



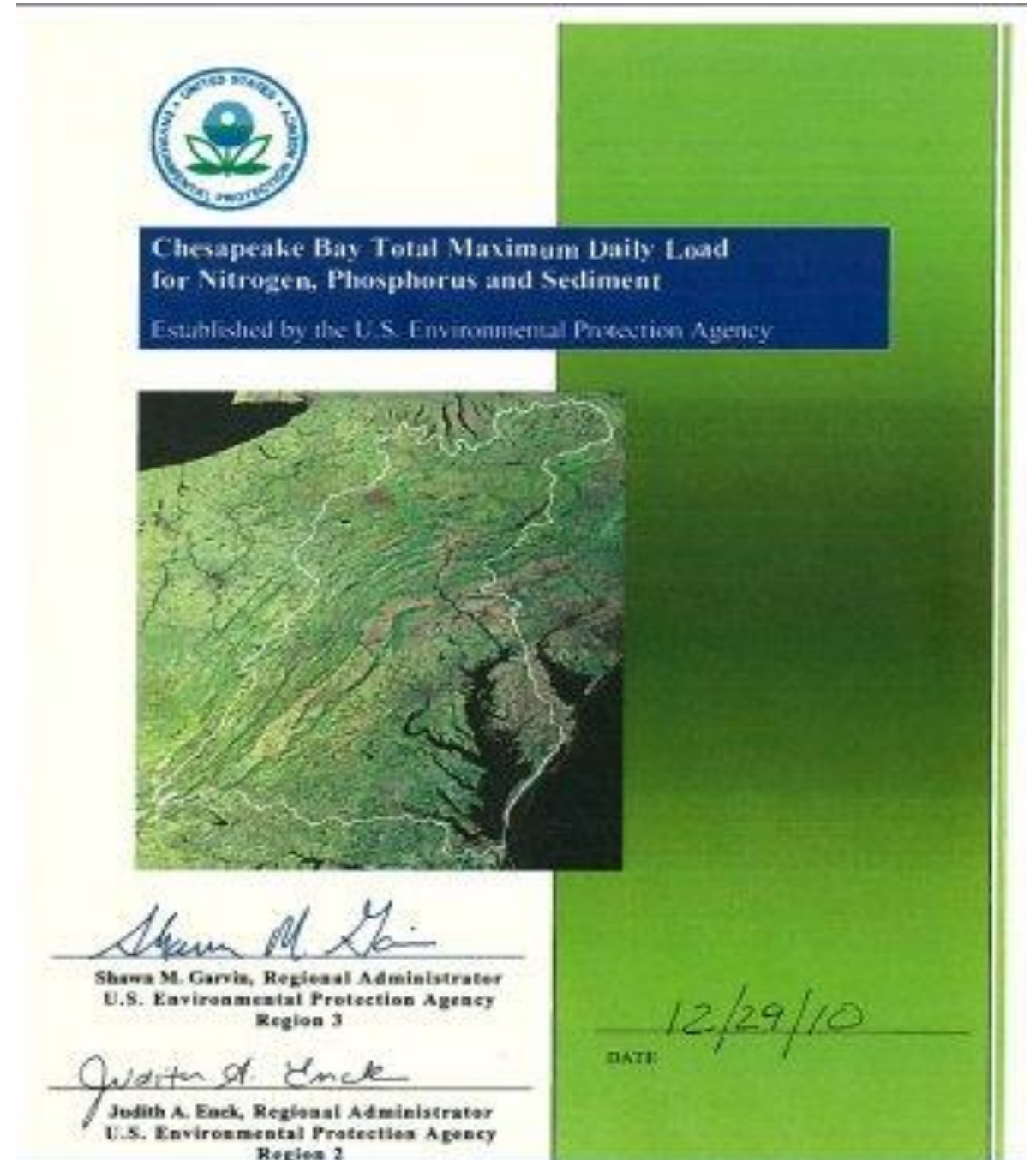
Chesapeake Bay Water Quality Standards Attainment Indicator

Qian Zhang (UMCES/CBP)
STAR Meeting
August 28, 2025



TMDL (2010)

- "Allocated loads [of nitrogen and phosphorus] should **protect living resources of the Bay and its tidal tributaries** and should result in all segments of the Bay mainstem, tidal tributaries and embayments meeting **water quality standards** for dissolved oxygen, chlorophyll a, water clarity and underwater Bay grasses."



WQSAM Outcome (WA 2014)

"Continually improve our capacity to monitor and assess the effects of the management actions being taken to implement the Chesapeake Bay Total Maximum Daily Load (Bay TMDL) and improve water quality. **Use monitoring results to report annual progress being made in attaining water quality standards and trends in reducing nutrients and sediment in the watershed.**"

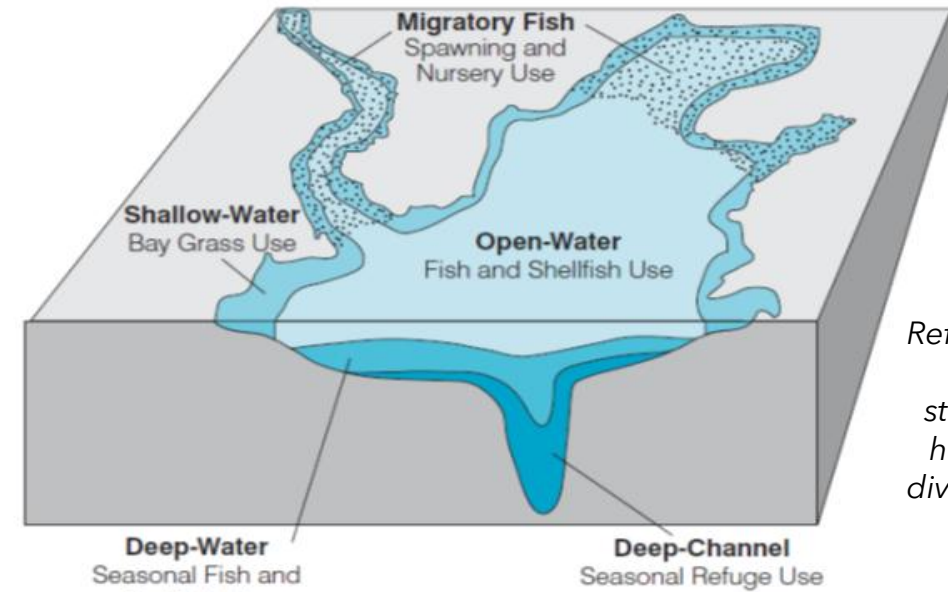
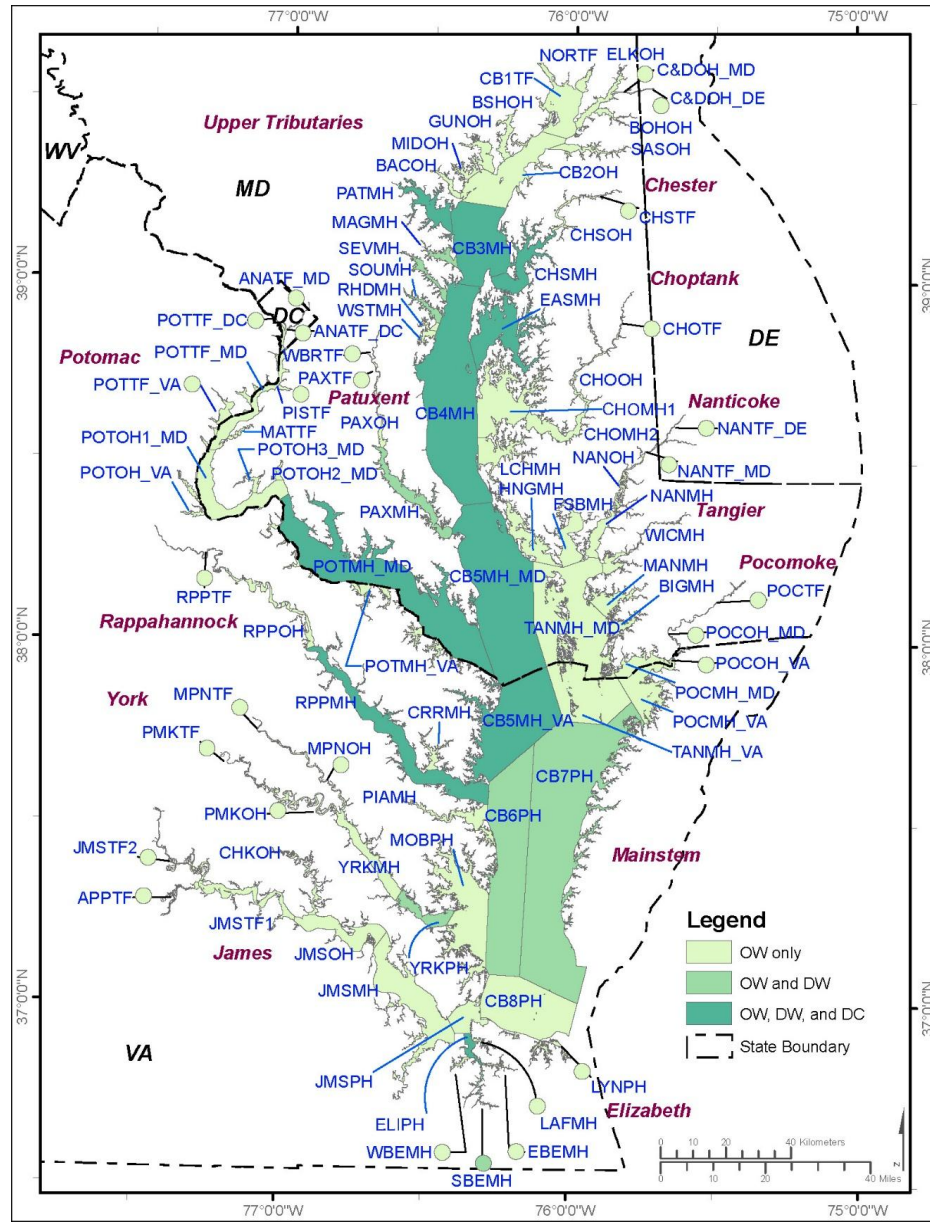
<https://www.chesapeakeprogress.com/clean-water/water-quality>

WQSAM Outcome (WA 2014)

Four indicators to assess change over time for measuring the effectiveness of our management actions to improve WQ:

1. water quality standards attainment for dissolved oxygen, water clarity/submerged aquatic vegetation and chlorophyll a in tidal waters of the Bay.
2. annual total nutrient and sediment pollution loads delivered to the Bay.
3. monitored nutrient and sediment trends in the watershed.
4. Bay TMDL progress, combining monitored and modeled data to estimate the progress of nitrogen and phosphorus load reductions in response to implemented management practices₄

Bay Segments and Designated Uses



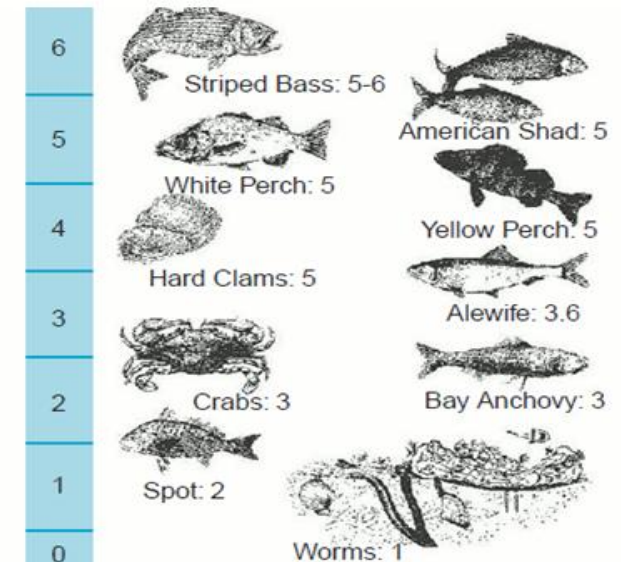
Reflecting seasonal water-column structure and the habitat needs of diverse aquatic life.

Migratory Spawning and Nursery Habitats

Shallow-Water and Open-Water Habitats

Deep-Water Habitats

Deep-Channel Habitats



WQS Criteria

Criteria	Designated Use	Threshold	Applicable Segments
Dissolved Oxygen	Migratory Fish Spawning & Nursery (MSN)	30-day mean, February-May	73
	Open Water (OW)	30-day mean, June-September	92
	Deep Water (DW)	30-day mean, June-September	18
	Deep Channel (DC)	Instantaneous, June-September	10
Chlorophyll-a	Open Water (OW)	Chlorophyll-a concentrations	7
SAV and/or Water Clarity	Shallow Water (SW)	Segment-specific water clarity and bay grass acreage goals	79

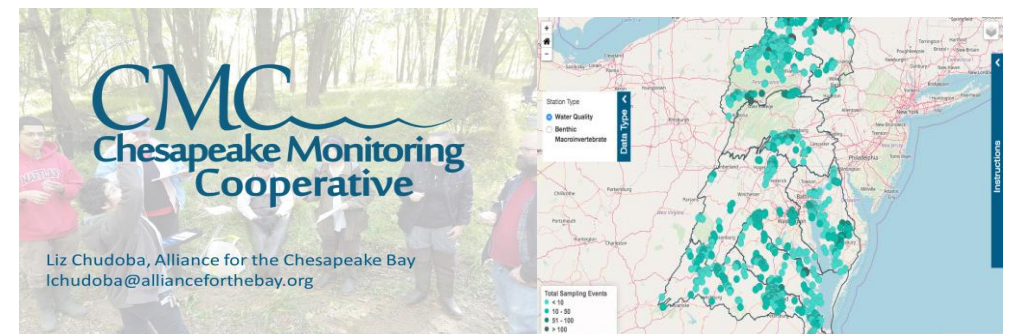
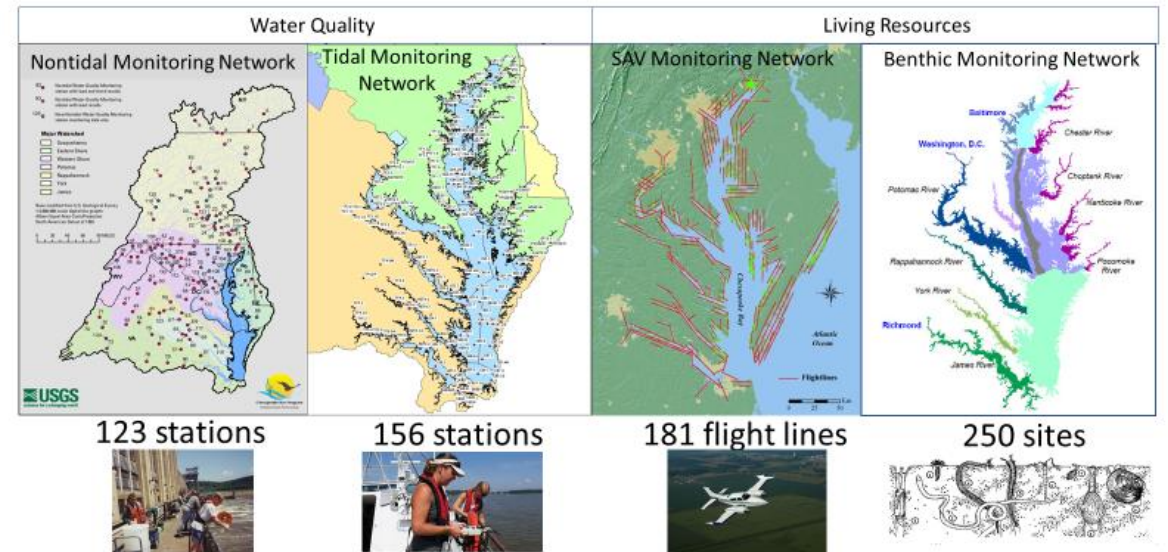
Note: The attainment indicator uses a subset of the complete accounting for the water quality criteria to ESTIMATE the attainment of water quality standards.

Monitoring Data

Data sources

- * Tidal water quality
- * SAV acreage
- * Community (Citizen) monitoring
- * Tidal benthic organisms
- * Nontidal nutrients and sediment

CBP Partnership Monitoring Networks: Annual Monitoring



Community Science Network support

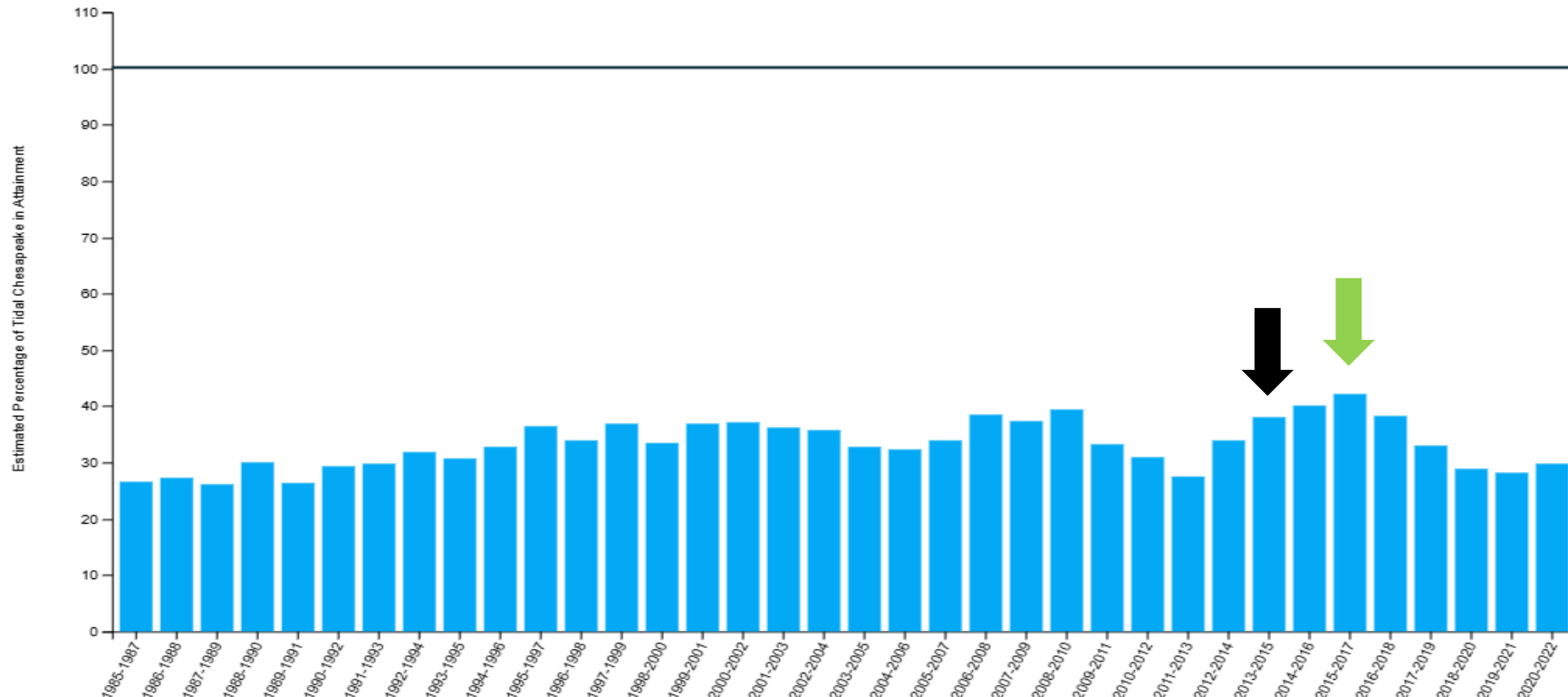
Slow, long-term improvement linked to long-term reduction in nutrient loads

Water Quality Standards Attainment (1985-2022) 📉

Water quality is evaluated using three parameters: dissolved oxygen, water clarity or underwater grass abundance, and chlorophyll a (a measure of algae growth).

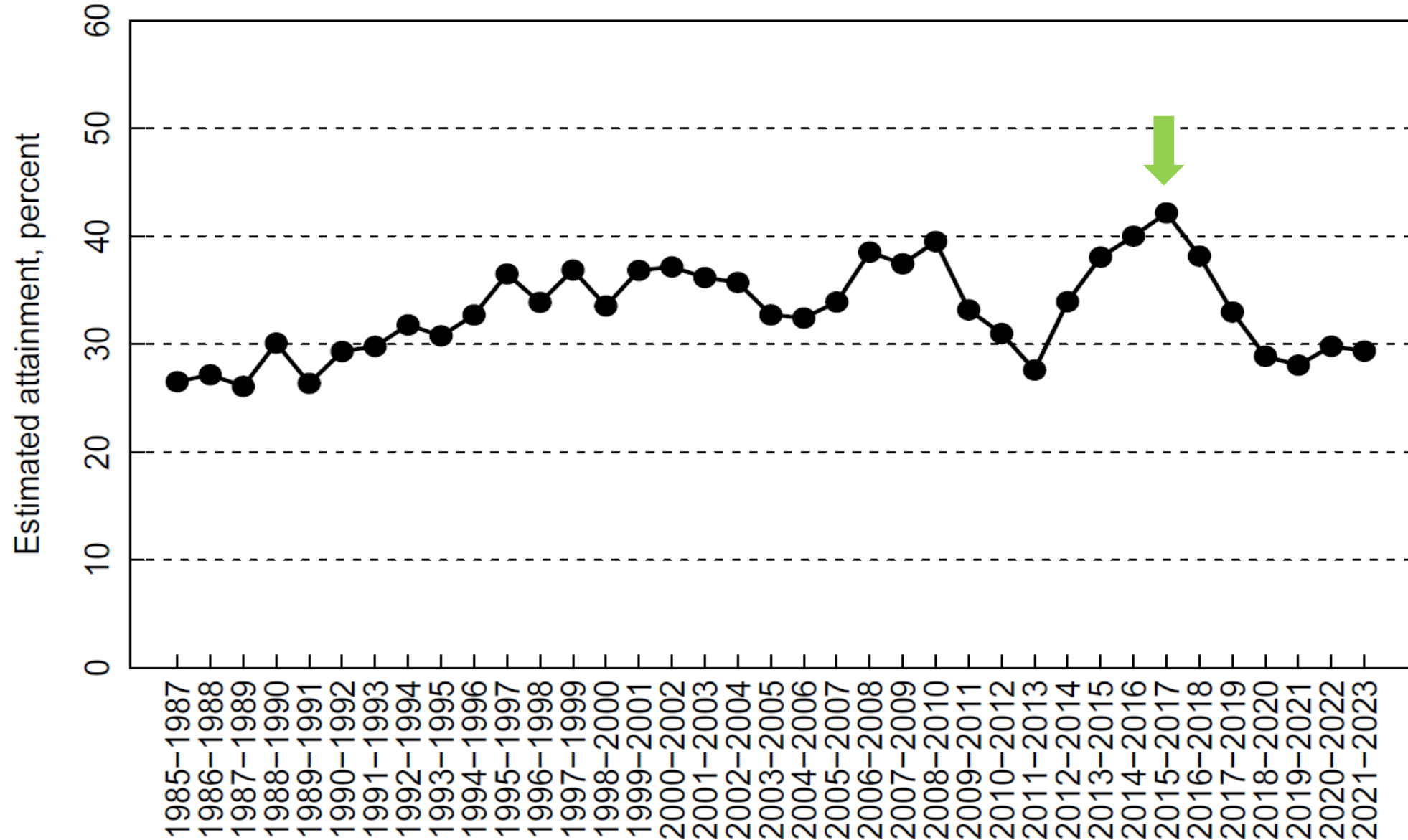
[VIEW CHART](#)

[VIEW TABLE](#)

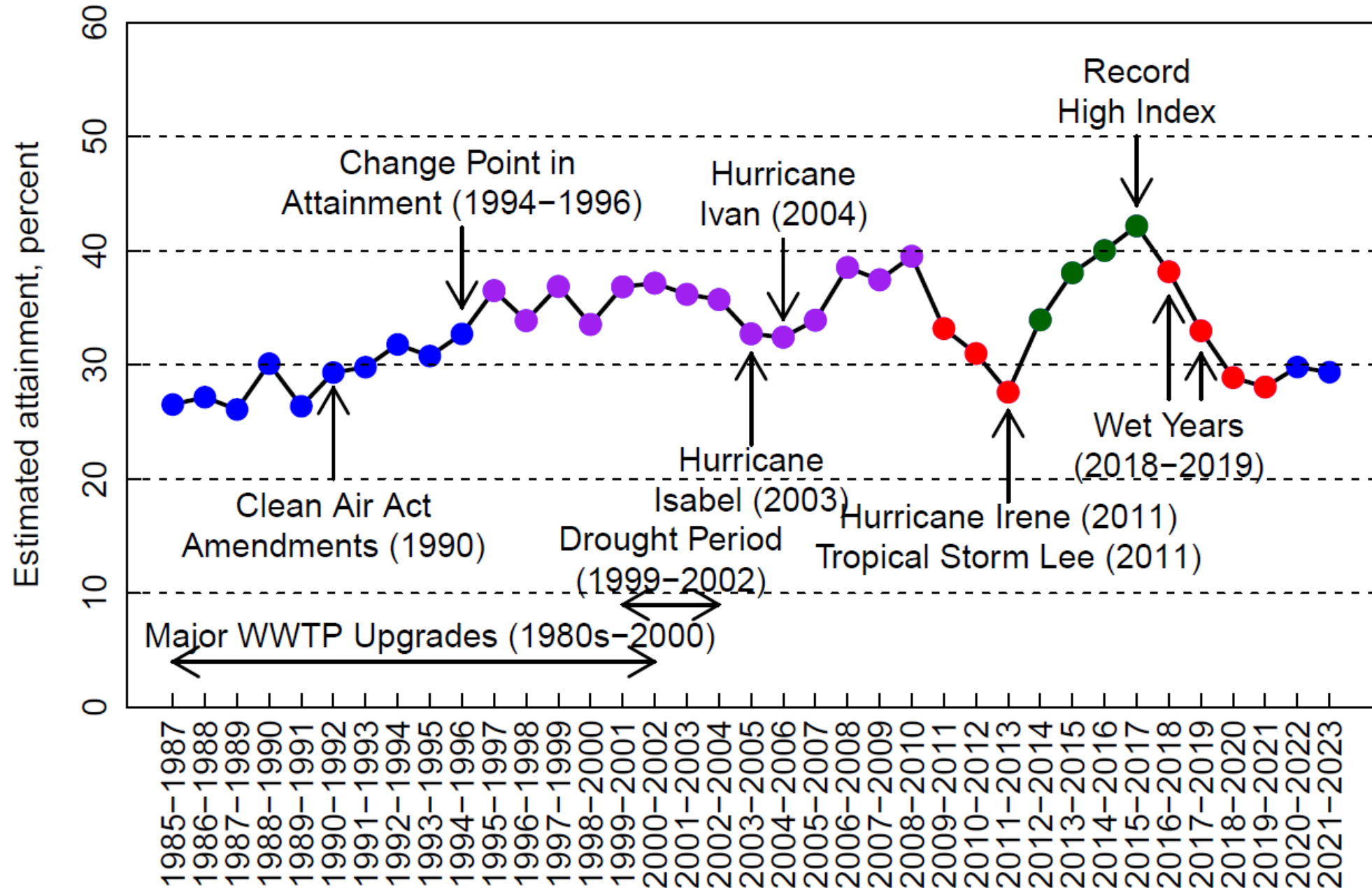


<https://www.chesapeakeprogress.com/clean-water/water-quality>

Slow, long-term improvement linked to long-term reduction in nutrient loads



Short-term variations driven by weather



R Shiny APP can provide location-specific results of the WQS attainment



- Segment-level results available as maps, time series plots, tables, and text summaries.
- These can be generated based on **user selections of inputs**.

<i>WQS Attainment Indicator or Deficit</i>
different assessment periods
different designated uses
different tidal segments
different WQS criterion
different tidal systems
different states
long-term and short-term trends

Attainment indicator app: https://wqs.chesapeakebay.net/wqs_attainment_indicator/

Attainment deficit app: https://wqs.chesapeakebay.net/wqs_attainment_deficit/



Geography, trajectories, and controls of coastal water quality: More rapid improvement in the shallow zone of the Chesapeake Bay

Qian Zhang ^{1,2}, Rebecca Murphy ^{1,2}, Richard Tian ^{1,2}, Peter Tango ^{2,3}

¹ University of Maryland Center for Environmental Science

² U.S. EPA Chesapeake Bay Program

³ U.S. Geological Survey



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Objective & Questions

Q1. What is the trajectory of the overall indicator scores over the last 37 years (i.e., 1985-2021), and how does the **trajectory** vary between the DZ and the SZ?

- *Hypothesis: WQS attainment has improved in both the DZ and the SZ after decades of nutrient reductions, but that response has been more rapid in the SZ due to its proximity to managed nutrient sources.*

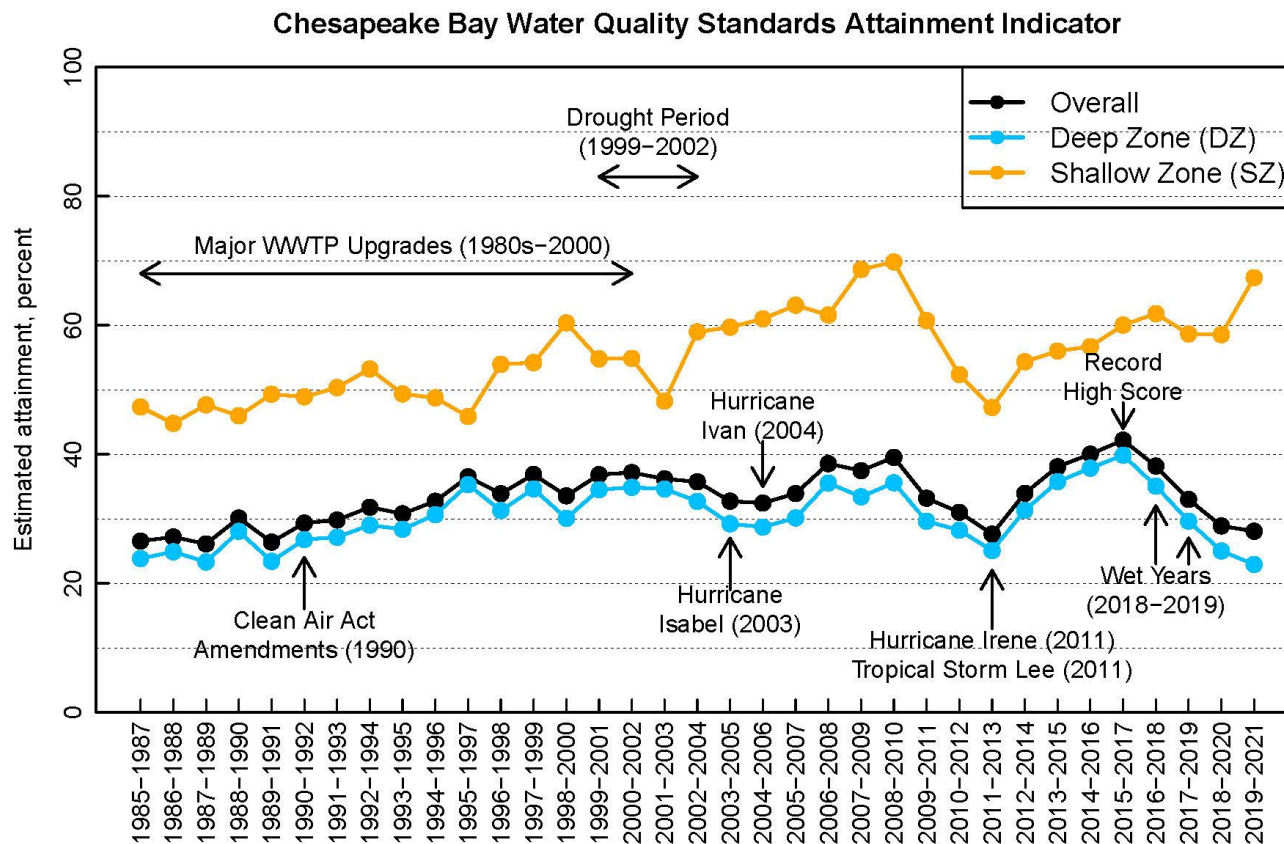
Q2. What are the main drivers affecting the indicator, and how do the **drivers** differ between the DZ and the SZ?

- *Hypothesis: Although the attainment indicator trajectory has been previously linked to the reduction in N load, it may have also been affected by other external and internal drivers.*

Data & Methods

- **Bay segmentation**
 - 92 management segments based on salinity, depth, and circulation.
- **Shallow Zone (SZ)**
 - Tidal fresh and oligohaline segments.
 - 47 segments; 142 segment-DU pairs.
 - 13% of total Bay area.
 - **Note:** Not equivalent to "< 2m" area.
- **Deep Zone (DZ)**
 - Mesohaline and polyhaline segments.
 - 45 segments; 147 segment-DU pairs.
 - 87% of total Bay area.

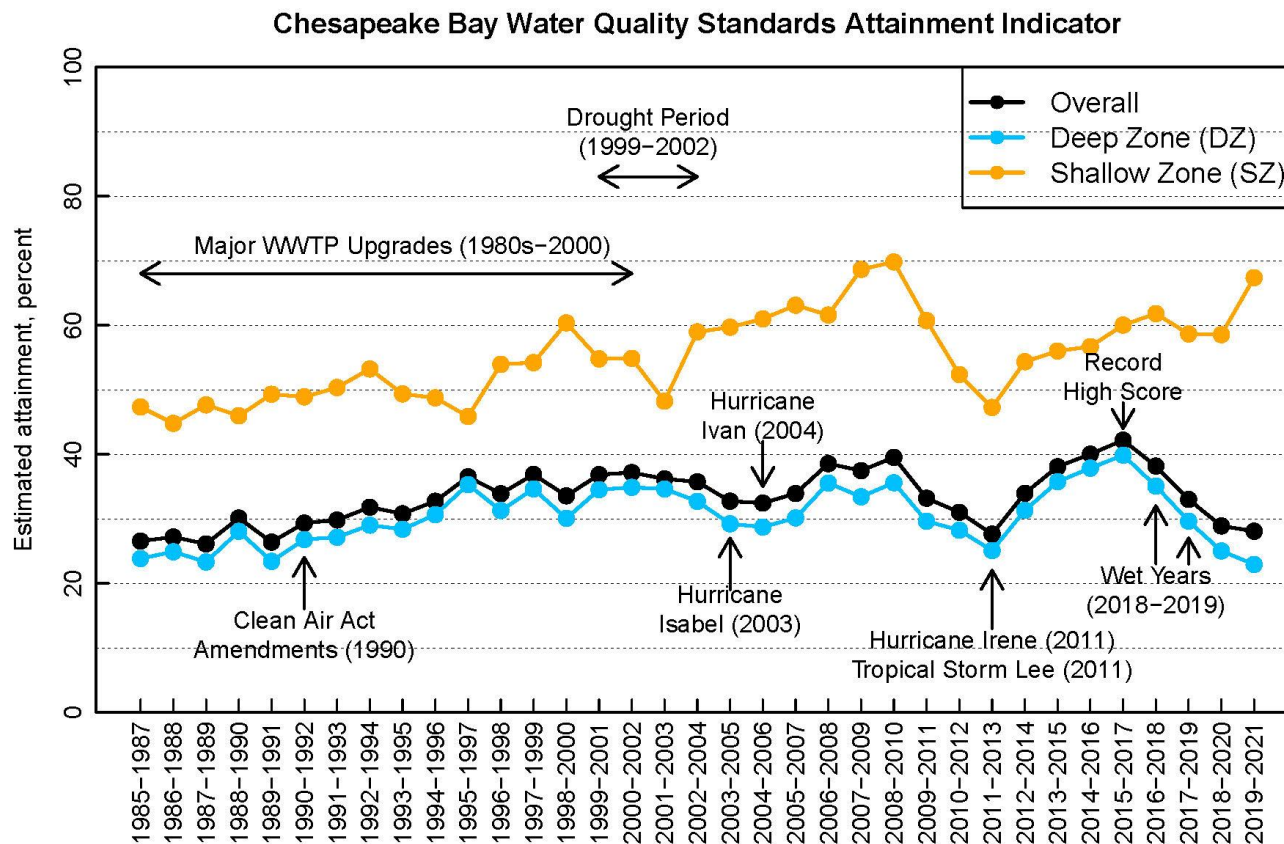
More rapid improvement in the SZ attainment than the DZ attainment



(Note: SZ = TF + OH; DZ = MH + PH)

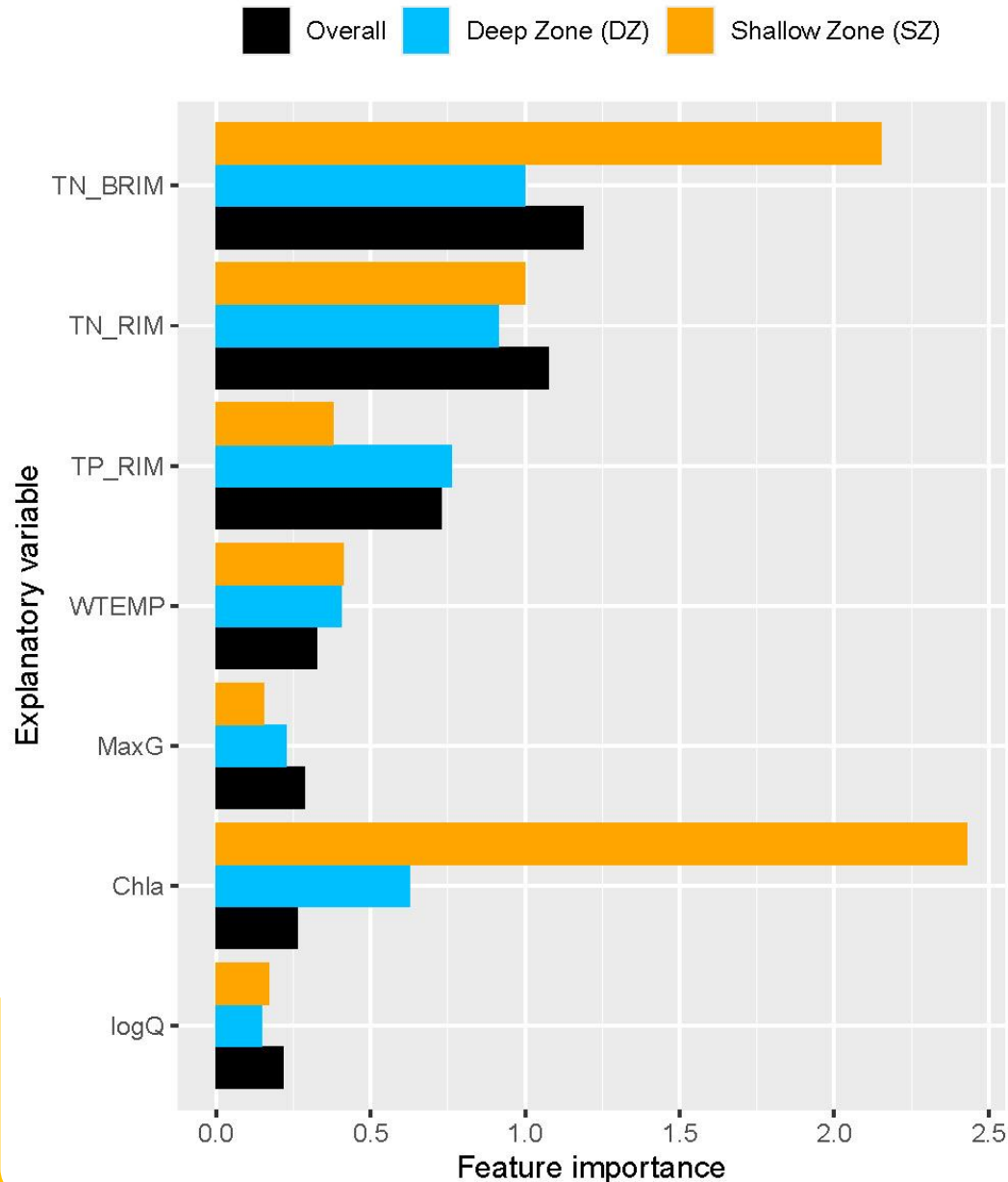
- **Overall attainment:** There has been a general increase since 1985, with a trend slope of 0.26%/year ($p < 0.05$).
- **DZ attainment:** The long-term trend slope is 0.21%/year ($p = 0.06$), with less variability in its trajectory.
- **SZ attainment:** The long-term trend slope is 0.49%/year ($p = 0.001$). SZ rebounded in the most recent assessment period - more rapid than DZ.

More rapid improvement in the SZ attainment than the DZ attainment



(Note: SZ = TF + OH; DZ = MH + PH)

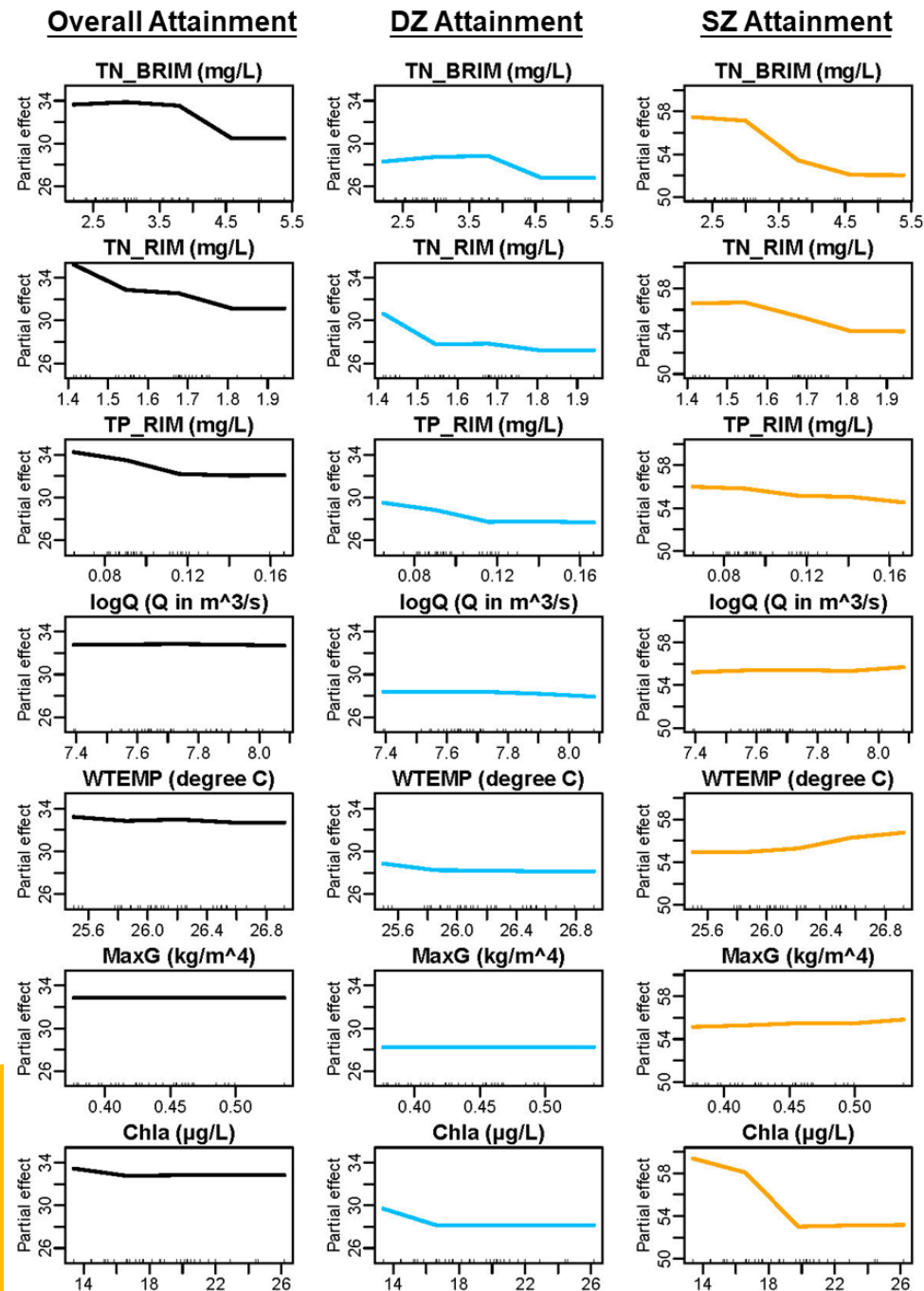
- Long-term improvements in the DZ and the SZ have both contributed to the long-term improvement in the overall indicator, but the more rapid response in the SZ has been masked by DZ.
- The **DZ trajectory** has been dominated by DO attainment.
- The **SZ trajectory** has been affected by both DO and water clarity/SAV, with the latter having a stronger impact.



Differential controls of DZ and SZ attainment

- **Overall attainment:** It has been more heavily affected by external drivers (i.e., TN_BRIM, TN_RIM, and TP_RIM) than internal drivers (i.e., WTEMP, MaxG, Chla).
- **SZ attainment:** TN_BRIM, TN_RIM, and TP_RIM are among the most important variables, but Chla ranks the highest. This may reflect the role of Chla (proxy of phytoplankton abundance) in modulating SAV/water clarity (e.g., shading) and DO (e.g., respiration, decomposition).

(Note: SZ = TF + OH; DZ = MH + PH)

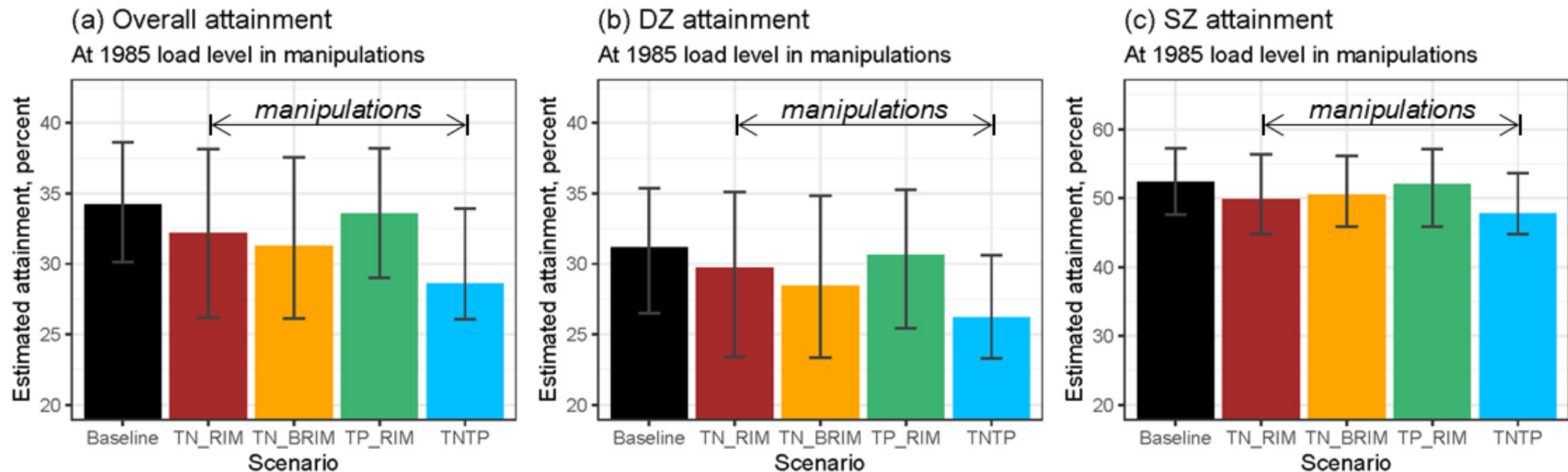


- **Overall attainment:** A higher attainment score corresponds to conditions of low TN_BRIM, low TN_RIM, and low TP_RIM, as well as low WTEMP and low MaxG. Thus, reductions in nutrient loads would improve attainment, whereas warming and stratification would degrade it.
- **DZ attainment:** Effects are generally similar to the overall attainment, but the negative effect of WTEMP is more evident.
- **SZ attainment:** The effects of the external drivers are also negative but more pronounced, potentially reflecting the proximity to managed nutrient sources. WTEMP has a positive effect, which reflect (a) an increase in DO attainment due to enhanced photosynthesis and/or (b) an increase in SAV/water clarity attainment due to enhanced SAV growth.

(Note: SZ = TF + OH; DZ = MH + PH)

Scenario analyses stressed the effects of nutrient load reductions

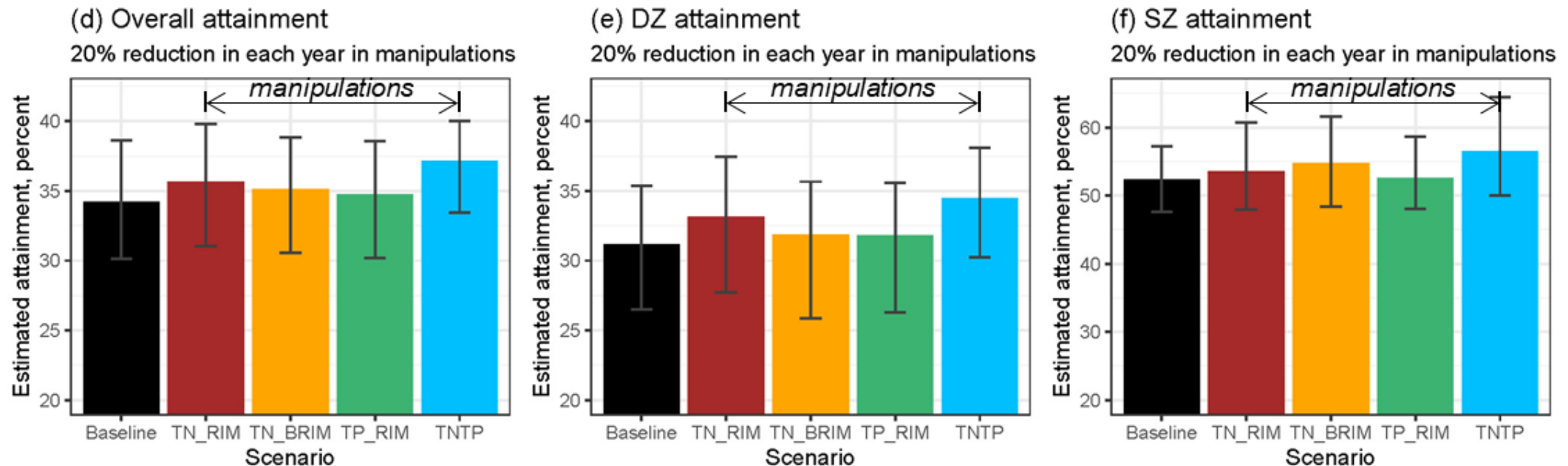
- **1st scenario:** If nutrient load levels were held at 1985 levels, the overall, DZ, and SZ attainments would all decline relative to baseline conditions. The worst scores would occur if TN_BRIM, TN_RIM, and TP_RIM were not managed.



(Note: SZ = TF + OH; DZ = MH + PH)

Scenario analyses stressed the effects of nutrient load reductions

- **2nd scenario**: Lowering nutrient load levels by 20% each year would lead to improvements in the overall, DZ, and SZ attainments. The best scores would occur if TN_RIM, TN_BRIM, and TP_RIM were reduced simultaneously.



(Note: SZ = TF + OH; DZ = MH + PH)

Key Takeaways

Q1. What is the trajectory of the overall indicator scores over the last 37 years (i.e., 1985–2021), and how does the trajectory vary between the DZ and the SZ?

- Water quality improved in **both the DZ and the SZ**, but the SZ improved at a faster rate than the DZ.
- Due to the dominance of the DZ segment, the overall attainment trajectory is similar to the DZ attainment.
- DZ and SZ showed differential responses: **A slow response in the DZ** (dominated by the signal of DO) vs. **a more rapid response in the SZ** (dominated by signals of DO and water clarity/SAV).

Key Takeaways

Q2. What are the main drivers affecting the indicator, and how do the drivers differ between the DZ and the SZ?

- The trajectory of the overall attainment has been affected by **mainly external drivers** (i.e., reductions in TN and TP loads) and, **to a lesser extent, internal drivers** (i.e., water temperature and stratification).
- **Nutrient load reductions** improved water quality, **whereas internal drivers like warming and stratification** hindered progress, which are consistent with findings from many prior studies.
- Scenario analyses demonstrate the importance of **managing both nitrogen and phosphorus loads** for better water quality outcomes.



Dissolved Oxygen Criteria Attainment in Chesapeake Bay: Where Has It Improved Since 1985?

Qian Zhang ^{1,2}, Rebecca Murphy ^{1,2}, Richard Tian ^{1,2}, Kaylyn Gootman ², Peter Tango ^{2,3}

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Objective

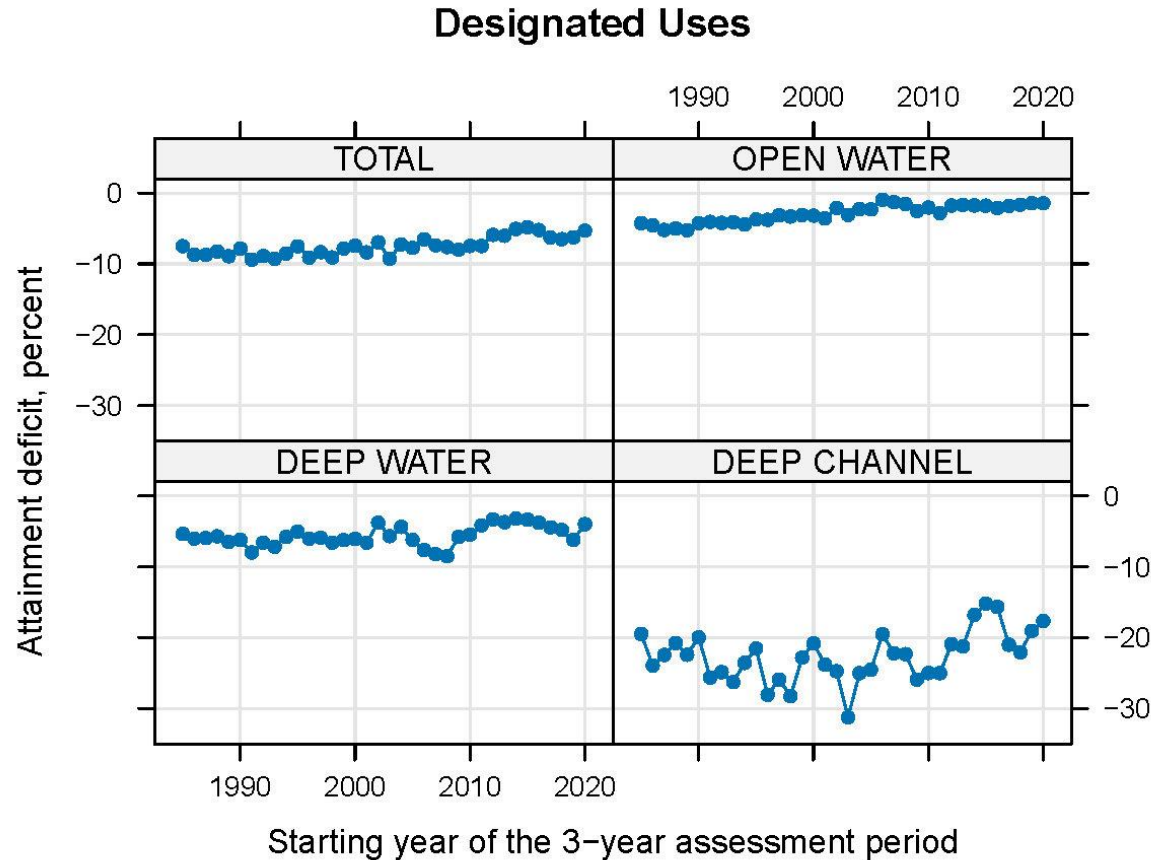
To provide updated information on the status and trends of DO criteria attainment in the Bay and help address a critical management question, i.e., ***where has the DO criteria attainment improved since 1985?***

- Extended our prior assessment to the latest 2020-2022 period.
- Focused on the comparison of trends among 13 tidal systems.
- Developed a “report card” summary for attainment trends.

Attainment Deficit (AD)

- **Attainment indicator and attainment deficit (AD)** aimed at providing temporally and spatially consistent assessments over time.
- **Attainment indicator (binary)**: 0 (non-attainment) or 1 (in attainment) for each segment-DU-criterion combination ($n = 291$).
- **Attainment deficit (AD)** digresses away from the indicator's binary nature by quantifying the amount of space-time violation.
 - **0% = best possible condition** (minimum WQ requirements are met for protecting aquatic life in the defined zones).
 - **-100% = the worst possible condition** (complete non-compliance).
 - **Note:** For AD, an improving trend indicates progress toward attainment, a declining trend indicates degradation, and neither trend means that the required water quality standards are met.

Overall DO Attainment Trends



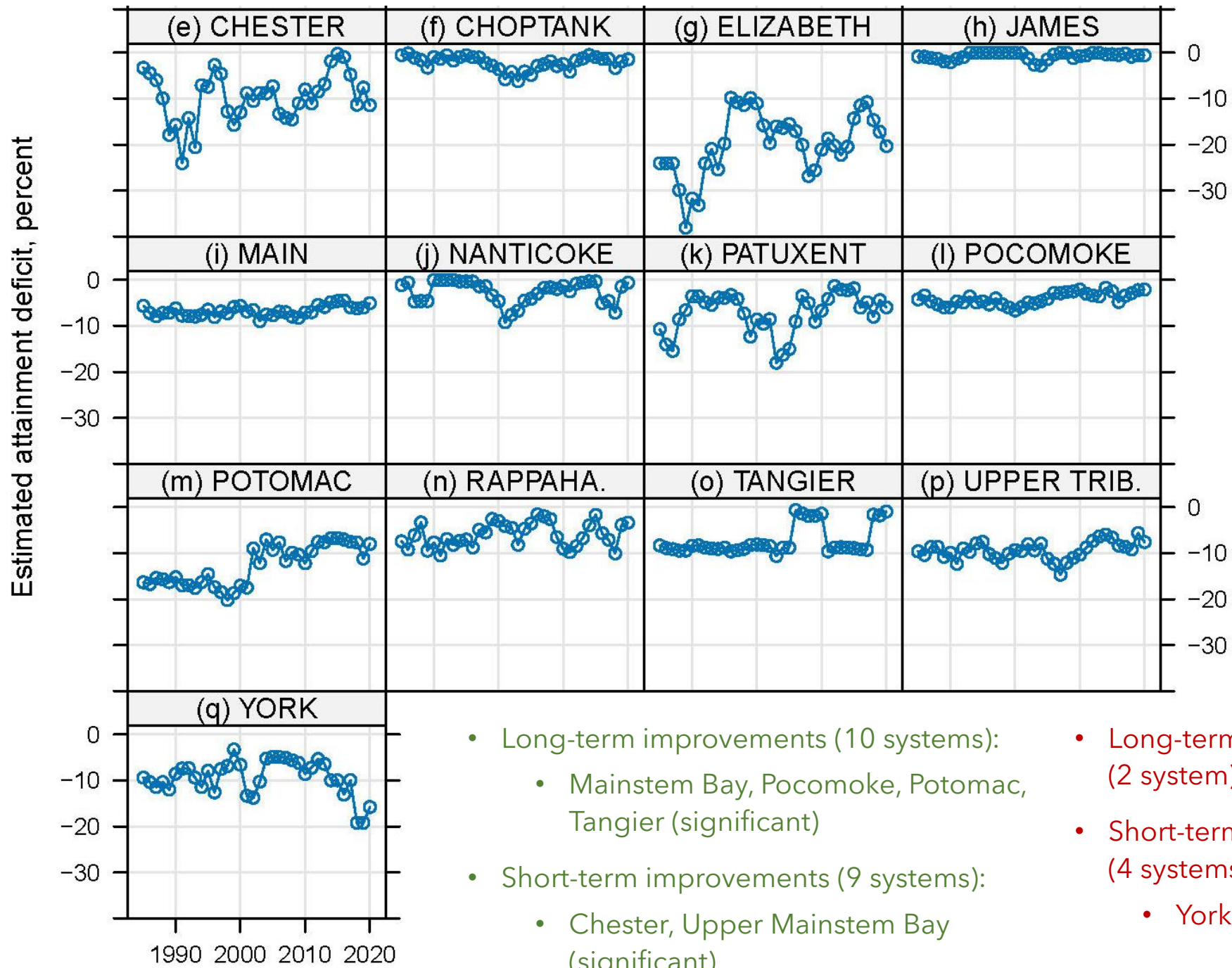
- Improvement observed from 1985 to 2022.
- **Long-term (LT) trend:** 0.10%/year improvement ($p < 0.05$).
- **Short-term (ST) trend:** 0.15%/year improvement ($p = 0.13$).

Trends by Designated Use

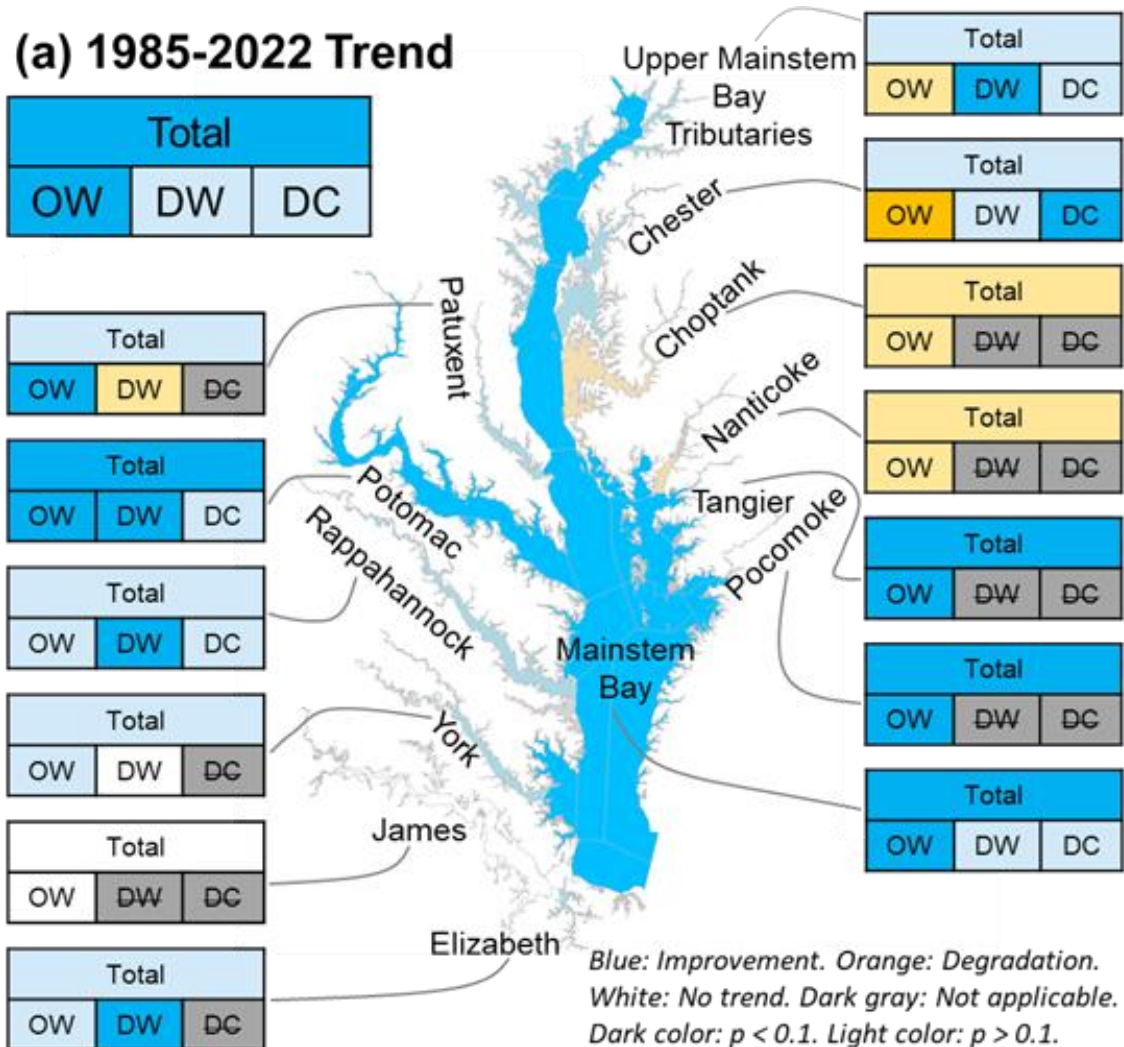
Subgroup	Initial deficit (1985–1987), percent	Current deficit (2020–2022), percent	Change point (3-year period)		Long-term trend, percent/year		Short-term trend, percent/year	
<i>Overall Attainment</i>								
TOTAL	-7.5	-5.3	2003–2005	***	0.10	***	0.15	–
<i>Designated Uses</i>								
Open water (OW)	-4.3	-1.4	2001–2003	***	0.11	***	0.004	–
Deep water (DW)	-5.4	-4.0	2008–2010	***	0.06	–	0.20	–
Deep channel (DC)	-19.5	-17.6	2011–2013	***	0.11	–	0.39	***

- **Open Water (OW):** Significant LT improvement (0.11%/year).
- **Deep Water (DW):** Improving, but not statistically significant.
- **Deep Channel (DC):** Significant ST improvement (0.39%/year).
- **Chang Points:** OW (2001–2003) occurred earlier than DW (2008–2010) & DC (2011–2013), suggests varying responses of different depths.

Trends by Tidal System



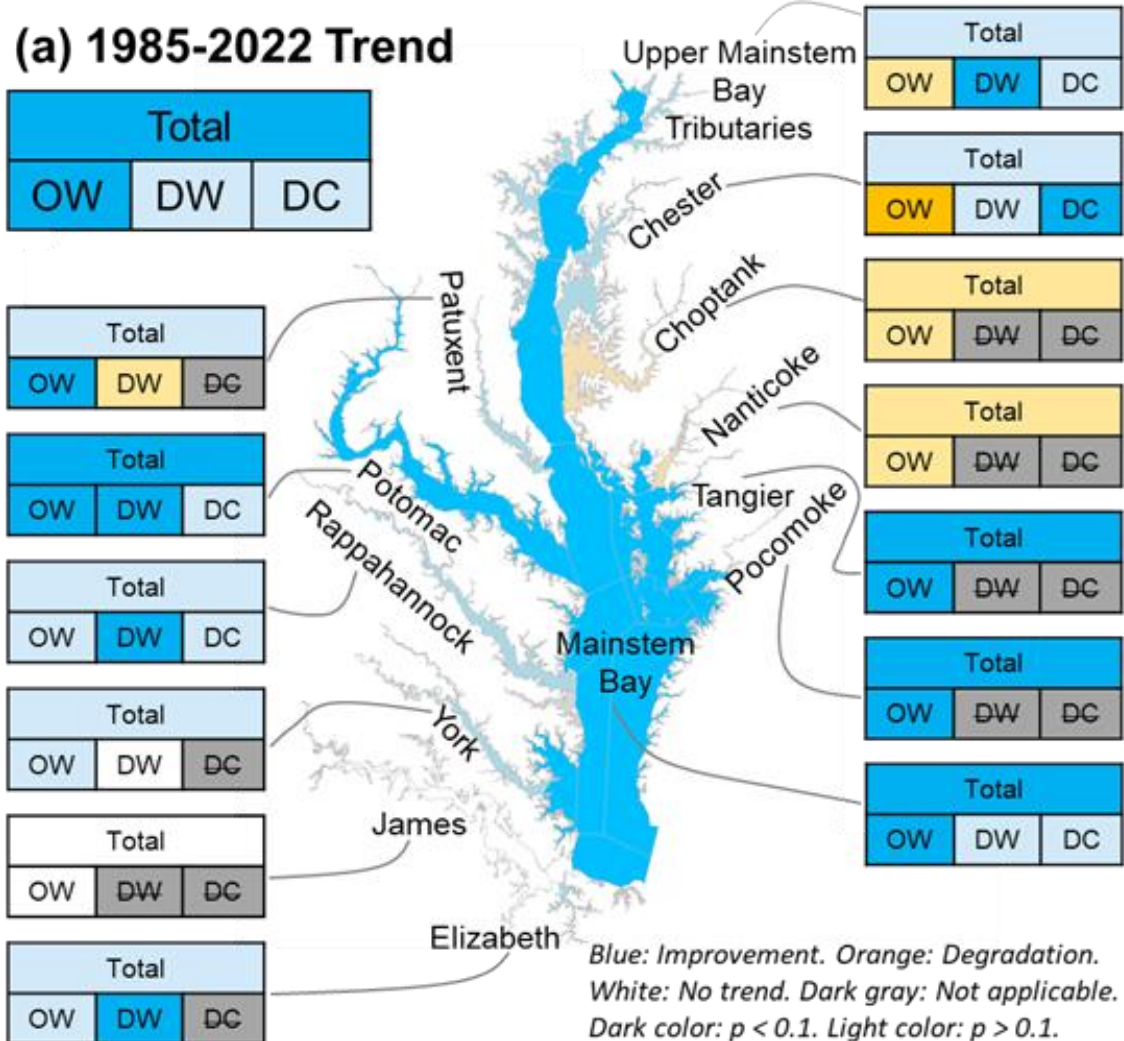
Trends by Tidal System and DU



- A report card summary was produced to provide a concise depiction of the various trends for each system.
- Blue and orange shades indicate improving and degrading trends, respectively.
- Dark and light shades indicate statistically significant ($p < 0.1$) and insignificant ($p > 0.1$) trends, respectively.
- **Note:** Not all systems have DW or DC. Also, for a system with DW and/or DC, not all segments within that system contributes to its DW or DC trend.

Trends by Tidal System and DU

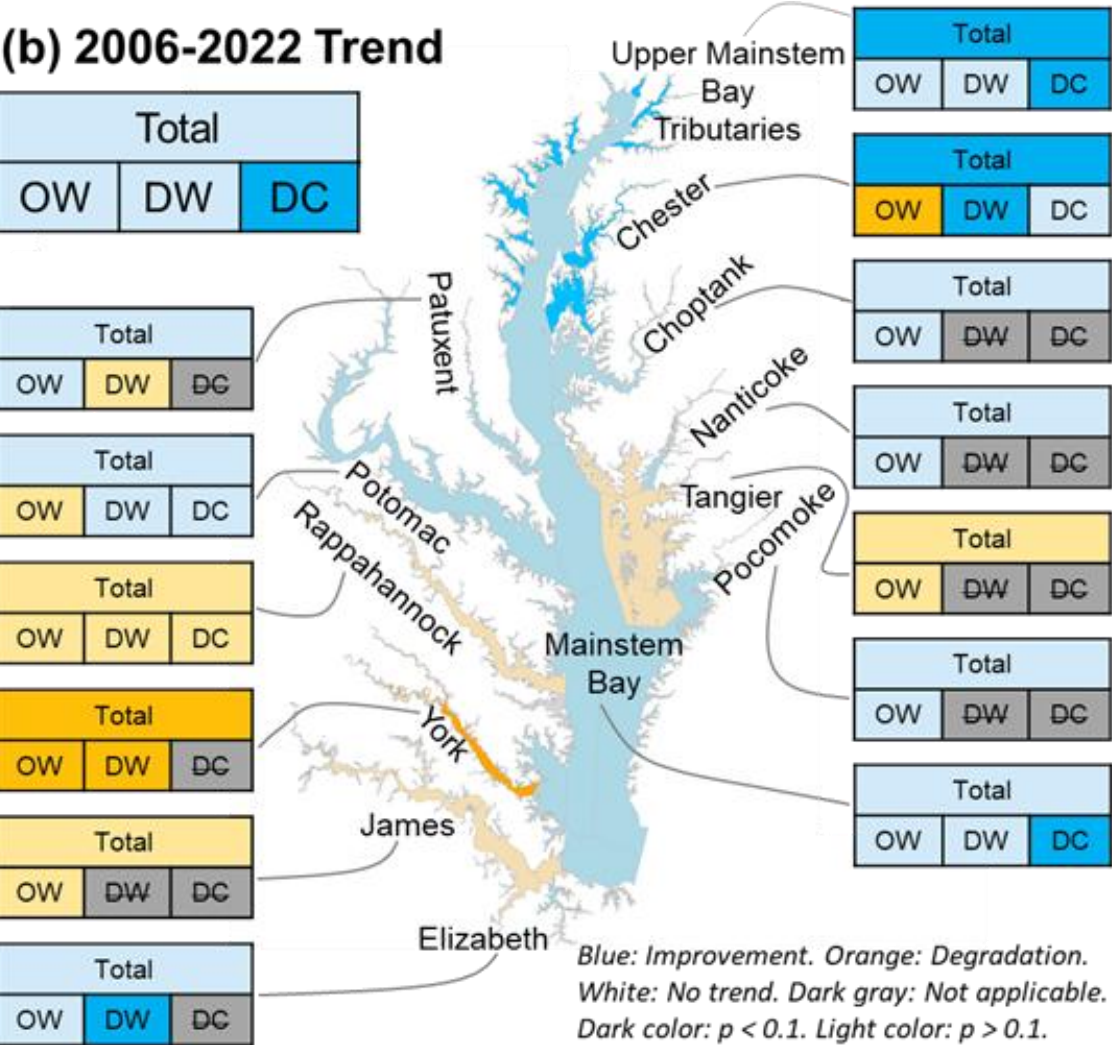
(a) 1985-2022 Trend



Long Term	OW	DW	DC
No. systems	13	8	5
Improvement (significant)	8 (5)	6 (4)	5 (1)
Degradation (significant)	4 (1)	1 (0)	0 (0)

Trends by Tidal System and DU

(b) 2006-2022 Trend



Short Tterm	OW	DW	DC
No. systems	13	8	5
Improvement (significant)	7 (0)	5 (2)	4 (2)
Degradation (significant)	6 (2)	3 (1)	1 (0)

Key Takeaways

- The overall attainment deficit showed improving trends in both long and short terms, which can be mainly attributed to OW and DC designated uses, respectively.
- Long-term and short-term trend slopes and p-values were quantified for 13 tidal systems. 10 and 9 systems had improvements in the long and short terms, respectively.
- A report card was produced to provide a concise depiction of the trends for the 13 systems and their DUs -- the first of its kind in the context of DO criteria assessment.



Thank you!

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