# Hot, Wet, and Crowded: Phase 6 Climate Change Model Findings

Climate Resiliency Workgroup
April 20, 2020

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# Key Points in Assessment of 2025 Climate Change Risk

- The new 2019 climate change assessment confirms the December 2017 climate change findings with a better model, providing better understanding of underlying processes, more specific findings on nutrient speciation, CSOs, wet deposition of nitrogen, etc.
- Consistent assessment of violation CB4MH Deep Channel and Deep Water nonattainment from December 2017 PSC meeting to today of about 1.4% and 1.0%, respectively, even though we’ve expanded our assessment to look at EVERYTHING in the CC analysis.

# Elements of Chesapeake Water Quality Climate Risk Assessment

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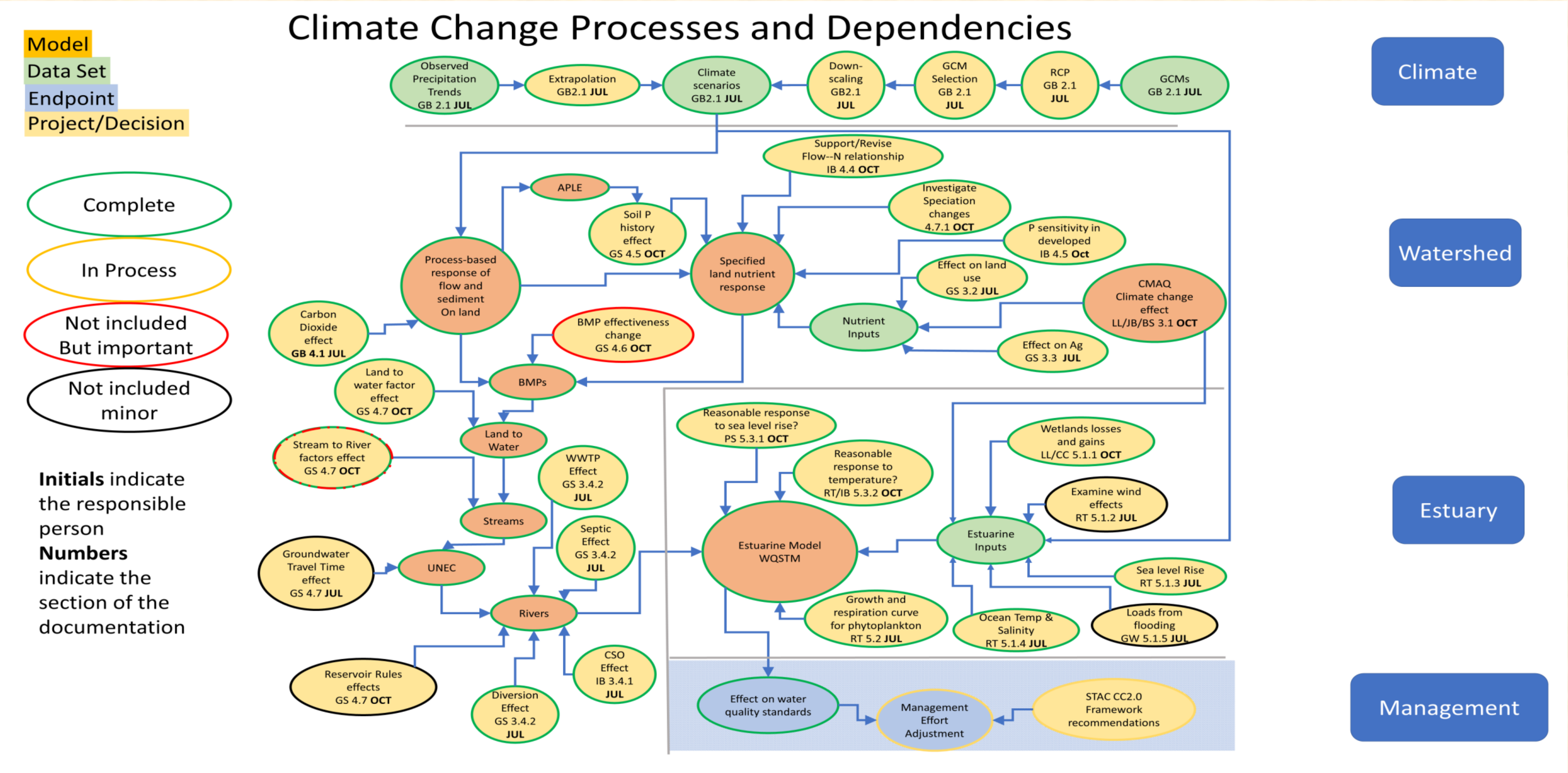
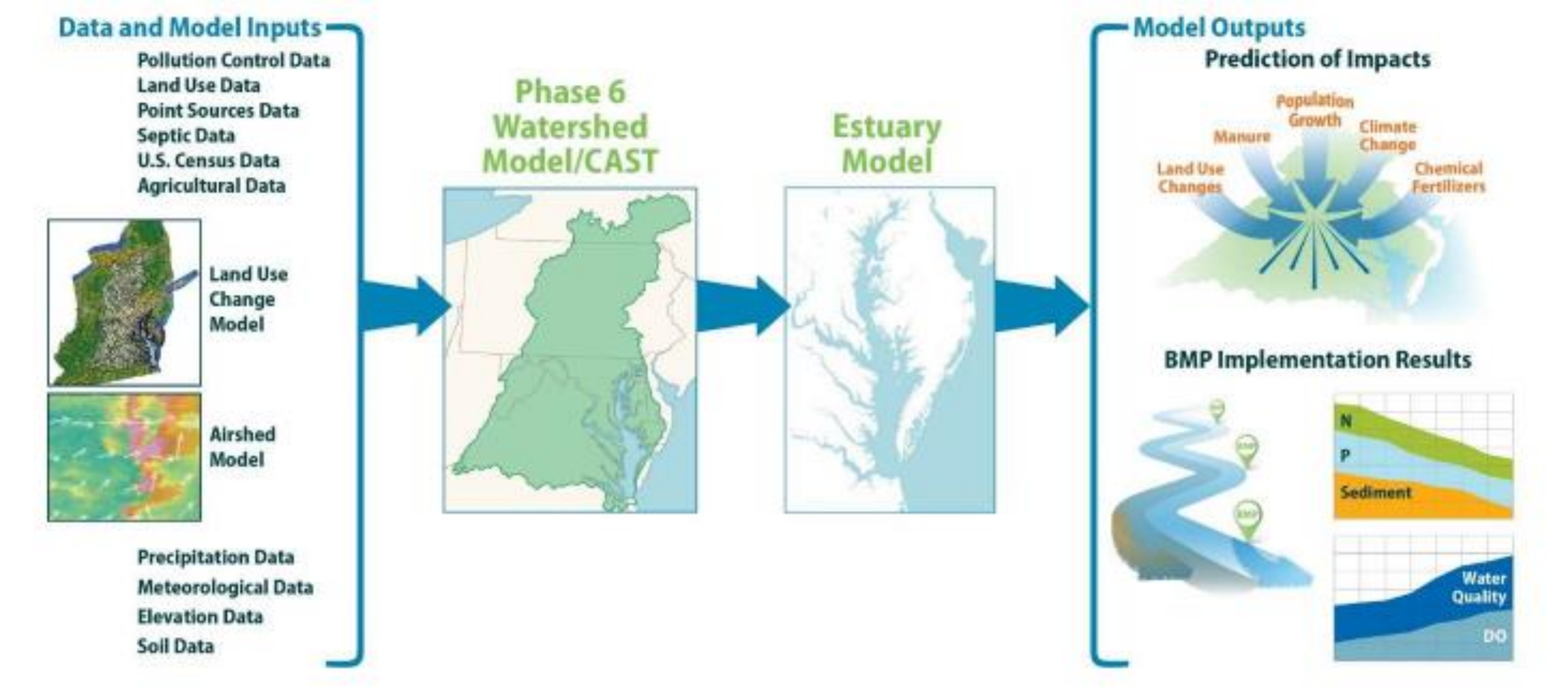


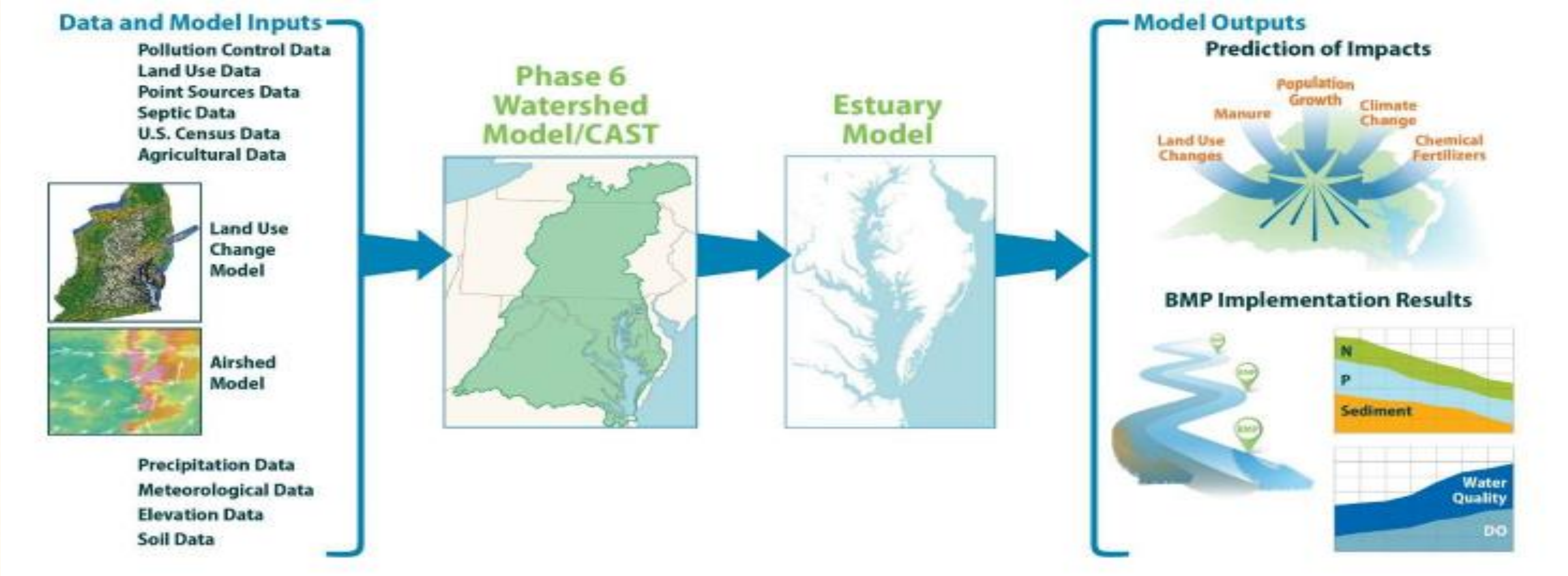
# Assessment of 2025 Climate Change in the Airshed

## Airshed Key Finding: Increased wet deposition N loads under increased precipitation.



# Assessment of 2025 Climate Change in the Watershed

Watershed Key Findings: Increased precipitation volume, precipitation intensity, and evapotranspiration are major determinates of changes in loads due to climate change. (Land use change beyond 2025 also increases nutrient and sediment loads.)



# Precipitation Volume Increasing

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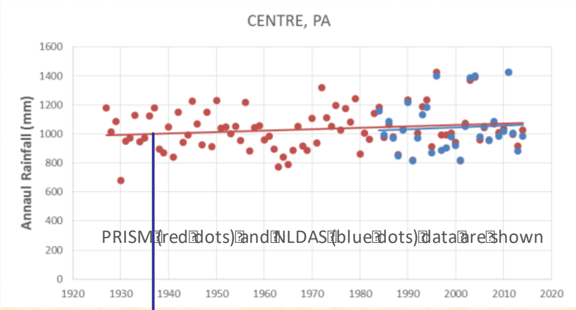
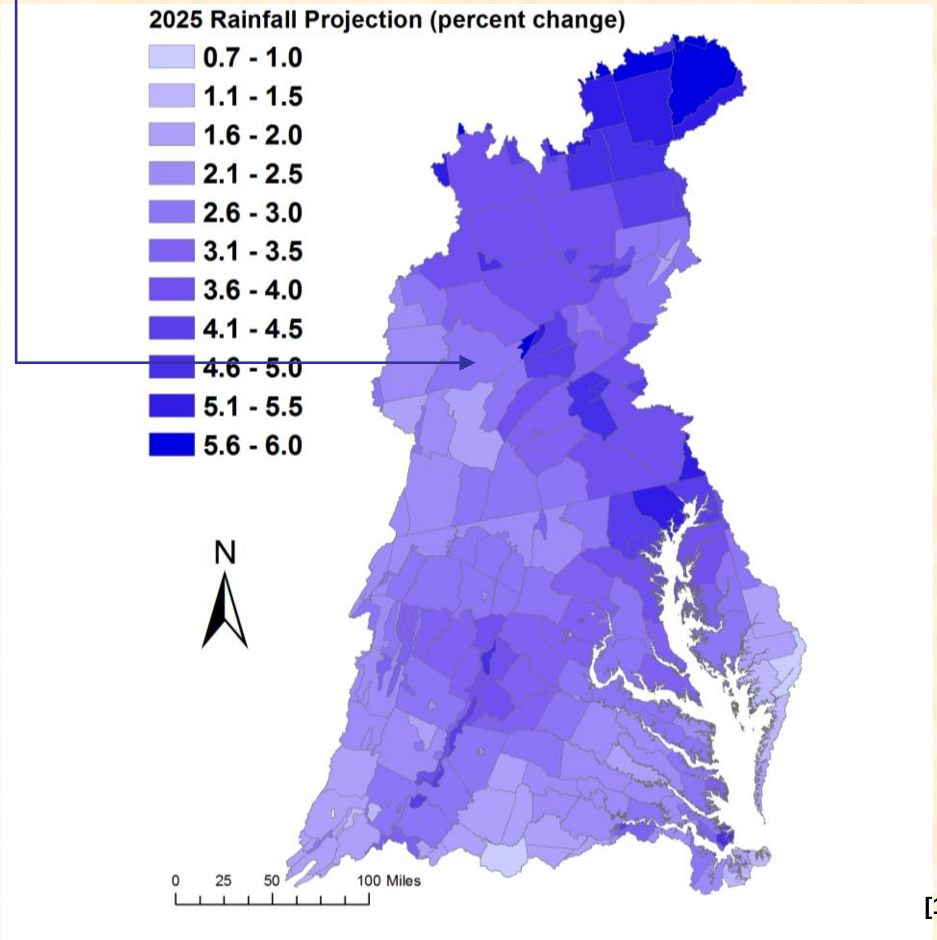



**Projections of rainfall increase using trend in 88-years of annual PRISM[1] data**

**Change in Rainfall Volume 2021-2030 vs. 1991-2000**




| Major Basins | PRISM Trend |
|---|---|
| Youghiogheny River | 2.1% |
| Patuxent River Basin | 3.3% |
| Western Shore | 4.1% |
| Rappahannock River Basin | 3.2% |
| York River Basin | 2.6% |
| Eastern Shore | 2.5% |
| James River Basin | 2.2% |
| Potomac River Basin | 2.8% |
| Susquehanna River Basin | 3.7% |
| **Chesapeake Bay Watershed** | **3.1%** |

[1] Parameter-elevation Relationships on Independent Slopes Model

**The 1991 – 2000 period of hydrology & nutrient loads is the basis of decisions in the Chesapeake TMDL.**

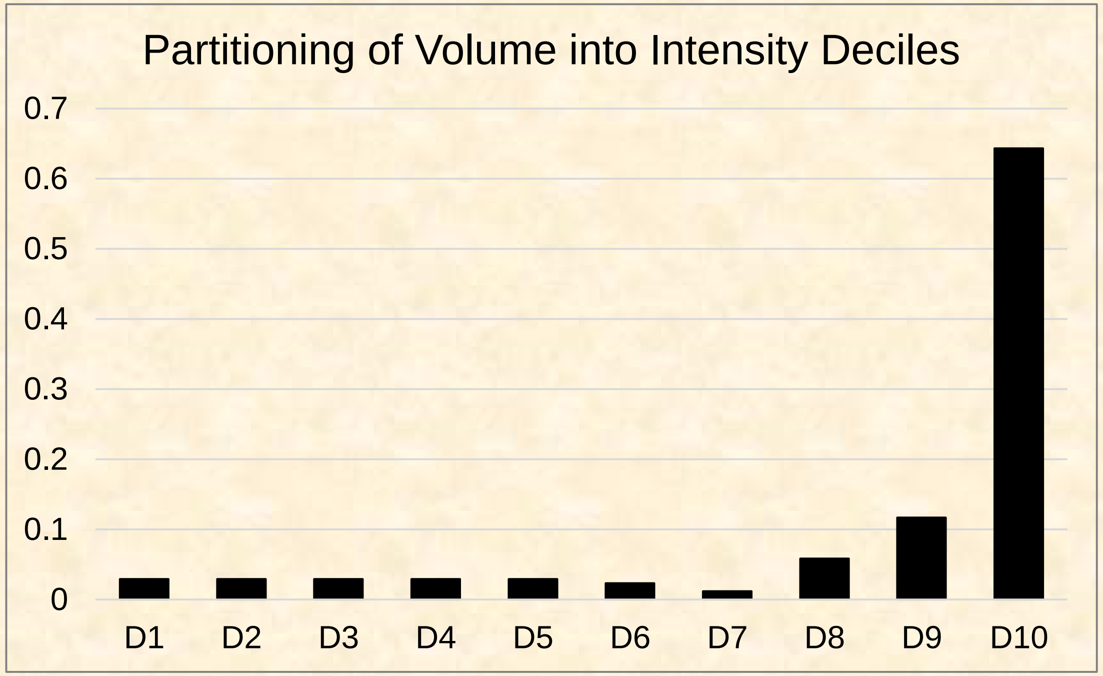
**There are 30 years between 1995 and 2025.**

**Long term mean precipitation increased 3.1% and temperature by 1º C.**

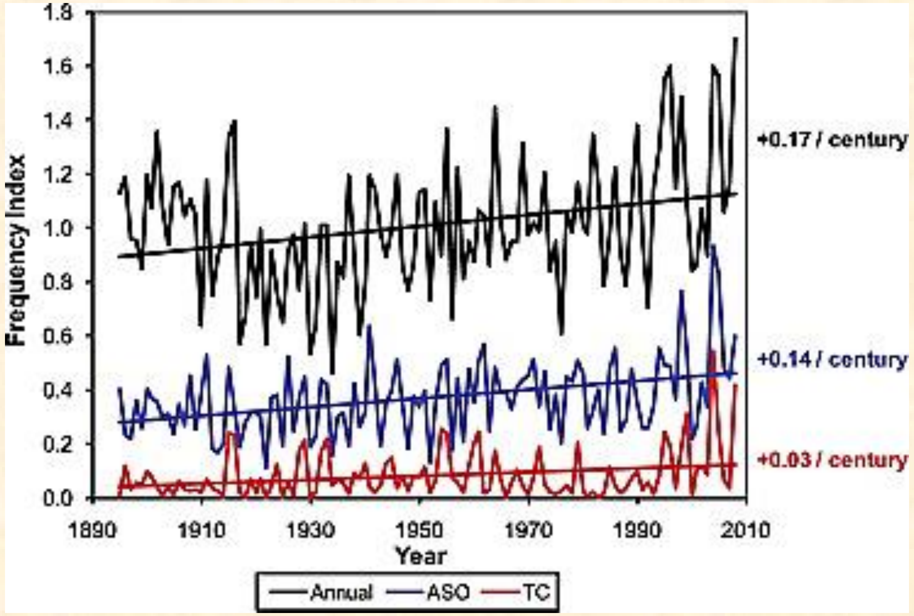
# Rainfall Intensity Increasing



*Observed trend of more precipitation volume in higher intensity events based on a century of observations.*




Source: Groisman et al., 2004




National average heavy precipitation event index (HPEI) for the entire year (annual, black), for August through October (ASO, blue), and for heavy events associated with tropical cyclones (TC, red). [Kunkel et al., 2010]

# Summary of Changes in Nutrient Species Delivery

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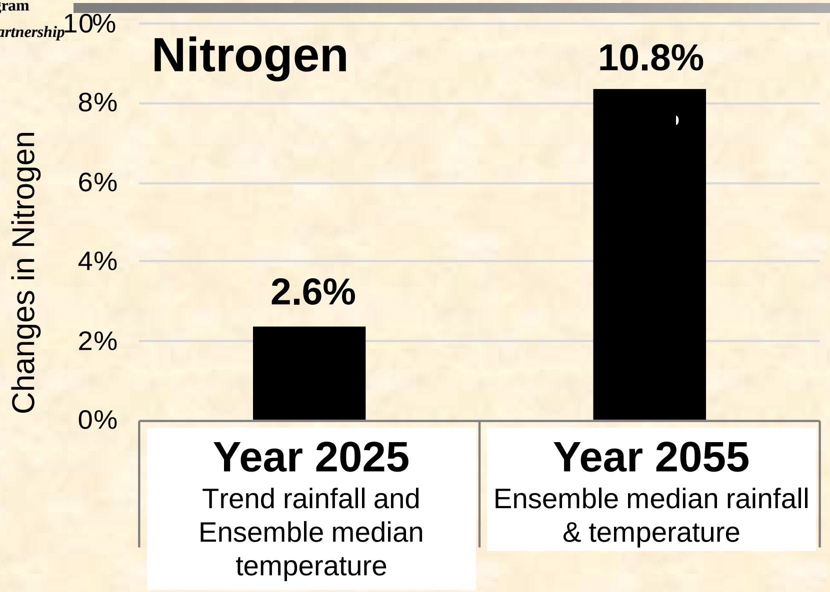
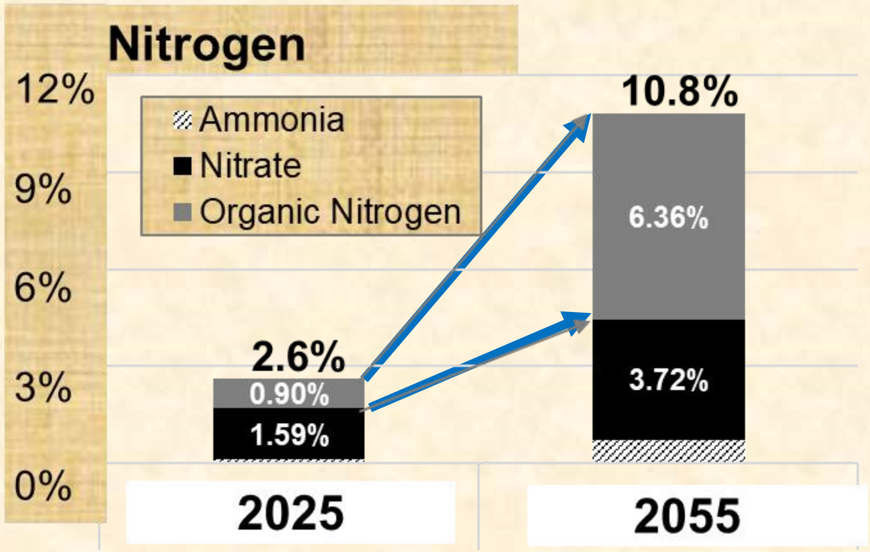
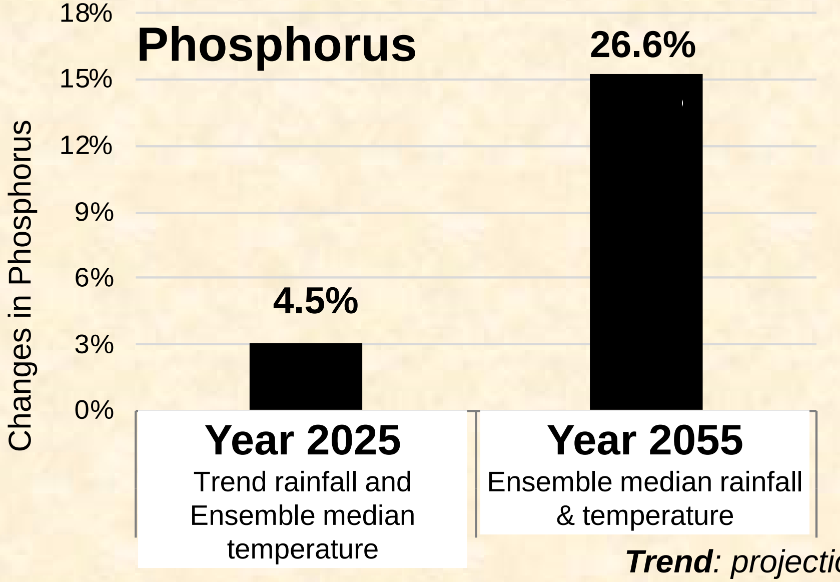
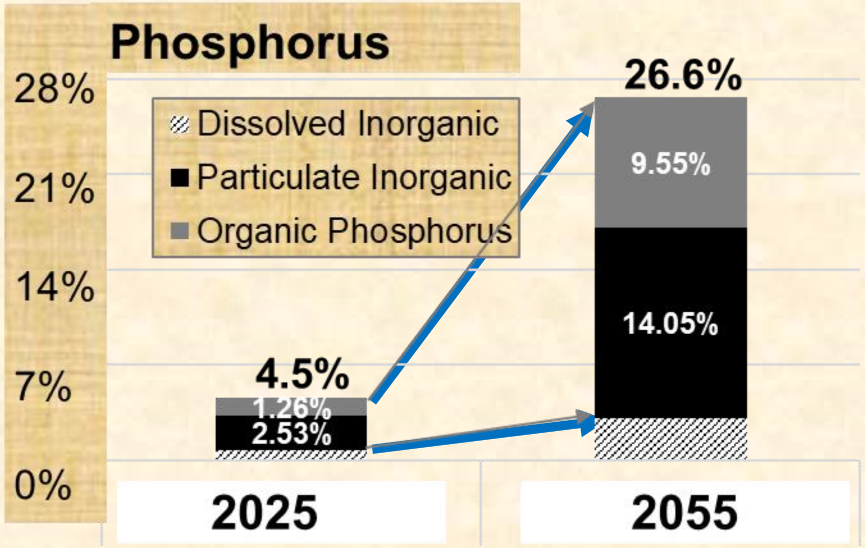



Arrows show relatively more increase in organic N & P or PIP compared to DIN or DIP.




The TN & TP loads are steadily increasing from 2025 to 2055 under climate change but there is a greater proportion of refractory N and P in the total N & P going forward.

***Trend****: projection of extrapolation of long-term trends*
***Ensemble****: 31-member ensemble of RCP4.5 GCMs*

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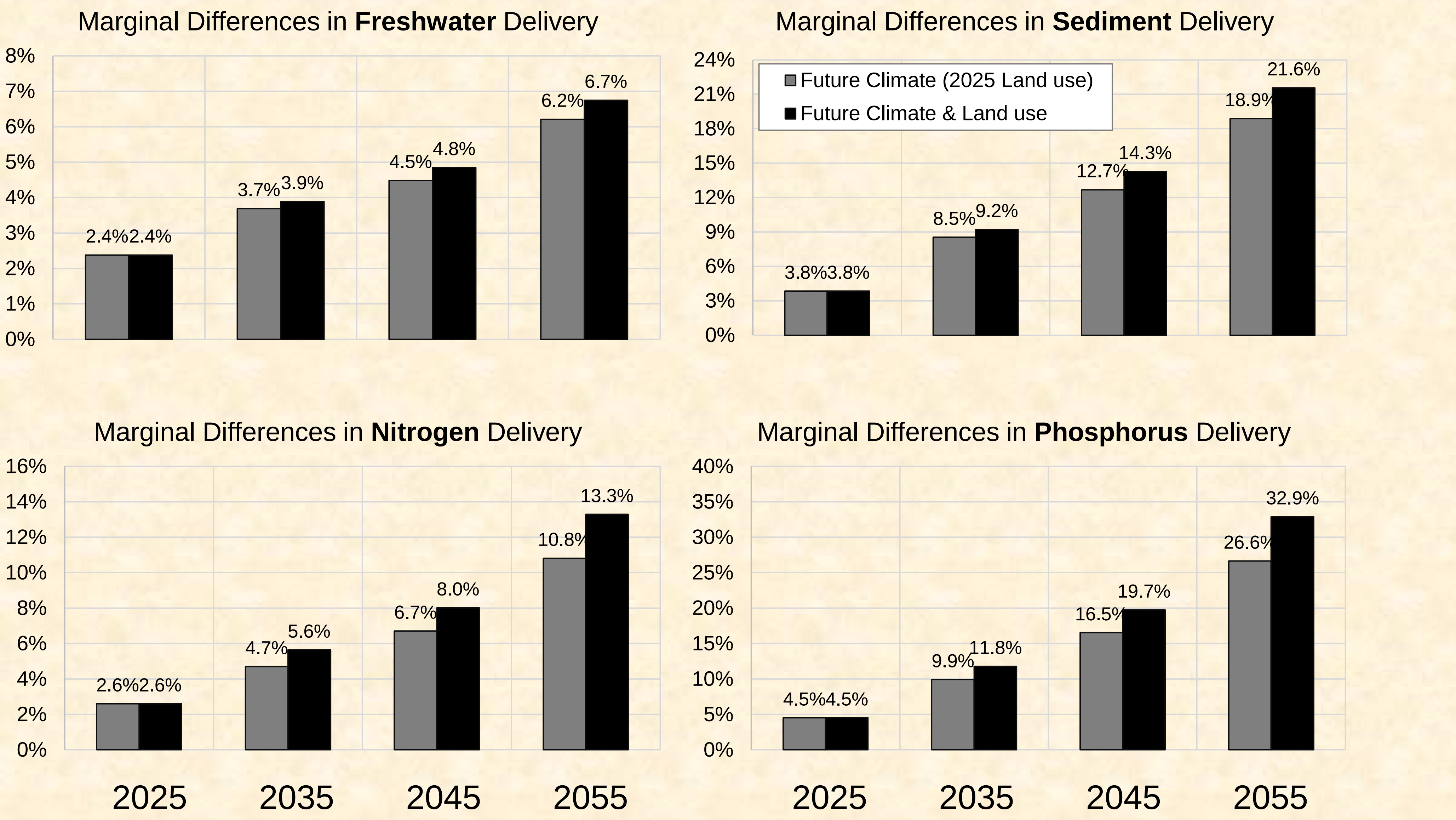
# Estimates of Climate Only and Climate and Land Use




Grey bar = climate only Black bar = Climate and Land Use

# Elements of 2025 Climate Change in the Estuary

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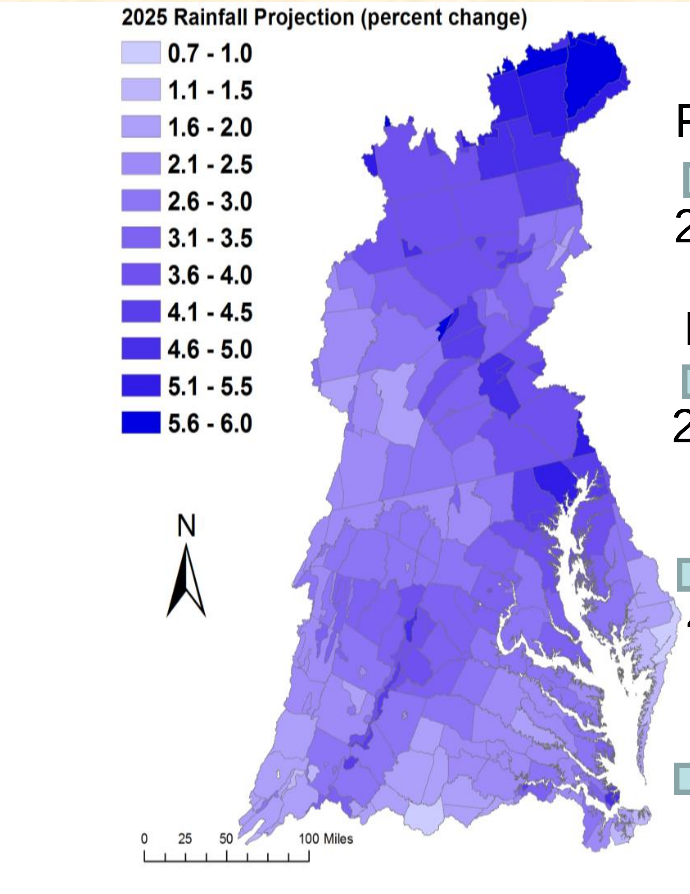
**Air-temperature increase: 1.06 °C**




**Phase 6 Watershed Model**

Flow
2.4% Increase

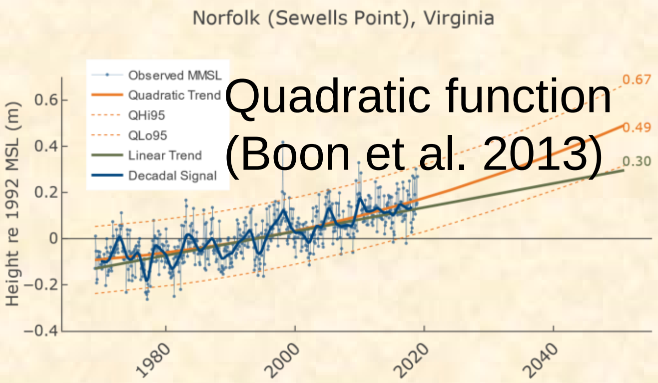
Nitrogen Load
2.6% Increase

Phosphorus Load
4.5% Increase

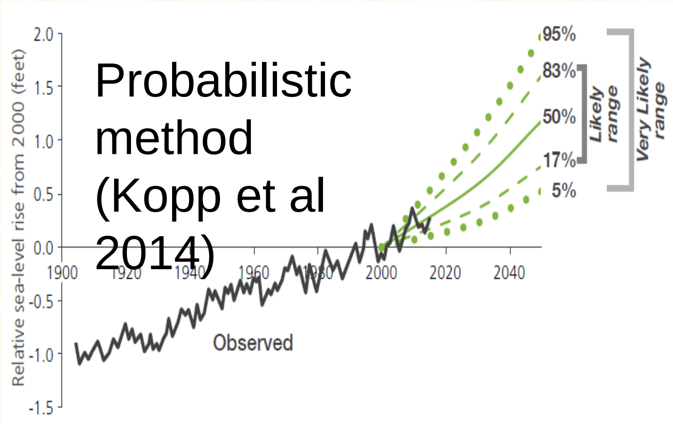
Sediment Load
3.8% Increase

**Model: CH3D-ICM**
**400m-1km Resolution**

**2025 Sea Level Rise: 0.22m**




Quadratic function (Boon et al. 2013)




Probabilistic method (Kopp et al 2014)

**Open boundary T: + 0.95 °C; S: + 0.18 psu (Thomas et al., 2017)**

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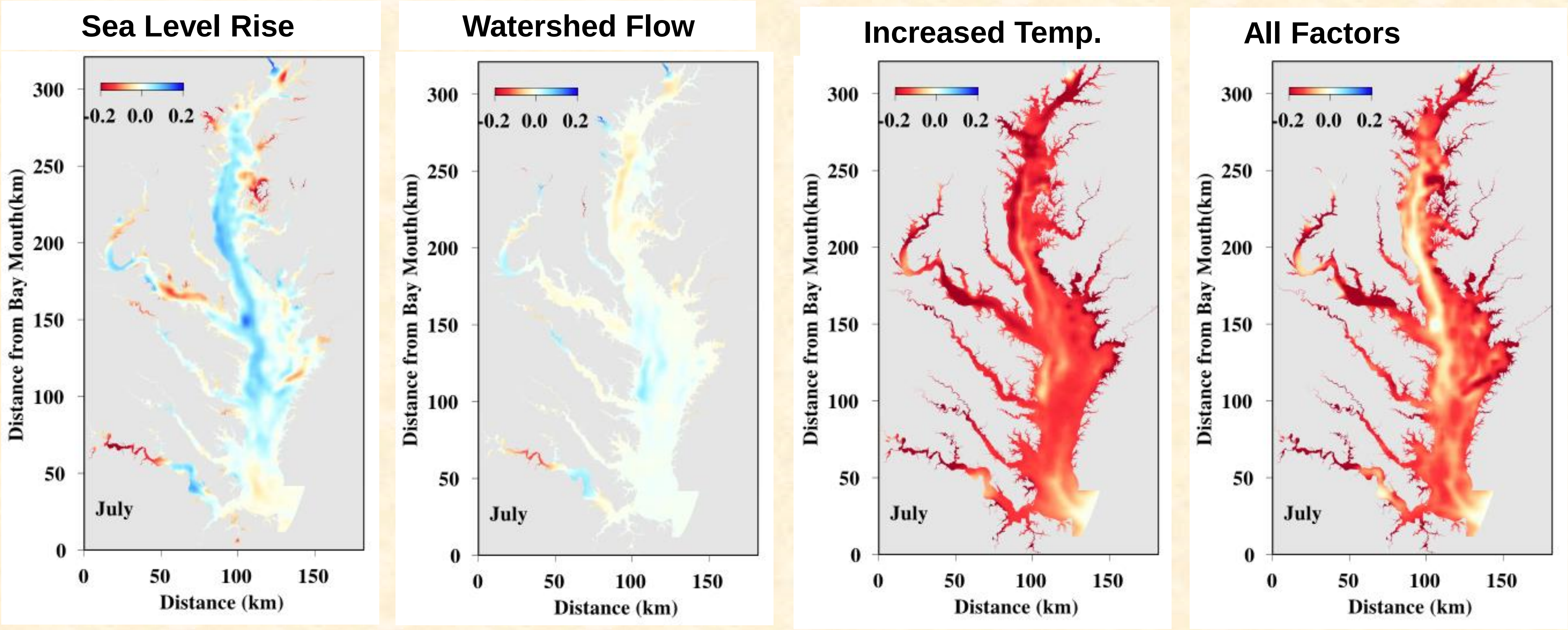
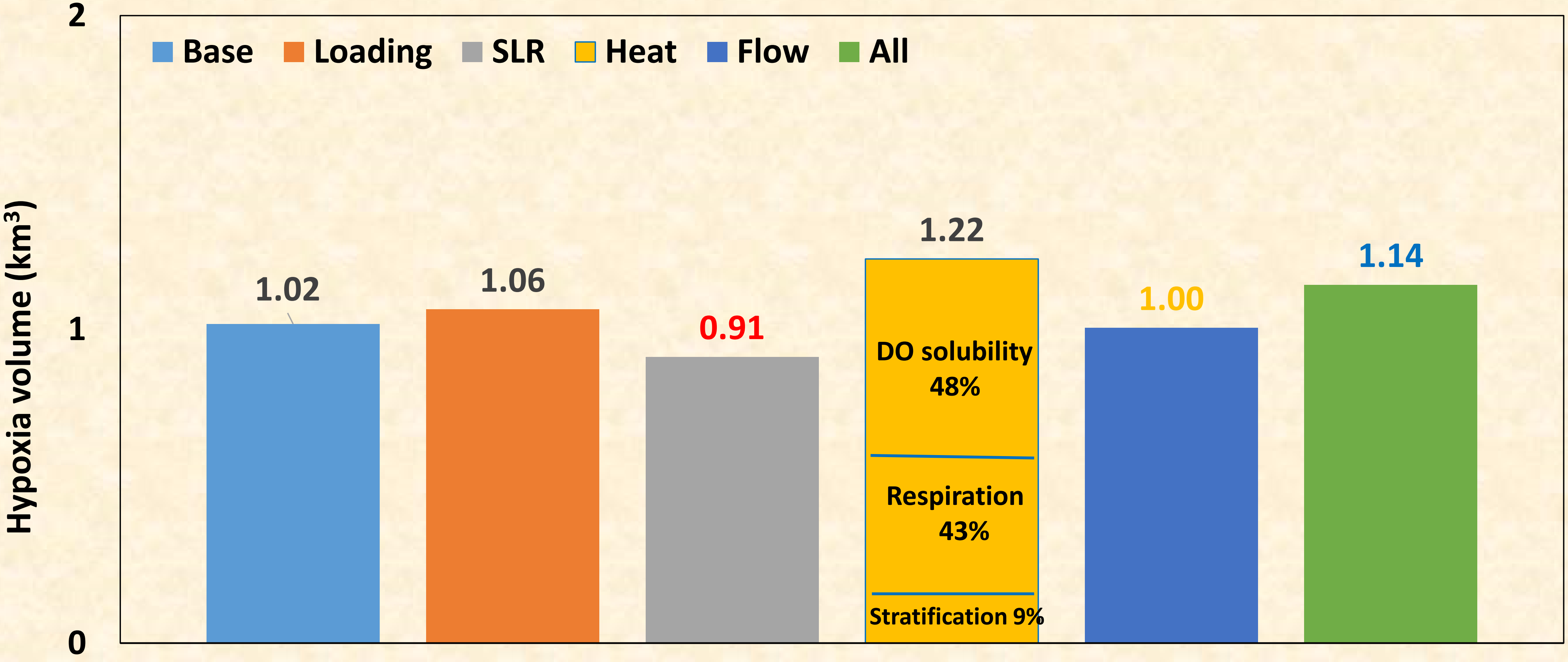
# Bottom DO Change: 1995 to 2025

Keeping all other factors constant, sea level rise and increased watershed flow reduce hypoxia in the Bay, but the predominant influence are the negative impacts of increased water column temperature.



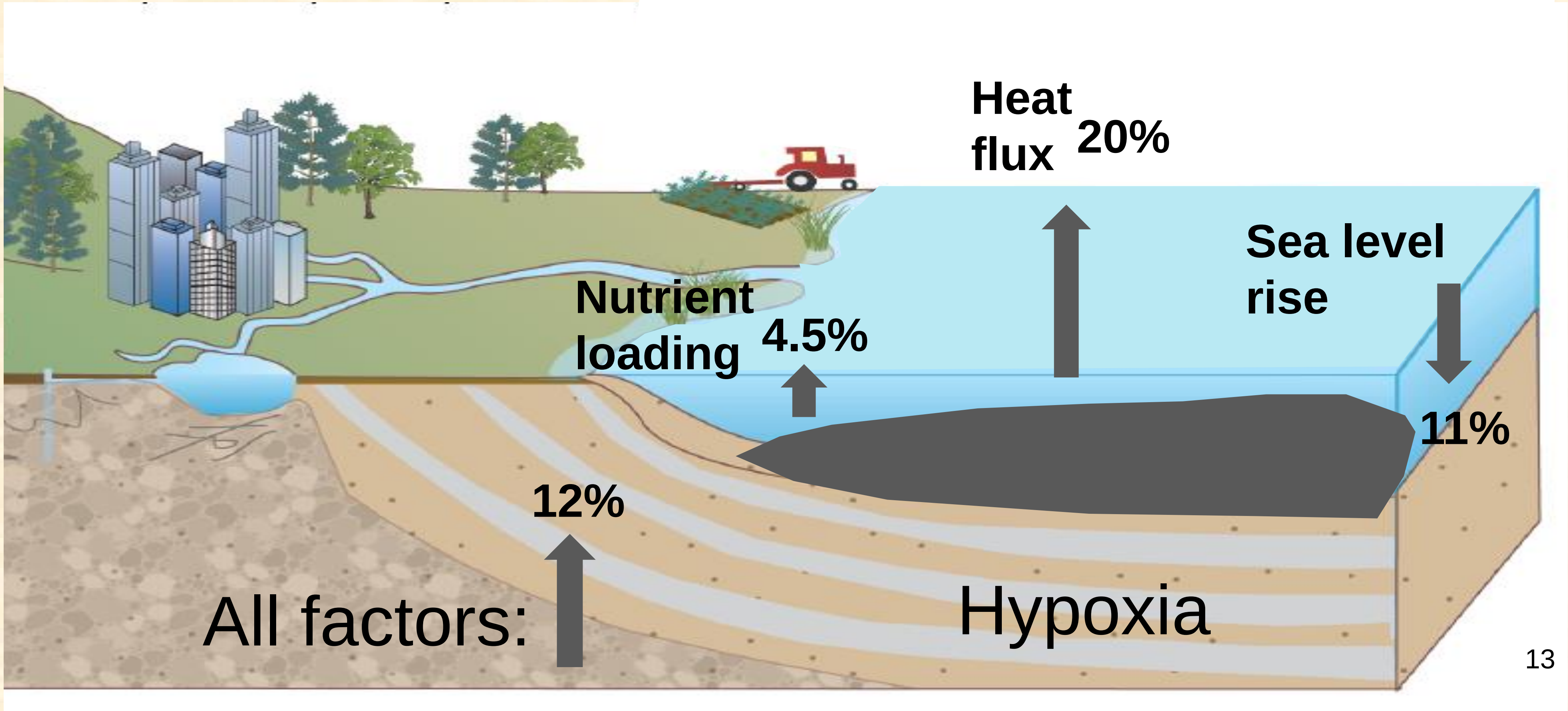
# Summer (Jun.-Sep.) Hypoxia Volume (<1 mg/l) 1991-2000 in the Whole Bay Under 2025 WIP3 Condition





12

# Elements of Hypoxia Volume Change: 1995 - 2025




**Summary**
**Hypoxia volume change by 2025**

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# Current Climate Change Only Scenarios

***Air-temperature increase: 1.06 °C***

***Sea Level Rise: 0.22m***

Flow

+2.4% est. 2025

TN

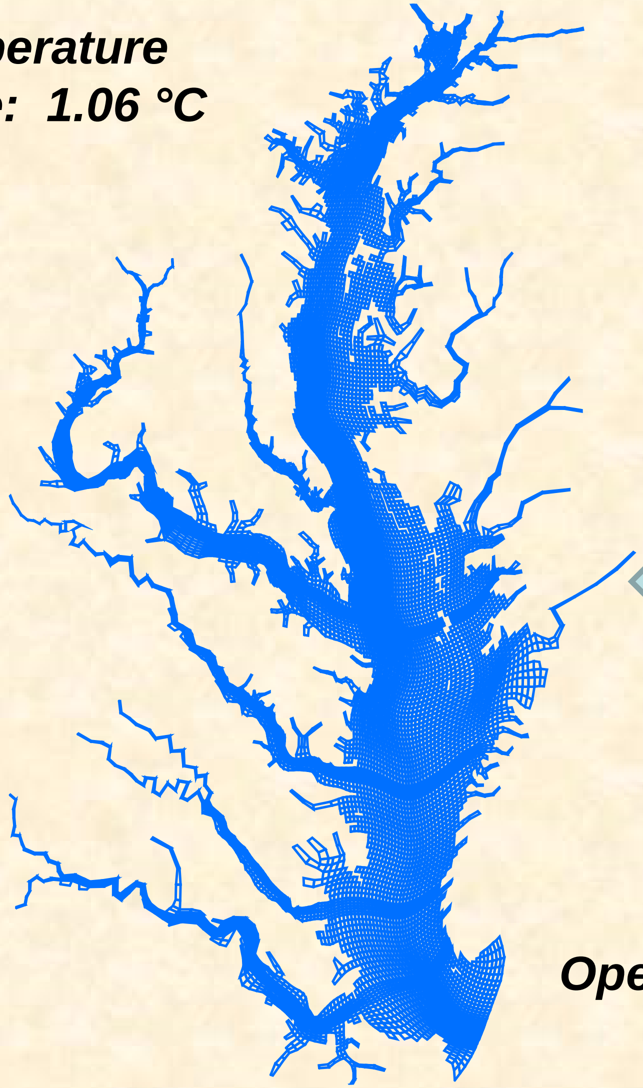
+2.6% est. 2025

TP

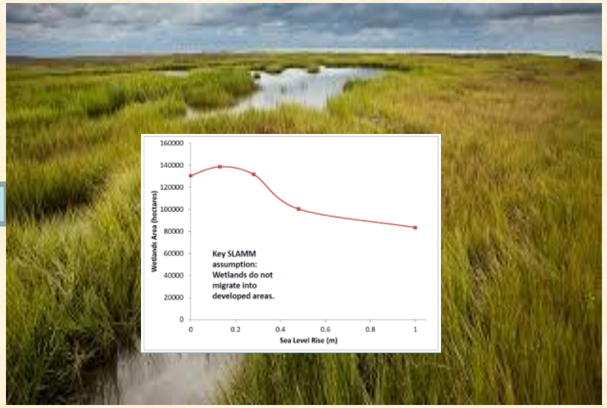
+4.5% est. 2025

Sediment

+3.8 est. 2025



**Tidal wetland change**




***Open boundary delta T: + 0.95 °C; delta S: + 0.18 psu***

(Thomas et al., 2017)

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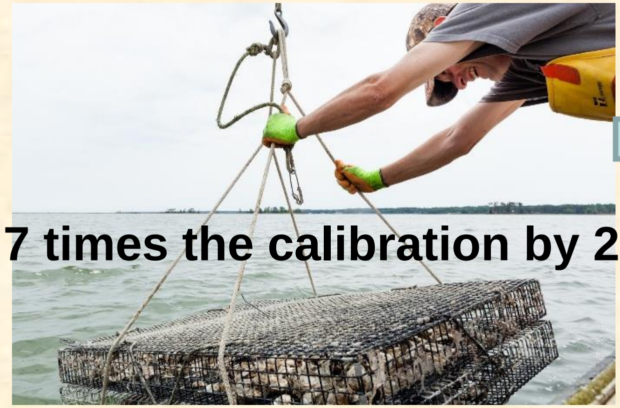
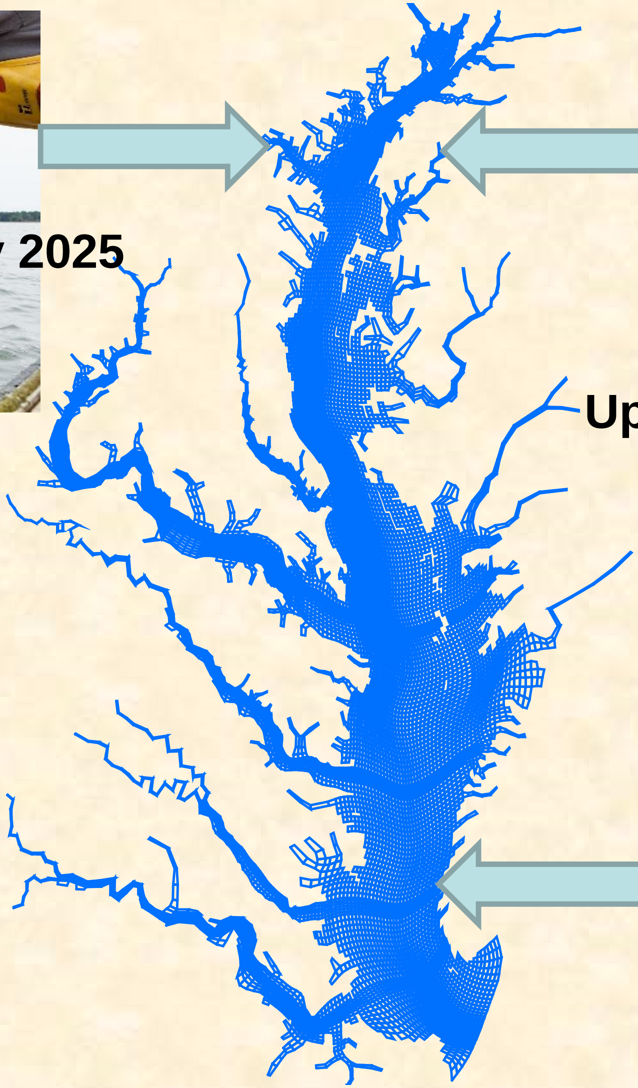
# Scenarios for Estimated Future Land Use and Estuarine Practices for 2035, 2045, and 2055

**Oyster aquaculture expansion**



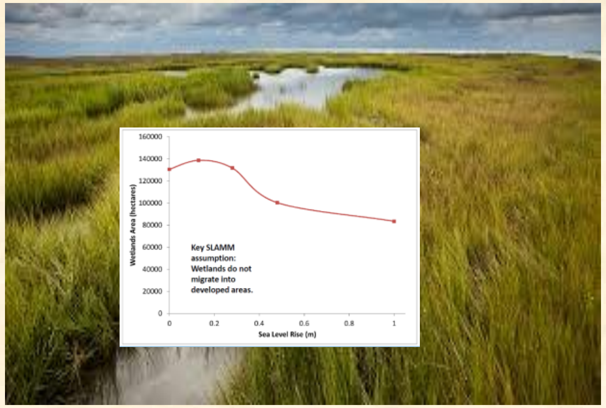
**7 times the calibration by 2025**



**Land use change**

**Up to 1% increase in TN and 2% in TP**

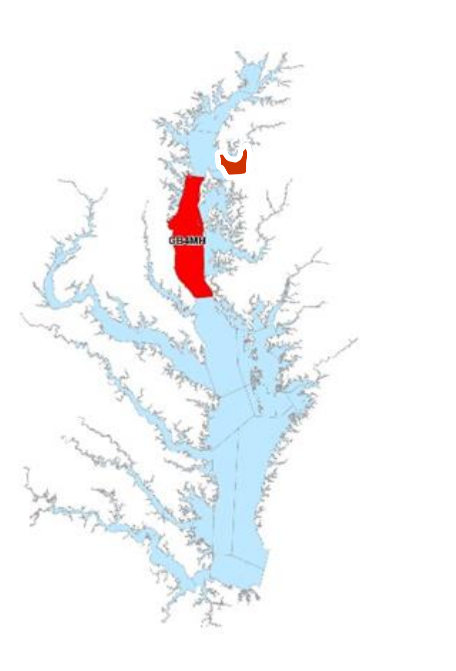
**Tidal wetland change**



# The CBP Climate Change Assessment

Achievement of **<u>Deep Channel DO</u>** water quality standard expressed as a incremental increase over the PSC agreed to (December 2017; July 2018) 2025 nutrient targets for growth and Conowingo Infill

| CB Segment | State | 2025 Climate 2025 Land Use 204TN 14.0TP 1993-1995 DO Deep Channel | 2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Deep Channel | 2035 Climate 2035 Land Use 209TN 14.7TP 1993-1995 DO Deep Channel | 2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Deep Channel | 2045 Climate 2045 Land Use 213TN 15.7TP 1993-1995 DO Deep Channel | 2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Deep Channel | 2055 Climate 2055 Land Use 222TN 17.1TP 1993-1995 DO Deep Channel |
|---|---|---|---|---|---|---|---|---|
| CB3MH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB4MH | MD | **1.4%** | **2.9%** | **3.1%** | **4.5%** | **5.2%** | **6.9%** | **8.2%** |
| CB5MH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB5MH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| POTMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| RPPMH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| ELIPH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CHSMH | MD | **1.1%** | **1.6%** | **1.6%** | **2.2%** | **2.2%** | **3.3%** | **3.3%** |



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# Achievement of Deep Water DO Water Quality Standard

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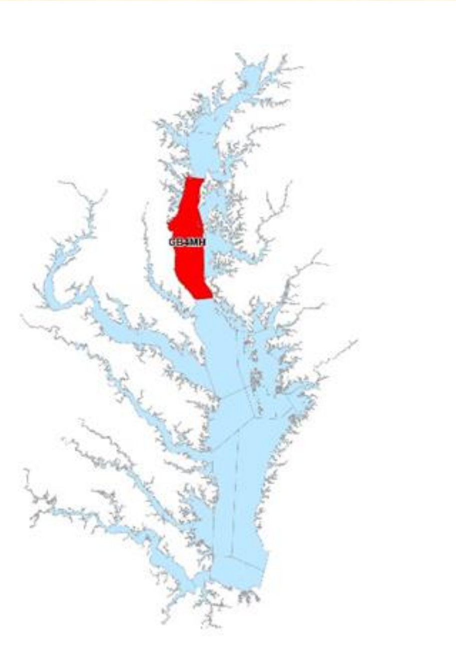
Achievement of **Deep Water DO** water quality standard expressed as a incremental increase over the PSC agreed to (December 2017; July 2018) 2025 nutrient targets for growth and Conowingo infill

| CB Segment | State | 2025 Climate 2025 Land Use 204TN 14.0TP 1993-1995 DO Deep Water | 2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Deep Water | 2035 Climate 2035 Land Use 209TN 14.7TP 1993-1995 DO Deep Water | 2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Deep Water | 2045 Climate 2045 Land Use 213TN 15.7TP 1993-1995 DO Deep Water | 2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Deep Water | 2055 Climate 2055 Land Use 222TN 17.1TP 1993-1995 DO Deep Water |
|---|---|---|---|---|---|---|---|---|
| CB3MH | MD | 0.1% | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% | 0.2% |
| CB4MH | MD | **1.0%** | **1.6%** | **1.6%** | **2.0%** | **2.1%** | **2.6%** | **2.9%** |
| CB5MH | MD | **0.5%** | **0.9%** | **1.0%** | **1.3%** | **1.3%** | **1.6%** | **1.6%** |
| CB5MH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB6PH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB7PH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| PATMH | MD | 0.0% | **0.7%** | **0.7%** | **2.0%** | **2.2%** | **3.0%** | **3.0%** |
| MAGMH | MD | 0.0% | 0.0% | 0.0% | 0.2% | 0.2% | -0.2% | 0.4% |
| SOUMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| SEVMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| PAXMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | 0.1% |
| POTMH | MD | 0.1% | 0.3% | 0.4% | 0.7% | 0.7% | 0.9% | 1.0% |
| RPPMH | VA | 0.2% | **1.2%** | **1.4%** | **1.7%** | **1.8%** | **1.9%** | **1.9%** |
| YRKPH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| ELIPH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| SBEMH | VA | 0.0% | 0.0% | 0.0% | 0.5% | **0.6%** | **3.3%** | **4.0%** |
| CHSMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| EASMH | MD | 0.1% | 0.2% | 0.2% | 0.4% | 0.5% | 0.5% | 0.5% |

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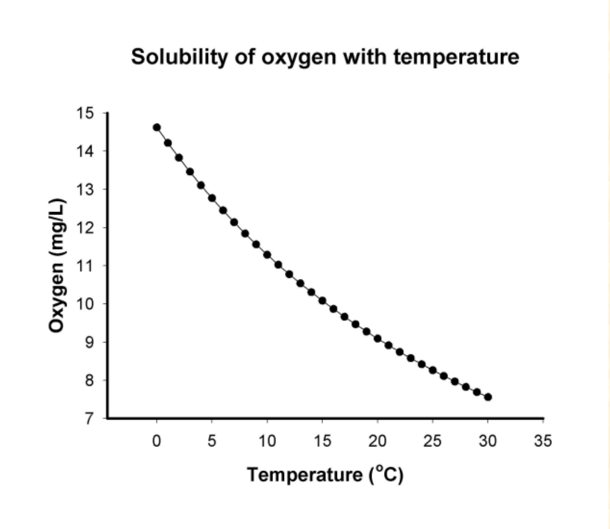
# Achievement of Open Water DO Water Quality Standard

| CB Segment | State | 2025 Climate 2025 Land Use 204TN 14.0TP 1993-1995 DO Open Water | 2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Open Water | 2035 Climate 2035 Land Use 209TN 14.7TP 1993-1995 DO Open Water | 2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Open Water | 2045 Climate 2045 Land Use 213TN 15.7TP 1993-1995 DO Open Water | 2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Open Water | 2055 Climate 2055 Land Use 222TN 17.1TP 1993-1995 DO Open Water |
|---|---|---|---|---|---|---|---|---|
| CB1TF | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB2OH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB3MH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB4MH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB5MH_MD | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB5MH_VA | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CB6PH | VA | 0.4% | 0.7% | 0.8% | 1.0% | 1.1% | 1.3% | 1.4% |
| CB7PH | VA | 1.1% | 1.8% | 1.9% | 2.8% | 2.9% | 4.0% | 4.1% |
| CB8PH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| BSHOH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| GUNOH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| MIDOH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| BACOH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| PATMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| MAGMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| SEVMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| SOUMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| RHDMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| WSTMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| PAXTF | MD | 3.3% | 3.4% | 3.3% | 4.3% | 4.3% | 5.1% | [illegible] |
| WBRTF | MD | 21.3% | 28.6% | 21.3% | 43.6% | 51.2% | 58.8% | [illegible] |
| PAXOH | MD | 6.1% | 9.5% | 11.0% | 10.7% | 12.0% | 12.9% | [illegible] |
| PAXMH | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% | [illegible] |
| POTTF_DC | DC | 1.8% | 2.6% | 2.7% | 3.0% | 3.2% | 3.9% | [illegible] |
| POTTF_MD | MD | 0.5% | 0.6% | 0.7% | 2.0% | 2.3% | 2.9% | [illegible] |
| ANATF_DC | DC | 5.1% | 6.0% | 6.4% | 8.6% | 9.2% | 10.6% | [illegible] |
| ANATF_MD | MD | 10.6% | 16.4% | 16.8% | 24.7% | 25.7% | 29.8% | [illegible] |
| PISTF | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| MATTF | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | [illegible] |
| POTOH1_MD | MD | 0.3% | 0.5% | 0.5% | 0.9% | 0.9% | 1.4% | [illegible] |
| POTMH_MD | MD | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| RPPTF | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 1.7% | 3.7% |
| RPPOH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| RPPMH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| CRRMH | VA | 4.2% | 5.6% | 5.6% | 7.1% | 7.1% | 8.9% | 9.7% |
| PIAMH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| MPNTF | VA | 16.6% | 18.5% | 18.1% | 15.7% | 16.2% | 10.0% | 11.0% |
| MPNOH | VA | 3.6% | 0.3% | 9.8% | 0.0% | 0.0% | 0.0% | 0.0% |
| PMKTF | VA | 8.9% | 14.6% | 10.0% | 10.2% | 10.2% | 2.8% | 3.3% |
| PMKOH | VA | 2.9% | 1.8% | 5.3% | -2.6% | -2.6% | -3.3% | -3.3% |
| YRKMH | VA | 2.3% | 1.8% | 4.5% | 2.5% | 3.2% | 4.3% | 5.3% |
| YRKPH | VA | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| MOBPH | VA | 0.0% | 0.0% | 0.0% | 0.1% | 0.1% | 0.2% | 0.2% |
| JMSTFL | VA | 0.0% | 0.6% | 0.5% | 1.1% | 1.2% | 1.2% | 1.4% |

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# Chesapeake Partnership Accountability Framework

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- December 2017 and updated July 2018 decisional model for tracking targets to 2025.
- 2019 CC Model for adjustment of July 2018 decisional model for CB watershed and Bay climate change risk.

- <u>7 Watershed Implementation Plans (WIPs</u>) describe what amount, how, where, and when for **all implementation required to achieve water quality standards by 2025.**
  - Phase I in 2010
  - Phase II in 2012
  - **<u>Phase III in 2019</u>**

- <u>2-Year Milestones</u> ensure short term progress

**By the 2022-2023 milestones there will be quantifiable reductions needed to defend water quality standards from future climate risk.**

# Climate Resiliency for Stormwater Management and Other BMPs

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The PSC gave specific direction to the CBP Partnership at their December 2017 meeting to "… develop a better understanding of the BMP responses, including new or other emerging BMPs, to climate change conditions".

In 2019, the Management Board of the Chesapeake Bay Partnership following the direction of the PSC directed that:

- The design and accelerated adoption of stormwater management practices appropriately designed for increased rainfall volumes and intensities that are expected in the future for all counties in the Chesapeake watershed.
- Examination of the top tier ag and urban BMPs that are most vulnerable to future climate risk, with an emphasis on structural practices, that could be adapted to become more resilient to future climate conditions of increased rainfall intensities and volumes.
- A description of the co-benefits of BMPs that mitigate future climate risk, especially as they relate to the protection of local infrastructure and public health and safety, including green infrastructure, urban floodplain management, riparian buffers, tidal and non-tidal wetlands and other management actions.

# Climate Resiliency for Stormwater Management and Other BMPs

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- In response to the direction the Urban Stormwater Workgroup and the Chesapeake Stormwater Network are working to maintain the resiliency of stormwater and restoration practices in the face of climate change in the Chesapeake watershed through an analysis of the vulnerability of urban stormwater BMPs to climate change and are leading the design of stormwater management practices that will maintain their performance despite increased rainfall and storm intensities under future climate conditions.
- In addition, under the Chesapeake Bay Trust GIT-funded projects the Urban Stormwater Workgroup will "Develop Probabilistic Intensity Duration Frequency (IDF) Curves" for the all counties of the Chesapeake Watershed by: 1) evaluation of downscaling methods and climate model combinations to assess their ability to replicate historical precipitation extremes, 2) downscaling of projected precipitation extremes for future periods, 3) quantification of methodological and climate model uncertainties for the projected precipitation extremes for future periods, 4) development of probabilistic intensity duration frequency (IDF) curves for all counties of Chesapeake Bay Watershed and the District of Columbia (DC), and 5) development of web-based tools and appropriate outreach to make results accessible to end-users.
- Finally, a STAC Science Synthesis Project will provide "A Systematic Review of Chesapeake Bay Climate Change Impacts and Uncertainty: Watershed Processes, Pollutant Delivery, and BMP Performance". The technical synthesis is designed to answer three specific questions:
    1. How do climate change and variability affect nutrient/sediment cycling in the watershed?
    2. How do climate change and variability affect BMP performance?
    3. Which BMPs will likely result in the best water quality outcomes under climate uncertainty?"

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# Key Points in Assessment of 2025 Climate Change Risk

- The new 2019 climate change assessment confirms the December 2017 climate change findings with a better model, providing better understanding of underlying processes, more specific findings on nutrient speciation, CSOs, wet deposition of nitrogen, etc.
- Loads have decreased by about half from the December 2017 estimates of the load required to respond to climate risks and achieve 2025 water quality standards. Now, depending on decisions to be made by the WQGIT, the additional load reduction estimated to be needed to respond to climate change risk are 5M lb TN (before was 9M lb TN). However, the estimated load reduction to address climate risk for 2035 is about twice that of the estimated 2025 nitrogen load reduction.