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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 2012

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 29 years until the 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;2012).

II. Methods and Materials

A. Monitoring Program Descriptions

Non-tidal water quality samples were collected from 1985 through 2012 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 the present. 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 in 1995. 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 to 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 (Williams 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 than 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 2012) 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 considered 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 were 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 2012. 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 Old Dominion University (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 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 2012 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 sediment 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 improving trends were detected for both total nitrogen and total phosphorus (Table 2). An improving trend in non-point source loads of total nitrogen above the fall-line in Appomattox River (Table 2) while no trends were detected for total phosphorus or total suspended sediment loads although overall both of these parameter appear to have decreased over the period of record of this study (Figure 6B-C).

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 36.0% and 37.2%, 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 63.2% and 62.4%, 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 7A-D).

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 a degrading trend in total phosphorus (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 through 2011 (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; Figure 11). Improving long term or post method change trends in surface and/or bottom total phosphorus and dissolved inorganic phosphorus were detected in the tidal freshwater segments of the James River, the Appomattox River (APPTF), and the Chickahominy River (CHKOH) (Figure 11). Improving post-method change trends in surface and bottom total phosphorus were also detected at the James River mouth (JMSPH) (Figure 11).

Improving trends in surface chlorophyll *a* were restricted to the lower portion of the tidal freshwater James River (JMSTF1) and the Chickahominy River (CHKOH) while a degrading trend in chlorophyll *a* was detected at the entrance to James River in segment JMSPH (Figure 12). Improving trends in surface total suspended solids were detected in the Appomattox River (APPTF) and lower portion of the tidal freshwater (JMSTF1) (Figure 12). 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 and segment JMSPH were an improved trend was observed (Figure 12). Salinity and temperature showed no change in most segments (Figure 12)

Water quality status based on the WQI was Very Poor in all segments of the Elizabeth River through 2011 (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). Improving trends in surface and bottom dissolved inorganic nitrogen and phosphorus were also observed in most segments (Figure 13). Additionally, improving trends in surface and bottom total suspended solids were observed in all segments of the Elizabeth River except segment ELIPH where an improving trend in only surface total suspended solids was observed (Figure 14). The only degrading trend observed was a decreasing trend in Secchi depth in the Elizabeth River Mainstem ELIPH (Figure 14). Water clarity in the Southern and Eastern Branch of the Elizabeth River was improving as indicated by the increasing trends in Secchi depth (Figure 14). Increasing trends in bottom temperature were detected in all segments except for the Mainstem of the Elizabeth River (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 significant trends in the P-IBI were observed at any of the stations (Figure 15). Improving trends in the James River are increasing chlorophyte biomass at station TF5.5 and declining picoplankton biomass at stations TF5.5 and RET5.2 (Appendix G- Figure 1). Several degrading trends were also detected including declining trends in Margalef species diversity at stations RET5.2; a declining trend in diatom biomass at station SBE5; and increasing trends cyanophyte biomass at station TF5.5 and LE5.5 (Appendix G- Figure 1).

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 granulata*., *Cyclotella* spp., *Skeletonema potamos*), plus a variety of cyanobacteria and chlorophytes are the dominant algal flora. The tidal freshwater James River represents one of the most diverse phytoplankton communities in the Chesapeake Bay. While some potentially harmful algal bloom (HAB) cyanobacterial species are present in the tidal-fresh James, including *Microcystis aeruginosa*, they tend to be present only at background densities. 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 meso/polyhaline 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. 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. *H. triquetra* has been responsible for very dense long lasting spring blooms in the mesohaline James for several years, notably from 2011-2013. The 2012 and 2013 *H. triquetra* blooms within the James River were extensive, lasting 5-8 weeks with maximum cell concentrations >170,000 cells/ml. 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. *P. minimum* is abundant throughout the meso/polyhaline waters of lower Chesapeake Bay and its tributaries, including the lower James River, with blooms common in the Hampton Roads tributaries (e.g. Elizabeth and Lafayette Rivers). 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 ichthyotoxic dinoflagellate is *Karlodinium veneficum* which has been historically more common in the Potomac River and its tributaries and inlets and has become more common throughout Virginia tributaries to Chesapeake Bay, including the James River. The major bloom producing dinoflagellate in the James is *Cochlodinium polykrikoides*, which becomes most dominant during summer and early autumn. Long-term monitoring suggests blooms of this species and others typically first occur in the Lafayette River, then spread into the Elizabeth and James Rivers (Morse et al. 2011, Egerton et al. 2014). Other tributaries to the James follow a similar pattern of development and cell dispersal (e.g. Warrick and Nansemond Rivers). These blooms are generally extensive in scope and long lastingAs this bloom spreads within the estuary, it will enter the Lower Chesapeake Bay, and at times pass out of the Bay and progress along the Atlantic coastline southward. During 2012, the *C. polykrikoides* bloom was amongst the largest recorded for the region, with bloom conditions lasting 7 weeks and cell concentrations >70,000 cells/ml (Egerton et al. 2012). Other potentially harmful and toxin producing species that have been noted in downstream locations, but less frequently are the raphidophytes *Chattonella subsalsa* and *Heterosigma akashiwo*, and the dinoflagellate *Alexandrium monilatum* (Marshall and Egerton 2012).

5. Benthic Communities

Status at all but one fixed point monitoring station in the James River, station LE5.4 in segment JMSPH, was either degraded or severely degraded (Figure 16). Status of benthic communities in the Southern Branch of the Elizabeth River at both stations was degraded and 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 most samples that met restoration goals were found at the mouth of the James River (JMSPH) and the lower portion of segment JMSMH (Figure 17). Only 40% of the total area of the James River meet restoration goals (Figure 18) and that there was a significant decreasing trend in the proportion of area failing the goal since

1996 (Figure 19). 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*. Its blooms are generally extensive, long lasting, and a concern to the various local and state agencies as producing potential toxins and anoxic conditions in the water column, and possible health risks to recreational users. Fishkills have been associated with these blooms in the past, and although no significant human health problems have reported to date, its presence has often curtailed public recreational activities. Several of the other toxin producers (*Alexandrium monilatum*, *Prorocentrum minimum*, *Karlodinium veneficum*, *Chattonella 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 can be 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 only 40% of the total area of the river 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 decrease in the proportion of area meeting 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 20-22). There were no significant trends in freshwater flow in the York River watershed (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 reflect the pattern exhibited by annual loads with the exception of a large decline in point source TP loadings from 2006 through 2010 and which reversed itself in 2011 (Figure 23B). The increase in total phosphorus loads in 2011 was followed by a substantial decline in 2012 (Figure 23B). Overall these trends have resulted in a 16.7% reduction and 16.8% increase in point source total nitrogen and total phosphorus loads above the fall-line, respectively (Table 4).

Significant improving trends were detected in both total nitrogen and total phosphorus point source loadings below the fall-line in the York River(Table 4). The plot of annual point source total nitrogen loads, indicated a general pattern of multiple periods of marked decline varying in length of 1 to 4 years followed by longer periods of gradual increase (2 or more years; Figure 23C) with the overall result being one of a slight decrease in total nitrogen point source nitrogen loads below the fall-line of approximately 3.9% (Table

4). In contrast, annual point source total phosphorus loads below the fall-line show what appear to be an asymptotic decline (Figure 23D).

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, staying relatively constant thereafter eventually declining to 0 by 2012 (Figures 24A-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 through 2011, 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 25). With respect to nutrients, post method change improving trends in surface dissolved inorganic phosphorus were detected in the upper Pamunkey and Mattaponi rivers (PMKTF and MPNTF) while degrading long term trends in bottom and/or surface dissolved inorganic phosphorus were detected in the lower segments of the Pamunkey (PMKOH) and York River (YRKMH and YRKPH). Improving trends in total nitrogen, dissolved inorganic nitrogen and total phosphorus were detected in Mobjack Bay (MOBPH; Figure 25) perhaps in direct relation to reductions in point source loadings of nitrogen and phosphorus in this region.

An improving trend and degrading trend in surface chlorophyll *a* concentrations were observed in the upper Mattaponi River (MPNTF) and the Middle York River (YRKMH), respectively (Figure 26). Degrading trends in total suspended solids were detected in the upper Pamunkey River (PMKTF) and the lower York River (YRKPH). Degrading trends in water clarity were detected in the upper segments of both the Pamunkey and Mattaponi rivers (PMKTF; MPNTF), as well as, the lower York River (YRKPH) and Mobjack Bay (MOBPH; Figure 26). Improving trends in summer dissolved oxygen were observed in the upper Pamunkey River (PMKTF) and Mobjack Bay (MOBPH; Figure 26).

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 through 2011 (Figure 27) . There were no significant trends in the P-IBI during this time period. In the tidal fresh Pamunkey station TF4.2, there is a significant increase in total phytoplankton abundance. This includes a degrading trend of increased cyanobacteria biomass and improving trend of increased chlorophytes biomass (Appendix G, Figure 3). Increased chlorophytes biomass is also present at station RET4.3 in segment YRKMH. Downstream, in segment MOBPH, station WE4.2 there is a trend towards reduced total phytoplankton biomass. However this station shows degrading trends in terms of decreased species diversity and increased cyanobacteria biomass (Appendix F, Figure 3).

The Pamunkey and Mattaponi rivers 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 meso/polyhaline 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 to a lesser degree, *Karlodinium veneficum*, which has been seen in a smaller number of spring blooms. The HAB dinoflagellate *Alexandrium monilatum* and raphidophyte *Chattonella subsalsa* have also been detected more recently in the York and its tributaries. In 2012, the region experienced a very dense *Alexandrium monilatum* bloom extending out of the York into the lower Chesapeake Bay mainstem. 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.

5. Benthic Communities

Status of benthic communities at fixed point stations in the York River were 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 28). 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 28). In 2012, results of the probability-based benthic monitoring indicated that samples meeting restoration goals showed no spatial distribution pattern (Figure 17). Only 44% of the total area of the York River met the restoration goals York River (Figure 18) and no significant trend in the proportion of area meeting the restoration goals was observed in the York River stratum (Figure 19).

6. Management Issues

Examination of patterns in both point and non-point source loadings in the York River suggest that overall water quality conditions with respect to nutrients should be improving within this watershed. Trends in nutrients in the upper segments of the Pamunkey and Mattaponi rivers appear to reflect those of the loads while those in segments downstream (YRKMH and YRKPH) appear to be decoupled from the pattern in loadings as do the trends in flow adjusted nutrient concentrations in the non-tidal portion of the Pamunkey River. Poor water quality status and degrading trends in water clarity were also found throughout this watershed.

Multiple improving trends in nutrients, total suspended solids and bottom dissolved oxygen were also 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. The tidal fresh Pamunkey has historically had low algal biomass, with little to no blooms, however the degrading trend of increased cyanobacterial biomass is a concern (Appendix G, Figure 3). In comparison, algal blooms are common events downstream 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, 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 only 44% of the bottom of the York River 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 proportion of area meeting 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 29A-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 29.7% increase in monthly point source total nitrogen loads was detected above the fall-line in the Rappahannock River (Table 4) however; a plot of the data suggests that loadings declined substantially after 2007 despite the statistically significant trend (Figure 30A). In contrast, an improving trend resulting in a 58.5% 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 2012 (Figure 30B). Improving trends in monthly point source loads of both total nitrogen and total phosphorus were detected below the fall-line resulting in 46.7% and 57.5% reductions in loads of these two parameters, respectively (Table 4). Plots of annual total loads confirm results of the trend analyses (Figure 30C-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 through 2011 (Figure 31). With respect to nutrients, water quality conditions in the largest segment of the Rappahannock River, segment RPPMH, showed little change except for improved post-method change trends in surface and bottom dissolved inorganic phosphorus (Figure 31). Improvements in surface and/or bottom total nitrogen were observed in the upper and middle Rappahannock River, respectively, as well as an improving post-method change trend in bottom total nitrogen in the Corrotoman River. There were no trends in surface dissolved inorganic nitrogen detected except a post-method trend in the Corrotoman River (Figure 31). An improving post-method change trend in surface total phosphorus was detected in and in bottom total phosphorus in both the middle Rappahannock River and Corrotoman River (CRRMH) (Figure 31). Improving post-method change trends in surface and/or bottom dissolved inorganic phosphorus were detected in all segments but the middle Rapphannock River (RPPOH).

Degrading trends in chlorophyll *a* were detected in the middle (RPPOH) and lower Rappahannock River (RPPMH), as were degrading trends in water clarity in the lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH) (Figure 32). A degrading trend in bottom dissolved oxygen was also detected in the upper Rappahannock River (segment RPPTF) (Figure 32).

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 Fair (Figure 33). An increasing trend in total phytoplankton abundance was observed at all stations in the tributary (Appendix G, Figure 5). At the tidal fresh TF3.3, this includes increased biomass of both beneficial (diatoms and chlorophytes) and detrimental (cyanobacteria) taxa (Appendix G, Figure 5). At station RET3.1, there is also an increase in chlorophytes and cyanobacteria biomass, while at station LE3.6 there is an increase in cyanobacteria biomass and a decrease in picoplankton and cryptophyte biomass (Appendix G, Figure 5). Due to the varied changes in taxonomic groups, there were no significant trends in the P-IBI, however, conditions appear to be largely degrading as indicated by the increasing trends in cyanophytes throughout the tributary.

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 mainstem. The tidal freshwater station is very diverse, and contains a variety of freshwater diatoms (pennate and centric), cyanobacteria, and chlorophytes as the predominant algae. Throughout the Rappahannock River a spring diatom bloom is often evident, with diatoms remaining prominent through summer with a slight increase in abundance in autumn. Cryptophytes were common components throughout the tributary, especially within the downstream regions of the river. Major non-harmful bloom taxa within the river were similar to those in the James and York, being represented by dinoflagellates (*Gymnodinium* spp, *Heterocapsa rotundata*, *Heterocapsa triquetra*, *Akashiwo sanguinea*, *Scrippsiella trochoidea*, et al.). Unlike these other rivers the dinoflagellate *Cochlodinium polykridoides* was rarely noted. The exception being 2012, when *Cochlodinium polykrikoides* was present at bloom levels throughout the meso/polyhaline waters. In 2012 two fishkills were reported in the lower Rapphannock River, which corresponded with minor blooms of *Cochlodinium polykrikoides* and the potentially toxic raphidophyte *Chatonella subsalsa*. The ichthyotoxic dinoflagellates *Karlodinium veneficum* and *Prorocentrum minimum* also occur in this river and often form annual blooms. Also, noted is the bloom forming ciliate *Myrionecta rubra*. In the tidal freshwater region the cyanobacteria *Microcystis aeruginosa* is present 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 34). Probability-based benthic monitoring results indicated that only 28% the total area of Rappahannock River met benthic community goals in 2012 (Figure 18). Samples that met restoration goals seemed to be clustered in the lower portion of the middle Rappahannock River (RPPMH) (Figure 17). There was a significant decreasing trend in the proportion of area meeting the restoration goal since 1996 for this sampling stratum (Figure 19). 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. 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 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 nutrient 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 clear response in water column concentrations; (2) the NPS and/or PS load data used do not reflect actual loads to this river for these 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.

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 and cyanobacteria in the downstream regions of the river. Increased nutrient loads would reduce water quality values within the river and likely 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 potentially 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 28% of the total area of the Rappahannock River failed to meet restoration goals and that there was a significant decreasing trend in the proportion of area meeting the restoration goals. Poor benthic communities in the lower Rappahannock River are due primarily to low dissolved oxygen.

D. Virginia Chesapeake Bay Mainstem

1. Tidal Water Quality

Water quality status in the Virginia Chesapeake Bay Mainstem was Very Poor in all segments through 2011 (Figure 35). With respect to nutrients, 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 and improving trends in dissolved inorganic nitrogen were detected in multiple segments. Improving long-term trends in surface and bottom total phosphorus were detected in all segments (Figure 35) as were improving trends in dissolved inorganic phosphorus 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 36) 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 36). Decreasing trends in surface and/or bottom salinity were detected in all segments of the Mainstem (Figure 36).

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 37). An increasing trend in phytoplankton abundance was detected at all stations except CB7.3E. This increase is associated with increased cyanobacteria biomass and decreasing cryptophyte biomass at all stations and degraded species diversity in all but CB6.1 (Appendix G, Figure 7). Decreased picoplankton biomass was also observed upstream at stations CB6.1 and CB6.4.

The Chesapeake Bay is a stratified system with the phytoplankton below the pycnocline containing species entering the Bay mouth from incoming offshore 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. The resulting flora represents a diverse assemblage of species, that is generally dominated in abundance and biomass by diatoms and seasonally by dinoflagellates. There 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, Marshall and Egerton 2012). 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). In recent years blooms of the dinoflagellate *Cochlodinium polykrikoides* in the lower York and James Rivers 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. This phenomenon was also observed with the toxic dinoflagellate *Alexandrium monilatum*, with bloom concentrations observed in the mainstem of the Bay in 2012.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 38) and relatively few trends in any of the individual benthic bioindicators (Appendix F - Section E). Probability-based benthic monitoring results for 2012 indicated that the distribution of samples meeting the restoration goals was widespread throughout the Virginia Mainstem with no discernable pattern (Figure 17) and that over 76% of the total area of the Virginia Chesapeake Bay Mainstem met the restoration goals (Figure 18). A significant increasing trend in proportion of area meeting restoration goals was detected in the Virginia Chesapeake Bay Mainstem (Figure 19).

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 six 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 degrading trends in Margalef species diversity and cyanobacteria biomass found at all stations. 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, Egerton et al. 2012). 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 76% of the total area of Virginia Chesapeake Bay Mainstem met 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 and Appomattox River where long-term improving trends were observed for nutrient parameters.
- Point source nutrient loads tended to be higher below than above the fall-line.
- Reductions in point source nutrient loads were widespread throughout all tributaries.
- 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 including increased cyanobacteria biomass;
  - few improvements at fixed point stations in the B-IBI;
  - reductions in area meeting benthic restorations goals in the James and Rappahannock rivers and an increase in the Virginia Mainstem.

- 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, magnitude and spatial expansion of bloom events, including HABS at some locations.

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

- Trends exhibited by probability-based strata indicated overall degrading conditions in the James and Rappahannock rivers but improvement overall in the Virginia Mainstem although no consistent causal stressor was identified.

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 phytoplankton communities throughout its tidal areas;
  - annual seasonal algal blooms in the lower segments and inlets produced by potentially toxic dinoflagellates, which appear to be increasing in duration and magnitude;
  - increasing number of bloom species including *C. polykrikoides*, *P. minimum*, *A. monilatum*, *C. subsalsa*;
  - little change at fixed point benthic monitoring stations coupled with a decreasing proportion of area meeting restoration goals throughout the watershed.

- 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 at fixed point monitoring stations;
    - significant ongoing annual algal bloom development particularly in the lower York of *C. polykrikoides* coupled with increased bloom activity of the invasive toxic HAB *A. monilatum;*
    - no change in the proportion of area meeting benthic restoration goals.

- The Rappahannock River can be described as having:

    - generally poor water quality despite improved point and non-point source loads;
    - no improving non-tidal and few improving tidal water quality trends;
    - poor or marginal phytoplankton communities coupled showing degrading long-term trends;
    - fewer blooms of HABs, but increased frequency and magnitude in recent years;
    - marginal or degraded status at fixed point station benthic communities coupled with no improving trends;
    - a decreasing proportion of area meeting benthic restoration goals.

- The Virginia Chesapeake Bay Mainstem was characterized by:

    - poor water quality status due primarily to water clarity;
    - widespread improving trends in nitrogen and phosphorus;
    - fair or good and relatively stable and/or improving living resources at fixed point stations;
    - beneficial phytoplankton taxa including diatoms but with more frequent expansion of summer/autumn dinoflagellate HABs in recent years;
    - an increasing trend in the proportion of area meeting benthic restoration goals.

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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 2012. Units for the slope and baseline medians are in lb/month.

River	Parameter	P value	Slope	Baseline Median	Absolute Change	% Change	Direction	Homogeneity test P value
James River	TN	0.0026	-2465	201548	-69006	-34.24	Improving	0.5847
James River	NO23	0.0002	-1129	77940	-31609	-40.56	Improving	0.5916
James River	TP	0.0000	-1110	41070	-31083	-75.68	Improving	0.1200
James River	DIP	0.0000	-1203	27296	-33693	-123.44	Improving	0.9984
James River	TSED	0.8866	11527	1055256	138320	13.11	No Trend	0.8132
Appomattox River	TN	0.0005	-401	29748	-11238	-37.78	Improving	0.7221
Appomattox River	NO23	0.0178	-71	6417	-1989	-31.00	No Trend	0.3341
Appomattox River	TP	0.0413	-16	1584	-434	-27.40	No Trend	0.7701
Appomattox River	DIP	0.0000	-11	474	-305	-64.51	Improving	0.3776
Appomattox River	TSED	0.1369	-10505	157842	-126063	-79.87	No Trend	0.7041
Mattaponi River	TN	0.1621	-93	20553	-2604	-12.67	No Trend	0.9631
Mattaponi River	NO23	0.6858	-5	3921	-146	-3.73	No Trend	0.9301
Mattaponi River	TP	0.3314	-6	1566	-163	-10.40	No Trend	0.9540
Mattaponi River	DIP	0.0000	-7	426	-193	-45.28	Improving	0.4766
Mattaponi River	TSED	0.7599	1075	57288	12896	22.51	No Trend	0.9704
Pamunkey River	TN	0.0325	-241	33372	-6747	-20.22	No Trend	0.8410
Pamunkey River	NO23	0.2078	-62	10819	-1736	-16.05	No Trend	0.6558
Pamunkey River	TP	0.7072	4	2635	105	3.98	No Trend	0.8162
Pamunkey River	DIP	0.0003	-13	839	-372	-44.36	Improving	0.7191
Pamunkey River	TSED	0.8866	795	159294	9540	5.99	No Trend	0.7954
Rappahannock River	TN	0.8943	25	46815	700	1.50	No Trend	0.8856
Rappahannock River	NO23	0.9172	11	28133	305	1.09	No Trend	0.8960
Rappahannock River	TP	0.3860	23	3777	630	16.68	No Trend	0.7248
Rappahannock River	DIP	0.4987	-4	885	-113	-12.79	No Trend	0.8859
Rappahannock River	TSED	0.5822	-30090	1211965	-361080	-29.79	No Trend	0.8530

Table 3. Long-term trends in freshwater flow at USGS fall-line stations in the Virginia tributaries for the period of 1985 through 2012. 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	Absolute Change	% Change	Direction	Homogeneity test P value
Appomattox River (1)	0.2008	-2.65	466	-68.94	-14.79	No Trend	0.9914
Chickahominy River (2)	0.7168	0.21	133	5.39	4.05	No Trend	0.9482
James River (3)	0.0212	-26.49	3575	-688.62	-19.26	No Trend	0.9720
Mattaponi River (4)	0.0109	-3.56	341	-92.44	-27.09	No Trend	0.9950
Pamunkey River (5)	0.2290	-1.38	265	-35.75	-13.52	No Trend	0.9993
York River (4+5)	0.0330	-5.16	599	-134.06	-22.40	No Trend	0.9989
Rappahannock River (6)	0.755184	-1.18	680	-30.77	-4.53	No Trend	0.9976

Table 4. Long-term trends in NPDES estimates of point source loads in total nitrogen and total phosphorus above the fall line (AFL) and below the fall (BFL) for each of the major Virginia tributaries and Mobjack Bay for the period of 1985 through 2012. Units for the slope and baseline medians are in lb/month.

Basin	Fall Line	Load	P value	Slope	Baseline	Absolute	% Change	Direction	Homogeneity test P value
James	AFL	TN	0.0000	-3681	286571	-103082	-35.97	Improving	0.9771
James	BFL	TN	0.0000	-38761	1717532	-1085300	-63.19	Improving	1.0000
James	AFL	TP	0.0000	-858	64554	-24015	-37.20	Improving	1.0000
James	BFL	TP	0.0000	-5371	241013	-150383	-62.40	Improving	1.0000
York	AFL	TN	0.0185	-57	9557	-1600	-16.74	Improving	0.6235
York	BFL	TN	0.4447	-136	96572	-3799	-3.93	Improving	0.5750
York	AFL	TP	0.1675	19	3209	540	16.83	Degrading	0.9993
York	BFL	TP	0.0000	-392	27842	-10972	-39.41	Improving	0.9891
Mobjack Bay	BFL	TN	0.0000	-22	689	-584	-84.71	Improving	0.9893
Mobjack Bay	BFL	TP	0.0000	-5	236	-133	-56.25	Improving	0.9975
Rappahannock	AFL	TN	0.0117	150	14104	4193	29.73	Degrading	0.8798
Rappahannock	BFL	TN	0.0000	-586	28052	-16403	-58.47	Improving	0.7825
Rappahannock	AFL	TP	0.0000	-95	5727	-2673	-46.67	Improving	0.9997
Rappahannock	BFL	TP	0.0000	-202	9843	-5661	-57.52	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 October 1984 through September, 2012. 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 Name	Parameter	LCL	Flow Adj Trend	UCL	Flow Adj. τ	p-value	Significance
Appomattox River at Matoaca (1)	TN	-3.7	4.7	13.7	0.0456	0.2808	NS
Appomattox River at Matoaca (1)	DNO23	-27.7	-11.5	8.4	-0.1218	0.2388	NS
Appomattox River at Matoaca (1)	TP	17.7	35	54.8	0.3003	<0.0001	Increasing
Appomattox River at Matoaca (1)	DIP	-39	-27.7	-14.4	-0.3248	0.0002	Decreasing
Appomattox River at Matoaca (1)	TSS	-6.2	15.6	42.4	0.1448	0.1742	NS
Appomattox River at Matoaca (1)	SSC	-34.7	-16.7	6.4	-0.1822	0.1428	NS
James River at Cartersville (3)	TN	-22.9	-14.6	-5.4	-0.1576	0.0026	Decreasing
James River at Cartersville (3)	DNO23	-45.9	-36.4	-25.1	-0.4521	<0.0001	Decreasing
James River at Cartersville (3)	TP	-67.4	-61.2	-53.7	-0.9465	<0.0001	Decreasing
James River at Cartersville (3)	DIP	-92.4	-90.9	-89.1	-2.3994	<0.0001	Decreasing
James River at Cartersville (3)	TSS	-25.4	-5.7	19.1	-0.059	0.6214	NS
James River at Cartersville (3)	SSC	-24.6	-2.2	26.9	-0.0224	0.8664	NS
Pamunkey River near Hanover (4)	TN	8.1	17.2	27	0.1585	0.0001	Increasing
Pamunkey River near Hanover (4)	DNO23	16.3	30.1	45.4	0.2628	<0.0001	Increasing
Pamunkey River near Hanover (4)	TP	79.7	106.9	138.3	0.7273	<0.0001	Increasing
Pamunkey River near Hanover (4)	DIP	12.4	30.1	50.6	0.2632	0.0004	Increasing
Pamunkey River near Hanover (4)	TSS	88.7	156.9	249.7	0.9434	<0.0001	Increasing
Pamunkey River near Hanover (4)	SSC	89	163.3	267	0.9683	<0.0001	Increasing
Mattaponi River near Beulahville (5)	TN	-11.6	-5.4	1.2	-0.0555	0.1084	NS
Mattaponi River near Beulahville (5)	DNO23	-7.9	7.7	25.8	0.0738	0.3534	NS
Mattaponi River near Beulahville (5)	TP	-13	-3.2	7.6	-0.0328	0.5464	NS
Mattaponi River near Beulahville (5)	DIP	-50.5	-42.7	-33.7	-0.5568	<0.0001	Decreasing
Mattaponi River near Beulahville (5)	TSS	-19.2	4	33.9	0.0391	0.7616	NS
Mattaponi River near Beulahville (5)	SSC	-37.5	-19.2	4.3	-0.2136	0.1017	NS
Rappahannock River near Fredericksburg (6)	TN	-26.5	-16.8	-5.9	-0.1842	0.0034	Decreasing
Rappahannock River near Fredericksburg (6)	DNO23	-42.2	-26.8	-7.3	-0.3125	0.0096	Decreasing
Rappahannock River near Fredericksburg (6)	TP	-22	-5.8	13.6	-0.0601	0.5308	NS
Rappahannock River near Fredericksburg (6)	DIP	-32.8	-20.1	-5.1	-0.2246	0.0107	Decreasing
Rappahannock River near Fredericksburg (6)	TSS	-44.5	-22.2	9.1	-0.2511	0.1457	NS
Rappahannock River near Fredericksburg (6)	SSC	-7.1	31.6	86.3	0.2743	0.1219	NS

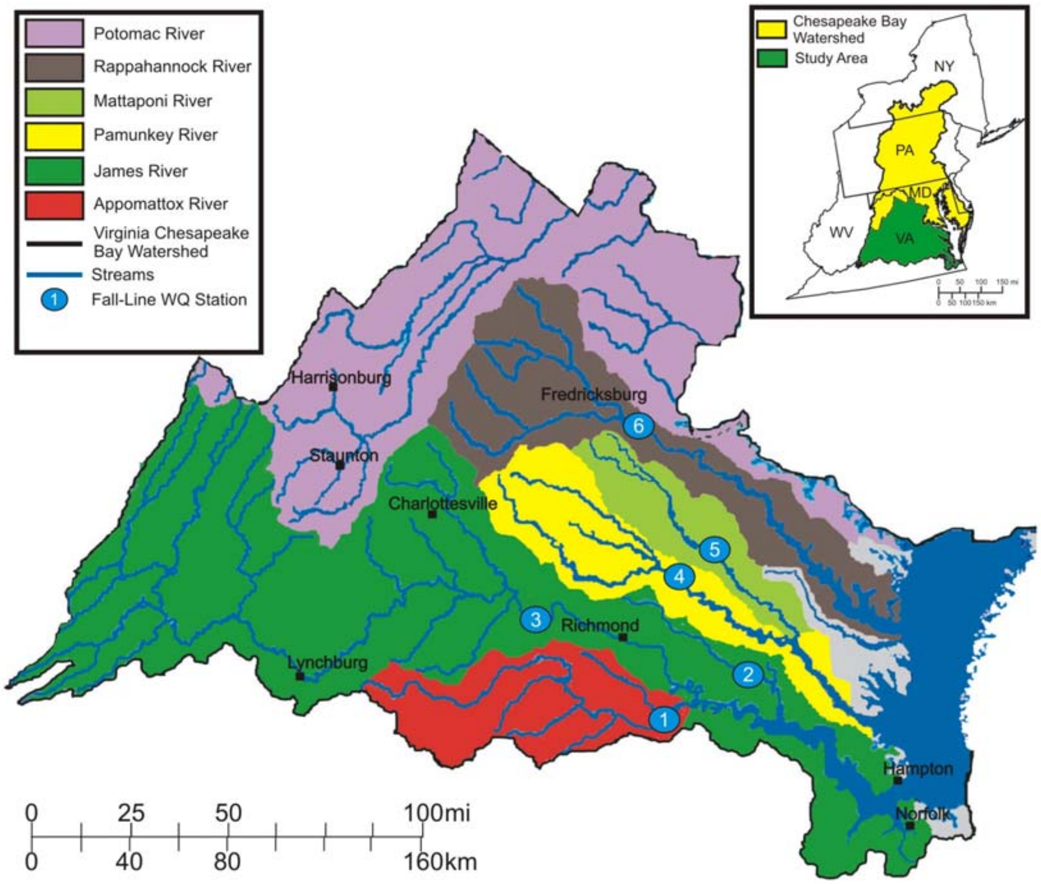


Figure 1. Location of the USGS/RIM stations in each of the Virginia tributaries.

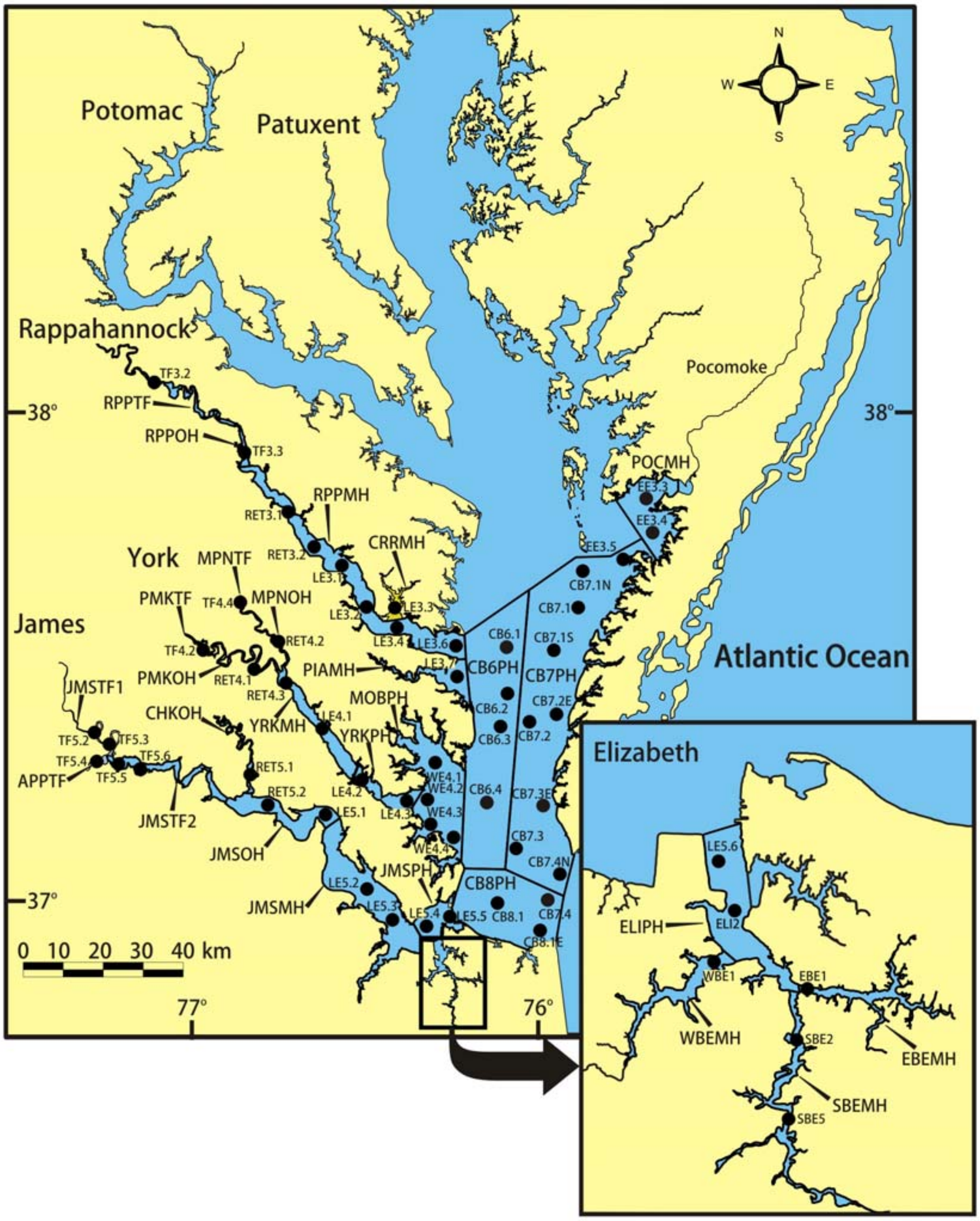


Figure 2. Chesapeake Bay Program segmentation scheme for the Virginia tributaries and Lower Chesapeake Bay Mainstem. Also shown are the locations of stations used in the statistical analyses.

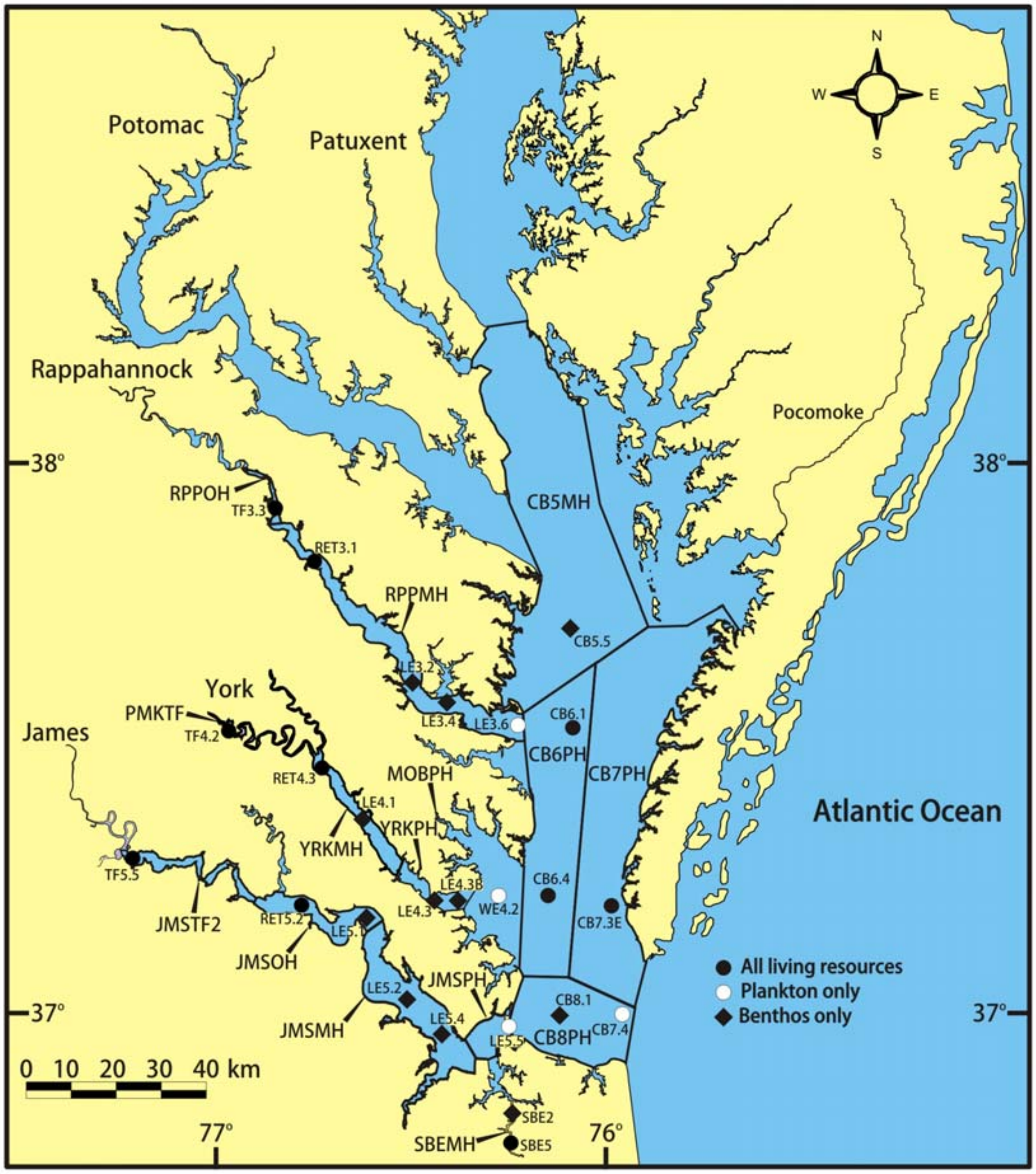
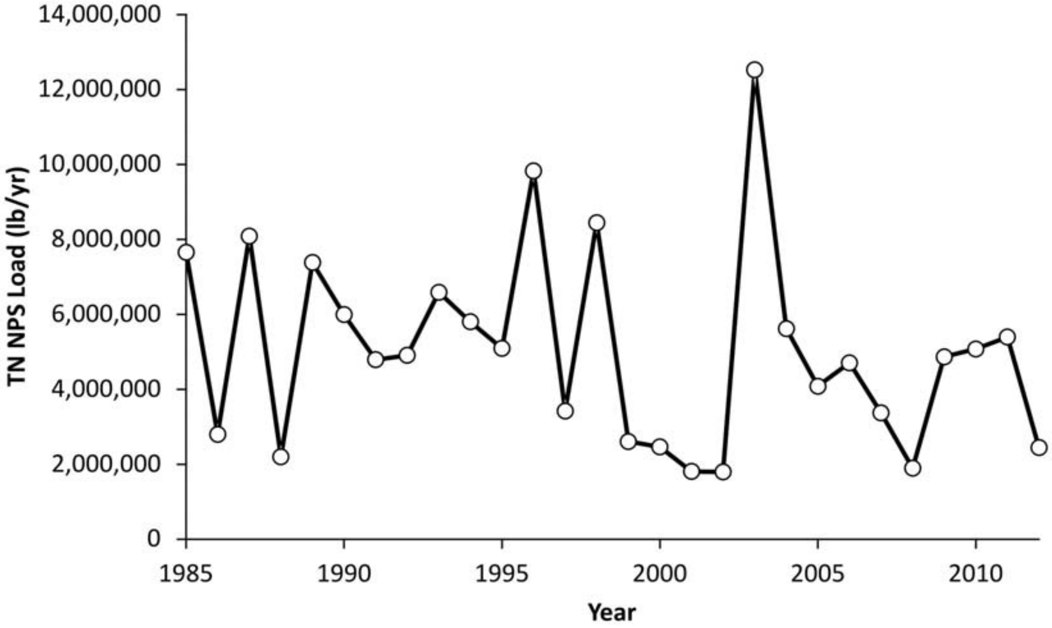


Figure 3. Living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem and their associated CBP segments.

A. James River



B. Appomattox River

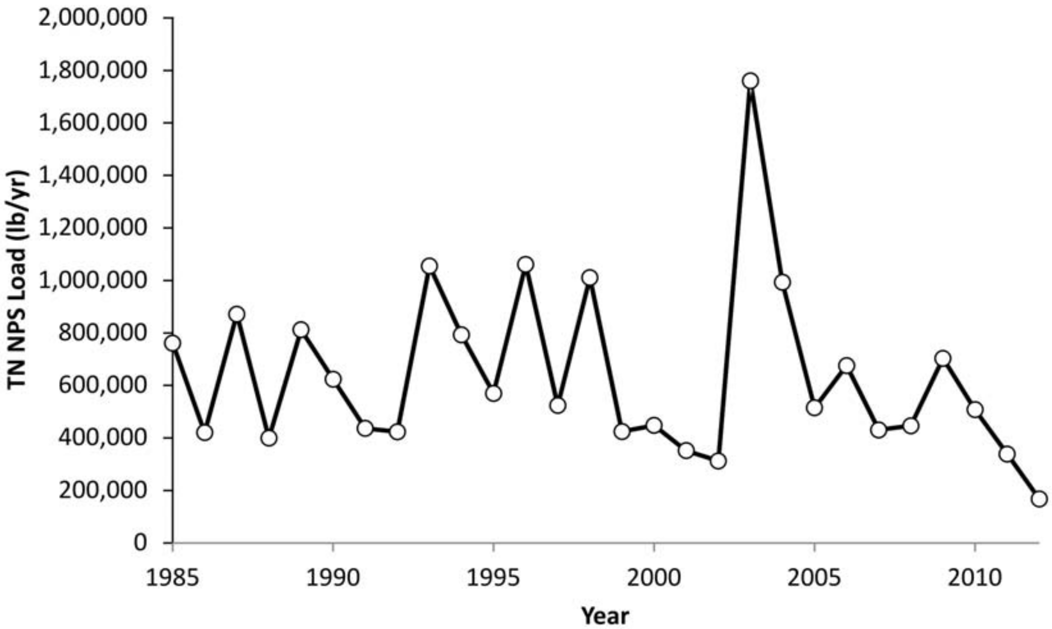
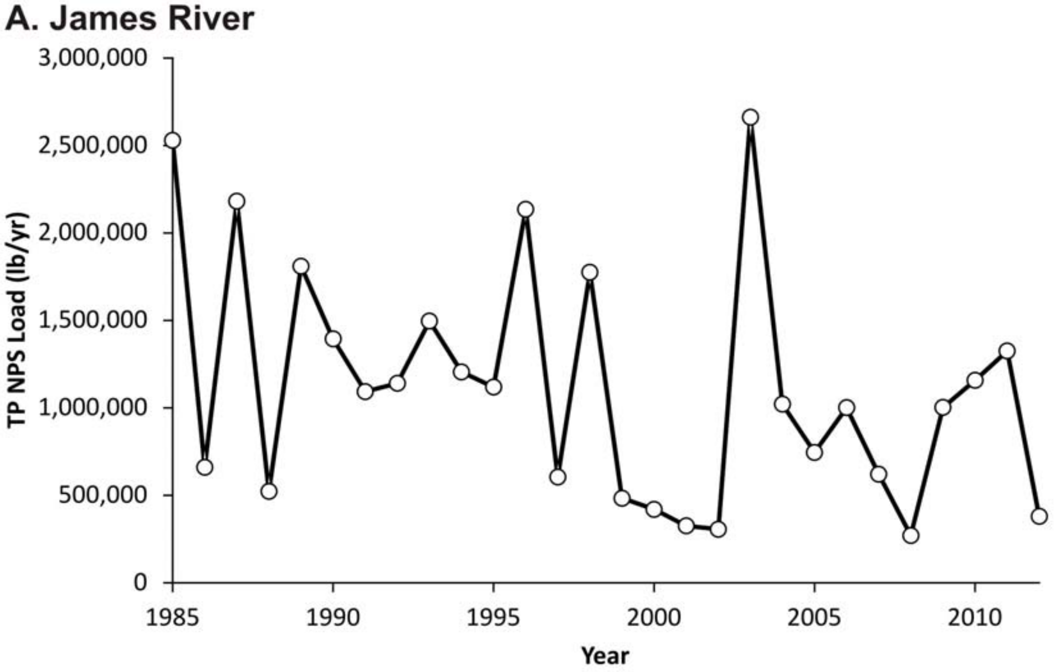


Figure 4. Long-term changes in total nitrogen load above the fall-line in the A) James River, and B) Appomattox River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).



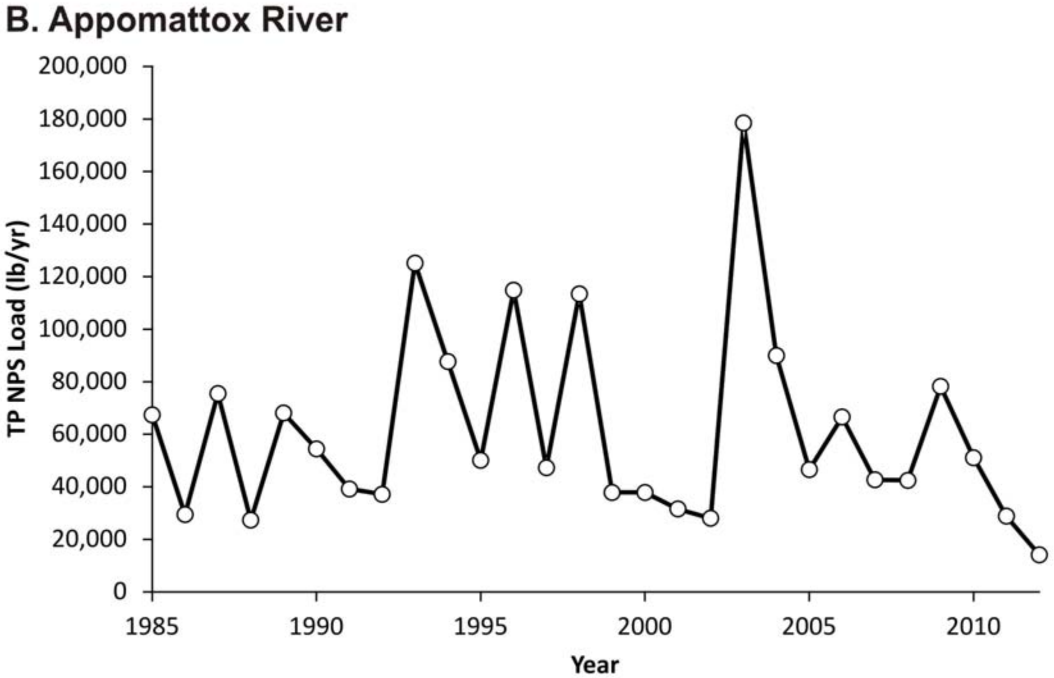


Figure 5. Long-term changes in total phosphorus load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

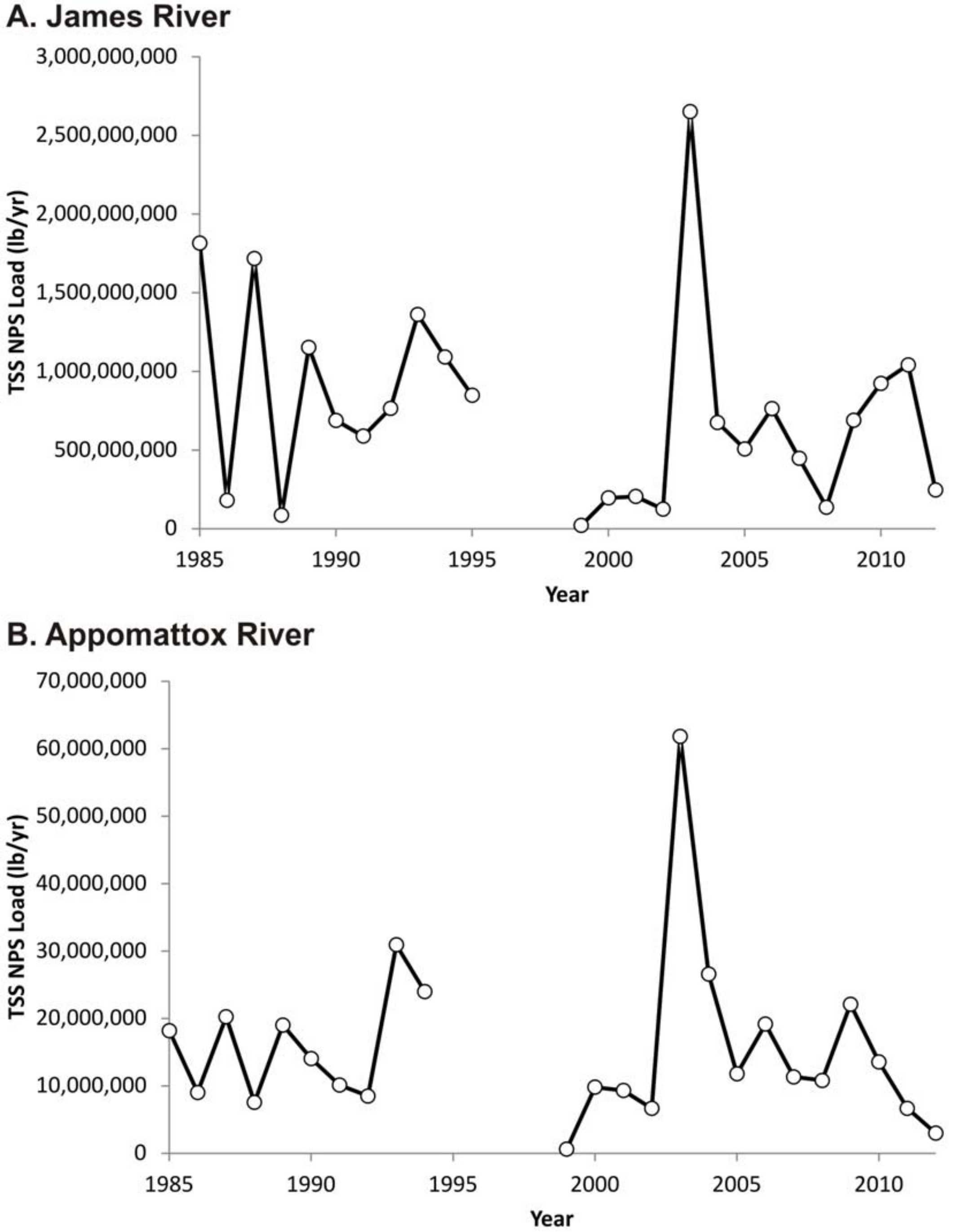
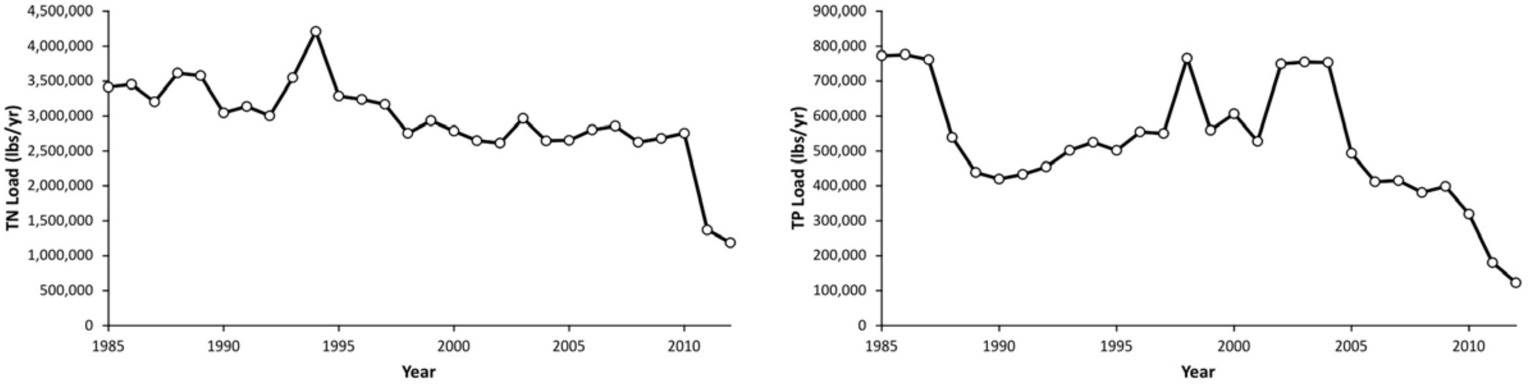


Figure 6. Long-term changes in total suspended solids load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

A) Above Fall Line Point Source Nitrogen

B) Above Fall Line Point Source Phosphorus



C) Below Fall Line Point Source Nitrogen

D) Below Fall Line Point Source Phosphorus

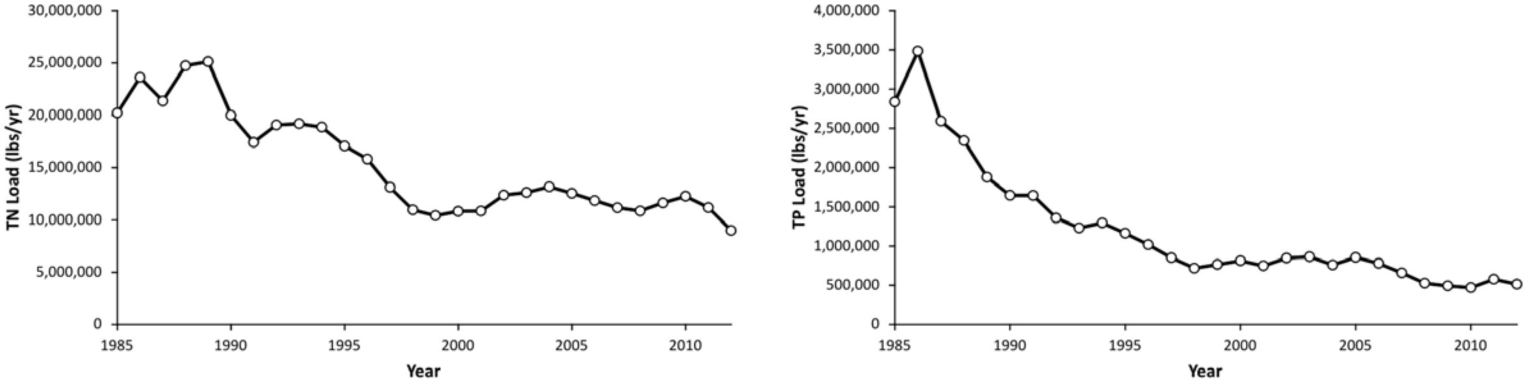


Figure 7. Long-term changes in A) Above the Fall-line Point Source Nitrogen; B) Above Fall-line Point Source Phosphorus; C) Below Fall Line Point Source Nitrogen; and D) Below Fall Line Point Source Phosphorus in the James River for 1985 through 2012. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system.

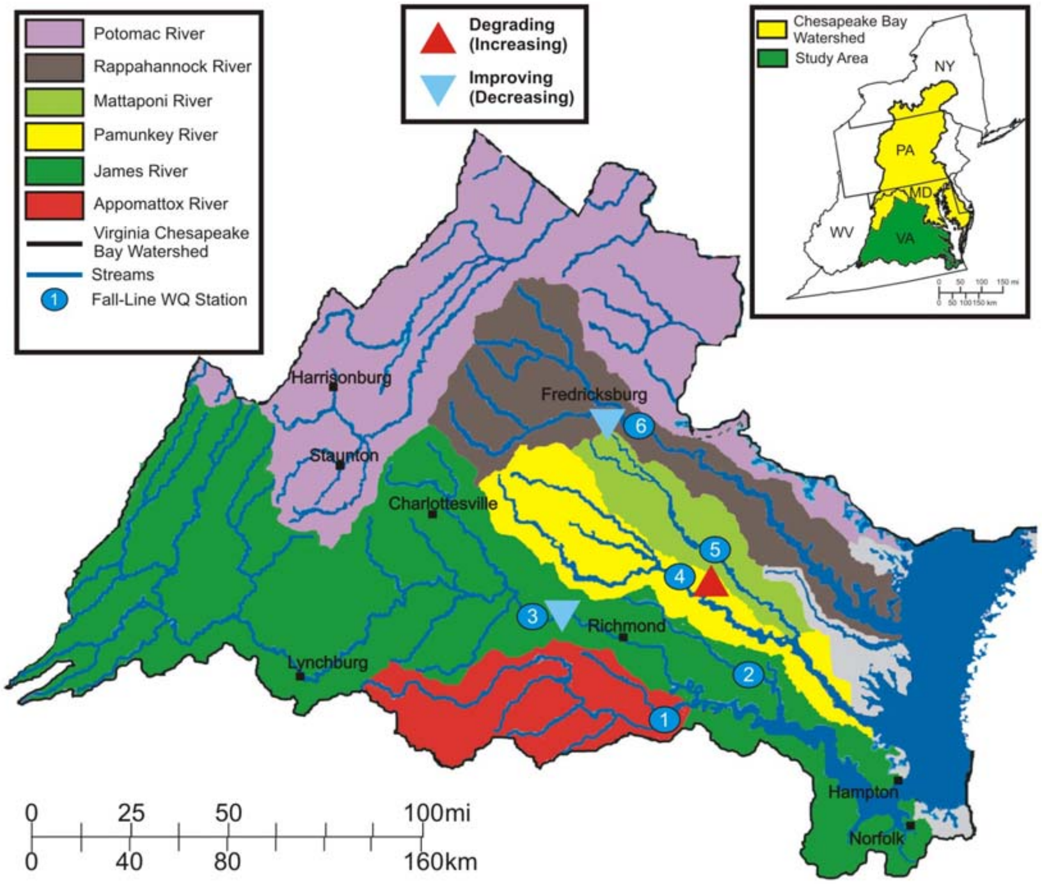


Figure 8. Long-term trends in flow-adjusted total nitrogen at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2012. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

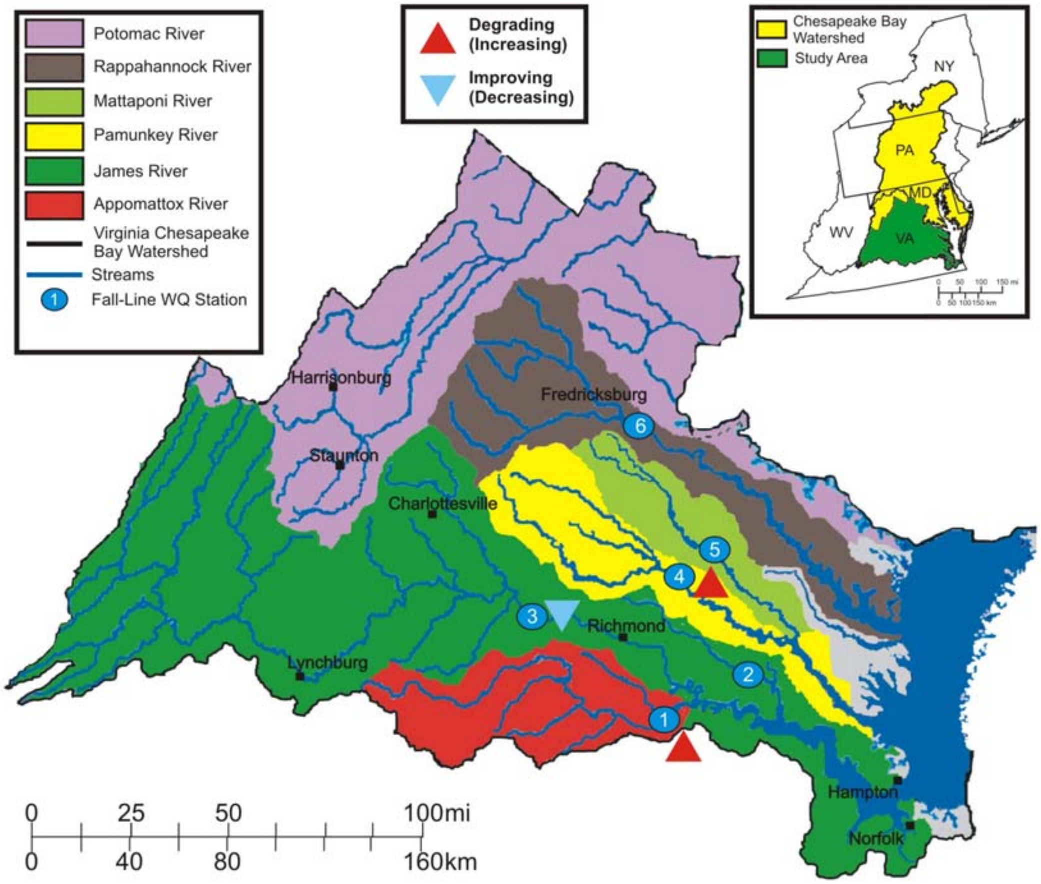


Figure 9. Long-term trends in flow-adjusted total phosphorus at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2012. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

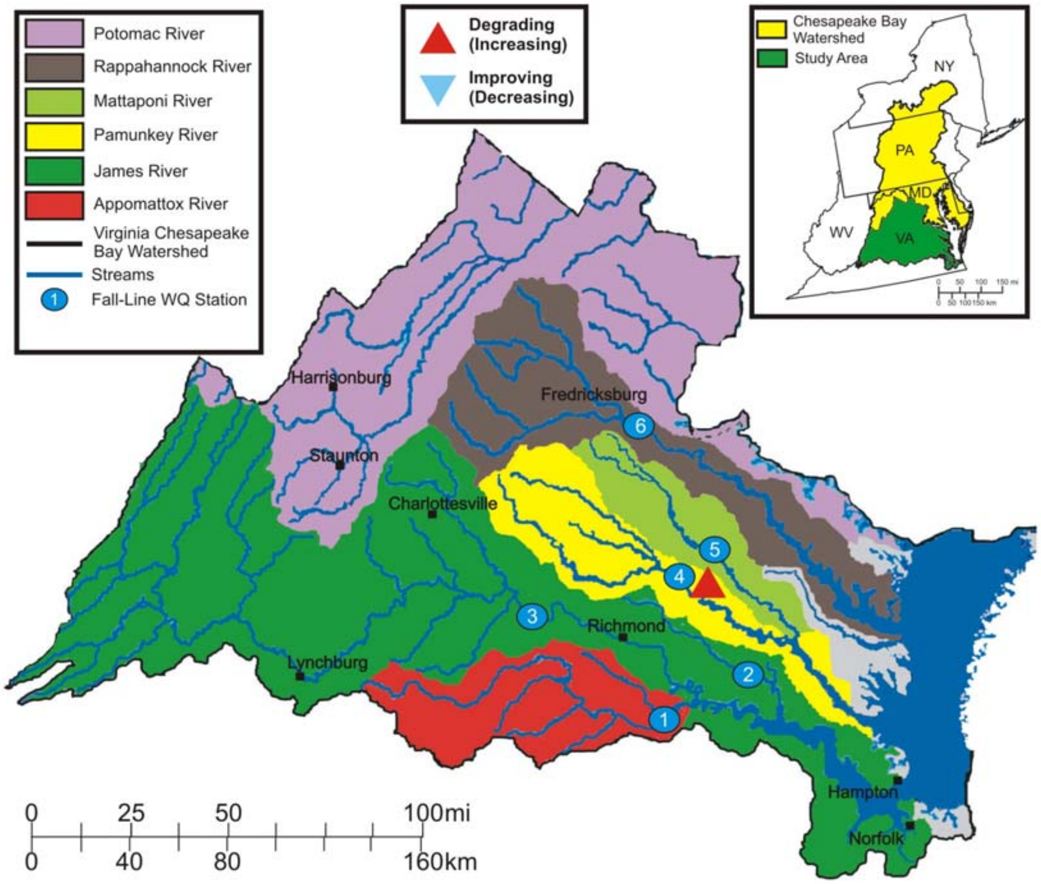
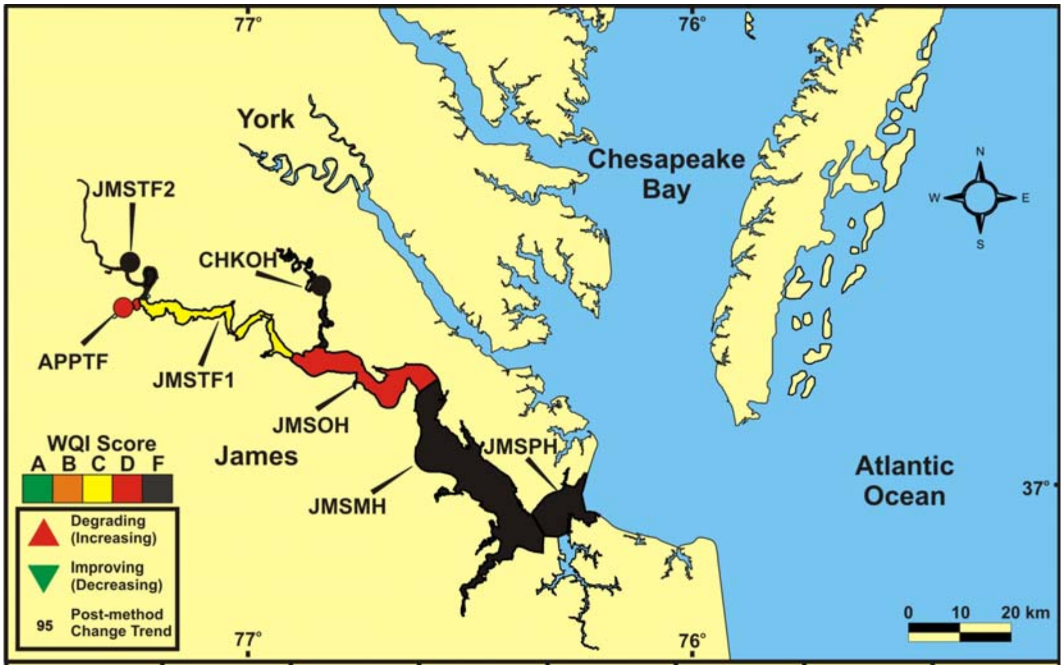
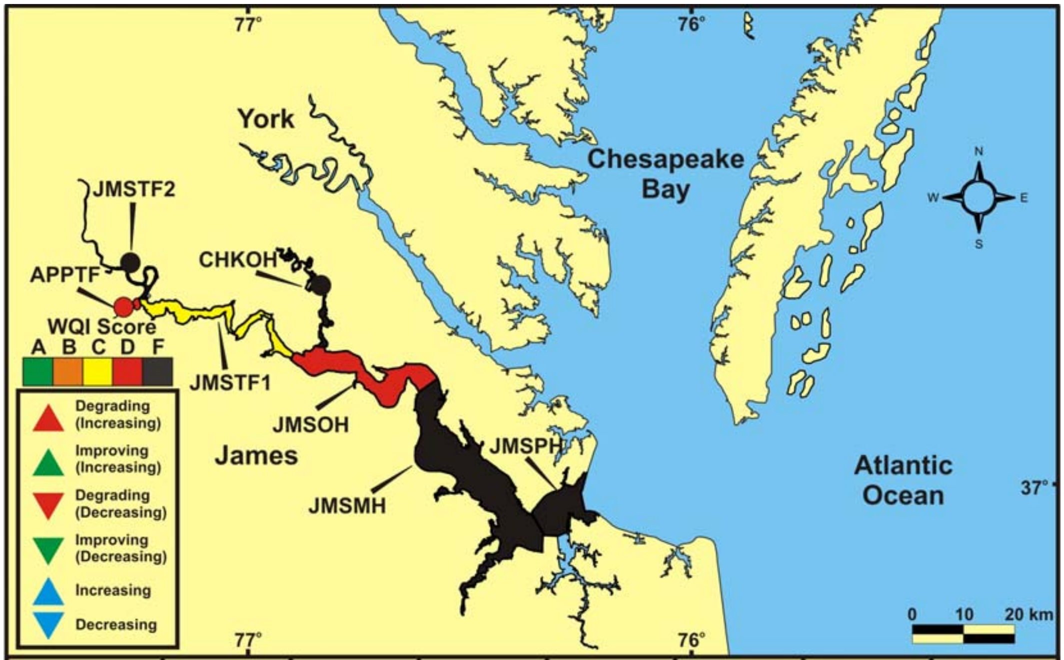


Figure 10. Long-term trends in flow-adjusted total suspended solids at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2012. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.



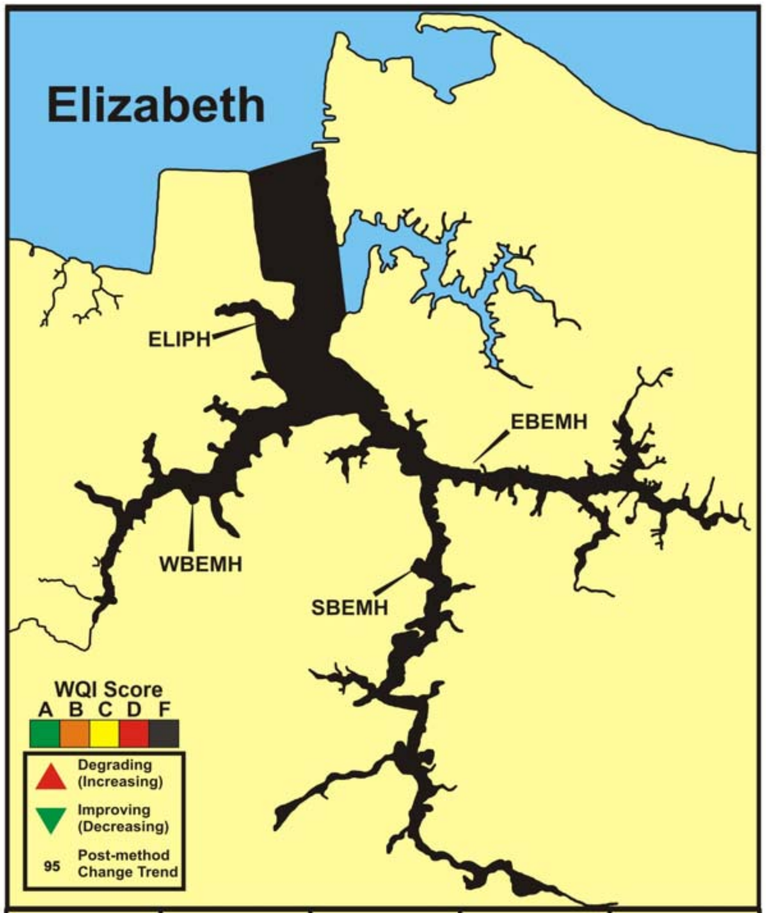
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
STN		▼ 95					
BTN		▼ 95	▼				
SDIN		▼		▲ 95			
BDIN		▼					
STP	▼ 95	▼ 95	▼				▼ 95
BTP	▼ 95	▼ 95	▼	▼ 95			▼ 95
SDIP	▼	▼	▼	▼ 95			
BDIP	▼	▼	▼	▼			

Figure 11. Water quality status and long-term trends in nutrient parameters in the tidal portion of the James River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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.



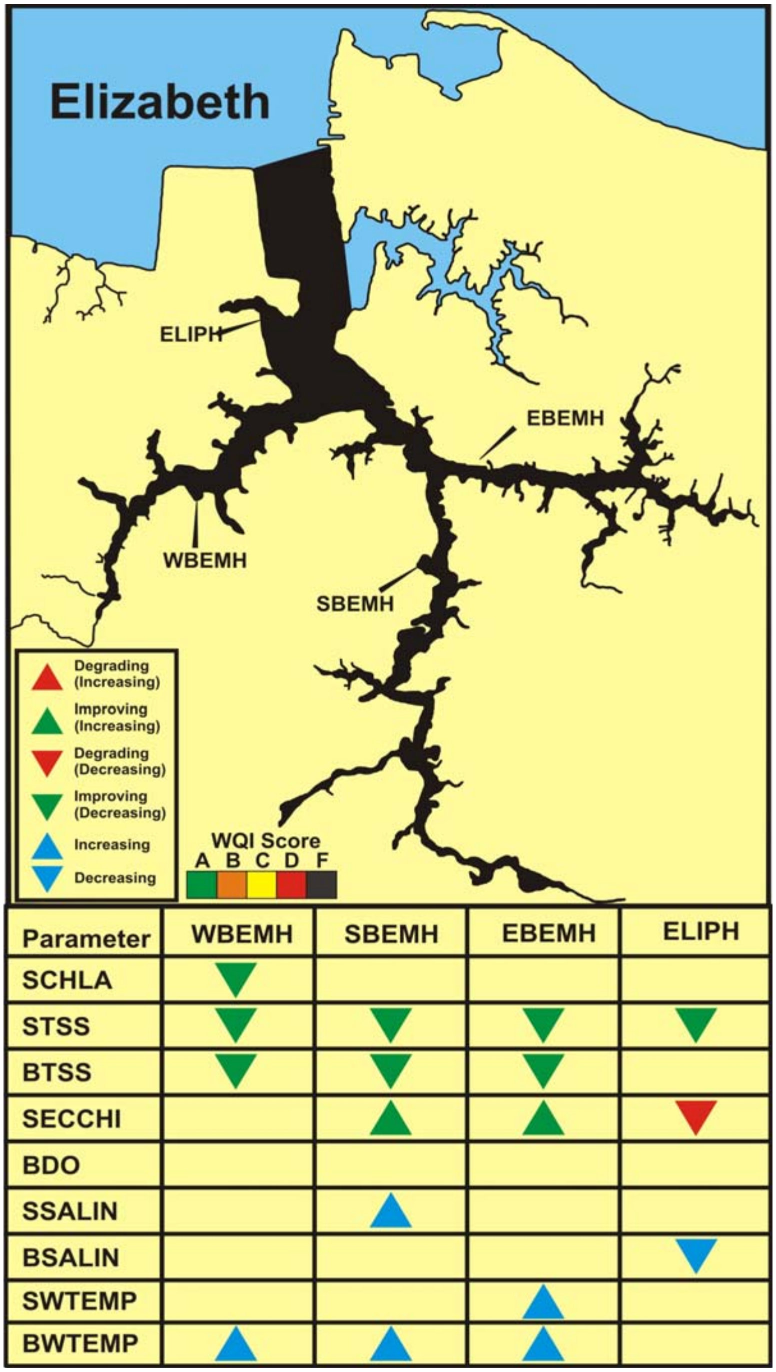
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
SCHLA			▼	▼			▲
STSS	▼		▼				
BTSS							▼
SECCHI		▼		▼			▼
BDO					▼		▲
SSALIN					▲		
BSALIN					▲		▼
SWTEMP	▲						
BWTEMP							▲

Figure 12. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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. 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) for the period of 1989 through 2011. Trends presented were those that were statistically significant (*P* < 0.01) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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	▼			
STSS	▼	▼	▼	▼
BTSS	▼	▼	▼	
SECCHI		▲	▲	🔻
BDO				
SSALIN		△		
BSALIN				▽
SWTEMP			△	
BWTEMP	△	△	△	

Figure 14. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012. 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.

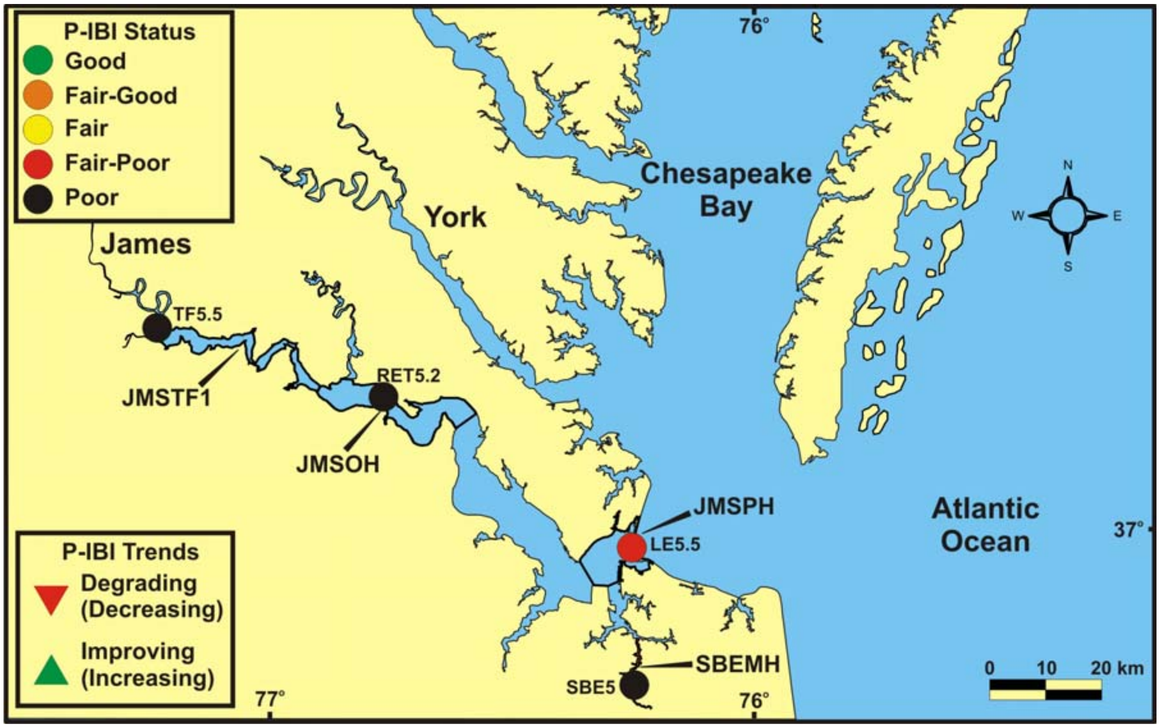


Figure 15. Status and long-term trends in phytoplankton community condition in the tidal portion of the James River basin for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the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

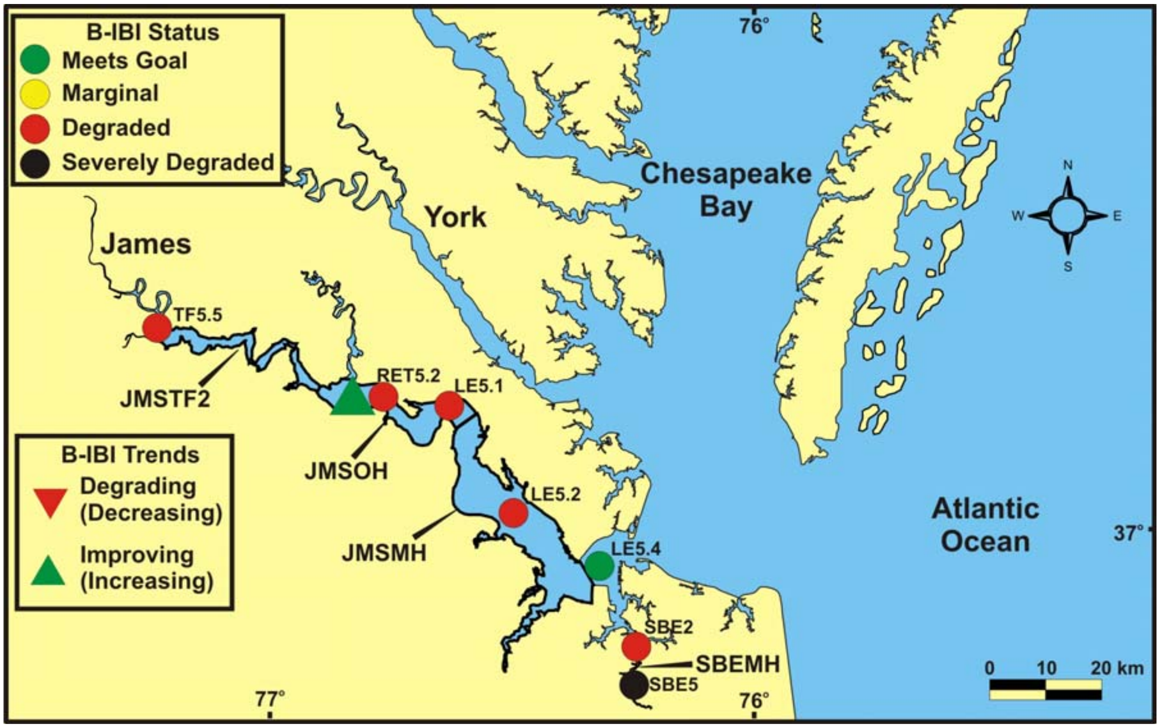


Figure 16. Status and long-term trends in benthic community condition in the tidal portion of the James River basin for the period of 1985 through 2012. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2012.

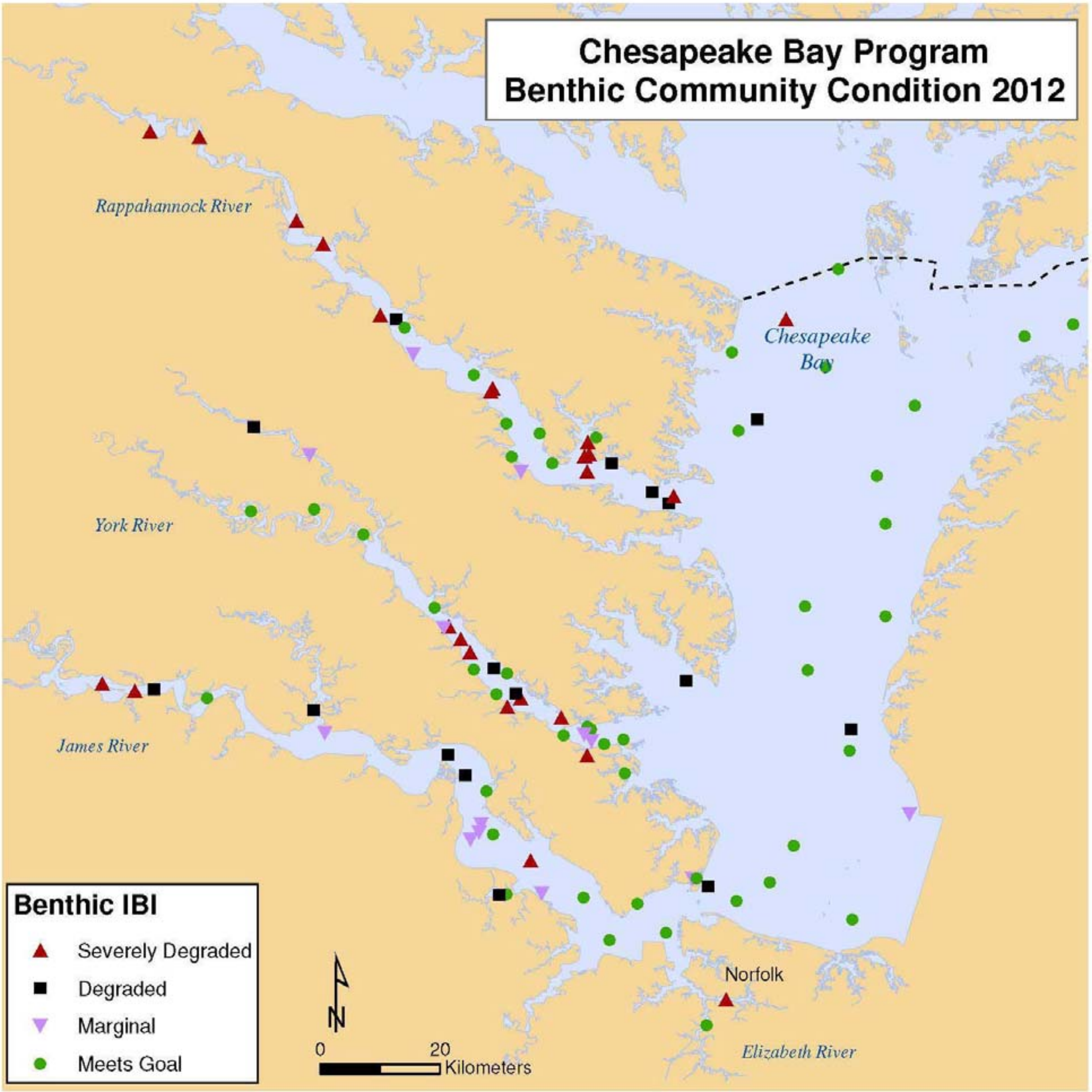


Figure 17. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2012. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals. Figure was reproduced from Llanso et al., 2013.

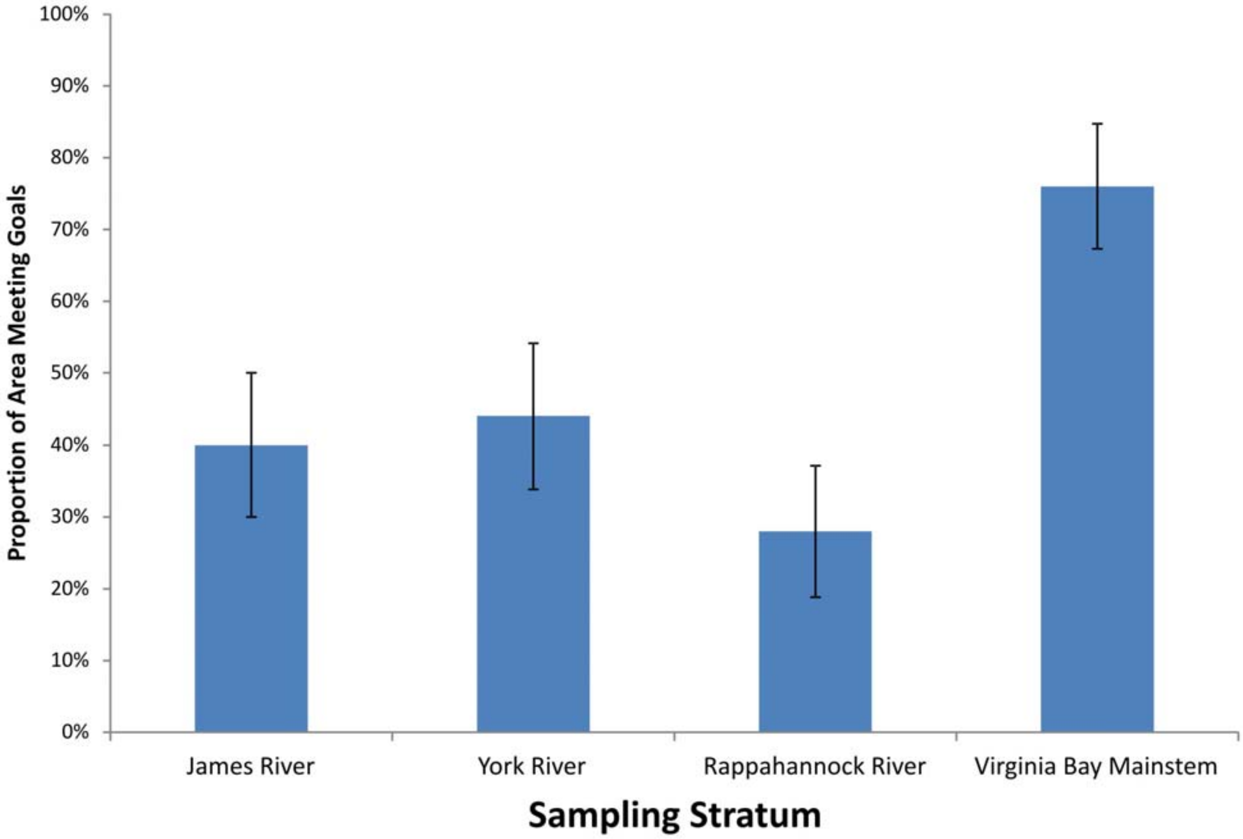


Figure 18. Percentage of area in the Virginia sampling strata meeting the benthic community Restoration Goals in Virginia for 2012(± 1S.E). Data provided by Versar Inc.

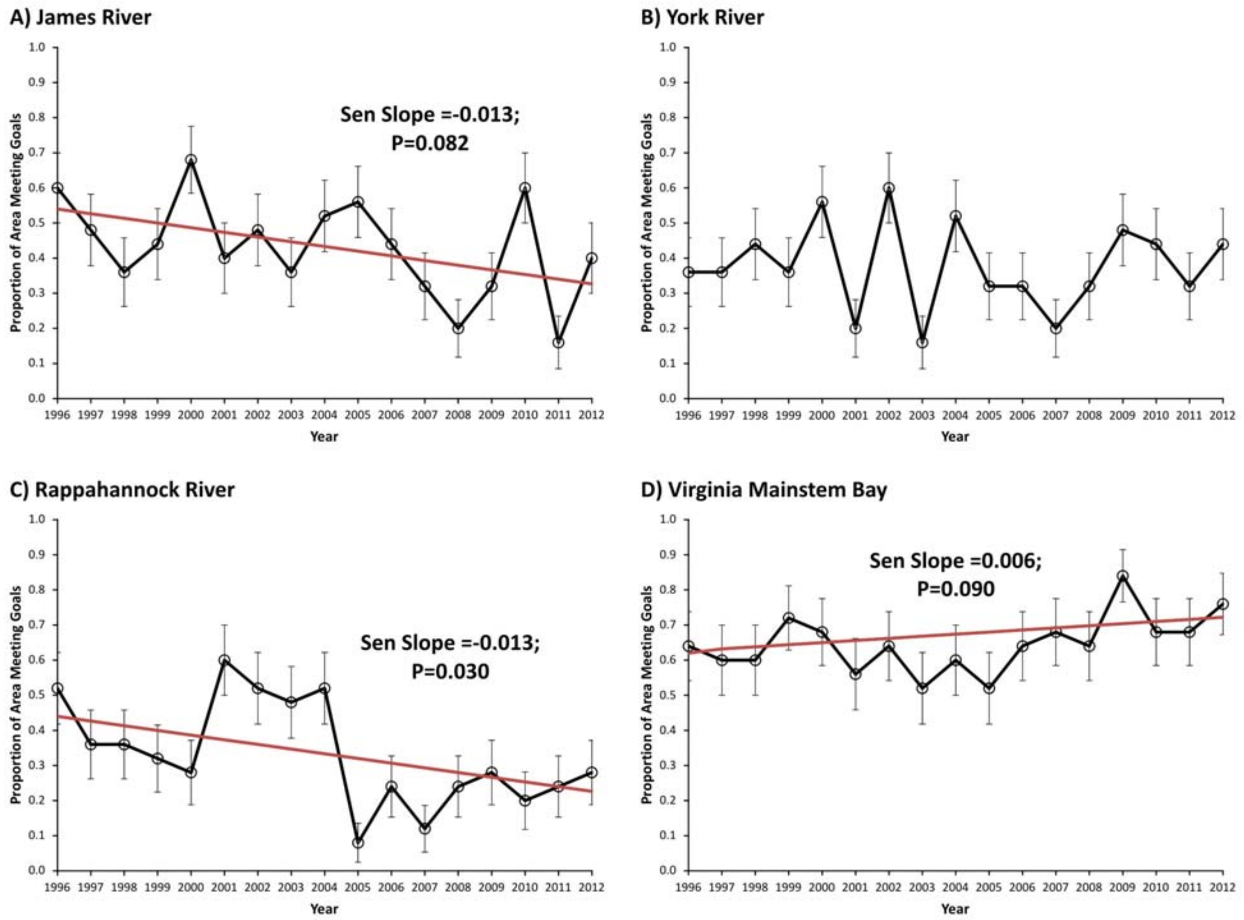
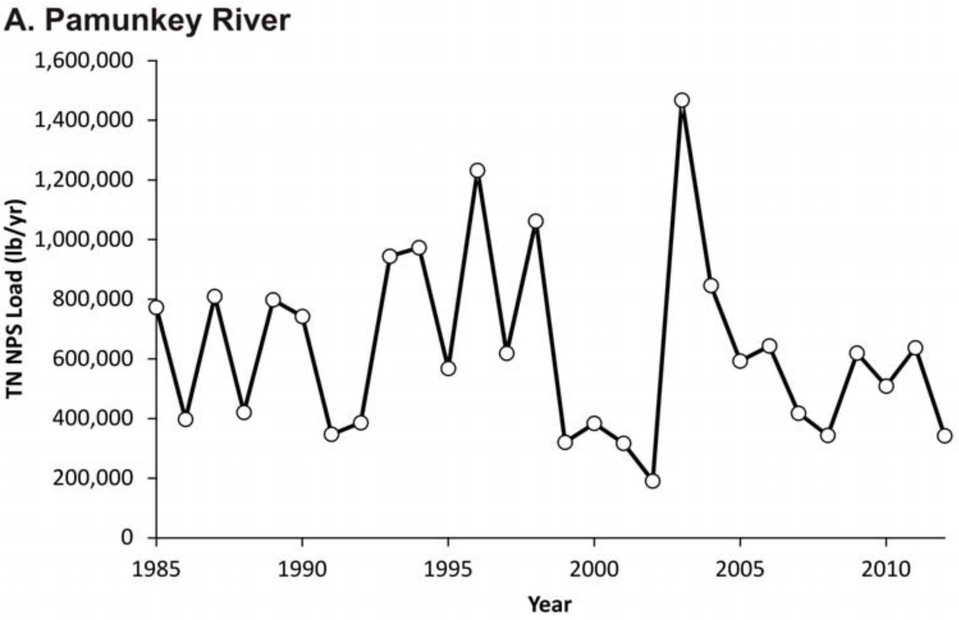


Figure 19. Long term trends of the proportion of area meeting the benthic community Restoration Goals for each of the major sampling strata in Virginia for the period of 1996 through 2012. Error bars are ± S.E. of the mean. Data provided by Versar Inc.



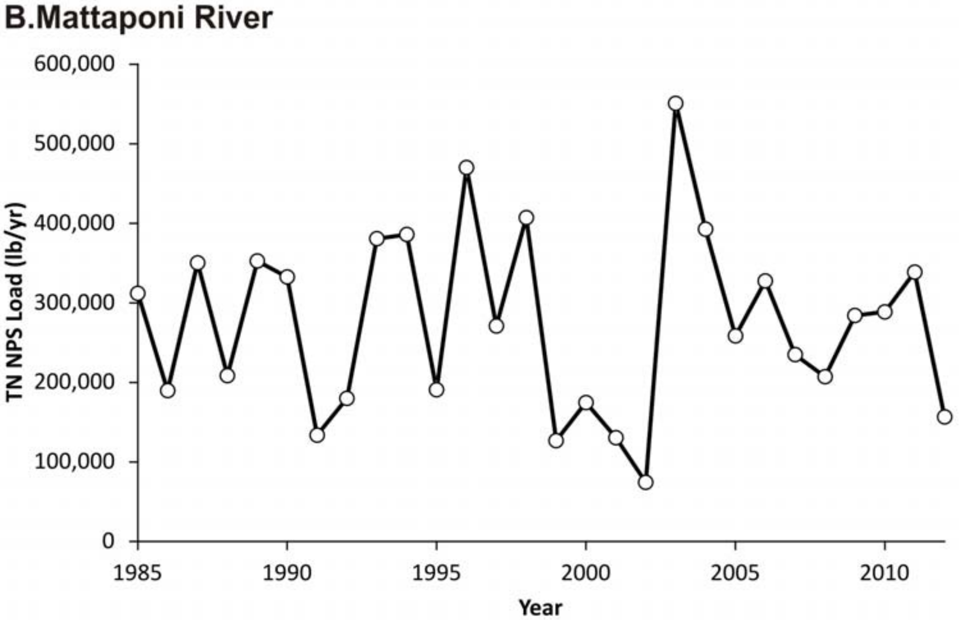
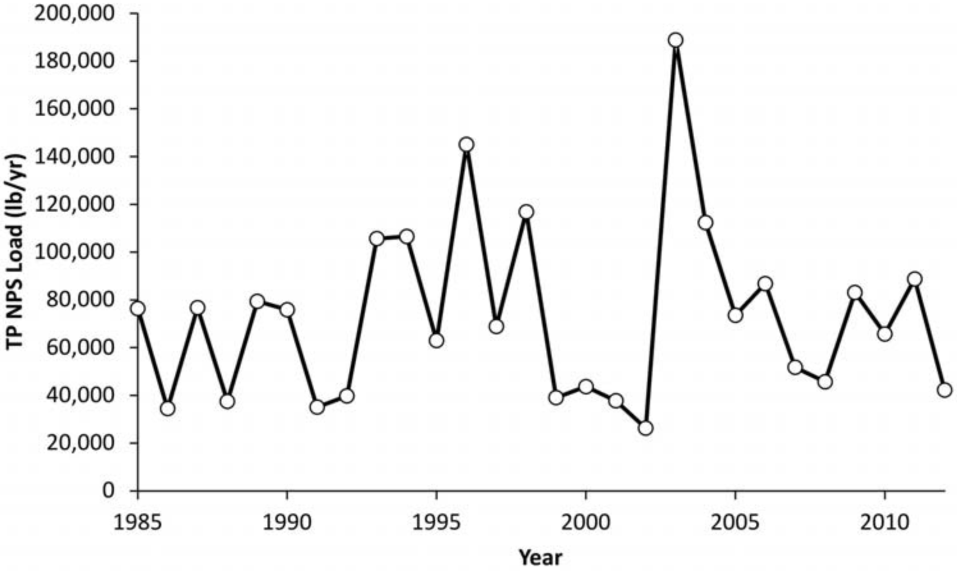


Figure 20. Long-term changes in total nitrogen load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

A. Pamunkey River



B. Mattaponi River

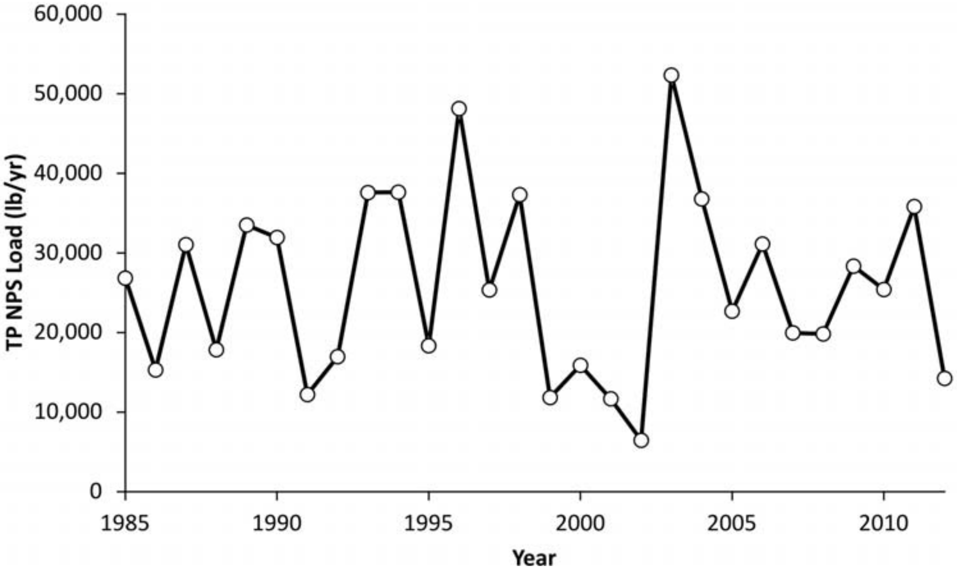
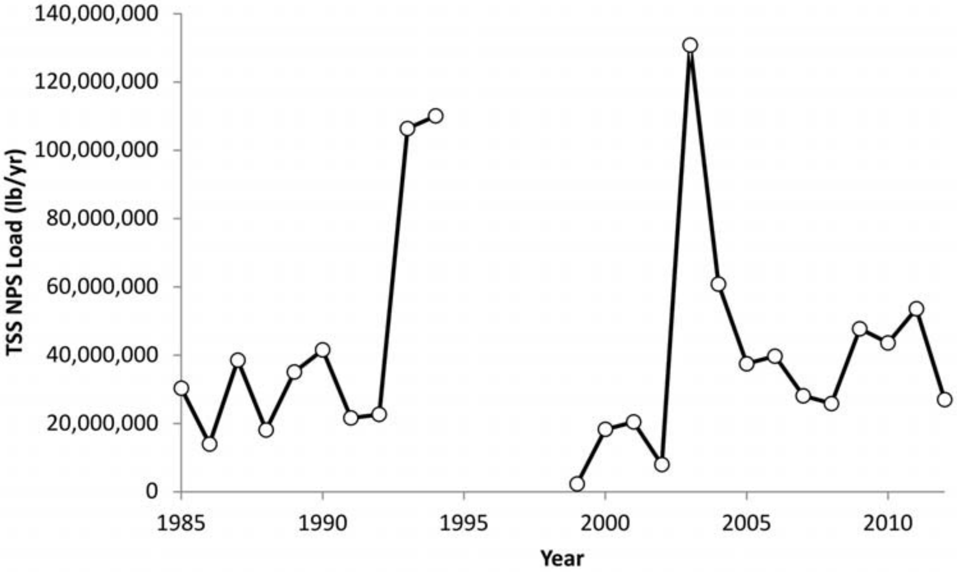


Figure 21. Long-term changes in total phosphorus load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

A. Pamunkey River



B. Mattaponi River

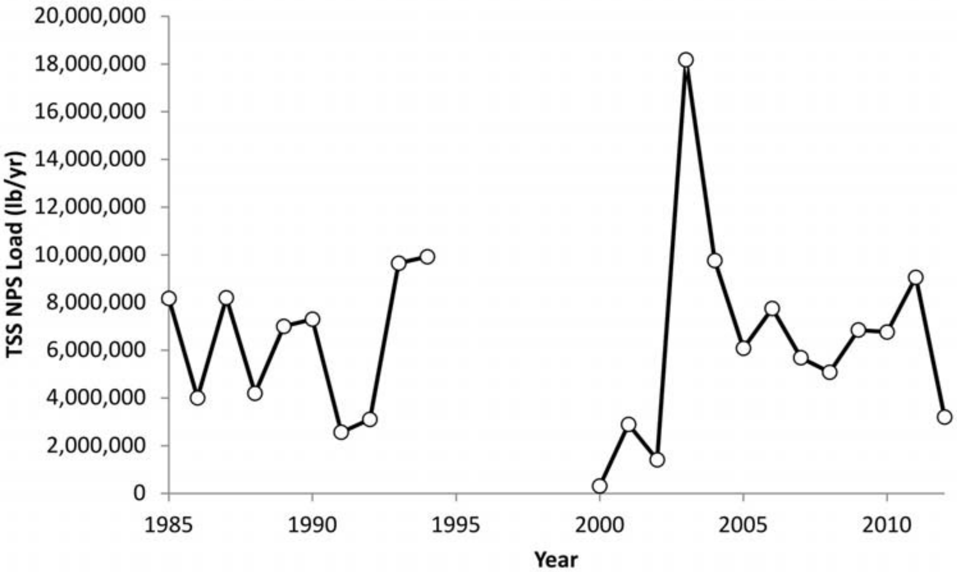
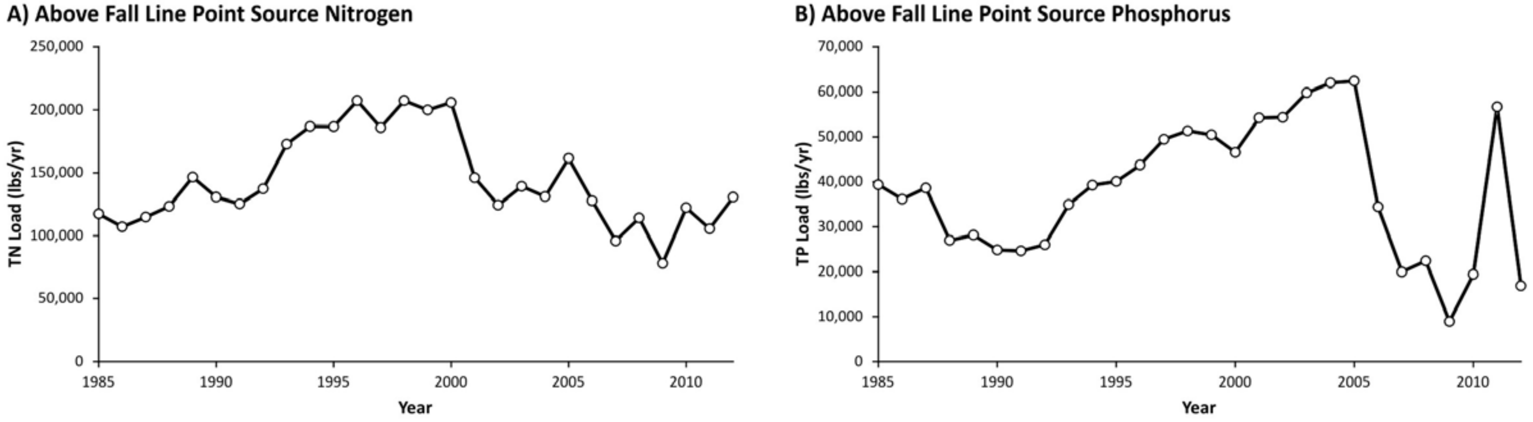
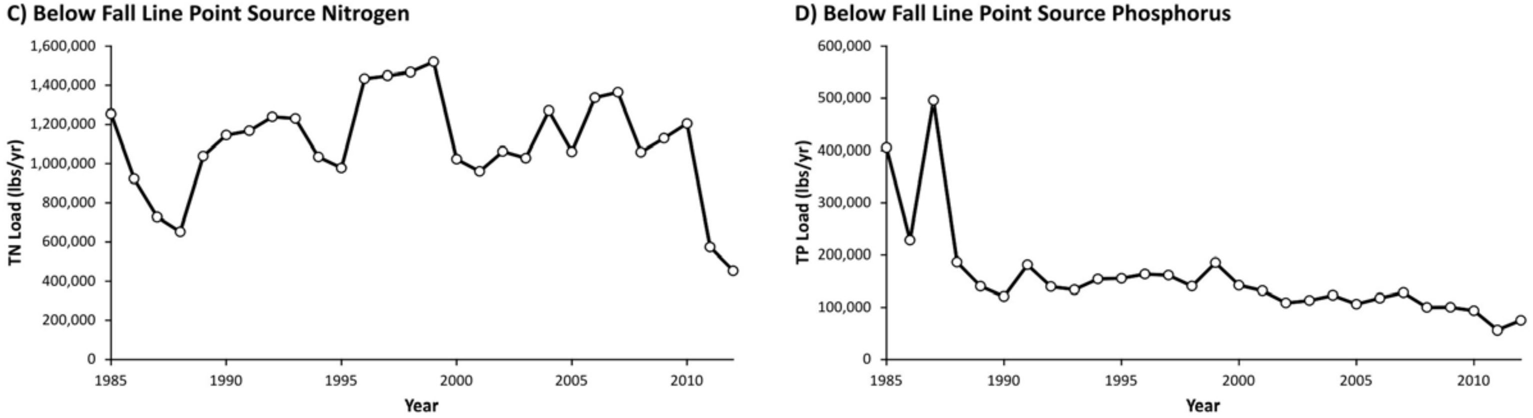


Figure 22. Long-term changes in total suspended solids load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.



A) Above Fall Line Point Source Nitrogen

B) Above Fall Line Point Source Phosphorus

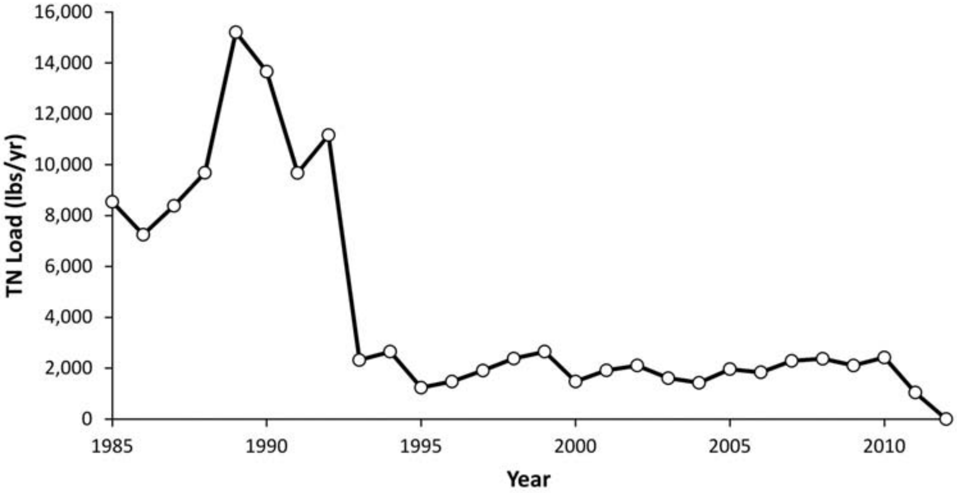


C) Below Fall Line Point Source Nitrogen

D) Below Fall Line Point Source Phosphorus

Figure 23. Long-term changes in A) Above Fall Line Point Source Nitrogen; B) Above Fall Line Point Source Phosphorus; C) Below Fall Line Point Source Nitrogen; and D) Below Fall Line Point Source Phosphorus in the York River for 1985 through 2012. Loadings presented from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

A) Below Fall-Line Point Source Nitrogen



B) Below Fall-line Point Source Phosphorus

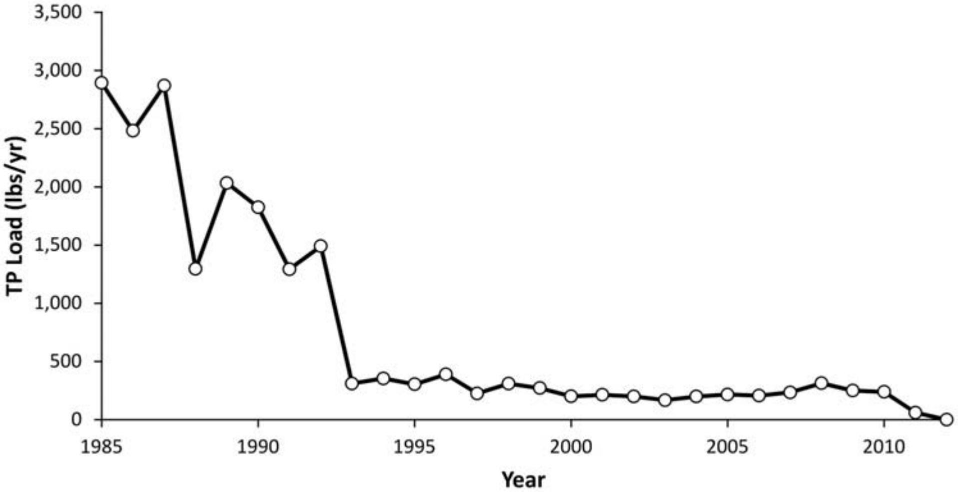
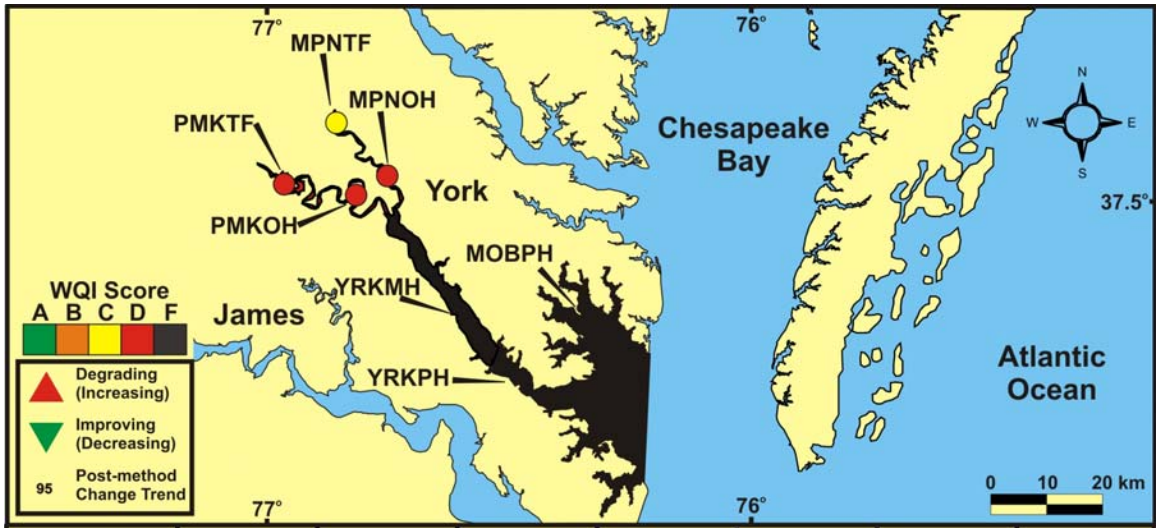
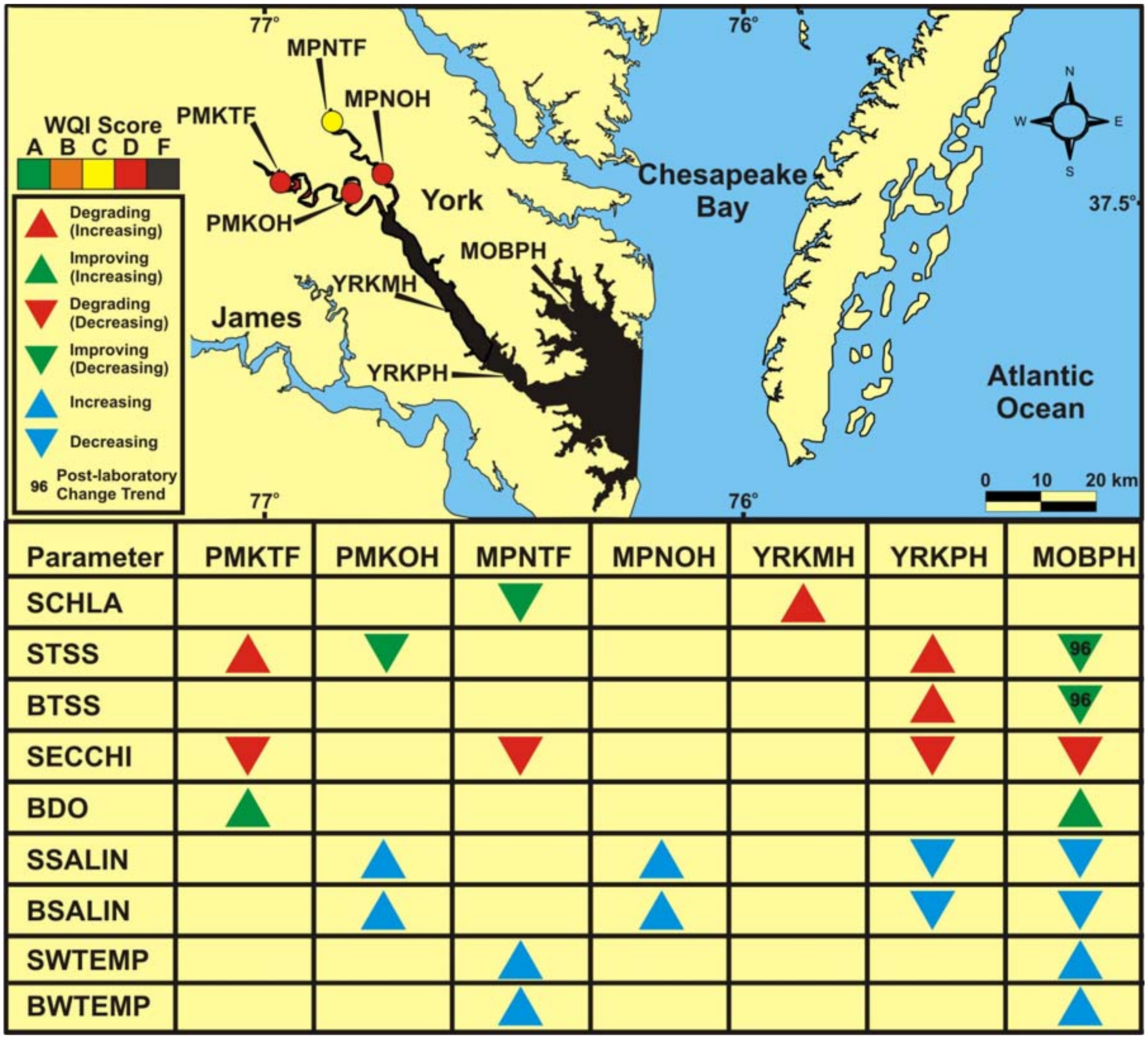


Figure 24. Long-term changes in A) Below Fall-Line Point Source Nitrogen and B) Below Fall-Line Point Source Total Phosphorus in Mobjack Bay for 1985 through 2012. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



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

Figure 25. Water quality status and long-term trends in nutrient parameters in the tidal portion of the York River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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			▼		▲		
STSS	▲	▼				▲	▼ 96
BTSS						▲	▼ 96
SECCHI	▼		▼			▼	▼
BDO	▲						▲
SSALIN		▲		▲		▼	▼
BSALIN		▲		▲		▼	▼
SWTEMP			▲				▲
BWTEMP			▲				▲

Figure 26. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the York River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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.

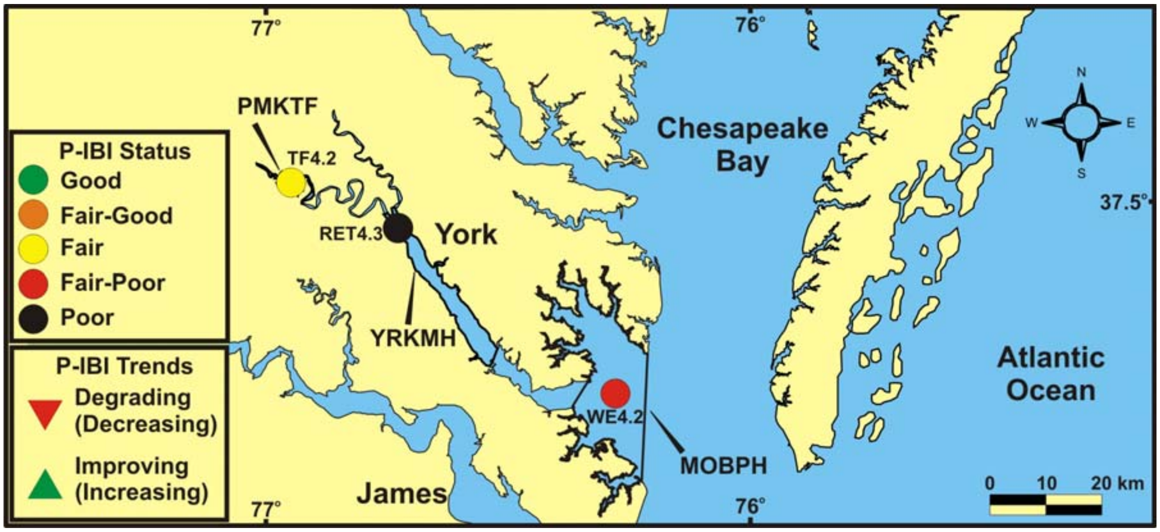


Figure 27. Status and long-term trends in phytoplankton community condition in the tidal portion of the York River basin for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

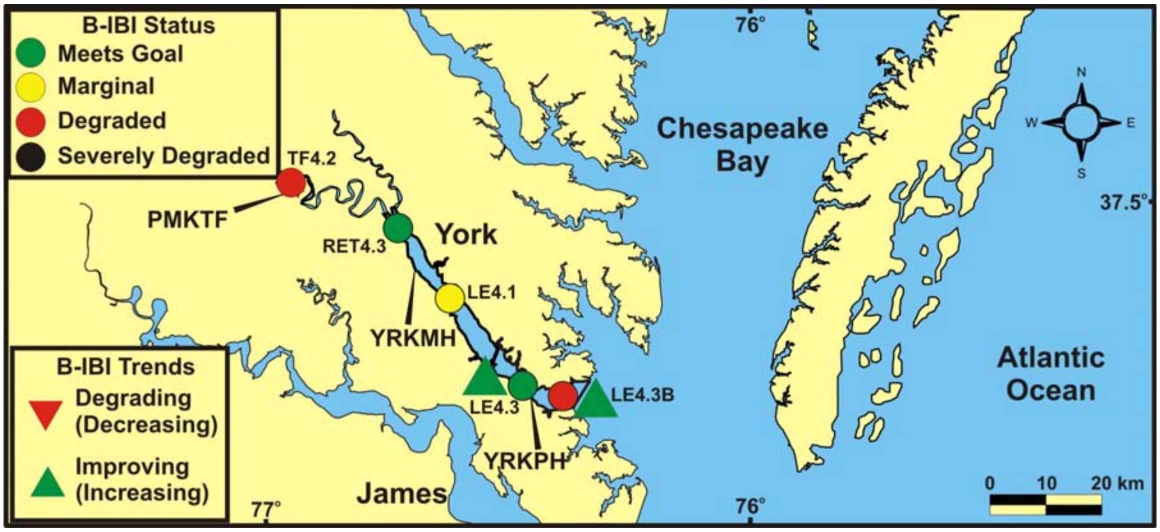
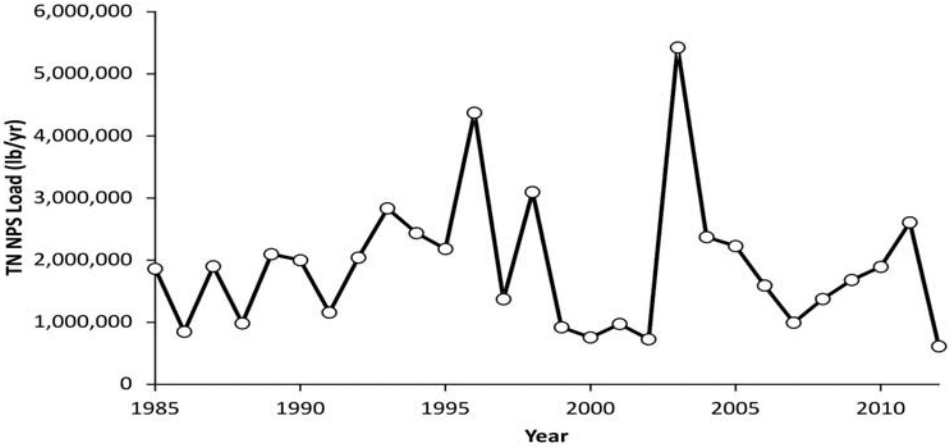
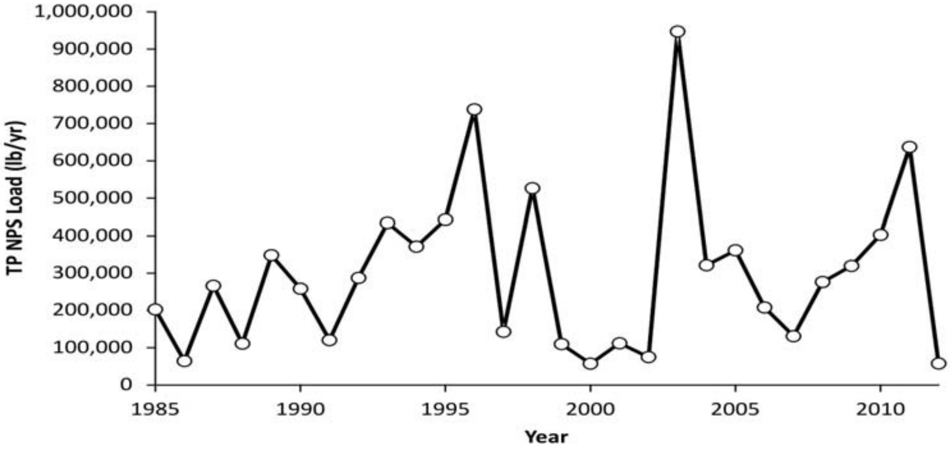


Figure 28. Status and long-term trends in benthic community condition in the tidal portion of the York River basin for the period of 1985 through 2012. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2012.

A. Total nitrogen



B. Total phosphorous



C. Total sediment

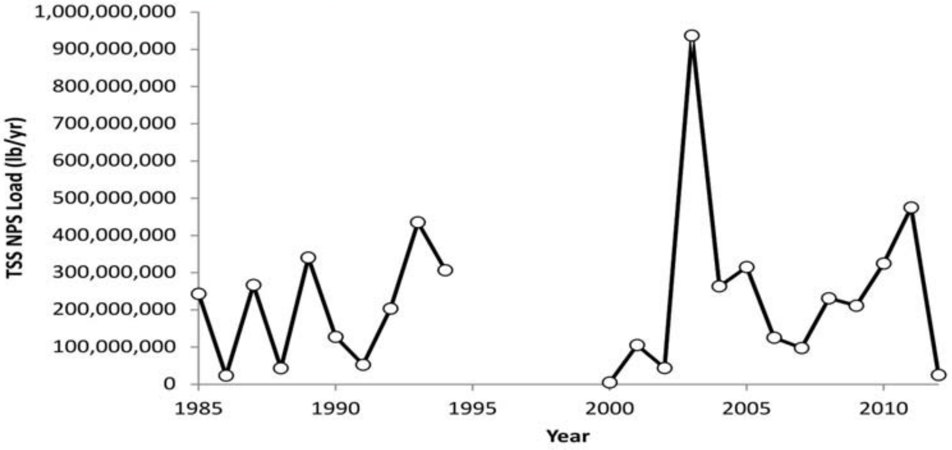


Figure 29. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment loads at the fall-line in the Rappahannock River from 1985 through 2012. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

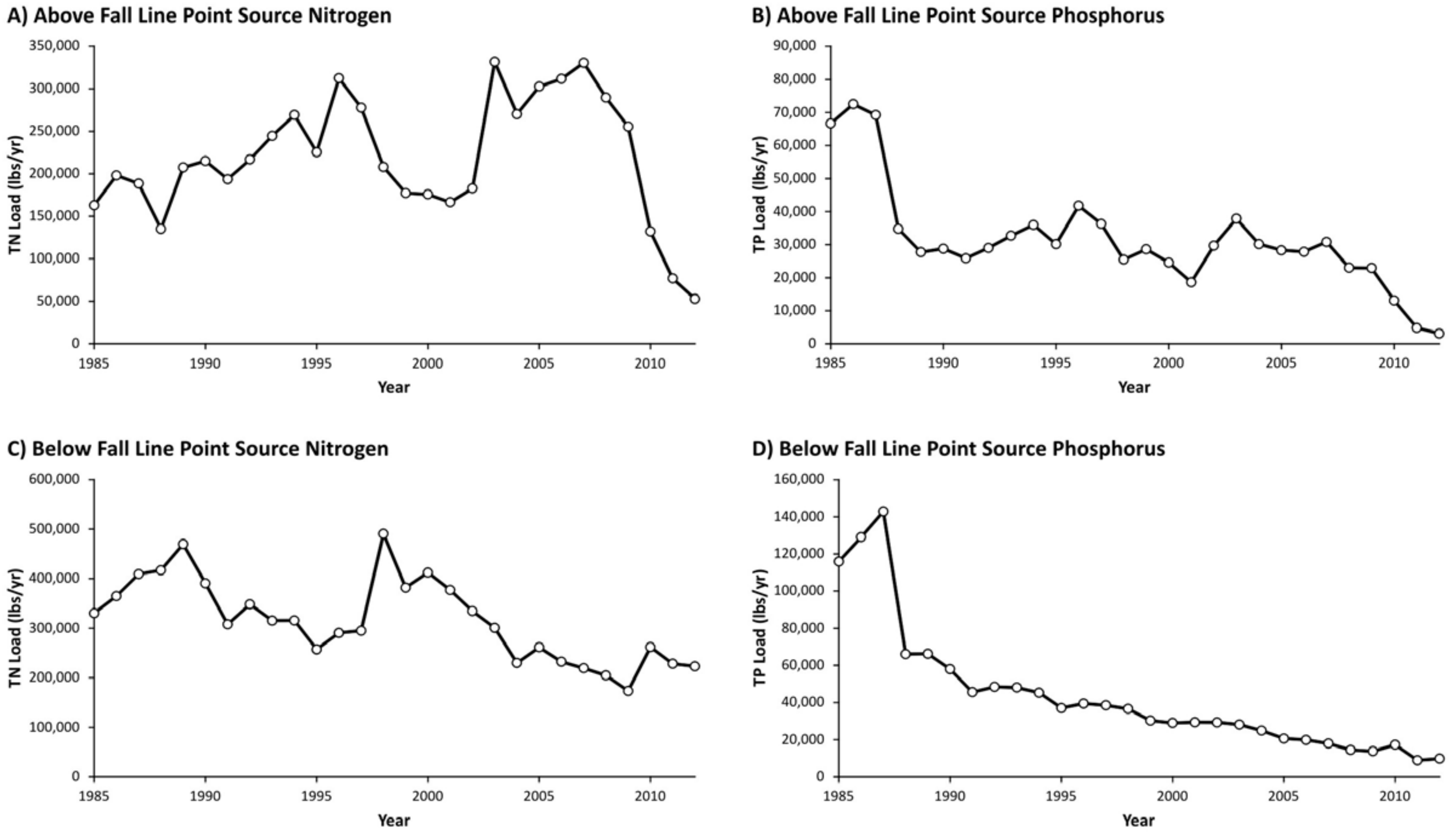
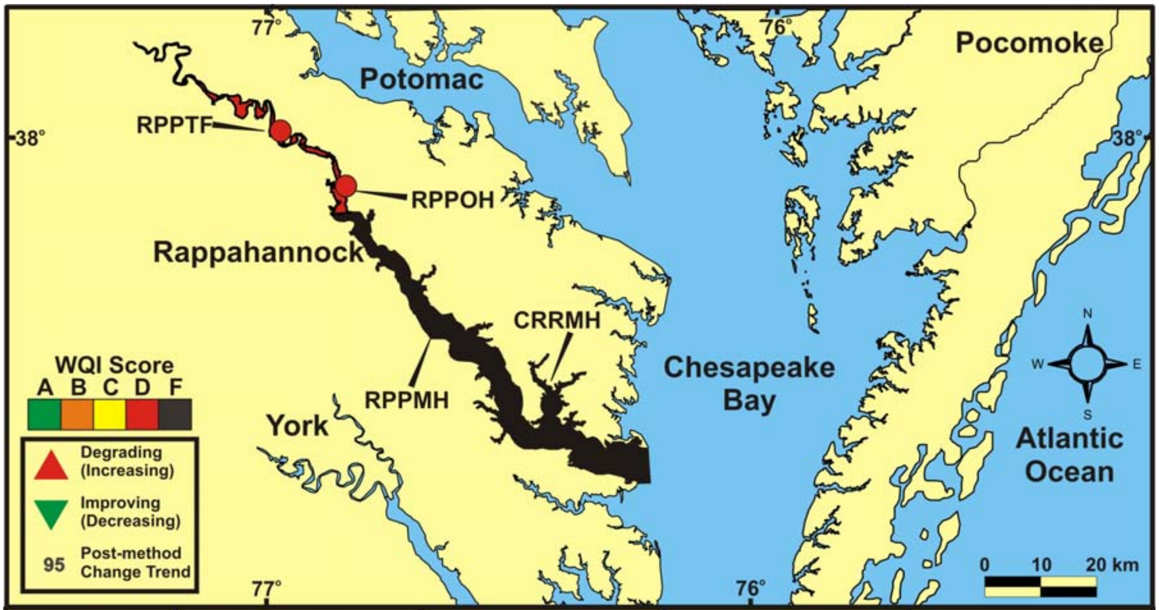
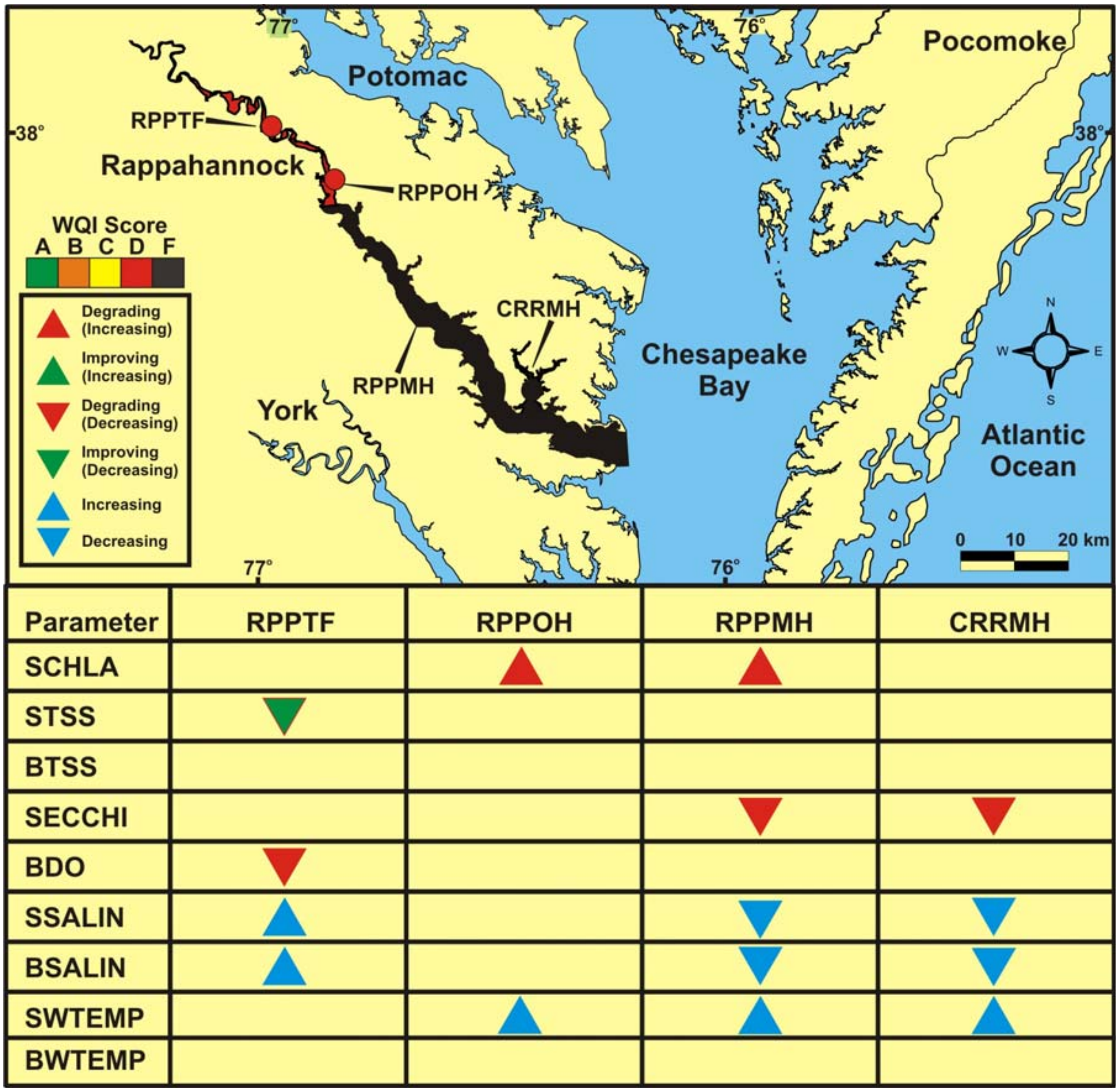


Figure 30. Long-term changes in point source loads in A) Above Fall Line Total Nitrogen; B) Above Fall Line Total Phosphorus; C) Below Fall Line Total Nitrogen; and D) Below Fall Line Total Phosphorus in the Rappahannock River for 1985 through 2012. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



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

Figure 31. Water quality status and long-term trends in nutrient parameters in the tidal portion of the Rappahannock River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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 32. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the Rappahannock River basin. 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) for the period of 1985 through 2011. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2012 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2012. 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 33. 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.

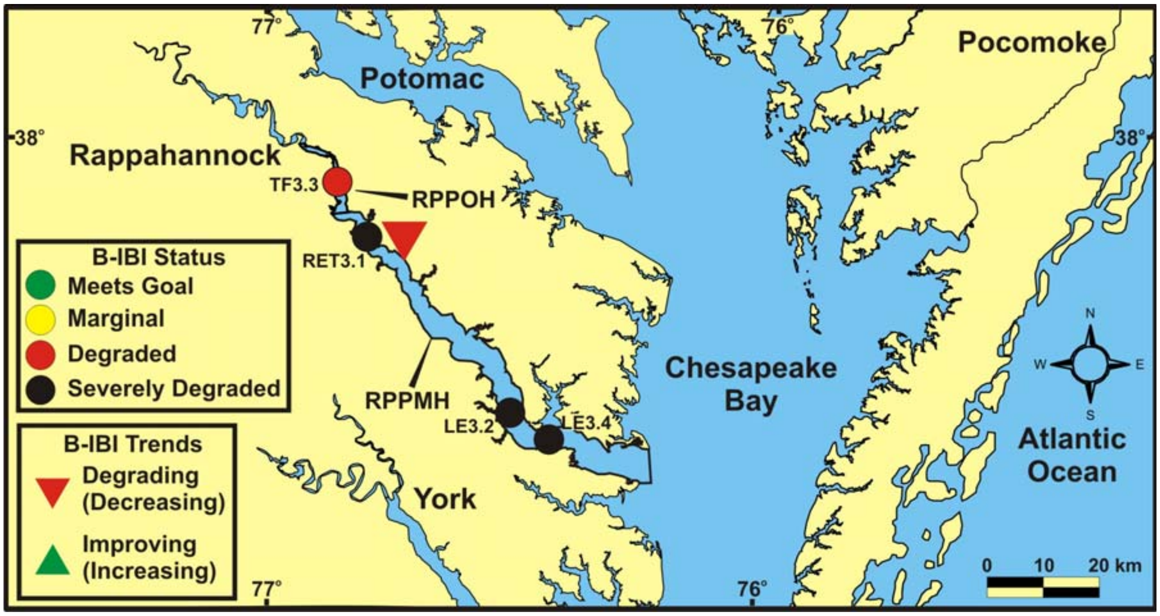
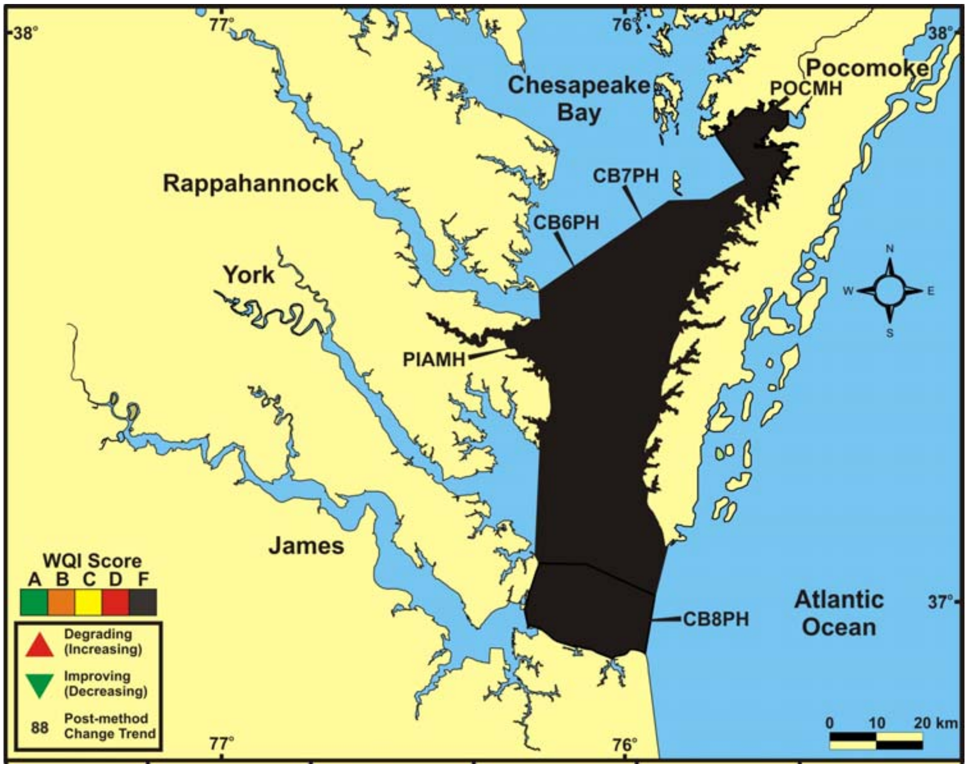
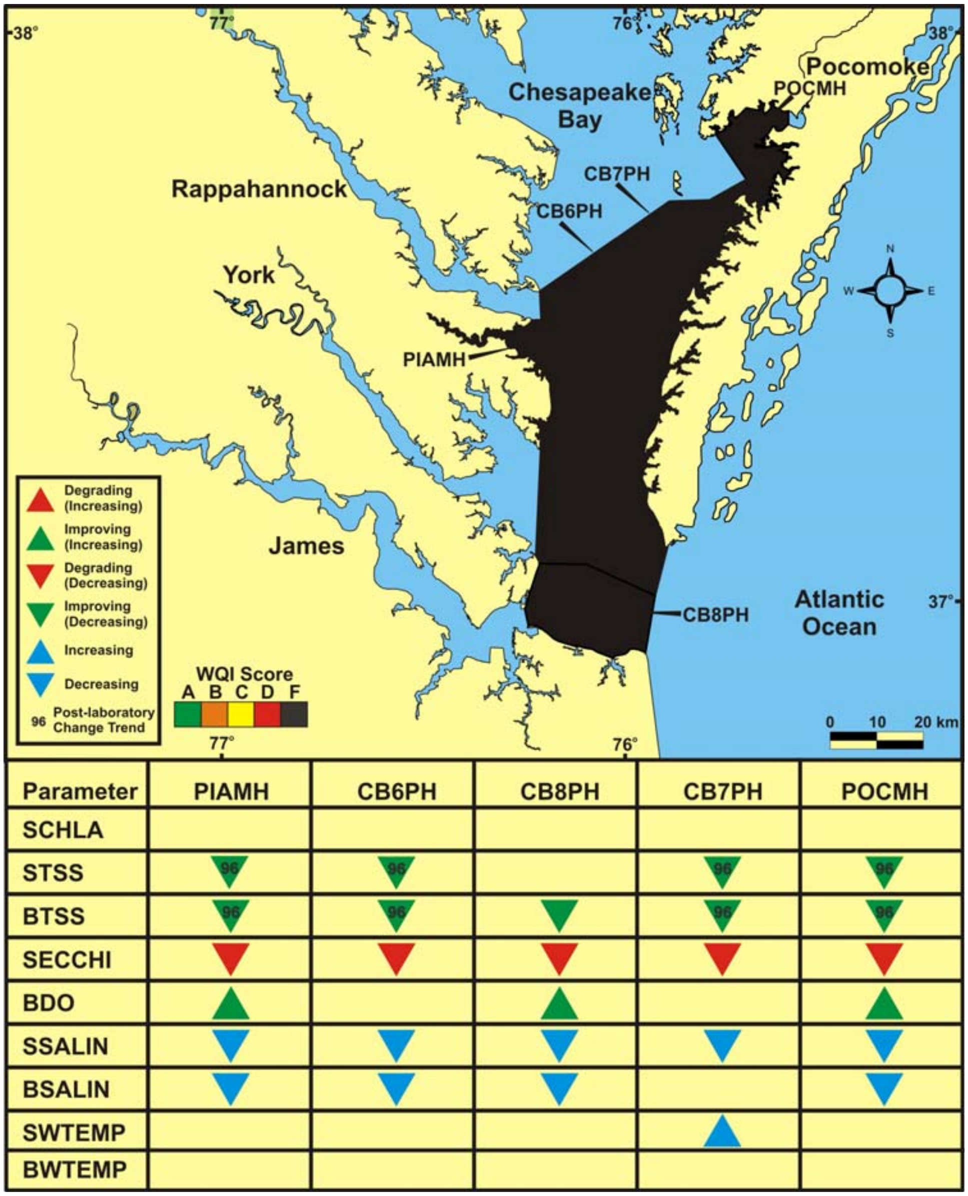


Figure 34. Status and long-term trends in benthic community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2012. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2012.



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

Figure 35. 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
SECCHI	🔻	🔻	🔻	🔻	🔻
BDO	▲		▲		▲
SSALIN	▽	▽	▽	▽	▽
BSALIN	▽	▽	▽		▽
SWTEMP				△	
BWTEMP					

Figure 36. 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.

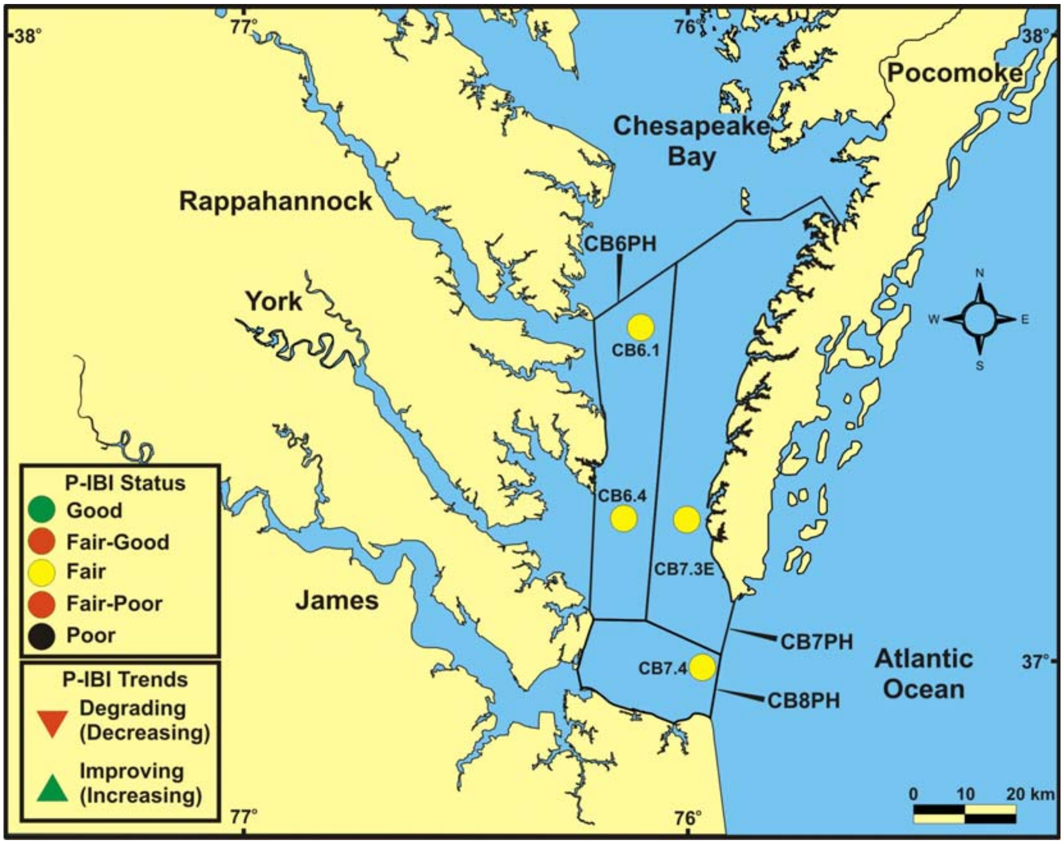


Figure 37. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

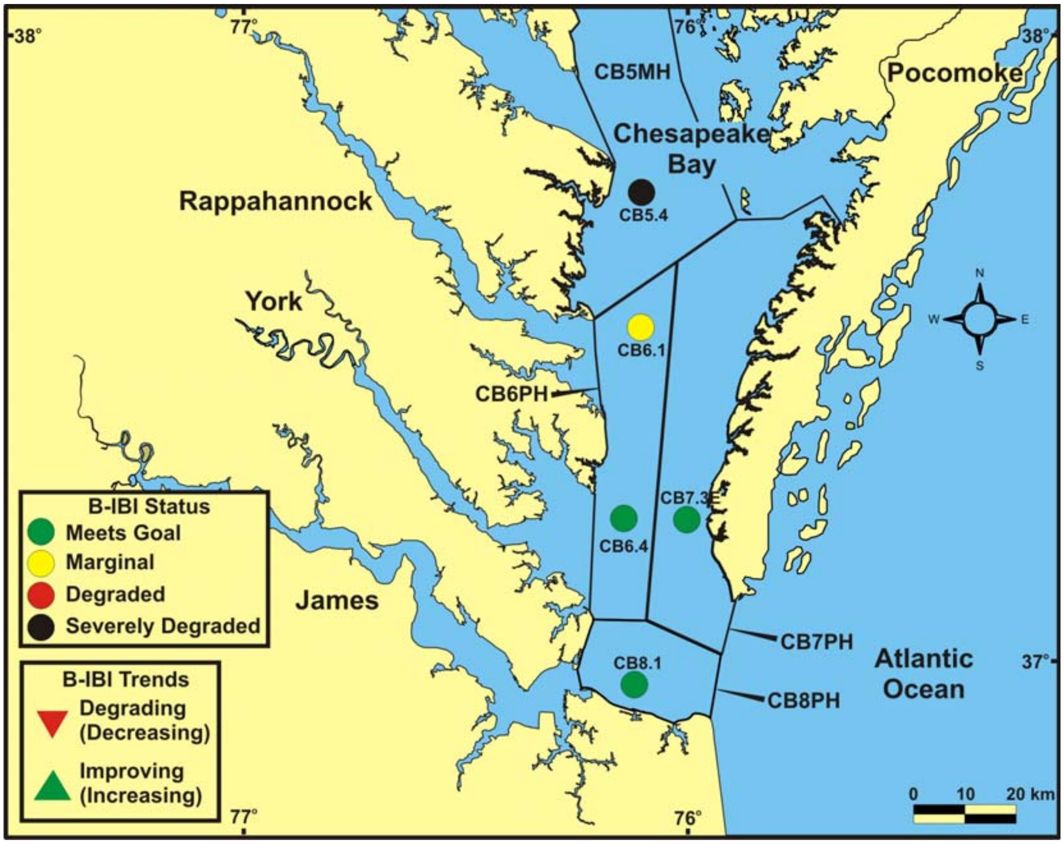
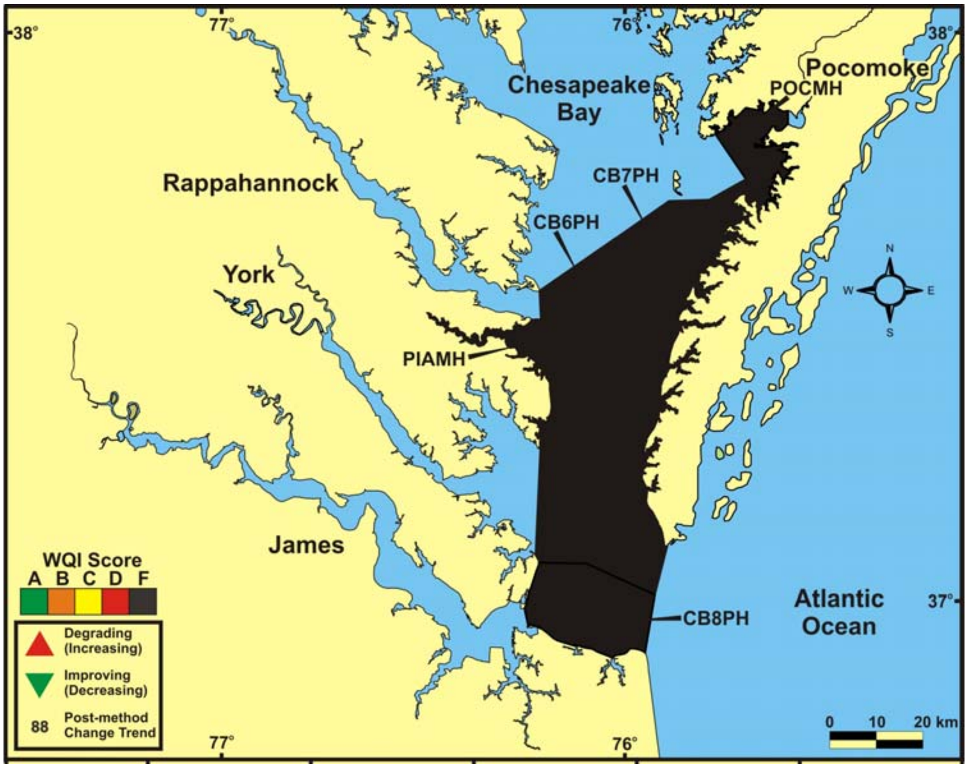
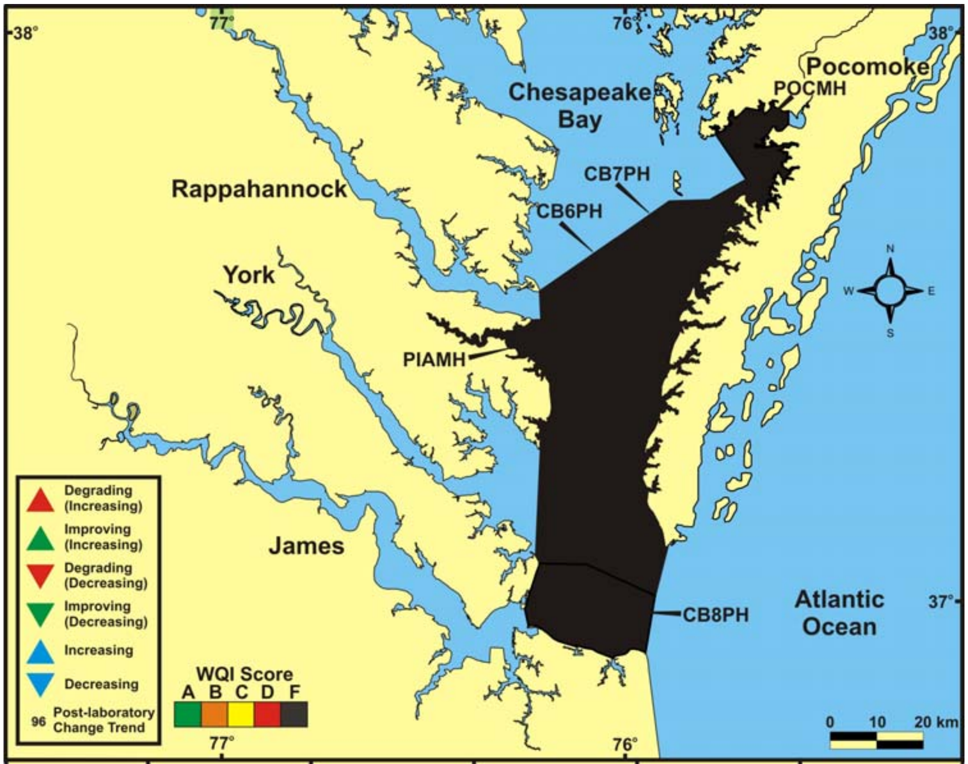


Figure 38. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2012. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2012.



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

Figure 35. 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
SECCHI	🔻	🔻	🔻	🔻	🔻
BDO	▲		▲		▲
SSALIN	▽	▽	▽	▽	▽
BSALIN	▽	▽	▽		▽
SWTEMP				△	
BWTEMP					

Figure 36. 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.

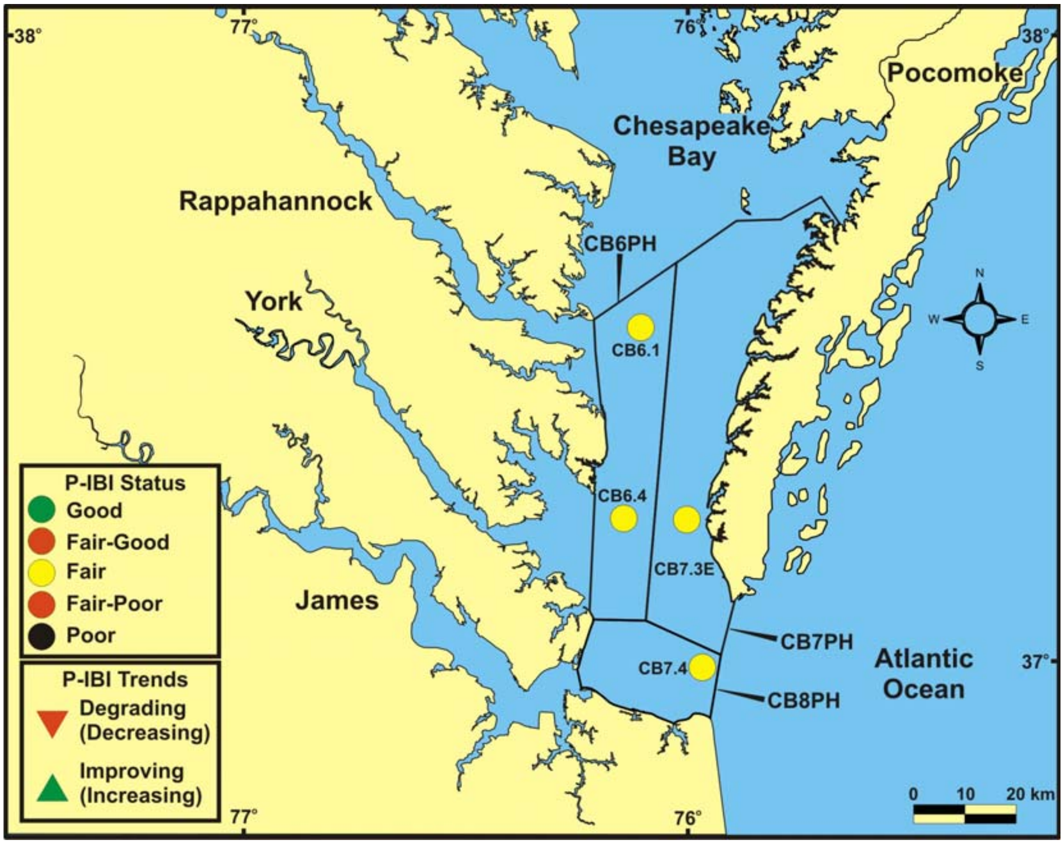


Figure 37. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2011. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2011.

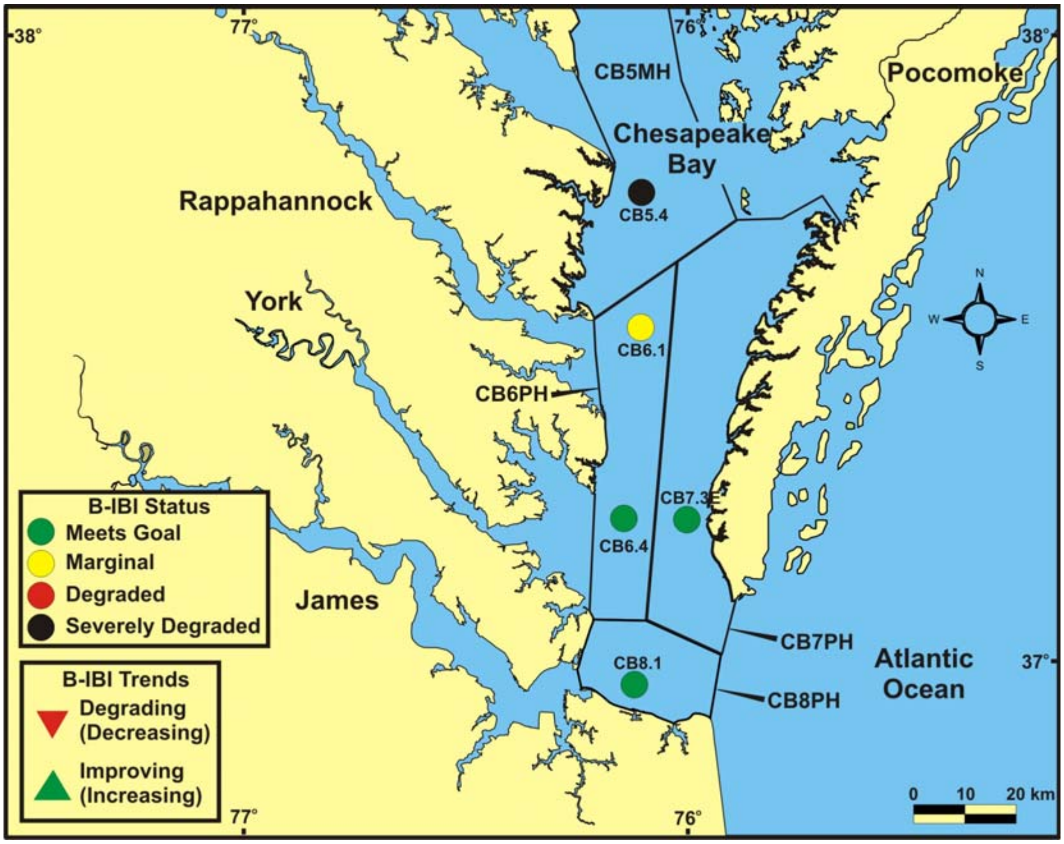


Figure 38. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2012. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant (*P* < 0.01) trends in the B-IBI from the start of monitoring through 2012.