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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 2013

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 (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 the Chesapeake Bay Program's website: http://www.chesapeakebay.net/. 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 a modification of the Water Quality Index (WQI) of Williams et al. (2009). This index combines the percentages of observations violating established thresholds for three different 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). For this study, we have added percentages of two new parameters, total nitrogen and total phosphorus, based on thresholds established for the Chesapeake Bay Report Cards produced by University of Maryland's Center for Environmental Studies located at:http://ian.umces.edu/.

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 based on water quality measurements collected during 2013.

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.

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-C) and long-term improving trends were detected for total nitrogen an total phosphorus as well as several other nutrient parameters in the James River (Table 2). There was no trend in freshwater flow at the fall-line (Table 3).

Significant improving long term trends in monthly point source loads of total nitrogen and total phosphorus were detected above the fall-line in the James River with an approximate reduction in loads of 41.4% and 45.6%, 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 65.2% and 60.6%, 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 5A-D).

2. Non-tidal Water Quality

Trends above the fall-line in the Appomattox River included an improving trend in dissolved inorganic phosphorus and degrading trends in total phosphorus and total suspended solids (Table 5; Station 1 in Figures 7 and 8). Overall, water quality conditions at the fall line in the James River appear to be improving as indicated by decreasing trends in flow adjusted concentrations of total nitrogen, and total phosphorus (Table 5; Station 2 in Figures 6 and 7), as well as, decreasing trends in flow adjusted nitrate-nitrites and dissolved inorganic phosphates (Table 5).

3. Tidal Water Quality

Water quality status as measured using the modified WQI ranged from Fair to Very Good in the James River with segments with higher status values generally being found in tidal freshwater or oligohaline segments except for the Appomattox River(APPTF) which was Poor (Figure 9). With respect to nitrogen, long term improving trends were limited primarily to the tidal freshwater segments of the James River main stem (JMSTF1 and JMSTF2) and to the Appomattox River (APPTF) (Figure 9). 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 (JMSTF1 and JMSTF2), the Appomattox River

(APPTF), and the Chickahominy River (CHKOH) (Figure 9). Improving post-method change trends in surface and bottom total phosphorus were also detected at the James River mouth (JMSPH) (Figure 9) and in surface total phosphorus in the oligohaline James River (JMSOH) (Figure 9).

Improving trends in surface chlorophyll *a* were restricted to the upper portion of the tidal freshwater James River (JMSTF2), the oligohaline James River (JMSOH) and the Chickahominy River (CHKOH) while a degrading trend in chlorophyll *a* was detected at the entrance to James River in segment JMSPH (Figure 10). Improving trends in surface total suspended solids were detected in the Appomattox River (APPTF) and in the bottom waters of the lower segments of the James River(JMSMH and JMSPH) while degrading trends in water clarity as measured by Secchi depth were detected in segments JMSTF1, CHKOH, and JMSPH (Figure 10). Summer bottom dissolved oxygen concentrations were unchanged for most segments except at segment JMSOH where a degrading trend was observed and segment JMSPH where an improving trend was observed (Figure 10). Salinity and temperature showed no change in most segments (Figure 10).

Water quality status based on the modified WQI was Fair in all segments of the Elizabeth River from 1989 to 2013 (Figure 11). Despite generally degraded water quality, conditions in the Elizabeth River appear to be improving in many segments. Improving trends in 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 these parameters were observed (Figure 11). Improving trends in surface and bottom dissolved inorganic nitrogen were also observed in the Southern and Eastern Branches of the Elizabeth River (SBEMH and EBEMH) and improving trends in dissolved inorganic phosphorus were observed in all segments except the Lafayette River (LAFMH) and the Elizabeth River Mainstem (ELIPH) (Figure 11).

Additionally, improving trends in both surface and bottom total suspended solids were observed in most segments of the Elizabeth River except for the Lafayette River (LAFMH) and the Elizabeth River Mainstem (ELIPH)(Figure 12). The only degrading trend observed was a decreasing trend in Secchi depth in the Elizabeth River Mainstem ELIPH (Figure 12) while water clarity in the Southern and Eastern Branch of the Elizabeth River appear to be improving as indicated by the increasing trends in Secchi depth (Figure 12). Few trends in chlorophyll *a*, salinity or temperature were detected in the Elizabeth River (Figure 12).

4. Phytoplankton Communities

With respect to phytoplankton communities conditions in the James River appear to be mixed with status ranging from Poor at station TF5.5 in the tidal freshwater James River (segment JMSTF1) to Fair at station LE5.5 at the mouth of the James River (JMSPH) where an improving trend in the P-IBI was detected (Figure 13). Additional degrading trends in several important phytoplankton bioindicators were detected at stations TF5.5 Status of the P-IBI in the Elizabeth River was Poor and appears to be degrading as indicated by a decreasing trend in the P-IBI (Figure 13) and several other bioindicators (Appendix G - Figure 1).

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 LE5.5; 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., *Leptocylindrus danicus*), plus a variety of cyanobacteria (e.g. *Merismopedia* spp., *Anacystis* spp., *Aphanocapsa* spp.) 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 2011-2014. The 2012,2013, and 2014 *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 dinoflagellate *Prorocentrum minimum* is 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, Morse et al. 2014). Other tributaries to the James follow a similar pattern of bloom development and cell dispersal (e.g. Warrick and Nansemond Rivers). These blooms are generally extensive in scope and long lasting. As the 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). The 2013 *Cochlodinium* bloom was lower than 2012, but comparable to previous years, while in 2014 *C. polykrikoides* was much lower in abundance, duration and spatial extent, being limited to portions of the Mesohaline James and Elizabeth/Lafayette Rivers. 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 most fixed point monitoring stations in the James River, except station LE5.4 in segment JMSPH, was either degraded or severely degraded (Figure 14). Status of benthic communities in the Southern Branch of the Elizabeth River was marginal at SBE2 and severely degraded at SBE5 (Figure 14). An improving trend in the B-IBI was detected at station RET5.2 in segment JMSOH (Figure 14). Over 60% of the total area of the James River failed to meet restoration goals (Figure 15) and there was a significant increasing trend in the proportion of area failing to meet the restoration goal since 1996 (Figure 16). 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 Fair throughout most of the entire basin. Improving trends in nutrients, both in nitrogen and phosphorus parameters were generally restricted to the tidal freshwater and oligohaline segments of the James River although some trends were observed further downstream. 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 were mixed with status of phytoplankton communities in the James River ranging from Good to Poor and an improving trend in the P-IBI at two 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 continues to be *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. While no major blooms occurred in 2014, fishkills have been associated with these blooms in the past, and although no significant human health problems have been reported to date, its presence has often curtailed public recreational activities. Several 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 River was Degraded or Severely Degraded and probability-based benthic monitoring indicated that 60% of the total area of the river failed to meet restoration goals. Only one improving trend in the B-IBI was detected at fixed point stations monitored in the James River 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 Fair and 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 Mattaponi rivers (Table 2). Plots of annual total loads generally confirm the trend results (Figure 17-19). Improving trends in dissolve inorganic phosphorous were detected in both of these two tributaries (Table 2). There were no significant trends in freshwater flow in the York River watershed (Table 3).

Significant improving long term trends in monthly point source loads of total nitrogen and total phosphorus were detected above the fall-line in the York River (Table 4). Plots of the data indicate a more complex pattern for both loadings parameters. Total nitrogen showed a gradual increase from 1985 through 2000 from about 100,000 lbs/yr to just under 200,000 lbs/yr and then a decline over the next decade to around 78,000 lbs/yr after which loadings increased again and stabilized at around 120,000 lbs/yr (Figure 20A). The pattern for TP was similar although it was marked by an initial six year decline followed by a more precipitous decline in 2010, a rapid increase in 2011 followed by another sharp decline thereafter (Figure 20B). Overall these trends have resulted in an 18.2% reduction and <1% reduction 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 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 20C) with the overall result being one of a slight decrease in total nitrogen point source nitrogen loads below the fall-line of approximately 11% (Table 4). In contrast, annual point source total phosphorus loads below the fall-line show what appear to be an asymptotic decline (Figure 20D) with an overall long term decrease of nearly 40% (Table 4).

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 2013 (Figures 21A-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 Figure 8). 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 2013, as measured using the modified WQI, was Fair to Very Good in most segments of the York River with the exception of the middle York River (YRKMH) where it was Poor (Figure 22). In general, status improved moving upstream from segment YRKMH to the tidal freshwater segments of the Pamunkey and Mattaponi rivers and improved moving downstream from segment YRKMH to Mobjack Bay (Figure 22). 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 segment of the Pamunkey (PMKOH) and in the middle York River (YRKMH) (Figure 22). Improving trends in total nitrogen, dissolved inorganic nitrogen and total phosphorus were detected in Mobjack Bay (MOBPH; Figure 22) 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 23). Degrading trends in total suspended solids were detected in the upper Pamunkey River (PMKTF) and the middle and lower York River (YRKMH and YRKPH) (Figure 23). Degrading trends in water clarity were detected in the upper segments of both the Pamunkey and Mattaponi rivers (PMKTF and MPNTF), as well as, the lower York River (YRKPH) and Mobjack Bay (MOBPH; Figure 23). Improving trends in summer dissolved oxygen were observed in the upper Pamunkey River (PMKTF) and Mobjack Bay (MOBPH; Figure 23). Increasing trends in salinity were detected in the lower Pamunkey and Mattaponi Rivers (PMKOH and MPNOH) while decreasing trends in this parameter were detected in the lower York (YRKPH) and Mobjack Bay (MOBPH) (Figure 23).

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-Poor at station WE4.2 in segment MOBPH from 2011 through 2013 (Figure 24) . There was a no significant degrading trend in the P-IBI at station RET4.3 in segment YRKMH. In the tidal fresh Pamunkey River (segment PMKTF) at station TF4.2, there were several improving trends in phytoplankton bioindicators including species diversity (Margalef Index), as well as diatom and chlorophyte biomass coupled with a significant increase in total phytoplankton abundance (Appendix G, Figure 3). There was also a significant degrading trend in cyanophyte biomass at this station (Appendix G, Figure 3). Downstream, in Mobjack Bay (segment MOBPH), at station WE4.2, a trend in decreasing total phytoplankton biomass was observed coupled with degrading trends in cyanophyte biomass and in species diversity (Margalef Index) (Appendix G, Figure 3).

The Pamunkey and Mattaponi rivers introduce freshwater algae into the estuarine waters of the York River leading to a diverse assemblage in the oligo/mesohaline waters (Marshall 2009). 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. *A. monilatum* was also present in the York during 2013. 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 (Cochlodinium and Alexandrium) may have persisted over several weeks in 2012 and 2013.

5. Benthic Communities

Status of benthic communities at fixed point stations in the York River were marginal at station TF4.2 in segment PMKTF and station LE4.1 in segment YRKMH and degraded at station LE4.3B in segment YRKPH (Figure 26). 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, both located in the lower York River in segment YRKPH (Figure 25). In 2013, results of the probability-based benthic monitoring indicated that 76% of the total area of the York River failed to meet restoration goals in the York River (Figure 15). There was no significant trend in the proportion of area failing to meet the restoration goals in the York River stratum (Figure 16).

6. Management Issues

Fair to Good water quality status was found throughout most of the York River watershed with the exception of the middle York River (YRKMH) where water quality status was Poor. 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. Despite this relatively few trends in nutrients were observed in the Pamunkey and Mattaponi River segments of this estuary except for post method-change improving trends in dissolved inorganic phosphorus in segments PMKTF and MPNTF and degrading long-term trends in dissolved inorganic phosphorus in segment PMKOH. Trends in the mainstem of the York River did not appear to be influenced by improvements in point or non-point source loadings since only degrading trends in surface total phosphorus and dissolved inorganic phosphorus were detected. Degrading trends in water clarity were also found throughout this watershed. Several improving trends in nutrients were detected in Mobjack were detected that could be tied to the reductions in point source loadings observed in that area. 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 bloom status for the toxin producers *Chattonella subsalsa* and *Alexandrium monilatum*. These taxa and other potential HABs, 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 clearly indicate substantial degradation in the York River. Although two of the fixed point stations met restoration goals, the remaining were classified as Degraded or Marginal while probability-based sampling indicated that 76% of the bottom of the York River failed to meet the restoration goals for benthic communities. There is some indication of localized improvement as indicated by the improving trends in the B-IBI at the fixed point 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 26A-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).

Although no trend was detected, monthly point source total nitrogen loads above the fall-line in the Rappahannock River plot of the data suggests that loadings declined substantially after 2007 despite the statistically significant trend (Figure 27A). In contrast, an improving trend resulting in a 51.7% 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, in general, agrees with the trend analysis results showing an asymptotic decline from 1985 through 2013 (Figure 27B). Improving trends in monthly point source loads of both total nitrogen and total phosphorus were detected below the fall-line resulting in 59.3% and 57.7% reductions in loads of these two parameters, respectively (Table 4). Plots of annual total loads confirm results of the trend analyses (Figure 27C-D).

2. Non-tidal Water Quality

Improving trends in flow-adjusted concentrations of total nitrogen (Figure 6), nitrate-nitrites, and dissolved inorganic phosphorus were detected at the fall-line in the Rappahannock River (Table 5).

3. Tidal Water Quality

Water quality status as measured using the modified WQI was Good in the upper Rappahannock River (RPPTF), Poor in the lower Rappahannock River (RPPMH) and Fair in the remaining segments during 2013 (Figure 28). Improving post-method changes trends were observed in surface or bottom total nitrogen in all segments except RPPOH while improving post-method change trends in surface and/or bottom total and/or dissolved inorganic phosphorus were detected in all segments of this tributary (Figure 28). 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 29). A degrading trend in bottom dissolved oxygen was also detected in the upper Rappahannock River (segment RPPTF) (Figure 29). Decreasing trends in salinity coupled with increasing trends in surface water temperature were detected in segments RPPMH and CRRMH (Figure 29).

4. Phytoplankton Communities

Phytoplankton communities in the Rappahannock River were mostly 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 30). Despite recent improvements in water quality, a decreasing trend in the P-IBI was detected at station RET3.1 (Figure 30).

An increasing trend in total phytoplankton abundance was observed at stations TF3.3 and RET3.1 in this tributary (Appendix G, Figure 5). At the tidal fresh TF3.3 and the oligohaline RET3.1, this includes increased biomass of both beneficial (diatoms and chlorophytes) and detrimental (cyanoophyte) taxa (Appendix G, Figure 5) while at station LE3.6 there is an increase in cyanophyte biomass and a decrease in picoplankton and cryptophyte biomass (Appendix G, Figure 5). Trends in the P-IBI would appear to be reflection of the trends of specific taxonomic groups conditions as indicated by the increasing (degrading) 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 River, 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*, etc.). 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*. Neither *Cochlodinium* nor *Chatonella* blooms were present in the Rappahannock River in 2013. The ichthyotoxic dinoflagellates *Karlodinium veneficum* and *Prorocentrum minimum* also occur in this river and often form annual blooms. 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 fixed point stations in the Rappahannock River except TF3.3 where it was Marginal. In general, status 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 31). Probability-based benthic monitoring results indicated that 76% the total area of Rappahannock River failed to met benthic community goals in 2013 (Figure 15). There was a significant increasing trend in the proportion of area failing to meet the restoration goal since 1996 for this sampling stratum (Figure 16). 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 status in the Rappahannock River basin as measured using the WQI was Poor in the largest geographic extent of the tidal portion of this estuary. Despite improvements in point source loadings in both nitrogen and phosphorus below the fall-line, water quality status in the lower portion of the Rappahannock River (segment RPPMH) is still Poor. Improving nutrient trends were observed but all were post-method change trends that have occurred since 1995. It is possible that these post-method change trends are a response to reduced loads. Degrading trends in chlorophyll *a*, Secchi depth, and bottom dissolved oxygen were detected in several segments of this tributary.

P-IBI values were characterized as either Poor or Fair and increasing (degrading) trends in cyanobacteria biomass were detected at all stations suggesting that phytoplankton communities in the Rappahannock River, particularly those upstream 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 31). Probability-based monitoring results indicated that 24% of the total area of the Rappahannock River failed to meet restoration goals (Figure 15) and that there was a significant decreasing trend in the proportion of area meeting the restoration goals (Figure 16). 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 either Good or Fair in all segments during 2013 (Figure 32), and water quality conditions with respect to nutrients 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 either surface and/or bottom dissolved inorganic nitrogen were detected in all segments. Improving long-term trends in surface and bottom total phosphorus were detected in all segments (Figure 32) and improving trends in dissolved inorganic phosphorus were observed 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 except CB8PH where only a long-term trend improving trend in bottom total suspended solids was observed (Figure 33). 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 33). However, improving trends in bottom dissolved oxygen were detected in the Piankatank River (segment PIAMH), Pocomoke Sound (segment POCMH) and the mouth of Chesapeake Bay (CB8PH). Decreasing trends in surface and/or bottom salinity were detected in all segments of the Mainstem (Figure 33) except CB7PH.

2. Phytoplankton Communities

Status of phytoplankton communities in the Virginia Chesapeake Bay Mainstem based on the P-IBI was Fair at all stations. No trends in the P-IBI where observed at any Mainstem stations(Figure 34). Decreasing trends in species diversity and increasing trends in cyanobacteria biomass were detected at all stations (Appendix G, Figure 7). Decreasing trends in cryptophyte biomass were also observed at all stations (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 (2012, 2013) blooms of the dinoflagellate *Cochlodinium polykrikoides* in the lower York and James rivers have entered the lower Chesapeake Bay at bloom status and subsequently continued 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 and 2013. 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 most fixed point stations in the Virginia portion of the Chesapeake Bay Mainstem except station CB5.4 were status was Severely Degraded and station CB6.1 were status was marginal (Figure 35). There were no trends in the B-IBI at any Mainstem stations (Figure 36) and relatively few trends in any of the individual benthic bioindicators (Appendix G - Figure 8). Probability-based benthic monitoring results for 2013 indicate that 32% of the total area of the Virginia Chesapeake Bay Mainstem failed to meet the restoration goals (Figure 15). A significant decreasing trend in the proportion of area failing to meet the restoration goals was detected in the Virginia Chesapeake Bay Mainstem (Figure 16).

4. Management Issues

Water quality conditions based on the WQI were generally Fair to Good in the Mainstem and there were widespread improvements with respect to nutrients observed. However, water clarity, as measured using Secchi depth, is a widespread problem in the Mainstem as evidenced by the degrading trends observed in all segments. This particular water quality issue has been consistently observed during the last seven 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 or Fair-Good 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 also provides 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 over two thirds of the total area of Virginia Chesapeake Bay Mainstem met benthic restoration goals. A significant decreasing trend in the proportion of area failing to meet the restoration goals was detected in the Virginia Chesapeake Bay Mainstem.

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 rather than above the fall-line.

- Reductions in point source nutrient loads were widespread throughout all tributaries.

- Water quality status based on the WQI was Fair in the Virginia Mainstem and in most segments of the Virginia tributaries.

- Status of living resources was best in the Virginia Mainstem and, in general, in the lower portions of the Virginia tributaries.

- Water quality trend results indicated:

  - generally improving nutrient concentrations in the Mainstem and in many segments in the tributaries (particularly upstream);
  - degrading trends in water clarity, and
  - relatively few trends in chlorophyll *a*, total suspended solids or dissolved oxygen.

- Living resource trend results indicated:

  - an improving trend in the P-IBI at one station in the lower portion of the James River and degrading trends in the Elizabeth, York and Rappahannock rivers;
  - widespread degrading trends in species diversity and cyanobacteria biomass were observed;
  - few improvements at fixed point stations in the B-IBI;
  - increases in the extent of the area failing benthic restorations goals in the James and Rappahannock rivers and a decrease in the Virginia Mainstem.

- 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.) and 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 changes to any common causal stressor could be 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 Fair to Good water quality status;
  - limited improvements and some degrading trends in water quality downstream;
  - highly variable phytoplankton community status (Poor to Good);
  - increasing cyanobacteria biomass upstream and annual seasonal algal blooms produced by potentially toxic dinoflagellates in the lower segments and inlets that 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 an increasing proportion of area failing to meet restoration goals throughout the watershed.

- The Elizabeth River was characterized as having:

    - fair water quality status throughout;
    - improving trends with respect to nutrients in multiple segments;
    - improving benthic communities in some segments;
    - but poor status and continued declines in phytoplankton community conditions.

- The York River exhibited:

    - fair to poor water quality and generally fair or marginal living resource status in all areas;
    - localized improvements and degradations in water quality in some cases potentially tied to changes in PS loads;
    - no improvements in the P-IBI but improvements in the B-IBI at fixed point monitoring stations downstream;
    - significant ongoing annual algal bloom development of *C. polykrikoides* coupled with increased bloom activity of the invasive toxic HAB *A. monilatum* particularly in the lower York;
    - no change in the proportion of area failing to meet benthic restoration goals.

- The Rappahannock River can be described as having:

    - fair water quality status in all segments except the lower Rappahanock River (RPPMH);
    - no improving non-tidal and few improving long-term tidal water quality trends, although there were several post-method change trends in nutrients;
    - poor or fair phytoplankton communities with one station (RET3.1) exhibiting a degrading long-term trend;
    - fewer HAB blooms than other tributaries, but recent increased frequency and magnitude;
    - marginal, degraded or severely degraded status at fixed point station benthic communities coupled with either no or degrading trends in the B-IBI;
    - an increasing proportion of the extent of area failing to meet benthic restoration goals.

- The Virginia Chesapeake Bay Mainstem was characterized by:

    - fair to good water quality status;
    - 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 widespread increases in cyanophyte biomass and more frequent expansion of summer/autumn dinoflagellate HABs in recent years;
    - a decreasing trend in the proportion of area failing to meet 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 loads of total nitrogen (TN), nitrate-nitrites (NO_{23}), total phosphorus (TP), dissolved inorganic phosphorus (DIP)and total suspended sediments (TSED), in the Virginia tributaries for the period of 1985 through 2013. Units for the slope and baseline medians are in lb/month.

Basin	Load	P value	Slope	Baseline	Absolute	% Change	Direction	Homogeneity test P value
James	TN	0.0017	-5659	485833	-164120	-33.78	Improving	0.9596
James	NO_{23}	0.0006	-2193	151998	-63588	-41.83	Improving	0.9547
James	TP	0.0000	-3045	128827	-88312	-68.55	Improving	0.3396
James	DIP	0.0000	-3210	118080	-93092	-78.84	Improving	0.9989
James	TSED	0.7014	57141	2320255	742834	32.02	No Trend	0.9716
Mattaponi	TN	0.0963	-212	47883	-6142	-12.83	No Trend	0.9874
Mattaponi	NO_{23}	0.6999	-12	8638	-341	-3.95	No Trend	0.9778
Mattaponi	TP	0.2613	-14	3509	-397	-11.31	No Trend	0.9288
Mattaponi	DIP	0.0000	-16	1107	-469	-42.39	Improving	0.4952
Mattaponi	TSED	0.6480	2654	126435	34496	27.28	No Trend	0.9789
Pamunkey	TN	0.1031	-416	72444	-12057	-16.64	No Trend	0.9177
Pamunkey	NO_{23}	0.3934	-79	22656	-2302	-10.16	No Trend	0.7308
Pamunkey	TP	0.3162	24	4655	698	14.98	No Trend	0.8754
Pamunkey	DIP	0.0004	-27	2091	-782	-37.41	Improving	0.8679
Pamunkey	TSED	0.6879	11738	350601	152594	43.52	No Trend	0.7789
Rappahannock	TN	0.9429	43	124010	1241	1.00	No Trend	0.9432
Rappahannock	NO_{23}	0.6596	114	65569	3319	5.06	No Trend	0.9426
Rappahannock	TP	0.3520	43	10856	1255	11.56	No Trend	0.8751
Rappahannock	DIP	0.6516	-7	2586	-203	-7.85	No Trend	0.8734
Rappahannock	TSED	0.8839	-24216.3	2666491	-314812	-11.81	No Trend	0.9179

Table 3. Long-term trends in freshwater flow at USGS fall-line stations in the Virginia tributaries for the period of 1985 through 2013. 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.

Segment	P value	Slope	Baseline Median	% Change	Direction	Homogeneity test P value
James River	0.0850	18.21	3575	14.77	No Trend	0.9634
Appomattox River	0.0157	3.95	466	24.59	No Trend	0.9151
Chickahominy River	0.4134	0.49	133	10.78	No Trend	0.7268
Pamunkey River	0.0243	2.79	341.25	23.78	No Trend	0.9597
Mattaponi River	0.2531	1.23	264.5	13.53	No Trend	0.9968
York River	0.0532	4.11	598.5	19.95	No Trend	0.9856
Rappahannock River	0.7006	1.08	680	4.58	No Trend	0.9889

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 2013. 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	<0.0001	-4092	286571	-118678	-41.41	Improving	0.9823
James	BFL	TN	<0.0001	-38595	1717532	-1119247	-65.17	Improving	1.0000
James	AFL	TP	<0.0001	-1015	64554	-29446	-45.61	Improving	1.0000
James	BFL	TP	<0.0001	-5033	241013	-145964	-60.56	Improving	1.0000
York	AFL	TN	0.0089	-60	9557	-1740	-18.21	Improving	0.6654
York	BFL	TN	0.0193	-368	96572	-10658	-11.04	Improving	0.6686
York	AFL	TP	1.0000	0	3209	-5	-0.14	Improving	0.9999
York	BFL	TP	<0.0001	-383	27842	-11111	-39.91	Improving	0.9768
Mobjack Bay	BFL	TN	<0.0001	-22	689	-584	-84.71	Improving	0.9893
Mobjack Bay	BFL	TP	<0.0001	-5	236	-133	-56.25	Improving	0.9975
Rappahannock	AFL	TN	0.4484	48	14104	1402	9.94	Degrading	0.9165
Rappahannock	BFL	TN	<0.0001	-574	28052	-16642	-59.33	Improving	0.9306
Rappahannock	AFL	TP	<0.0001	-102	5727	-2963	-51.74	Improving	0.9998
Rappahannock	BFL	TP	<0.0001	-196	9843	-5680	-57.71	Improving	1.0000

Table 5. Long-term trends in flow-adjusted water quality parameters for the River Input Monitoring and Multi-Agency Monitoring Program non-tidal stations in Virginia portion of the Chesapeake Bay Watershed for 1985 through September, 2013. Map ID #'s in parentheses refer to the station locations identified in Figure 1. Results presented in this table were provided by the U.S. Geological Survey.

		Flow Adjusted Trend					
Station Name (Map ID #)	Parameter	Kendall τ	*P* value	LCI	Slope	UCI	Direction
Appomattox River at Matoaca(1)	TSS	0.1962	0.0131	4.2	21.7	42.1	Increasing
Appomattox River at Matoaca(1)	TN	0.055	0.1778	-2.5	5.7	14.5	NS
Appomattox River at Matoaca(1)	NO_{23}	-0.136	0.1769	-28.3	-12.7	6.3	NS
Appomattox River at Matoaca(1)	TP	0.2848	<0.0001	16.4	32.9	51.9	Increasing
Appomattox River at Matoaca(1)	DIP	-0.367	<0.0001	-41.2	-30.7	-18.4	Decreasing
Appomattox River at Matoaca(1)	SSC	-0.173	0.1568	-33.8	-15.9	6.9	NS
James River at Cartersville(2)	TSS	0.0819	0.4204	-11.1	8.5	32.5	NS
James River at Cartersville(2)	TN	-0.172	0.0009	-24	-15.8	-6.8	Decreasing
James River at Cartersville(2)	NO_{23}	-0.475	<0.0001	-47	-37.8	-27	Decreasing
James River at Cartersville(2)	TP	-1.003	<0.0001	-69.1	-63.3	-56.4	Decreasing
James River at Cartersville(2)	DIP	-2.546	<0.0001	-93.5	-92.2	-90.6	Decreasing
James River at Cartersville(2)	SSC	-0.027	0.8344	-24.5	-2.7	25.5	NS
Pamunkey River near Hanover(3)	TSS	0.8777	<0.0001	89.5	140.5	205.4	Increasing
Pamunkey River near Hanover(3)	TN	0.1532	0.0001	7.7	16.6	26.1	Increasing
Pamunkey River near Hanover(3)	NO_{23}	0.2368	<0.0001	13.6	26.7	41.3	Increasing
Pamunkey River near Hanover(3)	TP	0.7061	<0.0001	76.5	102.6	132.5	Increasing
Pamunkey River near Hanover(3)	DIP	0.2215	0.0026	8	24.8	44.1	Increasing
Pamunkey River near Hanover(3)	SSC	0.9507	<0.0001	87.7	158.8	256.6	Increasing
Mattaponi River near Beulahville(4)	TSS	0.0539	0.5822	-12.9	5.5	27.9	NS
Mattaponi River near Beulahville(4)	TN	-0.044	0.1871	-10.5	-4.3	2.2	NS
Mattaponi River near Beulahville(4)	NO_{23}	0.0805	0.3014	-7	8.4	26.3	NS
Mattaponi River near Beulahville(4)	TP	-0.024	0.6546	-11.9	-2.3	8.3	NS
Mattaponi River near Beulahville(4)	DIP	-0.587	<0.0001	-51.7	-44.4	-36	Decreasing
Mattaponi River near Beulahville(4)	SSC	-0.133	0.2963	-31.8	-12.5	12.4	NS
Rappahannock River near Fredericksburg(5)	TSS	-0.142	0.3212	-34.5	-13.3	14.9	NS
Rappahannock River near Fredericksburg(5)	TN	-0.19	0.002	-26.7	-17.3	-6.7	Decreasing
Rappahannock River near Fredericksburg(5)	NO_{23}	-0.269	0.0218	-39.3	-23.6	-3.8	Decreasing
Rappahannock River near Fredericksburg(5)	TP	-0.057	0.5486	-21.4	-5.5	13.7	NS
Rappahannock River near Fredericksburg(5)	DIP	-0.194	0.0252	-30.5	-17.6	-2.4	Decreasing
Rappahannock River near Fredericksburg(5)	SSC	0.2172	0.2144	-11.9	24.3	75.2	NS

Figures

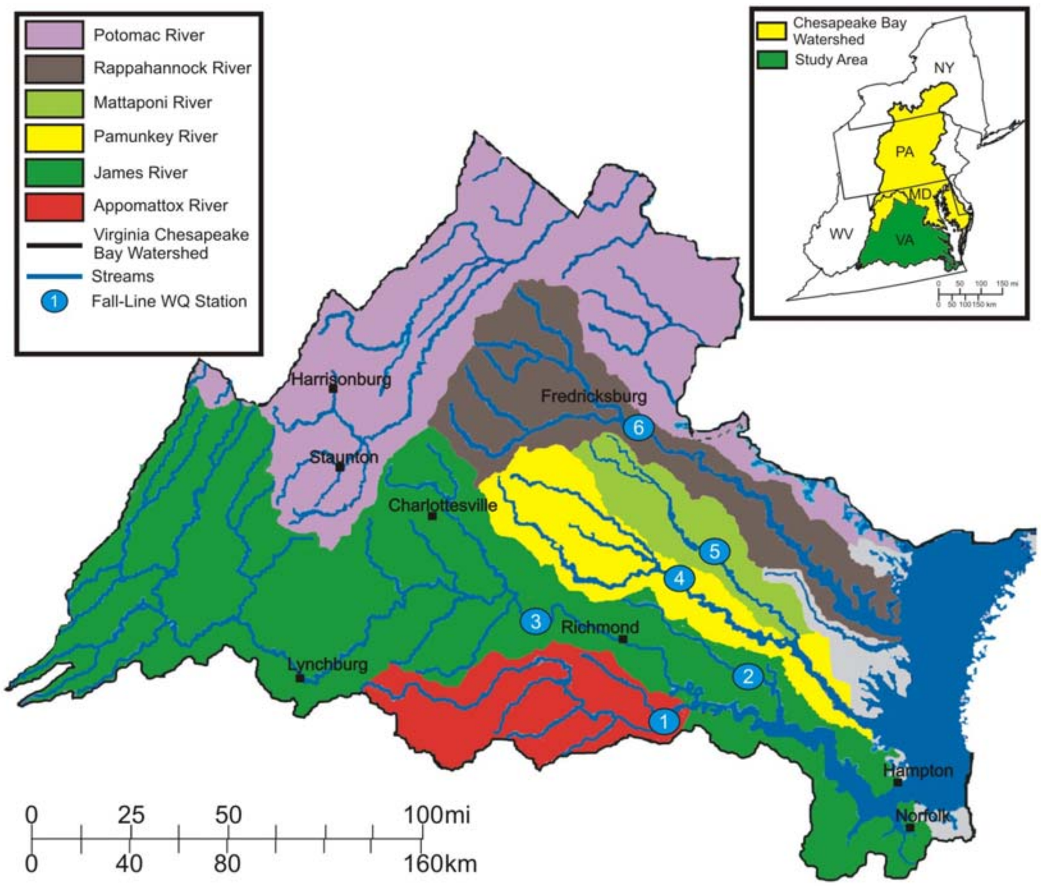


Figure 1. Location of the USGS/RIM stations in each of the Virginia tributaries.

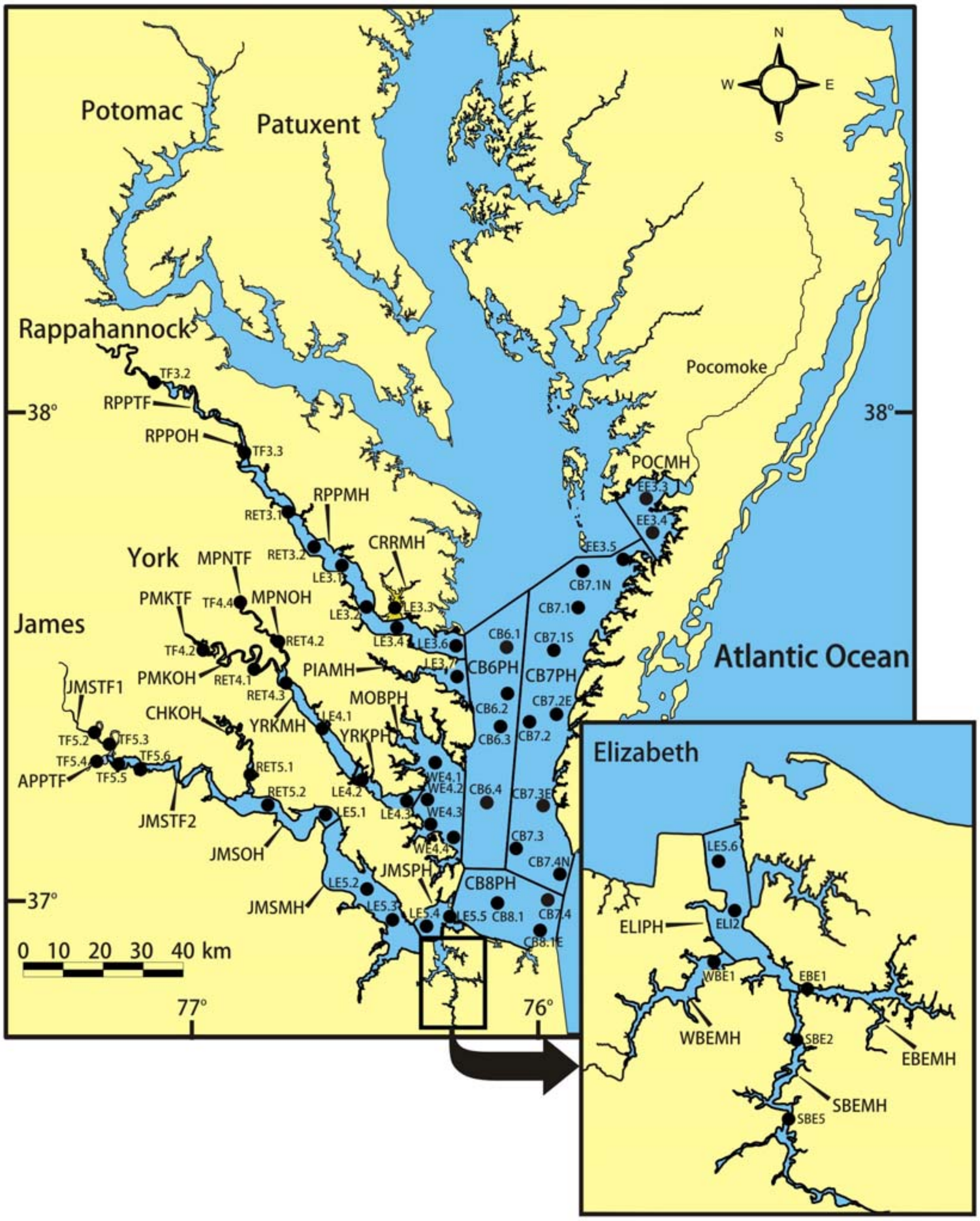


Figure 2. Chesapeake Bay Program segmentation scheme for the Virginia tributaries and Lower Chesapeake Bay Mainstem. Also shown are the locations of stations used in the statistical analyses.

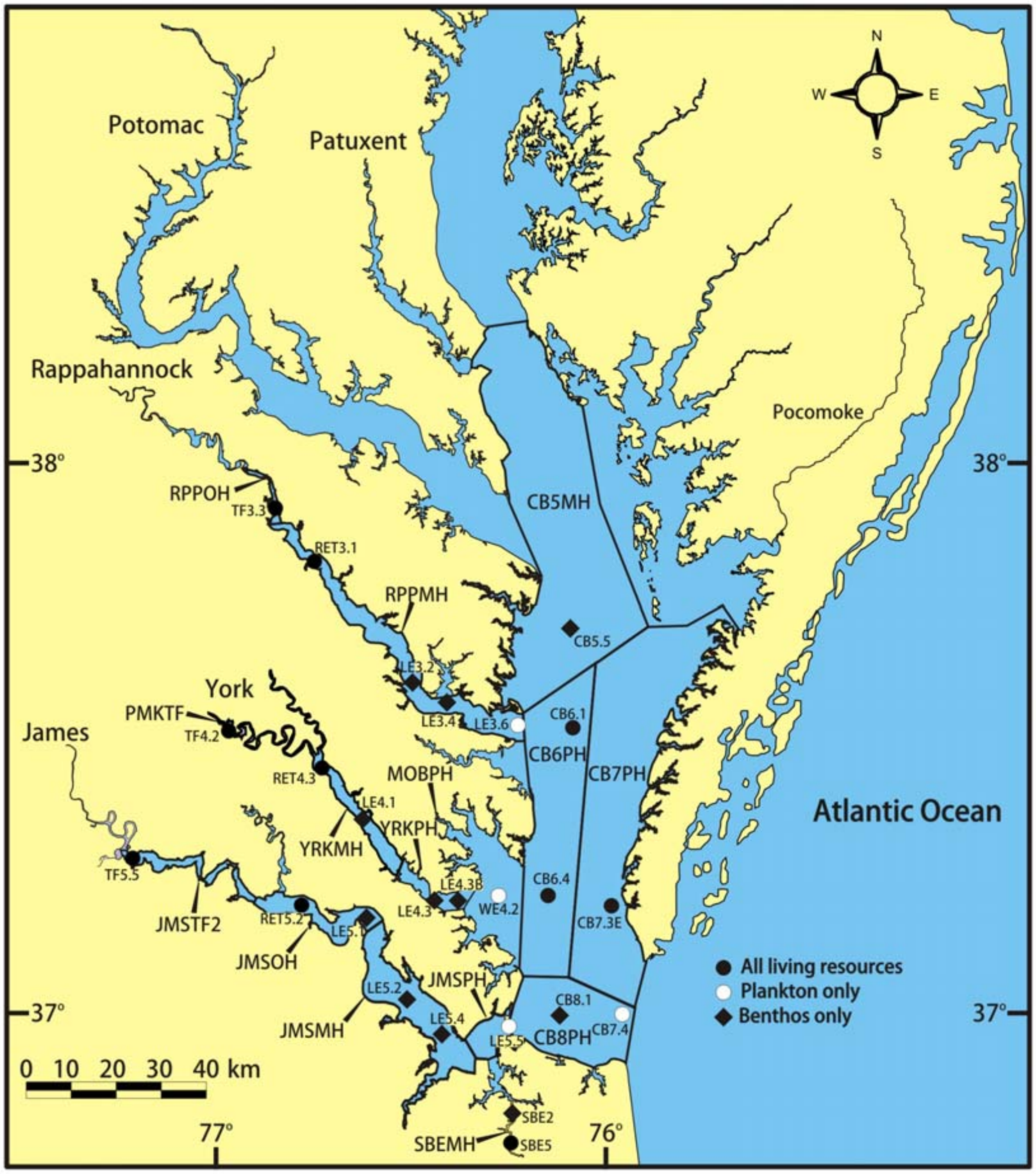


Figure 3. Living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem and their associated CBP segments.

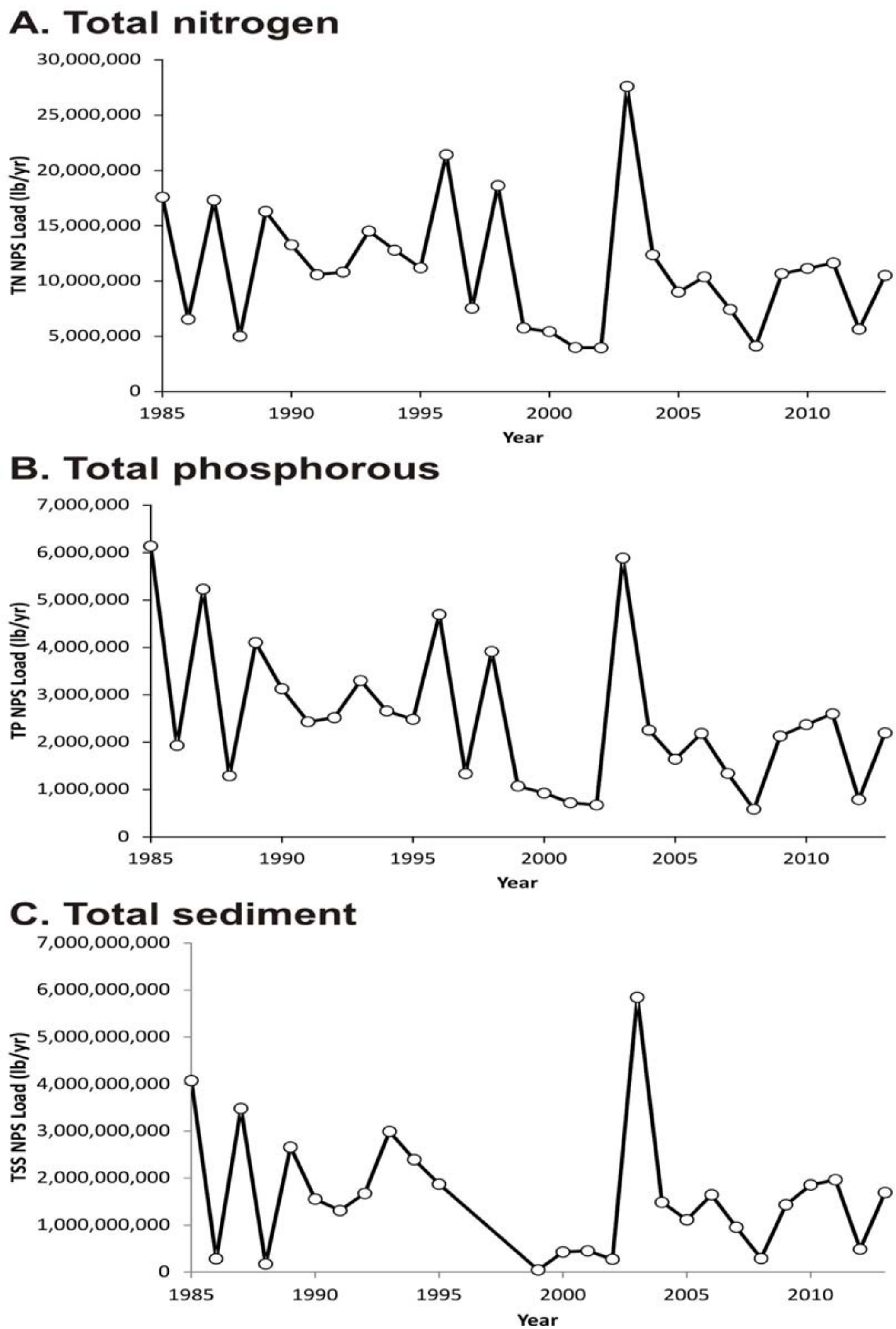


Figure 4. Long-term changes in A. Total nitrogen, B. Total phophorus and C. Total Sediment load above the fall-line in the James River from 1985 through 2013. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

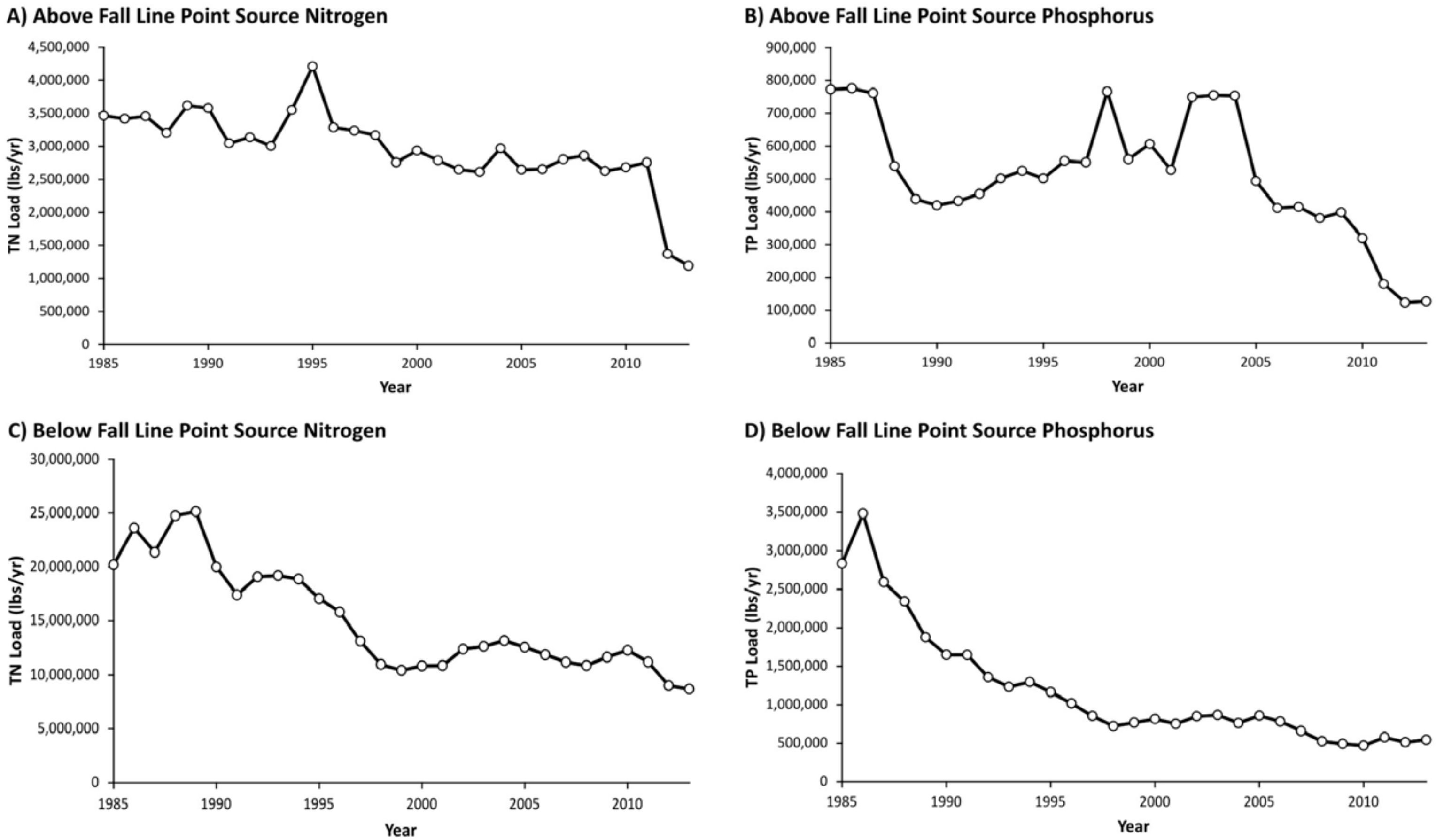


Figure 5. Long-term changes in A) Above the Fall-line Point Source Nitrogen; B) Above Fall-line Point Source Phosphorus; C) Below Fall Line Point Source Nitrogen; and D) Below Fall Line Point Source Phosphorus in the James River for 1985 through 2012. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system. Shown are trend lines represented by the significant (P<0.01) Sen slopes. Values shown are rounded to the nearest 100 lbs/yr.

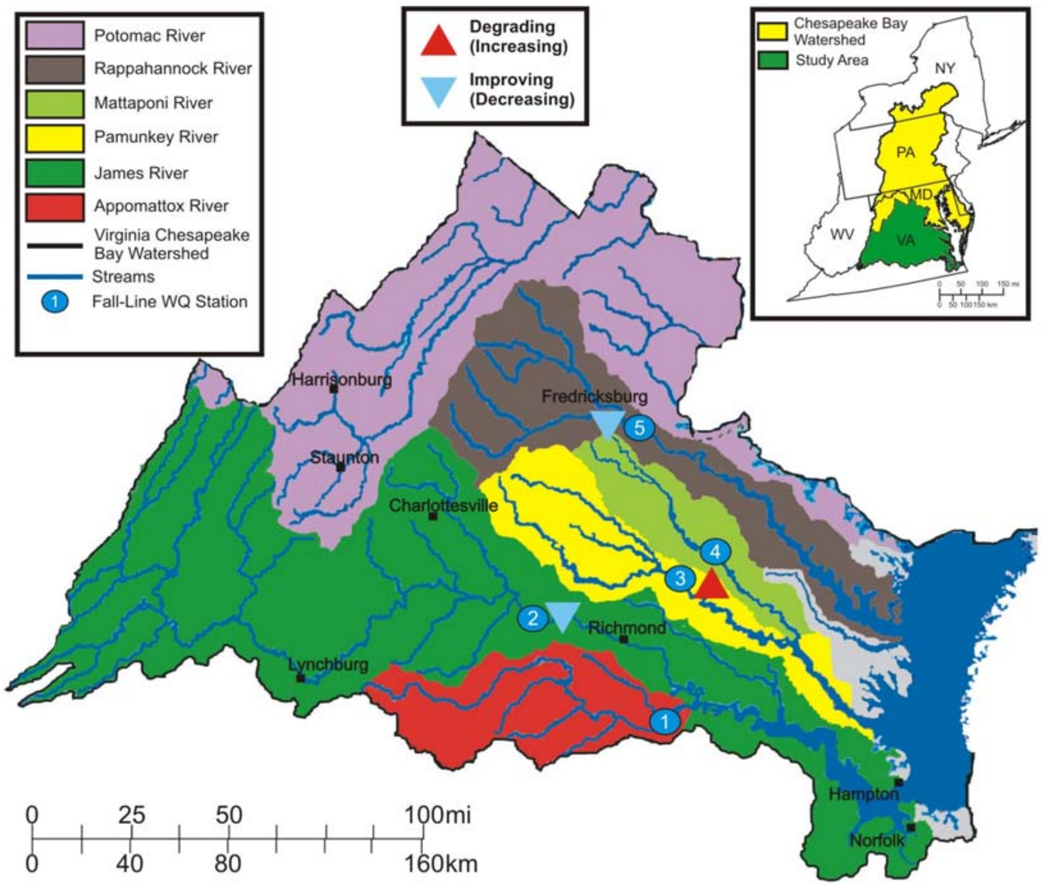


Figure 6. Long-term trends in flow-adjusted total nitrogen at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2013. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

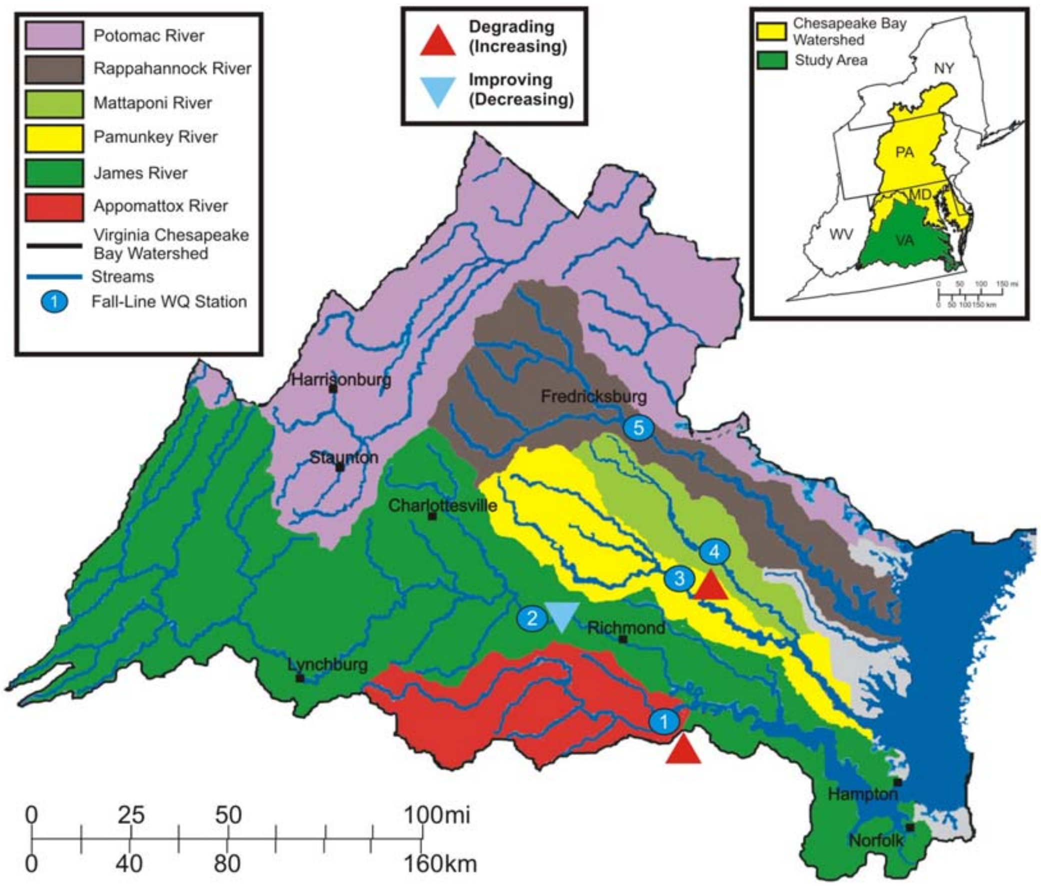


Figure 7. Long-term trends in flow-adjusted total phosphorus at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2013. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

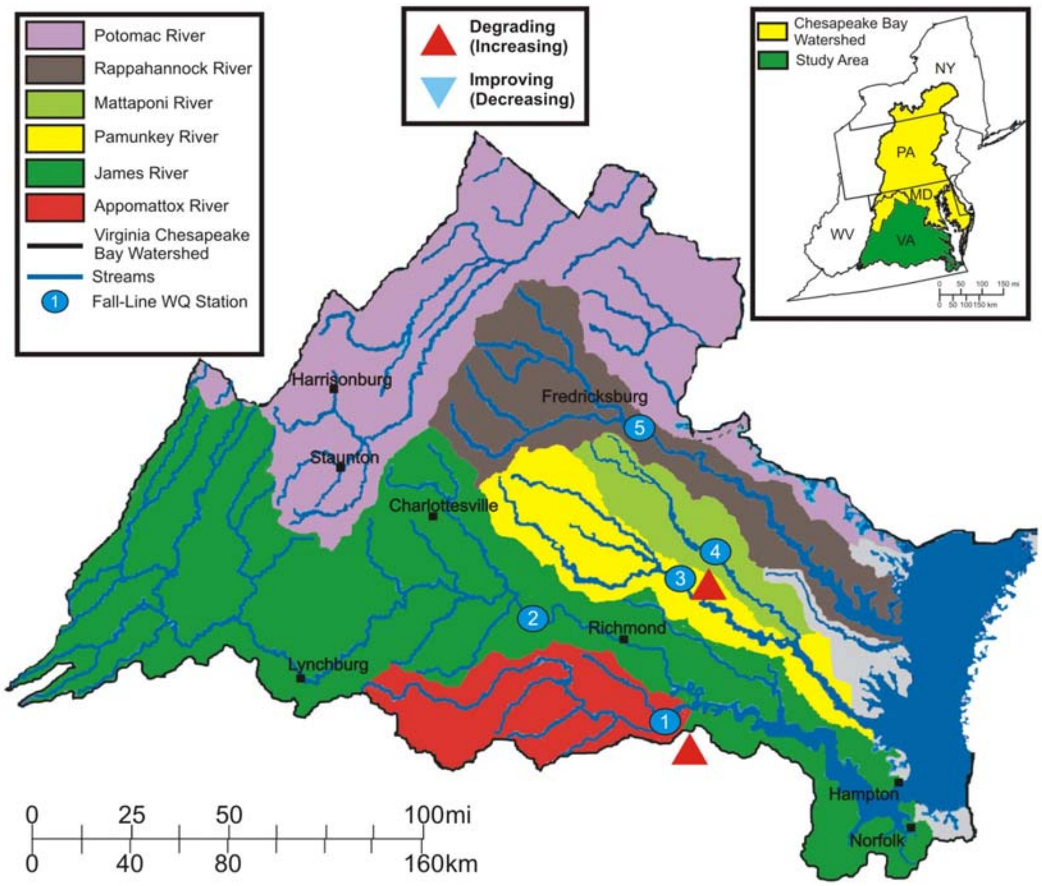
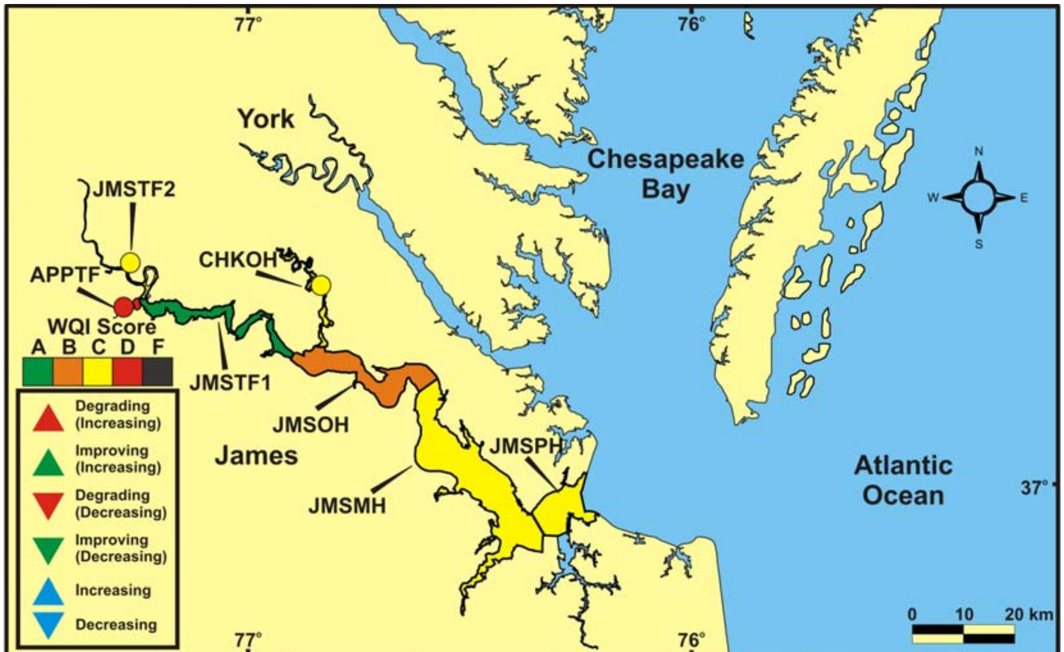


Figure 8. Long-term trends in flow-adjusted total suspended solids at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2013. Arrows indicate trends significant at $P \leq 0.05$. Listing of the station names corresponding to the numbers indicated on the map are provided in Table 5.

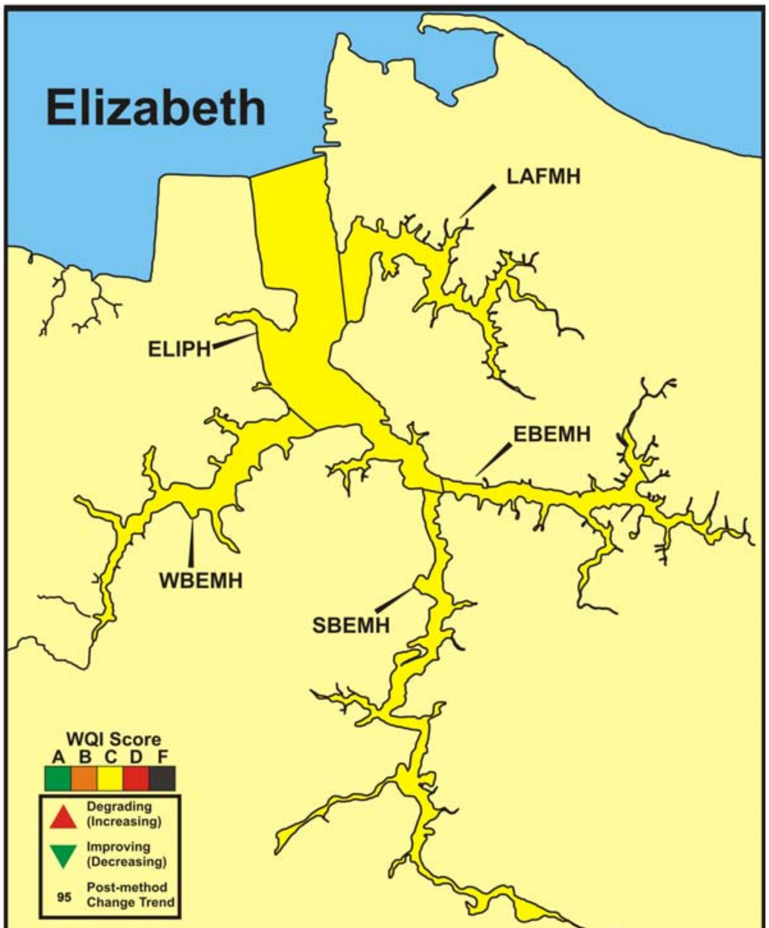
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
STN	▼	▼	▼ 95				▼ 95
BTN	▼	▼	▼ 95				
SDIN			▼	▲ 95			
BDIN			▼				
STP	▼ 95	▼	▼ 95		▼ 95		▼ 95
BTP	▼ 95	▼	▼ 95				▼ 95
SDIP	▼	▼	▼	▼ 95			
BDIP	▼	▼	▼	▼ 95			

Figure 9. 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 a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2013 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2013. 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.



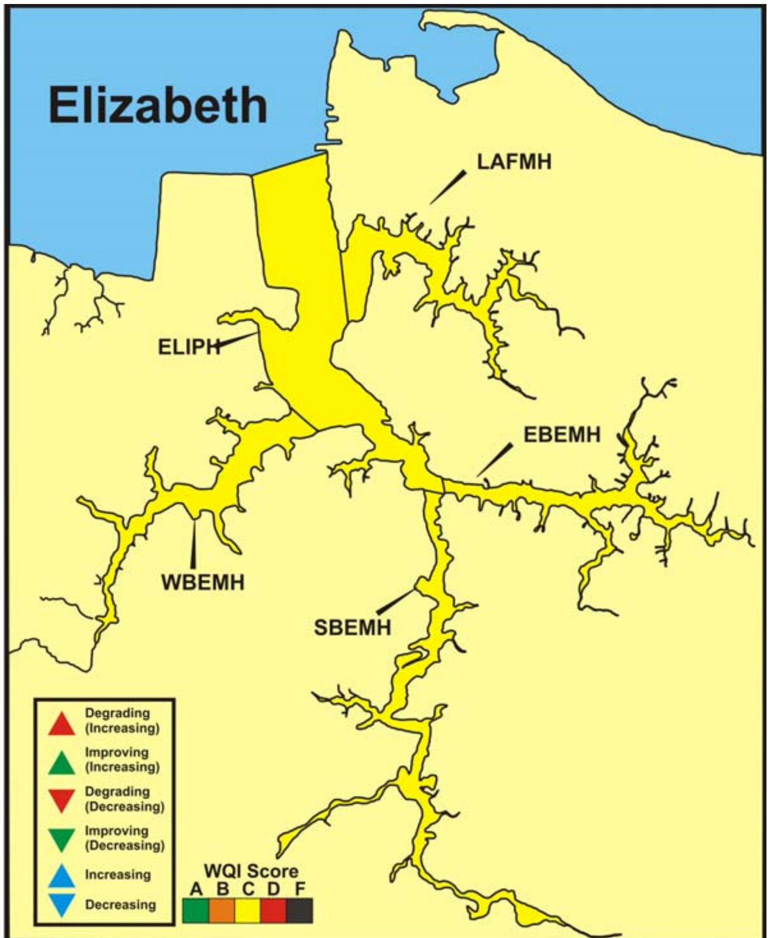
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
SCHLA		▼ (green)		▼ (green)	▼ (green)		▲ (red)
STSS	▼ (green)						
BTSS				▲ (red)		▼ (green)	▼ (green)
SECCHI			▼ (red)	▼ (red)			▼ (red)
BDO					▼ (red)		▲ (green)
SSALIN					▲ (blue)		
BSALIN					▲ (blue)		▼ (blue)
SWTEMP							
BWTEMP							▲ (blue)

Figure 10. 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 a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2013 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2013. 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	LAFMH	ELIPH
STN	▼	▼	▼	▼	▼ 95
BTN	▼	▼	▼		
SDIN		▼	▼		
BDIN		▼	▼		
STP	▼	▼	▼	▼	▼ 95
BTP	▼	▼	▼		▼ 95
SDIP	▼	▼	▼		
BDIP	▼	▼	▼		

Figure 11. 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 a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1989 through 2013. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2013 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2013. 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	LAFMH	ELIPH
SCHLA	▼ (green)				
STSS	▼ (green)	▼ (green)	▼ (green)		
BTSS	▼ (green)	▼ (green)	▼ (green)		
SECCHI		▲ (green)	▲ (green)		▼ (red)
SSALIN		▲ (blue)			
BSALIN					▼ (blue)
SWTEMP					
BWTEMP		▲ (blue)			

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 a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2013. 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.

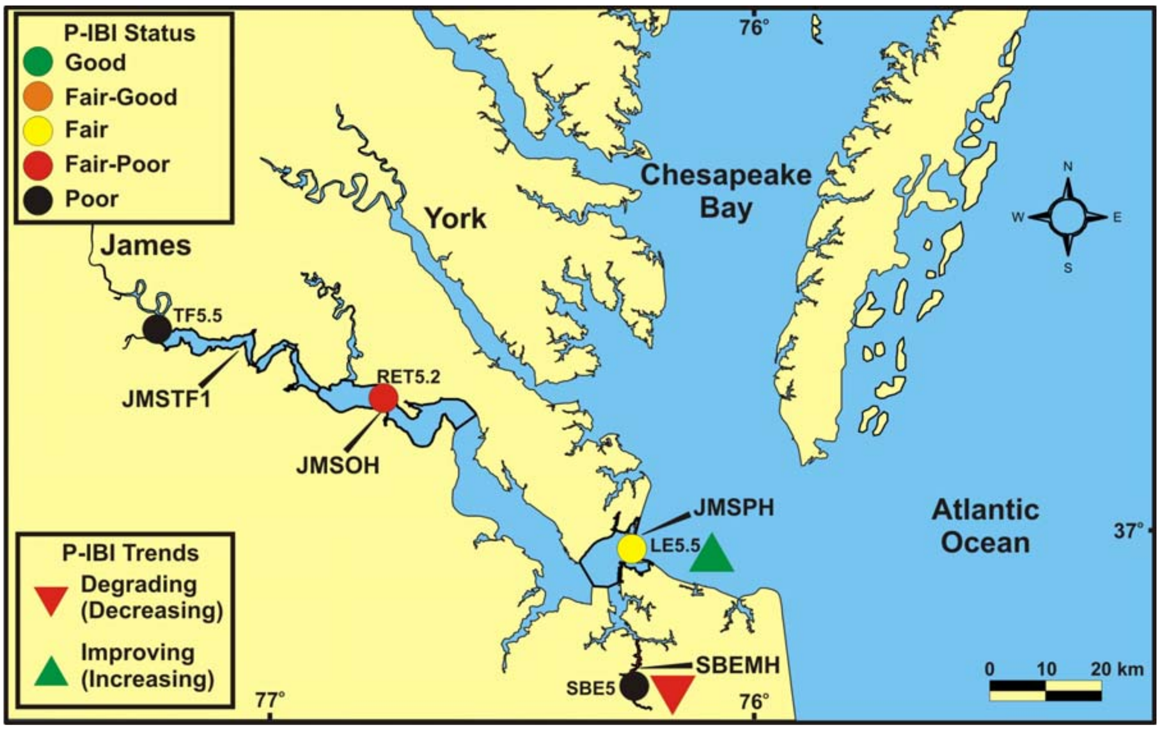


Figure 13. Status and long-term trends in phytoplankton community condition in the tidal portion of the James River basin for the period of 1985 through 2013. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2013.

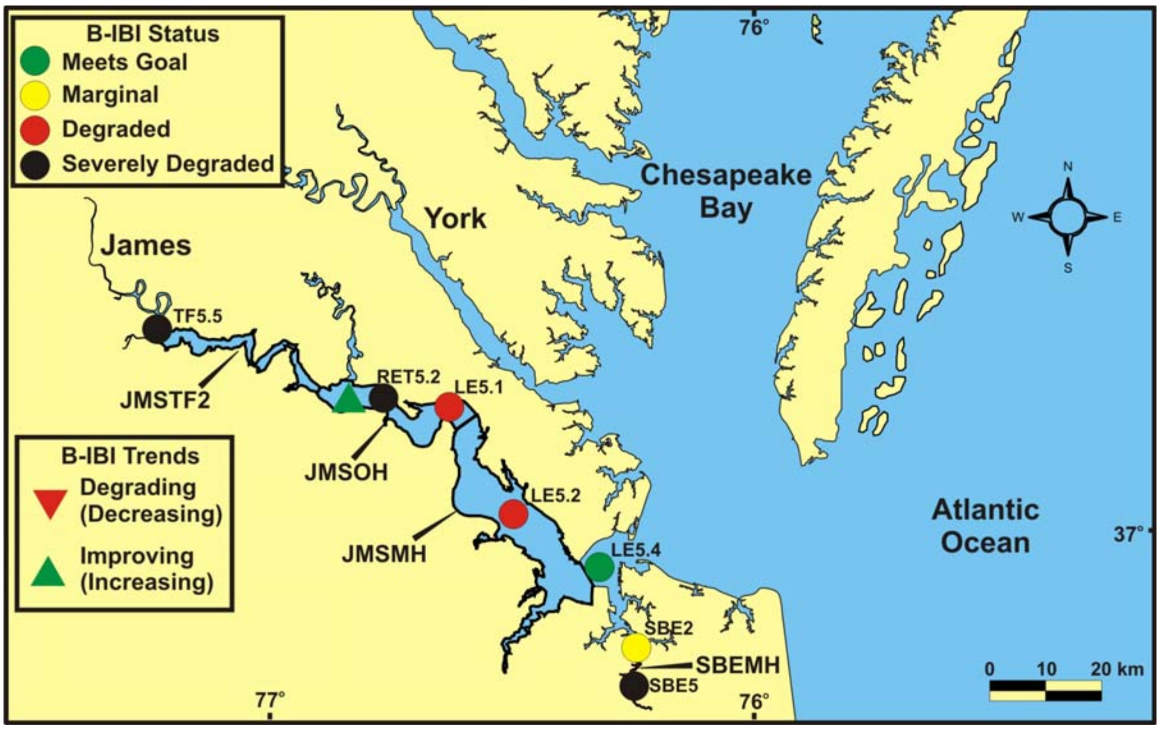


Figure 14. Status and long-term trends in benthic community condition in the tidal portion of the James River basin for the period of 1985 through 2013. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2013.

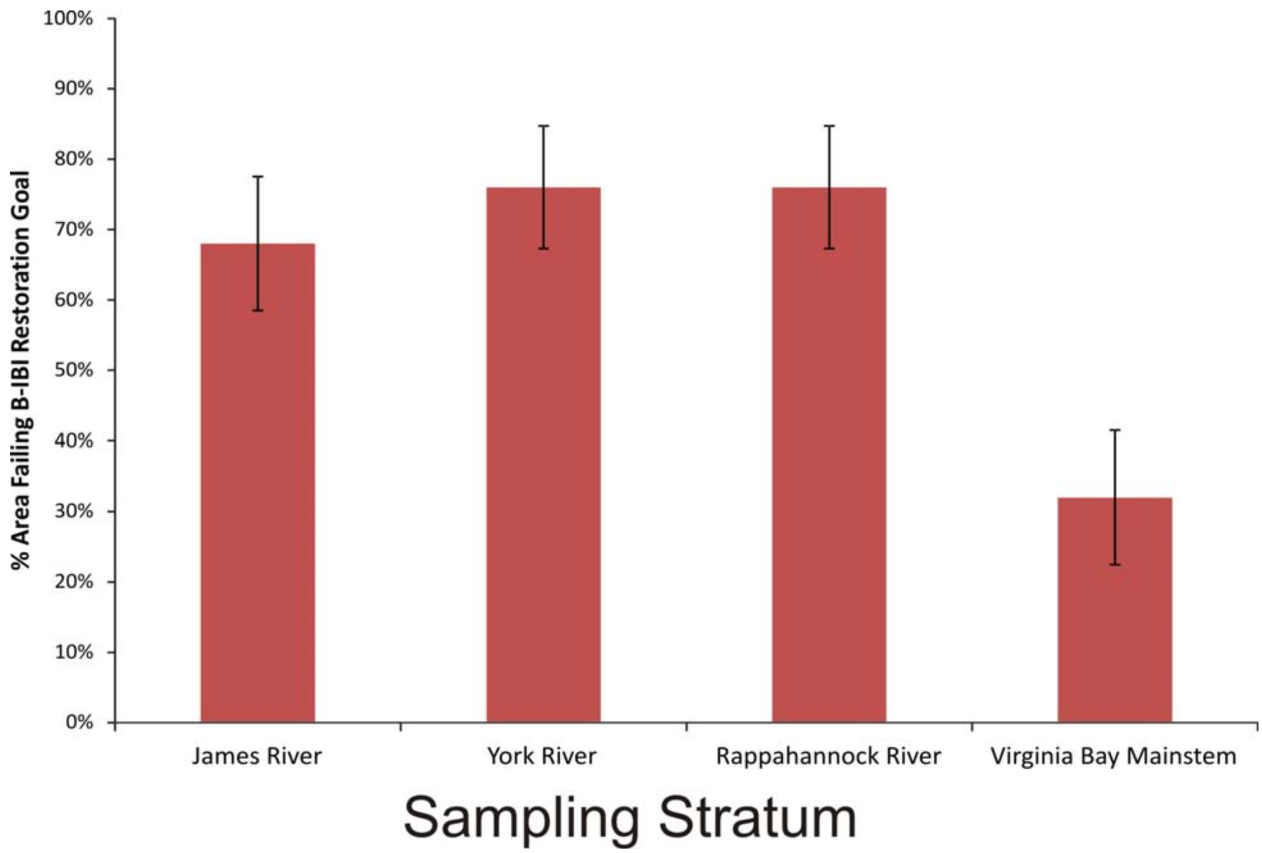


Figure 15. Percentage of area in the Virginia sampling strata failing to meet the benthic community Restoration Goals in Virginia for 2013(± 1S.E). Data provided by Versar Inc.

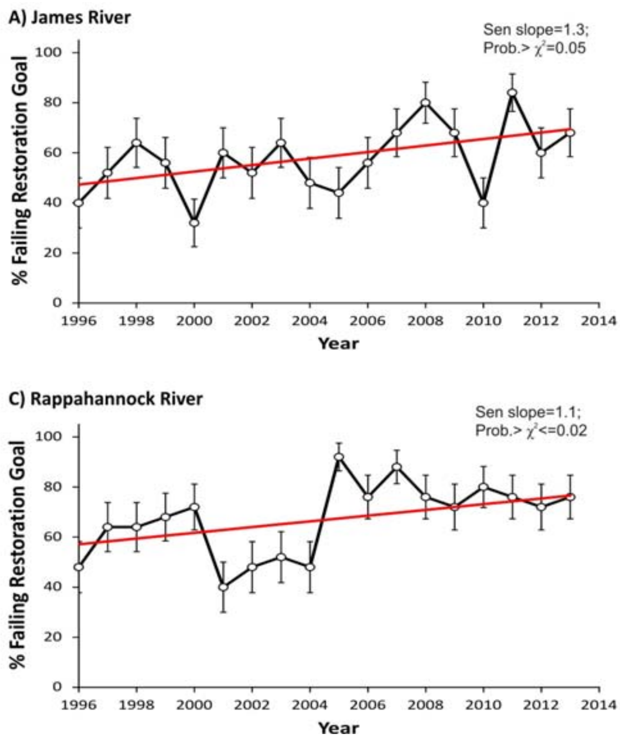


Figure 16. Long term trends in the proportion of area failing to meet the benthic community Restoration Goals for each of the major sampling strata in Virginia for the period of 1996 through 2013. Error bars are ± 1 S.E. of the mean. Data provided by Versar Inc.

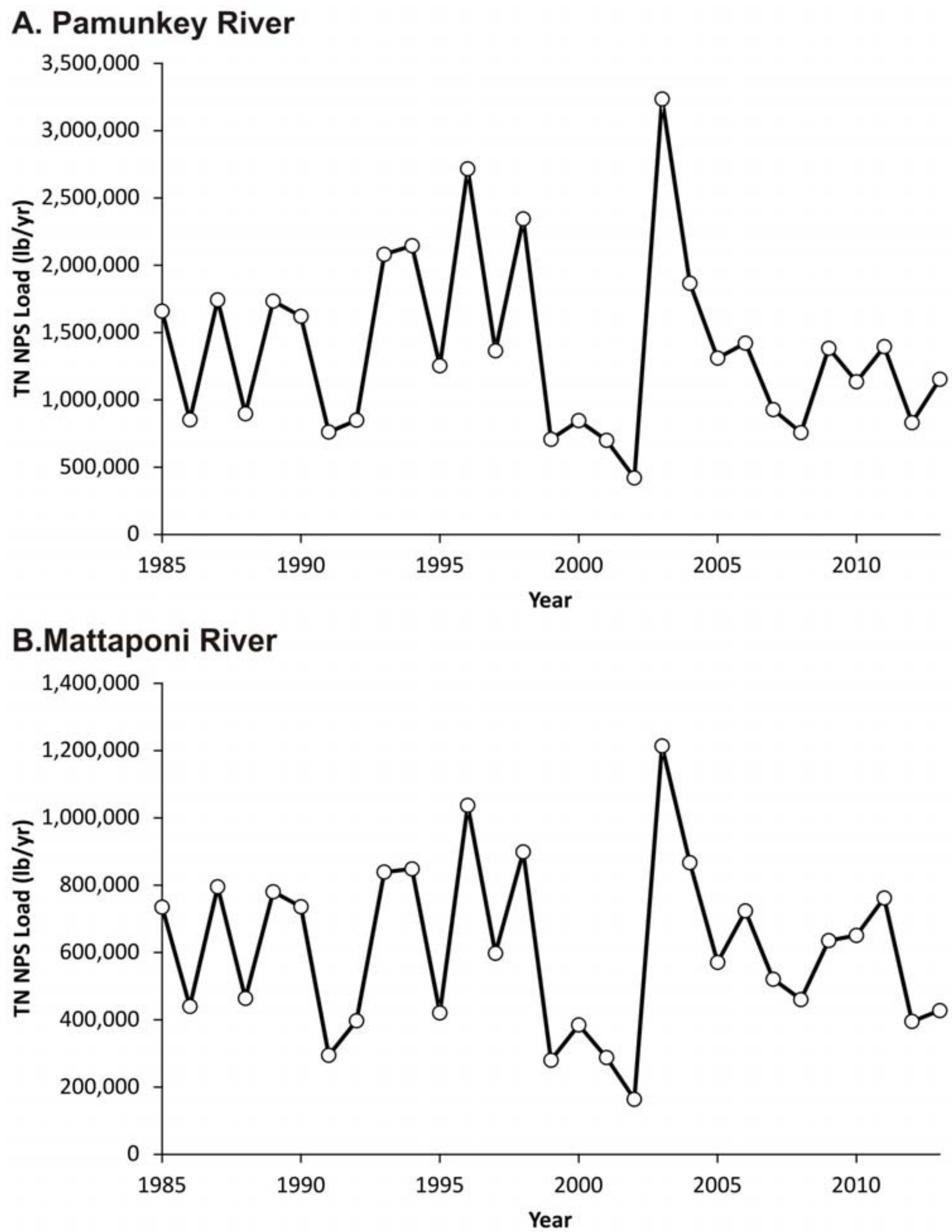


Figure 17. Long-term changes in total nitrogen load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2013. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

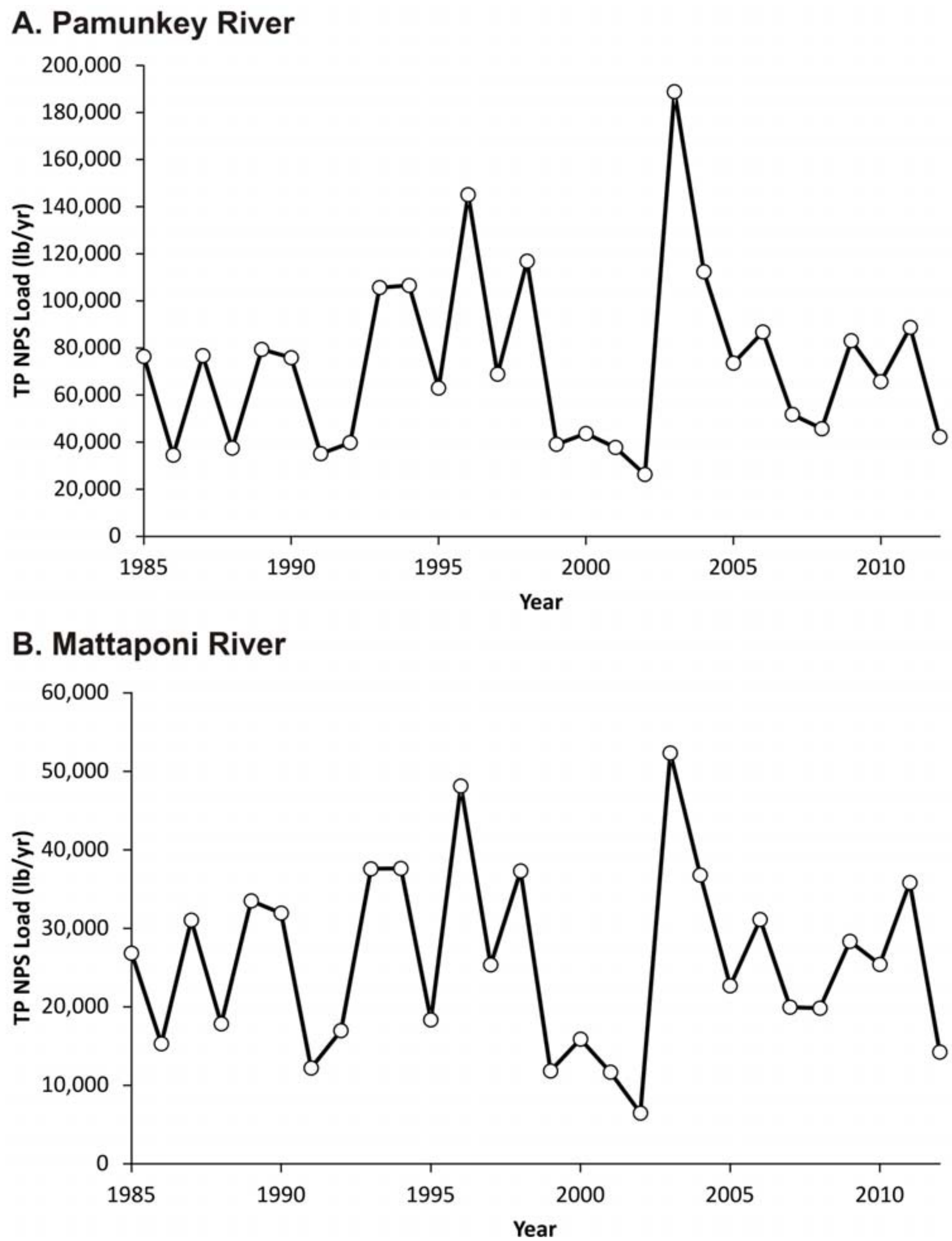


Figure 18. Long-term changes in total phosphorus load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2013. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

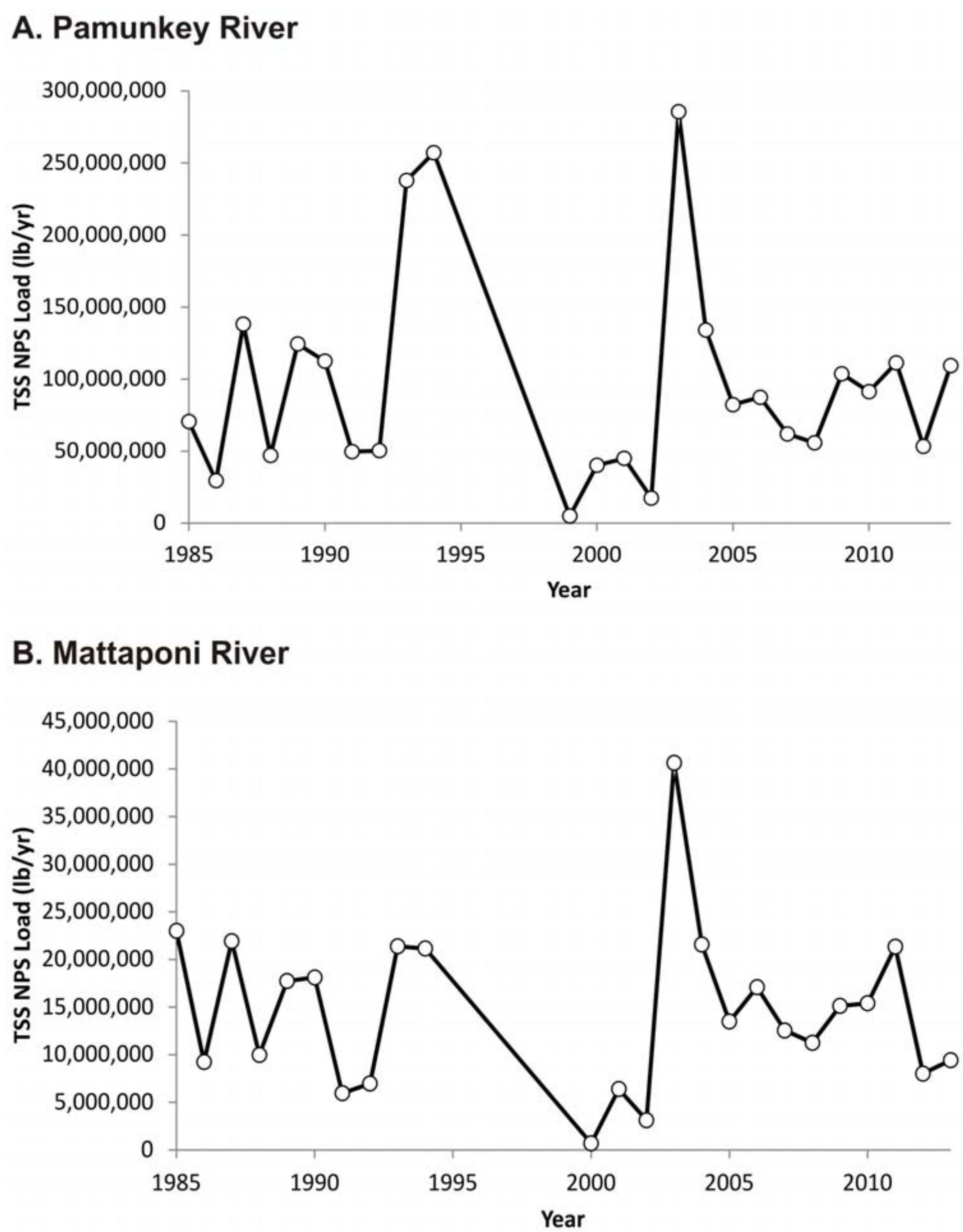


Figure 19. Long-term changes in total suspended solids load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2013. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

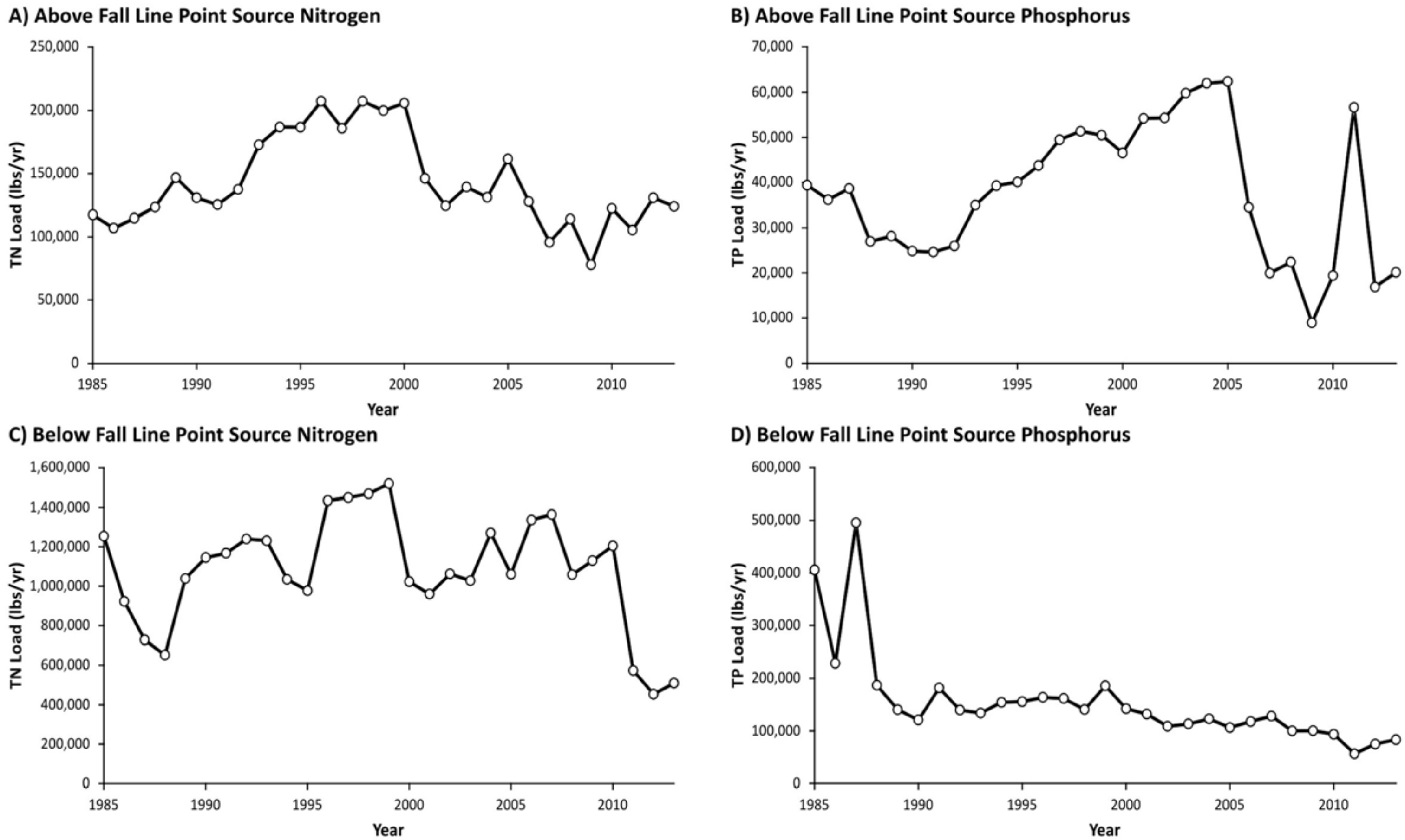


Figure 20. Long-term changes in A) Above Fall Line Point Source Nitrogen; B) Above Fall Line Point Source Phosphorus; C) Below Fall Line Point Source Nitrogen; and D) Below Fall Line Point Source Phosphorus in the York River for 1985 through 2013. Loadings presented from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

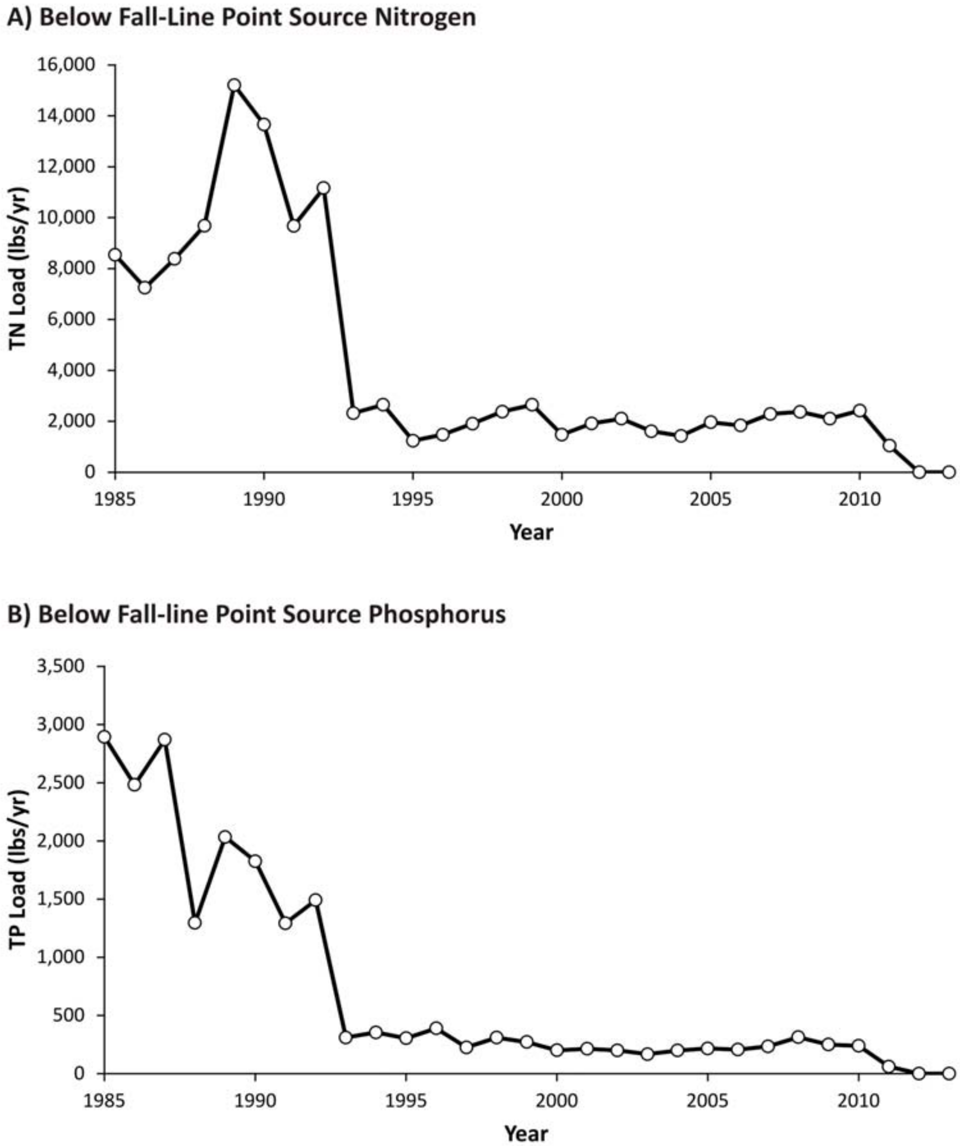


Figure 21. Long-term changes in A) Below Fall-Line Point Source Nitrogen and B) Below Fall-Line Point Source Total Phosphorus in Mobjack Bay for 1985 through 2013. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

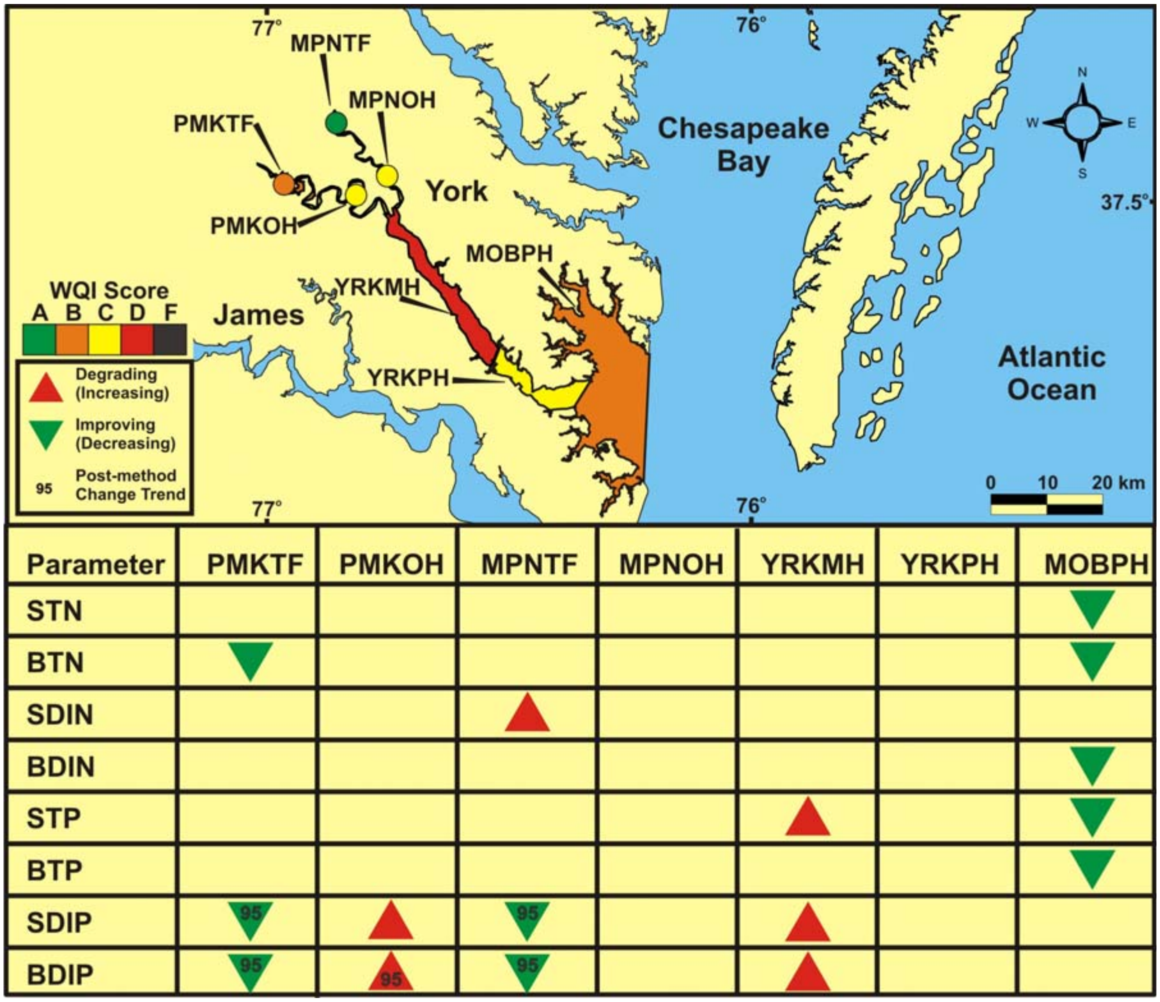


Figure 22. Water quality status and long-term trends in nutrient parameters in the tidal portion of the York River basin. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. 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 2013. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The prefixes S and B refer to surface and bottom measurements, respectively.

Parameter	PMKTF	PMKOH	MPNTF	MPNOH	YRKMH	YRKPH	MOBPH
SCHLA			▼ Improving (Decreasing)		▲ Degrading (Increasing)		
STSS	▲ Degrading (Increasing)	▼ Improving (Decreasing)				▲ Degrading (Increasing)	▼ Improving (Decreasing) 96
BTSS					▲ Degrading (Increasing)	▲ Degrading (Increasing)	▼ Improving (Decreasing) 96
SECCHI	▼ Degrading (Decreasing)		▼ Degrading (Decreasing)			▼ Degrading (Decreasing)	▼ Degrading (Decreasing)
BDO	▲ Improving (Increasing)						▲ Improving (Increasing)
SSALIN		▲ Increasing		▲ Increasing		▼ Decreasing	▼ Decreasing
BSALIN		▲ Increasing		▲ Increasing		▼ Decreasing	▼ Decreasing
SWTEMP			▲ Increasing				▲ Increasing
BWTEMP							▲ Increasing

Figure 23. 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 a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. 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 2013. 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.

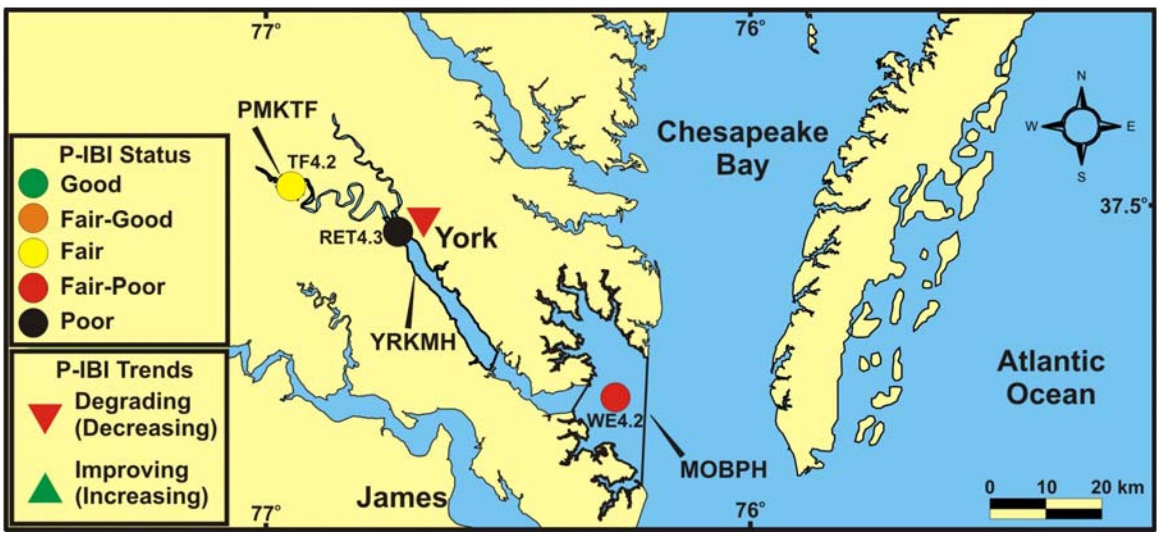


Figure 24. Status and long-term trends in phytoplankton community condition in the tidal portion of the York River basin for the period of 1985 through 2013. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2013.

Figure 25. Status and long-term trends in benthic community condition in the tidal portion of the York River basin for the period of 1985 through 2013. 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 2013.

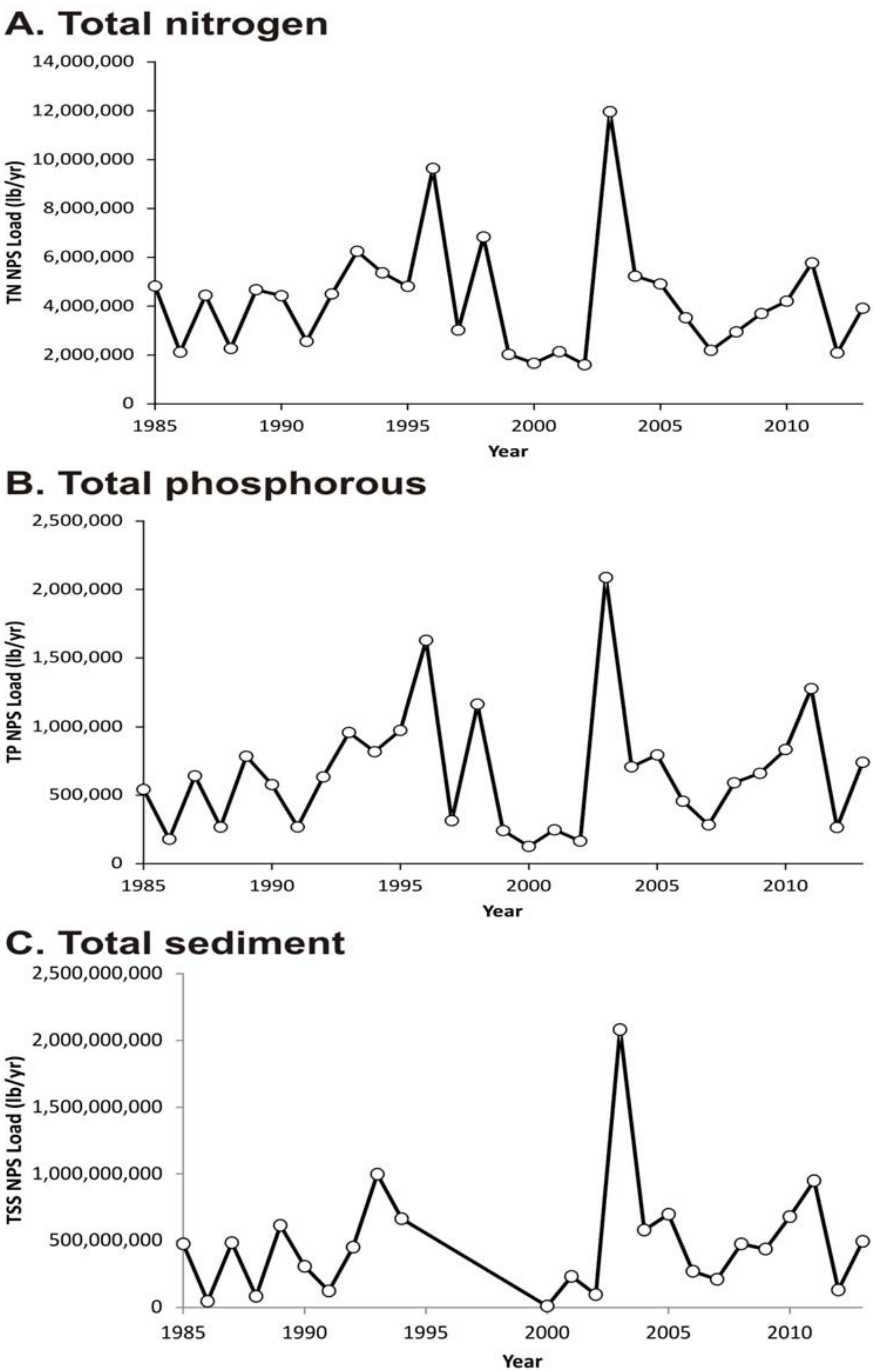


Figure 26. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment loads at the fall-line in the Rappahannock River from 1985 through 2013. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program.

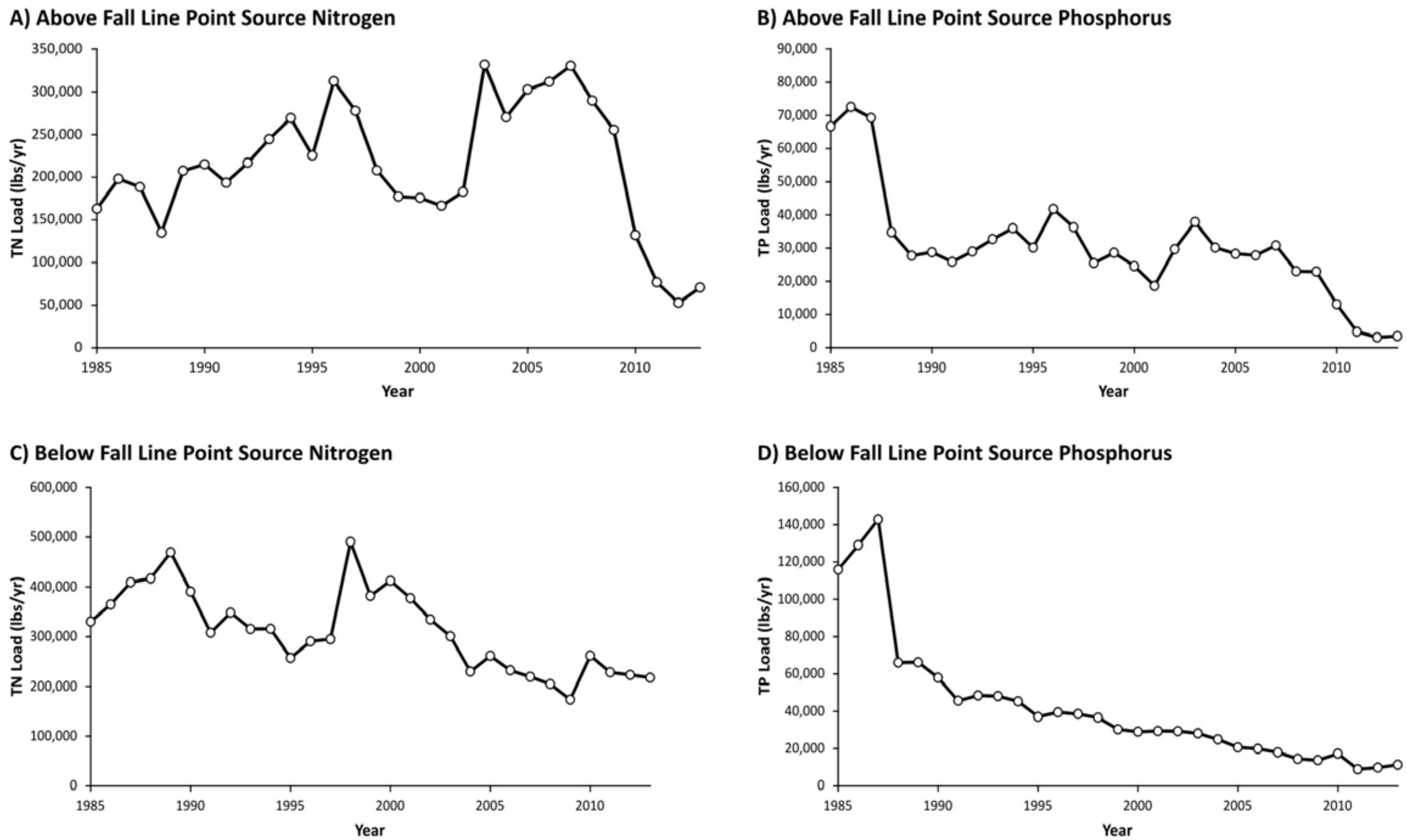
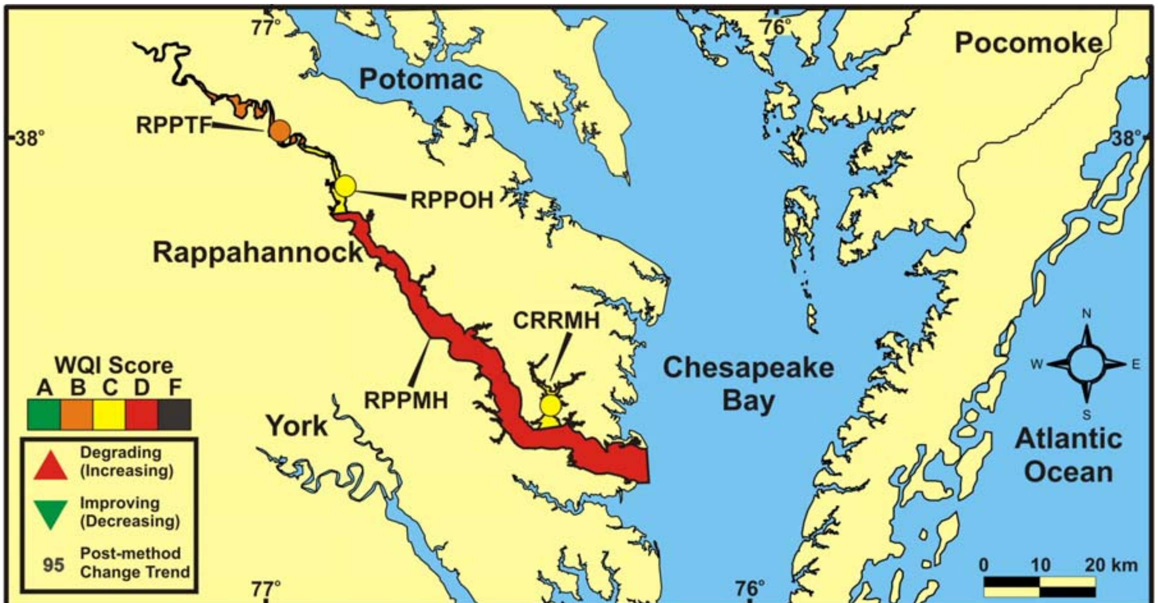


Figure 27. Long-term changes in point source loads in A) Above Fall Line Total Nitrogen; B) Above Fall Line Total Phosphorus; C) Below Fall Line Total Nitrogen; and D) Below Fall Line Total Phosphorus in the Rappahannock River for 1985 through 2013. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



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

Figure 28. 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 a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2013 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2013. 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.

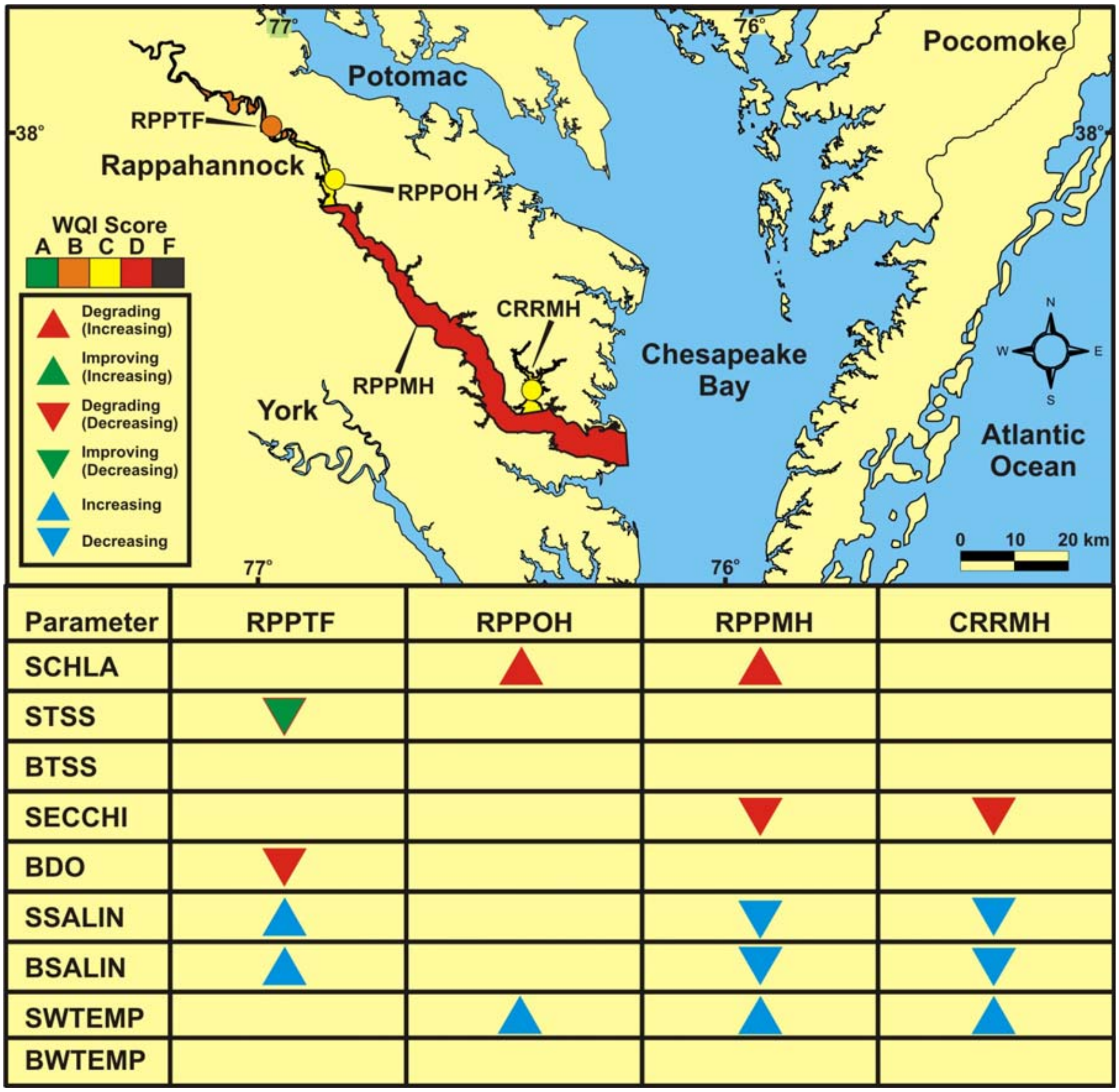


Figure 29. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the Rappahannock River basin. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2013. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2013 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2013. 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 30. Status and long-term trends in phytoplankton community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2013. 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 2013.

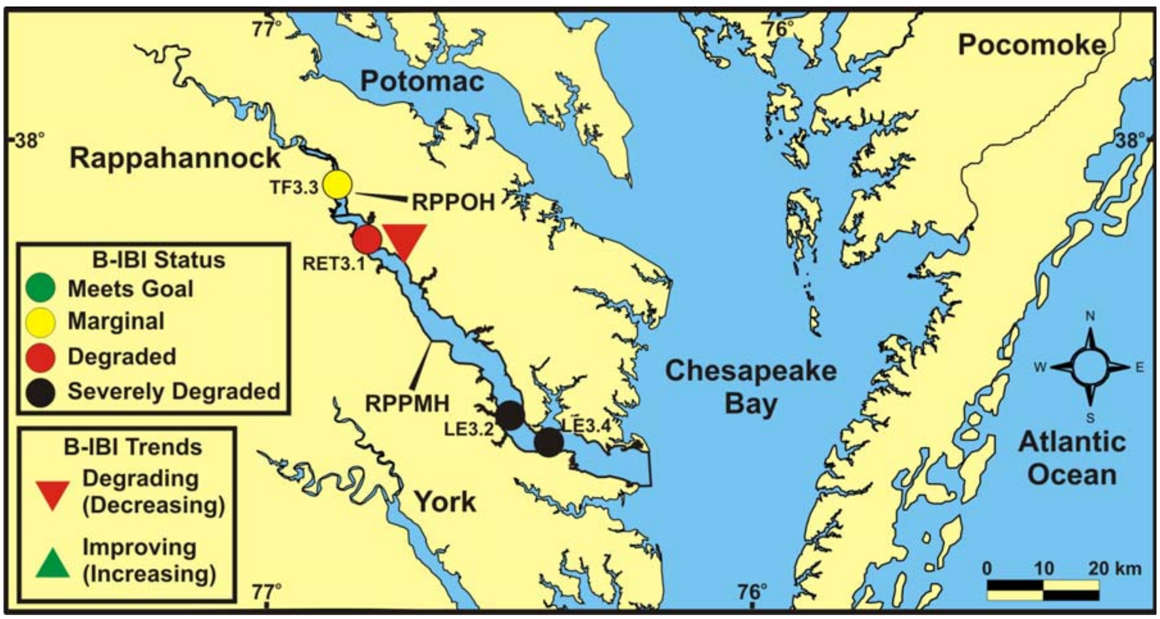
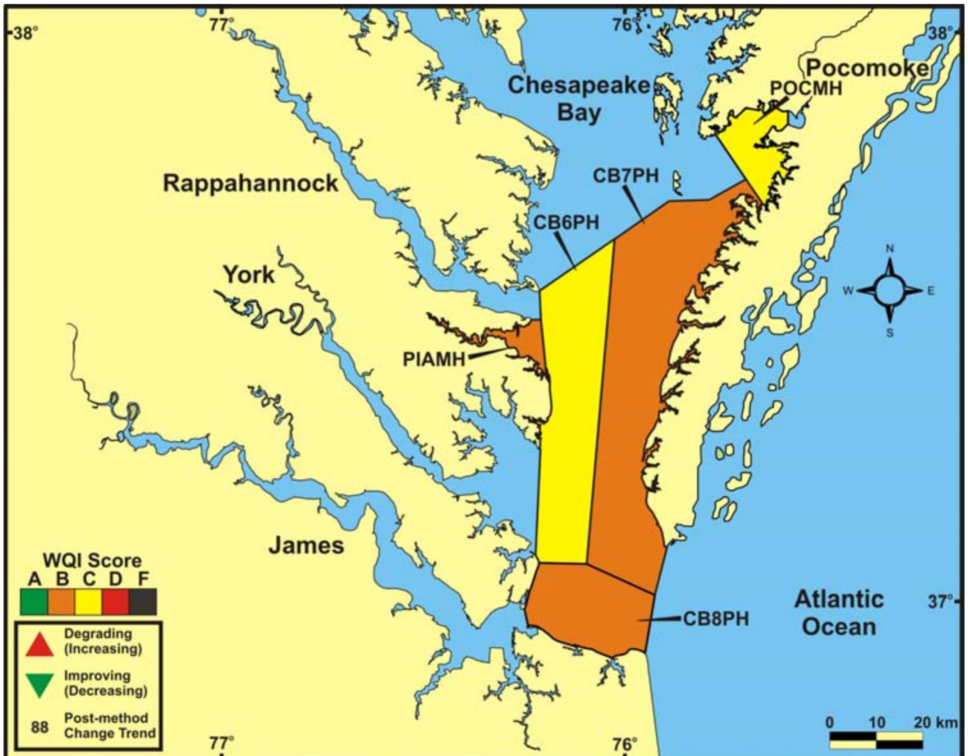
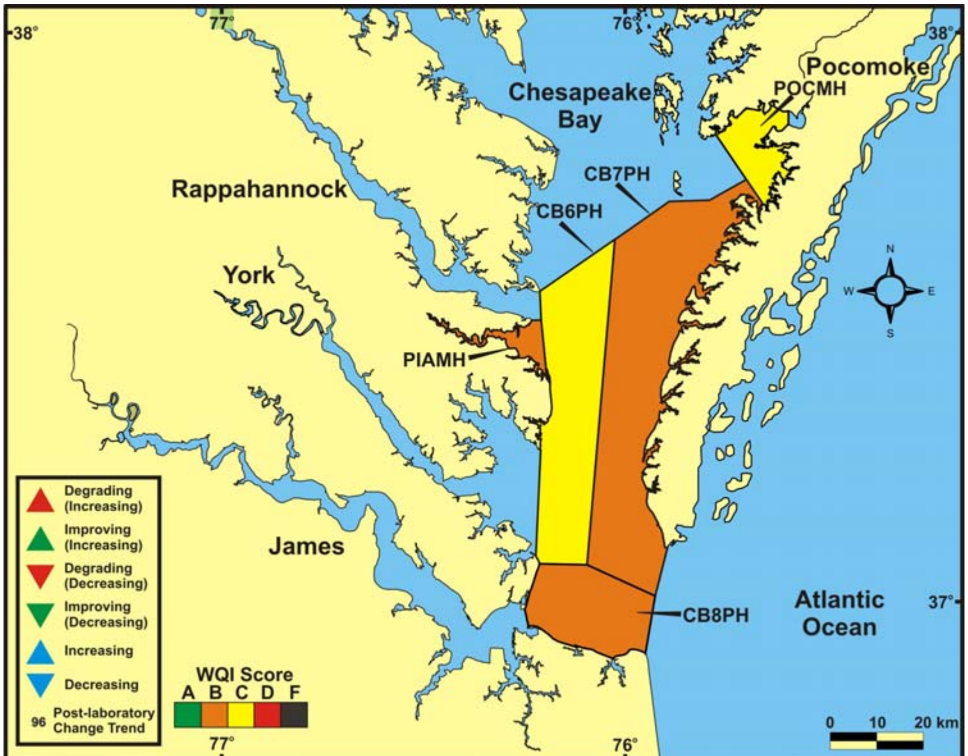


Figure 31. Status and long-term trends in benthic community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2013. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2013.



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

Figure 32. Water quality status and long-term trends in nutrient parameters in the Virginia Chesapeake Bay Mainstem for the period of 1988 through 2013. 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 2013 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1988 through 2013. 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	▼ Improving (Decreasing), 96	▼ Improving (Decreasing), 96		▼ Improving (Decreasing), 96	▼ Improving (Decreasing), 96
BTSS	▼ Improving (Decreasing), 96	▼ Improving (Decreasing), 96	▼ Improving (Decreasing)	▼ Improving (Decreasing), 96	▼ Improving (Decreasing), 96
SECCHI	▼ Degrading (Decreasing)	▼ Degrading (Decreasing)	▼ Degrading (Decreasing)	▼ Degrading (Decreasing)	▼ Degrading (Decreasing)
BDO	▲ Improving (Increasing)		▲ Improving (Increasing)		▲ Improving (Increasing)
SSALIN		▼ Decreasing	▼ Decreasing		▼ Decreasing
BSALIN	▼ Decreasing	▼ Decreasing	▼ Decreasing		▼ Decreasing
SWTEMP					
BWTEMP					

Figure 33. 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 2013. 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 2013. 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.

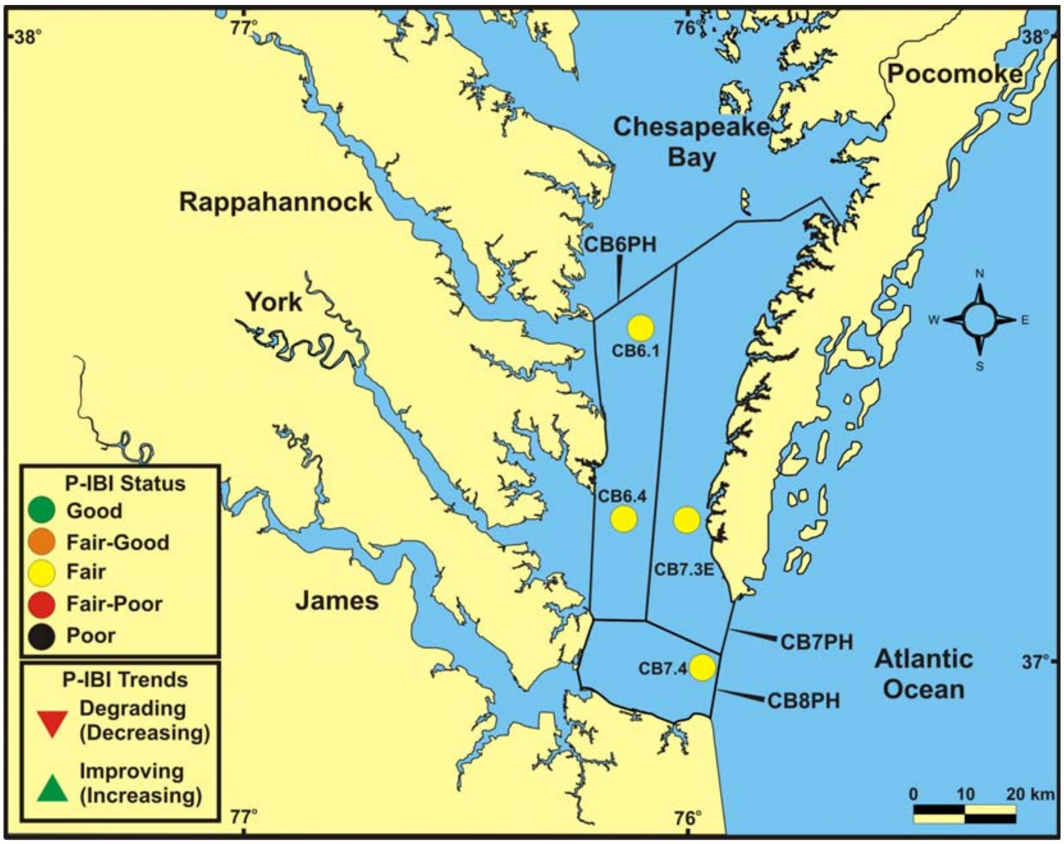


Figure 34. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2013. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2013.

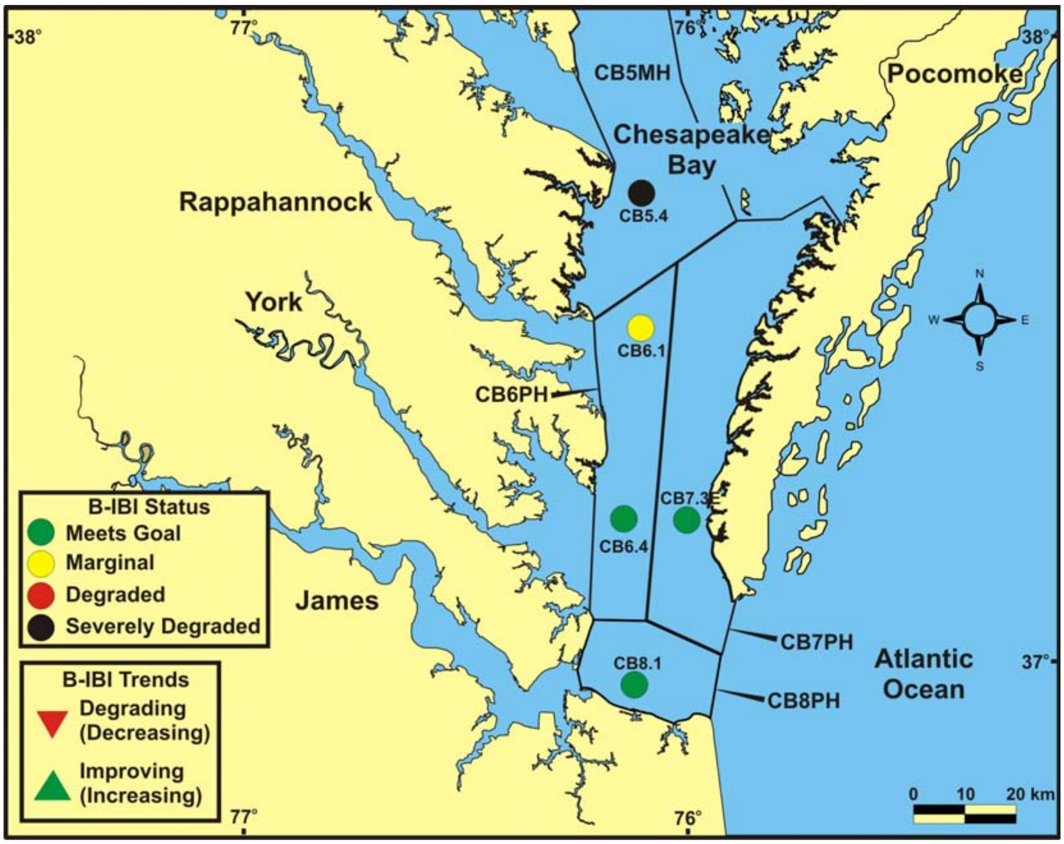


Figure 35. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2013. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2013.