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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 2009

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Submitted to:

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November, 2010

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I. Introduction

The period prior to the implementation of the Chesapeake Bay Monitoring Program was characterized by a marked decline in the water quality of the Chesapeake Bay. The disappearance of submerged aquatic vegetation in certain regions of the Bay, declines in the abundance of some commercially and recreationally important species, increases in the incidence of low dissolved oxygen events, changes in the Bay's food web, and other ecological problems have been related to the deteriorating water quality (e.g. USEPA, 1982,1983;Officer et al.,1984; Orth and Moore, 1984). The results of concentrated research efforts in the late 1970s and early 1980s stimulated the establishment of Federal and state directives to better manage the Chesapeake Bay watershed. By way of the Chesapeake Bay Agreements of 1983, 1987 and 2000, the State of Maryland, the Commonwealths of Virginia and Pennsylvania, and the District of Columbia, agreed to share the responsibility for improving environmental conditions in the Chesapeake Bay. As part of these agreements, a long-term monitoring program of the Chesapeake Bay was established and maintained in order to: 1) track long-term trends in water quality and living resource conditions over time, 2) assess current water quality and living resource conditions, and 3) establish linkages between water quality and living resources communities. By tracking long-term trends in water quality and living resources, managers may be able to determine if changes in water quality and living resource conditions have occurred over time and if those changes are a reflection of management actions. Assessments of current status allow managers to identify regions of concern that could benefit from the implementation of pollution abatement or management strategies. By identifying linkages between water quality and living resources it may be possible for managers to determine the impact of water quality management on living resource communities.

Water quality and living resource monitoring in the Virginia Mainstem and tributaries began in 1985 and has continued for 24 years. 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).

II. Methods and Materials

A. Monitoring Program Descriptions

Non-tidal water quality samples were collected from 1985 through 2009 at six stations at or near the fall-line in each of the major tributaries as part of the U.S. Geological Survey's (USGS) and the Virginia Department of Environmental Quality's (DEQ) River Input Monitoring Program and at an additional four stations above the fall-line (Figure 1). Tidal water quality was regularly monitored at 28 sites in the Bay Mainstem and at 27 sites in the James, York and Rappahannock rivers (Figure 2) beginning in July, 1985 and continuing through 2008. Six permanent water quality monitoring sites were established in the Elizabeth River in 1989 (Figure 2). Current sample collection and processing protocols are available online at: http://www.chesapeakebay.net/qatidal.htm. Details of changes in the monitoring program sampling regime are provided elsewhere (Dauer et al., 2005a, 2005b, 2005c).

Phytoplankton monitoring was conducted at seven stations in the Chesapeake Bay Mainstem beginning in 1985 and at six sites in the major tributaries beginning in 1986 (Figure 3). Two phytoplankton monitoring programs stations (SBE5 and SBE2) were added in the Elizabeth River in 1989 although SBE2 was eventually discontinued. Epi-fluorescent autotrophic picoplankton and C^{14} primary productivity analysis were added to all stations in 1989, with productivity analysis ending in December 2009. Details of changes in the monitoring program, field sampling and laboratory procedures are described by Dauer et al. (2005a, 2005b, 2005c).

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

In 1996, the benthic monitoring program was modified to add a probability-based sampling regime to supplement data collected at fixed-point stations and estimate the area of Chesapeake Bay and its tributaries that met restoration goals as indicated by the B-IBI (Ranasinghe et al., 1994; Weisberg et al., 1997; Alden et al., 2002). Data are collected at 25 randomly allocated stations in each of four separate strata in Virginia: 1) the James River, 2) the York River (including the Pamunkey and Mattaponi rivers), 3) the Rappahannock River, and 4) the Mainstem of the Chesapeake Bay (Figure 4). 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 coverage 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).

Long-term trend analyses of above fall-line total loads of nitrogen and phosphorus were conducted using the seasonal Kendall approach on monthly total load estimates produced by the US Geological Survey using concentration and freshwater flow measurements collected as part of their River Input Monitoring Program

(RIMP) and, when applicable, the Van Belle and Hughes tests for homogeneity of trends between seasons (months) (Gilbert, 1987). These data can be found at http://va.water.usgs.gov/chesbay/RIMP/index.html/. Long-term patterns in annual total loads were assessed using plots of the summation of the monthly values over time.

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). For this study, 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 an annual basis. Annual estimates from 1984 through 2009 were plotted to determine if there were any long-term changes in point source nutrients loads. Percent change in point source nutrient loads was estimated using data from 1984 as a baseline.

An assessment of changes in the relative contribution of point and non-point source nutrient and sediment loads were made by plotting annual estimates of discharged loads of nutrients and sediments generated from all available progress run scenarios of the Chesapeake Bay Watershed Model (Phase 4.3). Percent changes in these estimates were calculated using the results of the 1985 model assessment run values as a baseline for calculations. Model output data are available online at: www.chesapeakebay.net/data_modeling.aspx.

2. Status of Water Quality and Living Resources

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

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 2007 through 2009. Phytoplankton communities were classified as follows: (1) Poor for P-IBI values less than or equal to 2.00; (2) Fair-Poor for values greater than 2.00 and less than or equal to 2.67; (3) Fair for values greater then 2.67 and less than or equal to 3.00; (4) Fair-Good for values greater than 3.00 and less than or equal to 4.00; and (5) Good for values greater than 4.00. P-IBI values used in this study were generated and provided by the Chesapeake Bay Program Office of the USEPA and are available at http://www.chesapeakebay.net/data_plankton.aspx.

Status of benthic communities at each station was characterized using the three-year mean value (2007 through 2009) of the B-IBI (Weisberg et al., 1997). Status of benthic communities was classified as follows: (1) values less than or equal to 2 were classified as Severely Degraded; (2) values greater than 2.0 to 2.6 were classified as Degraded; (3) values greater than 2.6 but less than 3.0 were classified as Marginal; and (4) values of 3.0 or more were classified as Meeting Goals. Status of benthic communities was also quantified by using the probability-based sampling to estimate the bottom area of all strata classified as impaired using the B-IBI (Llansó et al., 2007).

3. Long-term Trend Analyses

Trend analysis for non-tidal water quality parameters was conducted using a seven parameter regression model that took into account the effects of flow, time, seasonal effects and other predictors conducted on flow-adjusted concentrations (Langland et al., 2006). Trends reported for non-tidal areas are considered to be those that were observed after natural effects such as flow have been removed from data set and that represent remaining positive or negative anthropogenic effects i.e management actions or increased pollution. Trend analyses of freshwater flow at the fall-line were conducted using a seasonal Kendall test for monotonic trends (Gilbert, 1987) on monthly means of daily observations of freshwater flow rates measured in-situ at the USGS fall-line stations shown in Figure 1.

Trend analyses of tidal water quality and living resource parameters were conducted using two separate approaches. A "blocked" seasonal Kendall approach (Gilbert, 1987) was used for water quality parameters for which an observed step trend occurred in association with known methodological or other institutional changes at various times during the monitoring program. For the blocked seasonal Kendall approach, separate trend analyses are conducted on the pre- and post-method change "blocks" of data using the seasonal Kendall approach. Trends for the two periods are statistically compared to determine if the direction is the same for both periods. If the trends for the two periods are not significantly different with respect to direction, then a trend for the entire period of record was reported (referred to in this report as long-term trends). If the trends are significantly different, only trends from the post-method change period were reported (referred to as post-method change trends). Analysis of all other water quality and living resource parameters were conducted using the seasonal Kendall approach and, when applicable, the Van Belle and Hughes tests for homogeneity of trends between stations, seasons (months), and station-season(month) combinations(Gilbert, 1987).

Method changes for nutrient parameters occurred at different times depending on the institution responsible for sample processing. Samples collected in most segments of the James, York and Rappahannock rivers as well as a portion of the Elizabeth River (one station in segment ELIPH) were collected by the Virginia DEQ and processed by Virginia state laboratories which changed nutrient methodologies after 1993. During 1994, samples from these areas were processed using the new methods but processing was carried out by the Virginia Institute of Marine Science (VIMS). After instituting the new methodologies, the Virginia state laboratories resumed sample processing in 1995. In order to account for the method change and to eliminate any effects due to the brief change in laboratories, the pre-method change period for these data was designed as 1985 through 1993 while the post-method change data period was 1995 through 2008. All data from 1994 were dropped from the trend analyses for these parameters. Nutrient determinations in the Chesapeake Bay Mainstem, Mobjack Bay, Pocomoke Sound, the Piankatank River and portions of the Elizabeth River were conducted either exclusively by Old Dominion University (ODU) or by VIMS until 1996 and solely by ODU thereafter. Method changes for both institutions occurred at the beginning of 1988 and there were no apparent step effects in the data associated with the change in laboratories for nutrients. As such, the pre-method change period was designated as 1985 through 1987 and the post-method change period was from 1988 through 2008. An additional step trend was observed for total suspended solids that occurred when ODU took over sampling and laboratory processing in the entire Mainstem from VIMS in 1996. As such, the pre- and post-method change periods were prior to 1996 and from 1996 to the present, respectively.

III. Results and Discussion

A. James River Basin

1. Basin Characteristics

The James River basin has the largest percentage of developed land, and the largest percentage of land with impervious surfaces of the three Virginia tributaries while at the same time having the highest total area, the second highest percentage of forested land and a relatively low percentage of agricultural land (Table 1A). Above the fall-line, the James River is predominantly rural with the dominant land use type being forest (66%) coupled with about 16% agricultural lands (Table 1B). The tidal portion of the river is characterized by higher percentages of developed land (38%) with over 15% being impervious surfaces. In addition, the tidal James River is characterized by relatively low forest coverage in comparison with other basins as well as a smaller percentage of agricultural land (Table 1B).

USGS estimates of total nitrogen, phosphorus and total suspended solids loads at the fall-line in the James River have fluctuated substantially but overall appear to be decreasing (Figures 5A,6A and 7A). Long-term improving trends in monthly loads for each of these parameters were detected at the James River fall-line (Table 2). No such improvements were observed in total loads for any of these parameters at the fall-line of the Appomattox River (Table 2) and, in fact, plots of annual total loads for total nitrogen and total phosphorus appear to show a slight increase (Figures 5B and 6B).

Above the fall-line, point source (PS) loads of nitrogen decreased slowly but steadily from 3,464,000 lb/yr in 1984 to 2,627,000 lb/yr in 2009 for a total reduction of just over 24% (Figure 8A). Below the fall-line, PS nitrogen loads showed an initial increase from 20,181,000 lb/yr in 1984 to 25,129,000 lb/yr in 1988. Thereafter, PS nitrogen loads showed a generally declining trend to 10,865,000 lb/yr in 2009 (Figure 8B). During the first four years of this study above fall-line PS phosphorus loads remained at levels above 750,000 lb/yr but dropped to around 540,000 lb/yr in 1988 and continued to drop for the next two years (Figure 9A). Thereafter PS phosphorus loads increased steadily with some fluctuations until 2004 when they declined again from around 754,000 in 2003 to just over 493,000 lb/yr in 2004. PS phosphorus loads have in general continued to slowly decline reaching a minimum of 381,000 lb/yr in 2008 (Figure 9A) but rose again slightly in 2009 to nearly 400,000 lb/yr (Figure 9A). Overall above fall-line PS phosphorus loads have declined over 49% since 1984. With the exception of a large pulse upwards in 1987 and several smaller ones later, PS phosphorus loads below the fall-line have declined steadily from 2,834,000 lb/yr in 1984 to 493,000 lb/yr in 2009 (Figure 9B), a decrease of just under 83%.

CBP watershed model estimates indicate that 46% of total nitrogen load and 55% of the total phosphorus load currently entering the James River basin comes from non-point sources above the fall-line (Figures 10-11). Substantial reductions in point source nutrients have occurred since 1985 resulting in a reduction in their relative contributions to total load to the James River (Figures 10-11). Model estimates indicate that reductions in all sources of both nitrogen and phosphorus have occurred (Figures 10-11) resulting in an overall decrease in total nitrogen and total phosphorus to the James River of approximately 23% and 42%, respectively.

2. Non-tidal Water Quality

No statistically significant long-term trends in freshwater flow were observed at the fall-line stations in the James, Appomattox and Chickahominy rivers (Table 3). Overall, water quality conditions in the non-tidal reaches of the James River and its tributaries appear to be improving. Improving trends in flow-adjusted total nitrogen and/or nitrate-nitrites were detected at all non-tidal stations in the basin except for Station 1 in the Appomattox River (Table 4; Figure 12). In addition, improving trends in flow-adjusted total phosphorus were detected at Stations 4 and 5 in the main stem of the non-tidal James River (Table 4; Figure 13) along with an improving trend in flow-adjusted dissolved inorganic phosphorus at Station 1 in the Appomattox River and Station 4 in the James River (Table 4). The only degrading trends observed above the fall-line were an increasing trend in flow-adjusted total phosphorus concentrations observed at Station 1 in the Appomattox River and an increasing trend in total suspended solids observed at station 3 in the James River near Richmond (Table 4;Figure 14).

3. Tidal Water Quality

Water quality status in the main stem of the James River, as measured using the WQI, generally decreased moving downstream from Good at the upper segments (JMSTF1, JMSTF2, and JMSOH) to Marginal at segment JMSMH and Poor at segment JMSPH (Figure 15). Status in both the tidal Appomattox (segment APPTF) and Chickahominy (segment CHKOH) rivers was Marginal (Figure 15). With respect to nutrients, improvements in water quality were limited primarily to the tidal freshwater segments of the James River main stem (JMSTF1 and JMSTF2) and to the Appomattox River and and Chickahominy River segments (APPTF and CHKOH) (Figure 15). Improving trends in surface and bottom dissolved inorganic phosphorus were detected in all of these segments, as were improving trends in bottom total nitrogen and in surface and bottom total phosphorus in segments JMSTF1 and JMSTF2, respectively (Figure 15). In addition, an improving post-method change trends were detected in surface and bottom total phosphorus in segment JMSTF1 (Figure 15). Despite the improvements observed in nutrients, improving trends in surface chlorophyll *a* were limited to the Chickahominy River (Figure 16). A degrading trend in chlorophyll *a* was also observed in segment JMSPH at the mouth of the James River (Figure 16). Degrading trends in bottom total suspended solids were detected in segments CHKOH and JMSMH while degrading trends in water clarity as measured by secchi depth were detected in segments JMSTF1, CHKOH, and JMSPH (Figure 16). Summer bottom dissolved oxygen concentrations were unchanged for most segments except segments JMSOH and JMSPH where a degrading trend and an improving were observed, respectively (Figure 16).

Water quality status was Poor or Very Poor in all segments of the Elizabeth River (Figure 17). Despite generally degraded water quality, conditions in the Elizabeth River appear to be improving. Improving trends in surface and bottom total nitrogen and total phosphorus were observed in all segments of the Elizabeth River except the Elizabeth River main stem (segment ELIPH) were a degrading trend in surface total nitrogen was observed (Figure 17). Improving trends in surface and bottom dissolved inorganic nitrogen were also observed in the Southern Branch (SBEMH) and Eastern Branch (EBEMH) (Figure 17). Improving trends in surface and/or bottom total suspended solids were also observed in all segments of the Elizabeth

River (Figure 18) along with a an improving trend in summer bottom dissolved oxygen in the Southern Branch (SBEMH). The only degrading trends observed were an increasing trend in bottom total nitrogen and a decreasing trend in secchi depth, both in segment ELIPH (Figure 18).

4. Phytoplankton Communities

In general, phytoplankton communities in the James River appear to be degrading. This degradation of phytoplankton communities appears to increase moving upstream with the P-IBI ranging from Fair at station LE5.5 in segment JMSPH, to Fair-Poor at station RET5.2 in segment JMSOH and Poor at station TF5.5 in segment JMSTF1 (Figure 19). Plankton community status at station SBE5 in segment SBEMH the Elizabeth River was Fair-Poor (Figure 19). No trends in the P-IBI were detected. No improving trends in phytoplankton communities were detected at any stations in the James River with the exception of an improving trend in primary productivity at station RET5.2 (Appendix C - Section A). Degrading trends in diatom biomass were detected at all stations along with degrading trends in chlorophyte biomass at all stations except station TF5.5 in segment JMSTF1 (Appendix C - Section A). Other degrading trends were detected for Margalef diversity at station RET5.2, primary productivity at station TF5.5 and picoplankton biomass at station LE5.5 (Appendix C - Section A). In addition, decreasing trends in total community abundance and biomass, as well as, cryptophyte biomass (Appendix C - Section A). Dinoflagellate blooms are common within the tributaries to the lower James River; often entering the upper James River, and sometimes into the lower Chesapeake Bay. A species of increased concern over this study period is the dinoflagellate *Cochlodinium polykrikoides*, a cyst producer and potentially harmful species that has spread its range of bloom development into many of the tidal creeks and rivers that feed into the lower James River (Marshall et al. 2008, Marshall and Egerton 2009a; 2009b). These include the Lafayette and Elizabeth rivers where dense late summer and early fall blooms of this species are annual events, and which subsequently enter the lower James River and into the lower Chesapeake Bay and often to the Virginia Beach coastal beaches and (Marshall 1996). Mean primary productivity in the James River ranged around 143±5.5 g C/L/hr at station TF5.5 to 70±1.7 g C/L/hr at station LE5.5, decreasing moving from downstream to the mouth of the River (Table 5). Average productivity in the Elizabeth River was lower than most tributary stations although the maximum value observed was among the highest of all stations (Table 5).

5. Benthic Communities

The B-IBI met restoration goals at only one station in the main stem of James River: station LE5.4 in segment JMSPH. Status at all other stations in the James River was Degraded (Figure 20). Status of the B-IBI at stations in the Southern Branch of the Elizabeth River (segment SBEMH)were degraded or severely degraded (Figure 20). Improving trends in the B-IBI were detected at station RET5.2 in segment JMSOH and at station SBE5 in the Southern Branch (SBEMH) of the Elizabeth River (Figure 20). In 2009, results of the probability-based benthic monitoring indicate that 68% of the total area of the James River is degraded (Table 6). In 2009, random sites in the lower portion of the James River generally met the restoration goals while degraded sites were located in the upper and middle portions of the James River main stem as well as the Nansemond and Elizabeth rivers (Figure 4). Previous studies suggest that anthropogenic contaminants may account for much of the degradation in the James River particularly in the Elizabeth River (Dauer et al., 2005a; Llansó et al.,2005).

6. Management Issues

Trends at the fall-line indicate that in general water quality is improving in the non-tidal portions of the James River basin with respect to nutrient concentrations although no change in suspended solids was observed. Water quality status in the tidal portions of the James River main stem decreased moving downstream and improving trends in nutrients, primarily total and dissolved inorganic phosphorus, observed were limited to tidal freshwater and oligohaline segments. The trends in phosphorus observed may be related to the reductions in NPS and/or PS total phosphorus loads for this parameter both above and below the fall-line. A closer examination of the geographical distribution and relative contribution of NPS and PS loads in various regions of the James River basin may provide more insight into direct causes of the decreasing trends observed. Other than in the tidal freshwater and oligohaline segments, water quality status was Marginal or Poor, few trends in nutrients were observed and degrading trends in chlorophyll a, total suspended solids and water clarity (Secchi depth) were observed. This suggests a disconnect or time lag between improvements observed in both NPS and PS loadings both above and below the fall-line from observed responses in the lowermost segments of the James River.

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

Overall living resources conditions in the James River are degraded. Phytoplankton communities throughout the James River were characterized as Poor to Fair-Poor at most stations and appear to be continuing to degrade as indicated by widespread degrading trends in diatom and chlorophyte biomass. Of additional concern is the more common occurrence of algal blooms of in the James River, Elizabeth River and its tributaries within the Tidewater urban complex. The duration of blooms produced by *Cochlodinium polykrikoides* appears also to be increasing, in addition to their spread into other tributaries and locations of this region. To date this trend has influenced and often curtailed public recreational activities during these blooms. Status of the benthos at most fixed-point stations in the James Rivers was Degraded and probability-based benthic monitoring indicated that 68% of the total area of the river did not meet restoration goals. In addition, only one improving trend in benthic community conditions was observed. 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.

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

USGS estimates of annual total nitrogen, phosphorus and total suspended solids loads at the fall-line have not changed substantially for either the Pamunkey or Mattponi rivers (Figures 21-23). No long-term trends in monthly loads were detected for any of these parameters in either the Pamunkey or Mattaponi rivers (Table 2).

Above the fall-line, PS nitrogen loads increased from approximately 112,000 lb/yr in 1984 to a maximum of over 207,000 lb/yr in 1996 but generally declined thereafter reaching a minimum of around 78,000 lb/yr in 2009 (Figure 24A) for a total increase of just over 30% from 1984 to 2009. Below the fall-line PS nitrogen loads showed an initial decrease from 1,258,000 lb/yr in 1984 to 653,000 lb/yr in 1988 but, in general, increased thereafter to a maximum of 1,519,000 lb/yr in 2000 (Figure 24B). From 2000 through 2009, PS nitrogen loads fluctuated from between approximately 960,000 to 1,400,000 lb/yr reaching just under 1,130,000 in 2009 (Figure 24B). Overall, below fall-line PS nitrogen loads decreased by approximately 10% from 1984 through 2009. Above the fall-line PS phosphorus loads in the York River showed an initial decline from about 38,000 lb/yr in 1984 to 28,000 lb/yr in 1992 but increased steadily to a maximum of just over 62,000 lb/yr in 2005 (Figure 25A). Above fall-line PS phosphorus loads during the last four years declined to less than 9,000 in 2009 (Figure 25A) for a total decrease from 1984 to 2009 of over 76%.

Below fall-line PS phosphorus loads increased initially from 407,000 lb/yr in 1984 to 496,000 lb/yr in 1987 declined substantially to 187,000 lb/yr in 1988 and, in general, continued to decrease reaching minimum of just over 100,000 lb/yr in 2009 (Figure 25B) for a total decrease of 75% since 1984. In Mobjack Bay, PS nitrogen loads showed a substantial decrease from 11,200 lb/yr in 1992 to 2,300 lb/yr in 1993 followed by a period during which loads generally fluctuated between 1,500 to 2,500 lb/yr (Figure 26A). Overall PS nitrogen loads in Mobjack Bay have decreased by over 75% since 1984. PS phosphorus loads in Mobjack Bay declined steadily from 2900 lb/yr in 1984 to 250 lb/yr in 2009 (Figure 26B) for a total decrease of more than 91%.

Based on CBP model estimates, the predominant contributors of both nitrogen and phosphorus loads to the York River are non-point sources from above the fall-line which currently account for 49% and 51% of the total load of these two nutrients, respectively (Figure 27-28) . With respect to nitrogen, below fall-line point sources increased somewhat since 1985 resulting in an increase in the relative contribution to total nitrogen load to the York River (Figure 27). Overall, however, total nitrogen loads to the York River decreased nearly 16% from 12,270,000 lb/yr in 1985 to 10,344,000 lb/yr in 2009 due to reductions of non-point sources both above and below the fall-line (Figure 27). All sources of phosphorus decreased from 1,310,000 lb/yr in 1985 to 924,000 lb/yr in 2009, although the relative contribution of above fall-line non-point sources to the total load increased (Figure 28).

2. Non-tidal Water Quality

No statistically significant trends in freshwater flow were observed in either the Pamunkey or Mattaponi rivers (Table 3). Water quality conditions in the non-tidal portion of the Pamunkey River are declining as indicated by the degrading trends in flow-adjusted concentrations of all measured water quality parameters at Station 5 near Hanover at the fall-line (Table 4; Figures 12-14) . However, the degrading trends at Station 5 seem to have occurred from 1985 to 2000 or 2002 and began to level out since then (Rick Hoffman, DEQ, personal communication). In addition, degrading trends in flow-adjusted total phosphorus and total suspended solids were detected at Station 7 in the North Anna River, a tributary to the Pamunkey River (Table 4; Figures 13 and 14). Water quality conditions in the non-tidal Mattaponi River may be improving as indicated by the declining trend in flow-adjusted dissolved inorganic phosphorus (Table 4).

3. Tidal Water Quality

Status, as measured using the WQI, declined from Good in the tidal freshwater of the Pamunkey and Mattaponi rivers (segments PMKTF and MPNTF) to Poor and Fair in the lower Pamunkey and Mattaponi, respectively (segments PMKOH and MPNOH) (Figure 29). Water quality status was Poor in all remaining segments of the York River and Mobjack Bay (Figure 29). With respect to nutrients, water quality conditions are declining throughout much of the tidal York River. Degrading long-term trends in total nitrogen were detected in the lower Pamunkey and Mattaponi rivers and also in middle and lower York River (segments YRKMH and YRKPH) (Figure 29). Degrading trends in surface and/or bottom total phosphorus were detected in several segments including both in the Pamunkey River (PMKTF and PMKOH) and both in the middle and lower segments of the York River (YRKMH and YRKPH) (Figure 29). In addition, degrading trends in both surface and bottom dissolved inorganic phosphorus were observed in segments YRKMH and YRKPH (Figure 29). The only improvements observed within this basin were the post-method change trends observed in dissolved inorganic phosphorus in the tidal freshwater Pamunkey and Mattaponi rivers (PMKTF and MPNTF) and the post-method change trends observed in total nitrogen and total phosphorus in Mobjack Bay (MOBPH) (Figure 29). No changes in chlorophyll *a* concentrations were observed in any segments of the York River while trends in total suspended solids was limited to degrading trends in surface concentrations at segment PMKTF and bottom concentrations in segment YRKMH along with improving post-method change trends in both surface and bottom concentrations in Mobjack Bay (MOBPH) (Figure 30). Degrading trends in water clarity as measured using Secchi depth were detected in the upper segments of the Pamunkey and Mattaponi (segments PMKTF and MPNTF), as well as the lower segment of the York River (YRKPH) and Mobjack Bay (MOBPH) (Figure 30). Improvements in summer bottom dissolved oxygen were detected in the tidal freshwater Pamunkey (PMKTF) and in Mobjack Bay (MOBPH) (Figure 30).

4. Phytoplankton Communities

Status of the phytoplankton communities based on the P-IBI was Fair at station TF4.2 in segment PMKTF, Poor at station RET4.3 in segment YRKMH and Fair to Poor at station WE4.2 in segment MOBPH(Figure 31). There were no significant trends in the P-IBI (Figure 31). No improving trends were detected for any phytoplankton indicators in the York River, however, degrading trends in primary productivity were detected at all stations along with degrading trends in chlorophyte abundance at stations RET4.3 and WE4.2, diatom biomass at station WE4.2, and picoplankton abundance at station TF4.2 (Appendix C - Section B). In contrast with the other tributaries, mean primary productivity in the York River was lowest at the tidal freshwater station TF4.2 and decreased moving downstream (Table 4). The lower York River continues to experience sporadic dinoflagellate blooms on an annual basis that are associated with potentially harmful species. Many of these blooms have encompassed larger areas of the York, lasted over extended time periods and often extend into the lower Chesapeake Bay. The most extensive bloom producer has been the dinoflagellate *Cochlodinium polykrikoides*, occurring generally in high concentrations during months in summer and early fall. Dense blooms typically occur in the lower York, then pass southward within the western coastal waters of Chesapeake Bay and represent a source of entry to the tidal rivers of this region. Of additional concern was the identification of another dinoflagellate, the ichthyotoxic *Alexandrium monilatum* during a 2007 bloom in the lower York River and Sarah Creek (Marshall and Egerton 2009a). It was observed again in 2008 and 2009 in the York and lower Chesapeake Bay. Since this species also produces cysts that may persist in the sediment and re-inoculate the water column, there is the high probability that it has established itself in the area and that future blooms may occur. Station TF4.2 in the York River had the lowest mean primary productivity values of all stations monitored while stations RET4.3 and WE4.2 were higher than the oligohaline and mesohaline stations in the James River but lower than those in the Rappahannock River (Table 5).

5. Benthic Communities

Status of benthic communities in the York River as measured using the B-IBI generally improved moving downstream from station TF4.2 in segment PMKTF where they were classified as degraded (Figure 32). Status continued to improve from marginal at station RET4.2 in upper portion of segment YRKMH to meeting goals at station LE4.1 in the lower portion of segment YRKMH and station LE4.3 in segment YRKPH. However, at station LE4.3B benthic community status was degraded although the increasing trend detected in the B-IBI indicated that communities at this station are improving (Figure 32). In 2009, results of the probability-based benthic monitoring indicate that 52% of the total area of the York River was degraded (Table 6). Most of the degraded random sites were located in the lower Pamunkey River (segment PMKOH), lower portion of segment YRKMH, and the upper portion of segment YRKPH (Figure 4). Previous studies indicate that a combination of anthropogenic contamination, eutrophication and low dissolved oxygen adversely affect benthic communities in the York River (Dauer et al., 2005b; Llansó et al.,2005).

6. Management Issues

Water quality in the non-tidal portion of the Pamunkey River may be degrading as indicated by increasing trends in flow-adjusted concentrations at the fall-line for all parameters measured. In the Mattaponi River, there appear to be few changes in water quality conditions although a decreasing trend in dissolved inorganic phosphorus suggests some improvement. The source of the degrading trends in nutrients observed above the fall-line in the Pamunkey River is unclear. Nitrogen and phosphorus PS nutrient loads appear to have both decreased at least during the last decade while model estimates of NPS loads indicate reductions as well. An examination of NPS and PS loads as well as land-use patterns at a more detailed geographical scale might help to more readily explain the trends observed.

Water quality status in the tidal portion of the York River tended to be better in upstream segments with the lower segments showing Poor or Very Poor status. Long-term degrading trends in nutrients were detected in multiple segments throughout the river with improvements being limited primarily to the tidal freshwater segments of the Pamunkey and Mattaponi rivers and to Mobjack Bay. Degrading trends in water clarity (Secchi depth) were also detected in several segments. Trends in nutrients may be related to the degrading trends observed above the fall-line, particularly in the tidal freshwater and oligohaline segments of the Pamunkey River, and/or in the case of nitrogen changes in PS loads below the fall-line. The improving trends in Mobjack Bay appear to be related to the reductions in PS loads of both nitrogen and phosphorus to 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.

Living resource conditions in the York River are reflective of the generally poor water quality status and degrading trends observed. Phytoplankton community status was only Fair and Poor throughout this tributary and continued degradation of these communities is indicated by the degrading trends in several bioindicators including diatom biomass, primary productivity and cyanobacteria biomass. The major location for algal blooms continues to be in the lower York, where dinoflagellate blooms can be extensive in areal coverage, long lasting, and potentially harmful to shellfish and fish. In addition to the extensive annual blooms of *Cochlodinium polykrikoides*, the recent identification of the ichthyotoxic species *Alexandrium monilatum* has produced another concern. This species has the ability through its cyst formation to maintain and potentially expand its presence in this and other tidal tributaries in the region. If this occurs it could pose a threat to various fish populations during bloom development. Future monitoring will focus emphasize on alerts for the presence, abundance, and distribution of this species.

With respect to the benthos, all but one of the fixed point monitoring stations in the York River were Degraded or Marginal and probability-based sampling indicated that 52% of the bottom of the York River does not met the restoration goals for benthic communities. Previous studies suggest that anthropogenic contamination appears to be the predominant source of stress to the benthos but eutrophication and low dissolved oxygen also play a role (Dauer et al., 2005b). There is a possibility that physical disturbance of the benthos caused by seabed mixing, a natural source of stress, may also be an important factor determining benthic community status in the York River (Dellapenna et al., 1998; 2003).

C. Rappahannock River Basin

1. Basin Characteristics

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

USGS estimates of total nitrogen, phosphorus and total suspended solids loads at the fall-line in the Rappahannock River have fluctuated with little discernable pattern (Figures 33A-C) and no long-term trends in monthly loads were detected for any of these parameters (Table 2).

Above the fall-line, PS loads of nitrogen increased from approximately 191,000 lb/yr in 1984 to 313,000 lb/yr in 1996, an increase of over 63% (Figure 34A). PS nitrogen loads declined for the next five years but increased again to reach a maximum in 2007 of nearly 331,000 lb/yr followed by decline thereafter that reached 255,000 lb/yr in 2009 (Figure 34A). Overall, however, PS nitrogen loads above the fall-line increased by over 33% between 1984 and 2009. Below the fall-line, PS nitrogen loads showed an initial increase from around 331,000 lb/yr in 1984 to nearly 470,000 lb/yr in 1989, declined during the following six years reaching a minimum of just over 257,000 lb/yr in 1995 but then steadily increased again reaching a maximum of just under 491,000 lb/yr in 1998 (Figure 34B). Thereafter PS nitrogen loads decreased reaching a minimum of about 176,000 in 2009 (Figure 34B) for a overall decrease nearly 48% between 1984 and 2009. Above the fall-line PS phosphorus loads have shown a relatively steady decrease, with some fluctuations, from just over 81,000 lb/yr in 1984 to just under 23,000 lb/yr in 2009 (Figure 35A) resulting in a total decrease in PS phosphorus loads of almost 72%. Below the fall-line, PS phosphorus loads below the fall-line dropped from around 143,000 lb/yr in 1987 to just over 66,000 lb/yr in 1988 (Figure 35B). This decrease continued steadily thereafter reaching a minimum of just under 14,000 lb/yr in 2009, a total decline of over 88%.

CBP model estimates indicate, the primary contributors of both nitrogen and phosphorus loads to the Rappahannock River are non-point sources from above the fall-line which currently account for 56% and 62% of the total load of these two nutrients, respectively (Figure 36-37) . With respect to nitrogen, all sources except above fall-line point sources decreased over time resulting in a decrease of 22% in total loads to the Rappahannock River from 12,460,000 lb/yr in 1985 to 9,723,000 lb/yr in 2009 (Figure36). All sources of phosphorus decreased resulting in a drop in total phosphorus load to the Rappahannock River from 1,313,000 lb/yr in 1985 to 890,000 lb/yr in 2009, although the relative contribution of above fall-line non-point sources to the total load increased (Figure 37).

2. Non-tidal Water Quality

There was no significant trend in freshwater flow at the Rappahannock River fall-line (Table 3). Long term flow-adjusted water quality conditions at the fall-line in the Rappahannock River remained unchanged although some improvements were detected upstream as indicated by the declining trends in flow-adjusted total nitrogen, dissolved nitrate-nitrites and total phosphorus at Station 9 in the Robinson River, a tributary of the Rappahannock River (Table 4;Figures 12-14).

3. Tidal Water Quality

Water quality status as measured using the WQI was Marginal in all segments except the Corrotoman River (segment CRRMH) (Figure 38). With respect to nutrients, there was little change in water quality conditions except for a degrading trend in bottom total nitrogen in segment RPPOH and several improving trends in dissolved inorganic phosphorus in segments RPPTF and RPPOH. Degrading trends in chlorophyll *a* were detected in the middle (RPPOH) and lower (RPPMH) Rappahannock River, as were degrading trends in water clarity in the Corrotoman River (CRRMH) and bottom dissolved oxygen in the upper Rappahannock River (segment RPPTF) (Figure 39).

4. Phytoplankton Communities

Phytoplankton communities in the Rappahannock River were typically degraded. Two stations, TF3.3 and RET3.1 in segment RPPOH, were characterized as Poor based on the P-IBI while the remaining station, LE3.6 in segment RPPMH was classified as only Fair (Figure 40). There were no significant trends in the P-IBI. No improving trends in phytoplankton indicators were detected at any stations of the Rappahannock River except for a decreasing trend in picoplankton biomass at station LE3.6. However, several degrading trends were detected including increasing trends in primary productivity at stations TF3.3 and RET3.1, increasing trends in cyanophyte and dinoflagellates at station TF3.3, an increasing trend in cyanophyte biomass and decreasing trends in diatom and chlorophyte biomass at station LE3.6 (Appendix C - Section D). Cyanobacteria of concern in the tidal fresh waters include *Microcystis aeruginosa* which is a toxin producer and has produced major blooms in the lower saline and tidal fresh waters of the Potomac River in recent years (Marshall et al. 2008a). To date blooms of this species in the Rappahannock have not been extensive. However, dinoflagellates that are mostly non-toxic are common in the lower segments of the river. On occasion blooms of *Cochlodinium polykrikoides* have also occurred in the lower Rappahannock River. Primary productivity in the Rappahannock River was generally higher than that observed in other tributaries and station TF3.3 had the highest observed maximum value of all of the stations monitored (Table 5).

5. Benthic Communities

Benthic community status was degraded or severely degraded at all stations in the Rappahannock River and in general became more degraded moving downstream with both stations in segment RPPMH being severely degraded. In addition, a degrading trend in the B-IBI was detected at station RET3.1 in segment RPPMH (Figure 41). Probability-based benthic monitoring results indicated that 72% of the total area of Rappahannock River failed to meet the benthic community goals in 2009 (Table 6). Degraded random sites were found throughout a large area extending from the lower portions of segment RPPMH through much of segment RPPOH (Figure 4). Previous studies indicate benthic degradation in the Upper Rappahannock River appears to be the result of anthropogenic contamination while degradation in the lower segments of the river may be the result of a combination of contamination and low dissolved oxygen effects (Dauer et al., 2005c; Llansó et al.,2005).

6. Management Issues

Water quality conditions in the Rappahannock River basin were Marginal overall and results of the trend analyses both above and below the fall-line suggest limited changes in conditions have occurred. Despite initial reductions in model estimates of nitrogen and phosphorus NPS loads above and below the fall-line, as well as, substantial initial reductions and continued declines in PS total phosphorus loads both above and below the fall-line few improving trends in nutrients were observed and degrading trends in chlorophyll *a*, secchi depth, and bottom dissolved oxygen were detected in several segments of this tributary. Lack of improving trends in nitrogen parameters may be the result of the general trend of increasing PS nitrogen loads above the fall-line. It is possible that this increase in PS loads may be offsetting any potential improvements associated with the reduced NPS loads as projected by the CBP model. Some improvement in phosphorus concentrations was indicated by the decreasing post-method change trends in dissolved inorganic phosphorus but these improvements were limited to the upper segments of the river. Although there is no clear explanation for the lack of response in total phosphorus concentrations to reductions in both NPS and PS loads of this nutrient, there are several possibilities: (1) reductions in loads were insufficient to result in a response in water column concentrations; (2) the NPS and/or PS load data used do not reflect actual loads to this river for this parameter; (3) lag times between load reductions and concentrations are longer than period of record of the current data set; or (4) sources other than non-point source runoff or point source outfalls such as atmospheric deposition or sediment flux constitute a substantially higher source of total phosphorus than previously believed.

Living resource conditions within much of the Rappahannock River appeared to be impacted due perhaps in large part to the lack of improvement in water quality conditions and potentially as a result of increasing PS nitrogen loads above the fall-line. P-IBI values were characterized as either Poor or Fair to Poor and increasing trends in primary productivity and cyanobacteria biomass were detected at some stations suggesting that phytoplankton communities in the Rappahannock River may be degrading. Potential for increased algal blooms are centered in the tidal fresh waters by cyanobacteria and in the lower Rappahannock by increasing dinoflagellate taxa. Benthic community conditions in the Rappahannock River was generally degraded and could be characterized as the worst of all the Virginia tributaries. Benthic community status at all fixed point monitoring stations in the Rappahannock River was Degraded or Severely Degraded and trend results indicate that conditions continue to degrade at one station in the uppermost portion of segment RPPMH. Probability-based monitoring results indicated that nearly three quarters of the total area of the Rappahannock River failed to meet restoration goals. Degraded benthic community conditions in the Rappahannock River are most likely due to low dissolved oxygen events particularly in the lower portions of the estuary.

D. Virginia Chesapeake Bay Mainstem

1. Tidal Water Quality

Water quality status in the Virginia Chesapeake Bay Mainstem was either Poor or Marginal with the exception of the Pianktank River (segment PIAMH). Overall, however, water quality conditions appear to be improving. Improving post-method change trends in surface and bottom total nitrogen were detected in all segments of the Mainstem except CB8PH, as were improving long-term or post-method change trends in surface and bottom total phosphorus in all segments (Figure 42). Improving post-method change trends in both surface and bottom total suspended solids were observed in all segments of the Mainstem (Figure 43) coupled with improving trends in bottom dissolved oxygen in the Piankatank River (segment PIAMH), Pocomoke Sound (segment POCMH) and the mouth of Chesapeake Bay (CB8PH). Despite the improvements in both nutrients and suspended solids, there were no concomitant improvements in chlorophyll *a* and degrading trends in water clarity were observed in all segments of Mainstem (Figure 43). Decreasing trends in surface and/or bottom salinity were detected in most segments of the Mainstem while increasing trends in surface and/or bottom percent dissolved oxygen saturation were detected in all segments (Figure 43).

2. Phytoplankton Communities

The Chesapeake Bay is a stratified system with the phytoplankton below the pycnocline containing species entering from the off shore Atlantic waters of Virginia, and waters above the pycnocline typically containing phytoplankton flowing out of the Bay. There are also indigenous Bay species within each stratum with various degrees of mixing and species representation throughout the ecosystem. Over a 1,400 phytoplankton species have been identified within the Bay and its tidal tributaries, with 37 identified as potentially harmful (Marshall 1994, Marshall et al. 2005, Marshall et al. 2008a). The identification of other potentially harmful taxa will likely continue. The phytoplankton composition is that of mainly flora from temperate waters with a diverse representation associated with the various salinity regions in the Bay (Marshall et al. 2006). There are numerous and common bloom producing species occurring typical during spring, summer, and autumn. In addition to algal bloom producers is the ciliate *Myrionecta rubra*, a frequent bloomer in the tidal tributaries and the Bay. However, the common bloom producers include the dinoflagellates *Akashiwo sanguinea*, *Cochlodinium polykrikoides*, *Heterocapsa rotundata*, *H. triquetra*, *Karlodinium veneficum*, *Prorocentrum minimum*, *Scrippsiella trochoidea*, among others. Status of phytoplankton communities in the Virginia Chesapeake Bay Mainstem based on the P-IBI was Fair at all stations and no significant trends were detected in the P-IBI (Figure 44). Degrading trends in diatom and chlorophyte biomass were detected at all stations in the Bay Mainstem along with degrading trends in cyanophyte biomass at station CB6.1 in segment CB6PH and Margalef diversity index at station CB7.4 in segment CB7PH (Appendix C - Section E). In addition, degrading trends in primary productivity were detected at station CB6.4 in segment CB6PH and station CB7.4 in segment CB8PH (Appendix C - Section E). There were no improving trends in phytoplankton indicators were detected. In addition, decreasing trends in both total community biomass and cryptophyte biomass were detected at all Mainstem stations. Primary productivity in the Virginia Chesapeake Bay Mainstem was generally lower than that at most tributary stations ranging from 29.0±1.0 g C/L/hr at station CB7.4 to 450±1.4 g C/L/hr at station CB6.4.

3. Benthic Communities

Status in benthic communities at the fixed point stations was severely degraded at station CB5.4 in segment CB5MH and marginal at station CB6.1 in segment CB6PH but good at all remaining stations in the Virginia Chesapeake Bay Mainstem. There were no trends in the B-IBI at any Mainstem stations (Figure 45) and relatively few trends in any of the individual benthic bioindicators (Appendix F - Section E). Probability-based benthic monitoring results for 2008 indicated that only 16% of the total area of the Virginia Chesapeake Bay Mainstem was impaired (Table 6). There was no discernable pattern with respect to the location of degraded random sites in the Virginia Chesapeake Bay Mainstem (Figure 4) .

4. Management Issues

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

With respect to living resources, the Virginia Chesapeake Bay Mainstem was probably the least impacted of all of the basins examined in this report. Phytoplankton community status, as measured using the P-IBI was Fair at all stations. However, there are some indications that phytoplankton communities may be degrading as indicated by the decreasing trends in diatom and chlorophyte biomass, as well as the increasing trends in productivity and cyanobacteria abundance found at several stations. Algal blooms originating within the tributaries have frequently extended into the lower Chesapeake Bay, even reaching the Virginia Beach coastal waters, but these are generally short-lived. However, the lower Chesapeake Bay provides the entrance pathway via sub-pycnocline waters to transport potentially harmful species into the Bay from the Atlantic coastal waters, and be conveyed to inlets and tributaries within the Bay. An example of an invasive species that has been noted in our recent monitoring is *Alexandrium monilatum* and its presences in the York River and lower Bay (Marshall and Egerton,2009a). Such taxa may be introduced in various ways (e.g. ballast water) and some find regional environmental conditions suitable for their existence. The existing environmental conditions may also be suitable for other invasive taxa (some harmless, other potentially harmful) to enter and become permanent residents. The monitoring program will provide an important alert system to the presence and significance of the potentially harmful algal species. Benthic communities in the Mainstem generally met living resource goals at fixed point stations, although no trends were observed for the B-IBI, and areal estimates using probability-based sampling indicate that only 16% of the total area of Virginia Chesapeake Bay Mainstem failed to meet benthic restoration goals.

V. Conclusions

A. Regional Patterns

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

- Total loads of nitrogen, phosphorus, and total suspended solids have fluctuated substantially but neither increased or decline over time in most tributaries with the exception of the James River where long-term improving trends were observed for all three parameters.
- NPS nutrient loads were generally higher than PS loads (Appendix H).
- PS nutrient loads tended to be higher below than above the fall-line (Appendix H).
- Status with respect to water quality was generally marginal or poor in much of the Virginia Mainstem and its tributaries.
- Status of water clarity was poor in nearly all segments of the Virginia Mainstem and tributaries with no apparently consistent explanation.
- Status of water quality and living resources was generally better in the Mainstem and James River than in the other tributaries.
- Water quality trend results indicated:
    - generally improving nutrient concentrations,
    - degrading trends in water clarity, and
    - few changes in either chlorophyll *a* or dissolved oxygen.
- Living resource trend results indicated:
    - no changes in the P-IBI coupled with degrading trends in diatoms, chlorophytes, diversity, cyanobacteria and/or phytoplankton productivity, and
    - some but very few improvements in the B-IBI.

- Lack of response in phytoplankton communities may be related to nutrient concentrations that are generally higher than “saturation” levels along with other factors (e.g. reduced oyster and menhaden populations).

- Algal blooms continue to be common occurrences in the lower segments of the Chesapeake Bay, its tributaries, and their associated inlets and sub-estuaries (e.g. Sarah's creek, the Lafayette and Elizabeth rivers, etc.). There are indications of increased duration and expansion of bloom events at some locations.

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

B. Basin Specific Patterns

- The James River was characterized by:

    - improving trends in nutrients above the fall-line and in tidal freshwater segments,
    - limited improvements and some degrading trends in water quality downstream, and
    - stable but mostly degraded living resource communities throughout its tidal areas.
    - well developed blooms in the lower segments and associated inlets.

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

- The York River exhibited poor water quality status, degrading trends in nutrients, total suspended solids and water clarity and had generally poor living resources that show some limited improvements.

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

- The Virginia Chesapeake Bay Mainstem was characterized by:

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

VI. Literature Cited

Alden, R.W. III., R.S. Birdsong, D.M. Dauer, H.G. Marshall and R.M. Ewing. 1992a. Virginia Chesapeake Bay water quality and living resources monitoring programs: Comprehensive technical report, 1985-1989. Applied Marine Research Laboratory Technical Report No. 848, Norfolk VA. Final Report to the Virginia State Water Control Board, Richmond, Virginia. pp. 366.

Alden, R.W. III, D.M. Dauer, H.G. Marshall, and S.W. Sokolowski. 1996. Long-term trends in the lower Chesapeake Bay (1985-1992). Virginia Department of Environmental Quality. AMRL Technical Report No. 966, 57 pp.

Alden, R.W. III, D.M. Dauer, J.A. Ranasinghe, L.C. Scott, and R.J. Llansó. 2002. Statistical verification of the Chesapeake Bay Benthic Index of Biotic Integrity. *Environmetrics*13: 473- 498.

Alden, R.W. III., R.M. Ewing, S.W. Sokolowski, J.C. Seibel. 1991. Long-term trends in water quality of the Lower Chesapeake Bay. p. 502-522, In: New Perspectives in the Chesapeake System: A Research and Management Partnership. Proceedings of a Conference. Chesapeake Research Consortium Publication No. 137, Solomons, MD., pp. 780.

Alden, R.W. III, S.B. Weisberg, J.A. Ranasinghe and D.M. Dauer. 1997. Optimizing temporal sampling strategies for benthic environmental monitoring programs. *Marine Pollution Bulletin* 34: 913-922.

Buchanan, C., R. Lacouture, H.G. Marshall, M. Olson, and J. Johnson. 2005. Phytoplankton reference communities for Chesapeake Bay and its tidal tributaries. Estuaries, 28(1):138-159.

Carpenter, K.E. and M.F. Lane. 1998. Zooplankton Status and Trends in the Virginia Tributaries and Chesapeake Bay: 1985-1996. AMRL Technical Report No. 3064. Final Report to the Virginia Department of Environmental Quality, Richmond, Virginia. Applied Marine Research Laboratory, Norfolk VA., pp. 28.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Mar. Pollut. Bull.* 26: 249-257.

Dauer, D.M. 1997. Virginia Chesapeake Bay Monitoring Program. Benthic Communities Report. 1985-1996. Final Report to the Virginia Department of Environmental Quality, pp. 92.

Dauer, D.M., M. F. Lane, H.G. Marshall, and K.E. Carpenter. 1998a. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: 1985-1997. Final report to the Virginia Department of Environmental Quality, pp. 86.

Dauer, D.M., M. F. Lane, H.G. Marshall, K.E. Carpenter and R.J. Diaz. 1999. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: 1985-1998. Final report to the Virginia Department of Environmental Quality. 65 pages.

Dauer, D.M., M. F. Lane, H.G. Marshall, K.E. Carpenter and J.R. Donat. 2002. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: 1985-2000. Final report to the Virginia Department of Environmental Quality. 149 pp.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, M.F. Lane, R.W. Alden III, K.K. Nesius and L.W. Haas. 1998b. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs: Executive Report, 1985-1996. Final Report to the Virginia Department of Environmental Quality, Richmond, Virginia. Applied Marine Research Laboratory, Norfolk VA., pp. 28.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat and M. F. Lane. 2003a. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2001). Final report to the Virginia Department of Environmental Quality. 108 pp.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat and M. F. Lane. 2003b. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: York River (1985-2001). Final report to the Virginia Department of Environmental Quality. 95 pp.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat and M. F. Lane. 2003c. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: Rappahannock River (1985-2001). Final report to the Virginia Department of Environmental Quality. 80 pp.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat, M. F. Lane, S. Doughten and F.J. Hoffman. 2003d. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2002). Final report to the Virginia Department of Environmental Quality. 94 pp.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat, M. F. Lane, S. Doughten and F.J. Hoffman. 2003e. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: York River (1985-2002). Final report to the Virginia Department of Environmental Quality. 75 pp.

Dauer, D.M., H.G. Marshall, K.E. Carpenter, J.R. Donat, M. F. Lane, S. Doughten and F.J. Hoffman. 2003f. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: Rappahannock River (1985-2002). Final report to the Virginia Department of Environmental Quality. 60 pp.

Dauer, D.M. H.G. Marshall, J.R. Donat, M.F.Lane, S.C.Doughten,P.L. Morton, and F.A. Hoffman, 2005a. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2004).Final Report to the Virginia Department of Environmental Quality, Richmond, Virginia. Applied Marine Research Laboratory, Norfolk VA., pp. 73.

Dauer, D.M. H.G. Marshall, J.R. Donat, M.F.Lane, S.C.Doughten, P.L. Morton, and F.A. Hoffman, 2005b. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: York River (1985-2004).Final Report to the Virginia Department of Environmental Quality, Richmond, Virginia. Applied Marine Research Laboratory, Norfolk VA., pp. 63.

Dauer, D.M., H.G. Marshall, J.R. Donat, M.F.Lane, S.C.Doughten, P.L. Morton, and F.A. Hoffman, 2005c. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: Rappahannock River (1985-2004). Final Report to the Virginia Department of Environmental Quality, Richmond, Virginia. Applied Marine Research Laboratory, Norfolk VA., pp. 66.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, P.L. Morton and F.J. Hoffman. 2005d. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: James River (1985-2004). Final report to the Virginia Department of Environmental Quality. 73 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, P.L. Morton and F.J. Hoffman. 2005e. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: York River (1985-2004). Final report to the Virginia Department of Environmental Quality. 63 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, P.L. Morton and F.J. Hoffman. 2005f. Status and trends in water quality and living resources in the Virginia Chesapeake Bay: Rappahannock River (1985-2004). Final report to the Virginia Department of Environmental Quality. 66 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, and F.J. Hoffman. 2007a. An update of current status and long-term trends in water quality and living resources in the Virginia tributaries from 1985 through 2005. Final report to the Virginia Department of Environmental Quality. 46 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, and F.J. Hoffman. 2007b. An update of current status and long-term trends in water quality and living resources in the Virginia tributaries from 1985 through 2006. Final report to the Virginia Department of Environmental Quality. 47 pp.

Dauer, D.M., H.G. Marshall, J.R. Donat, M. F. Lane, S. Doughten, and F.J. Hoffman. 2008. An update of current status and long-term trends in water quality and living resources in the Virginia tributaries from 1985 through 2007. Final report to the Virginia Department of Environmental Quality. 57 pp.

Dellapenna, T.M., S.A. Kuehl and L. C. Schaffner. 1998. Sea-bed mixing and particle residence times in biologically and physically dominated estuarine systems: a comparison of lower Chesapeake Bay and the York River subestuary *Estuar. Coast. Shelf Sci.* 46:777-795

Dellapenna, T.M., S.A. Kuehl, L.C. Schaffner. 2003. Ephemeral deposition, seabed mixing and fine-scale strata formation in the York River estuary, Chesapeake Bay. *Estuar. Coast. Shelf Sci.* 58:621-643.

Gilbert, R.O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold Co., New York, pp. 320.

Lacouture, R.V. J.M. Johnson, C. Buchanan, and H.G. Marshall, 2006. Phytoplankton index of biotic integrity for Chesapeake Bay and its tidal tributaries. Estuaries and Coasts 29:598-616.

Lane, M.F., R.W. Alden III, and A.W. Messing. 1998. Water Quality Status and Trends in the Virginia Tributaries and Chesapeake Bay: 1985-1996. AMRL Technical Report No. 3067. Final Report to the Virginia Department of Environmental Quality, Richmond, Virginia. Applied Marine Research Laboratory, Norfolk VA., pp. 116.

Langland, M.J., J.P. Raffensperger, D.L. Moyer, J.M. Landwehr, and G.E. Schwarz, 2006, Changes in streamflow and water quality in selected nontidal basins in the Chesapeake. U.S. Geological Survey Scientific Investigations Report 2006-5178, 75 p., plus appendixes (on CD).

Llansó, R.J., J. Vølstad, and D. M. Dauer. 2005. 2006 303(d) Assessment methods for Chesapeake Bay benthos. Final Report to the Virginia Department of Environmental Quality, Chesapeake Bay Program. pp. 32.

Llansó R.J., J. Dew, and L.C. Scott, 2007. Chesapeake Bay Water Quality Monitoring Program Long-term Benthic Monitoring and Assessment Component Level 1 Comprehensive Report July 1984-December 2006 (Volume 1), Final Report to the Maryland Department of Natural Resources, Annapolis, MD. Versar Inc. Columbia, MD. pp. 100.

Marshall, H.G. 1994. Chesapeake Bay phytoplankton: I. Composition. *Proc. Biological Soc. Washington*, 107:573-585.

Marshall, H.G. 1996. Toxin producing phytoplankton in Chesapeake Bay. *Virginia J. Science*, 47:29-37.
Marshall, H.G. 2009. Phytoplankton of the York River. Journal of Coastal Research, Sp. Issue No. 37, The Chesapeake Bay NEER in Virginia: A profile of the York River Ecosystem. Pp.59-65.

Marshall, H.G. and L. Burchardt. 1998. Phytoplankton composition within the tidal freshwater region of the James River, Virginia. *Proc. Biol Soc. Wash.* 111:720-730.

Marshall, H.G. and L. Burchardt. 2003. Characteristic seasonal phytoplankton relationships in tidal freshwater/oligohaline regions of two Virginia (U.S.A.) rivers. In: Algae and the Biological State of Water, *Acta Botanica Warmiae et Masuriae* 3:71-78.

Marshall, H.G. and L. Burchardt. 2004a. Monitoring phytoplankton populations and water quality parameters in estuarine rivers of Chesapeake Bay, U.S.A. *Oceanological and Hydrobiological Studies*, 33:55-64.

Marshall, H.G. and L. Burchardt. 2004b. Phytoplankton composition within the tidal freshwater-oligohaline regions of the Rappahannock and Pamunkey Rivers in Viginia. *Castanea* 69:272-283.

Marshall, H.G. and L. Burchardt. 2005. Phytoplankton development within tidal freshwater regions of two Virginia rivers, U.S.A. Virginia J. Science, 56:67-81.

Marshall, H.G., L. Burchardt, and R. Lacouture. 2005a. A review of phytoplankton composition within Chesapeake Bay and its tidal estuaries. J. Plankton Research. 27:1083-1102.

Marshall, H.G., L. Burchardt, T. Egerton, K. Stefaniak, and M. Lane. 2008b. Potentially toxic cyanobacteria in Chesapeake Bay estuaries and a Virginia lake. In: H. Hudnell (ed.) Cyanobacterial harmful algal blooms, State of the Science and Research needs. Springer Science Publ. N.Y., pp. 172-174..

Marshall, H.G. and T.A. Egerton. 2009a. Phytoplankton blooms: Their occurrence and composition within Virginia's tidal tributaries. Virginia Journal of Science, 60(3):149-164.

Marshall, H.G. and T.A. Egerton. 2009b. Increasing occurrence and development of potentially harmful algal blooms in Virginia tidal rivers. Conference Proceedings: Water Resources in Changing Climates. Virginia Tech Water Research Conference, Richmond, VA. Pp.89-101.

Marshall, H.G., T.A. Egerton, L. Burchardt, S. Cerbin, and M. Kokocinski. 2005b. Long term monitoring results of harmful algal populations in Chesapeake Bay and its major tributaries in Virginia, U.S.A. *Oceanological and Hydrobiological Studies*, 34(suppl. 3):35-41.

Marshall, H.G., R. Lacouture, C. Buchanan, and J. Johnson. 2006. Phytoplankton assemblages. associated with water quality and salinity regions in Chesapeake Bay, U.S.A. Estuarine, Coastal, and Shelf Science, 69:10-18.

Marshall, H.G., M.F. Lane, K. Nesius, and L. Burchardt. 2009. Assessment and significance of phytoplankton species composition within Chesapeake Bay and Virginia tributaries through a long-term monitoring program. Environment Monitoring and Assessment. 150:143-155.

Nesius, K.K. H.G. Marshall, and T.A. Egerton. 2007. Phytoplankton productivity in the tidal regions of four Chesapeake Bay (U.S.A.) tidal tributaries. Virginia Journal of Science, 58(4):191-2004.

Officer, C.B., R.B. Biggs, J.L. Taft, L.E. Cronin, M.A. Tyler, and W.R. Boynton, 1984. Chesapeake Bay anoxia: Origin, development and significance. Science 223:22-27.

Orth, R.J. and K.A. Moore, 1984. Distribution and Abundance of Submerged Aquatic Vegetation in Chesapeake Bay:An Historical Perspective. Estuaries. 7:531-540.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz and J.B. Frithsen. 1994. Chesapeake Bay benthic community restoration goals. Report for the U.S. Environmental Protection Agency, Chesapeake Bay Office and the Maryland Department of Natural Resources, pp. 49.

USEPA, 1982. Chesapeake Bay Program Technical Studies: A Synthesis. U.S. Environmental Protection Administration, Washington,D.C. Publ. No. 903R82100, pp. 635.

USEPA, 1983 Chesapeake Bay Program: Findings and Recommendations. U.S. Environmental Protection Agency, Region 3, Philadephia, PA. Publ. No.903R83100 pp. 48.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries.* 20: 149-158.

Williams M., B. Longstaff, C. Buchanan, R. Llansó, and W. Dennison, 2009. Development and evaluation of a spatially-explicit index of Chesapeake Bay health. Marine Pollution Bulletin 59:14-25.

Tables

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

A. Total Chesapeake Bay and Virginia Watersheds

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

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

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

Table 2. Long-term trends in USGS estimates of above-fall line total loads of nitrogen, phosphorus, and total suspended solids, in the Virginia tributaries for the period of 1985 through 2009. Units for the slope and baseline medians are in lb/month.

River	Parameter	P value	Slope	Baseline Mean	% Change	Direction	Homogeneity test P value
Appomattox River	TN Load	0.0162	-596	58963	-29.31	No Trend	0.7988
Appomattox River	TP Load	0.4984	-9	3774	-7.00	No Trend	0.6804
Appomattox River	TSS Load	0.0087	-13192	1623705	-17.06	Decreasing	0.5515
James River	TN Load	0.0001	-7685	493097	-45.20	Decreasing	0.6848
James River	TP Load	0.0000	-2838	95681	-86.01	Decreasing	0.2691
James River	TSS Load	0.0034	-407818	74990238	-11.42	Decreasing	0.7846
Pamunkey River	TN Load	0.1031	-362	52693	-19.90	No Trend	0.8668
Pamunkey River	TP Load	0.1176	41	4336	27.38	No Trend	0.6687
Pamunkey River	TSS Load	0.6463	-3307	4445732	-1.56	No Trend	0.7215
Mattaponi River	TN Load	0.4104	-97	26961	-10.44	No Trend	0.9289
Mattaponi River	TP Load	0.2984	-12	2084	-17.33	No Trend	0.9303
Mattaponi River	TSS Load	0.2731	-3159	849849	-7.81	No Trend	0.6766
Rappahannock River	TN Load	0.4135	-478	135661	-10.23	No Trend	0.6973
Rappahannock River	TP Load	0.6032	35	6739	15.15	No Trend	0.6558
Rappahannock River	TSS Load	0.0994	-80604	13289465	-12.74	No Trend	0.5062

Table 3. Long-term trends in freshwater flow at USGS fall-line stations in the Virginia tributaries for the period of 1985 through 2009. Note that the flows reported for the York River is for the combined flow values for the Pamunkey and Mattaponi rivers. Units for the slope and baseline medians are in ft^3/sec.

River	P value	Slope	Baseline Mean	% Change	Direction	Homogeneity test P value
James River	0.0279	-27.10	3575.00	-18.95	No Trend	0.9730
Chickahominy River	0.6417	0.31	133.00	5.80	No Trend	0.5078
Appomattox River	0.1416	-3.37	466.00	-18.08	No Trend	0.9068
Mattaponi River	0.2073	-1.63	264.50	-15.43	No Trend	0.9747
Pamunkey River	0.0252	-3.55	341.25	-26.03	No Trend	0.9487
York River	0.0438	-5.32	598.50	-22.24	No Trend	0.9577
Rappahannock River	0.8030	-1.07	680.00	-3.95	No Trend	0.9406
Susquehanna River	0.1362	174.38	24800.00	17.58	No Trend	0.9980

Table 4. Long-term trends in flow-adjusted water quality parameters for the River Input Monitoring and Multi-Agency Monitoring Program non-tidal stations in Virginia portion of the Chesapeake Bay Watershed for 1985 through September, 2009. Map ID #'s in parentheses refer to the station locations identified in Figure 1. Results presented in this table were provided by the U.S. Geological Survey. Units for the slope are in mg/L.

		Flow Adjusted Trend					
Station Name (Map ID #)	Parameter	Kendall τ	P value	LCI	Slope	UCI	Significance
Appomattox River at Matoaca(1)	TN	0.0408	0.3853	-5	4.2	14.2	NS
Appomattox River at Matoaca(1)	DNO23	-0.1689	0.1344	-	-15.5	5.4	NS
Appomattox River at Matoaca(1)	TP	0.2356	0.0023	8.8	26.6	47.2	Degrading
Appomattox River at Matoaca(1)	DIP	-0.2145	0.0226	-	-19.3	-3	Improving
Appomattox River at Matoaca(1)	TSS	0.0547	0.5234	-	5.6	24.9	NS
Chickahominy River near Providence Forge(2)	TN	-0.1635	0.0026	-	-15.1	-5.6	Improving
Chickahominy River near Providence Forge(2)	DNO23	-0.0057	0.9686	-	-0.6	32.2	NS
Chickahominy River near Providence Forge(2)	TP	-0.0962	0.2835	-	-9.2	8.3	NS
Chickahominy River near Providence Forge(2)	TSS	-0.1783	0.2379	-	-16.3	12.5	NS
James River near Richmond(3)	TN	-0.1642	0.0212	-	-15.1	-2.4	Improving
James River near Richmond(3)	DNO23	-0.7873	<0.0001	-	-54.5	-38.5	Improving
James River near Richmond(3)	TP	-0.3076	0.0175	-	-26.5	-5.3	Improving
James River near Richmond(3)	TSS	0.3956	0.0109	9.5	48.5	101.5	Degrading
James River at Cartersville(4)	TN	-0.2001	0.0005	-	-18.1	-8.4	Improving
James River at Cartersville(4)	DNO23	-0.3739	<0.0001	-	-31.2	-17.6	Improving
James River at Cartersville(4)	TP	-0.8955	<0.0001	-66	-59.2	-50.9	Improving
James River at Cartersville(4)	DIP	-1.9520	<0.0001	-	-85.8	-82.7	Improving
James River at Cartersville(4)	TSS	-0.0277	0.8130	-	-2.7	22.4	NS
Pamunkey River near Hanover(5)	TN	0.1515	0.0006	6.7	16.4	26.9	Degrading
Pamunkey River near Hanover(5)	DNO23	0.3147	<0.0001	21	37	55.1	Degrading
Pamunkey River near Hanover(5)	TP	0.6834	<0.0001	69.2	98.1	131.8	Degrading
Pamunkey River near Hanover(5)	DIP	0.4962	<0.0001	39.2	64.2	93.8	Degrading
Pamunkey River near Hanover(5)	TSS	0.6371	<0.0001	44.8	89.1	146.9	Degrading
North Anna River at Hart Corner near Doswell(6)	TN	0.0510	0.3647	-5.8	5.2	17.5	NS
North Anna River at Hart Corner near Doswell(6)	DNO23	-0.2412	0.0046	-	-21.4	-7.2	Improving
North Anna River at Hart Corner near Doswell(6)	TP	0.2882	0.0188	4.9	33.4	69.6	Degrading
North Anna River at Hart Corner near Doswell(6)	TSS	1.1469	<0.0001	93	214.8	413.5	Degrading
Mattaponi River near Beulahville(7)	TN	-0.0148	0.6946	-8.5	-1.5	6.1	NS
Mattaponi River near Beulahville(7)	DNO23	0.0505	0.5738	-	5.2	25.4	NS
Mattaponi River near Beulahville(7)	TP	-0.0800	0.1792	-	-7.7	3.7	NS
Mattaponi River near Beulahville(7)	DIP	-0.4840	<0.0001	-	-38.4	-27.7	Improving
Mattaponi River near Beulahville(7)	TSS	-0.0291	0.7933	-	-2.9	20.8	NS
Rappahannock River near Fredericksburg(8)	TN	-0.0926	0.1655	-20	-8.8	3.9	NS
Rappahannock River near Fredericksburg(8)	DNO23	-0.2170	0.0956	-	-19.5	3.9	NS
Rappahannock River near Fredericksburg(8)	TP	-0.1398	0.1798	-	-13	6.7	NS
Rappahannock River near Fredericksburg(8)	DIP	-0.0799	0.3998	-	-7.7	11.2	NS
Rappahannock River near Fredericksburg(8)	TSS	-0.0883	0.5843	-	-8.5	25.6	NS
Robinson River near Locust Dale(9)	TN	-0.1766	0.0038	-	-16.2	-5.6	Improving
Robinson River near Locust Dale(9)	DNO23	-0.2155	0.0041	-	-19.4	-6.7	Improving
Robinson River near Locust Dale(9)	TP	-0.3756	0.0483	-	-31.3	-0.3	Improving
Robinson River near Locust Dale(9)	TSS	-0.0333	0.8571	-	-3.3	39	NS

Table 5. Descriptive statistics of primary productivity for monitoring stations in the Virginia Mainstem and its tributaries for the period of 1989 through 2009. Values shown are expressed in g C/L/hr.

Station	N	Mean	Standard Error	Standard Deviation	Minimum	Maximum
TF5.5	856	142.72	5.45	159.55	0.03	757.25
RET5.2	844	78.51	2.52	73.16	0.12	482.41
LE5.5	1028	70.38	1.70	54.39	0.00	297.53
SBE5	900	54.77	2.60	77.91	0.32	617.85
TF4.2	864	24.89	1.07	31.31	0.00	303.84
RET4.3	852	67.08	2.43	71.07	0.39	657.03
WE4.2	1004	56.87	1.67	52.90	1.08	379.13
TF3.3	844	116.10	4.88	141.85	1.05	1049.61
RET3.1	844	104.36	4.28	124.27	0.42	875.40
LE3.6	988	47.24	1.47	46.23	0.18	363.36
CB6.1	984	39.51	1.23	38.52	0.00	357.21
CB6.4	996	45.29	1.36	42.80	2.10	413.50
CB7.3E	1000	34.26	0.99	31.35	0.00	237.09
CB7.4	1016	29.06	1.03	32.69	0.00	295.59

Table 6. Estimated tidal area (km^2) failing to meet the Chesapeake Bay Benthic Community Restoration Goals in each of Virginia's four probability-based sampling strata for 2009.

Stratum	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
James River	164	191	109	465	68.00%
York River	67	22	7	97	52.00%
Rappahannock River	119	104	45	268	72.00%
Virginia Bay Mainstem	330	0	330	659	16.00%

Figures

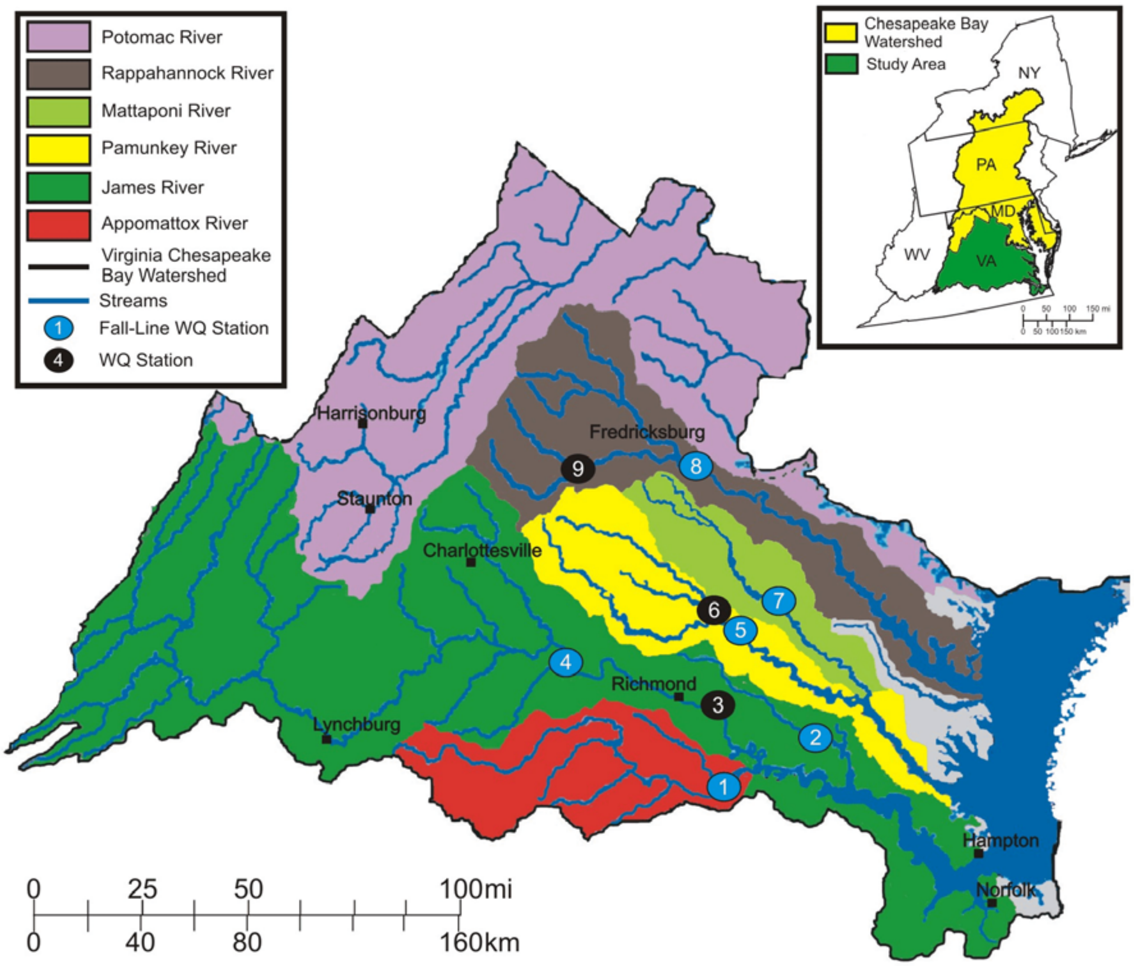


Figure 1. Locations of the USGS/DEQ River Input Monitoring stations in each of the Virginia tributaries.

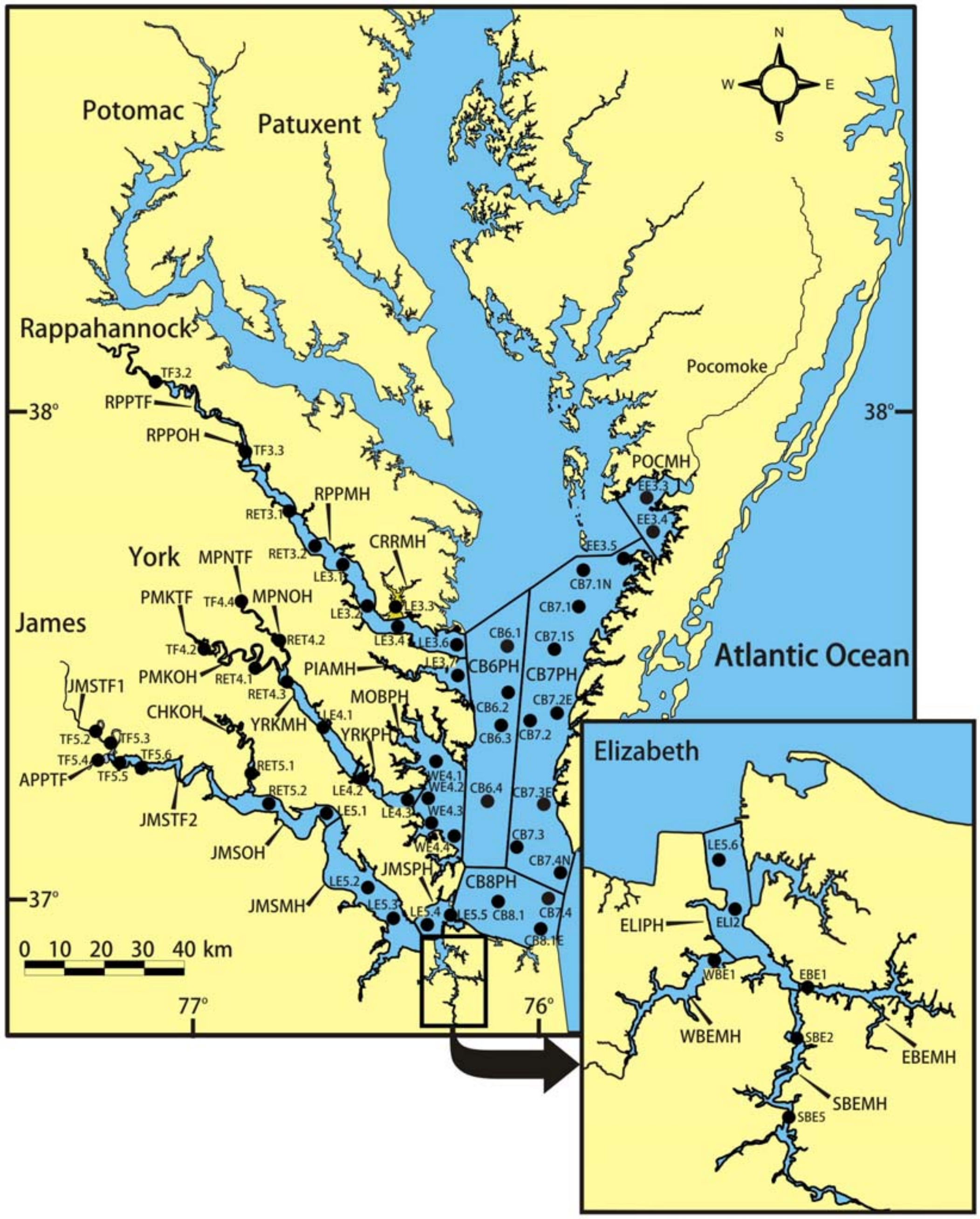


Figure 2. Chesapeake Bay Program segmentation scheme for the Virginia tributaries and Lower Chesapeake Bay Mainstem. Also shown are the locations of stations used in the statistical analyses.

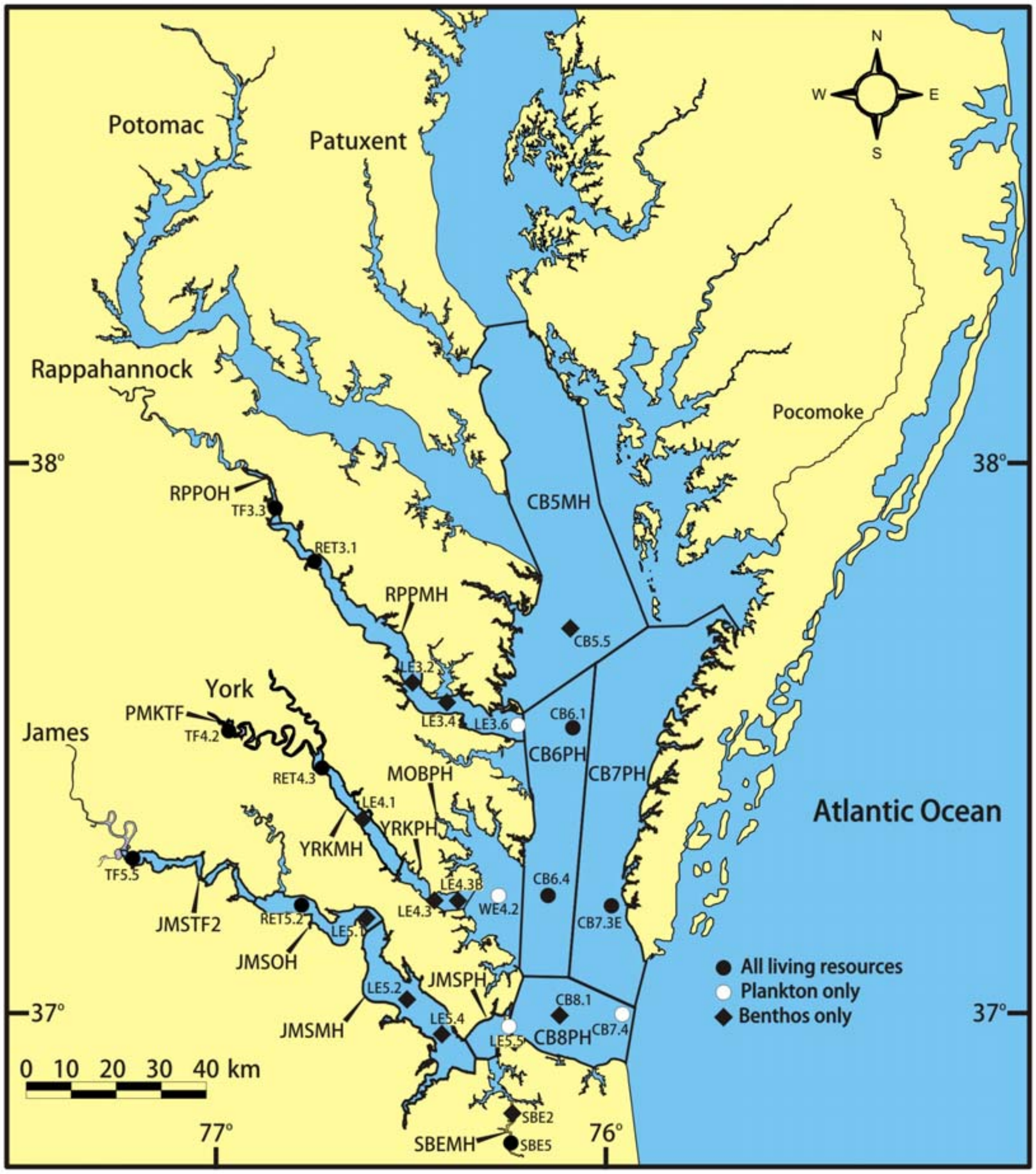


Figure 3. Living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem and their associated CBP segments.

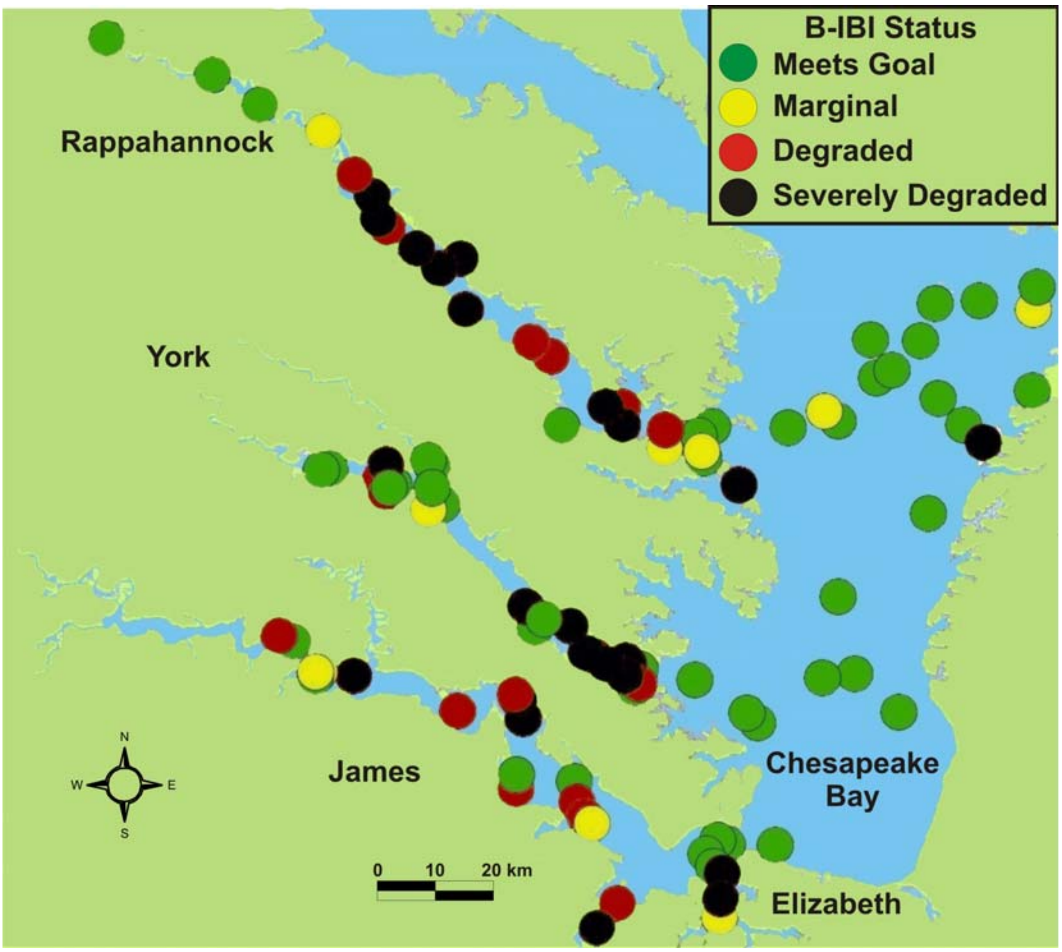


Figure 4. Locations and status based on the B-IBI of the probability-based benthic monitoring stations in Virginia for 2009.

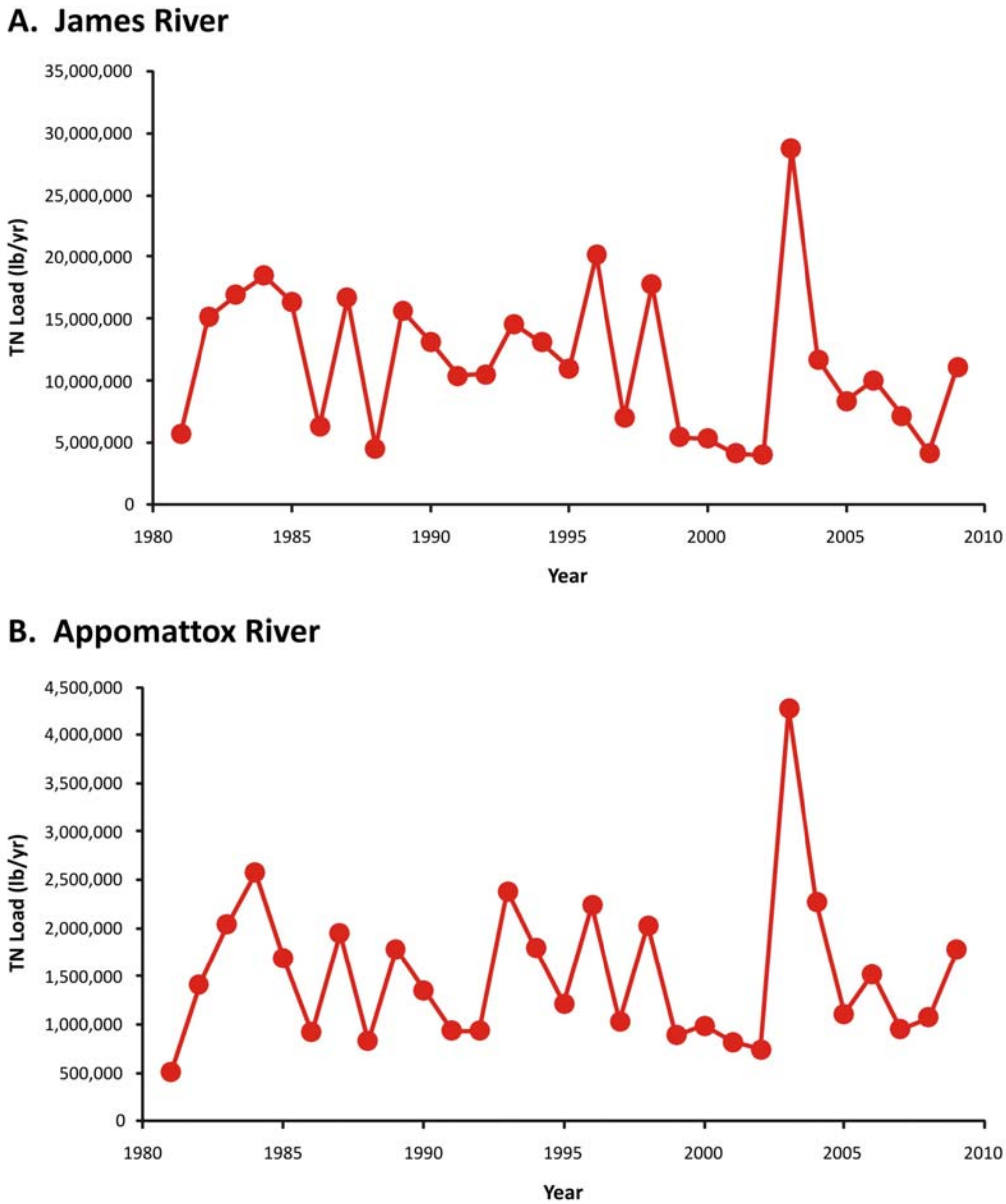


Figure 5. Long-term changes in total nitrogen load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

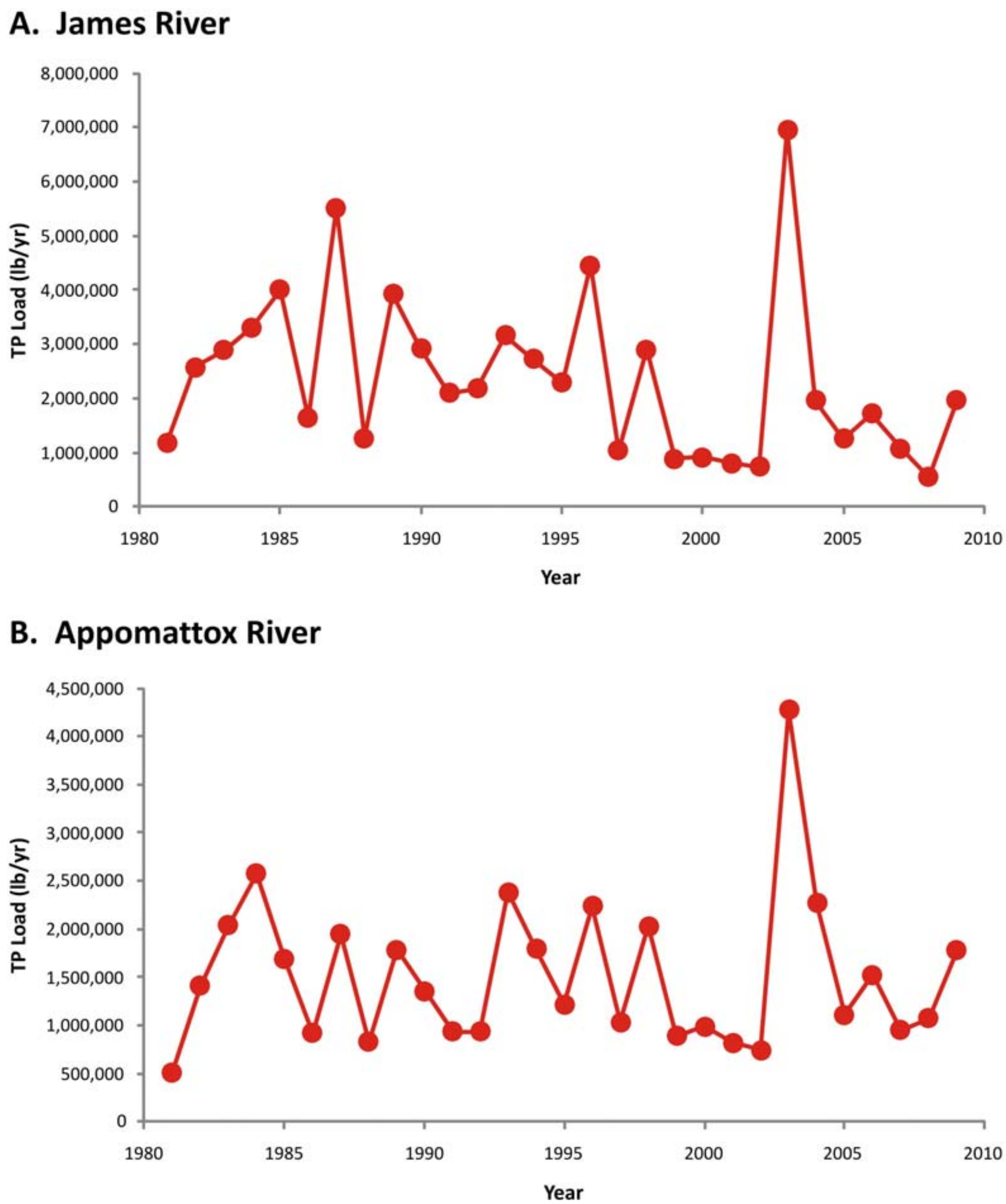
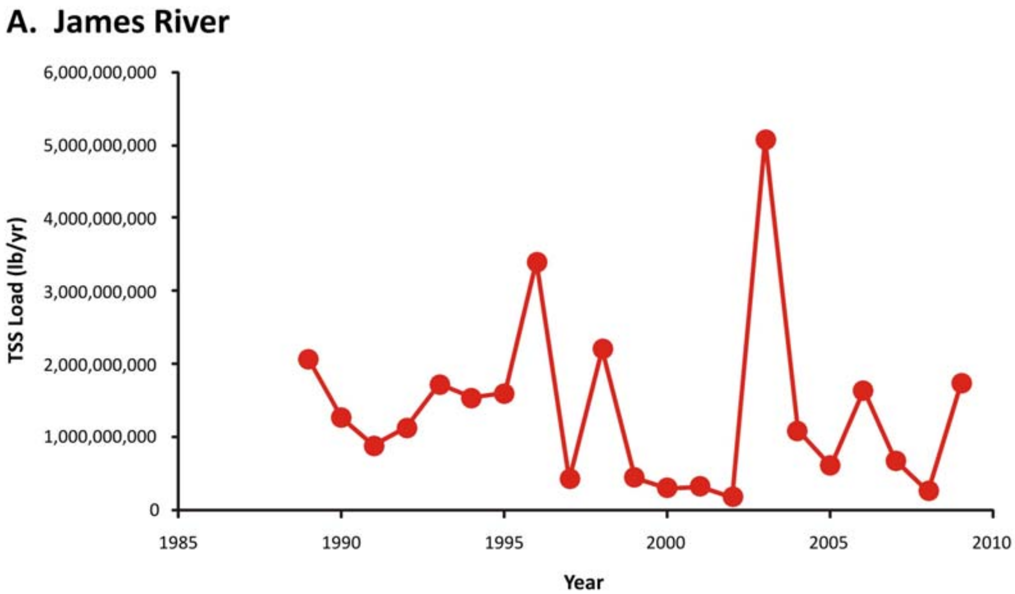


Figure 6. Long-term changes in total phosphorus load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).



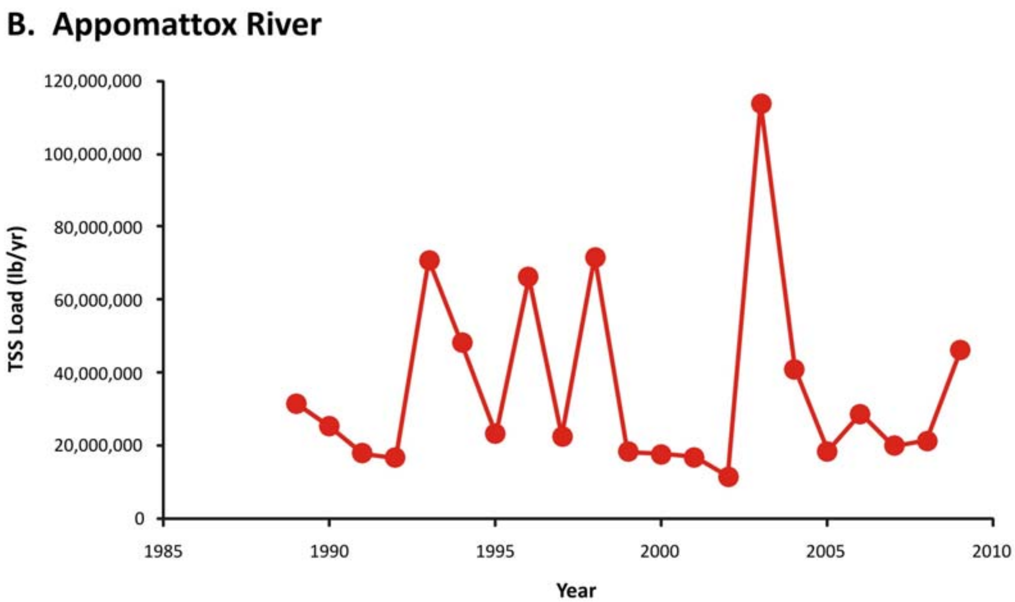
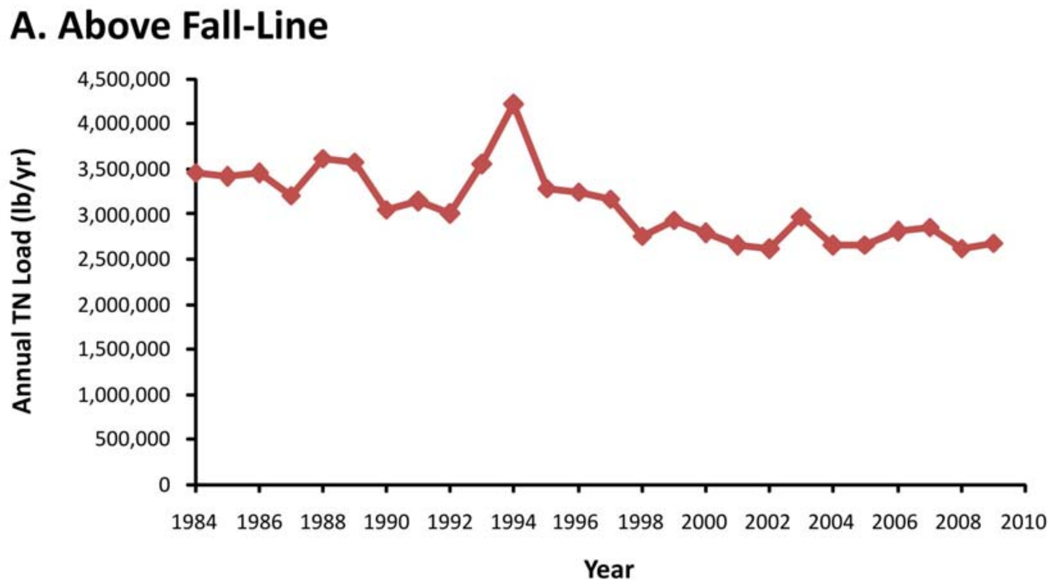


Figure 7. Long-term changes in total suspended solids load above the fall-line in the A. James River, and B. Appomattox River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).



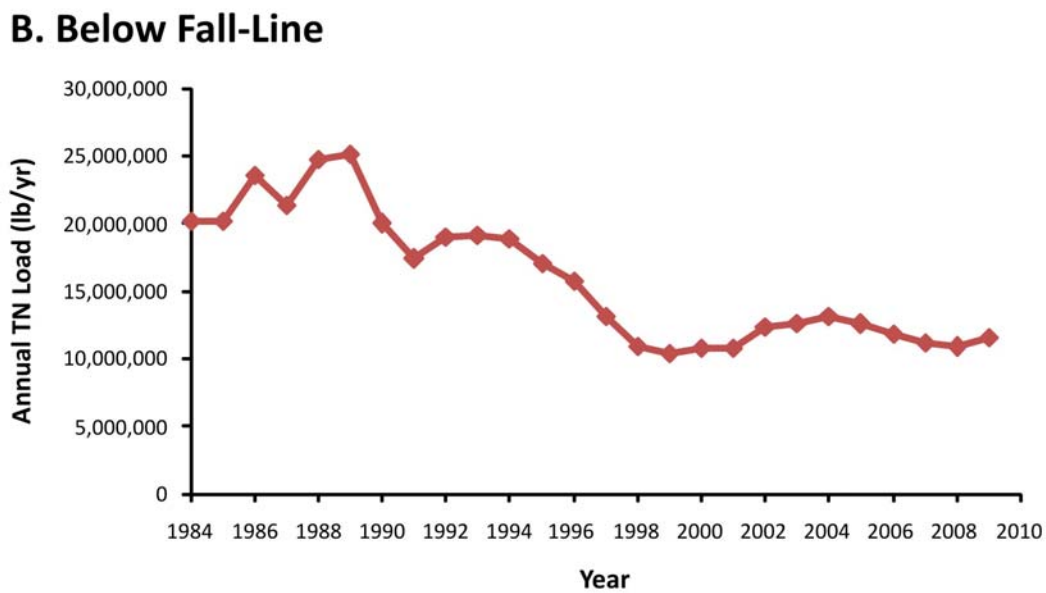


Figure 8. Long-term changes in point source total nitrogen load A. Above the Fall-line, and B. Below the Fall-line in the James River for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system.

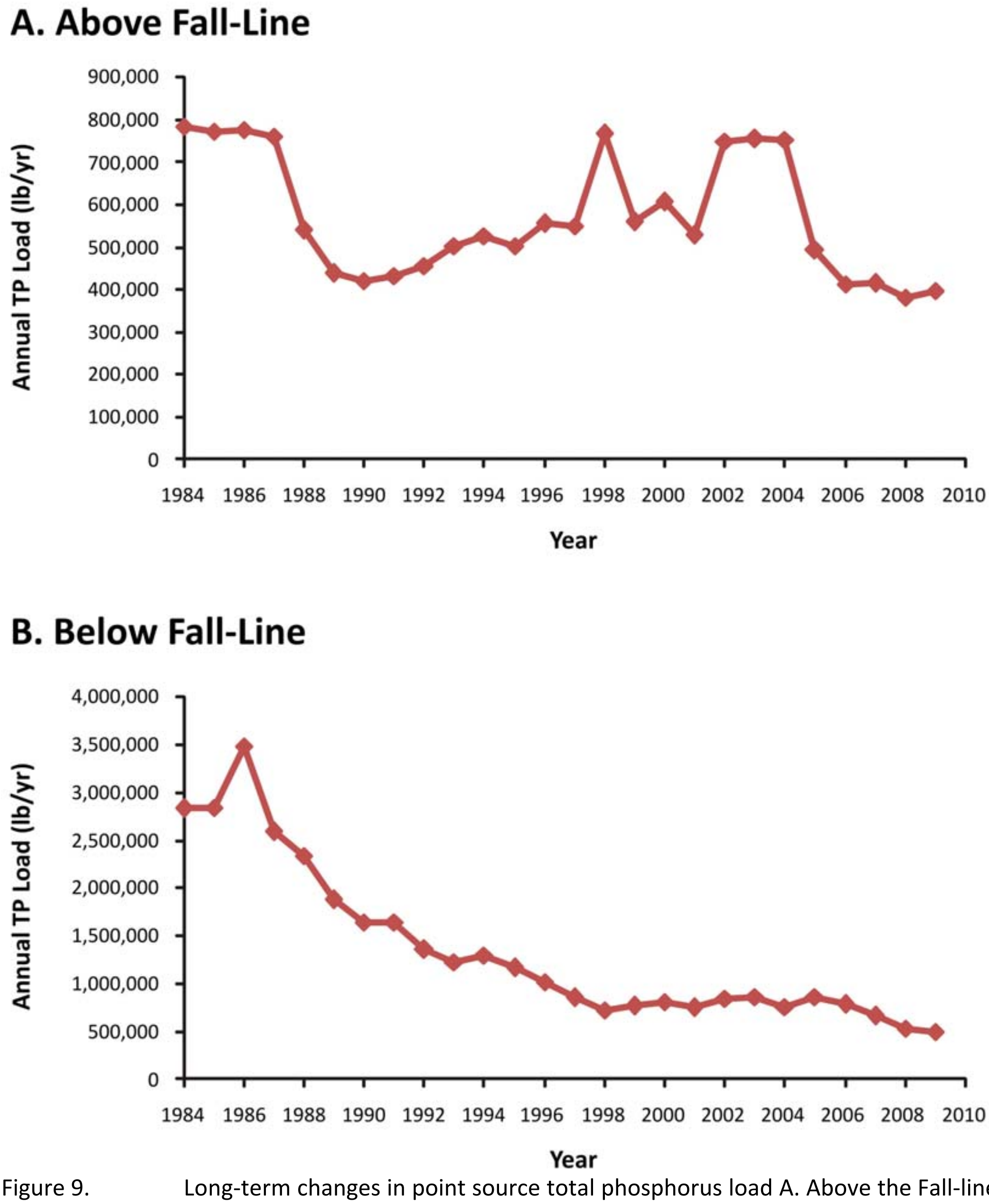


Figure 9. Long-term changes in point source total phosphorus load A. Above the Fall-line, and B. Below the Fall-line in the James River for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system.

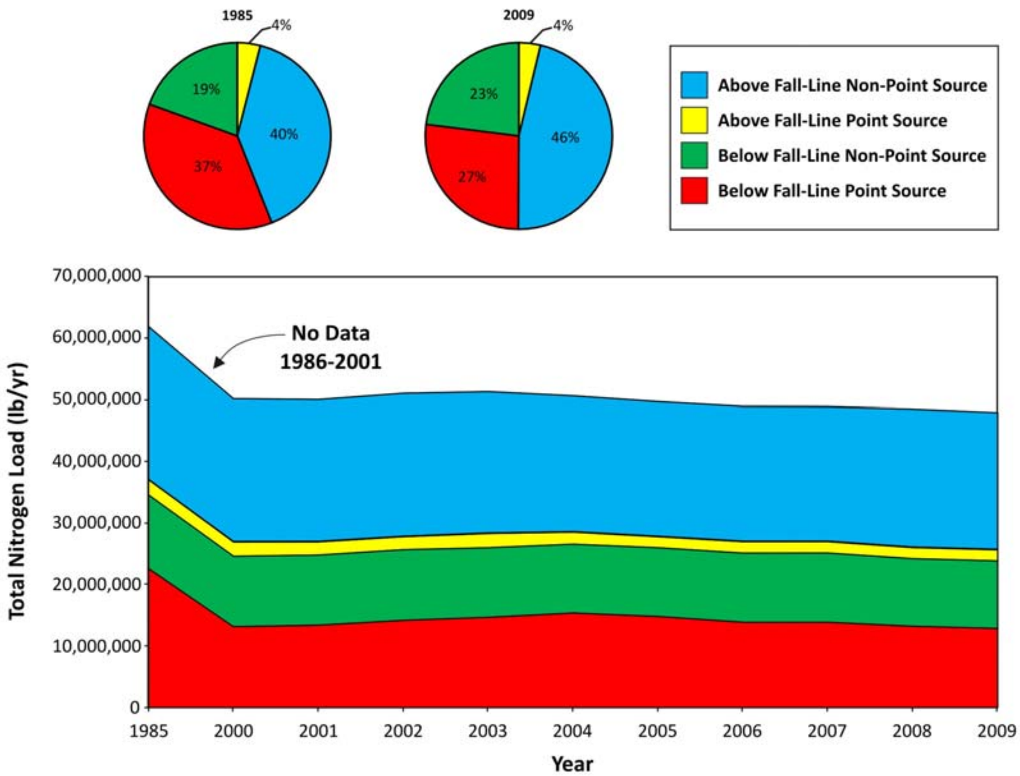


Figure 10. Long-term changes in and relative contribution to total nitrogen load to the James River for point and non-point sources both above and below the fall-line for the period of 1985 through 2009. Loadings presented are estimates produced by the USEPA's Chesapeake Bay Program Watershed Model version 4.3 and may differ in magnitude from estimates from other sources.

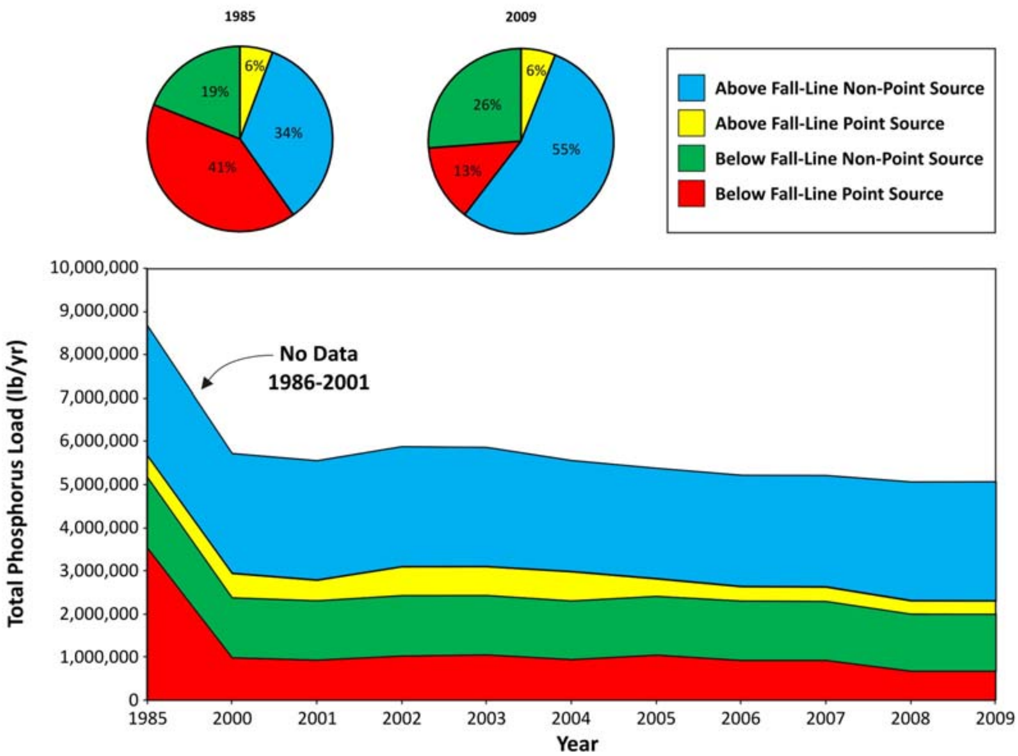


Figure 11. Long-term changes in and relative contribution to total phosphorus load to the James River for point and non-point sources both above and below the fall-line for the period of 1985 through 2009. Loadings presented are estimates produced by the USEPA's Chesapeake Bay Program Watershed Model version 4.3 and may differ in magnitude from estimates from other sources.

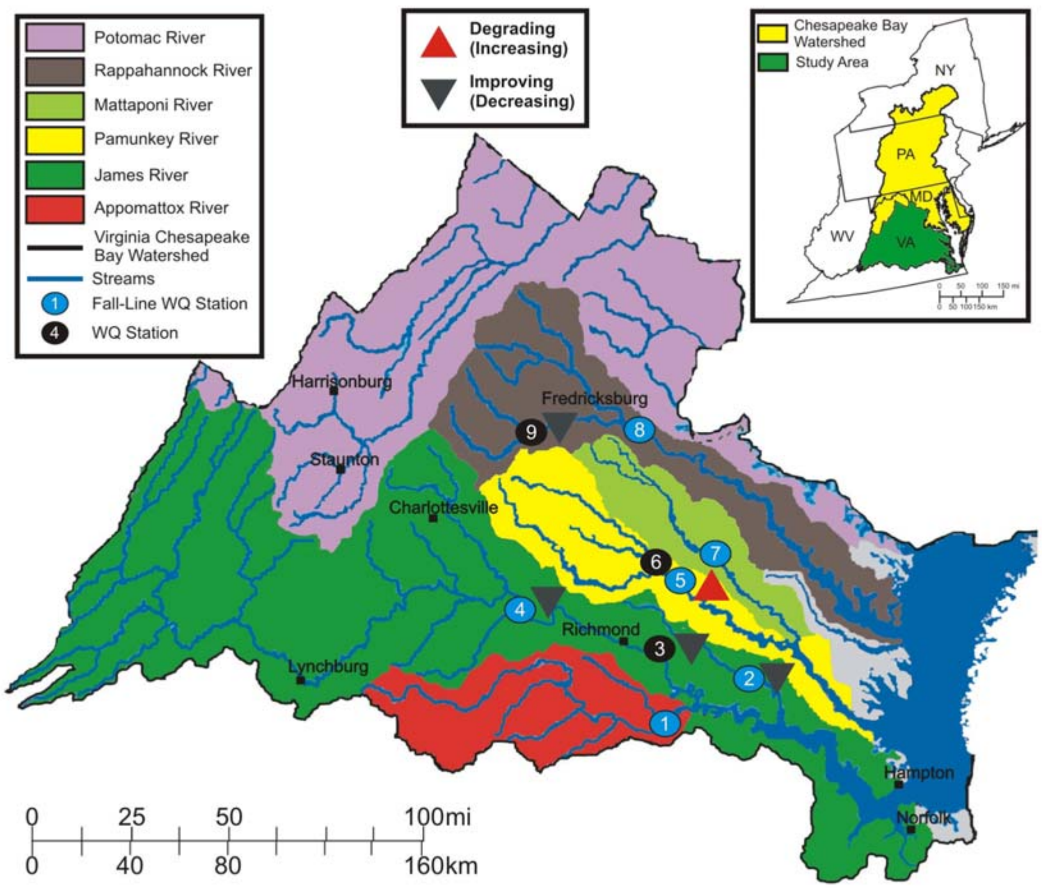


Figure 12. Long-term trends in flow-adjusted total nitrogen at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2009. Arrows indicate trends significant at $P \leq 0.05$.

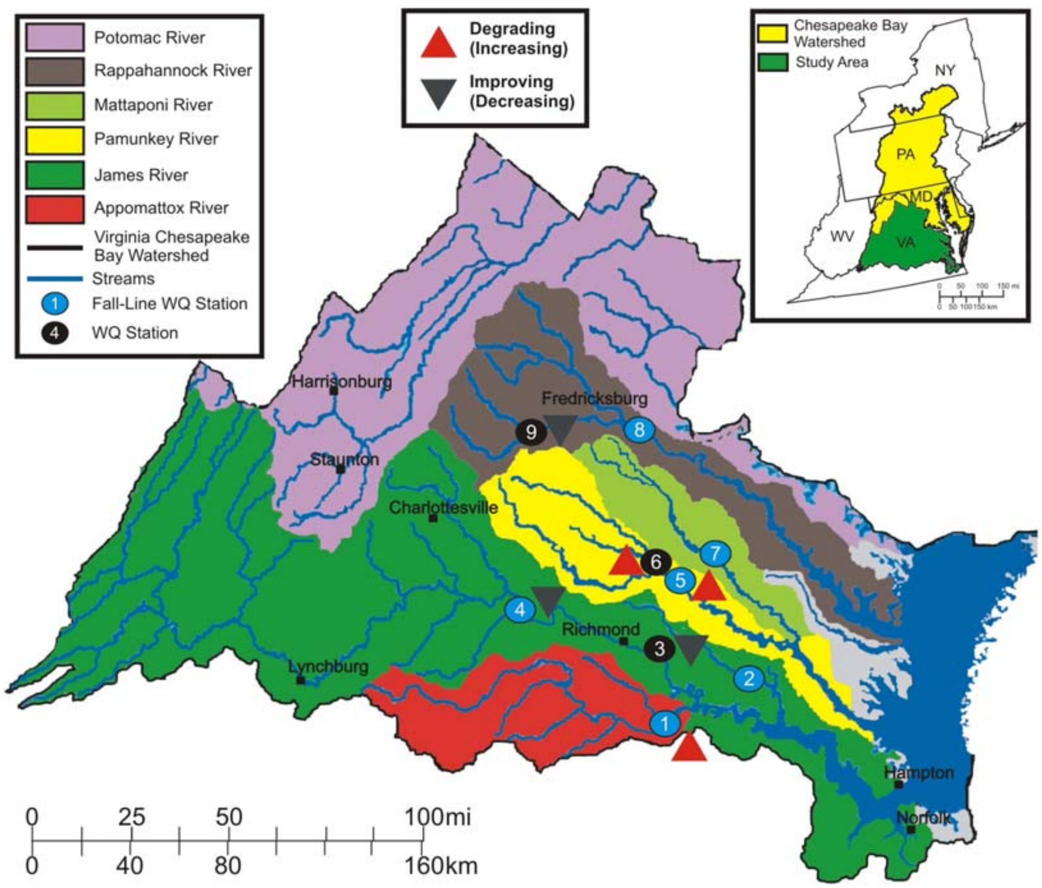


Figure 13. Long-term trends in flow-adjusted total phosphorus at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2009. Arrows indicate trends significant at $P \leq 0.05$.

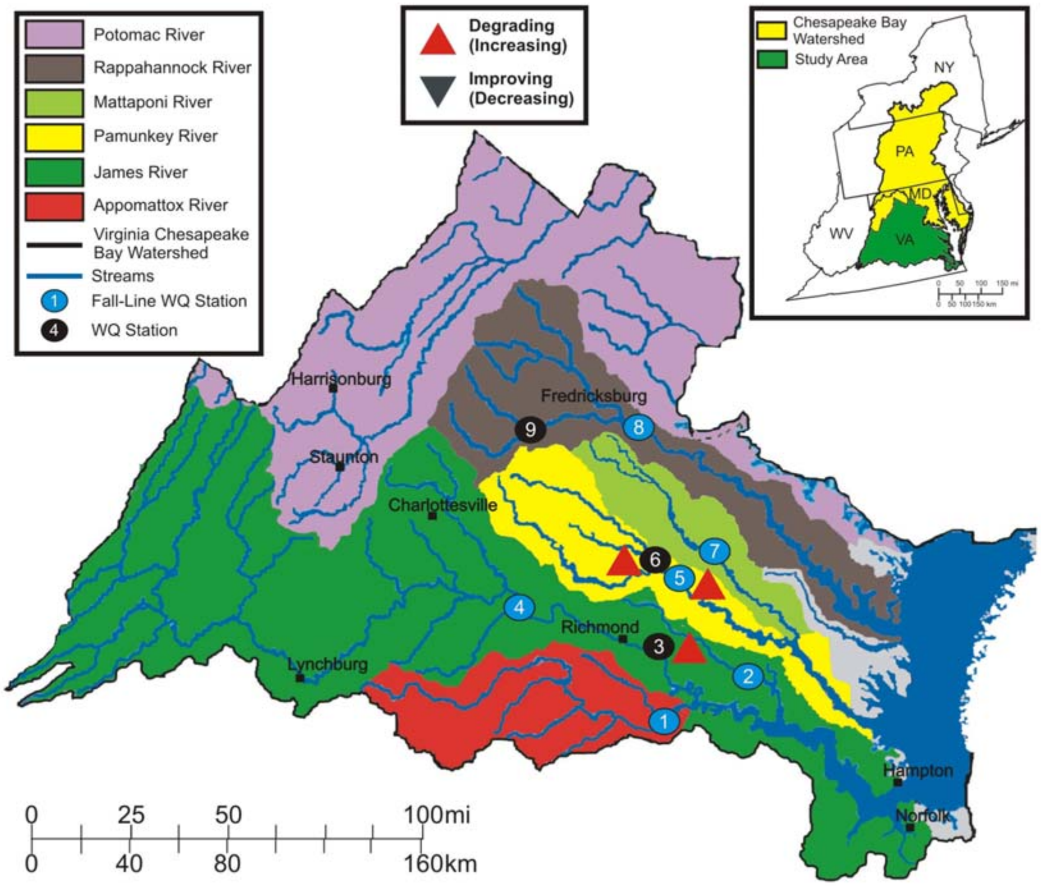


Figure 14. Long-term trends in flow-adjusted total suspended solids at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2009. Arrows indicate trends significant at $P \leq 0.05$.

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

Figure 15. Water quality status and long-term trends in nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant ($P < 0.01$) trends in water quality parameters from the start of monitoring through 2009 or trends significantly only from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2009. 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.

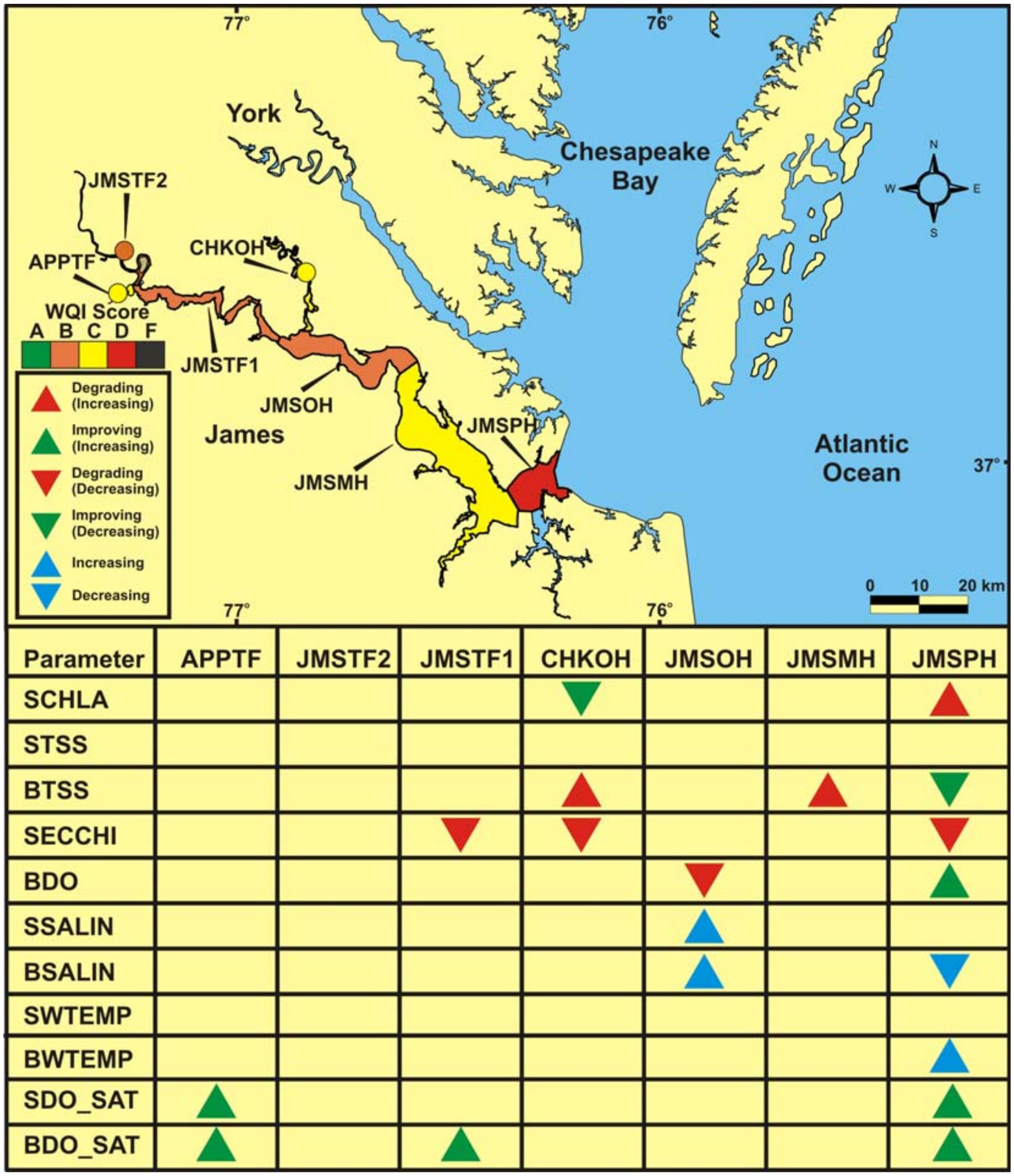
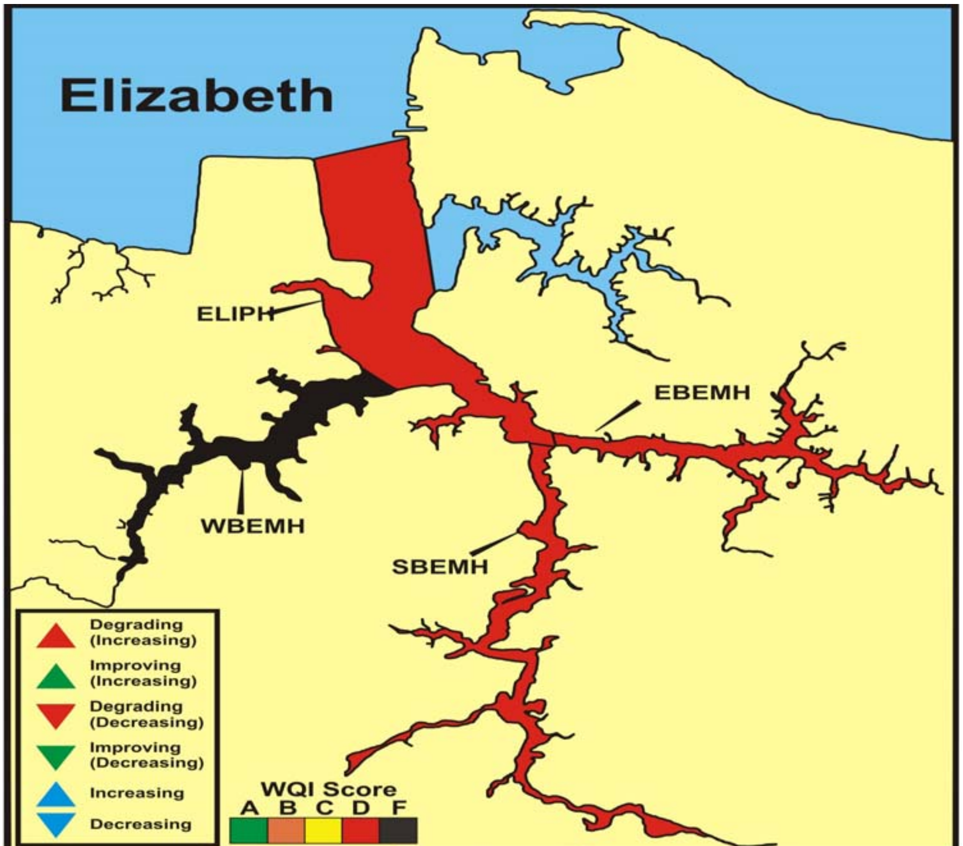


Figure 16. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant ($P < 0.01$) trends in water quality parameters from the start of monitoring through 2009. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

Parameter	WBEMH	SBEMH	EBEMH	ELIPH
STN	▼	▼	▼	▲
BTN	▼	▼	▼	
SDIN		▼	▼	
BDIN		▼	▼	
STP	▼	▼	▼	
BTP	▼	▼	▼	
SDIP				
BDIP		▼	▼	

Figure 17. Water quality status and long-term trends in nutrient parameters in the tidal portion of the Elizabeth River basin for the period of 1989 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant (P < 0.01) trends in water quality parameters from the start of monitoring through 2009. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The prefixes S and B refer to surface and bottom measurements, respectively.



Parameter	WBEMH	SBEMH	EBEMH	ELIPH
SCHLA				
STSS	▼ (Improving, Decreasing)	▼ (Improving, Decreasing)	▼ (Improving, Decreasing)	▼ (Improving, Decreasing)
BTSS	▼ (Improving, Decreasing)	▼ (Improving, Decreasing)	▼ (Improving, Decreasing)	
SECCHI				▼ (Degrading, Decreasing)
BDO		▲ (Improving, Increasing)		
SSALIN		▲ (Increasing)		
BSALIN				
SWTEMP		▲ (Increasing)	▲ (Increasing)	
BWTEMP		▲ (Increasing)	▲ (Increasing)	
SDO_SAT				▲ (Improving, Increasing)
BDO_SAT		▲ (Improving, Increasing)	▲ (Improving, Increasing)	

Figure 18. 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 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant (P < 0.01) trends in water quality parameters from the start of monitoring through 2009. 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.

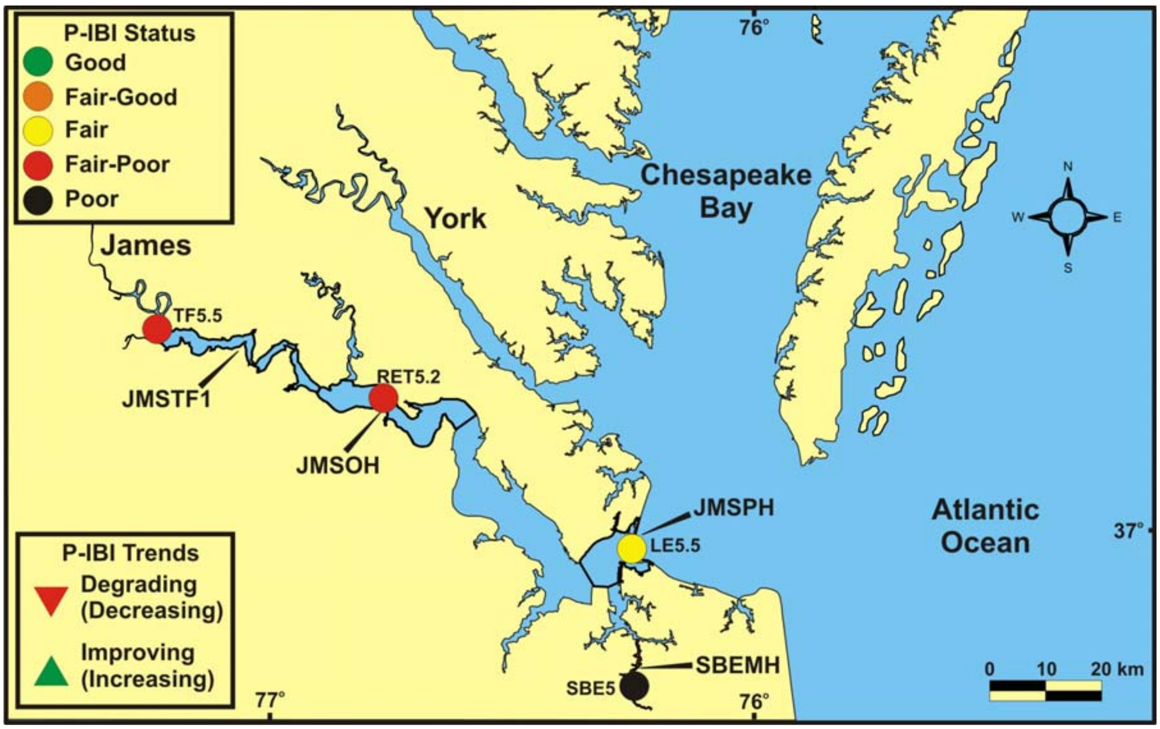


Figure 19. Status and long-term trends in phytoplankton community condition in the tidal portion of the James River basin for the period of 1985 through 2009. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2009.

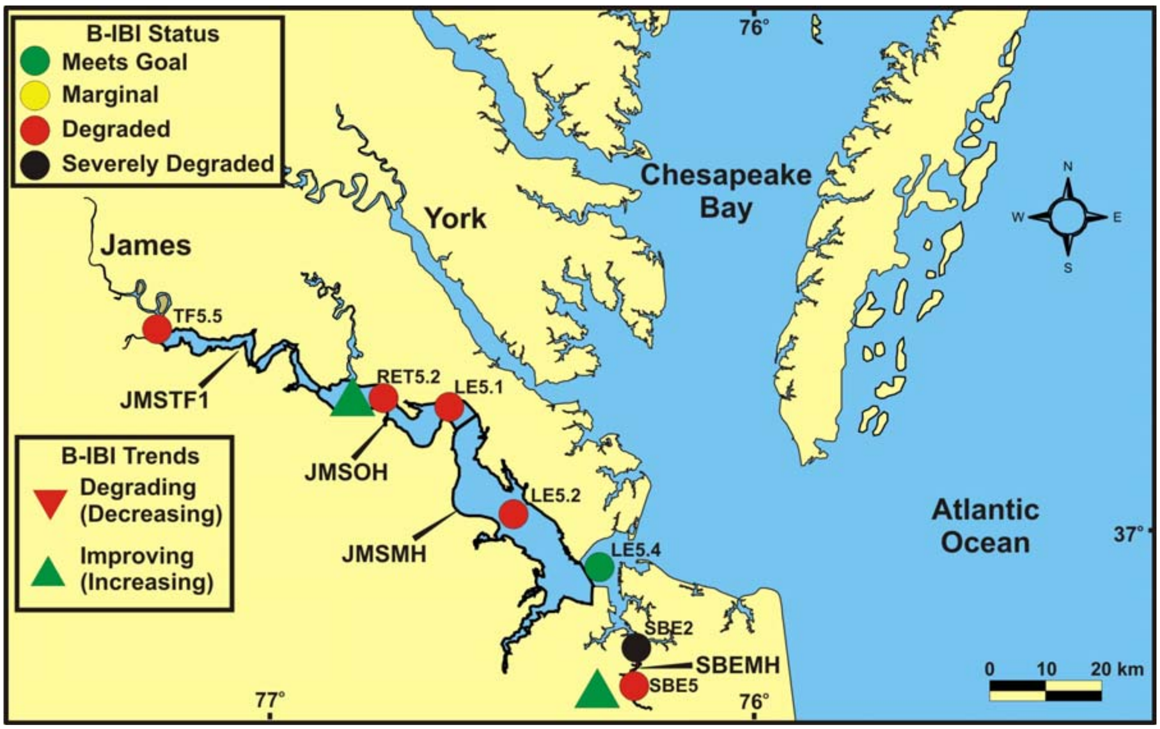


Figure 20. Status and long-term trends in benthic community condition in the tidal portion of the James River basin for the period of 1985 through 2009. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2009.

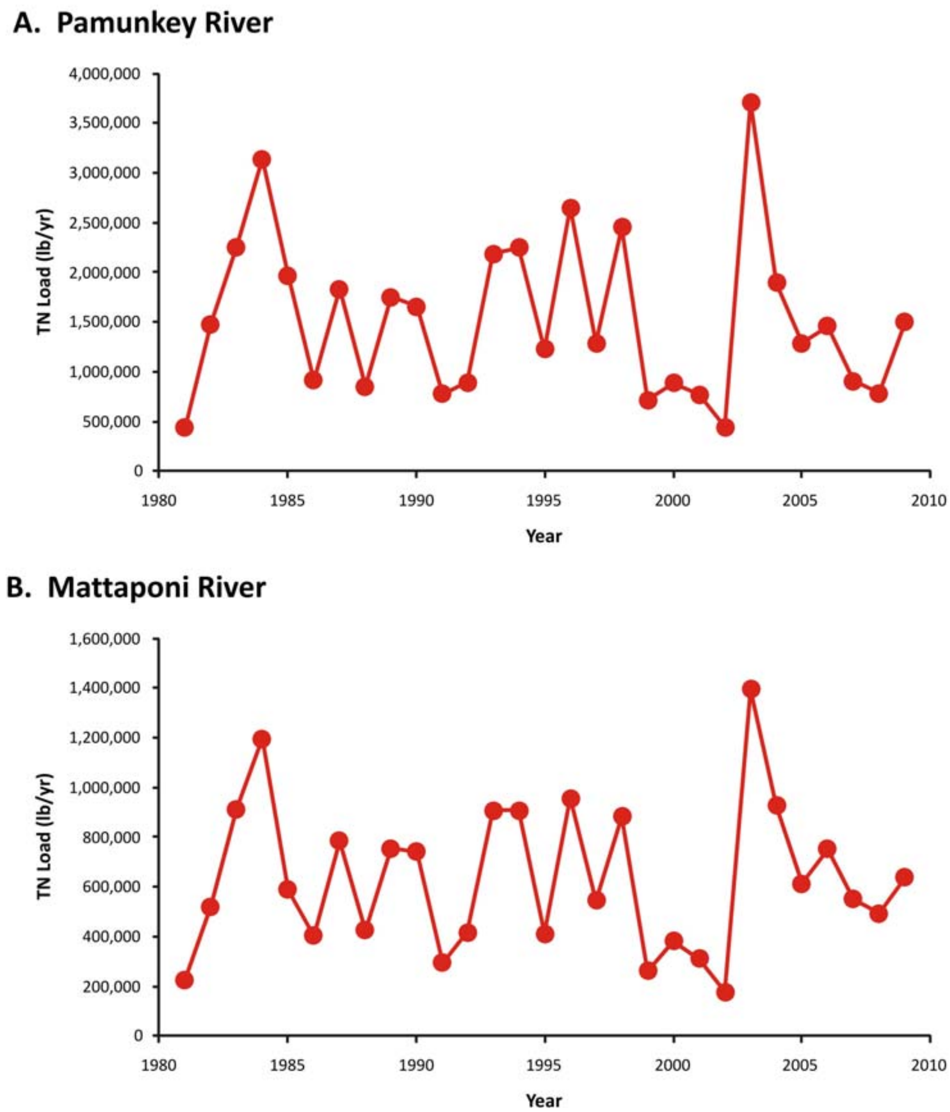


Figure 21. Long-term changes in total nitrogen load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP /index.html).

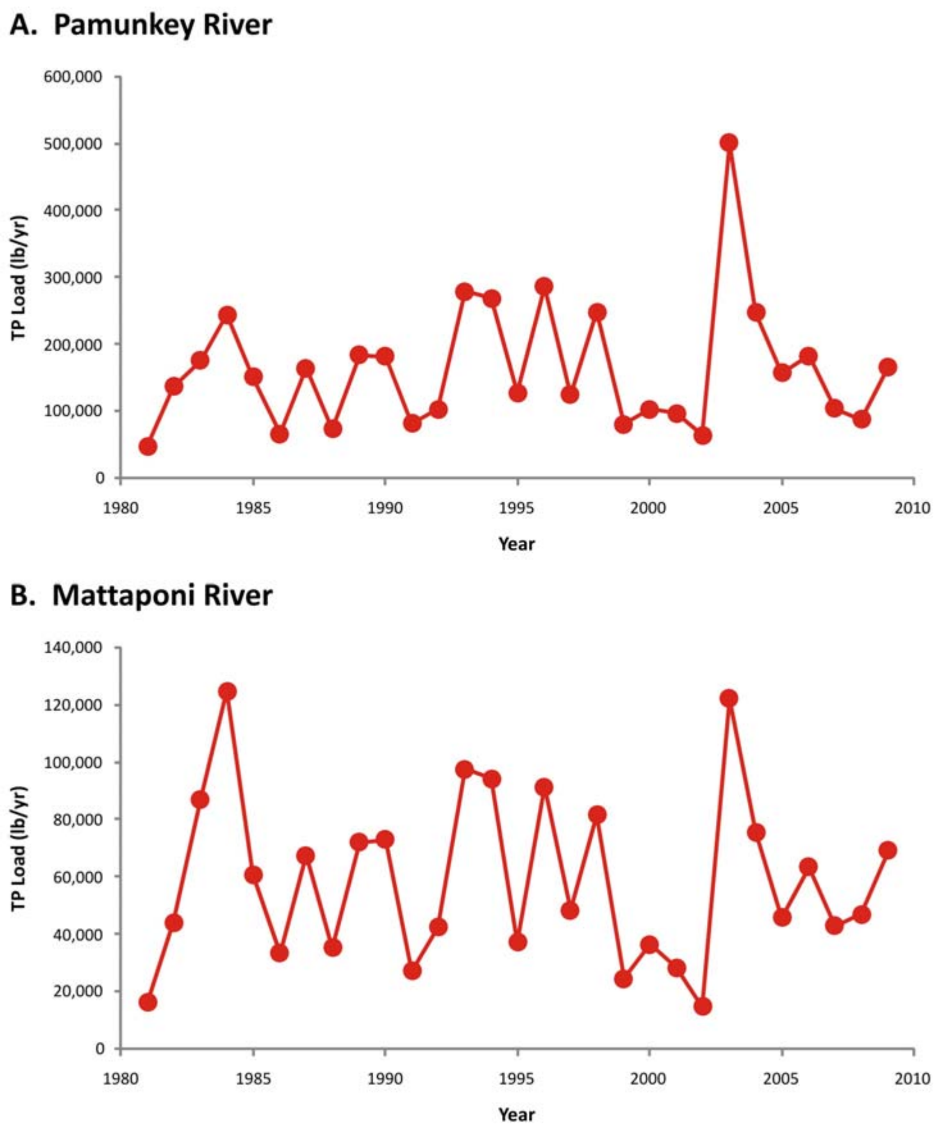


Figure 22. Long-term changes in total phosphorus load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

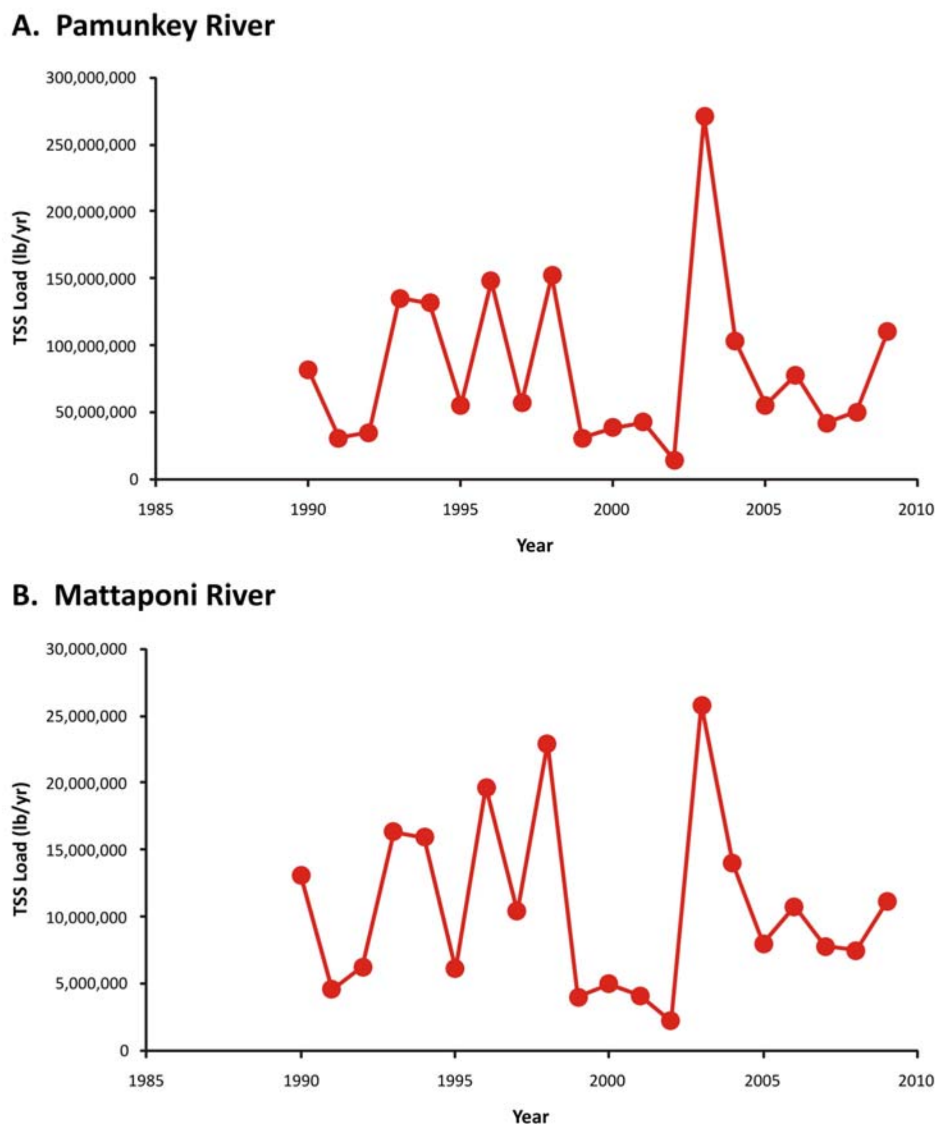
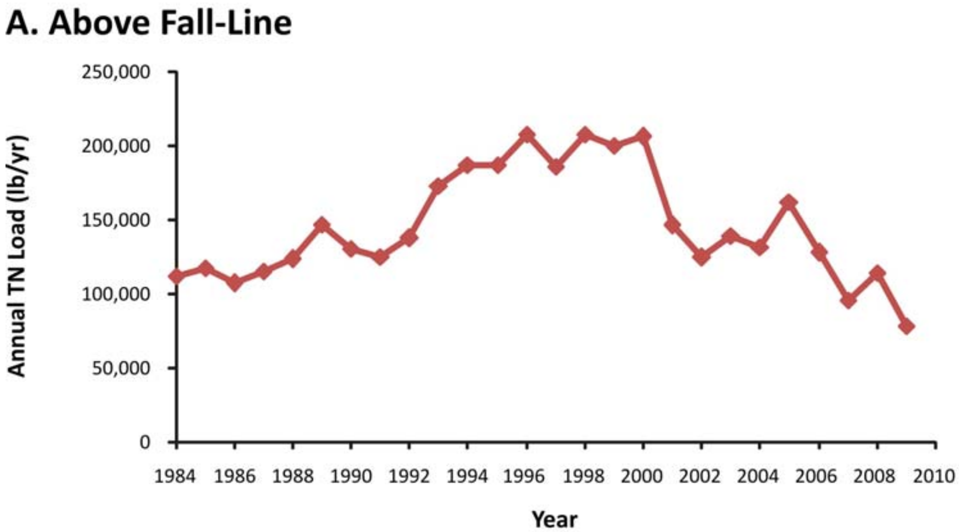


Figure 23. Long-term changes in total suspended solids load above the fall-line in the A. Pamunkey River and B. Mattaponi River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP /index.html).



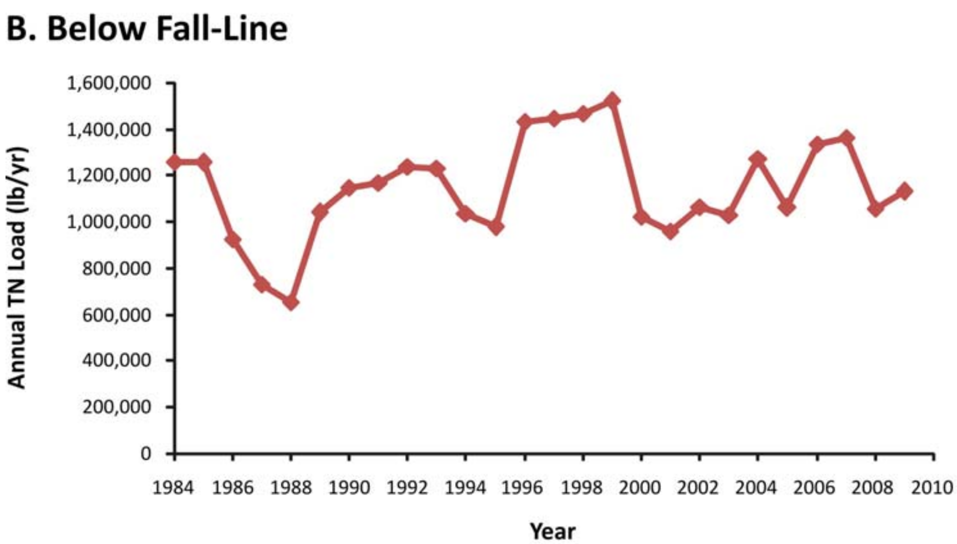


Figure 24. Long-term changes in point source total nitrogen load in the York River A)Above the Fall-Line and B) Below the Fall-line for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

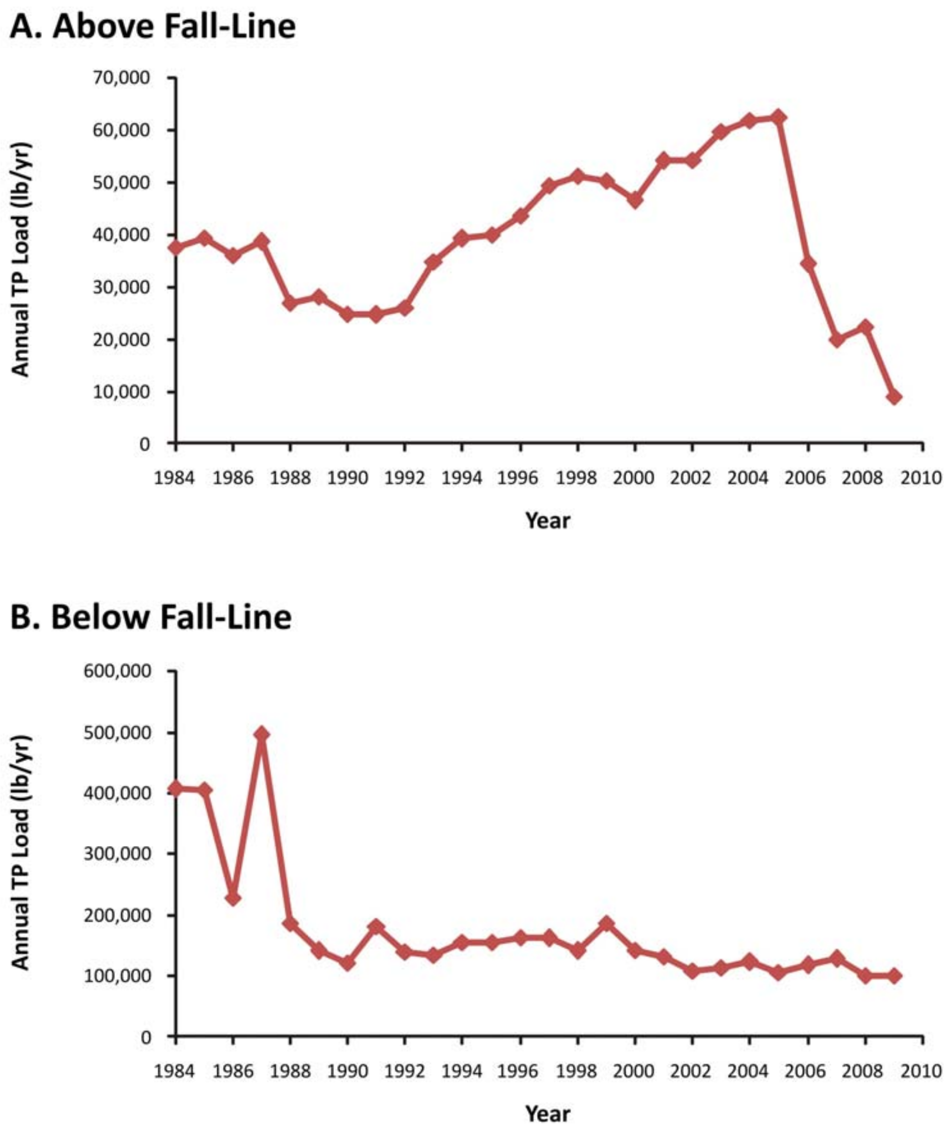
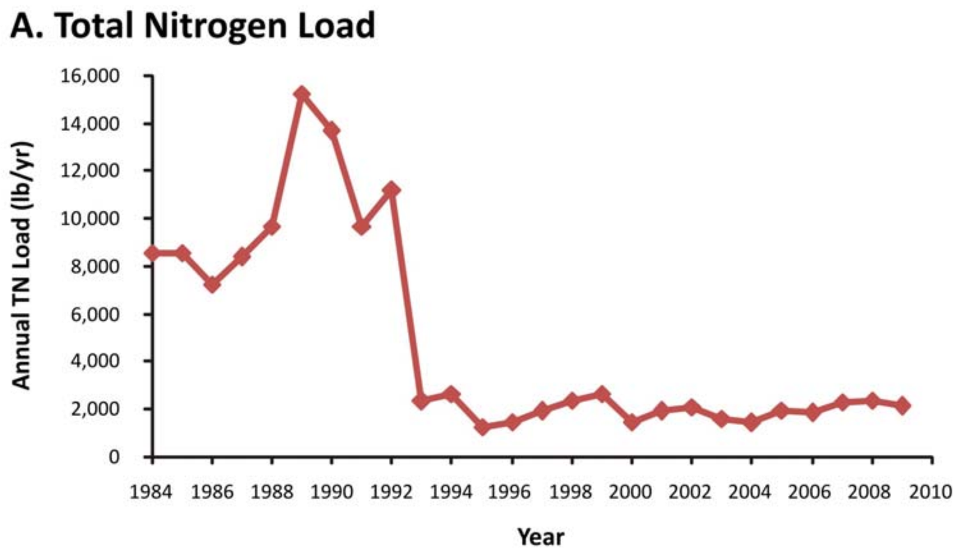


Figure 25. Long-term changes in point source total phosphorus load in the York River A)Above the Fall-Line and B) Below the Fall-line for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



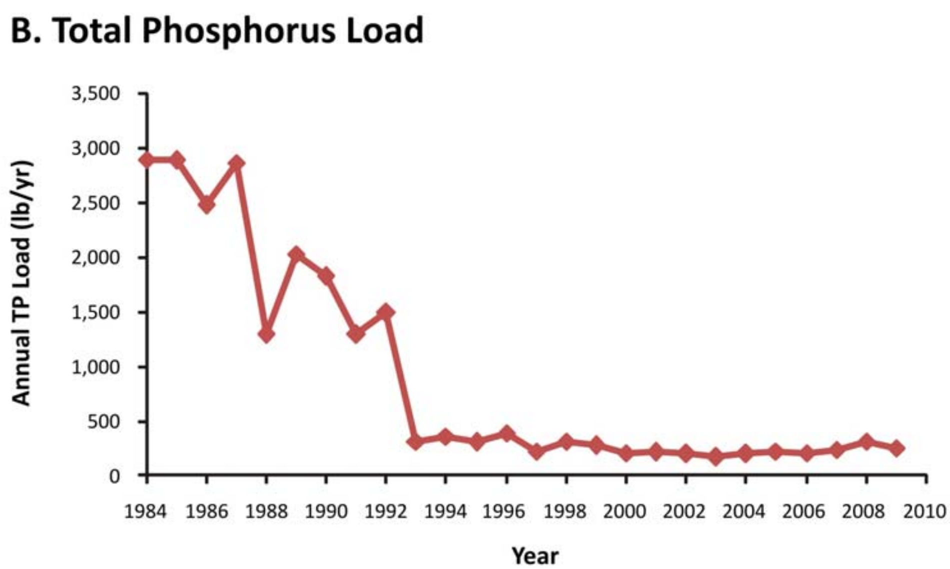


Figure 26. Long-term changes in point source A) Total Nitrogen Load and B) Total Phosphorus Load in Mobjack Bay for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

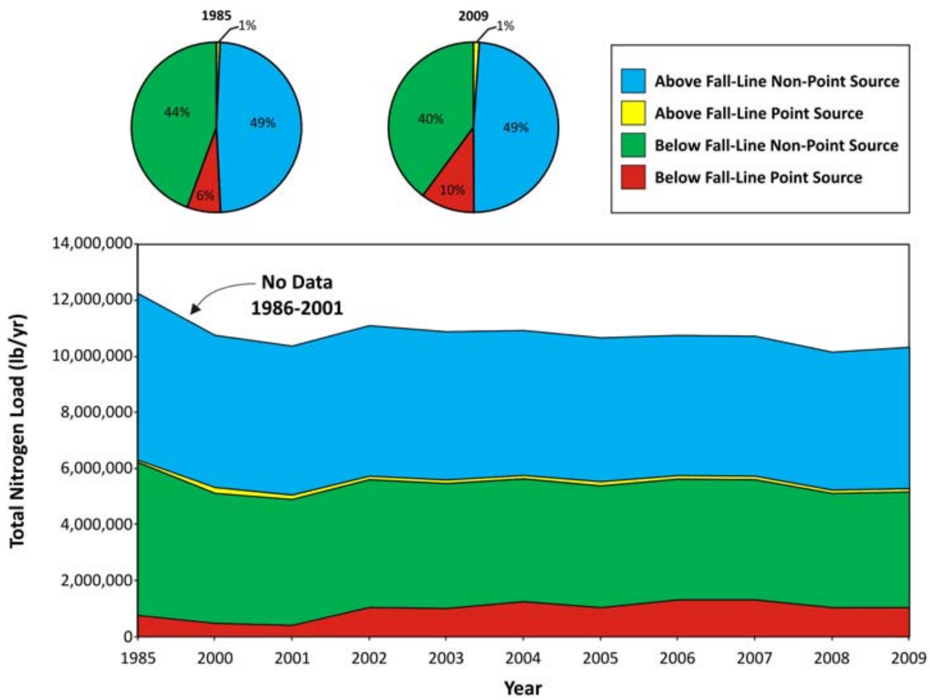


Figure 27. Long-term changes in and relative contribution to total nitrogen load to the York River for point and non-point sources both above and below the fall-line for the period of 1985 through 2009. Loadings presented are estimates produced by the USEPA's Chesapeake Bay Program Watershed Model version 4.3 and may differ in magnitude from estimates from other sources.

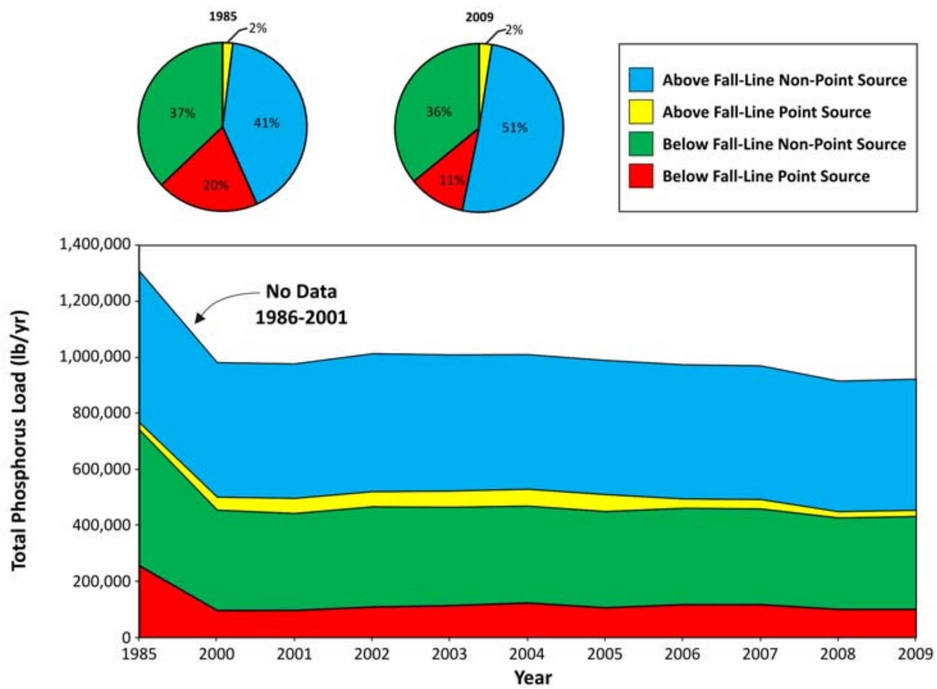


Figure 28. Long-term changes in and relative contribution to total phosphorus load to the York River for point and non-point sources both above and below the fall-line for the period of 1985 through 2009. Loadings presented are estimates produced by the USEPA's Chesapeake Bay Program Watershed Model version 4.3 and may differ in magnitude from estimates from other sources.

Parameter	PMKTF	PMKOH	MPNTF	MPNOH	YRKMH	YRKPH	MOBPH
STN		▲		▲	▲	▲	▼ 88
BTN		▲			▲		▼ 88
SDIN							
BDIN							
STP	▲				▲	▲	▼ 88
BTP	▲	▲			▲		▼ 88
SDIP	▼ 95		▼ 95		▲	▲	
BDIP	▼ 95		▼ 95		▲	▲	

Figure 29. Water quality status and long-term trends in nutrient parameters in the tidal portion of the York River basin for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant ($P < 0.01$) trends in water quality parameters from the start of monitoring through 2009 or trends significantly only from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2009. 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.

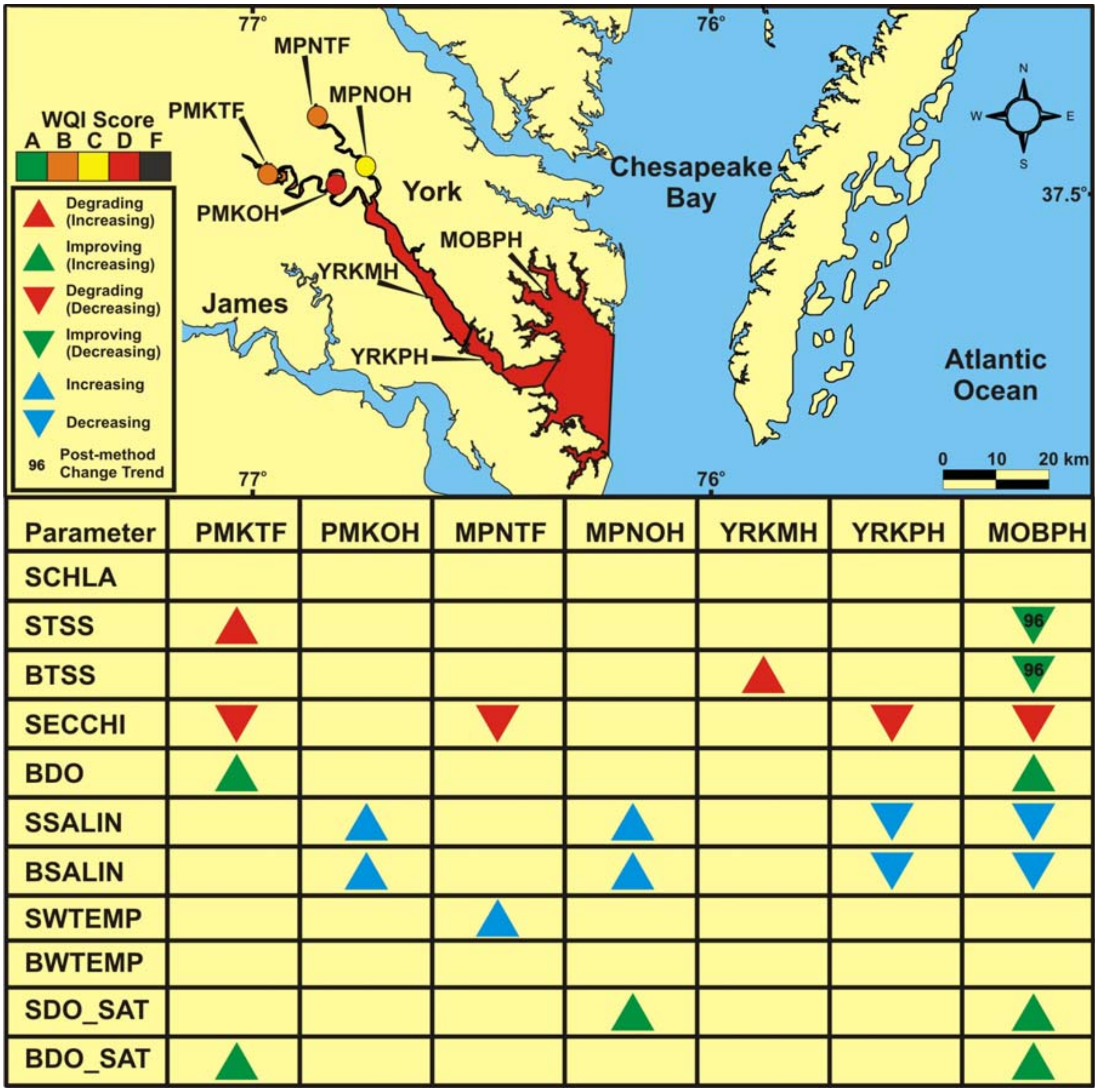


Figure 30. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the York River basin for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant (*P* < 0.01) trends in water quality parameters from the start of monitoring through 2009. 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..

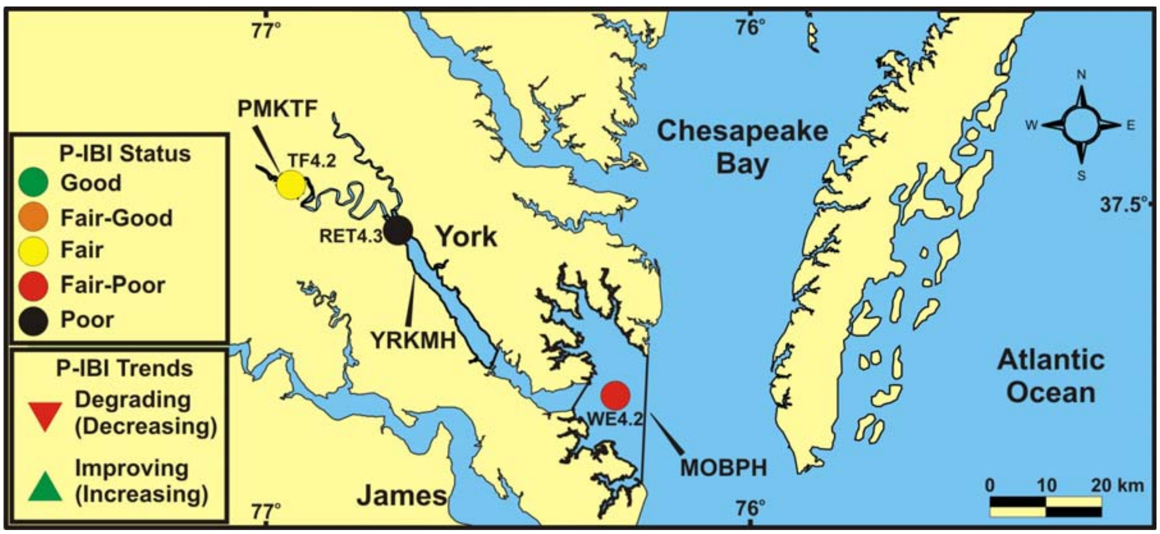


Figure 31. Status and long-term trends in phytoplankton community condition in the tidal portion of the York River basin for the period of 1985 through 2009. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2009.

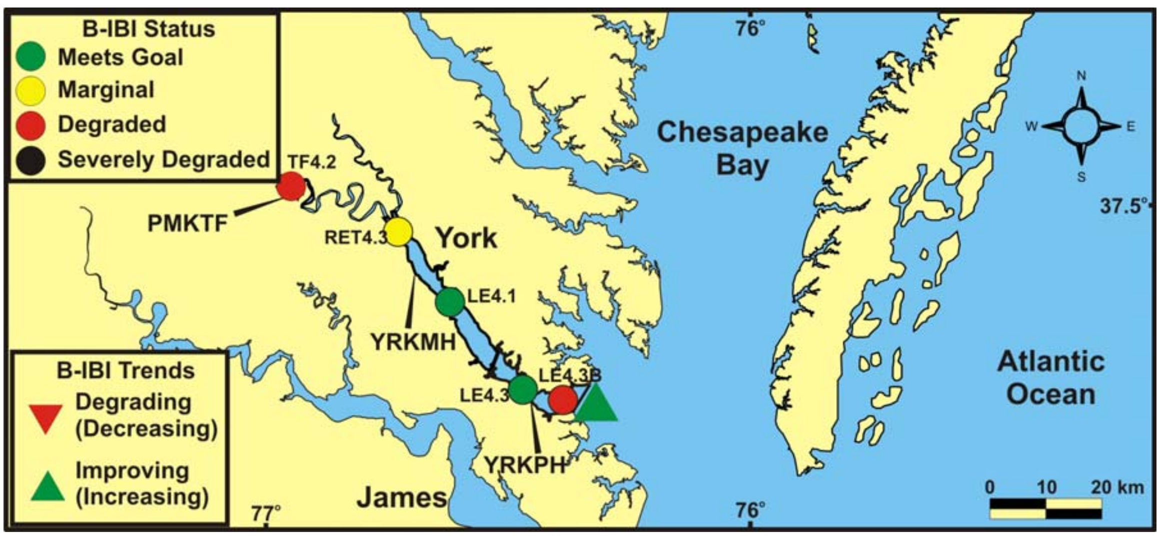


Figure 32. Status and long-term trends in benthic community condition in the tidal portion of the York River basin for the period of 1985 through 2009. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2009.

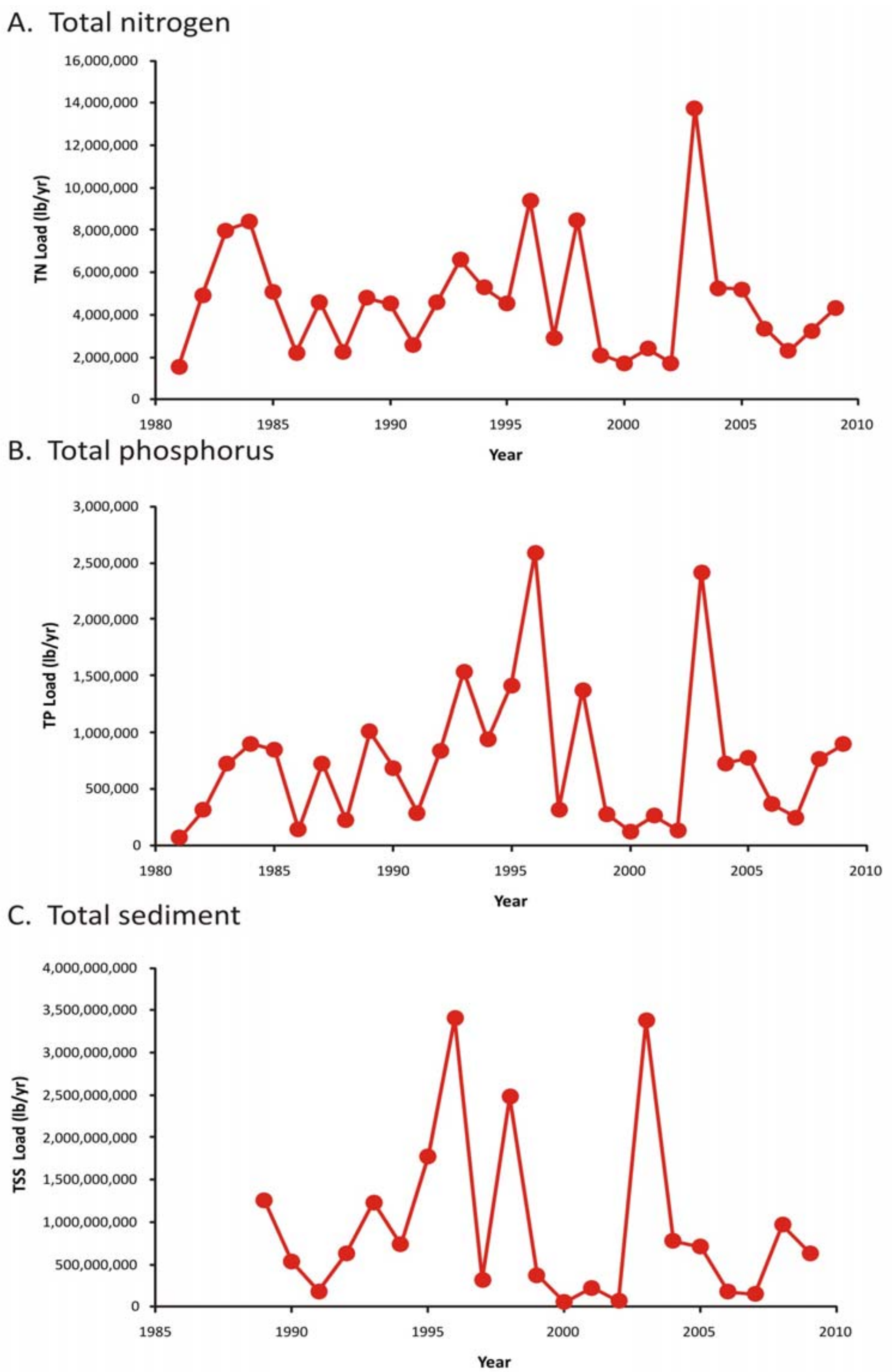
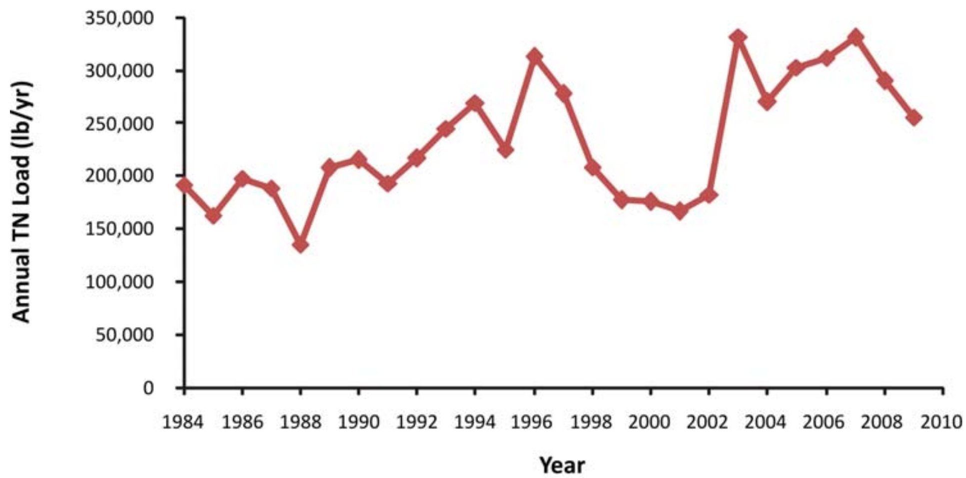


Figure 33. Long-term changes in A. Total nitrogen, B. Total phosphorus, and C. Total sediment loads at the fall-line in the Rappahannock River from 1985 through 2009. Data shown are estimates provided by the US Geological Survey's River Input Monitoring program (http://va.water.usgs.gov/chesbay/RIMP/index.html).

A. Above Fall-Line



B. Below Fall-Line

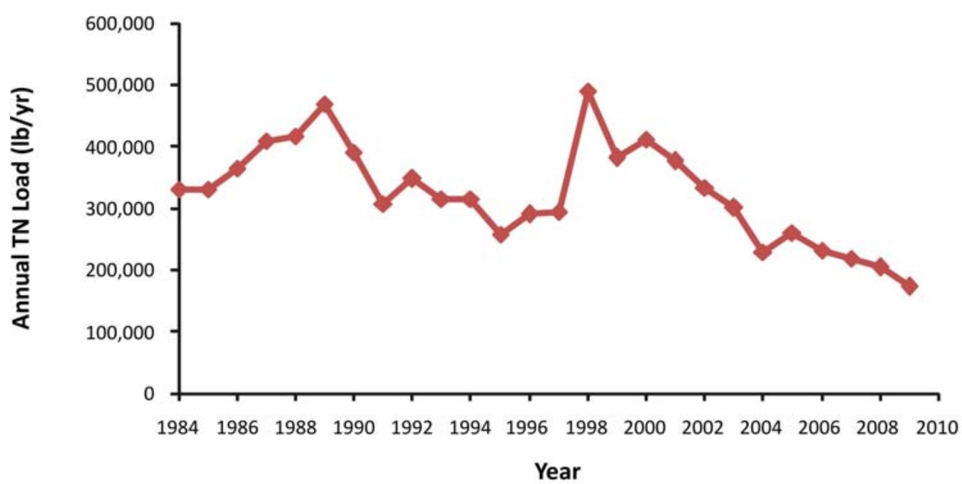
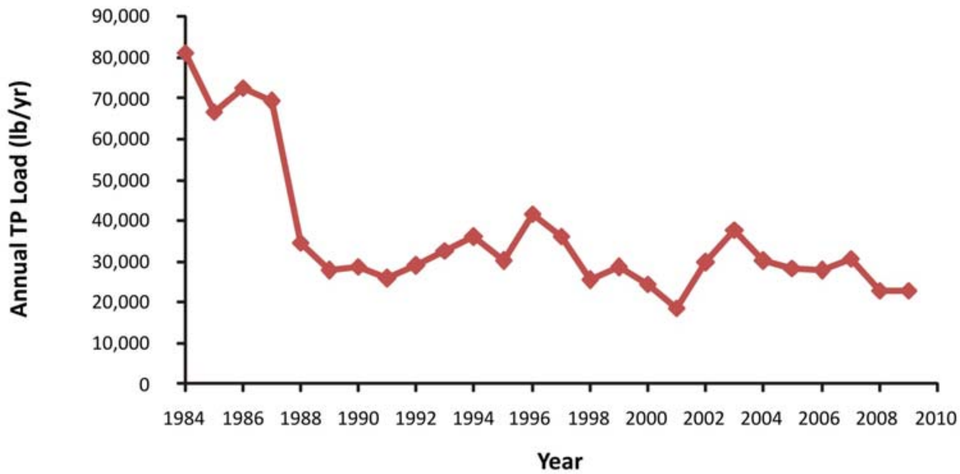


Figure 34. Long-term changes in point source total nitrogen loads A. Above the Fall-line, and B. Below the Fall-line in the Rappahannock River for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

A. Above Fall-Line



B. Below Fall-Line

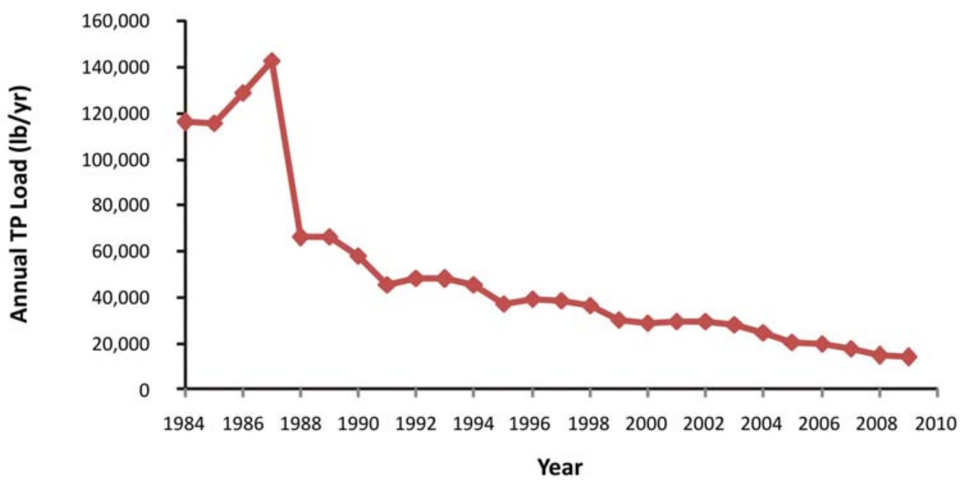


Figure 35. Long-term changes in point source total phosphorus loads A. Above the Fall-line, and B. Below the Fall-line in the Rappahannock River for 1984 through 2009. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

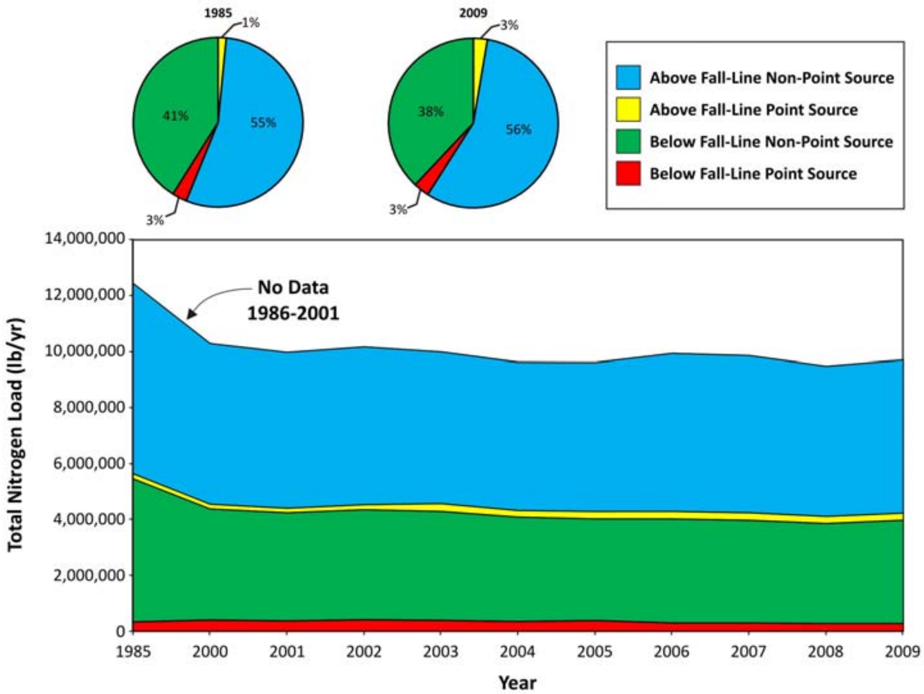


Figure 36. Long-term changes in and relative contribution to total nitrogen load to the Rappahannock River for point and non-point sources both above and below the fall-line for the period of 1985 through 2009. Loadings presented are estimates produced by the USEPA's Chesapeake Bay Program Watershed Model version 4.3 and may differ in magnitude from estimates from other sources.

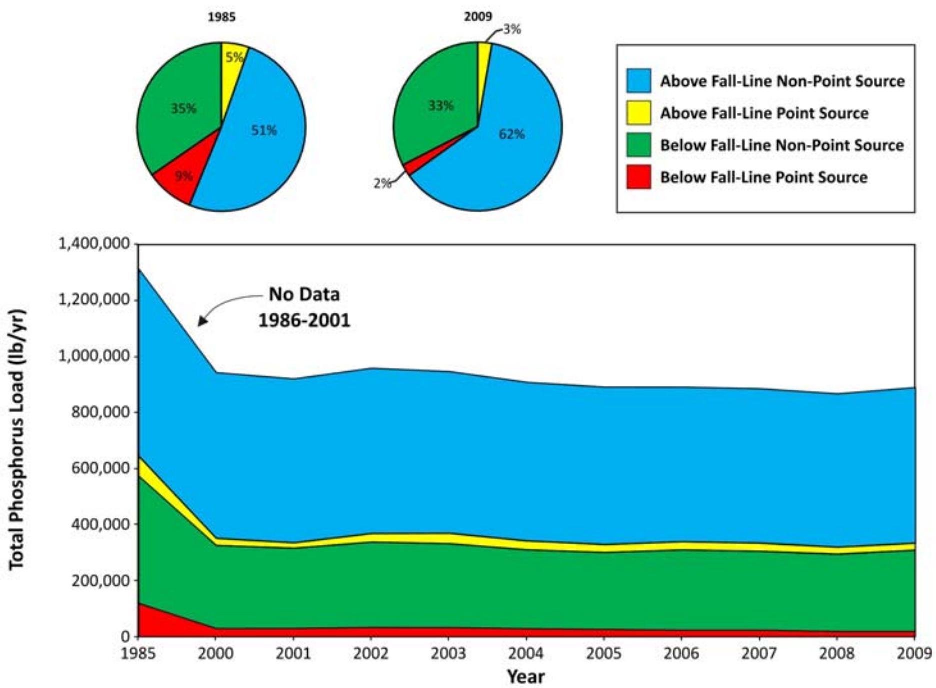
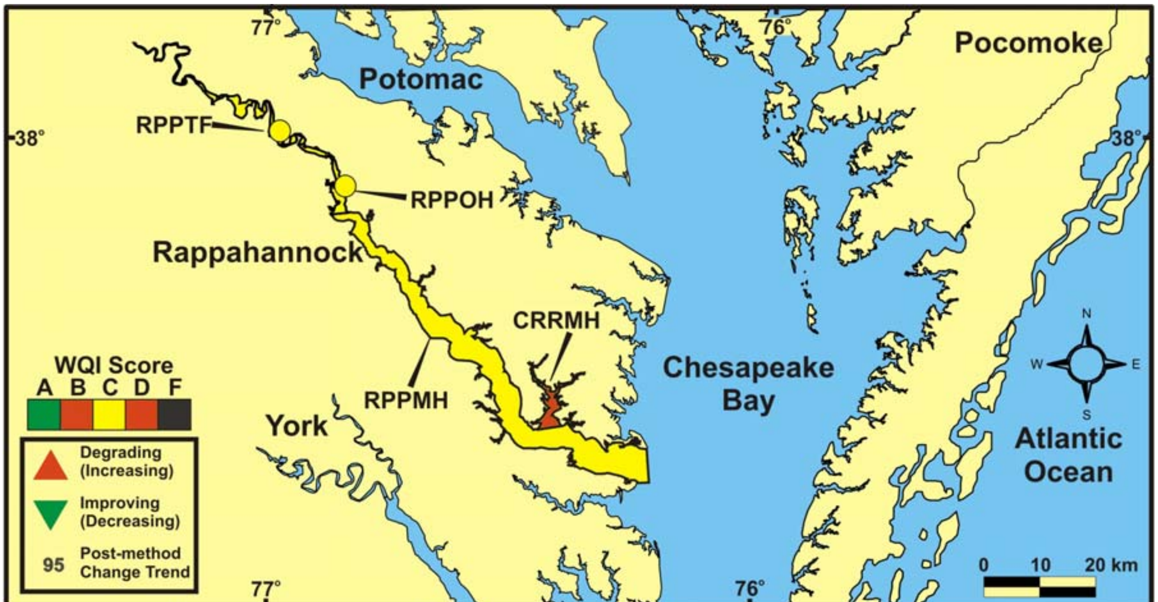
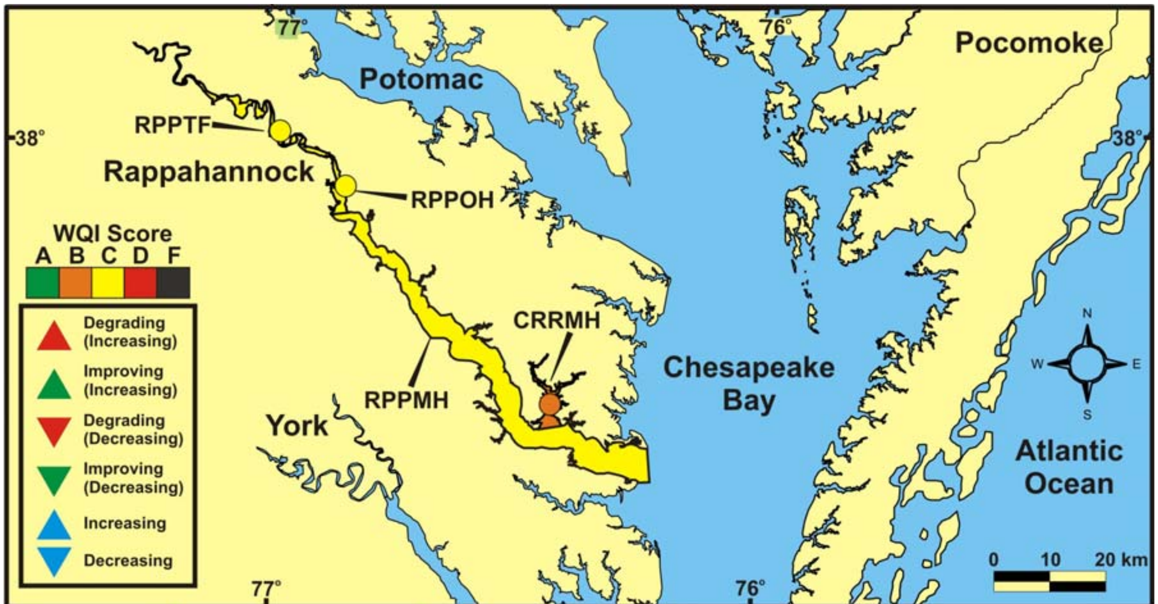


Figure 37. Long-term changes in and relative contribution to total phosphorus load to the Rappahannock River for point and non-point sources both above and below the fall-line for the period of 1985 through 2009. Loadings presented are estimates produced by the USEPA's Chesapeake Bay Program Watershed Model version 4.3 and may differ in magnitude from estimates from other sources.



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

Figure 38. Water quality status and long-term trends in nutrient parameters in the tidal portion of the Rappahannock River basin for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant (P < 0.01) trends in water quality parameters from the start of monitoring through 2008 or trends significantly only from the period after methodological changes in nutrient determinations were initiated i.e. from 1995 through 2009. 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		▲ Degrading (Increasing)	▲ Degrading (Increasing)	
STSS				
BTSS				
SECCHI				▼ Degrading (Decreasing)
BDO	▼ Degrading (Decreasing)			
SSALIN			▼ Decreasing	▼ Decreasing
BSALIN			▼ Decreasing	▼ Decreasing
SWTEMP				
BWTEMP				
SDO_SAT		▲ Improving (Increasing)	▲ Improving (Increasing)	
BDO_SAT				

Figure 39. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the Rappahannock River basin for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant ($P < 0.01$) trends in water quality parameters from the start of monitoring through 2009. 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 40. Status and long-term trends in phytoplankton community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2009. 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 2009.

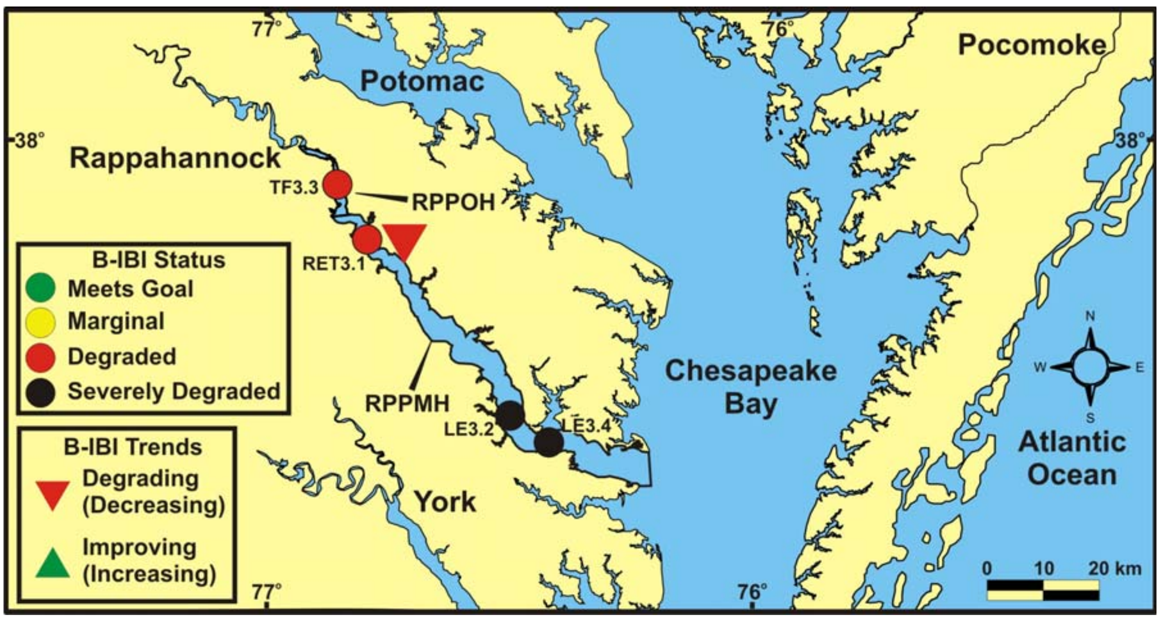


Figure 41. Status and long-term trends in benthic community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2009. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2009.

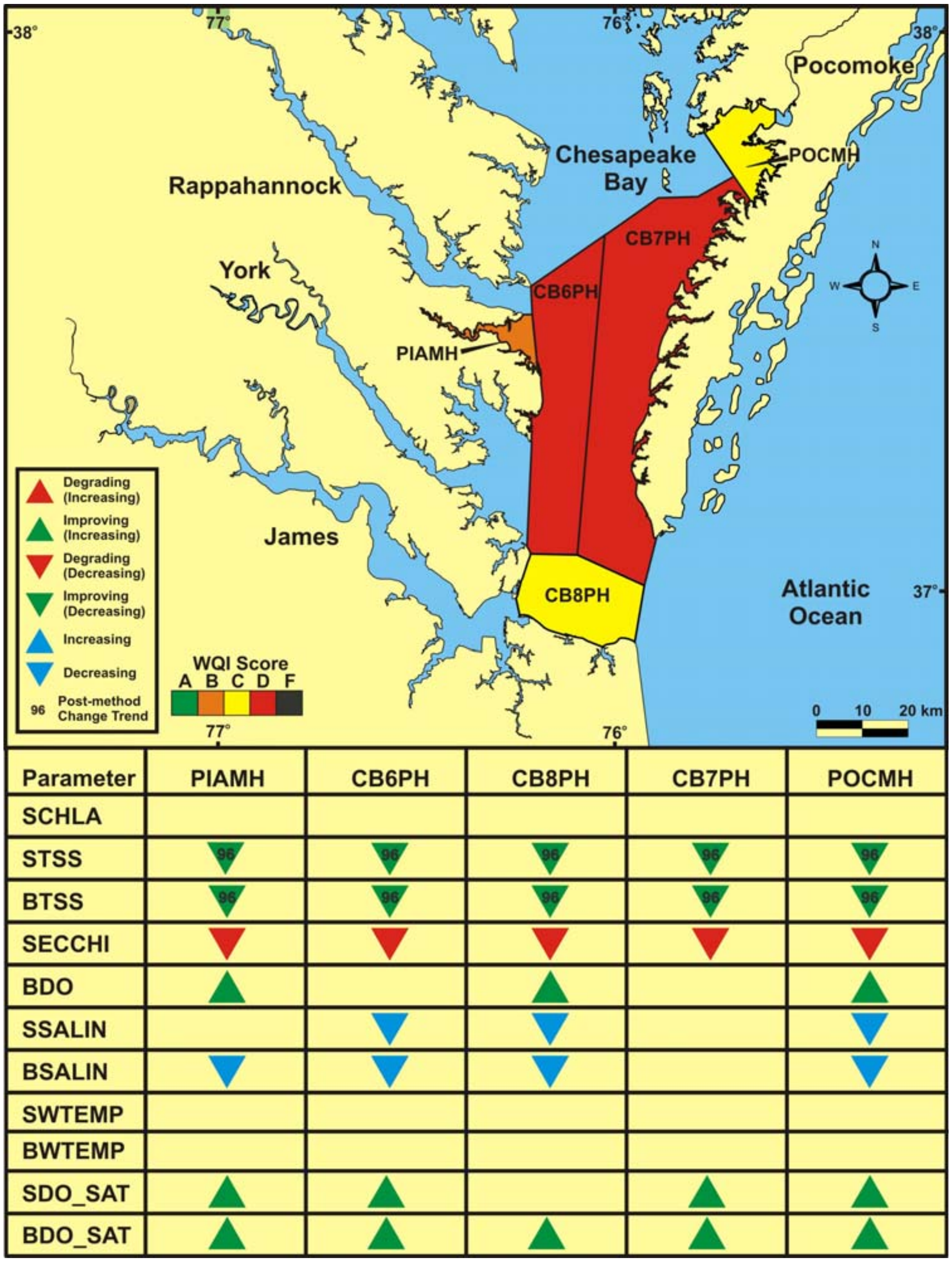
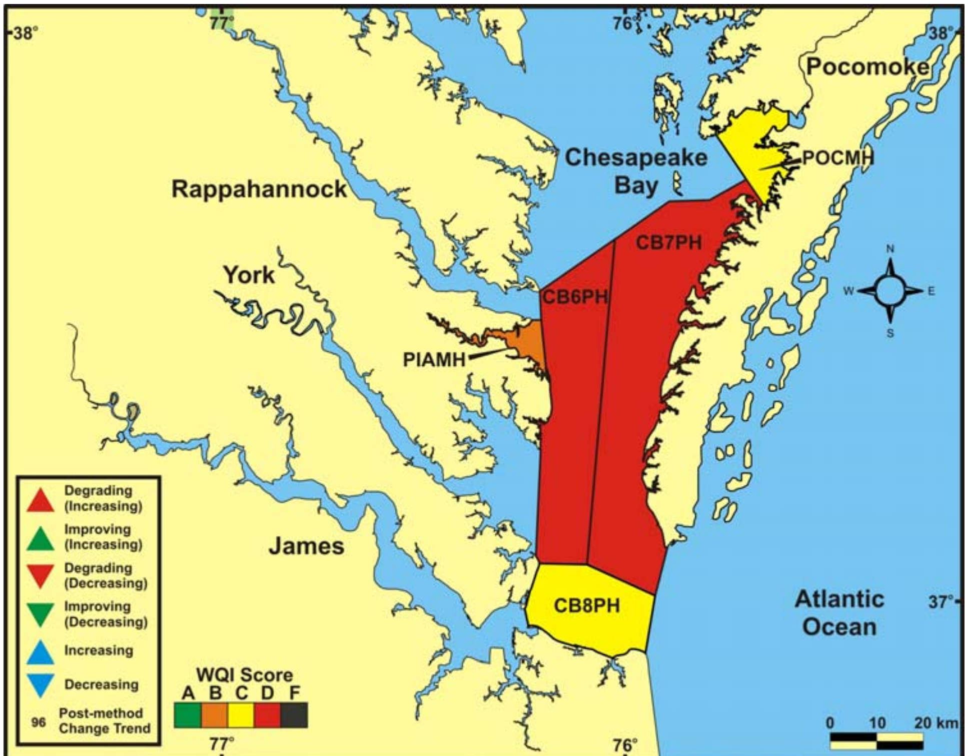


Figure 42. Water quality status and long-term trends in nutrient parameters in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2009. Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant ($P < 0.01$) trends in water quality parameters from the start of monitoring through 2009or trends significantly only from the period after methodological changes in nutrient determinations were initiated i.e. from 1988 through 2008. Abbreviations for each parameter are: TN=total nitrogen, DIN=dissolved inorganic nitrogen, TP=total phosphorus, DIP=dissolved inorganic phosphorus. The prefixes S and B refer to surface and bottom measurements, respectively.



Parameter	PIAMH	CB6PH	CB8PH	CB7PH	POCMH
SCHLA					
STSS	Improving (Decreasing) (96)	Improving (Decreasing) (96)	Improving (Decreasing) (96)	Improving (Decreasing) (96)	Improving (Decreasing) (96)
BTSS	Improving (Decreasing) (96)	Improving (Decreasing) (96)	Improving (Decreasing) (96)	Improving (Decreasing) (96)	Improving (Decreasing) (96)
SECCHI	Degrading (Decreasing)	Degrading (Decreasing)	Degrading (Decreasing)	Degrading (Decreasing)	Degrading (Decreasing)
BDO	Improving (Increasing)		Improving (Increasing)		Improving (Increasing)
SSALIN		Decreasing	Decreasing		Decreasing
BSALIN	Decreasing	Decreasing	Decreasing		Decreasing
SWTEMP					
BWTEMP					
SDO_SAT	Improving (Increasing)	Improving (Increasing)		Improving (Increasing)	Improving (Increasing)
BDO_SAT	Improving (Increasing)	Improving (Increasing)	Improving (Increasing)	Improving (Increasing)	Improving (Increasing)

Figure 43. 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 2009 Shown are status as measured using the Water Quality Index (WQI) of Williams et al. (2009) and statistically significant ($P < 0.01$) trends in water quality parameters from the start of monitoring through 2009.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.

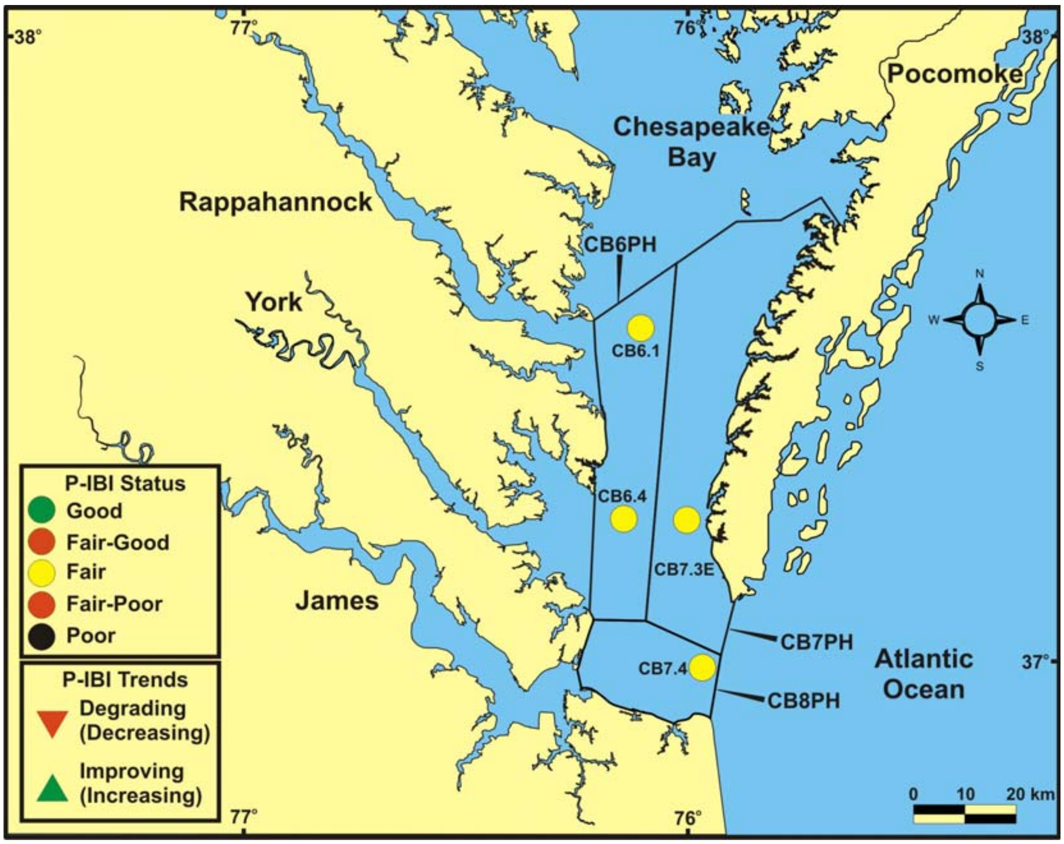


Figure 44. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2009. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2009.

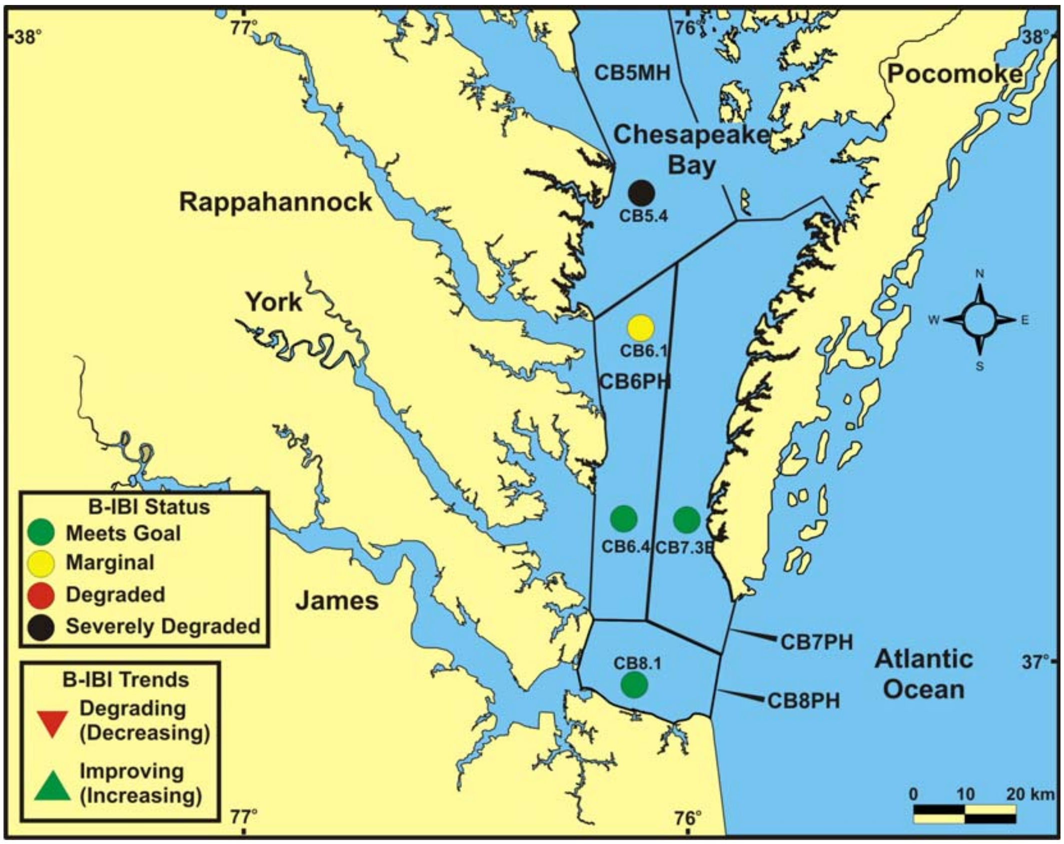


Figure 45. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2009. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2009.