Tidal Tributary Reports

Integrated Trends Analysis Team

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Who is the Integrated Trends Analysis Team (ITAT)?

A group of research analysts focused on explaining and linking *Change* in the estuary and watershed.

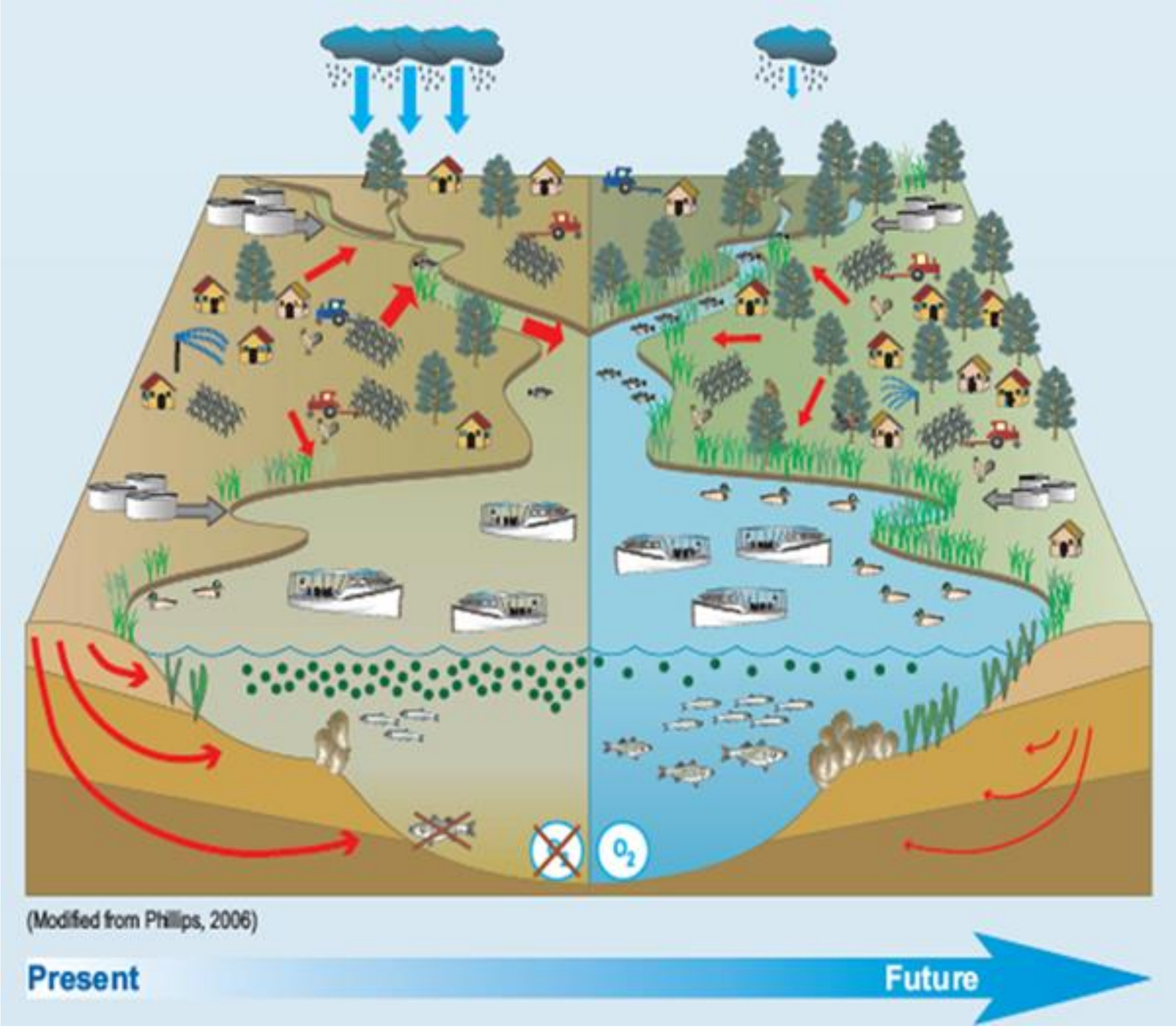
- **Team Lead:** Jeni Keisman
- **CBPO research team:** Rebecca Murphy, Qian Zhang, Cuiyin Wu, Breck Sullivan
- **MD core :** Renee Karrh, Tom Parham, Carol Cain
- **VA core:** Mike Lane, Cindy Johnson, Amanda Shaver, Tish Robertson
- **DC core:** George Onyullo, Efeturi Oghenekaro
- **With regular input from:**
    - Joel Blomquist (USGS)
    - Claire Buchanan (ICPRB)
    - Olivia Devereux (Devereux Consulting)
    - Marji Friedrichs lab (VIMS)
    - Carl Friedrichs lab (VIMS)
    - Jeremy Testa (UMCES)
    - Jimmy Webber (USGS VA-WV WSC)

ITAT Mission

To inform Chesapeake Bay Watershed and Estuary restoration by detecting and discerning the causes of restoration and degradation trajectories:

- In the tidal fresh Potomac, average TN and TP concentrations are declining and summer DO trends are static or improving, but average chlorophyll-a and Secchi depth are degrading. *Why?*

- Knowing *why* will help you keep doing what works, and stop doing what doesn't.



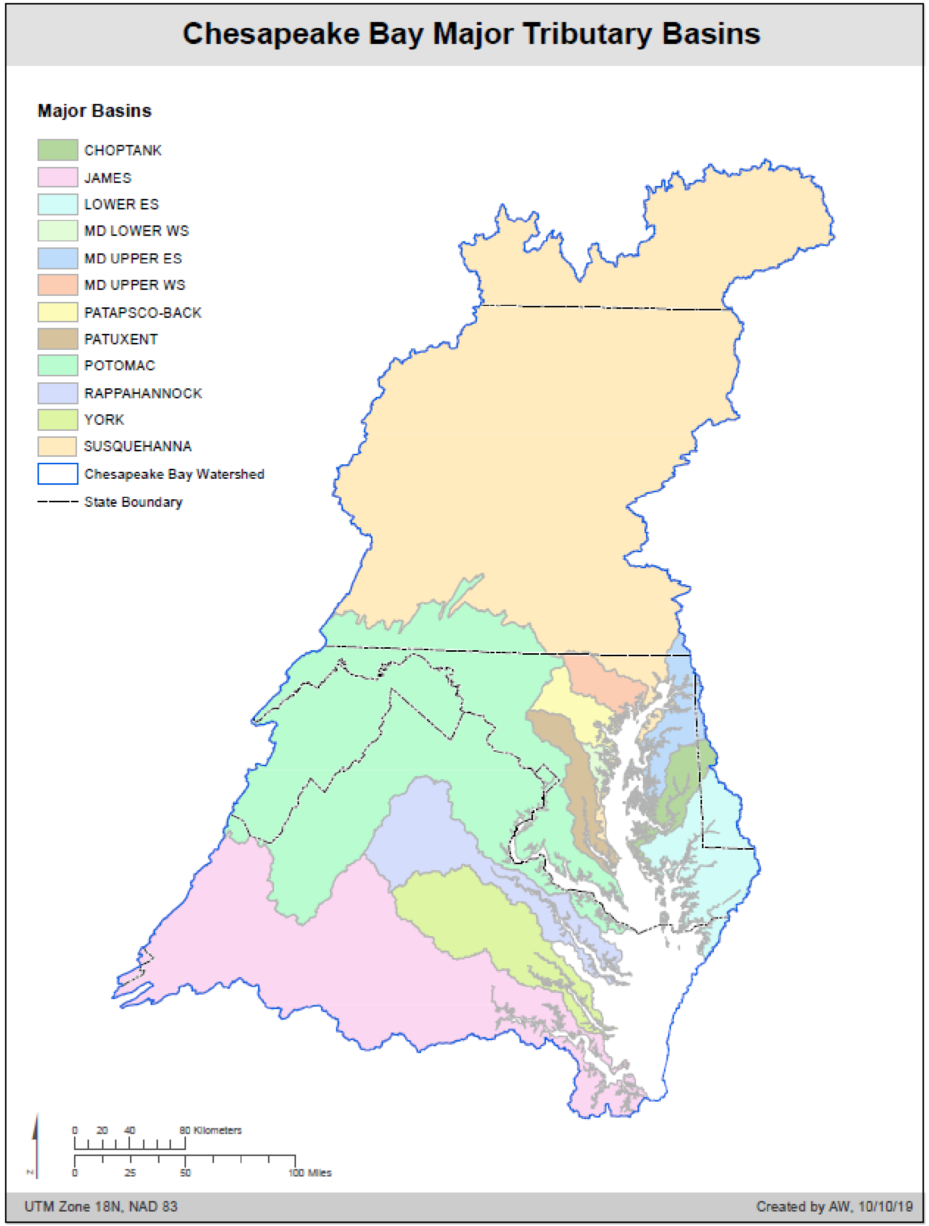
Our Marching Orders

SRS Outcome	Related Outcomes	Research Category	Need
Standards and Attainment	Fish habitat, oysters, blue crabs, vital habitats	Analysis	Improve understanding of tidal water quality response to loads and BMPs
Standards and Attainment	Fish habitat, oysters, blue crabs, vital habitats	Analysis	improve understanding of bay living resources response to watershed and bay management
Standards Attainment and Monitoring	WQ Indicator needs/ongoing interest in tracking wq progress	Analysis	Tracking/Explaining attainment/attainment deficit patterns and trends
Fish Habitat	habitat, water quality	Analysis	Tidal tributary Fish Habitat Assessment: 1. compile habitat and environmental, stressor, biological dataset; 2. analyze biological response data for relevance; 3. pilot fish habitat assessment; 4. conduct watershed regional assessment; 5. ID/develop spatial tools useful to partners
WQGIT/Modeling	Implement an estuary model in local waters	Analysis/Modeling	to assist tidal jurisdictions with local waters assessments and implementation efforts

What are the Tributary Reports?

We plan to compile tributary basin reports for 12 major tributaries or tributary groups in the Chesapeake Bay Watershed:

1. MD Upper Western Shore:
   - Bush, Gunpowder, Middle
2. Patapsco/Back
3. MD Lower W. Shore:
   - Severn, Magothy, Rhode/West, South
4. Patuxent
5. Potomac
6. Rappahannock
7. York (includes Mattaponi and Pamunkey)
8. James (includes Elizabeth and Lafayette)
9. MD Upper Eastern Shore:
   - Northeast, Back Creek, Elk, Sassafras, Chester, Eastern Bay
10. Choptank, Little Choptank, Honga
11. Lower E. Shore:
    - Fishing Bay, Nanticoke, Manokin, Wicomico, Big, Pocomoke, Tangier
12. Upper Mainstem



Preliminary Information-Subject to Revision. Not for Citation or Distribution

Why produce tributary reports?

To summarize in one place:

- How tidal water quality has changed over time;
- How factors that we believe drive those changes have changed over time;
- Current state of the science on connecting change in aquatic conditions to its drivers.

Who are the tributary reports for?

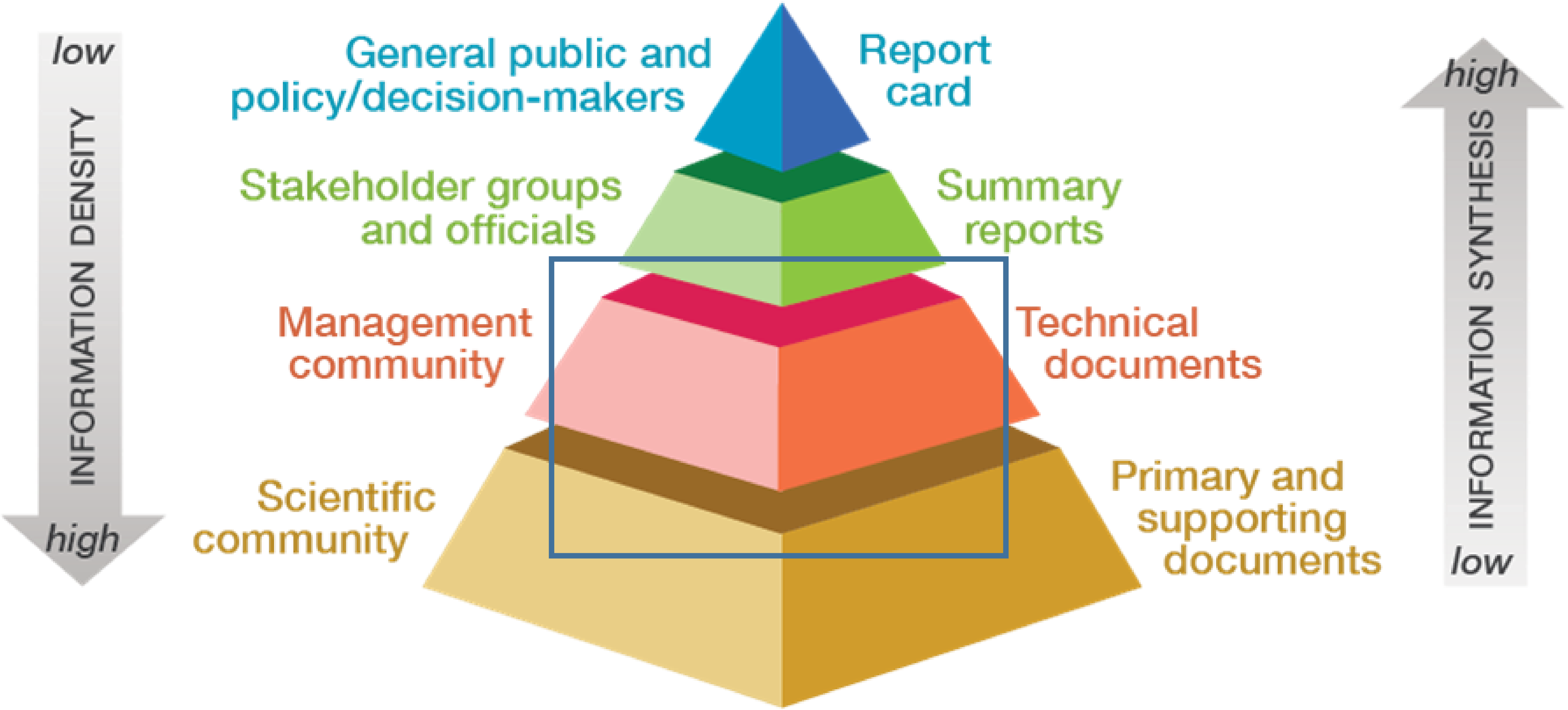


Figure courtesy UMCES Integration and Application Network, ian.umces.edu

Goals: What should people to get out of these reports?

For technical managers and watershed organizations:

- ✓ A summary of how your river is doing and how that has changed over time
- ✓ An understanding of the factors that affect water quality in your basin, and how those have changed over time
- ✓ A snapshot of the level of implementation in your basin for major BMPs that can improve water quality

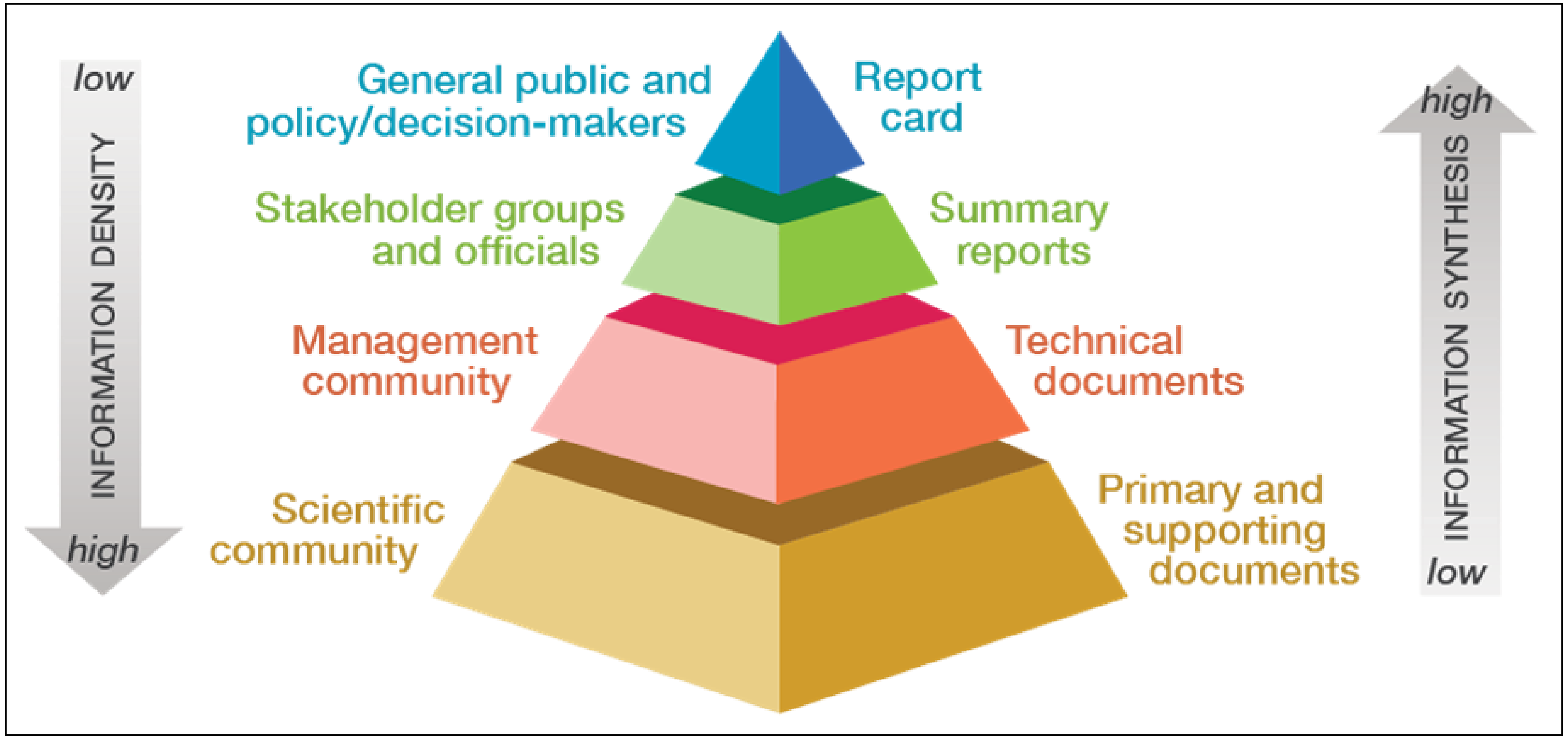
For researchers:

- ✓ All of the above, plus:
- ✓ Serve as a vehicle for discussion and hypothesis testing to advance our ability to predict future water quality change

Who are the tributary reports for?

BUT we need your input:

- Do you want this information?
- What's useful?
- What's missing?



Report Contents

“Here’s where we’re talking about”

“Here is the DO standards attainment status”

“This is how the most commonly considered water quality variables have changed over time”

“The possible reasons why”

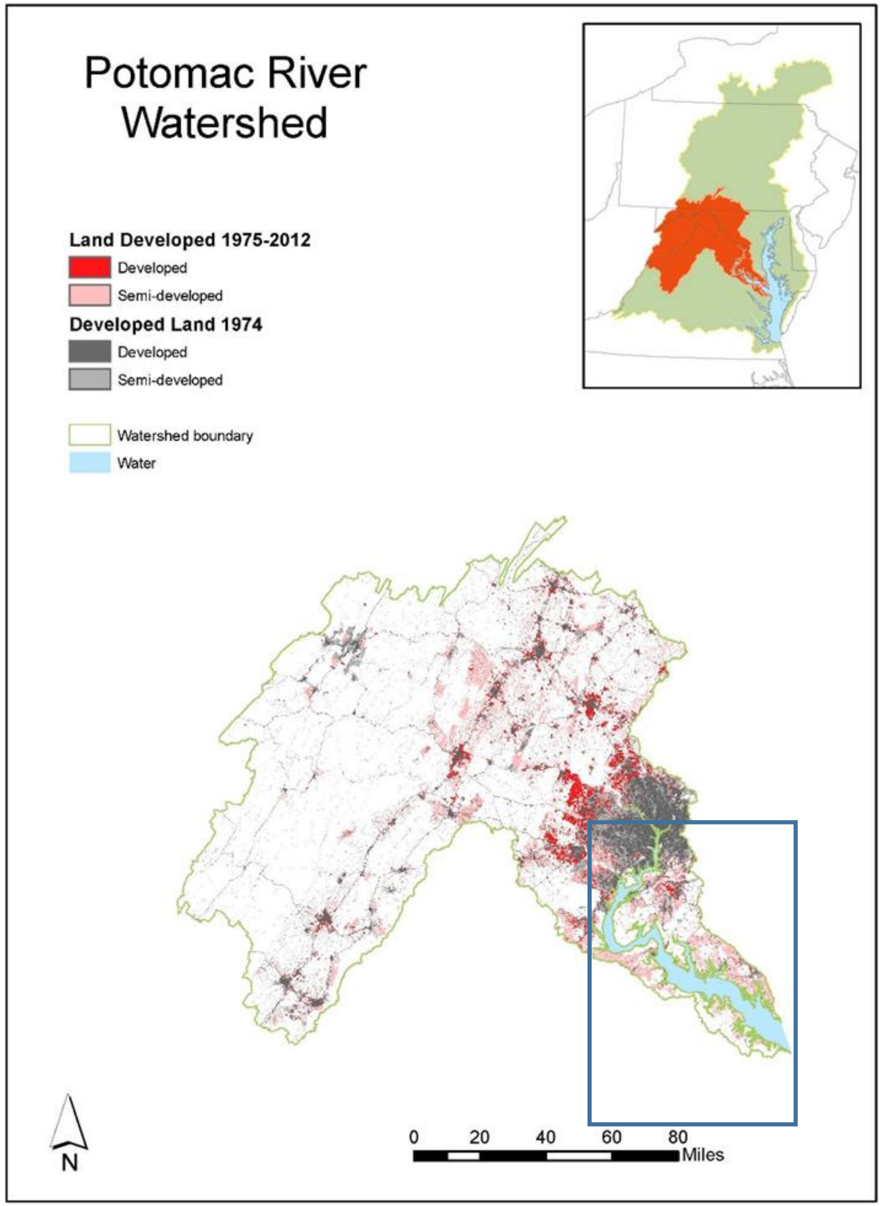
“In a nutshell”

“The rest of the water quality variables, for whomever is interested”

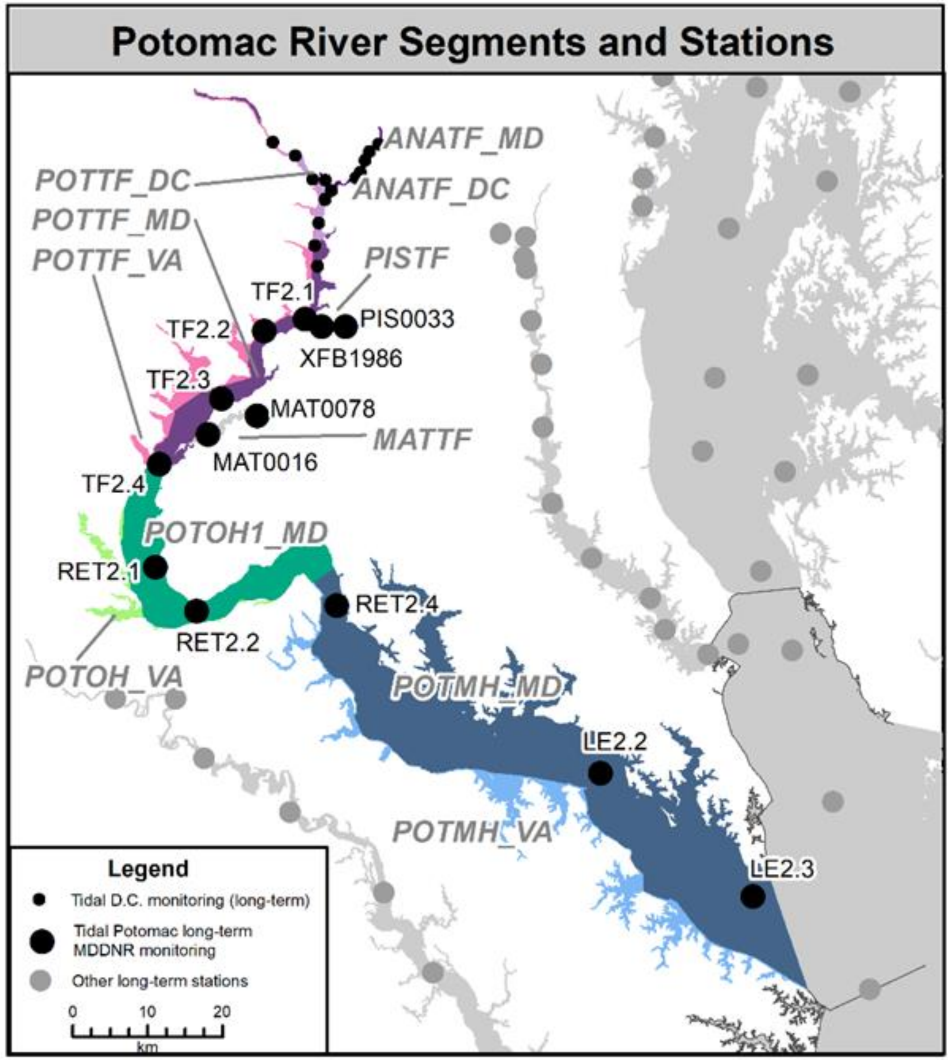
Contents

Potomac Example

Here’s the area that we’re talking about



Our Potomac tidal trends analyses include up to 13 stations, depending on the parameter



OW, DW, and DC Dissolved Oxygen Criteria Attainment Over Time

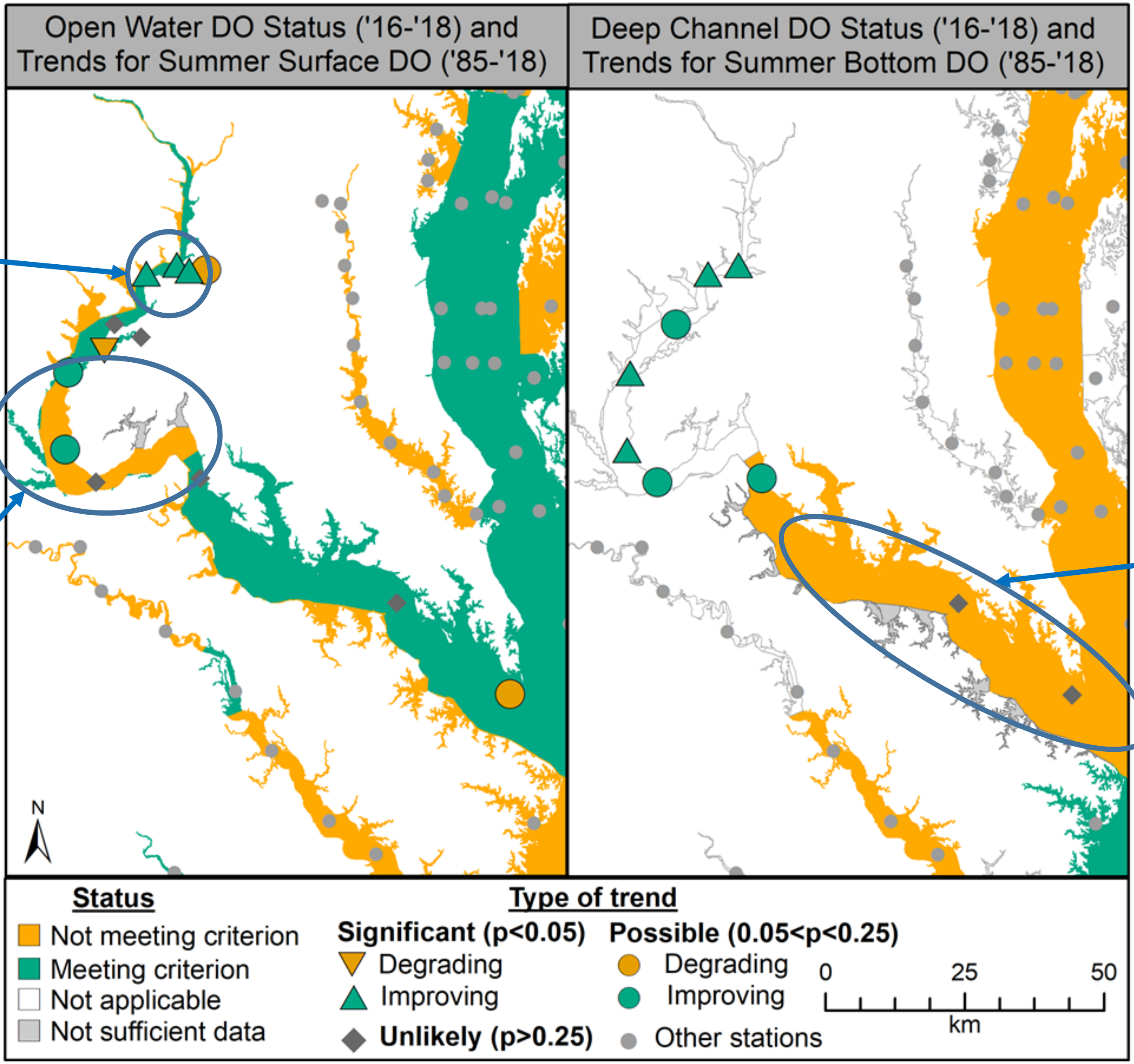
Open Water Segment	1985-1987	1986-1988	1987-1989	1988-1990	1989-1991	1990-1992	1991-1993	1992-1994	1993-1995	1994-1996	1995-1997	1996-1998	1997-1999	1998-2000	1999-2001	2000-2002	2001-2003	2002-2004	2003-2005	2004-2006	2005-2007	2006-2008	2007-2009	2008-2010	2009-2011	2010-2012	2011-2013	2012-2014	2013-2015	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																														

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									ND				
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							ND	ND	ND	ND	ND

Station-level trends give more insight into future attainment status

- The upper mainstem tidal fresh Potomac is attaining the open water monthly mean DO standard,
- *And* conditions continue to improve

- The oligohaline area of the Potomac is not attaining its open water DO standard
- *But* DO concentrations are probably better than in the mid-1980s



Preliminary Information-Subject to Revision. Not for Citation or Distribution

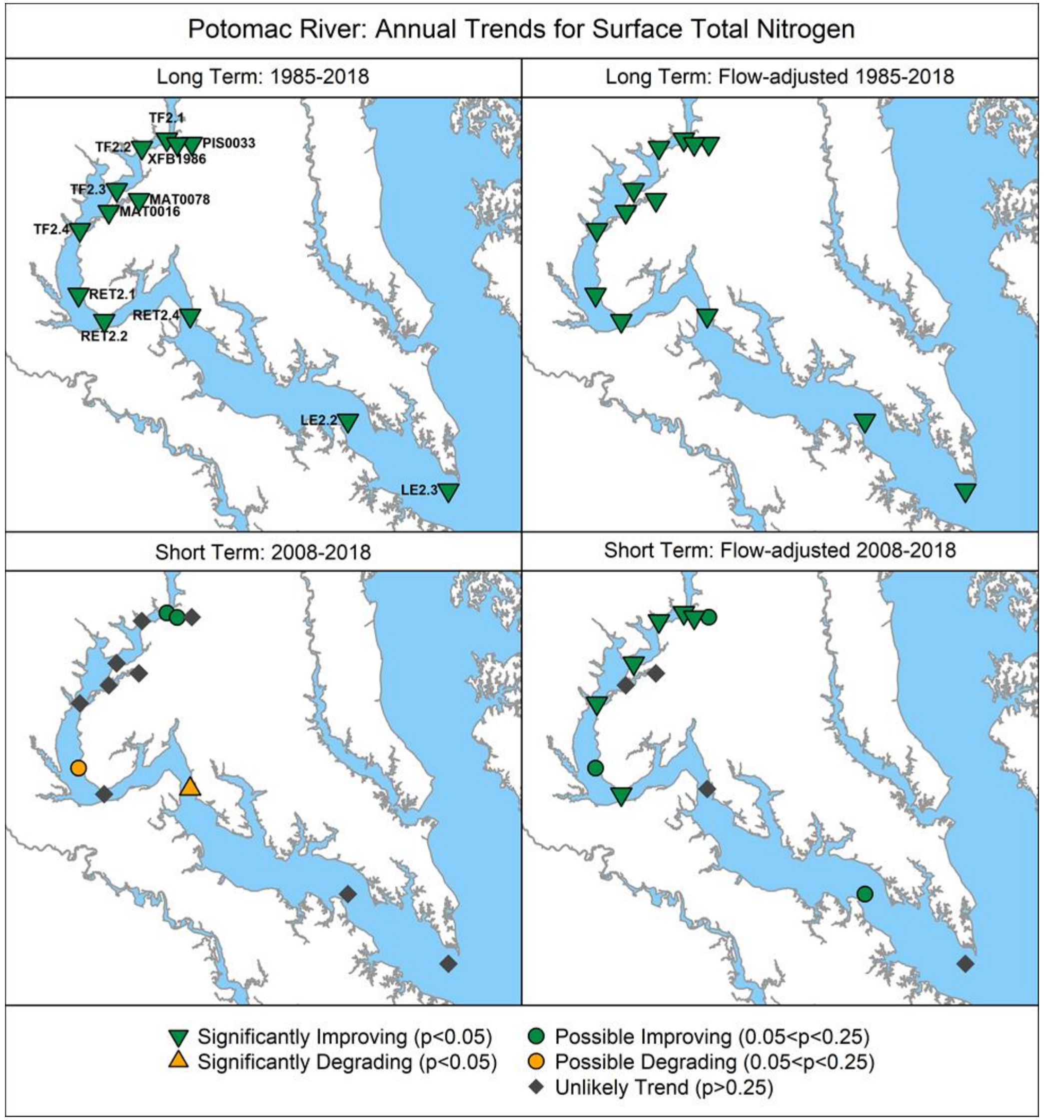
- The lower (mesohaline) Potomac is attaining the open water (surface) DO standard, but not the Deep Channel (bottom) DO standard.
- DO concentrations at the bottom of the water column haven't changed compared to the mid-1980s

Change over time in "primary" variables (TN, TP, Chlorophyll, Secchi, DO)

For each of the 5 major parameters, a panel map shows whether the variable is improving or degrading…

Observed Long-term (period of record) trend results

Observed most recent 10-year trend results



Preliminary Information-Subject to Revision. Not for Citation or Distribution

Flow-adjusted long-term trend results

Flow-adjusted most recent 10-year trend results

Note how flow-adjustment improves short-term trend

Change over time in “primary” variables (TN, TP, Chlorophyll, Secchi, DO)

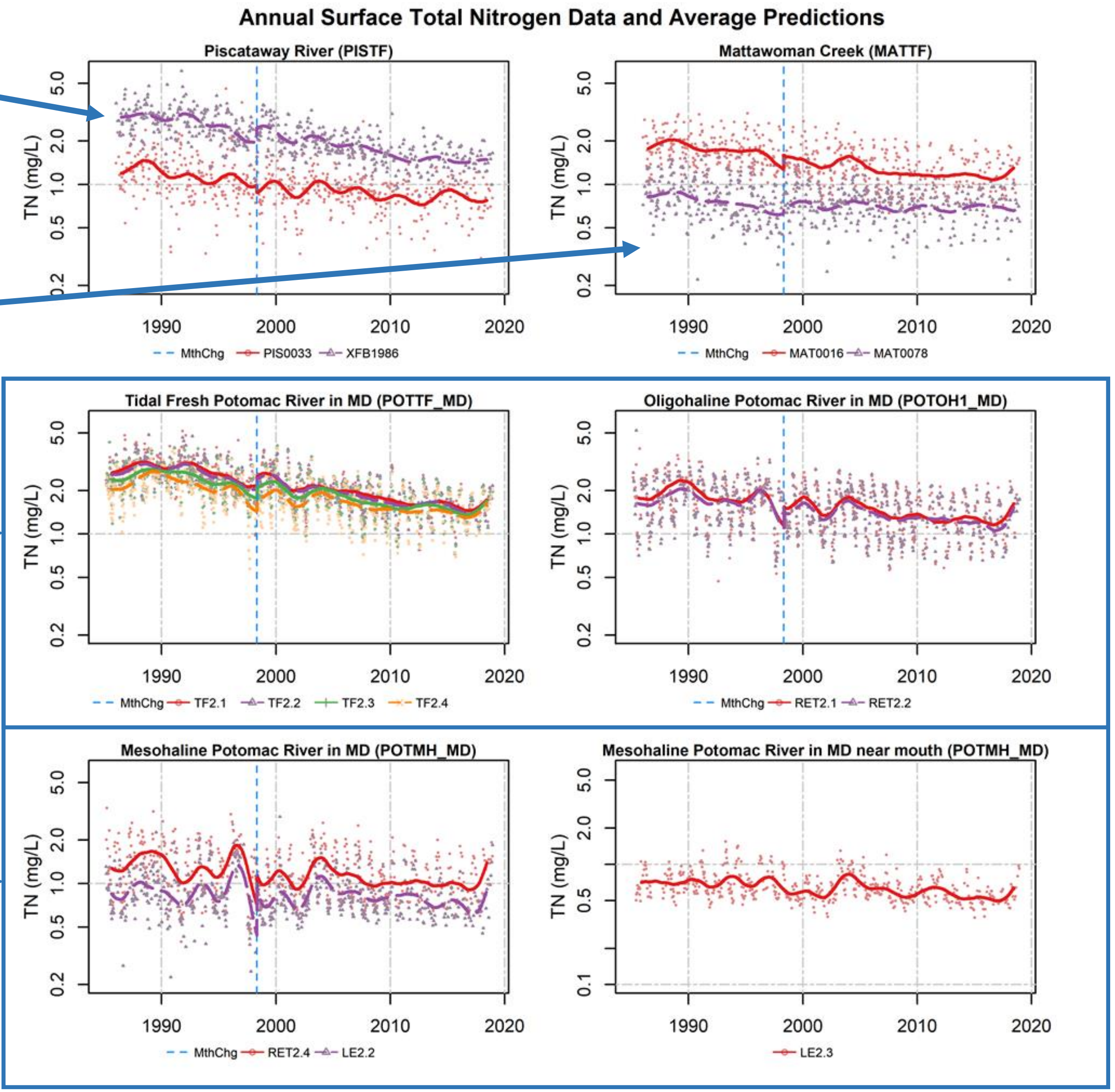
And a panel chart shows the pattern over time at each monitoring station, grouped by segment.

Piscataway River surface TN:
- Has declined steadily over time at both stations.
- Is consistently lower at the upstream station.

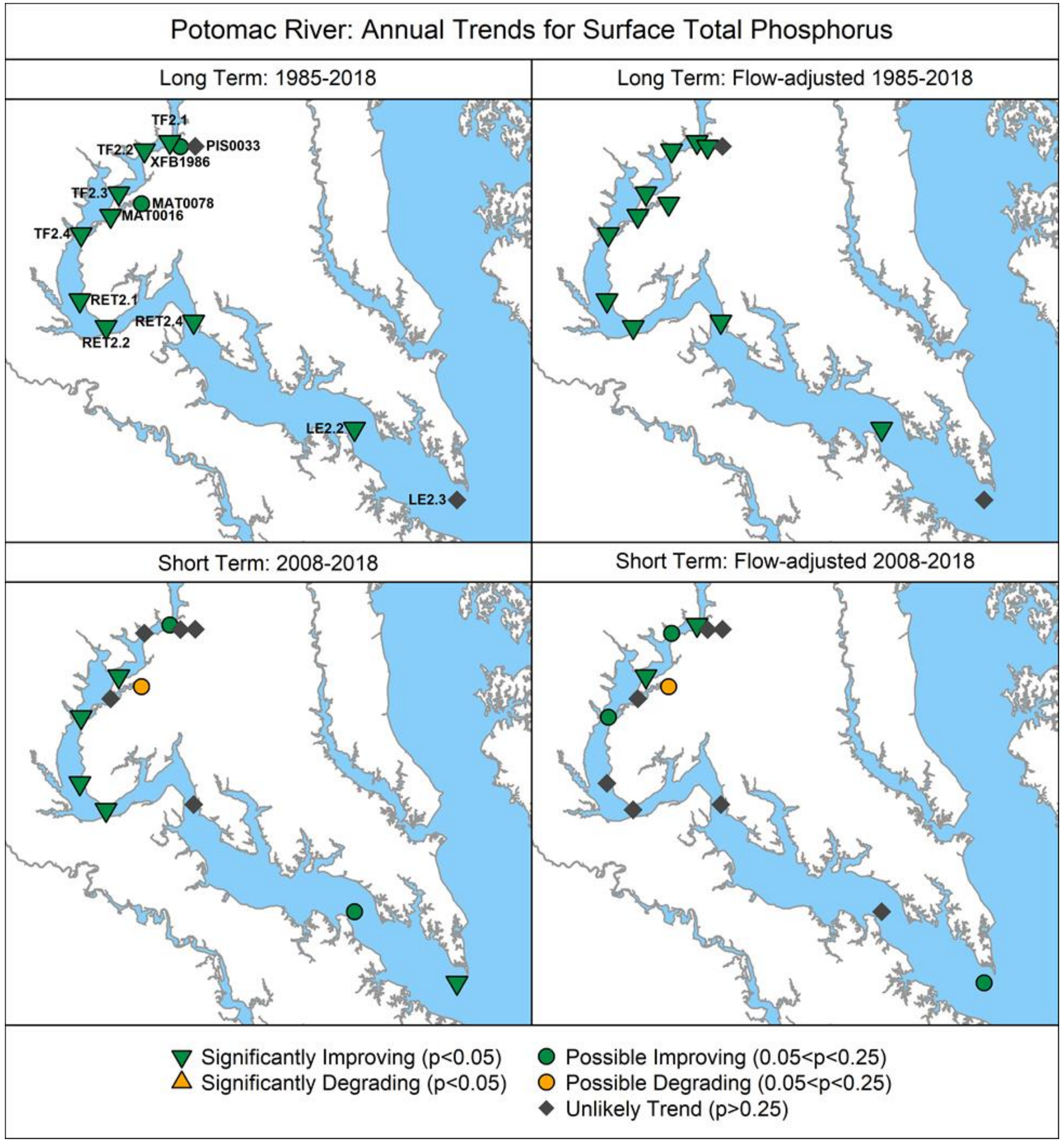
Mattawoman Creek surface TN:
- Early decline has flattened out in the last several years.
- Is consistently lower at the upstream station.

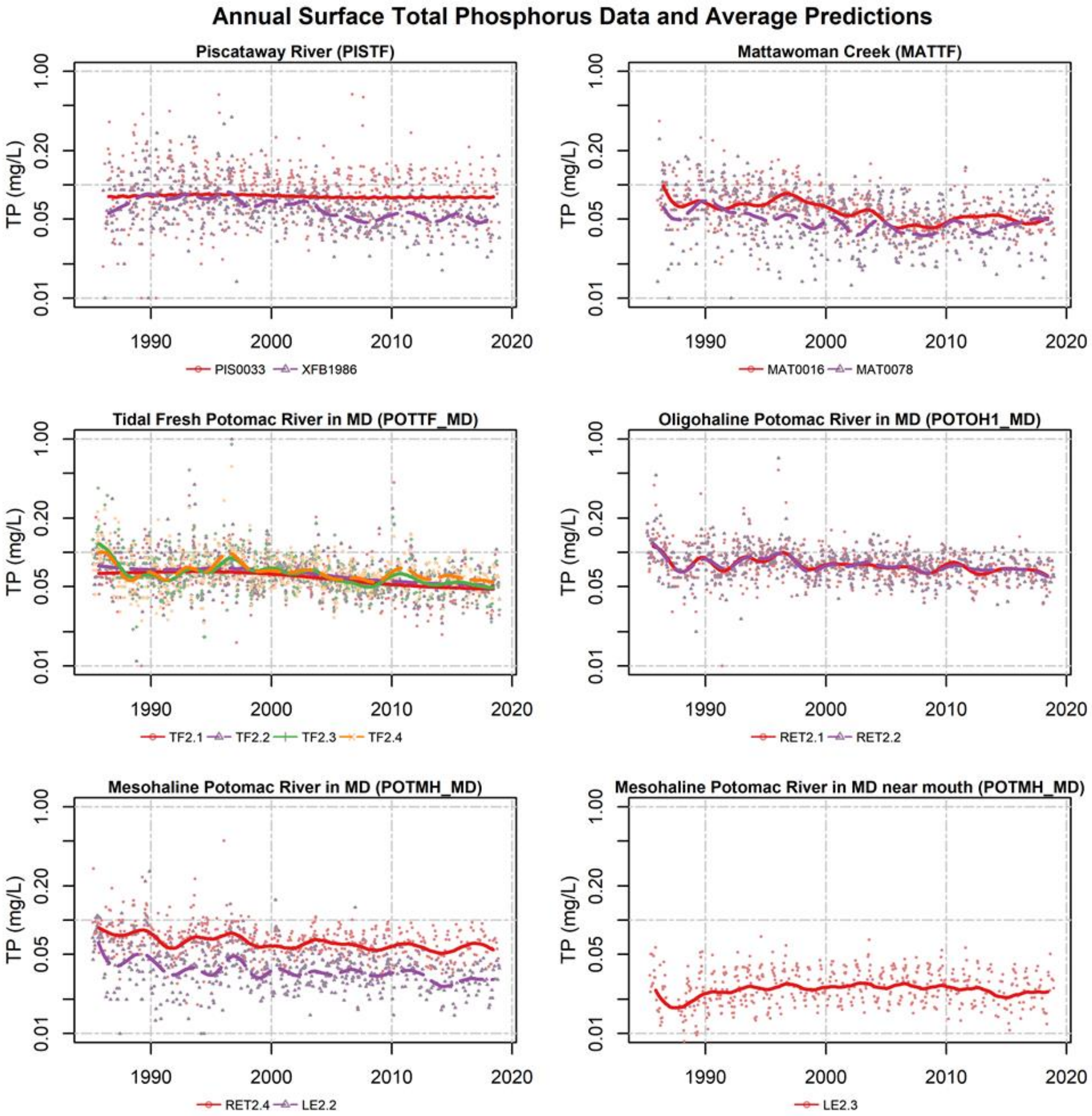
Tidal Fresh and Oligohaline Potomac surface TN:
- Concentrations and patterns of change over time are similar at all stations.

Mainstem Potomac, in general:
- The temporal pattern flattens out as you move downstream, particularly in the past 10 years
- Uptick at all mainstem Potomac stations last year (*recall the difference between observed and flow-adjusted 10-year trend)*

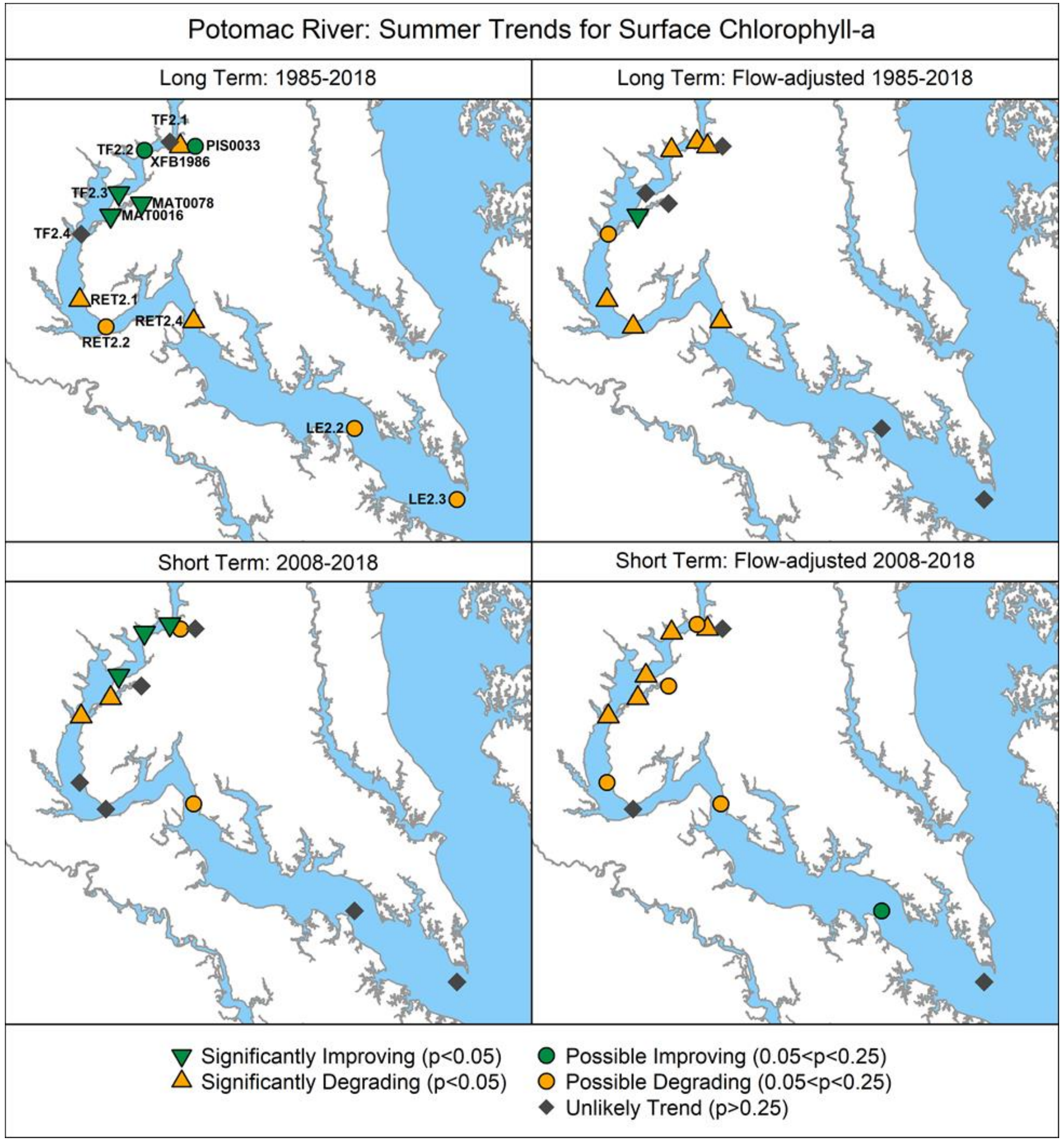


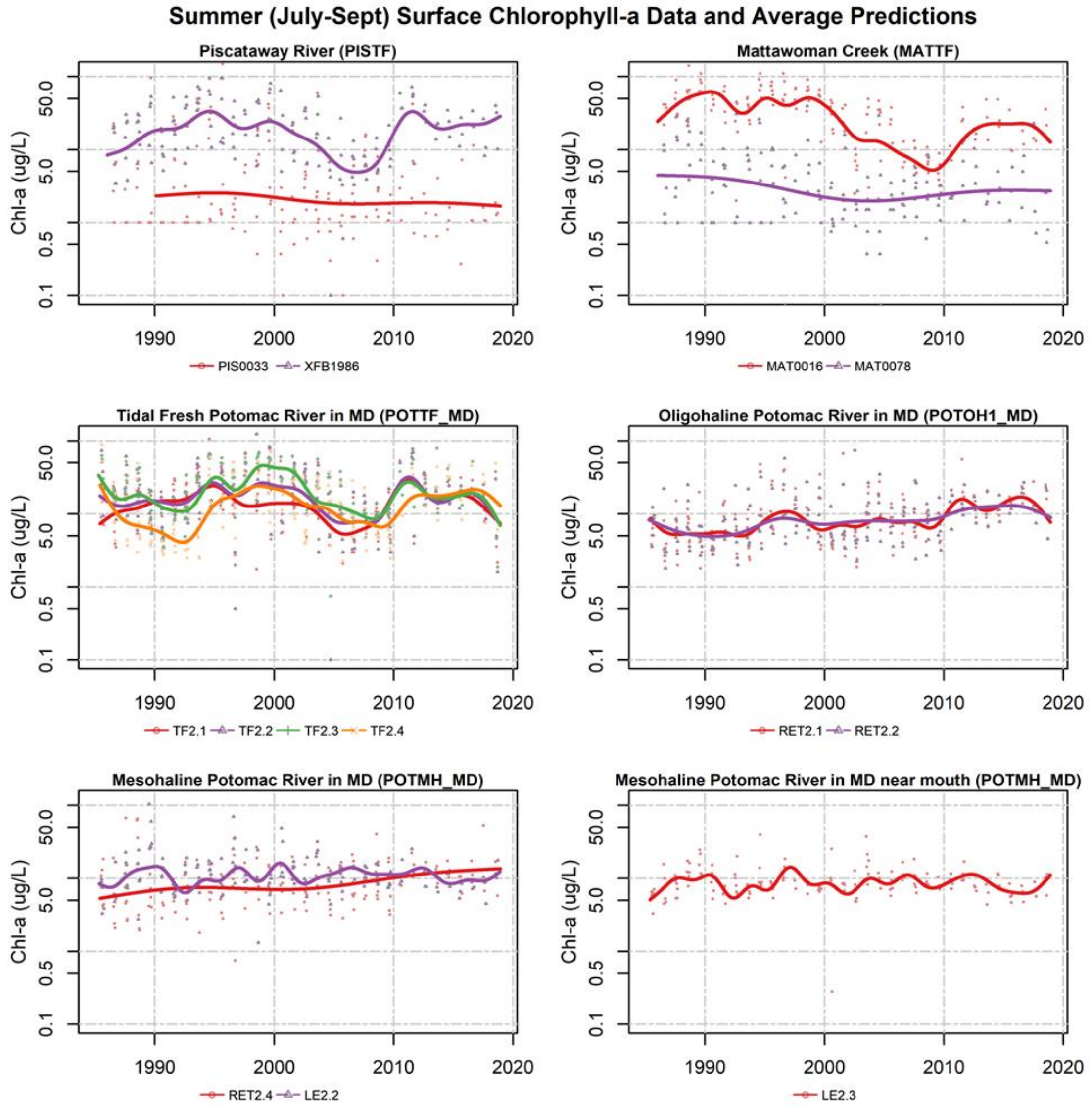
Change over time in Surface TP concentrations



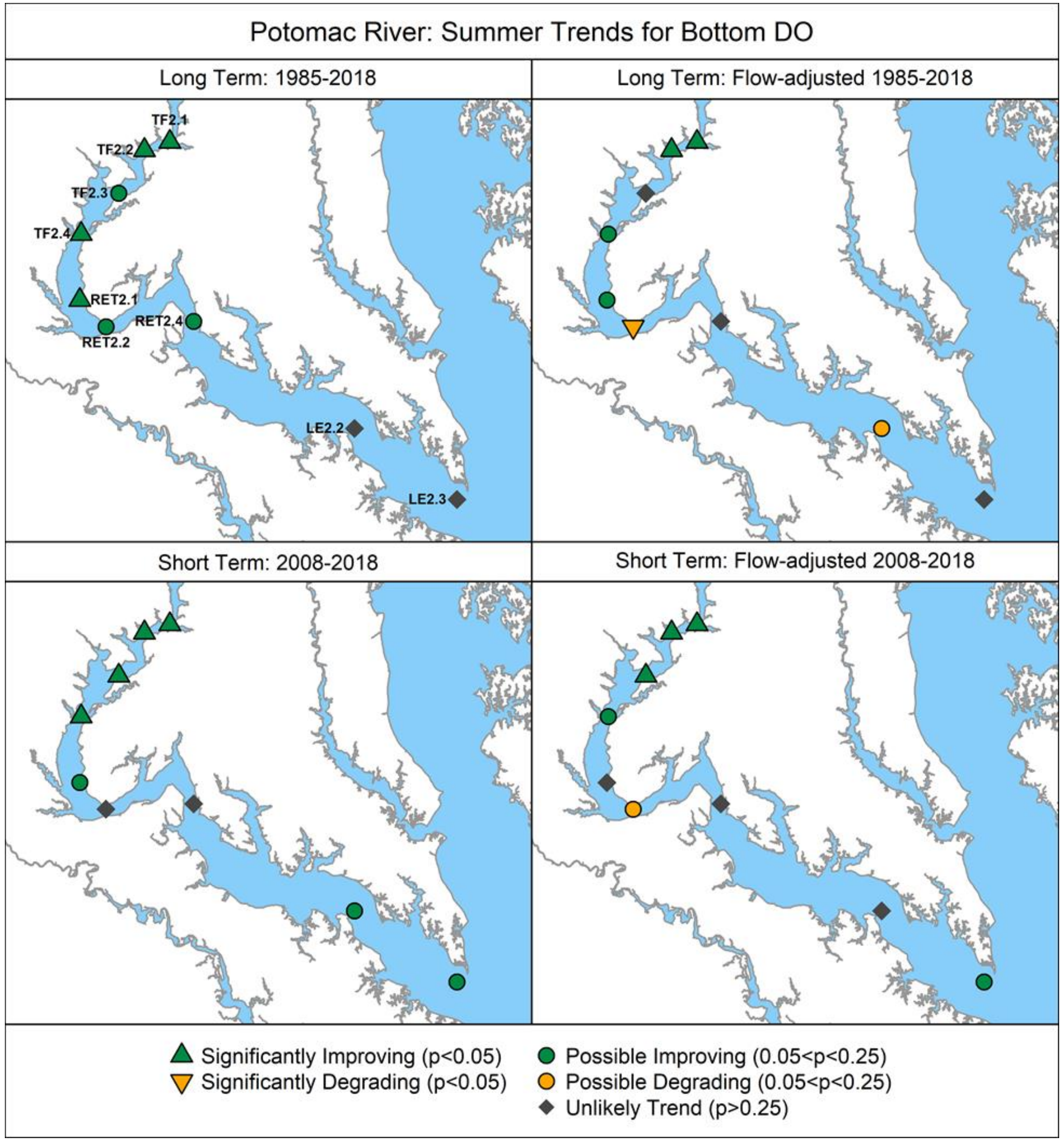


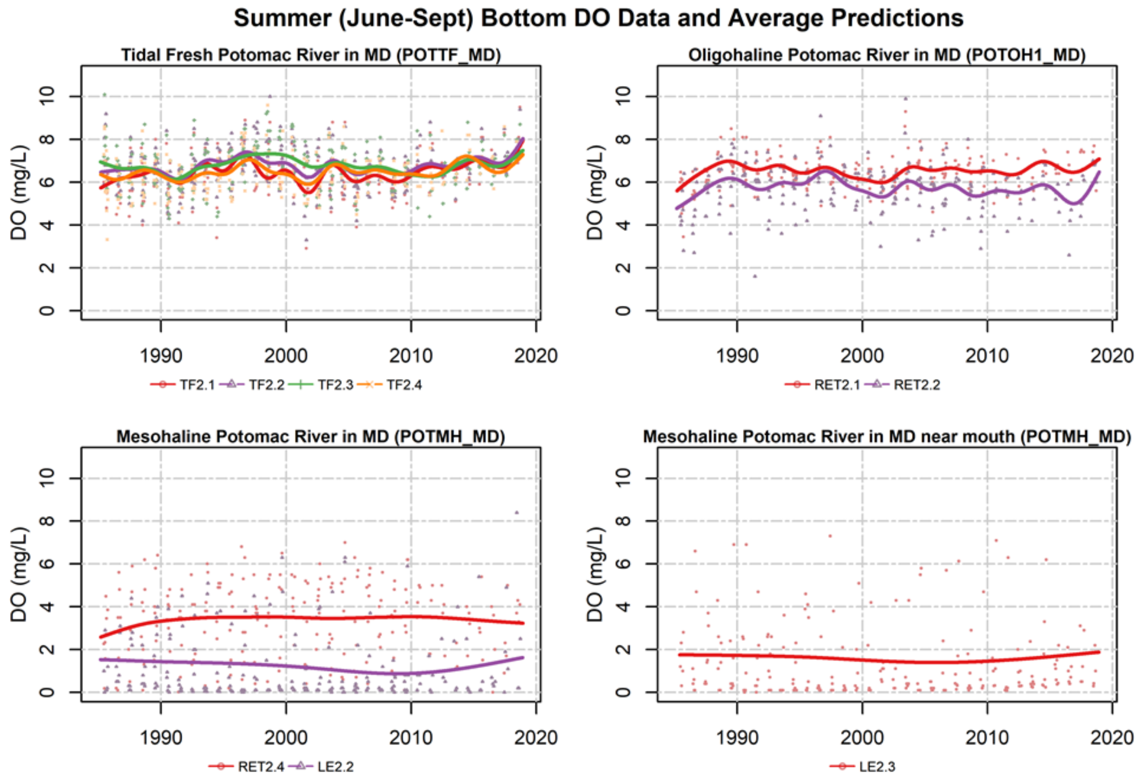
Change over time in Surface Chlorophyll-a concentrations



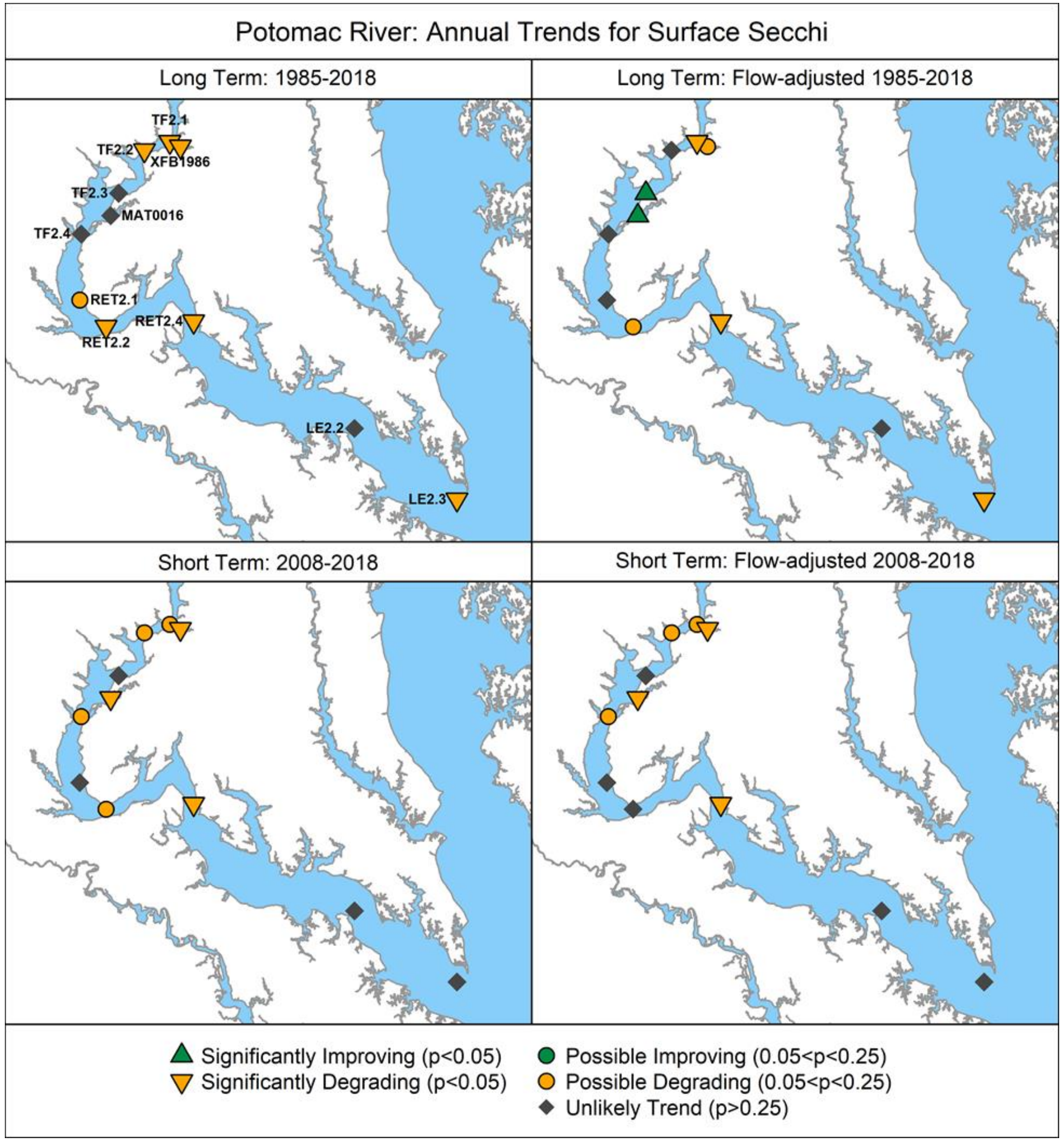


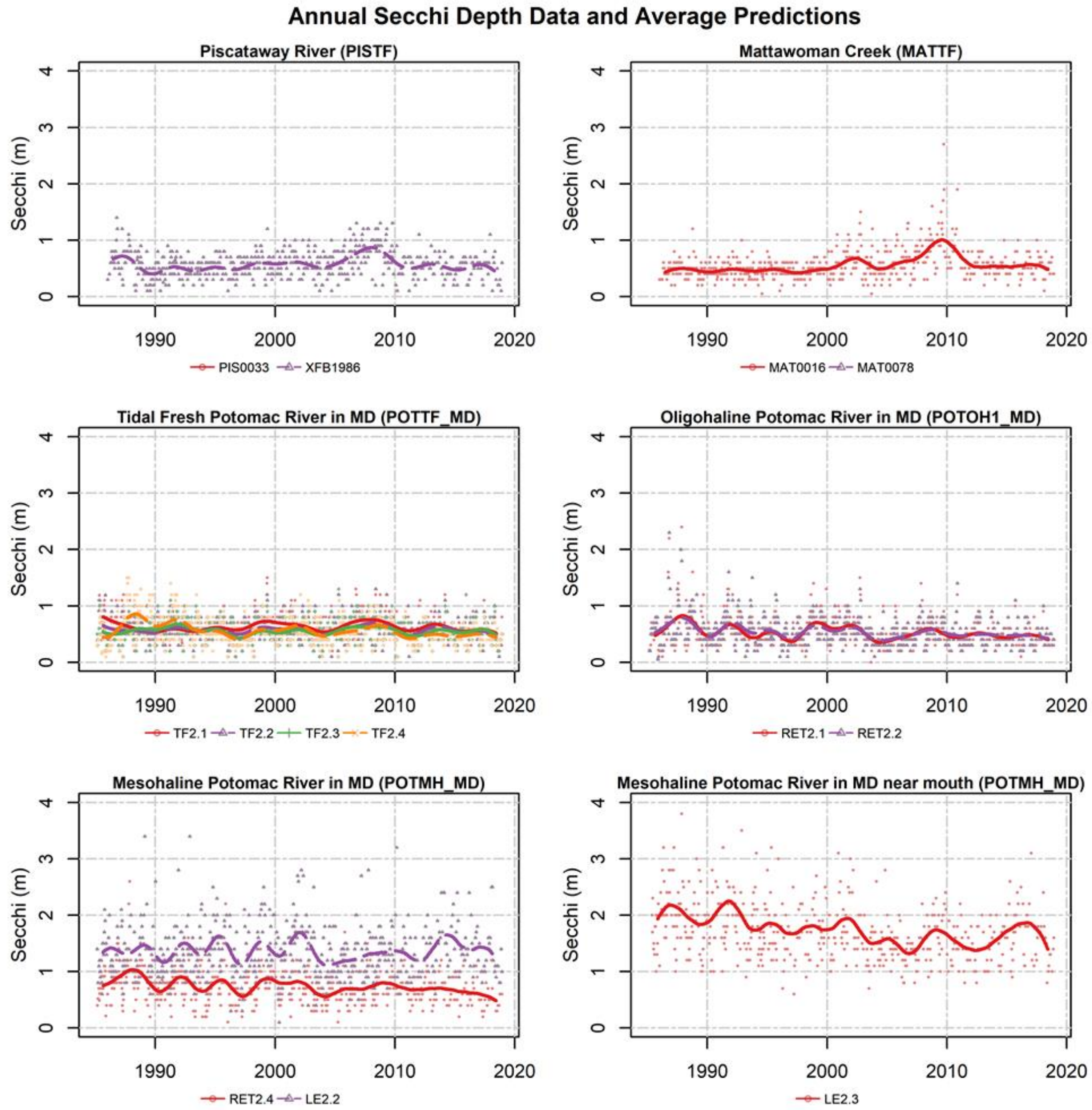
Change over time in Dissolved Oxygen concentrations





Change over time in Secchi depth



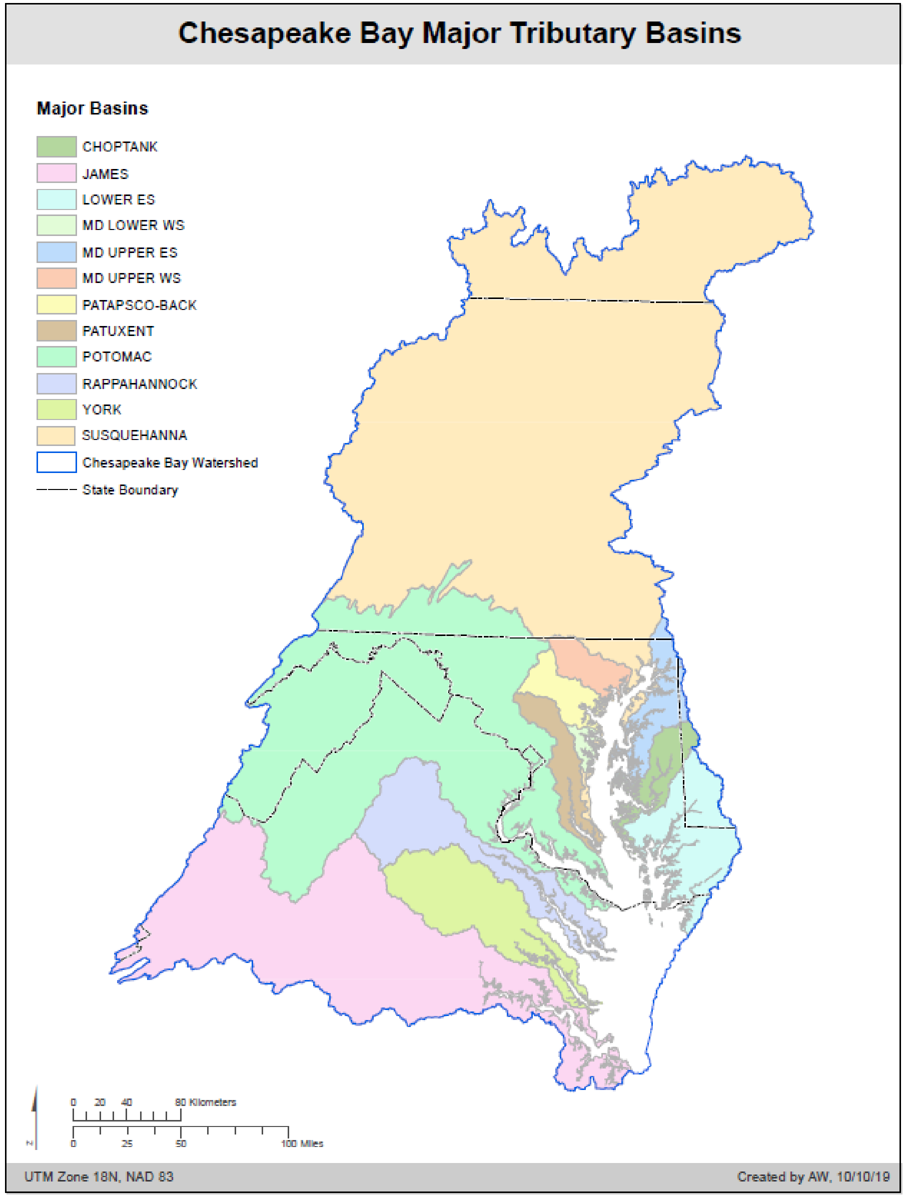


What could be driving these patterns?

"what's going on in the watershed"

Contents…

Watershed Factors: Geology and transport pathway matter



Map courtesy Zhaoying Wei

Where the water in Chesapeake streams comes from *on average*:

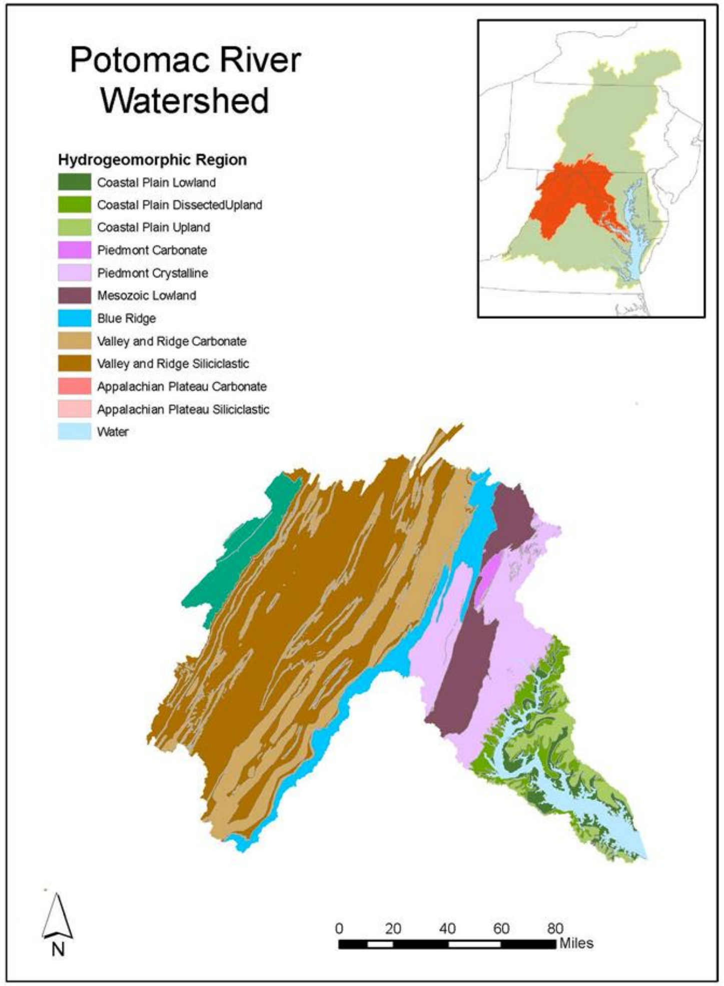
- ✓ About 50% from groundwater discharge.
- ✓ About 50% from surface runoff and soil moisture (e.g. water moving through shallow soils).

This is important for understanding nutrient transport:

- ✓ Groundwater is an important pathway of nitrogen to most streams in the watershed (*but its relative contribution varies substantially across settings).*
- ✓ Soil moisture and surface runoff are generally considered the dominant pathways for phosphorus (*but this also varies depending on where you are and when you measure it).*

Watershed Factors

Narrative summary environmental setting from the USGS synthesis on drivers of watershed nutrient trends, tailored to tributary setting



4. Factors Affecting Trends

4.1 Watershed Factors

Effects of physical setting

The geology of the Potomac River watershed and its associated land use affects the quantity and transmissivity of nitrogen, phosphorus, and sediment delivered to non-tidal and tidal streams. Flow-normalized nitrogen, phosphorus, and sediment trends in load are mixed throughout non-tidal streams in the Potomac River watershed and result from changes in (1) nutrient applications, (2) delivery from the landscape to streams, and (3) in-stream loss or retention (Table X).

Nitrogen

Groundwater is the primary delivery pathway of nitrogen to most streams in the Chesapeake Bay watershed (Ator and Denver, 2012; Lizarraga, 1997). Concentrations of groundwater nitrogen, as nitrate, are typically highest in the Potomac River watershed in portions of the Valley and Ridge physiographic province underlain by carbonate rocks and in areas of the Coastal Plain with permeable, oxic, well-drained soils (Greene and others, 2005; Terziotti and others). The geology of these areas provides suitable land for agriculture, but little potential for denitrification (Böhlke and Denver, 1995; Lizarraga, 1997; Miller and others, 2007; Sanford and Pope, 2013), so nitrogen that isn't removed by plants or exported in agricultural products can move relatively efficiently to groundwater. 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). In general, groundwater ages tend to be relatively short (0-10 years) in carbonate settings, where permeable soils and solution-enlarged fractures enhance groundwater connectivity (Lindsey and others, 2003). Groundwater represents about 50% of streamflow in most Chesapeake Bay streams, with the other half composed of soil moisture and runoff, which have residence times of months to days (Phillips, 2007).

Sediment

The delivery of sediment from upland soil erosion, streambank erosion, and tributary loading varies throughout the Potomac River watershed, but in-stream concentrations are typically highest in Piedmont watersheds (Brakebill and others, 2010). The erosivity of Piedmont soils results from its unique topography and from the prevalence of agricultural and urban land uses in these areas (Trimble 1975, Gellis et al. 2005, Brakebill et al. 2010). Factors affecting streambank erosion are highly variable throughout the Potomac River watershed and include drainage area (Gellis and others, 2015; Gellis and Noe, 2013; Gillespie and others, 2018; Hopkins and others, 2018), bank sediment density (Wynn and Mostaghimi, 2006), vegetation (Wynn and Mostaghimi, 2006), stream valley geomorphology (Hopkins and others, 2018), and developed land uses (Brakebill and others, 2010).

Phosphorus

Phosphorus binds to soil particles and most phosphorus delivered to the Bay is attached to sediment (Zhang and others, 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 of varies based on soil particle chemical composition and physical structure with clays typically having the greatest number of sorption

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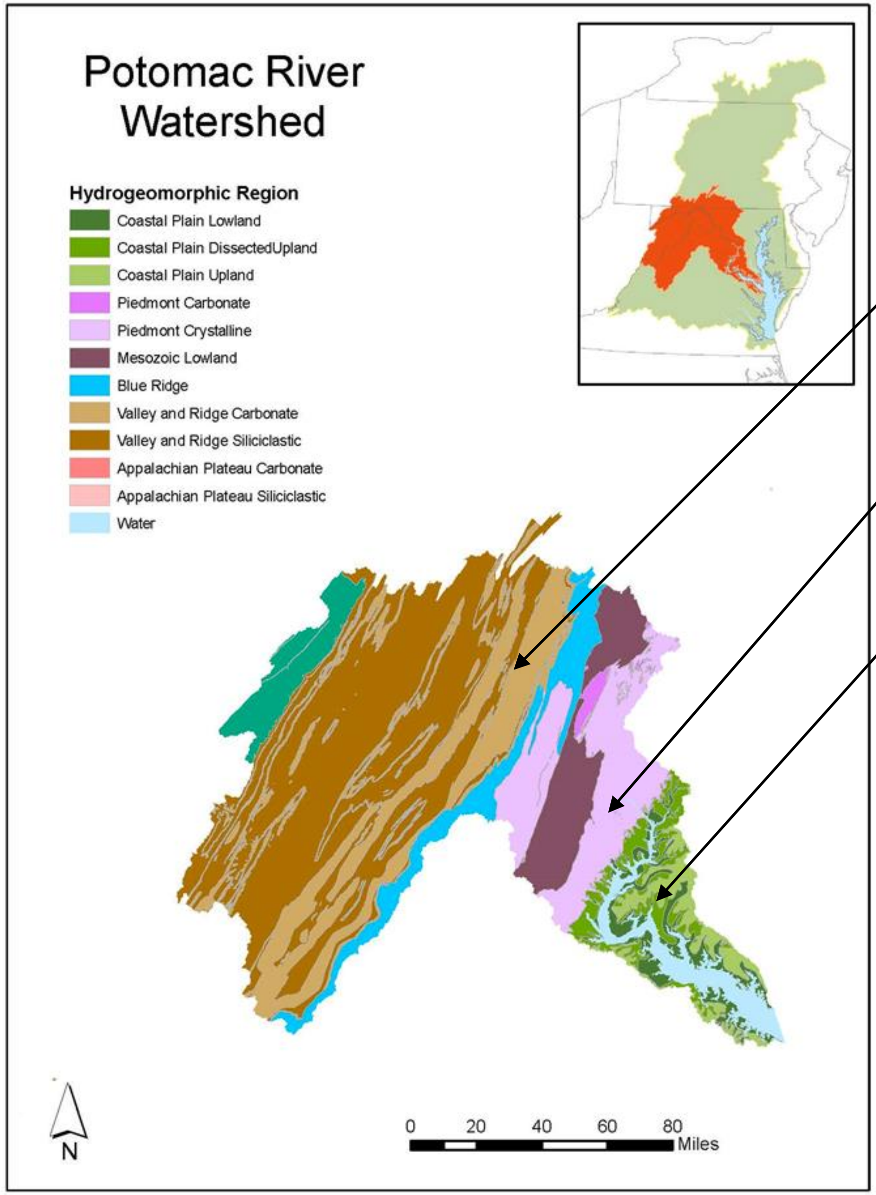
Watershed Factors: Geology and transport pathway matter



From USGS, this map courtesy Zhaoying Wei

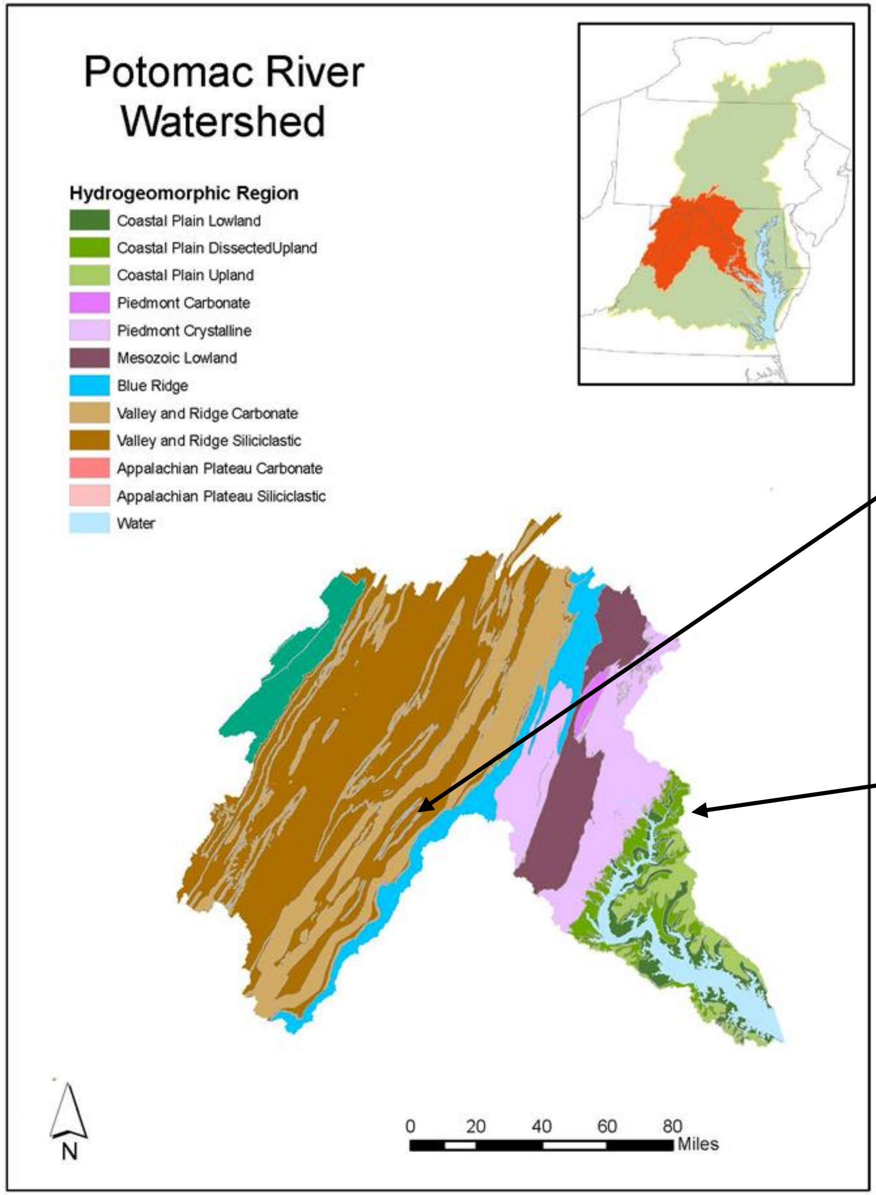
Valley and Ridge underlain by carbonate rocks (groundwater age ~ 0-10 yrs)

Piedmont crystalline settings (groundwater age ~ 0-22 yrs)

Coastal plain settings (groundwater age <1 to >100 years (median 20-40 yrs)

Soil moisture and surface runoff everywhere: days-to-months

Watershed Factors: Distance matters

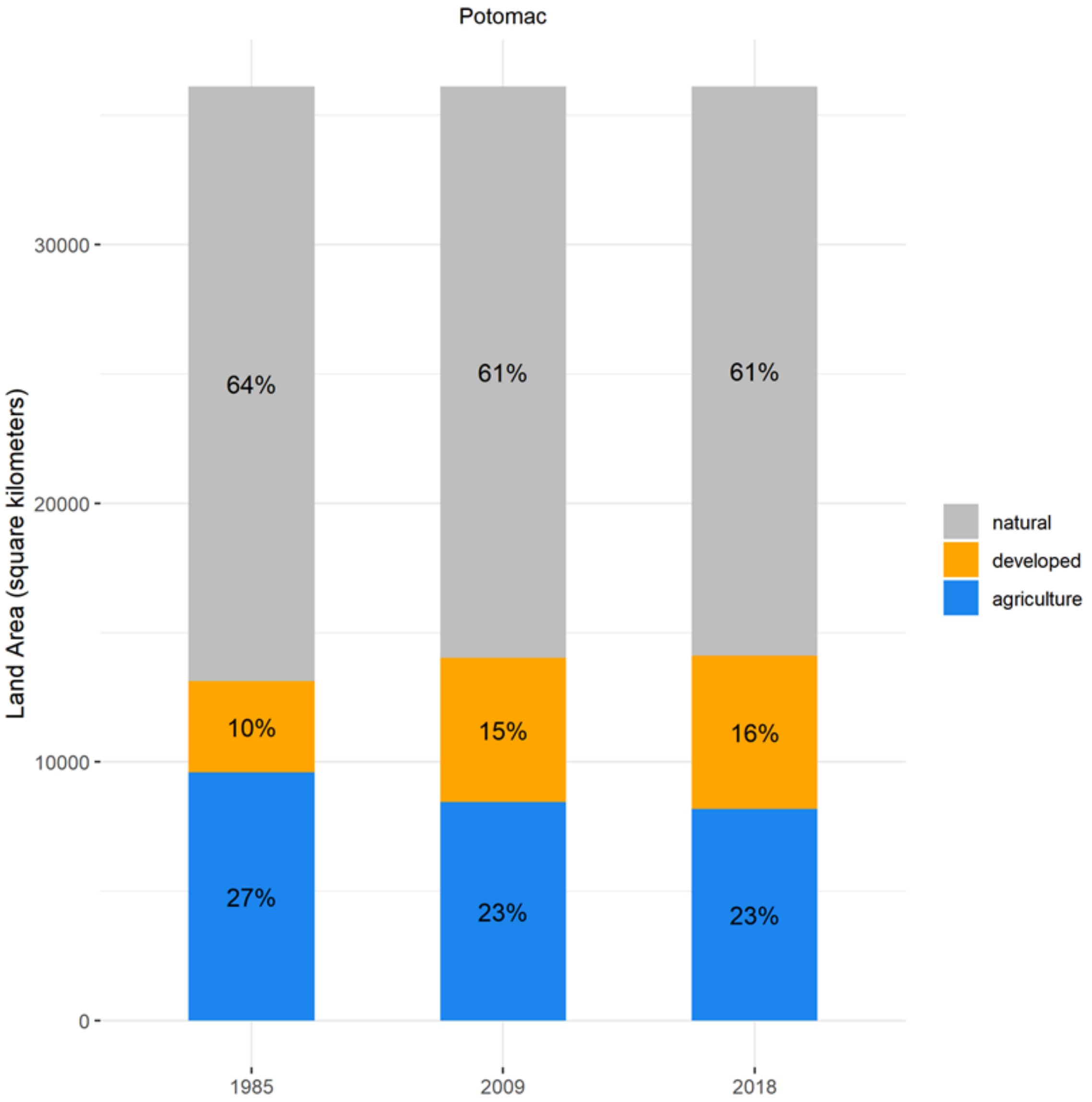


From USGS, this map courtesy Zhaoying Wei

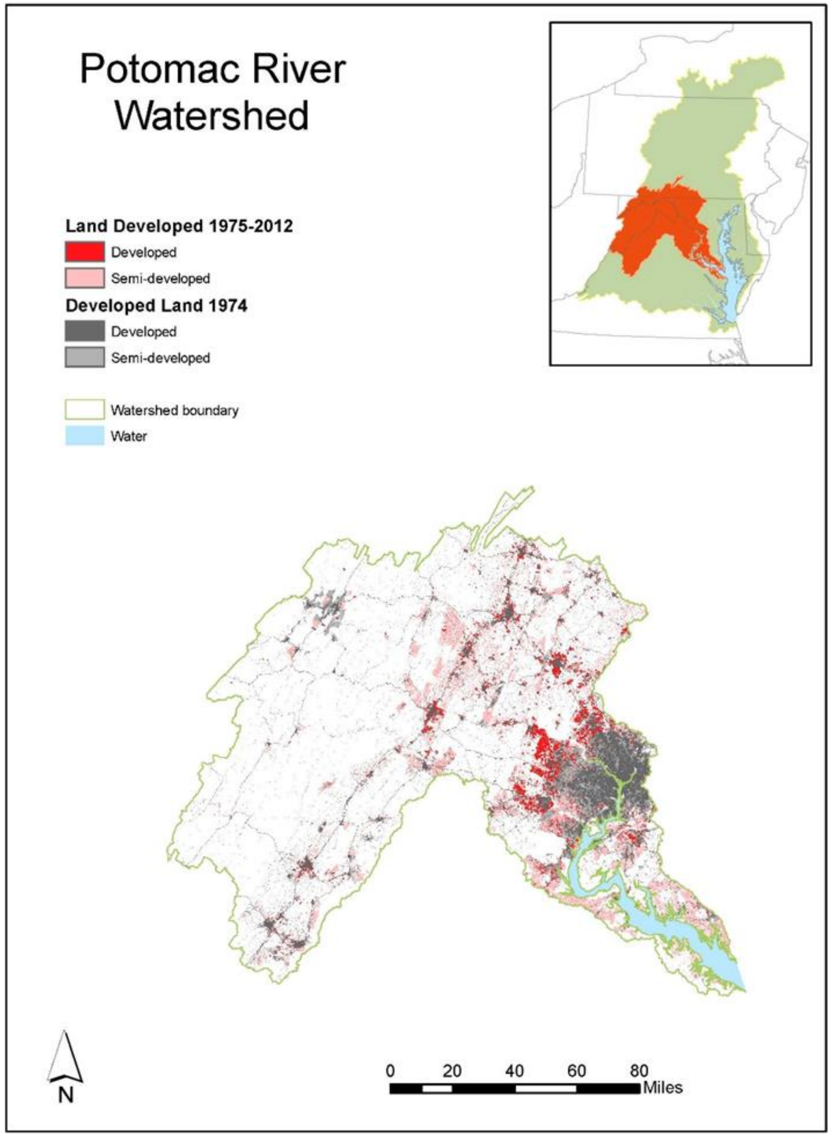
Distance matters:

- ✓ Nutrients entering streams in Virginia's Shenandoah Valley can be removed or delayed through in-stream processing before they reach the head of tide.
- ✓ Nutrients entering streams in areas surrounding Washington DC have less opportunity to be consumed or sequestered.

Watershed Characteristics: Land Use Change

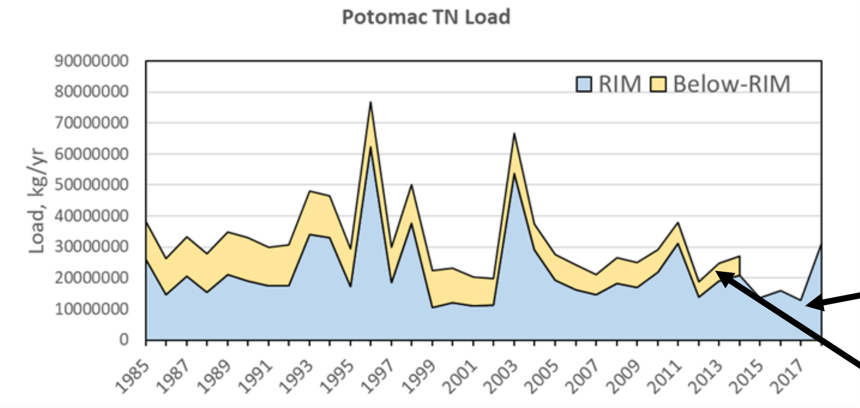


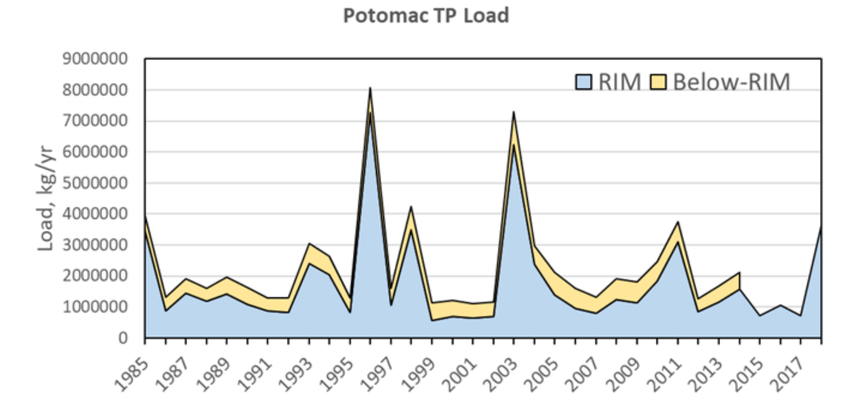
From CAST, courtesy Olivia Devereux

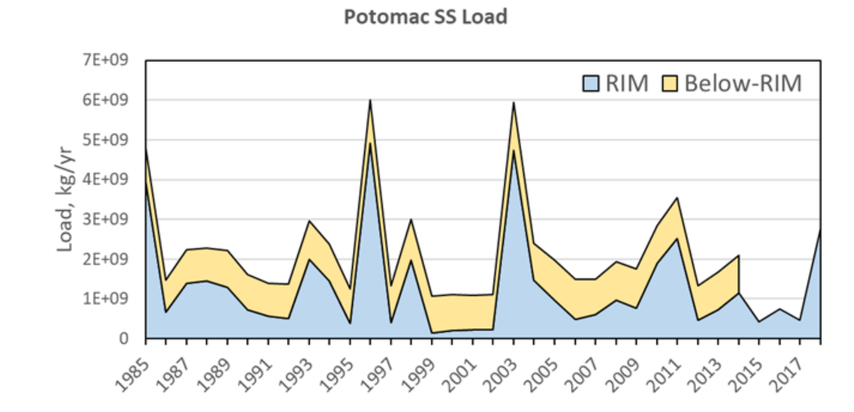


From Falcone 2015, courtesy Zhaoying Wei

Watershed characteristics and land use translate to nutrient and sediment loads







Estimated loads to tidal portions of Chesapeake Bay tributaries are a combination of:

- ✓ Monitored fluxes from USGS River Input Monitoring (RIM) stations located at the nontidal-tidal interface, and
- ✓ Below-RIM simulated loads from the Chesapeake Bay Program Watershed Model (CBWM).

Constituent	Change 1985-2014	p-value (MK)	Percent Fall-Line
TN	(11,257,117)	0.05	~ 72%
TP	(1,838,653)	0.94	~ 81%
SS	(2,696,070,671)	0.80	~ 69%

From the USGS and the CBP WSM, courtesy Qian Zhang and Gopal Bhatt

What load changes should we expect to see (eventually)?

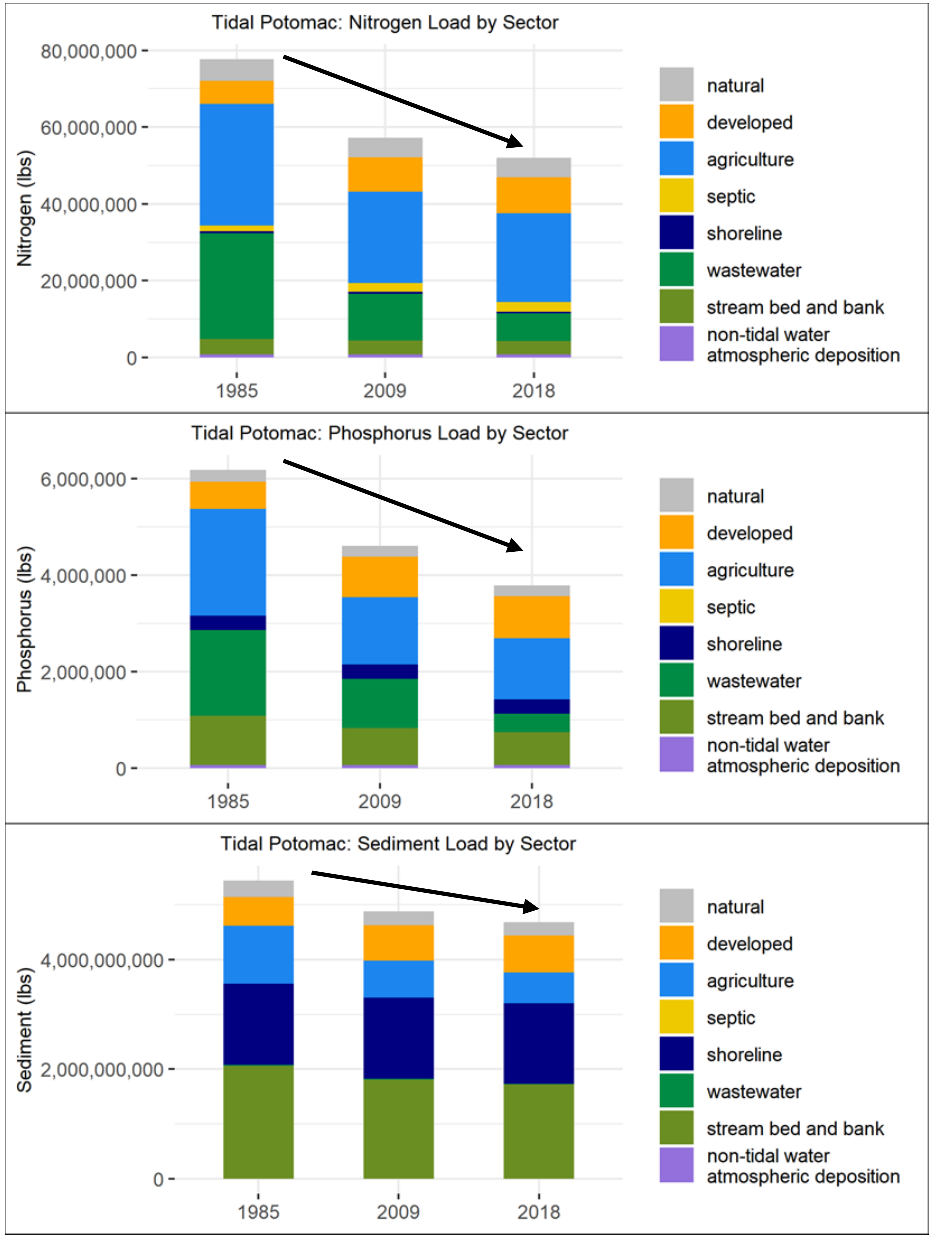
According to the CBP Phase 6 Watershed Model, changes in population size, land use, and pollution management controls between 1985 and 2018 are ***expected*** to:

- Reduce N loads to the tidal Potomac by 33%
- Reduce P loads to the tidal Potomac by 39%
- Reduce sediment loads to the tidal Potomac 14%

By sector:

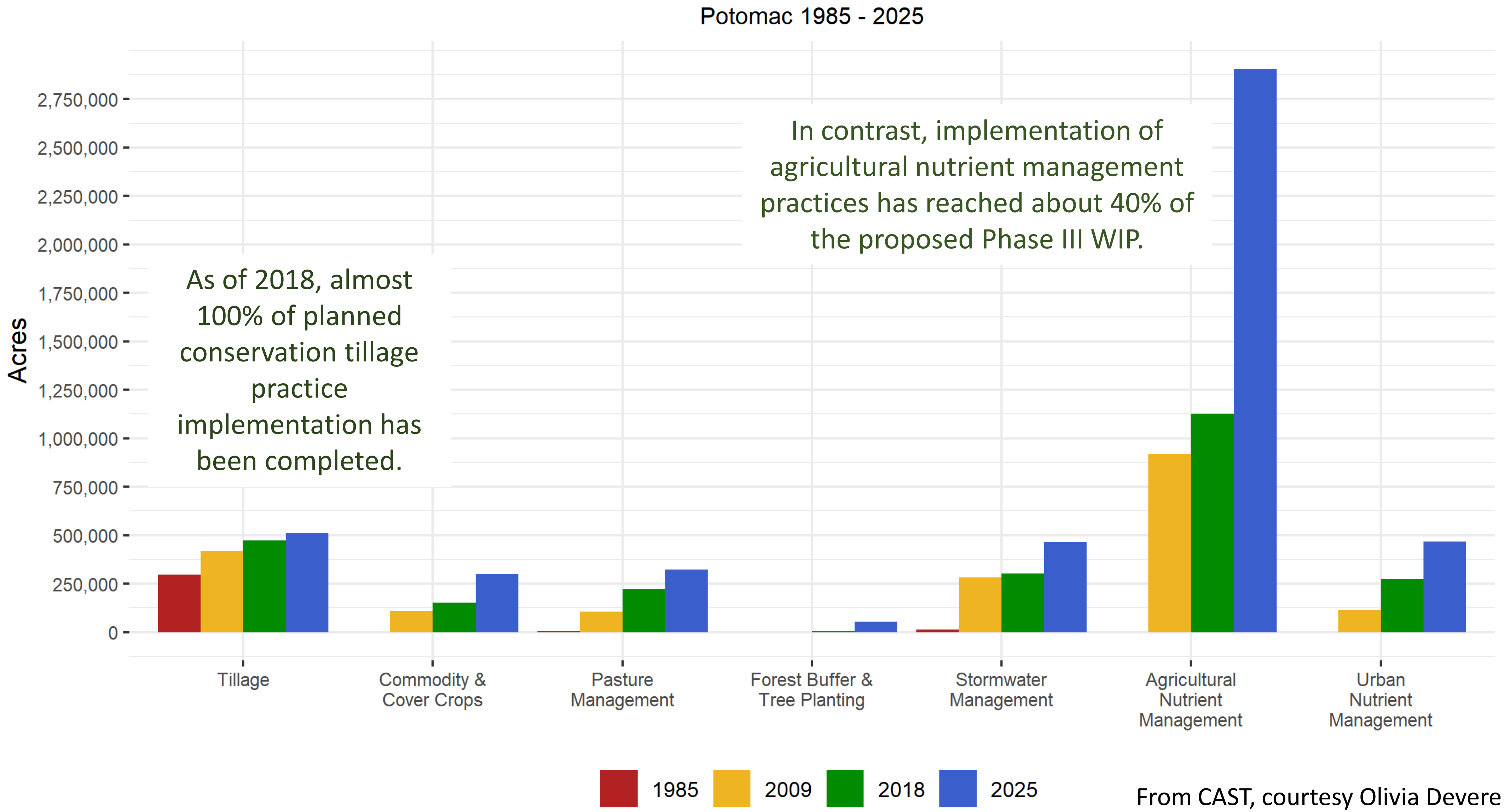
Source	Expected Change 1985-2018 (%)	
	TN	TP
Agriculture	-27	-43
Developed	56	56
Septic	58	114

Source	Expected Change 1985-2014 (%)
	Sediment
Agriculture	-47
Developed	28
stream bed/bank	-16
shoreline	0



From CAST, courtesy Olivia Devereux

Watershed Factors: BMP Implementation



As of 2018, almost 100% of planned conservation tillage practice implementation has been completed.

In contrast, implementation of agricultural nutrient management practices has reached about 40% of the proposed Phase III WIP.

From CAST, courtesy Olivia Devereux

What could be driving these patterns?

Contents…

"what's going on in the tidal waters" (bracketing 4.2 Tidal Factors)

Estuarine Factors

Within the tidal environment, nutrients and sediment interact with physical and chemical factors such as:

- Water temperature
- Salinity
- Wind, turbulence
- pH
- Oxygen

They affect, and are affected by, the presence of biological communities:

- Phytoplankton
- Benthic worms, clams, oysters
- SAV

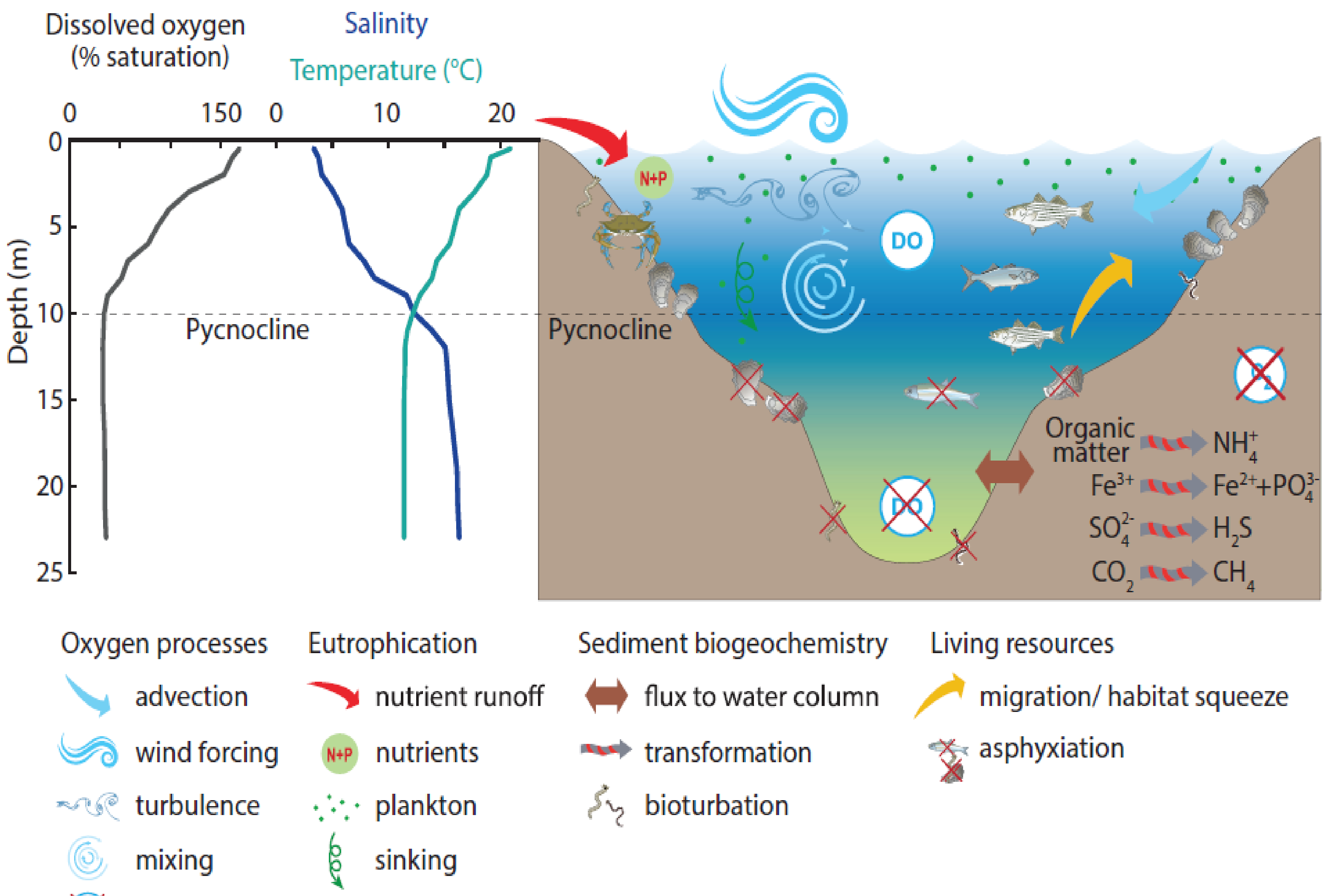


Figure from Testa et al. 2017. Bioscience 67(7): 614-626.

Biological Estuarine Factors: Indicators and Engineers

When bivalve populations reach sufficient numbers, local water clarity and SAV respond

- A dramatic increase in the Asiatic clam population in the tidal fresh Potomac between 1978 and 1984 was followed by resurgence of SAV beds.
- Phelps (1994) estimated that the summer 1986 Asiatic clam population could filter 50-100% of the local water volume in 3-7 days.
- Rapid decline in the clam population after 1986 was accompanied by disappearance of SAV.

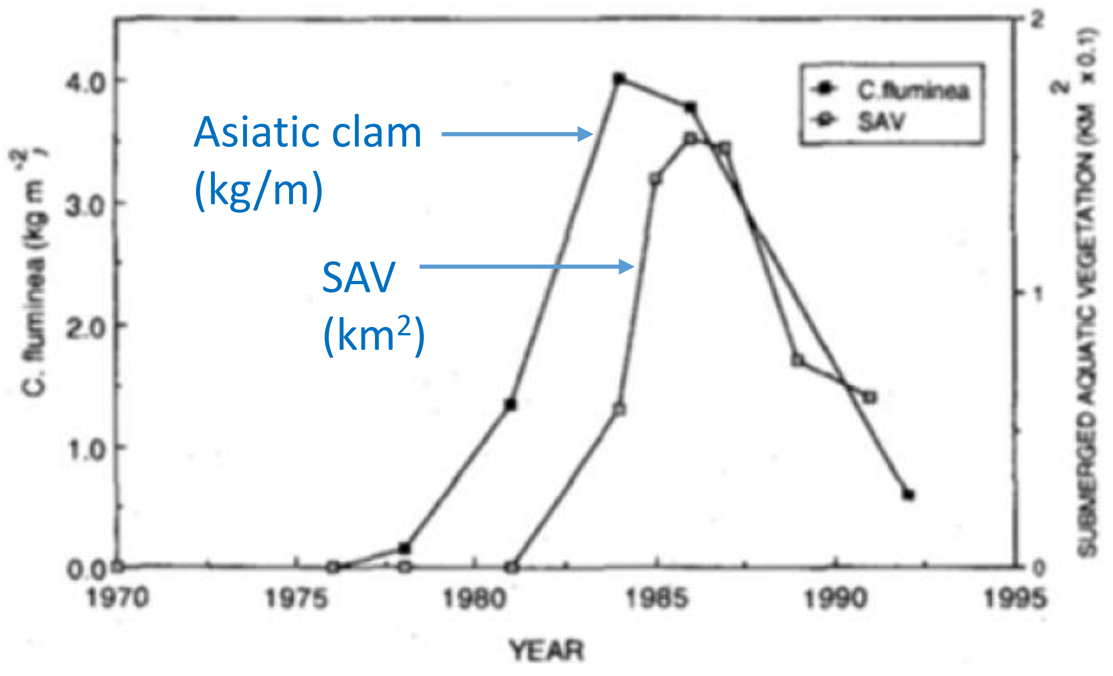
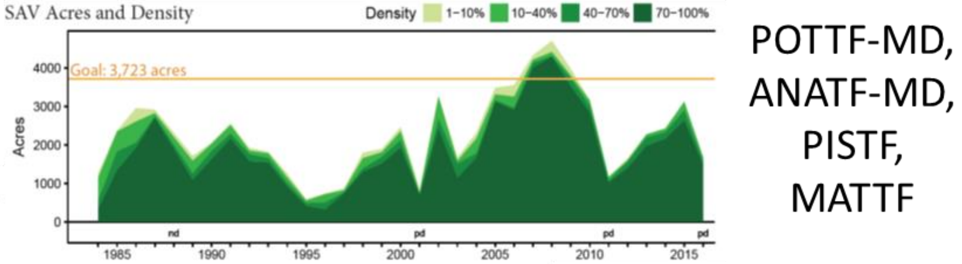


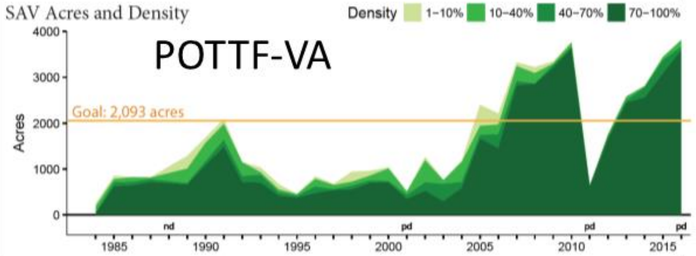
Fig. 3. *Corbicula fluminea* abundance and submerged aquatic vegetation acreage in the Potomac River estuary near Washington, D.C., 1970–1992.

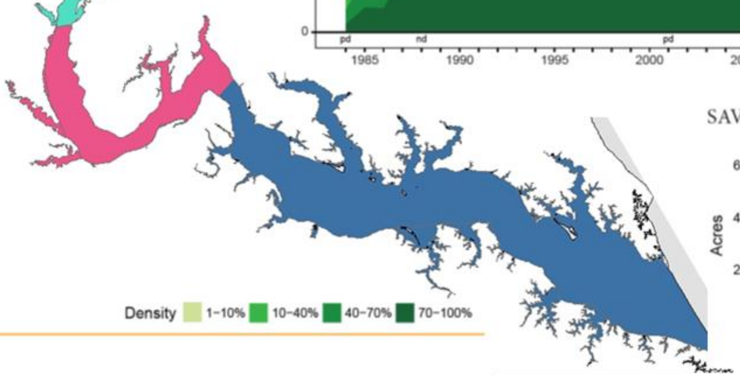
Phelps 1994 in Estuaries 17(3): 614-621

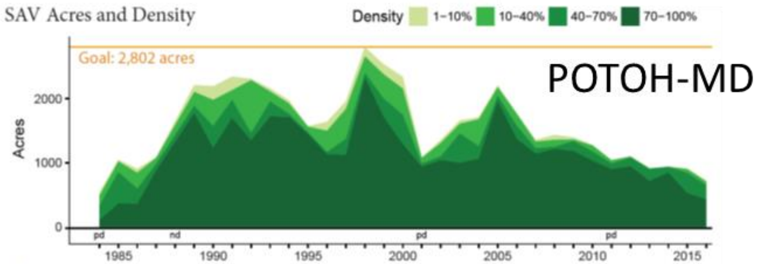
Biological Estuarine Factors: Indicators and Engineers

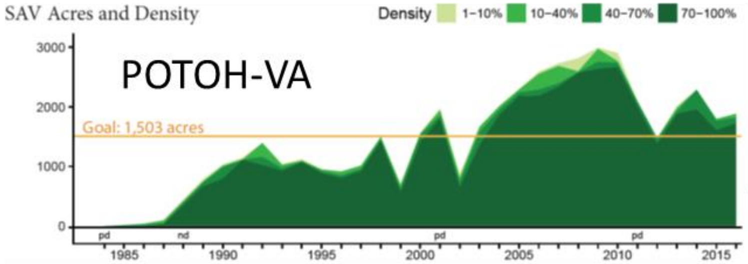
When nutrient concentrations decline and water clarity is sufficient, SAV communities rebound.

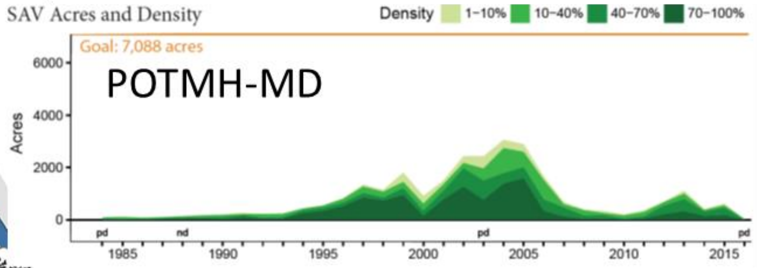


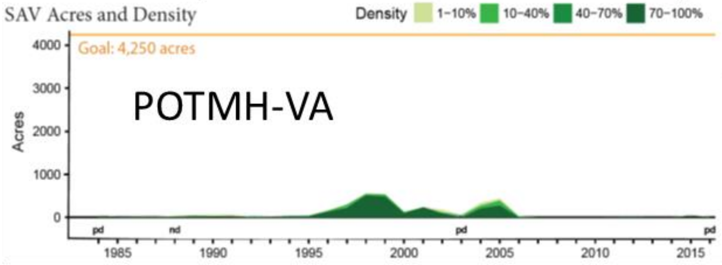










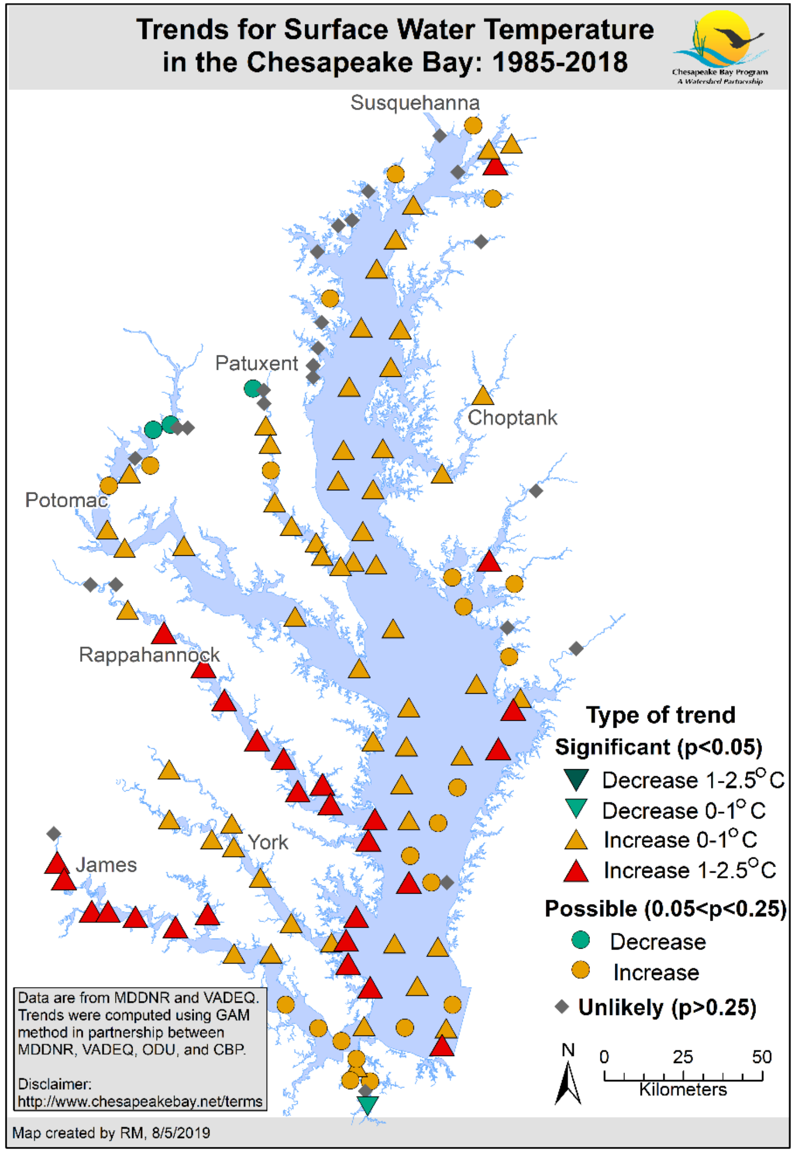


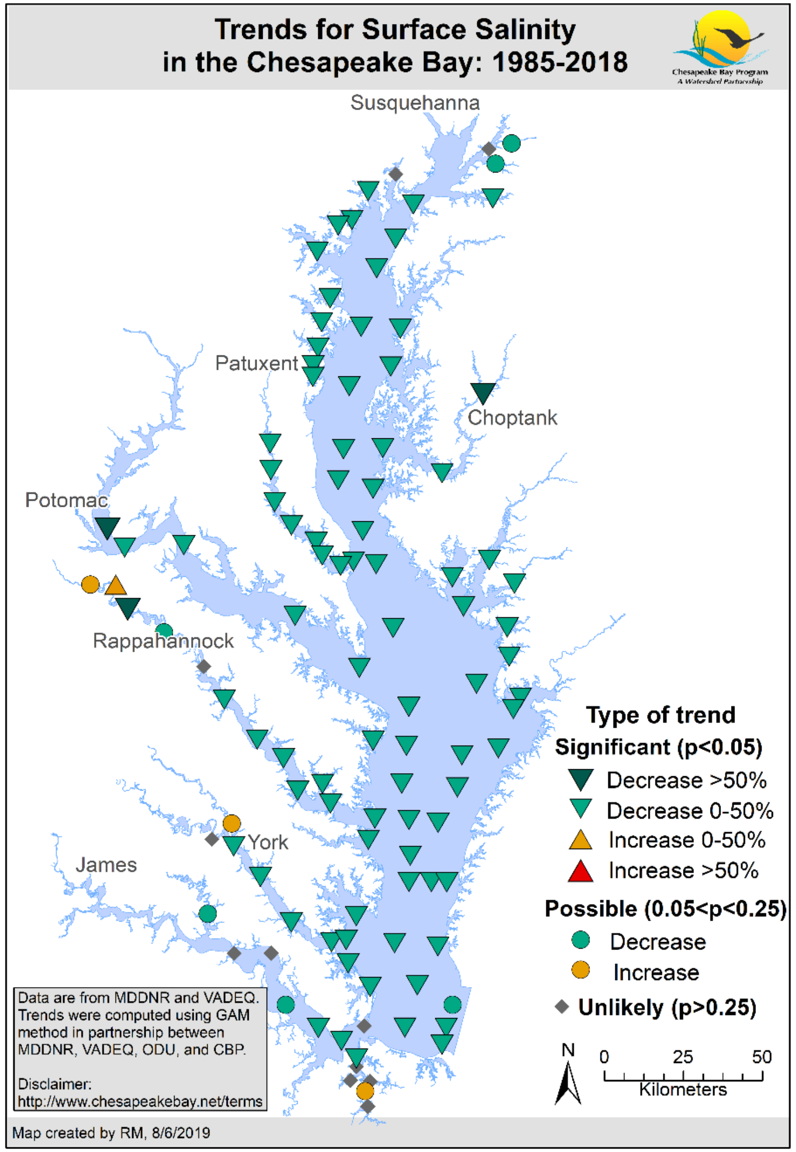
SAV struggles to persist in water with high nutrient concentrations and poor water clarity

Physical Estuarine Factors: A Changing Environment

At the majority of stations throughout Chesapeake Bay:

- Mean annual surface water temperature has increased since 1985.
- Mean annual surface salinity has declined since 1985.





What could be driving these patterns?

Contents…

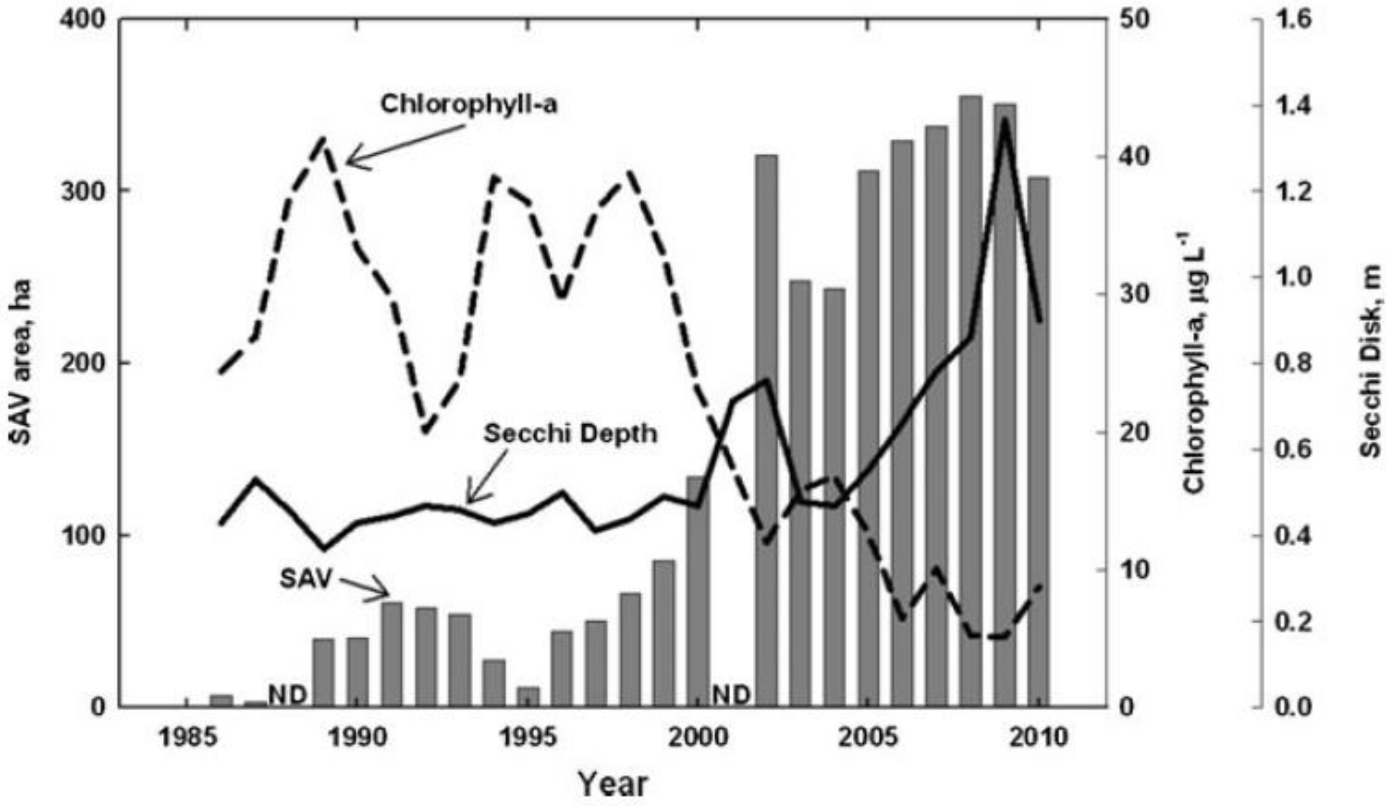
"important puzzle pieces from research"

Explaining Change: Incorporating research insights

Where wastewater is a dominant nutrient source, local water quality and habitat conditions improve after WWTP upgrades.

A WWTP upgrade completed in 1995 reduced annual average N and P discharge to Mattawoman Creek by over 50%.

Initial responses to nutrient load reductions occurred relatively quickly (1–4 years), but more "steady state" conditions took longer to emerge.



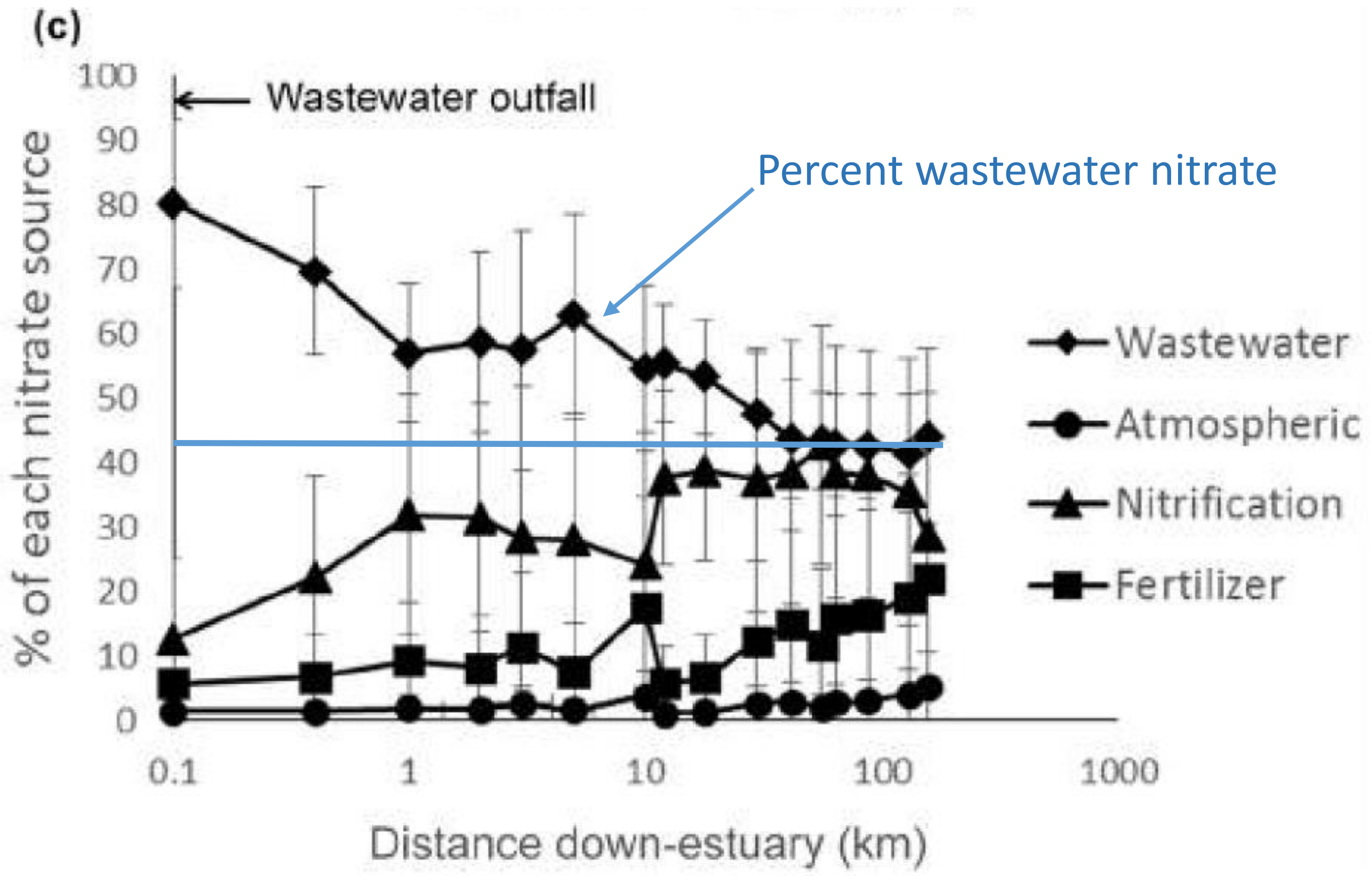
Boynton et al. 2014 in Estuaries and Coasts 37 (Suppl 1): 111.

Explaining Change: Incorporating research insights

WWTP loads do reach the mouth of the river

Nitrate measured at the mouth of Potomac was:

- ✓ Almost 50% from wastewater in the summer and fall.
- ✓ About 6-7% from wastewater in winter and spring.



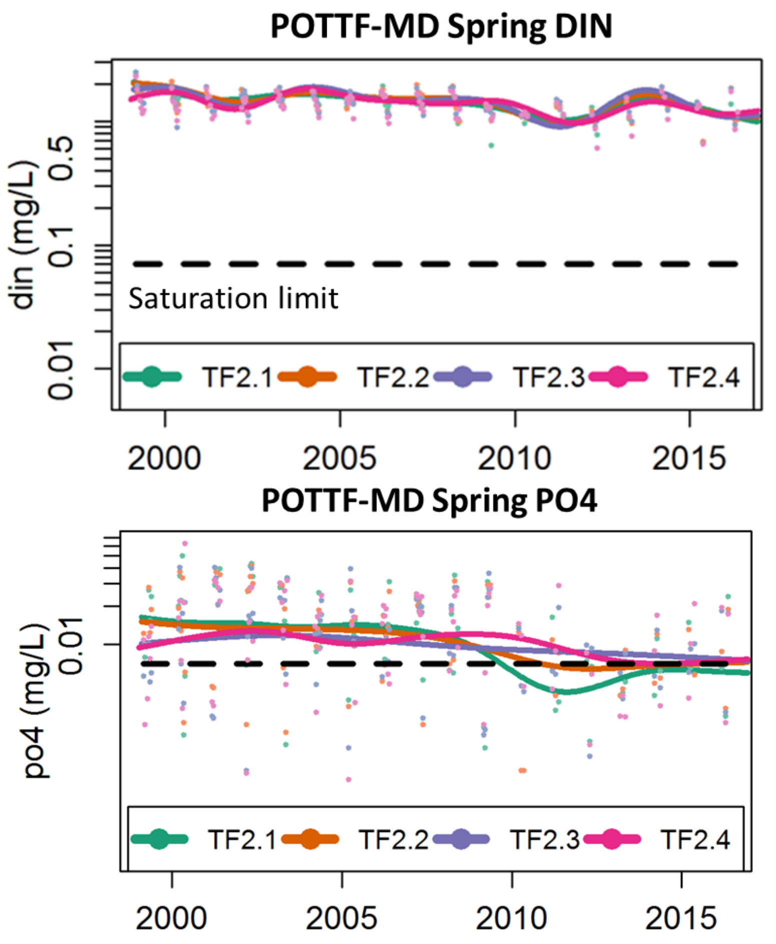
Pennino et al. 2016 in Biogeosciences 13: 6211-16228

Explaining Change: Incorporating research insights

Algal response to nutrient reductions may require concentrations to drop below a "saturation limit"*

Spring dissolved inorganic N concentrations in the tidal fresh Potomac are still well above the limitation threshold for phytoplankton

Spring phosphate concentrations in the tidal fresh Potomac have reached the limitation threshold in recent years



Courtesy Rebecca Murphy

- ✓ This *might* explain the observed lack of improving chlorophyll-a trends.
- ✓ **Statistical analysis of these relationships is underway.**

* Buchanan et al. 2005 in Estuaries 28(1) 138-159; Fisher and Gustafson 2003 report to MD DNR

What could be driving these patterns?

Contents…

"In a Nutshell" { 4.3 Research Insights – 5. Summary

Potomac Tributary Trends Summary

Total nutrient concentrations have been decreasing at most stations in the Potomac River over the long-term, with improvements persisting in the last 10 years as well.

- These trends follow from the decreasing discharge from TN and TP sources in the watershed.

Despite the overall improvements in both nitrogen and phosphorus concentrations observed in these studies and in the current trend results, many of the chlorophyll-a and secchi trends are still degrading.

- Research suggests that there is a "saturation limit" for phytoplankton use of nutrients (Buchanan et al., 2005; Fisher and Gustafson, 2003). There may only be a response in phytoplankton to nutrient reductions when the dissolved nitrogen and/or phosphorus concentrations cross under their saturation limits.

Recent improvements in oxygen concentrations are promising.

- Where chlorophyll-a concentrations have either leveled out or improved, there may be less phytoplankton biomass available to fuel summer oxygen depletion.

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.

Appendix

A map and panel plot each for:

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

Prioritizing Tributary Reports: Tributaries with Degrading DO Trends?

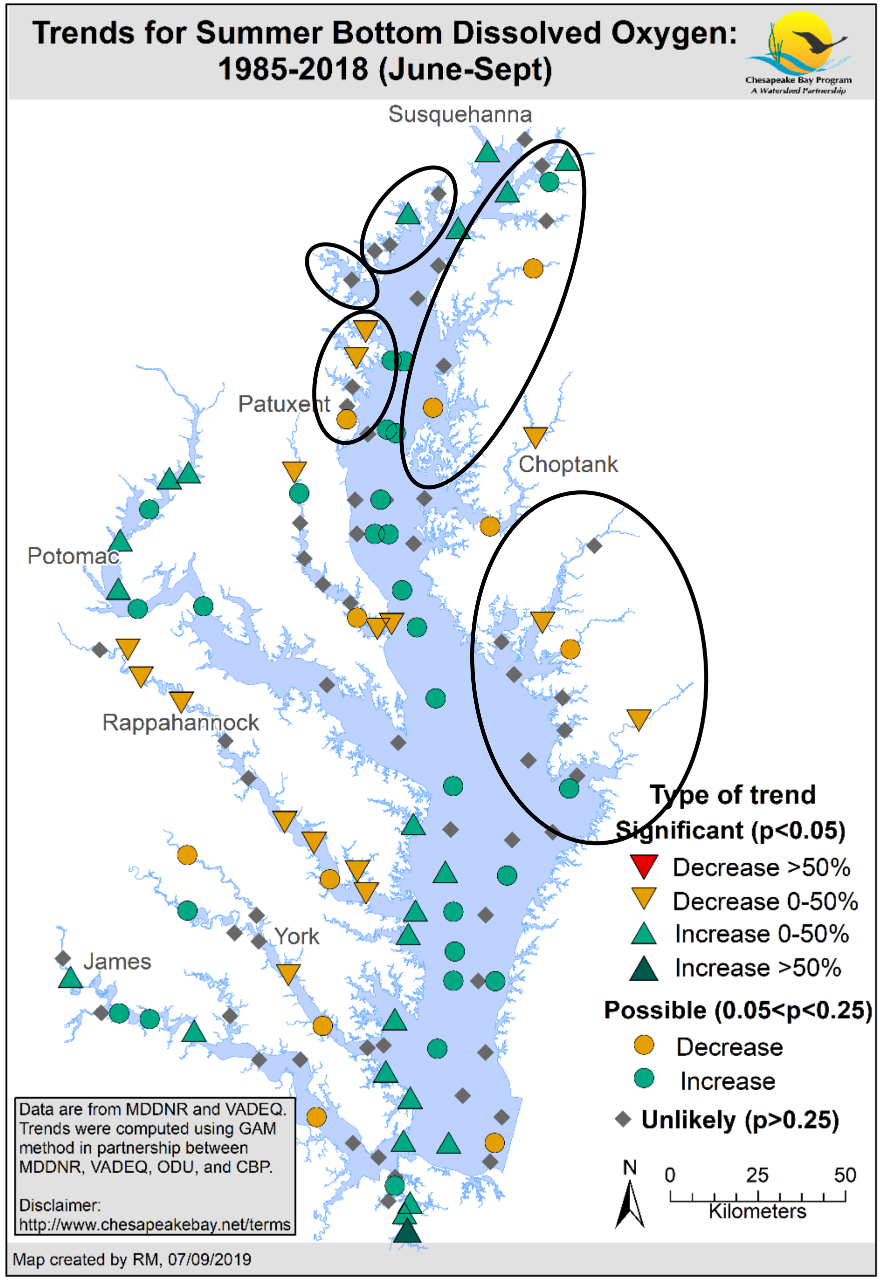
At our current pace:

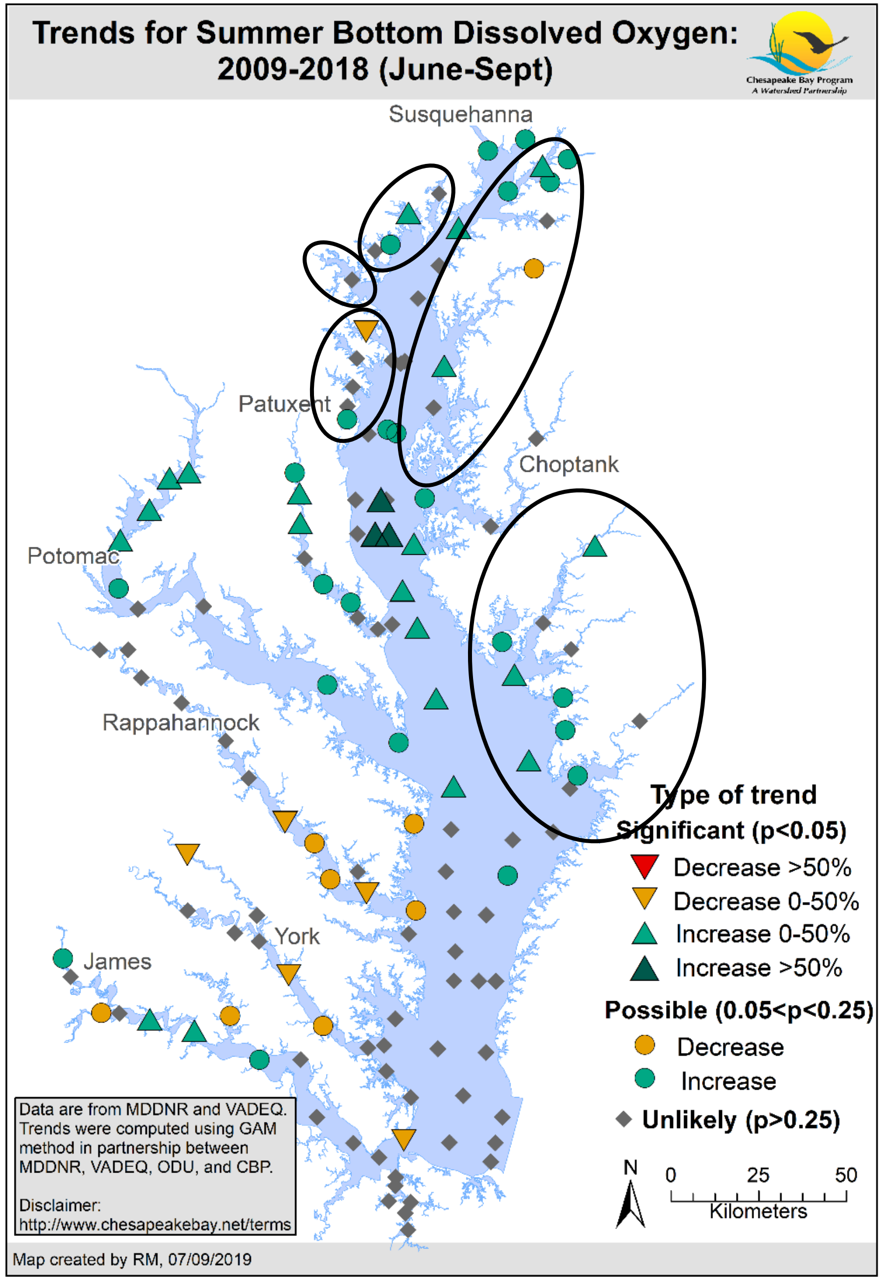
March 31, 2020:

- ✓ Potomac and Rappahannock reports

December 31, 2020:

- ✓ 2 additional tributary reports





END