Maryland Lower Western 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 Maryland Lower Western 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 Maryland's Lower Western Shore.

2. Location

The Maryland Lower Western Shore watershed covers approximately 0.3% of the Chesapeake Bay watershed. Its watershed is approximately 439 km^2 (Table 1.) and is contained within the state of Maryland (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 Maryland Lower Western 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 this physiography for nutrient and sediment transport are summarized in Section 5.1.1.

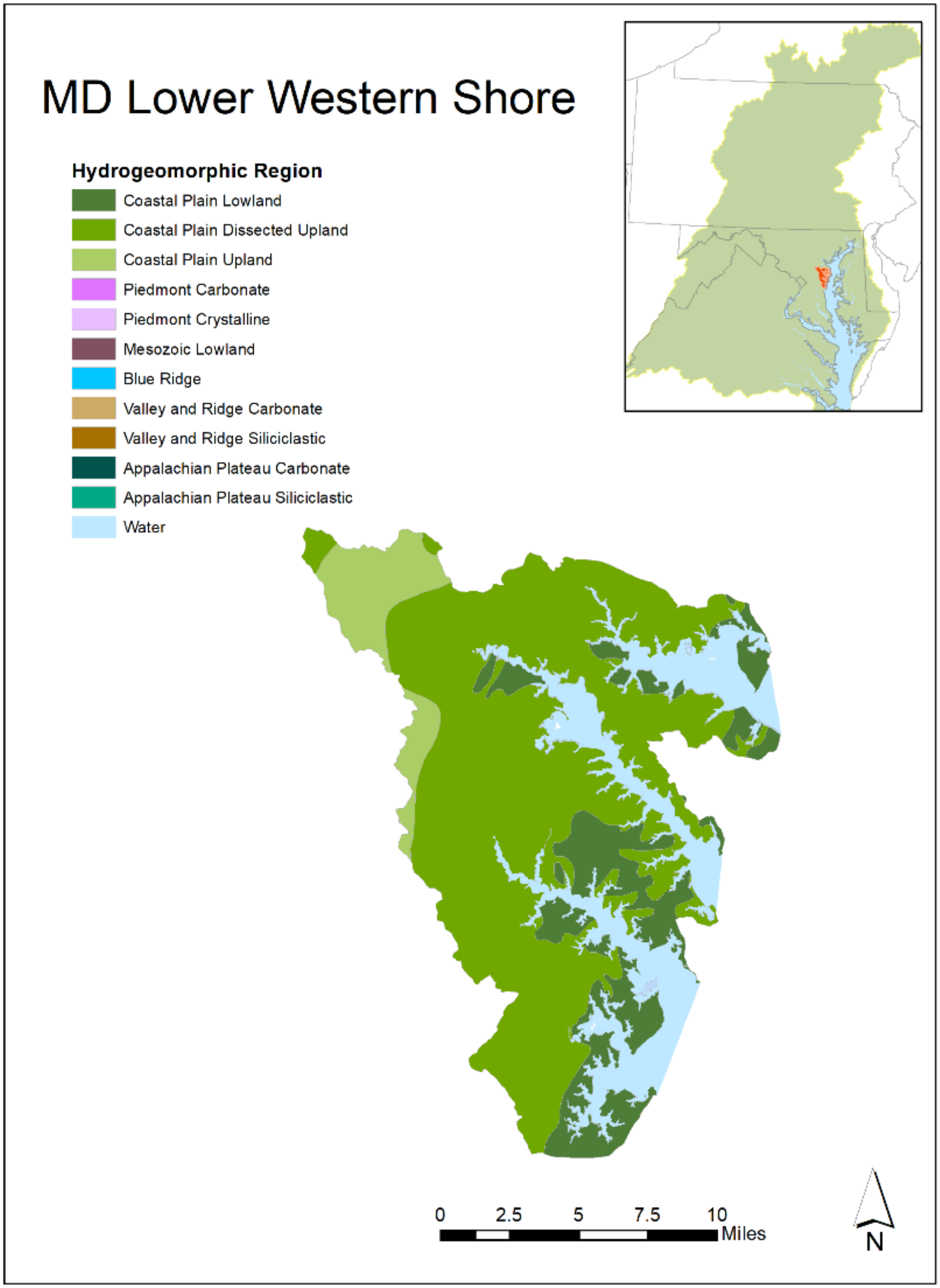

Figure 1. Distribution of physiography in the Maryland Lower Western Shore watershed.

2.2 Land Use

Land use in the Maryland Lower Western Shore watershed is dominated (51%) by natural areas. Urban and suburban land areas have increased by 18,934 acres since 1985, agricultural lands have decreased by 3,824 acres, and natural lands have decreased by 15,116 acres. Correspondingly, the proportion of urban land in this watershed has increased from 26% in 1985 to 44% in 2019 (Figure 2).

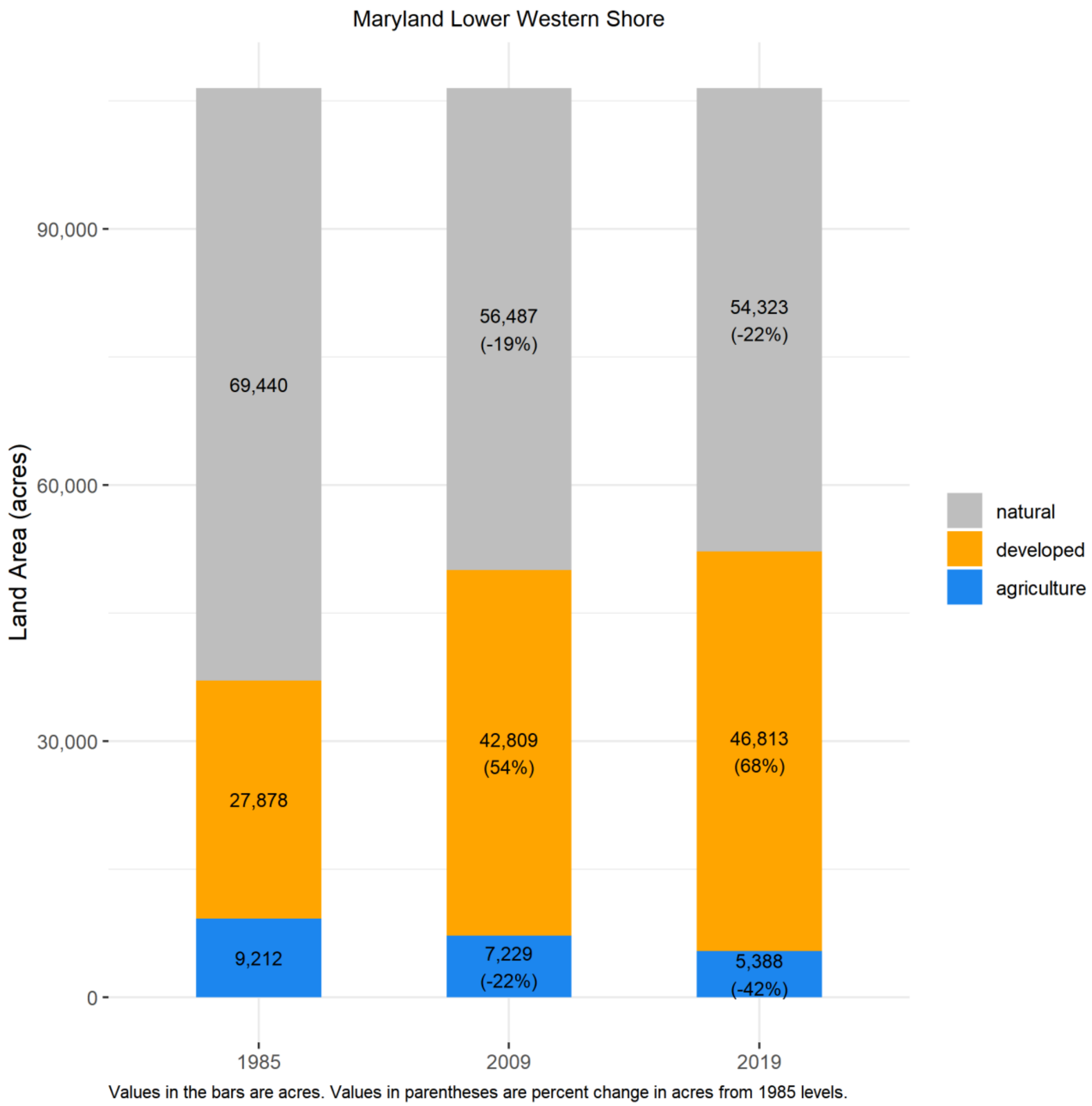

Figure 2. Distribution of land uses in the Maryland Lower Western Shore watershed. Percentages are the percent change from 1985 for each source sector.

The Maryland Lower Western Shore had already experienced significant development by the mid-1970s (Figure 3). Since then, developed and semi-developed lands have continued to expand into previously undeveloped regions. The impacts of land development differ depending on the use from which the land is converted (Keisman *et al.*, 2019; Ator *et al.*, 2019). Implications of changing land use for nutrient and sediment transport are summarized in Section 5.1.3.

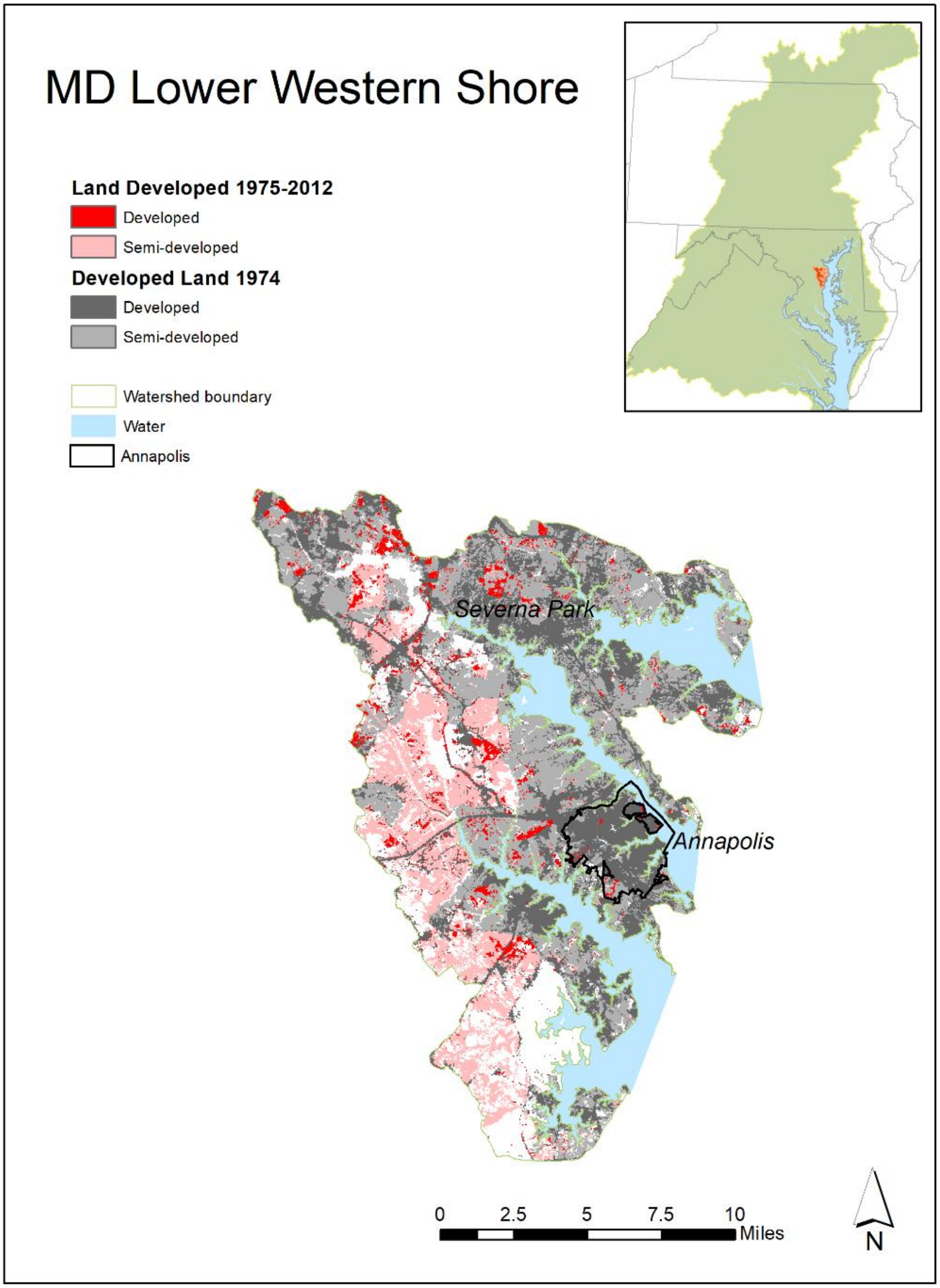

Figure 3. Distribution of developed land in the Maryland Lower Western Shore watershed. Derived from Falcone (2015). Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

2.3 Tidal Waters and Stations

For the purposes of water quality standards assessment and reporting, the tidal portions of the MD Lower Western Shore tributaries include five mesohaline segments (U.S. Environmental Protection Agency, 2004): the Magothy River (MAGMH), the Rhode River (RHDMH), the Severn River (SEVMH), and South River (SOUMH) and the West River (WSTMH) (Figure 4).

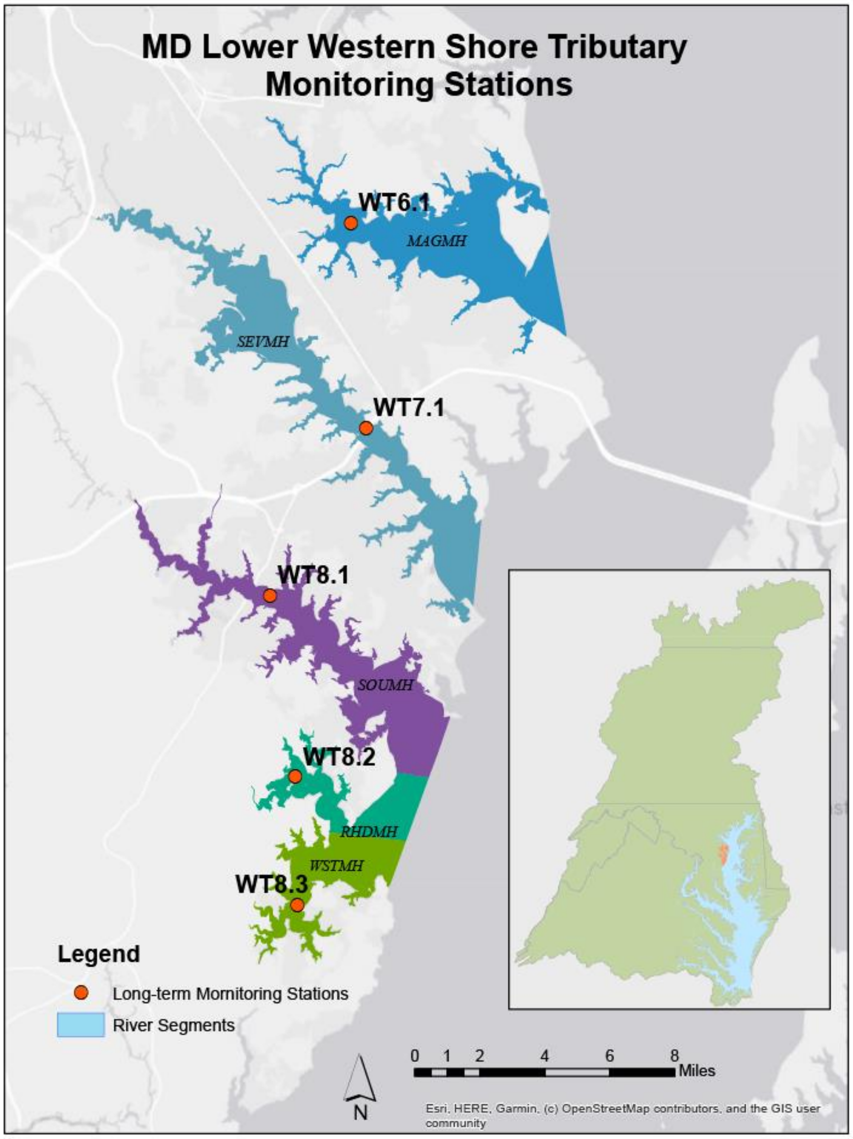

Figure 4. Map of tidal Maryland Lower Western Shore River segments and long-term monitoring stations. Base map credit Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, World Geodetic System 1984.

Long-term trends in water quality are analyzed by MD Department of Natural Resources at five stations, one in each of the Maryland Lower Western Shore 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 segments over time that may be used in the water quality criteria evaluation but not shown in the long-term trend graphics in subsequent sections because of its shorter duration.

3. Tidal Water Quality Dissolved Criteria Attainment

Multiple water quality standards were developed for the Maryland Lower Western Shore tributaries 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 each of these tributaries' segments have met or not met a subset of Open Water (OW) and Deep Water (DW) 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 (Tables 2 and 3) 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), none of the segments met the 30-day mean OW summer DO requirements and only one met the 30-day mean DW 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.

time period	MAGMH	SEVMH	SOUMH	RHDMH	WSTMH
1985-1987					
1986-1988					
1987-1989					
1988-1990					
1989-1991					
1990-1992					
1991-1993					
1992-1994					
1993-1995					
1994-1996					
1995-1997					
1996-1998					
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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					

Table 3. Deep Water summer DO (30-day mean) criteria evaluation results. Green indicates that the criterion was met. White indicates that the criterion was not met.

time period	MAGMH	SEVMH	SOUMH
1985-1987			
1986-1988			
1987-1989			
1988-1990			
1989-1991			
1990-1992			
1991-1993			
1992-1994			
1993-1995			
1994-1996			
1995-1997			
1996-1998			
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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			

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 and DW summer DO criteria shown in Tables 2 and 3 are overlain with the 1985-2018 change in summer surface DO concentration and the 1985-2018 change in bottom summer DO concentrations, respectively (Figure 5). The bottom depths at each of these stations is different due to varying bathymetry, but the bottom DO trends at these stations are expected to represent water in the DW designated use.

In general, the status and trends in these Maryland Lower Western Shore segments are not indicating progress in oxygen conditions. The 30-day mean OW summer DO criterion was not met in any of these segments for the 2016-2018 period, and the trends in surface DO are degrading at two stations and not changing at three. The DW criterion is only applicable in three of the segments and is being met in one of those (the Severn River segment). Degrading trends in bottom DO were computed at both the Magothy and Severn River stations.

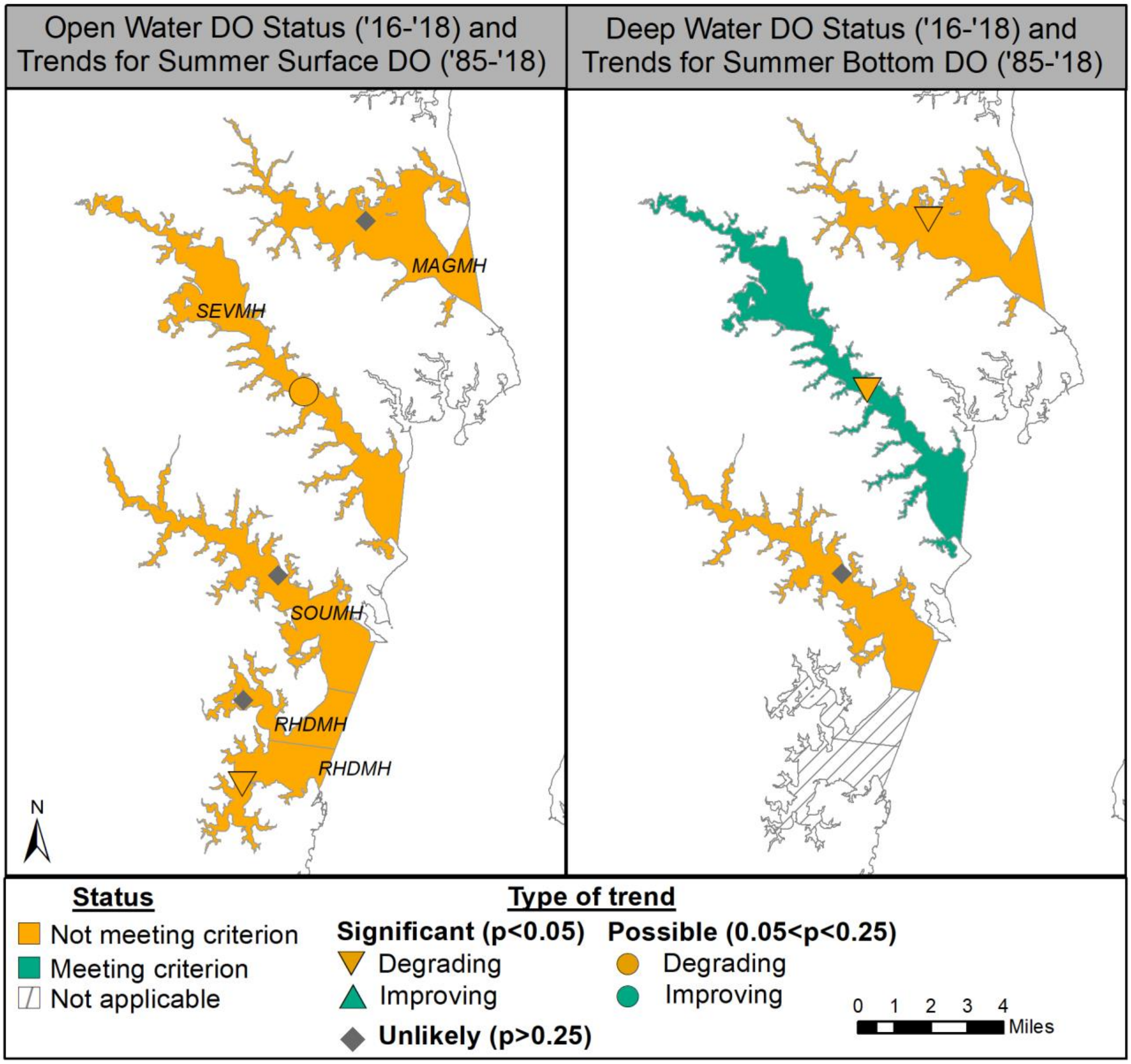

Figure 5. Pass-fail DO criterion status for 30-day OW summer DO and DW DO designated uses in Potomac segments along with long-term trends in DO concentrations. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

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 five Maryland Lower Western 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 for these stations in collaboration with the Chesapeake Bay Program and Virginia analysts, 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 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 over the long-term at all of the MD lower western shore stations, using both non-flow-adjusted results and flow-adjusted results (Figure 6). Over the short-term, there are no trends in TN at any of these stations, suggesting a leveling-out of any improvements over time.

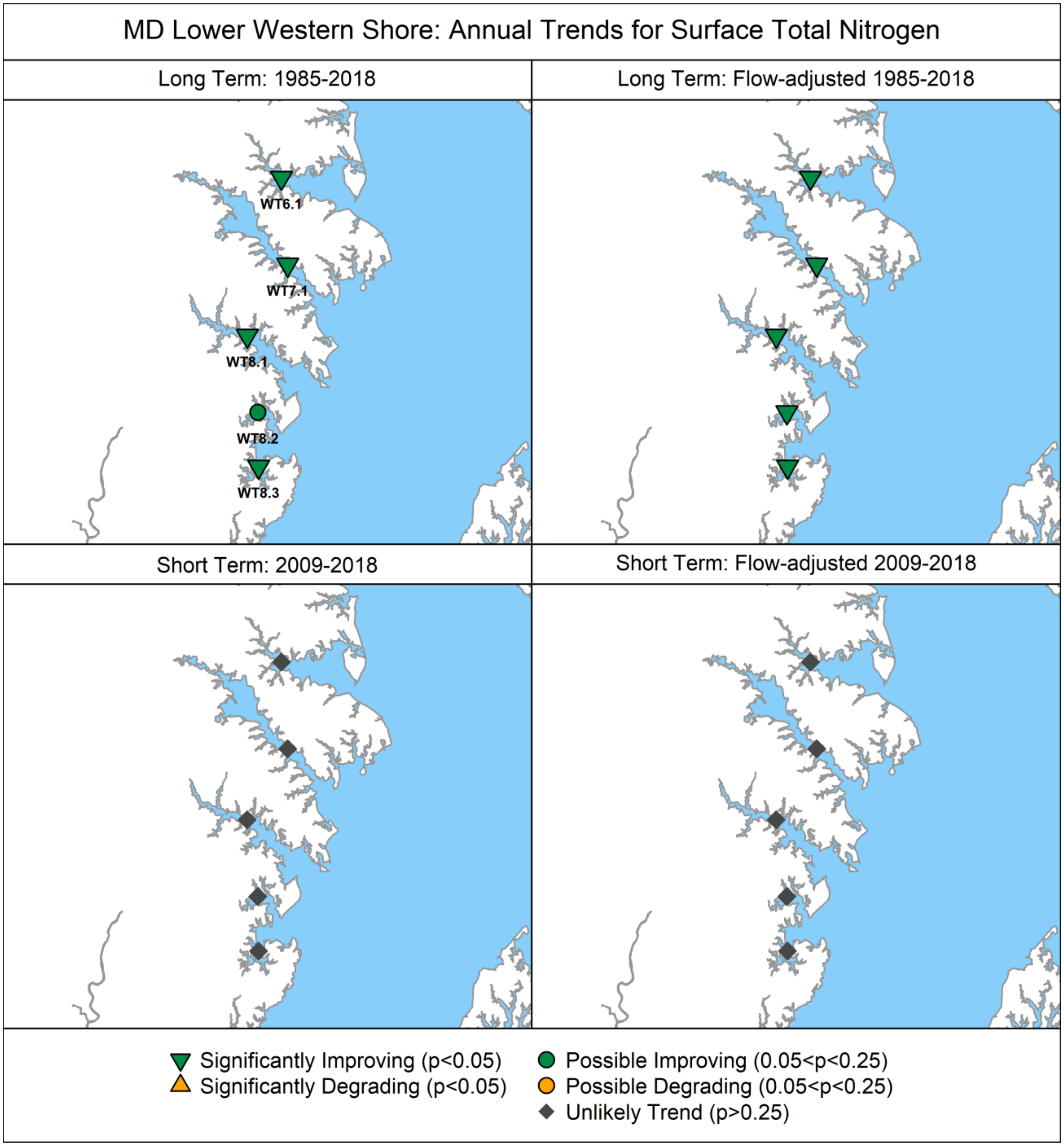

Figure 6. Surface TN trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The long-term TN patterns in the data and the non-flow-adjusted mean annual GAM estimates presented in Figure 7 are variable over time and likely influenced by freshwater flow. The estimated long-term improvements (Figure 6) are hard to distinguish in Figure 7, in part because a method change impacting the values. Vertical blue dotted lines represent a 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).

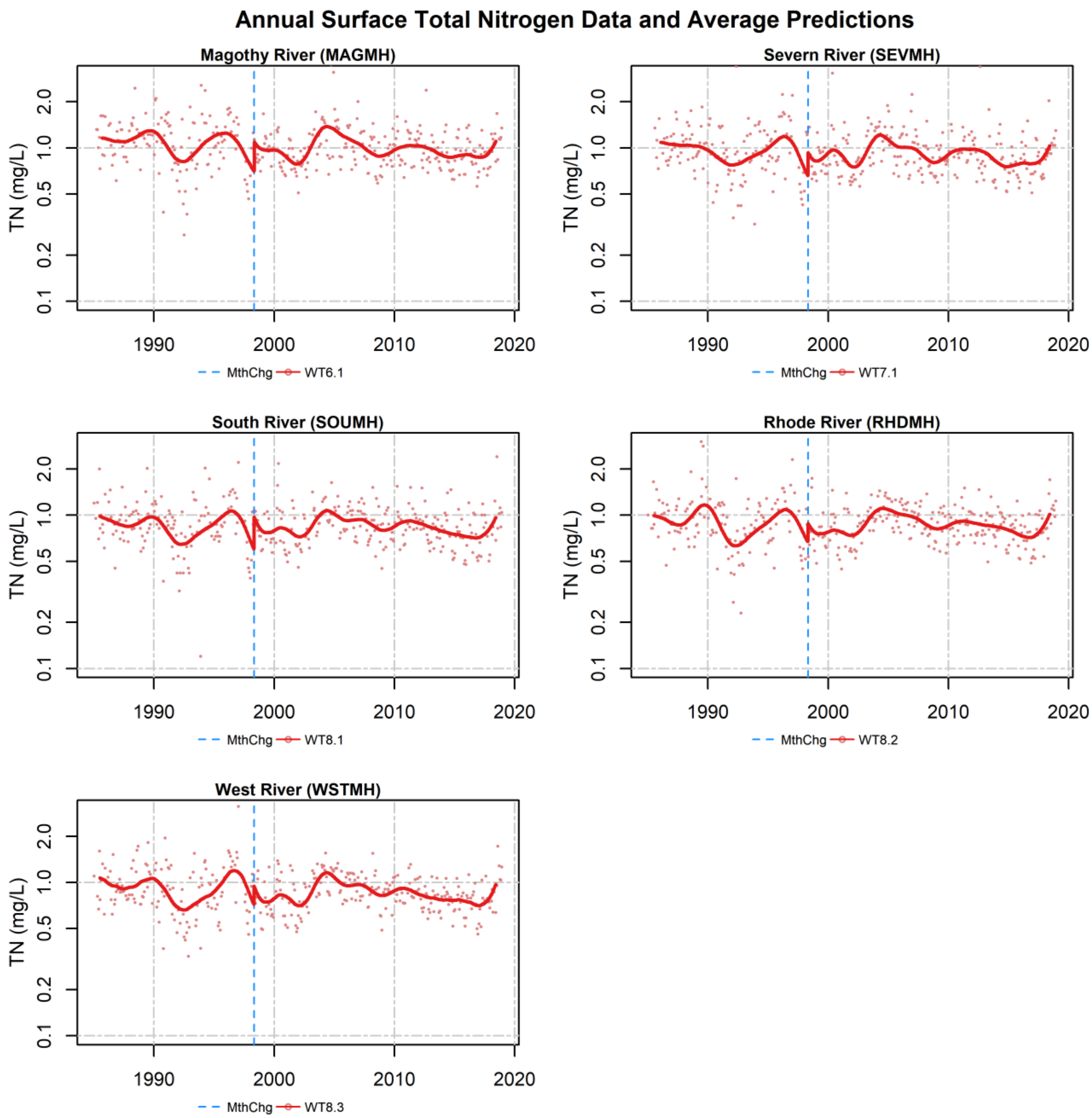

Figure 7. Surface TN data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent data corresponding to the monitoring station indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations. Vertical blue dotted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

4.2 Surface Total Phosphorus

Surface total phosphorus (TP) trends are also improving over the long-term at all five stations, with and without flow-adjustment (Figure 8). In the short-term, the trend at WT6.1 is possibly improving and at WT8.2 is possibly degrading. There are no short-term trends at the other stations.

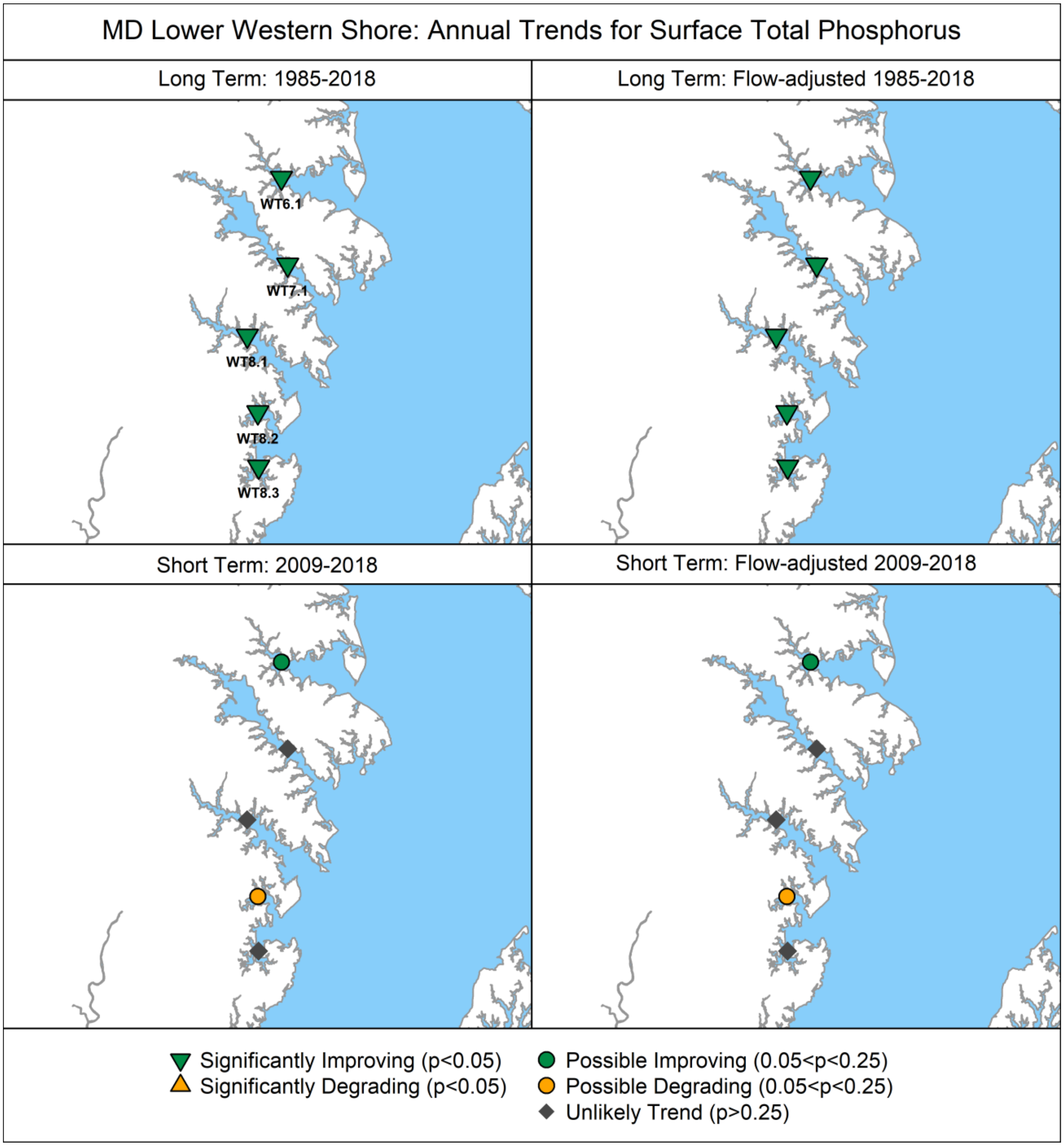

Figure 8. Surface TP trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The TP observations and mean annual GAM estimates at each of the Maryland Lower Western Shore stations decreased significantly at the beginning of the time period analyzed (Figure 9), resulting in the long-term improving trends (Figure 8). Since those sharp decreases in the 1980s and early 1990s, the Magothy River station (WT6.1) has the most obvious continued decrease, while patterns at the other stations have been relatively constant with some increases at the very end of the record.

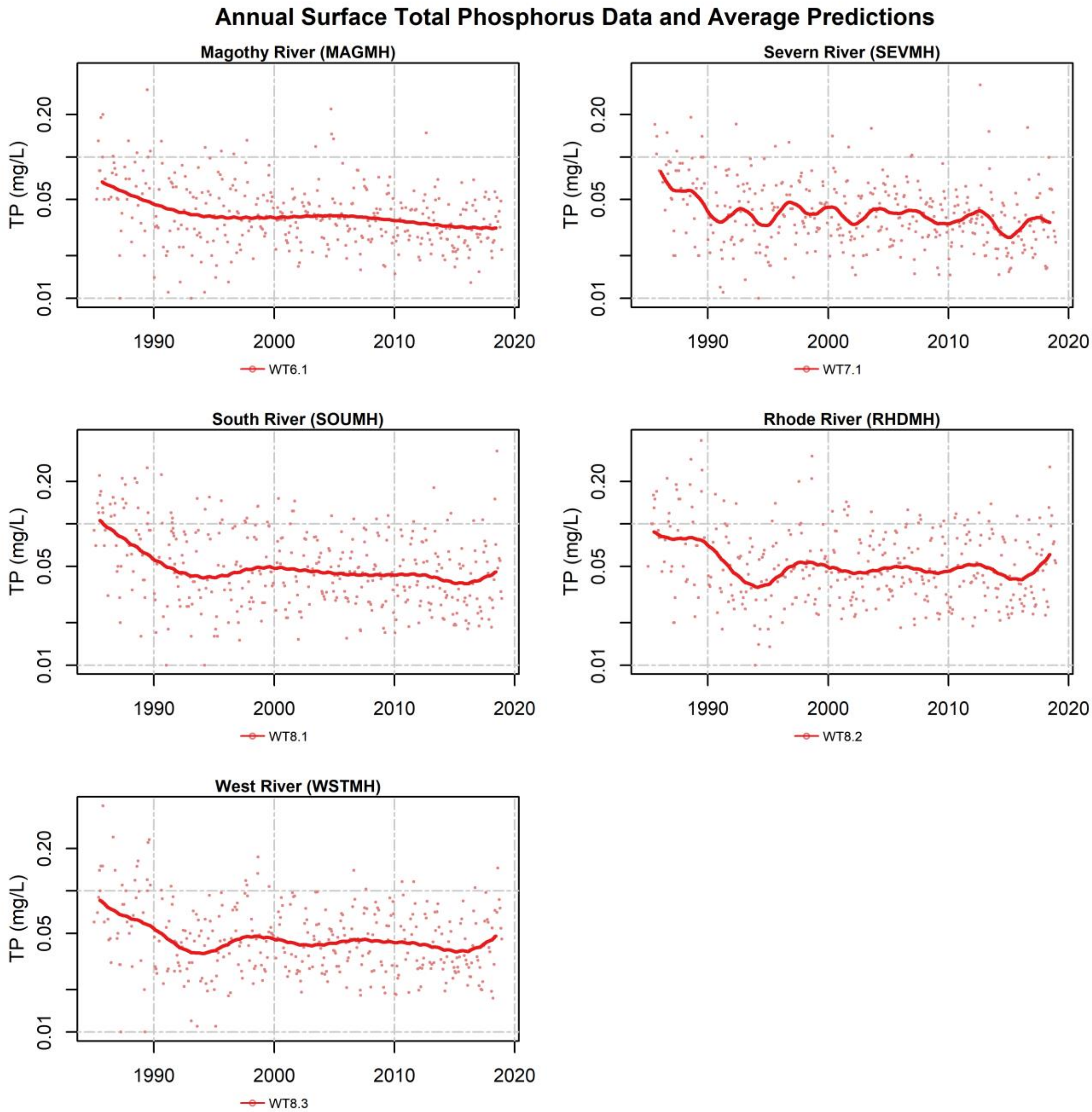

Figure 9. Surface TP data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent data corresponding to the monitoring station indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations.

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). There are not many long-term trends in spring chlorophyll *a* at these Maryland Lower Western Shore stations, and no short-term trends (Figure 10). Long-term spring chlorophyll *a* concentrations are possibly degrading at WT6.1 (Magothy River) with and without flow adjustment, WT7.1 (Severn River) with flow-adjustment, and WT8.2 (Rhode River) without flow-adjustment (Figure 10).

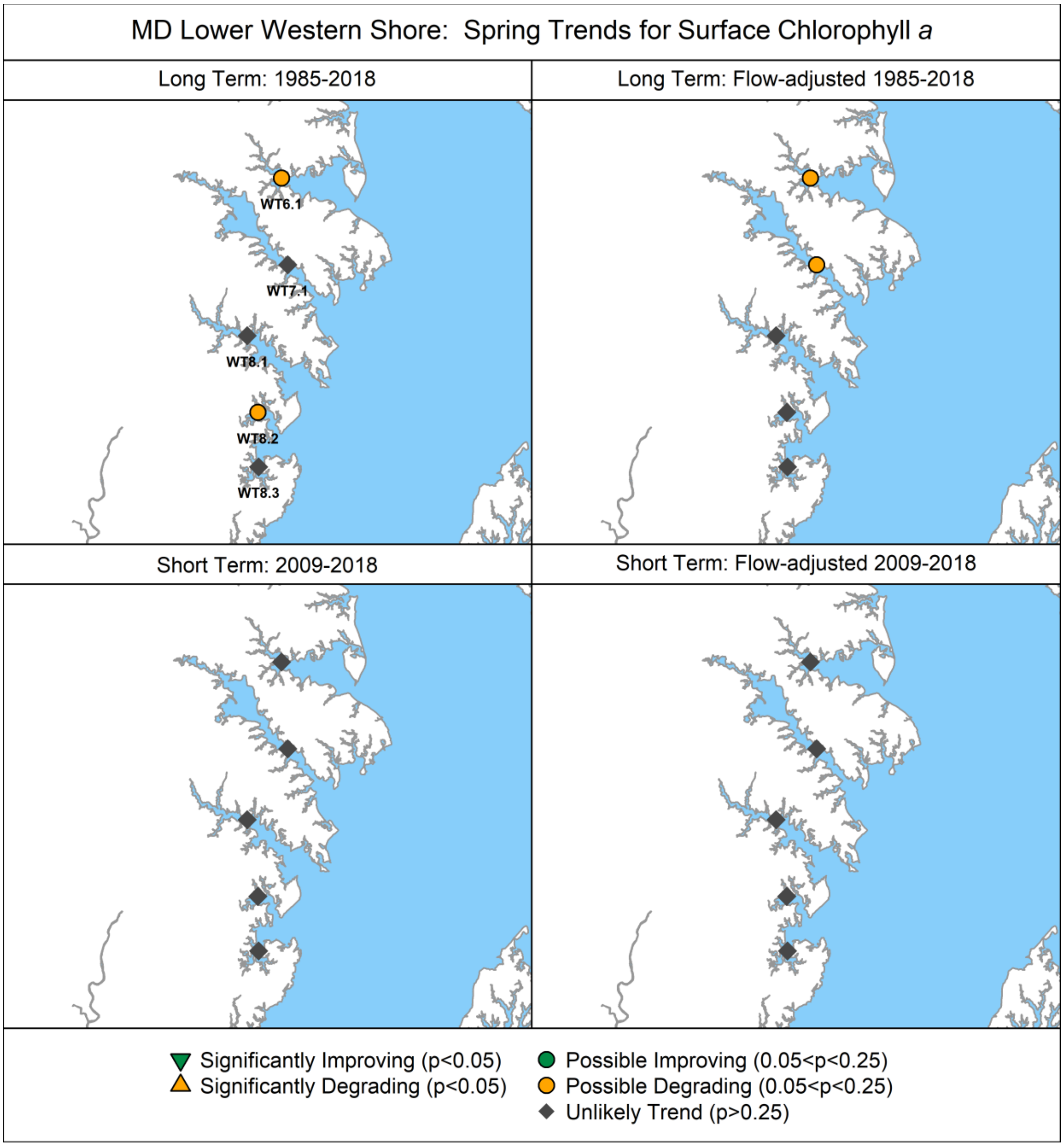

Figure 10. Surface spring (March-May) chlorophyll *a* trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

Spring chlorophyll *a* concentrations at these five stations all are fairly similar in magnitude (Figure 11). Slight increases over time are evident in the seasonal mean GAM estimates at many of the stations, leading to the possible degrading trends shown in Figure 10.

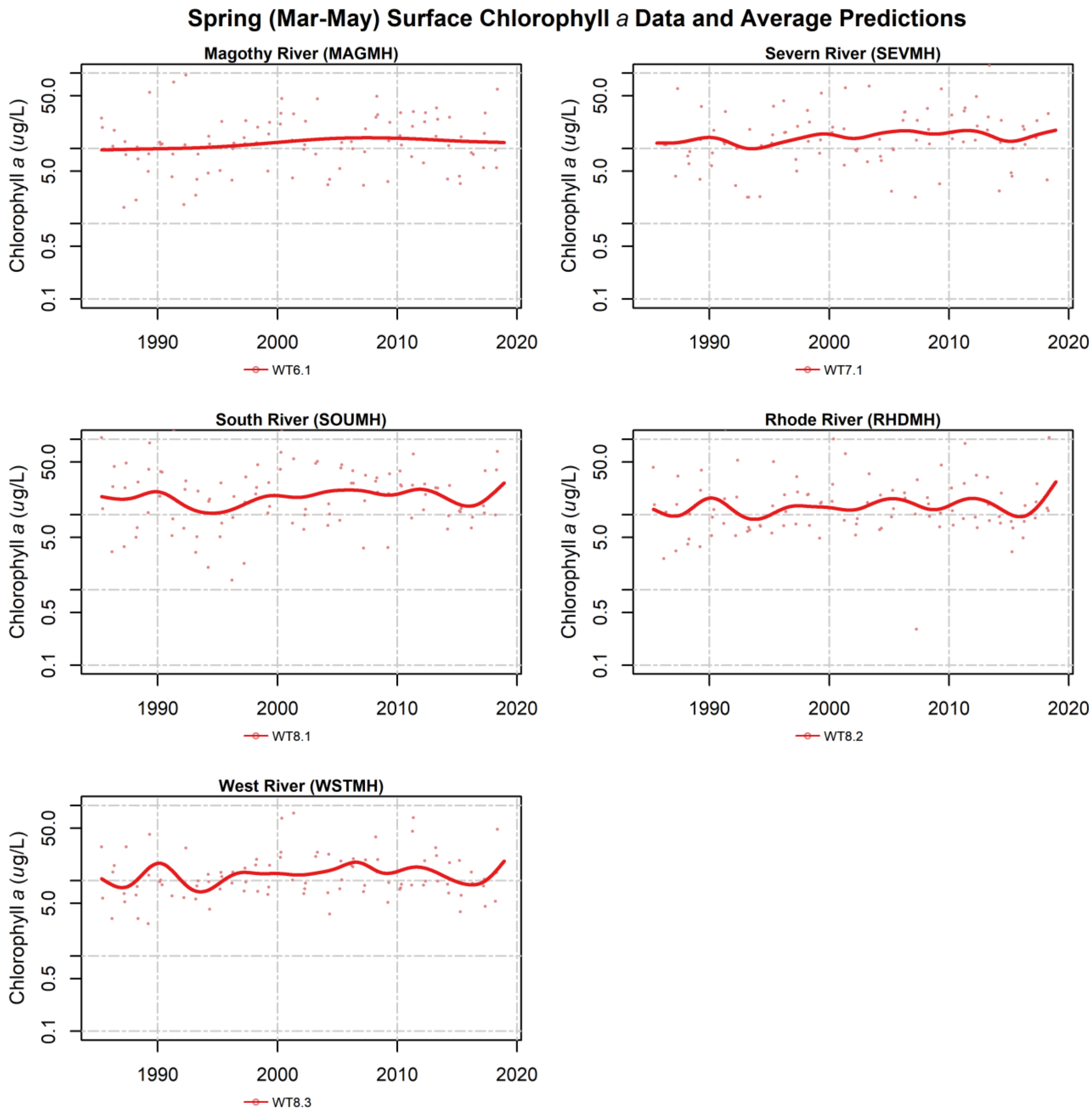

Figure 11. Surface spring chlorophyll *a* data (dots) and average long-term pattern generated from non-flow adjusted GAM. Colored dots represent March-May data corresponding to the monitoring station indicated in the legend; colored lines represent mean spring GAM estimates for the noted monitoring stations.

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

Summer long-term chlorophyll *a* trends are possibly degrading without flow-adjustment at WT6.1, WT8.1 and WT8.2 (Figure 12). With flow-adjustment, there are no trends at these stations over the long-term, and a possible improvement exists at WT8.3. Over the short-term, two of the stations continue with possible degrading trends without flow adjustment, and WT8.3 shows a possible improvement after flow-adjustment.

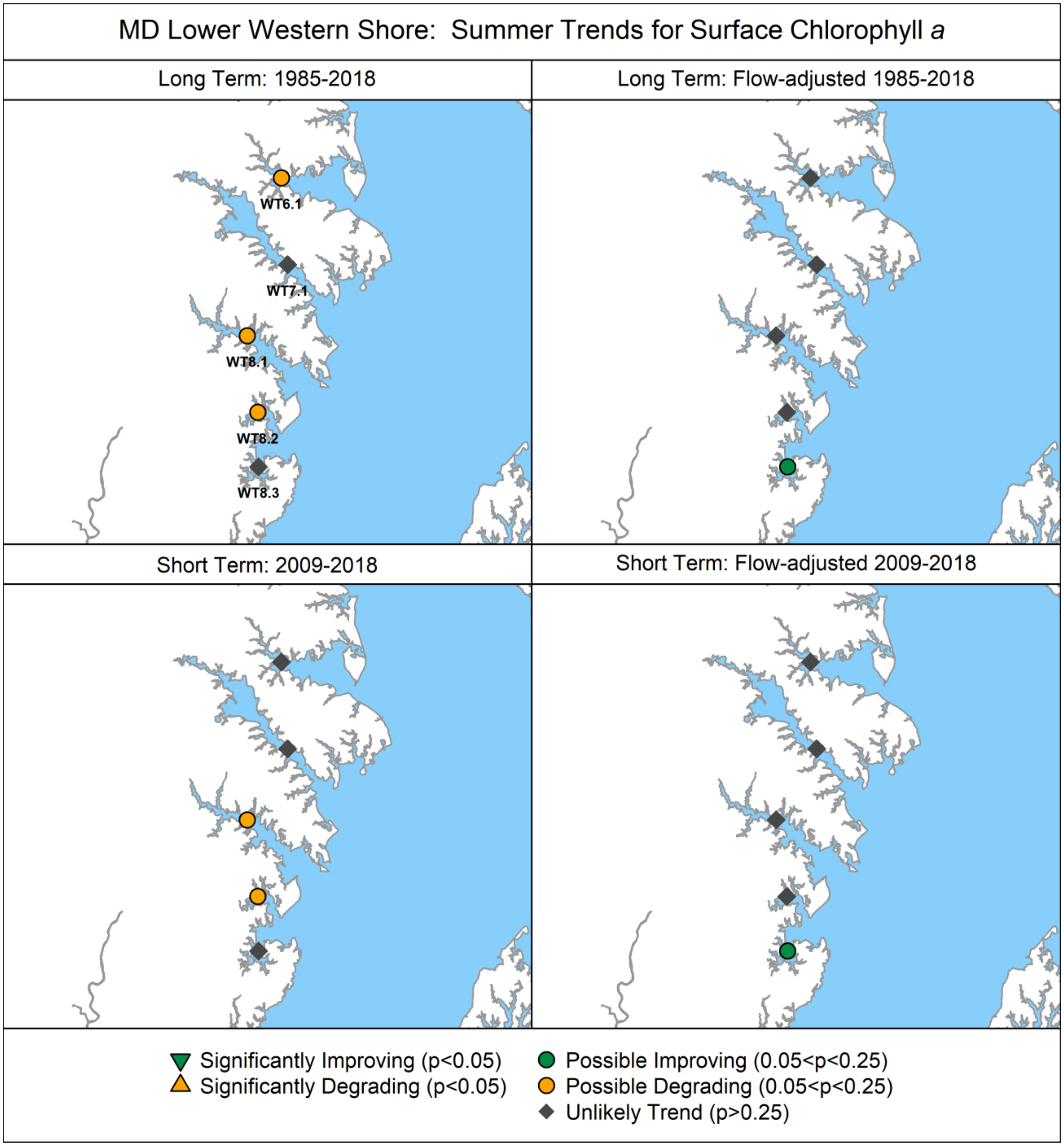

Figure 12. Surface summer (July-September) chlorophyll *a* trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The magnitude of the summer chlorophyll *a* concentrations is higher at all of these stations in the summer (Figure 13) than in the spring (Figure 11). An increase at the end of the record is responsible for the increasing trends reported above (Figure 12) especially at the South River (WT8.1) and Rhode River (WT8.2) stations (Figure 13). That increase appears to be flow-driven considering the lack of trends after flow-adjustment at these stations as well as the improving trend after flow is accounted for at the West River station (WT8.3).

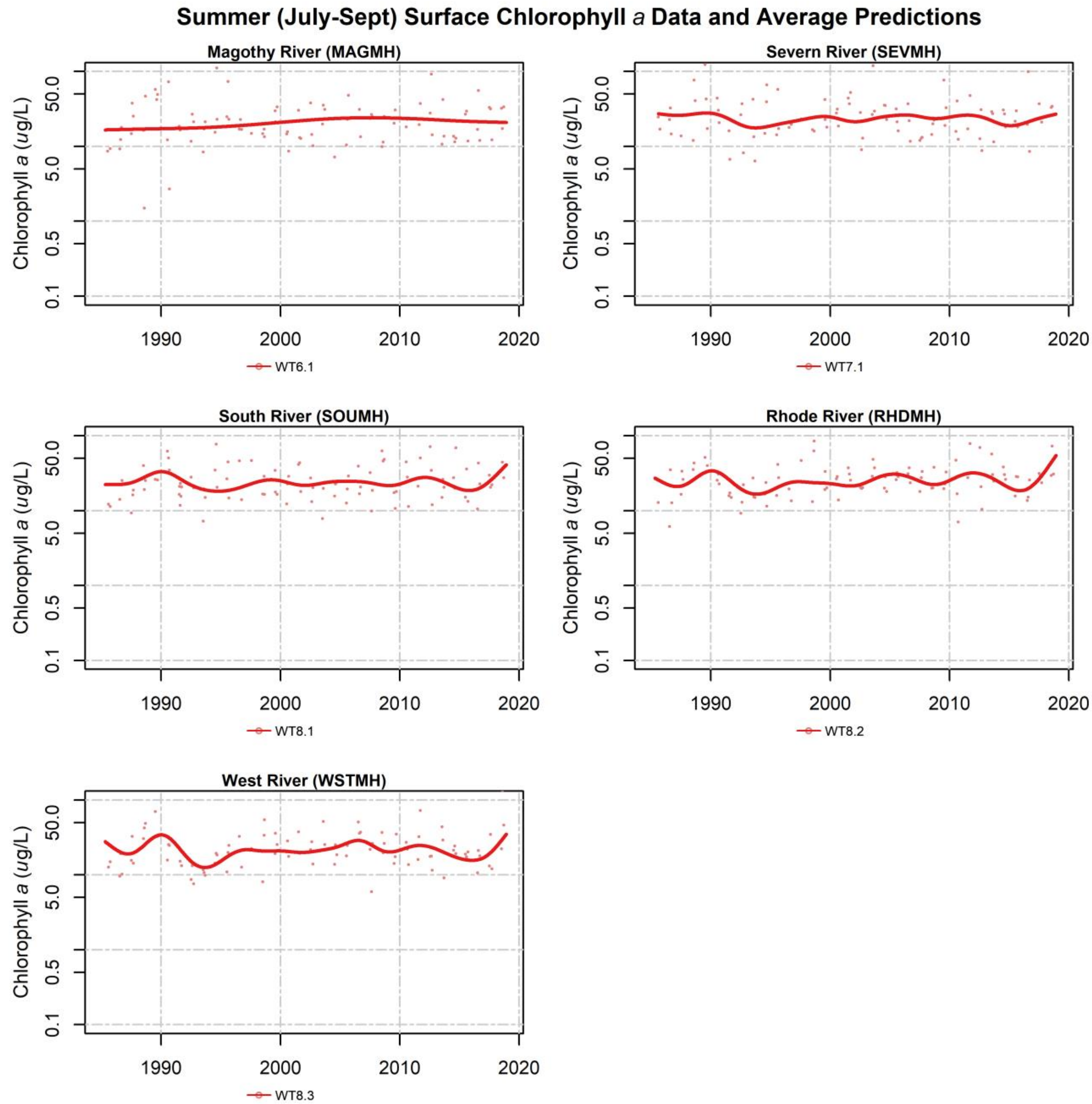

Figure 13. Surface summer chlorophyll *a* data (dots) and average long-term pattern generated from non-flow adjusted GAM. Colored dots represent July-September data corresponding to the monitoring

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 over the long-term at most of these stations both with and without flow-adjustment (Figure 14). Over the short-term, there are no trends without flow adjustment and with flow-adjustment WET8.2 and WT8.3 are possibly improving.

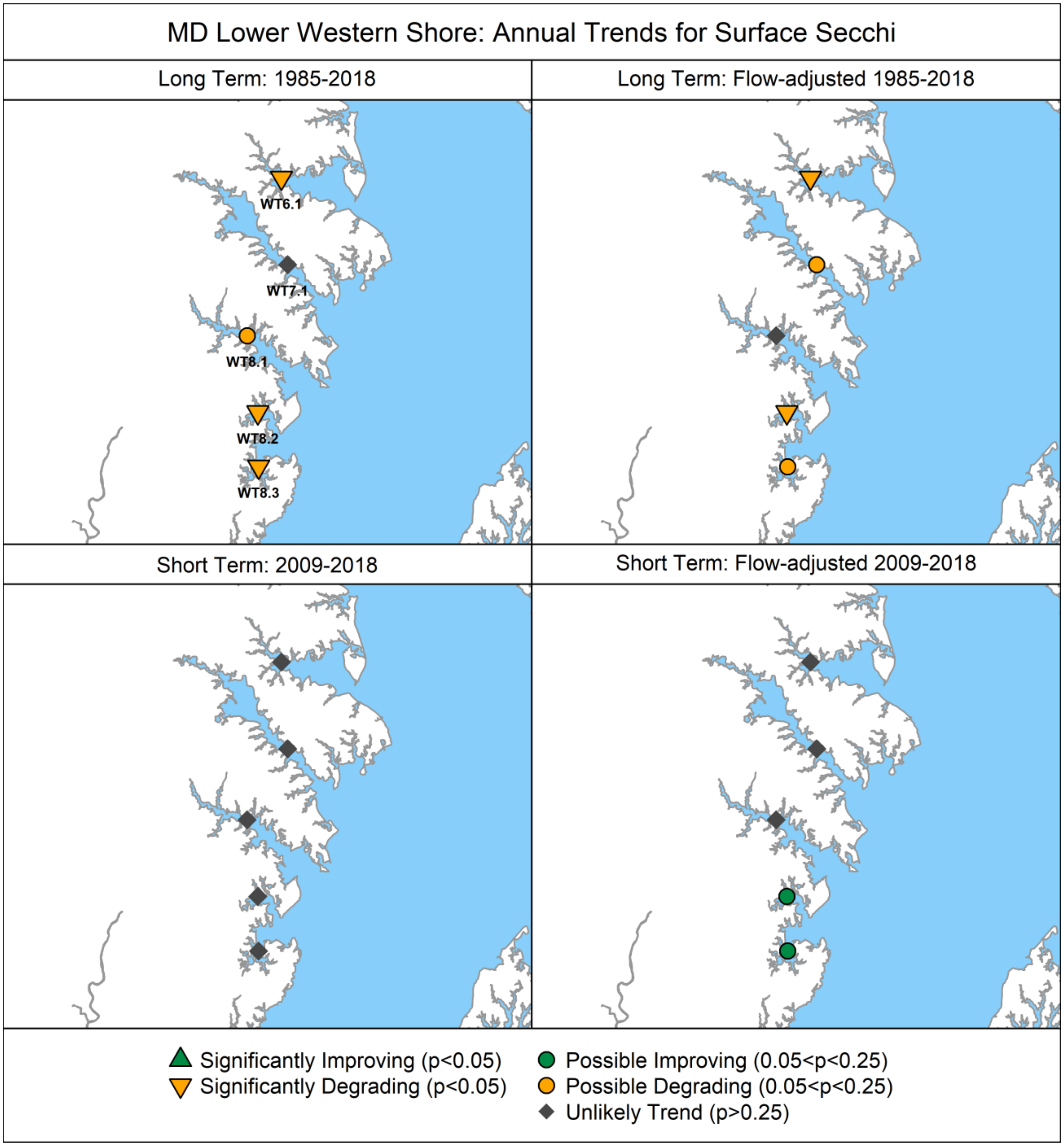

Figure 14. Annual Secchi depth trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

The possible or significant degradations in Secchi depth shown above (Figure 14) are apparent as decreases in the observed values and mean annual GAM estimates over the long-term in Figure 15 for each station. These patterns do level-out in the second half of the record for each station, and the possible increases at the Rhode River (WT8.2) and West River (WT8.3 stations) show up as slightly higher data values at the end of the record (Figure 15).

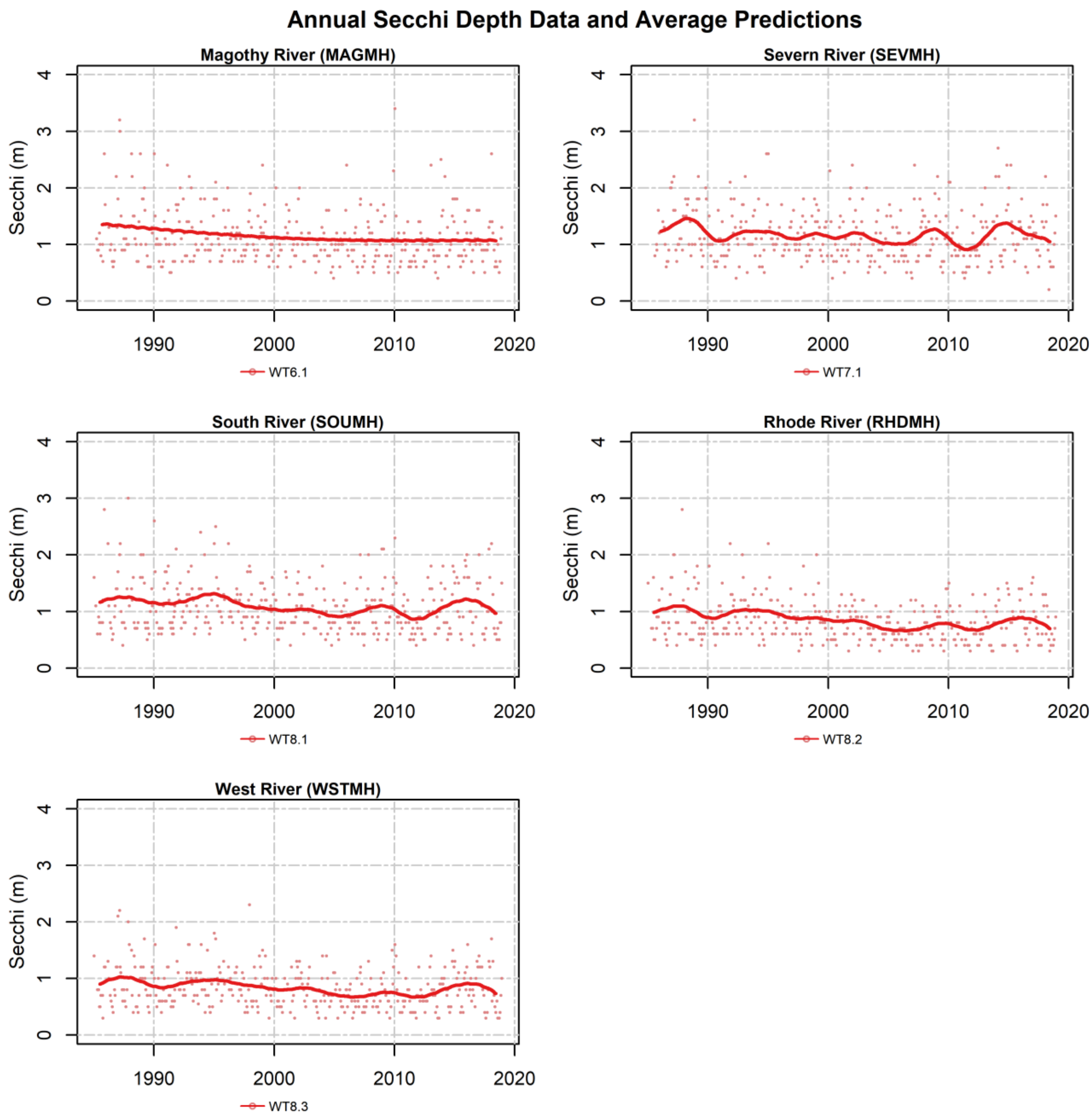

Figure 15. Annual Secchi depth data (dots) and average long-term pattern generated from non-flow adjusted GAMs. Colored dots represent data corresponding to the monitoring station shown indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations.

4.6 Summer Bottom Dissolved Oxygen (June-September)

Summer bottom DO has degraded at station WT6.1 over the long- and short-term, both with and without flow-adjustment (Figure 16). Long-term trends have also degraded at WT7.1. Over the short-term, the middle three stations have no trend and the WT8.3 trend is possibly improving.

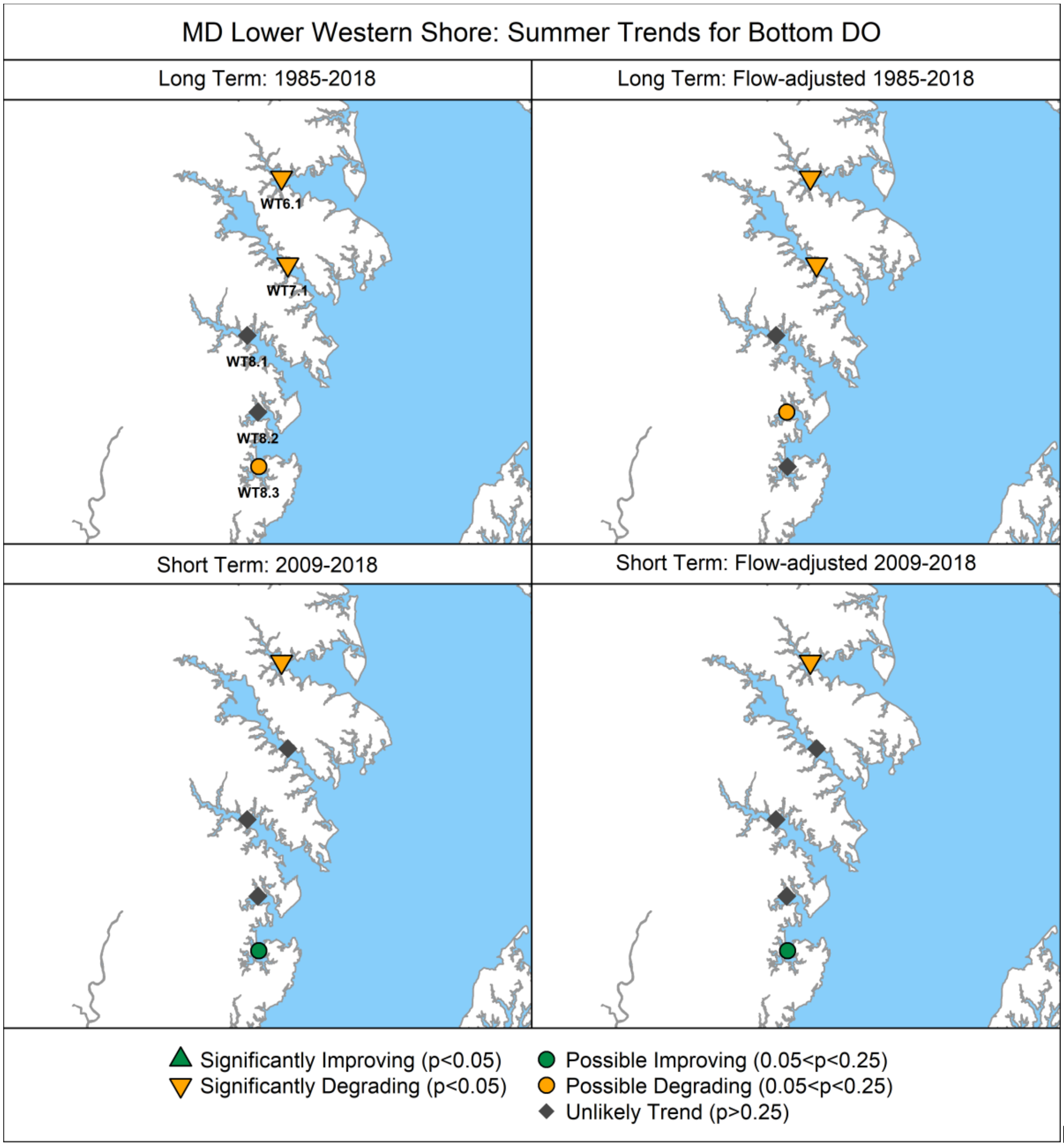

Figure 16. Summer (June-September) bottom DO trends. Base map credit Chesapeake Bay Program, www.chesapeakebay.net, North American Datum 1983.

Plots of the summer bottom DO data and mean seasonal GAM estimates demonstrate the spatial variability in bottom DO concentrations at these stations (Figure 17). The Magothy (WT6.1), Severn (WT7.1) and South River(WT8.1) stations experience very low DO concentrations, and these are tidal regions where deep water designated use applies. The Rhode (WT8.2) and West River (WT8.3) DO concentrations are relatively higher, and the deeper water criteria do not apply in these segments. The mean summer GAM pattern is clearly decreasing over time at station WT6.1 in the Magothy River (Figure 17) where degrading trends were observed (Figure 16). The other long-term degrading trend at the Severn River (WT7.1) is due to a decrease in concentrations at the beginning of the record. And the improvement noted in the West River (WT8.3) is indeed an upswing of DO concentrations observed where in the last decade (Figure 17).

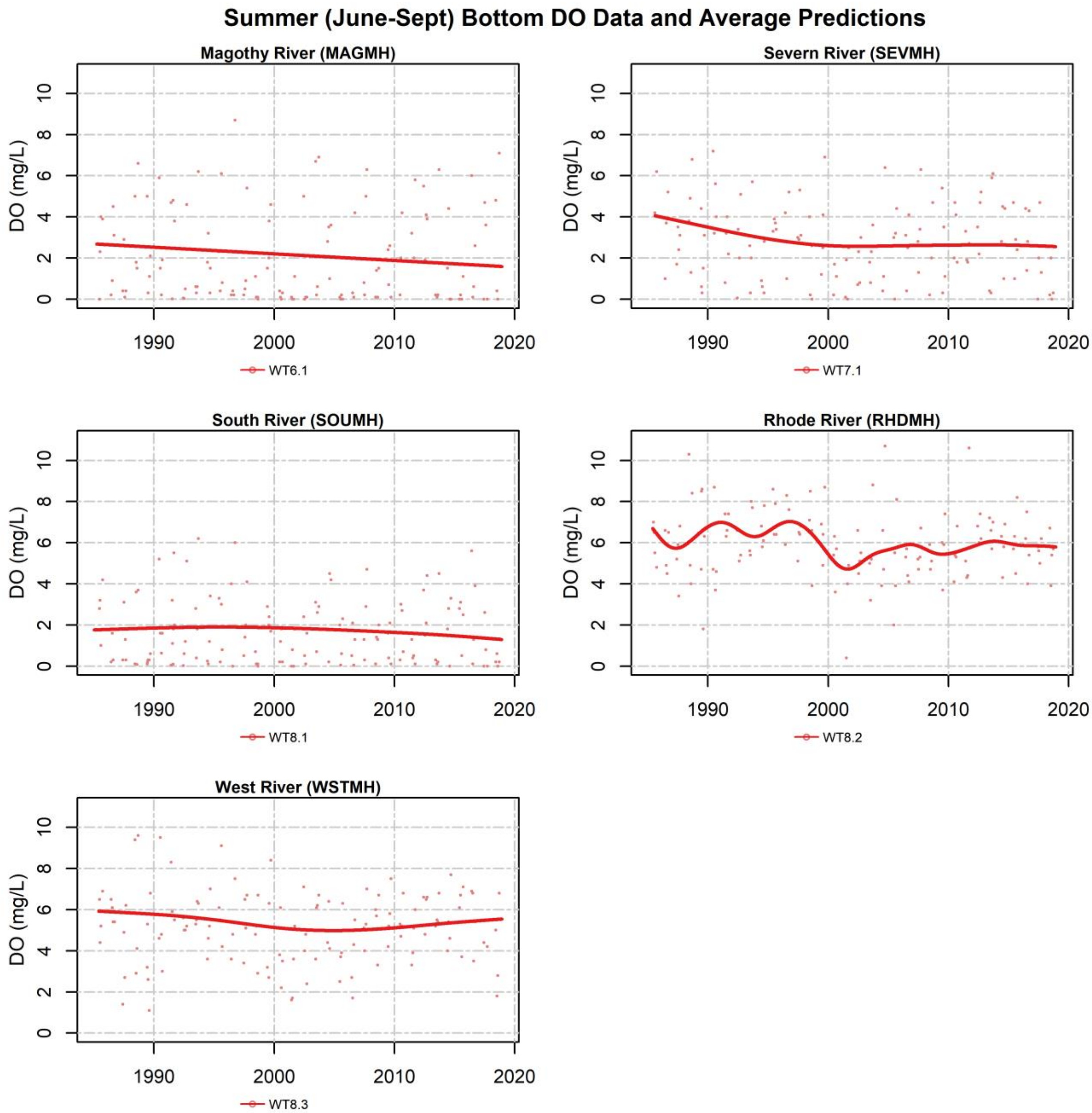

Figure 17. Summer (June-September) bottom DO data (dots) and average summer long-term pattern generated from non-flow adjusted GAM. Colored dots represent June-September data corresponding to

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

The geology of Maryland's Lower Western Shore and its associated land use affects the quantity and transmissivity of nitrogen, phosphorus, and sediment delivered to non-tidal and tidal streams (Figure 18) (Brakebill *et al.*, 2010; Ator *et al.*, 2011; Ator *et al.*, 2019; Ator *et al.*, 2020; Noe *et al.*, 2020).

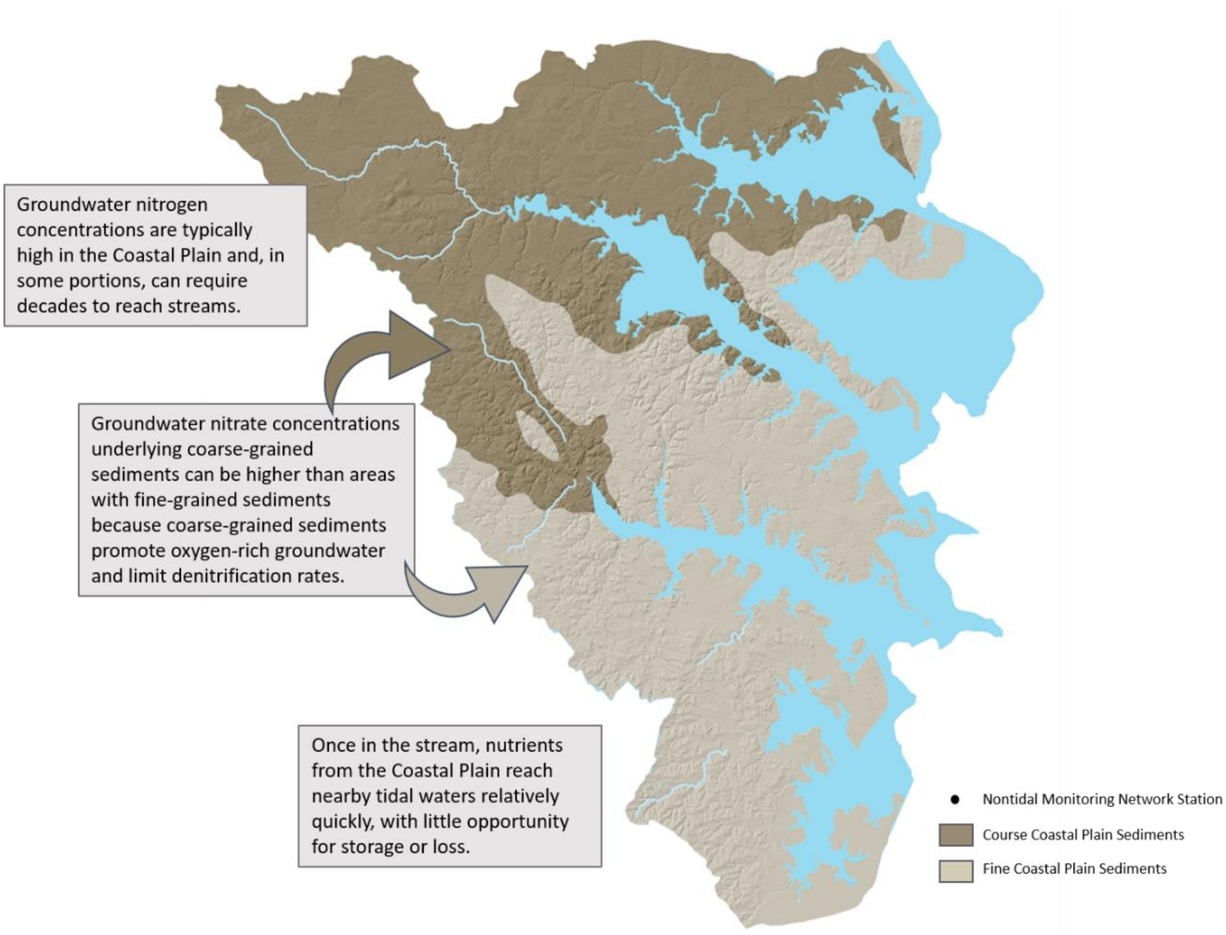

Figure 18. Effects of watershed hydrogeomorphology on nutrient transport to freshwater streams and tidal waters. Base map modified from King *et al.* (1974) and Ator *et al.* (2005), North American Datum 1983.

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). Groundwater nitrate concentrations are low throughout the Maryland's Lower Western Shore compared to surrounding regions that contain Piedmont geology (Greene and others, 2005; Terziotti and others, 2017). The Coastal Plain sediments that underlie Maryland's Lower Western Shore have geochemical properties that promote denitrification (Bachman and Krantz, 2000), which contrasts the oxic groundwater contained in Piedmont crystalline rocks that allow for nitrate transport (Tesoriero and others, 2015). The typical residence time of groundwater delivered to streams in the Chesapeake Bay watershed is about 10 years, but ages vary from less than one year to greater than 50 years based on bedrock structure, groundwater flow paths, and aquifer depths (Lindsey and others, 2003). The average transit time for nitrate carried through the surficial aquifer in the Maryland Coastal Plain has been estimated to be about 20 years (Focazio and others, 1998).

Phosphorus

Phosphorus binds to soil particles and most phosphorus delivered to the Bay is attached to sediment (Zhang *et al.*, 2015); however, once fully phosphorus saturated, soils will not retain new applications and export of dissolved phosphorus to streams, from shallow soils and groundwater, will increase (Staver and Brinsfield, 2001). Phosphorus sorption capacity varies based on soil particle chemical composition and physical structure with clays typically having the greatest number of sorption sites and highest average phosphorus concentrations (Sharpley, 1980). The highest soil phosphorus concentrations in Maryland's Lower Western Shore typically occur in agricultural areas where inputs of manure and fertilizer exceed crop needs. 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

The delivery of sediment from upland soil erosion, streambank erosion, and tributary loading is relatively low in Maryland's Lower Western Shore compared to surrounding regions (Brakebill *et al.*, 2010). Coastal Plain watersheds characteristically have low stream gradients and wide floodplains, which limits sediment transport (Hupp, 2000). Sediment load rates vary even in Coastal Plain settings based on factors affecting streambank erosion are highly variable throughout this watershed and include 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), stream valley geomorphology (Hopkins *et al.*, 2018), and developed land uses (Brakebill *et al.*, 2010).

Delivery to tidal waters

The delivery of nitrogen, phosphorus, and sediment in non-tidal streams to tidal waters in the Patuxent River watershed shore 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. 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 contributes more fine-grained sediment to estuarine waters in Maryland's western shore than is delivered from the watershed (Langland and Cronin, 2003), likely as a result of such trapping and relatively small upland watershed areas.

5.1.2 Estimated Nutrient and Sediment Loads

Estimated loads to tidal portions of the Maryland Lower Western 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, 0.022, 0.0020, and 4.5 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 4.

Nitrogen

Estimated TN loads showed an overall decline of 2.3 ton/yr in the period between 1985 and 2018, although it is not statistically significant ($p = 0.29$). Long-term, statistically significant declines were observed with both point sources (-2.5 ton/yr, $p < 0.01$) and atmospheric deposition to the tidal waters (-0.52 ton/yr, $p < 0.01$). By contrast, nonpoint sources showed a long-term increase in this period (0.54 ton/yr), although it is not statistically significant ($p = 0.84$). 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 (Boynton *et al.*, 2008; 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 decrease of 0.10 ton/yr in the period between 1985 and 2018, although it is statistically significant ($p = 0.57$). Point sources showed a long-term decline (-0.29 ton/yr, $p < 0.01$), whereas nonpoint sources showed a long-term increase (0.28 ton/yr, $p = 0.13$). 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 (Boynton *et al.*, 2008; Lyerly *et al.*, 2014).

Sediment

Estimated suspended sediment (SS) loads showed an overall increase of 293 ton/yr in the period between 1985 and 2018, which is statistically significant ($p < 0.05$). This increase is entirely driven by nonpoint sources (295 ton/yr, $p < 0.05$). Like TP and TN, point source load of SS showed a statistically significant decline in this period (-2.2 ton/yr; $p < 0.01$).

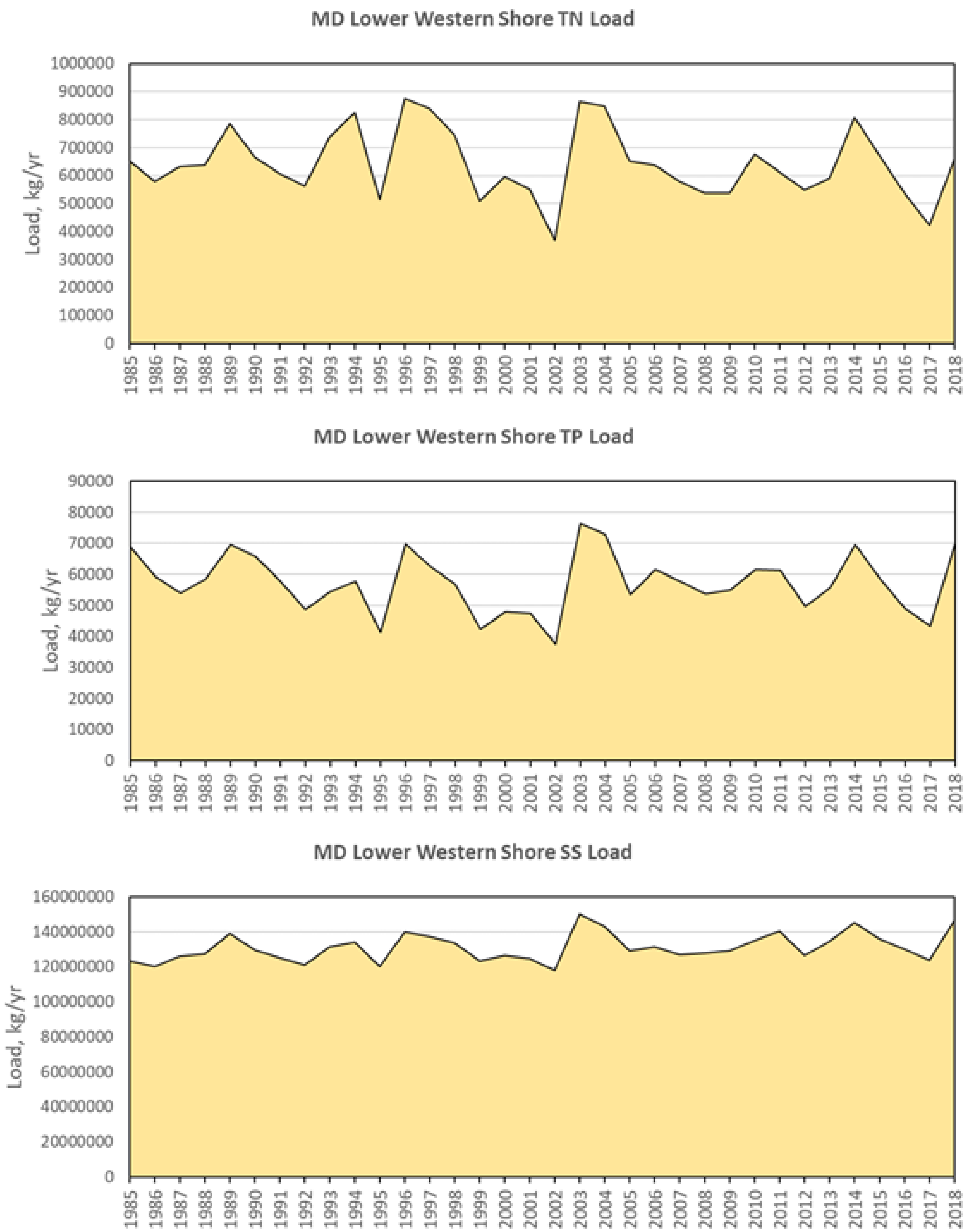

Figure 19. Estimated total loads of nitrogen (TN), phosphorus (TP), and suspended sediment (SS) to the Maryland Lower Western Shore Tributaries.

Table 4. 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 Maryland Lower Western Shore watershed.

Variable	Trend, metric ton/yr	Trend p-value
TN		
Total watershed[1]	-2.3	0.29
Point source	-2.5	< 0.01
Nonpoint source[2]	0.54	0.84
Tidal deposition	-0.52	< 0.01
TP		
Total watershed	-0.10	0.57
Point source	-0.29	< 0.01
Nonpoint source	0.28	0.13
SS		
Total watershed	293	< 0.05
Point source	-2.2	< 0.01
Nonpoint source	295	< 0.05

[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 Maryland Lower Western 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 Patuxent River was selected for two reasons: (1) it is geographically proximate to the Maryland Lower Western Shore Tributaries, and (2) it is hydrologically similar to the Maryland Lower Western 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 Maryland Lower Western Shore River by -12%, -42%, and -1%, 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, developed and wastewater were the two largest sources of nitrogen loads. By 2019, developed remained the largest nitrogen source; however, wastewater nitrogen loads had changed by -79% and the septic sector had taken its place as the second largest nitrogen source. Overall, decreasing nitrogen loads from agriculture (-55%), natural (-23%), and wastewater (-79%) sources were partially counteracted by increases from developed (43%), septic (27%), and stream bed and bank (2%) sources.

The two largest sources of phosphorus loads as of 2019 were the shoreline and developed sectors. Overall, expected declines from agriculture (-69%), natural (-25%), stream bed and bank (-44%), and wastewater (-92%) sources were partially counteracted by increases from developed (14%) sources.

For sediment, the largest sources are shoreline and stream bed and bank areas: these two sources changed by 0% and -2%, respectively between 1985 and 2019. Sediment loads from the agriculture sector changed by -72%, whereas sediment load from developed areas changed by 35%.

Overall, changing watershed conditions are expected to result in the agriculture, natural, 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.

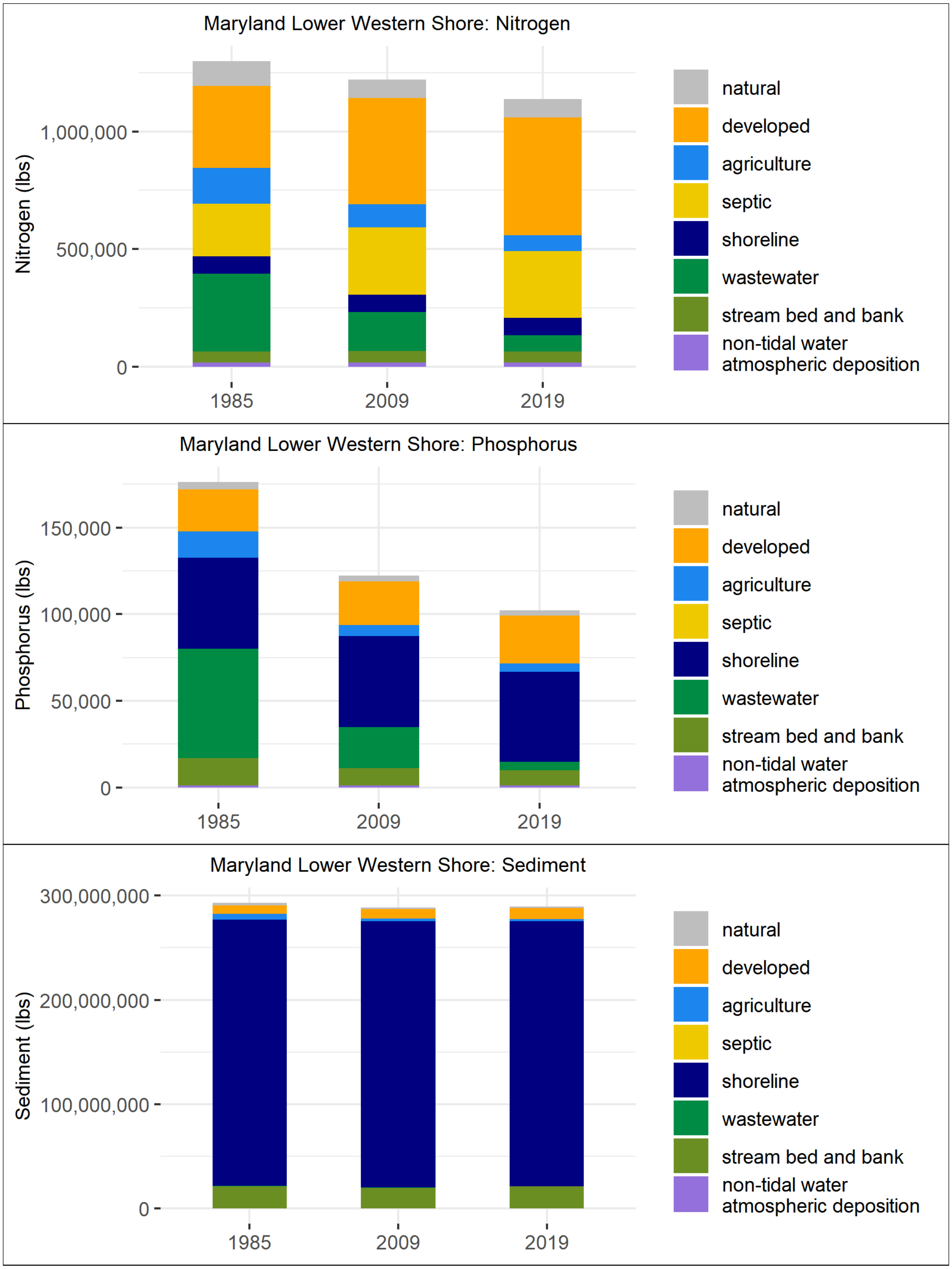

Figure 20. Expected long-term average loads of nitrogen, phosphorus, and sediment from different sources to the tidal Maryland Lower Western Shore tributaries, as obtained from the Chesapeake Assessment Scenario Tool (CAST-19). Data shown are time-average delivered loads over the average

hydrology of 1991-2000, once the steady state is reached for the conditions on the ground, as obtained from the 1985, 2009, and 2018 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 2.2, 1.3, 0.9, 0.0, 13, 8, and 22 thousand acres, respectively. Implementation levels for some practices are already close to achieving their planned 2025 levels: for example, 115% of planned acres for agricultural nutrient management had been achieved as of 2019. In contrast, about 98% of planned urban nutrient management implementation had been achieved as of 2019.

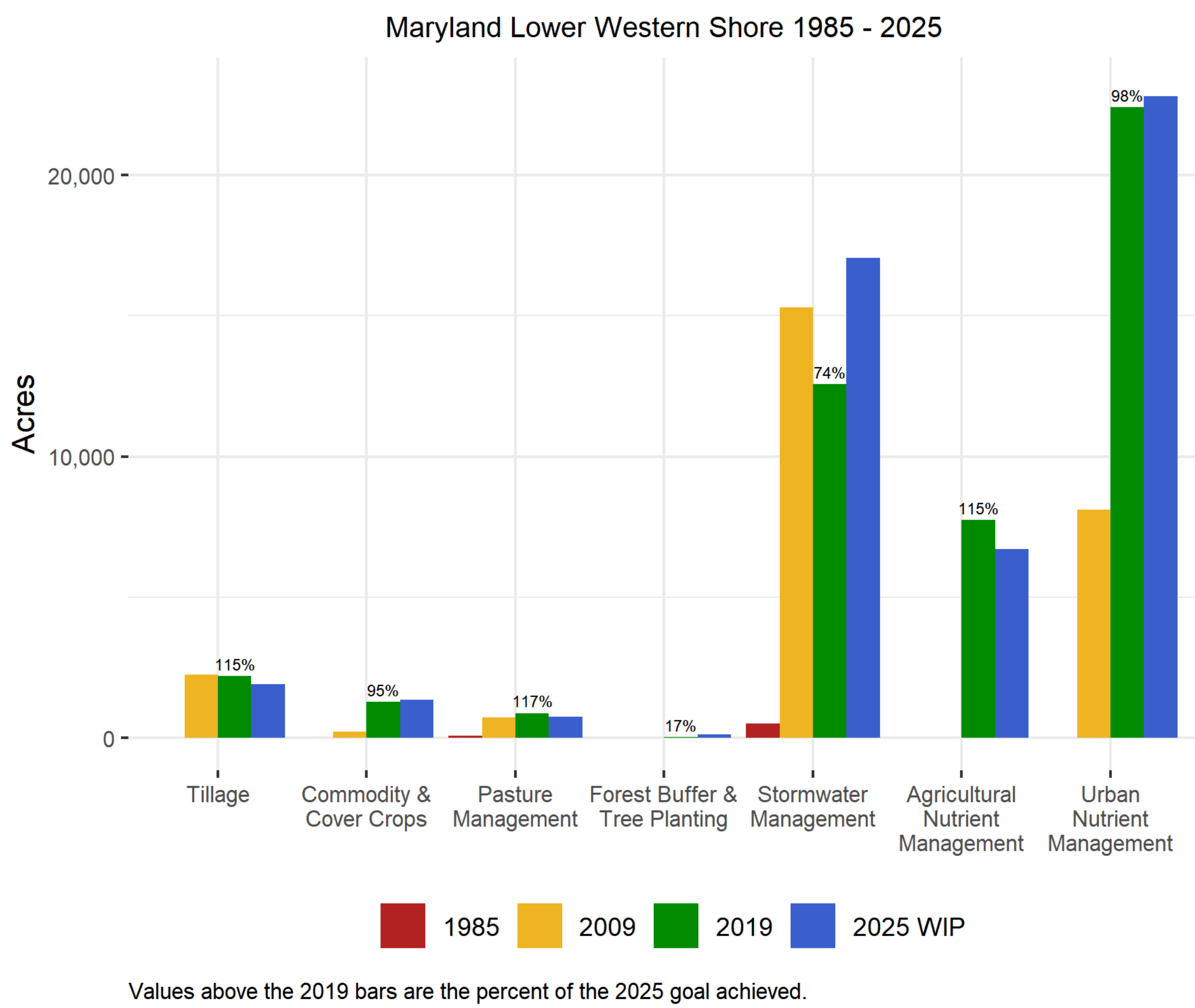

Figure 21. BMP implementation in the Maryland Lower Western Shore watershed

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 8,003 feet in 2019. Over the same period, animal waste management systems treated 0 animal units in 1985 and 52 animal units in 2019 (one animal unit represents 1,000 pounds of live animal). These implementation levels represent 8% and 3% 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. While there are no nontidal network (NTN) monitoring stations that drain to the Maryland's Lower Western Shore, loads and trends are available for stations in the adjacent watersheds. Flow-normalized nitrogen, phosphorus, and sediment trends have been reported for the long term (1985-2019) and short term (2009-2018) at nontidal network stations in the adjacent watersheds (Moyer and Langland, 2020) (Table 5). 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 5. Long-term (1985 - 2018) and 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 regions adjacent to the Maryland Lower Western 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.

Region	USGS Station ID	USGS Station Name	Trend start water year	Percent change in FN load, through water year 2018		
				TN	TP	SS
Upper Western Shore	01582500	GUNPOWDER FALLS AT GLENCOE, MD	1985	6.7	-	-
			2009	-6.6	65.7	134.0
Patapsco-Back River Watershed	01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	1985	2.2	-	-
			2009	-7.7	-15.4	-7.5
	01589300	GWYNNS FALLS AT VILLA NOVA, MD	2009	-11.9	-26.3	-9.8
Patuxent River Watershed	01591000	PATUXENT RIVER NEAR UNITY, MD	1985	2.7	-58.6	-1.3
			2009	7.5	18.5	19.4
	01594440	PATUXEN RIVER AT BOWIE, MD	1985	-65.4	-64.2	-39.8
			2009	-20.7	-6.4	1.2
	01594526	WESTERN BRANCH AT UPPER MARLBORO, MD	2009	-6.3	-10.4	-9.9

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).

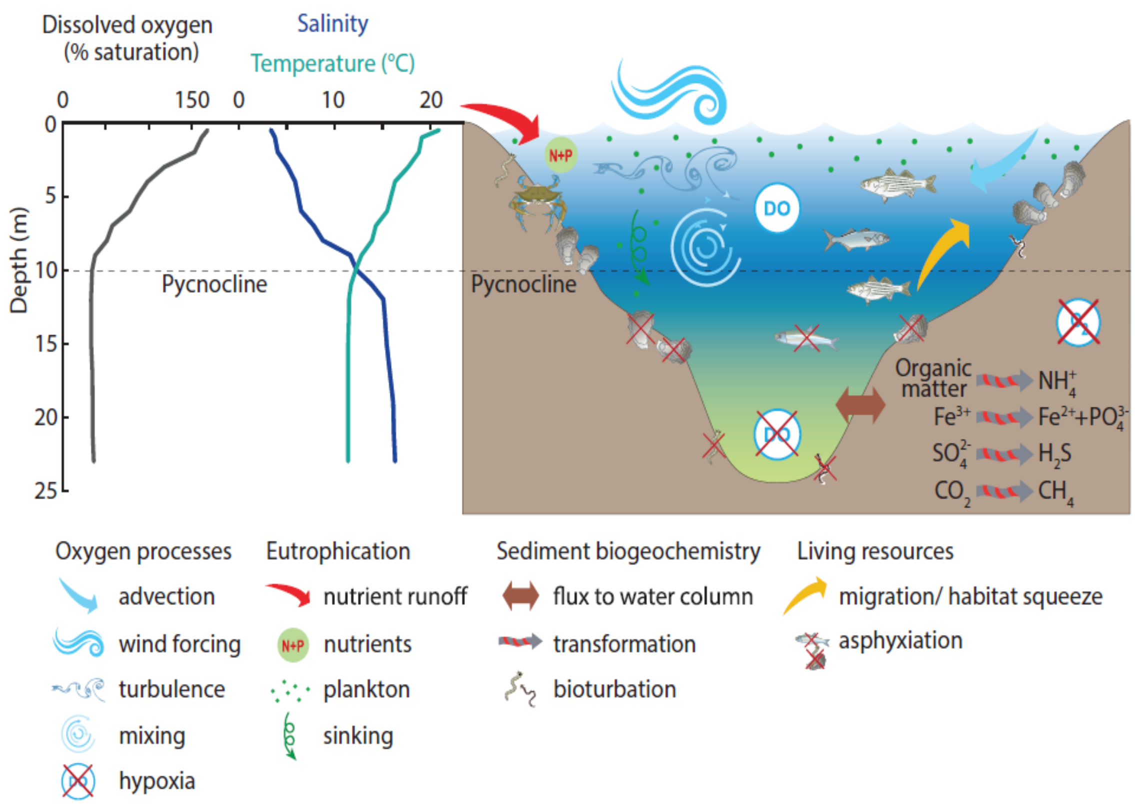

Figure 22. Conceptual diagram illustrating how hypoxia is driven by eutrophication and physical forcing, while affecting sediment biogeochemistry and living resources. From Testa *et al.* (2017).

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.

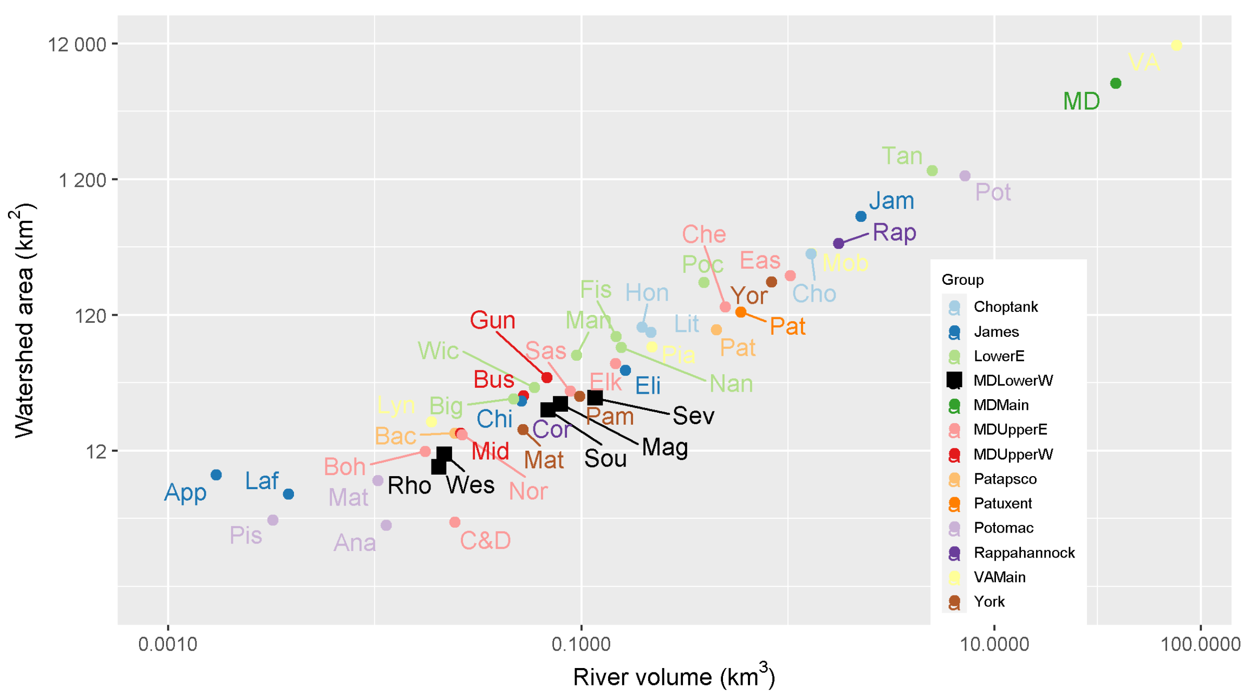

Figure 23. Watershed area vs estuarine volume.

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

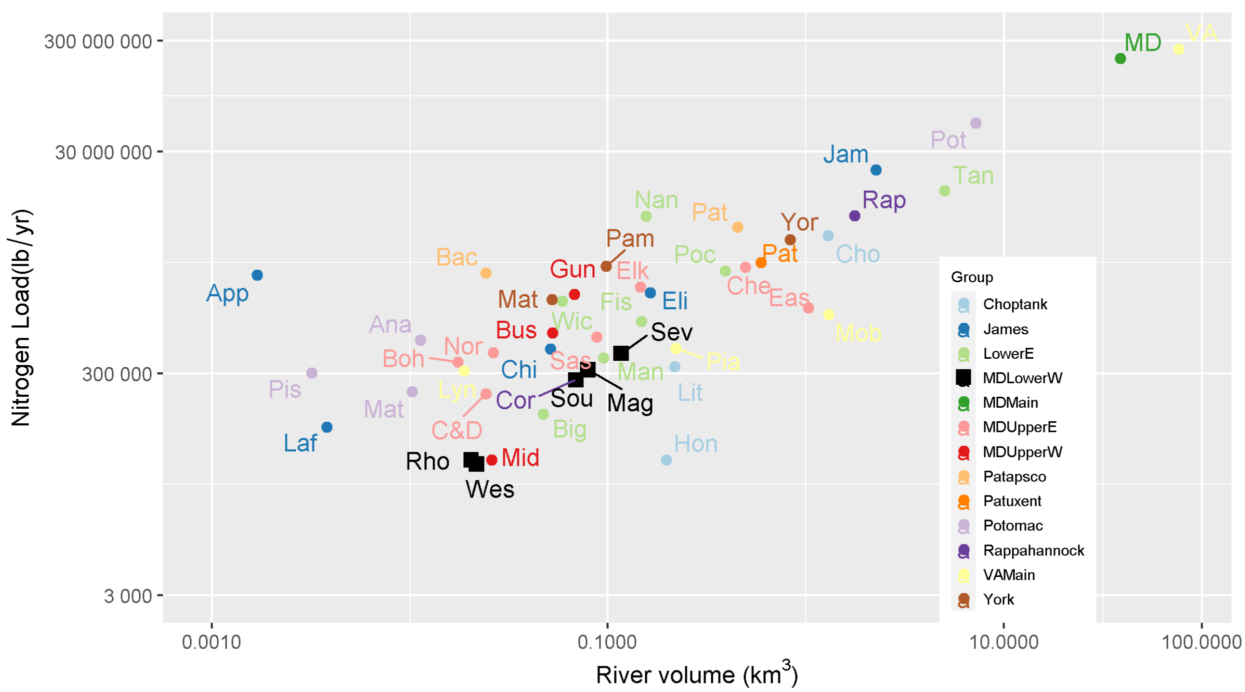

Figure 24. Annual average expected nitrogen loads versus estuarine volume. Nitrogen loads are from the 2018 progress scenarios in CAST (Chesapeake Bay Program, 2020), which is an estimate of nitrogen loads under long-term average hydrology given land use and reported management as of 2018.

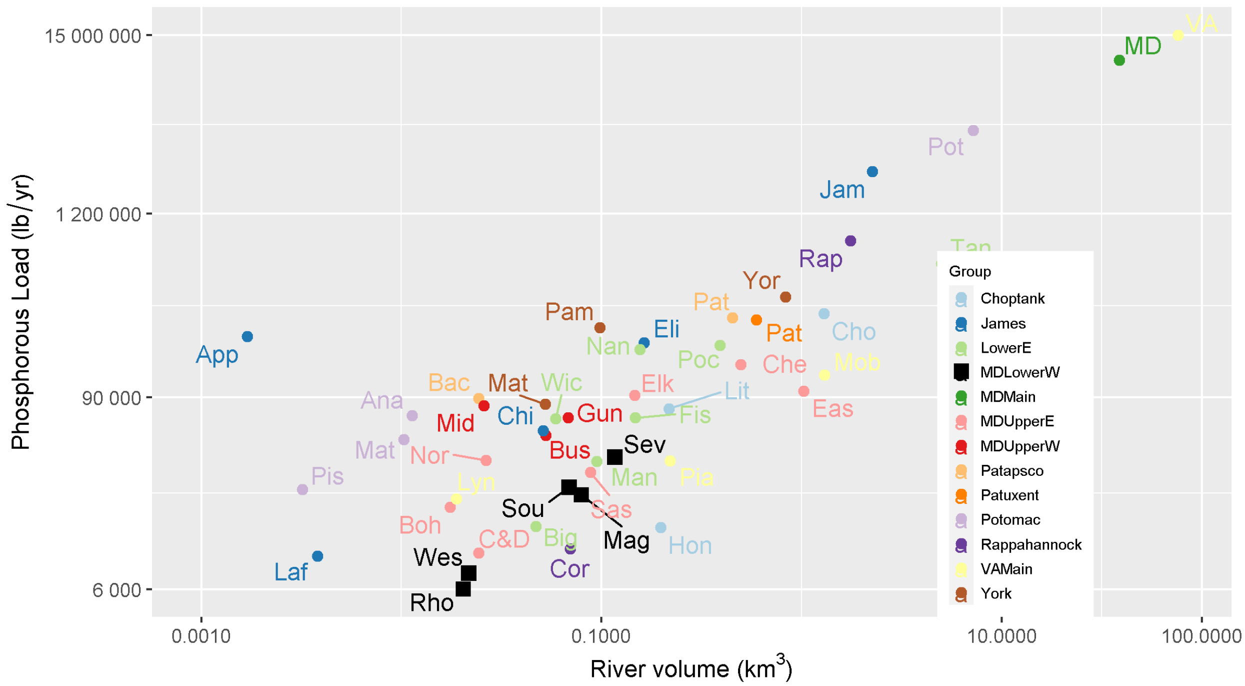

Figure 25. Annual average expected phosphorus loads versus estuarine volume. Phosphorus loads are from the 2018 progress scenarios in CAST (Chesapeake Bay Program, 2020), which is an estimate of phosphorus loads under long-term average hydrology given land use and reported management as of 2018.

The Maryland Lower Western Shore estuary volume and watershed contain approximately 0.4 and 0.3% of the total volume and watershed of the Chesapeake Bay. This ranks the Maryland Lower Western Shore as the 12th largest volume and 13th 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 Maryland Lower Western Shore system, the Magothy river, Rhode river, Severn river, West river, and South river all hold this same relationship. The Magothy river, Rhode river, Severn river, and South river all have consistent phosphorous loading relative to estuarine volume while the West and Rhode rivers tend to have somewhat lower phosphorus loads relative to estuarine volume. The same relationship for each tributary and nitrogen loading.

5.3 Insights on Changes in the Lower Western 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