DRAFT

Tidal Trends in Water Quality:

Potomac River 2017 Tributary Summary

Sept 26, 2018

Contents

1. Location

The Potomac River is the second largest tributary to Chesapeake Bay. Its watershed is approximately 38,000 km^2 and spans parts of four states and Washington D.C. The tidal Potomac begins just upstream of Washington D.C. at the boundary of the coastal plain and piedmont (Figure 1).

1.1 Watershed Physiography

The Potomac River watershed stretches across five major physiographic regions, namely, Valley and Ridge, Piedmont, Coastal Plain, Blue Ridge, and Mesozoic Lowland (Figure 1). The Valley and Ridge physiography covers both carbonate and siliciclastic areas. The Piedmont physiography covers both carbonate and crystalline areas. The Coastal Plain physiography covers lowland, dissected upland, and upland areas.

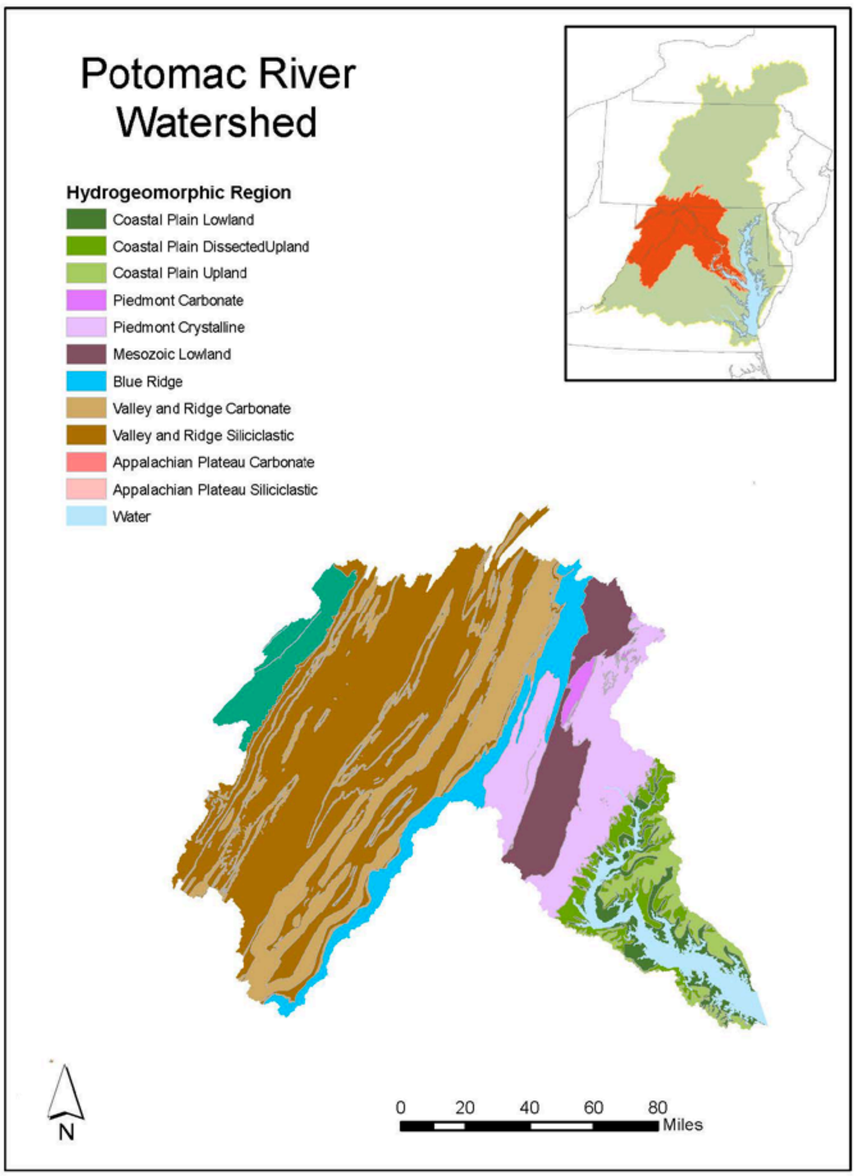


Figure 1. Distribution of physiography in the Potomac River watershed.

1.2 Tidal Waters and Stations

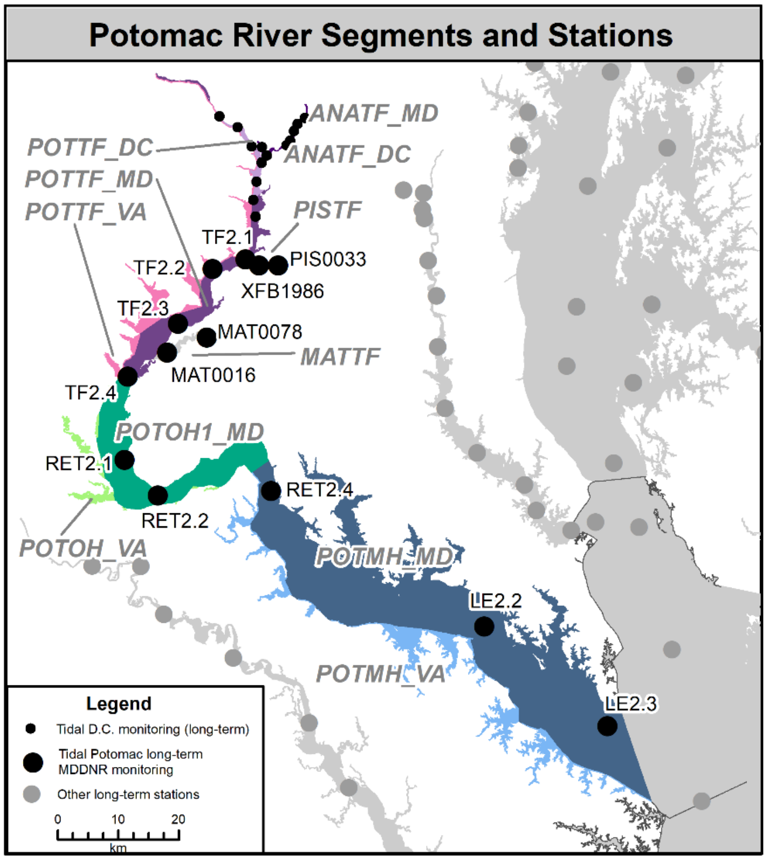


Figure 2. Map of Tidal Potomac River segments and long-term monitoring stations

For the purposes of water quality standards assessment and reporting, the tidal portion of the Potomac River is divided into multiple split segments: Tidal Fresh in DC, MD and VA (POTTF_DC, POTTF_MD, POTTF_VA), Oligohaline in MD and VA (POTOH1_MD, POTOH2_MD, POTOH3_MD, and POTOH_VA), and Mesohaline in MD and VA (POTMH_MH, POTMH_VA) (Figure 2). Three tributaries of the Potomac – the Anacostia (ANATF_MD, ANATF_DC) Piscataway River (PISTF) and Mattawoman Creek (MATTF) – are also represented. Long-term trends in water quality are analyzed by MDDNR at 13 stations stretching from Piscataway River to the mouth of the Potomac flowing into Chesapeake Bay. Water quality data at these stations are also used to assess attainment of dissolved oxygen (DO) water quality criteria. Other monitoring is conducted in the Washington D.C. tidal waters and used to assess water quality criteria for DO and chlorophyll-a. Those observations are not included in subsequent trend graphics. In addition, shallow-water monitoring has been conducted in the VA and some MD segments that is included in the water quality criteria evaluation but not shown in the long-term trend graphics in subsequent sections.

2. Tidal Water Quality Status

2.1 Water Quality Criteria Attainment

Multiple water quality criteria exist for the tidal Potomac. A record over time of whether or not three of these criteria have been met in each applicable segment is shown in Tables 1 and 2. In the most recent period (2014-2016), fewer than half of the segment-criterion combinations met these DO requirements. *(This will be updated to go through 2017 when computations are complete.)*

Table 1. Open Water Summer DO criterion status (30-day mean June-Sept assessment period)

Open Water Segment	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
ANATF_DC																														
ANATF_MD																														
POTTF_DC																														
POTTF_MD																														
POTTF_VA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND													
POTOH_VA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND													
POTOH1_MD																														
POTOH2_MD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND						ND	ND	ND	ND	ND	ND
POTOH3_MD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND						ND	ND	ND	ND	ND	ND
POTMH_MD																														
POTMH_VA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND													
MATTF																														
PISTF																														

Table 2. Summer DO Deep Water (30-day mean) and Deep Channel (Instantaneous) criteria status

DU	Segment	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
Deep Water	POTMH_MD																														
	POTMH_VA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0	0	0	0	0	0	0	0	ND				0
Deep Channel	POTMH_MD																														
	POTMH_VA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0	0	0	0	0	0	ND	ND	ND	ND	ND

DO concentration trends are shown together with the water quality criterion status for two of the applicable criteria (summer open water 30-day mean and summer deep channel instantaneous concentration) in Figure 3. The OW criterion was met in 6 of the 11 segments evaluated for the 2014-2016 period. Trends in surface oxygen are mixed across the tidal fresh stations, where the criterion is met already. In the middle and lower Potomac segments there are few significant trends and there is also a mix of attainment status. Bottom oxygen concentrations in the Potomac are improving or no trend, but most of the improvements are in upper river segments where the deep channel criterion does not apply. The one segment (POTMH_MD) with a deep channel criterion did not meet it in 2014-2016.

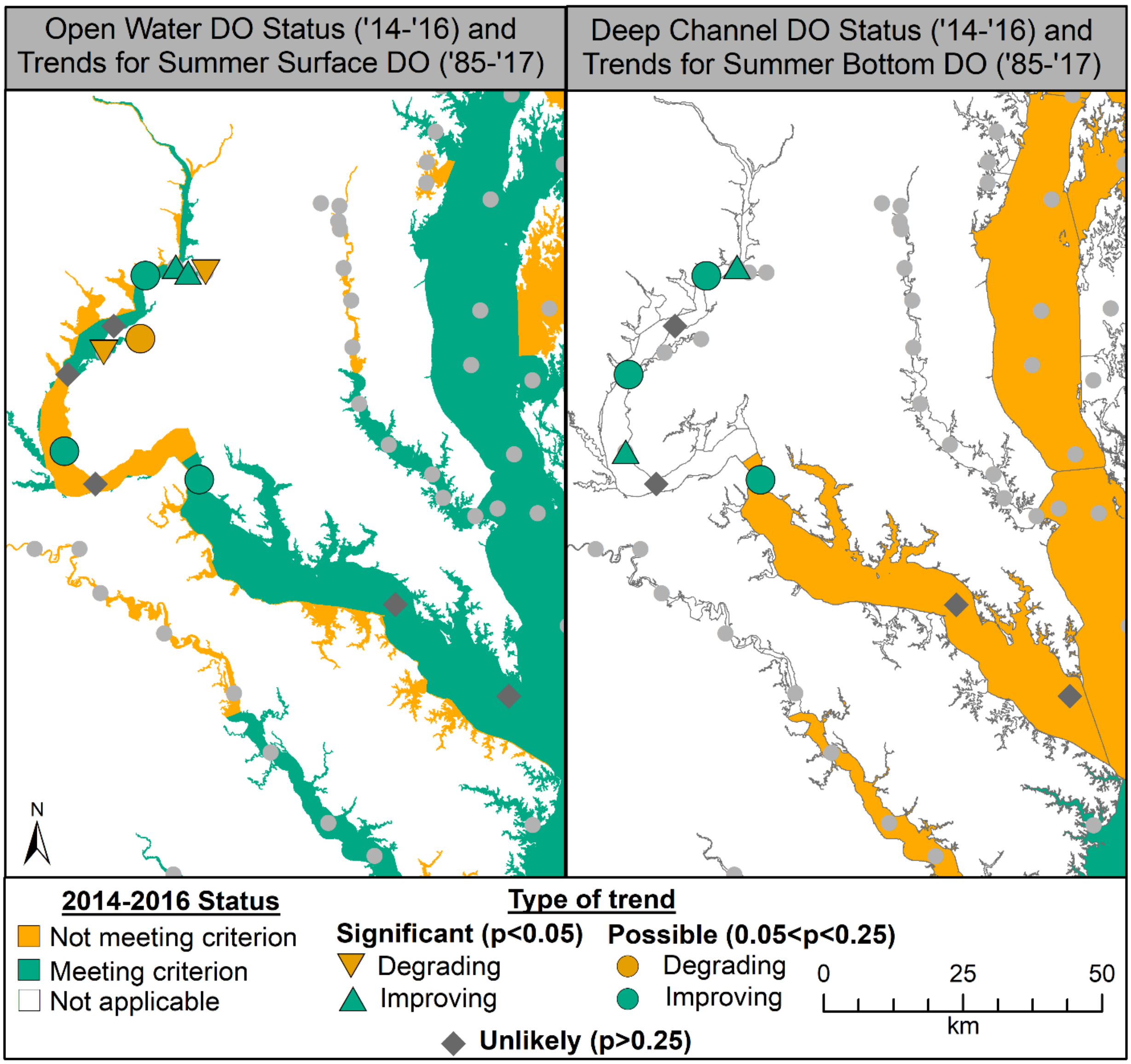


Figure 3. 2014-2016 oxygen criterion status for Potomac segments along with long-term trends in DO concentrations.

3. Tidal Water Quality Trends

3.1 Surface Total Nitrogen

Annual TN concentrations have declined since 1985 at all 13 of the tidal Potomac stations, using both non-flow/salinity-adjusted results and adjusted results (Figure 4). In the past 10 years, the majority, but not all, of the stations continue to show decreasing trends. One (MAT0078) shows a possible increase.

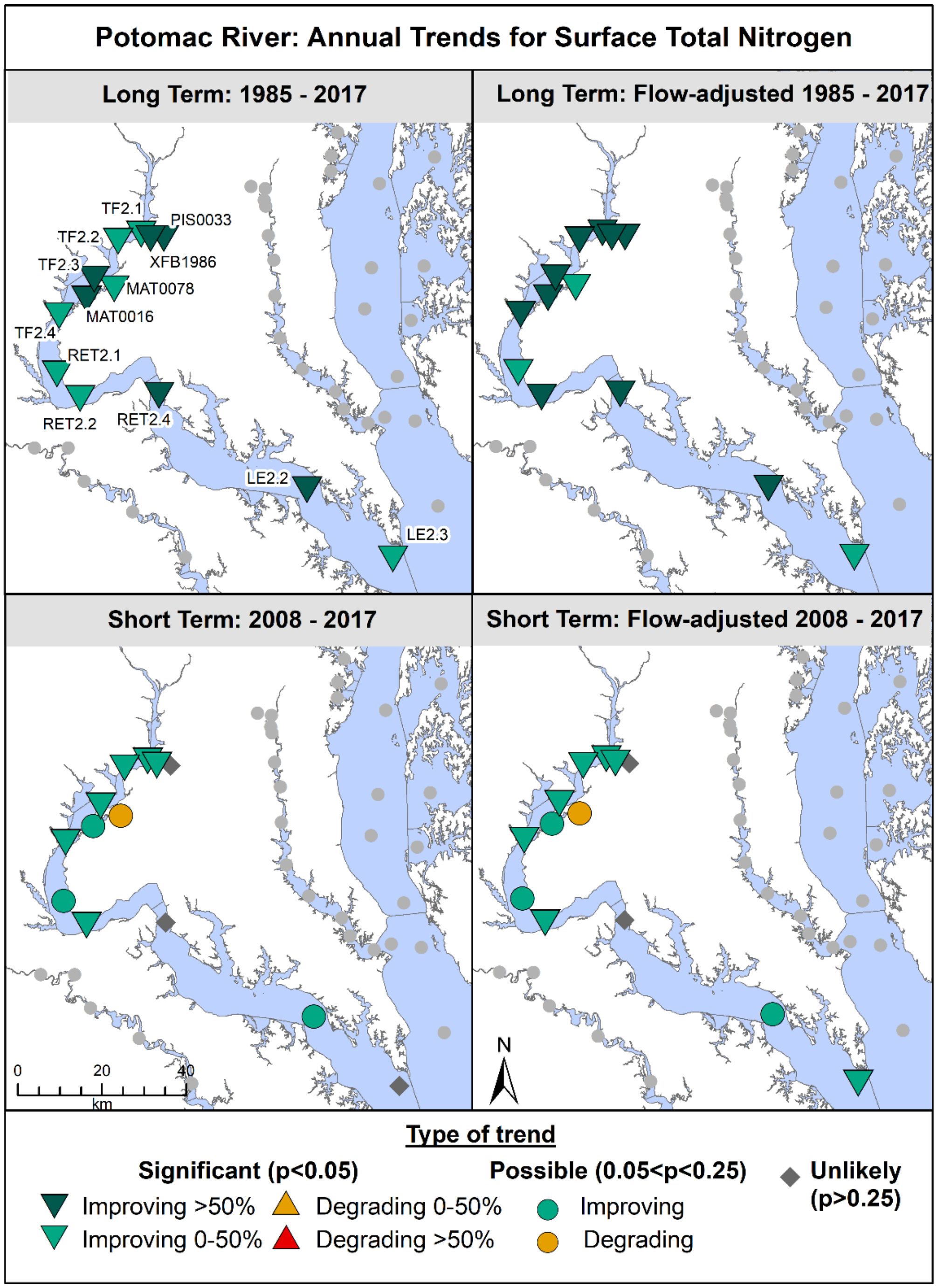


Figure 4. Surface Total Nitrogen Trends

The decreasing TN trends are evident in both the data and the non-flow adjusted average patterns from Generalized Additive Models (GAMs) presented in Figure 5. Vertical blue dotted lines in most of the panels represent a method change (7/12/1995) and a laboratory and method change (5/1/1998) that were tested for their 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 model predictions at these stops. With this technique, we can adjust the model results to predict long-term change after accounting for the artificial method change.

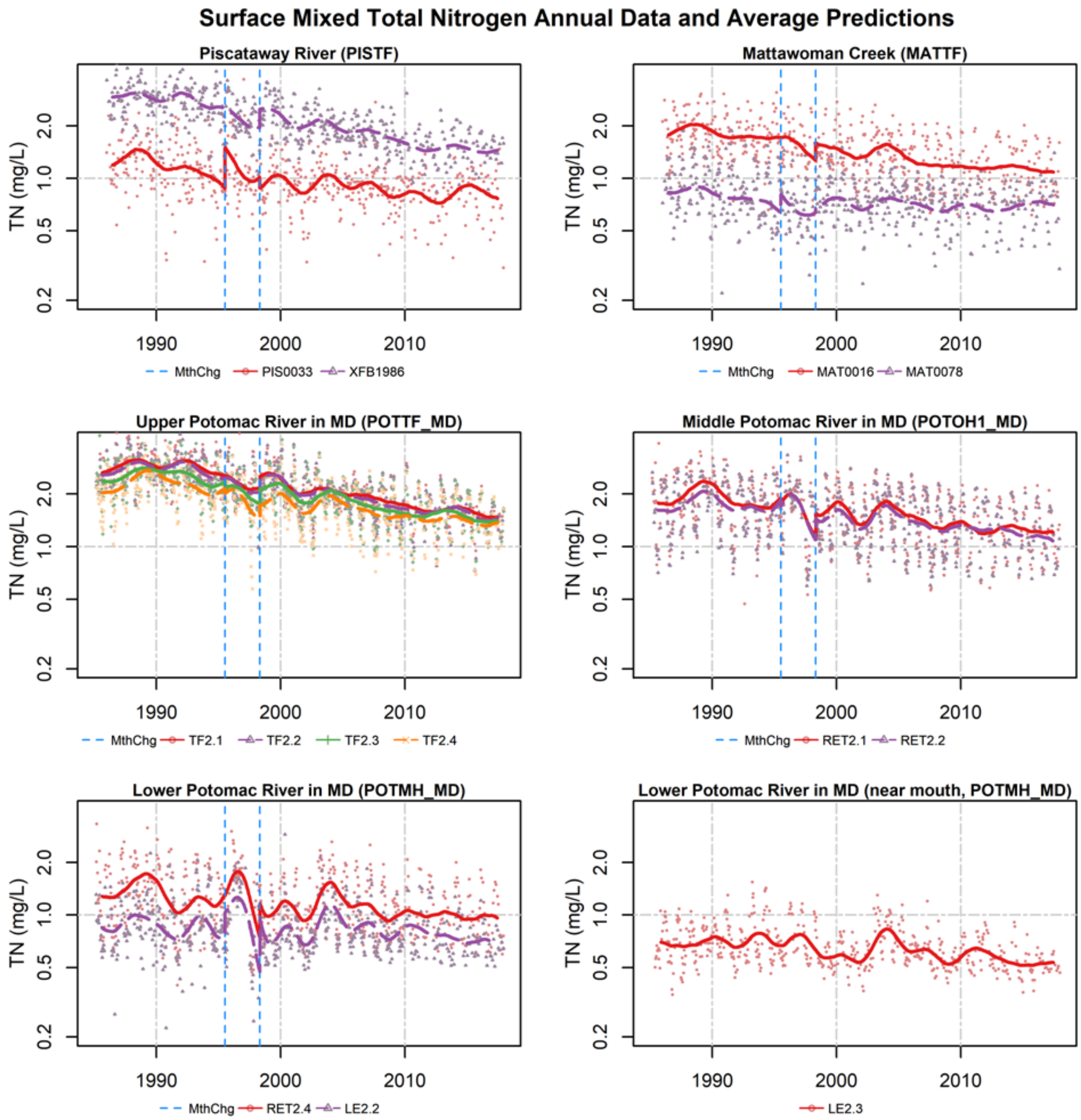


Figure 5. Surface Total Nitrogen data (dots) and average long-term pattern generated from non-flow adjusted GAM. Plots are on a log-scale.

3.2 Surface Total Phosphorus

Surface total phosphorus trends are more mixed than TN, but many are improving in the long-term, especially after flow-adjustment (Figure 6). In the short-term, there is some indication of improvement in the two stations closest to the mouth (LE2.2 and LE2.3), with significant improvement after flow adjustment. But otherwise the majority of the stations show no short-term trend in surface TP.

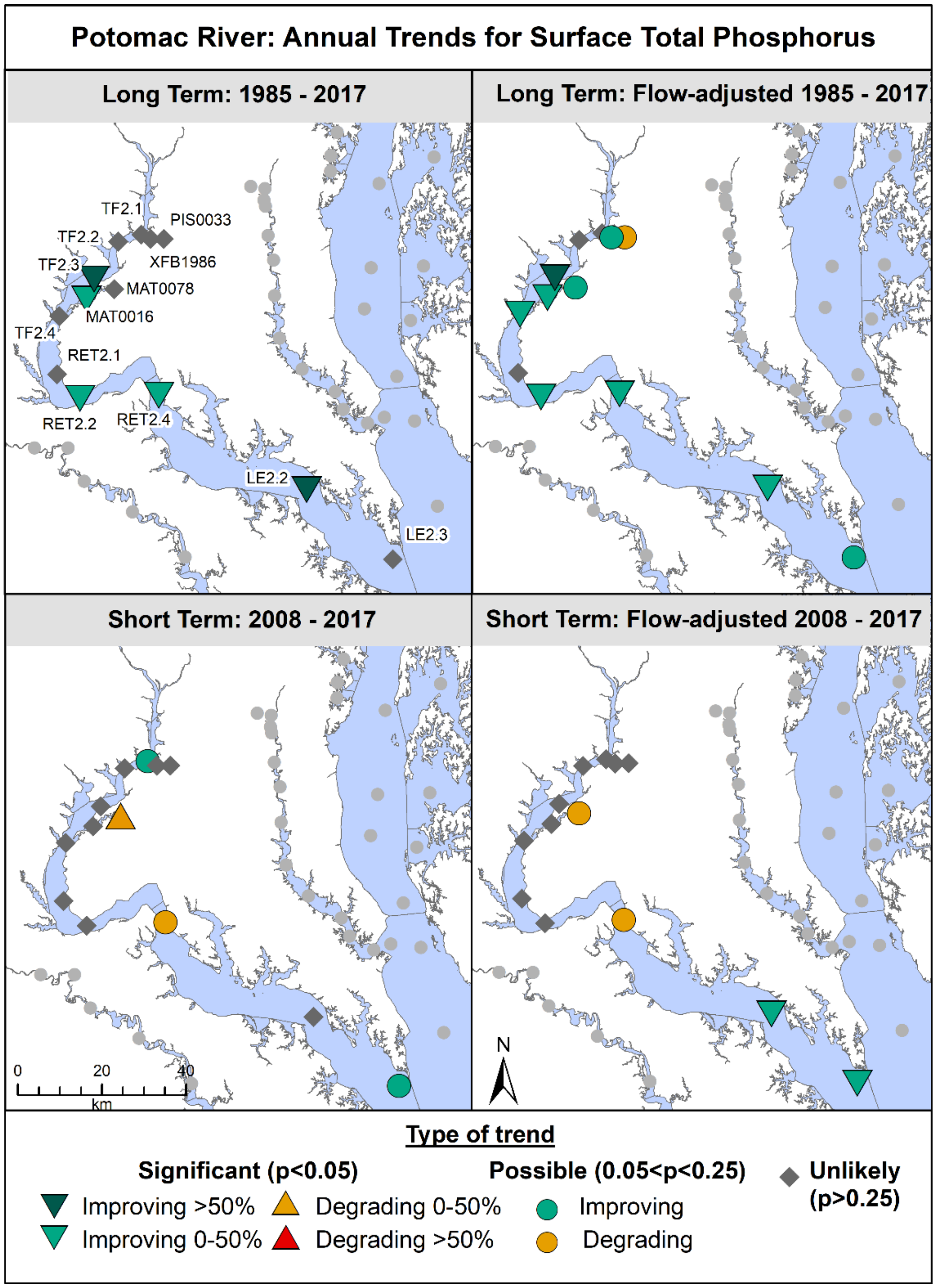


Figure 6. Surface TP Trends

Some long-term improvement in TP concentrations, and recent leveling out, is apparent in the data values and GAM model results in Figure 7. Like for TN, vertical blue dotted lines in most of the panels represent a laboratory and method change (5/1/1998) that was tested for their impact on data values. The model predictions jump at this point when the intervention was significant.

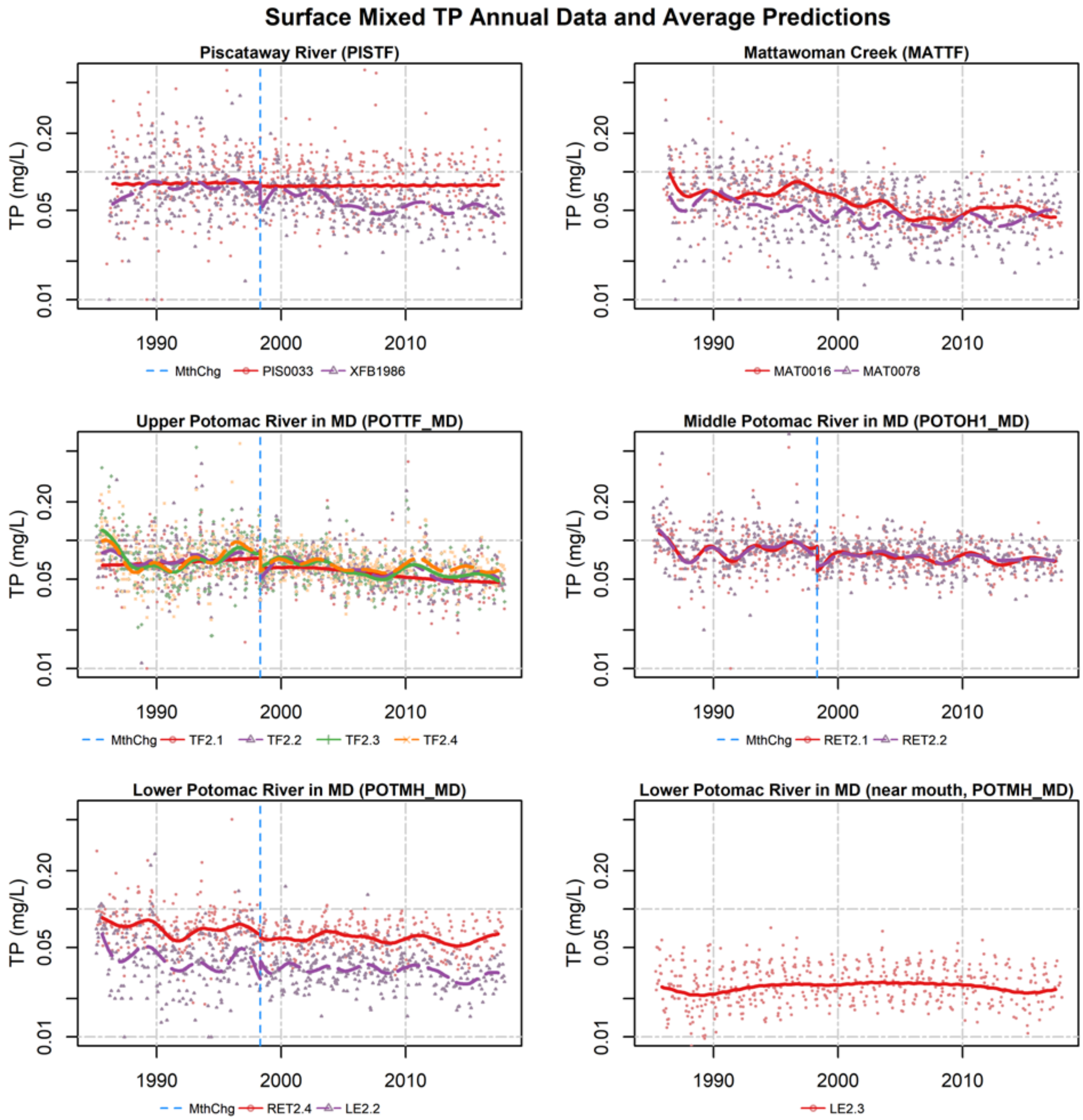


Figure 7. Surface TP data (dots) and average long-term pattern generated from non-flow adjusted GAM. Plots are on a log-scale.

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

Trends for chlorophyll-a are split into spring and summer to represent different features of the phytoplankton annual cycle. Spring trends (Figure 8) are mixed – long-term degrading trends are apparent after flow-adjustment in Piscataway and Mattawoman, but not in the main Potomac tidal fresh. Short term degradation is occurring at almost all of the tidal fresh stations. Most of the middle Potomac stations (RET) show long- and short-term degrading trends. The lower Potomac stations show either no trend, or when the short-term model is flow-adjusted, improving trends.

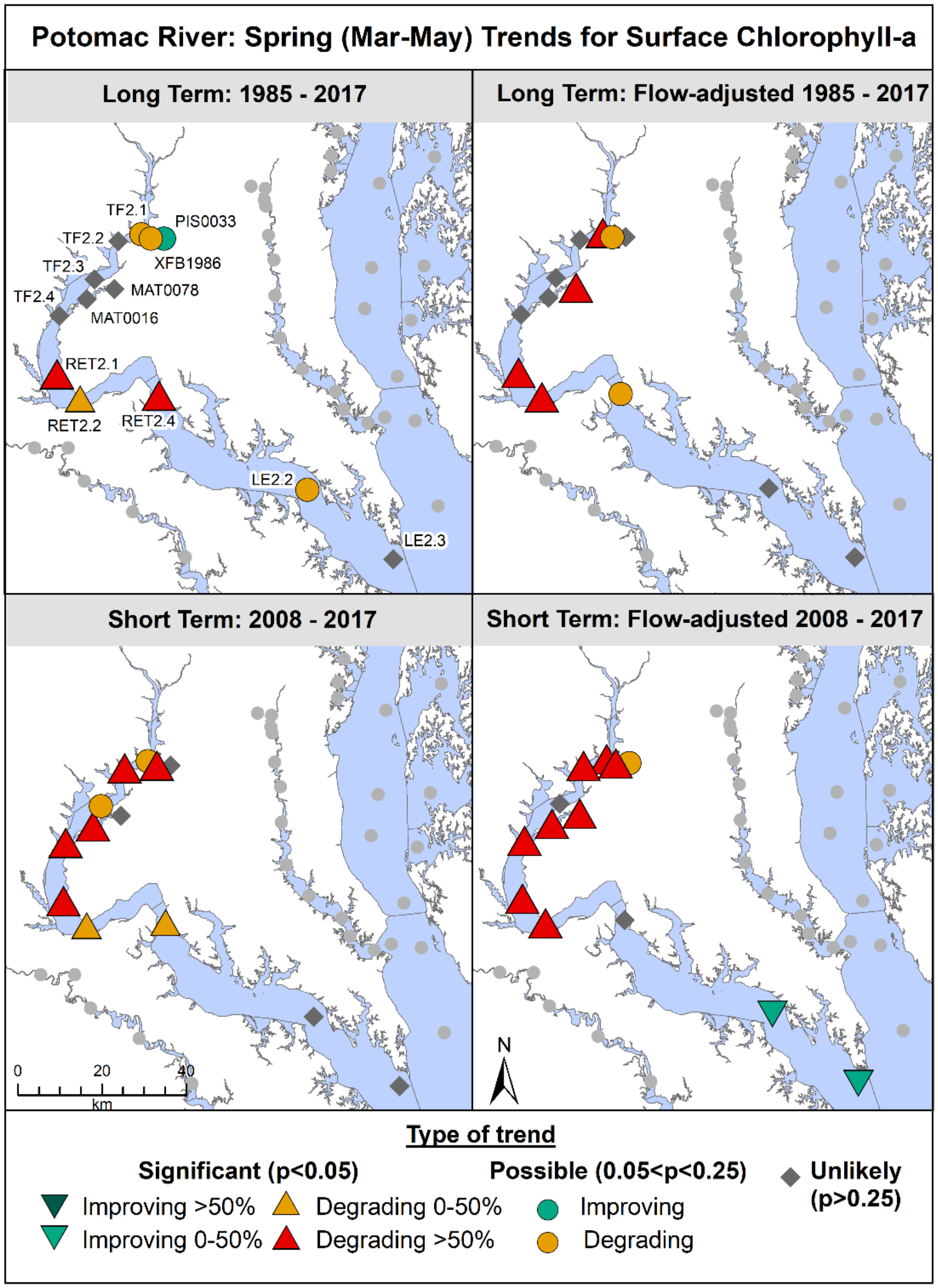


Figure 8. Surface Spring Chlorophyll-a trends

A high amount of variability in the long-term pattern can be seen in some of the chlorophyll-a data sets and average GAMs (Figure 9). Notably, a decrease in concentrations occurred around 2007 at many of the tidal fresh stations, followed by an increase around 2010. This feature is playing a role in the short-term degrading trends at those stations.

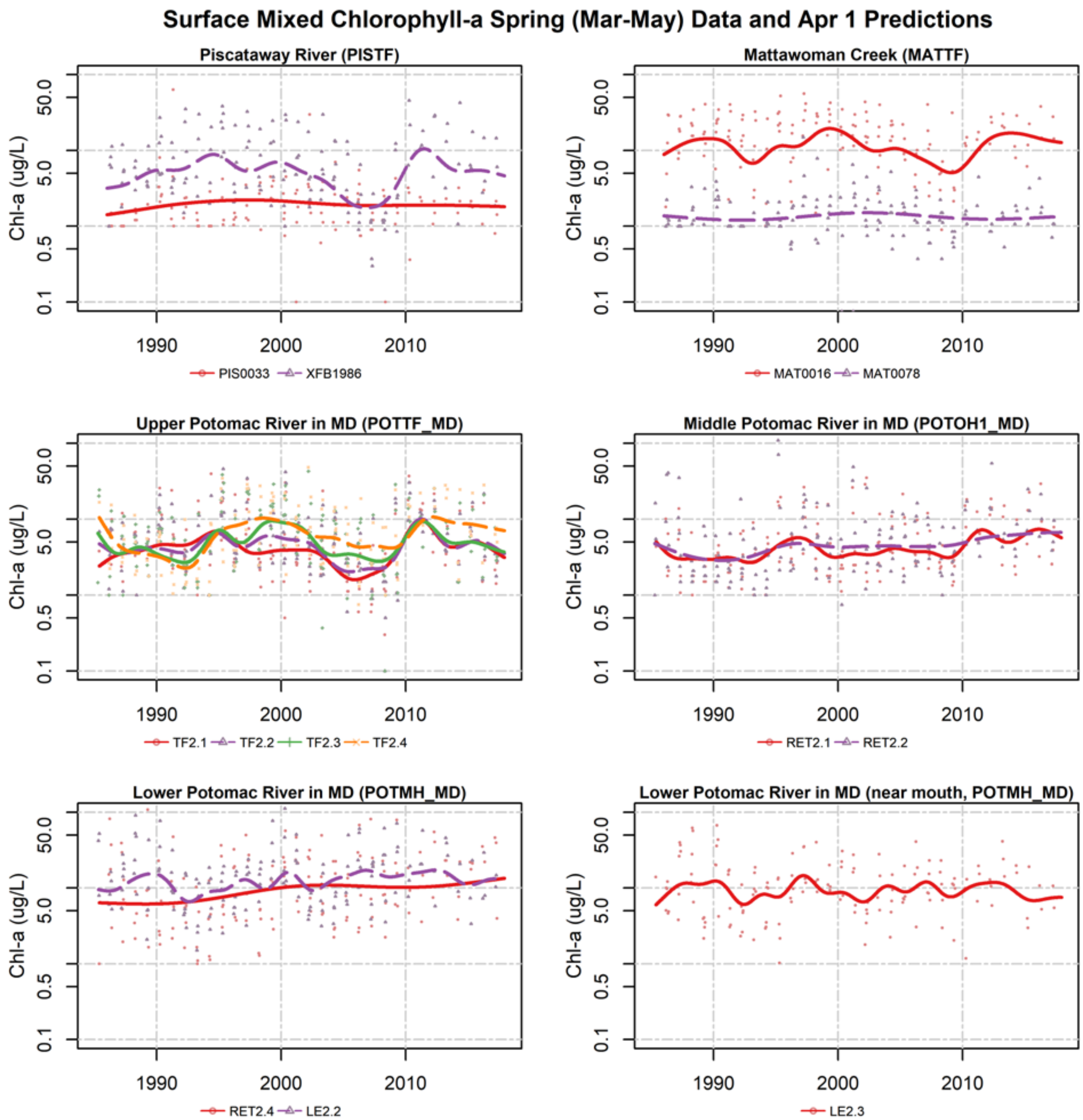


Figure 9. Surface spring Chlorophyll-a data (dots) and average long-term pattern generated from non-flow adjusted GAM. Plots are on a log-scale.

3.4 Surface Chlorophyll-*a:* Summer (July-Sept)

Summer long-term chlorophyll-a trends are fairly similar to spring trends, with exceptions being a long-term improving summer trend at MAT0016 and possibly more improvement in the summer data sets in the lower Potomac (Figure 10). The spatially consistent short-term degrading trends across the tidal fresh stations exist in the summer as well as the spring.

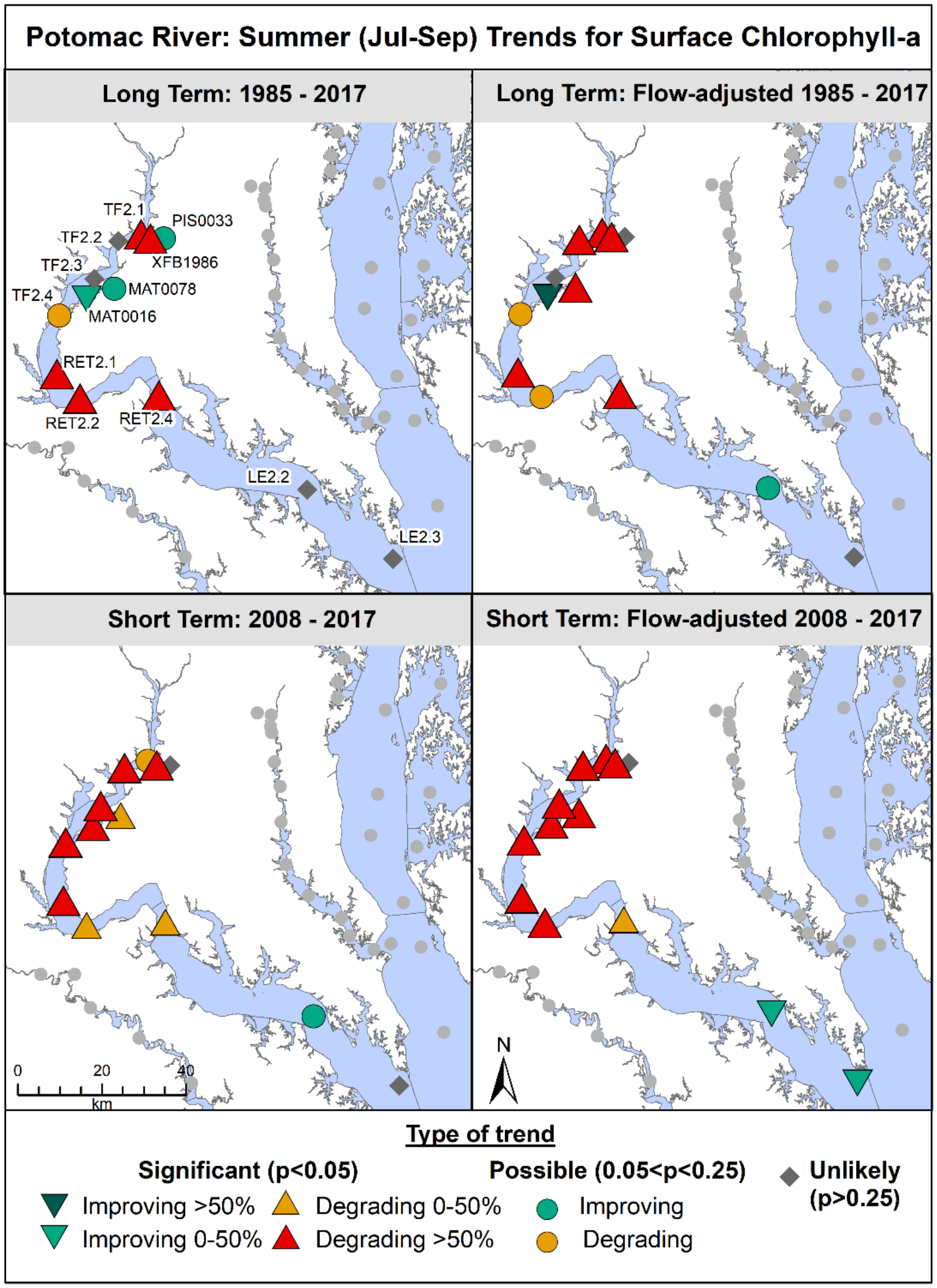


Figure 10. Surface Summer Chlorophyll-a trends

The magnitude of the summer chlorophyll-a concentrations is higher in the tidal fresh in the summer (Figure 11) than in the spring (Figure 9). The decreasing trend evident in the map (Figure 10) at MAT0016 can be seen in the time series and GAM model with much lower maximum concentrations in recent years than in the 1980s and 90s. The improvements at LE2.2 and LE2.3 appear very slight in these graphs, but the decrease in frequency of values above 10 µg/L in recent years is evident.

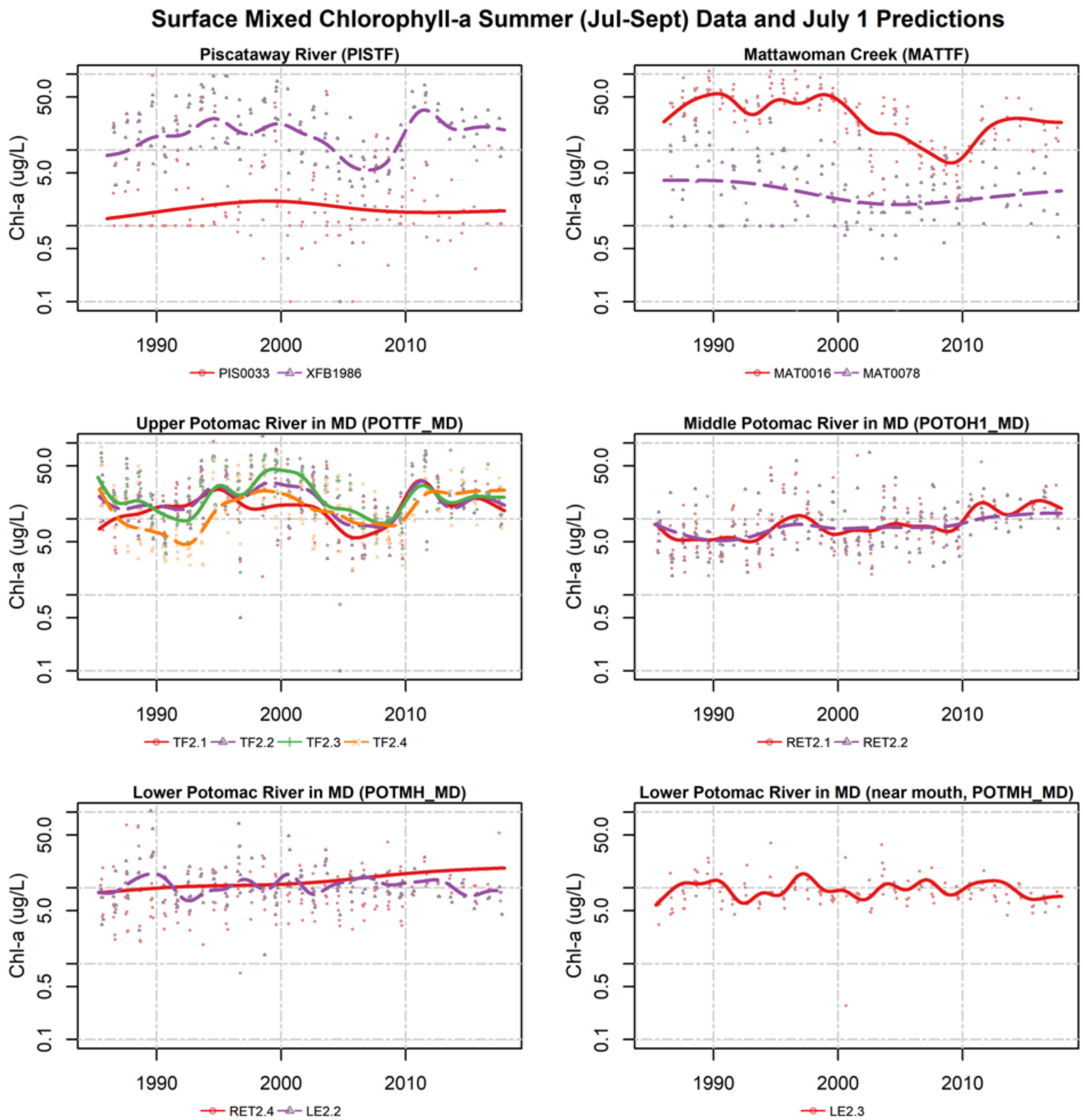


Figure 11. Surface summer chlorophyll-a data (dots) and average long-term pattern generated from non-flow adjusted GAM. Plots are on a log-scale.

3.5 Secchi Disk Depth

Secchi trends are degrading at many of the stations, particularly in the tidal fresh and middle Potomac over both the short and long term, regardless of flow-adjustment (Figure 12). A long-term improvement has occurred in the Mattawoman River, and short-term improvement appears after flow-adjustment in the Lower Potomac.

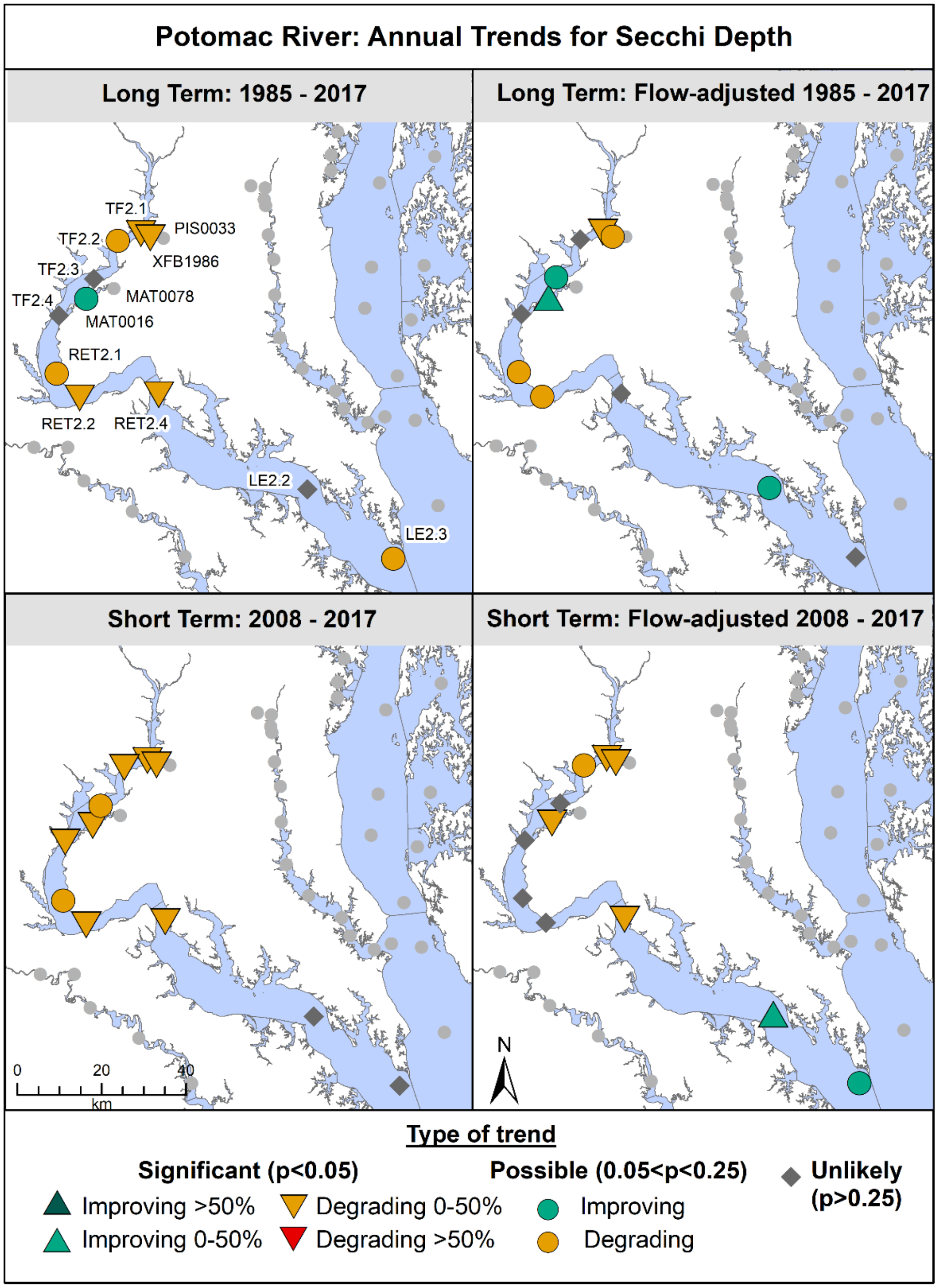


Figure 12. Annual Secchi Depth trends.

Secchi depth is generally less than 1 meter throughout the tidal Potomac, except for the lower Potomac stations where on average it's closer to 1.5-2 meters. Thus the changes that show up in the trend map (Figure 12) are hard to see in some of the data and GAM graphs (Figure 13). The Mattawoman increase does appear to be a slight improvement throughout the record, with two jumps in clarity in the 2000s. The lower Potomac station LE2.2 shows a clear decrease through most of the record until a slight upswing in recent years, matching the trend results.

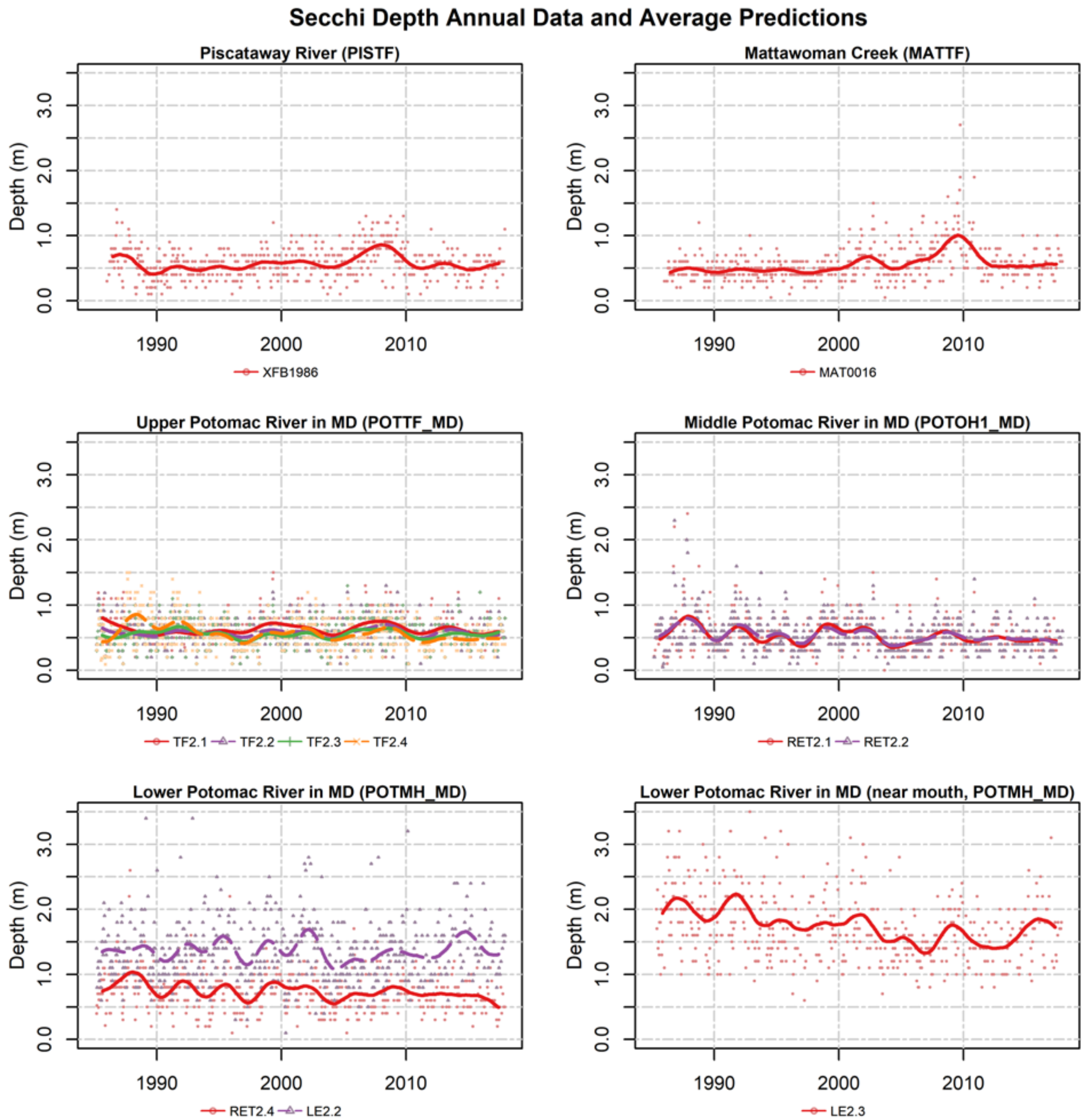


Figure 13. Annual Secchi depth data (dots) and average long-term pattern generated from non-flow adjusted GAM.

3.6 Summer Bottom Dissolved Oxygen

Upper Potomac bottom oxygen concentrations have improved at many stations both over the long- and short-term (Figure 14). The lower Potomac, where deep water and deep channel oxygen criteria exist, showed a possible degradation over the long-term after flow-adjustment. But over the short term there is no trend, with the exception of one station that shows possible improvement.

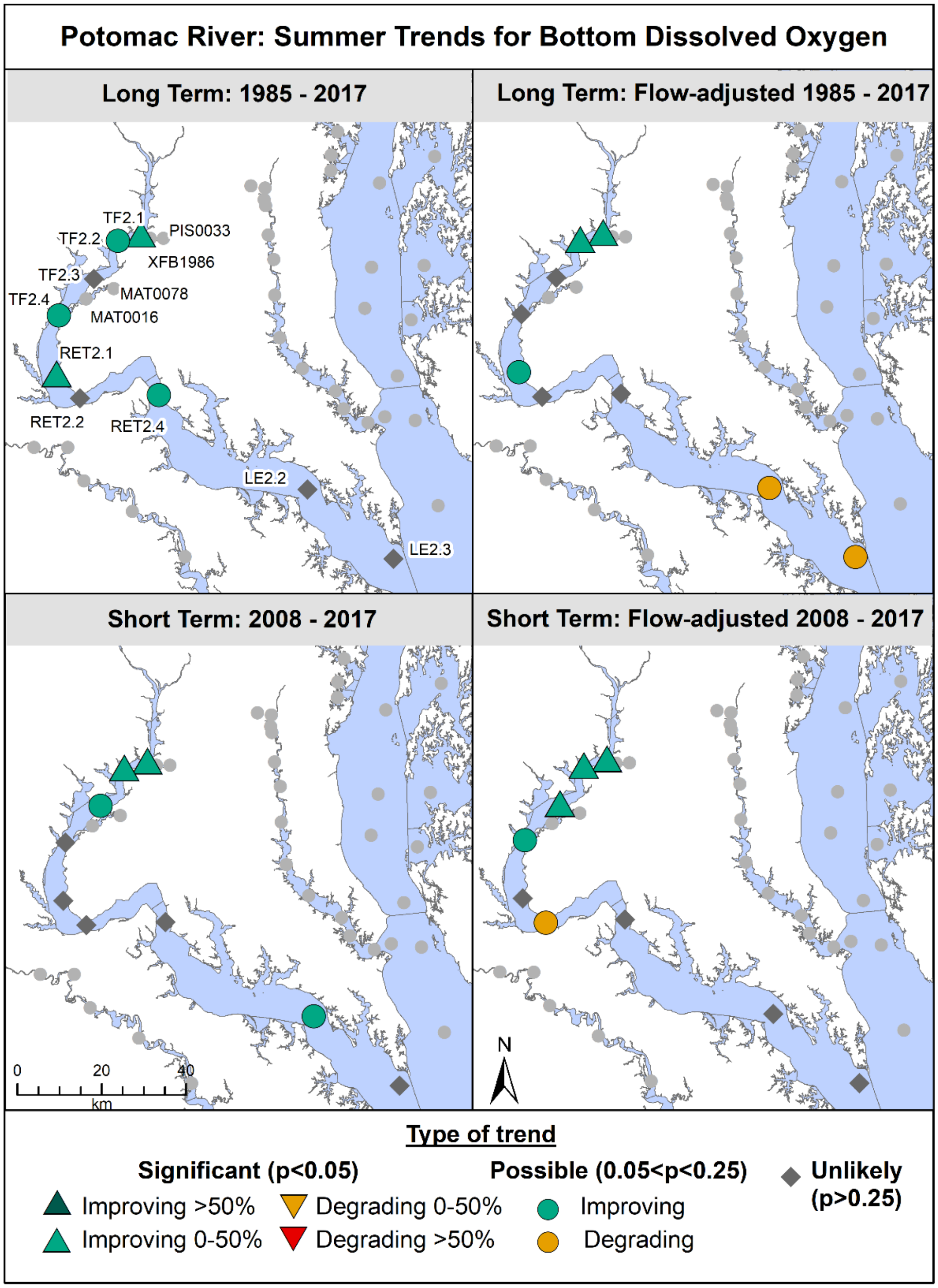


Figure 14. Summer (June-Sept) bottom DO trends.

Plots of the summer data and July 1 GAM predictions demonstrate the spatial variability in bottom DO concentrations (Figure 15). Concentrations in the tidal fresh and middle Potomac are much higher than the lower Potomac, although they do go below the 5 mg/L summer open water 30-day mean DO criterion. Concentration at LE2.2 and LE2.3 frequently are below deep channel instantaneous criterion of 1 mg/L. Lower concentrations were observed in the tidal fresh in the early part of the record, as well as some slightly higher concentration in recent years, leading to the improving trends in this region. Both LE2.2 and LE2.3 appear to have very slight degradations in the long-term followed by lines leveling or moving up in recent years. These slight changes are apparent in the possible trends show in Figure 14.

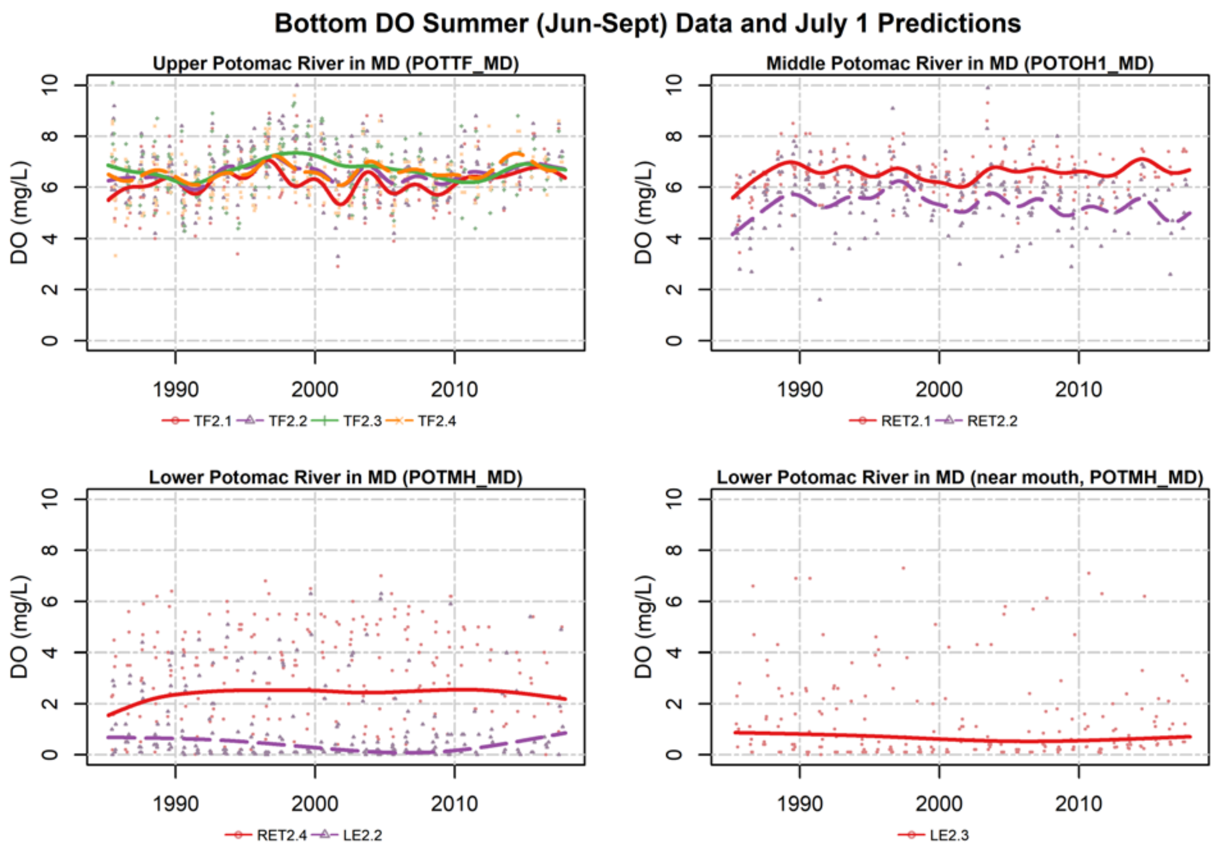


Figure 15. Summer (June-Sept) bottom DO data (dots) and July 1 long-term pattern generated from non-flow adjusted GAM.

4. Factors Affecting Trends

4.1 Watershed Factors

Land Use

Land use in the Potomac River watershed is dominated (~60%) by natural areas such as forest and parkland (Figure 16). Urban and suburban land area has grown by about 2,380 km^2 since 1985; about 1,380 km^2 were developed from agricultural lands and about 1,000 km^2 from natural lands.

Correspondingly, the proportion of urban land in the Potomac watershed has increased from 10% in 1985 to 16% in 2016. The impacts of land development differ depending on the use from which the land is converted (cite). In general, developed lands in 1970s were mainly located in the vicinity of the Washington D.C. Since then, developed lands have expanded to regions both further upstream into the watershed and further downstream into the tidal areas (Figure 17).

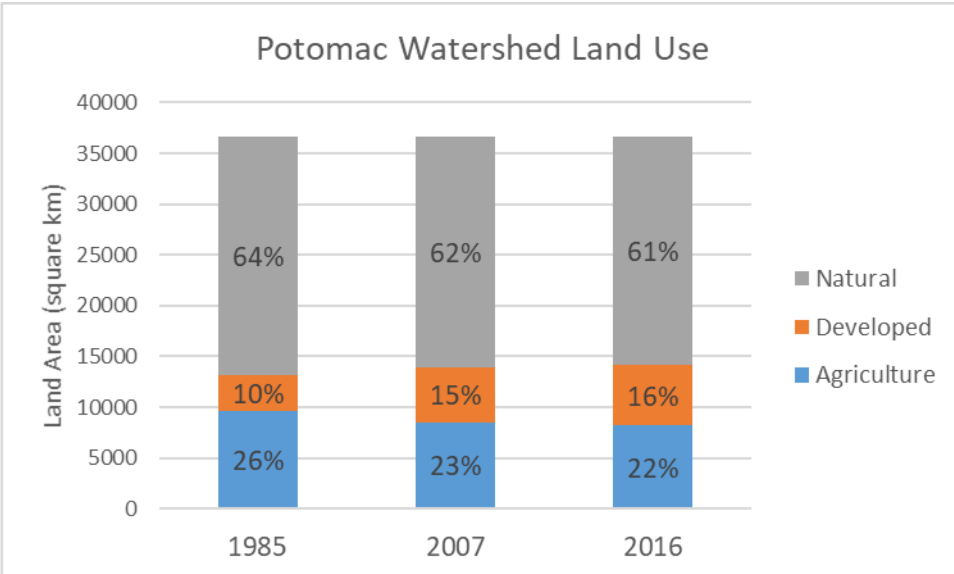


Figure 16. Distribution of land uses in the Potomac River watershed.

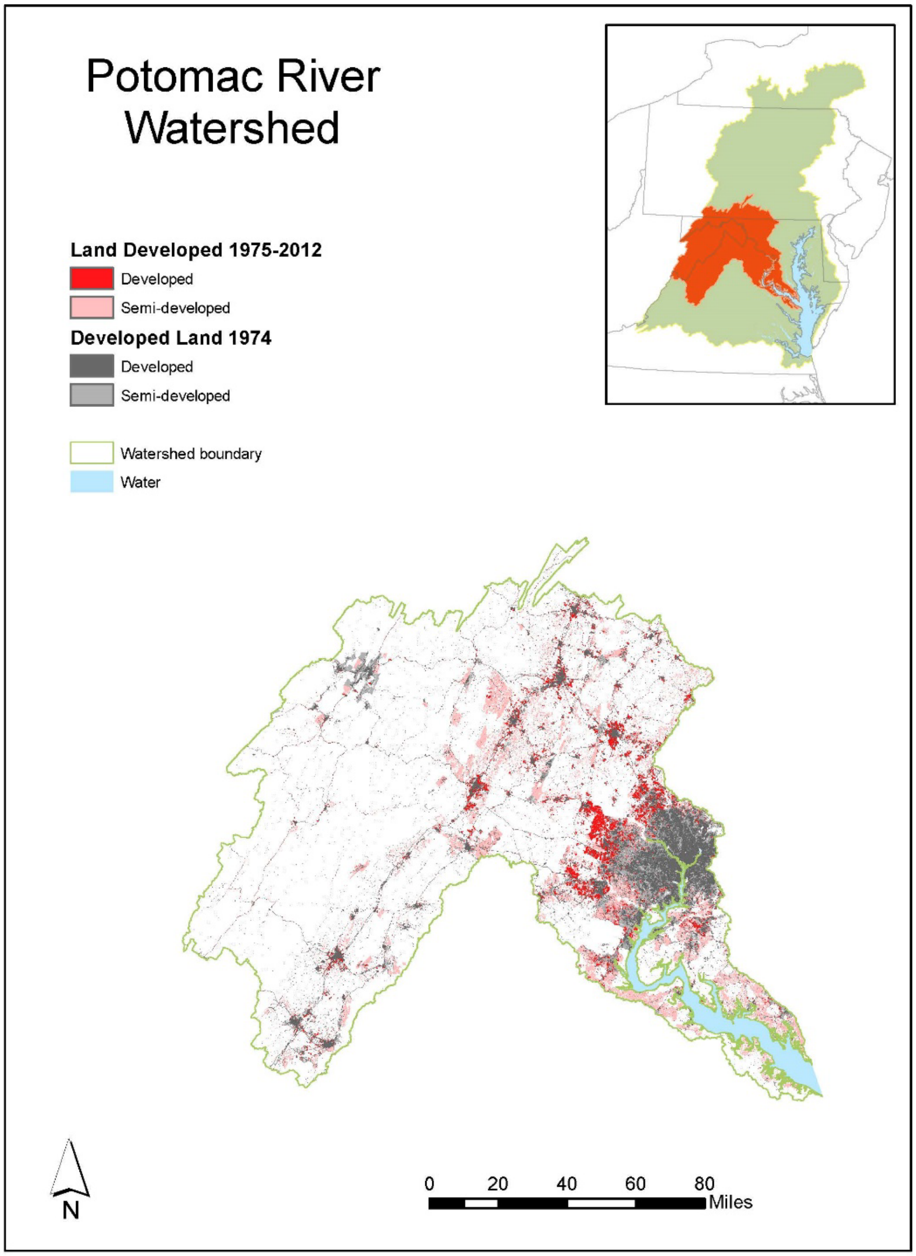


Figure 17. Distribution of developed land in the Potomac River watershed.

Nutrient and Sediment Loads

Nitrogen, phosphorus, and sediment loads to the tidal Potomac River declined by 33%, 37%, and 13%, respectively, between 1985 and 2016 (Figure 18). Agriculture and wastewater were the two largest sources of nitrogen and phosphorus loads. For nitrogen, these two sources declined by 26% and 74%, respectively in the same period. For phosphorus, the two sources declined by 41% and 75%, respectively. Developed areas and septic tanks were the two sources that have increased significantly (~50%) for both nitrogen and phosphorus between 1985 and 2016, which counteracted the reductions that were achieved in the agriculture, wastewater, and natural source sectors. For sediment, the largest sources were shoreline and natural areas. The former remained virtually unchanged between 1985 and

2016, while the latter declined by 16%. Sediment loads from the agriculture sector declined by 44%, whereas sediment load from developed areas increased by 26% in 1985-2016. Overall, the agricultural, natural, and wastewater sectors achieved reductions in nitrogen, phosphorus, and sediment loads between 1985 and 2016, whereas the developed and septic sectors had increased nitrogen, phosphorus, and sediment loads.

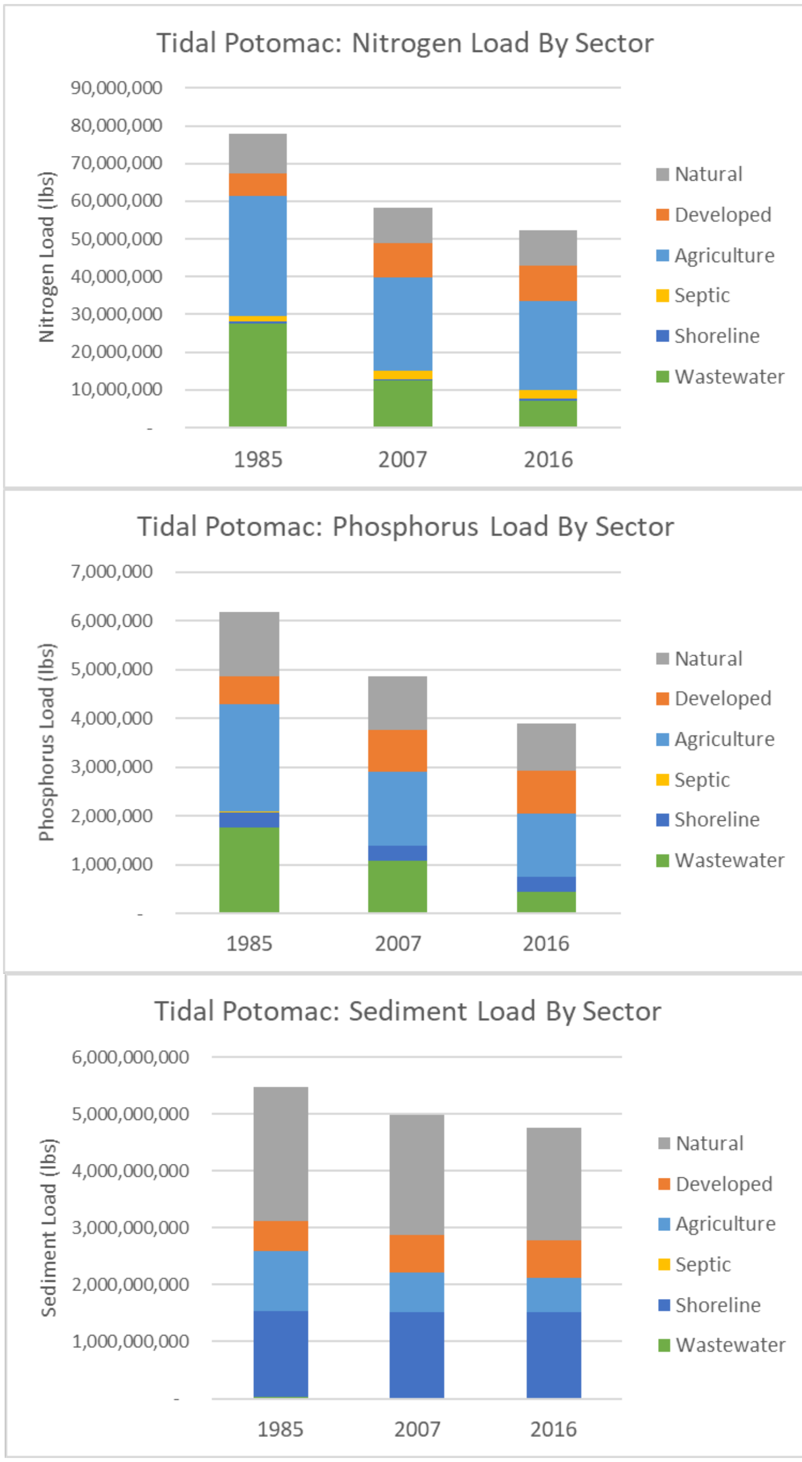
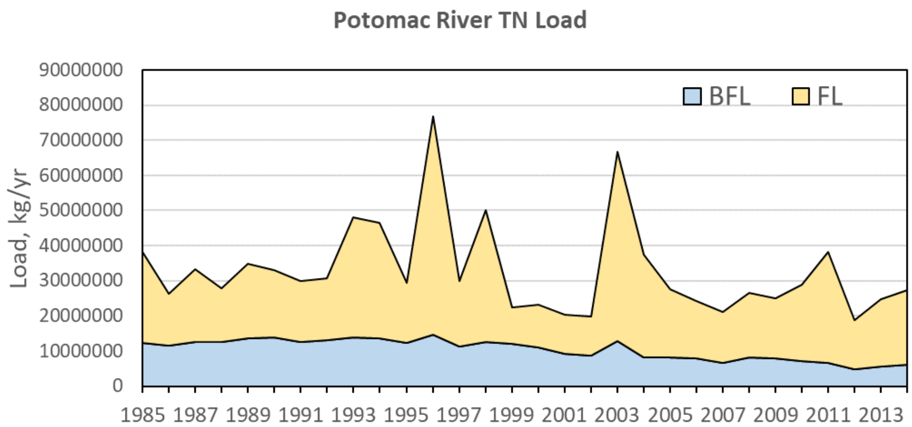
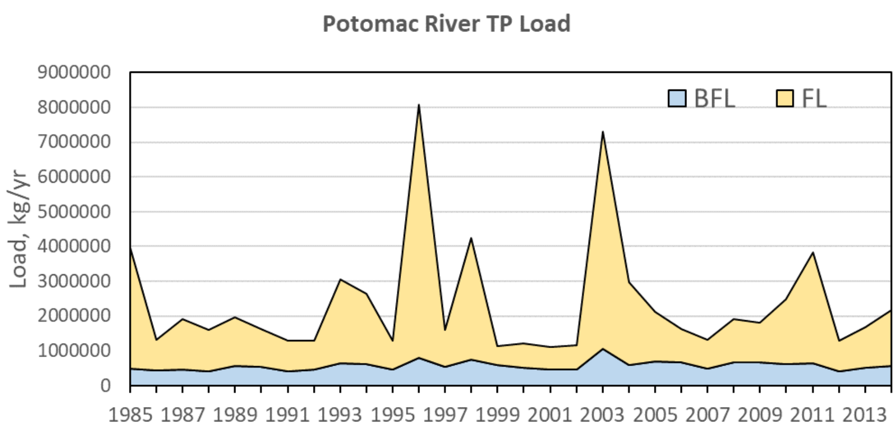


Figure 18. Loads of nitrogen, phosphorus, and sediment from different sources to the tidal Potomac.

Nitrogen, phosphorus, and sediment loads were primarily from the above-fall-line areas, although contributions from the below-fall-line areas were also substantial (Figure 19). Over the period from 1985 to 2014, 1.0, 0.07, and 67 million tons of nitrogen, phosphorus, and sediment loads were exported through Potomac, with 68%, 76%, and 59% of those loads from the above-fall-line areas, respectively.





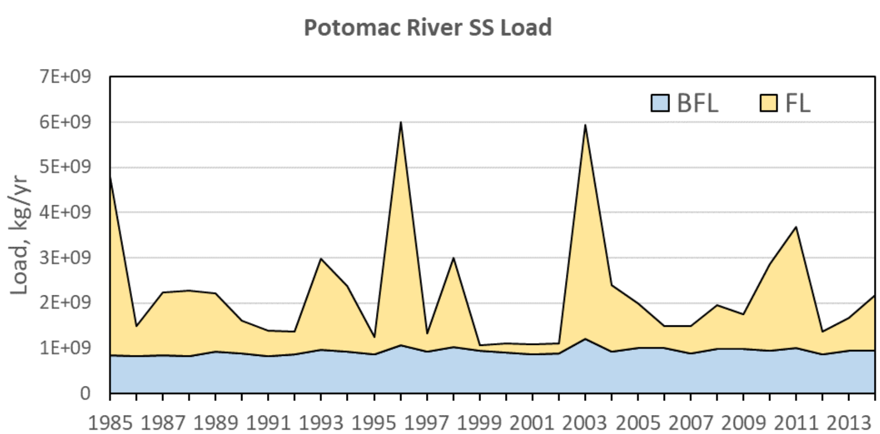


Figure 19. Loads of nitrogen, phosphorus, and sediment from the above-fall-line and below-fall-line areas.

Best Management Practices (BMP) Implementation

BMP implementation data as of 2016 are summarized in Figure 20, which are available at https://cast.chesapeakebay.net. Tillage BMPs, commodity & cover crops, pasture management, and stormwater management were credited for 444, 143, 253, and 89 thousand acres, respectively. Animal waste management systems and animal mortality composting were credited for 1.47 and 0.18 million animal units, respectively.

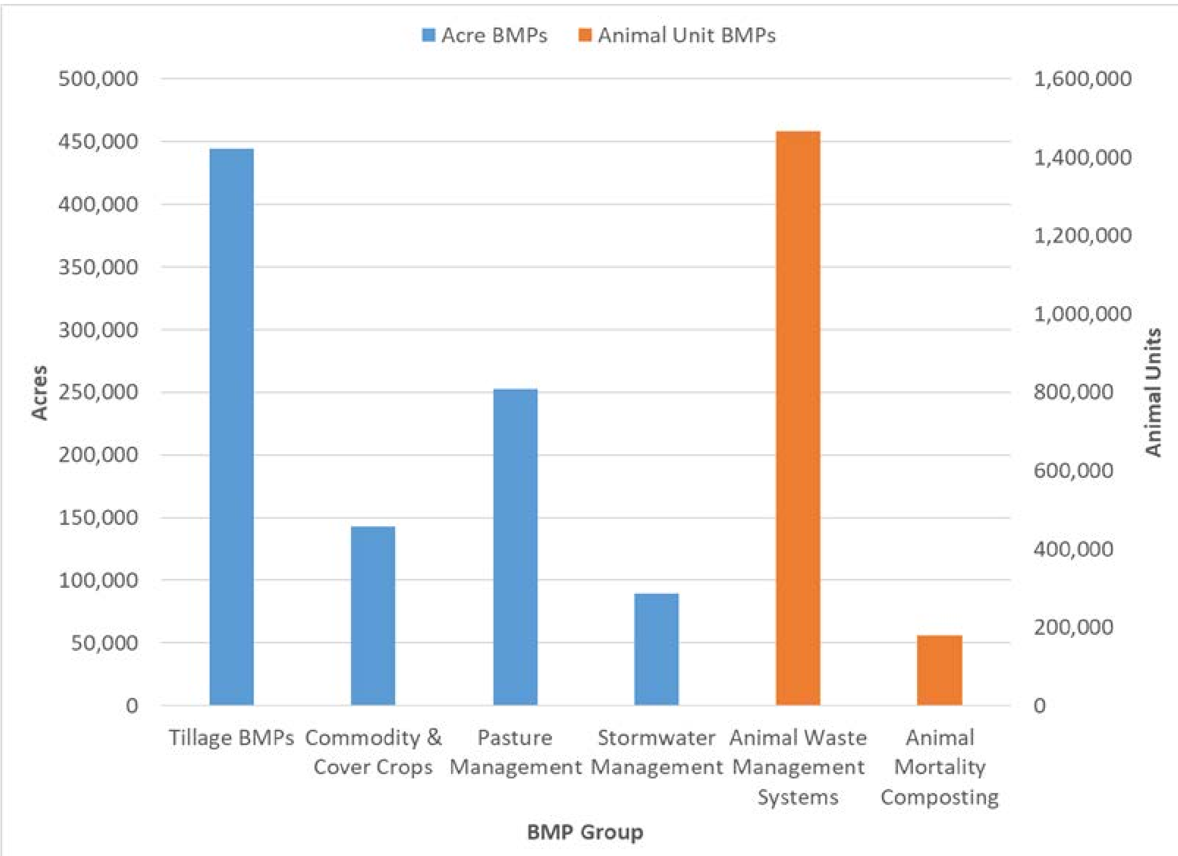


Figure 20. BMP implementation in the Potomac watershed.

4.2 Tidal Factors

Wastewater has been a major nitrogen and phosphorus source directly into the tidal Potomac (Figure 18) and has decreased in recent decades due to upgraded treatment processes. A recent study (Pennino et al., 2016) evaluated the spatial and temporal reach of the nitrogen directly from Blue Plains wastewater treatment facility, the largest in the Washington DC area, which discharges into the tidal fresh Potomac. The nitrate and total nitrogen concentrations in the tidal waters near the facility dropped dramatically with full implementation of biological nutrient removal in 2000. However, even using post-2000 data, nitrate originally from wastewater is still a major source in the Potomac. In fact, significant concentrations of wastewater-derived nitrate were detected at the mouth of the Potomac

River where it meets Chesapeake Bay, at varying percentages depending on the time of year. In the summer and fall, almost half of the nitrate at the mouth of the Potomac is from wastewater, whereas in winter and spring a much smaller percentage (6-7%) is originally from wastewater and other nonpoint sources dominate (Pennino et al., 2016).

Responses to reductions in nutrient loads from smaller local point sources have been observed in some of the Potomac tributaries evaluated here as well. In Mattawoman Creek, the impact of major point source reductions in the early 1990s and 2000s was investigated by Boynton et al. (2014). Point sources went from being the largest nitrogen source in the watershed to a small fraction of the total load by 2010. These load reductions were linked to water quality improvements through 2010 such as decreased chlorophyll-a concentrations and increased water clarity and SAV (Boynton et al., 2014). Those changes from the mid-1990s to 2010 in chlorophyll-a, secchi depth, and nitrogen concentrations are clear in the Mattawoman graphics in this report (Figures 5, 9, 11 and 13 top right panels). After 2010, however, there was degradation again in chlorophyll-a and secchi. It is not clear why this pattern has appeared since 2010, but it is consistent across the Potomac tidal fresh stations, not just in Mattawoman Creek.

Despite the overall improvements in both nitrogen and phosphorus concentrations observed in these studies and in the current trend results, chlorophyll-a, secchi and oxygen trends are not all improving in the 2017 trends (Figure 8-15). Research suggests that there is a “saturation limit” for phytoplankton use of nutrients (Buchanan et al., 2005; Fisher and Gustafson, 2003). If dissolved concentrations are above this limit, the nutrients are in such excess that the phytoplankton cannot use them all. There may not be a response in phytoplankton to nutrient reductions unless the dissolved nitrogen or phosphorus concentrations cross under their saturation limits. Dissolved nutrient concentrations at most of the tidal Potomac stations are still above these limits, which could possibly explain the observed lack of improving chlorophyll-a trends (*cite appendix or place with dissolved nutrients*). In addition, other factors such as import of nutrients from the mainstem bay (Pennino et al., 2016), varying bivalve populations (Phelps, 1994), SAV populations, and temperature increases (Ding and Elmore, 2015) could all be playing a role in the response trajectory of the Potomac River for all of these parameters.

5. Summary

Total nutrient concentrations have been decreasing at most stations in the Potomac River over the long-term, with improvements in TN persisting in the last 10 years as well. These trends follow from the decreasing discharge from TN and TP sources in the watershed (Figures 18). The TP source reductions are not as apparent in the direct loads to the river (Figure 19), which may be part of the reason that tidal TP concentrations are not decreasing during both time periods and at as many stations as TN concentrations (Figures 4 and 6).

As discussed in the previous section, the response of chlorophyll-a, secchi, and bottom DO is mixed in the Potomac tidal waters, but there are multiple possible reasons for this lag in response. Continuing to track water quality response and investigating these possibilities are important steps to understanding water quality changes in the Potomac River.

6. References

Boynton, W.R., Hodgkins, C.L.S., O'Leary, C.A., Bailey, E.M., Bayard, A.R., Wainger, L.A., 2014. Multi-decade Responses of a Tidal Creek System to Nutrient Load Reductions: Mattawoman Creek, Maryland USA. Estuaries and Coasts 37(1) 111-127. 10.1007/s12237-013-9690-4.

Buchanan, C., Lacouture, R.V., Marshall, H.G., Olson, M., Johnson, J.M., 2005. Phytoplankton reference communities for Chesapeake Bay and its tidal tributaries. Estuaries 28(1) 138-159. 10.1007/BF02732760.

Ding, H., Elmore, A.J., 2015. Spatio-temporal patterns in water surface temperature from Landsat time series data in the Chesapeake Bay, U.S.A. Remote Sensing of Environment 168 335-348. https://doi.org/10.1016/j.rse.2015.07.009.

Fisher, T.R., Gustafson, A.B., 2003. Nutrient-addition bio- assays in Chesapeake Bay to assess resources limiting algal growth. Progress report: August 1990-December 2002. Cambridge, Maryland. Prepared for Maryland Department of Natural Resources, Chesapeake Bay Water Quality Monitoring Program.

Pennino, M.J., Kaushal, S.S., Murthy, S.N., Blomquist, J.D., Cornwell, J.C., Harris, L.A., 2016. Sources and transformations of anthropogenic nitrogen along an urban river–estuarine continuum. Biogeosciences 13(22) 6211-6228. 10.5194/bg-13-6211-2016.

Phelps, H.L., 1994. The asiatic clam (Corbicula fluminea) invasion and system-level ecological change in the Potomac River Estuary near Washington, D.C. Estuaries 17(3) 614-621. 10.2307/1352409.

Ruhl, H.A., Rybicki, N.B., 2010. Long-term reductions in anthropogenic nutrients link to improvements in Chesapeake Bay habitat. Proceedings of the National Academy of Sciences 107(38) 16566.

Appendix

This will be a separate document, but a map and panel plot each for:

- Bottom TP
- Bottom TN
- Surface PO4
- Surface DIN
- Surface TSS
- Surface DO
- Surface Temperature
-