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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 2008

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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; Marshall and Burchardt, 1998, 2003, 2004a, 2004b, 2005; Marshall et al., 2005a;2005b;2006;2007; 2008). This report summarizes the status of and long-term trends in water quality and living resource conditions for the Virginia tributaries through 2008 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).

II. Methods and Materials

A. Monitoring Program Descriptions

Non-tidal water quality samples were collected from 1985 through 2008 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. 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). An additional set of 14 fixed point stations were collected in the Elizabeth River as a part of DEQ's Elizabeth River Monitoring Program beginning in 1999; however, this program was discontinued in 2008. 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 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 2008 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 patterns in 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. 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 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 2008 were plotted to determine if there were any long-term changes in nutrients loads. Percent change in point source nutrient loads was estimated using data from 1984 as a baseline.

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 criteria 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 violations for each criterion 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 as 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 2008.

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 2006 through 2008. 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.

Status of benthic communities at each station was characterized using the three-year mean value (2006 through 2008) 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 populated by benthos 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 a 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 the 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 data. 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. 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).

Above the fall-line, CBP watershed model estimates of non-point source (NPS) nitrogen loads decreased slightly but steadily since 1985 from approximately 25,000,000 to nearly 22,000,000 lb/yr in 2007 although they rose in 2008 to nearly 22,500,000 lb/yr (Figure 4A). Overall, the reduction in nitrogen NPS loads above the fall-line from 1985 and 2008 was 9.5%. Below the fall-line, NPS nitrogen load estimates decreased from around 12,100,000 lb/year in 1985 to just over 11,000,000 in 2008 (Figure 4B), a decrease of approximately 8.4%. Although dropping by nearly 3,000,000 lb/yr or 7.4% from 1985 to 2000, above fall-line NPS phosphorus loads have remained fairly consistent during the last several years, ranging from around 26,000,000 to 28,000,000 lb/yr (Figure 5A). Below the fall-line, NPS phosphorus loads decreased from about 1,650,000 lb/yr in 1985 to 1,400,000 lb/yr in 2000 and continued to decline thereafter to approximately 1,335,000 lb/yr in 2008, an overall decrease of nearly 19.1% (Figure 5B) . Above the fall-line, NPS sediment loads decreased fairly steadily from approximately 750,000 ton/yr in 1985 to 616,000 ton/yr in 2008 for an overall change of nearly 17.5% (Figure 6A). Below the fall-line, NPS sediment loads also decreased from approximately 139,000 ton/yr in 1985 to just under 127,000 ton/yr in 2008 for an overall change of 8.7% (Figure 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 2008 for a total reduction of just over 24% (Figure 7A). 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 2008 (Figure 7B). During the first four years of this study PS phosphorus loads remained at levels above 750,00 lb/yr but dropped to around 540,000 lb/yr in 1988 and continued to drop for the next two years (Figure 8A). 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 continued to decline reaching a minimum of 381,000 lb/yr in 2008 (Figure 8A). Overall above fall-line PS phosphorus loads have declined over 51% 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 2,384,000 lb/yr in 1984 to 526,000 lb/yr in 2008, a decrease of over 81% (Figure 8B).

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 2). 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 3;Figure 10). 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 along with improving trends in flow-adjusted dissolved inorganic phosphorus at Station 1 in the Appomattox River and Station 4 in the James River (Table 3;Figure 11). The degrading trend in water quality above the fall-line was an increasing trend in flow-adjusted total phosphorus concentrations observed at Station 1 in the Appomattox River (Table 3;Figure 11).

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 Very Good at the upper tidal freshwater segment (JMSTF1) to Poor at segment JMSPH at the mouth of the river (Figure 9). Status in both the tidal Appomattox (segment APPTF) and Chickahominy (segment CHKOH) rivers was Marginal (Figure 9). With respect to nutrients, improvements in water quality were limited 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 9). Improving trends in surface and bottom dissolved inorganic phosphorus were detected in all of these segments (Figure 9). Improving trends in bottom total nitrogen and in surface and bottom total phosphorus were also detected in segments JMSTF1 and JMSTF2, respectively (Figure 9). In addition, an improving post-method change trend was detected in surface total phosphorus in segment JMSTF1 (Figure 9). Despite the improvements observed in nutrients, improving trends in surface chlorophyll *a* were limited to the Chickahominy River (Figure 10). A degrading trend in chlorophyll *a* was also observed in segment JMSPH at the mouth of the James River (Figure 10). 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 10). Summer bottom dissolved oxygen concentrations were unchanged for most segments except segment JMSOH where a degrading trend was observed and in segment JMSPH where an improving trend was observed (Figure 10).

Water quality status was Poor or Very Poor in all segments of the Elizabeth River except the Southern Branch were it was Marginal (Figure 11). 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) (Figure 11). Improving trends in surface and bottom dissolved inorganic nitrogen were also observed in the Southern Branch (SBEMH) and Eastern Branch (EBEMH) (Figure 11). Improving trends in total suspended solids were also observed in all segments of the Elizabeth River (Figure 12) along with a an improving trend in summer bottom dissolved oxygen. The only degrading trend observed was a decreasing trend in secchi depth in segment ELIPH (Figure 12).

4. Phytoplankton Communities

In the James River, degradation of phytoplankton communities increased 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 13). Plankton community status at station SBE5 in segment SBEMH the Elizabeth River was Fair-Poor (Figure 13). There were no trends in the P-IBI. Degrading trends in cyanobacteria abundance were detected at all stations in this basin except RET5.2 in segment JMSOH (Appendix C - Section A). Degrading trends in primary productivity and the Margalef diversity index were detected at station TF5.5 in segment JMSTF1 and station RET5.2 in segment JMSOH, respectively (Appendix C - Section A). Improving trends in chlorophyte and picoplankton biomass were detected at stations TF5.5 in segment JMSTF1 and station RET5.2 in segment JMSOH, as was an improving trend in primary productivity at station RET5.2 (Appendix C - Section A). Dinoflagellate blooms are common within the tributaries to the lower James River; often entering the James River, and sometimes into the lower Chesapeake Bay.

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 JMSOH. Status at all other stations in the James River was Degraded except at station LE5.1 where it was Marginal (Figure 14). Status of the B-IBI at both stations in the Southern Branch of the Elizabeth River (segment SBEMH)was degraded (Figure 14). Improving trends in the B-IBI were detected at station RET5.2 in segment JMSOH and at stations SBE2 and SBE5 in the Southern Branch (SBEMH) of the Elizabeth River (Figure 14). In 2008, results of the probability-based benthic monitoring indicate that 80% of the total area of the James River is degraded (Table 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 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 in dissolved inorganic phosphorus observed. Elsewhere in the basin, water quality status was Marginal or Poor, no 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 substantial lag between improvements observed in both NPS and PS loadings both above and below the fall-line from observed responses in the tributaries to and lower 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 cyanobacteria biomass although some improvements in phytoplankton communities were indicated. Of additional concern is the common occurrence of algal blooms of within the Elizabeth River and its tributaries within the Tidewater urban complex. Status of the benthos at most fixed-point stations in the James Rivers was Degraded and probability-based benthic monitoring indicated that a high percentage (80%) 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 trends 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).

Above the fall-line, NPS nitrogen loads decreased by 17.3% from nearly 6,000,000 lb/yr in 1985 to 4,900,000 lb/yr in 2008 (Figure 15A). NPS nitrogen loads below the fall-line decreased by over 25% from 5,450,000 lb/yr in 1985 to nearly 4,100,000 lb/yr in 2008 (Figure 15B). Above the fall-line, NPS phosphorus loads decreased from approximately 542,000 lb/yr in 1985 to 482,000 lb/yr in 2000 and continued to decrease slightly though steadily during the next several years resulting in an overall decrease of 11.1% by 2008 (Figure 16A). Below the fall-line, NPS phosphorus loads dropped substantially from 486,000 lb/yr in 1985 to 358,000 lb/yr in 2000 and continued to decline thereafter to nearly 327,000 lb/yr in 2008 (Figure 16B), a total decrease of 32.8%. NPS sediment loads above the fall-line declined steadily from 265,000 ton/yr in 1985 to 207,000 ton/yr in 2008 (Figure 17A) for an overall change of nearly 22%. Below the fall-line, NPS sediment loads declined fairly steadily but with some fluctuations from 98,000 ton/yr in 1985 to 68,000 ton/yr in 2008 (Figure 17B) for an overall change of almost 31%.

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 thereafter declined until a minimum of around 96,000 lb/yr was reached in

2007 (Figure 18A). PS nitrogen loads increased again to just over 114,000 lb/yr in 2008 for a total increase of over 2% from 1984 to 2008 (Figure 18A). 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 18B). PS nitrogen loads then declined fairly steadily thereafter to about 1,059,000 lb/yr in 2008 (Figure 18B). 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 19A). Above fall-line PS phosphorus loads during the last three years declined to just over 22,000 in 2008 for a total decrease from 1984 to 2008 of just over 40% (Figure 19A). Below fall-line 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 2008 for a total decrease of 75% since 1984 (Figure 19B). In Mobjack Bay, PS nitrogen loads showed a substantial decreased 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 20A). Overall PS nitrogen loads in Mobjack Bay have decreased by over 72% since 1984. PS phosphorus loads in Mobjack Bay declined steadily from 2900 lb/yr in 1984 to just over 300 lb/yr in 2008 for a total decrease of 89% (Figure 20B).

2. Non-tidal Water Quality

No statistically significant trends in freshwater flow were observed in either the Pamunkey or Mattaponi rivers (Table 2). 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 6 near the fall-line (Table 3;Figures 10-12) . However, the degrading trends at Station 6 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 3;Figures 11-12). 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 3).

3. Tidal Water Quality

Water quality status as measured using the WQI was generally Poor throughout most of the York River basin (Figure 21). Overall status declined from Good and Very Good in the tidal freshwater of the Pamunkey and Mattaponi rivers to Very Poor in the middle reaches (segment YRKMH) of the York River improving slightly thereafter to Poor in segments YRKPH and MOBPH (Figure 21). With respect to nutrients, water quality conditions are declining throughout most of the York River. Degrading long-term or post-method change trends in either total nitrogen or dissolved inorganic nitrogen were detected in all segments except YRKMH and MOBPH (Figure 21). Degrading trends in surface and/or bottom total phosphorus were detected in many 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 21). In addition, degrading trends in both surface and bottom dissolved inorganic phosphorus were observed in segment YRKMH (Figure 21). 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 21). No changes in chlorophyll *a* concentrations were observed in any segments of the York River while trends in total suspended solids was limited to a degrading trend in surface concentrations at segment

PMKTF and an improving trend in Mobjack Bay (MOBPH) (Figure 22). 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 22). Improvements in summer bottom dissolved oxygen were detected in the tidal freshwater Pamunkey (PMKTF) and in Mobjack Bay (MOBPH) (Figure 22).

4. Phytoplankton Communities

Status of the phytoplankton communities based on the P-IBI was Fair at stations TF4.2 in segment PMKTF and WE4.2 in segment MOBPH but Poor at station RET4.3 in segment YRKMH (Figure 23). Although there were no significant trends in the P-IBI, degrading trends in primary productivity and cyanophyte biomass were detected at all stations along with a degrading trend in the Margalef diversity index at station WE4.2 in segment MOBPH (Appendix C - Section B). 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. In contrast, improving trends in chlorophyte abundance were detected at station TF4.2 in segment PMKTF and at station RET4.3 in segment YRKMH (Appendix C - Section B).

5. Benthic Communities

Benthic community status, as measured with the B-IBI, was good only at station LE4.3 in the Lower York River (YRKPH) and either degraded or marginal at all other stations (Figure 24). An improving trend in the B-IBI was detected at station LE4.3B in the Lower York River (YRKPH) but no other trends in the B-IBI were detected (Figure 24). In 2008, results of the probability-based benthic monitoring indicate that 68% of the total area of the York River was degraded (Table 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 is dissolved inorganic phosphorus suggests some improvement. The degrading trends in nutrients observed above the fall-line in the Pamunkey River may be related to changes in PS nutrient loads. After an initial reduction following the phosphate ban, NPS loads in both nitrogen and phosphorus above the fall-line have remained relatively stable while PS loads in both parameters exhibited long-term increasing trends that lasted for fifteen years in the case of nitrogen and over twenty years in the case of phosphorus. Although both trends reversed themselves temporarily, PS loads in both parameters have begun to increase again. The water quality trends may be related to these trends in PS loads. 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 many 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 it more susceptible to changes in loads.

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 increasing trends in both 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. All but one of the fixed point monitoring stations in the York River were Degraded or Marginal and probability-based sampling indicated that 68% 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).

Above fall-line NPS loads of nitrogen in the Rappahannock River dropped from approximately 6,810,000 lb/yr in 1985 to approximately 5,740,000 lb/yr in 2000, a decrease of over 15%. Since then, NPS nitrogen loads above the fall-line have remained relatively stable ranging from 5,740,000 lb/yr to 5,310,000 lb/yr (Figure 25A). Below the fall-line NPS nitrogen loads showed a similar drop from 5,120,000 lb/yr in 1985 to just under 4,000,000 lb/yr in 2000, a 22.4% decrease and thereafter exhibited a slight but steady decrease each year declining to 3,573,000 lb/yr in 2008, an overall decrease of over 30% (Figure 25B). Above fall-line NPS phosphorus load declined 18% from approximately 668,000 lb/yr in 1985 to nearly 548,000 lb/yr in 2008 (Figure 26A). Below the fall-line, NPS phosphorus loads decreased by nearly 40% from just under 455,000 lb/yr in 1985 to approximately 275,000 lb/yr in 2008 (Figure 26B). NPS sediment loads above the fall-line declined gradually by 20% from 117,000 ton/yr in 1985 to around 94,000 in 2008 (Figure 27A). Below the fall-line, NPS sediment loads showed a substantial decrease from 195,000 ton/yr in 1985 to around 129,000 ton/yr in 2000 with a slight but relatively steady decline to 122,000 ton/yr in 2008, an overall decline of nearly 37% (Figure 27B).

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 28A). 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 a drop back to 290,000 lb/yr in 2008 (Figure 28A). Overall PS nitrogen loads above the fall-line increased by over 51% between 1984 and 2008. 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 28B). Thereafter PS nitrogen loads decreased reaching a minimum of just under 205,000 lb/yr in 2008 for a overall decrease of 38% between 1984 and 2008 (Figure 28B). Above the fall-line PS phosphorus loads have shown a relatively steady decreased, with some fluctuations, from just over 81,000 lb/yr in 1984 to 23,000 lb/yr in 2008 (Figure 29A) 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 29B). This decrease continued thereafter at a much lower rate until PS phosphorus loads below the fall-line reached a minimum of just under 15,000 lb/yr in 2008, a total decline nearly 88%.

2. Non-tidal Water Quality

No significant trends in freshwater flow at the Rappahannock River fall-line were detected (Table 2). Long term water quality conditions above the fall-line in the Rappahannock River remain relatively unchanged although some improvement was indicated by the declining trend in flow-adjusted total phosphorus at Station 9 (Table 3;Figure 11). In addition, improving trends in flow-adjusted total nitrogen and nitrate-nitrites were detected at Station 10 in the Robinson River, a tributary of the Rappahannock River (Table 3; Figure 10).

3. Tidal Water Quality

Water quality status as measured using the WQI was Marginal in all segments except the lower portion of the Rappahannock River (segment RPPMH) (Figure 30). With respect to nutrients, there was little change in water quality conditions except for degrading trends in bottom total nitrogen and phosphorus in segment RPPOH. The only improvements in nutrients observed were post-method change decreasing trends in dissolved inorganic phosphorus in segments RPPTF and RPPOH and in surface dissolved inorganic nitrogen and bottom total phosphorus in the Corrotoman River (CRRMH) (Figure 30). Degrading trends in chlorophyll *a* were detected in the middle (RPPOH) and lower (RPPMH) Rappahannock River, as were degrading trends in water clarity in both the lower Rappahannock River (RPPMH) and Corrotoman River (CRRMH) (Figure 31).

4. Phytoplankton Communities

Status of phytoplankton communities based on the P-IBI was Fair at station LE3.6 in segment RPPMH and Fair-Poor at stations RET3.1 in segment RPPMH and TF3.3 in segment RPPOH. There were no significant trends in the P-IBI (Figure 32). Degrading trends in primary productivity and cyanobacteria biomass were detected at all stations along with a degrading trend in dinoflagellate biomass at station TF3.3 in segment RPPOH (Appendix C - Section D). Increasing trends in cyanobacteria biomass and dinoflagellates are of concern because each of these two categories contain potentially harmful and toxic species. Improving trends in diatom and chlorophyte biomass were detected at stations TF3.3 in segment RPPOH and station RET3.1 in segment RPPMH along with an improving trend in picoplankton biomass at station LE3.6 in segment RPPMH (Appendix C - Section D).

5. Benthic Communities

Benthic community status was degraded or severely degraded at all stations in the Rappahannock River and in general became more degraded moving downstream with both stations in segment RPPMH being severely degraded. In addition, a degrading trend in the B-IBI was detected at station RET3.1 in segment RPPMH (Figure 33). Probability-based benthic monitoring results indicated that 76% of the total area of failed to meet the benthic community goals in the Rappahannock River in 2008 (Table 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. Althought 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 to not reflect actual loads to this river for this parameter; (3) lag times between load reductions and concentrations is longer than the current data; or (4) sources other than non-point source runoff or point source outfalls such as atmospheric deposition 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 Fair-Poor or Fair and increasing trends in primary productivity and cyanobacteria biomass were detected at all stations suggest that phytoplankton communities in the Rappahannock River may be degrading. Benthic community conditions in the Rappahannock River was generally degraded. 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 over 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; however, 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 (Figure 34). Improving long-term or post-method change trends in bottom dissolved inorganic nitrogen were also observed in all segments (Figure 34). Improving long-term or post-method change trends in surface total phosphorus were detected in all segments (Figure 34). Improving post-method change trends in both surface and bottom total suspended solids were observed in all segments of the Mainstem except CB8PH (Figure 35). Despite the improvements in both nutrients and suspended solids, there were no concomitant improvements in chlorophyll *a* and only one improving trend in bottom dissolved oxygen was observed (Figure 35). In addition, degrading trends in water clarity were observed in all segments of Mainstem (Figure 35).

2. Phytoplankton Communities

Status of phytoplankton communities in the Virginia Chesapeake Bay Mainstem based on the P-IBI was Fair or Fair-Good at all stations and no significant trends were detected in the P-IBI (Figure 36). Degrading trends in cyanobacteria biomass were detected at all stations in the Bay Mainstem while degrading trends were detected in the Margalef diversity index at all stations except CB6.1 in segment CB6PH (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). Improving trends in picoplankton biomass were detected at stations CB6.1 and CB6.4 in segment CB6PH.

3. Benthic Communities

Status in benthic communities at the fixed point stations was severely degraded at station CB5.4 and marginal at station CB6.1 in segment CB6PH and good at all remaining stations in the Virginia Chesapeake Bay Mainstem. There were no trends in the B-IBI at any Mainstem stations (Figure 37) and relatively few trends in any of the individual benthic bioindicators (Appendix F - Section E). Probability-based benthic monitoring results for 2008 indicated that 36% of the total area of the Virginia Chesapeake Bay Mainstem was impaired (Table 4).

4. Management Issues

Water quality conditions based on the WQI were only 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 three reports. Reductions in water clarity do not appear to be related to changes in total suspended solids concentrations and do not reflect the improvements observed in nutrients. The lack of long term changes in freshwater input suggest that there is a limited connection between trends in water clarity and changes in the flow regime. However a more rigorous statistical investigation of the relationships between water clarity (Secchi depth) and other water quality parameters as well as other potential causative factors such as freshwater flow, individual phytoplankton groups or species, colored dissolved organic material is required before the underlying causes of poor water clarity in the Mainstem can be adequately explained.

With respect to living resources, the Virginia Chesapeake Bay Mainstem was probably the least impacted of all of the basins examined in this report. Phytoplankton community status, as measured using the P-IBI was Fair or Fair-good at all stations. However, there are some indications that phytoplankton communities may be degrading as indicated by the increasing trends in productivity, decreasing trends in species diversity and increasing trends in cyanobacteria and dinoflagellate biomass 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. No trends were observed for the B-IBI but it met the restoration goal at most stations and only 36% of the total area of Virginia Chesapeake Bay Mainstem failed to meet benthic restoration goals.

V. Conclusions

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.

- Model output indicates that estimates of NPS nutrient (Appendix H) and sediment loadings have declined.
- PS loads of both nitrogen and phosphorus have declined in most areas however, increasing trends in loads were observed in some areas (e.g. nitrogen in the Rappahannock River).
- 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 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,
  - widespread 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 both cyanobacteria and 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 in combination with other factors (e.g. reduced oyster and menhaden populations).

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

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Tables

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

A. Total Chesapeake Bay and Virginia Watersheds

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

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

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

Table 2. Long-term trends in freshwater flow at USGS fall-line stations in the Virginia tributaries for the period of 1985 through 2008. Station numbers refer to the station locations presented in Figure 1.

River (Station #)	P value	Slope	Baseline Mean	% Change	Direction	Homogeneity test P value
James River (3)	0.0245	-32.93	3575.00	-22.11	No Trend	0.9926
Appomattox River (1)	0.0689	-4.07	466.00	-20.98	No Trend	0.9703
Chickahominy River (2)	0.5764	0.38	133.00	6.77	No Trend	0.7127
Pamunkey River (6)	0.0532	-3.55	341.25	-24.99	No Trend	0.9961
Mattaponi River (8)	0.3265	-1.50	264.50	-13.61	No Trend	0.9988
Rappahannock River (9)	0.9031	-0.83	680.00	-2.92	No Trend	0.9945

Table 3. 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, 2008. Map ID #'s in parentheses refer to the station locations identified in Figure 1. Results presented in this table were provided by the U.S. Geological Survey.

		Flow Adjusted Trend					
Station Name (Map ID #)	Parameter	Kendall τ	*P* value	LCI	Slope	UCI	Direction
Appomattox River at Matoaca (1)	TN	0.0281	0.5636	-6.5	2.9	13.1	NS
Appomattox River at Matoaca (1)	NO23	-0.1865	0.1103	-34.0	-17.0	4.3	NS
Appomattox River at Matoaca (1)	TP	0.2208	0.0056	6.7	24.7	45.8	Degrading
Appomattox River at Matoaca (1)	DIP	-0.2022	0.0369	-32.4	-18.3	-1.2	Improving
Appomattox River at Matoaca (1)	TSS	0.0322	0.7178	-13.3	3.3	23.0	NS
Chickahominy River near Providence Forge (2)	TN	-0.1493	0.0116	-23.3	-13.9	-3.3	Improving
Chickahominy River near Providence Forge (2)	NO23	0.1661	0.2850	-12.9	18.1	60.1	NS
Chickahominy River near Providence Forge (2)	TP	0.0027	0.9794	-18.2	0.3	23.0	NS
Chickahominy River near Providence Forge (2)	TSS	-0.2342	0.1700	-43.4	-20.9	10.6	NS
James River near Richmond (3)	TN	-0.1658	0.0249	-26.7	-15.3	-2.1	Improving
James River near Richmond (3)	NO23	-0.6088	<0.000	-59.2	-45.6	-27.5	Improving
James River near Richmond (3)	TP	-0.1706	0.2120	-35.5	-15.7	10.3	NS
James River near Richmond (3)	TSS	0.2957	0.0679	-2.2	34.4	84.6	NS
James River at Cartersville (4)	TN	-0.2266	0.0001	-28.9	-20.3	-10.6	Improving
James River at Cartersville (4)	NO23	-0.3778	<0.000	-43.0	-31.5	-17.6	Improving
James River at Cartersville (4)	TP	-0.9206	<0.000	-66.9	-60.2	-52.1	Improving
James River at Cartersville (4)	DIP	-1.8547	<0.000	-87.2	-84.3	-80.8	Improving
James River at Cartersville (4)	TSS	-0.1495	0.2088	-31.8	-13.9	8.7	NS
James River at Bent Creek (5)	TN	-0.1275	0.1350	-25.6	-12.0	4.1	NS
James River at Bent Creek (5)	NO23	-0.4510	0.0016	-51.7	-36.3	-15.9	Improving
James River at Bent Creek (5)	TP	-1.6926	<0.000	-87.1	-81.6	-73.6	Improving
James River at Bent Creek (5)	TSS	0.1225	0.6552	-34.0	13.0	93.5	NS
Pamunkey River near Hanover (6)	TN	0.1473	0.0010	6.1	15.9	26.5	Degrading
Pamunkey River near Hanover (6)	NO23	0.3389	<0.000	23.7	40.3	59.3	Degrading
Pamunkey River near Hanover (6)	TP	0.7034	<0.000	72.2	102.1	137.2	Degrading
Pamunkey River near Hanover (6)	DIP	0.6103	<0.000	55.6	84.1	117.9	Degrading
Pamunkey River near Hanover (6)	TSS	0.5865	<0.000	37.7	79.8	134.8	Degrading
North Anna River at Hart Corner (7)	TN	0.0900	0.1260	-2.5	9.4	22.8	NS
North Anna River at Hart Corner (7)	NO23	-0.1283	0.1496	-26.1	-12.0	4.7	NS
North Anna River at Hart Corner (7)	TP	0.4451	0.0008	20.4	56.1	102.3	Degrading
North Anna River at Hart Corner (7)	TSS	1.1377	<0.000	85.6	211.9	424.2	Degrading
Mattaponi River near Beulahville (8)	TN	-0.0327	0.3978	-10.3	-3.2	4.4	NS
Mattaponi River near Beulahville (8)	NO23	0.0372	0.6840	-13.2	3.8	24.1	NS
Mattaponi River near Beulahville (8)	TP	-0.0814	0.1838	-18.2	-7.8	3.9	NS
Mattaponi River near Beulahville (8)	DIP	-0.4090	<0.000	-43.6	-33.6	-21.8	Improving
Mattaponi River near Beulahville (8)	TSS	-0.0268	0.8117	-21.9	-2.6	21.4	NS
Rappahannock River near Fredericksburg (9)	TN	-0.1080	0.1138	-21.5	-10.2	2.6	NS
Rappahannock River near Fredericksburg (9)	NO23	-0.2343	0.0779	-39.0	-20.9	2.6	NS
Rappahannock River near Fredericksburg (9)	TP	-0.2168	0.0432	-34.8	-19.5	-0.7	Improving
Rappahannock River near Fredericksburg (9)	DIP	-0.1232	0.2075	-27.0	-11.6	7.1	NS
Rappahannock River near Fredericksburg (9)	TSS	-0.1839	0.2666	-39.8	-16.8	15.1	NS
Robinson River near Locust Dale (10)	TN	-0.1736	0.0031	-25.0	-15.9	-5.7	Improving
Robinson River near Locust Dale (10)	NO23	-0.2744	0.0007	-35.0	-24.0	-11.1	Improving
Robinson River near Locust Dale (10)	TSS	-0.0353	0.8538	-33.7	-3.5	40.5	NS
Robinson River near Locust Dale (10)	TP	-0.4110	0.0525	-56.2	-33.7	0.5	NS

Table 4. 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 2008.

Stratum	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Virginia Mainstem	330	494	659	1,483	36.0
Rappahannock River	194	45	45	283	76.0
York River	60	30	37	127	68.0
James River	164	219	164	547	80.0

Figures

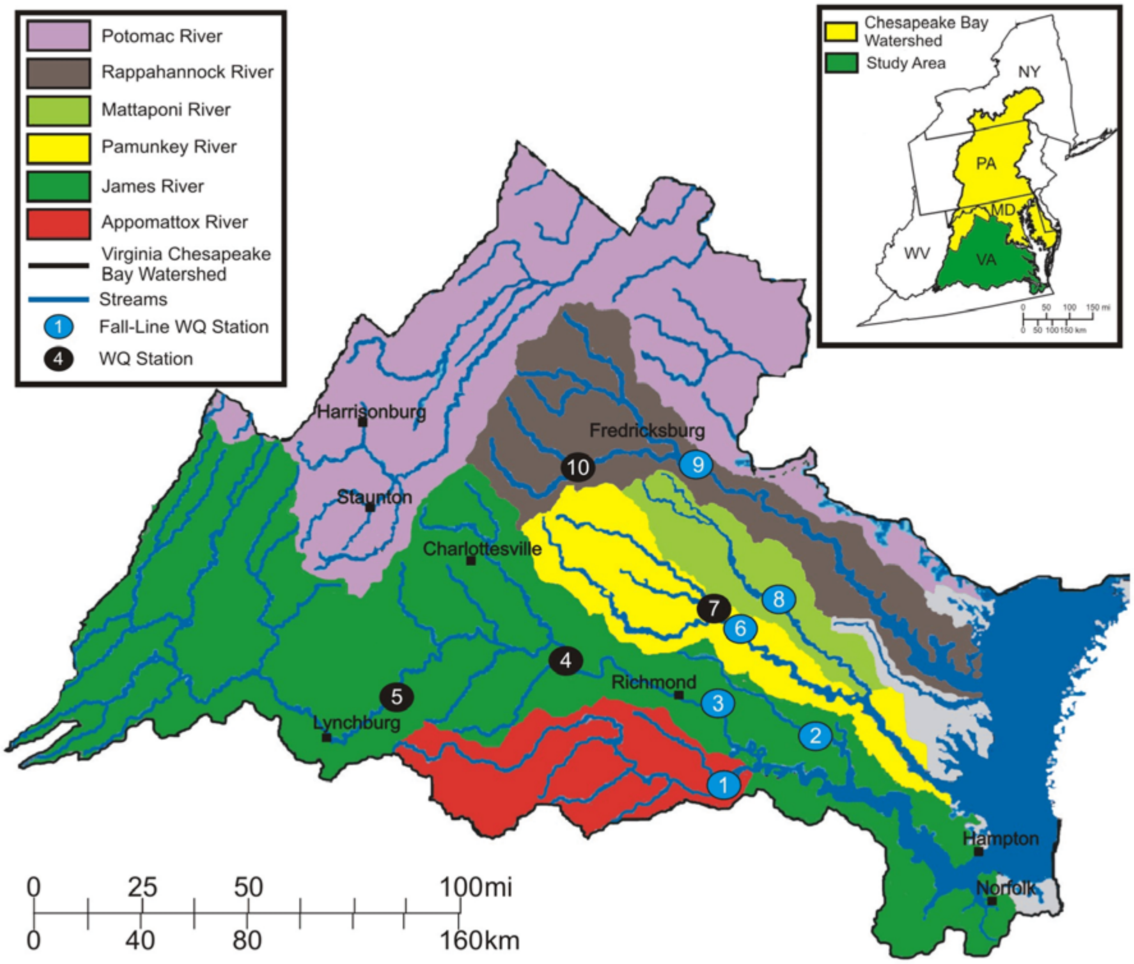


Figure 1. Locations of the USGS/DEQ River Input Monitoring stations in each of the Virginia tributaries.

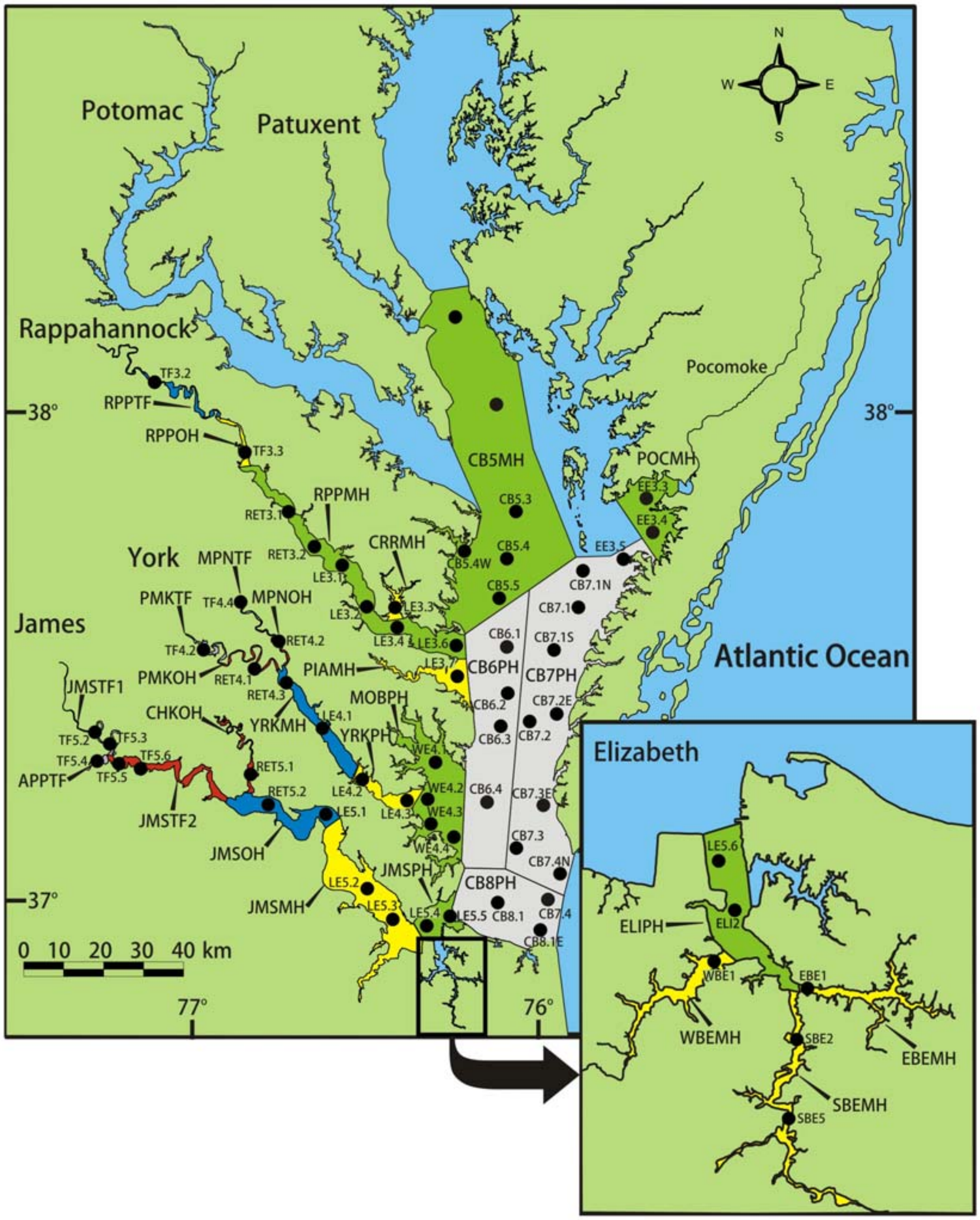


Figure 2. Chesapeake Bay Program segmentation scheme for the Virginia tributaries and Lower Chesapeake Bay Mainstem. Also shown are the locations of stations used in the statistical analyses. Segment colors are used solely to aid in delineating segment boundaries.

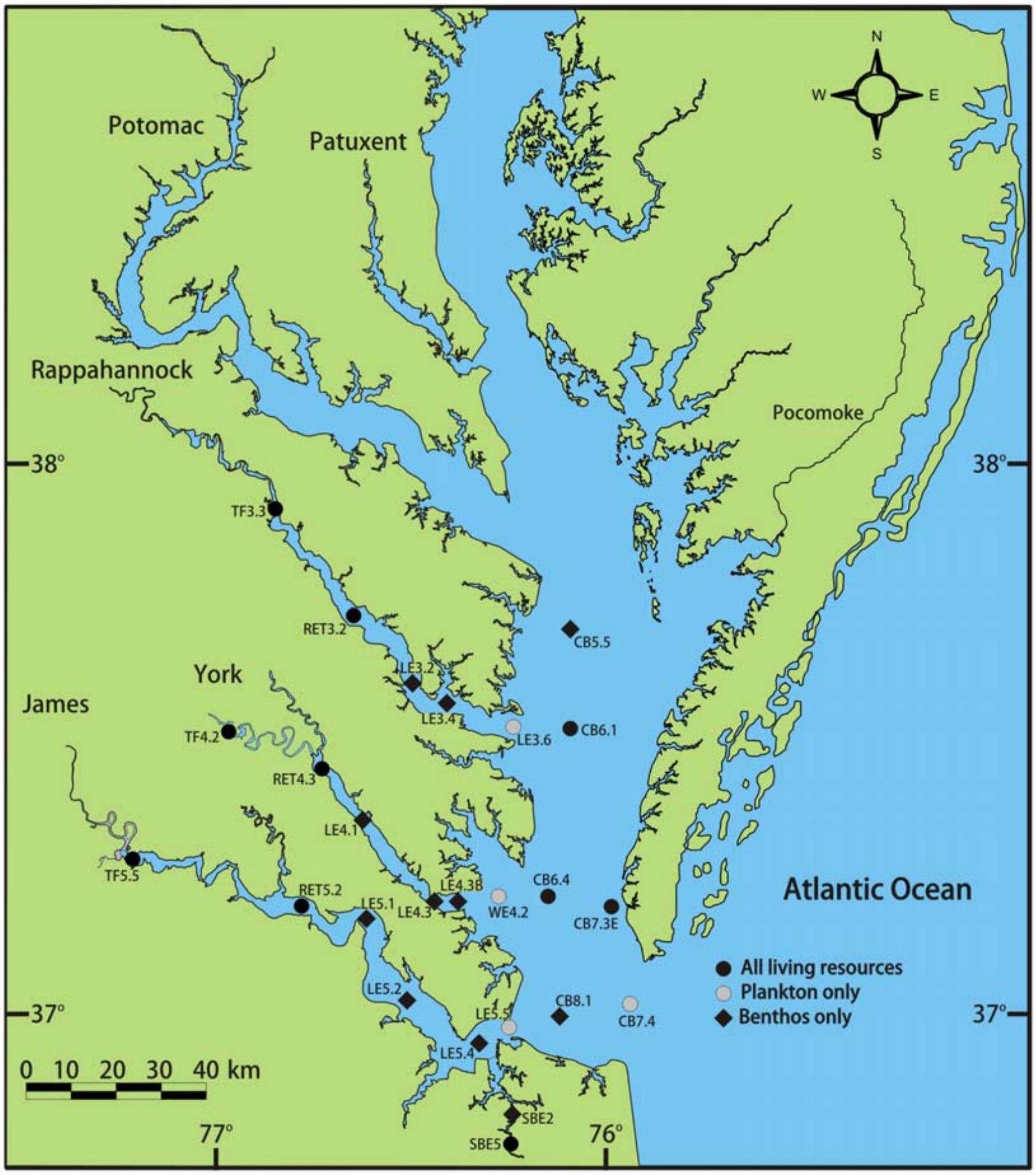


Figure 3. Living resource monitoring stations in the Virginia tributaries and the Lower Chesapeake Bay Mainstem and their associated CBP segments.

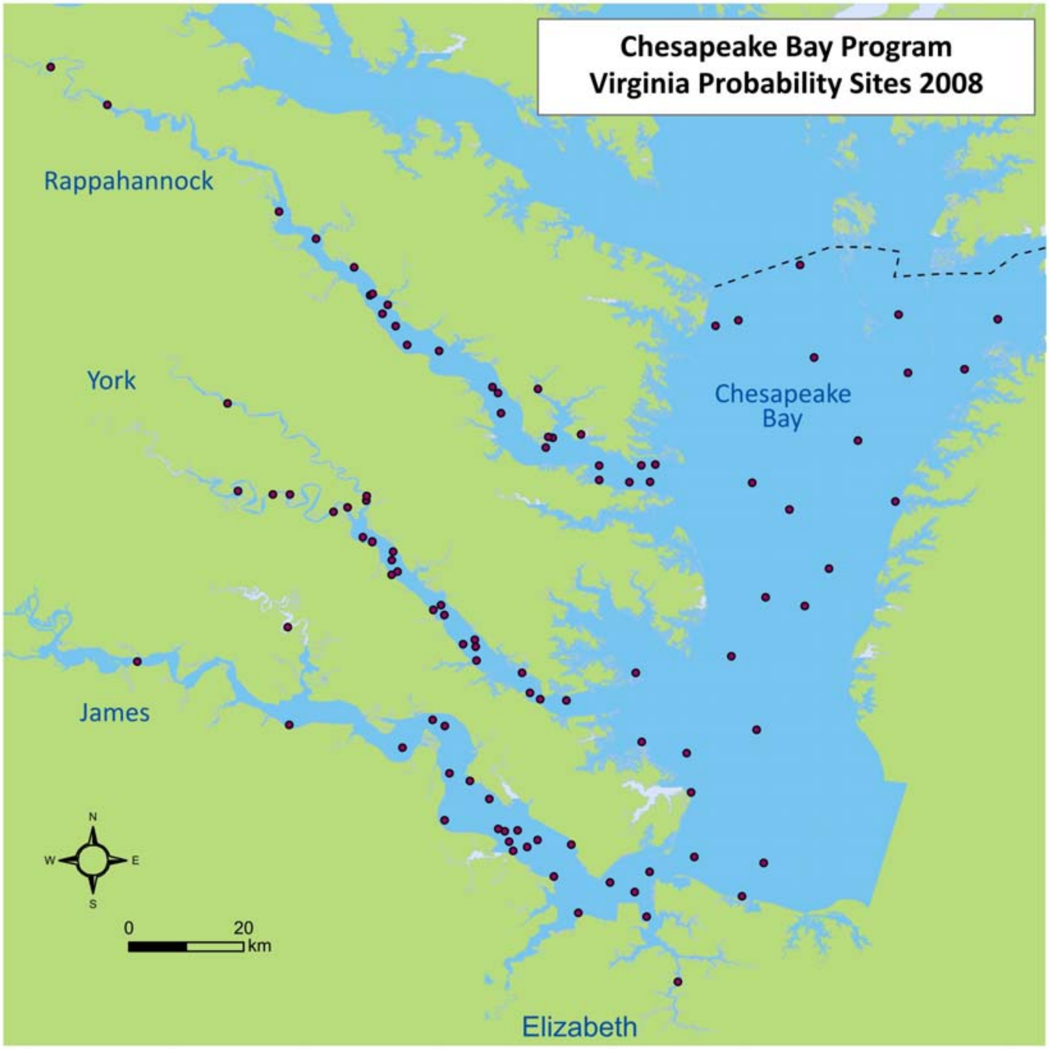
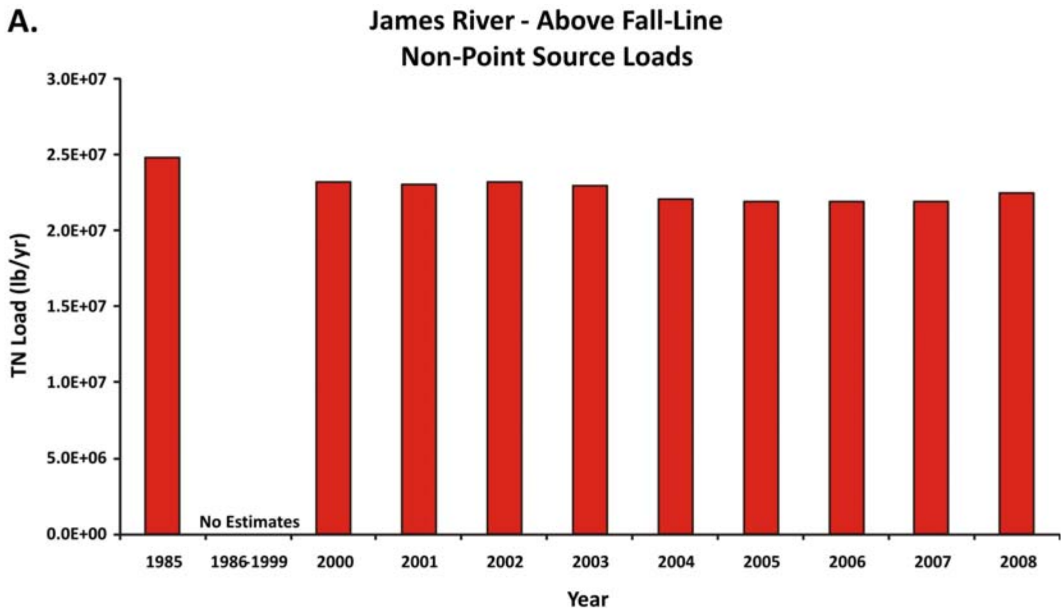


Figure 4. Locations of the probability-based benthic monitoring stations in Virginia for 2008.



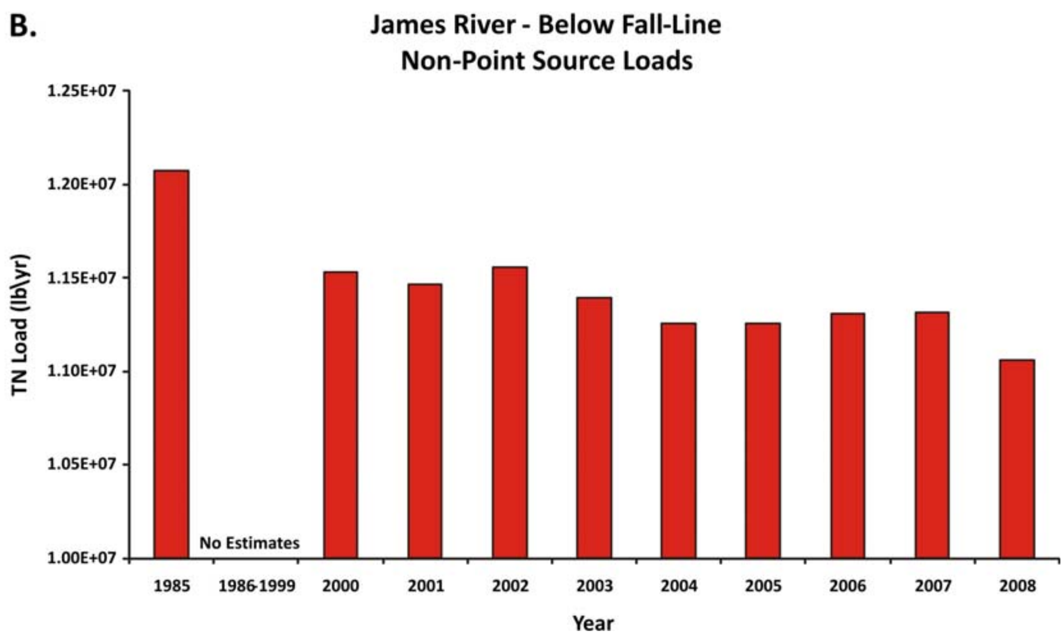
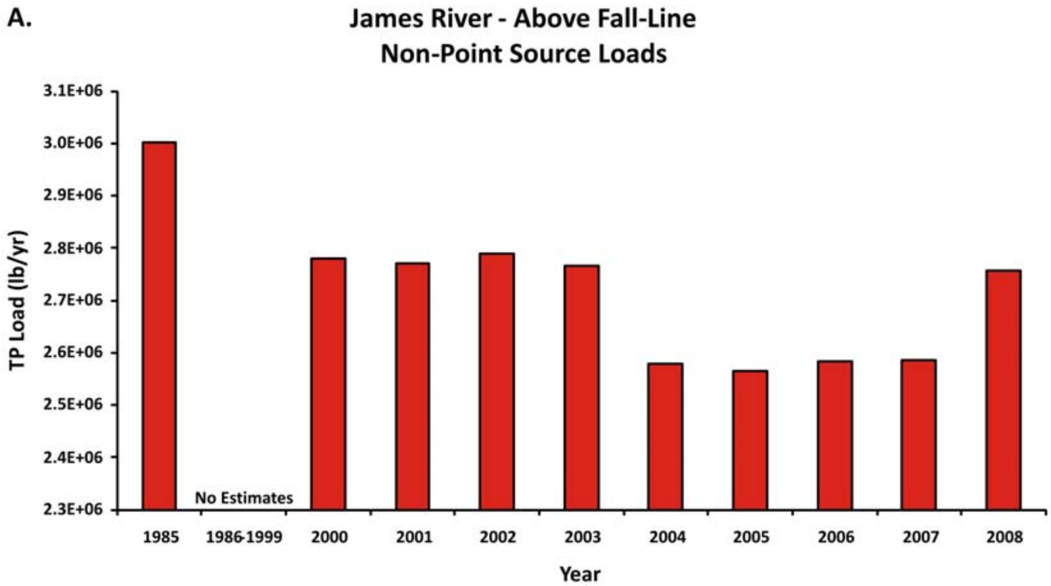


Figure 5. Long-term changes in non-point source total nitrogen loads A. Above the Fall-line, and B. Below the Fall-line in the James River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.



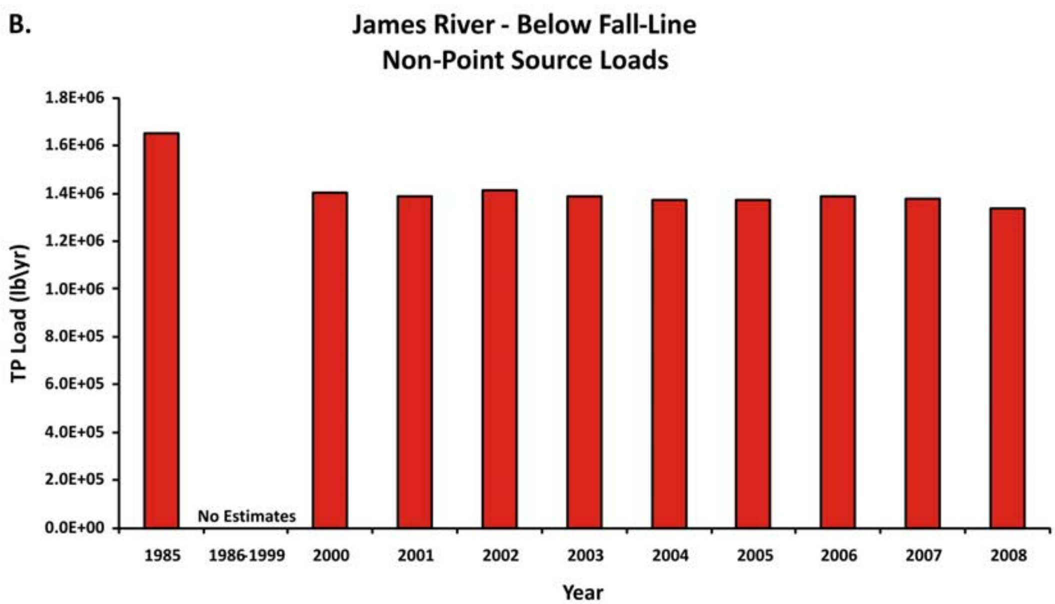
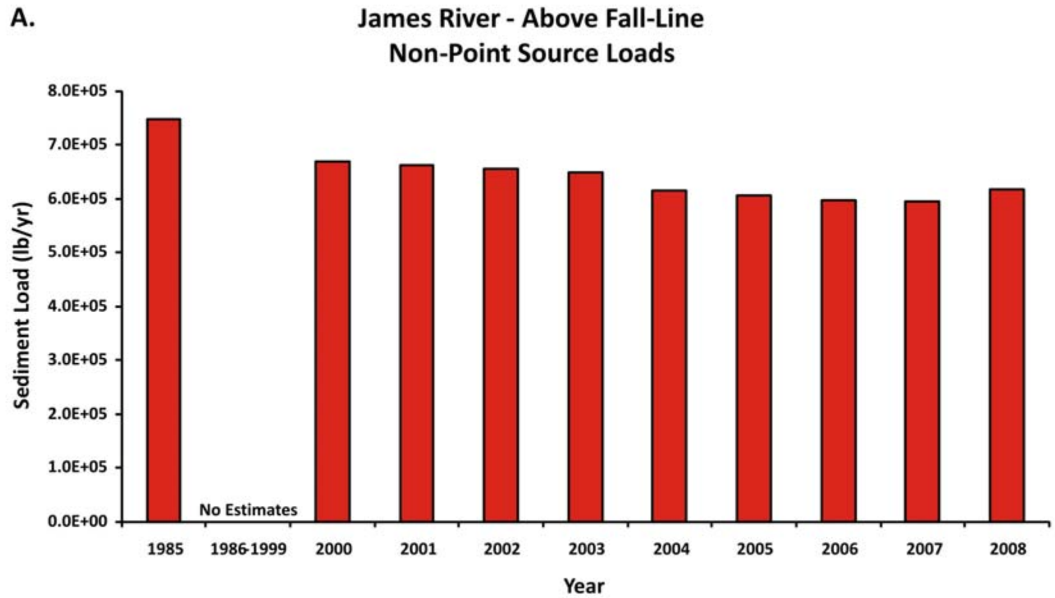


Figure 6. Long-term changes in non-point source total phosphorus loads A. Above the Fall-line, and B. Below the Fall-line in the James River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.



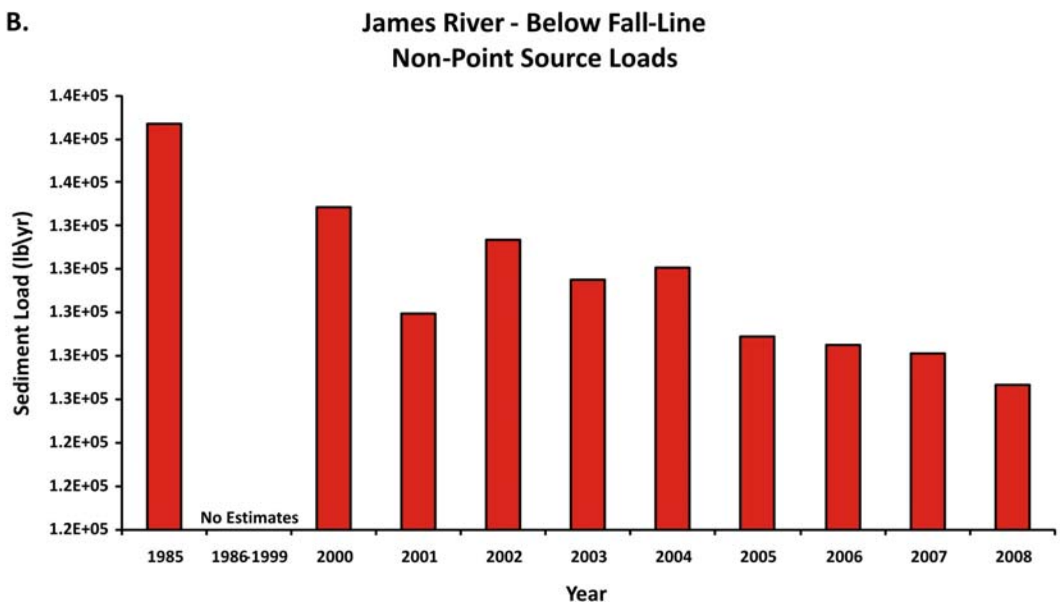
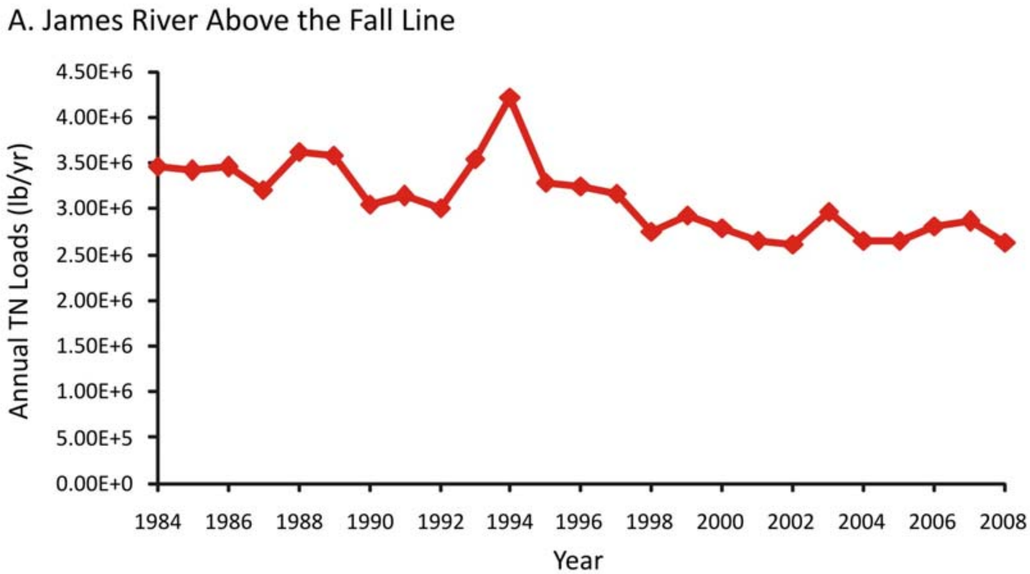


Figure 7. Long-term changes in non-point source total sediment loads A. Above the Fall-line, and B. Below the Fall-line in the James River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.



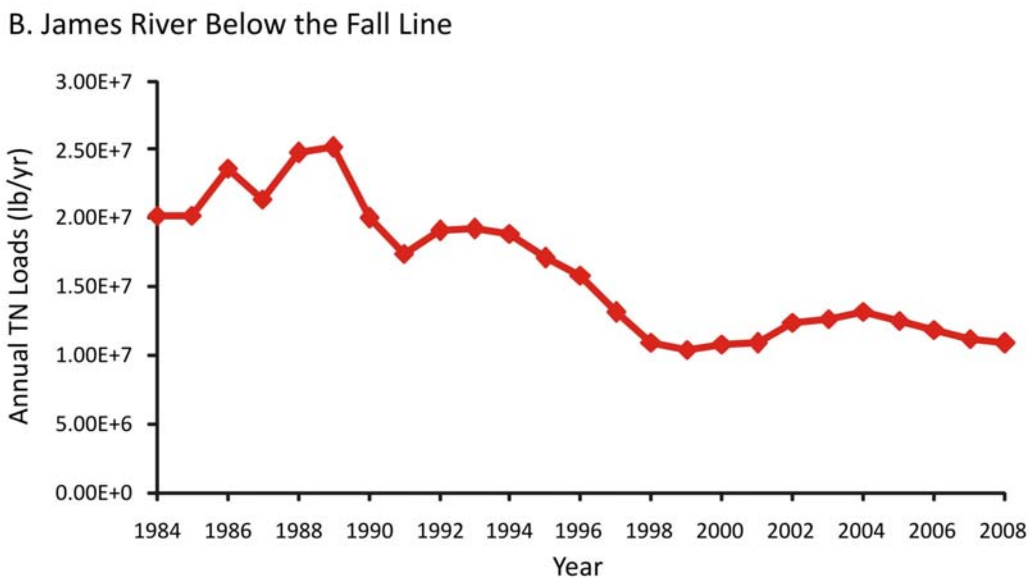
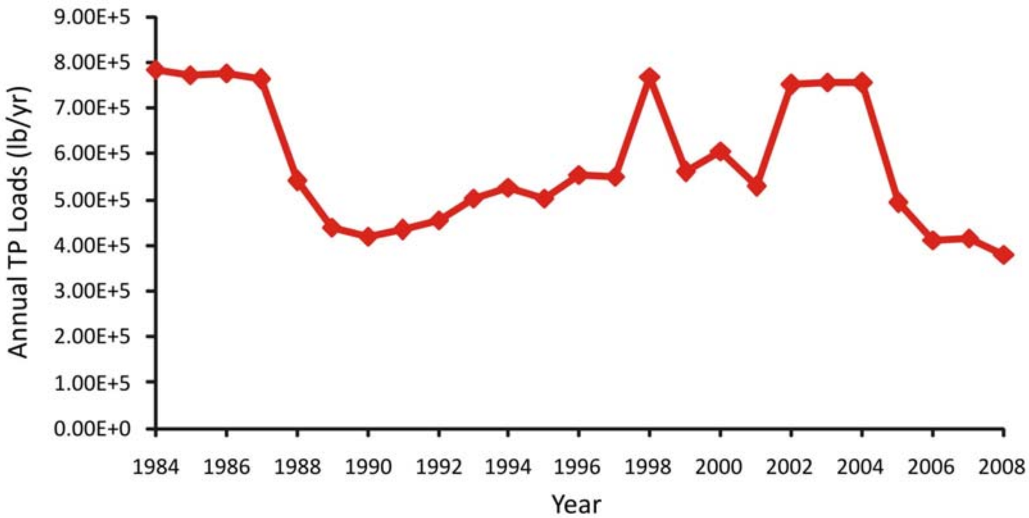


Figure 8. Long-term changes in point source total nitrogen loads A. Above the Fall-line, and B. Below the Fall-line in the James River for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system.

A. James River Above the Fall Line



B. James River Below the Fall Line

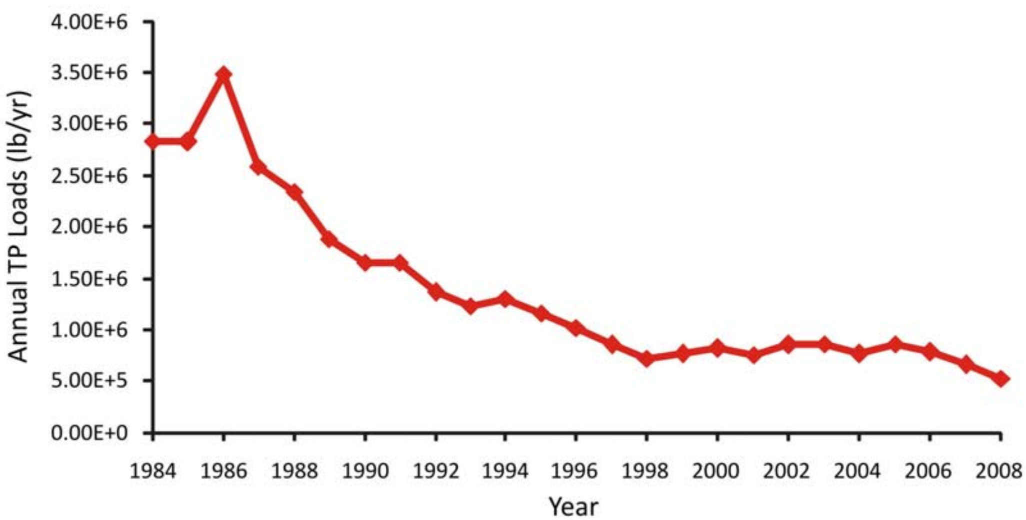


Figure 9. Long-term changes in point source total phosphorus loads A. Above the Fall-line, and B. Below the Fall-line in the James River for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers as part of the voluntary NPDES system.

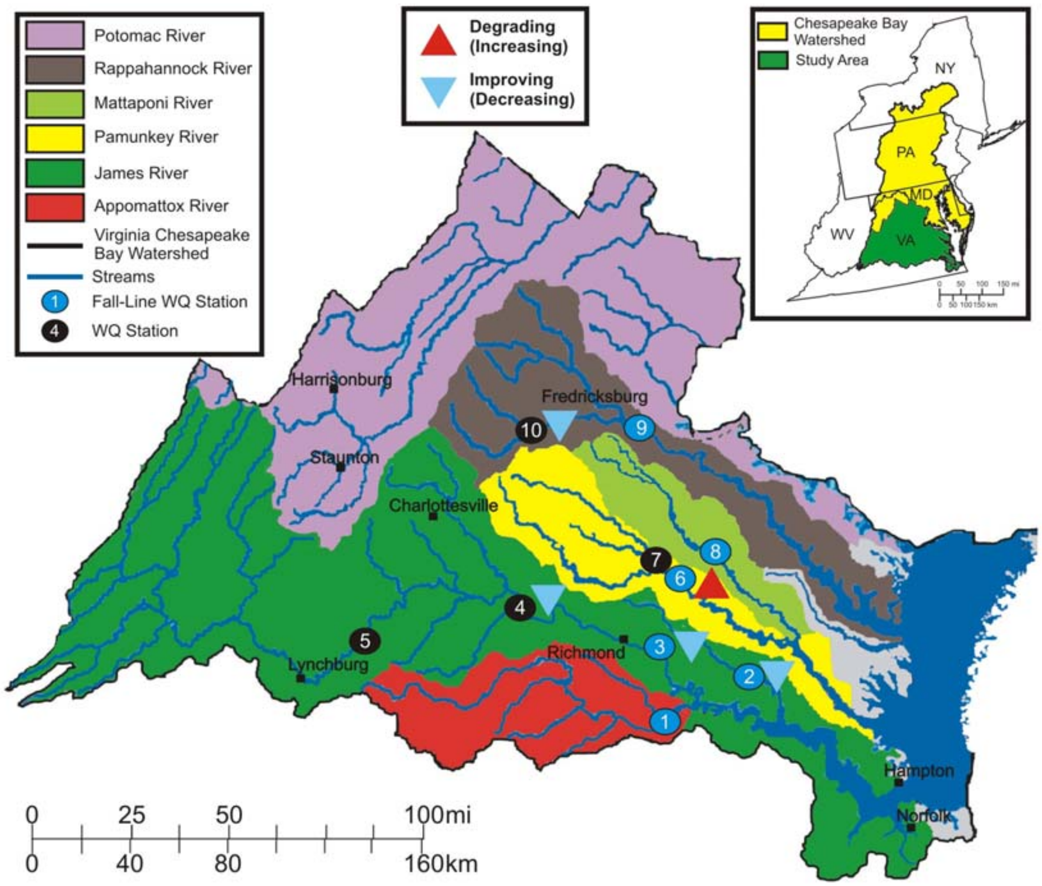


Figure 10. Long-term trends in flow-adjusted total nitrogen at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2008. Arrows indicate trends significant at $P \leq 0.05$.

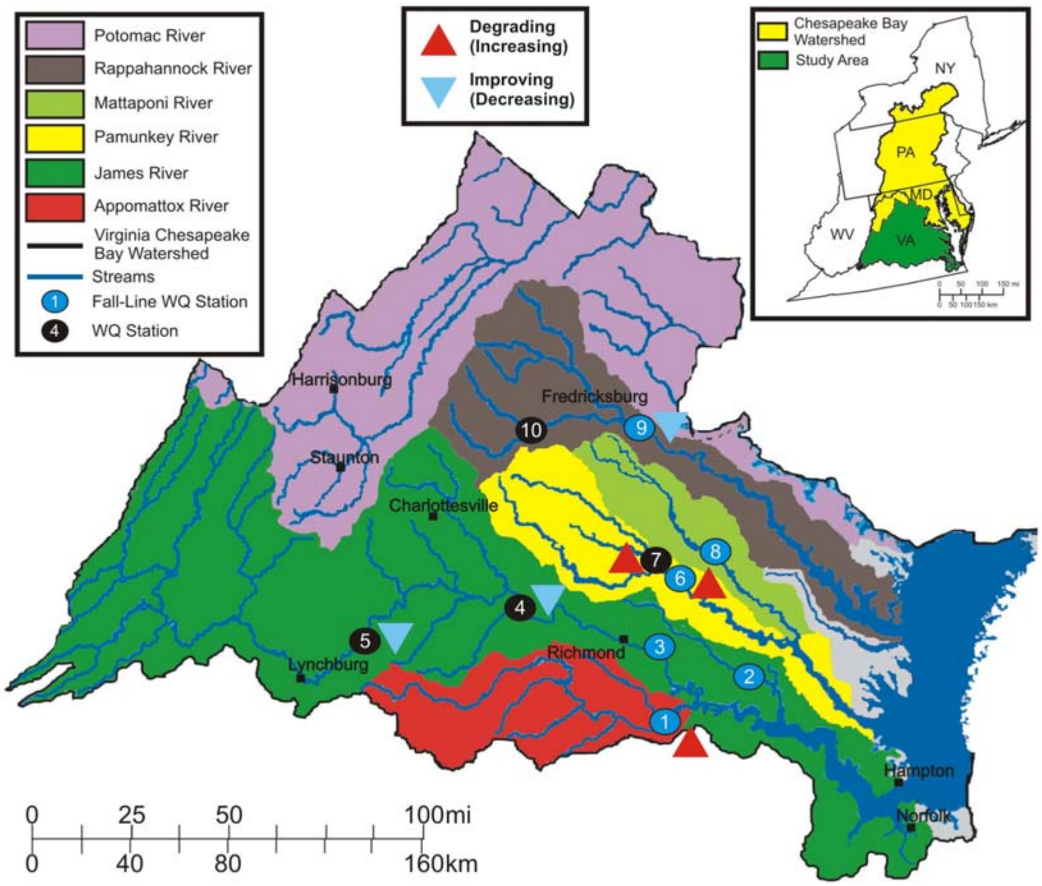


Figure 11. Long-term trends in flow-adjusted total phosphorus at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2008. Arrows indicate trends significant at $P \leq 0.05$.

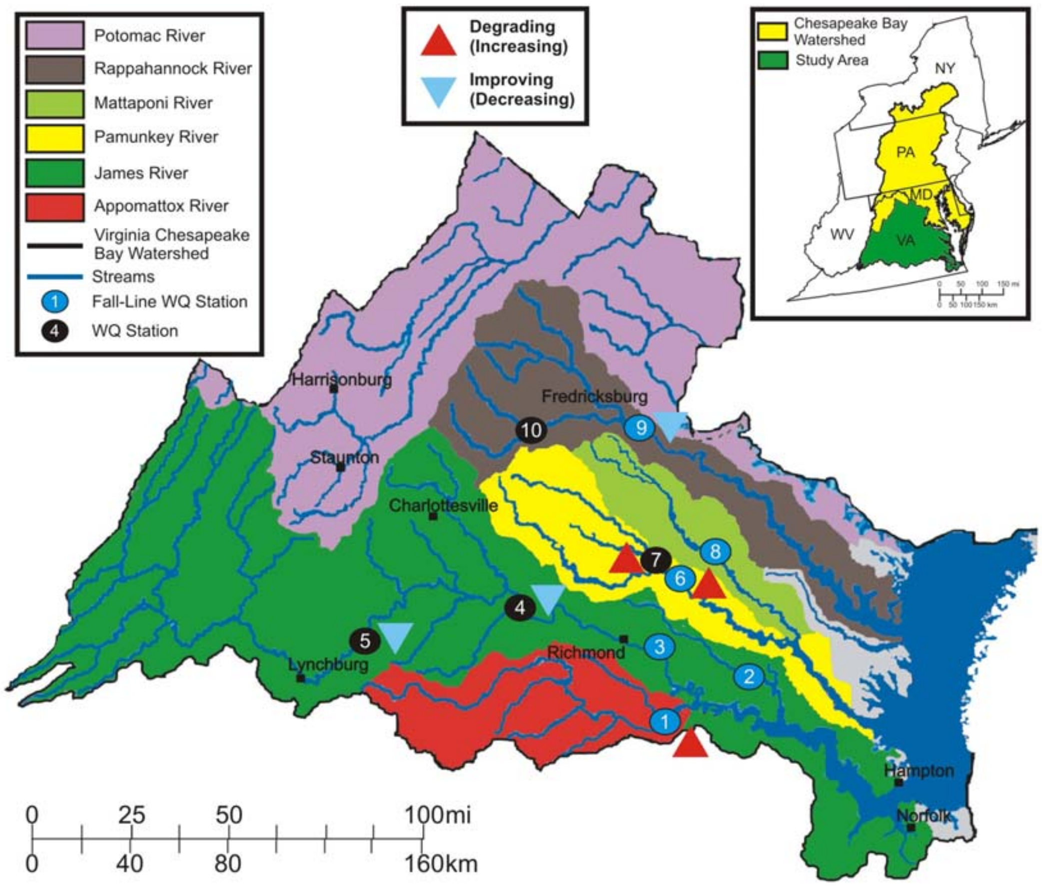
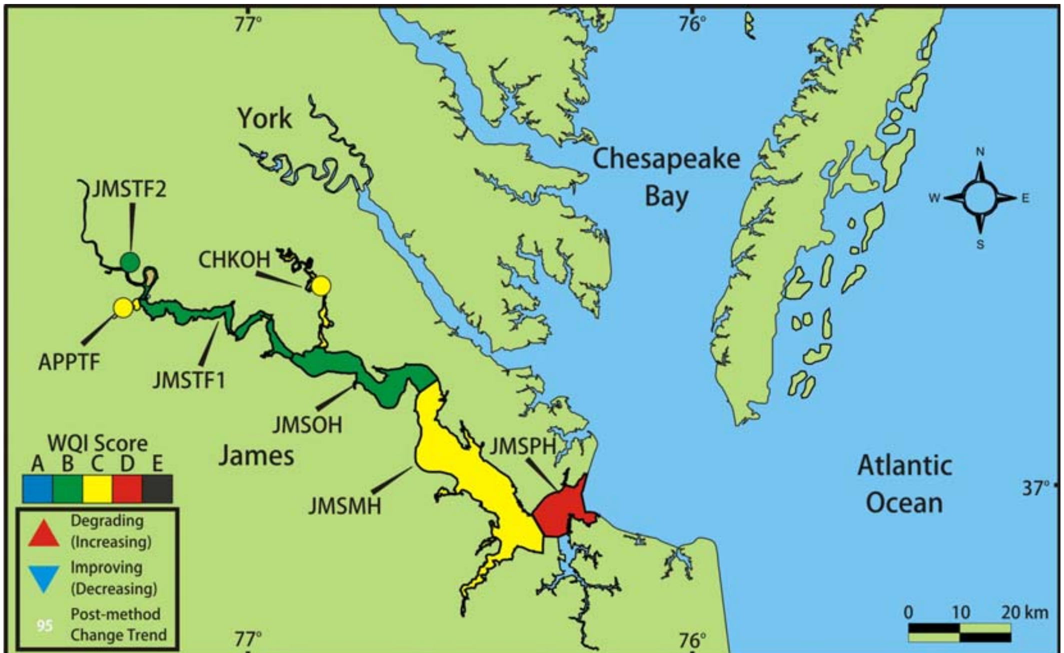
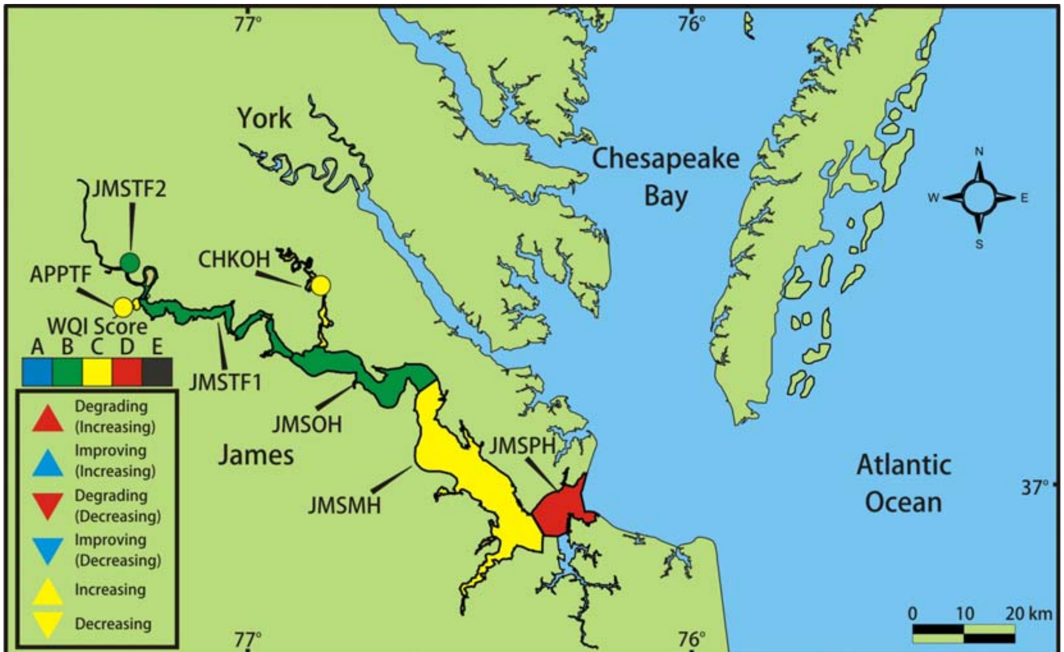


Figure 12. Long-term trends in flow-adjusted total suspended solids at USGS/DEQ stations in the non-tidal portion of the Virginia tributaries for the period of 1985 through 2008. Arrows indicate trends significant at $P \leq 0.05$.



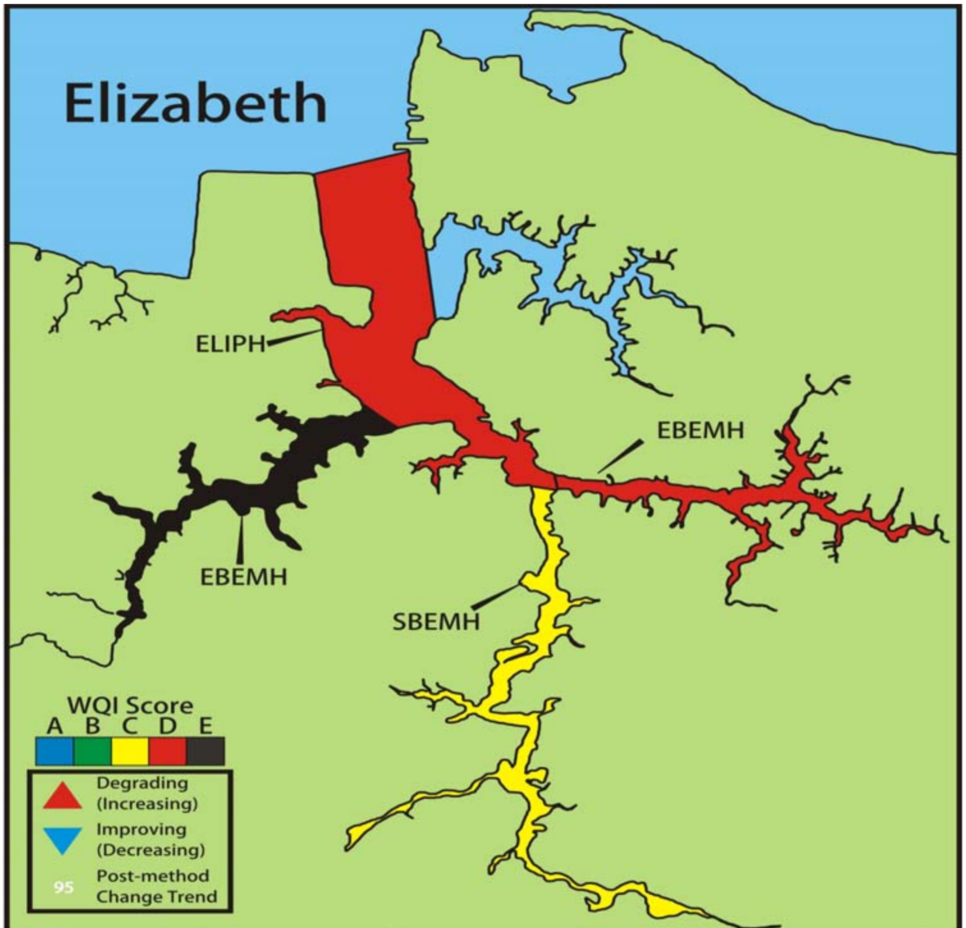
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
STN							
BTN			▼				
SDIN							
BDIN		▲ 95					
STP		▼	▼ 95				
BTP		▼					
SDIP	▼	▼	▼	▼			
BDIP	▼	▼	▼	▼			

Figure 13. 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 2008. 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 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.



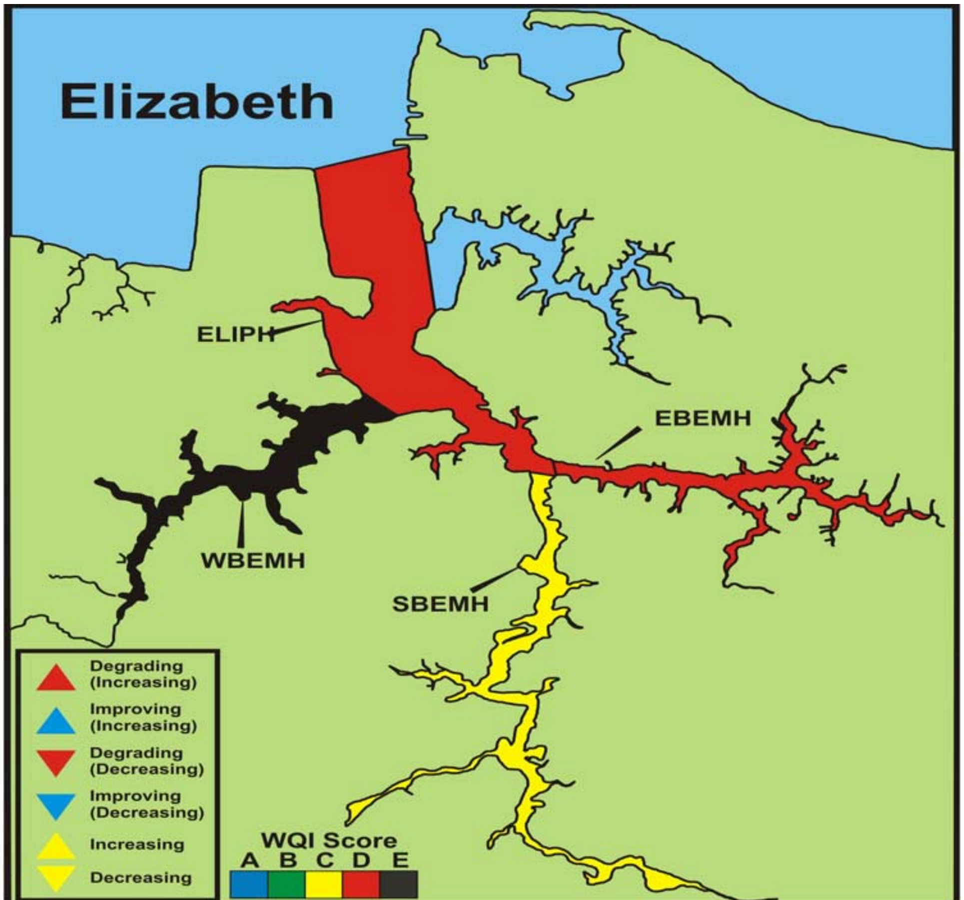
Parameter	APPTF	JMSTF2	JMSTF1	CHKOH	JMSOH	JMSMH	JMSPH
SCHLA				▼ (blue)			▲ (red)
STSS							
BTSS				▲ (red)		▲ (red)	▼ (blue)
SECCHI			▼ (red)	▼ (red)			▼ (red)
BDO					▼ (red)		▲ (blue)
SSALIN					▲ (yellow)		
BSALIN					▲ (yellow)		▼ (yellow)
SWTEMP	▲ (yellow)						
BWTEMP							▲ (yellow)

Figure 14. Water quality status and long-term trends in non-nutrient parameters in the tidal portion of the James River basin for the period of 1985 through 2008. 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. 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 15. 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 2008. 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. 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	▼ (blue)	▼ (blue)	▼ (blue)	▼ (blue)
BTSS	▼ (blue)	▼ (blue)	▼ (blue)	
SECCHI				▼ (red)
BDO		▲ (blue)		
SSALIN		▲ (yellow)		
BSALIN				
SWTEMP		▲ (yellow)	▲ (yellow)	
BWTEMP		▲ (yellow)	▲ (yellow)	

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 2008. 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. 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.

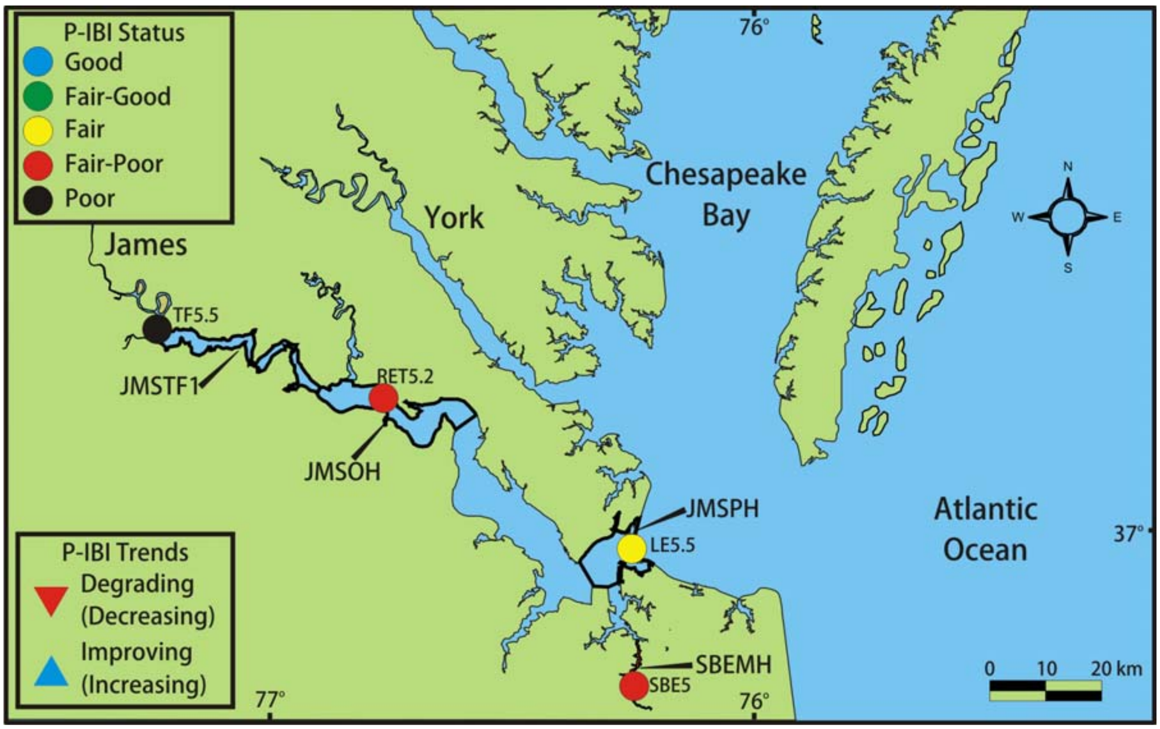


Figure 17. Status and long-term trends in phytoplankton community condition in the tidal portion of the James River basin for the period of 1985 through 2008. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2008.

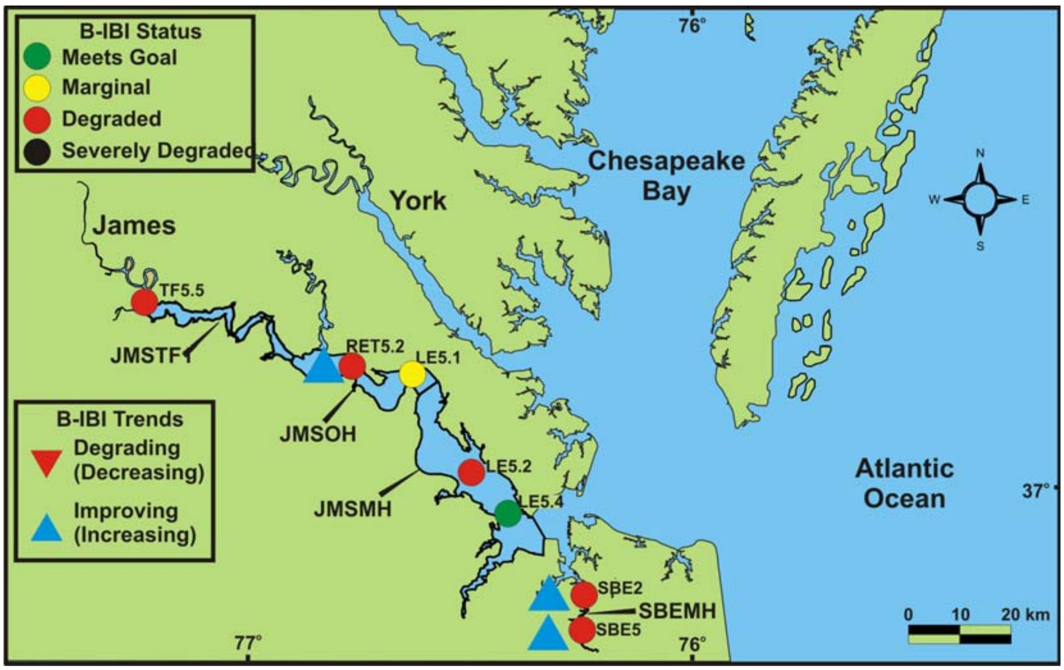


Figure 18. Status and long-term trends in benthic community condition in the tidal portion of the James River basin for the period of 1985 through 2008. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2008.

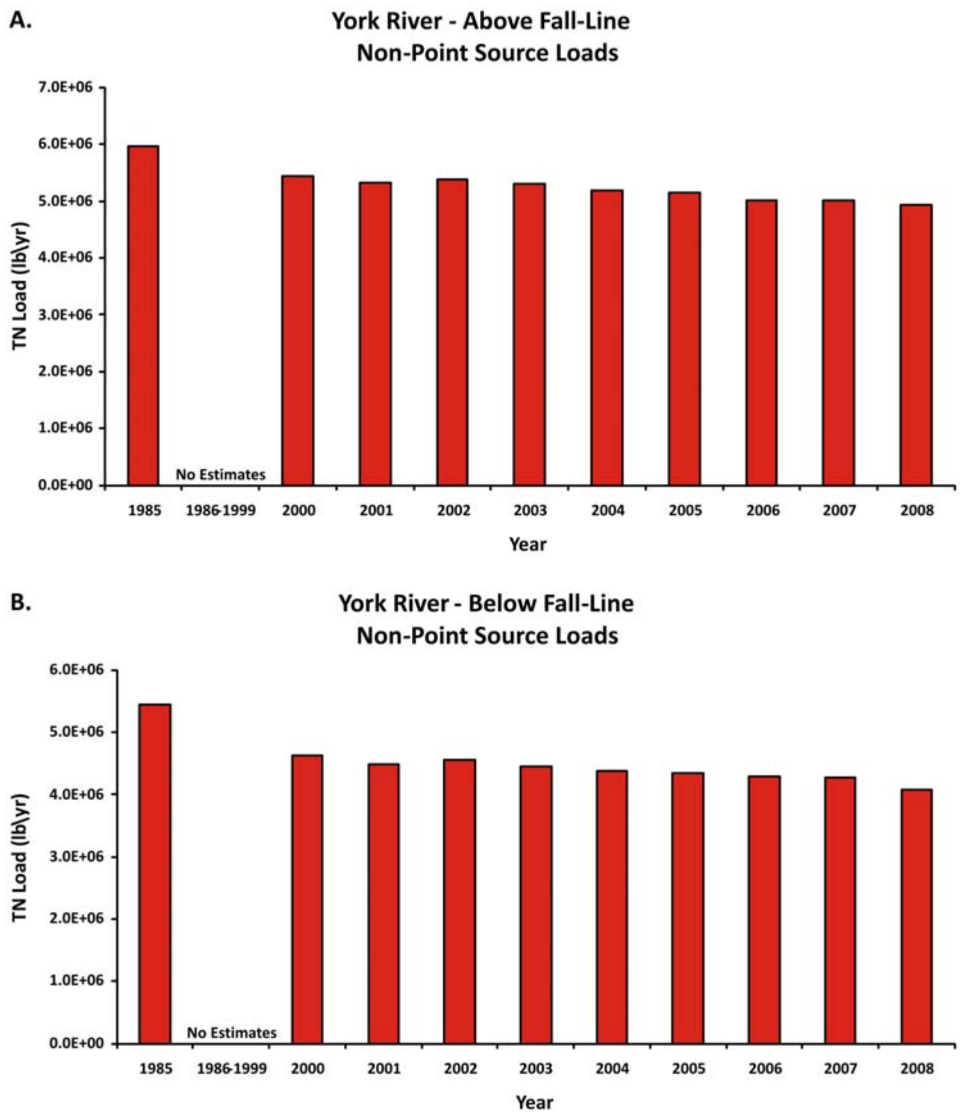
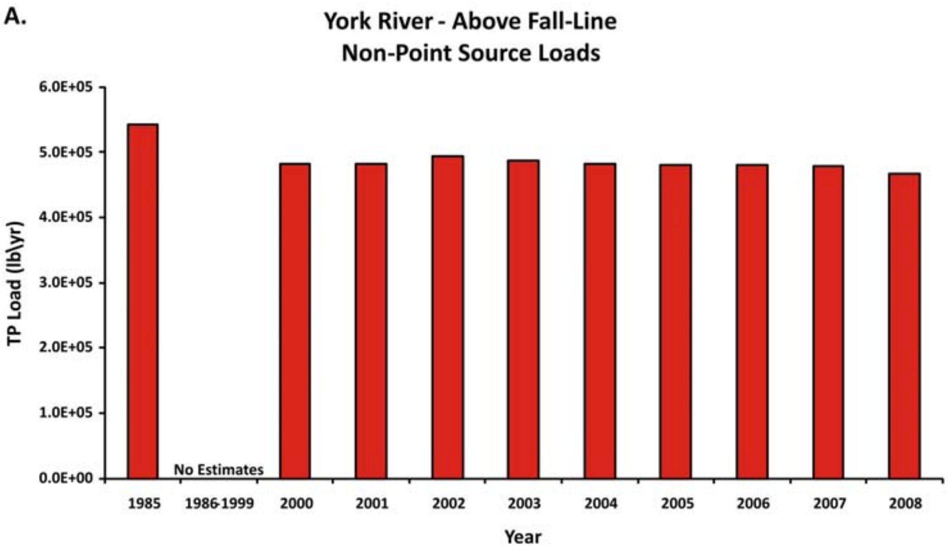


Figure 19. Long-term changes in non-point source total nitrogen loads A. Above the Fall-line, and B. Below the Fall-line in the York River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.

A.



B.

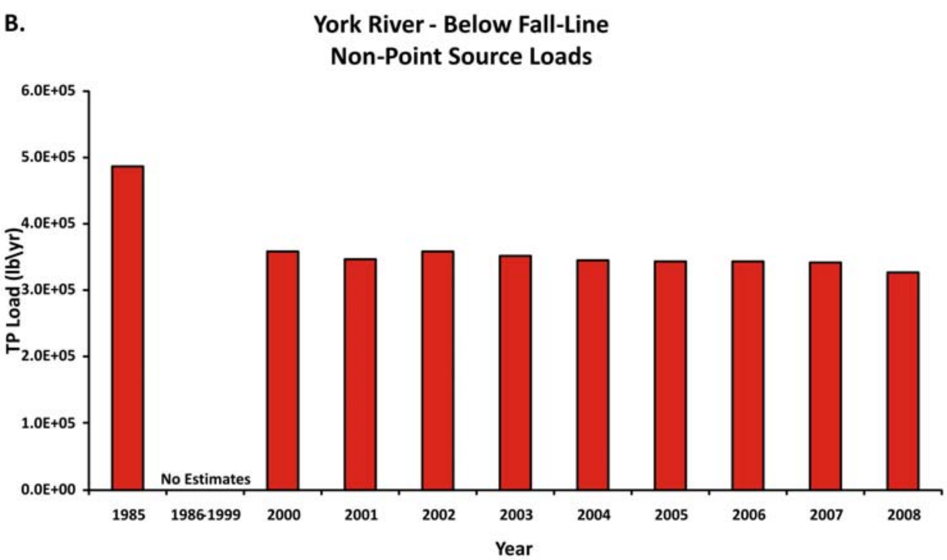


Figure 20. Long-term changes in non-point source total phosphorus loads A. Above the Fall-line, and B. Below the Fall-line in the York River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.

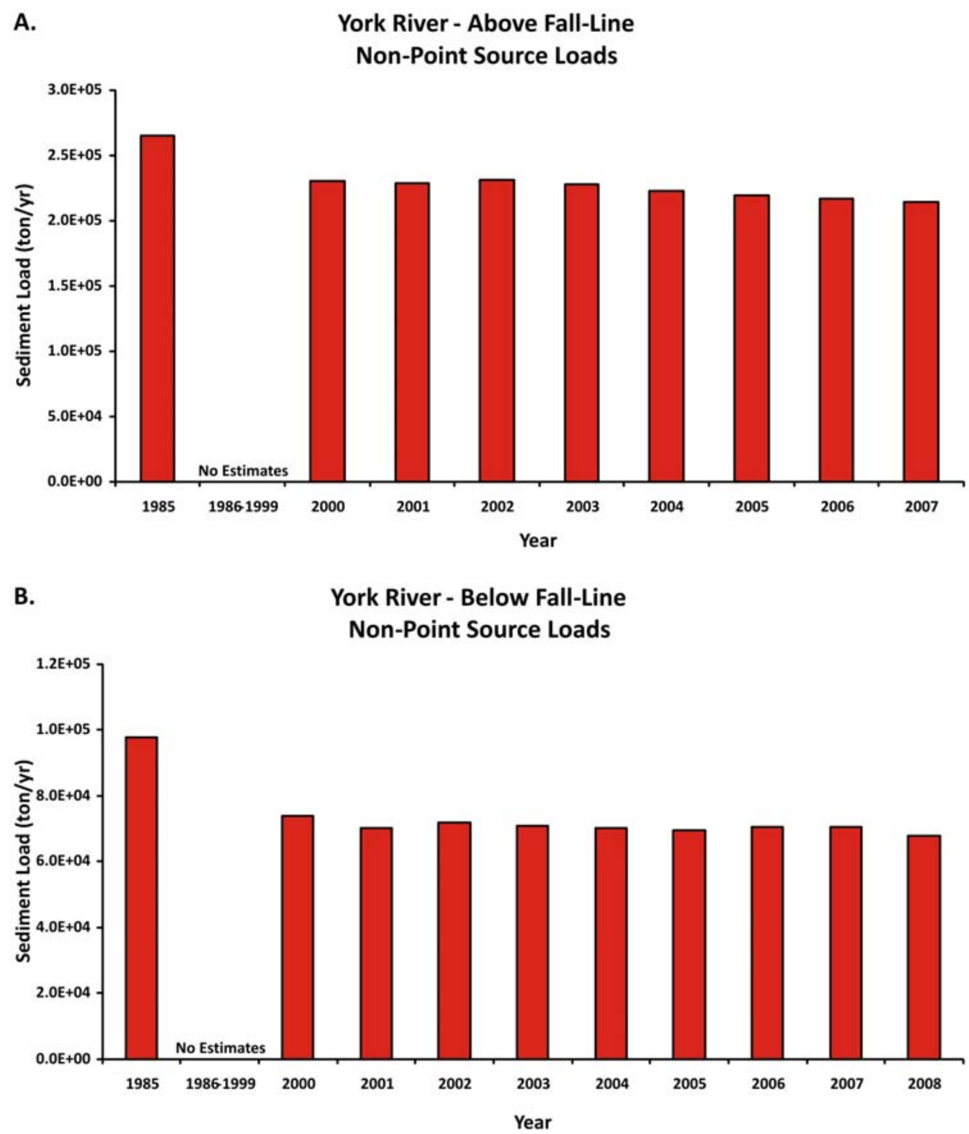


Figure 21. Long-term changes in non-point source total sediment loads A. Above the Fall-line, and B. Below the Fall-line in the York River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.

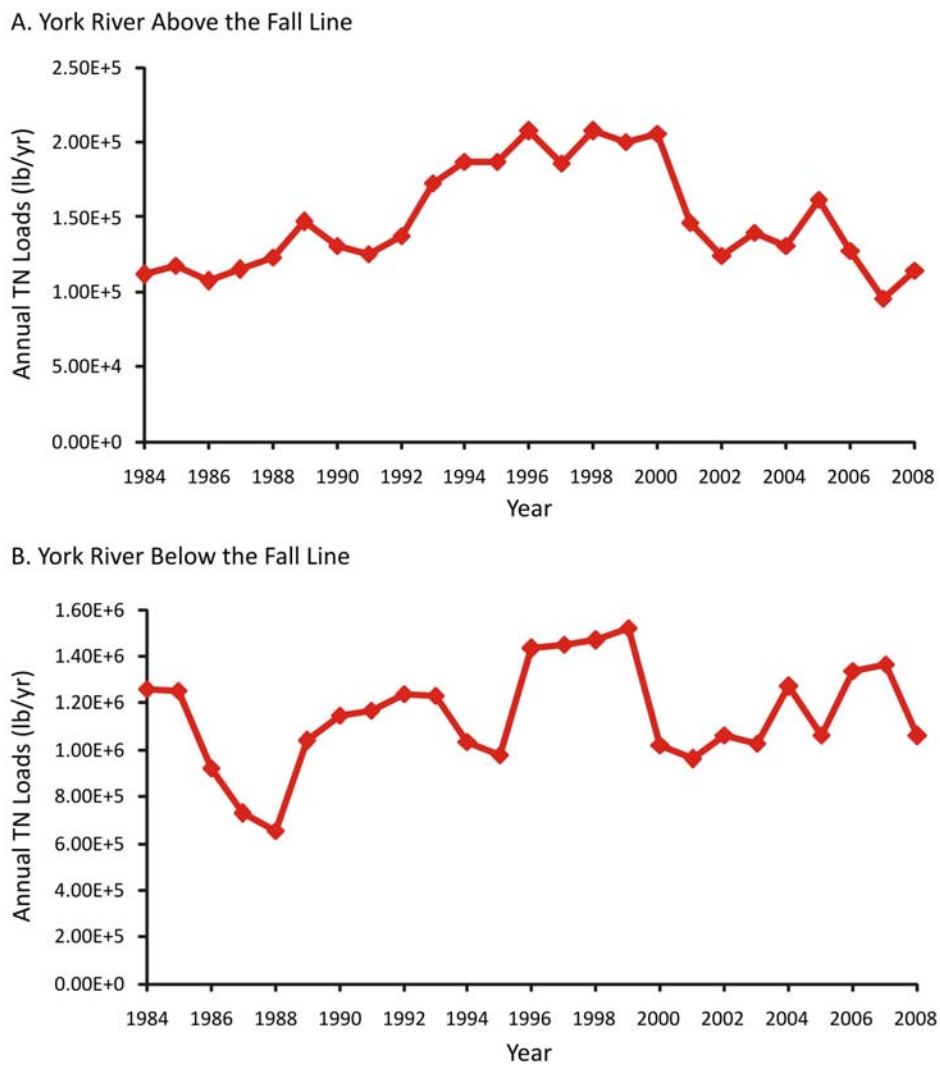


Figure 22. Long-term changes in point source total nitrogen loads in the York River A)Above the Fall-Line and B) Below the Fall-line for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

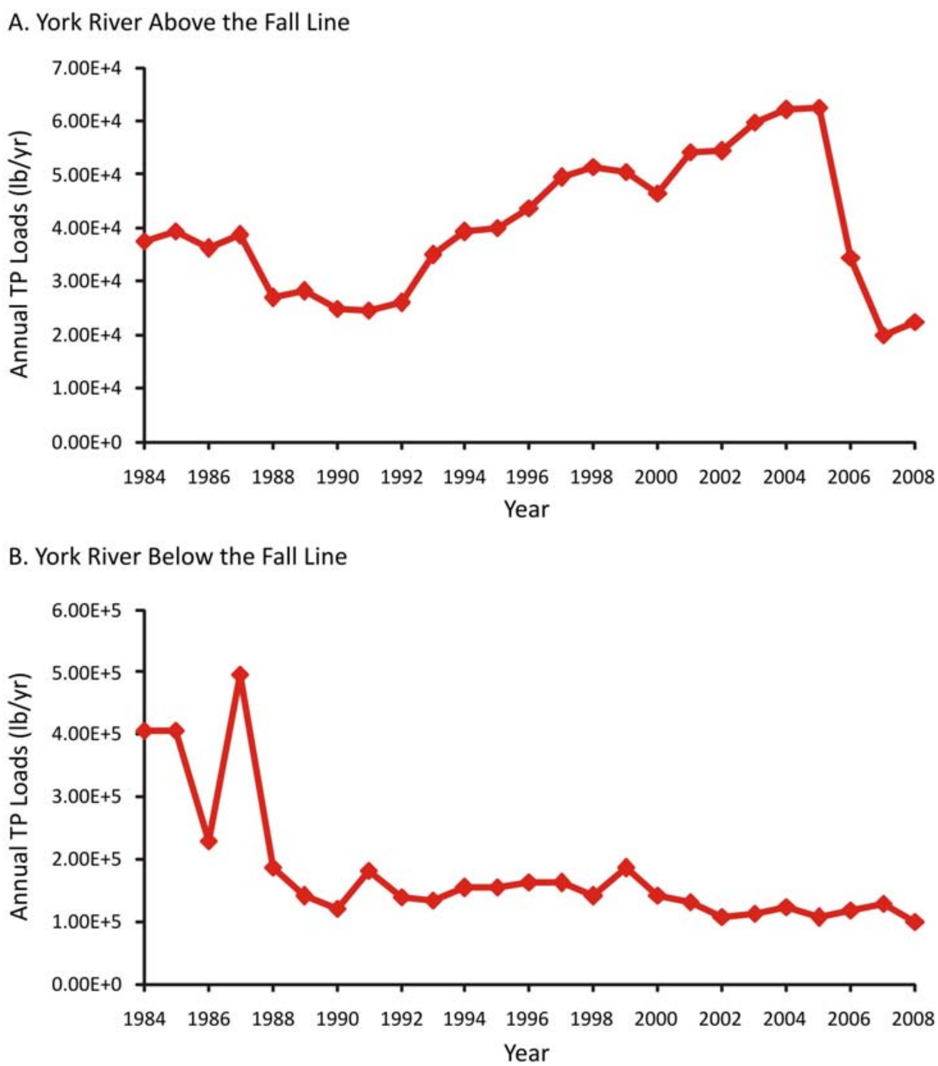


Figure 23. Long-term changes in point source total phosphorus loads in the York River A)Above the Fall-Line and B) Below the Fall-line for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

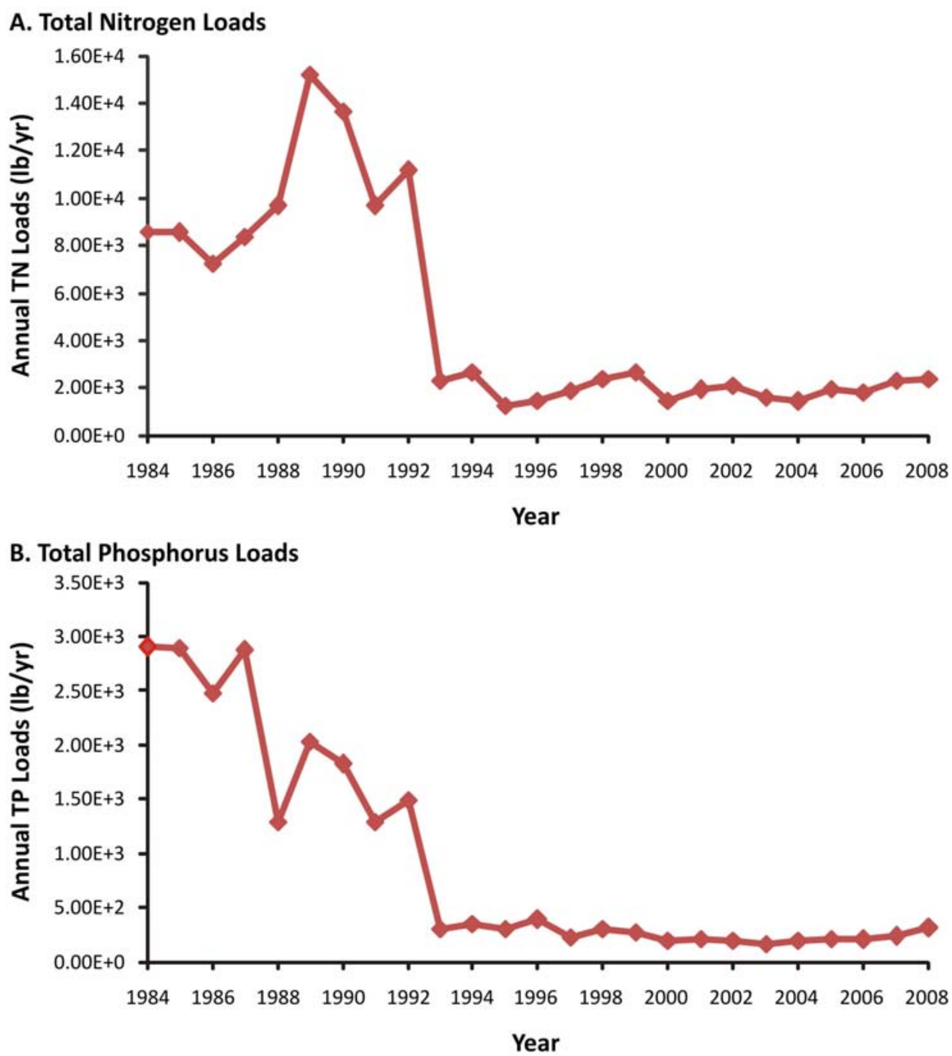
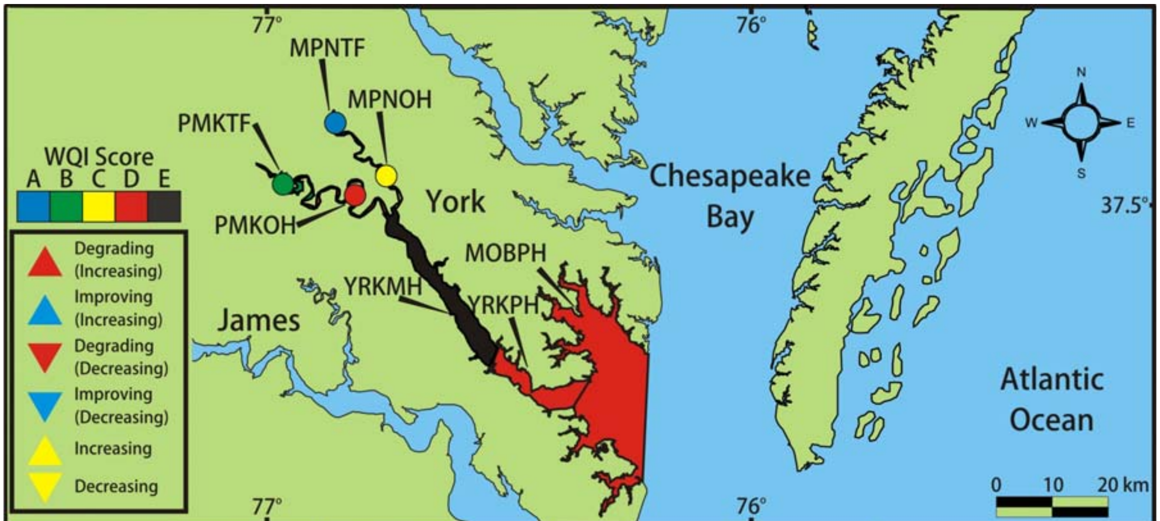


Figure 24. Long-term changes in point source A) Total Nitrogen Loads and B) Total Phosphorus Loads in Mobjack Bay for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

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

Figure 25. Water quality status and long-term trends in nutrient parameters in the tidal portion of the York River basin for the period of 1985 through 2008. 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 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	PMKTF	PMKOH	MPNTF	MPNOH	YRKMH	YRKPH	MOBPH
SCHLA							
STSS	▲ (red)						▼ (blue)
BTSS							▼ (blue)
SECCHI	▼ (red)		▼ (red)			▼ (red)	▼ (red)
BDO	▲ (blue)						▲ (blue)
SSALIN		▲ (yellow)		▲ (yellow)		▼ (yellow)	▼ (yellow)
BSALIN		▲ (yellow)		▲ (yellow)			▼ (yellow)
SWTEMP			▲ (yellow)				
BWTEMP							

Figure 26. 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 2008. 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. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively..

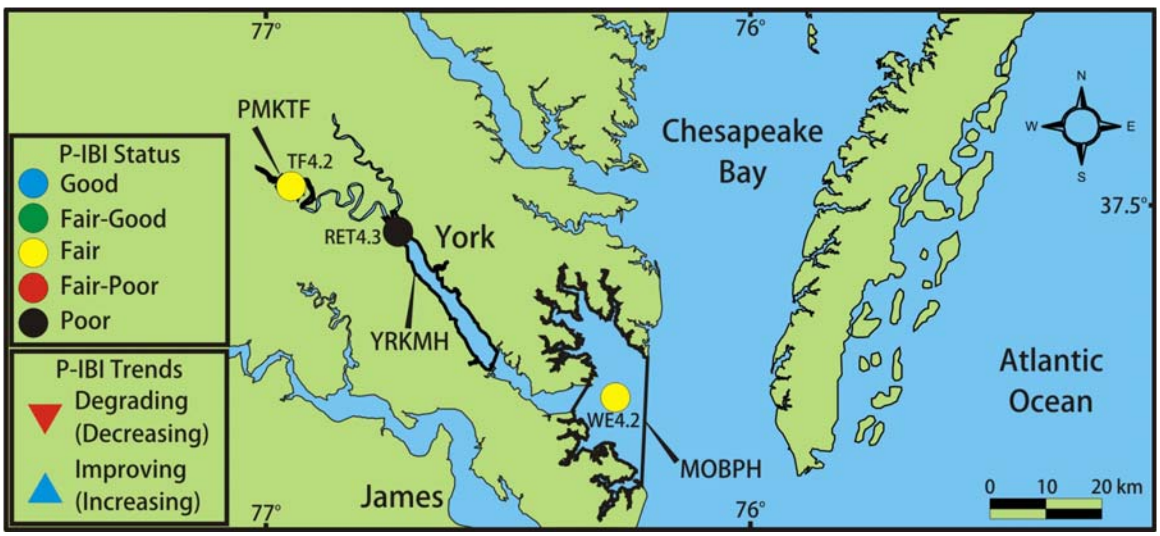


Figure 27. Status and long-term trends in phytoplankton community condition in the tidal portion of the York River basin for the period of 1985 through 2008. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2008.

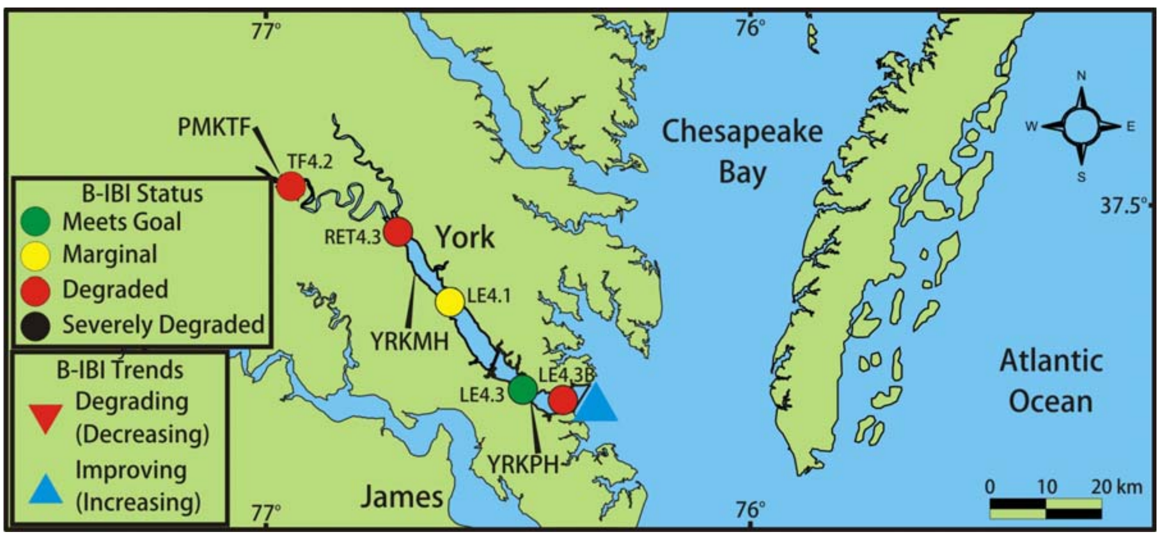
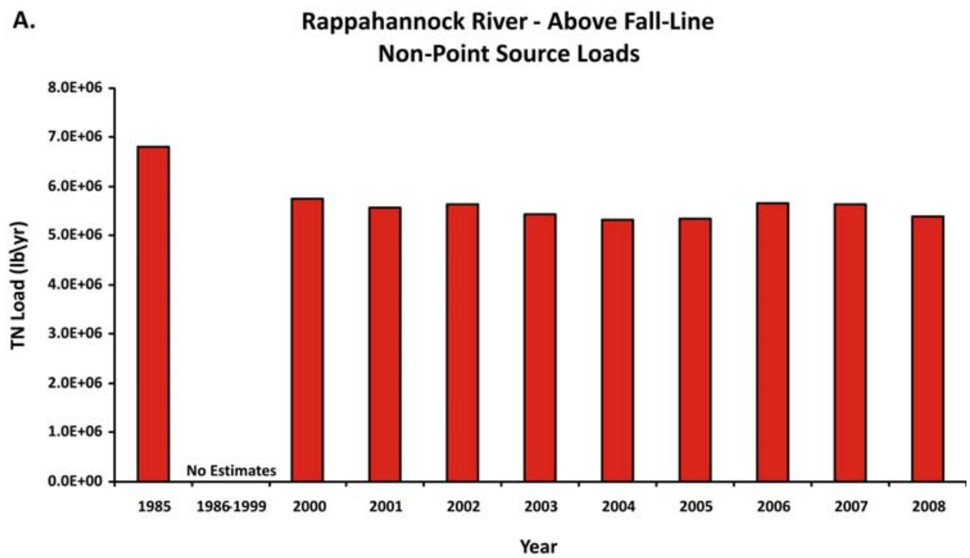


Figure 28. Status and long-term trends in benthic community condition in the tidal portion of the York River basin for the period of 1985 through 2008. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2008.



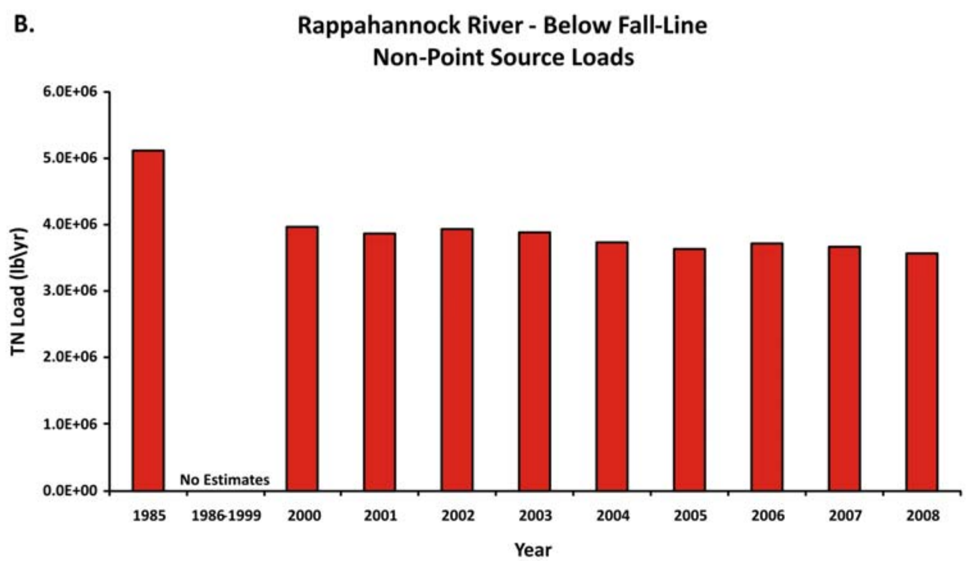


Figure 29. Long-term changes in non-point source total nitrogen loads A. Above the Fall-line, and B. Below the Fall-line in the Rapphannock River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.

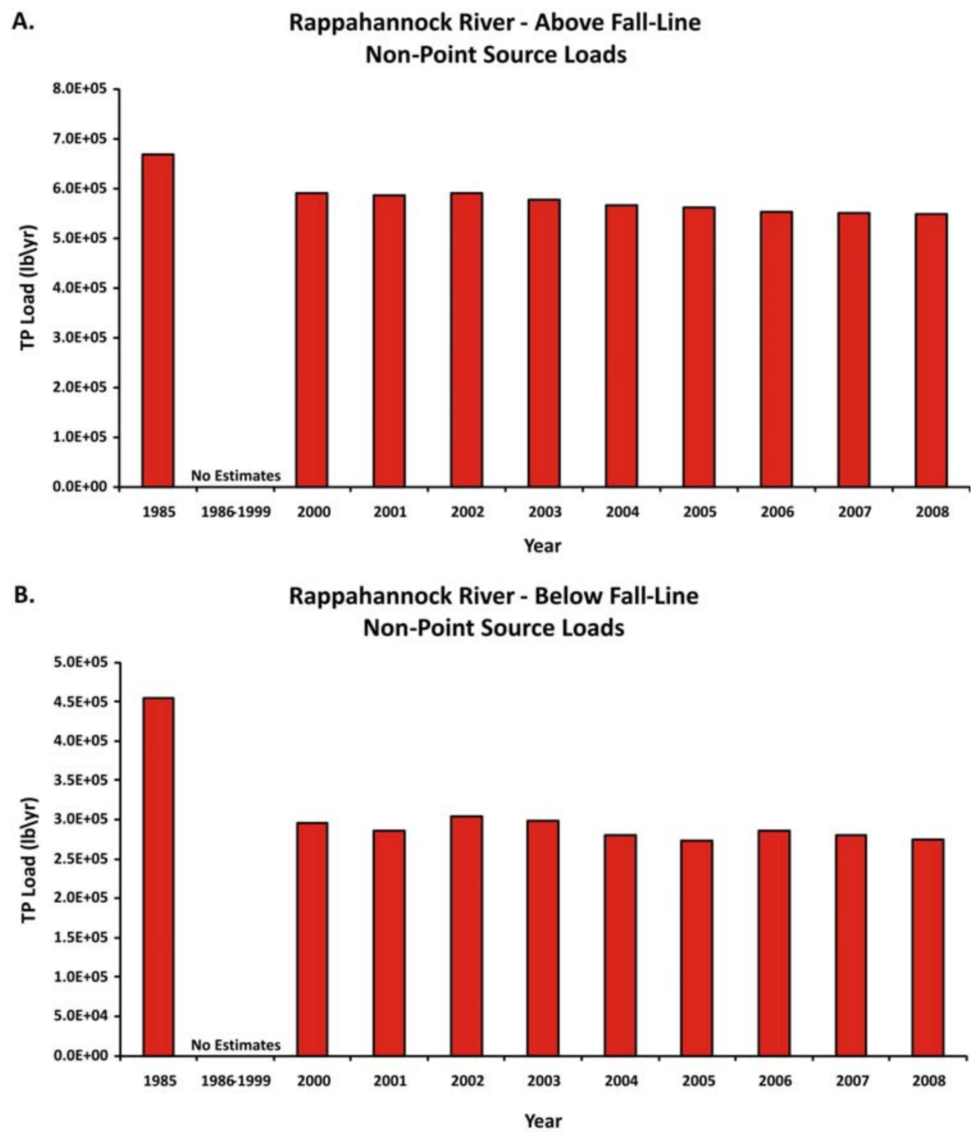


Figure 30. Long-term changes in non-point source total phosphorus loads A. Above the Fall-line, and B. Below the Fall-line in the Rapphannock River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.

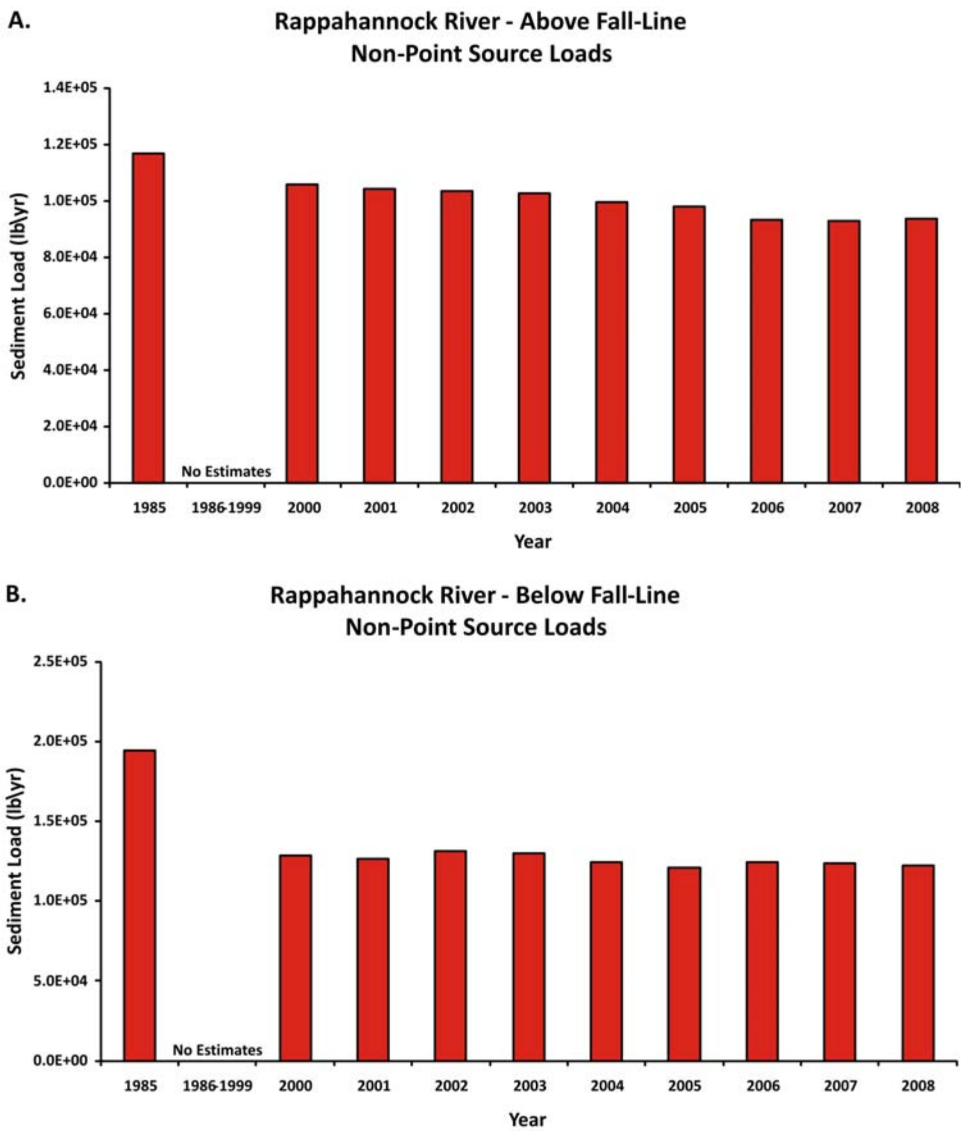


Figure 31. Long-term changes in non-point source total sediment loads A. Above the Fall-line, and B. Below the Fall-line in the Rapphannock River from 1985 through 2008 based on CBP Watershed Model (ver.4.3) estimates.

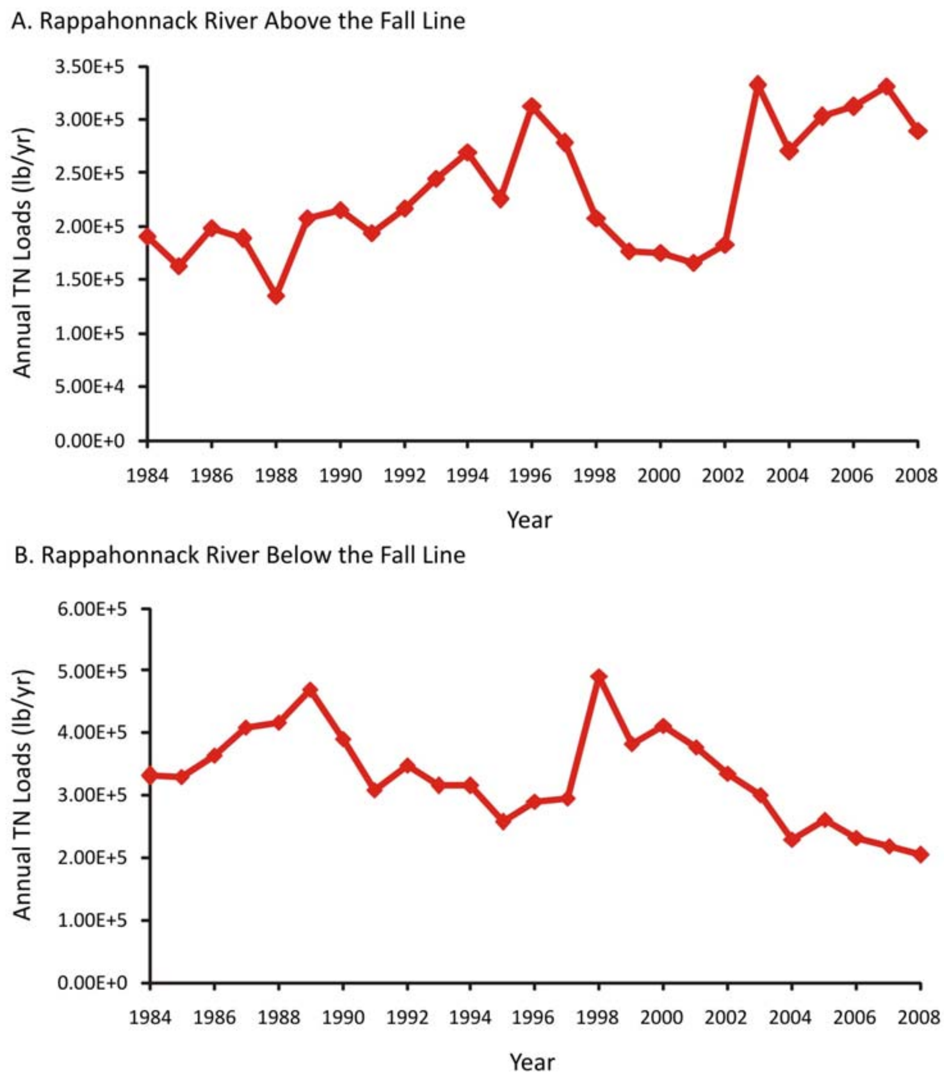


Figure 32. Long-term changes in point source total nitrogen loads A. Above the Fall-line, and B. Below the Fall-line in the Rappahannock River for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.

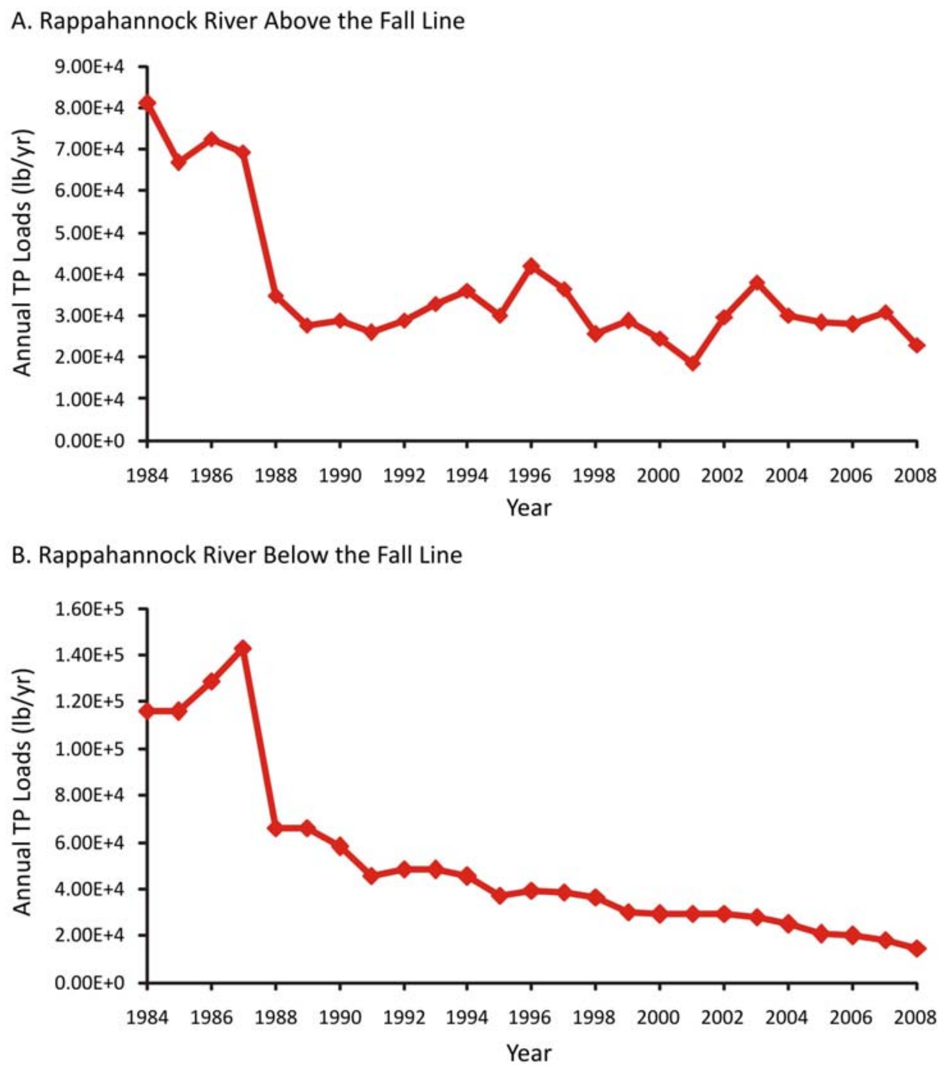
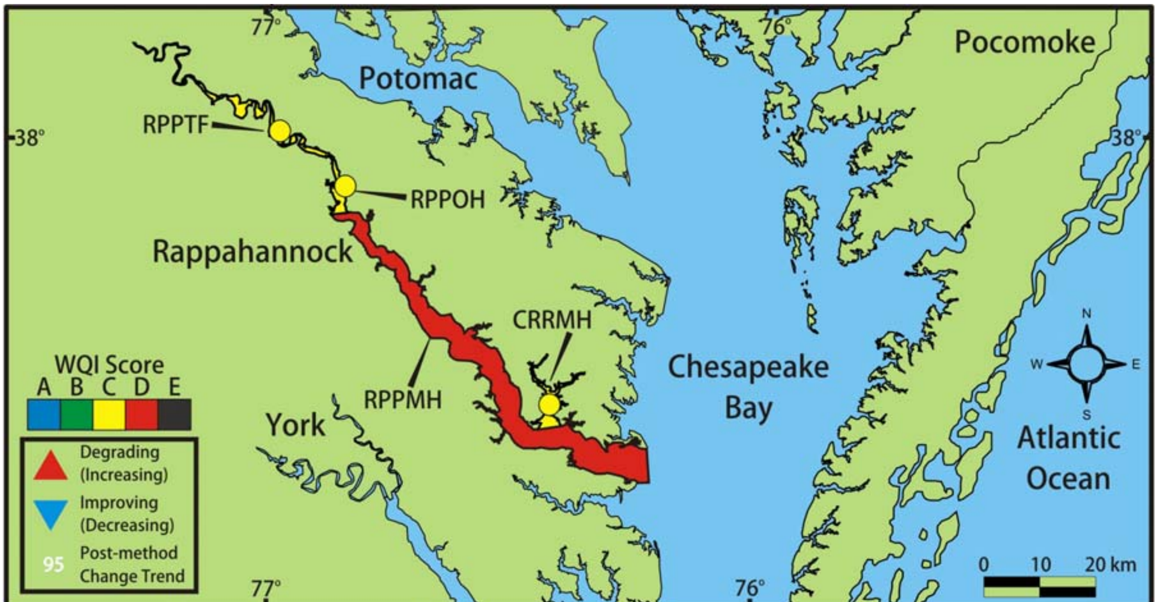
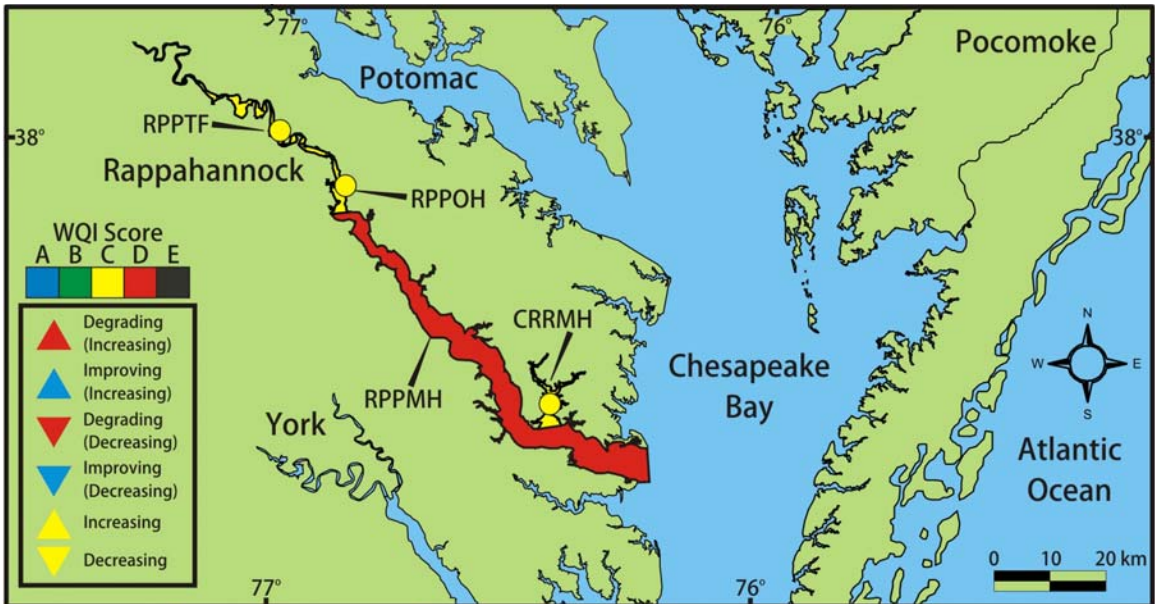


Figure 33. Long-term changes in point source total phosphorus loads A. Above the Fall-line, and B. Below the Fall-line in the Rappahannock River for 1984 through 2008. Loadings presented are from data reported to the Virginia Department of Environmental Quality directly from point source dischargers.



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

Figure 34. 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 2008. 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 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	RPPTF	RPPOH	RPPMH	CRRMH
SCHLA		▲ (red)	▲ (red)	
STSS				
BTSS				
SECCHI			▼ (red)	▼ (red)
BDO	▼ (red)			
SSALIN			▼ (yellow)	▼ (yellow)
BSALIN			▼ (yellow)	▼ (yellow)
SWTEMP				
BWTEMP				

Figure 35. 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 2008. 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. Abbreviations for each parameter are: CHLA=chlorophyll *a*, TSS=total suspended solids, SECCHI=secchi depth, DO=dissolved oxygen, WTEMP=water temperature, SALIN=salinity. The prefixes S and B refer to surface and bottom measurements, respectively.

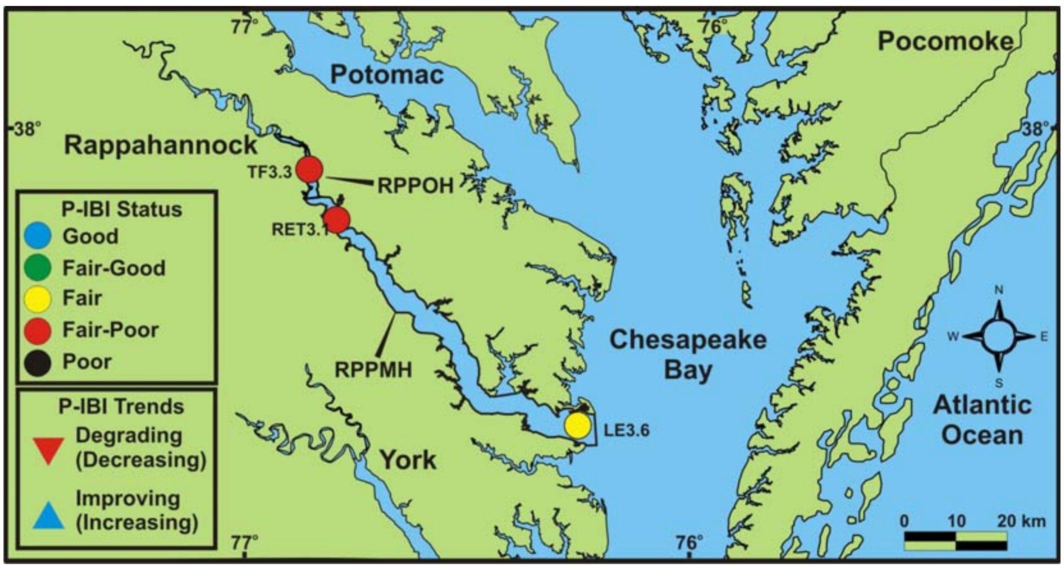


Figure 36. Status and long-term trends in phytoplankton community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2008. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant (P < 0.01) trends in the P-IBI from the start of monitoring through 2008.

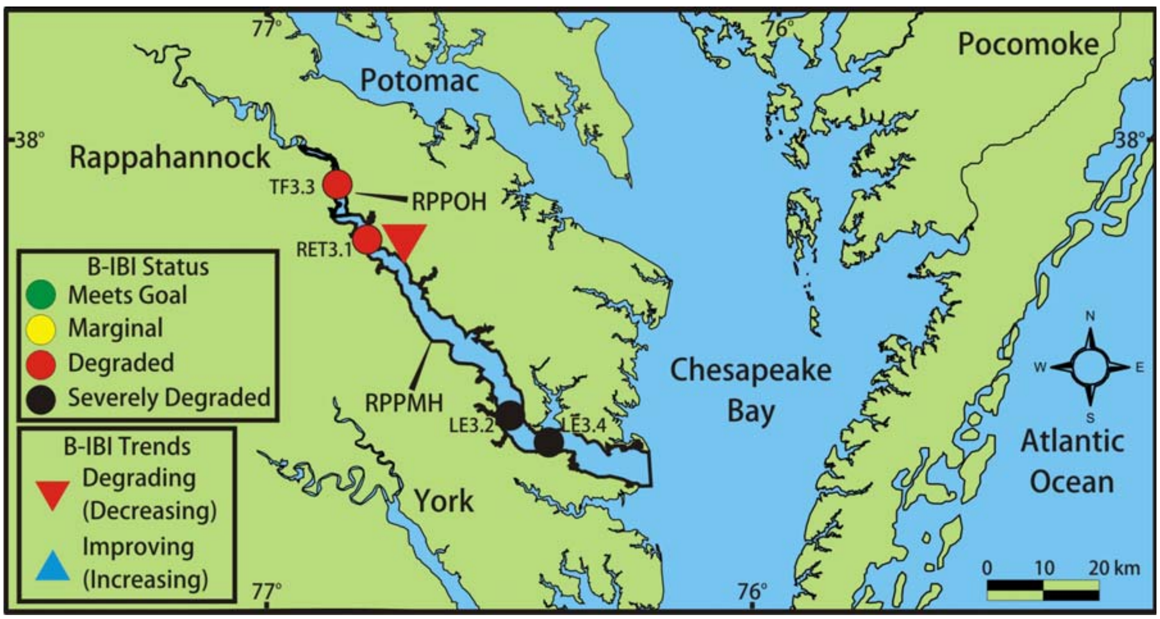
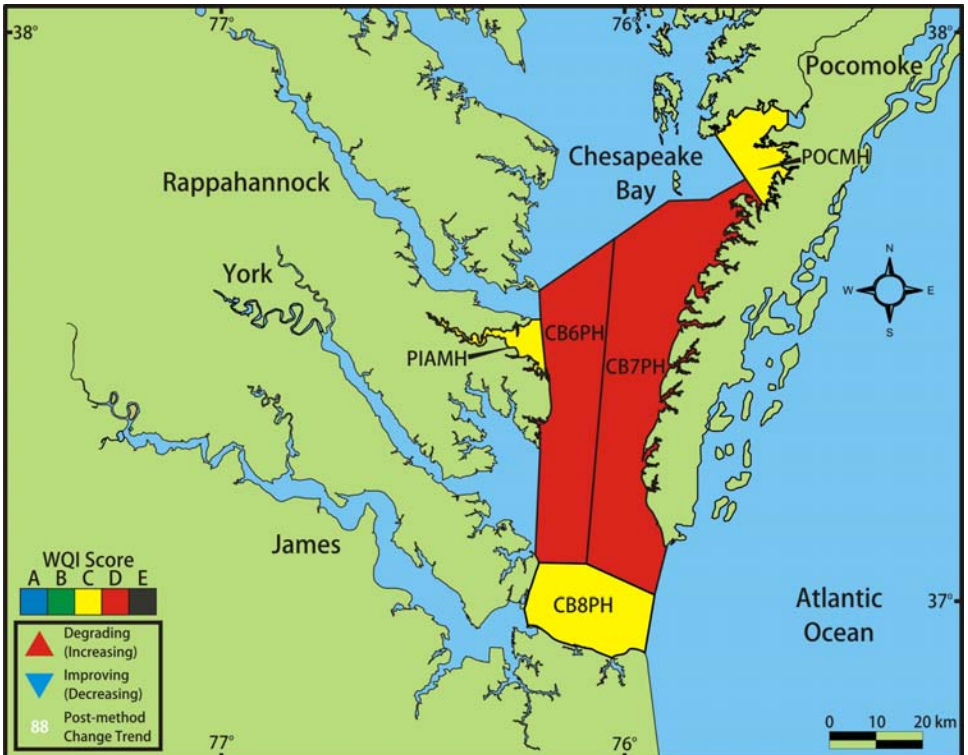
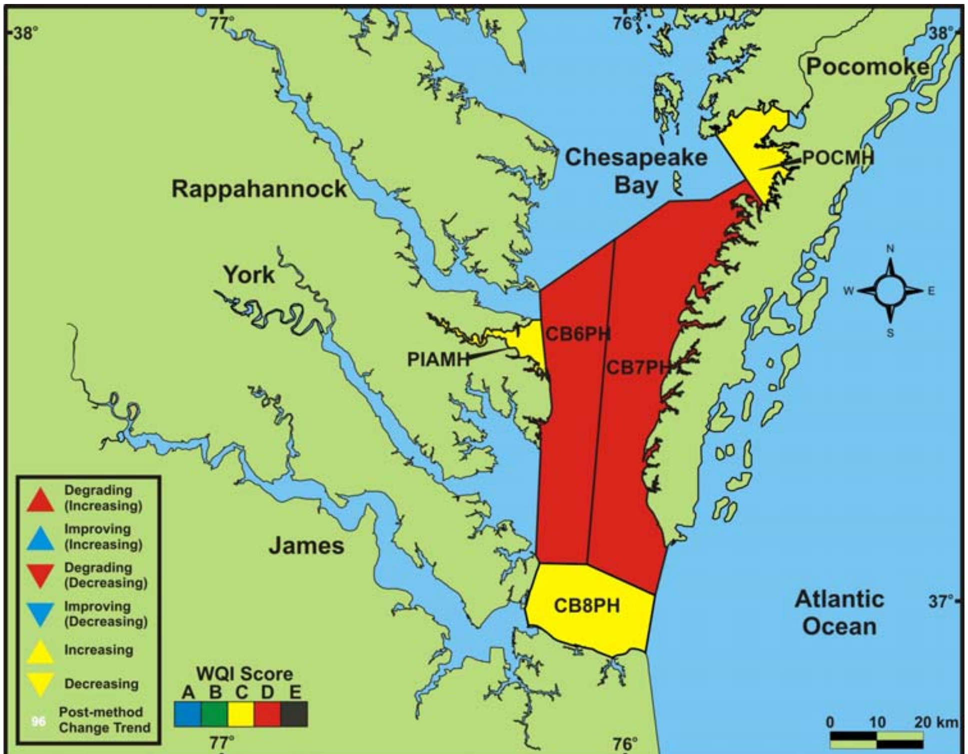


Figure 37. Status and long-term trends in benthic community condition in the tidal portion of the Rappahannock River basin for the period of 1985 through 2008. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant (*P* < 0.01) trends in the B-IBI from the start of monitoring through 2008.



Parameter	PIAMH	CB6PH	CB8PH	CB7PH	POCMH
STN	▼ 88	▼ 88		▼ 88	▼ 88
BTN	▼ 88	▼ 88		▼ 88	▼ 88
SDIN					▼ 88
BDIN	▼ 88	▼ 88	▼	▼ 88	▼ 88
STP	▼ 88	▼ 88	▼	▼ 88	▼ 88
BTP					▼ 88
SDIP					
BDIP			▼		

Figure 38. Water quality status and long-term trends in nutrient parameters in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2008. 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 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)
BTSS	▼ 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)		
SSALIN	▼ Decreasing		▼ Decreasing		▼ Decreasing
BSALIN	▼ Decreasing	▼ Decreasing	▼ Decreasing		▼ Decreasing
SWTEMP					
BWTEMP					

Figure 39. 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 2008. 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. 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.

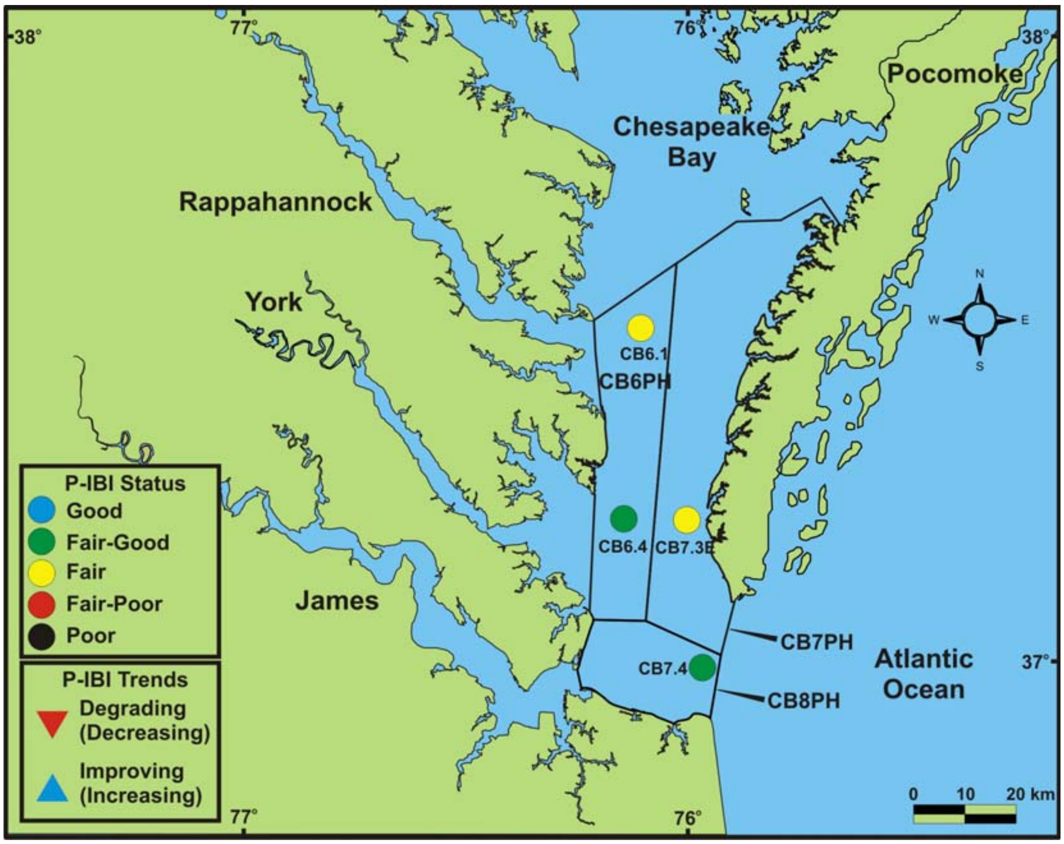


Figure 40. Status and long-term trends in phytoplankton community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2008. Shown are status as measured using the P-IBI of Buchanan et al. (2009) and statistically significant ($P < 0.01$) trends in the P-IBI from the start of monitoring through 2008.

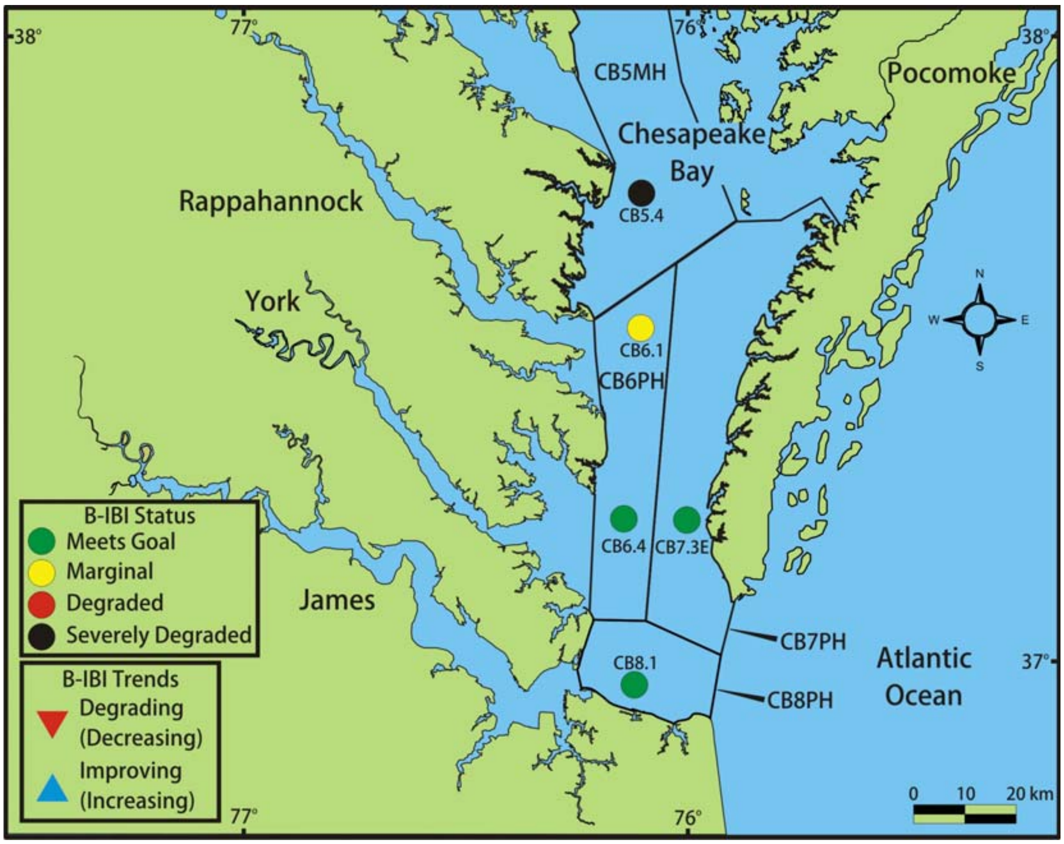


Figure 41. Status and long-term trends in benthic community condition in the Virginia Chesapeake Bay Mainstem for the period of 1985 through 2008. Shown are status as measured using the B-IBI of Weisburg et al. (1997) and statistically significant ($P < 0.01$) trends in the B-IBI from the start of monitoring through 2008.