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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 2014

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 concerted 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 indicative 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 30 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 2014 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 2014. 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 Benthic Index of Biotic Integrity (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 2014.

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 2012 through 2014. 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 (2012 through 2014) 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 the Weighted Regressions on Time, Discharge, and Season (WRTDS) method originally described by Hirsch et al. (2010; 2015). This technique applies a flexible multiplicative regression model that uses sample values to make estimates of concentration for every day of the entire period of record. The model considers the concentrations to be the product of four components: 1) trend - a smooth function of time typical of a moving average of a time series where the moving average is over a window of several years duration; 2) seasonality i.e. the annual cycle of variation in water quality that is usually consistent each year but that may evolve over a period of years ((i.e. amplitude, phase and shape); 3) discharge -the influence of river discharge on water quality; 4) random unexplained variation. All trends reported for fall-line non point source loads were based on results generated and provided by Doug Moyer of the US Geological Survey (pers. comm.) Annual summaries of non-point total nutrient and sediment loads are sums of the daily WRTDS values.

Trend analyses of fall-line freshwater flow, point source loads, 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 that 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).

2. Non-point Source Loads

There was no trend in freshwater flow at the fall-line in the James River (Table 2). Trend analysis of USGS load estimates in the James River indicated that there was degrading trend in dissolved inorganic phosphorus at the fall-line in the James River as well as a degrading trend in total phosphorus loads at the Appomattox River fall-line (Table 3; Figure 4). USGS estimates of annual 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 5A-C) while annual loads of these parameters in the Appomattox River showed a roughly U-shaped pattern culminating in a long-term decrease overall (Figure 6A-C) .

3. Point Source Loads

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 47.2% and 53.2%, respectively (Table 4). Significant trends in monthly point source loads of total nitrogen and total phosphorus were also detected below the fall-line although reductions there were higher at 65.5% and 59.4%, respectively (Table 4). Plots of annual total loads both above and below the fall-line tend to confirm the results of the trend analyses (Figure 7A-D).

4. 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 (Figure 8). Improving long-term trends in surface and bottom total nitrogen were observed in segment JMSTF1 (Figure 8). Improving long-term trends in surface and/or bottom dissolved inorganic nitrogen were observed in both tidal freshwater segments of the James River (JMSTF1 and JMSTF2) (Figure 8). Post method change improving trends in total nitrogen were found in the Appomattox River (APPTF), the upper tidal fresh James River (JMSTF2) and the James River mouth (JMSPH) (Figure 8). Improving long term or post method change trends in surface and/or bottom total phosphorus were detected in all segments of the mainstem of the James River and in the Appomattox and Chickahominy rivers as well (Figure 8). Improving long term or post method change trends were found in all segments of James River basin except JMSOH and JMSMH (Figure 8).

Improving trends in surface chlorophyll *a* were restricted to the lower portion of the tidal freshwater James River (JMSTF1), and the Chickahominy River (CHKOH) while a degrading trend in chlorophyll *a* was detected at the entrance to James River in segment JMSPH (Figure 9). An improving trend in surface total suspended solids was detected in the Appomattox River (APPTF) while degrading trends in water clarity as measured by Secchi depth were detected in segments JMSTF2, CHKOH, and JMSPH (Figure 9). Summer bottom dissolved oxygen concentrations were unchanged for most segments except at segments JMSTF2 and JMSPH where improving trends were observed (Figure 9). Salinity and temperature showed no change in most segments (Figure 9).

Water quality status based on the modified WQI was Fair in all segments of the Elizabeth River and results of trend analyses suggest continued improvements in water quality conditions (Figure 10). 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 10). Improving trends in surface and bottom dissolved inorganic nitrogen were observed in the Southern and Eastern Branches of the Elizabeth River (SBEMH and EBEMH) while improving trends in dissolved inorganic phosphorus were observed in Southern, Western, and Eastern Branches of the Elizabeth River (SBEMH, WBEMH, and EBEMH) (Figure 10).

Additionally, improving trends in surface and bottom total suspended solids and in Secchi depth were observed in most segments of the Elizabeth River except for Mainstem (ELIPH) and the Lafayette River (LAFMH) (Figure 11). There were few trends in chlorophyll *a*, and none in summer bottom dissolved oxygen, salinity or temperature (Figure 11).

5. Phytoplankton Communities

Phytoplankton communities in the James River were characterized Poor or Fair-Poor as measured by the P-IBI (Figure 12). Although no trends in P-IBI were observed at any of the James River mainstem stations (Figure 12), some degrading trends in several important phytoplankton indicators were observed at station RET5.2 including a decreasing trend in chlorophyte biomass and an increasing trend in cyanophyte biomass Appendix G - Figure 1). Improving trends in picoplankton abundance were detected at all stations in the James River as was an improving trend in chlorophyte biomass at station TF5.5 (Appendix G - Figure 1). Phytoplankton communities at station SBE5 in the Elizabeth River as measured using the P-IBI were Poor and a degrading trend in the P-IBI was observed indicating community conditions are continuing to degrade despite improvements in water quality.

There is a transition in phytoplankton composition moving downstream from the tidal freshwater James River station (TF5.5) 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., *Anabaena* spp., *Chroococcus* spp. , additional filamentous and colonial taxa) and chlorophytes are the dominant algal flora. The tidal freshwater James River represents not only the most productive (highest algal abundance) but one of the most diverse phytoplankton communities in the Chesapeake Bay. While some potentially harmful algal bloom (HAB) cyanobacterial species have been present in the tidal-fresh James, including Microcystis aeruginosa (not observed in 2014 James River CBMP samples), 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. 2014 represented a minor bloom year for Heterocapsa triquetra in the James, with a maximum of only 6200 cells/ml in the mesohaline James during April. 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) No major *P. minimum* bloom occurred in the James during 2014. 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. 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 2012-2013, the *C. polykrikoides* bloom was amongst the largest recorded for the James River region, with bloom conditions lasting approximately 7 weeks and cell concentrations >70,000 cells/ml (Egerton et al. 2012). In comparison, in 2014 *C. polykrikoides* was much lower in abundance, duration and spatial extent than previous years, 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, which was not observed in 2014, but has expanded its bloom range into the meso/polyhaline James River during 2015(Marshall and Egerton 2012).

6. Benthic Communities

Status based on the B-IBI at fixed point monitoring stations in the James River generally improved moving downstream from Severely Degraded at station TF5.5 in the lower tidal freshwater segment (JMSTF1) to Degraded at stations RET5.2 and LE5.1 in the oligohaline portion of the James River, to Meets Goals at stations LE5.2 and LE5.4 in segment JMSMH (Figure 13).

Status of benthic communities in the Southern Branch of the Elizabeth River was Marginal at SBE2 and Degraded at SBE5 (Figure 13). An improving trend in the B-IBI was detected at station RET5.2 in segment JMSOH (Figure 13). Fifty-two percent of the total area of the James River failed to meet restoration goals (Figure 14) and there was a significant increasing trend in the proportion of area failing to meet the restoration goal since 1996 (Figure 15). 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).

7. Management Issues

Estimates of nutrient and sediment loads at the fall-line in the James River have fluctuated substantially but overall appear to be decreasing and long-term improving trends were detected in nitrate-nitrite, total phosphorus and dissolved inorganic phosphorus loads. Long-term improving trends in point source total nitrogen and phosphorus loads were detected both above and below the fall-line in the James River.

Water quality status in the tidal portions of the James River was generally Fair throughout most of the basin. Improving trends in nutrients, both in nitrogen and phosphorus parameters were found throughout most of the James River although some trends were observed farther downstream. 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 non point source and point source 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 to answer this question.

Overall phytoplankton conditions were characterized as Fair-Poor in the James River and Poor in the Elizabeth River and either show no sign of improvement or in the case of the Elizabeth River are degrading as indicated by the decreasing trend in the P-IBI. 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. While absent in 2014, the toxic *Alexandrium monilatum* was present in the Elizabeth River in 2015 at concentrations >103 cells ml^{-1}, and responsible for widespread bioluminescence. No fish kills were observed. Several other toxin producers (*Prorocentrum minimum*, *Karlodinium veneficum*, *Chattonella subsalsa*) are also present in the Elizabeth and 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 52% 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 non-point source runoff into the Elizabeth River coupled with high point source 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 point source loads of nutrients. Reductions in total suspended solids concentrations are probably due to the reductions in non-point source 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. 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).

2. Non-Point Source Loads

There were no significant trends in freshwater flow in either of the tributaries of the York River watershed (Table 2). A degrading trend in USGS estimates non-point source total phosphorus loads was observed at the fall-line in the Mattaponi River but no other trends non-point source loads were detected (Table 3; Figure 4). For both the Pamunkey and Mattaponi rivers, plots of annual non-point source nutrient and sediment loads indicate an initial period of high variability and gradual increase in loads in total nitrogen, phosphorus, and sediments from 1984 through 1998 followed by a substantial decline and period of relative stability from 1993 until 2003 when loads of all three parameters spiked probably due to Hurricane Isabel after which loads of all three parameters declined substantially (Figures 16-17).

3. Point Source Loads

Significant improving long term trends in decreasing 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 117,000 lbs/yr to just under 206,000 lbs/yr and then a decline over the next decade to around 78,000 lbs/yr in 2009. Since then above fall-line point source loads in total nitrogen have remained relatively stable at between 120,000 to 140,000 lbs/yr (Figure 18A). The pattern for TP was similar although it was marked by an initial eight year decline from around 40,000 lb/yr to approximately 26,000 lb/yr followed by a steady increase until 2005 when it reached over 62,000 lb/yr (Figure 18B). This was followed by a substantial decline in 2006 to around 34,000 lb/yr after which loads in total phosphorus have remained relatively stable at values between 9,000 lbs/yr to 22,000 lbs/yr with the exception of a large spike in 2011 to nearly 57,000 lbs/yr (Figure 18B). Overall these trends have resulted in a 31% reduction and 17% 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 18C) with the overall result being one of a slight decrease in total nitrogen point source nitrogen loads below the fall-line of approximately 19% (Table 4). In contrast, annual point source total phosphorus loads below the fall-line show what appear to be an asymptotic decline (Figure 18D) with an overall long term decrease of nearly 42% (Table 4). Point source inputs to Mobjack Bay have been eliminated and as a result trends of point source loads for this region will no longer be reported.

4. Tidal Water Quality

Water quality status through 2014, as measured using the modified WQI, ranged from 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 19). 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 19). With respect to nutrients, improving trends in surface dissolved inorganic phosphorus were detected in the upper Pamunkey and Mattaponi rivers (PMKTF and MPNTF) while degrading post-method change and long-term trends in bottom and surface dissolved inorganic phosphorus were detected in the lower segment of the Pamunkey (PMKOH) and in the middle York River (YRKMH) (Figure 19). Improving trends in total nitrogen, dissolved inorganic nitrogen and total phosphorus were detected in Mobjack Bay (MOBPH; Figure 19) perhaps in direct relation to the elimination of point sources in that segment.

An improving trend in surface chlorophyll *a* concentrations was observed in the upper Mattaponi River (MPNTF) while degrading trends were observed in the same parameter in the middle and lower York River (YRKMH and YRKPH) (Figure 20). Degrading trends in total suspended solids were detected in the upper Pamunkey River (PMKTF) and the middle and lower York River (YRKMH and YRKPH) and an improving trend in this parameter was detected in the lower Pamunkey River (MPNTF) (Figure 20). 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 20). Improving trends in summer dissolved oxygen were observed in the upper Pamunkey River (PMKTF) and Mobjack Bay (MOBPH; Figure 20). 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 20).

5. 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 2012 through 2014 (Figure 21). No trends in the P-IBI were observed in the York River (Figure 21).

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 although cyanobacterial biomass appears to be increasing (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 Margalef species diversity, diatom biomass and cyanophyte biomass (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). The tidal fresh Pamunkey (TF4.2) differs significantly from the freshwater segments of the Rappahannock (TF3.3) and James rivers (TF5.5). Station TF4.2 has significantly lower algal concentrations, along with a generally reduced number of species compared to the other freshwater stations. 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 and 2013 the region experienced a dense *Alexandrium monilatum* bloom extending out of the York into the lower Chesapeake Bay mainstem. No *Alexandrium* bloom was observed in 2014, however the 2015 bloom was the largest ever for the region, with cell concentrations >105 cells ml^{-1}. *Cochlodinium polykrikoides* has a long historical record of annual summer/early autumn blooms occurring in the lower reaches of the York River, including large blooms in 2012, 2013 and 2015. The 2014 bloom was notably reduced compared to other years.

6. Benthic Communities

Benthic communities met restoration goals at stations TF4.2 in the upper Pamunkey River (PMKTF) and LE4.3 in middle York River (YRKMH) in the York River (Figure 22). Status of benthic communities at stations RET4.3 in the middle York River and LE4.3B in the lower York River (YRKPH) were Marginal and Poor at station LE4.1 in the middle York River (Figure 22). An improving trend in the B-IBI was detected at station LE4.3B in the lower York River (YRKPH) (Figure 22). In 2014, results of the probability-based benthic monitoring indicated that 56% of the total area of the York River failed to meet restoration goals in the York River (Figure 14). There was no significant trend in the proportion of area failing to meet the restoration goals in the York River stratum (Figure 15).

7. 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. There were relatively few trends in nutrients observed in the Pamunkey River, Mattaponi River and mainstem 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. Relatively few trends in non-nutrient parameters were observed although degrading trends in water clarity were found throughout this watershed. Examination of patterns in both point and non-point source loadings in the York River and its tributaries suggest that trends in water quality conditions did not appear to be directly tied to trends or patterns observed in point or non point source loads with the possible exception of Mobjack Bay.

Several improving trends in nutrients were detected in Mobjack Bay that could be tied to the reductions in point source loadings. Multiple improving trends in nutrients, total suspended solids and bottom dissolved oxygen were also detected in Mobjack Bay that 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 with status ranging between Fair and Poor and no improvements in the P-IBI 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 are the dinoflagellates *Cochlodinium polykrikoides* and *Alexandrium monilatum*, which now appears to be well established and responsible for persistent annual HABs. 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 over half 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 station 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).

2. Non Point Source Loads

There was no trend in freshwater flow at the Rappahannock River fall-line (Table 2). Improving trend in USGS monthly estimates of total nitrogen, nitrate-nitrite and dissolved inorganic phosphorus loads were detected at the fall-line in the Rappahannock River (Tables 3; Figure 4). Plots of annual estimates of total non point source total nitrogen, total phosphorus and suspended sediment loads suggest that all three of these stressors may be increasing in the watershed although the change appears to be minimal (Figure 23).

3. Point Source Loads

Improving trends in both total nitrogen and total phosphorus loads were detected that resulted in reductions of approximately 14% and 55% of monthly loads of these parameters above the fall-line in the Rappahannock River (Table 4). A plot of annual total nitrogen loads increased from nearly 163,000 lbs/yr in 1985 to about 313,000 lbs/yr in 1996, after which loads declined and ranged between 167,000 to 208,000 lbs/yr (Figure 24A). Total nitrogen loads peaked again in 2003 at 332,000 lbs/yr and stabilized at values between 270,000 lbs/yr to 331,000 lbs/yr after which loads in total nitrogen declined markedly (Figure 24A). A plot of annual loads of total phosphorus, in general, agrees with the trend analysis results showing an asymptotic decline from 1985 through 2014 above the fall-line (Figure 24B). Improving trends in monthly point source loads resulted in 58% reductions in both total nitrogen and total phosphorus were detected below the fall-line (Table 4). In general, plots of annual total loads confirm results of the trend analyses (Figure 24C-D).

4. Tidal Water Quality

Water quality status as measured using the modified WQI was Good in the upper Rappahannock River (RPPTF), and Fair in the remaining segments of the Rappahannock (RPPMH and RPPOH) and Corrotoman

(CRRMH) rivers (Figure 25). 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 total and dissolved inorganic phosphorus were detected in all segments of this tributary (Figure 25).

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 middle (RPPOH) and lower Rappahannock River (RPPMH) and the Corrotoman River (CRRMH) (Figure 26). A degrading trend in bottom dissolved oxygen was also detected in the upper Rappahannock River (segment RPPTF) (Figure 26). Decreasing trends in salinity were detected in the lower Rappahannock River (RPPMH) and Corrotoman River CRRMH while increasing trends in salinity were detected in the upper Rappahannock River segment (RPPTF) (Figure 26).

5. Phytoplankton Communities

Overall phytoplankton communities in the Rappahannock River could be generally characterized as 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 27). Despite recent improvements in water quality, a decreasing trend in the P-IBI was detected at station RET3.1 (Figure 27). Increasing trends in cyanobacterial biomass observed also suggest that phytoplankton community conditions are degrading throughout the Rappahannock River (Appendix G, Figure 5). However, increasing trends were observed in chlorophyte biomass observed at stations TF3.3 and RET3.1 and decreasing trends in picoplankton biomass at stations RET3.1 and LE3.6 which, in contrast, indicate improving phytoplankton conditions (Appendix G; Figure 5).

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 phytoplankton community at the tidal freshwater station is very diverse, and contains a variety of freshwater diatoms (pennate and centric), cyanobacteria, and chlorophytes as the predominant algae, very similar to the composition found in the tidalfresh James River. Throughout the Rappahannock River a spring diatom bloom (*Skeletonema*, *Chaetoceros*, *Cyclotella*, *Ceratulina* spp.) 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. *Cochlodinium* blooms were not present in the Rappahannock River in 2013 or 2014, with relatively low concentrations observed in 2015. The ichthyotoxic dinoflagellates *Karlodinium veneficum* and *Prorocentrum minimum* also occur in this river and often form annual blooms, including in 2014. In the tidal freshwater region the cyanobacteria *Microcystis aeruginosa* is present and a potential toxin producer.

6. Benthic Communities

Benthic community status was Degraded or Severely Degraded at all fixed point stations in the Rappahannock River. In addition, a degrading trend in the B-IBI was detected at station RET3.1 in segment RPPMH (Figure 28). Probability-based benthic monitoring results indicated that 60% the total area of

Rappahannock River failed to meet benthic community goals in 2014 (Figure 14). There was a significant increasing trend in the proportion of area failing to meet the restoration goal since 1996 for this sampling stratum (Figure 15). 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).

7. Management Issues

Water quality status in the lower segments of the Rappahannock River basin as measured using the WQI was Fair and Good in the upper Rappahannock River (RPPTF). Improving nutrient trends were observed but all were post-method change trends that have occurred since 1995. This maybe reflective of the change in point source loads since patterns in non-point source loads are somewhat indicative of an increasing trend although no statistically significant trend was observed. Degrading trends in chlorophyll *a*, Secchi depth, and bottom dissolved oxygen were detected in 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 in some areas. Probability-based monitoring results indicated that 60% of the total area of the Rappahannock River failed to meet restoration goals (Figure 14) and that there was a significant increasing trend in the proportion of area failing the restoration goals (Figure 15). Poor benthic communities in the Rappahannock River are most likely due primarily to low dissolved oxygen.

D. Virginia Chesapeake Bay Mainstem

1. Non Point Source Loads

Although there was no significant trend in freshwater flow to the Susquehanna River at the fall-line (Table 2), results of the trend analyses on USGS estimates of total nitrogen loads indicated an improving trend at the fall-line (Table 3; Figure 4). In contrast, degrading trends in total phosphorus and suspended sediment loads were detected at the fall-line in the Susquehanna (Table 3; Figure 4). Plots of annual non-point source total load nutrient and sediment loads appear to confirm the results of trend analyses (Figures 29A-C).

2. Tidal Water Quality

Water quality status in the Virginia Chesapeake Bay Mainstem was either Good or Fair in all segments during 2014 (Figure 30), 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 exceptCB8PH 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 30) and improving trends in dissolved inorganic phosphorus were also observed in segments CB7PH and CB8PH.

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 improving trend in bottom total suspended solids was observed (Figure 31). 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 31). 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 31) except CB7PH.

3. Phytoplankton Communities

Status of phytoplankton communities in the Virginia Chesapeake Bay Mainstem based on the P-IBI was Fair at all stations and no trends in the P-IBI were observed (Figure 32). Increasing trends in cyanobacteria biomass were detected at all stations as were decreasing trends in species diversity at all stations (Appendix G, Figure 7) . Decreasing trends in cryptophyte biomass were also observed at all stations (Appendix G, Figure 7). Decreasing trends in picoplankton biomass were observed at two stations, CB6.1 and CB6.4, perhaps in response to improvements in water quality (Appendix G, Figure 7).

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 (*Skeletonema, Chaetoceros, Dactyliosolen, Ceratulina* spp.) 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, 2015) 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 2012,2013, and 2015. No major blooms were observed in the mainstem in 2014. Major environmental factors influencing the presence and development of the mainstem algal community 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.

4. 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 33). There were no trends in the B-IBI at any Mainstem stations (Figure 33) and relatively few trends in any of the individual benthic bioindicators (Appendix G - Figure 8). Probability-based benthic monitoring results for 2014 indicate that only 8% of the total area of the Virginia Chesapeake Bay Mainstem failed to meet the restoration goals (Figure 14). A significant decreasing trend in the proportion of area failing to meet the restoration goals was detected in the Virginia Chesapeake Bay Mainstem (Figure 15).

5. 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 eight 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 the basins examined in this report. Phytoplankton community status, as measured using the P-IBI was Fair at all stations. However, there are indications that phytoplankton communities are degrading specifically the widespread increasing trends in cyanobacteria biomass and declines in Margalef species diversity. 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, 2015 monitoring data). 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 and areal estimates using probability-based sampling indicate that over 90% of the total area of Virginia Chesapeake Bay Mainstem met benthic restoration goals. Although there were no trends were observed for the B-IBI at fixed point stations, a significant decreasing trend in the proportion of area failing to meet the restoration goals was detected in the Virginia Chesapeake Bay Mainstem.

IV. 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 is great 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 have showed relatively few statistically significant trends.

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

- Significant reductions in point source nutrient loads were widespread throughout all tributaries in particular for both total nitrogen and total phosphorus.

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

- Status of living resources was typically better 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 that:

    - the status of phytoplankton communities was characterized as Fair or Fair-Poor in the Mainstem and most stations in the lower portions of the tributaries;
    - degrading trends in the P-IBI were observed at one station in the Elizabeth and Rappahannock rivers;
    - degrading trends in species diversity and cyanobacteria biomass were found throughout much of the region;
    - phytoplankton algal blooms continue to be common occurrences in the lower segments of the Chesapeake Bay, its tributaries, and their associated inlets and sub-estuaries and there are indications of increased duration, magnitude and spatial expansion of bloom events, including HABS at some locations;
    - blooms were considerably reduced in 2014 from those observed over the last 5-10 years in both the tributaries and Mainstem;

- status of just over half of benthic fixed point stations was degraded and all but one of the trends in the B-IBI observed at fixed point stations were degrading;
- there were increases in the extent of the area failing benthic restorations goals in the James and Rappahannock rivers but a decrease in the Virginia Mainstem.
- there was a lack of a consistent widespread response in the benthos at fixed point stations that 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:

  - few trends in non point nutrient and sediment loads above the fall-line;
  - substantial reductions in point source loads both above and below the fall-line;
  - generally Fair to Very Good water quality status;
  - widespread improving trends in nutrients and some degrading trends in water quality downstream;
  - Poor to Fair-Poor phytoplankton community status throughout;
  - no trends in the P-IBI however, some limited improvement indicated by decreasing trends in picoplankton biomass throughout the basin;
  - an increasing number of bloom species including *C. polykrikoides*, *P. minimum*, *A. monilatum*, *C. subsalsa*;
  - degraded status of benthic communities upstream with communities downstream meeting restoration goals;
  - 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;
  - but poor status and continued declines in phytoplankton community conditions;
  - improving benthic communities in some segments.

- The York River and its tributaries exhibited:

  - few changes in non-point source nutrient and sediment loadings;
  - significant reductions in point source total nitrogen and total phosphorus loads above and below the fall-line;
  - highly variable water quality status ranging from Poor to Very Good but Fair in most segments;
  - localized improvements in water quality in some cases potentially tied to changes in point source loads e.g. Mobjack Bay;

- phytoplankton status ranging from Fair to Poor with no trends in the P-IBI;
- 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;
- benthic communities that met community restoration goals or were marginal;
- improving trends in the B-IBI at fixed point monitoring stations downstream and;
- no change in the proportion of area failing to meet benthic restoration goals.

- The Rappahannock River was characterized by:

  - few trends in fall-line loads of non-point source nutrients and sediments;
  - significant reductions in point source nutrients both above and below the fall-line;
  - no improving non-tidal and few improving long-term tidal water quality trends, although there were several post-method change trends in nutrients;
  - generally Good or Fair water quality status in all segments;
  - Poor or Fair-Poor 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;
  - Degraded or Severely Degraded status at fixed point station benthic communities coupled with either no or degrading trends in the B-IBI and;
  - an increasing proportion 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 freshwater flow at USGS fall-line stations in the Virginia tributaries for the period of 1985 through 2014. 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.

Station Name (Map ID #)	P value	Slope	Baseline Median	% Change	Direction	Homogeneity test P value
Appomattox River at Matoaca, VA(1)	0.0148	-3.5	466	-22.53	Decreasing	0.99
James River at Cartersville, VA(2)	0.2261	-13.21	3575	-11.08	No Trend	0.94
Pamunkey River near Hanover, VA(3)	0.0756	-2.01	341	-17.70	No Trend	0.98
Mattaponi River near Beulahville, VA(4)	0.3674	-0.79	265	-8.98	No Trend	0.99
York River	0.2550	3.07	680	13.55	No Trend	0.99
Rappahannock River near Fredericksburg, VA(5)	0.1326	-3.00	599	-15.04	No Trend	0.99
Susquehanna River at Conowingo, MD(6)	0.1014	131.01	24800	15.85	No Trend	0.87

Table 3. Long-term trends in non point and sediment loads at the River Input Monitoring and Multi-Agency Monitoring Program non-tidal stations in the Virginia portion of the Chesapeake Bay Watershed and the Susquehanna River for 1985 through September, 2014. Map ID #'s in parentheses refer to the station locations identified in Figure 1. Results presented in this table were provided by Doug Moyer of the U.S. Geological Survey.

Station Name (Map ID #)	Load	P value	Baseline Flux	WRTDS Change Estimate	Lower 90% C.L.	Upper 90% C.L.	Trend Direction
Appomattox River at Matoaca, VA(1)	TN	0.5750	0.69	-0.13	-0.03	0.16	No Trend
Appomattox River at Matoaca, VA(1)	NO_{23}	0.2250	0.20	-0.10	-0.03	0.04	No Trend
Appomattox River at Matoaca, VA(1)	TP	0.0250	0.04	0.00	0.02	0.04	Degrading
Appomattox River at Matoaca, VA(1)	DIP	0.9250	0.01	0.00	0.00	0.00	No Trend
Appomattox River at Matoaca, VA(1)	TSED	0.7750	19.94	-6.67	-0.94	21.83	No Trend
Appomattox River at Matoaca, VA(1)	TSS	0.8750	15.88	-7.07	-0.63	3.94	No Trend
James River at Cartersville, VA(2)	TN	0.2250	6.00	-2.57	-0.73	0.70	No Trend
James River at Cartersville, VA(2)	NO_{23}	0.1875	1.75	-0.64	-0.39	0.30	No Trend
James River at Cartersville, VA(2)	TP	0.2750	1.72	-1.06	-0.48	0.50	No Trend
James River at Cartersville, VA(2)	DIP	0.0250	0.77	-0.97	-0.72	-0.30	Improving
James River at Cartersville, VA(2)	TSED	0.2250	744	-217	186	1424	No Trend
James River at Cartersville, VA(2)	TSS	0.2750	544	-274	151	764	No Trend
Pamunkey River near Hanover, VA(3)	TN	0.2750	0.32	-0.07	-0.03	0.02	No Trend
Pamunkey River near Hanover, VA(3)	NO_{23}	0.9250	0.07	-0.03	0.00	0.03	No Trend
Pamunkey River near Hanover, VA(3)	TP	0.6750	0.03	-0.01	0.00	0.01	No Trend
Pamunkey River near Hanover, VA(3)	DIP	0.2750	0.01	0.00	0.00	0.00	No Trend
Pamunkey River near Hanover, VA(3)	TSED	0.3250	8.45	-4.52	-2.00	3.48	No Trend
Pamunkey River near Hanover, VA(3)	TSS	0.7750	4.43	-1.65	-0.12	1.29	No Trend
Mattaponi River near Beulahville, VA(4)	TN	0.9250	0.66	-0.11	0.01	0.12	No Trend
Mattaponi River near Beulahville, VA(4)	NO_{23}	0.5750	0.18	-0.03	0.01	0.06	No Trend
Mattaponi River near Beulahville, VA(4)	TP	0.1089	0.05	0.00	0.03	0.06	Degrading
Mattaponi River near Beulahville, VA(4)	DIP	0.3250	0.01	-0.01	0.00	0.00	No Trend
Mattaponi River near Beulahville, VA(4)	TSED	0.1899	34.18	-13.88	22.32	55.86	No Trend
Mattaponi River near Beulahville, VA(4)	TSS	0.1089	24.32	-9.83	14.42	27.79	No Trend
Rappahannock River near Fredericksburg, VA(5)	TN	0.0556	2.40	-0.94	-0.61	0.07	Improving
Rappahannock River near Fredericksburg, VA(5)	NO_{23}	0.2037	0.98	-0.32	-0.18	0.07	No Trend
Rappahannock River near Fredericksburg, VA(5)	TP	0.7250	0.31	-0.10	0.02	0.27	No Trend
Rappahannock River near Fredericksburg, VA(5)	DIP	0.5750	0.04	-0.01	0.00	0.01	No Trend
Rappahannock River near Fredericksburg, VA(5)	TSED	0.7750	193.94	-82.39	27.64	200.46	No Trend
Rappahannock River near Fredericksburg, VA(5)	TSS	0.5750	226.20	-183.21	-49.69	321.43	No Trend
Susquehanna River at Conowingo, MD(6)	TN	0.0556	75.34	-22.32	-13.16	0.05	Improving
Susquehanna River at Conowingo, MD(6)	NO_{23}	0.1897	46.67	-8.70	-4.94	4.02	No Trend
Susquehanna River at Conowingo, MD(6)	TP	0.0250	2.59	0.69	1.40	3.71	Degrading
Susquehanna River at Conowingo, MD(6)	DIP	0.4250	0.42	-0.19	0.11	0.36	No Trend
Susquehanna River at Conowingo, MD(6)	TSED	0.0693	1130	-1048	1511	2252.6	Degrading

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 2014. 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	-4504	286571	-135110	-47.15	Improving	0.9897
James	BFL	TN	<0.0001	-37501	1717532	-1125037	-65.50	Improving	1.0000
James	AFL	TP	<0.0001	-1145	64554	-34353	-53.22	Improving	1.0000
James	BFL	TP	<0.0001	-4770	241013	-143087	-59.37	Improving	1.0000
York	AFL	TN	<0.0001	-98	9557	-2942	-30.79	Improving	0.7246
York	BFL	TN	0.0002	-609	96572	-18266	-18.91	Improving	0.7450
York	AFL	TP	0.1127	-18	3209	-549	-17.11	Improving	0.9999
York	BFL	TP	<0.0001	-386	27842	-11569	-41.55	Improving	0.9811
Mobjack Bay	BFL	TN	Point Source Discontinued						
Mobjack Bay	BFL	TP							
Rappahannock	AFL	TN	0.3593	-64	14104	-1909	-13.54	Improving	0.9436
Rappahannock	BFL	TN	<0.0001	-541	28052	-16243	-57.91	Improving	0.8392
Rappahannock	AFL	TP	<0.0001	-106	5727	-3170	-55.36	Improving	0.9998
Rappahannock	BFL	TP	<0.0001	-189	9843	-5683	-57.74	Improving	1.0000

Figures

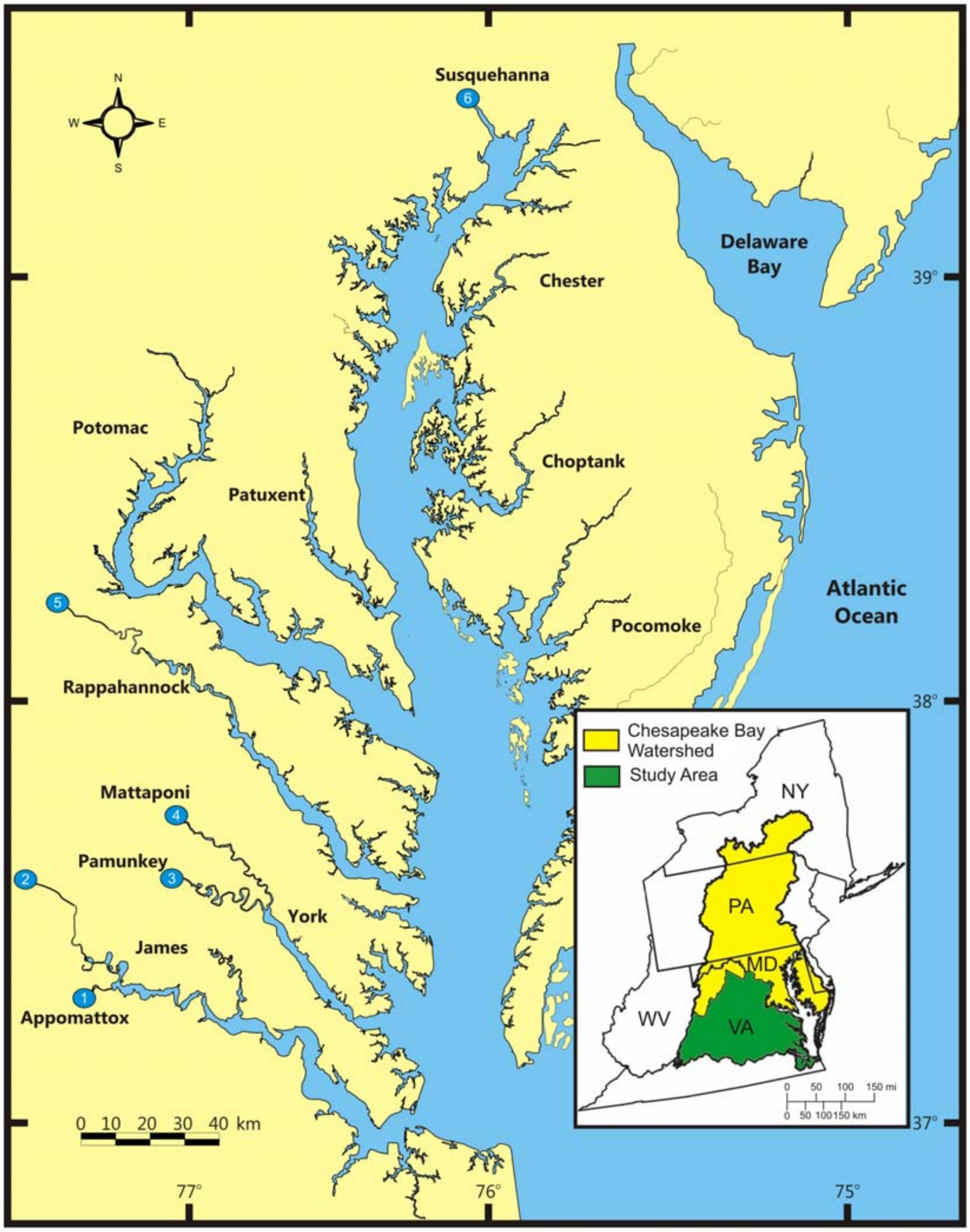


Figure 1. Location of the USGS/RIM stations in the Virginia tributaries and Susquehanna River.

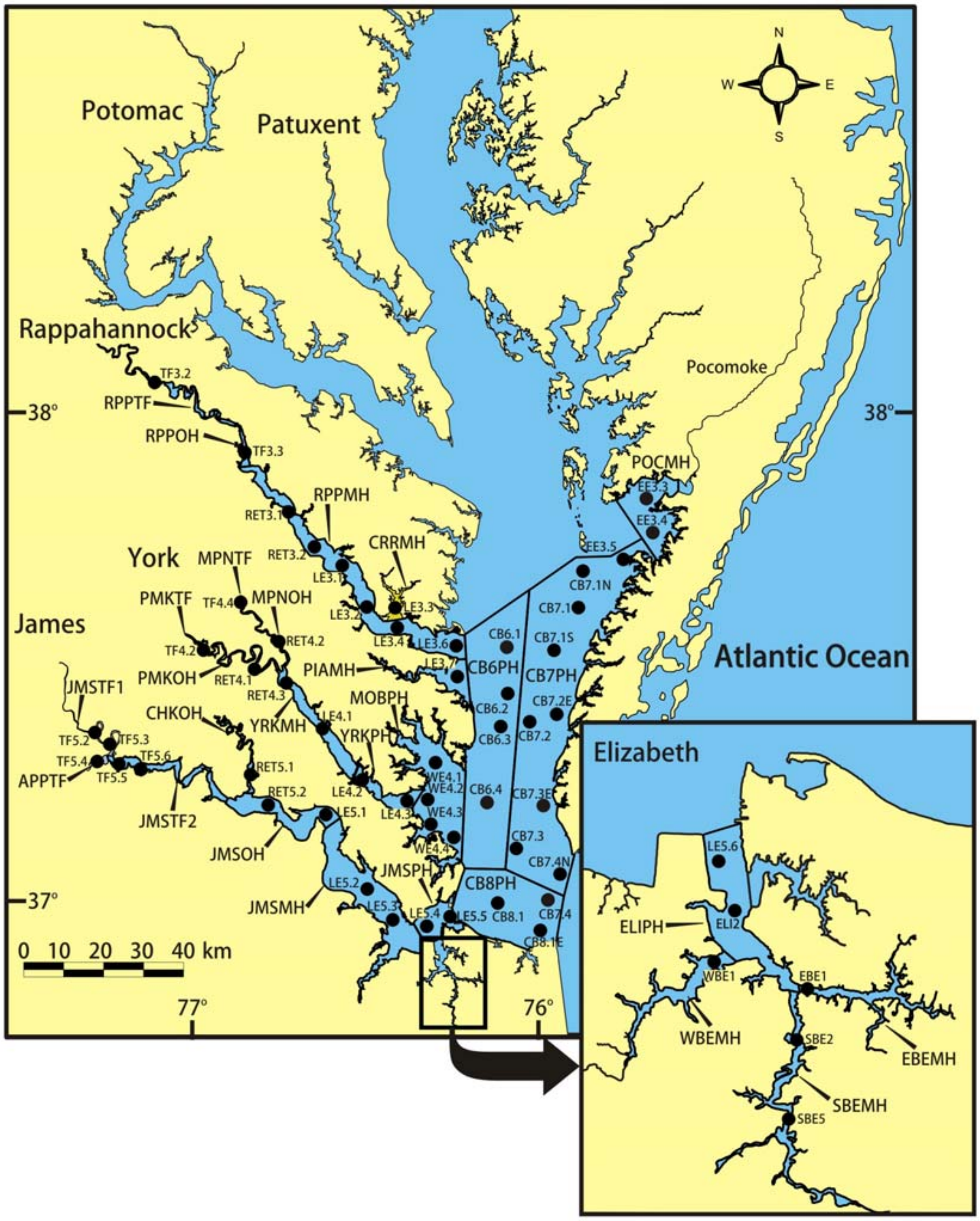


Figure 2. Chesapeake Bay Program segmentation scheme for the Virginia tributaries and Lower Chesapeake Bay Mainstem. Also shown are the locations of stations used in the statistical analyses.

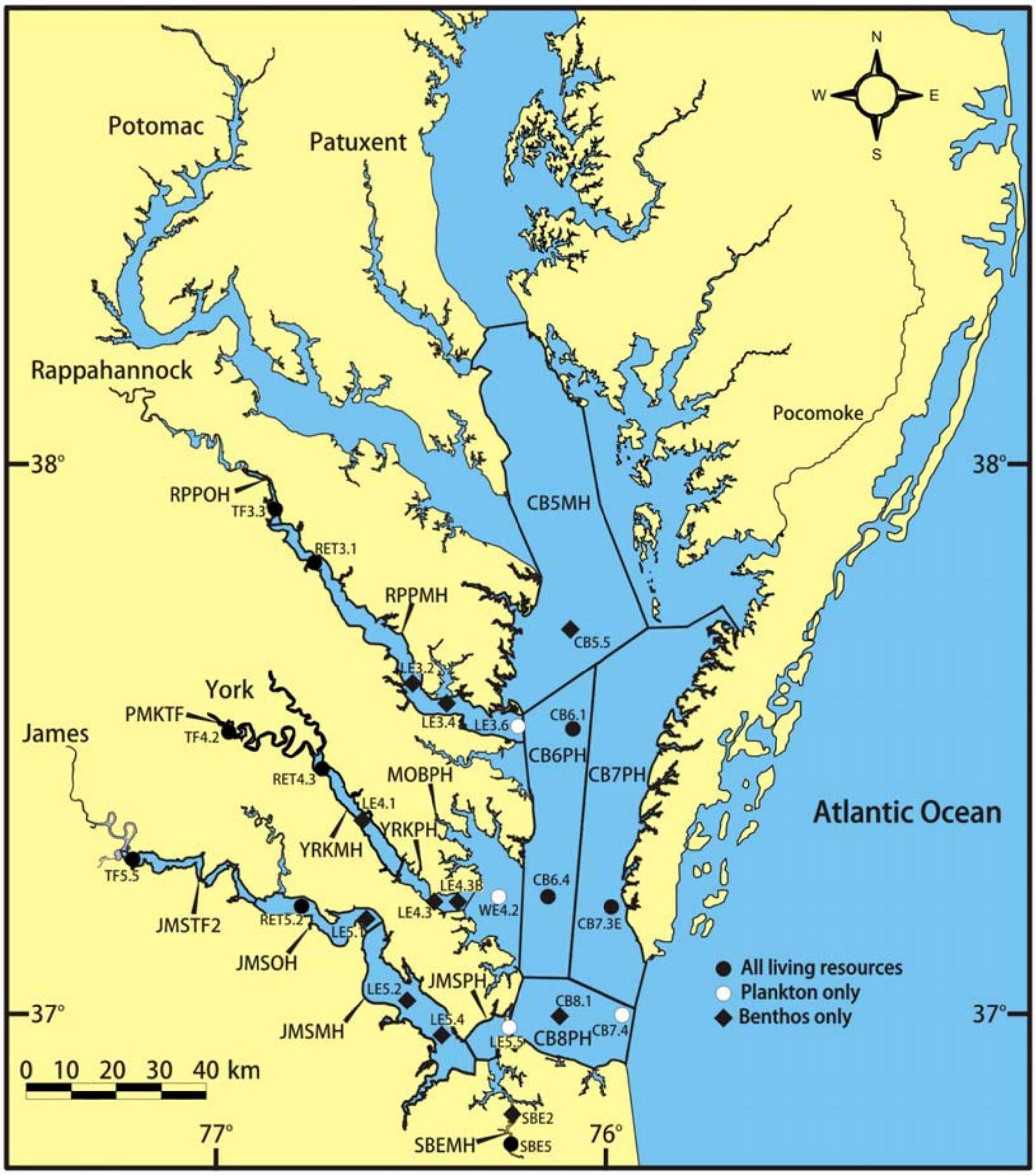


Figure 3. Living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem and their associated CBP segments.

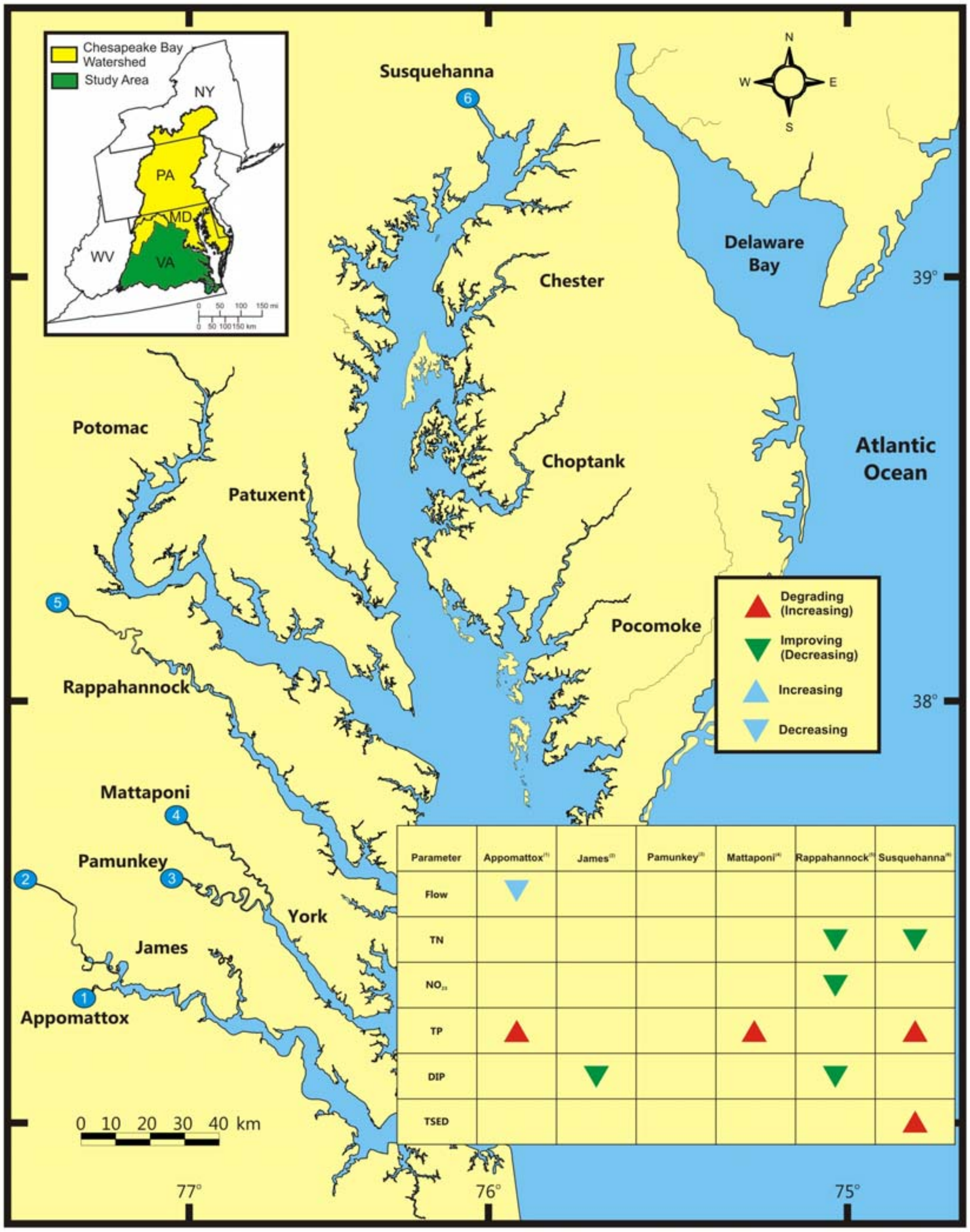


Figure 4. Long-term trends in freshwater flow, nutrient and sediment loads at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries and Susquehanna River for the period of 1985 through 2014. Arrows indicate trends significant at $P \leq 0.05$. Provided are summaries of the USGS WRTDS Estimator method results conducted on flow normalized loads as described by Hirsch et al. (2012; 2015). Station numbers on the map correspond to numbers next to the river name in superscript in the summary trend table and also correspond to the stations provided in Tables 2 and 3.

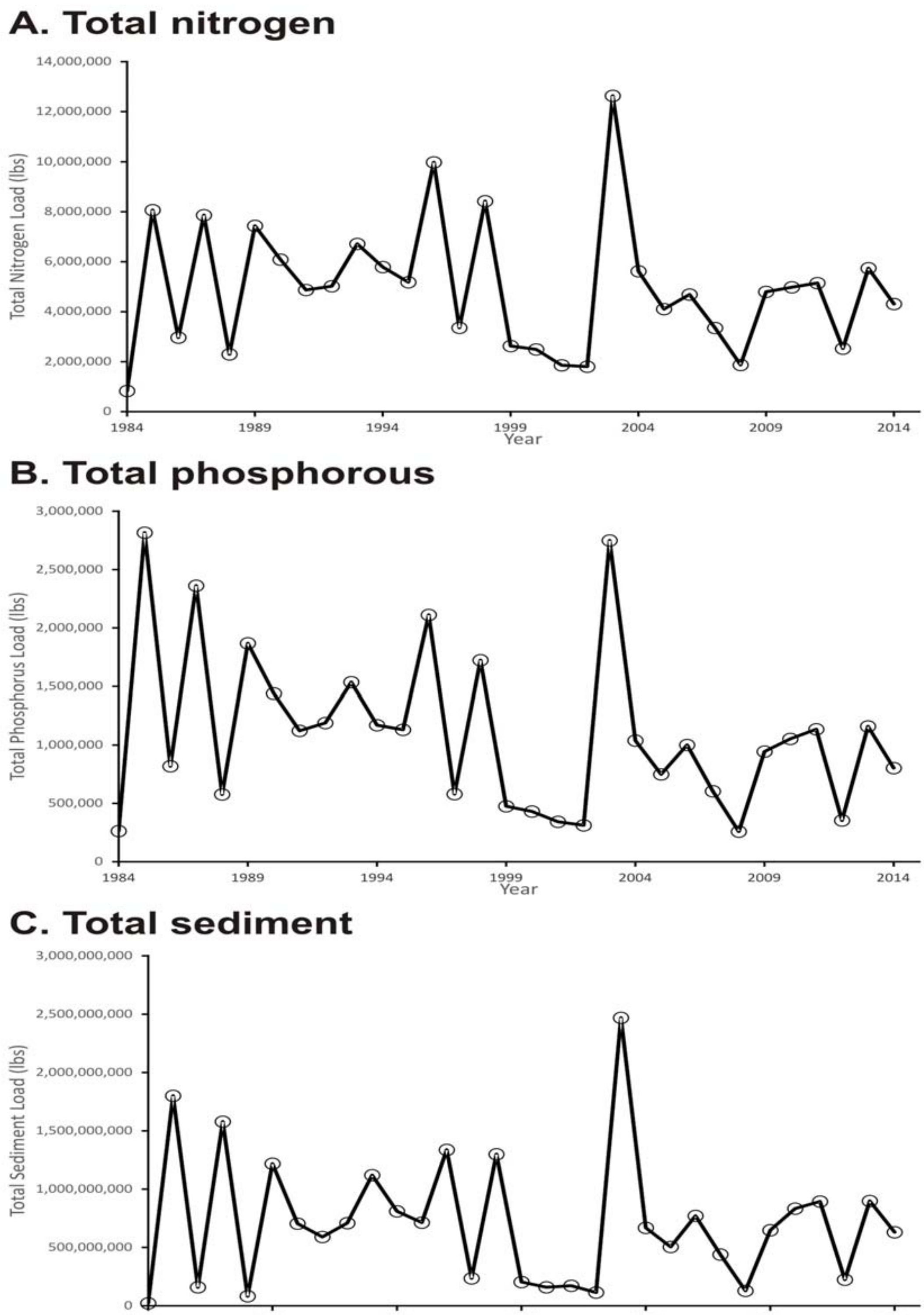


Figure 5. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment load above the fall-line in the James River from 1984 through 2014. Data shown are estimates (without flow normalization) provided by the US Geological Survey's River Input Monitoring program.

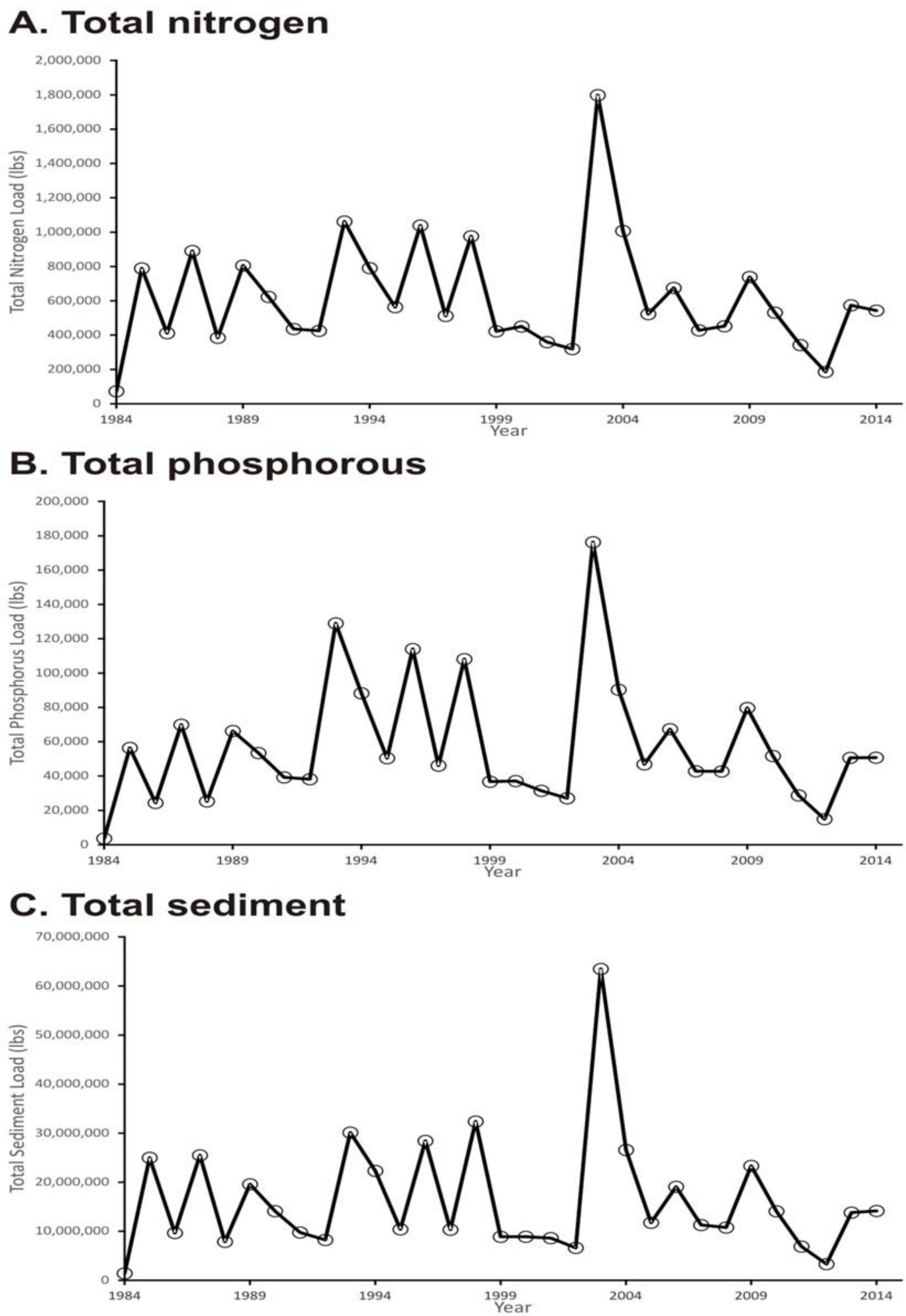


Figure 6. Long-term changes in A. Total nitrogen, B. Total phosphorus and C. Total sediment load above the fall-line in the Appomattox River from 1984 through 2014. Data shown are estimates (without flow normalization) provided by the US Geological Survey's River Input Monitoring program.

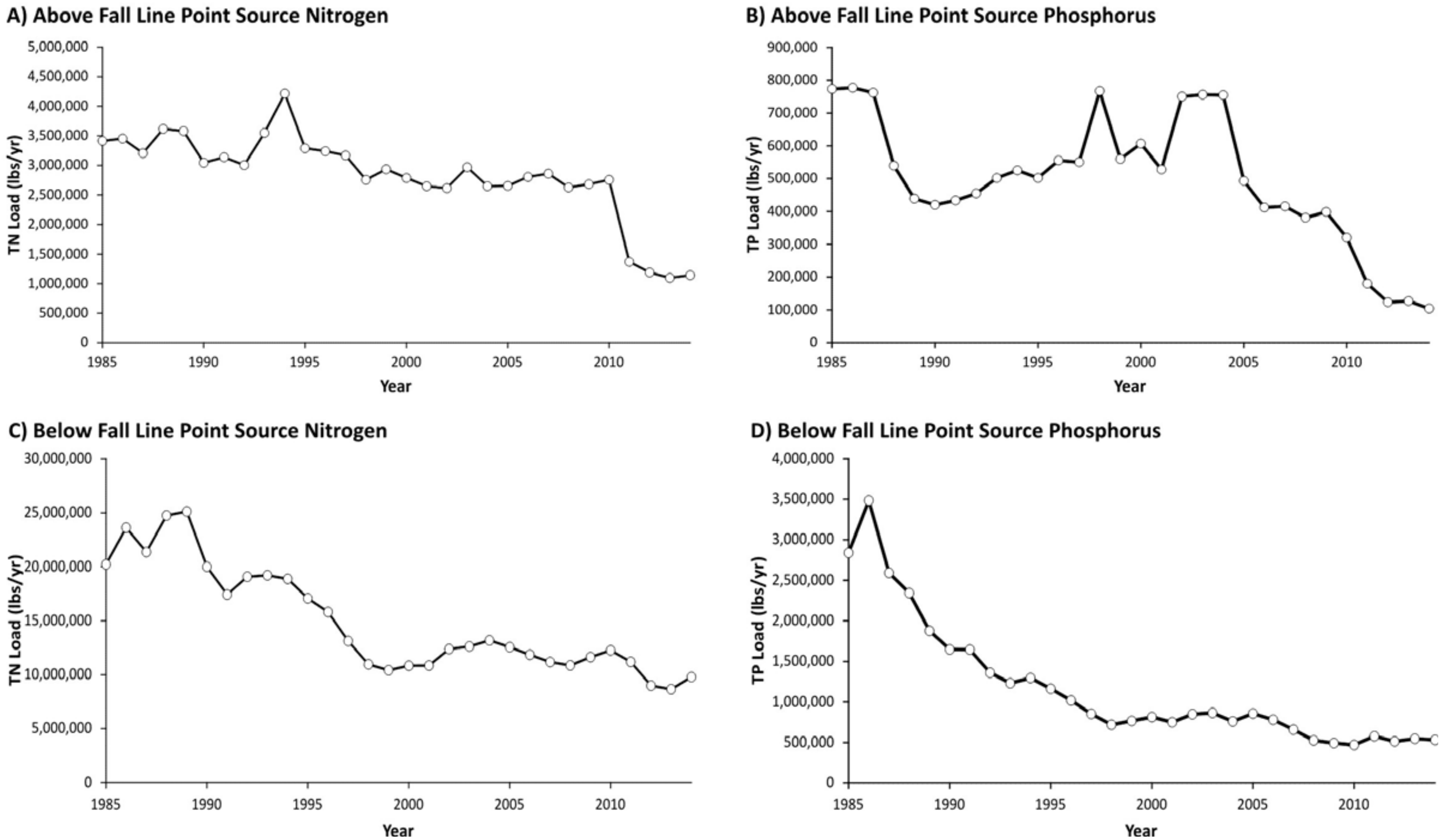
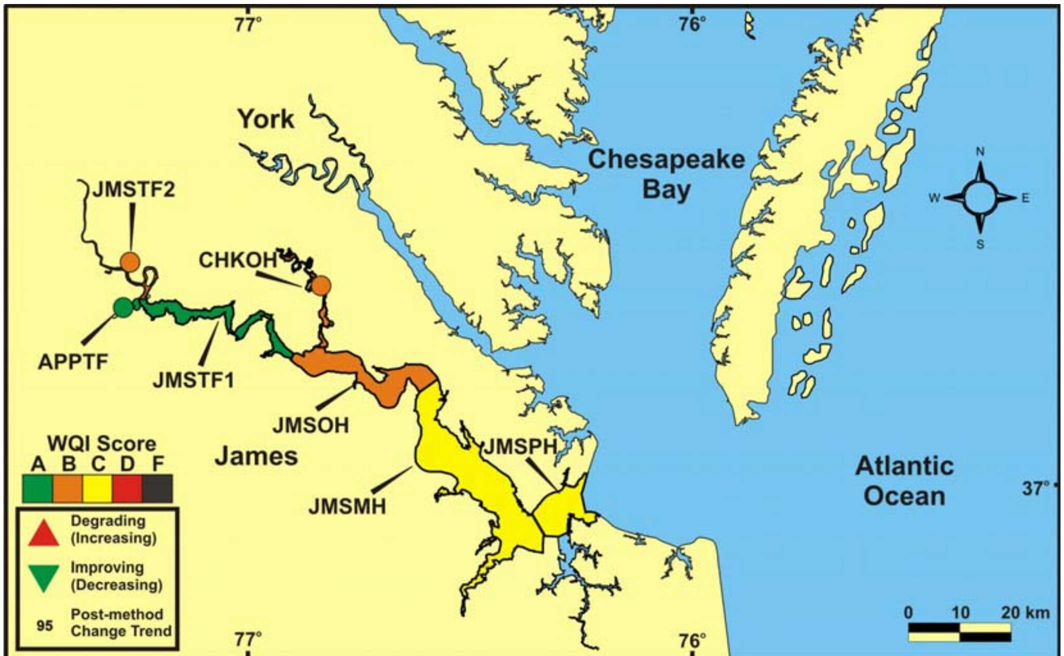


Figure 7. Long-term changes in A) Above the Fall-line Point Source Nitrogen; B) Above Fall-line Point Source Phosphorus; C) Below Fall Line Point Source Nitrogen; and D) Below Fall Line Point Source Phosphorus in the James River for 1985 through 2014. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system. Values shown are rounded to the nearest 100 lbs/yr.



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

Figure 8. 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 2014. Trends presented were those that were statistically significant (P < 0.01) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. 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.

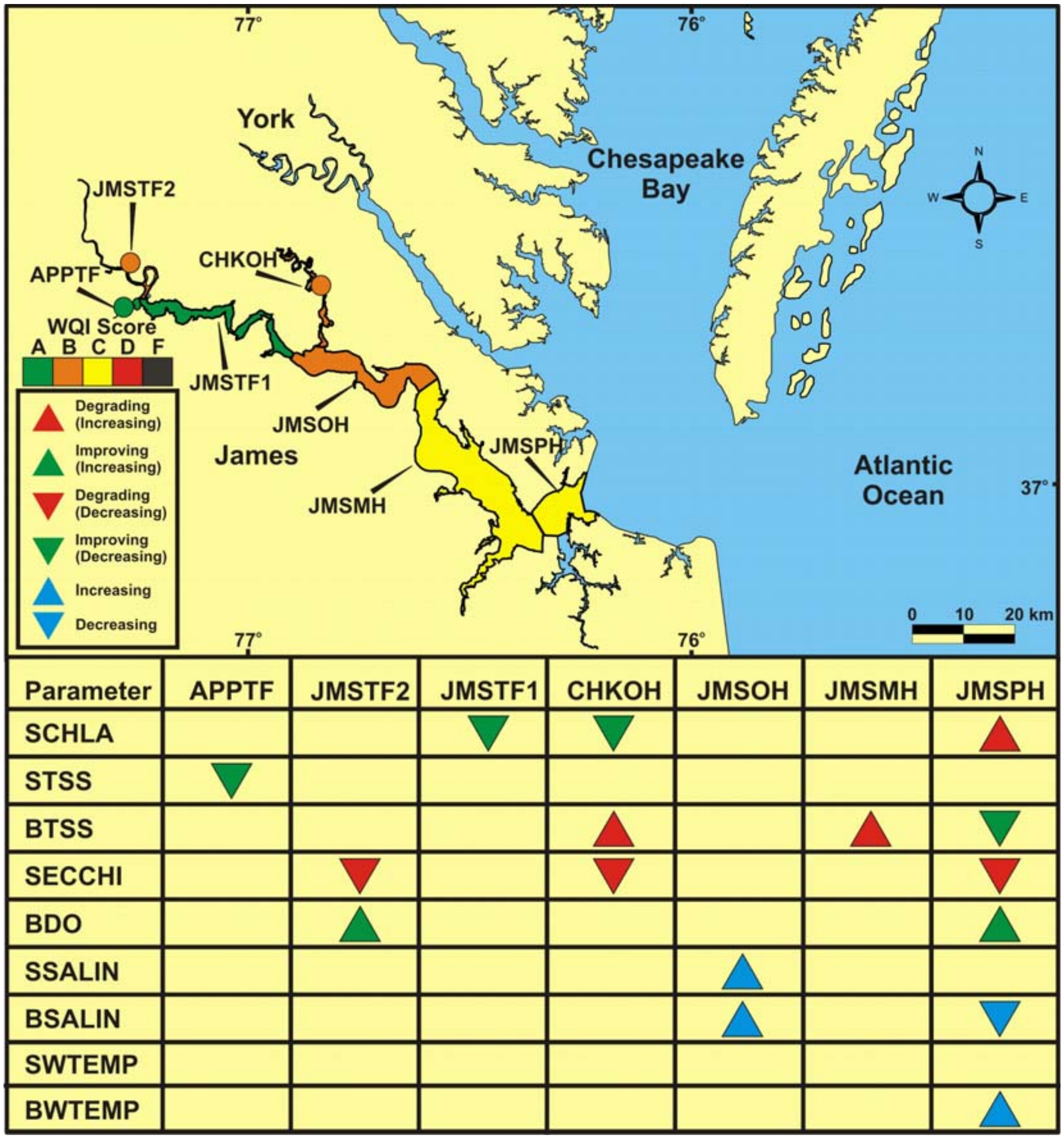
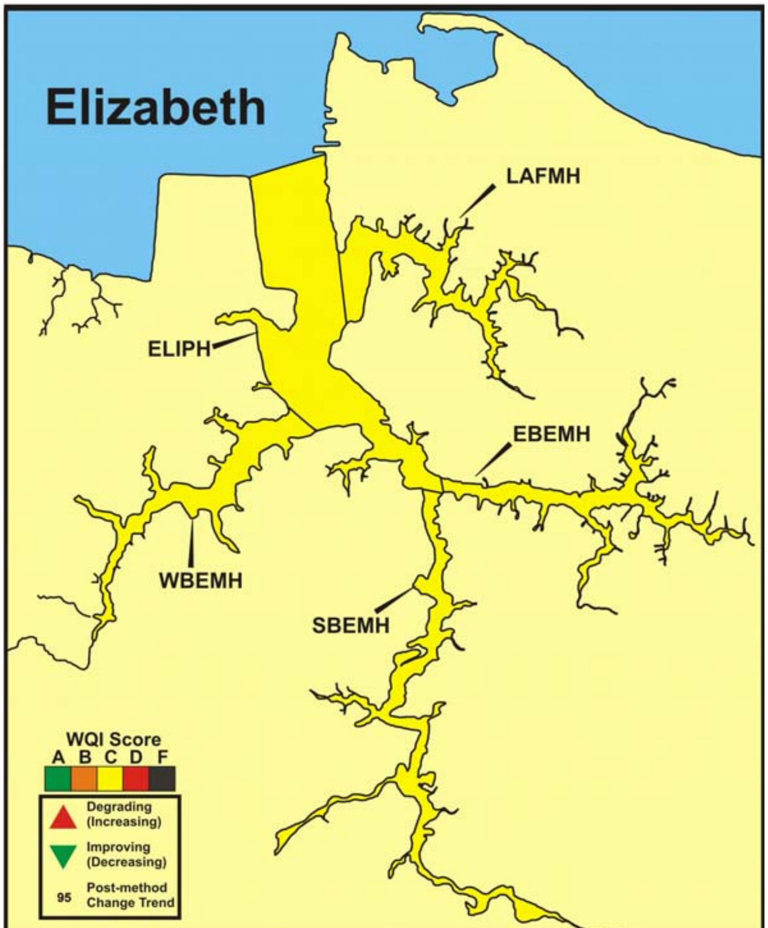
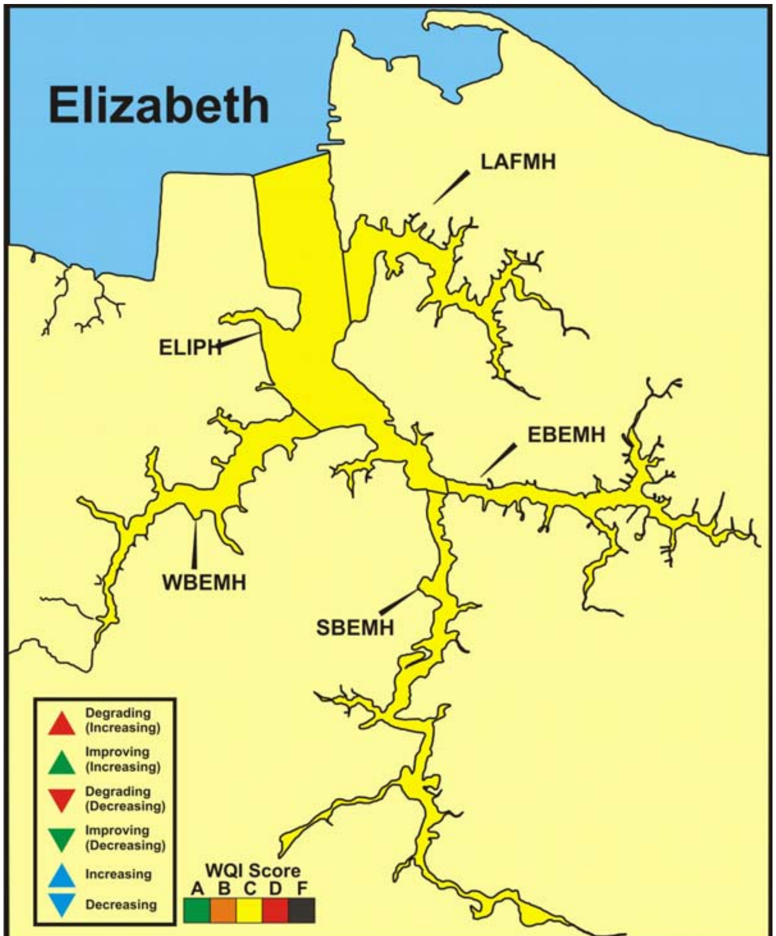


Figure 9. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. 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	▼	▼	▼	▼	▼ 95
SDIN		▼	▼		
BDIN		▼	▼		
STP	▼	▼	▼	▼	▼ 95
BTP	▼	▼	▼		▼ 95
SDIP		▼	▼		
BDIP	▼	▼	▼		

Figure 10. 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 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. 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	▼				
STSS	▼	▼	▼	▲	
BTSS	▼	▼	▼	▲	
SECCHI	▲	▲	▲		
BDO					
SSALIN					
BSALIN					
SWTEMP					
BWTEMP					

Figure 11. 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 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014. 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.

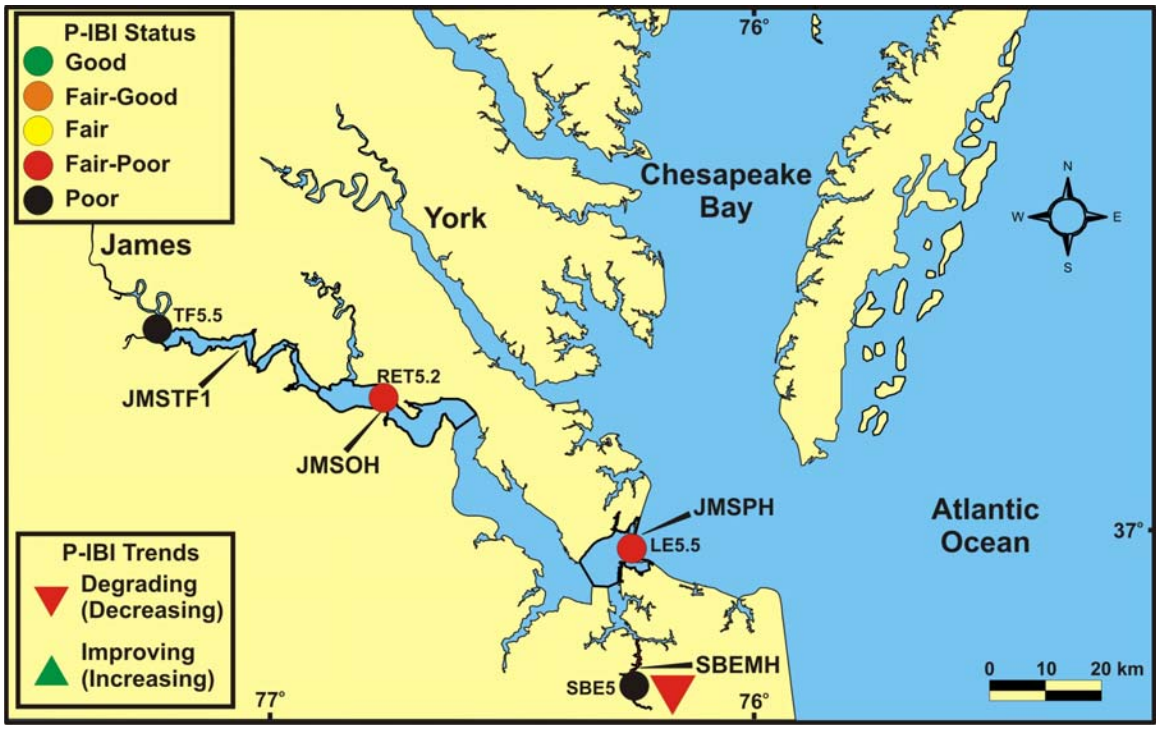


Figure 12. Status and long-term trends in phytoplankton community condition in the tidal portion of the James River basin for the period of 1985 through 2014. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2014.

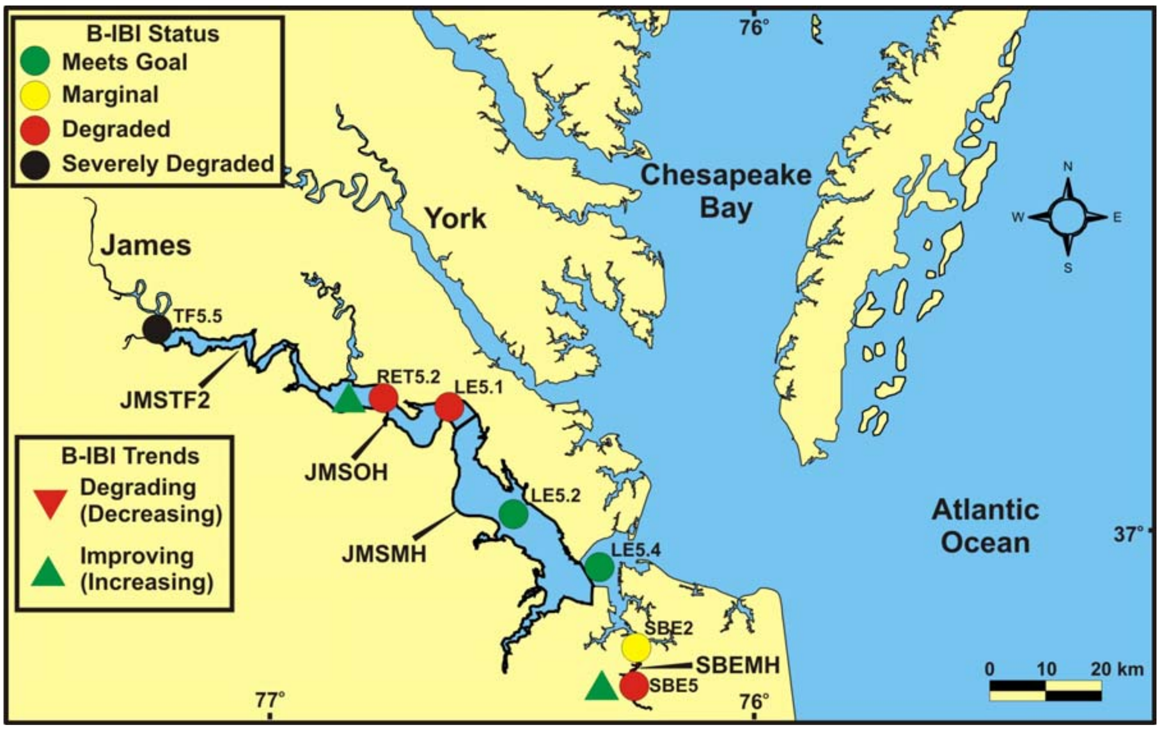


Figure 13. Status and long-term trends in benthic community condition in the tidal portion of the James River basin for the period of 1985 through 2014. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2014.

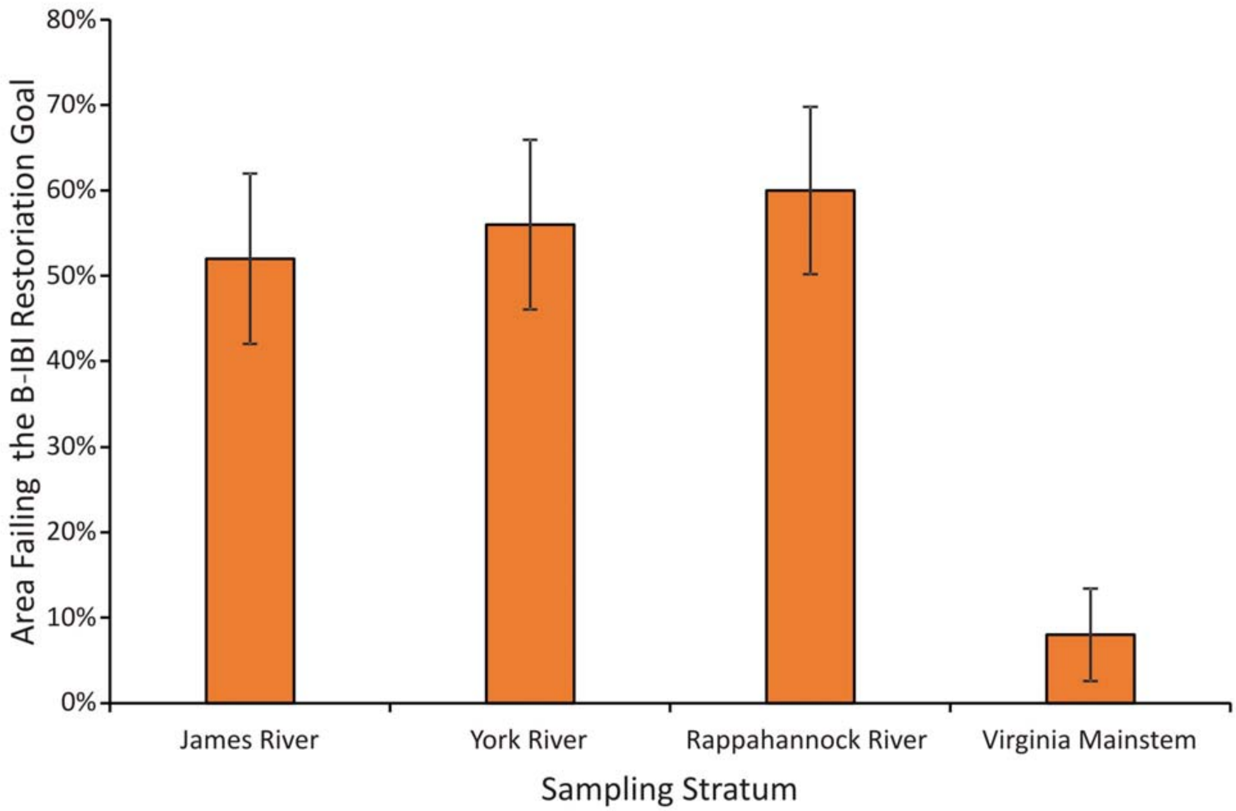


Figure 14. Percentage of area in the Virginia sampling strata failing to meet the benthic community Restoration Goals in Virginia for 2014 (± 1S.D). Data provided by Roberto Llanso of Versar Inc.

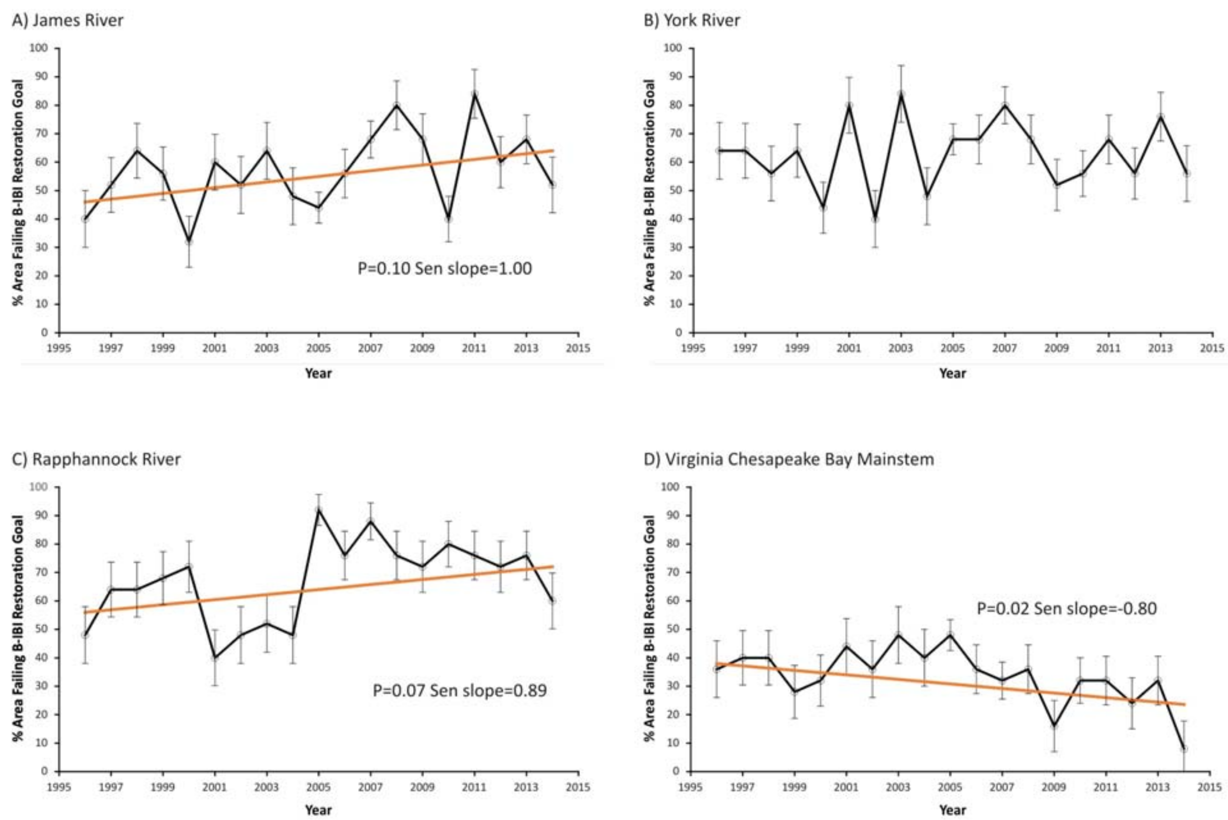


Figure 15. Long term trends in the proportion of area failing to meet the benthic community Restoration Goals for each of the major sampling strata in Virginia for the period of 1996 through 2014. Error bars are ± 1 S.D. of the mean. Data were provided Roberto Llanso of Versar Inc.

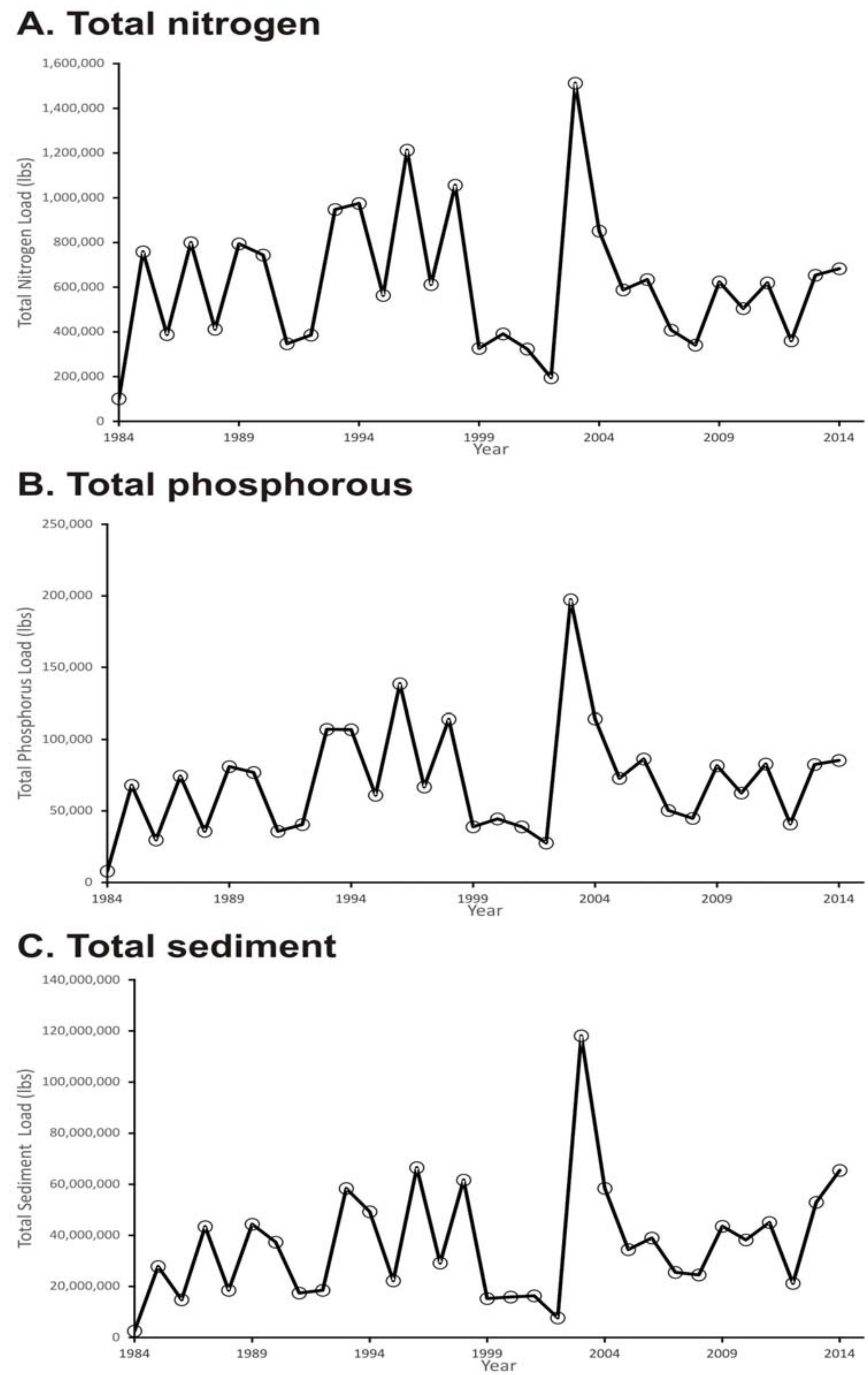


Figure 16. Long-term changes in A.Total nitrogen, B. Total phosphorus, and C. Total sediments above the fall-line in the Pamunkey River from 1984 through 2014. Data shown are estimates (without flow normalization) provided by the US Geological Survey's River Input Monitoring program.

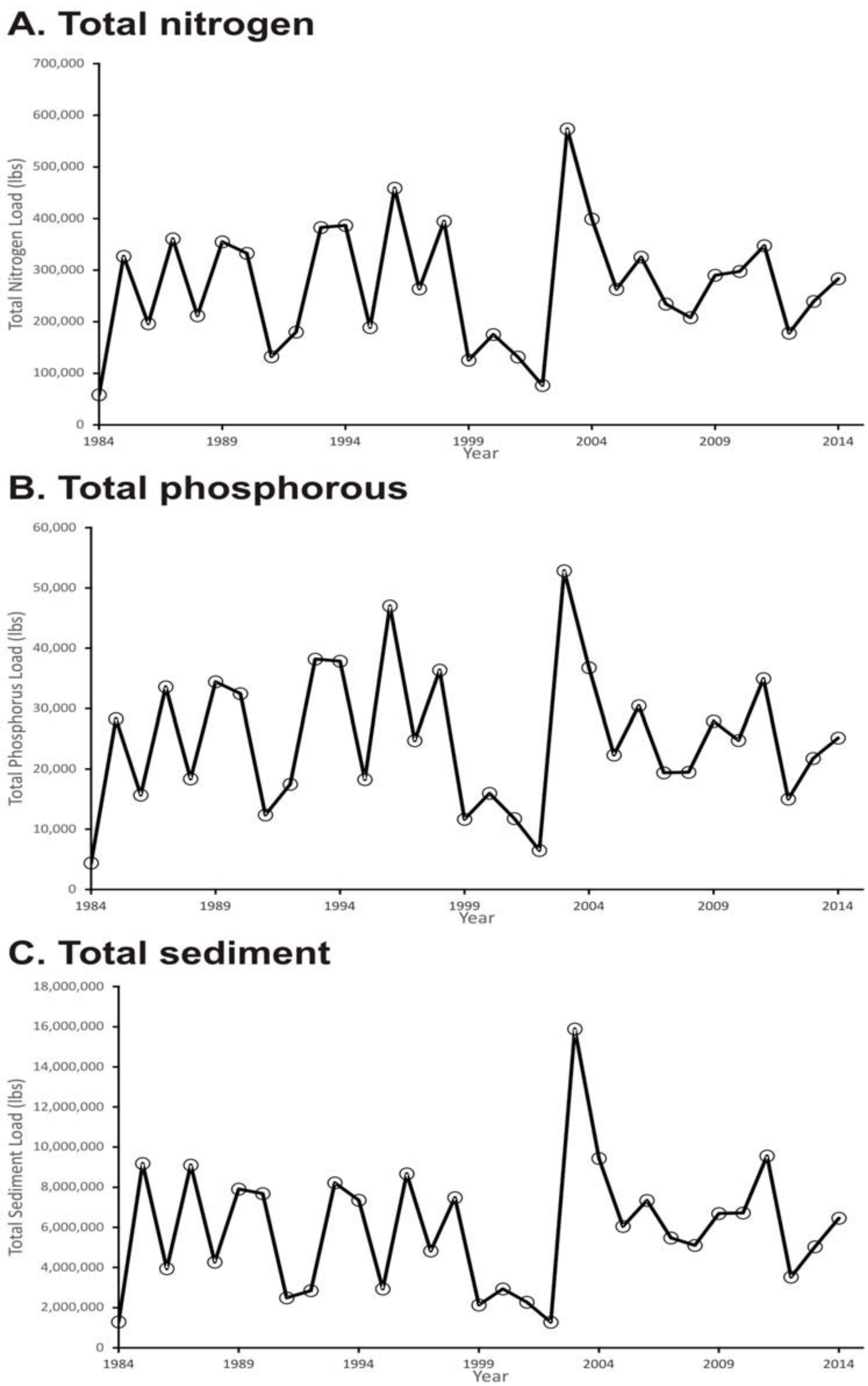


Figure 17. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediments above the fall-line in the Mattaponi River from 1984 through 2014. Data shown are estimates (without flow normalization) provided by the US Geological Survey's River Input Monitoring program.

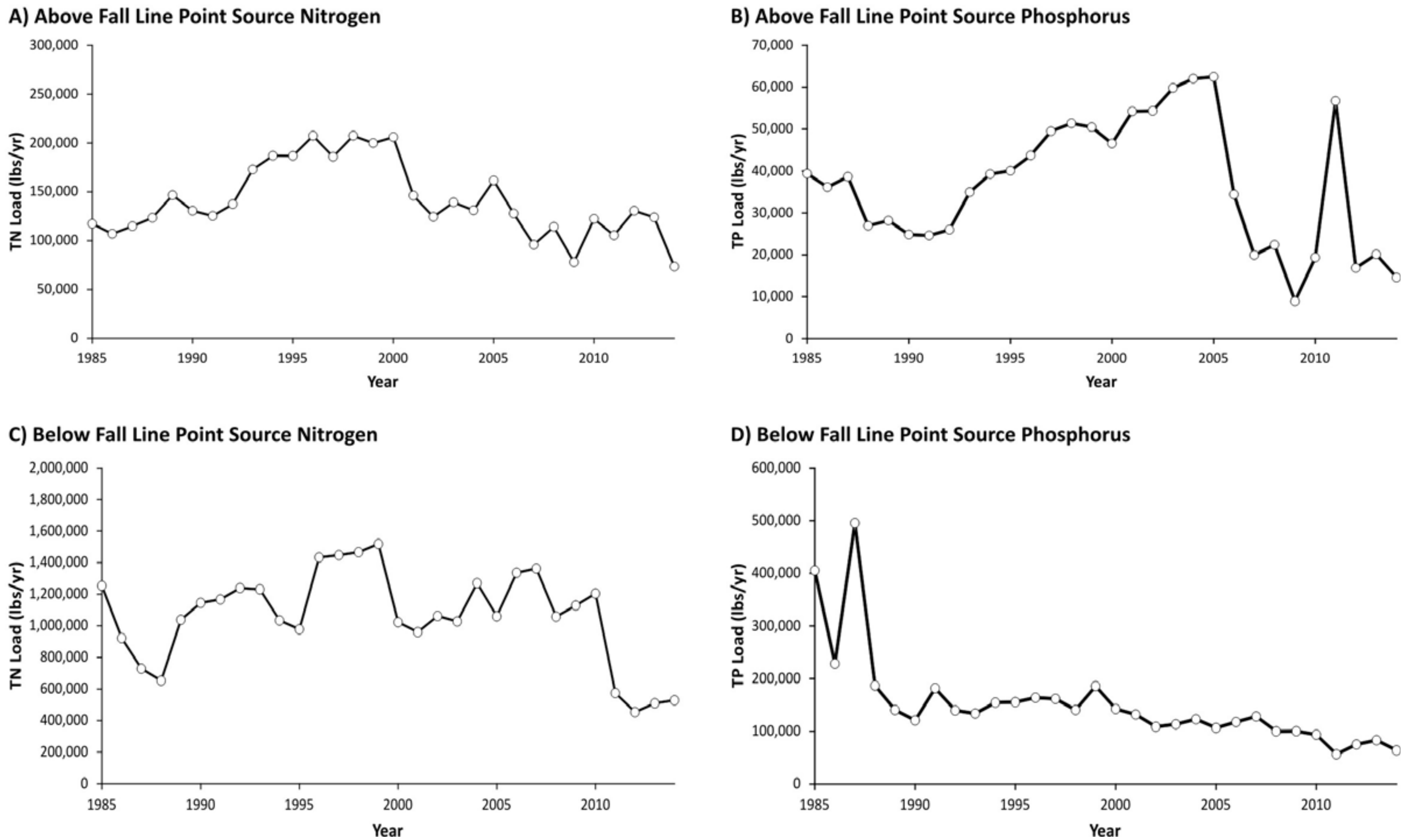
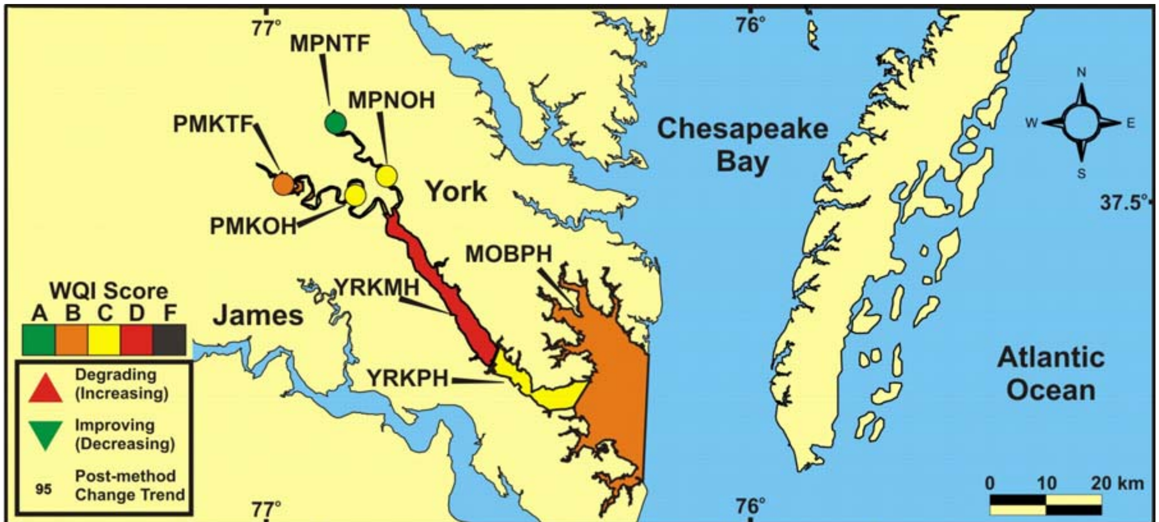


Figure 18. Long-term changes in A) Above Fall Line Point Source Nitrogen; B) Above Fall Line Point Source Phosphorus; C) Below Fall Line Point Source Nitrogen; and D) Below Fall Line Point Source Phosphorus in the York River for 1985 through 2014. Loadings presented from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



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

Figure 19. 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 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. 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.

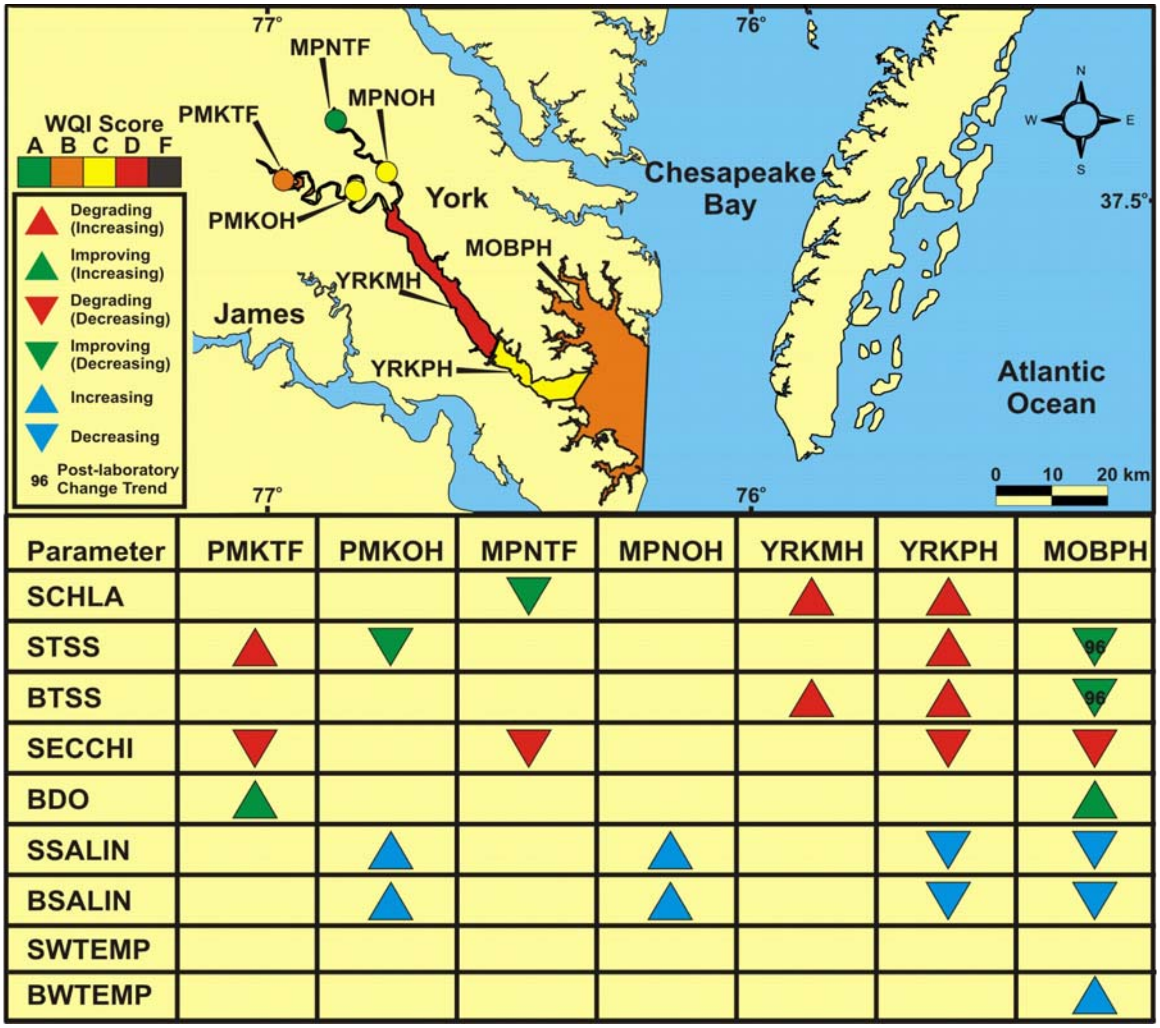


Figure 20. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the York River basin. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using a modified version of the Water Quality Index (WQI) of Williams et al. (2009) for the period of 1985 through 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. 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.

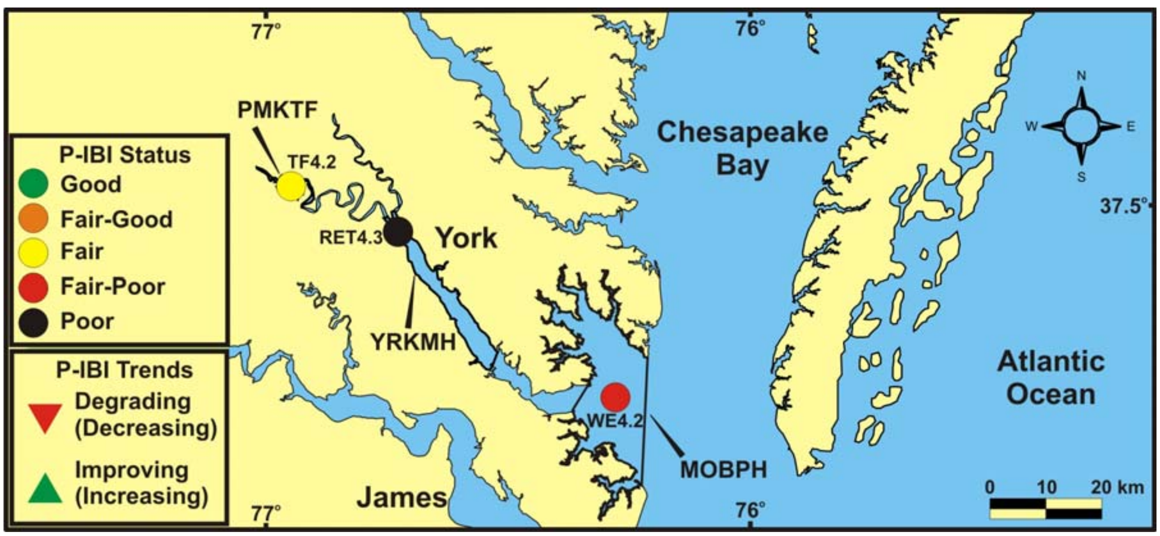


Figure 21. Status and long-term trends in phytoplankton community condition in the tidal portion of the York River basin for the period of 1985 through 2014. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2014.

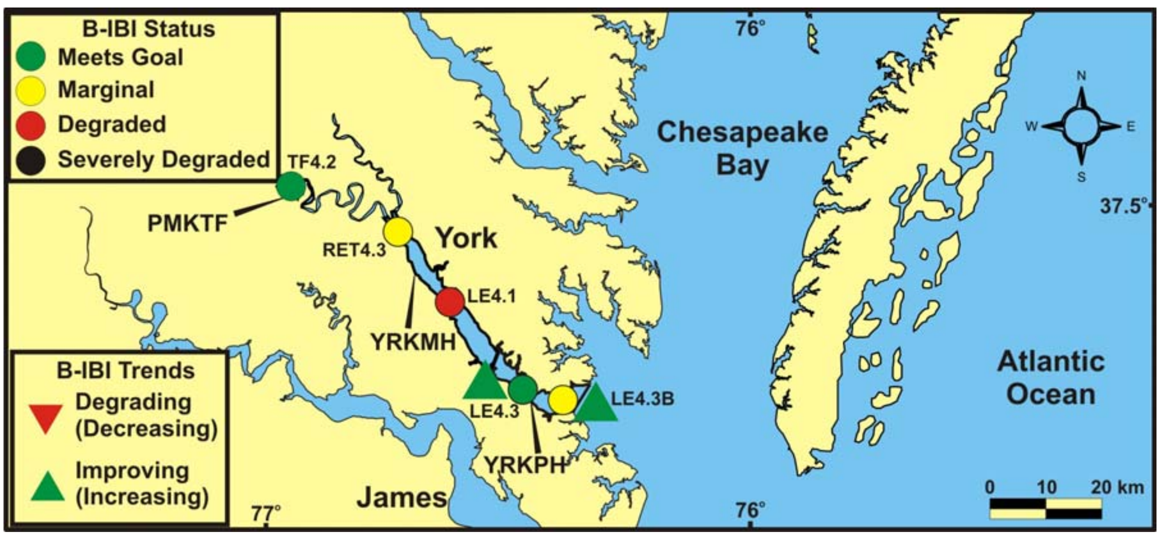


Figure 22. Status and long-term trends in benthic community condition in the tidal portion of the York River basin for the period of 1985 through 2014. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.10$) trends in the B-IBI from the start of monitoring through 2014.

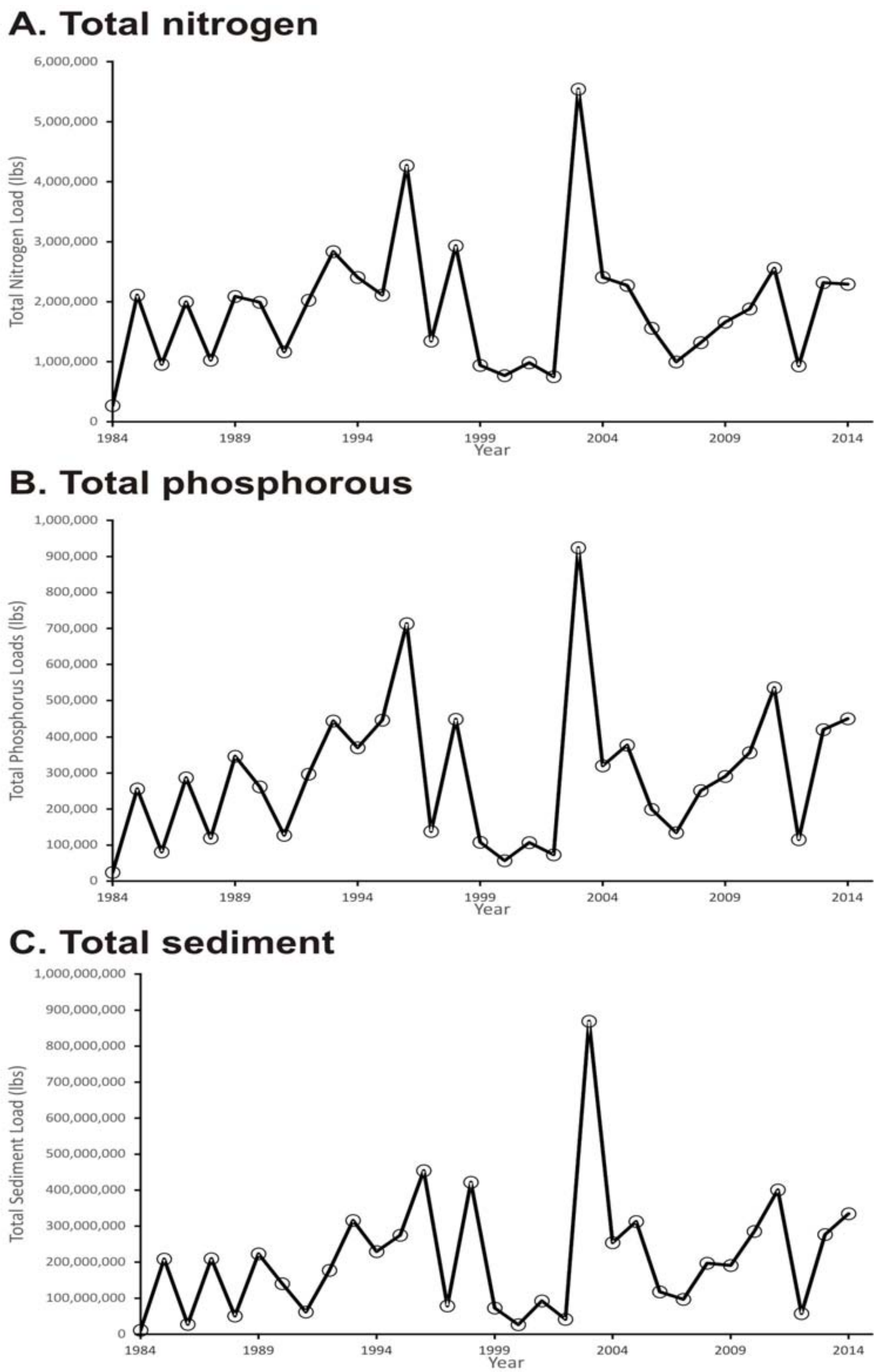


Figure 23. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment loads at the fall-line in the Rappahannock River from 1985 through 2014. Data shown are estimates (without flow normalization) provided by the US Geological Survey's River Input Monitoring program.

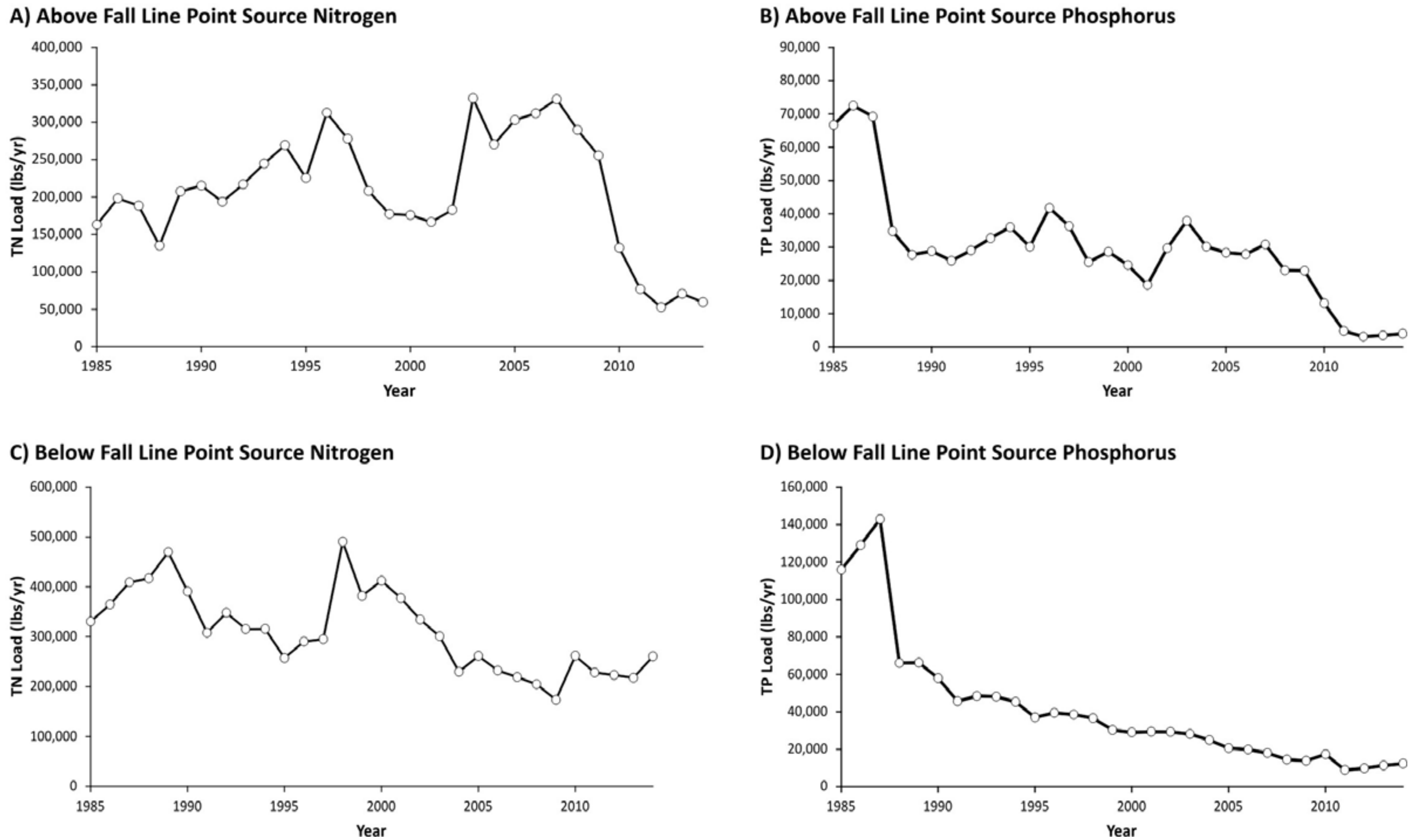
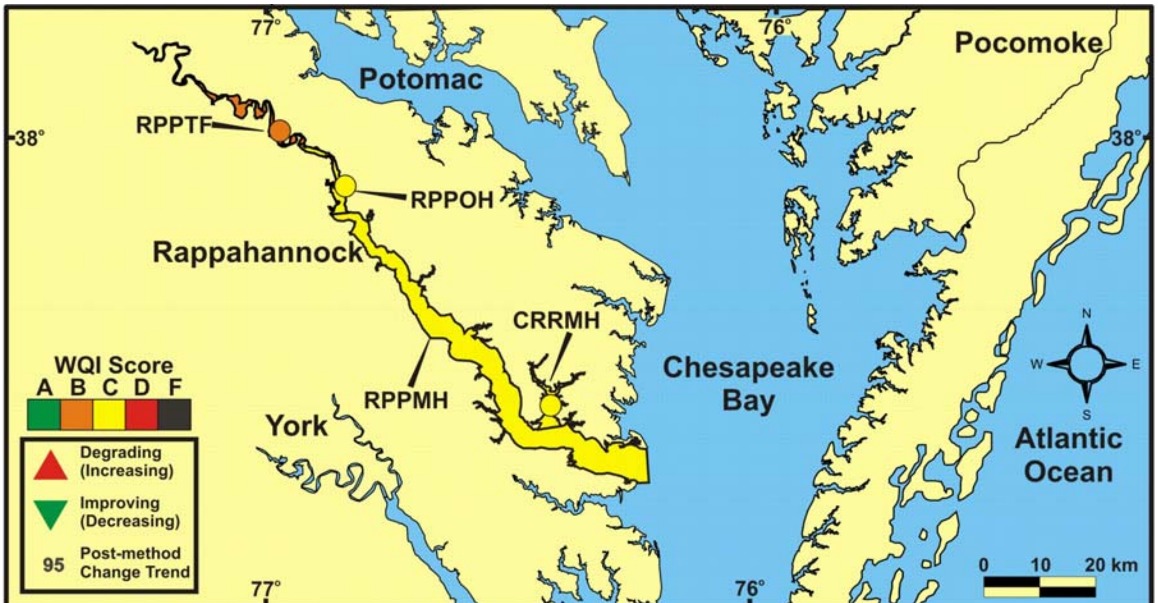
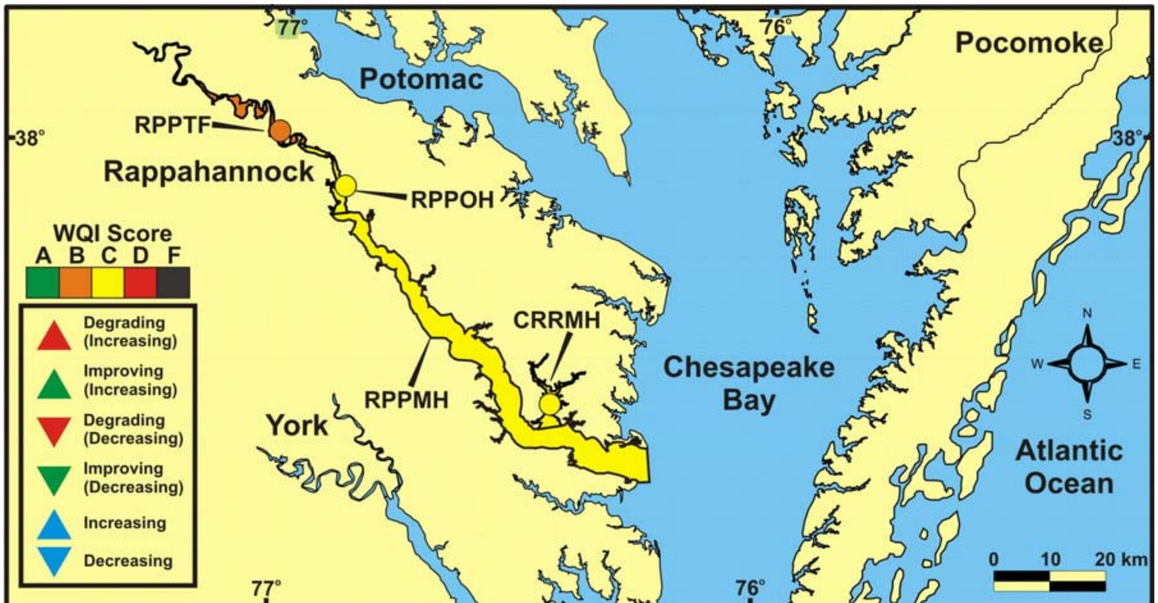


Figure 24. Long-term changes in point source loads in A) Above Fall Line Total Nitrogen; B) Above Fall Line Total Phosphorus; C) Below Fall Line Total Nitrogen; and D) Below Fall Line Total Phosphorus in the Rappahannock River for 1985 through 2014. Loadings presented are from data reported to the Virginia 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	▼ 95
SDIP	▼ 95	▼ 95	▼ 95	▼ 95
BDIP	▼ 95	▼ 95	▼ 95	▼ 95

Figure 25. 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 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The prefixes S and B refer to surface and bottom measurements, respectively.



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

Figure 26. 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 2014. Trends presented were those that were statistically significant ($P < 0.01$) from the start of monitoring through 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2014. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

Figure 27. Status and long-term trends in phytoplankton community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2014. 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 2014.

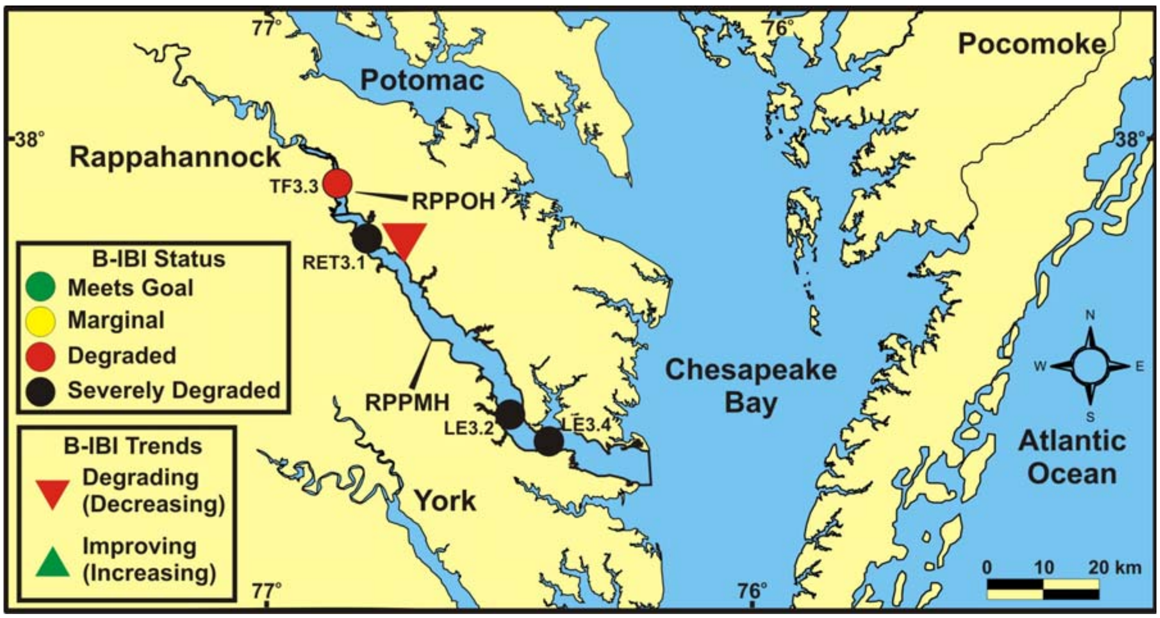


Figure 28. Status and long-term trends in benthic community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2014. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2014.

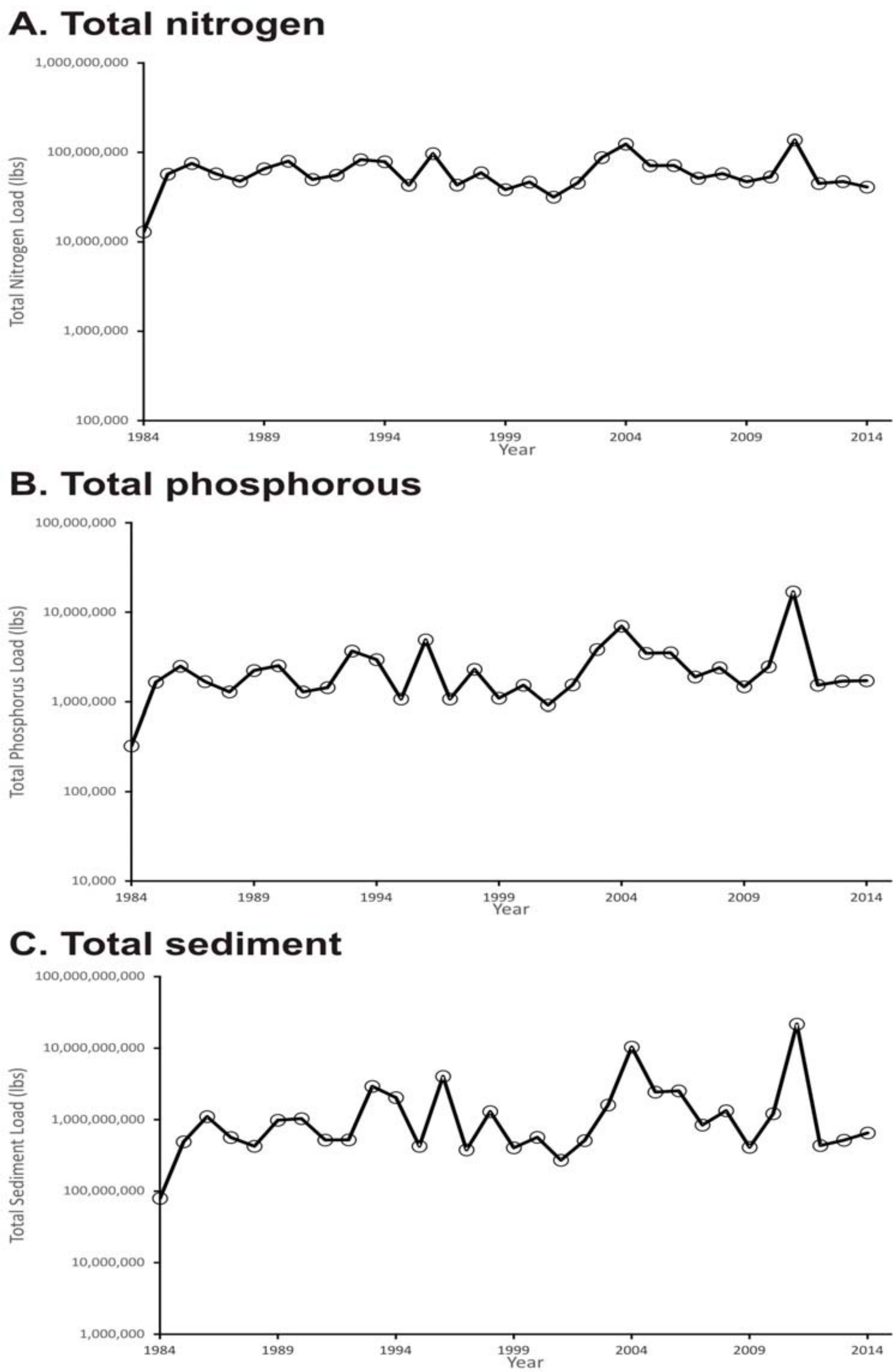
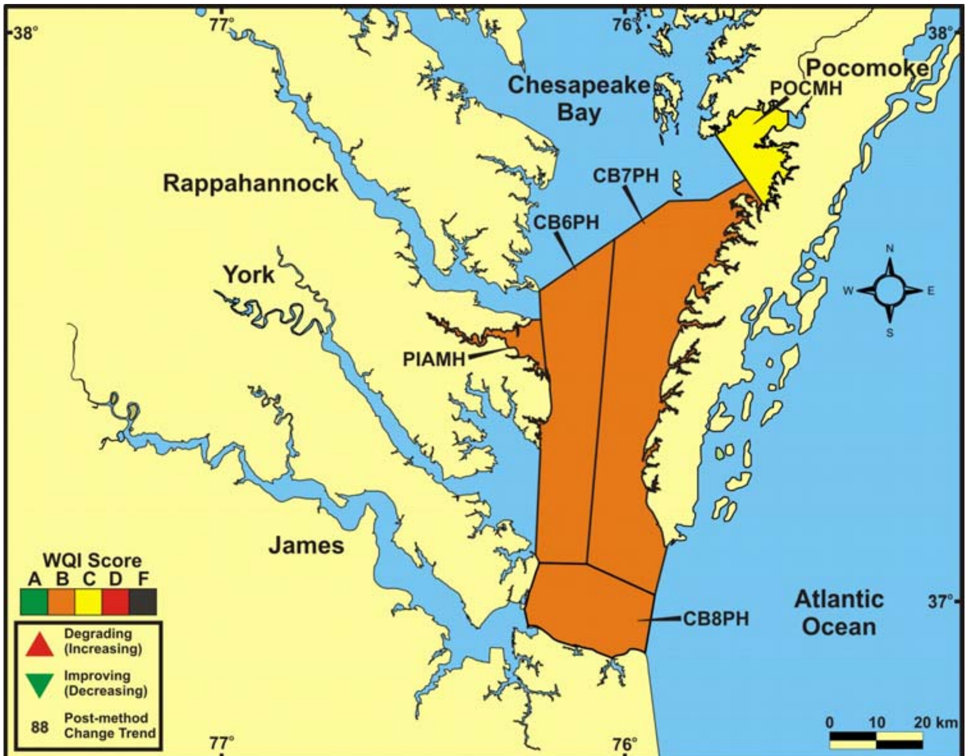


Figure 29. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment loads at the fall-line in the Susquehanna River from 1985 through 2014. Data shown are log-transformed estimates (without flow normalization) provided by the US Geological Survey's River Input Monitoring program.



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

Figure 30. Water quality status and long-term trends in nutrient parameters in the Virginia Chesapeake Bay Mainstem for the period of 1988 through 2014. 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 2014 or from the period after methodological changes in nutrient determinations were initiated i.e. from 1988 through 2014. 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.

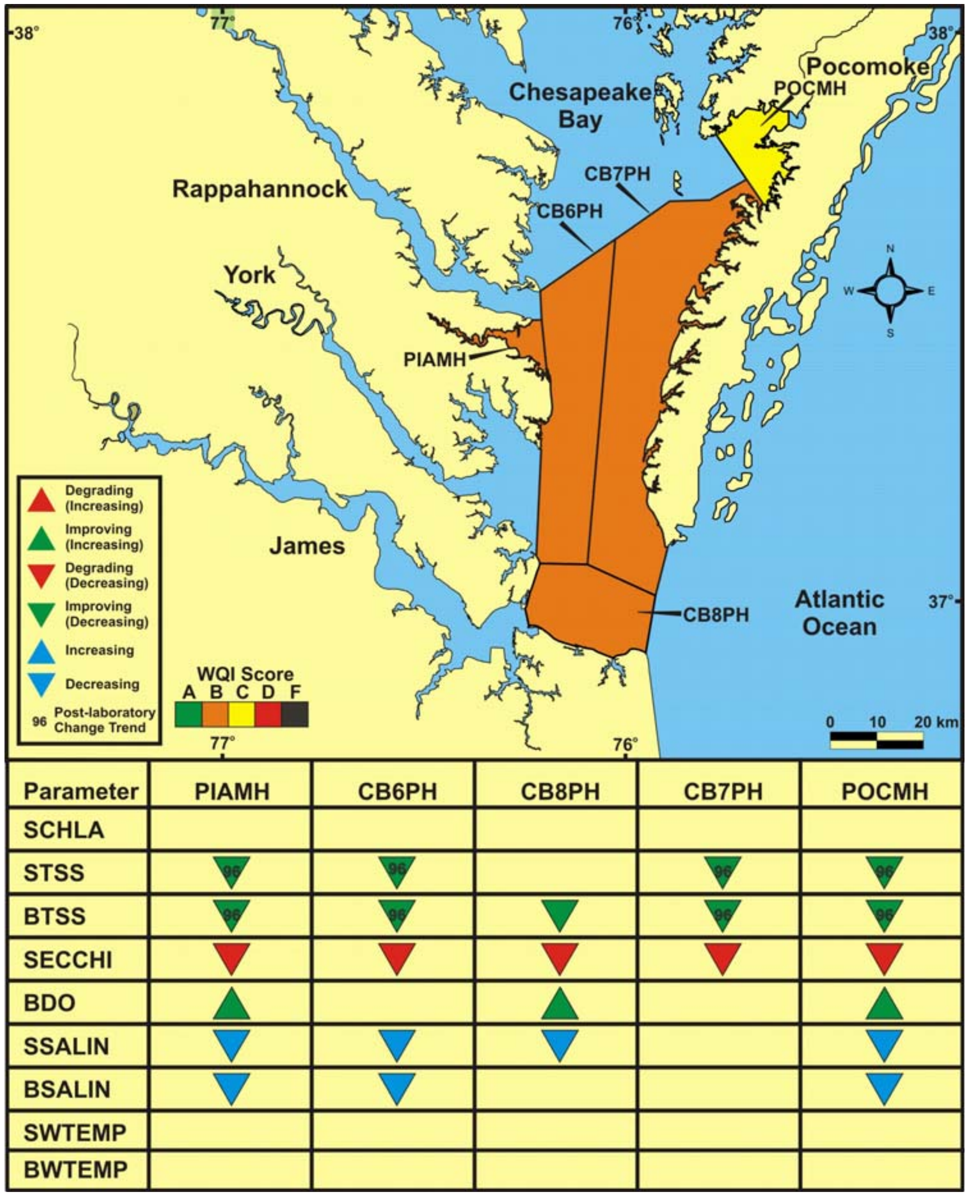


Figure 31. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2014. Status is presented as values from A through F that represent a quantitative scale of decreasing water quality as measured using the Water 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 2014. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

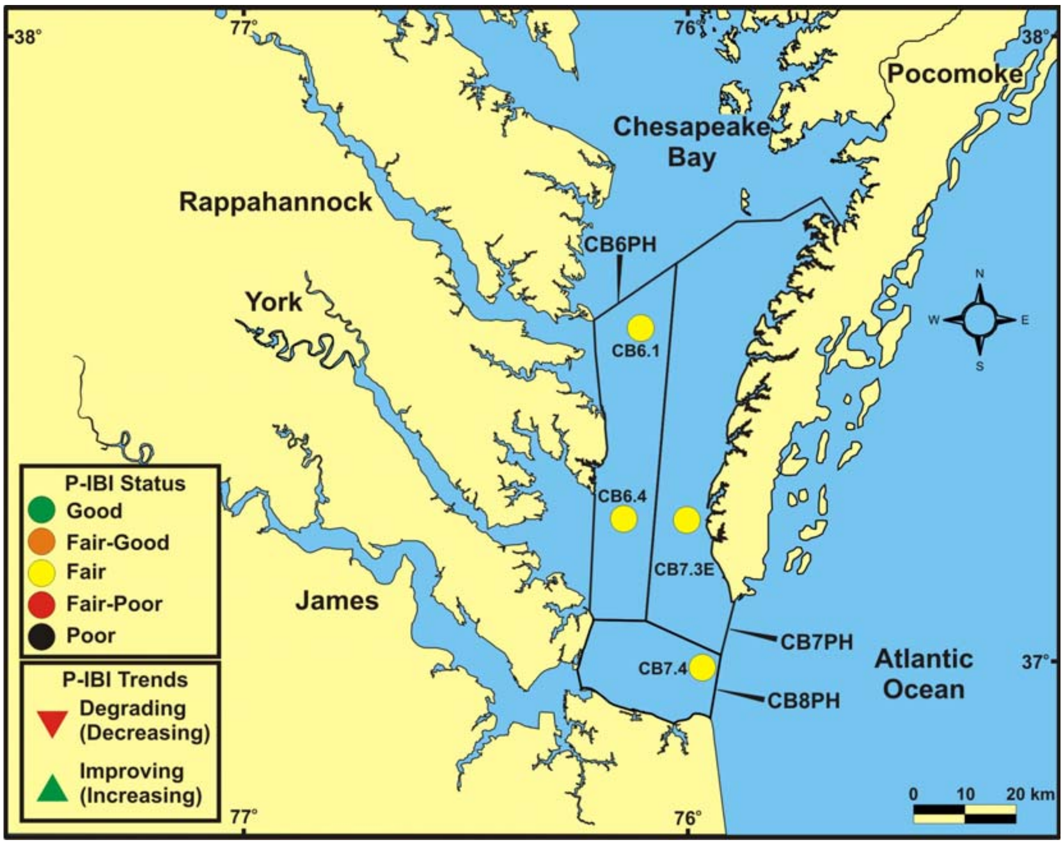


Figure 32. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2014. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2014.

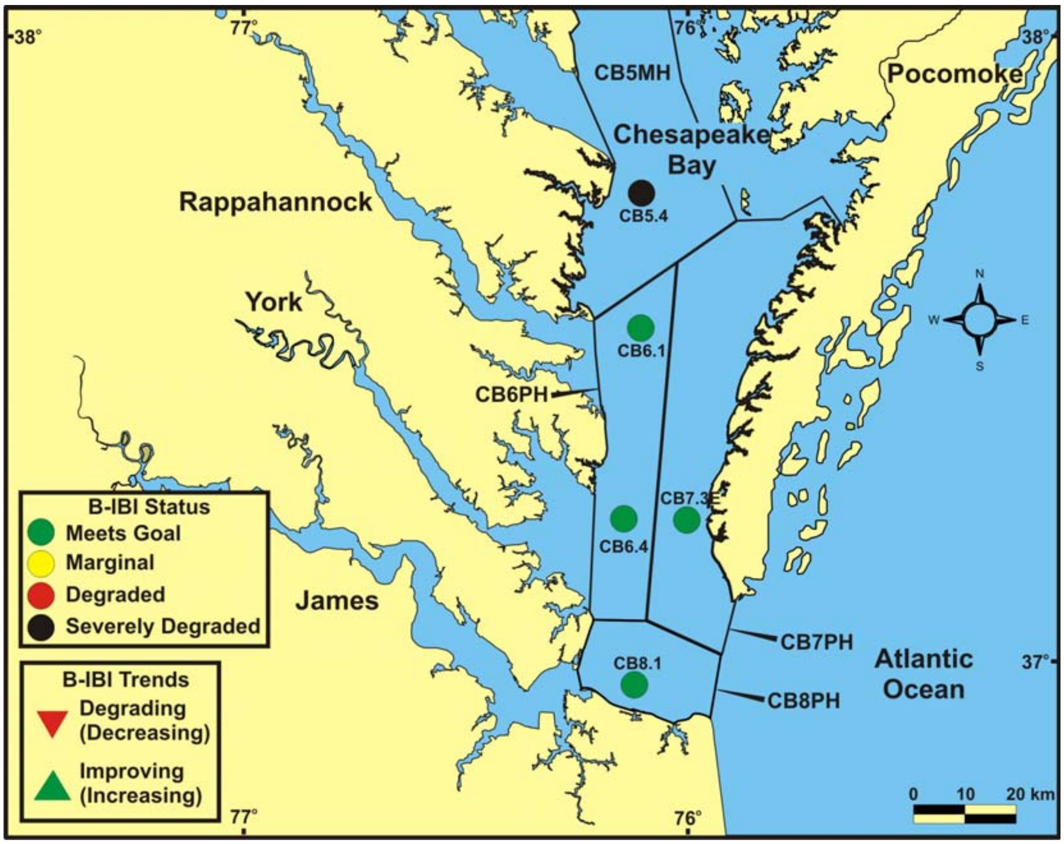


Figure 33. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2014. Shown are status as measured using the B-IBI of Weisberg et al. (1997) and statistically significant (*P* < 0.01) trends in the B-IBI from the start of monitoring through 2014.