Updated Climate Change Scenarios

Modeling Quarterly Review
January 7, 2020

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Key Points in Assessment of 2025 Climate Change Risk – A Recap

- The PSC's December 2017 and July 2018 decisions were, "No change in the target loads set by the PSC until 2025, or unless PSC decides to do otherwise."
- Therefore, we have one CBP decisional model finalized in July 2018 and then used to generate WIP3 target loads for the CBP partnership which are now fixed until 2025 (unless adjusted by PSC).

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Key Points in Assessment of 2025 Climate Change Risk - Recap

- We also have a climate change analysis model completed in December 2018 that the CBP partnership will review over the next two years for technical policy sufficiency for adjusting the decisional model to address climate change risk in the 2022-2023 Milestones as directed by the PSC.
- The current climate change assessment (Dec. 2019 – Jan. 2020) 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.

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Key Points in Assessment of 2025 Climate Change Risk – What's Changed

- At our December 2019 meeting it was decided that there would be a clear distinction between "climate change only" forcing for the 2025, 2035, 2045, and 2055 series of scenarios and the companion series of scenarios that combine climate change forcing with estimated future land use and estuarine practices in 2025, 2035, 2045, and 2055.

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Current Climate Change Only Scenarios

Air-temperature increase: 1.06 °C

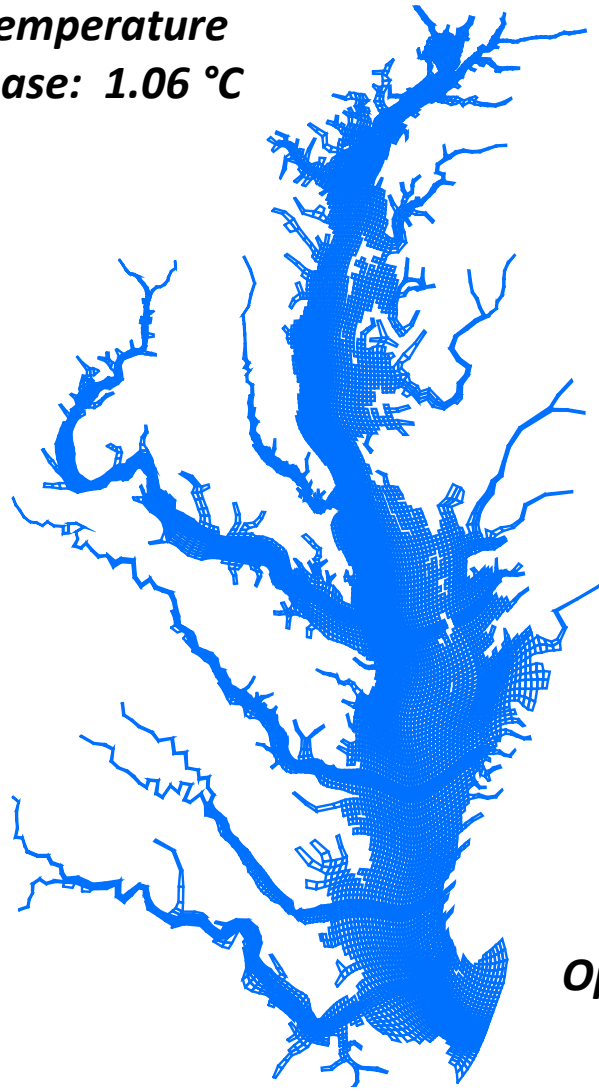
Sea Level Rise: 0.22m

Flow → +2.4% est. 2025

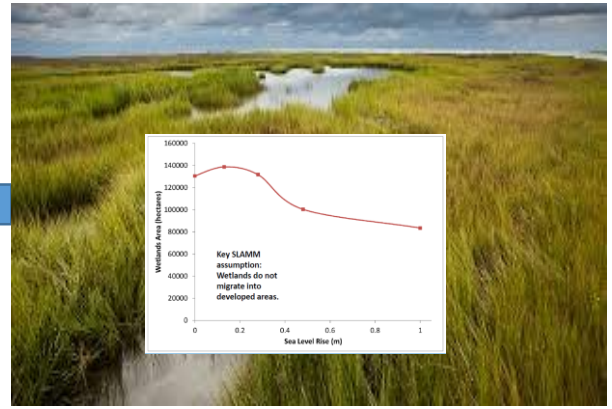
TN → +2.6% est. 2025

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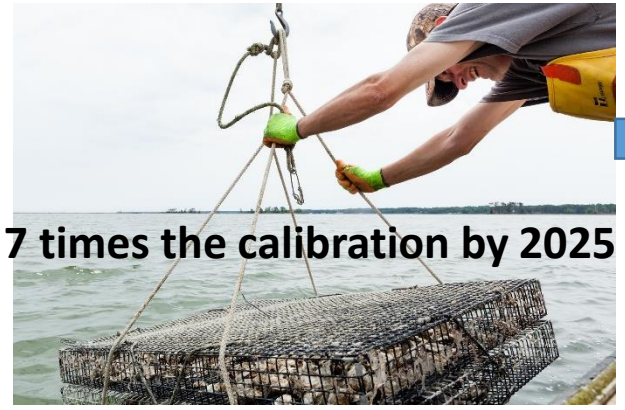
Scenarios for Estimated Future Land Use and Estuarine Practices for 2035, 2045, and 2055

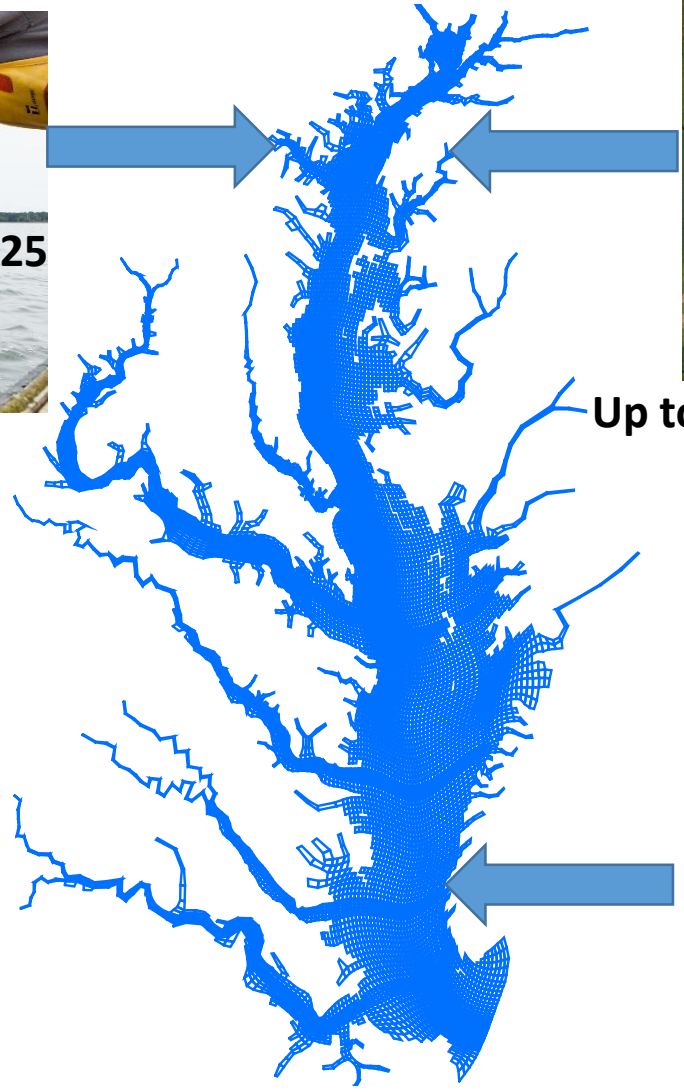
Oyster aquaculture expansion



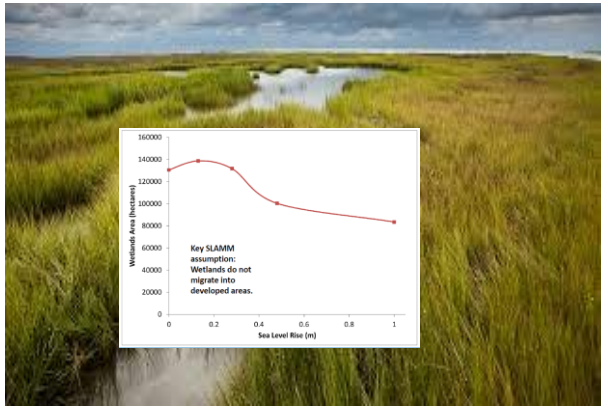
7 times the calibration by 2025

Land use change

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



Tidal wetland change



Major Climate Change Forcing for 2025

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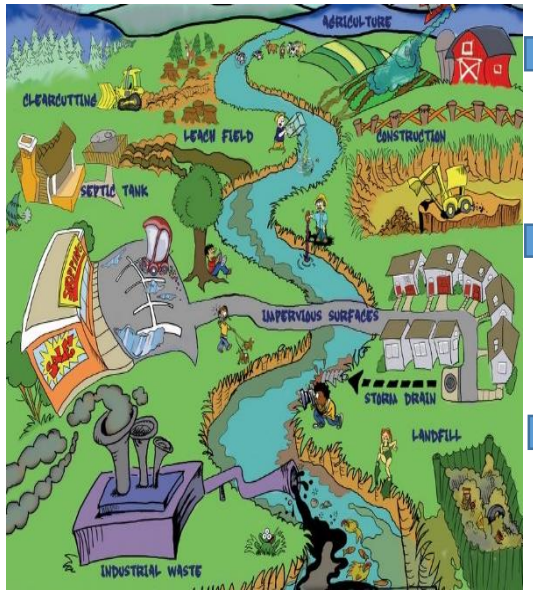
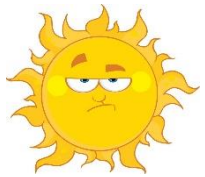
Rain

Watershed



Warming



31 GCMs

Air-temperature increase: 1.06 °C

Flow

+2.4%

TN

+2.6%

TP

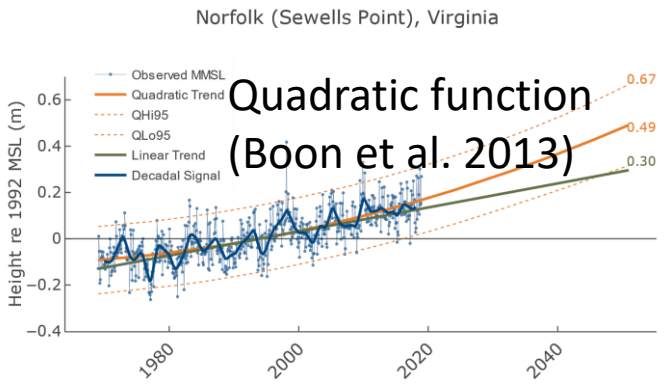
+4.5%

Sediment

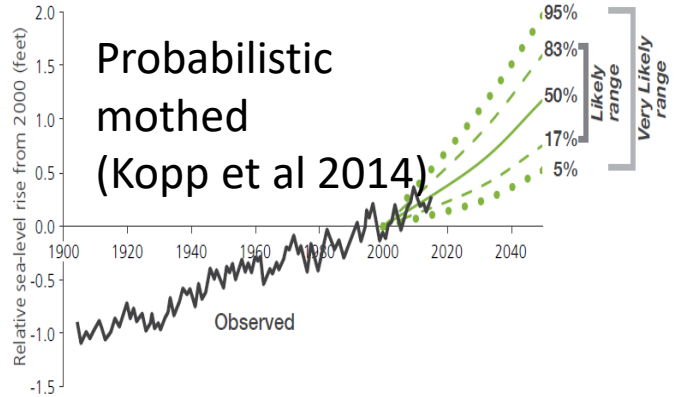
+3.8

Model: CH3D-ICM 400m-1km resolution

Sea Level Rise: 0.22m



Quadratic function (Boon et al. 2013)



Probabilistic mothed (Kopp et al 2014)

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

From Gopal Bhatt

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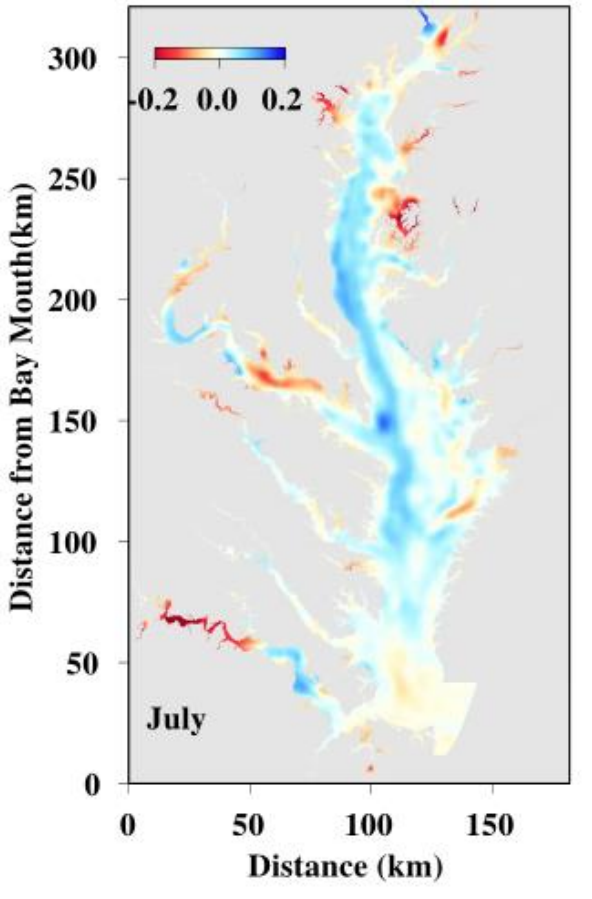
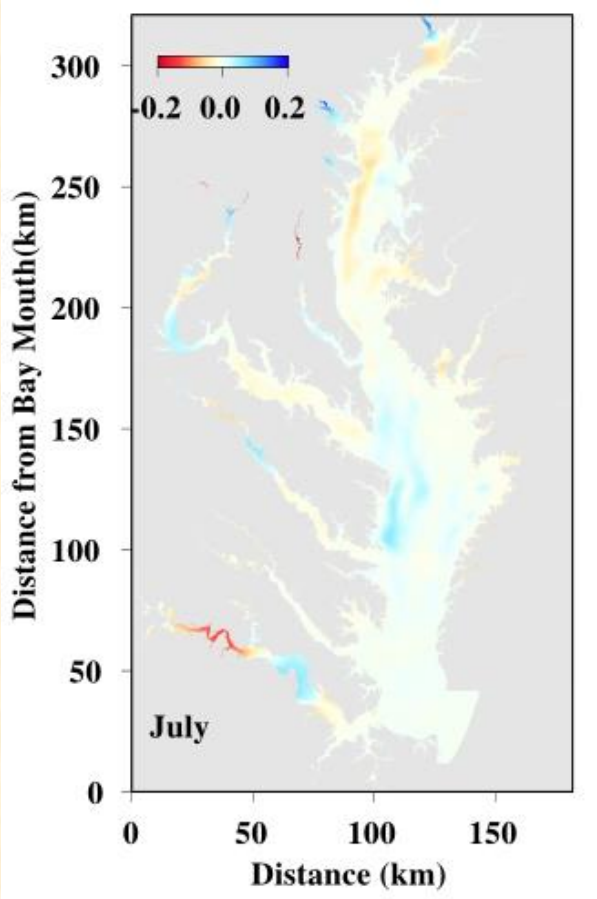
Bottom DO Change: 1995 to 2025

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.

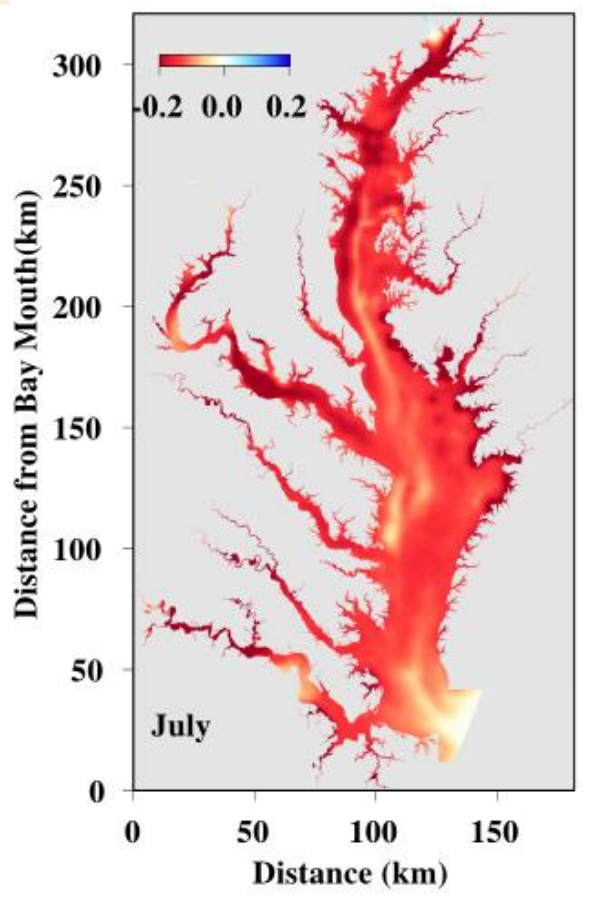
Sea Level Rise



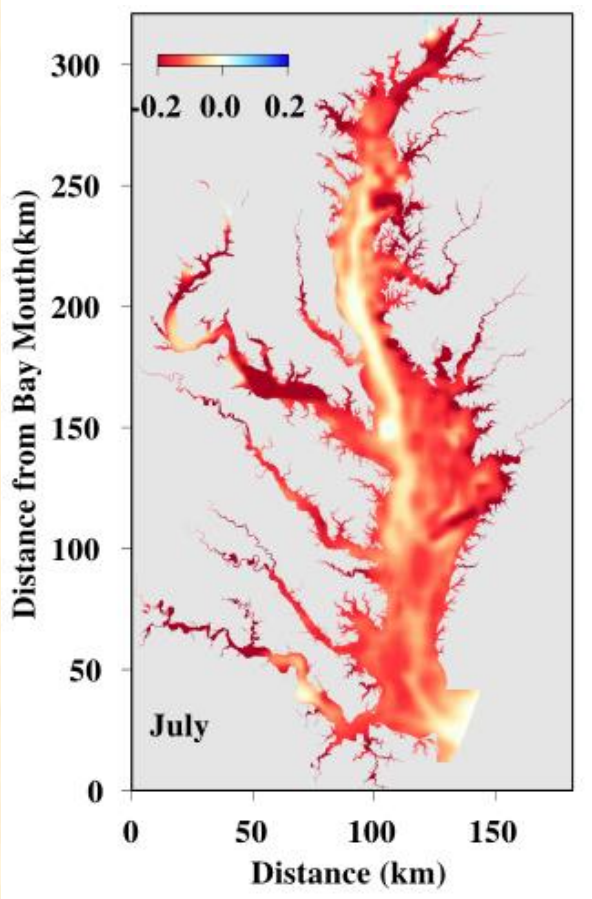
Watershed Flow



Increased Temp.



All Factors



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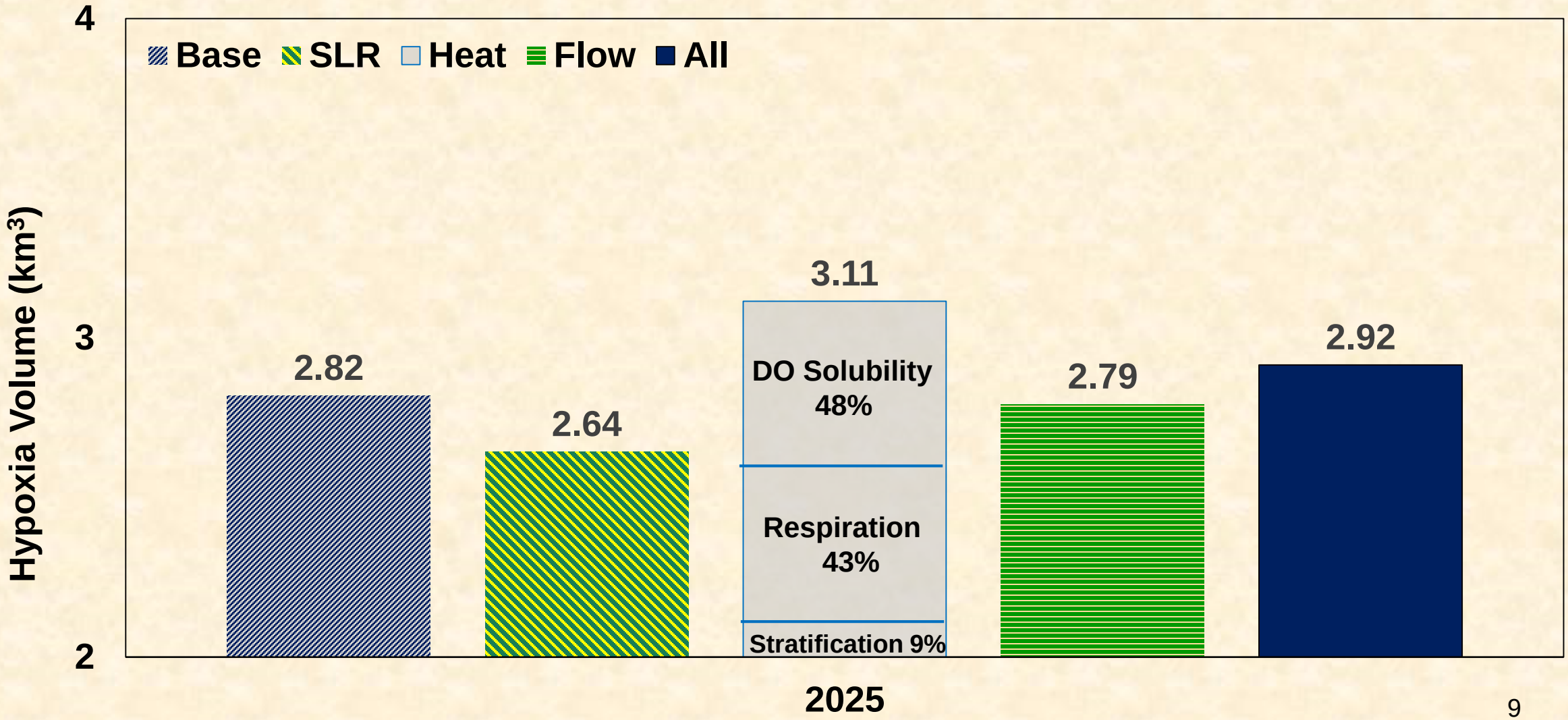
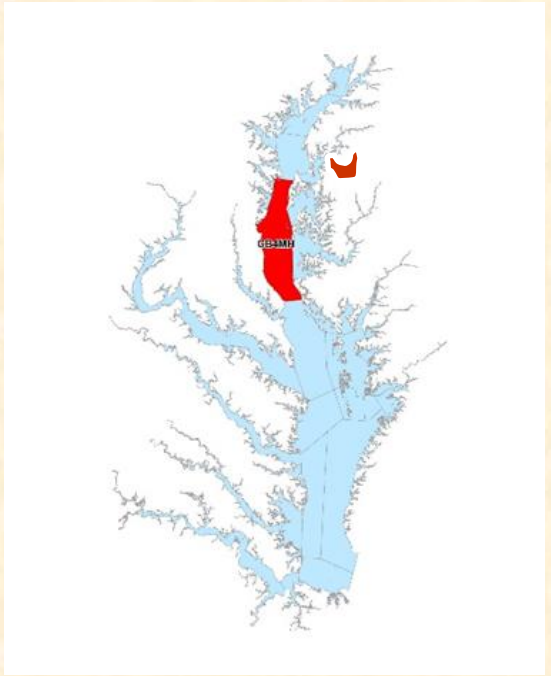
Summer (Jun.-Sep.) Hypoxia Volume (<1 mg/l) 1991-2000 In the Whole Bay



The CBP Climate Change Assessment

Achievement of **Deep Channel 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 Channel	2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Deep Channel	2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Deep Channel	2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Deep Channel
CB3MH	MD	0.00%	0.00%	0.00%	0.00%
CB4MH	MD	1.47%	3.15%	4.62%	7.31%
CB5MH	MD	0.00%	0.00%	0.00%	0.00%
CB5MH	VA	0.00%	0.00%	0.00%	0.00%
POTMH	MD	0.00%	0.00%	0.00%	0.00%
RPPMH	VA	0.00%	0.00%	0.00%	0.00%
ELIPH	VA	0.00%	0.00%	0.00%	0.00%
CHSMH	MD	0.01%	0.92%	1.08%	2.34%



Achievement of Deep Water DO Water Quality Standard

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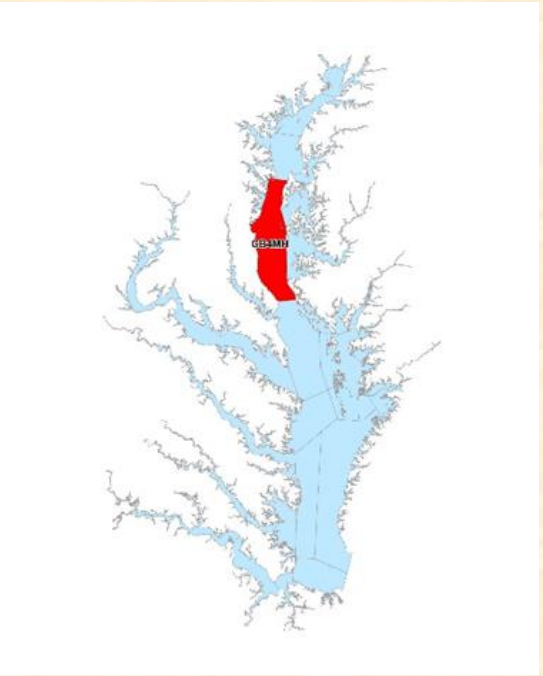
Achievement of **Deep Water DO** water quality standard expressed as a incremental increase over the PSC agreed to (December 2017; July 2018) 2025 nutrient targets for growth and Conowingo infill

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	2045 Climate 2025 Land Use 212TN, 15.4TP 1993-1995 DO Deep Water	2055 Climate 2025 Land Use 220TN, 16.7TP 1993-1995 DO Deep Water
CB3MH	MD	0.01%	0.15%	0.16%	0.21%
CB4MH	MD	0.94%	1.61%	2.00%	2.66%
CB5MH	MD	0.52%	1.01%	1.32%	1.66%
CB5MH	VA	0.00%	0.00%	0.00%	0.00%
CB6PH	VA	0.00%	0.00%	0.00%	0.00%
CB7PH	VA	0.00%	0.00%	0.00%	0.00%
PATMH	MD	0.01%	0.02%	0.42%	2.66%
MAGMH	MD	1.66%	1.66%	1.91%	1.91%
SOUMH	MD	0.00%	0.00%	0.00%	0.00%
SEVMH	MD	0.00%	0.00%	0.00%	0.00%
PAXMH	MD	0.00%	0.00%	0.00%	0.00%
POTMH	MD	0.03%	0.15%	0.56%	0.81%
RPPMH	VA	0.00%	0.24%	1.48%	1.85%
YRKPH	VA	0.00%	0.00%	0.00%	0.00%
ELIPH	VA	0.00%	0.00%	0.00%	0.00%
SBEMH	VA	0.00%	0.00%	0.44%	3.12%
CHSMH	MD	0.00%	0.00%	0.00%	0.00%



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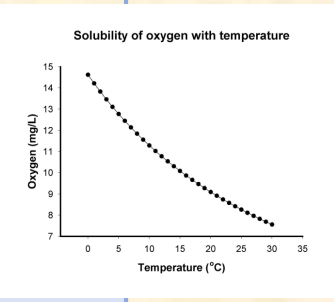
Achievement of Open Water DO Water Quality Standard

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	2045 Climate 2025 Land Use 212TN, 15.4TP 1993-1995 DO Open Water	2055 Climate 2025 Land Use 220TN, 16.7TP 1993-1995 DO Open Water
CB1TF	MD	0.0%	0.0%	0.0%	0.0%
CB2OH	MD	0.0%	0.0%	0.0%	0.0%
CB3MH	MD	0.0%	0.0%	0.0%	0.0%
CB4MH	MD	0.0%	0.0%	0.0%	0.0%
CB5MH	MD	0.0%	0.0%	0.0%	0.0%
CB5MH	VA	0.0%	0.0%	0.0%	0.0%
CB6PH	VA	0.4%	0.7%	1.0%	1.3%
CB7PH	VA	1.1%	1.8%	2.7%	3.9%
CB8PH	VA	0.0%	0.0%	0.0%	0.0%
BSHOH	MD	0.0%	0.0%	0.0%	0.0%
GUNOH	MD	0.0%	0.0%	0.0%	0.0%
MIDOH	MD	0.0%	0.0%	0.0%	0.0%
BACOH	MD	0.0%	0.0%	0.0%	0.0%
PATMH	MD	0.0%	0.0%	0.0%	0.0%
MAGMH	MD	0.0%	0.0%	0.0%	0.0%
SEVMH	MD	0.0%	0.0%	0.0%	0.0%
SOUMH	MD	0.0%	0.0%	0.0%	0.0%
RHDMH	MD	0.0%	0.0%	0.0%	0.0%
WSTMH	MD	0.0%	0.0%	0.0%	0.0%
PAXTF	MD	9.1%	9.1%	9.6%	10.5%
WBRTF	MD	32.3%	32.3%	39.6%	54.6%
PAXOH	MD	5.6%	8.2%	9.9%	11.7%
PAXMH	MD	0.0%	0.0%	0.0%	0.0%
POTTF	DC	0.6%	0.9%	1.2%	1.4%
POTTF	MD	0.0%	0.0%	0.0%	0.4%
ANATF	DC	7.0%	9.5%	12.3%	14.7%
ANATF	MD	10.2%	16.0%	24.1%	29.3%
PISTF	MD	0.0%	0.0%	0.0%	0.0%
MATTF	MD	0.0%	0.0%	0.0%	0.0%
POTOH1	MD	0.1%	0.2%	0.5%	0.8%
POTMH	MD	0.0%	0.0%	0.0%	0.0%
RPPTF	VA	0.0%	0.0%	0.0%	1.6%
RPPOH	VA	0.0%	0.0%	0.0%	0.0%
RPPMH	VA	0.0%	0.0%	0.0%	0.0%
CRRMH	VA	9.8%	11.3%	11.3%	13.8%
PIAMH	VA	0.0%	0.0%	0.0%	0.0%
MPNTF	VA	25.7%	35.6%	39.9%	34.4%
MPNOH	VA	2.1%	0.3%	0.0%	0.0%
PMKTF	VA	64.4%	74.6%	67.5%	62.9%
PMKOH	VA	10.7%	9.9%	3.3%	1.9%
YRKMH	VA	0.9%	0.2%	1.0%	2.8%
YRKPH	VA	0.0%	0.0%	0.0%	0.0%
MOBPH	VA	0.0%	0.0%	0.1%	0.2%
JMSTFL	VA	0.0%	0.4%	1.0%	1.0%



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Achievement of Open Water DO Water Quality Standard

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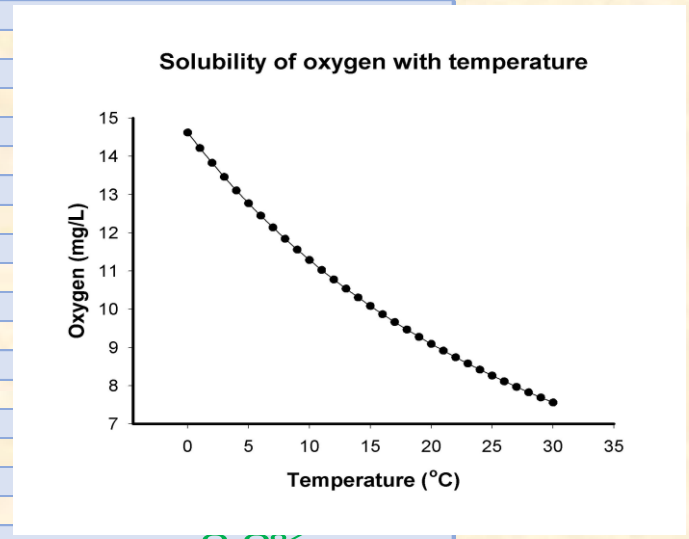
JMSTFU	VA	0.0%	0.0%	0.0%	0.0%
APPTF	VA	-4.6%	-4.6%	-4.6%	0.0%
JMSOH	VA	0.0%	0.0%	0.0%	0.0%
CHKOH	VA	13.4%	22.4%	27.3%	29.4%
JMSMH	VA	0.0%	0.0%	0.0%	0.0%
JMSPH	VA	0.0%	0.0%	0.0%	0.0%
WBEMH	VA	0.3%	0.3%	0.3%	0.3%
SBEMH	VA	11.0%	19.0%	27.3%	30.8%
EBEMH	VA	3.2%	6.2%	6.2%	6.2%
ELIPH	VA	0.0%	0.0%	0.0%	0.1%
NORTF	MD	0.0%	0.0%	0.0%	
C&Dcanal	MD/DE	0.0%	0.0%	0.0%	
BOHOH	MD	0.0%	0.0%	0.0%	
ELKOH	MD	0.0%	0.0%	0.0%	
SASOH	MD	0.0%	0.0%	0.0%	
CHSTF	MD	0.0%	0.0%	0.0%	
CHSOH	MD	0.0%	0.0%	0.0%	
CHSMH	MD	0.0%	0.0%	0.0%	
EASMH	MD	0.0%	0.0%	0.0%	
CHOTF	MD	0.0%	0.0%	0.0%	
CHOOH	MD	0.0%	0.0%	0.0%	
CHOMH2	MD	0.0%	0.0%	0.0%	
CHOMH1	MD	0.0%	0.0%	0.1%	
LCHMH	MD	0.0%	0.0%	0.1%	
FSBMH	MD	58.3%	14.3%	0.0%	
NANTF	DE	0.0%	0.2%	0.0%	
NANTF	MD	0.7%	4.7%	0.7%	
NANOH	MD	0.4%	1.7%	0.0%	
NANMH	MD	0.0%	0.0%	0.0%	0.0%
WICMH	MD	11.5%	11.7%	21.5%	28.2%
MANMH	MD	4.1%	4.4%	4.0%	0.0%
BIGMH	MD	0.0%	0.0%	0.0%	0.0%
POCTF	MD	69.8%	77.5%	77.5%	77.5%
POCOH	MD	69.8%	77.5%	77.5%	77.5%
POCOH	VA	69.8%	77.5%	77.5%	77.5%
POCMH	MD	0.0%	0.0%	0.0%	0.0%
POCMH	VA	0.0%	0.0%	0.0%	0.0%
TANMH	MD	0.0%	0.0%	0.0%	0.0%
TANMH	VA	0.0%	0.0%	0.0%	0.0%



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Sensitivity Runs With Land Use Change and Oyster Aquaculture Expansion

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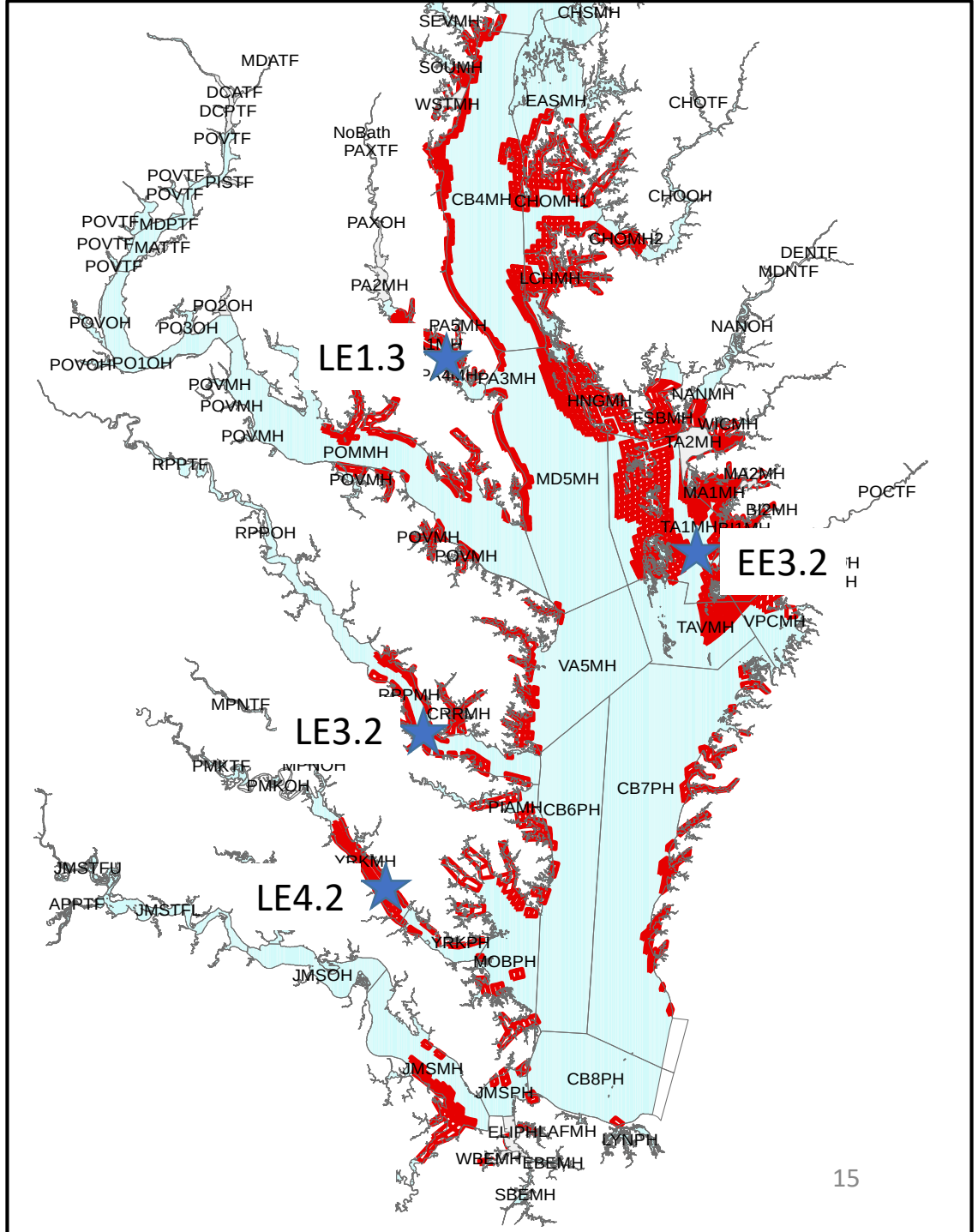
Oyster Aquaculture sites

- MD: Salinity ≥7 ppt, depth ≤ 12 ft.
- VA: Lease sites
- Sufficient phytoplankton and suspended solids

Model setup

- 392 million oysters harvested in 2025, equivalent to 468k lbs C in biomass.
- 78k lbs N and 8k lbs P reduction in nutrient loads (from soft tissue harvest).
- Oyster biomass in the water column is 1.5 times the annual harvest for aquaculture in cages (20% in MD and 80% in VA).
- Oyster biomass on the bottom is twice the annual harvest for bottom culture (80% in MD and 20% in VA).



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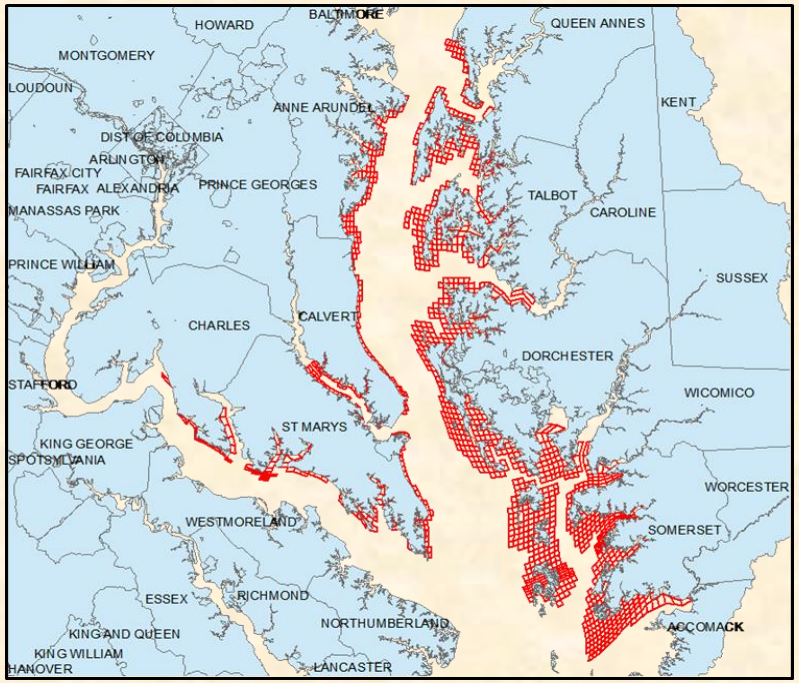
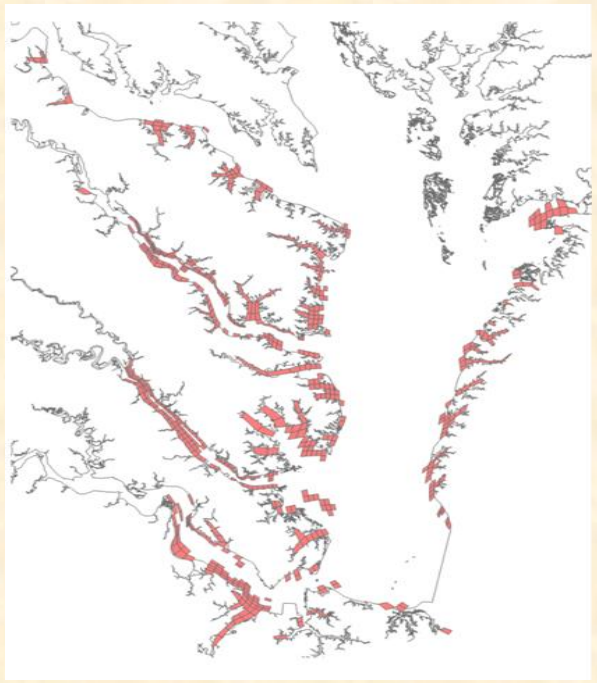
Aquaculture Oysters at 2025 Buildout Levels

The 2017 WQSTM oyster module considers four populations:

- Natural populations on reefs and subject to harvest
- Natural populations in sanctuaries and not subject to harvest
- Smaller areas within sanctuaries where oyster habitat is restored
- Aquaculture operations





Year	VA Biomass (kg DW)	VA Harvest (kg DW)	MD Biomass (kg DW)	MD Harvest (kg DW)
2005	3398	2124		
2006	11892	7433		
2007	16989	10618		
2008	25483	15927		
2009	32279	20174		
2010	56063	35039		
2011	79847	49904		
2012	93438	58399		
2013	103631	64770		
2014	134211	83882	40905	21529
2015	118921	74326	60612	31901
2016			64550	33974
2025	508032	317520	241315	127008

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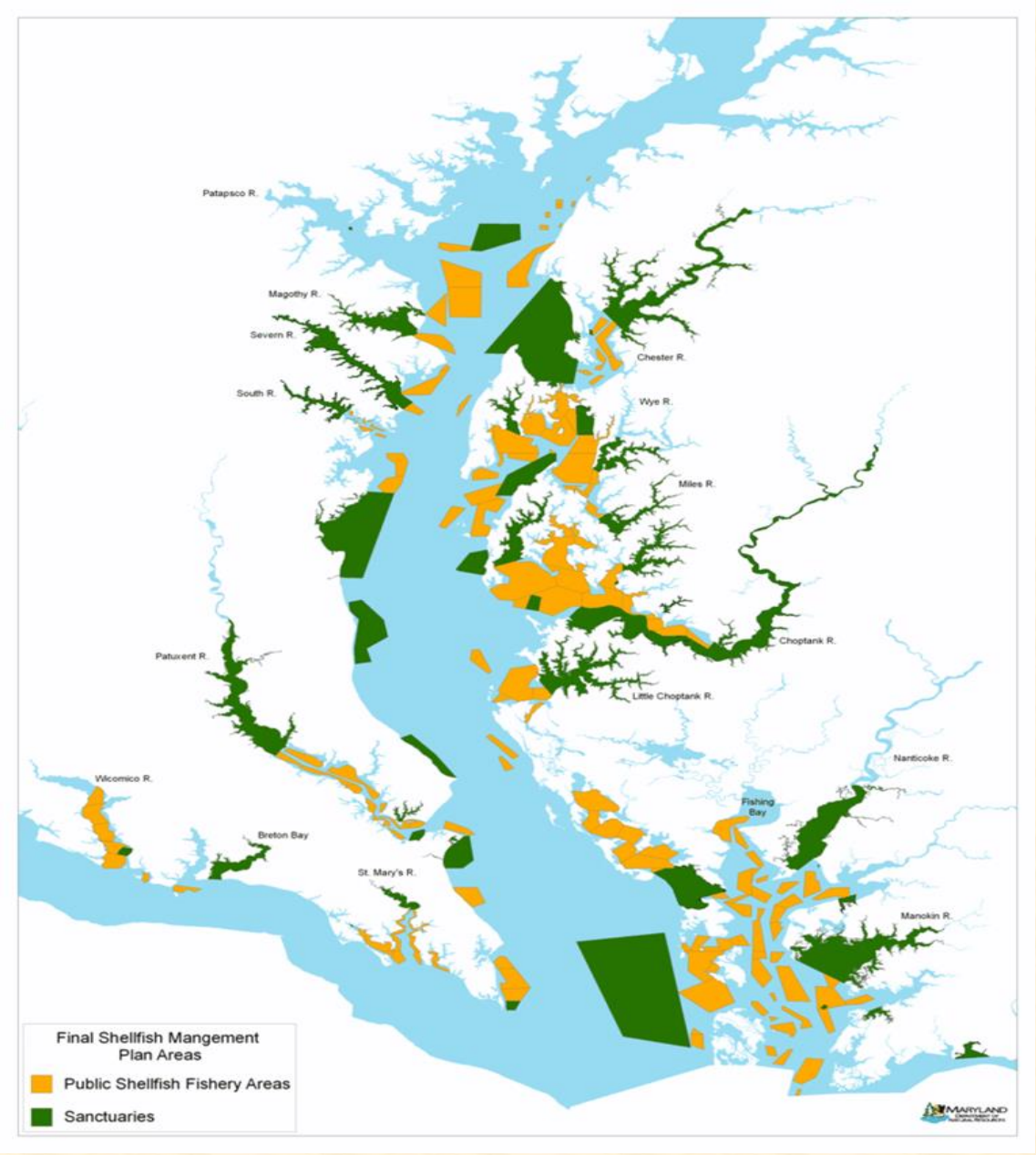
Oyster Sanctuaries Influence Included In Future Scenarios

The elimination of oyster mortality in sanctuaries increases oyster biomass slightly and makes DO Deep Channel and Deep Water standards easier to achieve for all CBP partners.



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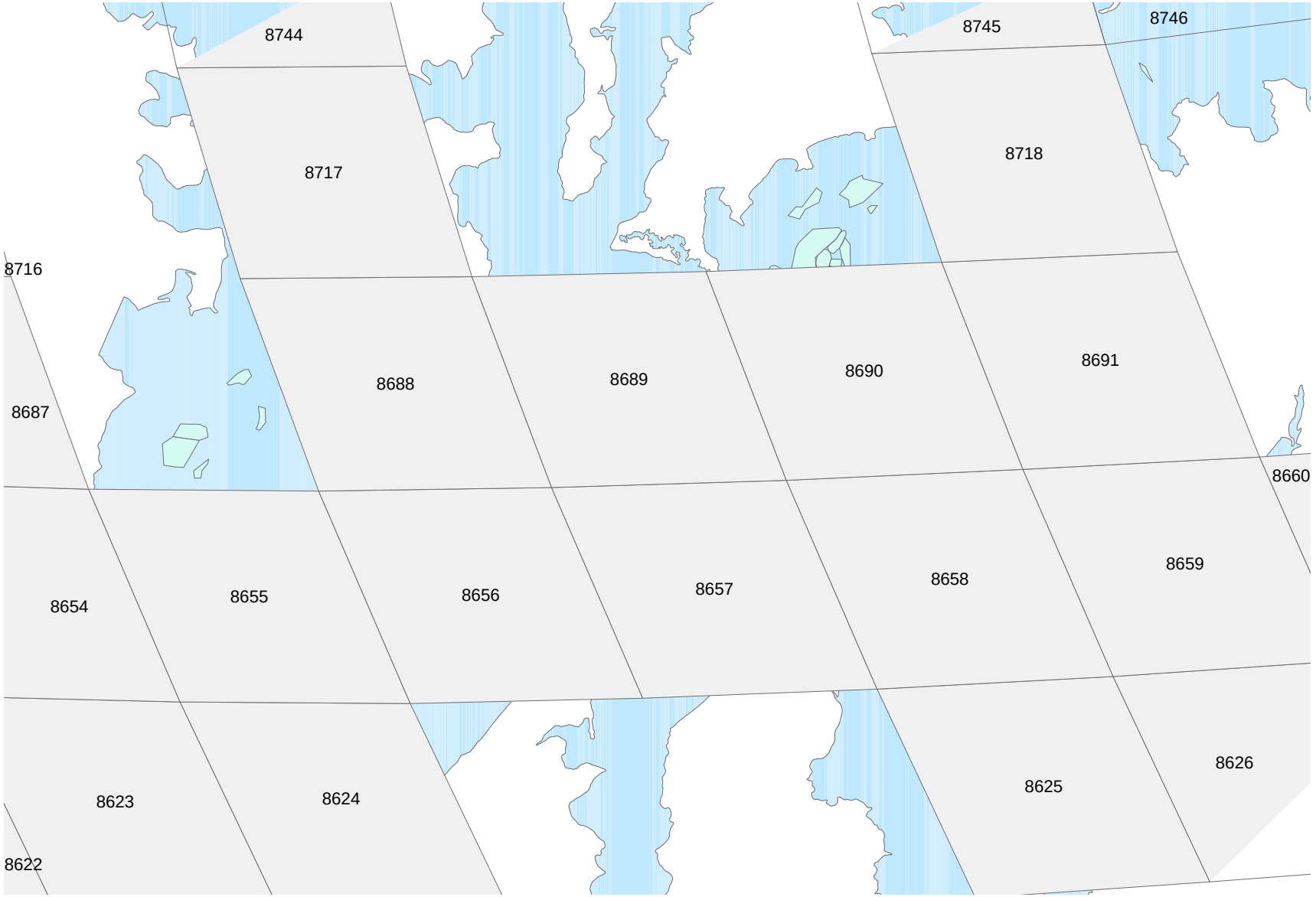
Habitat Restoration In Oyster Sanctuaries

Oyster sanctuary areas with habitat reconstruction are not in simulation and are handled by nutrient reduction recommendations of 2nd Expert Panel Report (in preparation for March 2020 Review by WQGIT).

Little Choptank Sanctuary restoration sites

Restoration credited as BMP on watershed and has to be removed from the simulation



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Deep Channel DO Nonattainment Change With Oyster Aquaculture and Sanctuaries

CB Segment	State	2025 Scenario With Oyster Aquaculture 1993-1995 DO Deep Channel	2025 Scenario Without Oyster Aquaculture 1993-1995 DO Deep Channel
CB3MH	MD	0.00%	0.00%
CB4MH	MD	9.36%	10.05%
CB5MH_MD	MD	0.00%	0.00%
CB5MH_VA	VA	0.00%	0.00%
POTMH_MD	MD	0.00%	0.00%
RPPMH	VA	0.00%	0.00%
ELIPH	VA	0.00%	0.00%
CHSMH	MD	1.09%	1.09%

Delta DO CB4MH = 0.69

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Deep Channel DO Nonattainment Change With Land Use Only

CB Segment	State	2035 Climate 2035 Land Use Compared to 2035 Climate 2025 Land Use	2045 Climate 2045 Land Use Compared to 2045 Climate 2025 Land Use	2055 Climate 2055 Land Use Compared to 2055 Climate 2025 Land Use
CB3MH	MD	0.00%	0.00%	0.00%
CB4MH	MD	0.19%	0.70%	1.26%
CB5MH_MD	MD	0.00%	0.00%	0.02%
CB5MH_VA	VA	0.00%	0.00%	0.00%
POTMH_MD	MD	0.00%	0.00%	0.00%
RPPMH	VA	0.00%	0.00%	0.00%
ELIPH	VA	0.00%	0.00%	0.00%
CHSMH	MD	0.00%	0.00%	0.00%
EASMH	MD	0.01%	0.10%	0.46%

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Current Climate Change Only Scenarios

Air-temperature increase: 1.06 °C

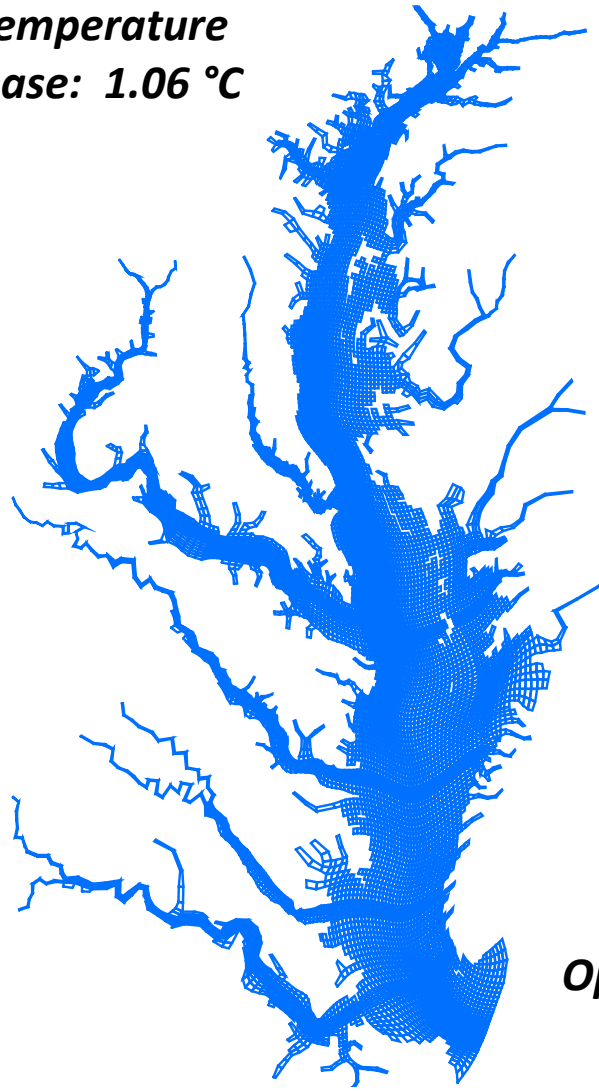
Sea Level Rise: 0.22m

Flow
+2.4% est. 2025

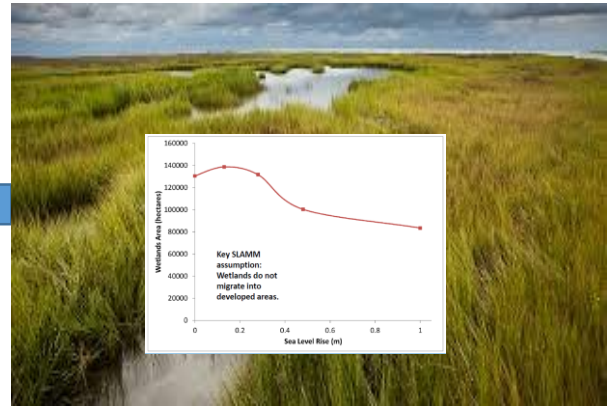
TN
+2.6% est. 2025

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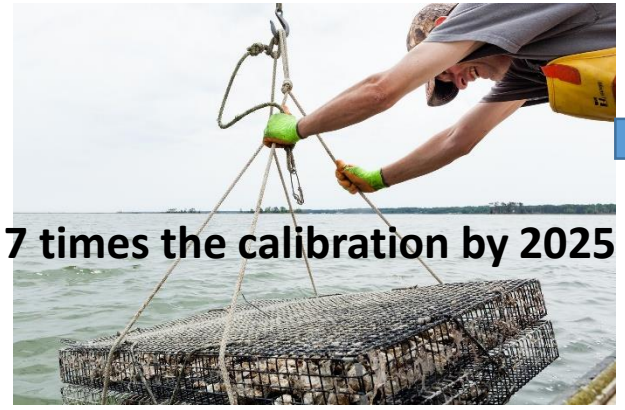
Scenarios for Estimated Future Land Use and Estuarine Practices for 2035, 2045, and 2055

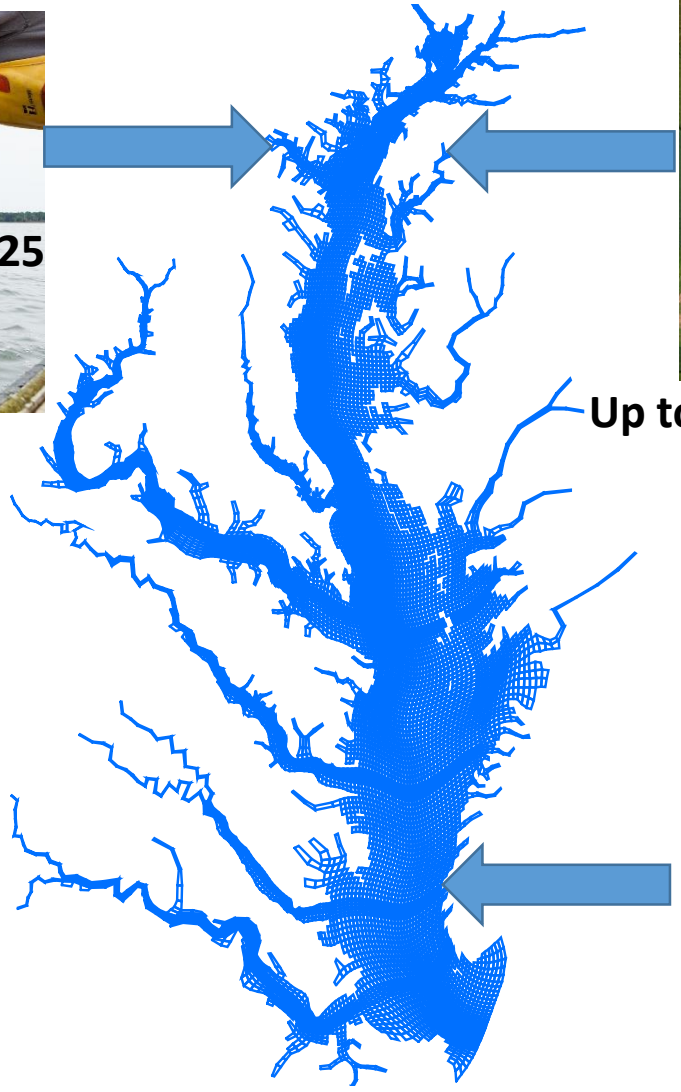
Oyster aquaculture expansion



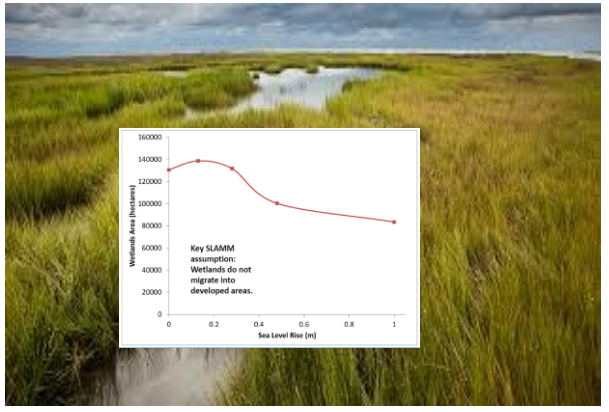
7 times the calibration by 2025

Land use change

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



Tidal wetland change



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Deep Channel DO Estimates of 2025, 2035, 2045, and 2055 Climate Change Only Scenarios and Equivalent Scenarios with Full Land Use and Estuarine Practices

		2035 Climate Only (2025 LU)	2035 Climate 2035 Land Use	2045 Climate Only (2025 LU)	2045 Climate Only 2045 Land Use	2055 Climate Only (2025 LU)	2055 Climate 2055 Land Use
CB		208TN	209TN	212TN	213TN	220TN	222TN
Segment	State	14.6TP	14.7TP	15.4TP	15.7TP	16.7TP	17.1TP
SLR		0.31m	0.31m	0.42m	0.42m	0.53m	0.53m
Delta T_{air}		1.39°C	1.39°C	1.70°C	1.70°C	1.96°C	1.96°C
CB3MH	MD	3.15%	2.70%	4.62%	4.57%	7.31%	7.94%
CB4MH	MD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
CB5MH	MD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
CB5MH	VA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
POTMH	MD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
RPPMH	VA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
ELIPH	VA	0.92%	0.92%	1.08%	1.08%	2.34%	3.00%
CHSMH	MD	2.03%	1.54%	2.69%	2.75%	3.07%	3.20%

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The CBP Climate Change Assessment

- The CBP has developed the tools to quantify the effects of climate change on watershed flows and loads, storm intensity, increased estuarine temperatures, sea level rise, and ecosystem influences including loss of tidal wetland attenuation with sea level rise.
- Future climate change analyses on estimated on a 2025 (short term), 2035, 2045, (moderate term), and 2055 (long term) conditions for CBP management decisions.
- Additional load reductions to address future climate risk will be incorporated into the 2022-2023 Milestone Assessment.

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CBP Climate Change Assessment *(continued)*

- The 2025 full buildout of oyster aquaculture and oyster sanctuaries are estimated to improve water quality, but estimated 2035, 2045, and 2055 land use generally have higher nutrient loads and hypoxia. The combined simulation of estimated future land use and estuarine activities of oyster aquaculture and estimates a slight improvement in Deep Channel DO attainment in 2035 and 2045 compared to the Climate Change Only Scenarios.

- Applying 2025 full buildout of oyster aquaculture and oyster sanctuaries to the 2025 Climate Scenario will improve estimated Deep Channel DO attainment (from ~ 1.5% to ~ 0.8% nonattainment in CB4MH Deep Channel).