improvements in either phytoplankton communities or benthic communities in the Elizabeth River were indicated based on trend analyses of the P-IBI and B-IBI, respectively. The primary stress to living resources in this area is anthropogenic nutrient and chemical contamination from a variety of sources including historical contamination, municipal and industrial point sources, non-point source storm water run-off, and automobile emissions. Recent BMPs and reductions in point source loads may be ameliorating both the problems with water quality and living resource conditions in some areas and expansion of these practices may result in further improvements.

B. York River Basin

1. Basin Characteristics

The York River watershed is predominantly rural having the highest percentage of forested land of all three of the major Virginia tributaries (63%) coupled with a very low percentage of developed land (Table 1A). The percentage of agricultural land in the York River watershed was similar to that in the James River at 15%

(Table 1A). Only 6% of the basin was characterized as developed (Table 1A). Percentages of the various land use categories were similar above and below the fall-line for this basin (Table 1B).

No significant trends in USGS estimates of total nitrogen, phosphorus and total suspended solids loads at the fall-line have been detected for either the Pamunkey or Mattponi rivers (Table 2). Plots of annual total loads generally confirm the trend results (Figure 19-21). There was a significant decreasing trend in freshwater flow at the fall-line in the Pamunkey River but no trend in flow in the Mattaponi River was observed (Table 3).

A significant improving long term trend in monthly point source loads of total nitrogen coupled with a degrading trend in monthly point source total phosphorus was detected above the fall-line in the York River (Table 4). Both trends appear to reflect the pattern exhibited by annual loads with the exception of a large decline in point source TP loadings from 2006 through 2010 which reversed itself in 2011 (Figures 22A-B). Overall these trends have resulted in long term in a 16.5% reduction and 34% increase in point source total nitrogen and total phosphorus loads, respectively (Table 4).

Although there was no trend in total nitrogen loadings, a significant improving trend in monthly point source total phosphorus loads resulted in a reduction of nearly 38% below the fall-line for the York River (Table 4). Overall, plots of annual point source total nitrogen loads, with the exception of 2011, indicate a general pattern of gradual increase over time while annual point source total phosphorus loads show what appears to be an asymptotic decline that is in general agreement with the trend analysis results (Figure 22C-D). Significant improving trends in both point source total nitrogen and total phosphorus loadings resulted in reductions of 84.7% and 56.3%, respectively, for these two stressors in Mobjack Bay (Table 4). Both annual total nitrogen and total phosphorus loadings in Mobjack Bay declined precipitously after 1992 and stayed relatively constant thereafter (Figures 23A-B).

2. Non-tidal Water Quality

Water quality conditions in the non-tidal portion of the Pamunkey River are declining as indicated by the degrading trends in flow-adjusted concentrations of all measured water quality parameters near Hanover at the fall-line (Table 5; Station 4 in Figures 8-10) . However, the degrading trends at the Pamunkey fall-line seem to have occurred from 1985 to 2000 or 2002 and began to level out since then (Rick Hoffman, DEQ, personal communication). Water quality conditions in the non-tidal Mattaponi River may be improving as indicated by the declining trend in flow-adjusted dissolved inorganic phosphorus (Table 5).

3. Tidal Water Quality

Status, as measured using the WQI, was either Poor or Very Poor in all segments of the York River with the exception of the upper Mattaponi River were it was Marginal (Figure 24). With respect to nutrients, post method change improving trends in surface dissolved inorganic phosphorus were detected in the upper Pamunkey and Mattaponi rivers (segments PMKTF and MPNTF) while degrading trends in both surface and bottom total phosphorus and dissolved inorganic phosphorus were detected in the lower segments of the York River (YRKMH and YRKPH). Improving trends in total nitrogen, dissolved inorganic nitrogen and total phosphorus were detected in Mobjack Bay (segment MOBPH; Figure 24) perhaps in direct relation to reductions in point source loadings of nitrogen and phosphorus in this region.

Improving trends in chlorophyll *a* concentrations were observed in the upper Pamunkey and Mattaponi rivers (segments PMKTF and MPNTF) coupled incongruously with degrading trades in water clarity (Figure 25). Degrading trends in water clarity were also observed in both the mouth of the York River (segment YRKPH) and Mobjack Bay (MOBPH) (Figure 25). The decline in the Pamunkey tidal freshwater and lower York River segments were associated with degrading trends in total suspended solids (Figure 25). Improvements in summer bottom dissolved oxygen were detected in the tidal freshwater Pamunkey (PMKTF) and in Mobjack Bay (MOBPH) (Figure 25).

4. Phytoplankton Communities

Status of the phytoplankton communities based on the P-IBI was Fair at station TF4.2 in segment PMKTF, Poor at station RET4.3 in segment YRKMH and Fair to Poor at station WE4.2 in segment MOBPH (Figure 26). There were no significant trends in the P-IBI (Figure 26). Although improving trends were detected for chlorophyte biomass at stations TF4.2 in segment PMKTF and RET4.3 in segment YRKMH, degrading trends in cyanophyte biomass were detected at station TF4.2 and station WE4.2 in segment MOBPH (Appendix C - Section B). A degrading trend in Margalef species diversity was also detected in at station WE4.2 (Appendix C - Section B).

The Pamunkey and Mattaponi rivers will introduce freshwater algae into the estuarine waters of the York River. These algae include a variety of pennate and centric diatoms, plus various chlorophytes, cyanobacteria, and cryptomonads among others. The phytoplankton taxa in the York are mostly dominated by estuarine species common to the Chesapeake Bay. These include a similar Bay diatom representation plus a variety of bloom forming dinoflagellates such as *Heterocapsa rotundata*, *Heterocapsa triquetra*, *Akashiwo sanquinea*, *Gymnodinium* spp., and *Scrippsiella trochoidea*. The potentially harmful taxa include several HAB species that are also bloom producers. These include *Prorocentrum minimum* which may produce local blooms throughout the year, and *Karlodinium veneficum* a common spring bloom producer. *Alexandrium monilatum* and *Chattonella subsalsa* have also been detected more recently in the York and its tributaries. However, the major bloom producer is the dinoflagellate *Cochlodinium polykrikoides* which has a long historical record of annual summer/early autumn blooms occurring in the lower reaches of the river, and which often extend into the Chesapeake Bay. These blooms may persist over several weeks. These waters also contain an abundant array of pennate and centric diatoms, also with seasonal periods of bloom development (e.g. spring diatom bloom). Cryptophytes represent another common component throughout the river, with the chlorophytes and cyanobacteria more prominent upstream in tidal freshwater locations.

5. Benthic Communities

Status of benthic communities in the York River based on the B-IBI was degraded at station TF4.2 in segment PMKTF and station LE4.3B in segment YRKPH and marginal at station LE4.1 in segment YRKMH (Figure 27). However, benthic communities meet restoration goals at the remaining fixed point stations in the York River and improving trends in the B-IBI were observed at stations LE4.3 and LE4.3B in segment YRKPH (Figure 27). In 2011, results of the probability-based benthic monitoring indicated that 68% of the total area of the York River was degraded (Figure 17). No significant trend in the percent area failing the restoration goal was observed in the York River stratum (Figure 18).

6. Management Issues

Water quality in the non-tidal portion of the Pamunkey River is degrading as indicated by increasing trends in flow-adjusted concentrations at the fall-line for all parameters measured. In the Mattaponi River, there appear to be few changes in water quality conditions although a decreasing trend in dissolved inorganic phosphorus suggests some improvement. The source of the degrading trends in nutrients observed above the fall-line in the Pamunkey River is unclear although increased point source loads might explain the increasing trends in phosphorus parameters.

Water quality status in the tidal portion of the York River was generally Poor. Long-term degrading trends in phosphorus were detected in the lower segments of the river (YRKMH and YRKPH) while improving trends in these parameters were limited to the tidal freshwater segments of the Pamunkey and Mattaponi rivers and to Mobjack Bay. Degrading trends in water clarity were also detected in several segments. Trends in nutrients may be related to the degrading trends observed above the fall-line. Multiple improving trend in nutrients, total suspended solids and bottom dissolved oxygen were detected in Mobjack Bay which may be related to the reductions in point source loads of both nitrogen and phosphorus in that segment. Although the changes in point source nutrients observed were relatively small, the small total area and low flow rates of the York River may make Mobjack Bay more susceptible to changes in loads from local point sources. Alternatively, the improving trends in the adjacent Mainstem Chesapeake Bay may be also be responsible for the improvements in this segment.

Phytoplankton conditions in the York River are reflective of the generally poor water quality status. Phytoplankton community status was only Fair or Poor, no trends in the P-IBI and few improving trends in phytoplankton bioindicators were observed. Algal blooms are common events in the lower York, where they can be extensive in areal coverage, long lasting, and potentially harmful to shellfish and fish. The most noticeable of these bloom producers is the dinoflagellate *Cochlodinium polykrikoides*. Of concern is the establishment of other potentially harmful species in these waters, such as the presence and subsequent establishment and eventual bloom status for the toxin producers *Chattonella subsalsa* and *Alexandrium monilatum*. These taxa with further development, and other algal bloomers, may be enhanced with increased nutrient enrichment into these waters. All of these potentially harmful species are to be monitored throughout the year to appraise management of their status. Since increased nutrient levels support these blooms continued management efforts to reduce their entry into these waters should be emphasized.

With respect to the benthos, status results were mixed with two of the fixed point stations meeting restoration goals and the remaining being classified as Degraded or Marginal while probability-based sampling indicated that 68% of the bottom of the York River did not met the restoration goals for benthic communities. Conditions in the lower York River may be improving as indicated by the increasing trends in the B-IBI at stations LE4.3 and LE4.3B although the results of the trend analysis on the probability based data indicated no change in the percentage of area failing the restoration goal since 1996. Previous studies indicate that anthropogenic contamination appears to be a source of stress to the benthos but eutrophication coupled with low dissolved oxygen (Dauer et al., 2005b) as well as seabed mixing, a natural source of stress, may also affect benthic community conditions and status assessments in the York River (Dellapenna et al., 1998; 2003).

C. Rappahannock River Basin

1. Basin Characteristics

The Rappahannock River is predominantly rural with forest and agricultural land use types accounting for 80% of the total area of this watershed (Table 1A). It has the highest area of agricultural land of all three of the Virginia tributaries (Table 1A). Agricultural land was substantially higher above the fall-line while forested land was higher below the fall-line (Table 1B). Developed land in both areas was less than 10% (Table 1B).

USGS estimates of total nitrogen, phosphorus and total suspended solids loads at the fall-line in the Rappahannock River have fluctuated with little discernible pattern (Figures 28A-C) and no long-term trends in monthly loads were detected for any of these parameters (Table 2). There was no trend in freshwater flow at the Rappahannock River fall-line (Table 3).

A degrading trend resulting in a 45% increase in monthly point source total nitrogen loads was detected above the fall-line in the Rappahannock River (Table 4). In contrast, an improving trend resulting in a 58% reduction in point source total phosphorus loads above the fall-line was also detected in the Rappahannock River (Table 4). A plot of annual loads of total phosphorus agrees with the trend analysis results showing an asymptotic decline from 1985 through 2011 (Figure 29B) while the plot of annual point source total nitrogen loads shows a general increase through 2007 after which total annual point nitrogen loads declined substantially in the Rappahannock River (Figure 29A).

Improving trends in monthly point source loads of both total nitrogen and total phosphorus were detected below the fall-line resulting in 58% and 57% reductions in loads of these two parameters, respectively (Table 4). Plots of annual total loads confirm results of the trend analyses (Figure 29C-D).

2. Non-tidal Water Quality

No long term trends in flow-adjusted water quality parameters were detected at the fall-line in the Rappahannock River (Table 5; Figures 9-10).

3. Tidal Water Quality

Water quality status as measured using the WQI was Poor or Very Poor in all segments of the Rappahannock River (Figure 30). Water quality conditions in the largest segment of the Rappahannock River, segment RPPMH, appear to be degrading as indicated by increasing trends in bottom total nitrogen and surface and bottom total phosphorus (Figure 30). Improvements in nutrients were observed in the main stem of Rappahannock River but these were limited to decreasing long term trends in bottom total nitrogen in segment RPPTF and surface dissolved inorganic phosphorus in segment RPPOH (Figure 30). Improving post method change trends in dissolved inorganic phosphorus were detected in both segments RPPTF and RPPOH (Figure 30). Post-method change improving trends in bottom total nitrogen, surface dissolve inorganic nitrogen and bottom total phosphorus were also detected in the Corrotoman River (Figure 30).

Degrading trends in chlorophyll *a* was detected in the middle (RPPOH) and lower Rappahannock River (RPPMH), as were degrading trends in water clarity in the middle Rappahannock River (RPPOH) and the Corrotoman River (CRRMH) (Figure 31). A degrading trend in bottom dissolved oxygen was also detected in the upper Rappahannock River (segment RPPTF) (Figure 31).

4. Phytoplankton Communities

Phytoplankton communities in the Rappahannock River were typically degraded. Two stations, TF3.3 and RET3.1 in segment RPPOH, were characterized as Poor based on the P-IBI while the remaining station, LE3.6 in segment RPPMH was classified as only Fair (Figure 32). There were no significant trends in the P-IBI however; conditions appear to be degrading as indicated by the increasing trends in cyanophytes detected at all stations in this tributary (Appendix C - Section B). Some improvements are indicated by the increasing trends in chlorophyte biomass at stations TF3.3 and RET3.1 (Appendix C - Section B).

Similar estuarine phytoplankton flora as noted above in the James and York rivers exist in the various saline regions of the Rappahannock, as well as, populations corresponding to those found in the Chesapeake Bay main stem. The tidal freshwater station contains a variety of freshwater diatoms (pennate and centric), cyanobacteria, and chlorophytes as the predominant algae. Throughout the Rappahannock River a spring diatom bloom was evident, with the diatoms remaining prominent background species through summer with a slight increase in abundance in autumn. Cryptophytes were common components throughout the system, especially within the downstream regions of the river. Major non-harmful bloomers within the river were similar to those in the James and York, being represented by *Gymnodinium* spp, *Heterocapsa rotundata*, *Heterocapsa triquetra*, *Akashiwo sanguinea*, and *Scrippsiella trochoidea*. Unlike these other rivers the dinoflagellate *Cochlodinium polykridoides* was rarely noted. However, the ichthyotoxic dinoflagellate *Karlodinium veneficum* and *Prorocentrum minimum* occur in this river. Also, noted is the bloom forming ciliate *Myrionecta rubra*. In the tidal freshwater region the cyanobacteria *Microcystis aeruginosa* is a bloom producer and a potential toxin producer.

5. Benthic Communities

Benthic community status was degraded or severely degraded at all stations in the Rappahannock River and in general became more degraded moving downstream with both stations in segment RPPMH being severely degraded. In addition, a degrading trend in the B-IBI was detected at station RET3.1 in segment RPPMH (Figure 33). Probability-based benthic monitoring results indicated that 84% of the total area of Rappahannock River failed to meet the benthic community goals in 2010 (Figure 17) and there was a significant trend in the percentage of area failing to meet the restoration goal since 1996 for this sampling stratum (Figure 18). Previous studies indicate benthic degradation in the Upper Rappahannock River appears to be the result of anthropogenic contamination while degradation in the lower segments of the river may be the result of a combination of contamination and low dissolved oxygen effects (Dauer et al., 2005c; Llansó et al.,2005).

6. Management Issues

Water quality conditions in the Rappahannock River basin were generally poor. The lack of change in non-point source nutrient loads above the fall-line and in point source nitrogen loads above the fall-line might account for the lack of improvements observed in flow adjusted water quality parameters at the fall-line. Despite improvements in point source loadings in both nitrogen and phosphorus below the fall-line, water quality status in the tidal portion of the Rappahannock River is still poor and limited improving trends were observed. Additionally, degrading trends in both total nitrogen and total phosphorus were observed in the largest segment of this tributary as well as degrading trends in chlorophyll *a*, secchi depth, and bottom dissolved oxygen were detected in several segments of this tributary. Although there is no clear explanation for the lack of response in total phosphorus concentrations to reductions in both NPS and PS loads of this nutrient, there are several possibilities: (1) reductions in loads were insufficient to result in a response in water column concentrations; (2) the NPS and/or PS load data used do not reflect actual loads to this river for this parameter; (3) lag times between load reductions and concentrations are longer than period of record of the current data set; or (4) sources other than non-point source runoff or point source outfalls such as atmospheric deposition or sediment flux constitute a substantially higher source of total phosphorus than previously believed.

Living resource conditions within much of the Rappahannock River appeared to be impacted due perhaps in large part to the lack of improvement in water quality conditions. P-IBI values were characterized as either Poor or Fair and increasing trends in cyanobacteria biomass were detected at all stations suggesting that phytoplankton communities in the Rappahannock River may be degrading. There is concern that increased nutrient loads for the river would support further algal growth throughout the system; for cyanobacteria in the upper reaches of the river and dinoflagellates in the down stream regions of the river. Increased nutrient loads would reduce water quality values within the river and favor development of less desirable algal species. It is important that monitoring of the potentially harmful taxa continue to allow management to appraise any environmental concerns to the river’s shellfish and fish populations, and any potentiallly related human health effects.

Benthic community status at most fixed point monitoring stations in the Rappahannock River was Degraded or Severely Degraded and trend results indicate that conditions continue to degrade at station RET3.1 in the uppermost portion of segment RPPMH (Figure 33). Probability-based monitoring results indicated that 84% of the total area of the Rappahannock River failed to meet restoration goals and that there is a significant increasing trend in the percentage of area failing to meet restoration goals. Degraded benthic community conditions in the Rappahannock River are most likely due to low dissolved oxygen events particularly in the lower portions of the estuary.

D. Virginia Chesapeake Bay Mainstem

1. Tidal Water Quality

Water quality status in the Virginia Chesapeake Bay Mainstem was Very Poor in all segments (Figure 34). Overall, however, water quality conditions appear to be improving. Improving trends in surface and bottom total nitrogen were detected in all segments of the Mainstem except CB8PH. Improving long-term trends in surface and bottom total phosphorus were detected in all segments (Figure 34) and improving trends in surface and/or bottom dissolved inorganic were detected in all segments except the Piankatank River (segment PIAMH) and Pocomoke Sound (segment POCMH).

Improving post- laboratory change trends in surface and/or bottom total suspended solids were observed in all segments of the Mainstem (Figure 35) coupled with improving trends in bottom dissolved oxygen in the Piankatank River (segment PIAMH), Pocomoke Sound (segment POCMH) and the mouth of Chesapeake Bay (CB8PH). Despite the improvements in both nutrients and suspended solids, there were no concomitant improvements in chlorophyll *a* and degrading trends in water clarity were observed in all segments of Mainstem (Figure 35). Decreasing trends in surface and/or bottom salinity were detected in most segments of the Mainstem (Figure 35).

2. Phytoplankton Communities

Status of phytoplankton communities in the Virginia Chesapeake Bay Mainstem based on the P-IBI was Fair at all stations and no significant trends were detected in the P-IBI (Figure 36). Degrading trends in cyanophyte biomass were detected at all stations in the Bay Mainstem along with degrading trends in Margalef species diversity at all stations except station CB6.1 in segment CB6PH (Appendix C - Section E). No improving trends in phytoplankton indicators were detected. In addition, decreasing trends in cryptophyte biomass were detected at all Mainstem stations.

The Chesapeake Bay is a stratified system with the phytoplankton below the pycnocline containing species entering the Bay from incoming off shore Atlantic waters of Virginia, and waters above the pycnocline typically include estuarine phytoplankton flowing out of the Bay, providing a mixed array of algal taxa. These sub-pycnocline waters have carried various algae to upper regions of the Bay as well as entering the lower reaches of the tidal tributaries of the Bay. The are over 1,400 phytoplankton species that have been identified within the Bay and its tidal tributaries, including 37 of these identified as potentially harmful (Marshall 1994, Marshall et al. 2005, Marshall et al. 2008a, 2009). The resulting flora represents a diverse assemblage of species, that is generally dominated in abundance and biomass seasonally by diatoms and dinoflagellates. These represent numerous bloom producing species occurring annually throughout the year, and may include oceanic species introduced to the Bay at its entrance (e.g. the dinoflagellates *Ceratium furca*, *Prorocentrum micans*, *Polykrikos kofoidii*, *Dinophysis* spp., and a variety of marine diatoms). Also, the ciliate *Myrionecta rubra*, is a frequent bloomer in the tidal tributaries and the Bay. In recent years blooms of the dinoflagellate *Cochlodinium polykrikoides* in the lower James River complex have entered the lower Chesapeake Bay at bloom status and subsequently continue out of the Bay along the Atlantic shoreline in high cell concentrations. Major environmental factors influencing the presence and development of the Bay algae will include their response to salinity levels, nutrient concentrations, light intensity, prevailing water temperatures, plus any physical and climatic factors (e.g. tidal action, river flow, storm and hurricane events) that seasonally occur.

3. Benthic Communities

Benthic communities met restoration goals for the B-IBI at all fixed point stations in the Virginia portion of the Chesapeake Bay Mainstem except station CB5.4 were status was Severely Degraded. There were no trends in the B-IBI at any Mainstem stations (Figure 37) and relatively few trends in any of the individual benthic bioindicators (Appendix F - Section E). Probability-based benthic monitoring results for 2008 indicated that only 32% of the total area of the Virginia Chesapeake Bay Mainstem was impaired (Table 6) and there was no trend in percentage of area failing to meet restoration goals (Figure 18).

4. Management Issues

Water quality conditions based on the WQI were Very Poor in the Mainstem but improvements with respect to nutrients were observed that could eventually result in improvements in the WQI. However, water clarity, as measured using Secchi depth, is a widespread problem in the Mainstem as evidenced both by the low WQI values and the degrading trends observed in all segments. This particular water quality issue has been consistently observed during the last five years. Reductions in water clarity do not appear to be related to changes in total suspended solids concentrations and have occurred despite the reductions in nutrients. The lack of long term changes in freshwater input suggest that there is a limited connection between trends in water clarity and changes in the flow regime. However a more rigorous statistical investigation of the relationships between water clarity (Secchi depth) and other water quality parameters as well as other potential causative factors such as freshwater flow, individual phytoplankton groups or species, colored dissolved organic material is required before the underlying causes of poor water clarity in the Mainstem can be adequately explained.

With respect to living resources, the Virginia Chesapeake Bay Mainstem was probably the least impacted of all of the basins examined in this report. Phytoplankton community status, as measured using the P-IBI was Fair at all stations. However, there are some indications that phytoplankton communities are degrading as indicated by the increasing trends in cyanobacteria biomass found at all stations and the decreasing trends in Margalef species diversity found at most stations in the Mainstem.

These degrading conditions may also be favorable to a variety of new invasive species entering Bay waters. An example of this is the toxic dinoflagellate *Alexandrium monilatum* and its presences in the York River and lower Bay reported that occurred in 2007 and following years, possibly establishing its future presence in these waters (Marshall and Egerton, 2009a). Reduction of nutrients in the Bay should continue to be a focus of management actions to insure reductions in algal blooms in the Bay and provide a less hospitable environment for invasive species. A major indicator regarding the health status of the Bay and an indicator of any significant trends, are the phytoplankton species living in the Bay. The monitoring program provides management with a first-hand and immediate appraisal of this status. It will also provide an important alert system to the presence and significance of potentially harmful algal species present, and indications of the environmental factors associated with their development. These factors work in tandem with the individual rivers in this monitoring program**.** Appropriate management practices for the Bay begins with and centers on each tributary that enters the Bay.

Benthic communities in the Mainstem generally met living resource goals at fixed point stations, although no trends were observed for the B-IBI, and areal estimates using probability-based sampling indicate that only 32% of the total area of Virginia Chesapeake Bay Mainstem failed to meet benthic restoration goals.

V. Conclusions

A. Regional Patterns

Broad scale generalizations with respect to water quality and living resource conditions are difficult to make for the entire region since there are high degrees of variability both between and within individual waterbodies. However, some general statements can be made.

- Above fall-line total loads of nitrogen, phosphorus, and total suspended solids have fluctuated substantially but neither increased or declined over time in most tributaries with the exception of the James River where long-term improving trends were observed for all three parameters.

- Point source nutrient loads tended to be higher below than above the fall-line .

- Point source nutrient loads tended to be higher below than above the fall-line .

- Water quality status based on the WQI was generally Poor in the Virginia Mainstem and its tributaries.

- Status of water clarity was poor in nearly all segments of the Virginia Mainstem and tributaries with no apparently consistent explanation..

- Status of water quality and living resources was generally better in the Mainstem and James River than in the other tributaries.

- Water quality trend results indicated:

    - generally improving nutrient concentrations in the Mainstem and some segments in the tributaries
    - degrading trends in water clarity, and
    - few changes in either chlorophyll *a*, total suspended solids or dissolved oxygen.

- Living resource trend results indicated:

    - no changes in the P-IBI coupled with basin specific degrading trends in some bioindicators.
    - few improvements in the B-IBI.

- Lack of improvement in the P-IBI and the degrading trends observed may be related to nutrient concentrations that are generally higher than “saturation” levels along with other factors (e.g. reduced oyster and menhaden populations).

- Algal blooms continue to be common occurrences in the lower segments of the Chesapeake Bay, its tributaries, and their associated inlets and sub-estuaries (e.g. the James, York, and Elizabeth rivers, etc.). There are indications of increased duration and expansion of bloom events at some locations. These waters also contain several potentially harmful species capable of extensive bloom production (HABs).

- Lack of a widespread response in the benthos may be due to a variety of factors including limited improvement in dissolved oxygen, chemical contamination, and other factors.

B. Basin Specific Patterns

- The James River was characterized by:

    - improving trends in nutrients above the fall-line and in tidal freshwater segments;
    - generally poor water quality status;
    - limited improvements and some degrading trends in water quality downstream;
    - stable but mostly degraded living resource communities throughout its tidal areas;
    - well developed algal blooms in the lower segments and inlets produced by dinoflagellates, with potential for increased levels of cyanobacteria blooms in upper segments.

- The Elizabeth River, although having poor water quality and living resource status, improved with respect to nutrients and benthic communities in some segments.

- The York River exhibited:

  - poor water quality and living resource status in all areas,
  - localized improvements and degradations in water quality in some cases potentially tied to improvements in PS loads,
  - poor living resource status that show some limited improvements.
  - significant annual algal bloom development particularly in the lower York.

- The Rappahannock River can be described as having poor water quality coupled with generally degraded living resources communities that show little sign of improvement.

- The Virginia Chesapeake Bay Mainstem was characterized by:

  - poor water quality status due primarily to water clarity,
  - widespread improving trends in nitrogen and phosphorus, and
  - generally fair or good and relatively stable living resource communities

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Tables

Table 1. Comparison of land use patterns. A. Total Chesapeake Bay and Virginia Watersheds and B. Virginia Watersheds Above (AFL) and Below the Fall-line (BFL). Land use values are expressed as the total area in acres within each area and in parentheses as percentages of the total watershed area for the basin represented by that land use. Note that the Developed land use is a combination of Pervious Urban and Impervious Urban land use types. Land use estimates are from the data produced by the USEPA's Chesapeake Bay Program Watershed Model Phase 4.3 available at http://www.chesapeakebay.net/.

A. Total Chesapeake Bay and Virginia Watersheds

Basin	Total	Forested	Developed	Agricultural	Mixed	Open Water	Impervious Urban	Pervious Urban
Total Chesapeake Bay	40,686,381	23,597,640(58)	3,932,588(10)	8,793,109(22)	4,363,043(11)	423,590(1)	1,302,943(3)	2,629,646(6)
James River	6,486,920	3,992,974(62)	790,118(12)	973,055(15)	730,772(11)	70,587(1)	277,521(4)	512,597(8)
York River	1,876,518	1,187,662(63)	104,886(6)	288,178(15)	295,792(16)	29,376(2)	27,025(1)	77,861(4)
Rappahannock River	1,698,976	896,967(53)	121,303(7)	451,721(27)	228,985(13)	10,783(1)	23,990(1)	97,313(6)
VA Eastern Shore	185,966	79,978(43)	10,689(6)	77,848(42)	17,452(9)	3,937(2)	2,282(1)	8,406(5)

B. Virginia Watersheds Above (AFL) and Below the Fall-line (BFL)

Basin	Fall Line	Total	Forested	Developed	Agricultural	Mixed	Open Water	Impervious Surfaces	Pervious Urban
James River	AFL	5,156,073	3,427,546(66)	286,268(6)	827,336(16)	614,922(12)	37,586(1)	78,163(2)	208,105(4)
James River	BFL	1,330,847	565,428(42)	503,849(38)	145,719(11)	115,850(9)	33,001(2)	199,358(15)	304,491(23)
York River	AFL	1,058,011	654,862(62)	45,698(4)	169,224(16)	188,226(18)	18,043(2)	9,567(1)	36,131(3)
York River	BFL	818,507	532,800(65)	59,187(7)	118,954(15)	107,566(13)	11,334(1)	17,457(2)	41,730(5)
Rappahannock River	AFL	1,019,480	487,495(48)	68,651(7)	326,956(32)	136,378(13)	3,124(0)	11,086(1)	57,565(6)
Rappahannock River	BFL	679,496	409,472(60)	52,653(8)	124,765(18)	92,607(14)	7,658(1)	12,904(2)	39,748(6)
VA Eastern Shore	BFL	185,966	79,978(43)	10,689(6)	77,848(42)	17,452(9)	3,937(2)	2,282(1)	8,406(5)

Table 2. Long-term trends in USGS estimates of above-fall line total loads of nitrogen, phosphorus, and total suspended solids, in the Virginia tributaries for the period of 1985 through 2011. Units for the slope and baseline medians are in lb/month.

River	Parameter	P value	Slope	Baseline Mean	% Change	Direction	Homogeneity test P value
James River	STN	0.0012	-6098	470202	-35.0	Improving	0.6832
James River	STP	0.0000	-2591	92484	-75.6	Improving	0.1514
James River	STSS	0.0023	-309284	73314725	-9.7	Improving	0.6192
Appomattox River	STN	0.0398	-530	58632	-24.4	No Trend	0.8587
Appomattox River	STP	0.5617	-11	2895	-9.9	No Trend	0.8301
Appomattox River	STSS	0.0179	-9906	1623705	-14.0	No Trend	0.5805
Mattaponi River	STN	0.5455	-92	43693	-5.7	No Trend	0.9889
Mattaponi River	STP	0.3742	-14	3257	-11.6	No Trend	0.9723
Mattaponi River	STSS	0.4084	-2050	849849	-5.5	No Trend	0.7176
Pamunkey River	STN	0.0964	-467	74152	-17.0	No Trend	0.8984
Pamunkey River	STP	0.3841	29	4579	17.1	No Trend	0.9085
Pamunkey River	STSS	0.9739	308	4445732	0.2	No Trend	0.6708
Rappahannock River	STN	0.9278	108	132277	2.2	No Trend	0.9141
Rappahannock River	STP	0.5415	29	9370	8.4	No Trend	0.8208
Rappahannock River	STSS	0.2088	-55116	13289465	-9.5	No Trend	0.4057

Table 3. Long-term trends in freshwater flow at USGS fall-line stations in the Virginia tributaries for the period of 1985 through 2011. Note that the flows reported for the York River are for the combined flow values for the Pamunkey and Mattaponi rivers. Units for the slope and baseline medians are in ft^3/sec. Numbers in parentheses correspond to station identification numbers showing the location of monitoring stations presented in Figure 1.

River	P value	Slope	Baseline Mean	% Change	Direction	Homogeneity test P value
Appomattox River (1)	0.0788	-3.4	466.0	-19.78	No Trend	0.9387
Chickahominy River (2)	0.7406	0.2	133.0	4.06	No Trend	0.7398
James River (3)	0.0317	-25.0	3575.0	-18.88	Decreasing	0.9277
Mattaponi River (4)	0.3447	-1.1	264.5	-10.75	No Trend	0.9891
Pamunkey River (5)	0.0104	-3.5	341.3	-27.39	Decreasing	0.9725
York River (4+5)	0.0491	-4.6	598.5	-20.67	Decreasing	0.9800
Rappahannock River (6)	0.9090	0.4	680.0	1.43	No Trend	0.9660

Table 4. Long-term trends in NPDES estimates of point source loads in total nitrogen and total phosphorus above the fall line and below the fall for each of the major Virginia tributaries and Mobjack Bay for the period of 1985 through 2011. Units for the slope and baseline medians are in lb/month.

River	Fall Line	Parameter	P value	Slope	Baseline	% Change	Direction	Homogeneity Test P value
James River	AFL	TN Load	>0.001	-3229	286571	-30.42	Improving	0.9677
James River	AFL	TP Load	>0.001	-657	64554	-27.50	Improving	1.0000
James River	BFL	TN Load	>0.001	-38704	1717532	-60.84	Improving	1.0000
James River	BFL	TP Load	>0.001	-5596	241013	-62.69	Improving	1.0000
York River	AFL	TN Load	0.030	-58	9557	-16.50	Improving	0.6247
York River	AFL	TP Load	0.002	40	3209	34.05	Degrading	0.9986
York River	BFL	TN Load	0.312	157	96572	4.39	No Trend	0.4978
York River	BFL	TP Load	>0.001	-391	27842	-37.92	Improving	0.9854
Mobjack Bay	BFL	TN Load	>0.001	-22	689	-84.71	Improving	0.9893
Mobjack Bay	BFL	TP Load	>0.001	-5	236	-56.25	Improving	0.9975
Rappahannock River	AFL	TN Load	>0.001	237	14104	45.45	Degrading	0.8258
Rappahannock River	AFL	TP Load	>0.001	-85	5727	-39.90	Improving	0.9996
Rappahannock River	BFL	TN Load	>0.001	-601	28052	-57.84	Improving	0.6440
Rappahannock River	BFL	TP Load	>0.001	-208	9843	-57.06	Improving	1.0000

Table 5. Long-term trends in flow-adjusted water quality concentrations for the River Input Monitoring and in Virginia portion of the Chesapeake Bay Watershed for 1985 through September, 2011. Station #'s in parentheses refer to the station locations identified in Figures 8-10. Results presented in this table were provided by the U.S. Geological Survey.

Station	Parameter	LCL	Flow Adjusted Trend	UCI	Std. Error	Direction
Appomattox River at Matoaca, VA (1)	TN	-2.5	6.3	16	4.5	NS
Appomattox River at Matoaca, VA (1)	NO_{23}	-31.8	-15.6	4.5	11.5	NS
Appomattox River at Matoaca, VA (1)	TP	10.1	27.0	46.4	7.5	Increasing
Appomattox River at Matoaca, VA (1)	DIP	-37.9	-25.9	-11.7	9.4	Decreasing
Appomattox River at Matoaca, VA (1)	TSS	9.7	28.6	50.9	8.5	Increasing
James River at Cartersville, VA (3)	TN	-24.8	-16.2	-6.7	5.7	Decreasing
James River at Cartersville, VA (3)	NO_{23}	-43.4	-32.1	-18.7	9.7	Decreasing
James River at Cartersville, VA (3)	TP	-68.0	-61.6	-53.9	9.7	Decreasing
James River at Cartersville, VA (3)	DIP	-91.4	-89.6	-87.3	10.5	Decreasing
James River at Cartersville, VA (3)	TSS	-17.2	3.2	28.7	11.9	NS
Pamunkey River near Hanover, VA (4)	TN	11.5	21.1	31.6	4.3	Increasing
Pamunkey River near Hanover, VA (4)	NO_{23}	16.6	31.2	47.6	6.2	Increasing
Pamunkey River near Hanover, VA (4)	TP	74.6	102.8	135.7	8.0	Increasing
Pamunkey River near Hanover, VA (4)	DIP	17.8	37.6	60.8	8.3	Increasing
Pamunkey River near Hanover, VA (4)	TSS	88.4	143.7	215.2	14.0	Increasing
Mattaponi River near Beulahville, VA (5)	TN	-4.9	1.9	9.1	3.6	NS
Mattaponi River near Beulahville, VA (5)	NO_{23}	-12.3	3.6	22.4	8.9	NS
Mattaponi River near Beulahville, VA (5)	TP	-15.9	-6.1	4.8	5.8	NS
Mattaponi River near Beulahville, VA (5)	DIP	-50.9	-42.8	-33.4	8.1	Decreasing
Mattaponi River near Beulahville, VA (5)	TSS	-14.8	4.5	28.2	11.0	NS
Rappahannock River near Fredericksburg, VA (6)	TN	-19.8	-8.9	3.5	6.7	NS
Rappahannock River near Fredericksburg, VA (6)	NO_{23}	-40.5	-22.8	0.0	14.1	NS
Rappahannock River near Fredericksburg, VA (6)	TP	-22.8	-6.1	14.4	10.6	NS
Rappahannock River near Fredericksburg, VA (6)	DIP	-26.1	-11.1	7.0	9.9	NS
Rappahannock River near Fredericksburg, VA (6)	TSS	-27.6	-2.0	32.8	16.7	NS

Figures

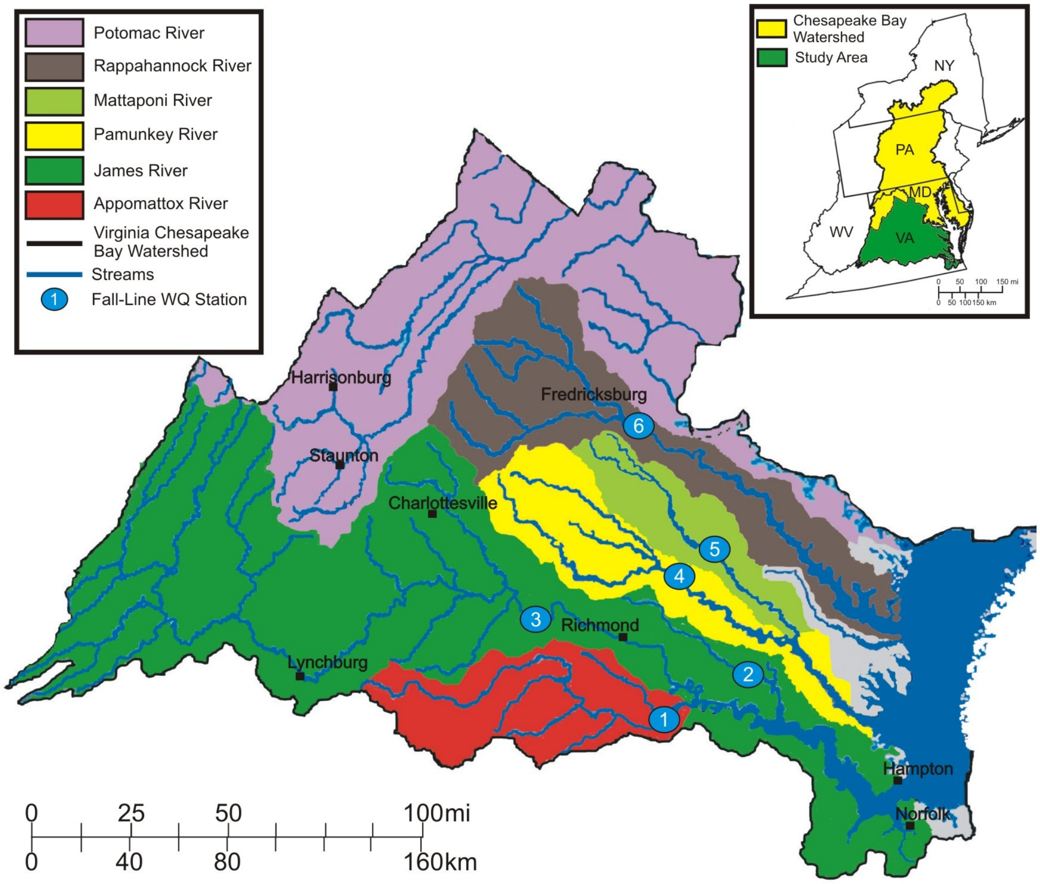


Figure 1. Location of the USGS/RIM stations in each of the Virginia tributaries.

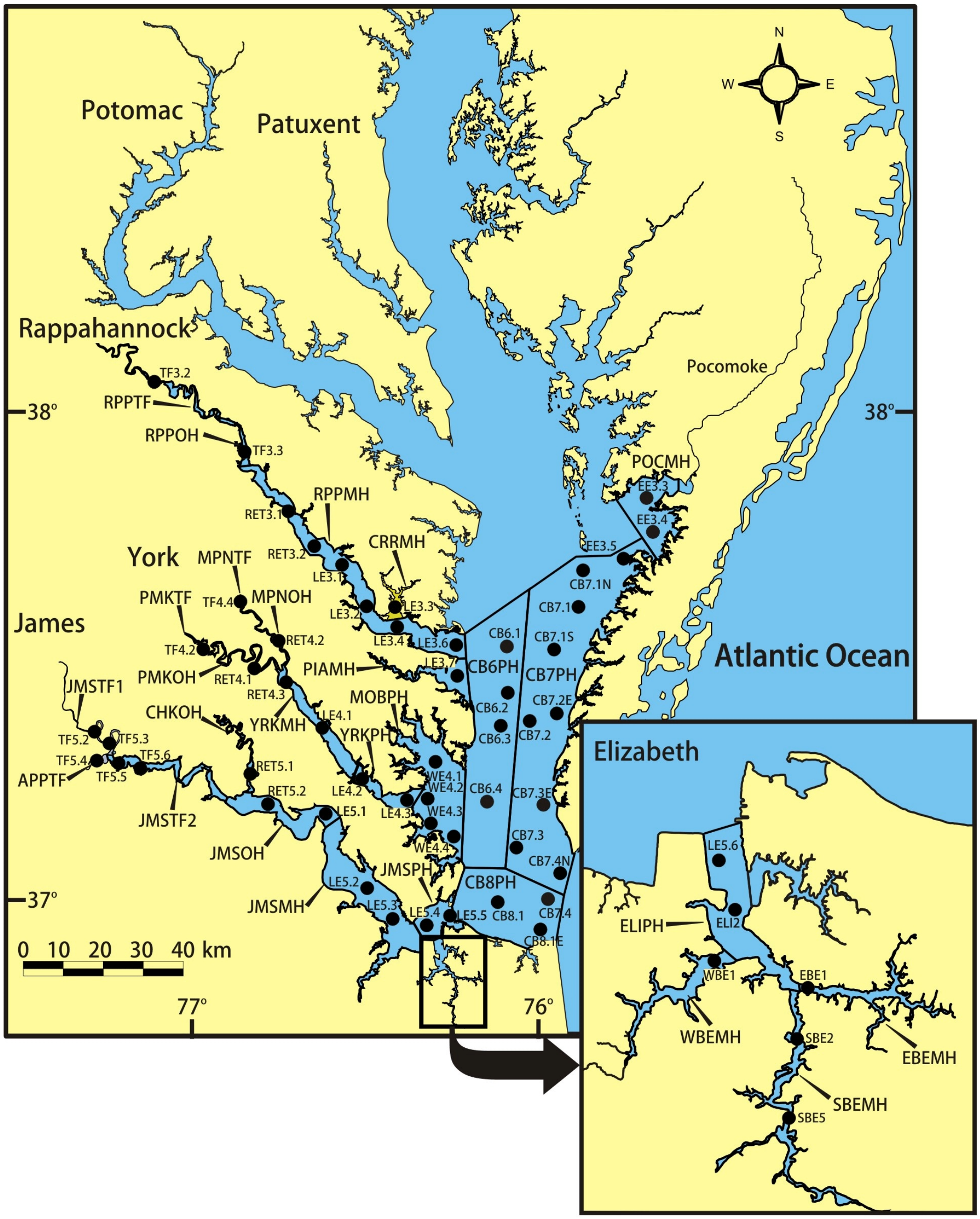


Figure 2. Chesapeake Bay Program segmentation scheme for the Virginia tributaries and Lower Chesapeake Bay Mainstem. Also shown are the locations of stations used in the statistical analyses.

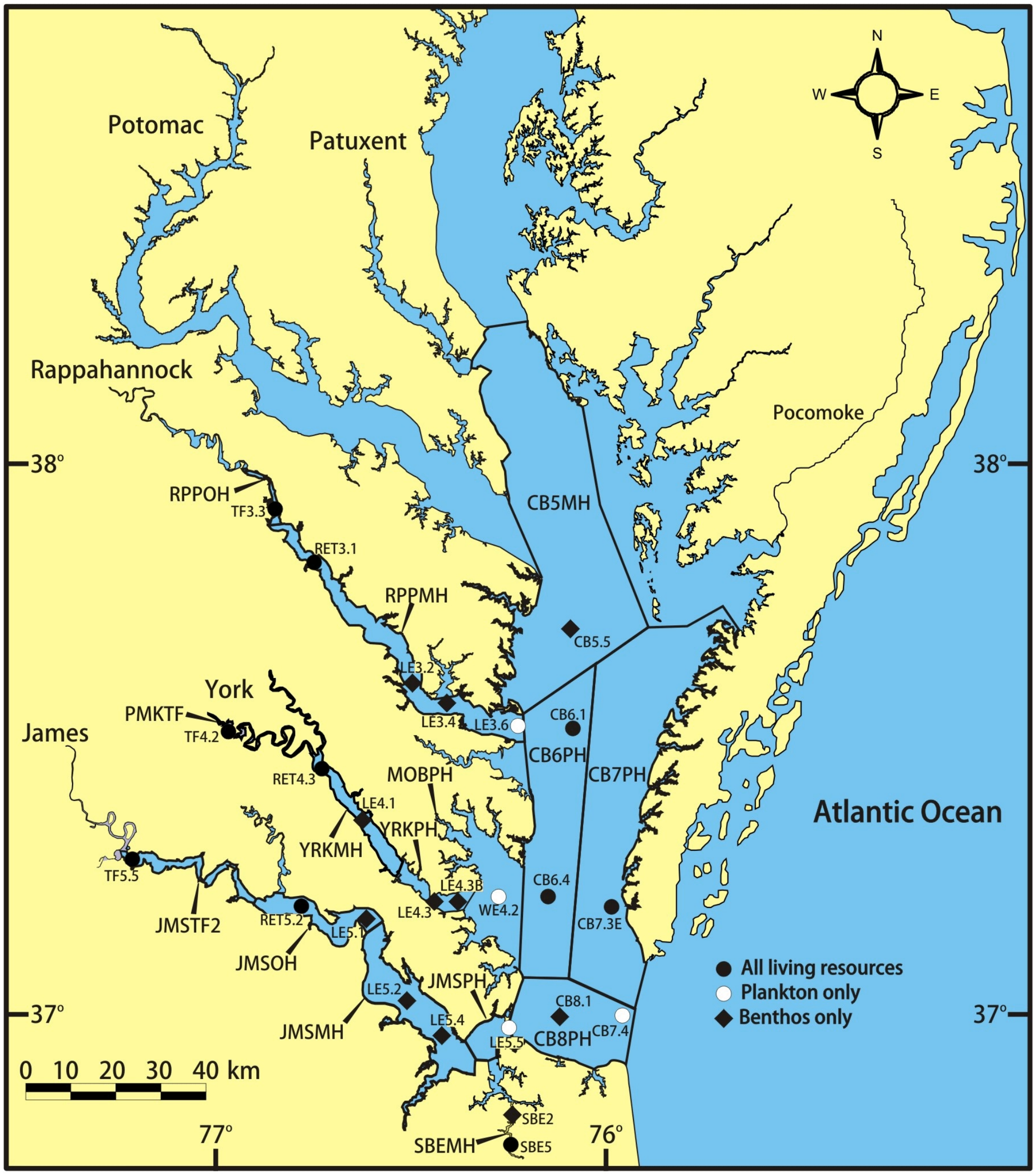
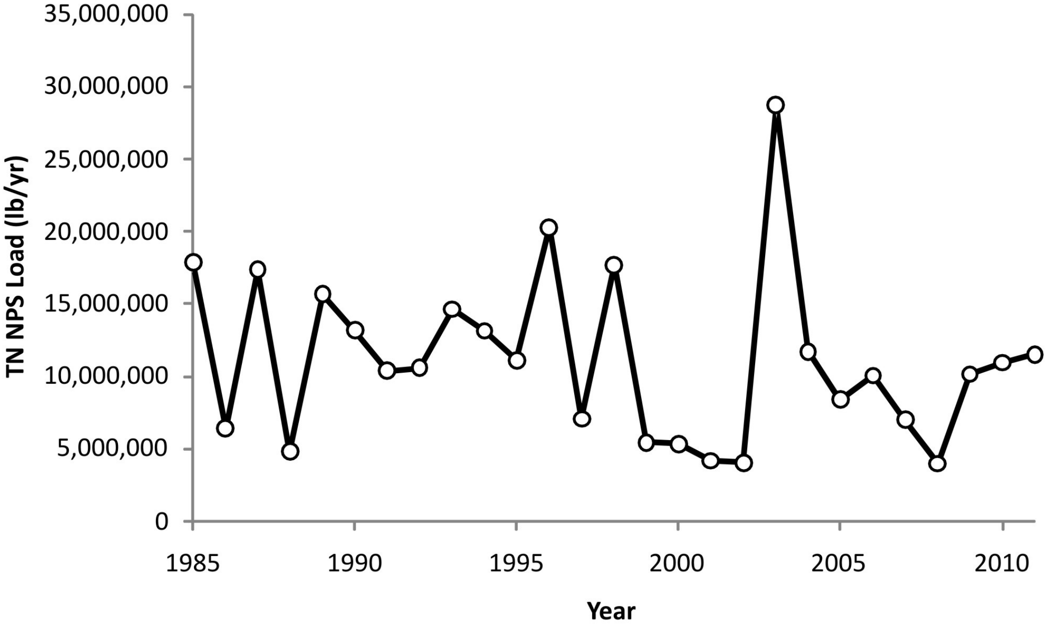


Figure 3. Living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem and their associated CBP segments.

A) James River



B) Appomattox River

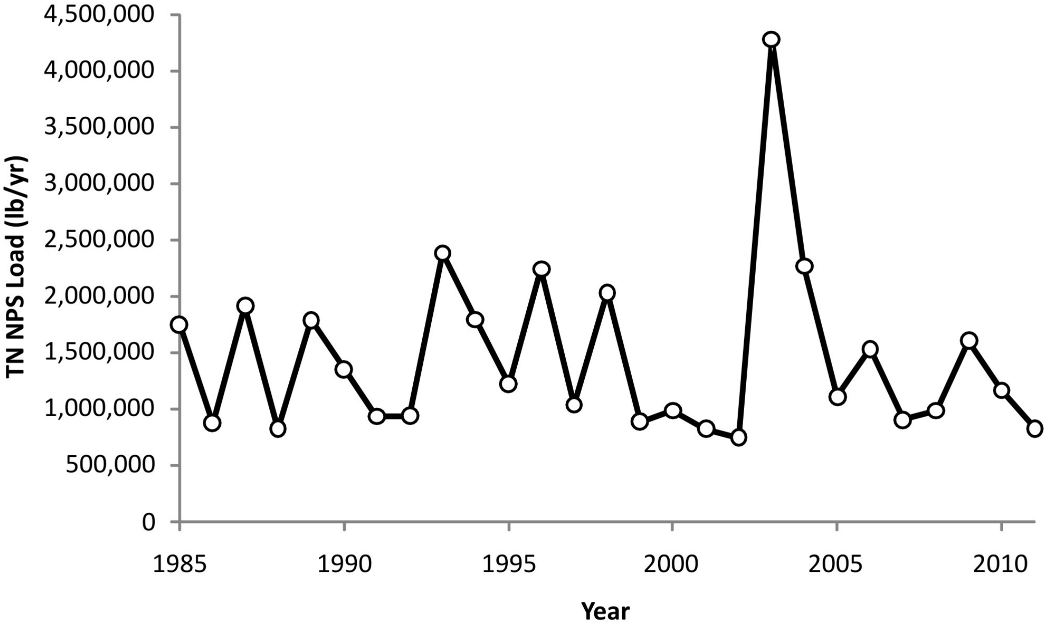
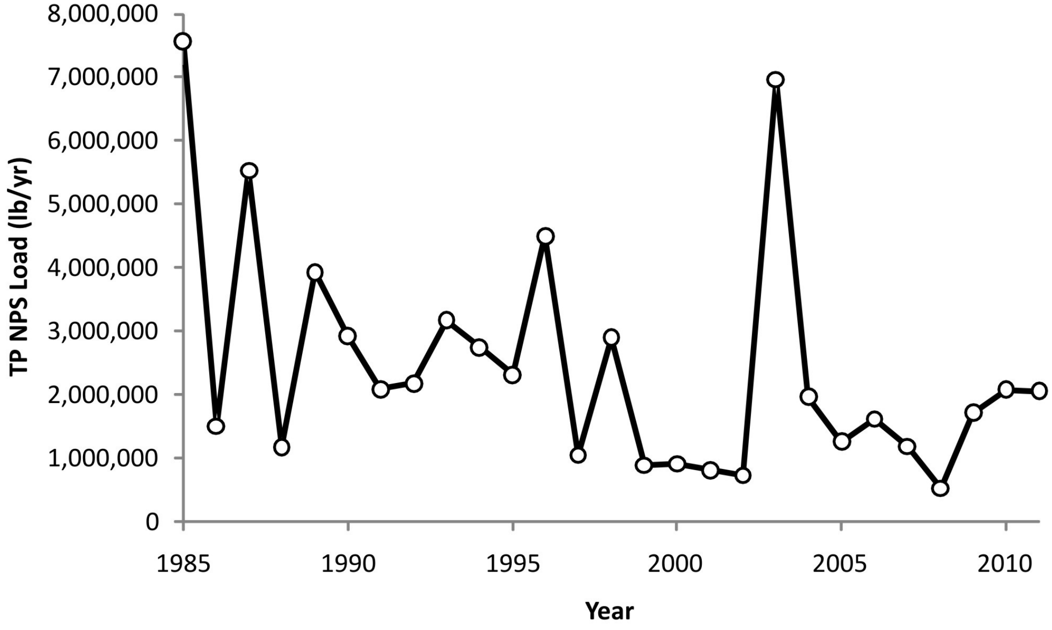


Figure 4. Long-term changes in total nitrogen load above the fall-line in the A) James River, and B) Appomattox River from 1985 through 2011. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

A) James River



B) Appomattox River

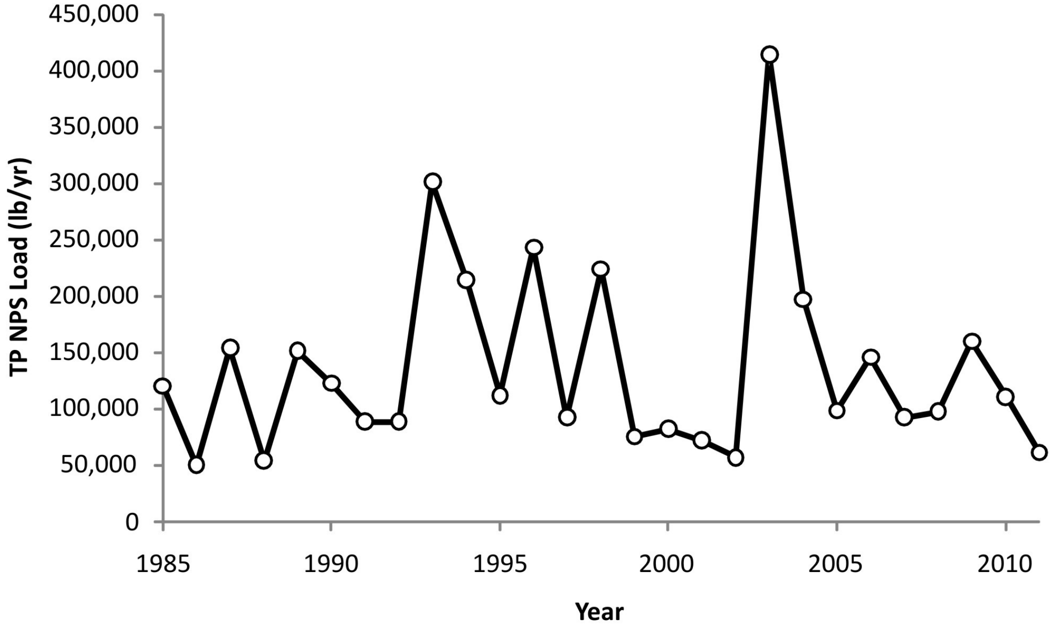
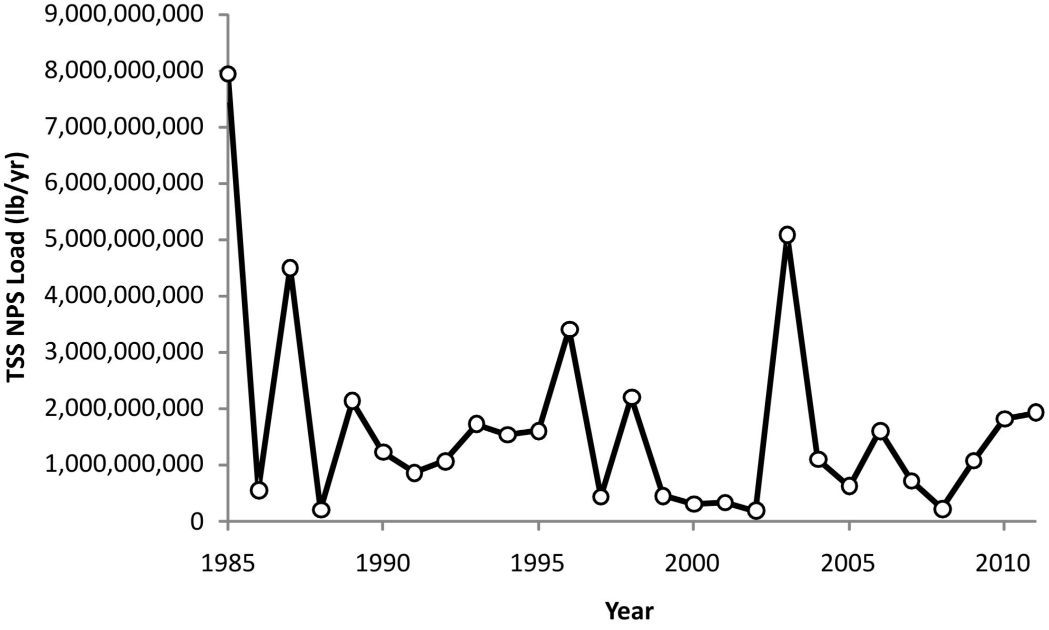


Figure 5. Long-term changes in total phosphorus load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2011. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

A) James River



B) Appomattox River

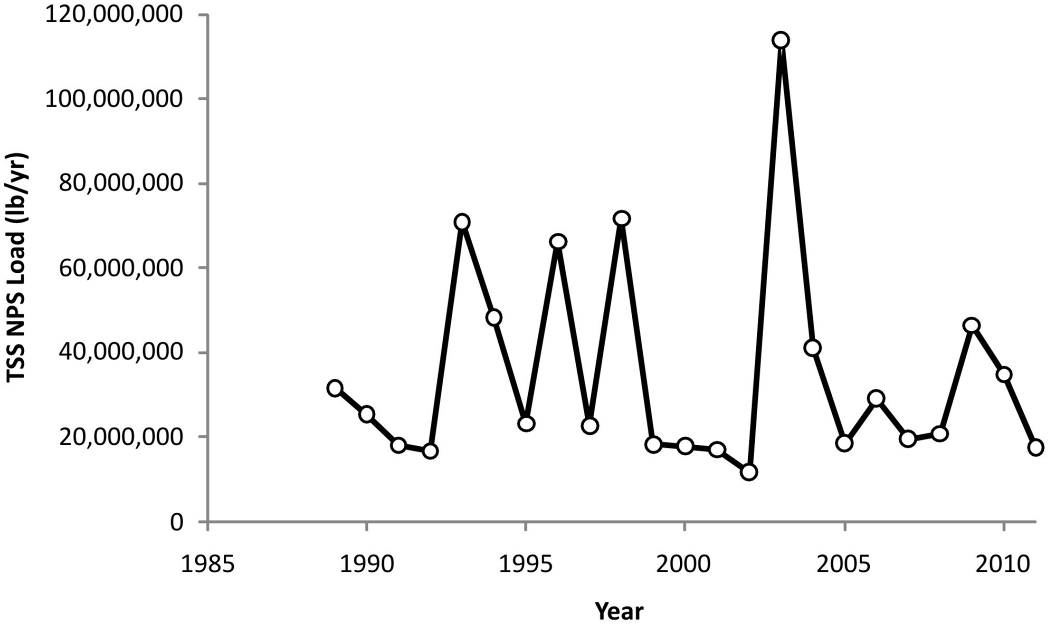
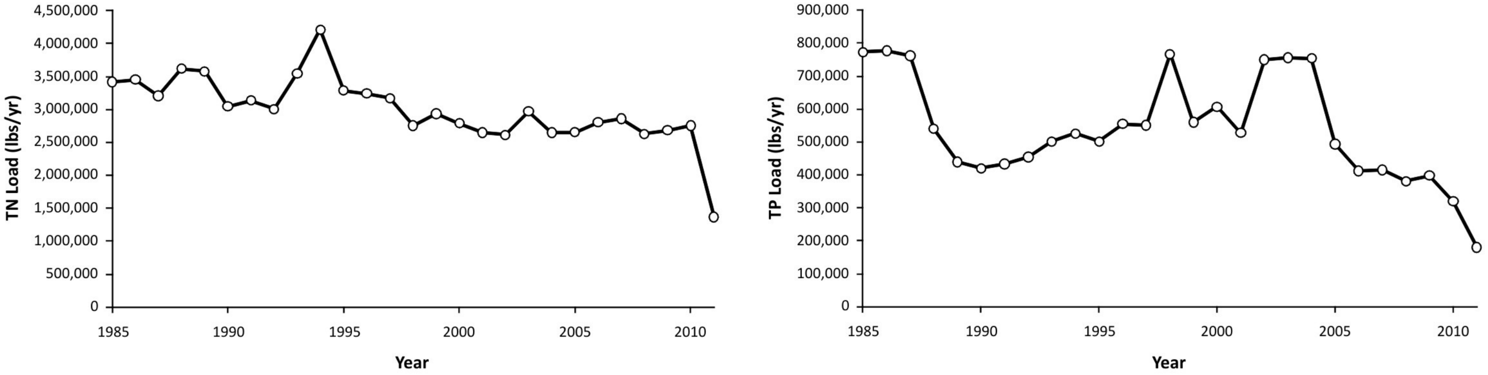


Figure 6. Long-term changes in total suspended solids load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2010. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

A) Above Fall Line Total Nitrogen

B) Above Fall Line Total Phosphorus



C) Below Fall Line Total Nitrogen

D) Below Fall Line Total Phosphorus

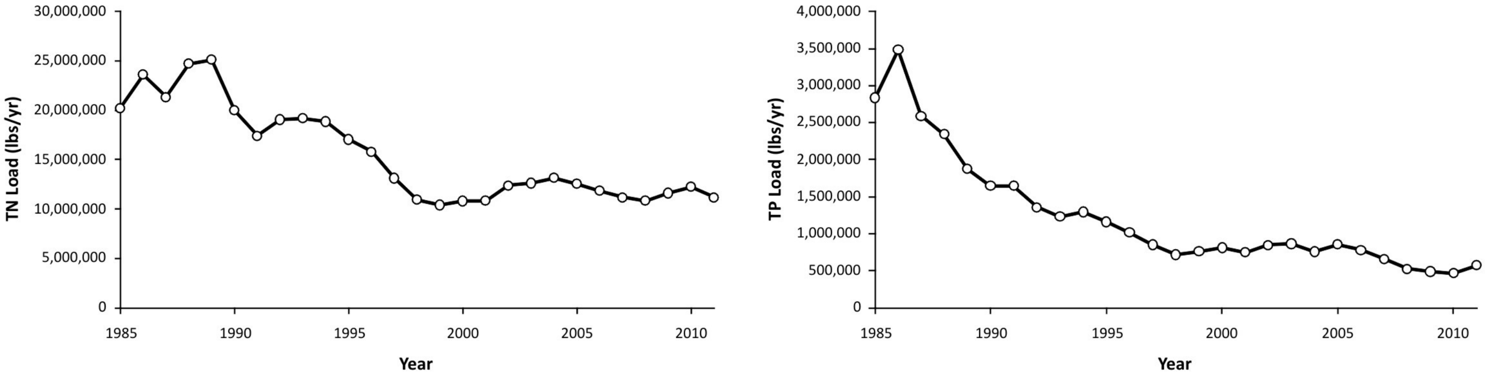


Figure 7. Long-term changes in point source A) Above the Fall-line Total Nitrogen; B) Above Fall-line Total Phosphorus; C) Below Fall Line Total Nitrogen; and D) Below Fall Line Total Phosphorus in the James River for 1985 through 2011. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system.

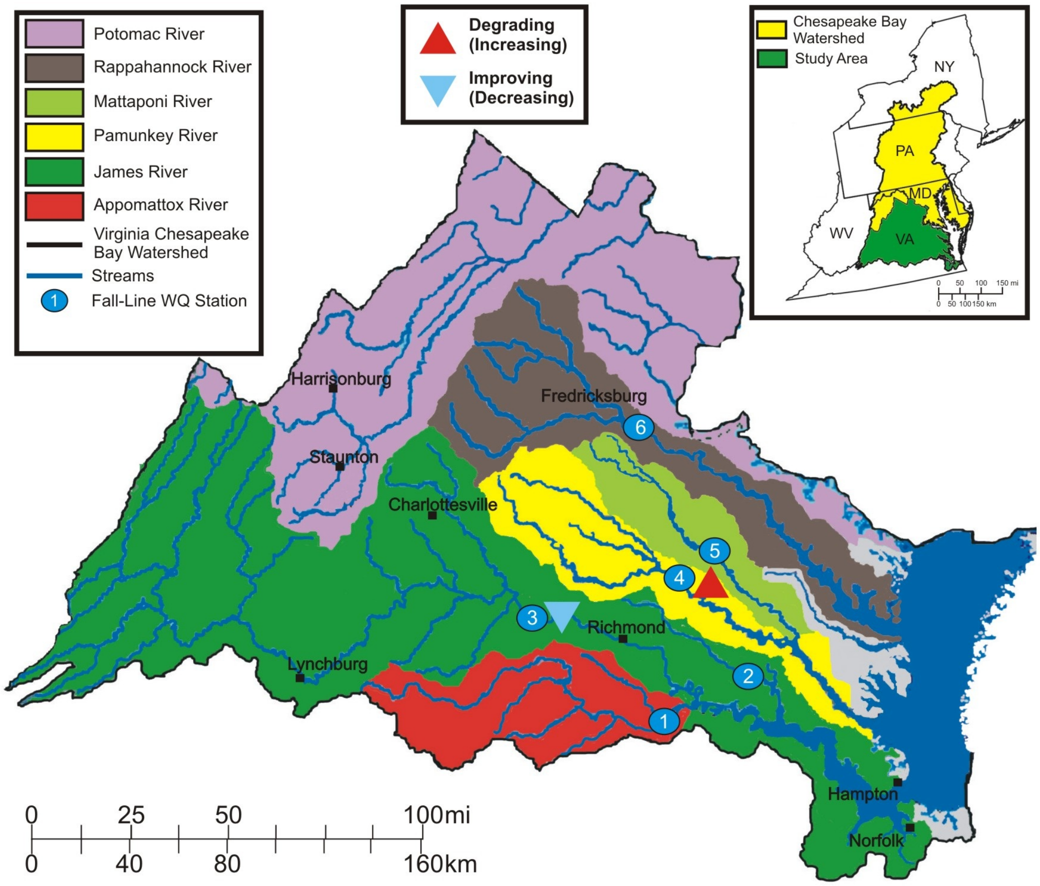


Figure 8. Long-term trends in flow-adjusted total nitrogen at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2011. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

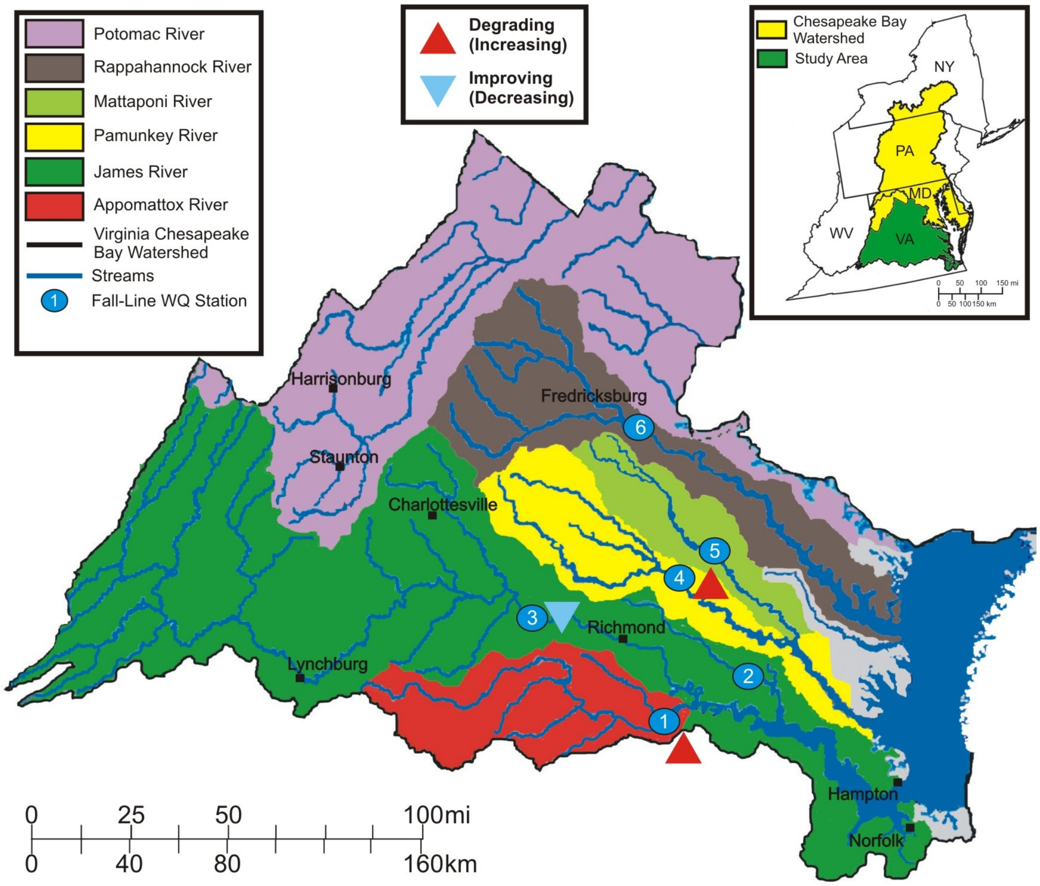


Figure 9. Long-term trends in flow-adjusted total phosphorus at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2011. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

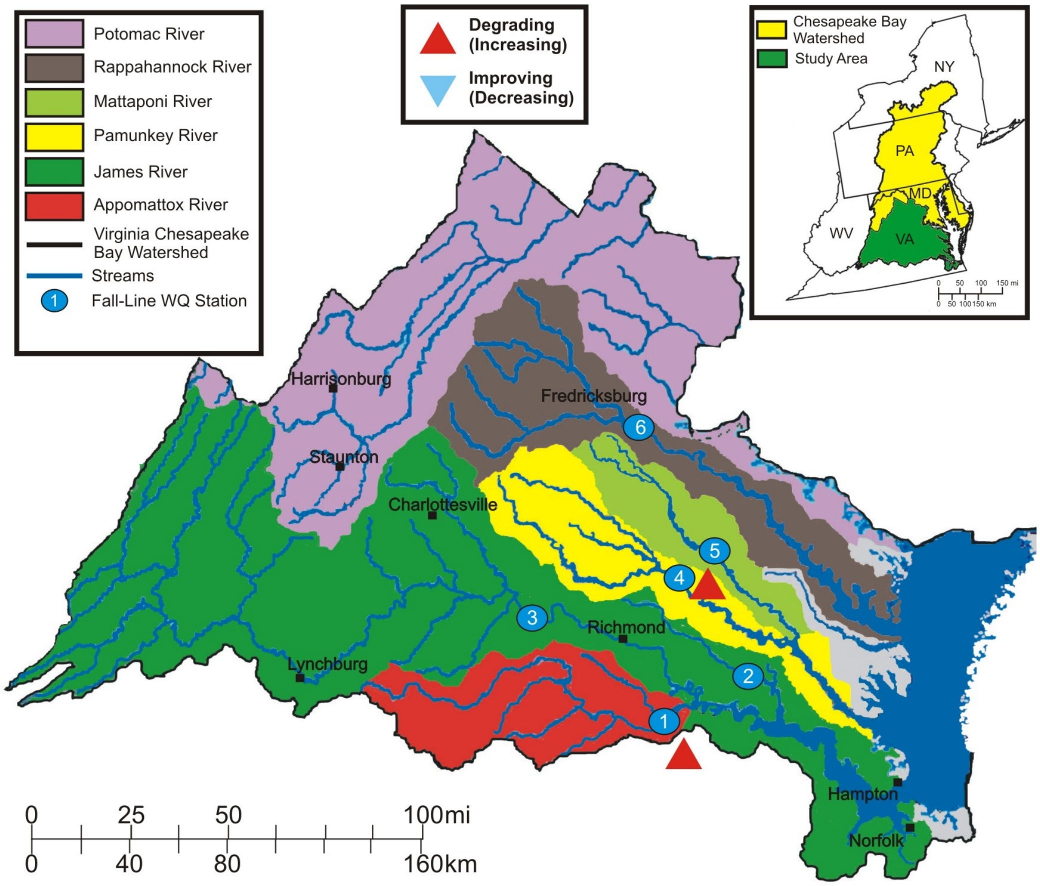
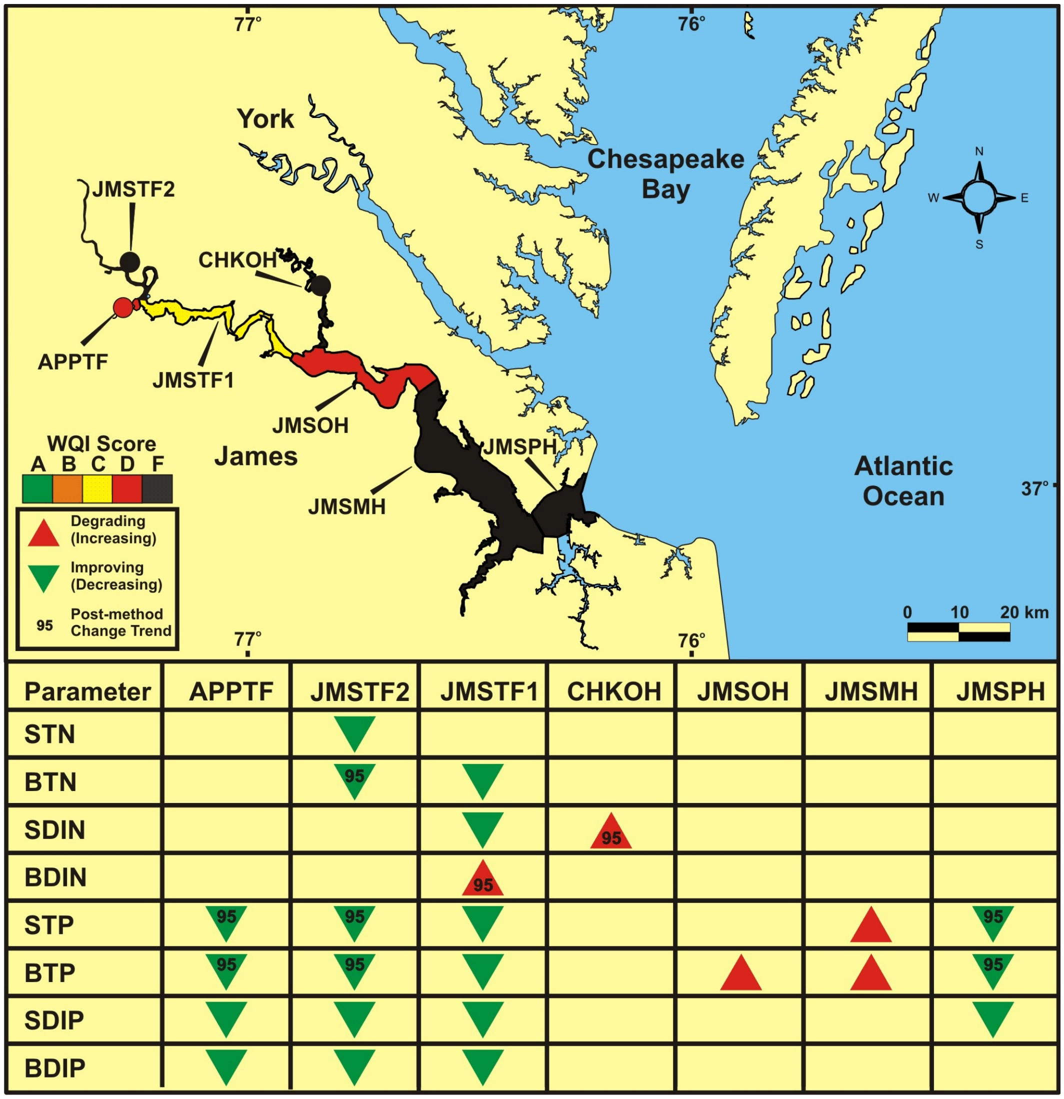
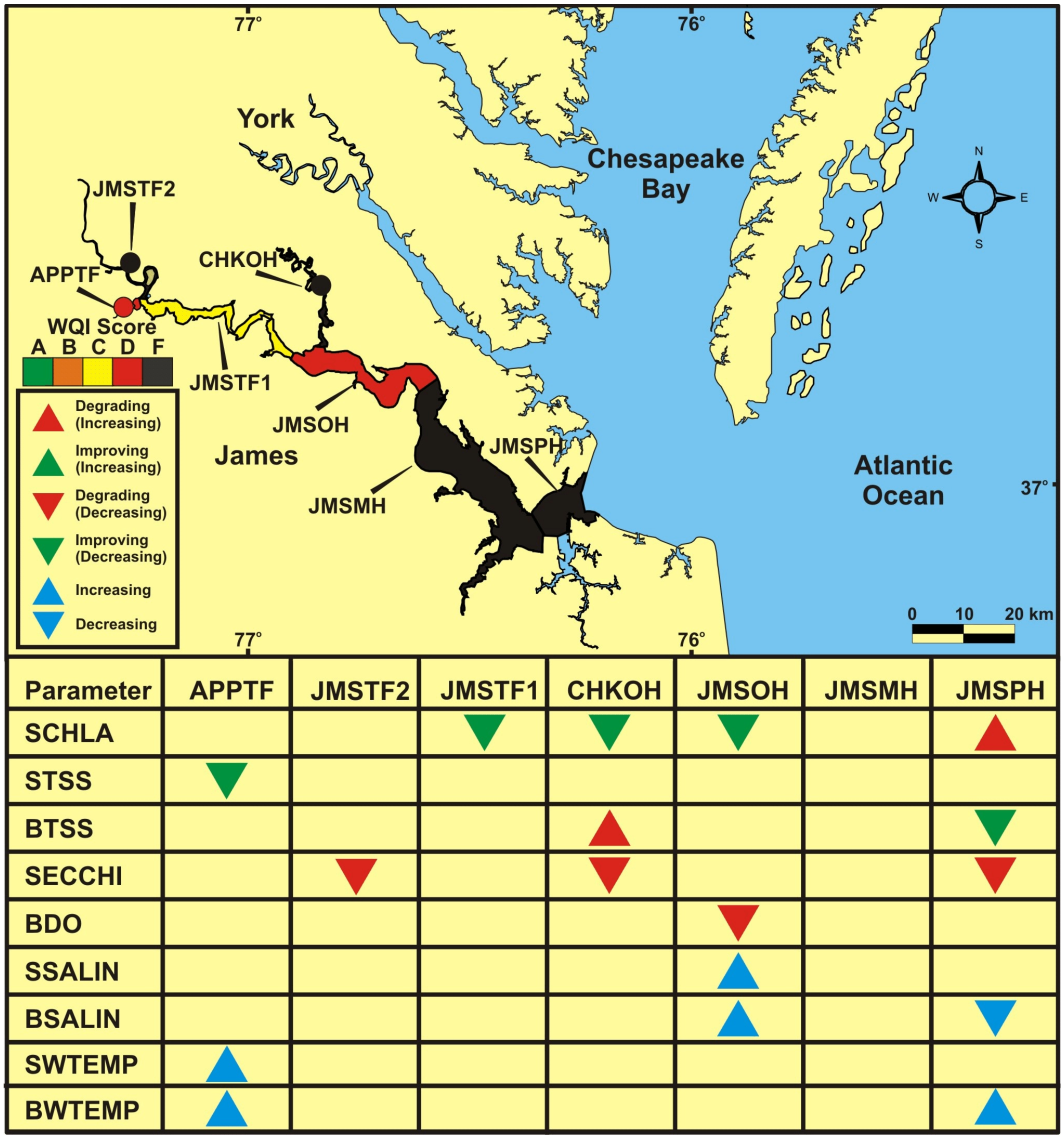


Figure 10. Long-term trends in flow-adjusted total suspended solids at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2011. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.



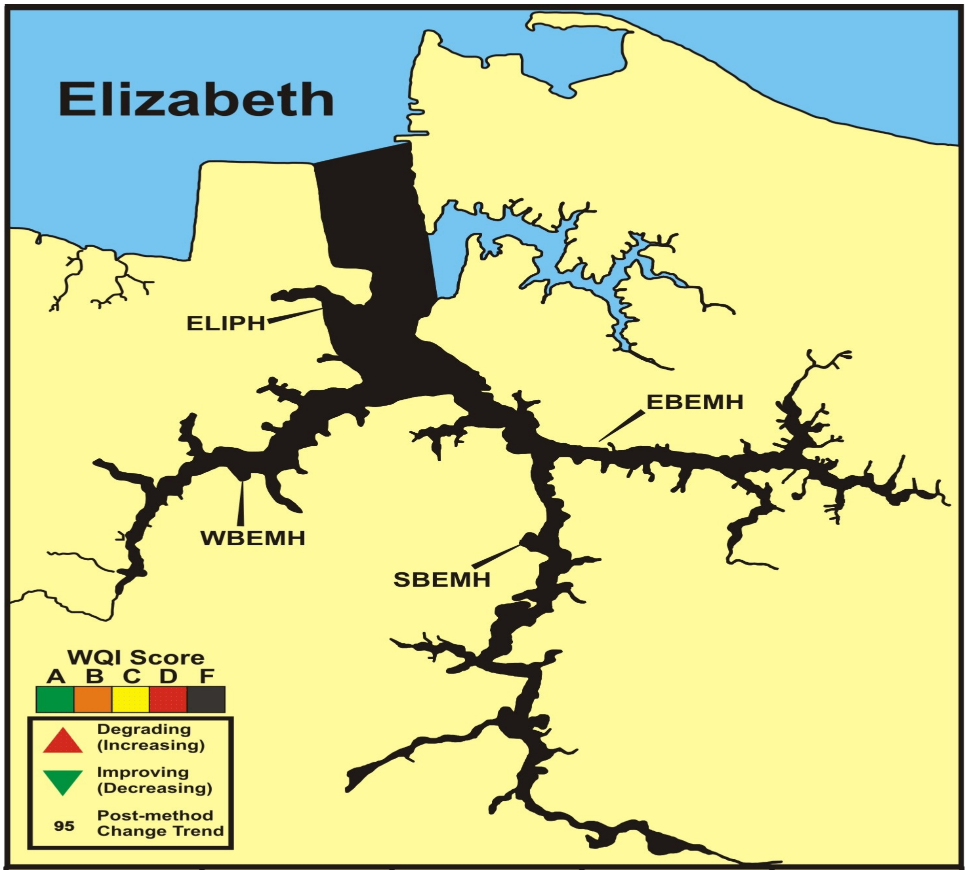
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
STN		▼					
BTN		▼ 95	▼				
SDIN			▼	▲ 95			
BDIN			▲ 95				
STP	▼ 95	▼ 95	▼			▲	▼ 95
BTP	▼ 95	▼ 95	▼		▲	▲	▼ 95
SDIP	▼	▼	▼				▼
BDIP	▼	▼	▼				

Figure 11. Water quality status and long-term trends in nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. 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.



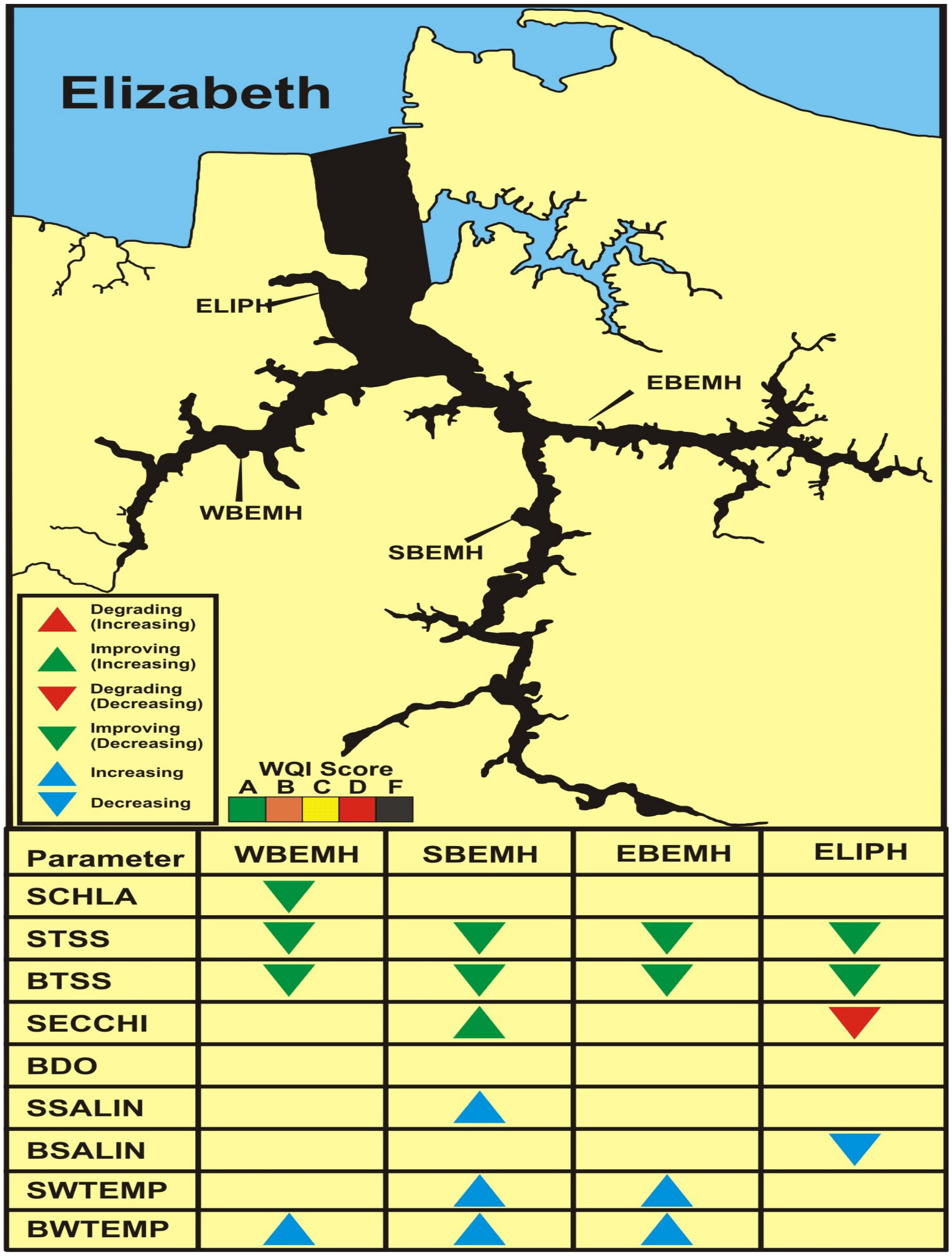
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
SCHLA			▼	▼	▼		▲
STSS	▼						
BTSS				▲			▼
SECCHI		▼		▼			▼
BDO					▼		
SSALIN					▲		
BSALIN					▲		▼
SWTEMP	▲						
BWTEMP	▲						▲

Figure 12. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. 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	WBEMH	SBEMH	EBEMH	ELIPH
STN	▼	▼	▼	
BTN	▼	▼	▼	
SDIN		▼	▼	
BDIN		▼	▼	
STP	▼	▼	▼	▼ 95
BTP	▼	▼	▼	▼ 95
SDIP	▼	▼	▼	
BDIP	▼	▼	▼	

Figure 13. Water quality status and long-term trends in nutrient parameters in the tidal portion of the Elizabeth River basin for the period of 1989 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. 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	WBEMH	SBEMH	EBEMH	ELIPH
SCHLA	▼ Improving (Decreasing)			
STSS	▼ Improving (Decreasing)	▼ Improving (Decreasing)	▼ Improving (Decreasing)	▼ Improving (Decreasing)
BTSS	▼ Improving (Decreasing)	▼ Improving (Decreasing)	▼ Improving (Decreasing)	▼ Improving (Decreasing)
SECCHI		▲ Improving (Increasing)		▼ Degrading (Decreasing)
BDO				
SSALIN		▲ Increasing		
BSALIN				▼ Decreasing
SWTEMP		▲ Increasing	▲ Increasing	
BWTEMP	▲ Increasing	▲ Increasing	▲ Increasing	

Figure 14. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

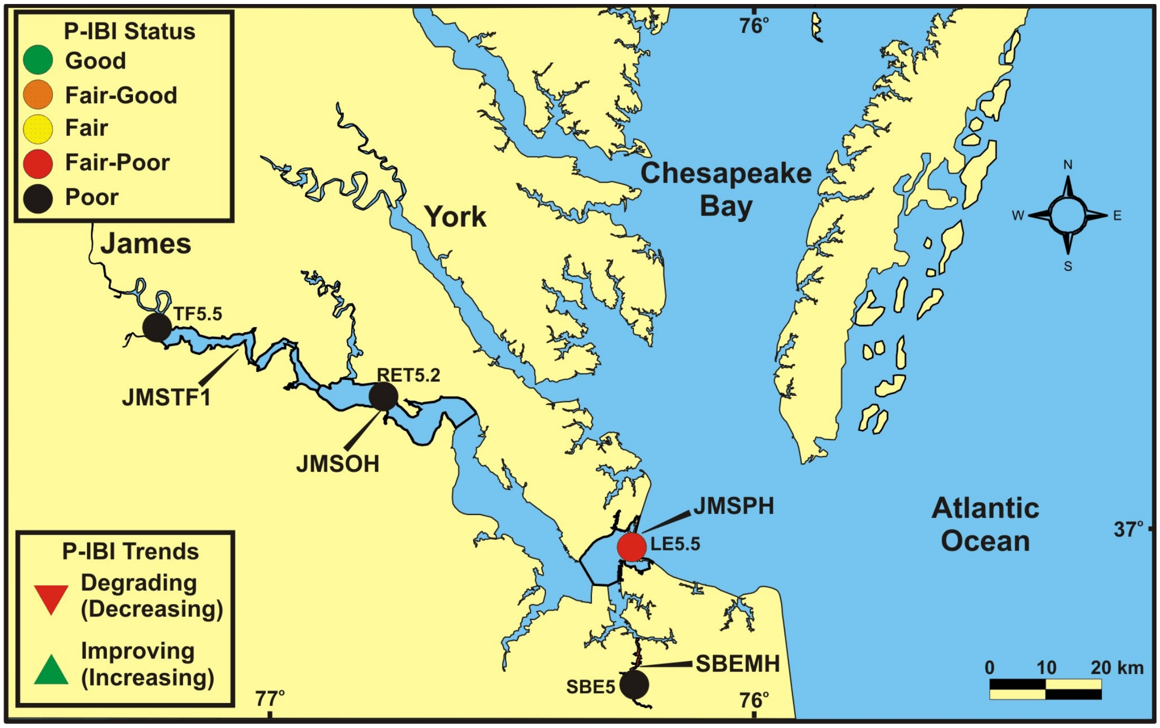


Figure 15. Status and long-term trends in phytoplankton community condition in the tidal portion of the James River basin for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

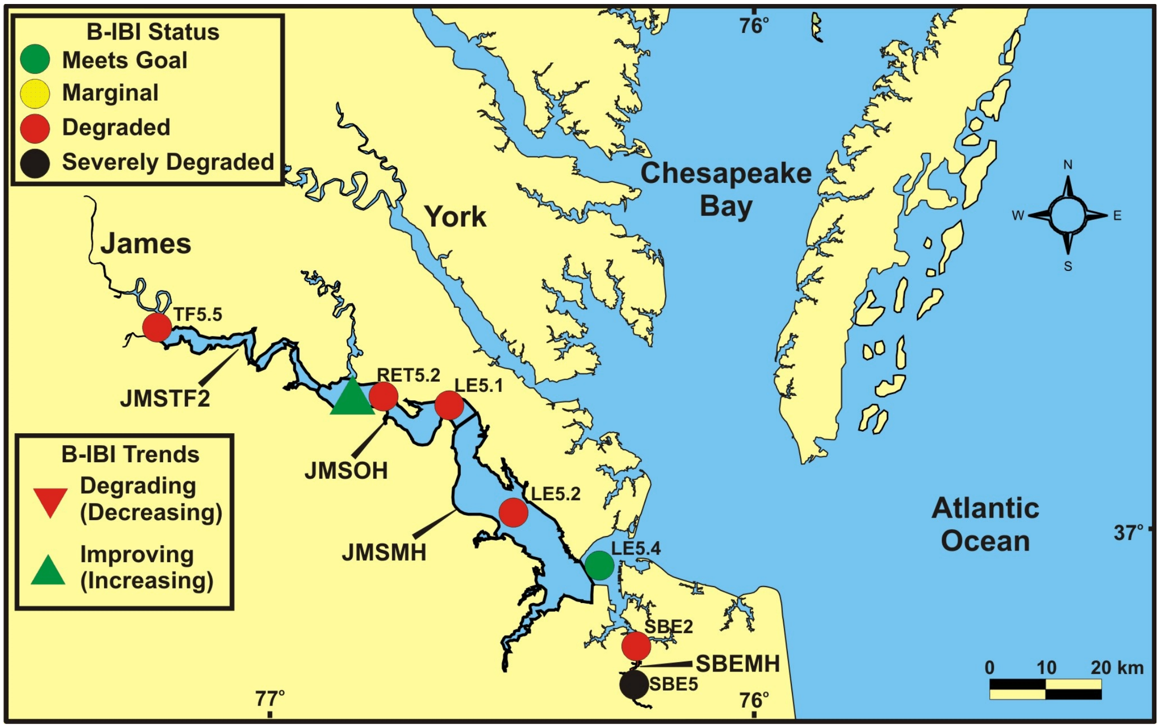


Figure 16. Status and long-term trends in benthic community condition in the tidal portion of the James River basin for the period of 1985 through 2011. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2011.

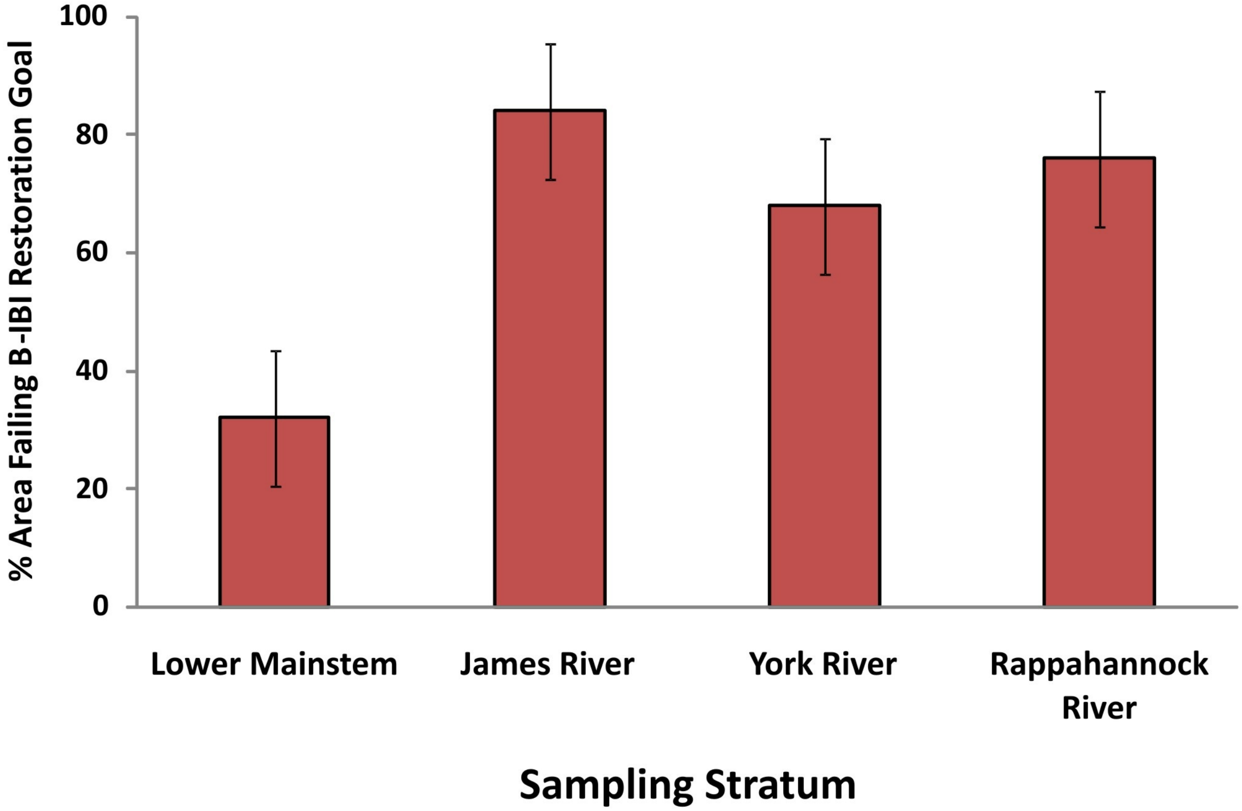


Figure 17. Percent area of benthic communities in the Virginia sampling strata failing the B-IBI Restoration Goals in Virginia for 2011(± 1S.E). Data provided by permission from Versar Inc.

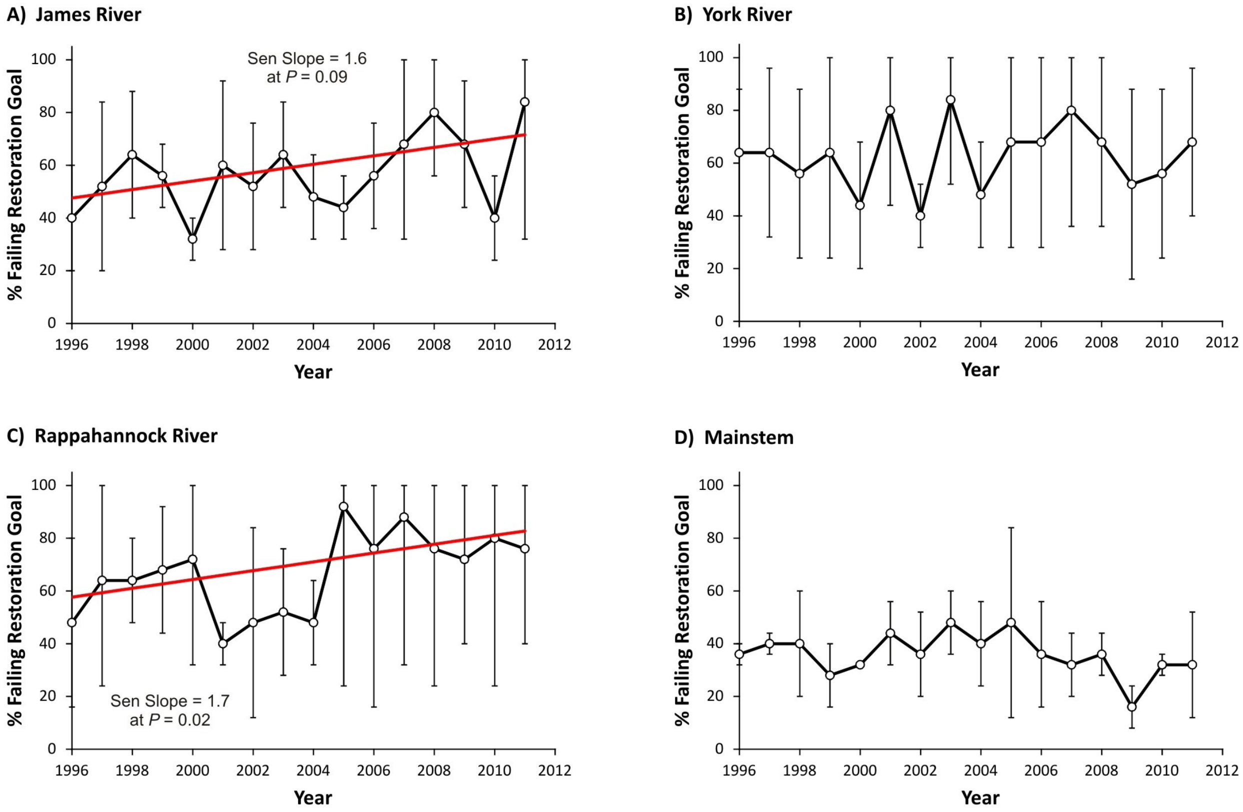
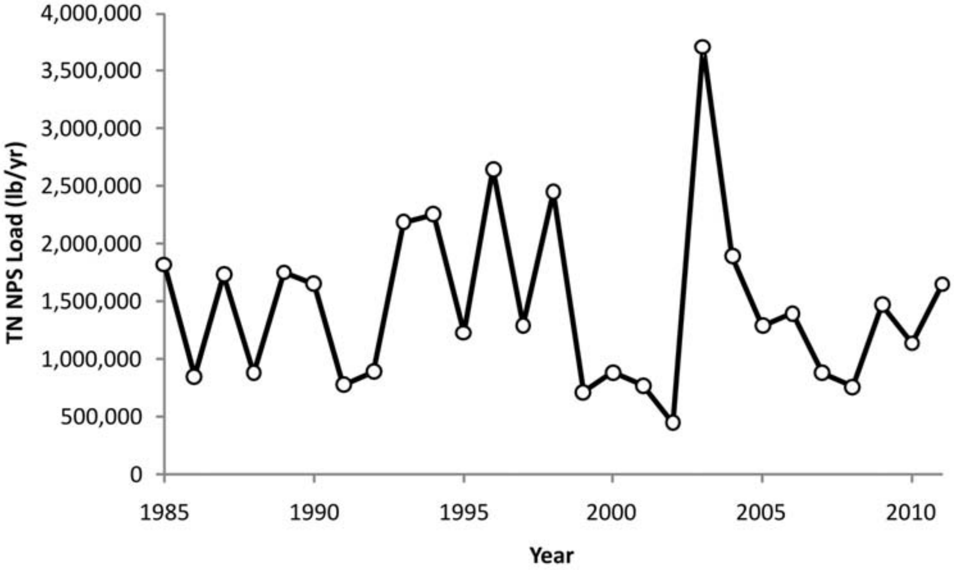
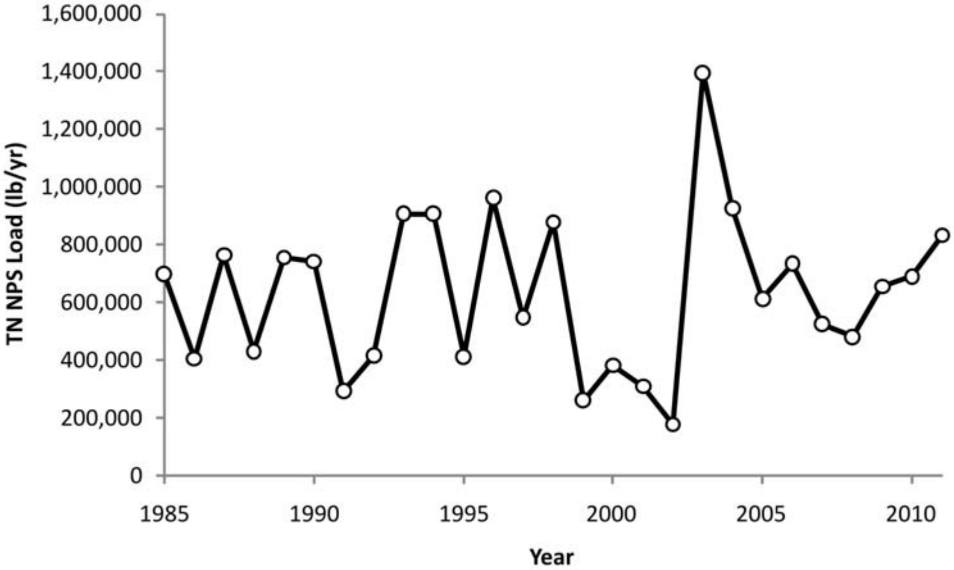


Figure 18. Long term trends in area of benthic communities failing the B-IBI Restoration Goals for each of the major sampling strata in Virginia for the period of 1996 through 2011. Error bars are ± S.E. of the mean.



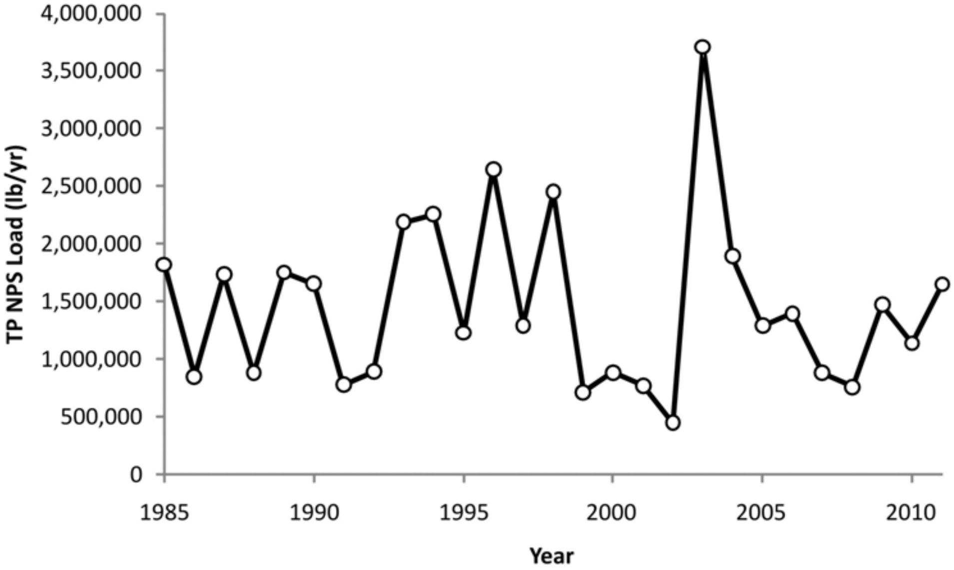
A) Pamunkey River



B) Mattaponi River

Figure 19. Long-term changes in total nitrogen load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2011. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

A) Pamunkey River



B) Mattaponi River

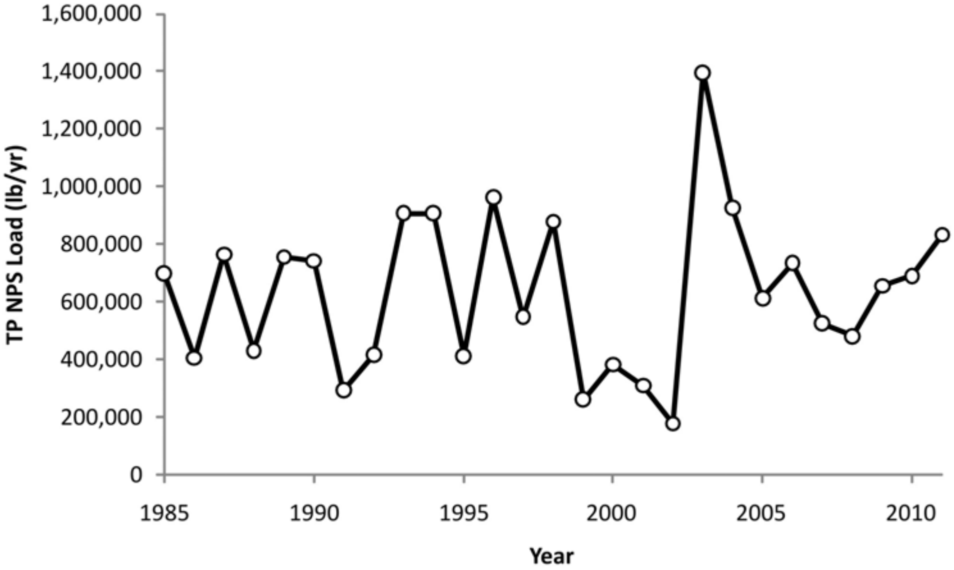
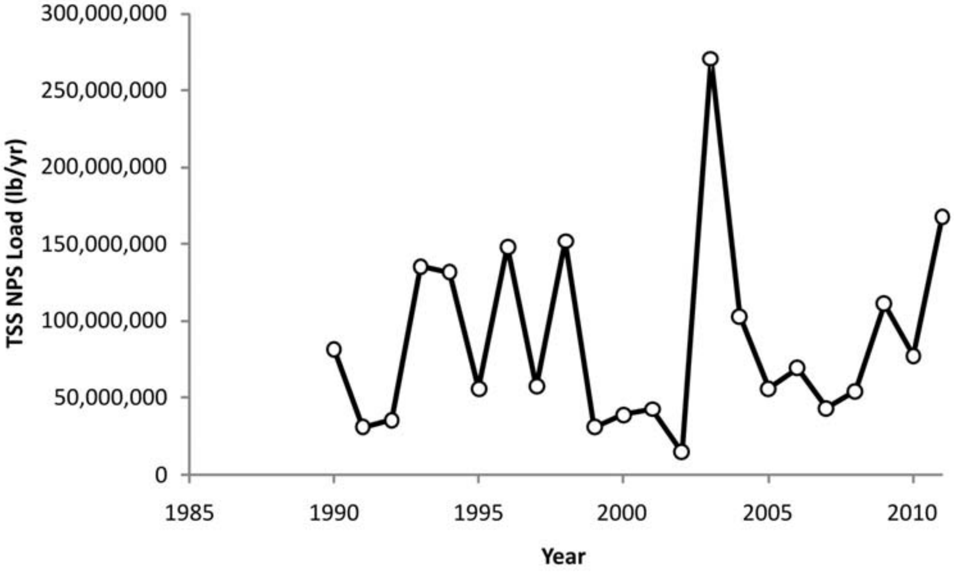


Figure 20. Long-term changes in total phosphorus load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2011. Data shown are estimates provided by the US Geological Survey’s River Input Monitoring program.

A) Pamunkey River



B) Mattaponi River

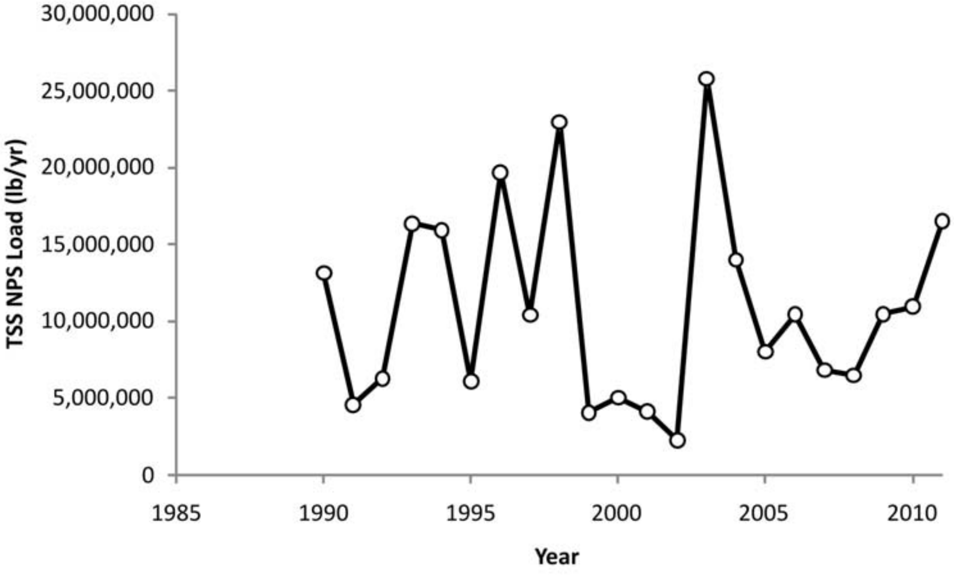


Figure 21. Long-term changes in total suspended solids load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2011. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

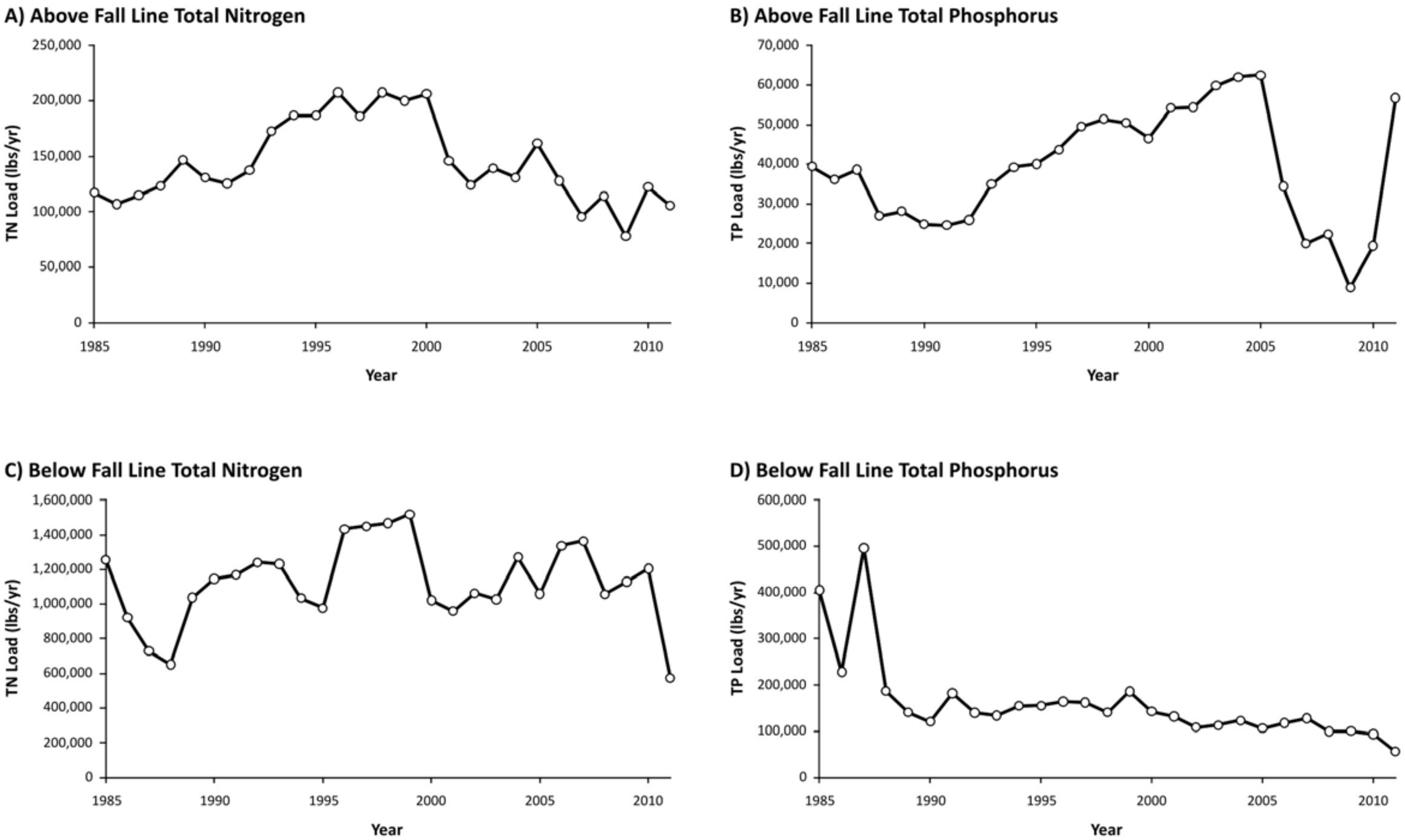
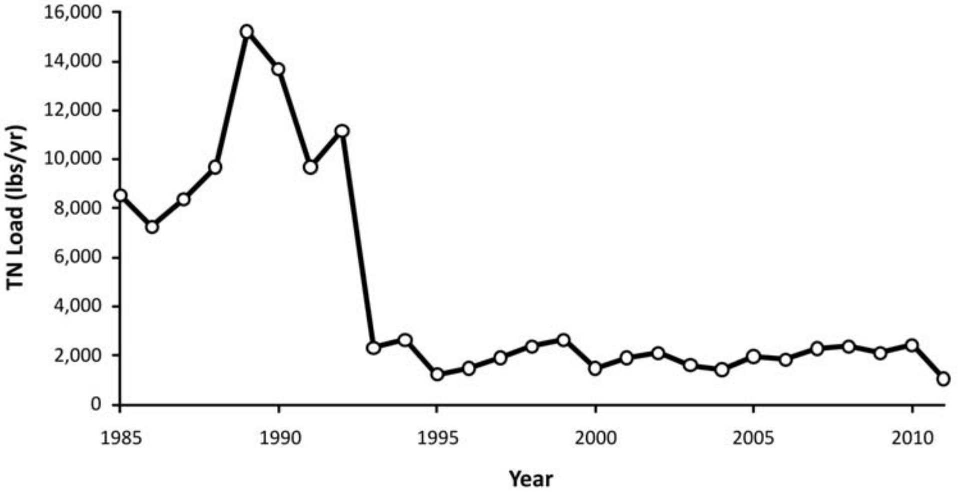


Figure 22. Long-term changes in point source loads in A) Above Fall Line Total Nitrogen; B) Above Fall Line Total Phosphorus; C) Below Fall Line Total Nitrogen; and D) Below Fall Line Total Phosphorus in the York River for 1985 through 2011. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

A) Total Nitrogen



B) Total Phosphorus

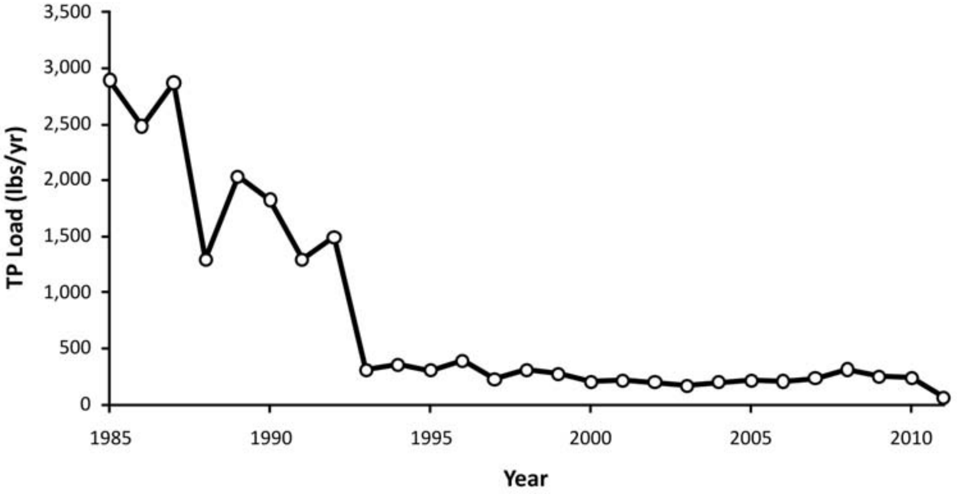
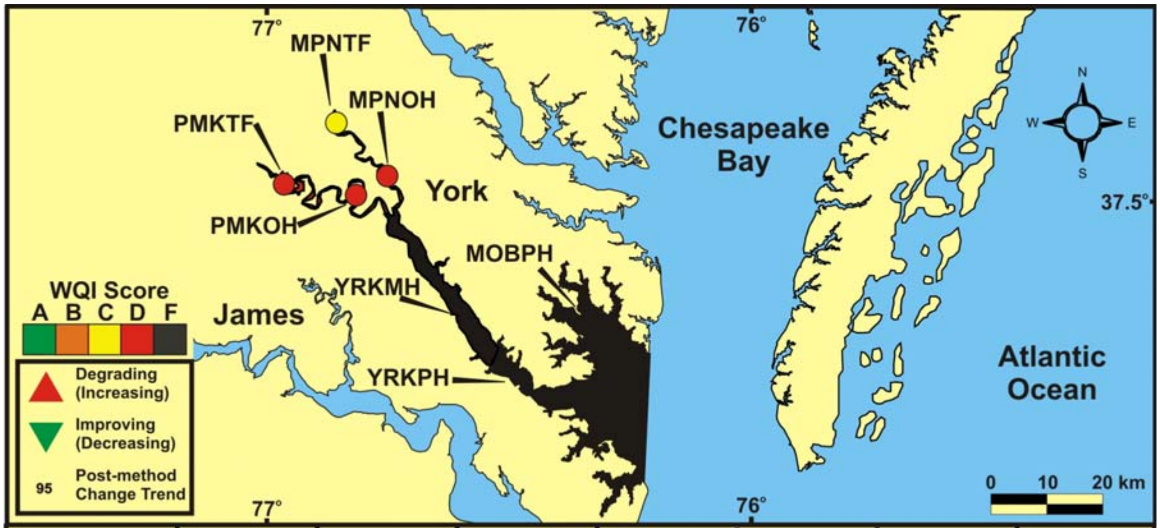
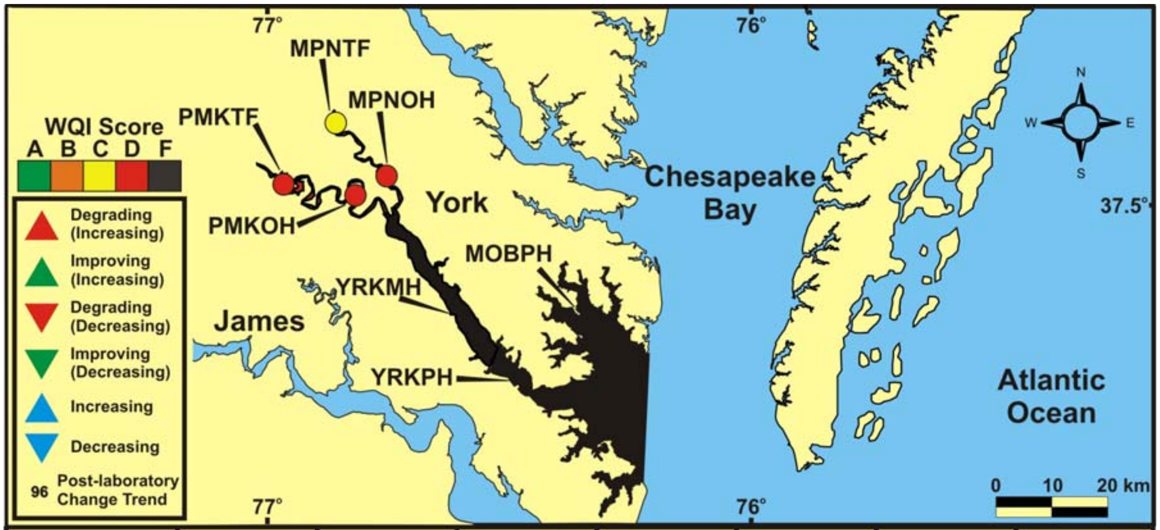


Figure 23. Long-term changes in point source A) Total Nitrogen Load and B) Total Phosphorus Load in Mobjack Bay for 1985 through 2011. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



Parameter	PMKTF	PMKOH	MPNTF	MPNOH	YRKMH	YRKPH	MOBPH
STN						▲	▼
BTN							▼
SDIN							
BDIN							▼
STP	▲				▲	▲	▼
BTP					▲		▼
SDIP	▼ 95	▲	▼ 95		▲	▲	
BDIP	▼ 95	▲	▼ 95		▲		

Figure 24. Water quality status and long-term trends in nutrient parameters in the tidal portion of the York River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. 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	PMKTF	PMKOH	MPNTF	MPNOH	YRKMH	YRKPH	MOBPH
SCHLA	▼ Improving (Decreasing)		▼ Improving (Decreasing)				
STSS	▲ Degrading (Increasing)						▼ Improving (Decreasing) 96
BTSS						▲ Degrading (Increasing)	▼ Improving (Decreasing) 96
SECCHI	▼ Degrading (Decreasing)		▼ Degrading (Decreasing)			▼ Degrading (Decreasing)	▼ Degrading (Decreasing)
BDO	▲ Improving (Increasing)						▲ Improving (Increasing)
SSALIN		▲ Increasing		▲ Increasing		▼ Decreasing	▼ Decreasing
BSALIN		▲ Increasing		▲ Increasing		▼ Decreasing	▼ Decreasing
SWTEMP			▲ Increasing				
BWTEMP							

Figure 25. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the York River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

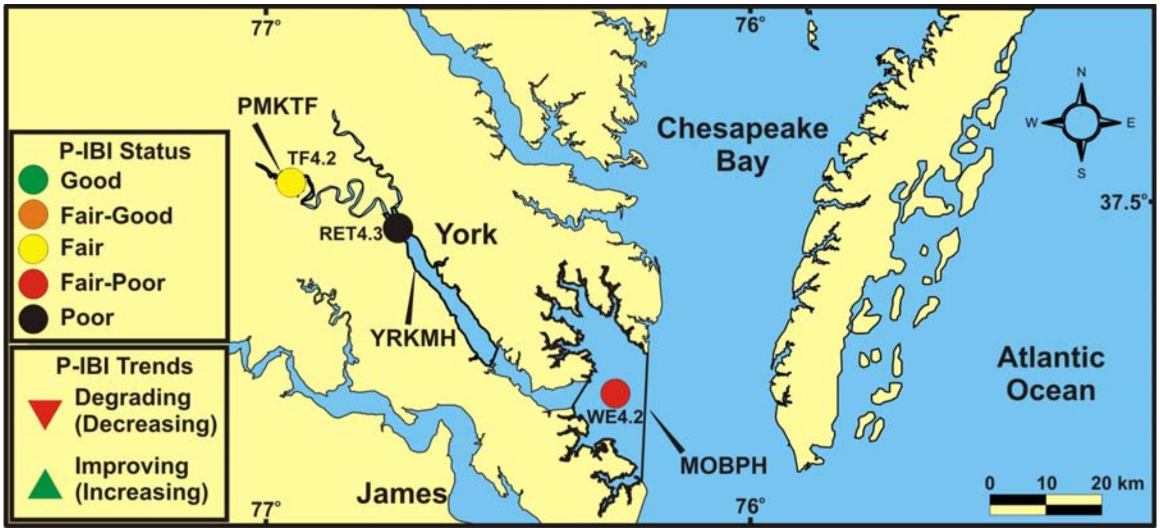


Figure 26. Status and long-term trends in phytoplankton community condition in the tidal portion of the York River basin for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

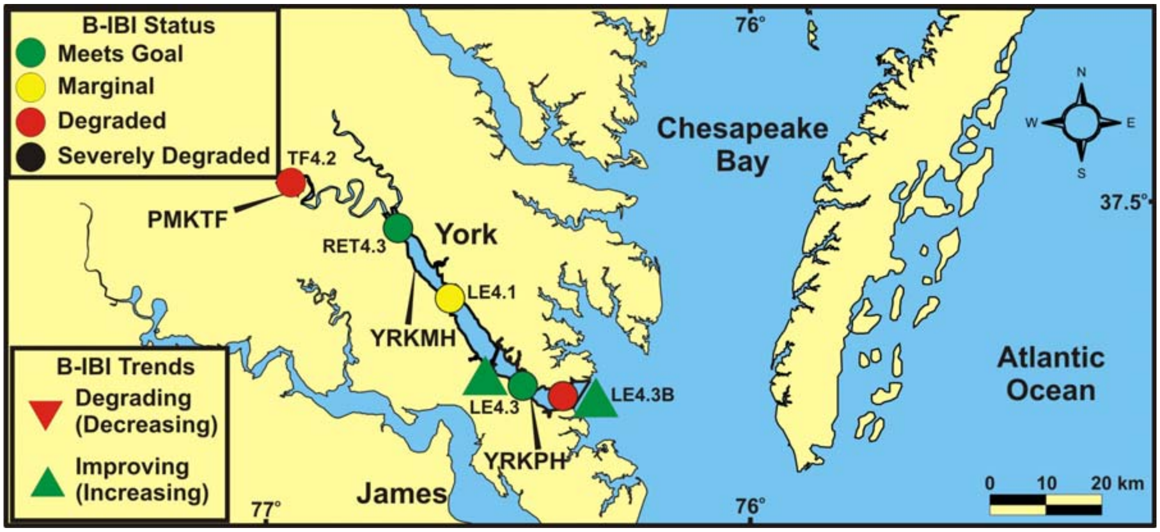
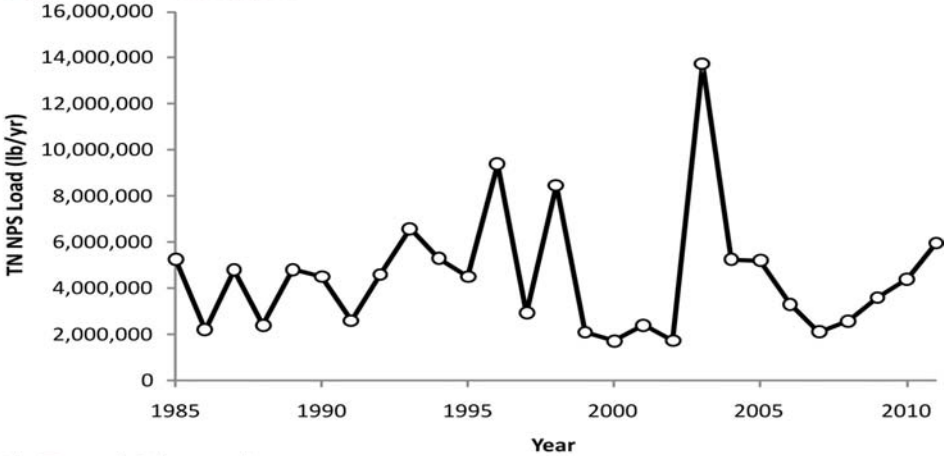
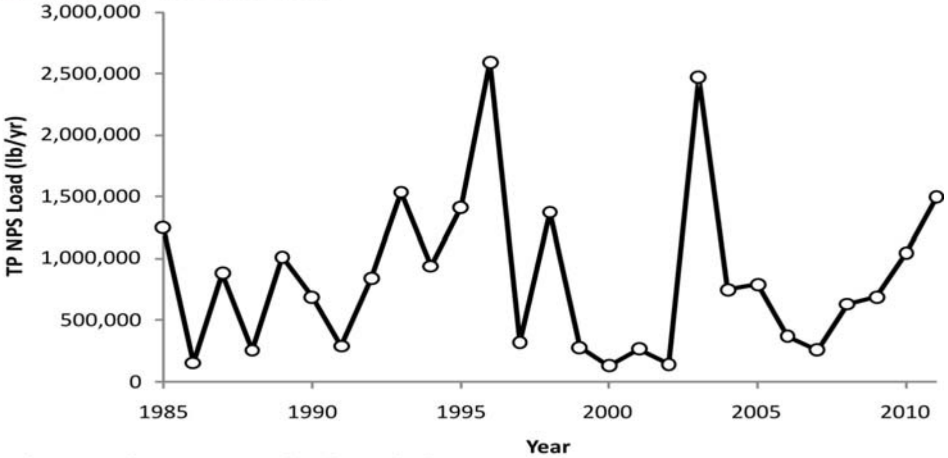


Figure 27. Status and long-term trends in benthic community condition in the tidal portion of the York River basin for the period of 1985 through 2011. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2011.

A) Total Nitrogen



B) Total Phosphorus



C) Total Suspended Solids

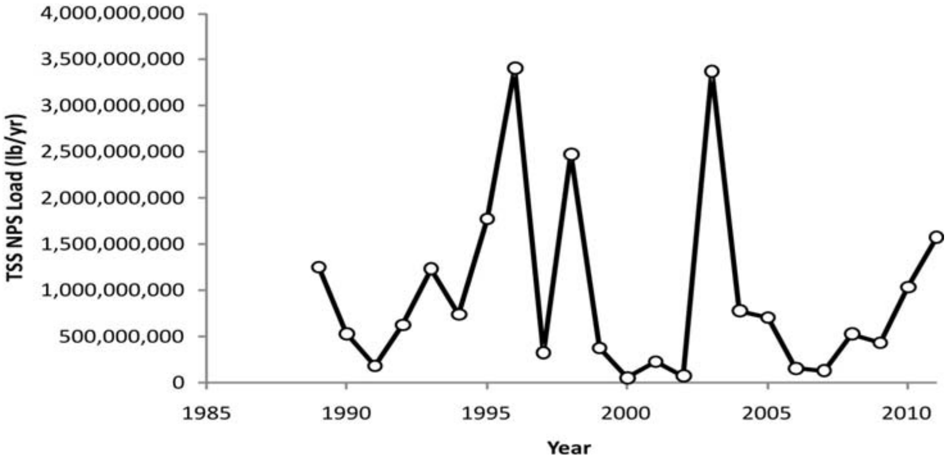
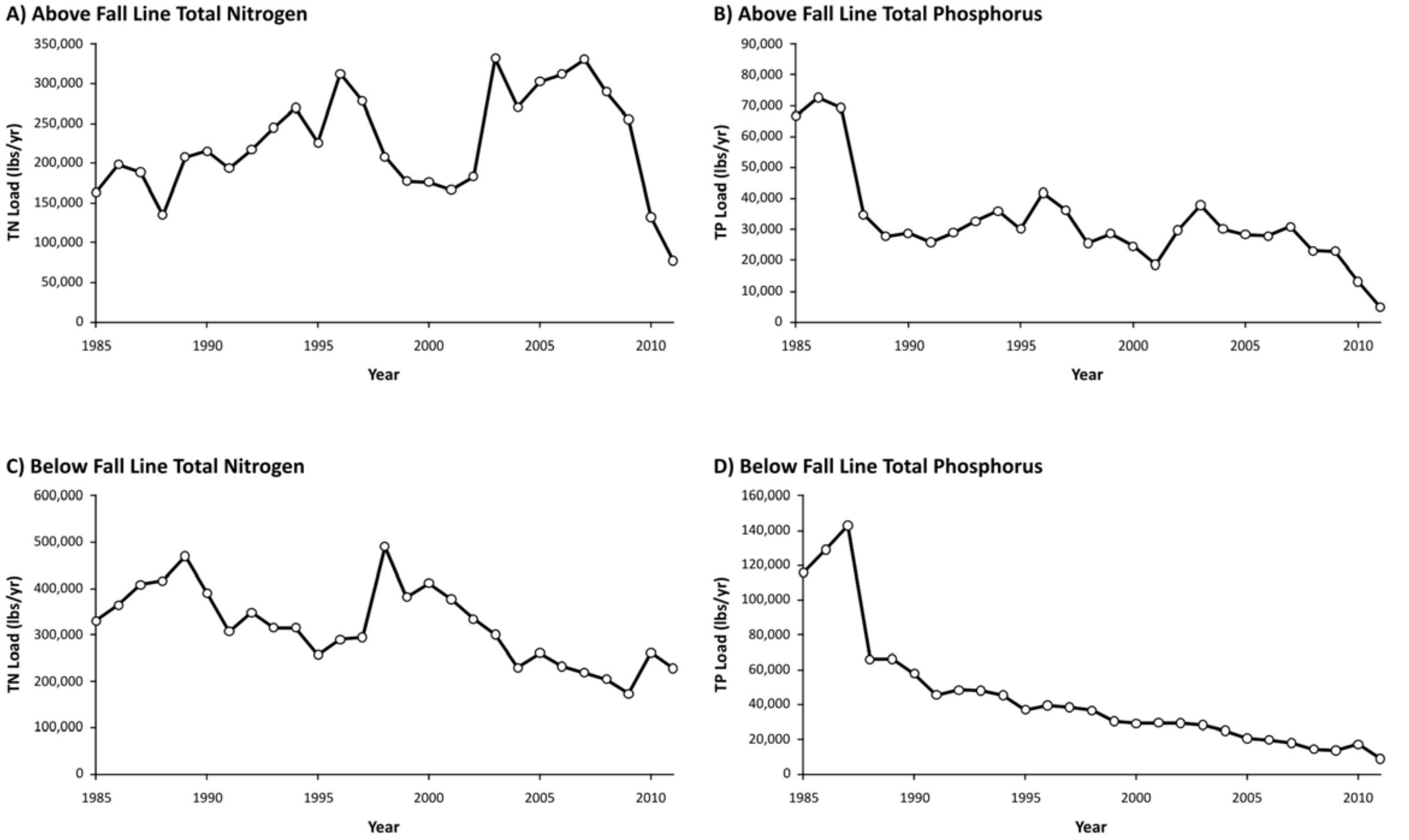


Figure 28. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment loads at the fall-line in the Rappahannock River from 1985 through 2011. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

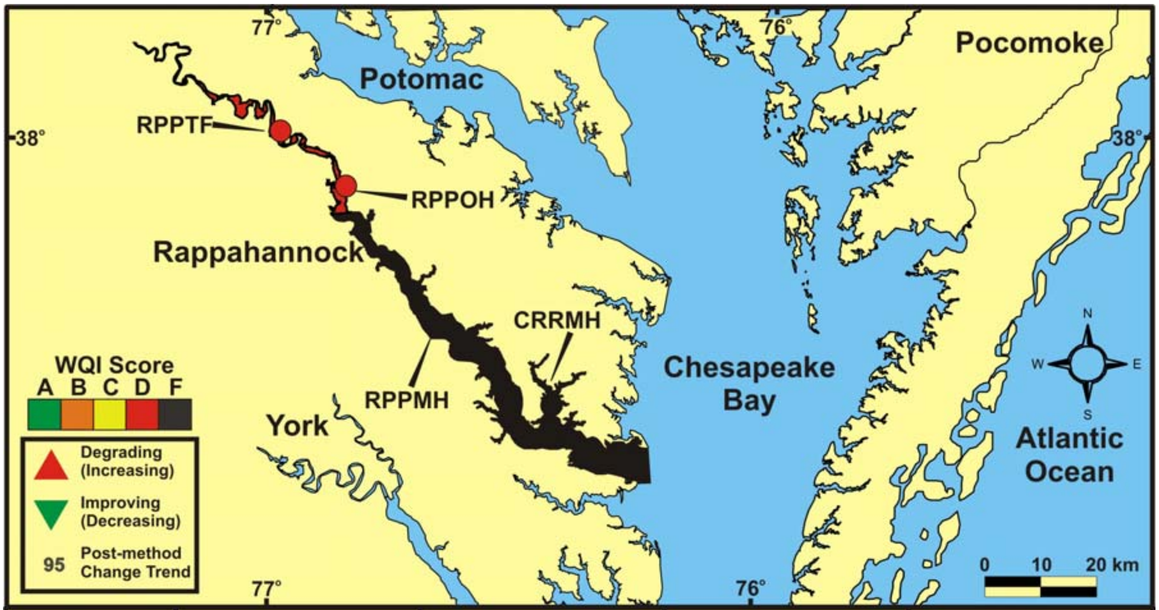

A) Above Fall Line Total Nitrogen

B) Above Fall Line Total Phosphorus

C) Below Fall Line Total Nitrogen

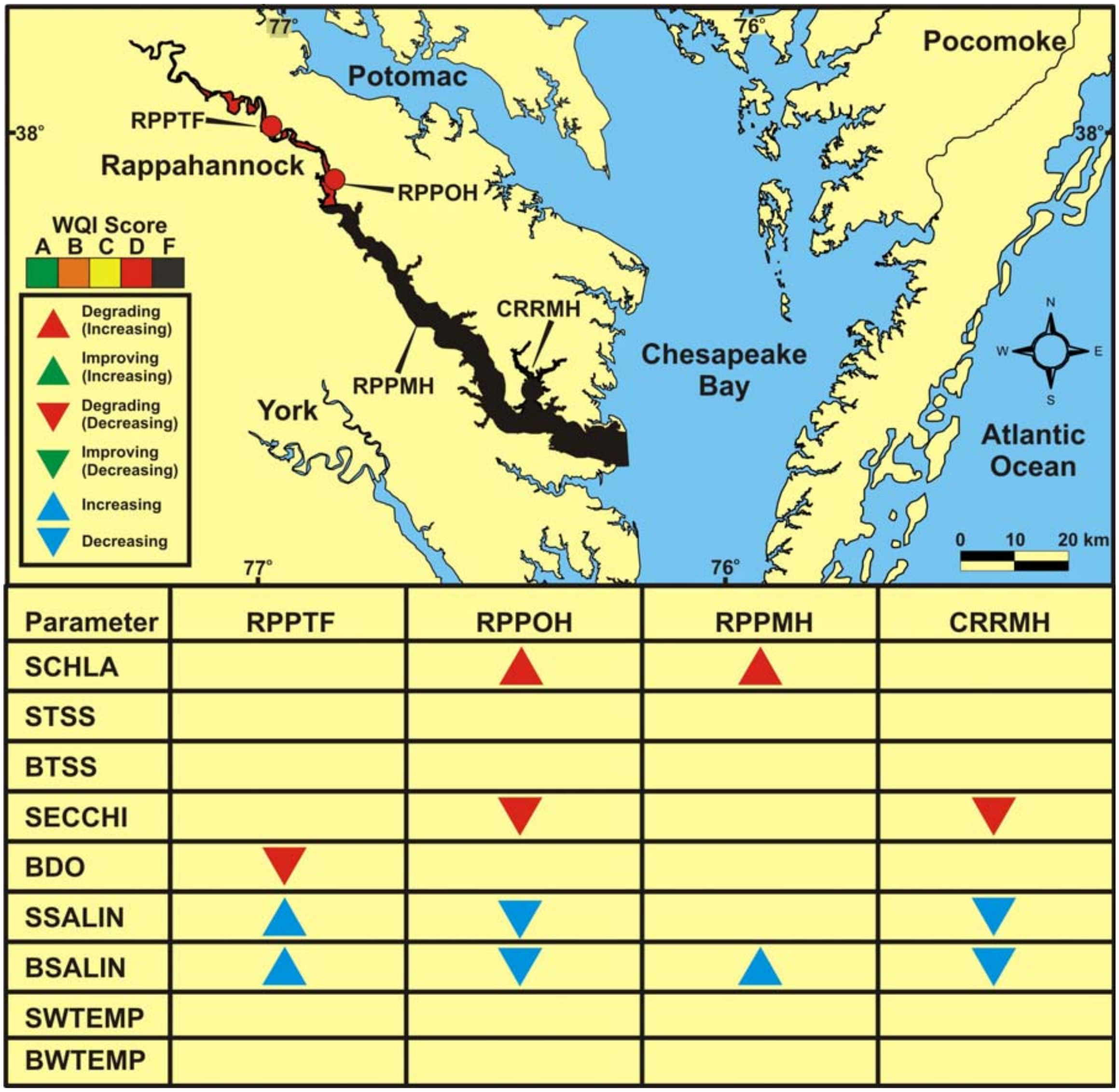
D) Below Fall Line Total Phosphorus

Figure 29. Long-term changes in point source loads in A) Above Fall Line Total Nitrogen; B) Above Fall Line Total Phosphorus; C) Below Fall Line Total Nitrogen; and D) Below Fall Line Total Phosphorus in the Rappahannock River for 1985 through 2011. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



Parameter	RPPTF	RPPOH	RPPMH	CRRMH
STN				
BTN	▼		▲	▼ 95
SDIN				▼ 95
BDIN				
STP			▲	
BTP			▲	▼ 95
SDIP	▼ 95	▼		
BDIP	▼ 95	▼ 95		

Figure 30. Water quality status and long-term trends in nutrient parameters in the tidal portion of the Rappahannock River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. 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.

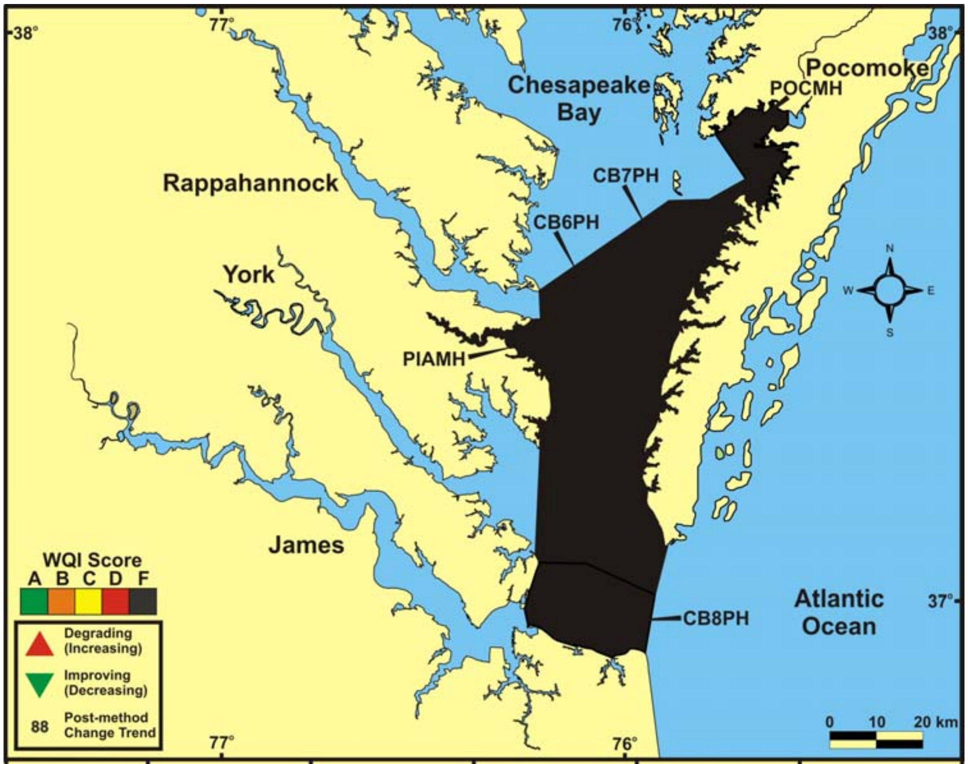


Parameter	RPPTF	RPPOH	RPPMH	CRRMH
SCHLA		🔺	🔺	
STSS				
BTSS				
SECCHI		🔻		🔻
BDO	🔻			
SSALIN	▲	▼		▼
BSALIN	▲	▼	▲	▼
SWTEMP				
BWTEMP				

Figure 31. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the Rappahannock River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2011. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

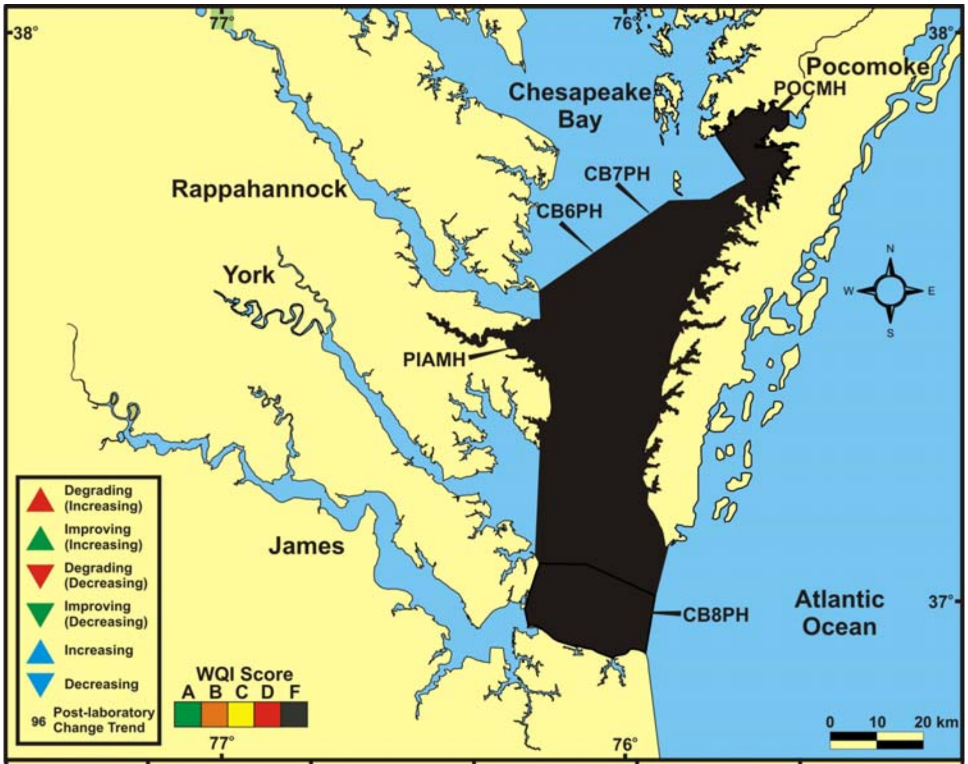
Figure 32. Status and long-term trends in phytoplankton community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

Figure 33. Status and long-term trends in benthic community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2011. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2011.



Parameter	PIAMH	CB6PH	CB8PH	CB7PH	POCMH
STN	▼	▼		▼	▼
BTN	▼	▼		▼	▼
SDIN					▼
BDIN		▼			▼
STP	▼	▼	▼	▼	▼
BTP	▼	▼	▼	▼	▼
SDIP			▼		
BDIP		▼	▼	▼	

Figure 34. Water quality status and long-term trends in nutrient parameters in the Virginia Chesapeake Bay Mainstem for the period of 1988 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1988 through 2011. 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	PIAMH	CB6PH	CB8PH	CB7PH	POCMH
SCHLA					
STSS	▼ 96	▼ 96		▼ 96	▼ 96
BTSS	▼ 96	▼ 96	▼ 96	▼ 96	▼ 96
SECCHI	🔻	🔻	🔻	🔻	🔻
BDO	▲		▲		▲
SSALIN	▼	▼	▼	▼	▼
BSALIN	▼	▼	▼		▼
SWTEMP					
BWTEMP					

Figure 35. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2011. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water Quality Index (WQI) of Williams et al. (2009). Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2011. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

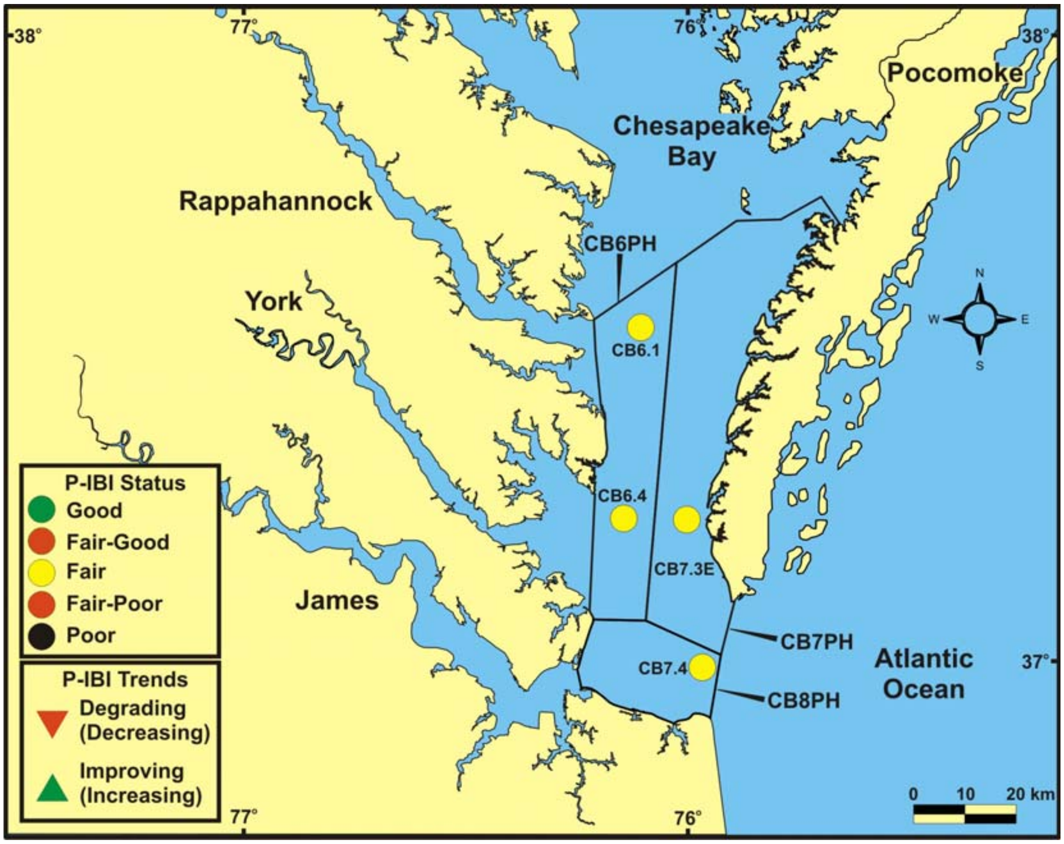


Figure 36. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

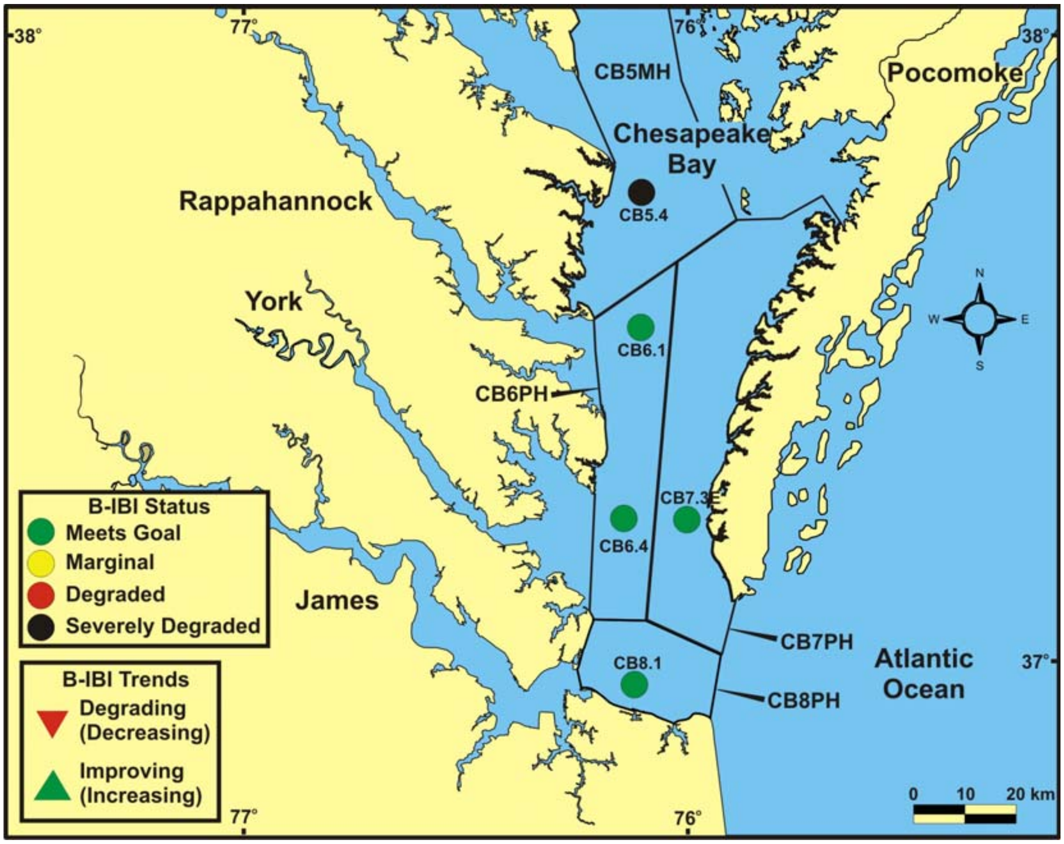


Figure 37. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2011. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2011.