Lower Eastern Shore Tributary Summary:

A summary of trends in tidal water quality and associated factors, 1985-2018.

June 7, 2021

Prepared for the Chesapeake Bay Program (CBP) Partnership by the CBP Integrated Trends Analysis Team (ITAT)

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This tributary summary is a living document in draft form and has not gone through a formal peer review process. We are grateful for contributions to the development of these materials from the following individuals: Jeni Keisman, Rebecca Murphy, Olivia Devereux, Jimmy Webber, Qian Zhang, Meghan Petenbrink, Tom Butler, Zhaoying Wei, Jon Harcum, Renee Karrh, Mike Lane, and Elgin Perry.

Contents

1. Purpose and Scope

The Lower Eastern Shore Tributary Summary outlines change over time in a suite of monitored tidal water quality parameters and associated potential drivers of those trends for the time period 1985 – 2018, and provides a brief description of the current state of knowledge explaining these observed changes. Water quality parameters described include surface (above pycnocline) total nitrogen (TN), surface total phosphorus (TP), spring and summer (June, July, August) surface chlorophyll *a*, summer bottom (below pycnocline) dissolved oxygen (DO) concentrations, and Secchi disk depth (a measure of water clarity). Results for annual surface water temperature, bottom TP, bottom TN, surface ortho-phosphate (PO4), surface dissolved inorganic nitrogen (DIN), surface total suspended solids (TSS), and summer surface DO concentrations are provided in an Appendix. Drivers discussed include physiographic watershed characteristics, changes in TN, TP, and sediment loads from the watershed to tidal waters, expected effects of changing land use, and implementation of nutrient management and natural resource conservation practices. Factors internal to estuarine waters that also play a role as drivers are described including biogeochemical processes, physical forces such as wind-driven mixing of the water column, and biological factors such as phytoplankton biomass and the presence of submerged aquatic vegetation. Continuing to track water quality response and investigating these influencing factors are important steps to understanding water quality patterns and changes in the Lower Eastern Shore.

2. Location

The Lower Eastern Shore watershed covers approximately 2.8% of the Chesapeake Bay watershed. Its watershed is approximately 4532 km^2 (Table 1.) and is contained within three states: Delaware, Maryland, and Virginia (Figure 1).

Tributary Name	Watershed Area km2
MARYLAND MAINSTEM	71967
POTOMAC	36611
JAMES	25831
YORK	6537
RAPPAHANNOCK	6530
LOWER EASTERN SHORE	4532
MARYLAND UPPER EASTERN SHORE	2441
PATUXENT	2236
VIRGINIA MAINSTEM	2052
CHOPTANK	1844
PATAPSCO-BACK	1647
MARYLAND UPPER WESTERN SHORE	1523
MARYLAND LOWER WESTERN SHORE	439

Table 1. "Watershed areas for each of the thirteen tributary or tributary groups for which Tributary Trends summaries have been produced. All of the tributary summaries can be accessed at the following link: https://cast.chesapeakebay.net/Home/TMDLTracking#tributaryRptsSection".

2.1 Watershed Physiography

The Lower Eastern Shore watershed is entirely located in the Coastal Plain region (Bachman *et al.*, 1998) (Figure 1). This physiography covers lowland, dissected upland, and upland areas. Implications of these physiographies for nutrient and sediment transport are summarized in Section 5.1.1.

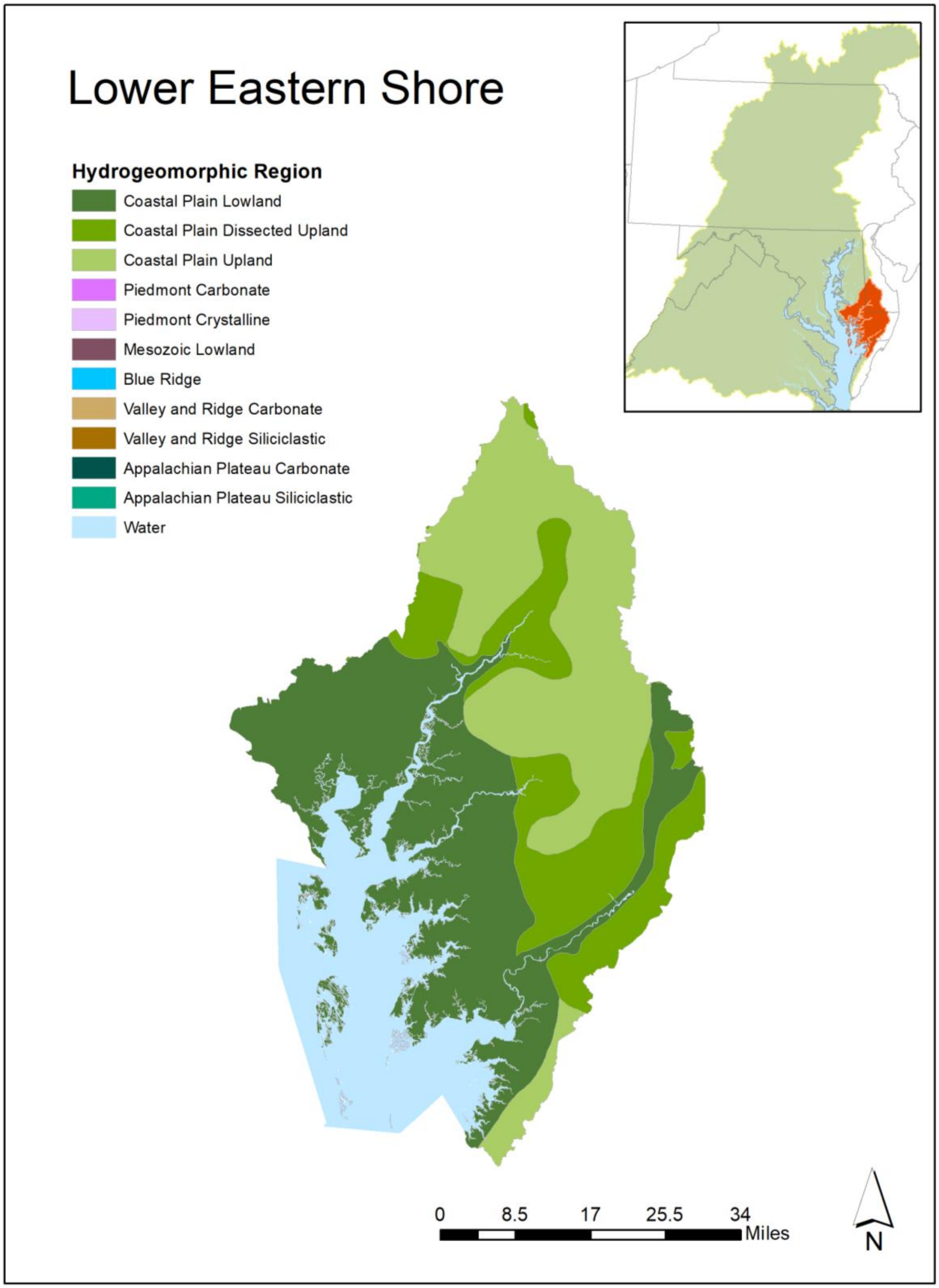


Figure 1. Distribution of physiography in the Lower Eastern Shore watershed.

2.2 Land Use

Land use in the Lower Eastern Shore watershed is dominated (50%) by natural areas. Urban and suburban land areas have increased by 43,776 acres since 1985, agricultural lands have decreased by 26,725 acres, and natural lands have decreased by 17,235 acres. Correspondingly, the proportion of urban land in this watershed has increased from 8% in 1985 to 12% in 2019 (Figure 2).

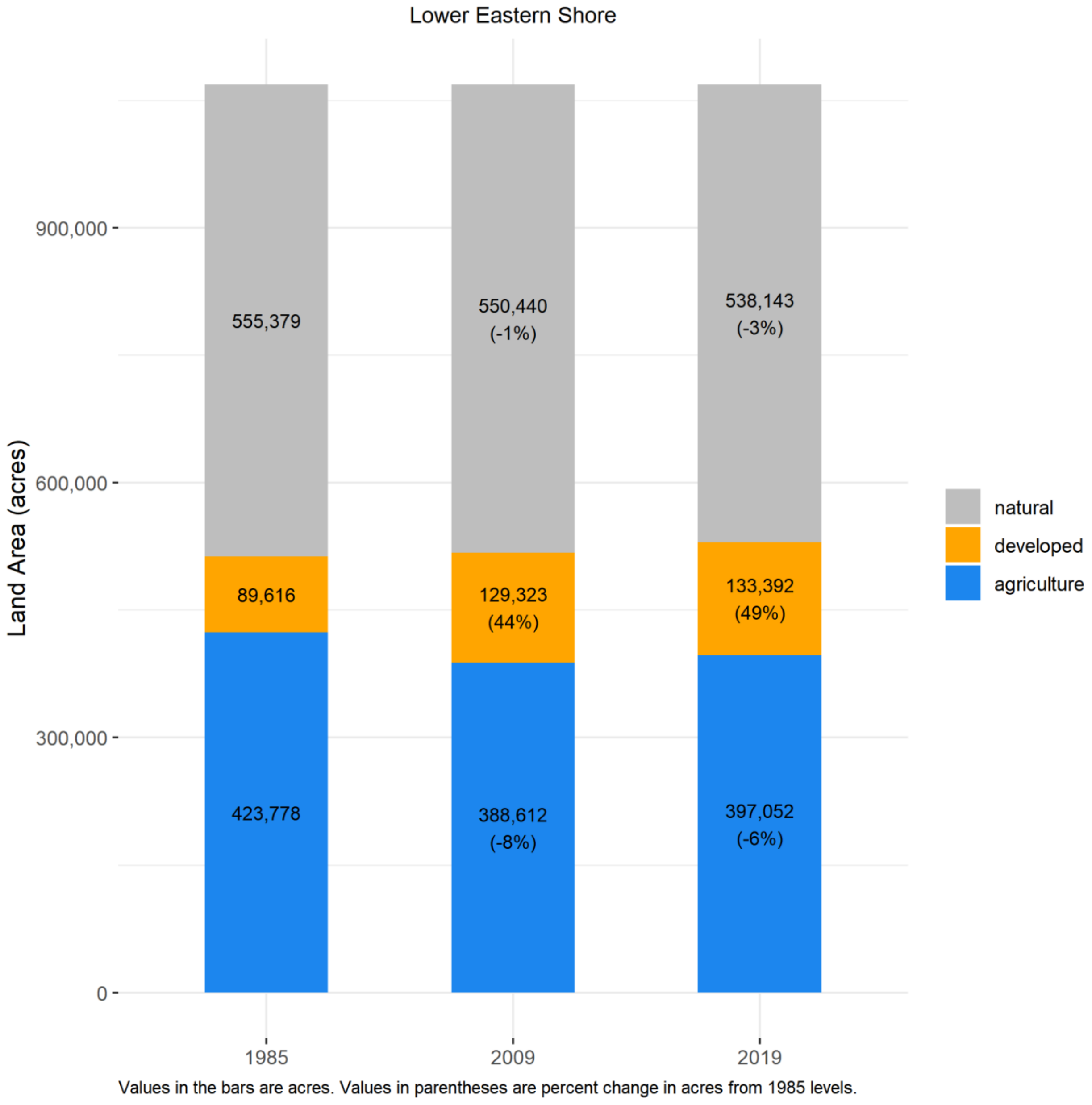


Figure 2. Distribution of land uses in the Lower Eastern Shore watershed. Percentages are the percent change from 1985 for each source sector.

In general, developed lands in the 1970s were more concentrated within towns and major metropolitan areas. Since then, developed and semi-developed lands have expanded around these areas, as well as extending into previously undeveloped regions (Figure 3). The impacts of land development differ depending on the use from which the land is converted (Keisman *et al.*, 2018; Ator *et al.*, 2019). Implications of changing land use for nutrient and sediment transport are summarized in Section 5.1.3.

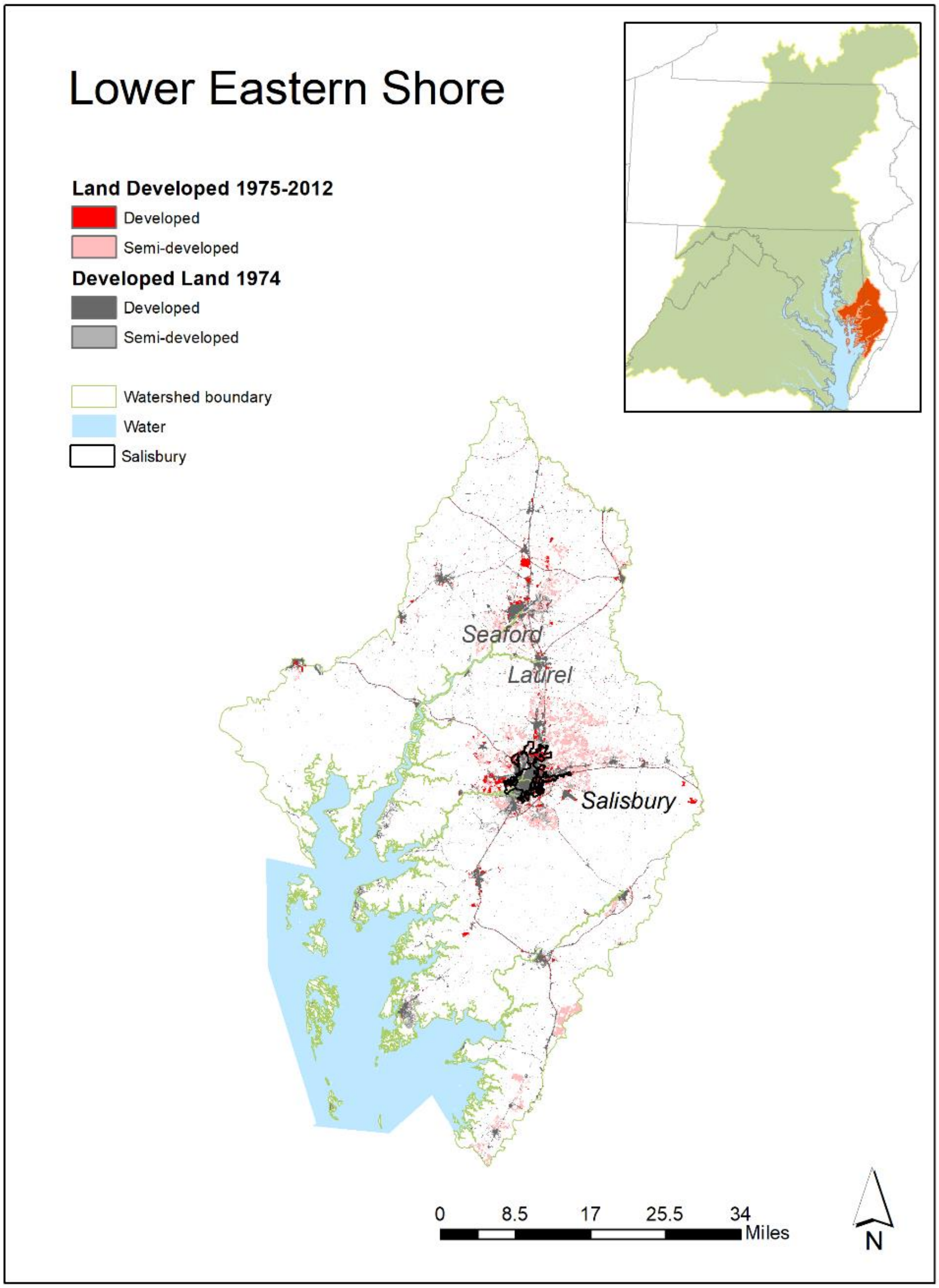


Figure 3. Distribution of developed land in the Lower Eastern Shore watershed. Derived from Falcone (2015). Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

2.3 Tidal Waters and Stations

For the purposes of water quality standards assessment and reporting, the tidal waters associated with the Lower Eastern Shore Tributaries are divided into 15 split segments across three states (U.S. Environmental Protection Agency, 2004) (Figure 4). The Tidal Fresh Nanticoke River is split between Delaware (NANTF_DE) and in Maryland (NANTF_MD). Other segments in Maryland include Mesohaline Fishing Bay (FSBMH), Oligohaline and Mesohaline Nanticoke River (NANOH, NANMH), Mesohaline Wicomico River (WICMH), Manokin River (MANMH), and Big Annemessex River (BIGMH); the Tidal Fresh, Oligohaline and Mesohaline Pocomoke River (POCTF, POCOH_MD, POCMH_MD); and the Maryland portion of the Mesohaline Tangier Sound (TANMH_MD). Segments in Virginia include Oligohaline and Mesohaline Pocomoke River (POCOH_VA, POCMH_VA) and the Virginia portion of the Mesohaline Tangier Sound (TANMH_VA).

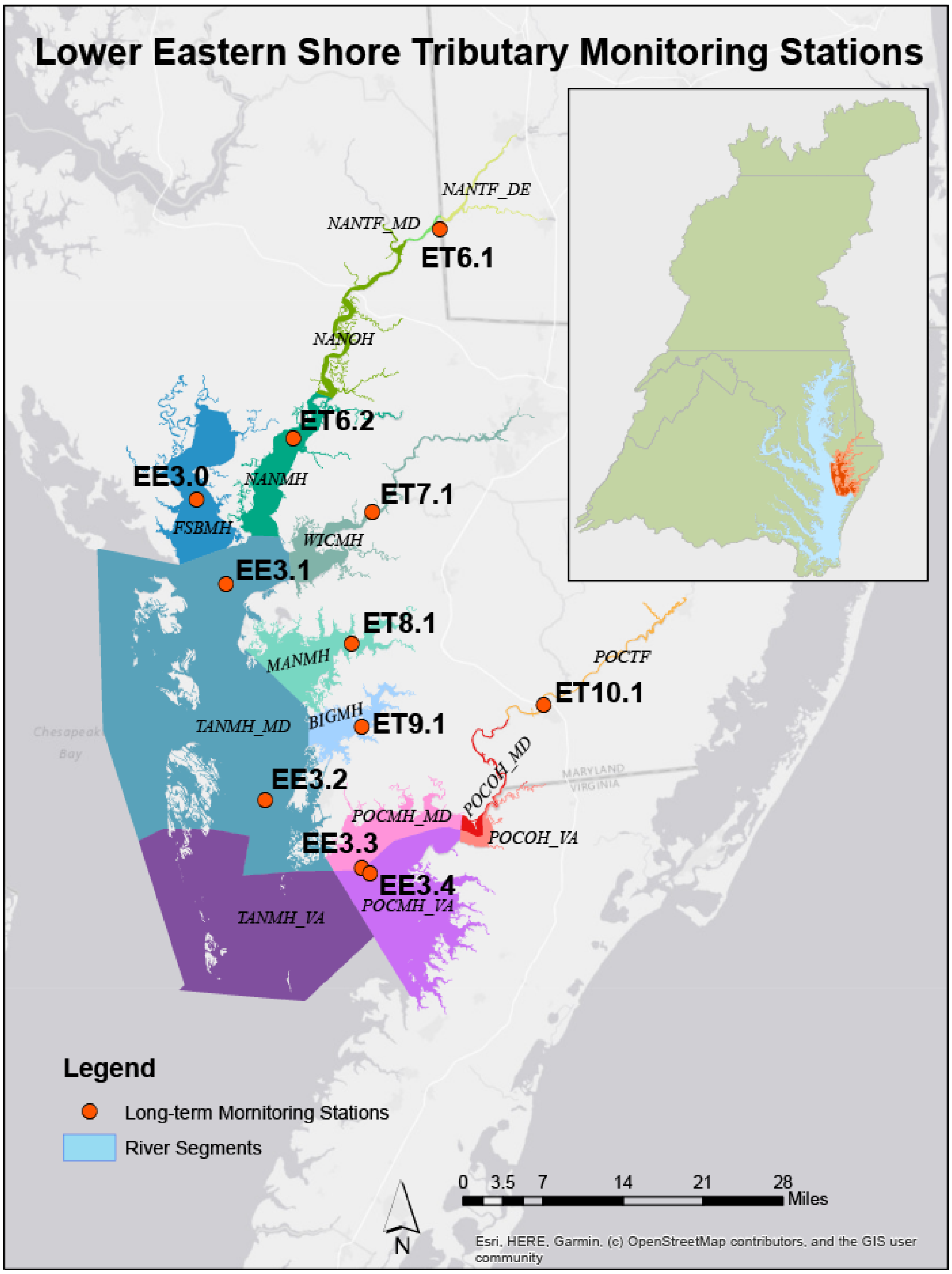


Figure 4. Map of tidal Lower Eastern Shore River segments and long-term monitoring stations. Base map credit Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, World Geodetic System 1984.

Long-term trends in water quality are analyzed by both MD Department of Natural Resources and VA Department of Environmental Quality at 11 stations throughout these tributaries (Figure 4). Water quality data at these stations are also used to assess attainment of dissolved oxygen (DO) water quality criteria. All tidal water quality data analyzed for this summary are available from the Chesapeake Bay Program Data Hub (Chesapeake Bay Program, 2018). Other shallow-water monitoring has been conducted in these waters but it not included in the long-term trend graphics in subsequent sections because of its shorter duration.

3. Tidal Water Quality Dissolved Oxygen Criteria Attainment

Multiple water quality standards were developed for the Lower Eastern Shore tributaries and bays to protect aquatic living resources (U.S. Environmental Protection Agency, 2003; Tango and Batiuk, 2013). These standards include specific criteria for dissolved oxygen (DO) and water clarity/underwater bay grasses. For the purposes of this summary, a record of the evaluation results indicating whether the different segments have met or not met one of the Open Water (OW) DO criteria over time is shown below (Zhang *et al.*, 2018a; Hernandez Cordero *et al.*, 2020). While analysis of water quality standards attainment is not the focus of this summary, the results (Table 2) provide context for the importance of understanding factors affecting water quality trends. For more information on water quality standards, criteria, and standards attainment, visit the CBP's "Chesapeake Progress" website at www.chesapeakeprogress.com. In the recent period (2016-2018), seven of the 15 segments met the 30-day mean OW summer DO requirements (Zhang *et al.*, 2018b).

Table 2. Open Water summer DO criterion evaluation results (30-day mean June-September assessment period). Green indicates that the criterion was met. White indicates that the criterion was not met. "ND" indicates no data.

time period	FSBMH	NANTF_DE	NANTF_MD	NANOH	NANMH	WICMH	MANMH	BIGMH	POCTF	POCOH_MD	POCOH_VA	POCMH_MD	POCMH_VA	TANMH_MD	TANMH_VA
1985-1987	🟩				🟩	🟩	🟩	🟩				🟩	🟩	🟩	
1986-1988	🟩				🟩	🟩	🟩	🟩				🟩	🟩		
1987-1989	🟩						🟩	🟩				🟩	🟩		
1988-1990	🟩						🟩	🟩				🟩	🟩		
1989-1991	🟩						🟩	🟩				🟩	🟩		
1990-1992	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩		
1991-1993	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩		
1992-1994	🟩	🟩	🟩	🟩	🟩		🟩	🟩				🟩	🟩	🟩	
1993-1995	🟩	🟩	🟩	🟩	🟩			🟩				🟩	🟩	🟩	
1994-1996	🟩				🟩			🟩				🟩	🟩	🟩	
1995-1997					🟩			🟩				🟩	🟩	🟩	
1996-1998					🟩		🟩	🟩				🟩	🟩	🟩	
1997-1999					🟩		🟩	🟩				🟩	🟩	🟩	
1998-2000	🟩				🟩		🟩	🟩				🟩	🟩	🟩	
1999-2001	🟩				🟩		🟩	🟩				🟩	🟩	🟩	🟩
2000-2002	🟩				🟩		🟩	🟩				🟩	🟩	🟩	🟩
2001-2003	🟩				🟩			🟩				🟩	🟩	🟩	🟩
2002-2004	🟩				🟩			🟩				🟩	🟩	🟩	
2003-2005	🟩				🟩			🟩				🟩	🟩		
2004-2006	🟩				🟩			🟩				🟩	🟩		
2005-2007	🟩				🟩			🟩				🟩	🟩		
2006-2008	🟩				🟩		🟩	🟩				🟩	🟩		
2007-2009	🟩				🟩		🟩	🟩				🟩	🟩		
2008-2010	🟩				🟩		🟩	🟩				🟩	🟩		
2009-2011	🟩				🟩		🟩	🟩				🟩	🟩		
2010-2012	🟩				🟩		🟩	🟩				🟩	🟩	🟩	
2011-2013	🟩				🟩		🟩	🟩				🟩	🟩		
2012-2014	🟩				🟩		🟩	🟩				🟩	🟩	🟩	
2013-2015	🟩				🟩		🟩	🟩				🟩	🟩	🟩	
2014-2016	🟩				🟩		🟩	🟩				🟩	🟩	🟩	
2015-2017	🟩			🟩	🟩		🟩	🟩				🟩	🟩	🟩	🟩
2016-2018	🟩						🟩	🟩	ND			🟩	🟩	🟩	🟩

Comparing trends in station-level DO concentrations to the computed DO criterion status for a recent assessment period can reveal valuable information, such as whether progress is being made towards attainment in a segment that is not meeting the water quality criteria, or conversely the possibility that conditions are degrading even if the criteria are currently being met. To illustrate this, the 2016-2018 attainment status for the OW summer DO criteria shown in Table 2 is overlain with the 1985-2018 change in summer surface DO concentration (Figure 5). In this region, a distinct spatial pattern appears with the more upstream segments in the Nanticoke, Wicomico, and Pocomoke Rivers not meeting the 30-day mean OW summer DO criterion and having degrading oxygen concentrations. All other mesohaline segments, including Fishing Bay, Tangier Sound, Manokin, Big Annemessex, and mesohaline Pocomoke segments, are meeting the criterion and having improving or no trend in oxygen.

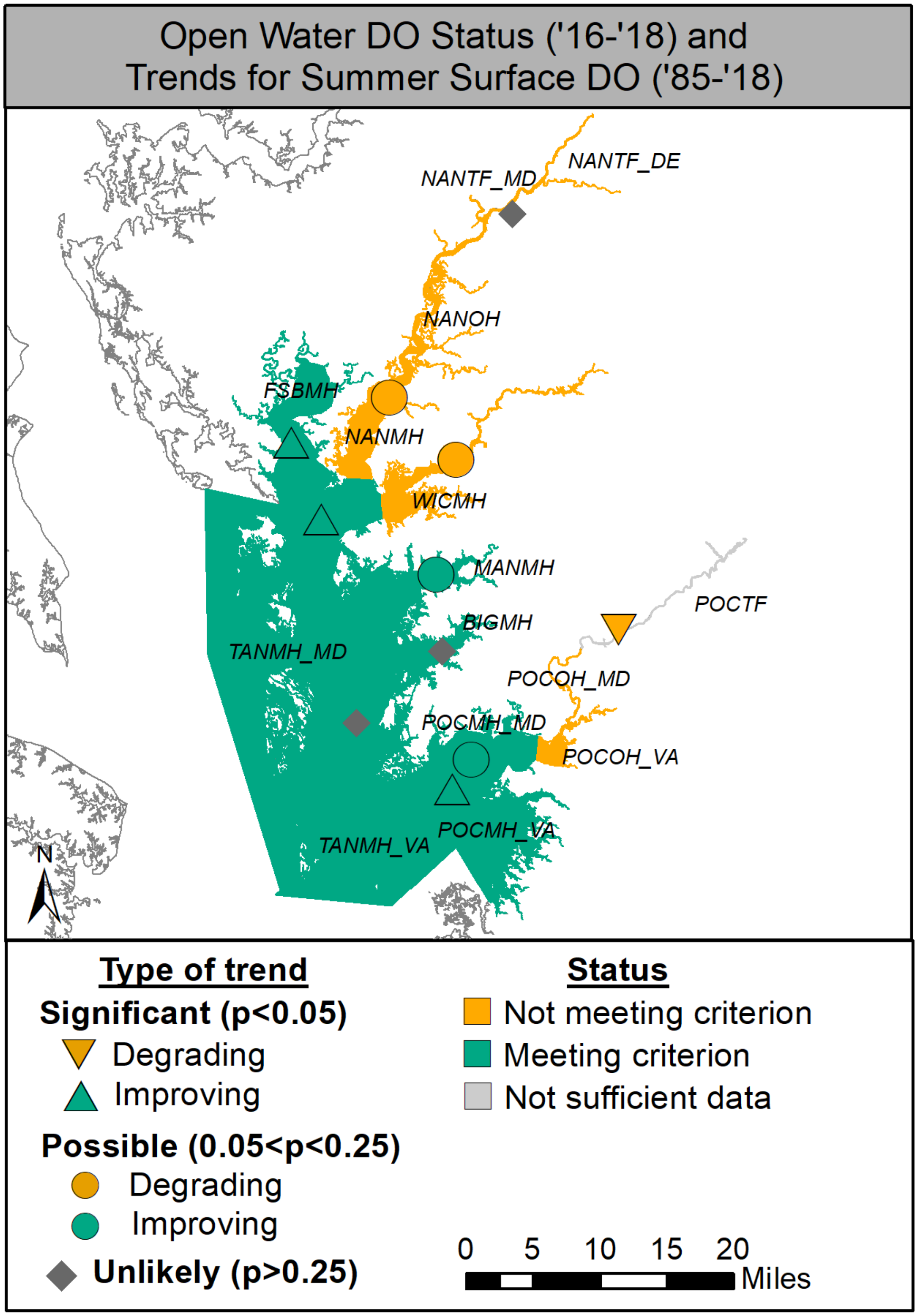


Figure 5. Pass-fail DO criterion status for 30-day OW summer DO designated use in Lower Eastern Shore segments along with long-term trends in DO concentrations. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

4. Tidal Water Quality Trends

Tidal water quality trends are computed by fitting generalized additive models (GAMs) to the water quality observations that have been collected one or two times per month since the 1980s at the 11 Lower Eastern Shore tidal stations labeled in Figure 4. For more details on the GAM implementation that is applied each year by MD Department of Natural Resources and VA Department of Environmental Quality for these stations in collaboration with the Chesapeake Bay Program, see Murphy *et al.* (2019).

Results shown below in each set of maps (e.g., Figure 6) include those generated using two different GAM fits to each station-parameter combination. The first approach involves fitting a GAM to the raw observations to generate a mean estimate of the concentrations over time, as observed in the estuary. The second approach involves including monitored river flow or *in situ* salinity (as an aggregated measure of multiple river flows) in the GAM to explain some of the variation in the water quality parameter. From the results of this second approach, it is possible to estimate the "flow-adjusted" change over time, which gives a mean estimate of what the water quality parameter trend would have been if river flow had been average over the period of record. Note that depending on station and parameter, sometimes gaged river flow is used for this adjustment and sometimes salinity is used, but we refer to all these results as "flow-adjusted" for simplicity.

To determine if there has been a change over time (i.e., a trend) at a particular station for a given parameter, we compute a percent change between the estimates at beginning and end of a period of interest from the GAM fit. For each percent change computation, the level of statistical confidence can be computed as well. Change is called significant if $p < 0.05$ and possible if the p-value is up to 0.25. That upper limit is higher than usually reported for hypothesis tests but allows us to provide a more complete picture of the results, identifying locations where change might be starting to occur and should be investigated (Murphy *et al.*, 2019). In addition to the maps of trends, for each parameter, there is a set of graphs (e.g., Figure 7) that include the raw observations (dots on the graphs) and lines representing the mean annual or seasonal GAM estimates, without flow-adjustment. The flow-adjusted GAM line graphs are not shown.

4.1 Surface Total Nitrogen

Annual total nitrogen (TN) trends have improved at most of the Lower Eastern Shore stations over the long-term, with and without flow-adjustment (Figure 6). Stations ET6.1 and ET6.2 in the Nanticoke River stand out in this region as having long-term degrading or no trends in TN. Over the short-term, most of the stations have no trend although four stations still showing possible or improving trends when considering both non-adjusted and flow-adjusted sets. The tidal fresh Nanticoke station (ET6.1), however, has a degrading trend over the short-term as well as the long-term (Figure 6).

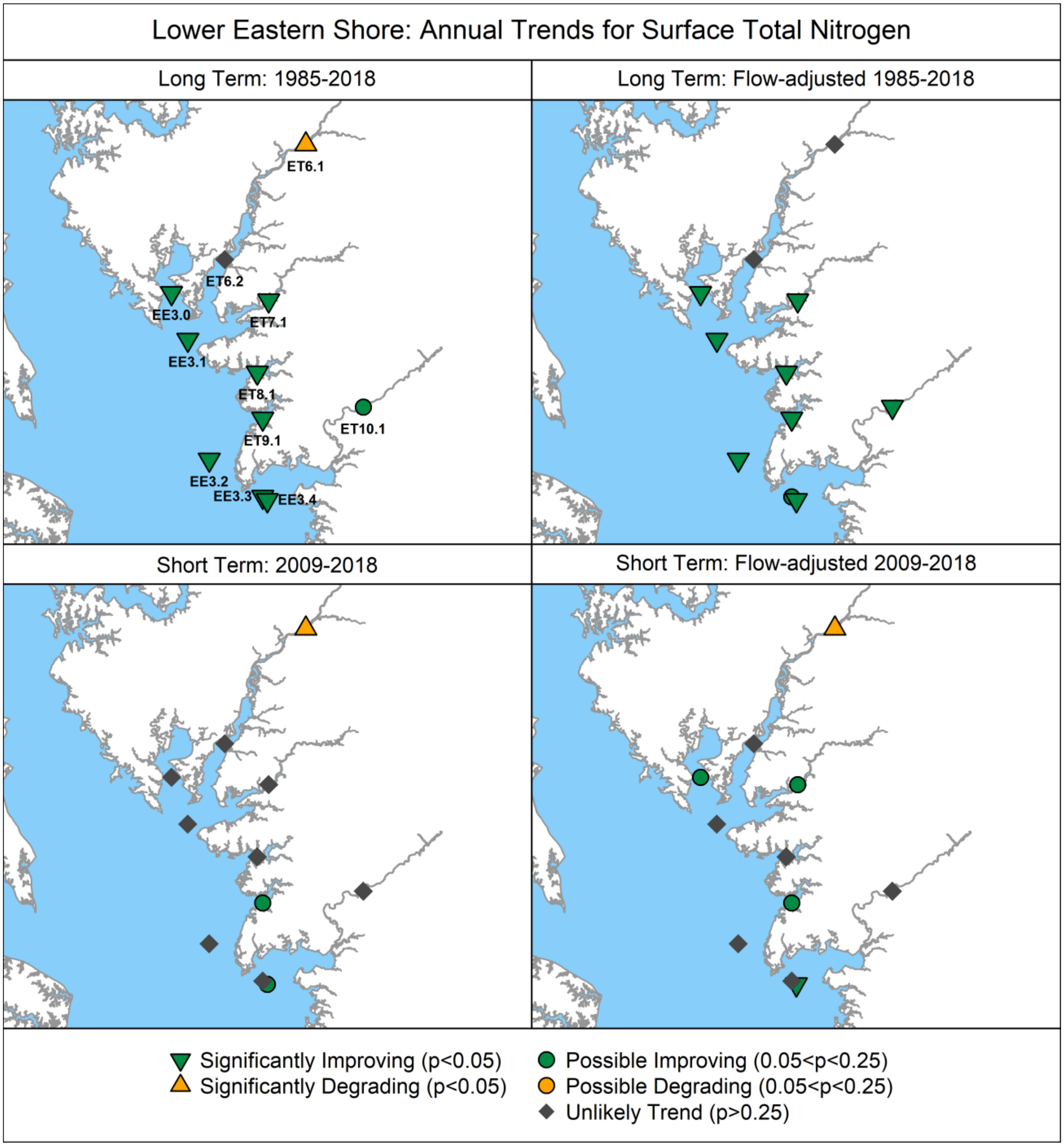


Figure 6. Surface TN trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The TN mean annual GAM estimates fluctuate year-to-year (Figure 7), likely due to variability in freshwater flow. The two tidal fresh stations in this group (ET6.1 and ET10.1) have higher TN concentrations than the remaining mesohaline stations (Figure 7), and the increase at ET6.1 is evident. Other long-term trends are difficult to discern, likely because of a method change in 1998 that caused a shift in the data values. Vertical blue dotted lines represent this laboratory and method change (May 1,

1998) that was tested for its impact on data values. A statistical intervention test within the GAM models showed that these changes were significant at most stations. This is evident by the vertical jump in the mean annual GAM estimates shown with the lines. With this technique, we can estimate long-term change after accounting for the artificial jump from the method change (Murphy *et al.*, 2019).

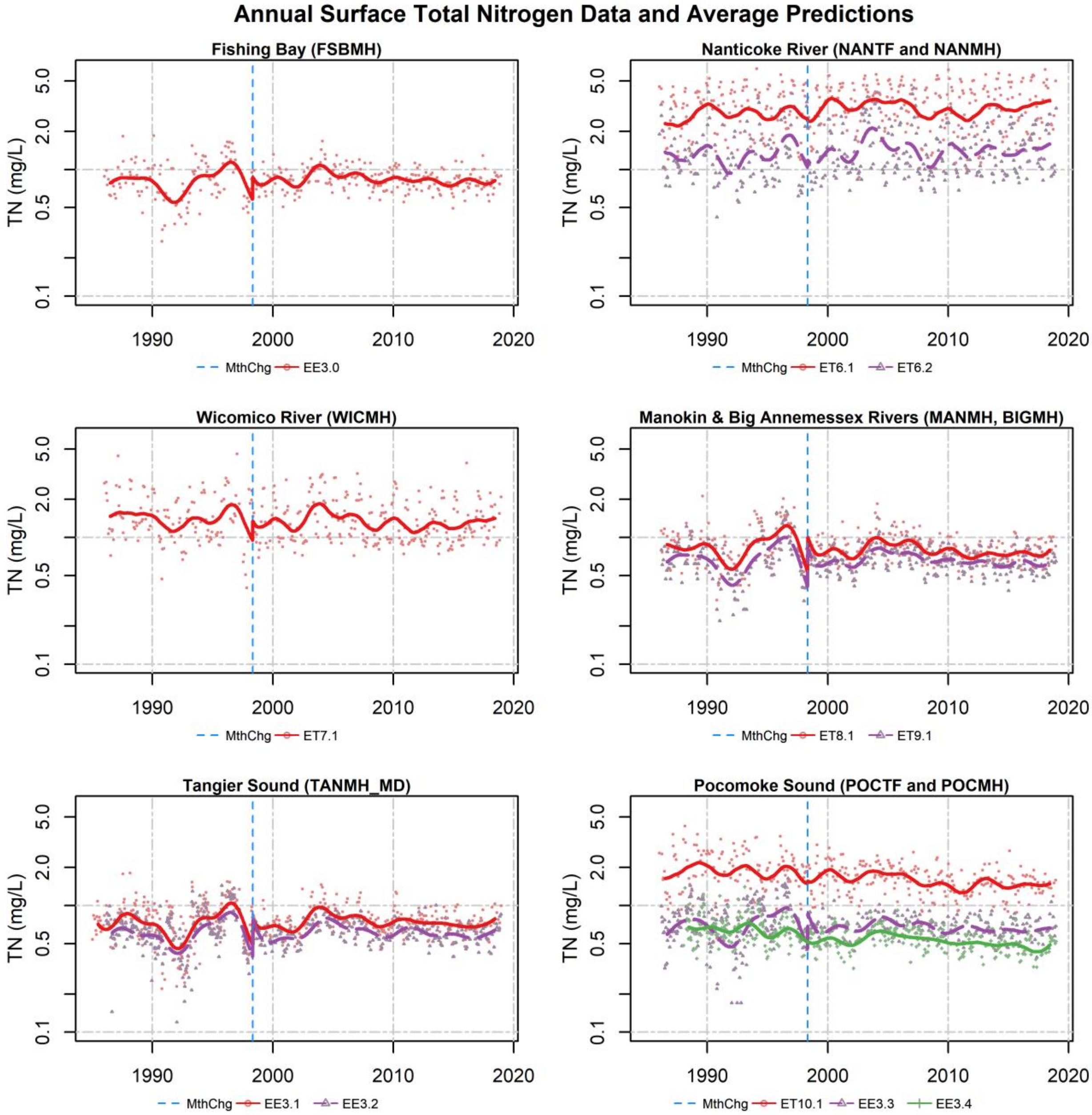


Figure 7. Surface TN data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent data corresponding to the monitoring station indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations. Vertical blue dotted lines represent timing of changes in laboratory and/or sampling methods.

4.2 Surface Total Phosphorus

Surface total phosphorus (TP) trends are improving at the majority of the stations over the long-term, both with and without flow-adjustment (Figure 8). Station ET10.1 is the only station showing a possible degradation over the long-term in this region. Over the short-term, however, there are four stations showing degradation or possible degradation, with two of the degradations persisting with flow-adjustment (Figure 8).

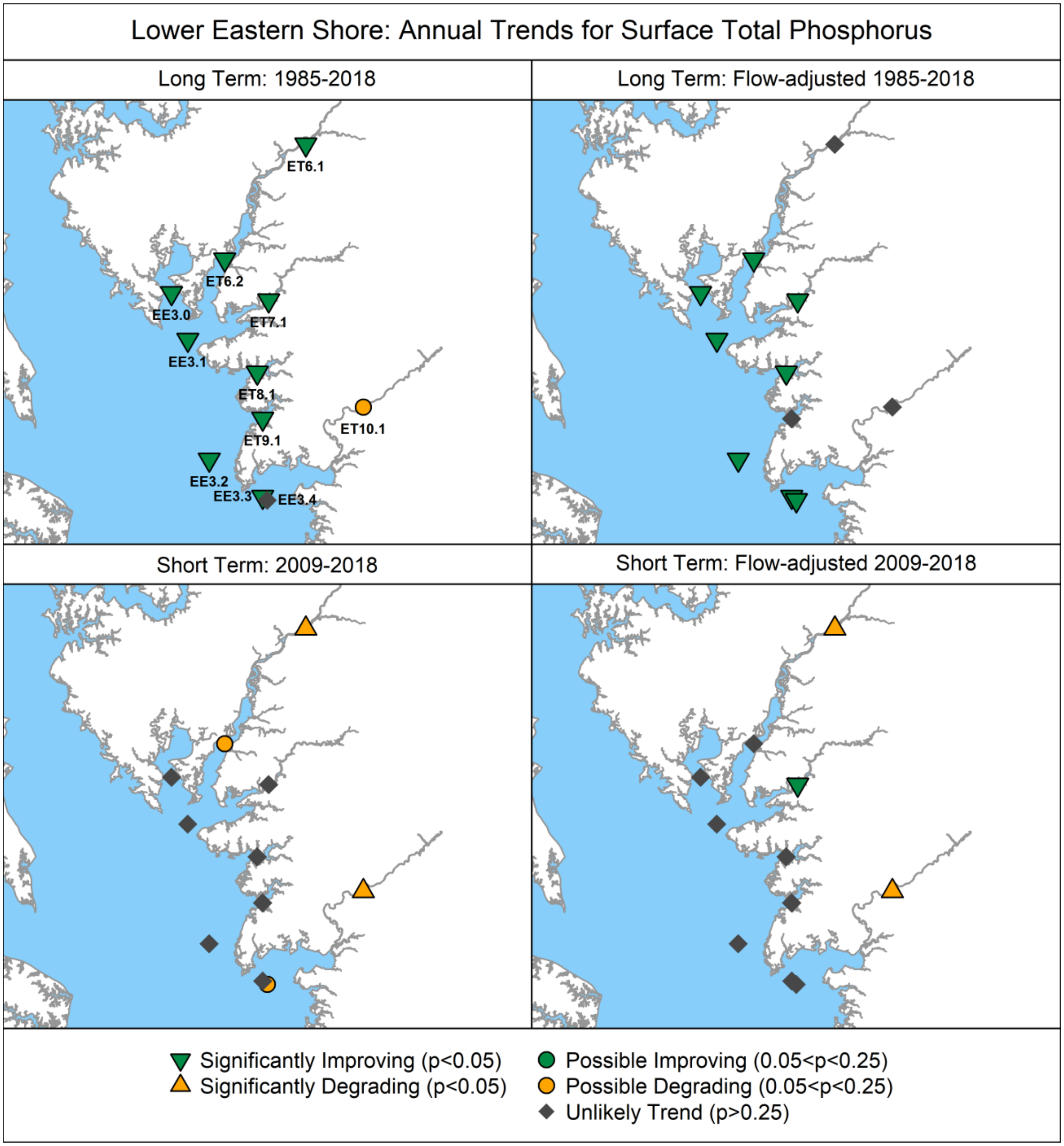


Figure 8. Surface TP trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The long-term improvements at most of the Lower Eastern Shore stations are evident in the data values and mean annual GAM estimates (Figure 9). Many of the decreases are in the first decade of the record and concentrations level-out in the second half of the record. The upswing during the last 10 years at the two tidal fresh stations (ET6.1 and ET10.1) is the cause of those short-term degrading trends (Figure 8).

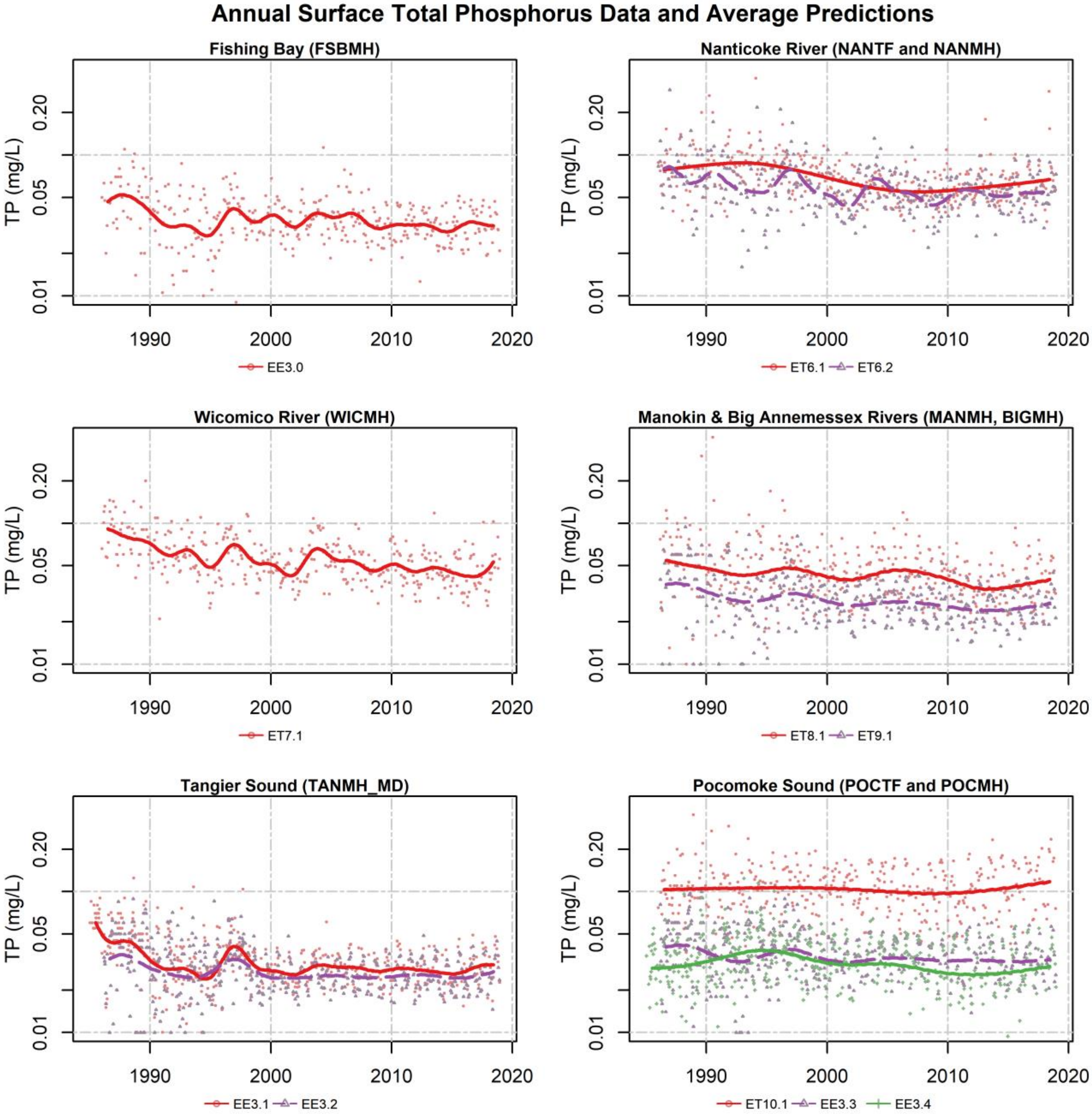


Figure 9. Surface TP data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent data corresponding to the monitoring station shown indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations.

4.3 Surface Chlorophyll *a:* Spring (March-May)

Trends for chlorophyll *a* are split into spring and summer to analyze chlorophyll *a* during the two seasons when phytoplankton blooms are commonly observed in different parts of Chesapeake Bay (Smith and Kemp, 1995; Harding and Perry, 1997). Spring long-term chlorophyll *a* trends are degrading at the majority of the stations without flow-adjustment (Figure 10). With flow-adjustment, the five more northern stations in this region show degradation while the others show no long-term trend and an improvement at ET10.1. Over the short-term, only ET6.1 still has a degrading trend with and without flow-adjustment, and ET7.1 and ET10.1 have improvements both with and without flow adjustment (Figure 10).

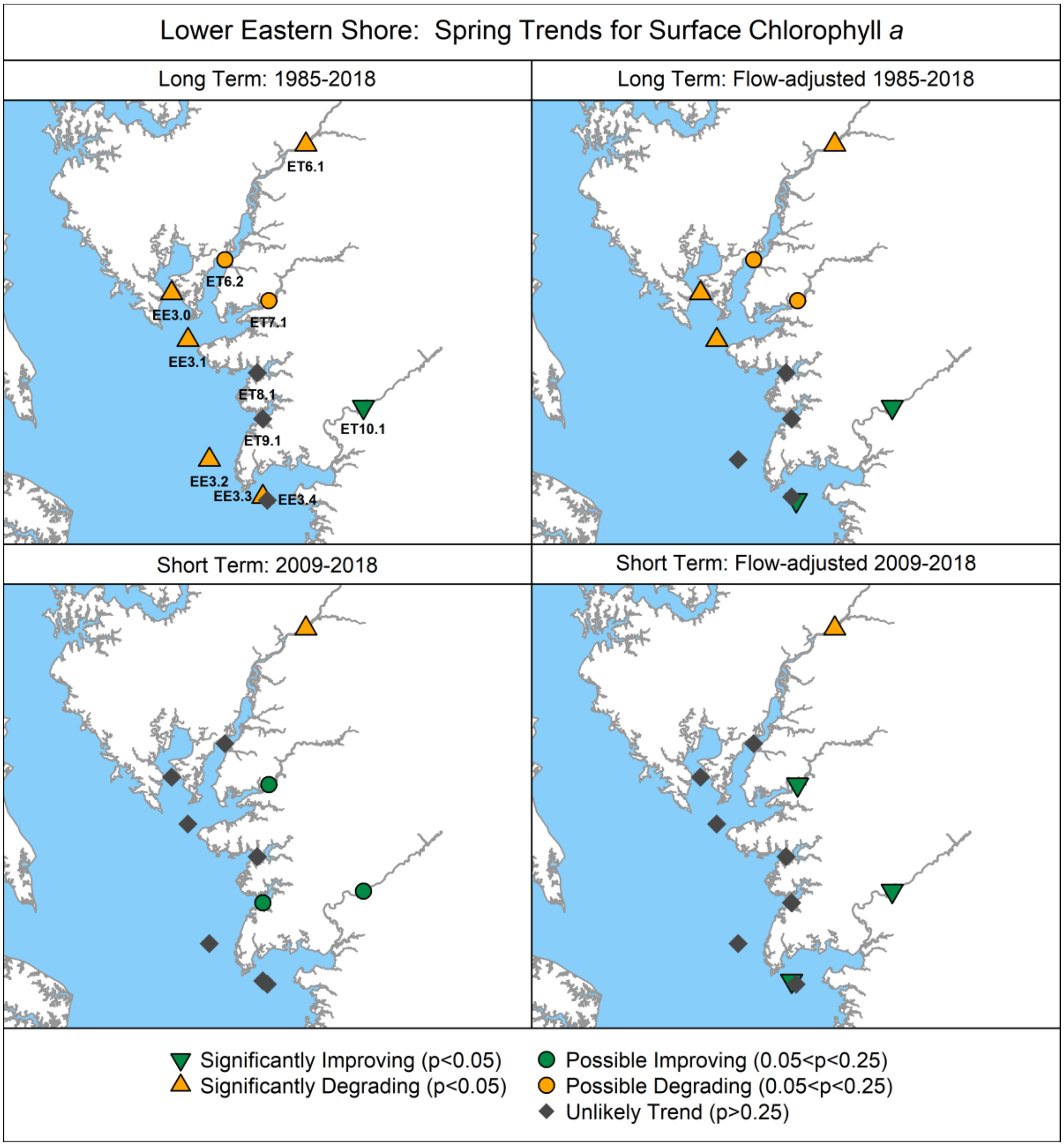


Figure 10. Surface spring (March-May) chlorophyll *a* trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

A variety of patterns in spring chlorophyll *a* concentrations and seasonal mean GAM estimates exist (Figure 11). Long-term increases in Fishing Bay (EE3.0), Nanticoke River (ET6.1 and ET6.2) and Wicomico River (ET7.1) all take on very different shapes. The short-term decrease in the Wicomico River (ET7.1) is due to some low values at the end of the record, and the decrease in the tidal fresh Pocomoke (ET10.1) appears to be the result of low values after a high amount of variability (Figure 11).

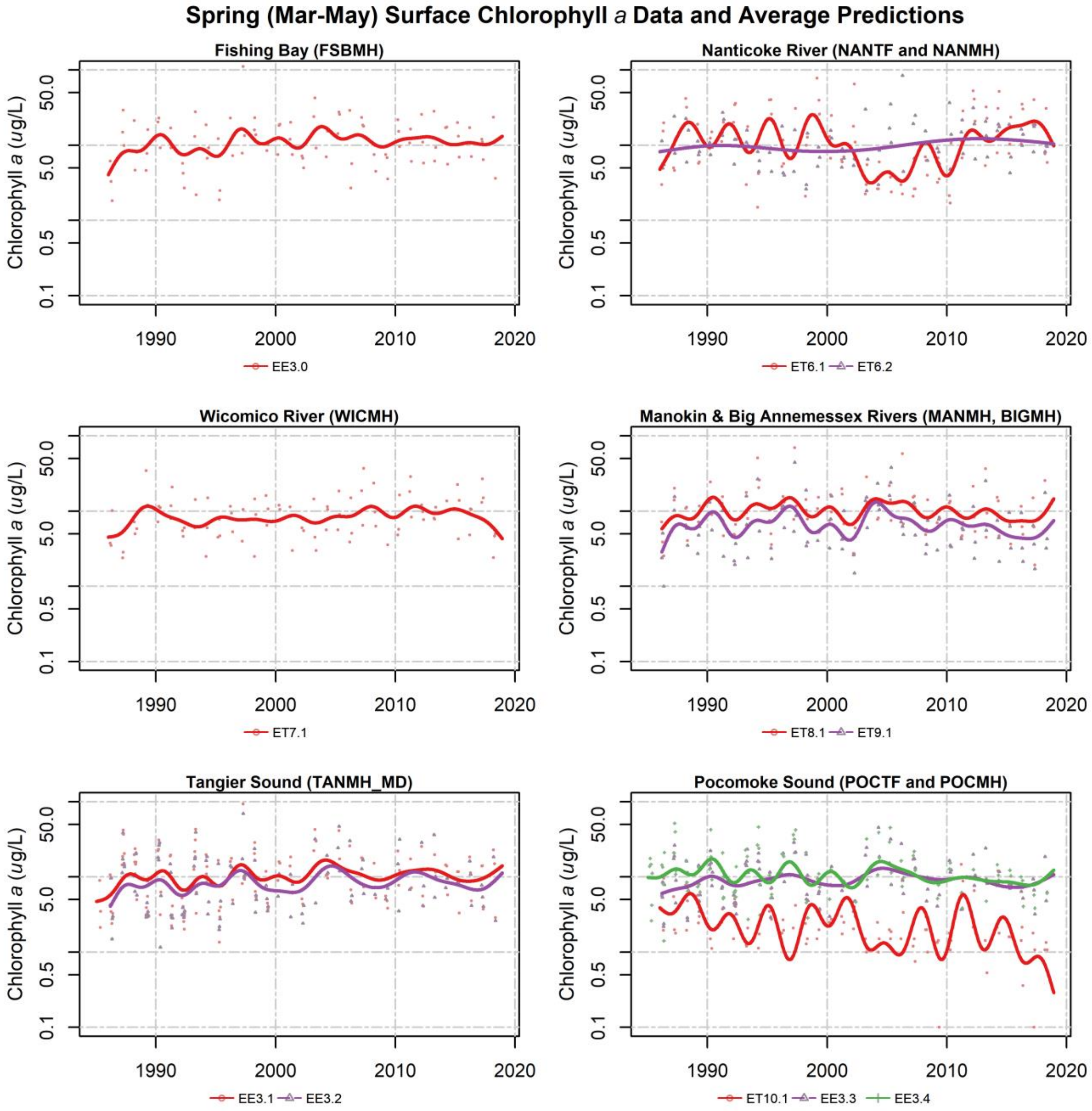


Figure 11. Surface spring chlorophyll *a* data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent March-May data corresponding to the monitoring station

indicated in the legend; colored lines represent mean spring GAM estimates for the noted monitoring stations.

4.4 Surface Chlorophyll *a:* Summer (July-September)

Summer long-term chlorophyll *a* trends (Figure 12) are similar to spring with an exception being summer long-term flow-adjusted improvements at ET7.1 and ET8.1 which were possibly degrading and no trend in the spring (Figure 10). Short-term trends are similar too, with ET6.1 still standing out as the station with long- and short-term degradation while ET10.1 has long and short-term improvements (Figure 12).

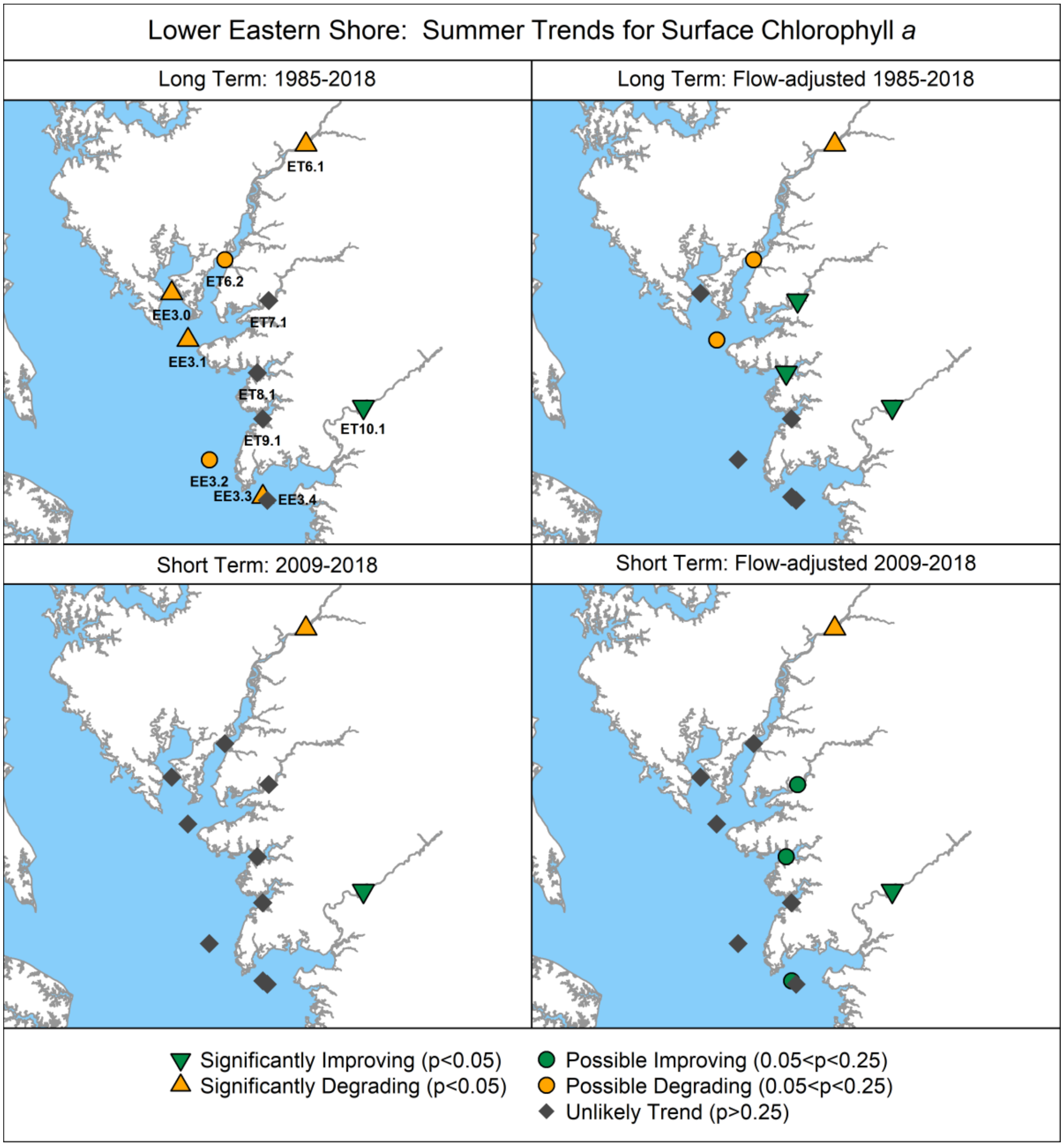


Figure 12. Surface summer (July-September) chlorophyll *a* trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The patterns in the summer chlorophyll *a* mean GAM estimates (Figure 13) are mostly similar to the spring (Figure 11). Slight long-term increases and decreases over time are apparent in some of the mesohaline station data sets, while the two tidal fresh stations (ET6.1 and ET10.1) show dramatic swings in values from year-to-year (Figure 13). The decline over time in the summer ET10.1 (tidal fresh Pocomoke) appears larger than the decrease at the same station in the spring (Figure 11).

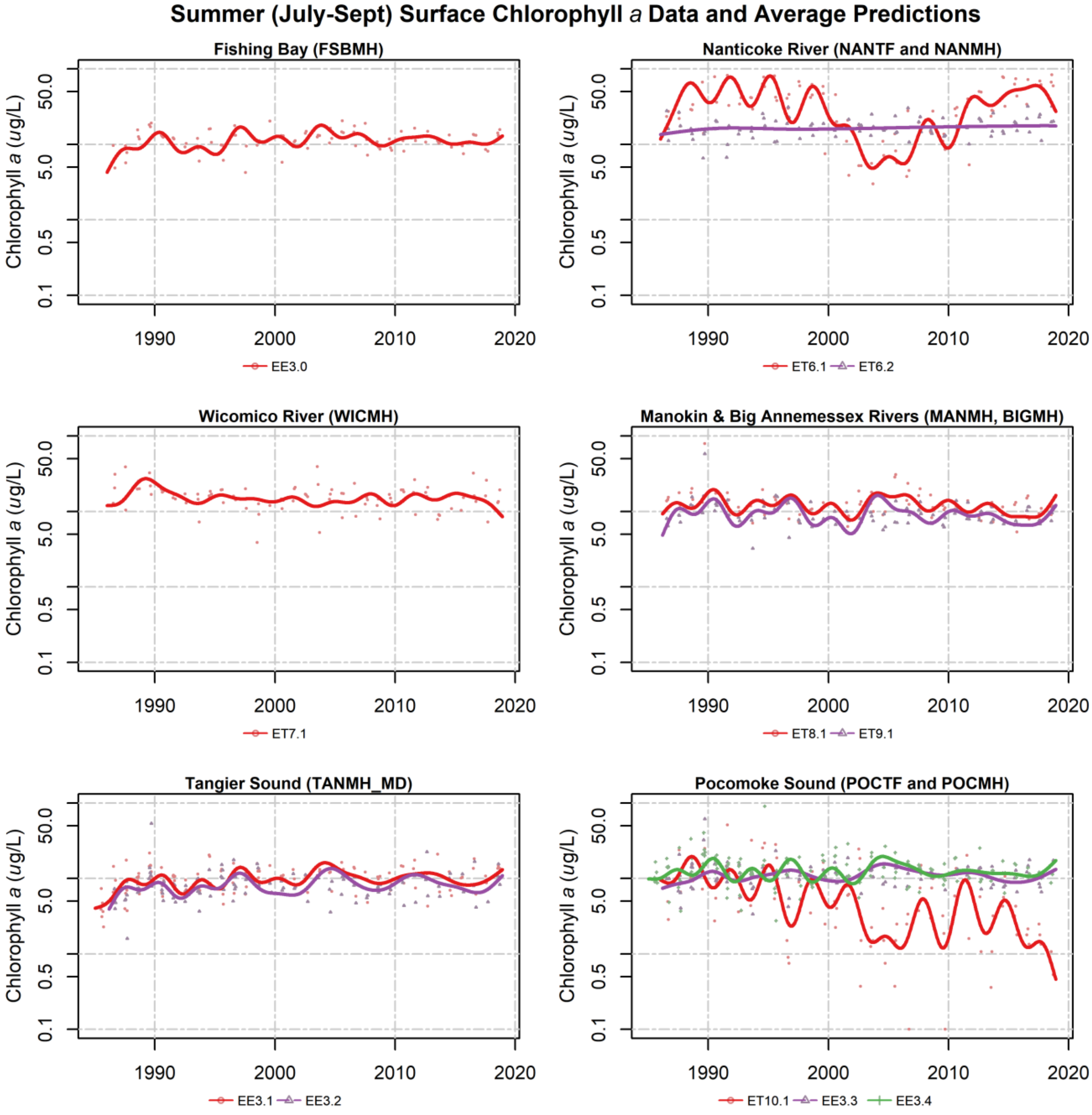


Figure 13. Surface summer chlorophyll *a* data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent July-September data corresponding to the monitoring station indicated in the legend; colored lines represent mean summer GAM estimates for the noted monitoring stations.

4.5 Secchi Disk Depth

Trends in Secchi disk depth, a measure of visibility through the water column, are degrading at most of these Lower Eastern Shore stations over the long-term without flow adjustment (Figure 14). With flow-adjustment, a few more stations have no trend and one (ET10.1) is improving. Over the short-term, three of the stations show possible improvements, while ET6.1 shows a significant degradation.

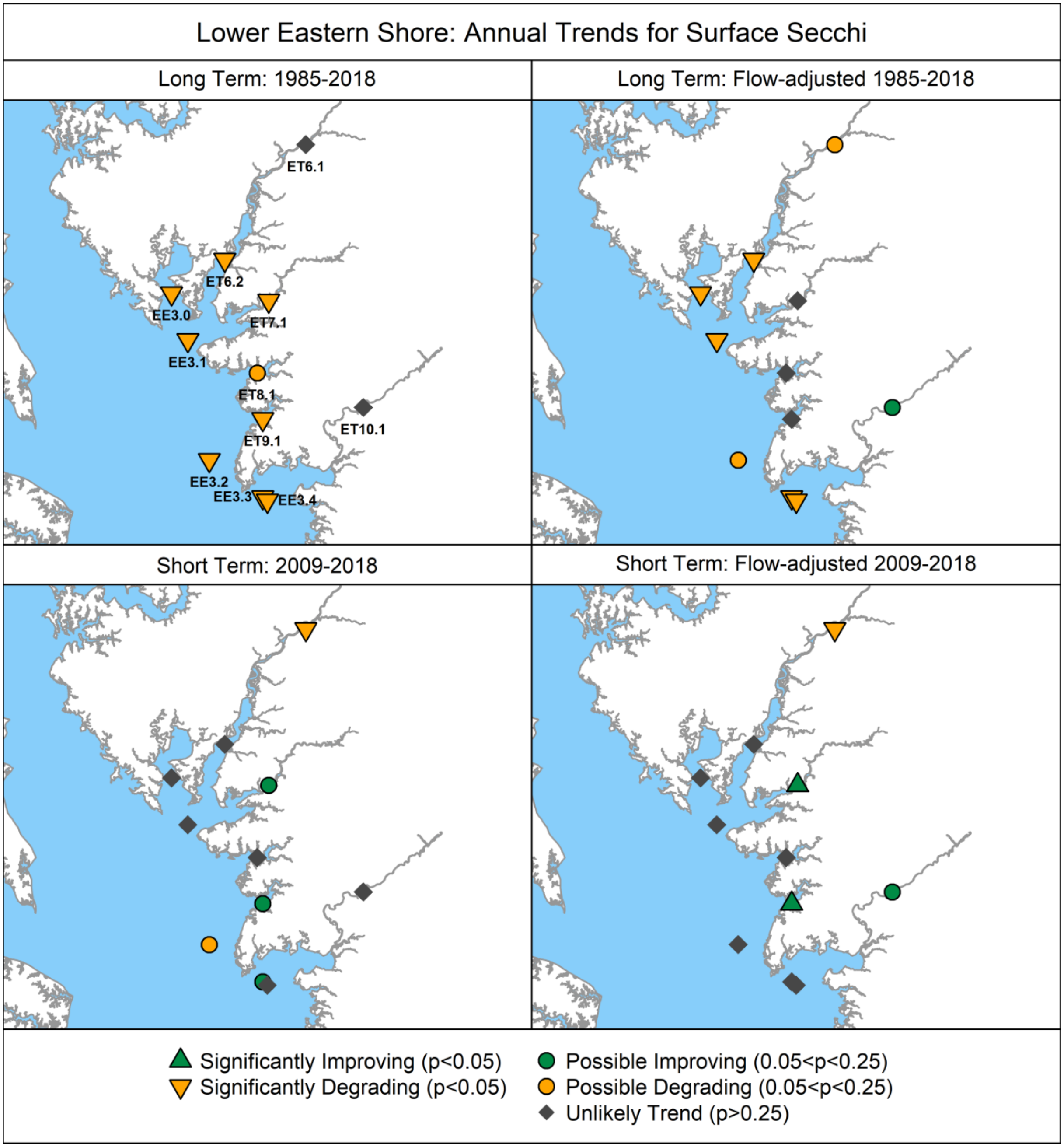


Figure 14. Annual Secchi depth trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The long-term degrading trends in Secchi depth are apparent in the data and mean annual GAM estimates for most of the stations (Figure 15). The tidal fresh stations (ET6.1 and ET10.1) that have no long-term trends have very low, seemingly constant, Secchi patterns over time. A short-term increase at several stations is apparent in the graphics, with the upswing at ET9.1 (Big Annemessex River) particularly notable (Figure 15).

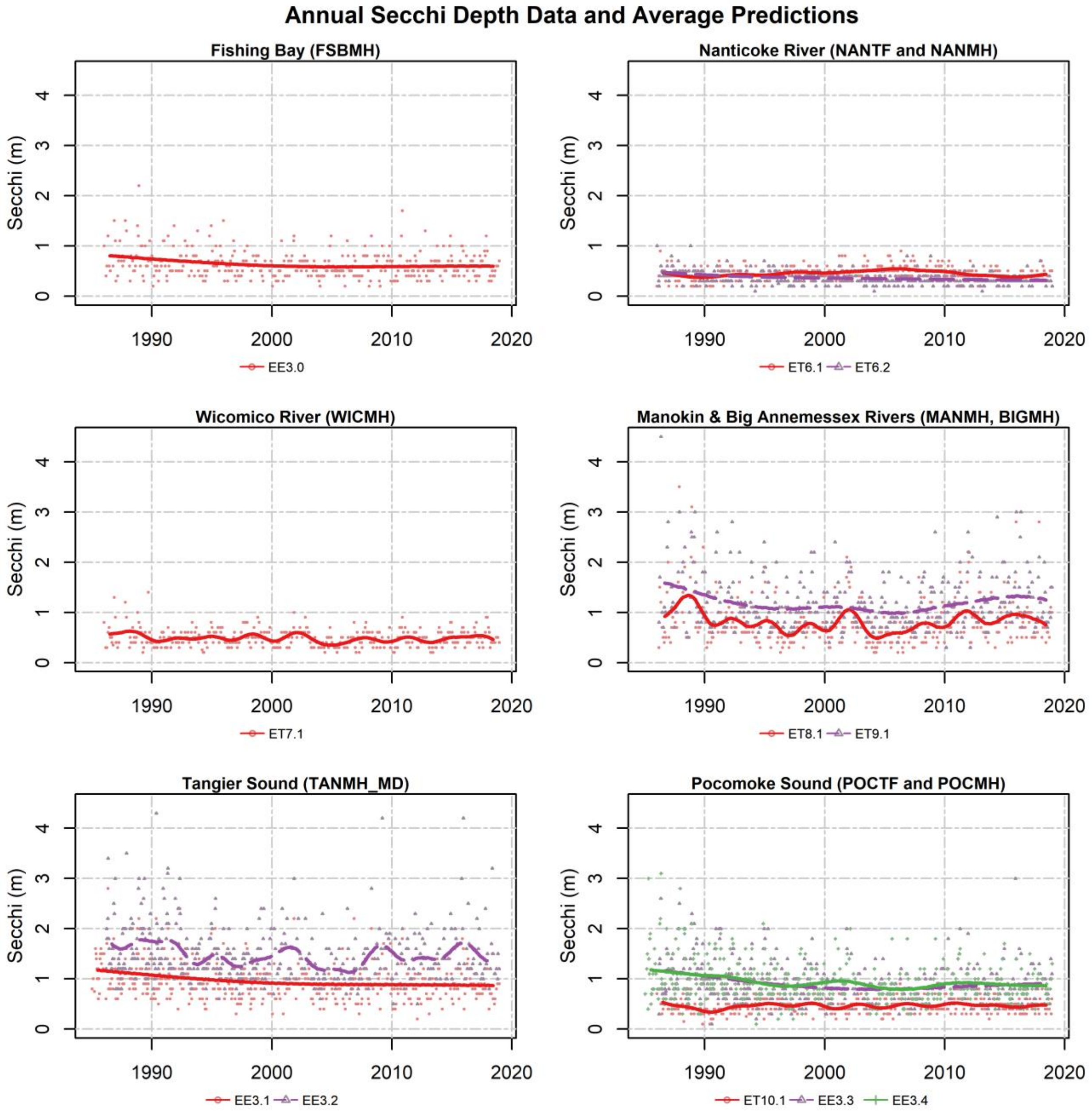


Figure 15. Annual Secchi depth data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent data corresponding to the monitoring station shown indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations.

4.6 Summer Bottom Dissolved Oxygen (June-September)

Summer bottom DO concentrations have no trend over the long-term at the majority of the Lower Eastern Shore stations, although three stations show degrading trends before flow adjustment (ET6.2, ET7.1, ET10.1) and one shows a possible improvement (EE3.4) (Figure 16). Over the short-term, however, seven of 11 stations show improvements before flow adjustment, and most of them are still improving with flow-adjustment (Figure 16).

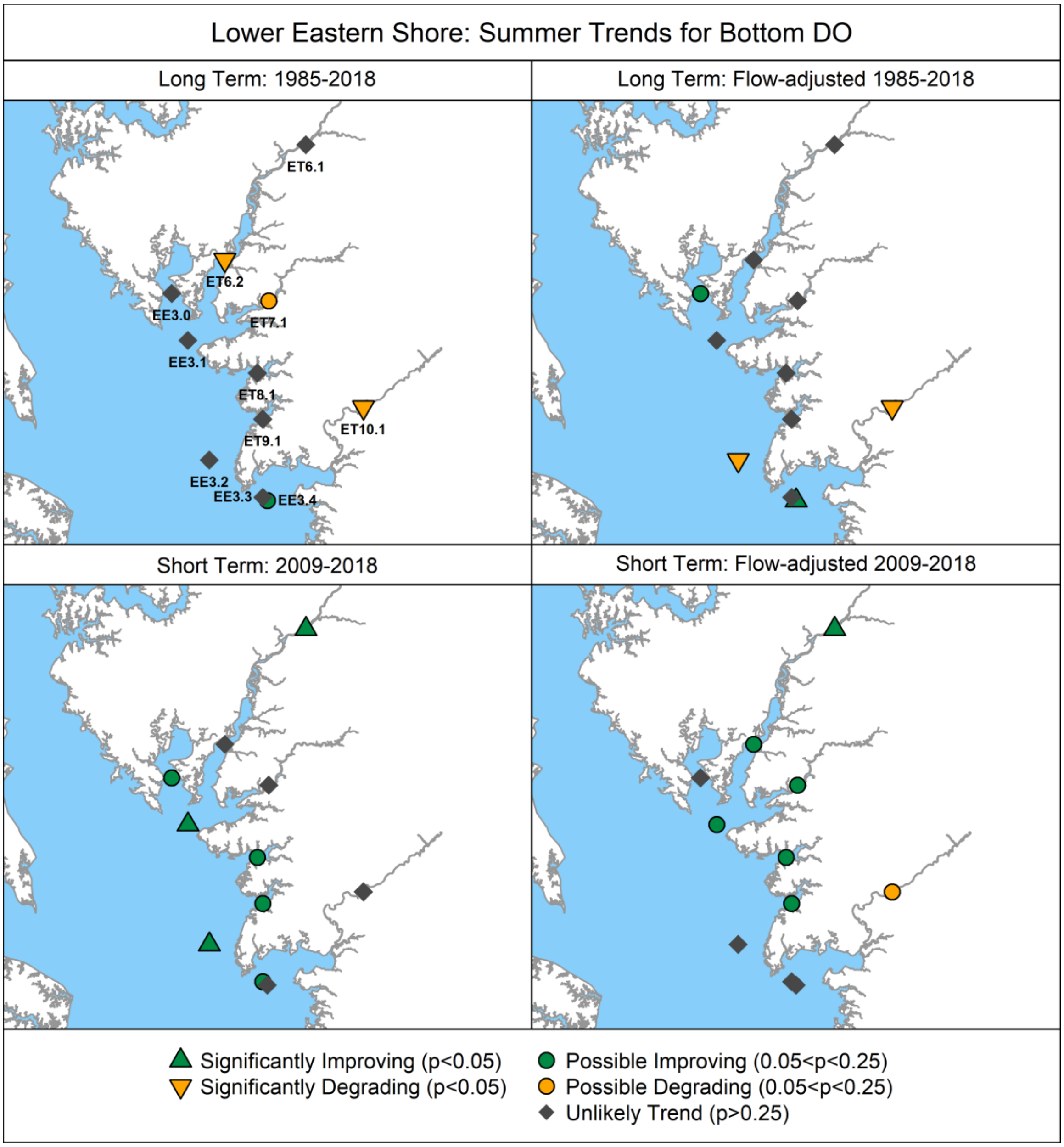


Figure 16. Summer (June-September) bottom DO trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

Summer bottom DO concentrations are relatively high in this region compared to other parts of the Chesapeake Bay, although concentrations less than 3 mg/L occur throughout the record sporadically at the Tangier Sound stations (mostly EE3.2) and have begun to occur more frequently at ET10.1 (Figure 17). The recent increases at may of these stations are apparent in the data values and mean summer GAM estimates, particularly Fishing Bay (EE3.0), tidal fresh Nanticoke (ET6.1), and Tangier Sound (EE3.1 and EE3.2). A steady decrease has occurred at the Pocomoke tidal fresh station (ET10.1), taking the values well below the applicable 5 mg/L summer Open Water 30-day mean DO criterion.

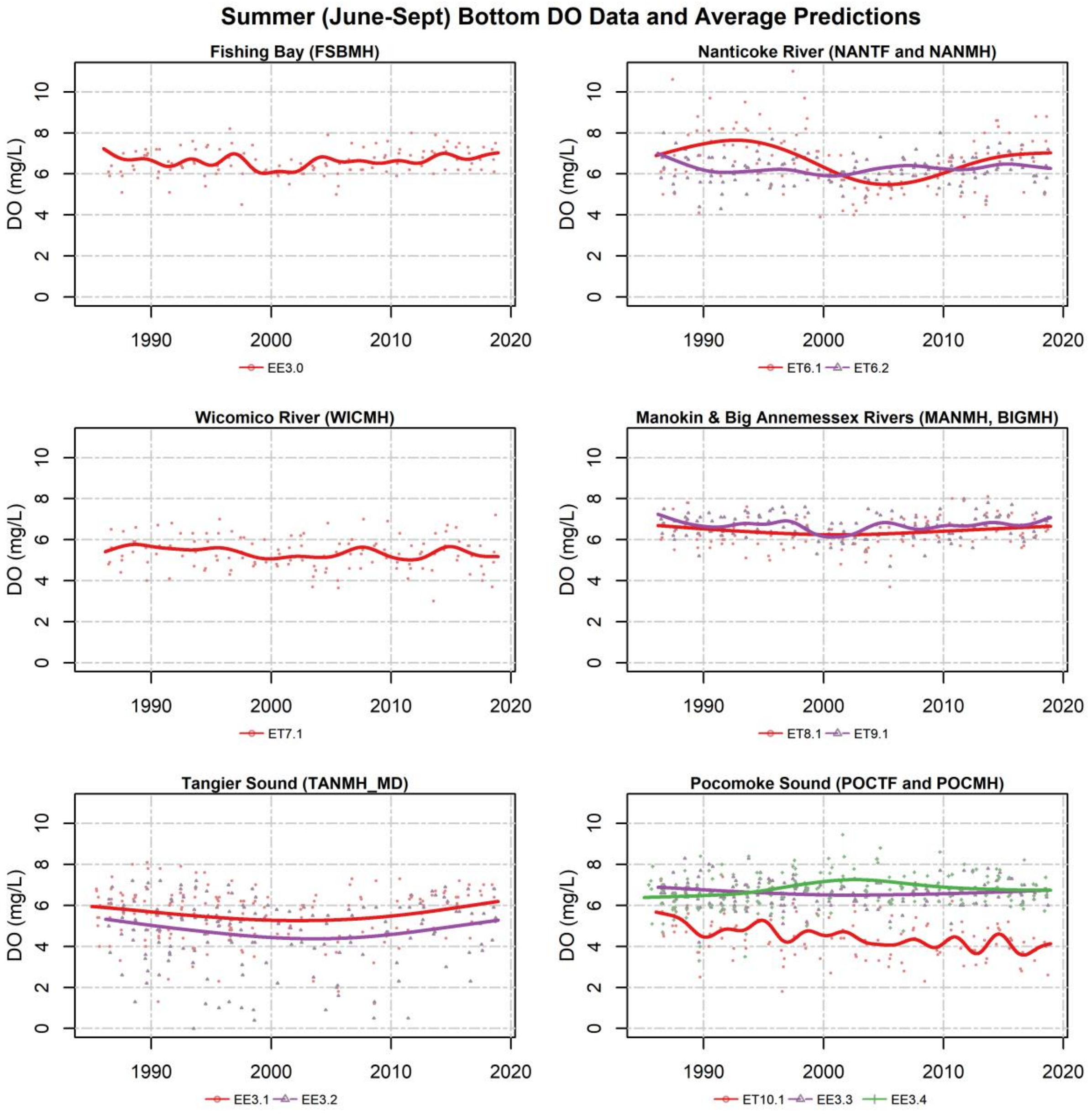


Figure 17. Summer (June-September) bottom DO data (dots) and summer mean long-term pattern generated from non-flow adjusted GAMs. Colored dots represent June-September data corresponding to the monitoring station indicated in the legend; colored lines represent mean summer GAM estimates for the noted monitoring stations.

5. Factors Affecting Trends

5.1 Watershed Factors

5.1.1 Effects of Physical Setting

Large nitrogen and phosphorus loads occur throughout the Eastern Shore because unique combinations of hydrogeology, topography, and soils promote the efficient transport of agricultural-associated nutrient applications to streams and tidal waters (Figure 18) (Brakebill *et al.*, 2010; Ator *et al.*, 2011; Ator *et al.*, 2019; Ator *et al.*, 2020; Noe *et al.*, 2020). Sediment loads are typically low throughout the Eastern Shore because of the relatively flat topography of the Atlantic Coastal Plain.

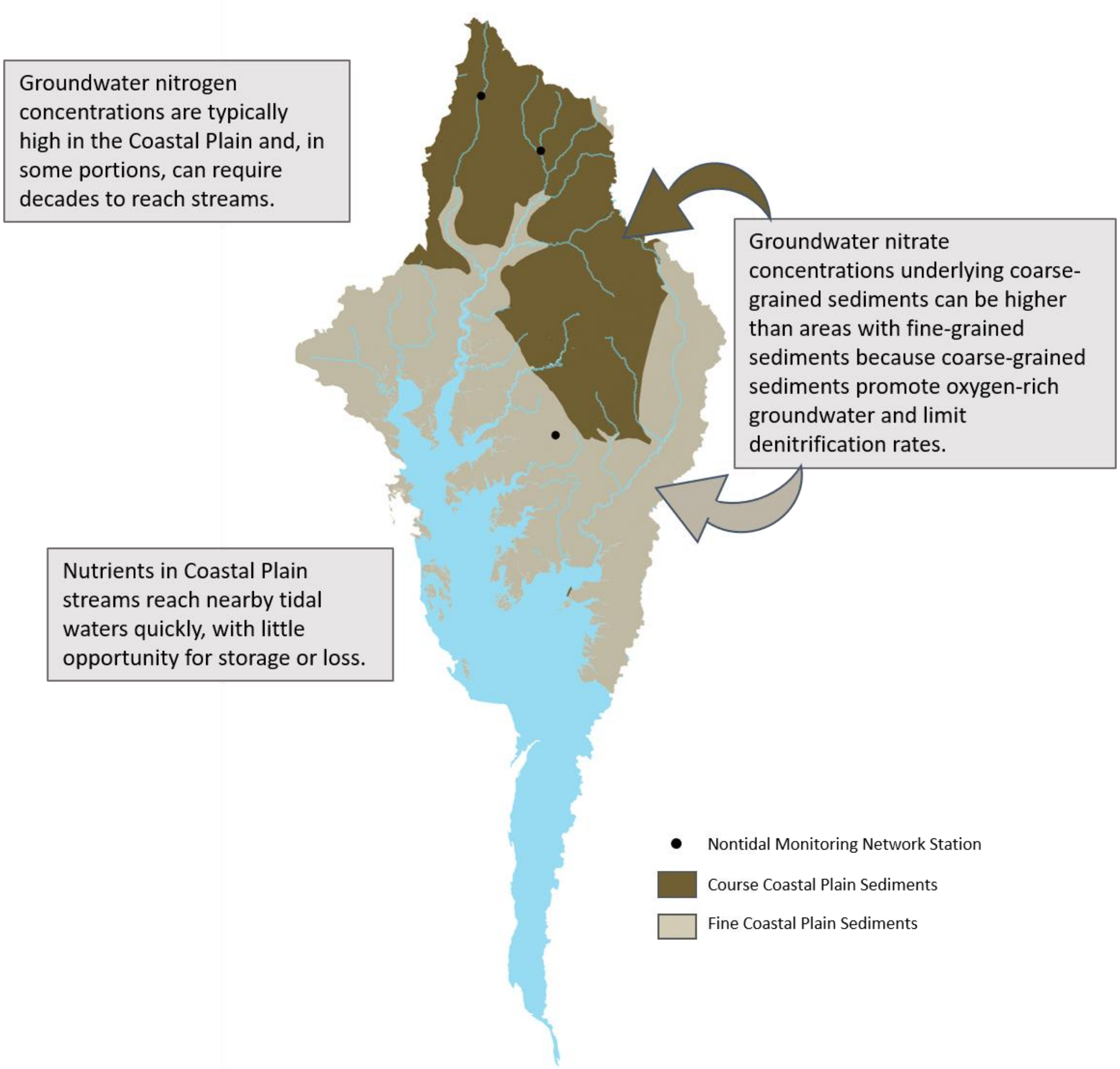


Figure 18. Effects of watershed hydrogeomorphology on nutrient transport to freshwater streams and tidal waters. Base map modified from King *et al.* (1974) and Ator *et al.* (2005), North American Datum 1983.

Nitrogen

Groundwater is an important delivery pathway of nitrogen, as nitrate, to most streams in the Chesapeake Bay watershed (Ator and Denver, 2012; Lizarraga, 1997) and contributes about 70% of the nitrogen to Eastern Shore streams. Some of the highest concentrations of groundwater nitrogen in the Bay watershed are present in portions of the Eastern Shore where oxygen-rich groundwater limits denitrification (Debrewer and others, 2008; Greene and others, 2005). Eastern Shore denitrification rates are low and nitrate concentrations are high in sandy soils and sediments (Böhlke and Denver, 1995; Denver and others 2004), in soils that have been drained to support agricultural activities (Staver and Brinsfield, 2001), and in areas underlain by a thick surficial aquifer that prevents contact with deeper, anoxic groundwater (Böhlke and Denver, 1995). These features vary substantially from place to place throughout the Eastern Shore, but conditions limiting denitrification are common. In general, the lowest Eastern Shore nitrate concentrations discharge to streams along the perimeter of the Delmarva Peninsula, where less permeable soils and a thinner surficial aquifer result in groundwater flowpaths that are more likely to encounter anoxic conditions (Ator and Denver, 2015). The extremely low topographic relief of the Lower Eastern Shore requires extensive ditching of agricultural fields and stream channelization, providing very short pathways for nitrogen movement into streams (Ator and Denver, 2015). Most Eastern Shore streamflow is generated from groundwater that discharges from the uppermost few meters of a shallow, surficial unconfined aquifer (Cushing and others, 1973, Sanford and others, 2012). More than half of the groundwater discharging to streams is older than thirteen years (Sanford and Pope, 2013), so the high concentrations of nitrate that have increased in portions of the Eastern Shore aquifer (Debrewer and others, 2008), will likely contribute to streams for decades.

Phosphorus

Eastern Shore phosphorus concentrations are higher than most other regions of the Chesapeake Bay watershed (Ator *et al.*, 2011) because phosphorus concentrations are high in soils underlaying agricultural watersheds. Phosphorus applications have exceeded Eastern Shore cropping needs and have accumulated in such soils for decades (Staver and Brinsfield, 2001; Ator and Denver, 2015). Such conditions can increase the amount of sediment-bound and dissolved phosphorus carried in runoff (Heckrath *et al.*, 1995). Sandy soils common throughout the Eastern Shore can become fully phosphorus saturated relatively quickly because of their low phosphorus sorption capacity (Sharpley, 1980). As a result of such conditions, phosphorus can also be exported to streams from shallow soils and groundwater (Staver and Brinsfield, 2001). Reducing soil phosphorus concentrations can take a decade or more (Kleinman *et al.*, 2011) and, until this occurs, watershed phosphorus loads may be unresponsive to management practices (Jarvie *et al.*, 2013; Sharpley *et al.*, 2013).

Sediment

Despite increased sediment erosion associated with agricultural land uses, Eastern Shore sediment loads are typically as low as some undeveloped regions of the Bay watershed (Brakebill *et al.*, 2010) because of the relatively flat topography of the Atlantic Coastal Plain. The sediment load of a given stream reach is a balance of sediment eroded from uploads and streambanks and sediment stored in floodplains and stream channels. Eastern Shore streambank erosion rates are reduced in areas with low topographic gradient, but are also affected by watershed drainage area (Gellis and Noe, 2013; Gellis *et al.*, 2015;

Gillespie *et al.*, 2018; Hopkins *et al.*, 2018), bank sediment density (Wynn and Mostaghimi, 2006), vegetation (Wynn and Mostaghimi, 2006), and other stream valley geomorphic properties (Hopkins *et al.*, 2018). The lowest Eastern Shore sediment concentrations are present in portions of the Lower Eastern Shore (Brakebill *et al.*, 2010), likely as a result of this area's extremely low topographic gradient.

Delivery to tidal waters

The delivery of nitrogen, phosphorus, and sediment in non-tidal Eastern Shore streams to tidal waters varies based on physical and chemical factors that affect in-stream retention, loss, or storage. In general, the proximity of much of the Eastern Shore to tidal waters limits opportunities for in-stream denitrification (Staver and Brinsfield, 2001). There are no natural chemical processes that remove phosphorus from streams, but sediment, and associated phosphorus, can be trapped in floodplains before reaching tidal waters. High rates of sediment trapping by Coastal Plain nontidal floodplains and head-of-tide tidal freshwater wetlands creates a sediment shadow in many tidal rivers and limits sediment delivery to the bay (Noe and Hupp, 2009; Ensign *et al.*, 2014). Shoreline erosion can be larger source of sediment delivered to Eastern Shore estuaries than upland runoff or streambank erosion because of such trapping and because of the low relief of the Atlantic Coastal Plain (Yarbro *et al.*, 1983).

5.1.2 Estimated Nutrient and Sediment Loads

Estimated loads to tidal portions of the Lower Eastern Shore Tributaries are a combination of simulated non-point source, atmospheric deposition, and reported point-source loads. These loads were obtained from the Chesapeake Bay Program Watershed Model's progress runs specific to each year from 1985 and 2018 (https://cast.chesapeakebay.net/). Nonpoint source loads were adjusted to reflect actual hydrology using the method of the Chesapeake Bay Program's Loads to the Bay indicator (see https://www.chesapeakeprogress.com/clean-water/water-quality). Over the period of 1985-2018, 0.29, 0.015, and 8.6 million tons of nitrogen, phosphorus, and suspended sediment loads were exported from this watershed, respectively (Figure 19).

Mann-Kendall trends and Sen's slope estimates are summarized for each loading source in Table 3.

Nitrogen

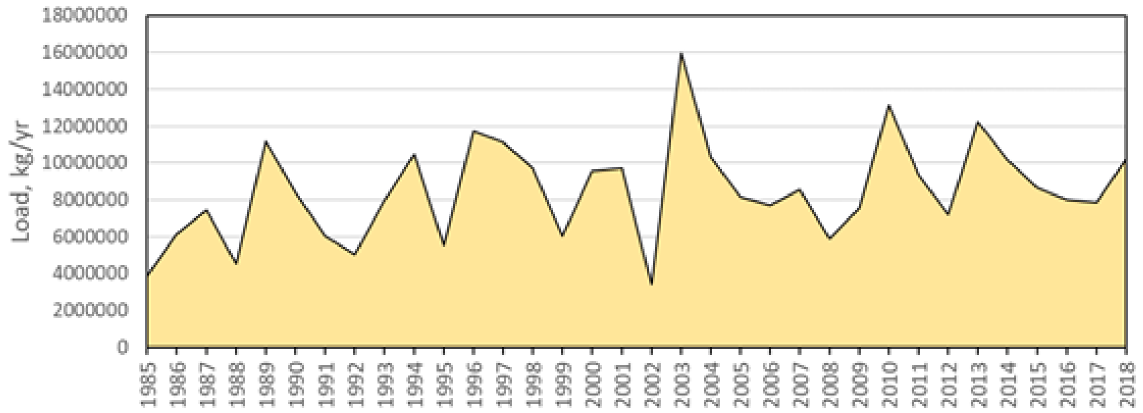
Estimated TN loads showed an overall increase of 89 ton/yr in the period between 1985 and 2018, although it is not statistically significant ($p = 0.12$). Long-term, statistically significant declines were observed with both point sources (-4.8 ton/yr, $p < 0.01$) and atmospheric deposition to the tidal waters (-8.6 ton/yr, $p < 0.01$). By contrast, the nonpoint sources showed a long-term increase in this period (99 ton/yr), although it is not statistically significant ($p = 0.06$). The significant point source reductions in TN are a result of substantial efforts to reduce nitrogen loads from major wastewater treatment facilities by implementing biological nutrient removal (Lyerly *et al.*, 2014). The significant decline in atmospheric deposition of TN to the tidal waters is consistent with findings that atmospheric deposition of nitrogen has decreased due to benefits from the Clean Air Act implementation (Eshleman *et al.*, 2013; Lyerly *et al.*, 2014).

Phosphorus

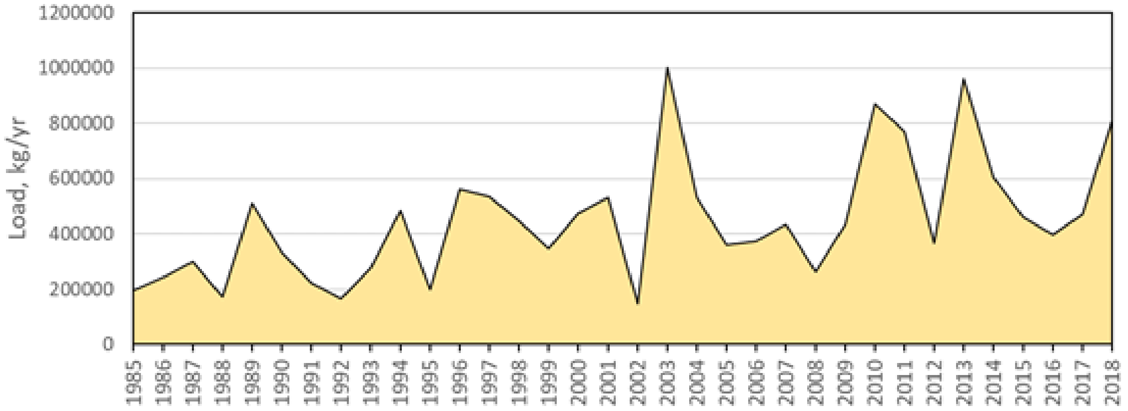
Estimated TP loads showed an overall increase of 10 ton/yr in the period between 1985 and 2018, which is statistically significant ($p < 0.01$). This increase is entirely driven by nonpoint sources (12 ton/yr, $p < 0.01$). By contrast, point sources showed a statistically significant decline (-1.8 ton/yr, $p < 0.01$). This TP point source load reduction has also been attributed to significant efforts to reduce phosphorus in wastewater discharge through the phosphorus detergent ban in the early part of this record, as well as technology upgrades at wastewater treatment facilities (Lyerly *et al.*, 2014).

Sediment

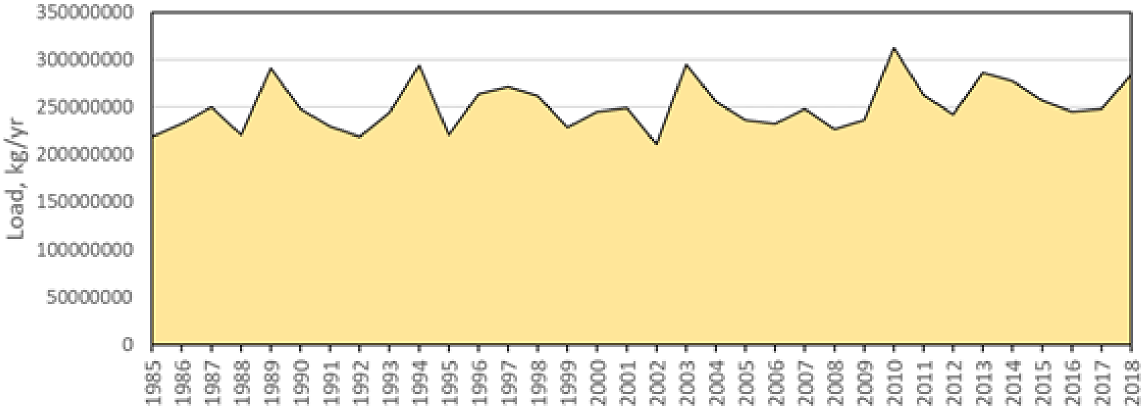
Estimated suspended sediment (SS) loads showed an overall increase of 857 ton/yr in the period between 1985 and 2018, although it is not statistically significant ($p = 0.09$). This increase is entirely driven by nonpoint sources (860 ton/yr, $p = 0.09$). Like TP and TN, point source load of SS showed a statistically significant decline in this period (-5.8 ton/yr; $p < 0.01$).



Lower Eastern Shore TN Load



Lower Eastern Shore TP Load



Lower Eastern Shore SS Load

Figure 19. Estimated total loads of nitrogen (TN), phosphorus (TP), and suspended sediment (SS) to the Lower Eastern Shore Tributaries.

Table 3. Summary of Mann-Kendall trends for the period of 1985-2018 for total nitrogen (TN), total phosphorus (TP), and suspended sediment (SS) loads from the Lower Eastern Shore watershed.

Variable	Trend, metric ton/yr	Trend p-value
TN		
Total watershed[1]	89	0.12
Point source	-4.8	< 0.01
Nonpoint source[2]	99	0.06
Tidal deposition	-8.6	< 0.01
TP		
Total watershed	10	< 0.01
Point source	-1.8	< 0.01
Nonpoint source	12	< 0.01
SS		
Total watershed	857	0.09
Point source	-5.8	< 0.01
Nonpoint source	860	0.09

[1] Loads from the different sources were obtained from the Chesapeake Bay Program Watershed Model progress runs specific to each year from 1985 and 2018, (https://cast.chesapeakebay.net/).

[2] Nonpoint source loads were adjusted to reflect actual hydrology using the method of the Chesapeake Bay Program's Loads to the Bay indicator (see https://www.chesapeakeprogress.com/clean-water/water-quality). The adjustment factor for each year is defined as the ratio between monitored load and watershed model simulated load for an applicable USGS River Input Monitoring (RIM) station. Because the Lower Eastern Shore Tributaries do not have RIM stations, adjustment factors need to be transferred from a different tributary that has a RIM station. In this regard, the Choptank River was selected for two reasons: (1) it is geographically proximate to the Lower Eastern Shore Tributaries, and (2) it is hydrologically similar to the Lower Eastern Shore Tributaries based on an analysis of annual riverflow anomalies.

5.1.3 Expected Effects of Changing Watershed Conditions

According to the Chesapeake Bay Program's Watershed Model known as the Chesapeake Assessment Scenario Tool (CAST; https://cast.chesapeakebay.net, version CAST-2019), changes in population size, land use, and pollution management controls between 1985 and 2019 would be expected to change long-term average nitrogen, phosphorus, and sediment loads to the tidal Lower Eastern Shore River by -19%, -47%, and -14%, respectively (Figure 20). In contrast to the annual loads analysis above, CAST loads are based on changes in management only and do not include annual fluctuations in weather. CAST loads are calculated without lag times for delivery of pollutants or lags related to BMPs becoming fully effective after installation. In 1985, agriculture and developed were the two largest sources of nitrogen loads. By 2019, agriculture and developed remained the two largest sources of nitrogen loads. Overall, decreasing nitrogen loads from agriculture (-24%), natural (-4%), stream bed and bank (-18%), and wastewater (-78%) sources were partially counteracted by increases from developed (45%) and septic (50%) sources.

The two largest sources of phosphorus loads as of 2019 were the agriculture and stream bed and bank sectors. Overall, expected declines from agriculture (-54%), natural (-3%), stream bed and bank (-48%), and wastewater (-89%) sources were partially counteracted by increases from developed (22%) sources.

For sediment, the largest sources are shoreline and stream bed and bank areas: these two sources changed by 0% and -53%, respectively between 1985 and 2019. Sediment loads from the agriculture sector changed by -64%, whereas sediment load from developed areas changed by 38%.

Overall, changing watershed conditions are expected to result in the agriculture, natural, stream bed and bank, and wastewater sectors achieving reductions in nitrogen, phosphorus, and sediment loads between 1985 and 2019, whereas the developed sectors are expected to increase in nitrogen, phosphorus, and sediment loads.

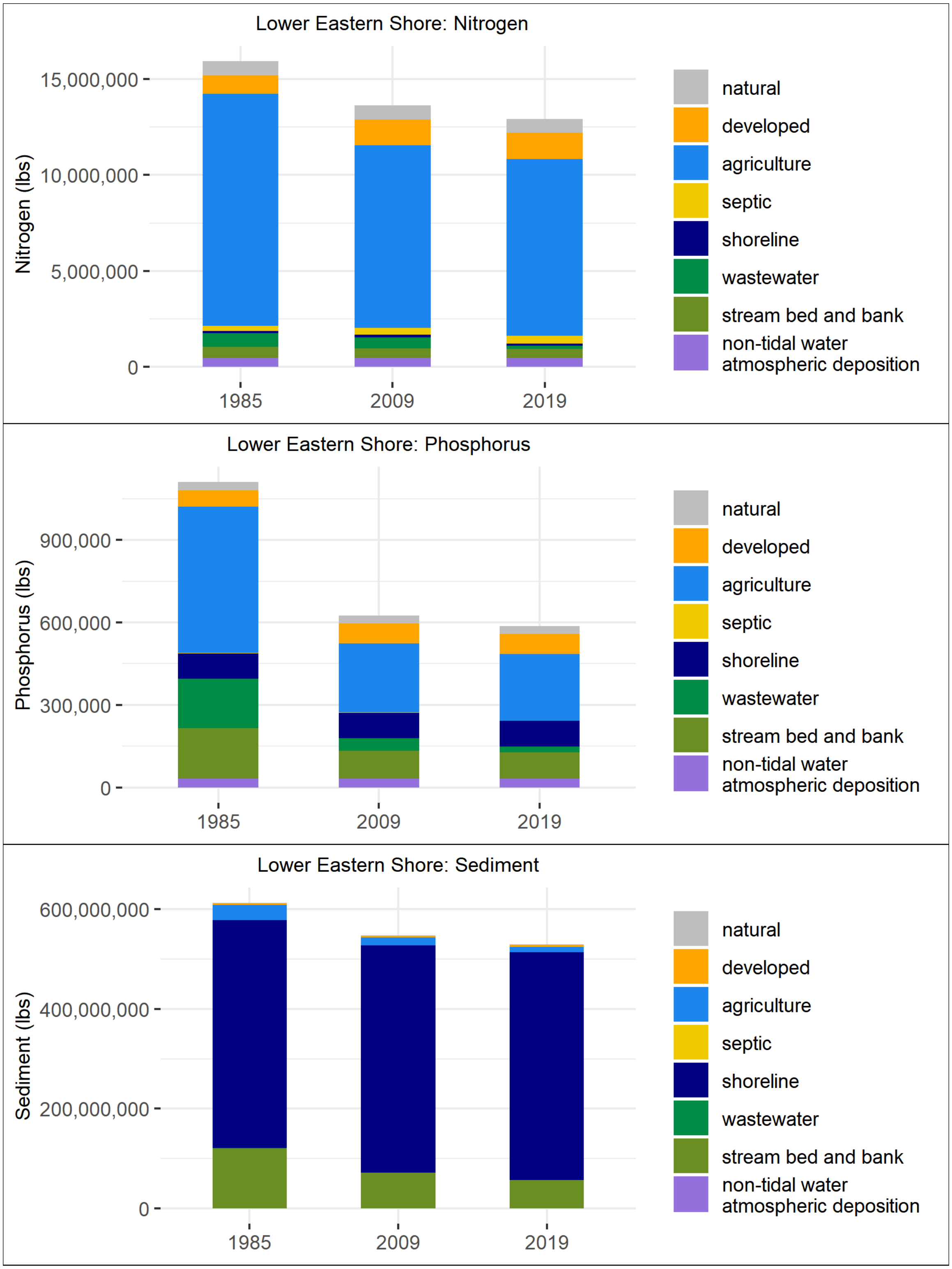
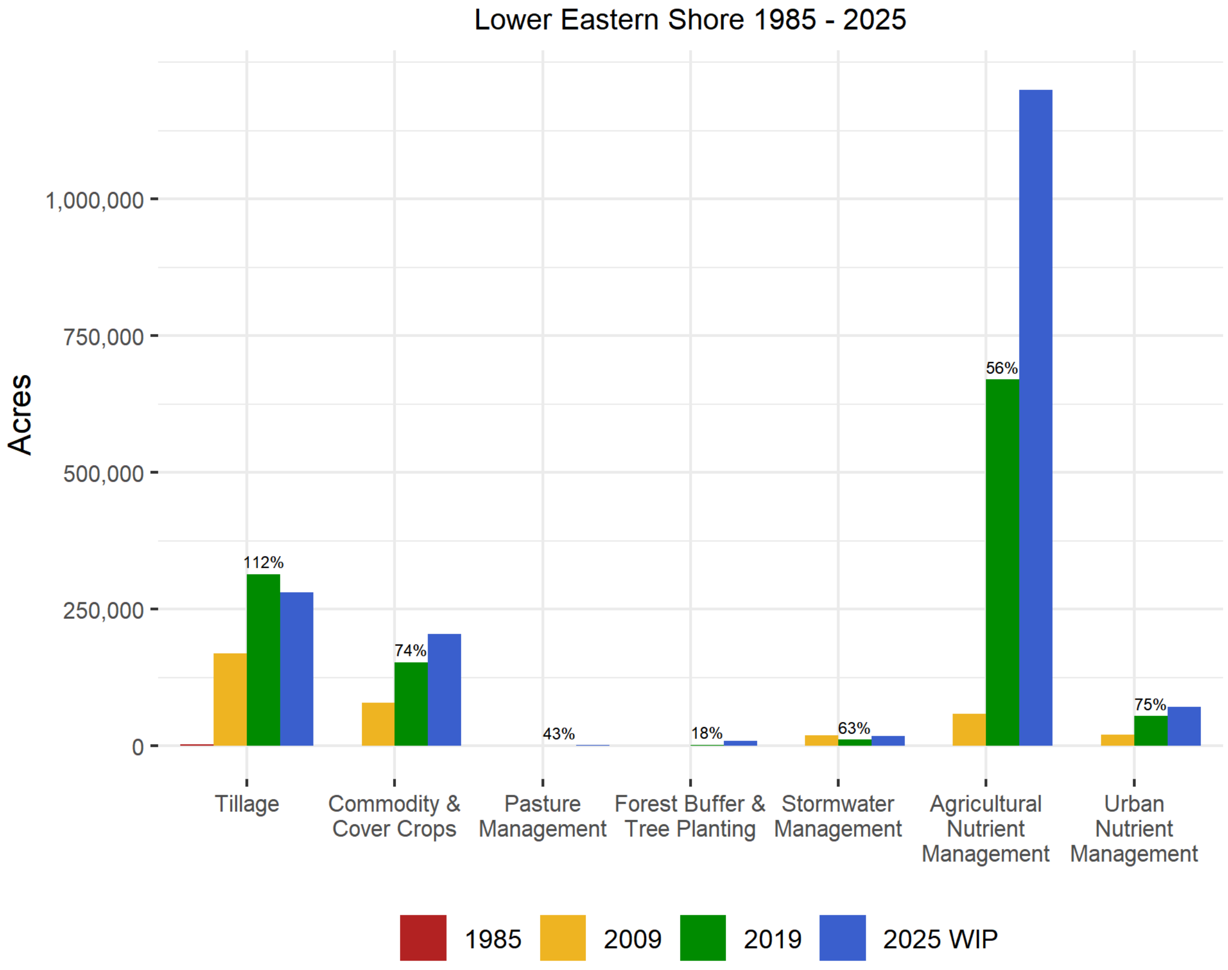


Figure 20. Expected long-term average loads of nitrogen, phosphorus, and sediment from different sources to the tidal Lower Eastern Shore, as obtained from the Chesapeake Assessment Scenario Tool (CAST-19). Data shown are time-average delivered loads over the average hydrology of 1991-2000, once

the steady state is reached for the conditions on the ground, as obtained from the 1985, 2009, and 2019 progress (management) scenarios.

5.1.4 Best Management Practices (BMPs) Implementation

Data on reported BMP implementation are available for download from CAST (https://cast.chesapeakebay.net, version CAST-2019). Reported BMP implementations on the ground as of 1985, 2009, and 2019 are compared to planned 2025 implementation levels in Figure 21 for a subset of major BMP groups measured in acres. As of 2019, tillage, cover crops, pasture management, forest buffer and tree planting, stormwater management, agricultural nutrient management, and urban nutrient management were credited for 314, 153, 0.9, 1.7, 11, 670, and 54 thousand acres, respectively. Implementation levels for some practices are already close to achieving their planned 2025 levels: for example, 112% of planned acres for tillage had been achieved as of 2019. In contrast, about 74% of planned commodity & cover crops implementation had been achieved as of 2019.



Values above the 2019 bars are the percent of the 2025 goal achieved.

Figure 21. BMP implementation in the Lower Eastern Shore watershed

Stream restoration and animal waste management system systems are two important BMPs that cannot be compared directly with those above because they are measured in different units. However, progress towards implementation goals can still be documented. Stream restoration (agricultural and urban) had increased from 0 feet in 1985 to 12,377 feet in 2019. Over the same period, animal waste management systems treated 9,872 animal units in 1985 and 1,760,958 animal units in 2019 (one animal unit represents 1,000 pounds of live animal). These implementation levels represent 19% and 85% of their planned 2025 implementation levels, respectively.

5.1.5 Flow-Normalized Watershed Nutrient and Sediment Loads

Flow normalization can better reveal temporal trends in river water quality by removing the effect of inter-annual variability in streamflow. Flow-normalized trends help scientists evaluate changes in load resulting from changing sources, delays associated with storage or transport of historical inputs, and/or implemented management actions. Flow-normalized nitrogen, phosphorus, and sediment trends have been reported for the short term (2009-2018) at nontidal network stations throughout the watershed (Moyer and Langland, 2020) (Table 4). These trends result from variability in nutrient applications, the delivery of nutrients and sediment from the landscape to streams, and from processes that affect in-stream loss or retention of nutrients and sediment.

Table 4. Short-term trends (2009 - 2018) of flow-normalized total nitrogen (TN), total phosphorus (TP), and suspended sediment (SS) loads for nontidal network monitoring locations in the Lower Eastern Shore watershed. A more detailed summary of flow-normalized loads and trends measured at all USGS Chesapeake Bay Nontidal Network stations can be found at https://cbrim.er.usgs.gov/summary.html.

USGS Station ID	USGS Station Name	Percent change in FN load, through water year 2018			
		Trend start water year	TN	TP	SS
01487000	NANTICOKE RIVER NEAR BRIDGEVILLE, DE	2009	**4.9**	**24.8**	**50.2**
01488500	MARSHYHOPE CREEK NEAR ADAMSVILLE, DE	2009	**15.3**	**60.8**	**44.2**

Decreasing trends listed in green, increasing trends listed in orange, results reported as "no trend" listed in black. TN = total nitrogen, TP = total phosphorus, SS = suspended sediment

5.2 Tidal Factors

Once pollutants reach tidal waters, a complex set of environmental factors interact with them to affect key habitat indicators like algal biomass, DO concentrations, water clarity, submerged aquatic vegetation (SAV) abundance, and fish populations (Kemp *et al.*, 2005; Testa *et al.*, 2017) (Figure 22). For example, phytoplankton growth depends not just on nitrogen and phosphorus (Fisher *et al.*, 1992; Kemp *et al.*, 2005; Zhang *et al.*, 2021), but also on light and water temperature (Buchanan *et al.*, 2005; Buchanan, 2020). In general, the saline waters of the lower Bay tend to be more transparent than tidal-fresh regions, and waters adjacent to nutrient input points are more affected by these inputs than more distant regions (Keisman *et al.*, 2019; Testa *et al.*, 2019). Dissolved oxygen concentrations are affected by salinity- and temperature-driven stratification of the water column, and conversely by wind-driven mixing, in addition to phytoplankton respiration and decomposition (Scully, 2010; Murphy *et al.*, 2011).

When anoxia occurs at the water-sediment interface, nitrogen and phosphorus stored in the sediments can be released through anaerobic chemical reactions (Testa and Kemp, 2012). When low-oxygen water and sediment burial suffocate benthic plant and animal communities, their nutrient consumption and water filtration services are lost. Conversely, when conditions improve enough to support abundant SAV and benthic communities, their functions can sustain and even advance progress towards a healthier ecosystem (Cloern, 1982; Phelps, 1994; Ruhl and Rybicki, 2010; Gurbisz and Kemp, 2014).

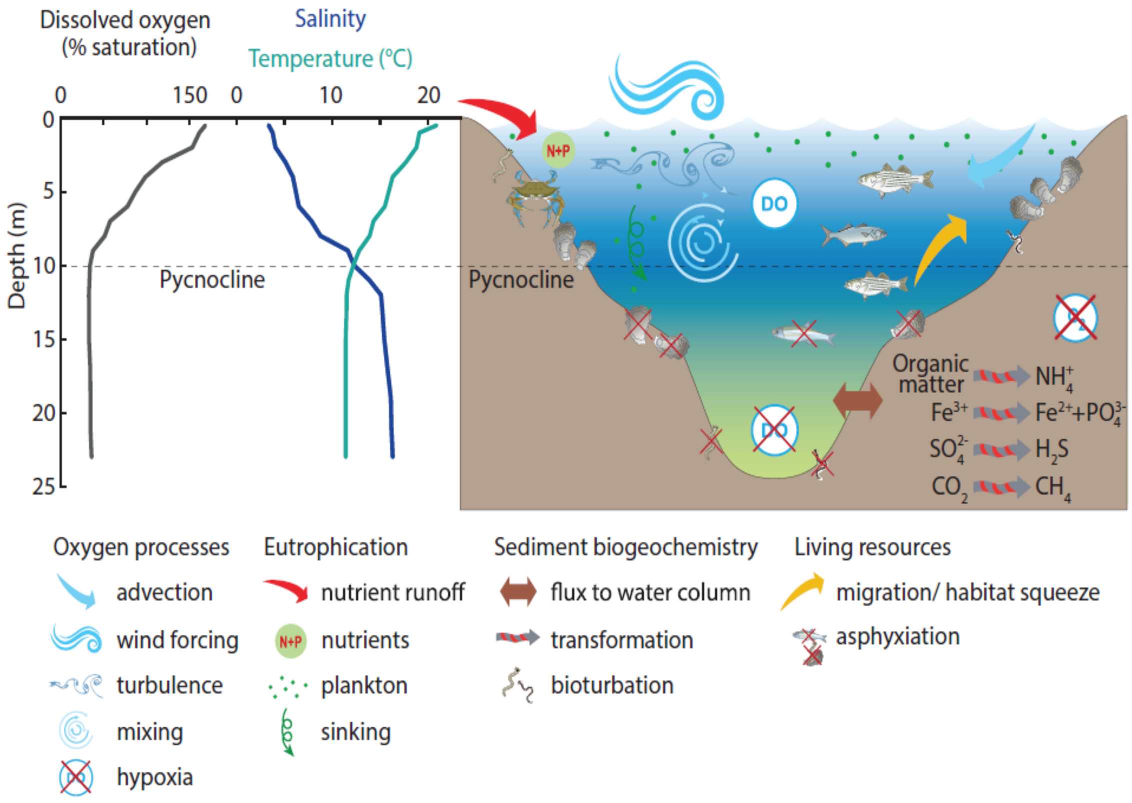


Figure 22. Conceptual diagram illustrating how hypoxia is driven by eutrophication and physical forcing, while affecting sediment biogeochemistry and living resources. From Testa *et al.* (2017).

High nutrient loads relative to tidal river size are indicative of areas that are more susceptible to eutrophication (Bricker *et al.*, 2003; Ferreira *et al.*, 2007). The relationship between watershed area and tidal river size may also be an important indicator of eutrophication potential, however there are competing effects. A large watershed relative to the volume of receiving water would likely correlate with higher nutrient loads, however it would also correlate with a higher flow rate and decreased flushing time (Bricker *et al.*, 2008). Figure 23 is a comparison of watershed area versus estuarine volume for all estuaries and sub-estuaries identified in the CBP monitoring segment scheme. Larger estuaries will contain multiple monitoring segments and, in many cases, sub-estuaries. For example, the Potomac River contains monitoring segments in the tidal fresh, oligohaline, and mesohaline sections of the river as well as the entire Anacostia River and other sub-estuaries. Figures 24 and 25 are comparisons of estimated annual average nitrogen and phosphorus loads, respectively, for the 2018 progress scenario in CAST versus the estuarine volume for the same set of estuaries and sub-estuaries.

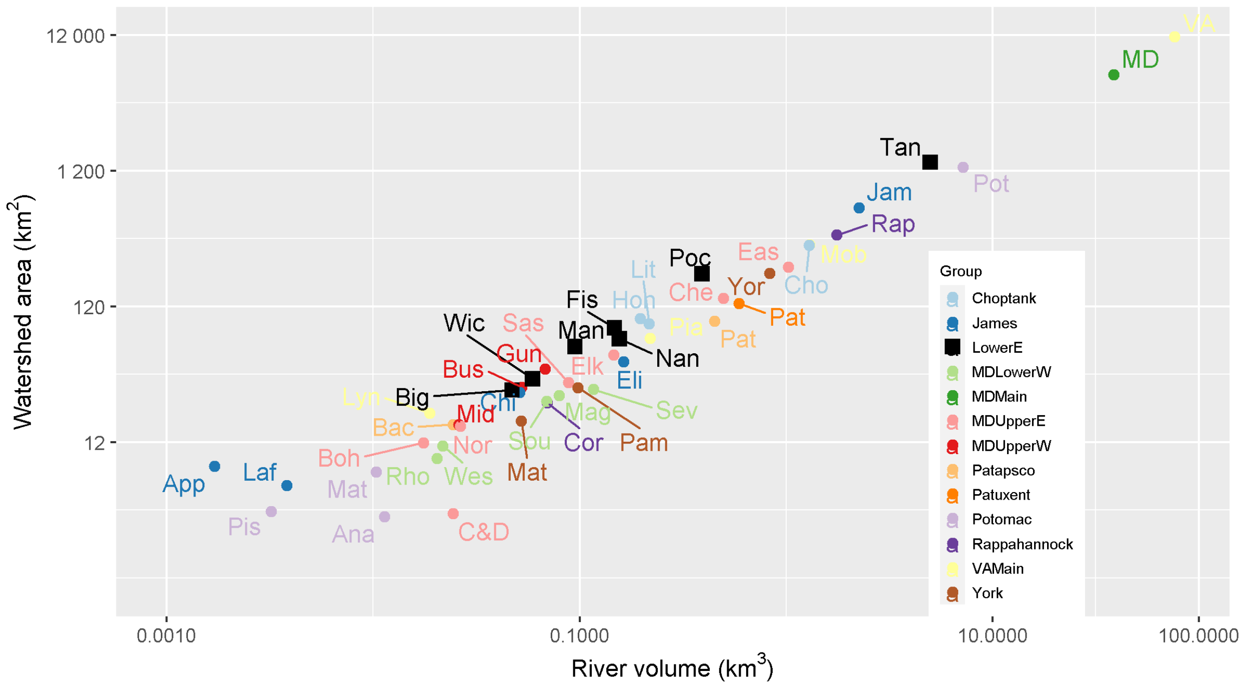


Figure 23. Watershed area vs estuarine volume.

Abbreviated tributary name	**Full tributary name**	**Abbreviated tributary name**	**Full tributary name**
Ana	Anacostia River	Mat	Mattaponi River
App	Appomattox River	MD	MD MAINSTEM
Bac	Back River	Mid	Middle River
Big	Big Annemessex River	Mob	Mobjack Bay
Boh	Bohemia River	Nan	Nanticoke River
Bus	Bush River	Nor	Northeast River
C&D	C&D Canal	Pam	Pamunkey River
Che	Chester River	Pat	Patapsco River
Chi	Chickahominy River	Pat	Patuxent River
Cho	Choptank River	Pia	Piankatank River
Cor	Corrotoman River	Pis	Piscataway Creek
Eas	Eastern Bay	Poc	Pocomoke River
Eli	Elizabeth River	Pot	Potomac River
Elk	Elk River	Rap	Rappahannock River
Fis	Fishing Bay	Rho	Rhode River
Gun	Gunpowder River	Sas	Sassafras River
Hon	Honga River	Sev	Severn River
Jam	James River	Sou	South River
Laf	Lafayette River	Tan	Tangier Sound
Lit	Little Choptank River	VA	VA MAINSTEM
Lyn	Lynnhaven River	Wes	West River
Mag	Magothy River	Wes	Western Branch (Patuxent River)
Man	Manokin River	Wic	Wicomico River
Mat	Mattawoman Creek	Yor	York River

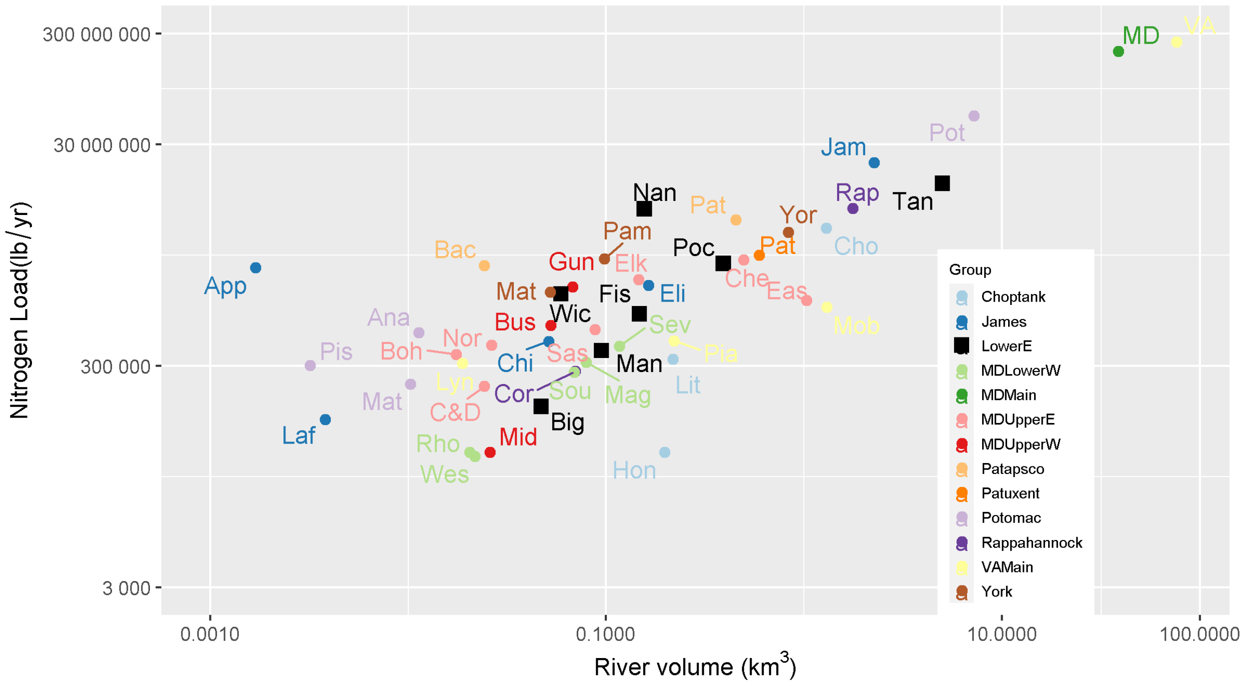


Figure 24. Annual average expected nitrogen loads versus estuarine volume. Nitrogen loads are from the 2018 progress scenarios in CAST (Chesapeake Bay Program, 2020), which is an estimate of nitrogen loads under long-term average hydrology given land use and reported management as of 2018.

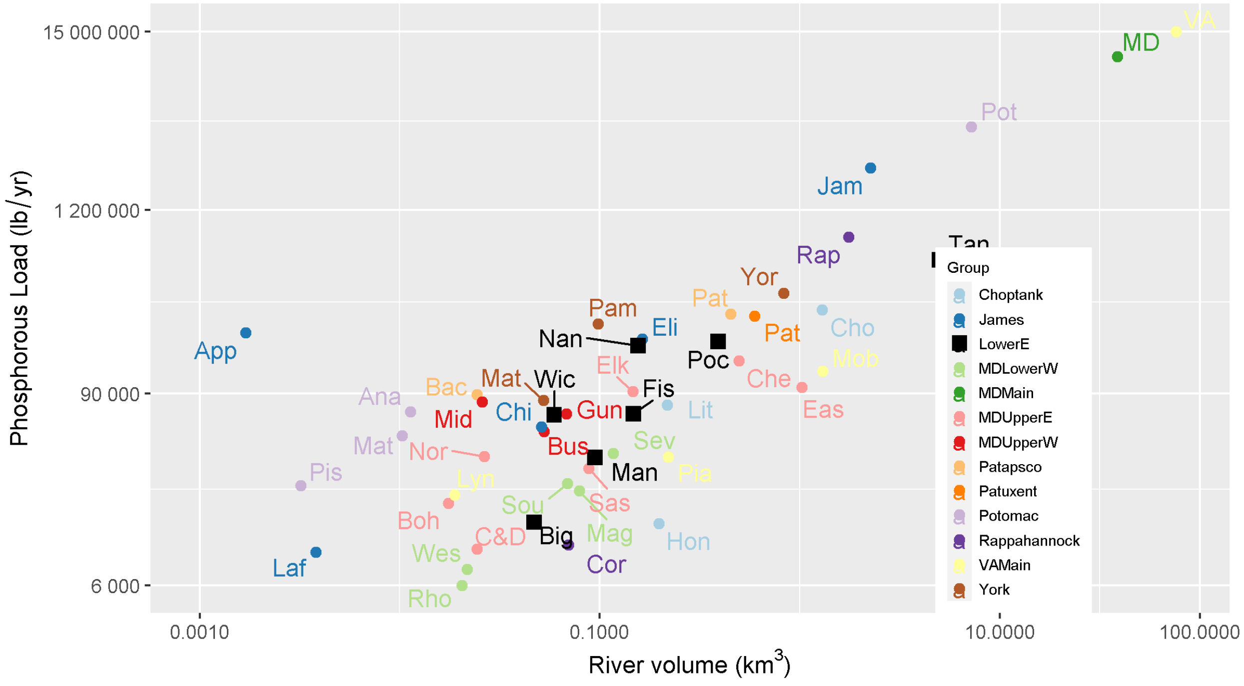


Figure 25. Annual average expected phosphorus loads versus estuarine volume. Phosphorus loads are from the 2018 progress scenarios in CAST (Chesapeake Bay Program, 2020), which is an estimate of

phosphorus loads under long-term average hydrology given land use and reported management as of 2018.

The Lower Eastern Shore estuary volume and watershed contain approximately 7 and 3% of the total volume and watershed of the Chesapeake Bay. This ranks the Lower Eastern Shore as the 4th largest volume and 6th largest watershed area aggregated tributary in this summary (Figures 23, 24, and 25). The ratios of watershed area, nitrogen loading, and phosphorus loading to estuarine volume are consistent with other estuaries in the Chesapeake system, indicating a moderate level of susceptibility to eutrophication. The tributaries within the Lower Eastern Shore system, the Tangier sound, Big Annamessex river, Fishing Bay, Manokin river, Nanticoke river, Pocomoke river, and Wicomico river all follow this same trend indicating similar susceptibility to eutrophication. Tangier sound has a lower amount of P relative to its river volume while the other smaller tributaries within the Lower Eastern Shore have P loads that are more moderate. The Nanticoke river has a high relative load of nitrogen, the while the Tangier sound, Big Annamessex river, Fishing Bay, Manokin river, Pocomoke river, and Wicomico river nitrogen loads are more moderate.

5.3 Insights on Change in the Lower Easter Shore

Completion of Section 5.3 is contingent upon stakeholder interest and availability of resources.
It requires:

- *Synthesis of the information provided in previous sections and of the recent literature on explaining trends in general and any work conducted on this tributary in particular;*
- *Discussion with local technical experts to clarify insights and vet hypotheses and preliminary findings.*

6. Summary

Completion of Section 6 is contingent upon completion of Section 5.3.

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Appendix

Additional tidal trend maps and plots are in a separate Appendix document for:

- Bottom Total Nitrogen
- Bottom Total Phosphorus
- Surface Dissolved Inorganic Nitrogen
- Surface Orthophosphate
- Surface Total Suspended Solids
- Summer Surface Dissolved Oxygen
- Surface Water Temperature