Assessment of Chesapeake Climate Change Using A Suite of Airshed, Watershed, and Estuary Models

STAC Climate Change 3 Workshop

May 7, 2024

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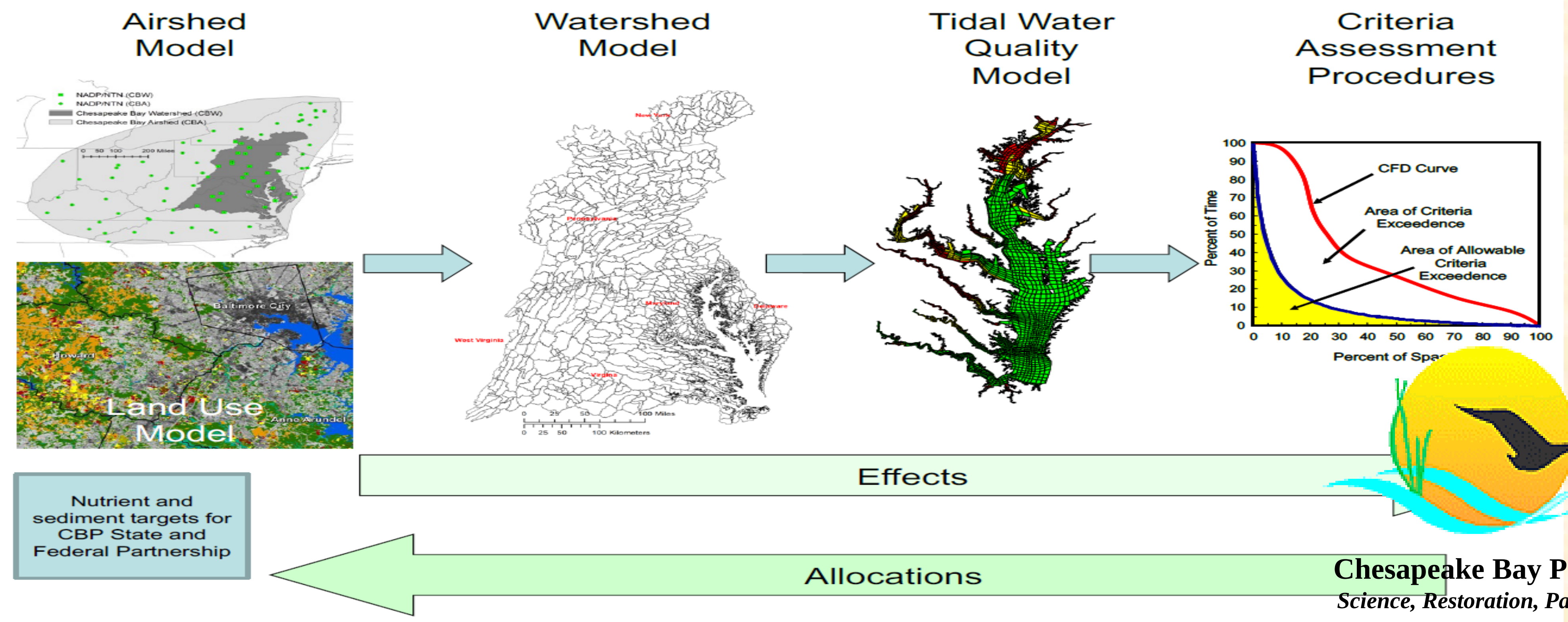

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Setting the Stage: Limitations of the Phase 6 Climate Change Simulation

- A major limitation of Phase 6 was that only deep water and deep channel DO water quality standards of hypoxia were examined but many living resource benefits are dependent upon conditions in the shallow water habitat.
- Another limitation was the absence of an investigation into phenological, or seasonal biological phenomena correlated to climatic conditions. For example, are longer growing seasons, different crop types, or a deceased spring freshet important aspects of the Phase 7 simulation?
- Absence of shallow water simulation capacity.
- A multiple model approach was unavailable.
- Effectiveness of BMPs was unchanged under climate change conditions.
- Understanding of phosphorus dynamics needed refinement.

Setting the Stage: Advantages of the Phase 7 Climate Change Simulation

- The Phase 7 Main Bay Model (MBM) and Multiple Tributary Models (MTMs) have a sigma or orthogonal grid option and fine-scale features that can fully support all 92 Chesapeake TMDL segments. The IMC water quality code from 30 years of CBP development is good but needs to be applied at a finer scale.
- For the first time, CBP has the capability to simulate shallow water processes.
- For the first time, CBP has multiple tributary models simulating tidal waters.
- Through a cooperative agreement with RAND there will be an assessment of climate change impacts to CBP BMP efficiencies .

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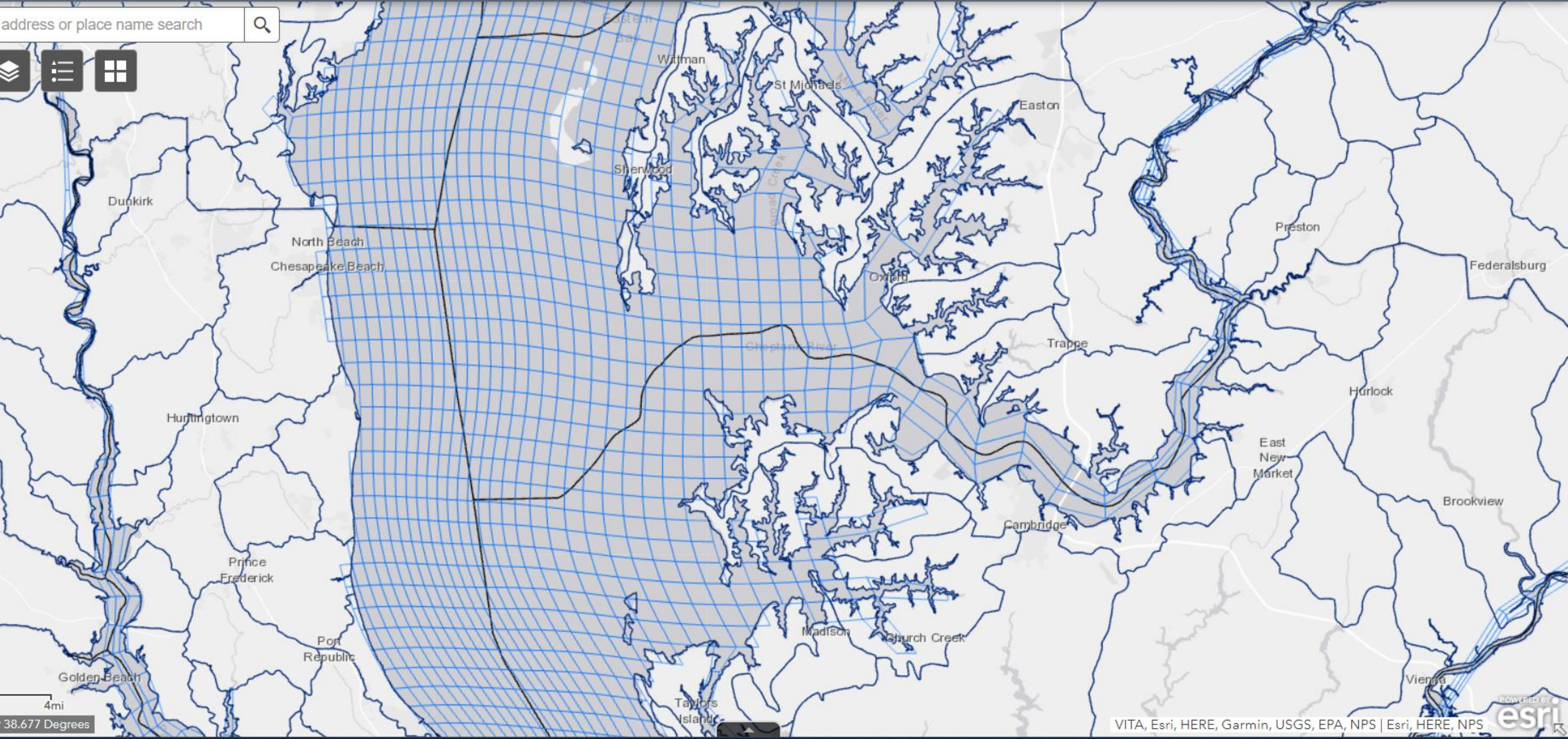

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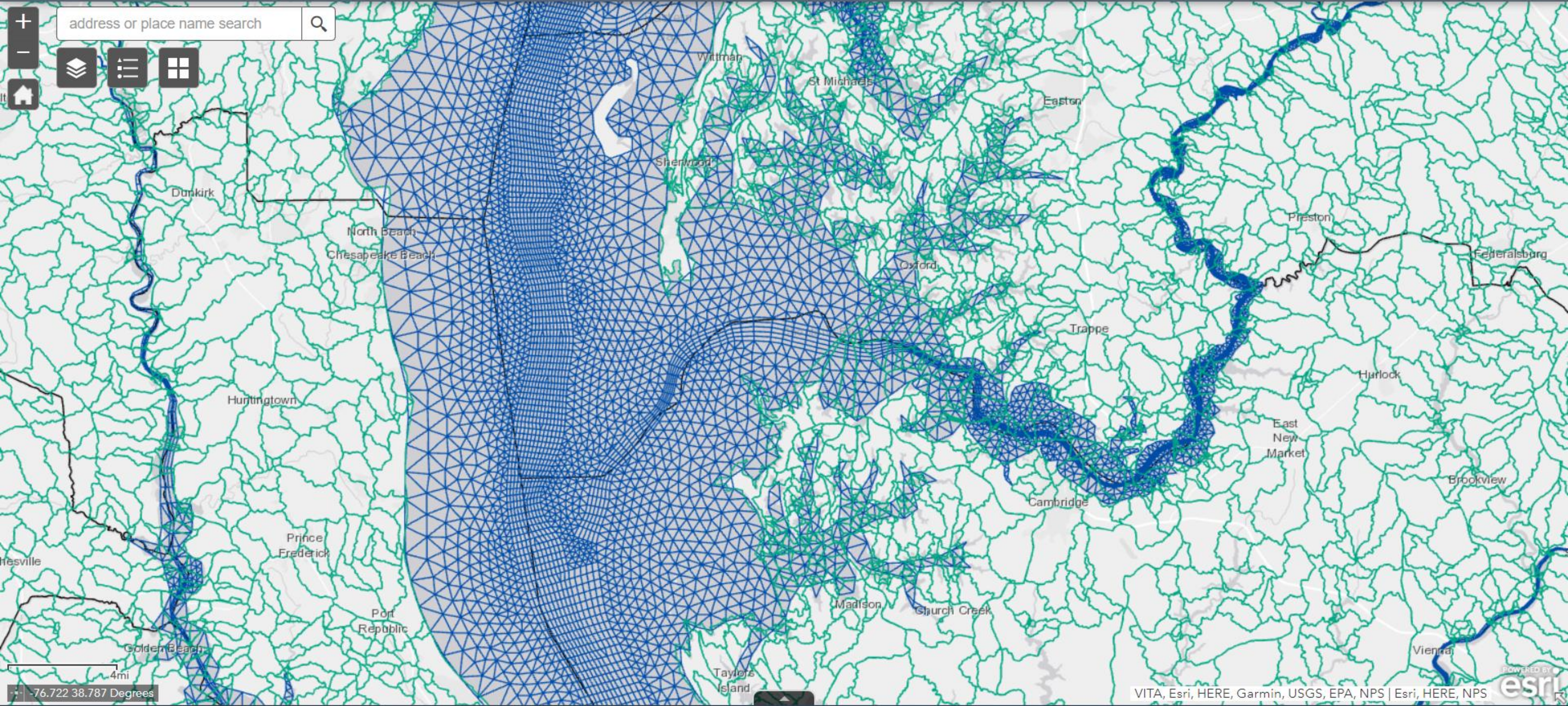

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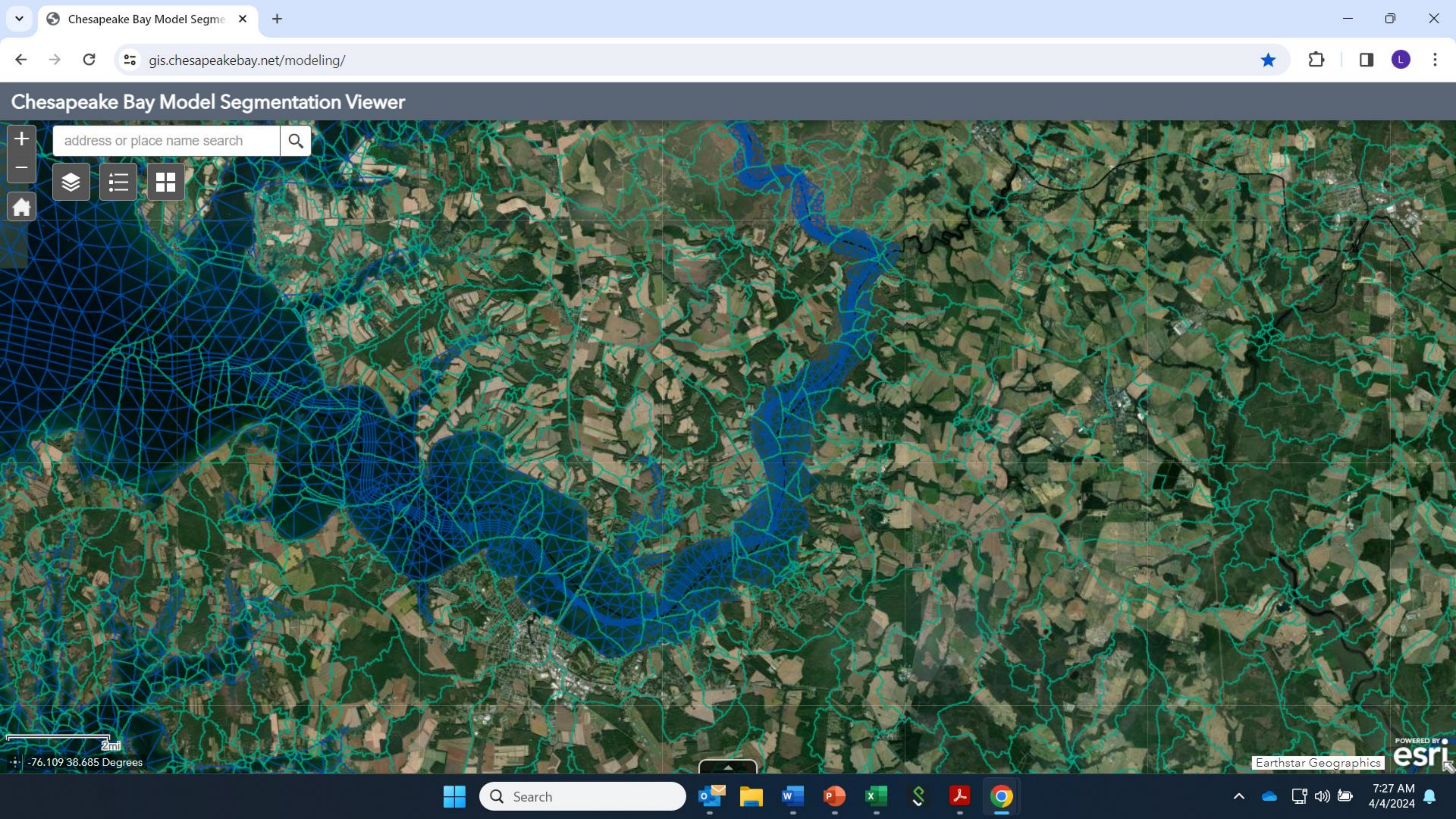
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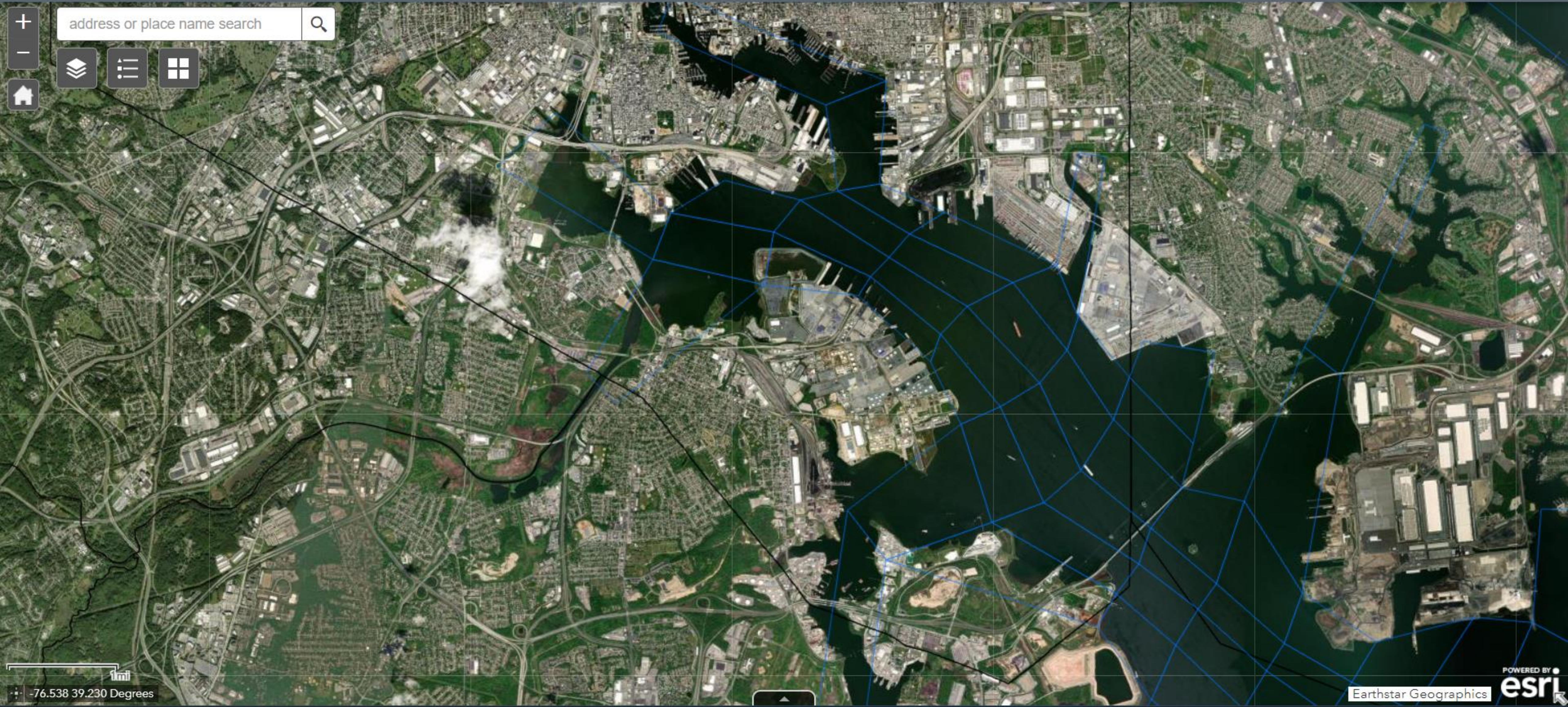

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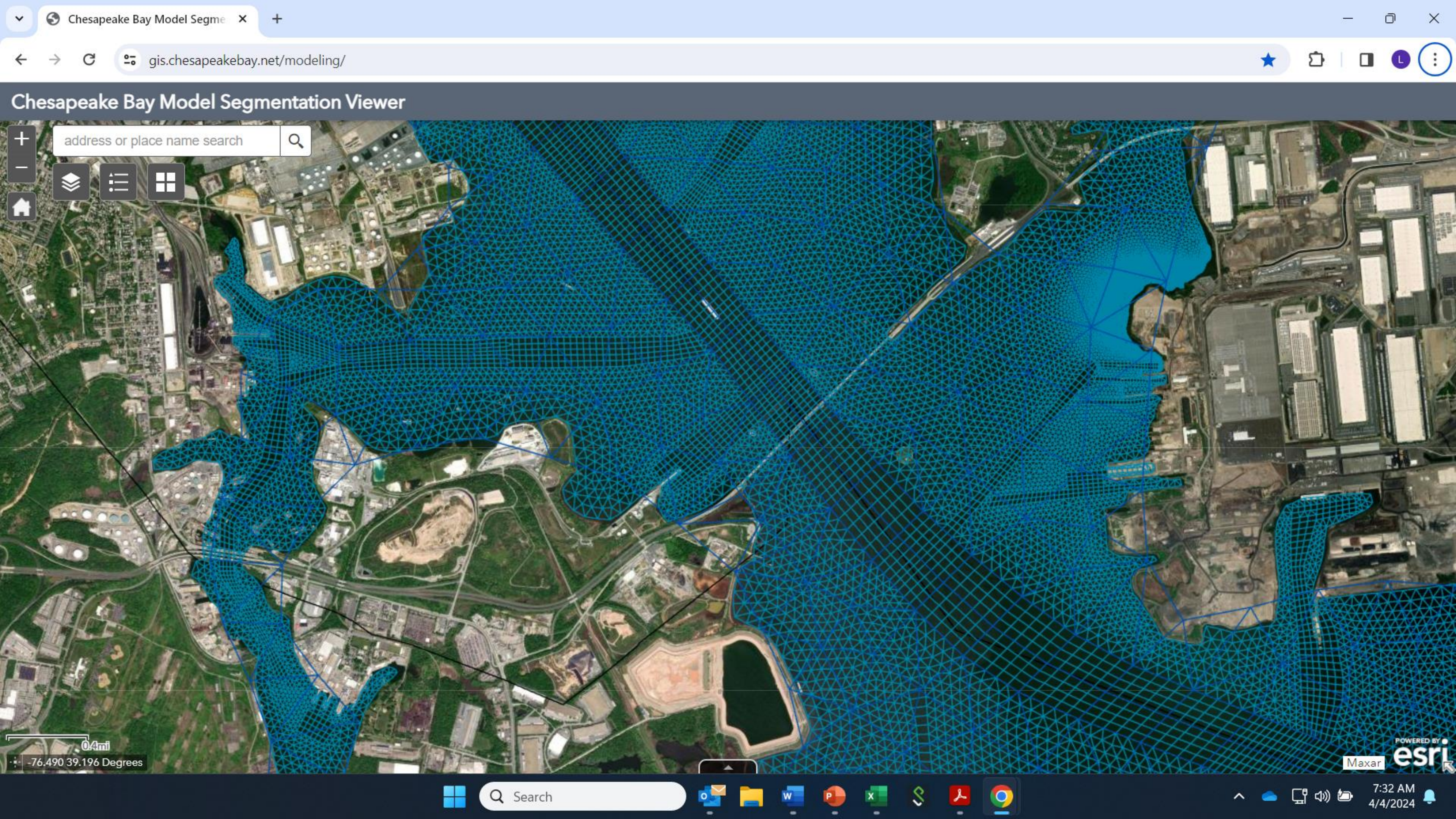
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Setting the Stage: Considerations of CBP Climate Change in the STAC Climate Change 3.0 Workshop

- EC charge to the CBP to assess 2035 climate change and how that influences current CBP efforts.
- What the CBP learned from the previous *STAC Climate Change Workshop 2.0.*
- Guidance from the workshop *CBP Modeling in 2025 and Beyond.*

The EC Directive on Climate Change

Chesapeake Executive Council

Directive No. 21-1 Collective Action for Climate Change

In the 2014 *Chesapeake Bay Watershed Agreement*, the Chesapeake Executive Council committed to *increase the resiliency of the watershed, including its living resources, habitats, public infrastructure and communities, to withstand adverse impacts from changing environmental and climate conditions*. In recognition of the growing body of science documenting the impacts of climate change and the urgent need for action, we must build upon previous commitments and hasten our efforts

"Directive No. 21-1 Collective Action for Climate Change commits the Chesapeake Bay Program to utilize their world-class scientific, modeling, monitoring and planning capabilities to prioritize the communities, working lands and habitats that are most vulnerable to the risks that a changing climate is bringing to the region..."

https://www.chesapeakebay.net/news/blog/the-chesapeake-bay-program-takes-action-on-climate-change

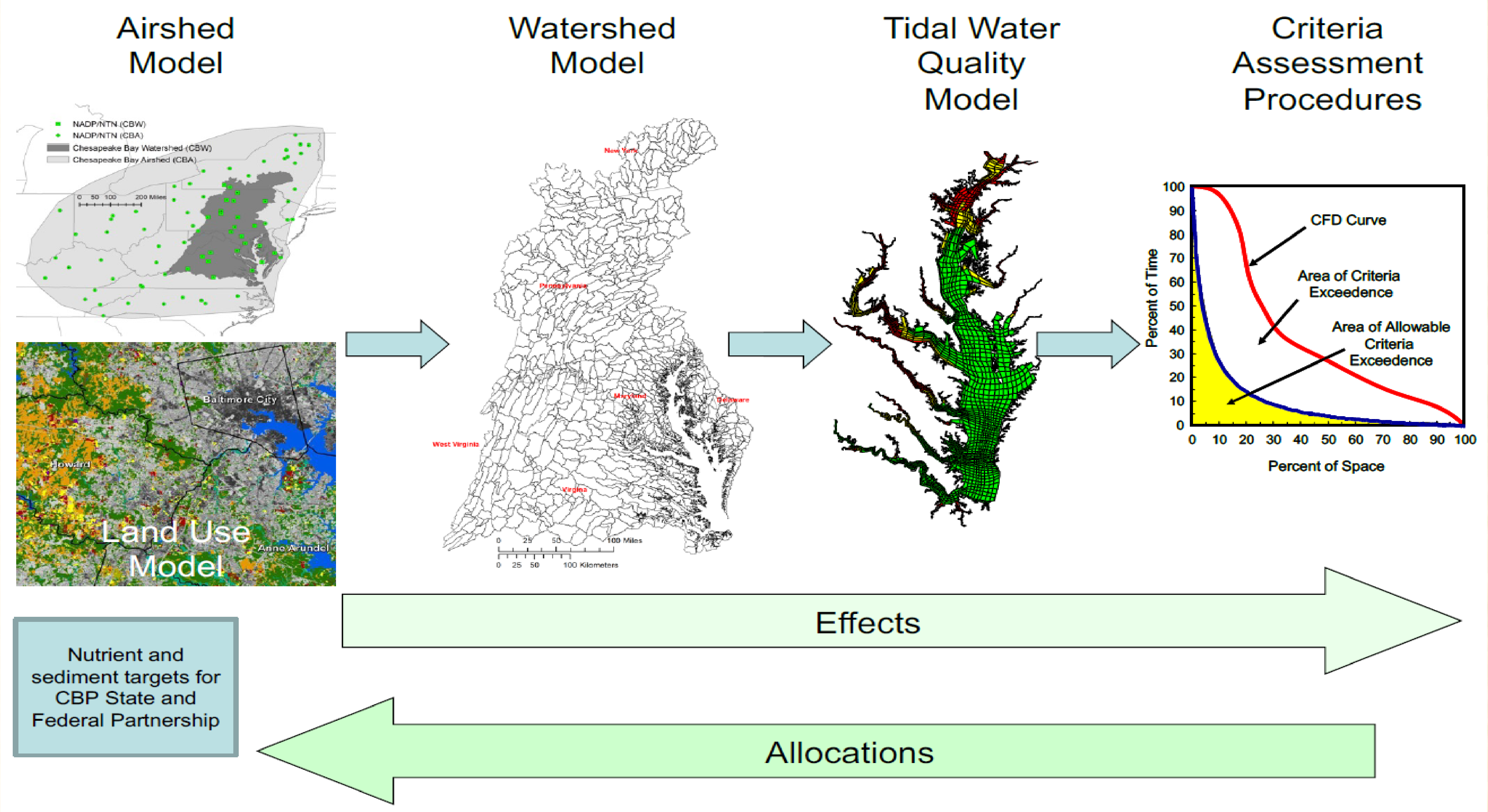
Specifically, for CBP Technical Workgroups of Modeling, Urban Stormwater, and Climate Resiliency

"Apply the best scientific, modeling, monitoring and planning capabilities of the Chesapeake Bay Program [to assess 2035 climate change conditions, and].

- Emphasize the continued need to update best management practice design standards to account for the impacts of climate change, using leading predictive models and tools, to ensure investments made today continue to yield benefits even as the climate changes.
- Determine capacity needed to monitor the impacts of climate change on our natural resources within the existing Chesapeake Bay Program partnership's science programs and evaluate the opportunity to fill those needs with ongoing climate change monitoring programs."
- [Also directs CBP in climate mitigation, and protection of vulnerable communities and habitats.]

https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/climatedirective_final.pdf

The CBP Climate Change Assessment



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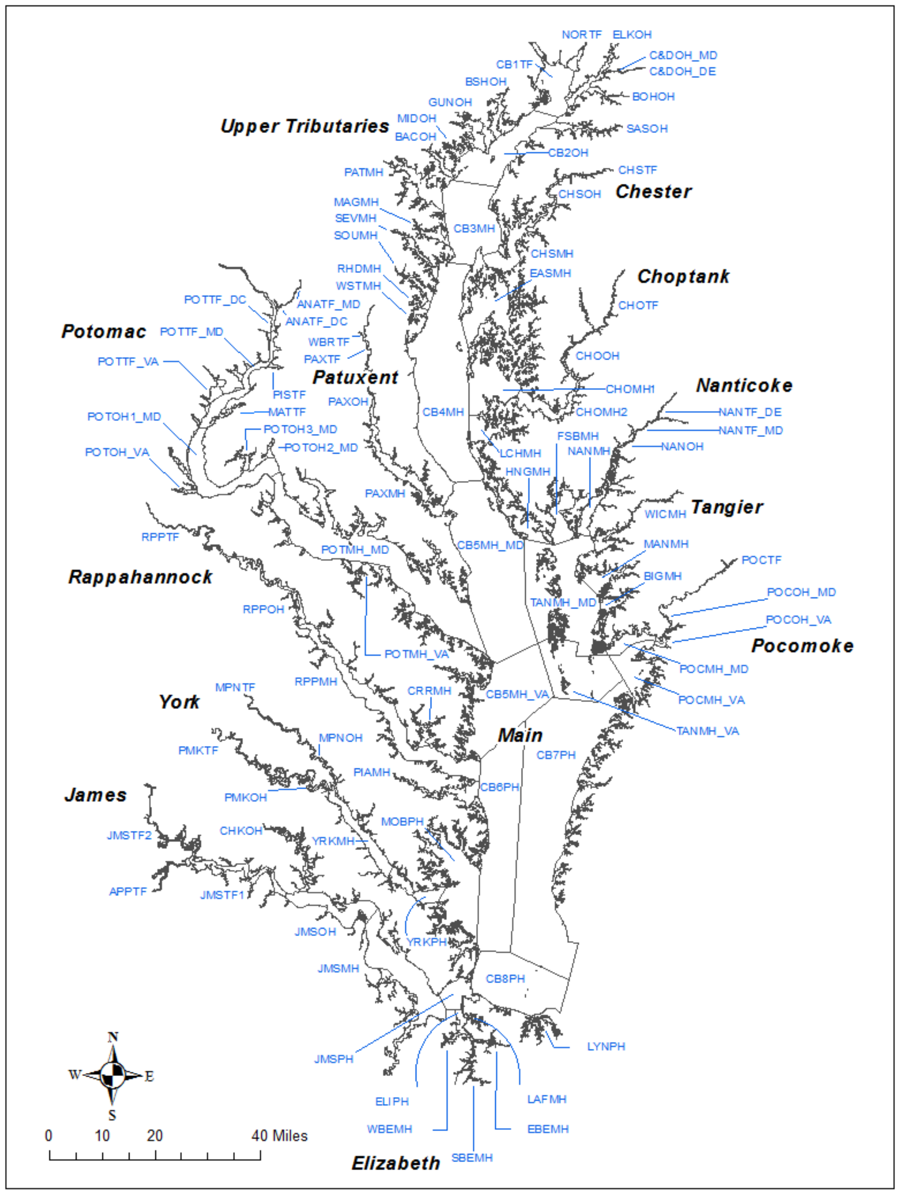
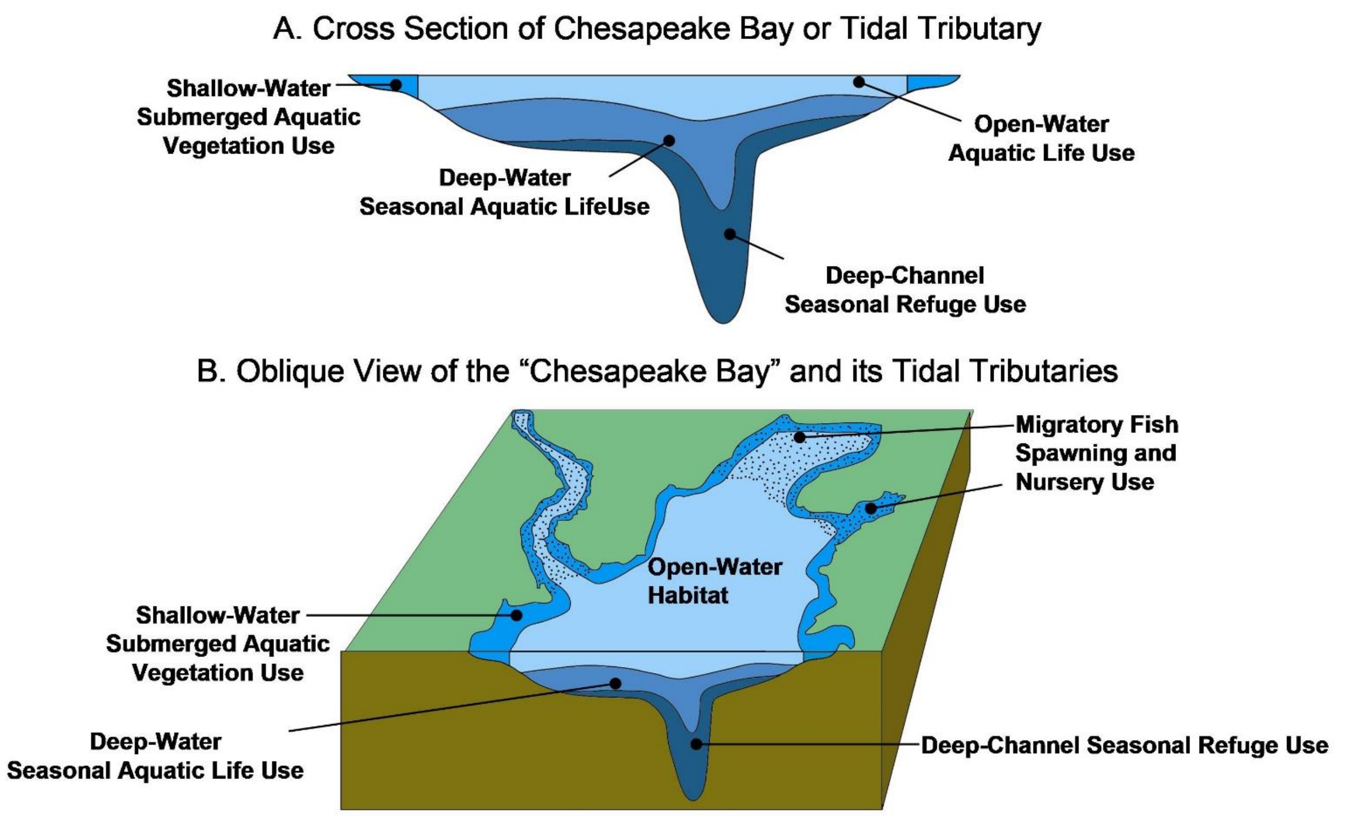
Overview of Bay Designated Uses





Recommendations from the STAC Workshop *Development of Climate Projections for Use in Chesapeake Bay Program Assessments* (2016)

1. The Partnership should seek agreement on the use of consistent climate scenarios for regional projections of Chesapeake Bay condition…
2. For the 2017 Midpoint Assessment, use historical (~100 years) trends to project precipitation to 2025…
3. The Partnership should carefully consider the representation of evapotranspiration in Watershed Model calibration and scenarios…
4. Looking forward, the 2050 timeframe is more appropriate for selecting and incorporating a suite of global climate scenarios and simulations to provide long-term projections for the management community...
5. Beyond the 2017 Midpoint Assessment, it is recommended that the CBP use 2050 projections for best management practice (BMP) design, efficiencies, effectiveness, selection, and performance – given that many of the BMPs implemented now could be in use beyond 2050.
6. For any 2050 assessment, use an ensemble or multiple global climate model approach…
7. Select an existing system to access GCM downscaled scenario data…

What We Learned from the Chesapeake Bay Program Climate Change Modeling 2.0 STAC Workshop September 24-25, 2018

- The CBP's approach to select projections and global circulation models largely follows accepted practices…
- The CBP's use of Representative Concentration Pathways (RCPs) is in line with best practices … RCP8.5 and RCP4.5 are reasonable choices…
- …generally, the use of readily available downscaled product rather than creating a customized downscaling procedure for the Chesapeake domain seems appropriate…
- …the Sea Level Affecting Marshes Model (SLAMM) provides the most useful and applicable tool available for the geographic region at this time.
- …the current treatment of relative and global mean sea level rise (SLR) in the framework of the CBP modeling suite (i.e., WQSTM) seems appropriate…
- The panel has concerns related to the decision to extrapolate precipitation from the last 100 years out to 2025.
- The Delta Approach is well-designed to address changes in mean conditions but is not fully capable of analyzing future changes in variability and extreme events.
- The full uncertainty in future climate effects is underestimated by the current set-up of the Delta Approach…

Guidance from the 2019 STAC Workshop *CBP Modeling in 2025 and Beyond*

3. Efforts to incorporate living resources should start by using living resource models that are forced using output from the CBP partnership models – e.g., water quality parameters. The CBP estuarine water quality model should define habitat quality and/or impacts on higher trophic level organisms; it should have a structure that supports direct coupling with models of higher trophic level species.

7. The CBP partnership should expand its efforts to make its models applicable to smaller “local” scales, appropriate to decision making for smaller-scale jurisdictions and watersheds.

10. The CBP should continue to employ and develop the Phase 6 Watershed Model that uses multiple models to determine responses to management actions.

11. Potential future development of the hydrodynamic and biogeochemical models should focus on transition to a hydrodynamic model with an unstructured grid that can provide much greater resolution in the shallow tributaries of the Bay.

12. The current living resource simulation in the CBP water quality model, which includes submerged aquatic vegetation (SAV) and oysters, should continue to be developed with the goal of improving these models.

17. Future model development should continue to be driven by management needs and future models must support time-certain management deadlines.

18. The 2025 next generation CBP suite of models should provide support of better understanding across a wide range of scales. Models that use unstructured grids are particularly well suited to cover this wide range of scales.

Elements of Chesapeake Water Quality Climate Risk Assessment

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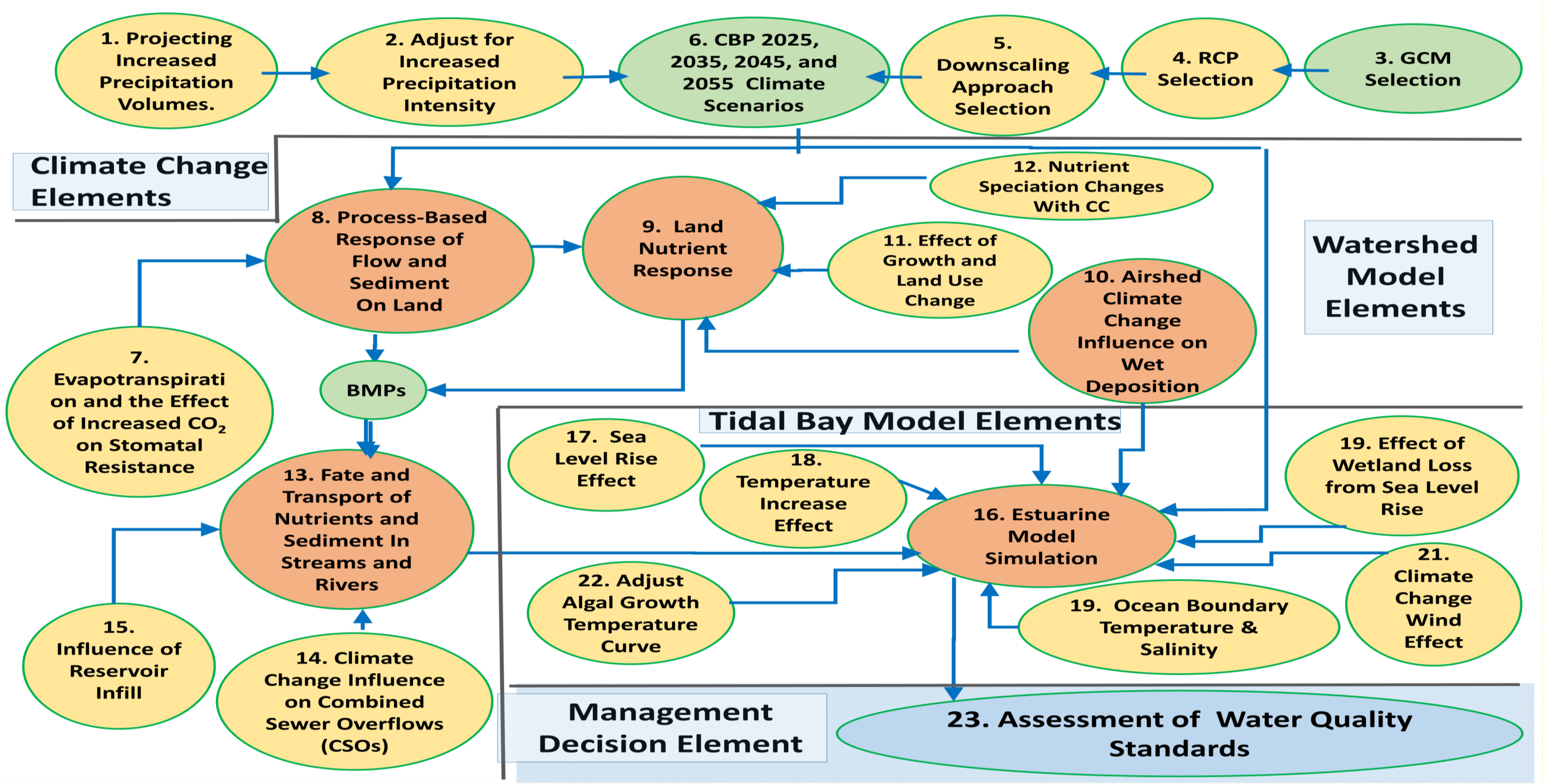

Big Things and Little Things Influencing 2025 Water Quality

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Big things:

Higher precipitation volume, flows, and N, P, S loads.

Temperature and ET

Sea Level Rise

Little things: **(Less than 3 percent change of total nitrogen load when comparing the 2055 climate change load estimates to the 1995 base conditions load.)**

Influence of temperature increases on phytoplankton biomass

Tidal wetland loss (then about midcentury it's a big thing)

Wind effects

CSOs

Greater wet deposition of atmospheric deposition of nitrogen

Increased CO_2 and stomatal resistance

Nutrient speciation changes

1940-2014 streamflow trends based on observations

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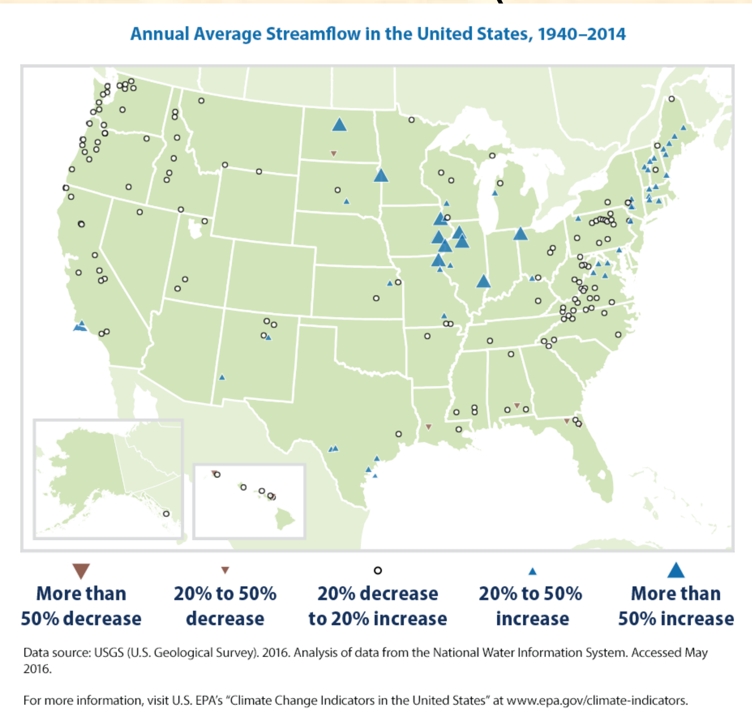
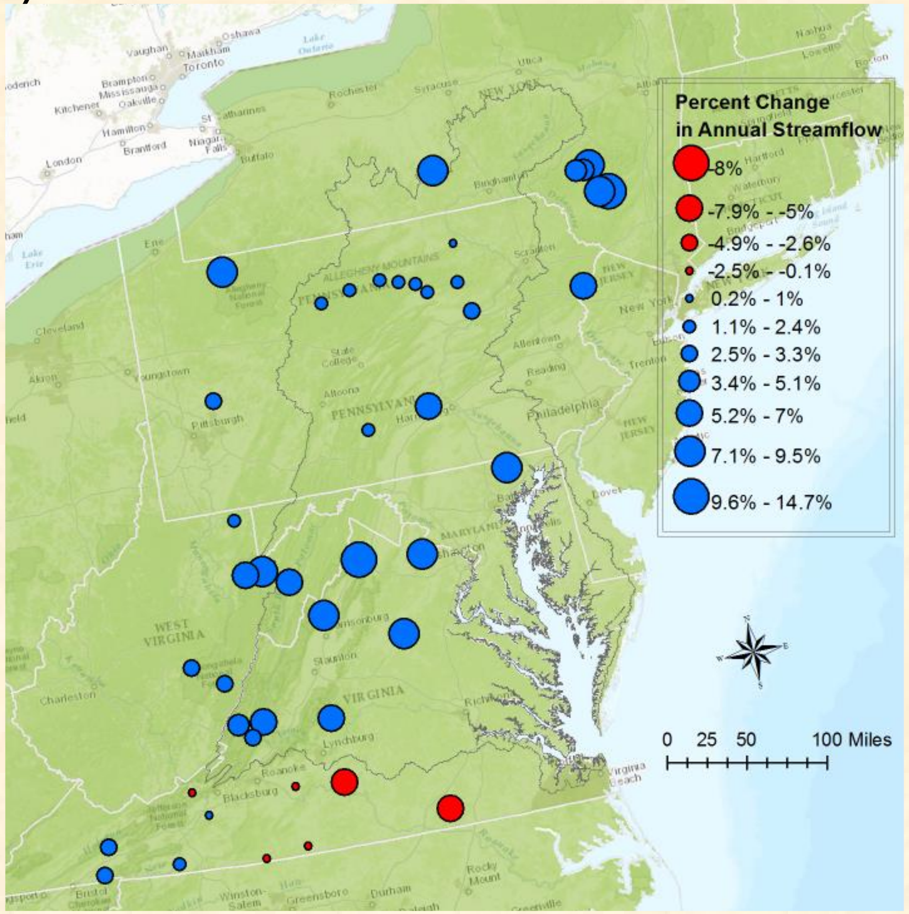
The study analyzed USGS GAGES-II data for a subset of Hydro-Climatic Data Network 2009 (HCDN-2009).





U.S. Environmental Protection Agency. 2016. Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004. www.epa.gov/climate-indicators.

Karen C. Rice, Douglas L. Moyer, and Aaron L. Mills, 2017. Riverine discharges to Chesapeake Bay: Analysis of long-term (1927 - 2014) records and implications for future flows in the Chesapeake Bay basin *JEM* 204 (2017) 246-254

USGS station ID	Precipitation		Discharge	
	Slope	p-value	Slope	p-value
04252500	0.0007	**0.0011**	0.0021	**<0.0001**
01512500	0.0008	**0.0007**	0.0016	**0.0028**
01503000	0.0007	**0.0022**	0.0013	**0.0181**
01531000	0.0006	**0.0219**	0.0018	**0.0030**
01531500	0.0007	**0.0044**	0.0016	**0.0029**
01532000	0.0006	**0.0374**	0.0015	**0.0330**
01534000	0.0005	**0.0497**	0.0015	**0.0120**
01550000	0.0005	**0.0493**	0.0019	**0.0015**
01543000	0.0004	0.1000	0.0018	**0.0058**
01545500	0.0004	0.0953	0.0017	**0.0026**
01536500	0.0006	**0.0078**	0.0016	**0.0027**
01551500	0.0005	0.0612	0.0017	**0.0017**
01439500	0.0005	0.0972	0.0007	0.1661
01541500	0.0003	0.2357	0.0017	**0.0017**
01540500	0.0006	**0.0111**	0.0016	**0.0023**
01541000	0.0004	0.0985	0.0016	**0.0021**
01567000	0.0004	0.1577	0.0011	**0.0250**
01570500	0.0005	**0.0260**	0.0013	**0.0088**
North-South Split				
01562000	0.0004	0.1693	0.0007	0.2082
01638500	0.0004	0.1150	0.0008	0.1026
01608500	0.0004	0.1725	0.0010	0.0833
01636500	0.0005	0.1245	0.0008	0.0624
01606500	0.0003	0.1958	0.0009	0.1108
01668000	0.0006	0.0794	0.0004	0.4727
02035000	0.0003	0.2653	−0.0001	0.8243
02019500	0.0002	0.4333	0.0003	0.4836
03488000	0.0003	0.2480	0.0006	0.2841

Annual average percent change were calculated using Sen slope (Helsel and Hirsch, 2002).

Lins, H.F. 2012. USGS Hydro-Climatic Data Network 2009 (HCDN-2009). U.S. Geological Survey Fact Sheet 2012-3047. https://pubs.usgs.gov/fs/2012/3047.
Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources. Techniques of water resources investigations, Book 4. Chap. A3. U.S. Geological Survey. https://pubs.usgs.gov/twri/twri4a3.

Estimates of Climate Only and Climate and Land Use

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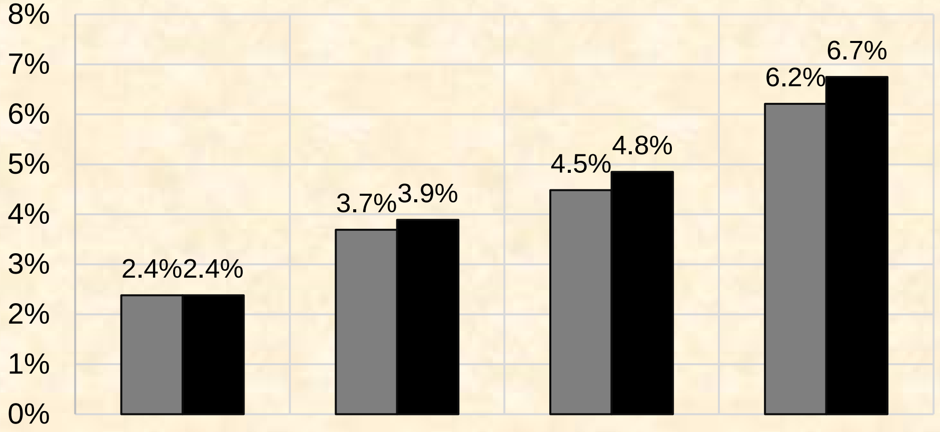
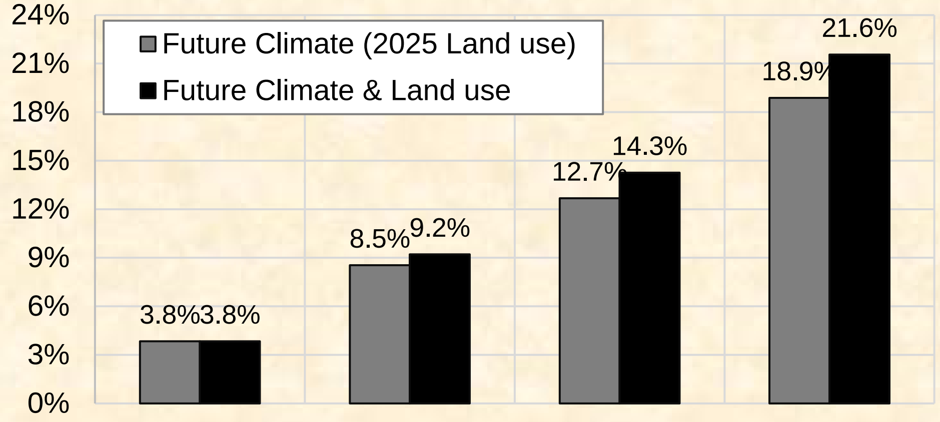
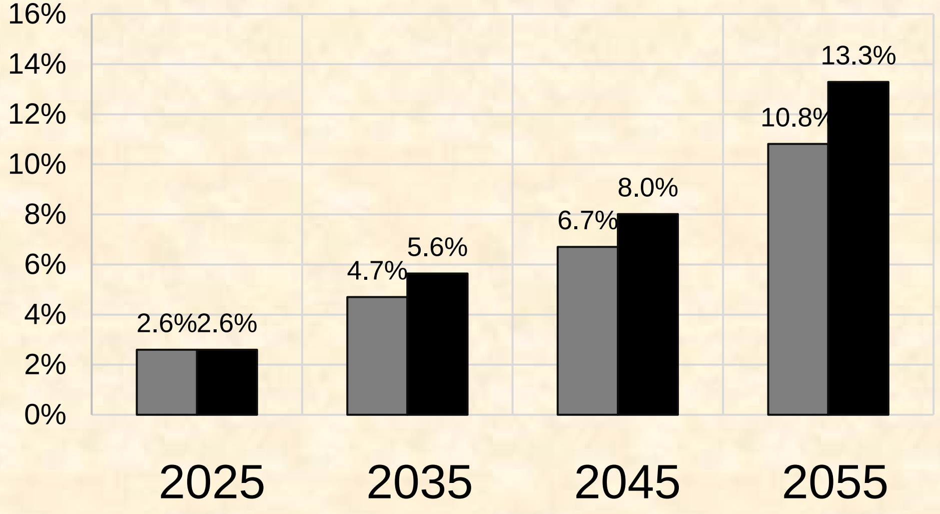
Marginal Differences in **Freshwater** Delivery



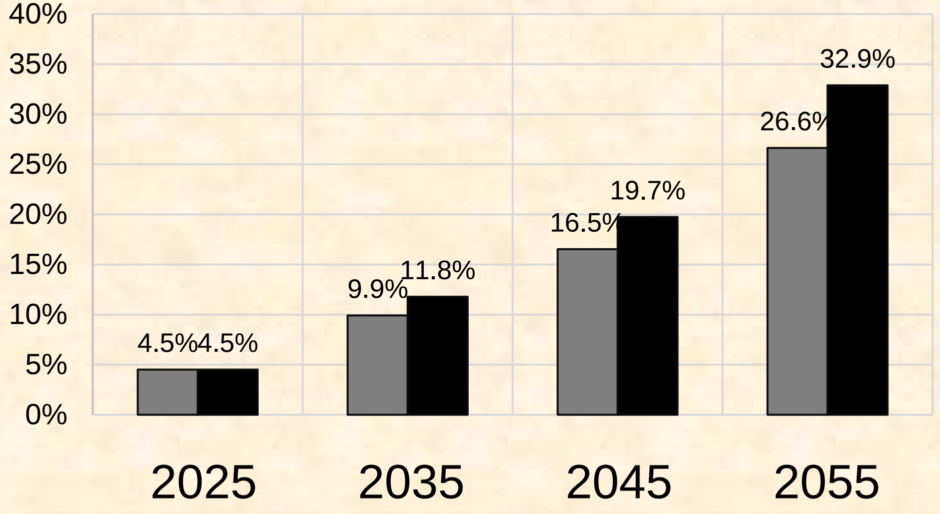
Marginal Differences in **Sediment** Delivery



Marginal Differences in **Nitrogen** Delivery



Marginal Differences in **Phosphorus** Delivery



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

Elements of 2025 Climate Change (1995-2025)

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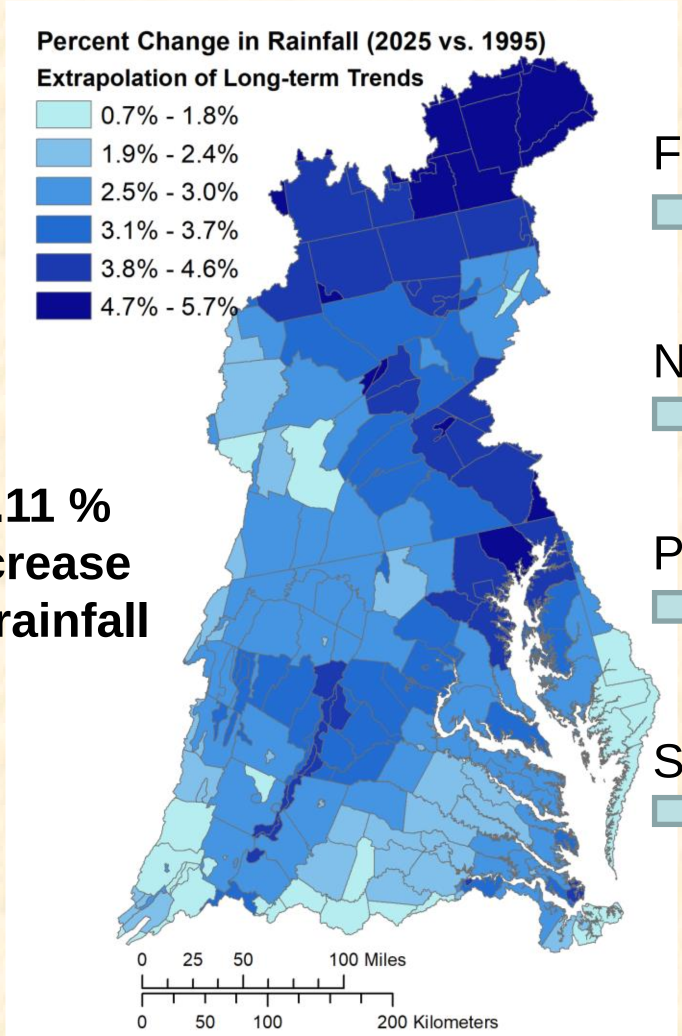
+3.11 % Increase in rainfall



Phase 6 Watershed Model

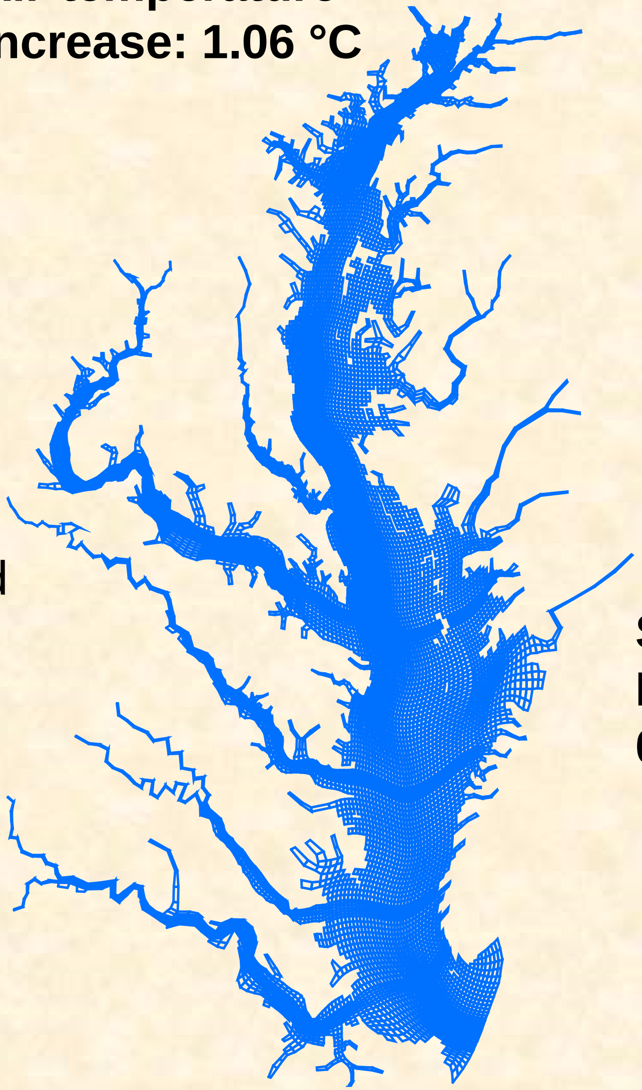
Flow
2.4% Increase

Nitrogen Load
2.6% Increase

Phosphorus Load
4.5% Increase

Sediment Load
3.8% Increase

Air-temperature increase: 1.06 °C



Model: CH3D-ICM
400m-1km Resolution

Sea Level Rise: 0.22m

Open boundary:
Temperature: +0.95 °C;
Salinity: +0.18 psu
(Thomas et al., 2017)

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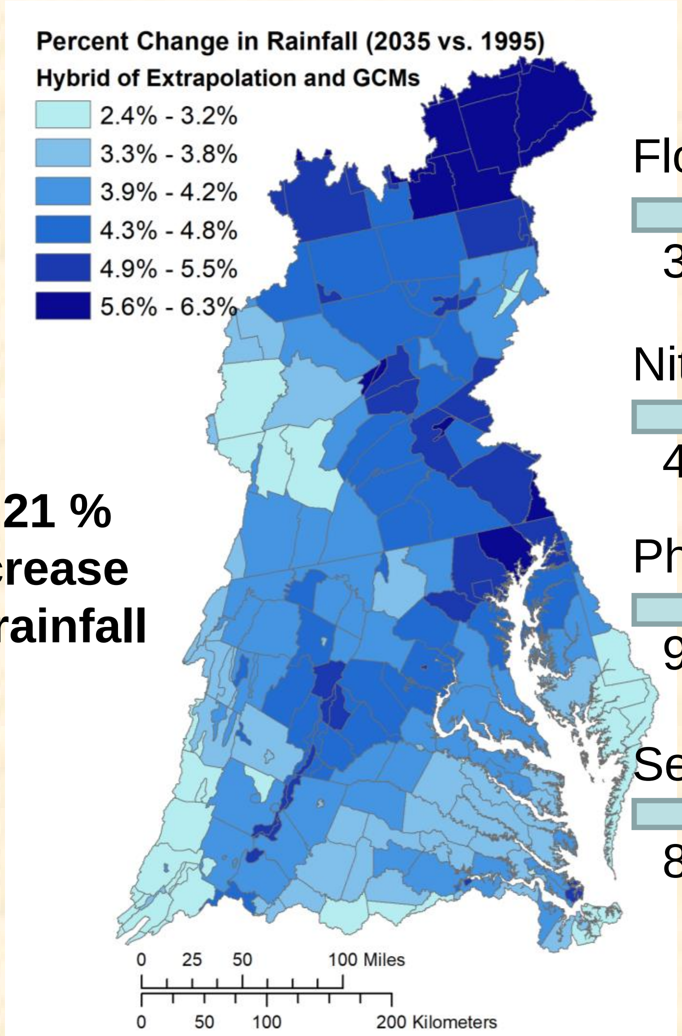
Elements of 2035 Climate Change (1995-2035)

Air-temperature increase: 1.39 °C



+4.21 % Increase in rainfall

Phase 6 Watershed Model

Flow
3.7% Increase

Nitrogen Load
4.7% Increase

Phosphorus Load
9.9% Increase

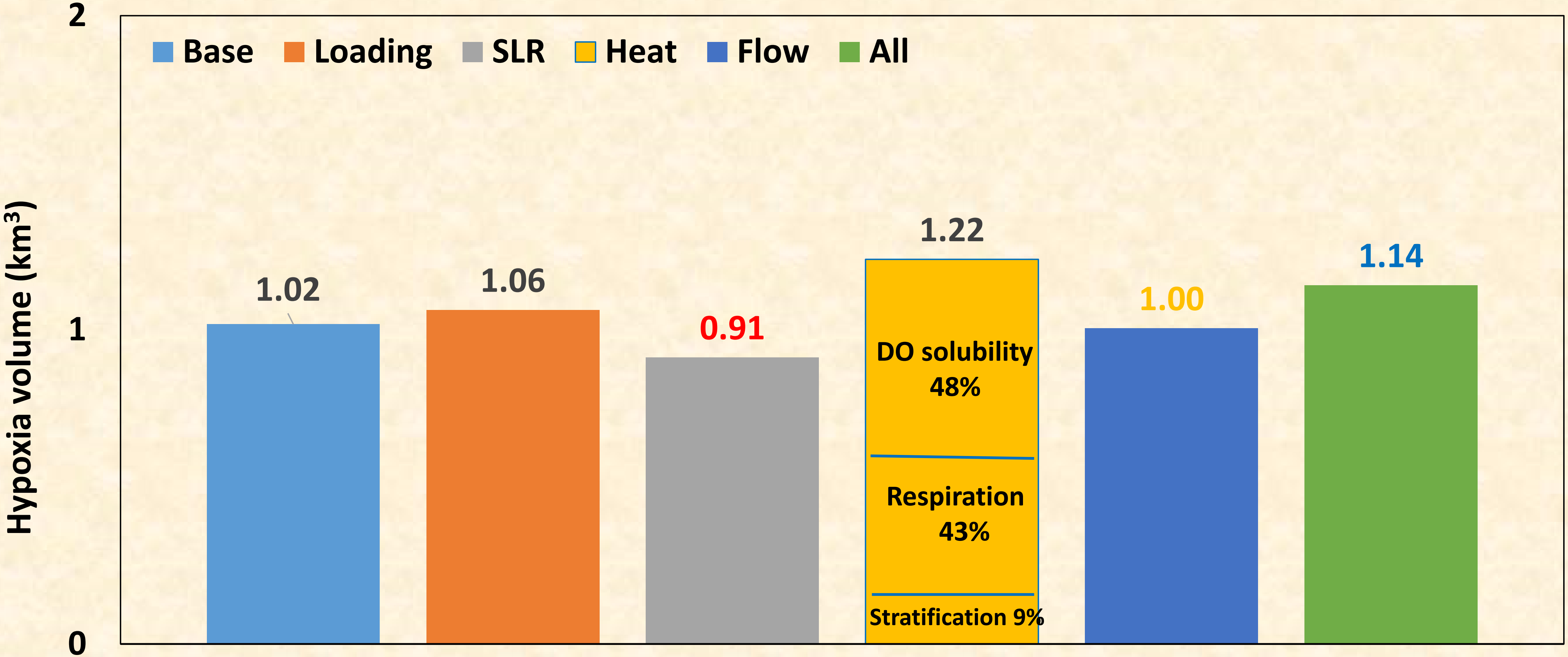
Sediment Load
8.5% Increase

Model: CH3D-ICM
400m-1km Resolution

Sea Level Rise: 0.31m

Open boundary:
Temperature: +1.32 °C;
Salinity: +0.25 psu
(Thomas et al., 2017)

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



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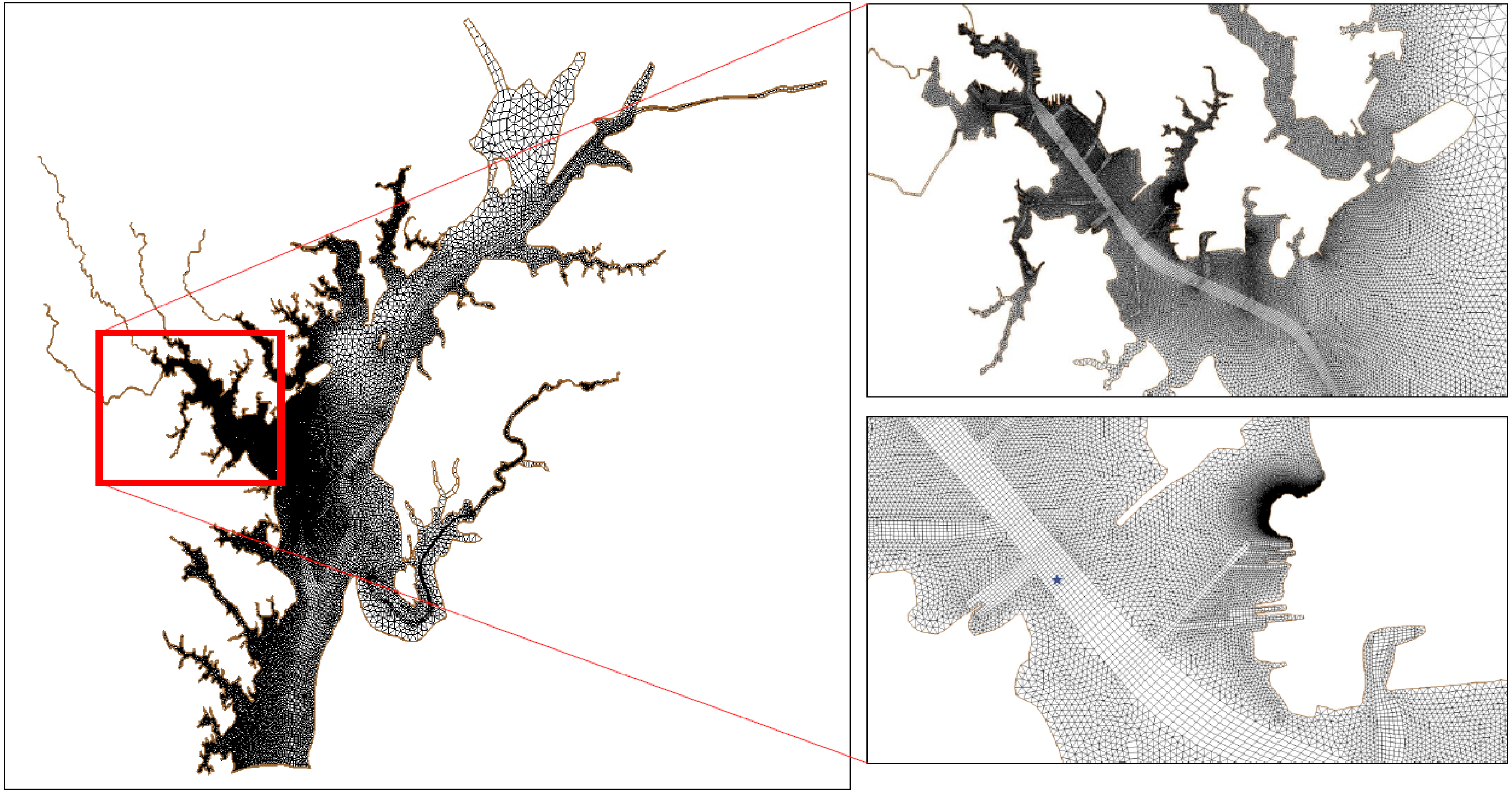
I. High-resolution modeling grid in Patapsco/Back River

(1) 3D SCHISM model domain

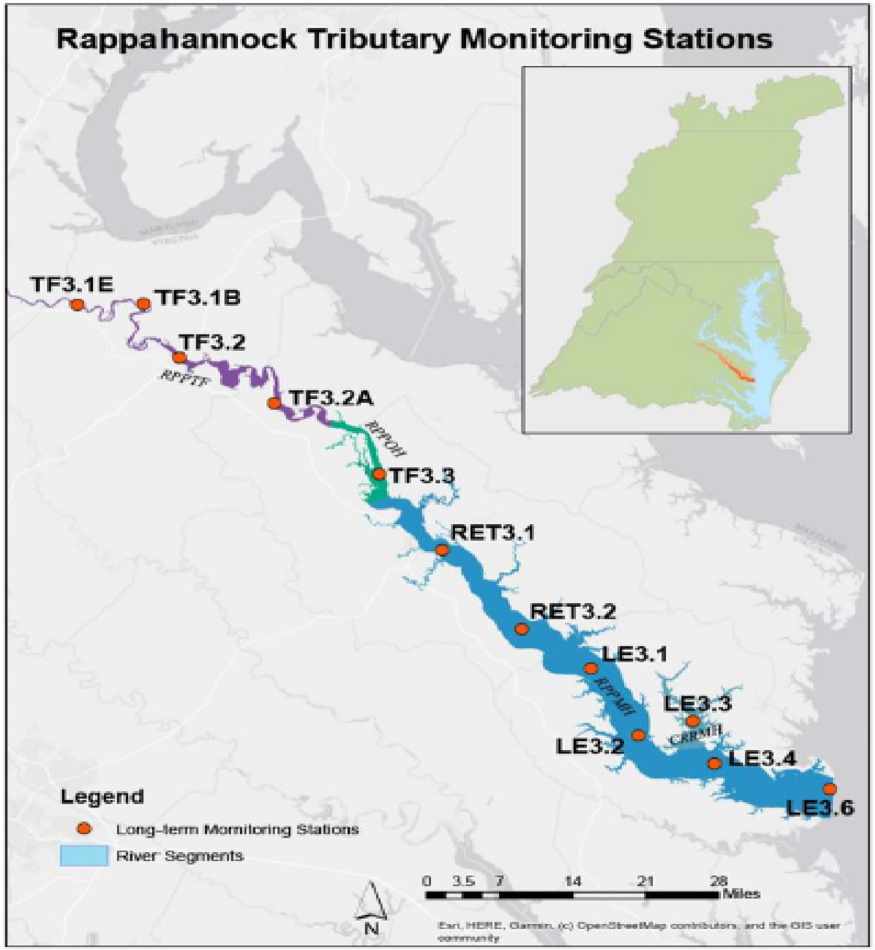


Overall resolution 50-100 m with a total of 61 k grid cells

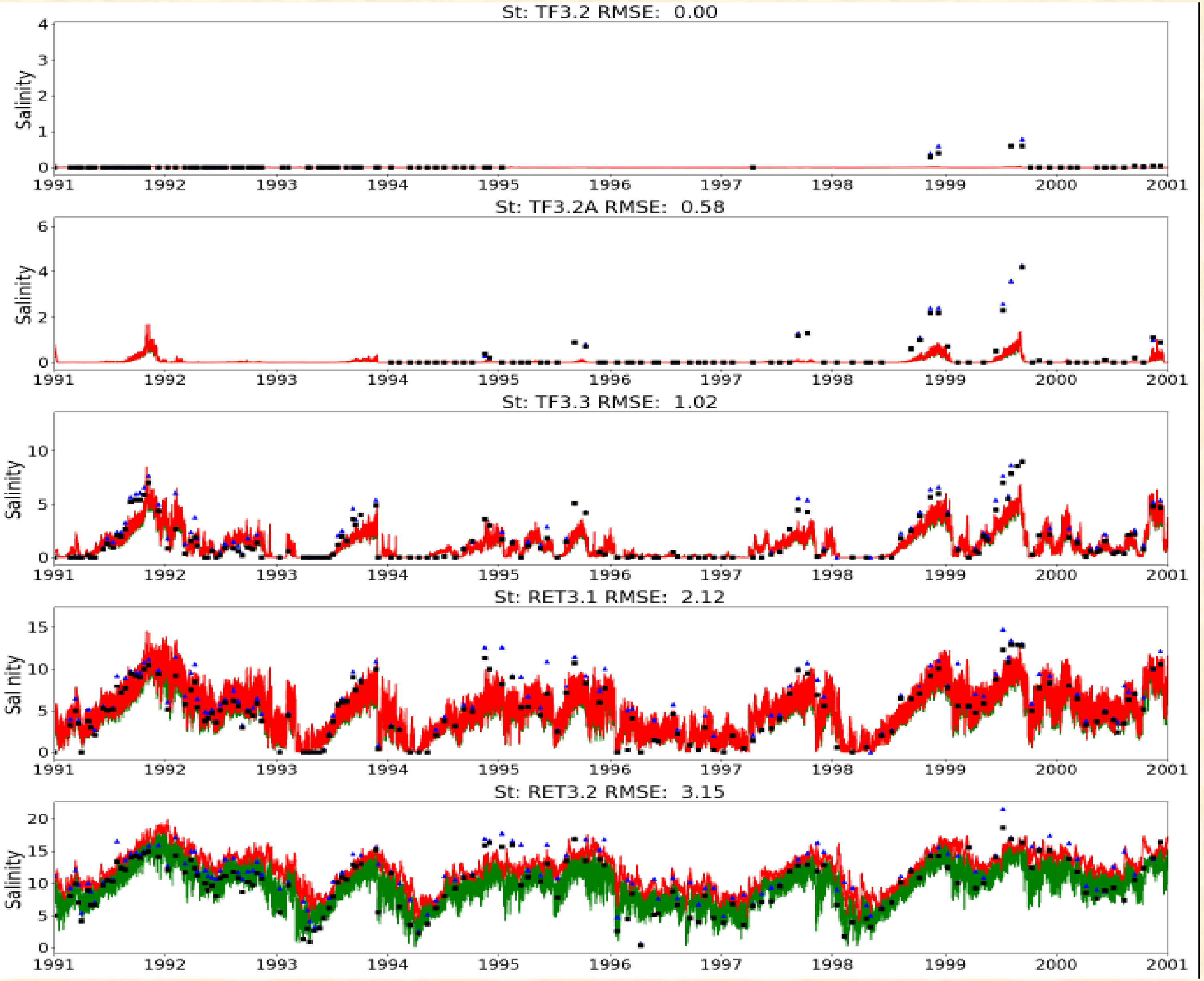
Figure 1: The model domain to be used in evaluating near-field mixing and far-field dilution factors in (a) Upper Chesapeake Bay (b) Baltimore Harbor (c) Near Sparrow Point and Bear Creek. The resolution in the Beak Creek from the mouth to the headwater of Bear Creek is around 20 meters, sufficient for the particle tracking simulation

Rappahannock Multiple Tributary Model (MTM)

Salinity



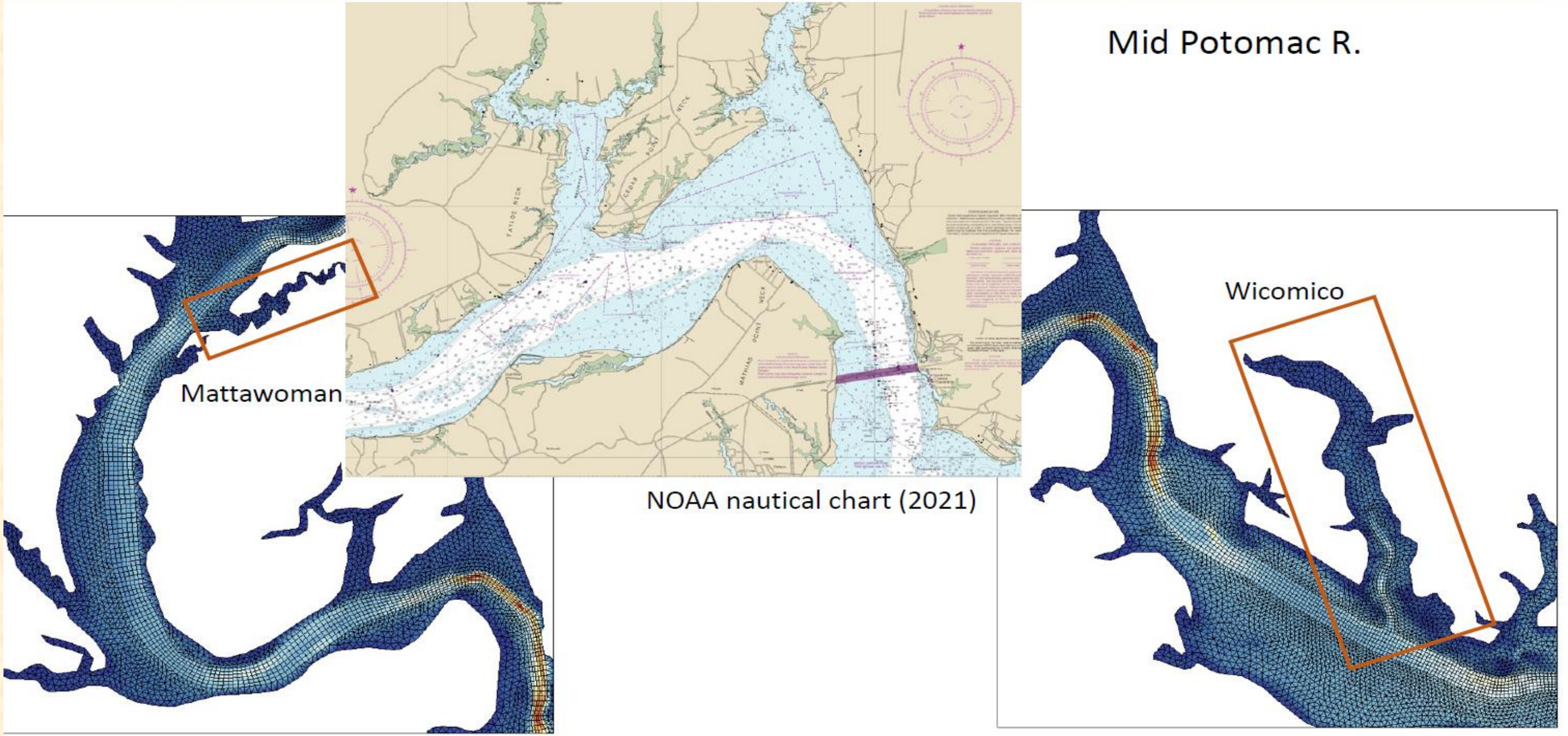
Devereux et al. (2021)



Rappahannock MTM PIs: Qubin Qin, Jian Shen, Zhengui Wang, and Pierre St-Laurent

Potomac Multiple Tributary Model (MTM)

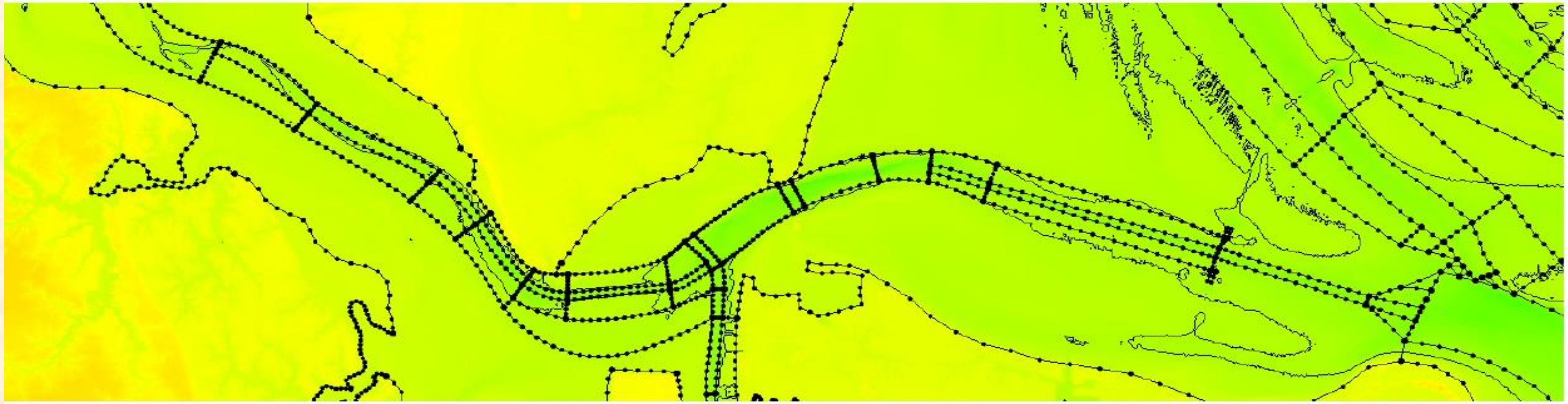
Potomac River horizontal grids

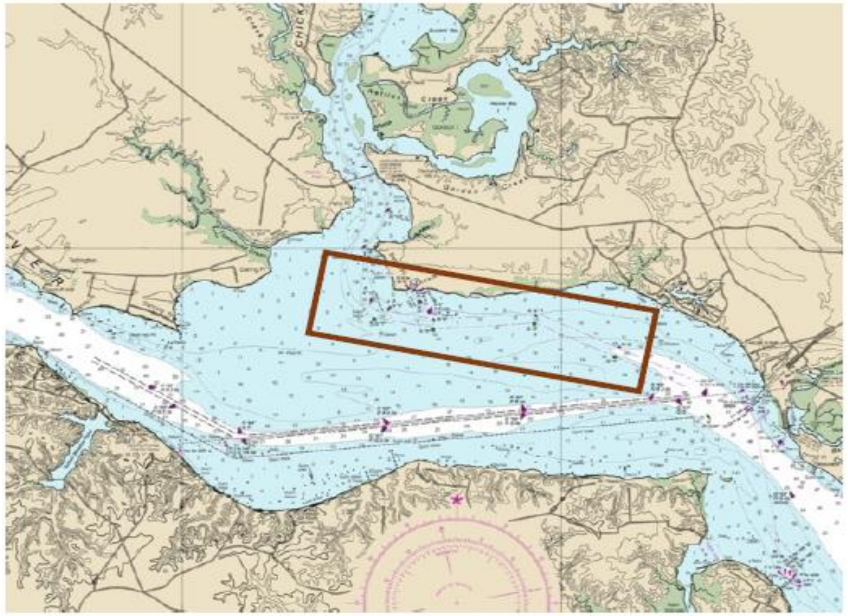


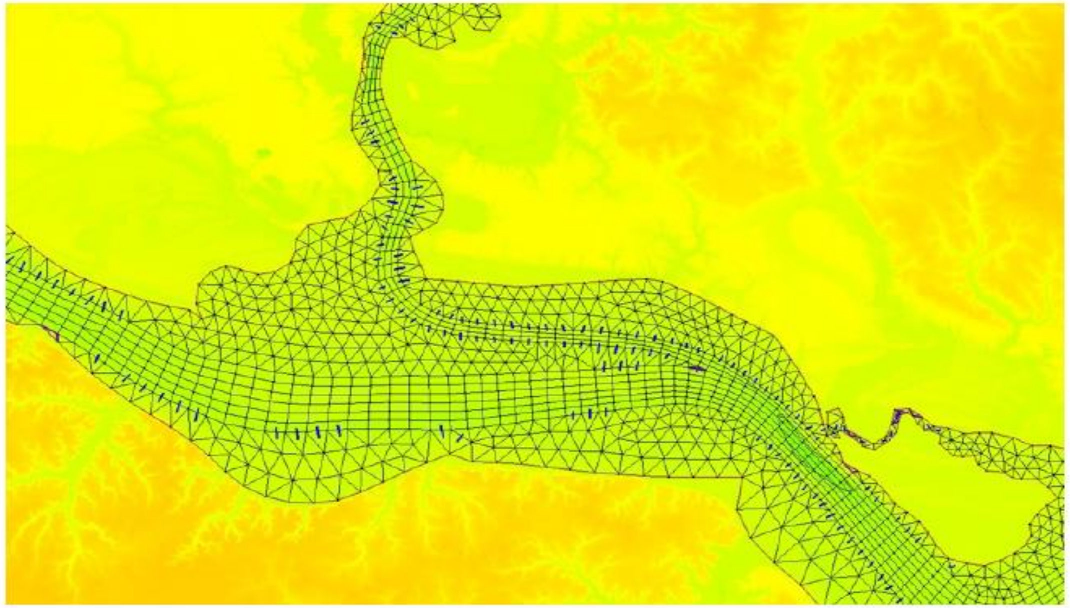
Potomac MTM PI: Nicole Cai

James Multiple Tributary Model (MTM)

James River horizontal grids





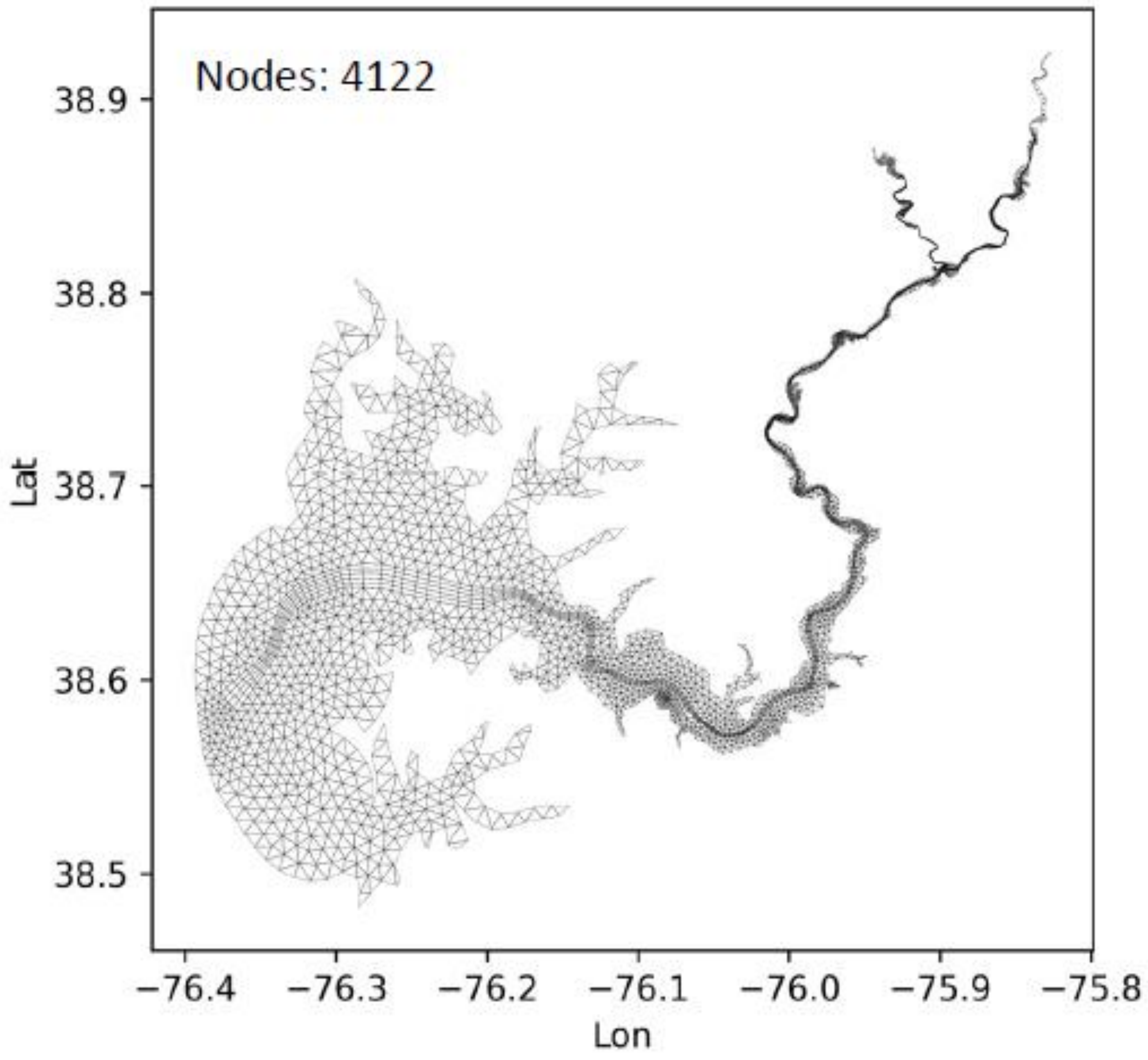


James MTM PI: Nicole Cai

Choptank Multiple Tributary Model (MTM)

Model Grid

- Number of grid nodes: 4122
- Grids along the river channel are refined.
- The same bathymetry used in MBM.
- Same vertical grid (LSC^2) is applied, with maximum layer of 32 (Maximum layer in MBM is 52).



Choptank MTM PIs: Qubin Qin, Jian Shen, Zhengui Wang, and Pierre St-Laurent

Questions the Practitioners are Posing to Themselves

- What are the correct processes and scale to simulate climate effects in estuarine shallow water? Are the simulation of tidal wetlands, SAV, benthic algae, and filter feeders sufficient for the simulation of key shallow water processes?
- The Phase 6 Bay Model could only represent a 2 meter depth as the shallowest cell. The Phase 7 MBM and MTMs can represent multiple depths in shallow water. What would be the optimal depths to represent? What depth representation would be sufficient?
- What are we missing in the Main Bay Model (MBM) or Multiple Tributary Models (MTMs)? What can be improved?
- Can the MBM and MTMs simulate potential climate change effects due to the altered timing of nutrient delivery and subsequent hypoxia including increased winter flows, a decreased spring freshet, and decreased summer flows?
- What is the proper scale of the information needed for effective shallow water modeling? What scale is needed for the WSM & MBM & the passing of information for MBM, MTM, or shallow water simulation?