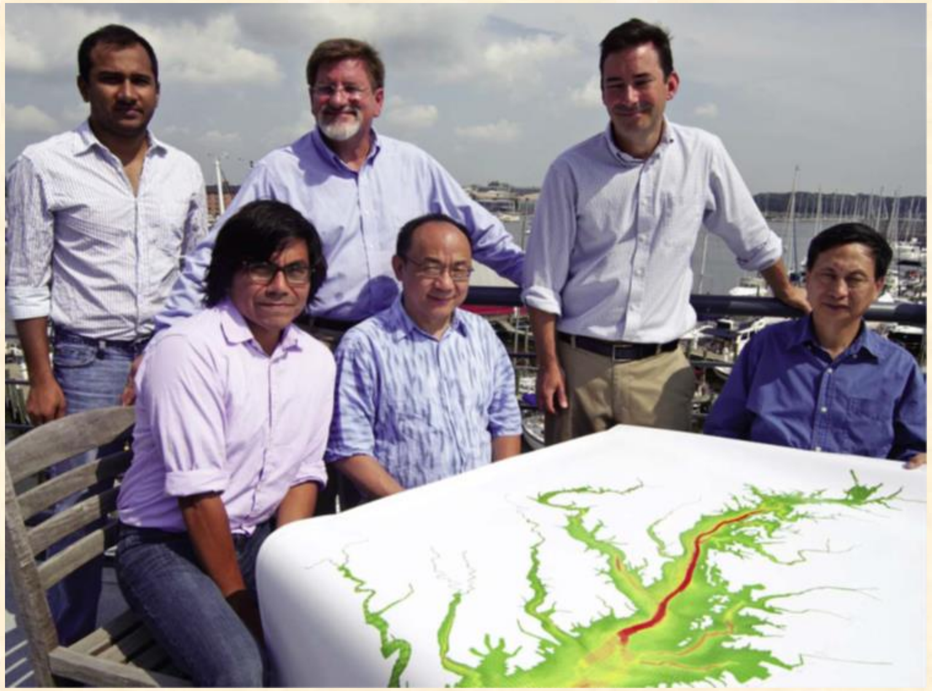
Assessment and Management of Climate Change in the Chesapeake TMDL

2021 NATIONAL CWA 303(d) Training Workshop: Session 4
Accounting for Climate Change – Approaches and Lessons

June 8, 2021

Lew Linker (EPA-CBP) and the CBPO Modeling Team
llinker@chesapeakebay.net

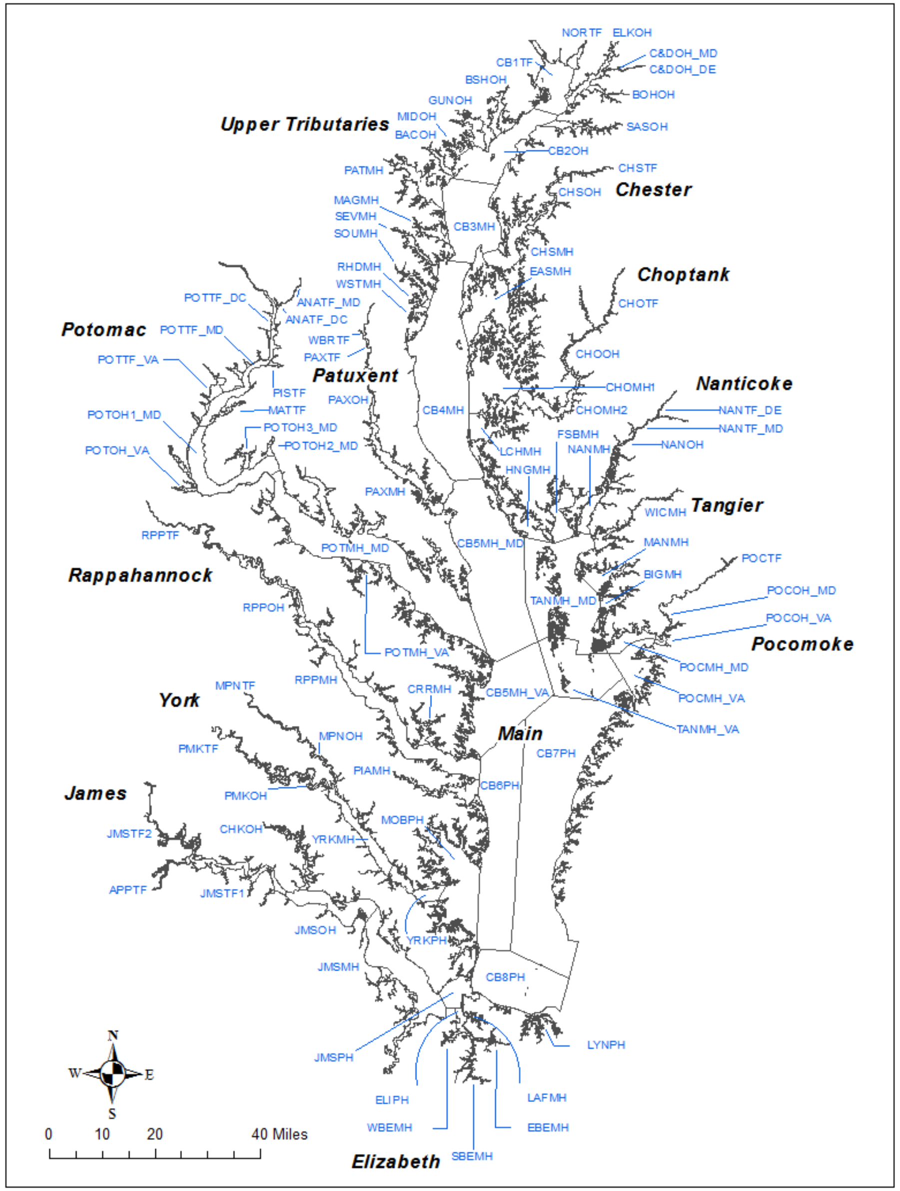


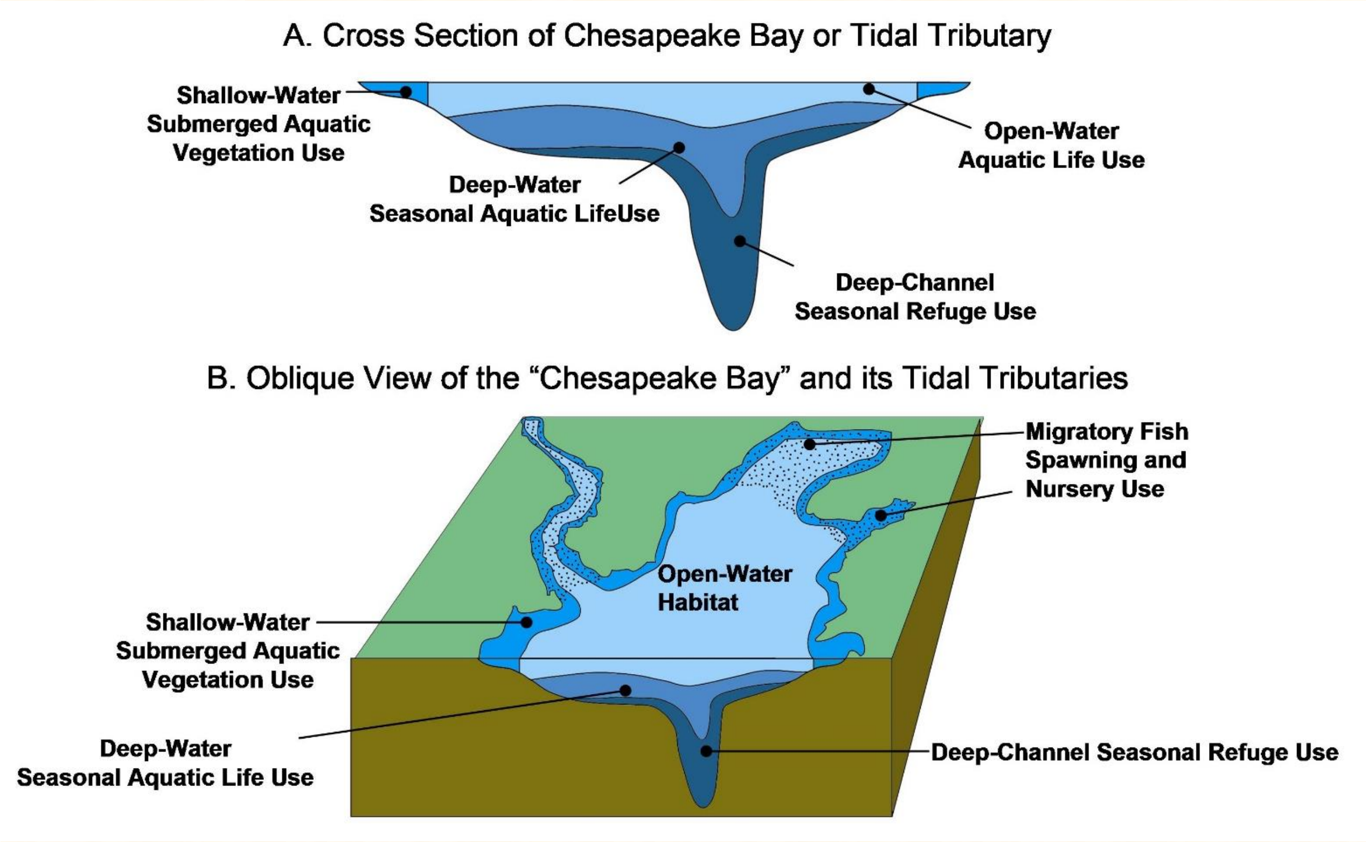
Chesapeake Bay Program
Science, Restoration, Partnership

The CBP Climate Change Assessment

- The CBP has developed the tools to quantify the effects of three decades of climate change (1995 to 2025) on Chesapeake water quality standards through changes in watershed flows and loads, storm intensity, estuarine temperatures, sea level rise, and ecosystem influences including loss of tidal wetland attenuation with sea level rise.
- Using the climate change assessment tools, the CBP decided in December 2020 to implement management practices to meet new nutrient and sediment targets that address current climate change in the Chesapeake watershed by 2025.
- Current efforts are to develop new assessment tools for the airshed, watershed and tidal estuary to estimate climate change risk to Chesapeake TMDL water quality standards from 2025 to 2035.

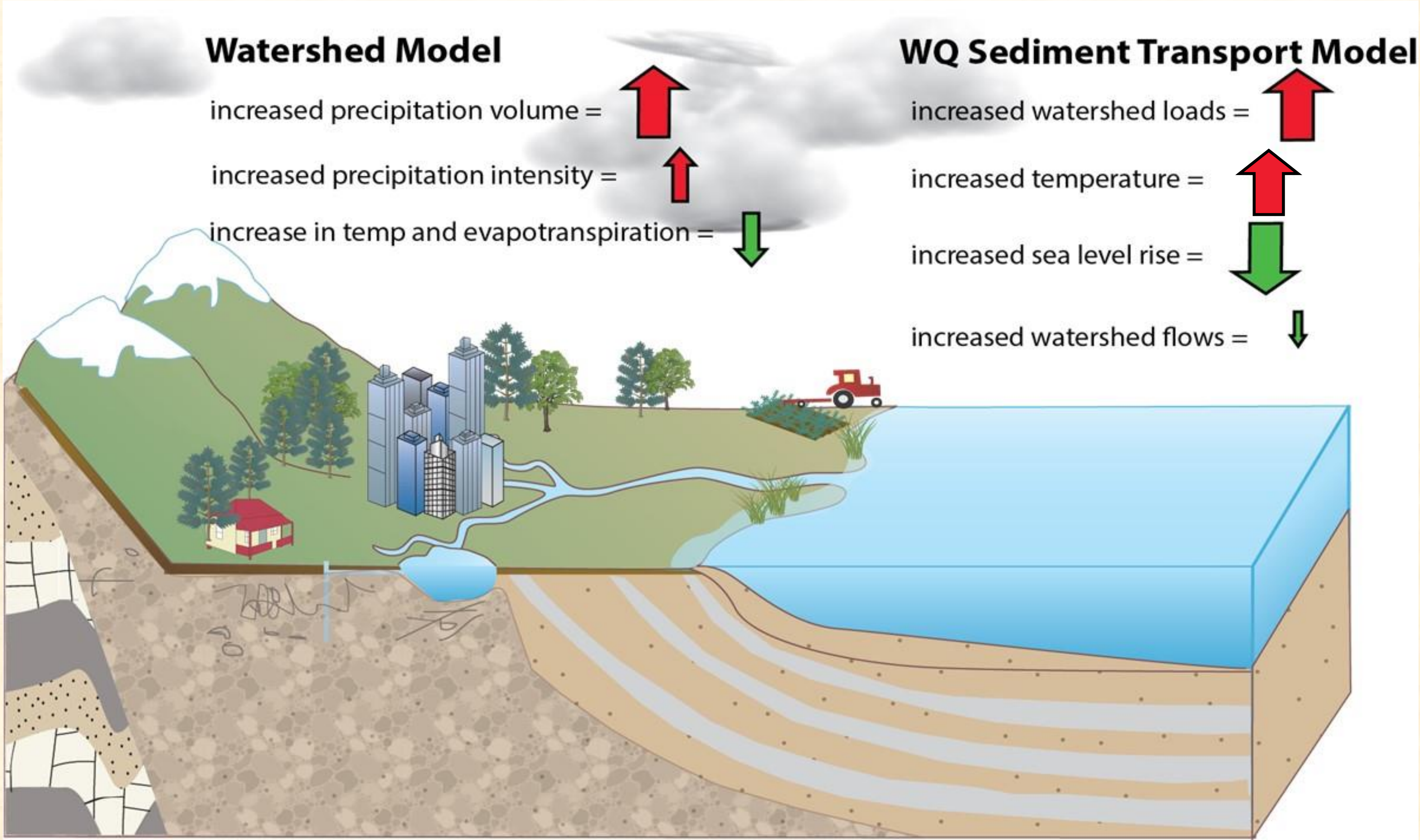
Overview of Bay Designated Uses




A. Cross Section of Chesapeake Bay or Tidal Tributary

B. Oblique View of the "Chesapeake Bay" and its Tidal Tributaries

Components of Climate Change – Effect on Tidal Dissolved Oxygen



Watershed Model

increased precipitation volume = ↑

increased precipitation intensity = ↑

increase in temp and evapotranspiration = ↓

WQ Sediment Transport Model

increased watershed loads = ↑

increased temperature = ↑

increased sea level rise = ↓

increased watershed flows = ↓

Chesapeake Bay Program
Science, Restoration, Partnership

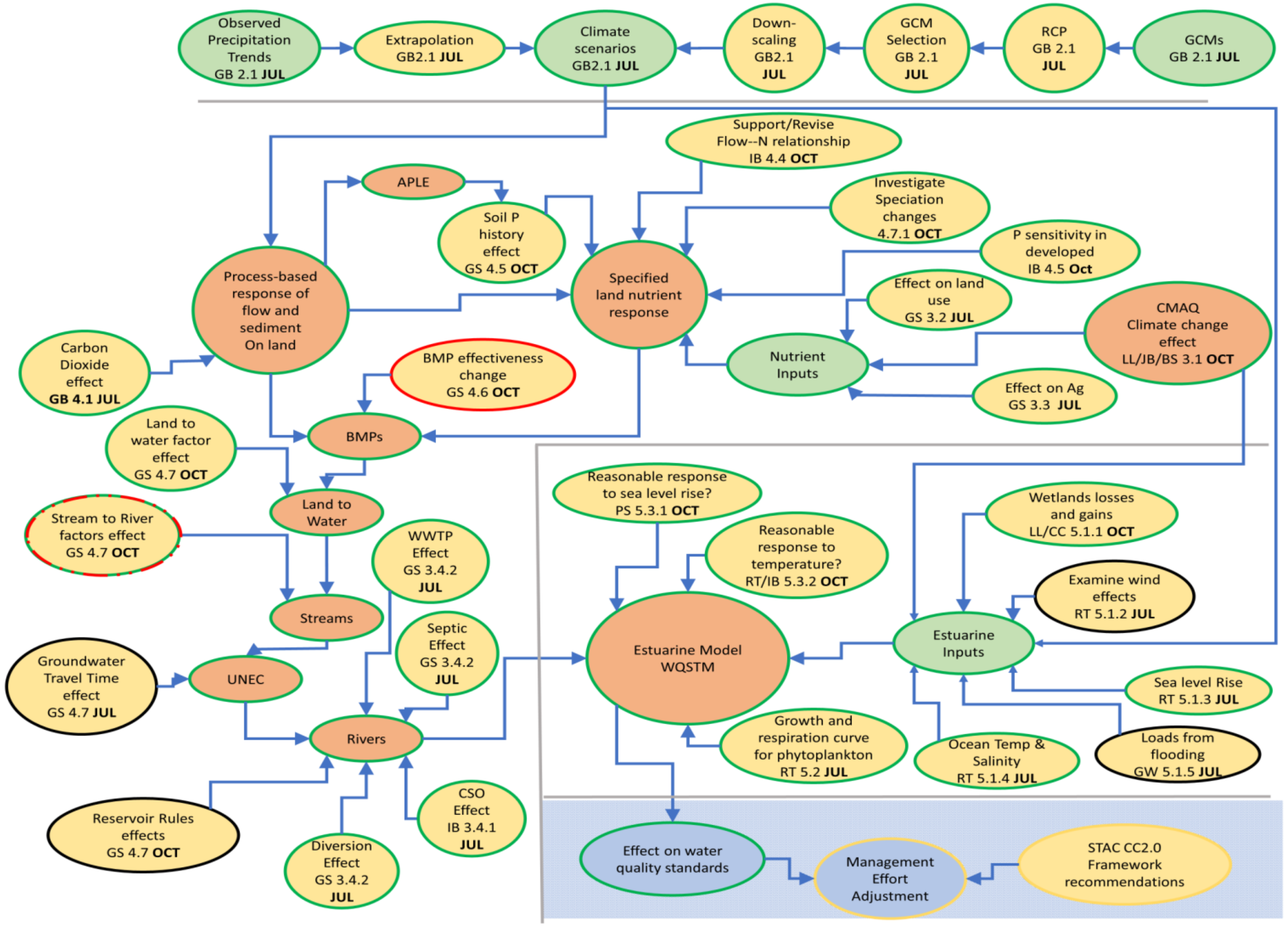
Elements of Chesapeake Water Quality Climate Risk Assessment

Climate Change Processes and Dependencies

Model
Data Set
Endpoint
Project/Decision

Complete
In Process
Not included But important
Not included minor

Initials indicate the responsible person
Numbers indicate the section of the documentation



Observed Precipitation Trends GB 2.1 **JUL**
Extrapolation GB2.1 **JUL**
Climate scenarios GB2.1 **JUL**
Down-scaling GB2.1 **JUL**
GCM Selection GB 2.1 **JUL**
RCP GB 2.1 **JUL**
GCMs GB 2.1 **JUL**

Support/Revise Flow--N relationship IB 4.4 **OCT**
APLE
Soil P history effect GS 4.5 **OCT**
Investigate Speciation changes 4.7.1 **OCT**
P sensitivity in developed IB 4.5 **Oct**
Process-based response of flow and sediment On land
Specified land nutrient response
Effect on land use GS 3.2 **JUL**
CMAQ Climate change effect LL/JB/BS 3.1 **OCT**
Carbon Dioxide effect **GB 4.1 JUL**
BMP effectiveness change GS 4.6 **OCT**
Nutrient Inputs
Effect on Ag GS 3.3 **JUL**
Land to water factor effect GS 4.7 **OCT**
BMPs
Land to Water
Stream to River factors effect GS 4.7 **OCT**
WWTP Effect GS 3.4.2 **JUL**
Streams
Septic Effect GS 3.4.2 **JUL**
Groundwater Travel Time effect GS 4.7 **JUL**
UNEC
Rivers
CSO Effect IB 3.4.1 **JUL**
Reservoir Rules effects GS 4.7 **OCT**
Diversion Effect GS 3.4.2 **JUL**

Reasonable response to sea level rise? PS 5.3.1 **OCT**
Reasonable response to temperature? RT/IB 5.3.2 **OCT**
Wetlands losses and gains LL/CC 5.1.1 **OCT**
Examine wind effects RT 5.1.2 **JUL**
Estuarine Model WQSTM
Estuarine Inputs
Sea level Rise RT 5.1.3 **JUL**
Growth and respiration curve for phytoplankton RT 5.2 **JUL**
Ocean Temp & Salinity RT 5.1.4 **JUL**
Loads from flooding GW 5.1.5 **JUL**

Effect on water quality standards
Management Effort Adjustment
STAC CC2.0 Framework recommendations

Climate
Watershed
Estuary
Management

Approaches, Methods, and Findings from the Watershed

Chesapeake Bay Program
Science, Restoration, Partnership

Analysis of Climate Change in the Chesapeake Watershed

For the analysis of climate change in the Chesapeake watershed, the primary components considered are precipitation volume, precipitation intensity, temperature, and evapotranspiration with an additional consideration to CO_2 concentrations.

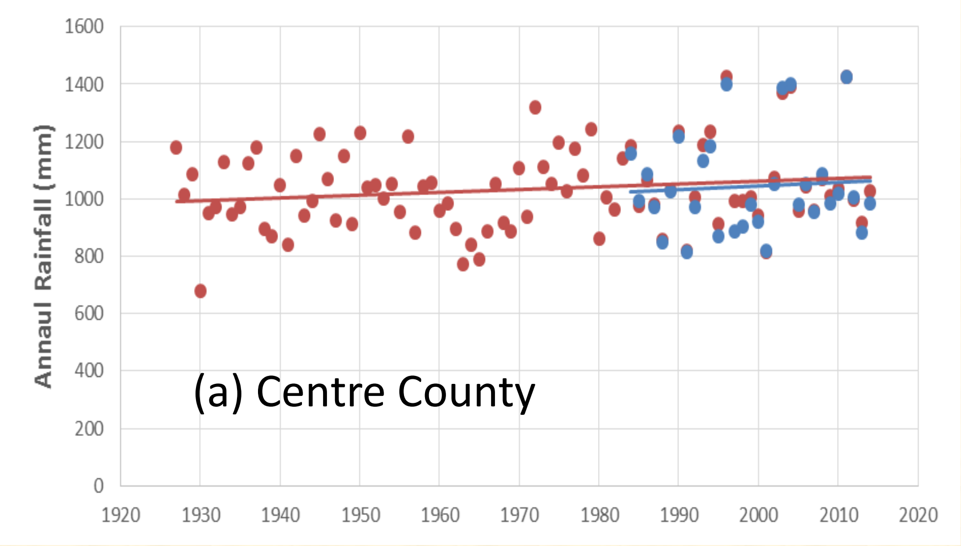
Overall, increased precipitation volumes and intensity are estimated to increase nutrient and sediment loads from the watershed in 2025, 2035, 2045, and 2055 compared to 1995.

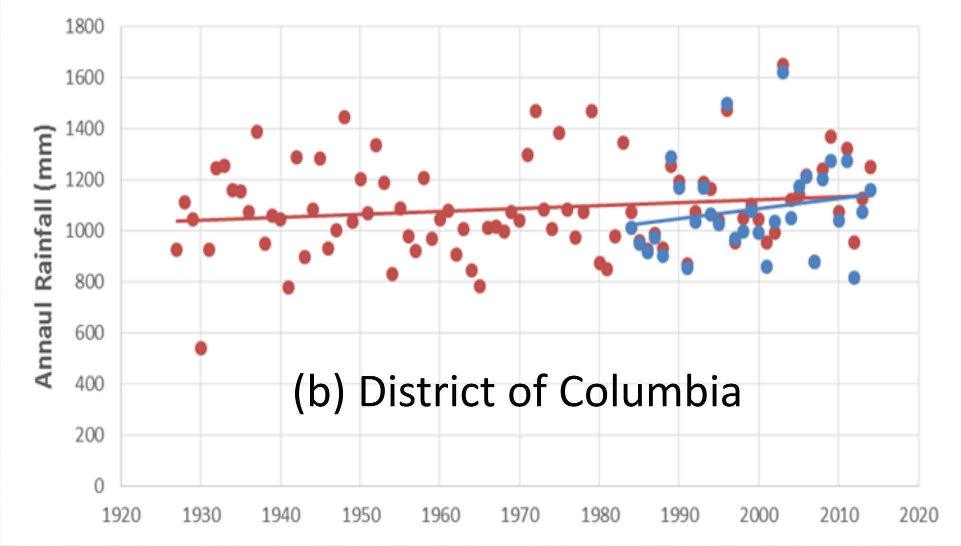
However, increased future temperatures substantially ameliorates the effect of estimated increased precipitation volume in the watershed through evapotranspiration.

Chesapeake Bay Program
Science, Restoration, Partnership

For the 2025 Climate Change Estimate:

The trends in annual precipitation on a county level were developed through the application of PRISM data and analysis provided and recommended by Jason Lynch, EPA, and Karen Rice, USGS. The annual PRISM dataset for the years 1927 to 2014 (88 years) were used in for the regression trend analysis. For the analysis PRISM data were first spatially aggregated for each Phase 6 land segments. The Phase 6 land segments typically represent a county. For each land segment a simple linear trend was fitted to the annual rainfall dataset.



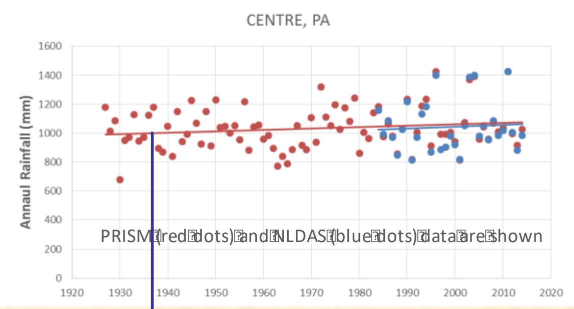


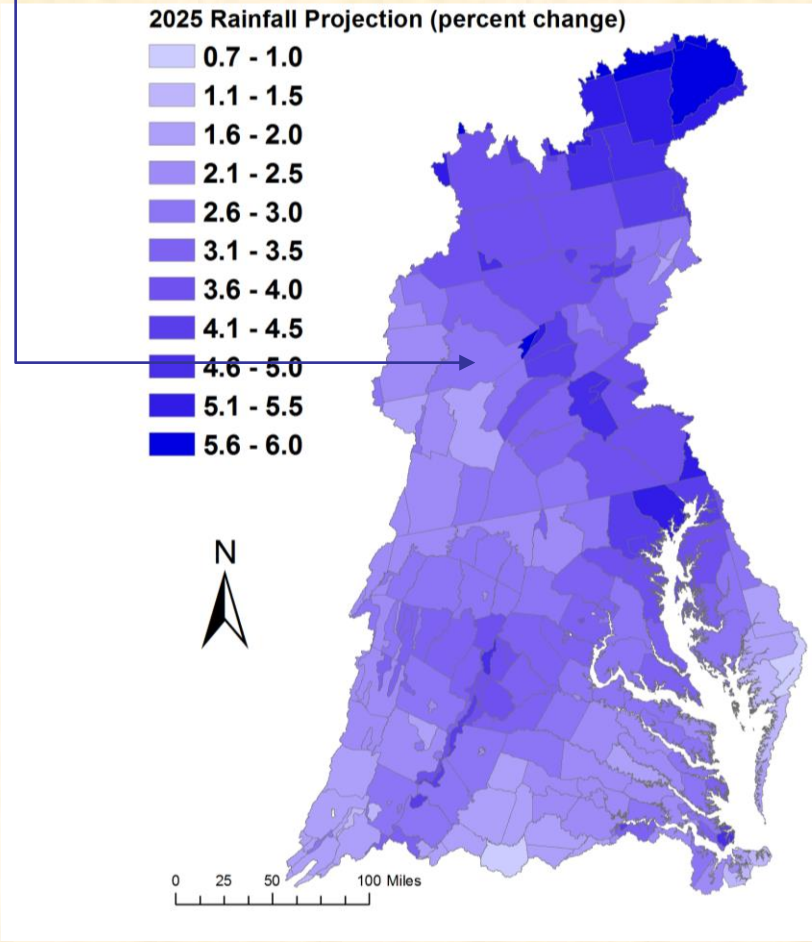
Annual rainfall volumes for the 88-year period linear regression lines are shown in red for the two land segments (counties) – (a) Centre County in Pennsylvania and (b) District of Columbia. The values for the slope of the regression lines, and the corresponding 30-year projections in the rainfall volume (1995 to 2025) are also shown.

Source: Section 12 of Phase 6 Documentation

Assessment of Influence of 2025 Climate Change in the Watershed

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





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

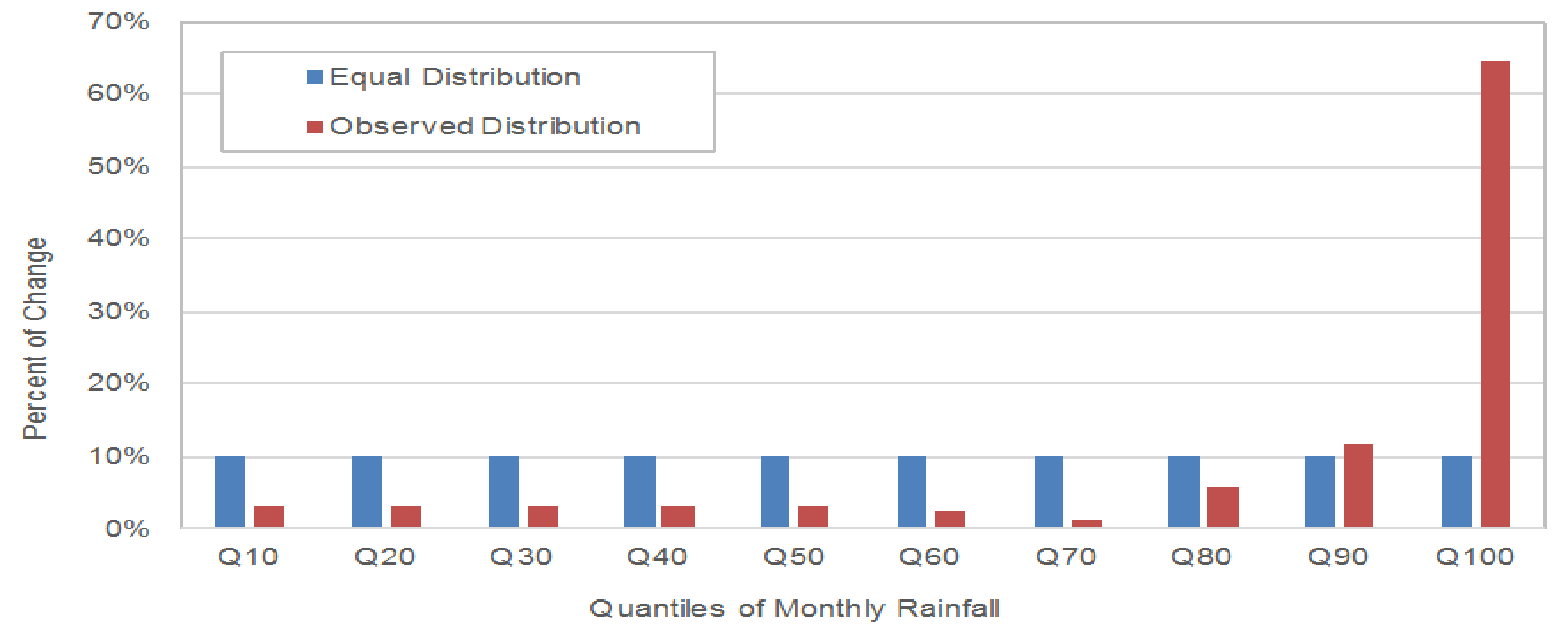
Major Basins	PRISM Trend
Youghiogheny River	2.1%
Patuxent River Basin	3.3%
Western Shore	4.1%
Rappahannock River Basin	3.2%
York River Basin	2.6%
Eastern Shore	2.5%
James River Basin	2.2%
Potomac River Basin	2.8%
Susquehanna River Basin	3.7%
Chesapeake Bay Watershed	**3.1%**

[1] Parameter-elevation Relationships on Independent Slopes Model

Chesapeake Bay Program

Science, Restoration, Partnership

Trends in Observed Rainfall Intensity

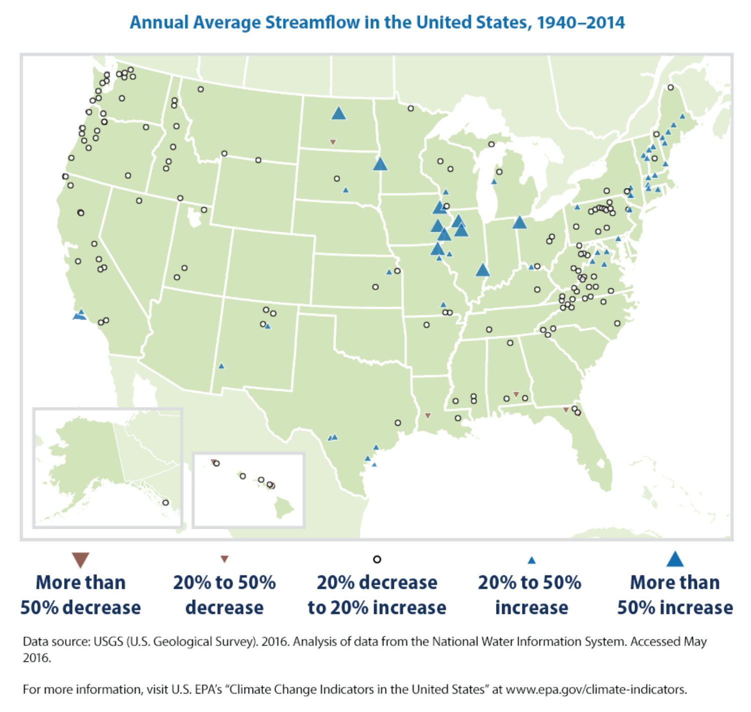


Observed changes in rainfall intensity in the Chesapeake region over the last century. The equal allocation distribution (blue) is contrasted with the distribution obtained based on observed changes (red).

Source: Groisman et al. 2004

1940-2014 streamflow trends based on observations

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

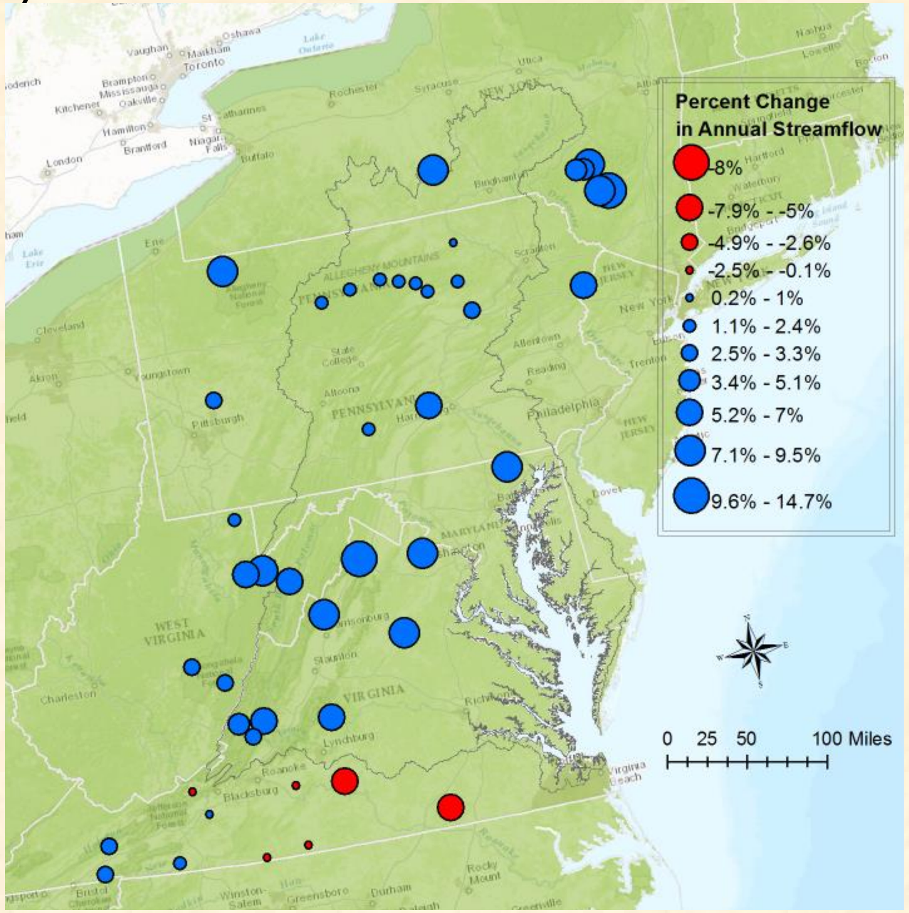


Annual Average Streamflow in the United States, 1940–2014

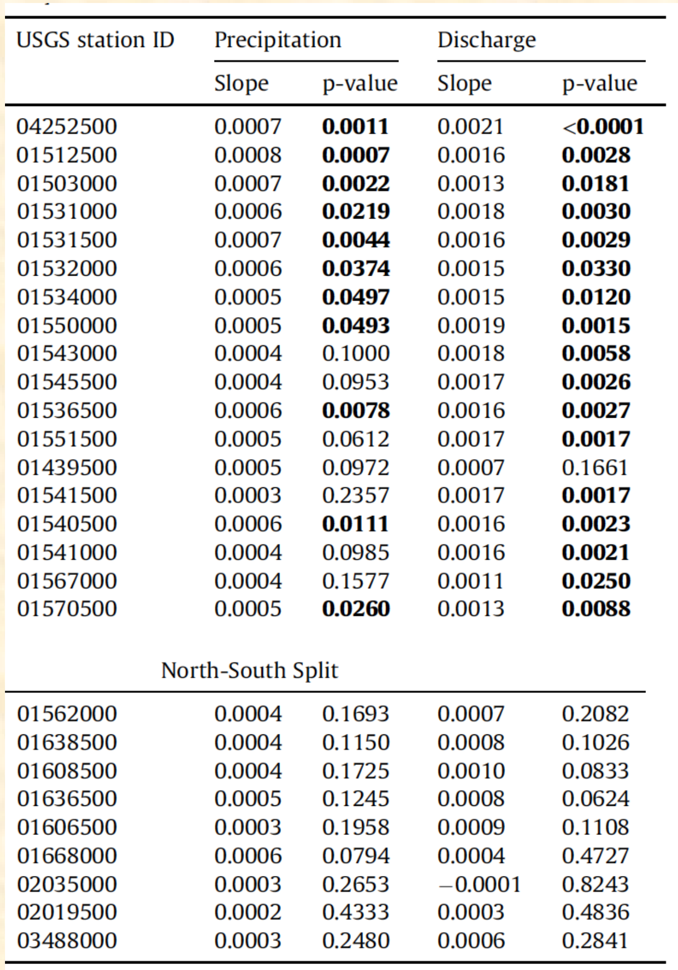
Data source: USGS (U.S. Geological Survey). 2016. Analysis of data from the National Water Information System. Accessed May 2016.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

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.

Chesapeake Bay Program
Science, Restoration, Partnership

An ensemble of GCM projections from BCSD CMIP5[1] was used to estimate 1995-2025 temperature change.

🟧 Data unavailable

🟩 GCM Used

Selection updated

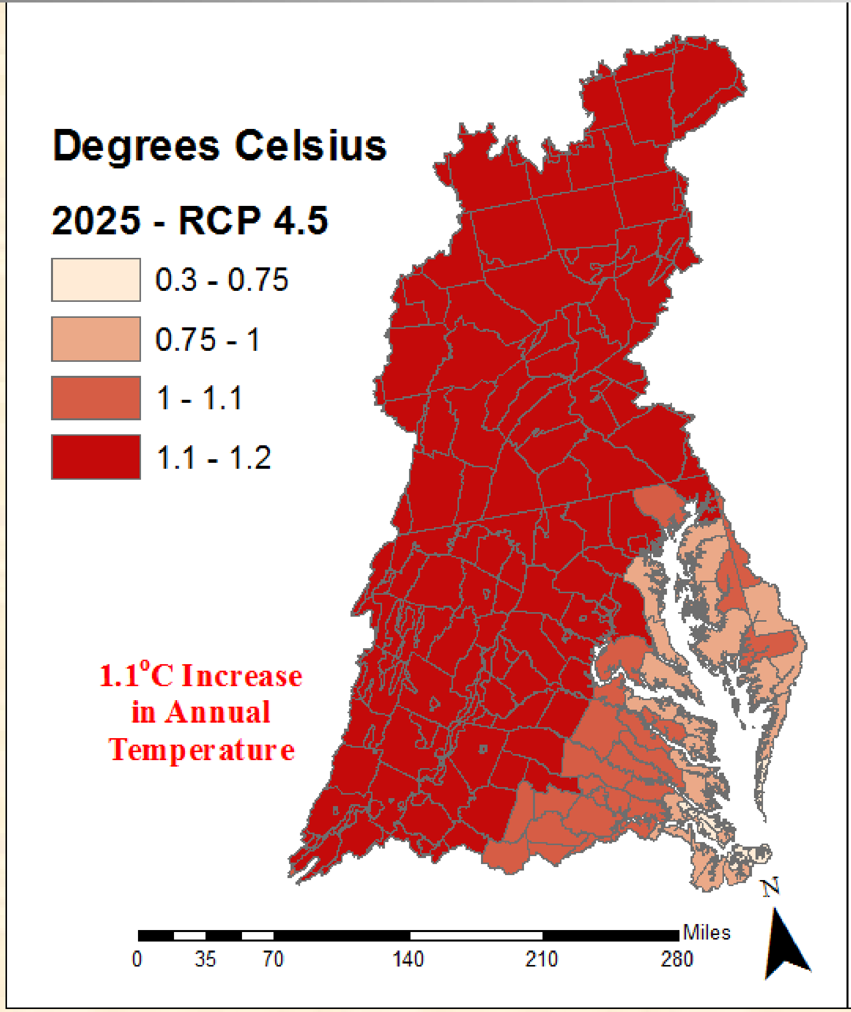
Updated Ensemble members		
🟩 ACCESS1-0	🟩 FGOALS-g2	🟩 IPSL-CM5A-LR
🟩 BCC-CSM1-1	🟩 FIO-ESM	🟩 IPSL-CM5A-MR
🟩 BCC-CSM1-1-M	🟩 GFDL-CM3	🟩 IPSL-CM5B-LR
🟧 BNU-ESM	🟩 GFDL-ESM2G	🟩 MIROC-ESM
🟩 CanESM2	🟩 GFDL-ESM2M	🟩 MIROC-ESM-CHEM
🟩 CCSM4	🟧 GISS-E2-H-CC	🟩 MIROC5
🟩 CESM1-BGC	🟩 GISS-E2-R	🟩 MPI-ESM-LR
🟩 CESM1-CAM5	🟧 GISS-E2-R-CC	🟩 **MPI-ESM-MR**
🟩 CMCC-CM	🟩 HadGEM2-AO	🟩 MRI-CGCM3
🟩 CNRM-CM5	🟩 HadGEM2-CC	🟩 NorESM1-M
🟩 CSIRO-MK3-6-0	🟩 HadGEM2-ES	31 member ensemble
🟩 EC-EARTH	🟩 INMCM4	

[1] BCSD – Bias Correction Spatial Disaggregation;
[1] CMIP5 – Coupled Model Intercomparison Project 5

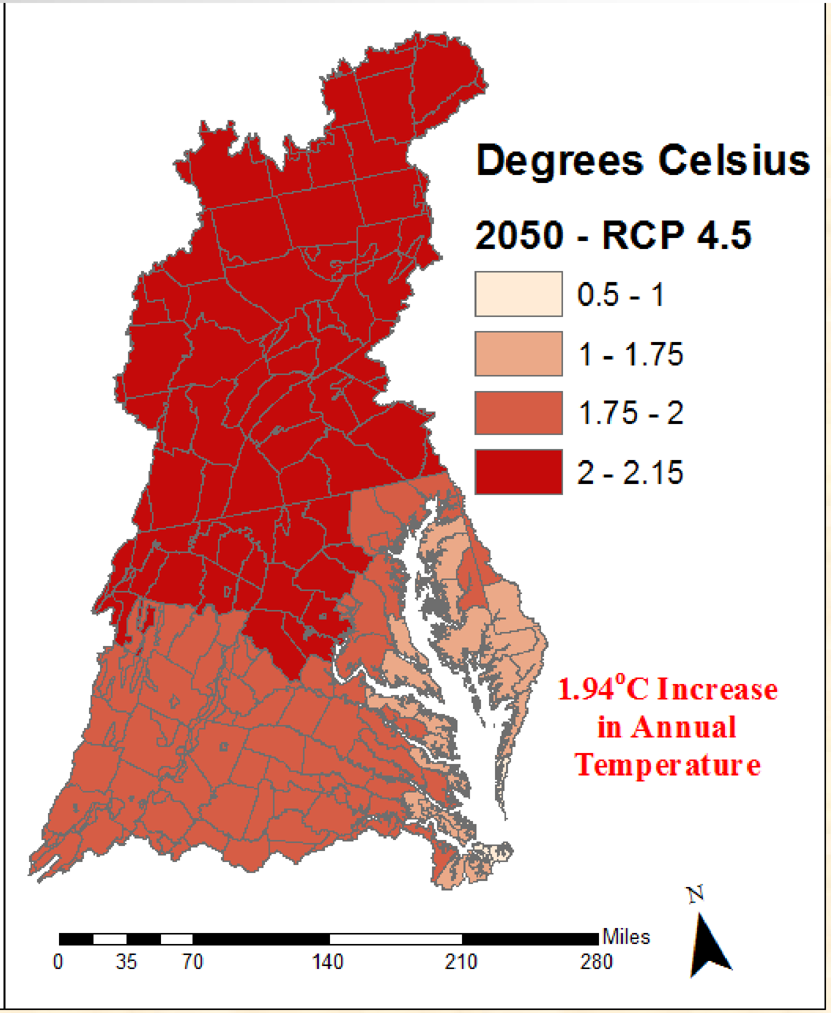
Source: Kyle Hinson, VIMS

Reclamation, 2013. 'Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with preceding Information, and Summary of User Needs', prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 47pp.

Chesapeake Bay Watershed Annual Change in Temperature



1.1°C Increase in Annual Temperature

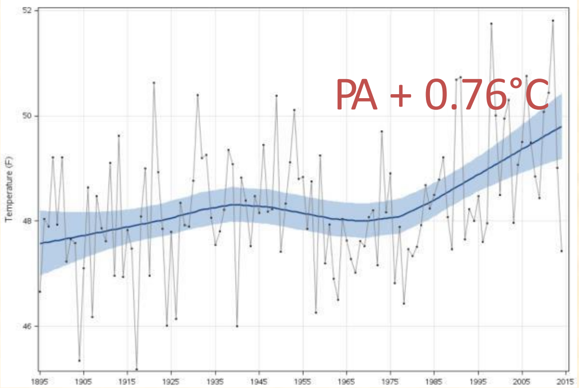


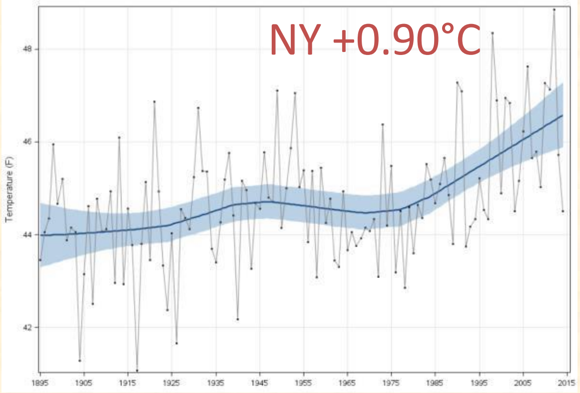
1.94°C Increase in Annual Temperature

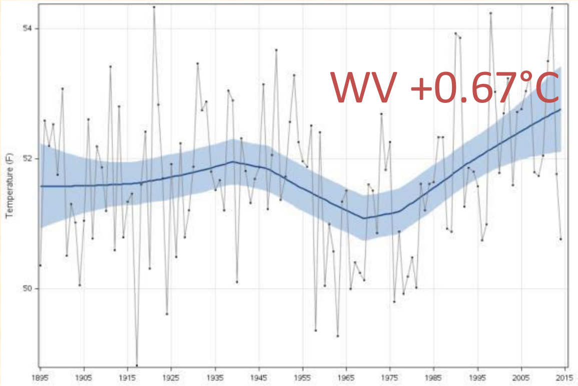
Temperature trends for the six CBP states

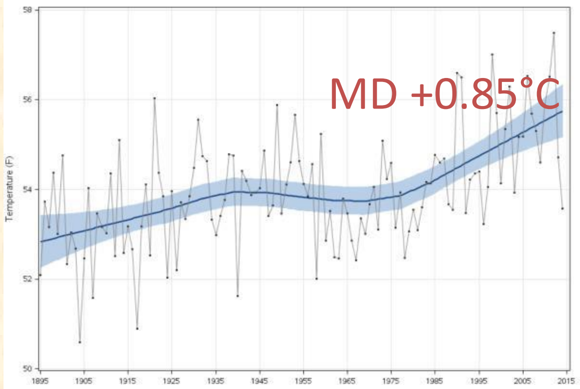
Annual temperature for 1895 to 2015 are shown.

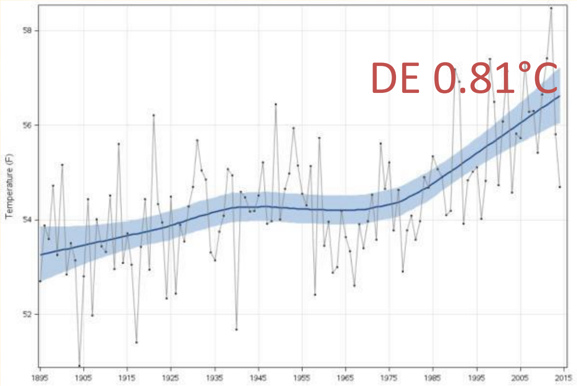
— Annual Temperature
— Trend Line
☐ 95% Confidence Limits

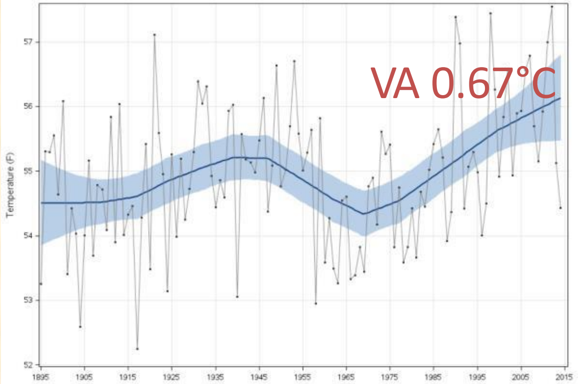








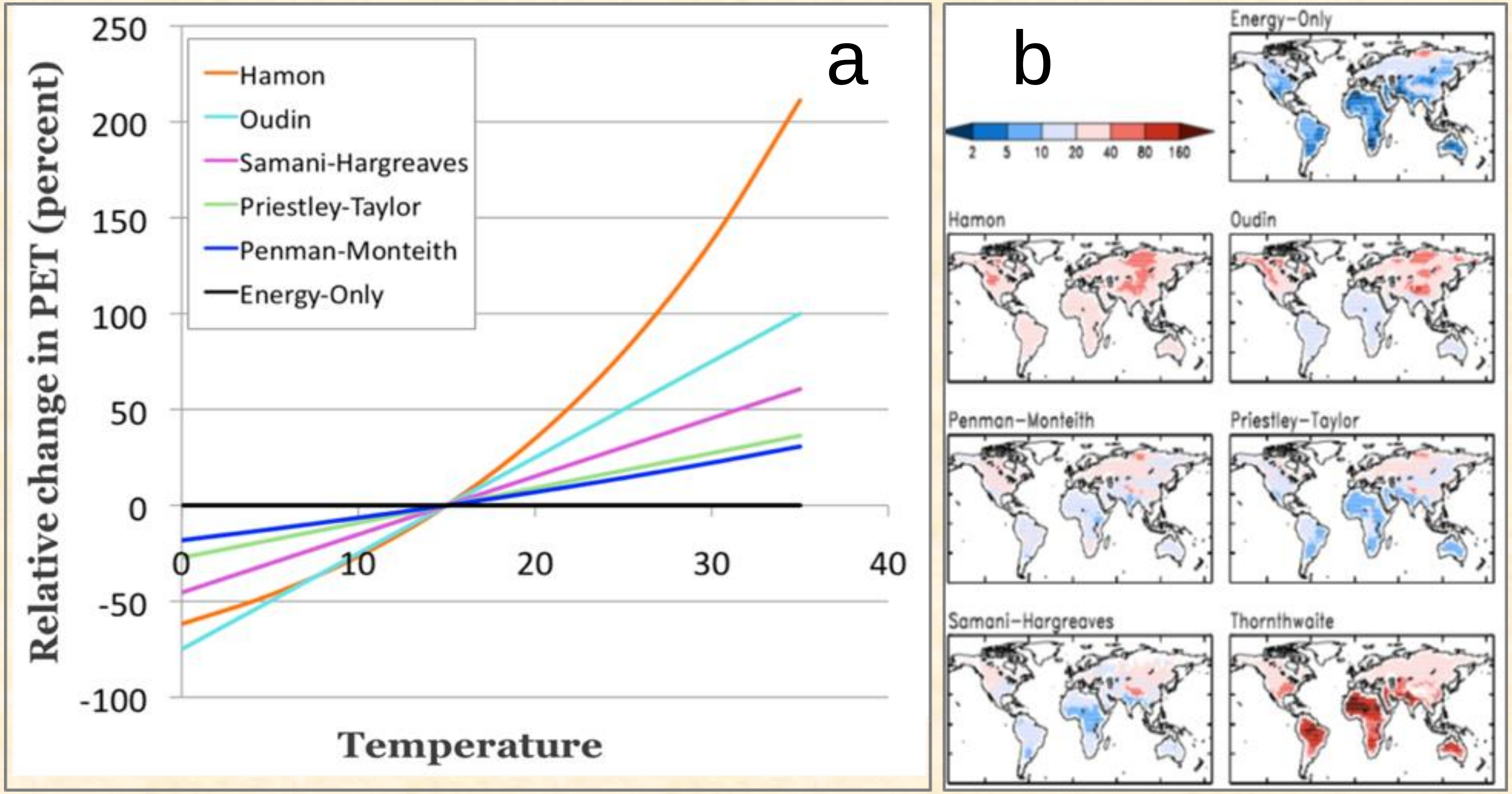




Approx. increases over the last 30 years based on the trend line are shown.

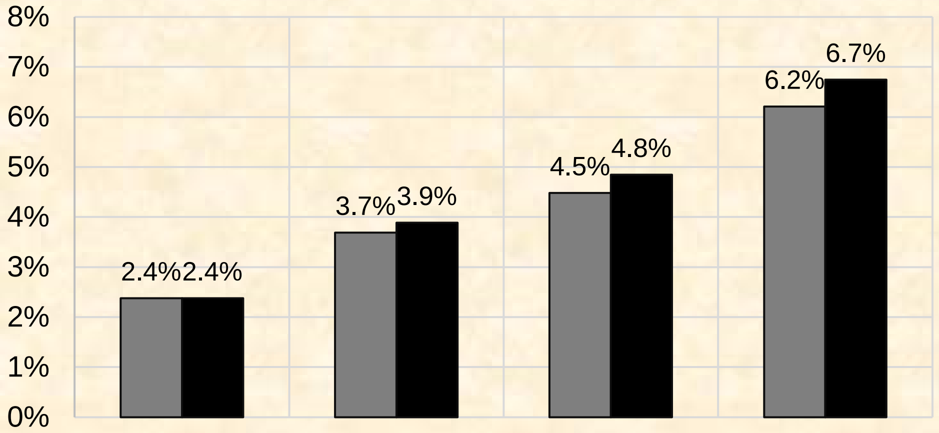
NOAA National Climatic Data Center
https://www.ncdc.noaa.gov/temp-and-precip/state-temps/

Estimated potential evapotranspiration

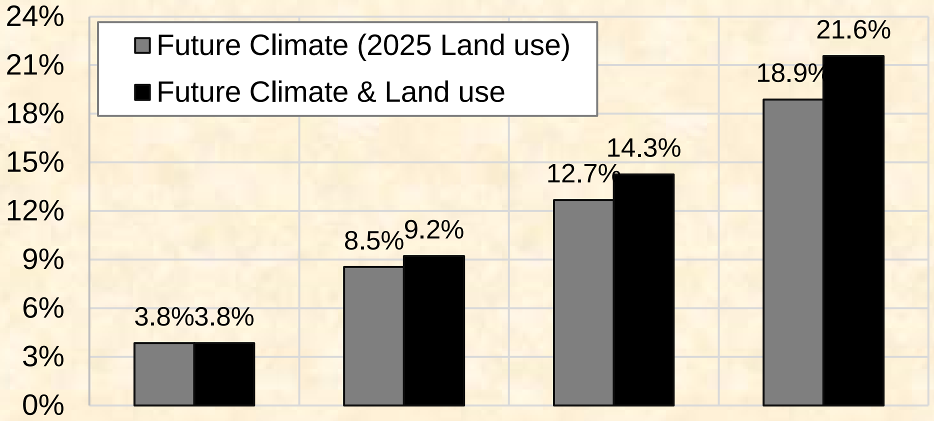


(a) Relative change in estimated change in potential evapotranspiration due to change in temperature is shown from different methods. It shows temperature alone can introduce considerable differences in estimation of potential evapotranspiration with the selection of method. (b) Estimate of percent changes in potential evapotranspiration

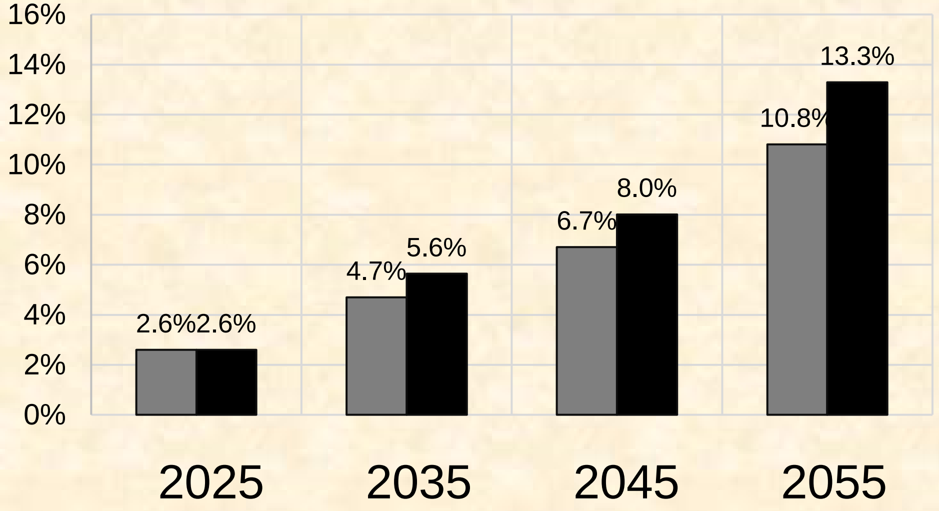
Estimates of Climate Only and Climate and Land Use



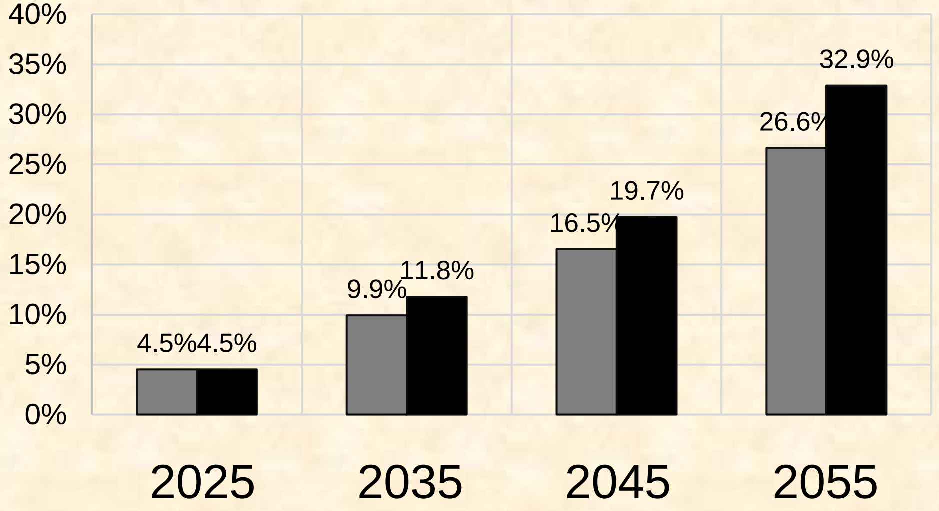
Marginal Differences in **Freshwater** Delivery



Marginal Differences in **Sediment** Delivery



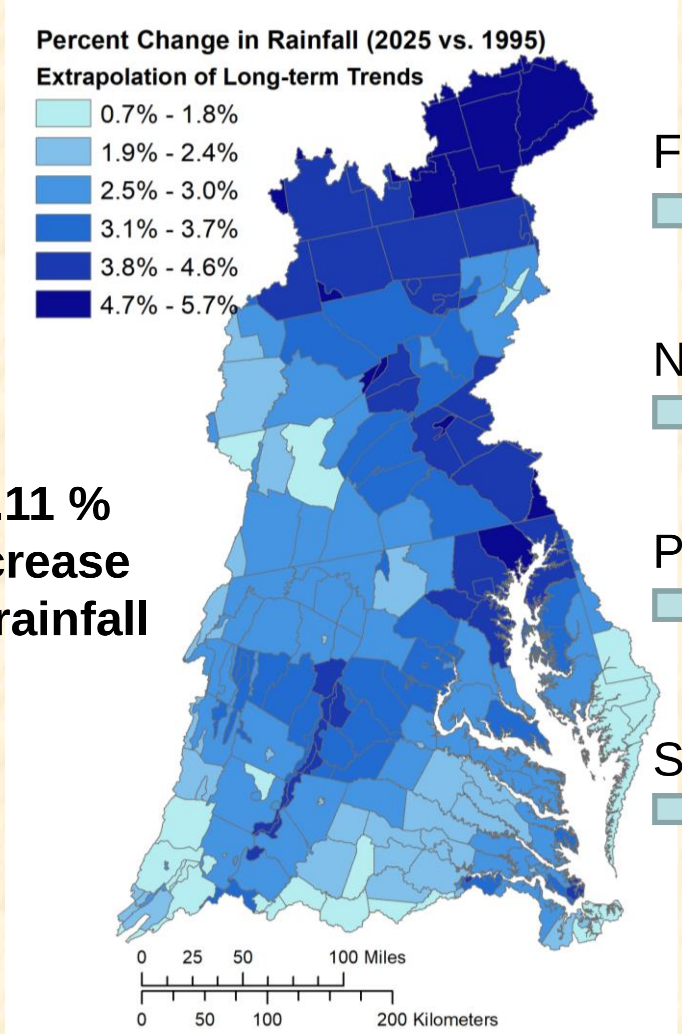
Marginal Differences in **Nitrogen** Delivery



Marginal Differences in **Phosphorus** Delivery

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

Elements of 2025 Climate Change (1995-2025)



Phase 6 Watershed Model

**+3.11 %
Increase
in rainfall**

Flow

2.4% Increase

Nitrogen Load

2.6% Increase

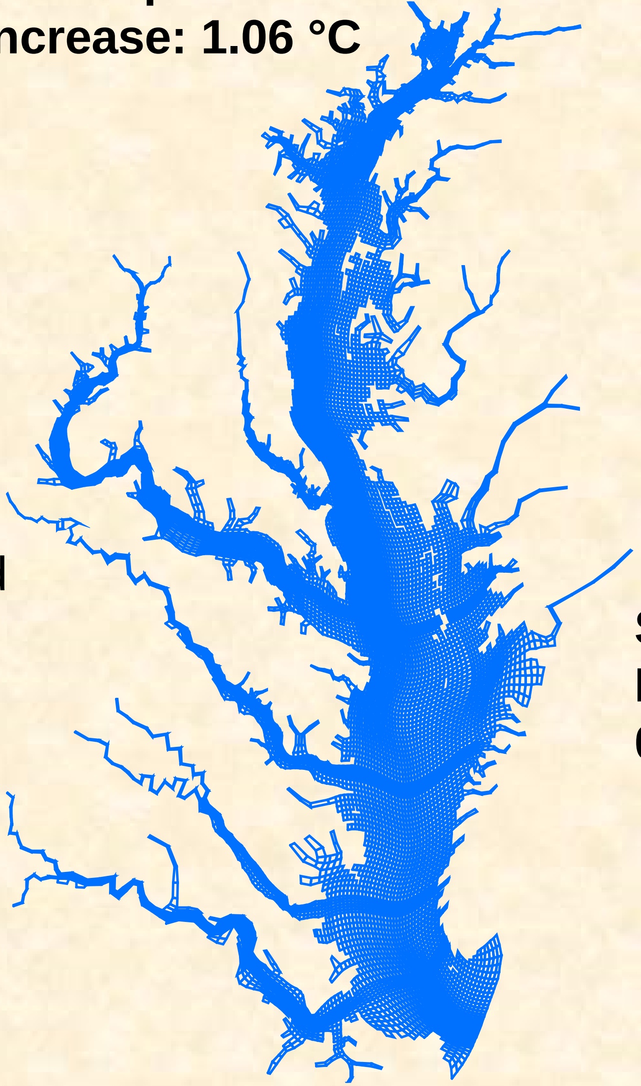
Phosphorus Load

4.5% Increase

Sediment Load

3.8% Increase

**Air-temperature
increase: 1.06 °C**



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

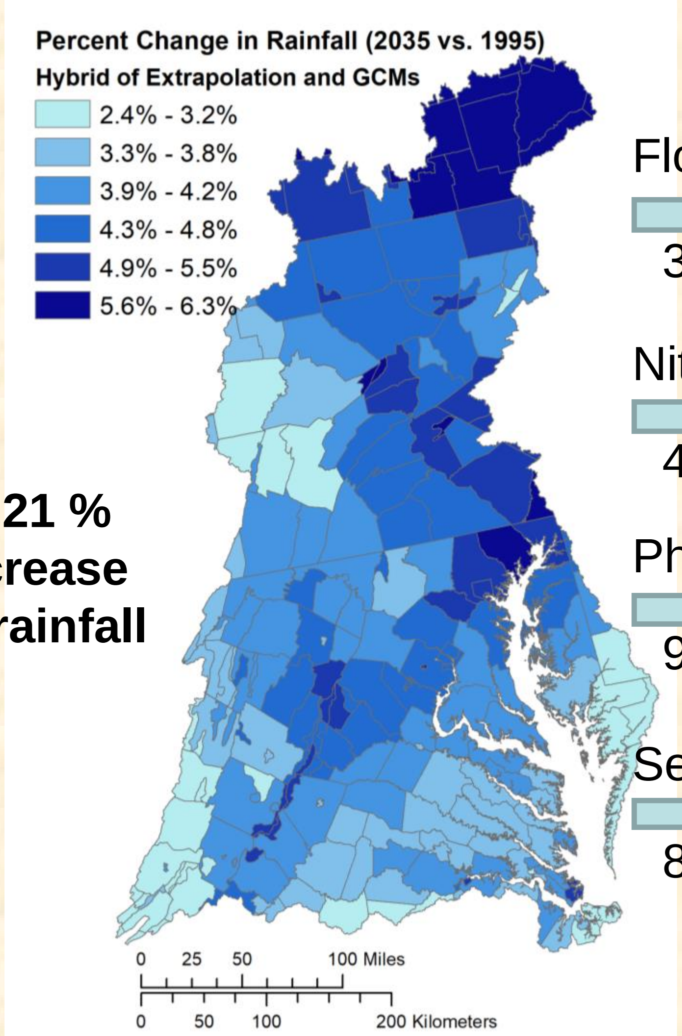
**Sea Level
Rise:
0.22m**

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

Chesapeake Bay Program
Science, Restoration, Partnership

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

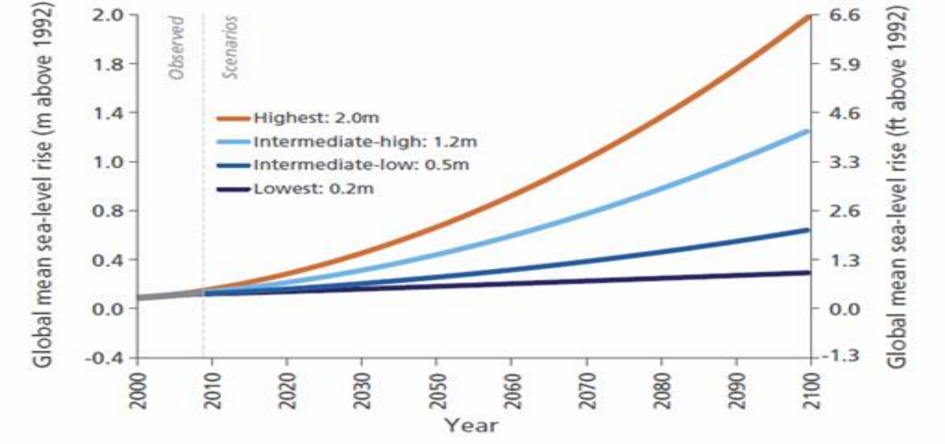
Open boundary:
Temperature: +1.32 °C;
Salinity: +0.25 psu
(Thomas et al., 2017)

Approaches, Methods, and Findings from the Tidal Bay

Chesapeake Bay Program
Science, Restoration, Partnership

Analysis of Climate Change in the Tidal Bay

Estimates of the influence of sea level rise, increased temperature of tidal waters, and tidal wetland loss were incorporated into the Water Quality and Sediment Transport Model (WQSTM) of the tidal Bay (Cerco and Noel 2017). Guidance for increasing levels of regional sea level rise based upon global tide gauge rates and regional land subsidence rates came from the Climate Resiliency Workgroup CRWG). Specifically, the CRWG recommended that sea level rise projections for 2025 be based on long term observations at Sewells Point, VA (0.22 m).

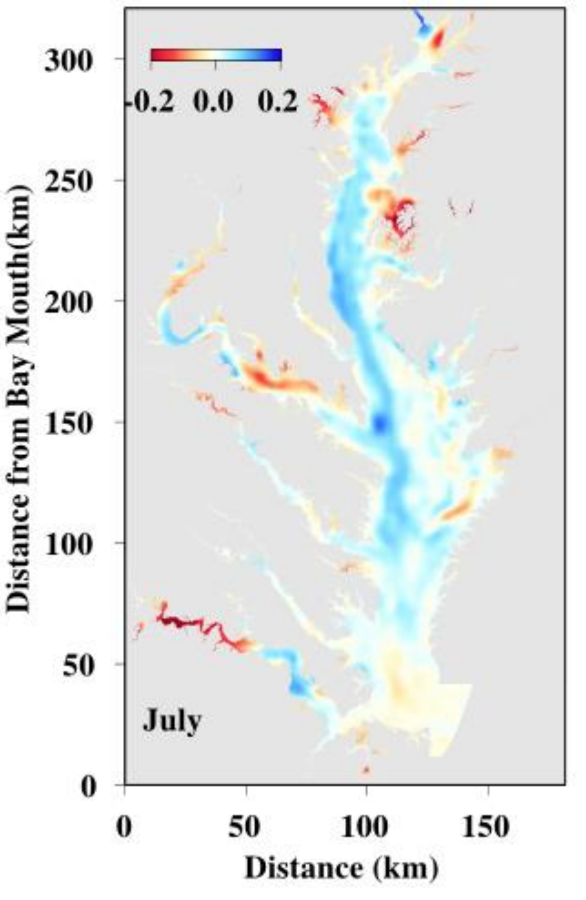


Chesapeake Bay Program
Science, Restoration, Partnership

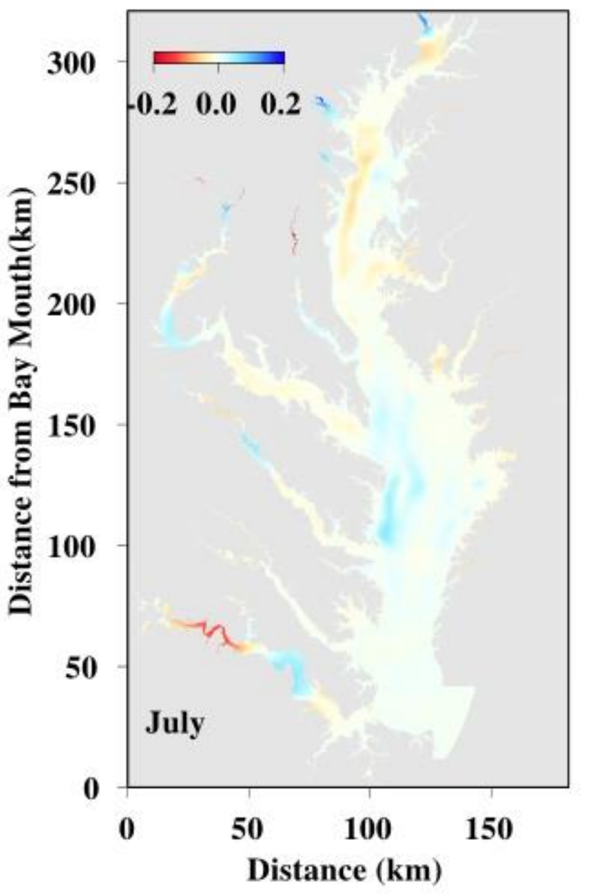
Bottom DO Change: 1995 to 2025

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.

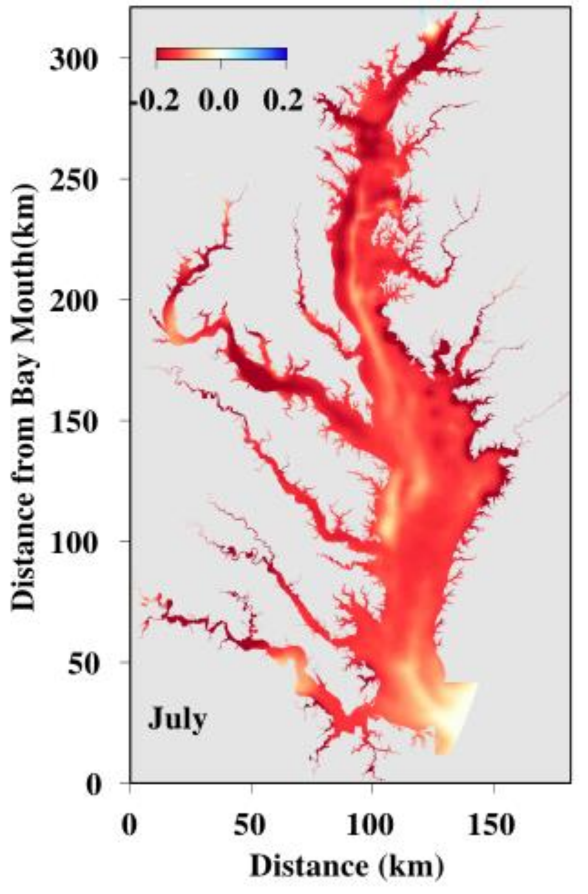
Sea Level Rise



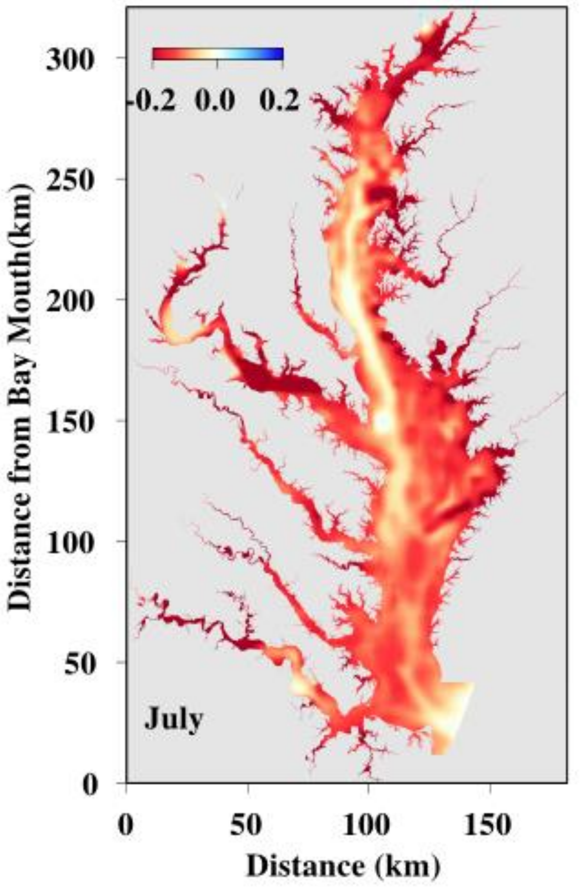
Watershed Flow



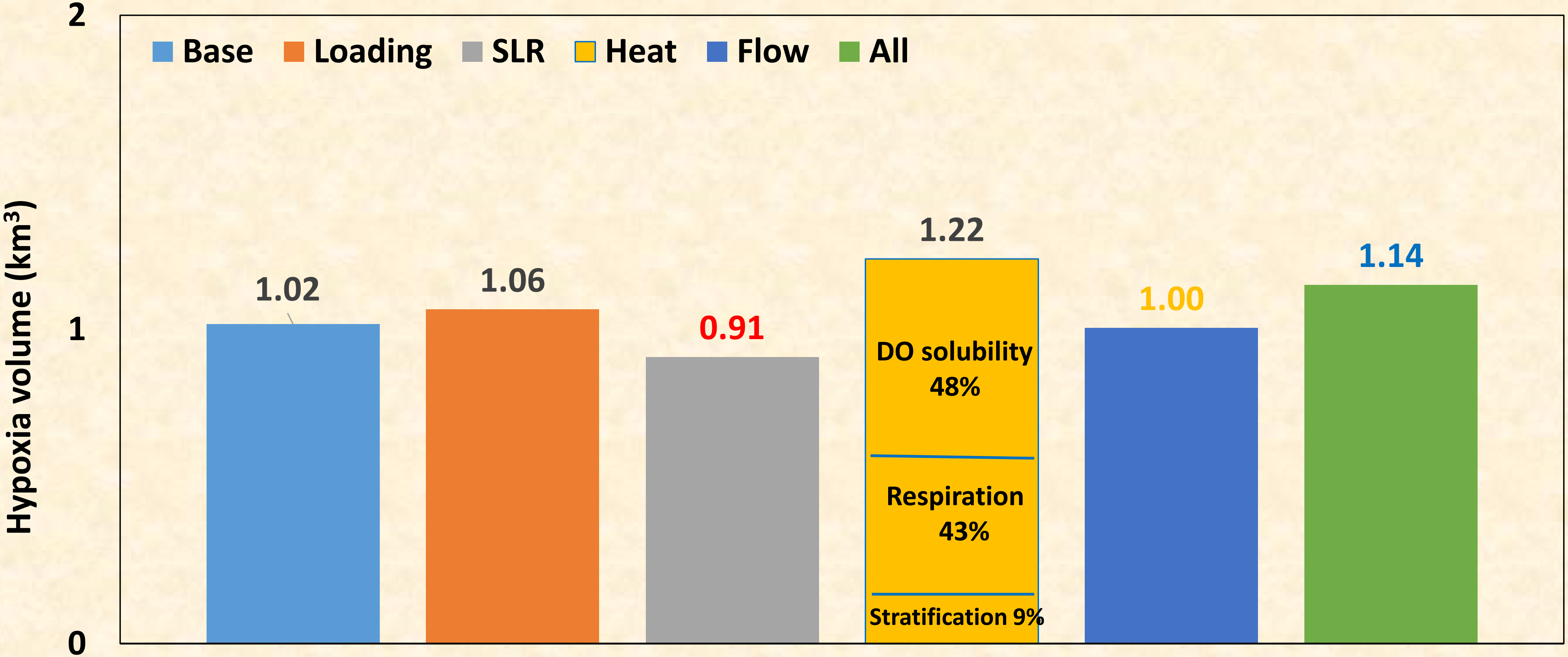
Increased Temp.



All Factors



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



22

Chesapeake Bay Program
Science, Restoration, Partnership

Estimated 2025 Climate Change Influence

Air-temperature increase: 1.06 °C

Sea Level Rise: 0.22m

Flow

+2.4% est. 2025

TN

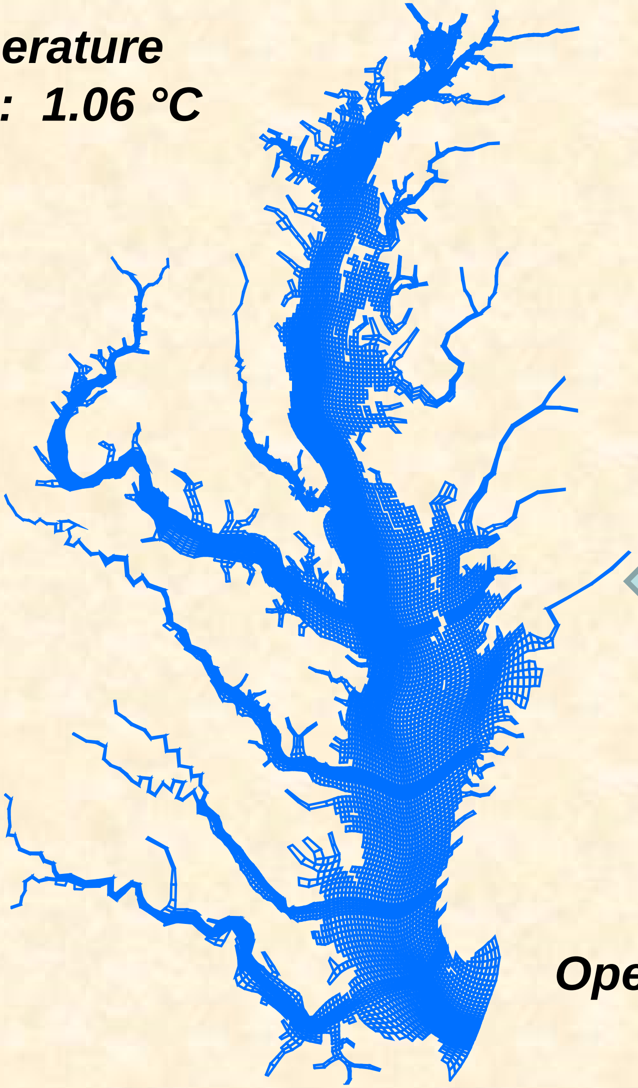
+2.6% est. 2025

TP

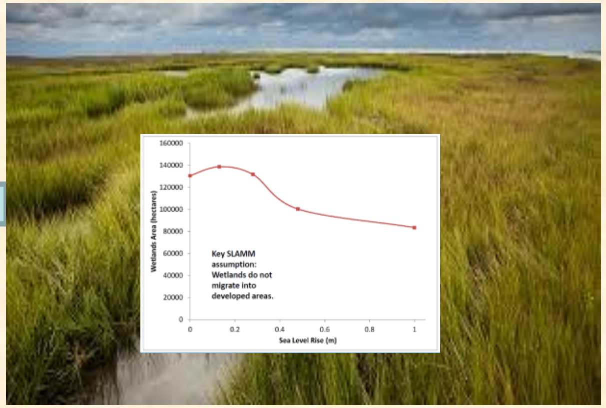
+4.5% est. 2025

Sediment

+3.8 est. 2025

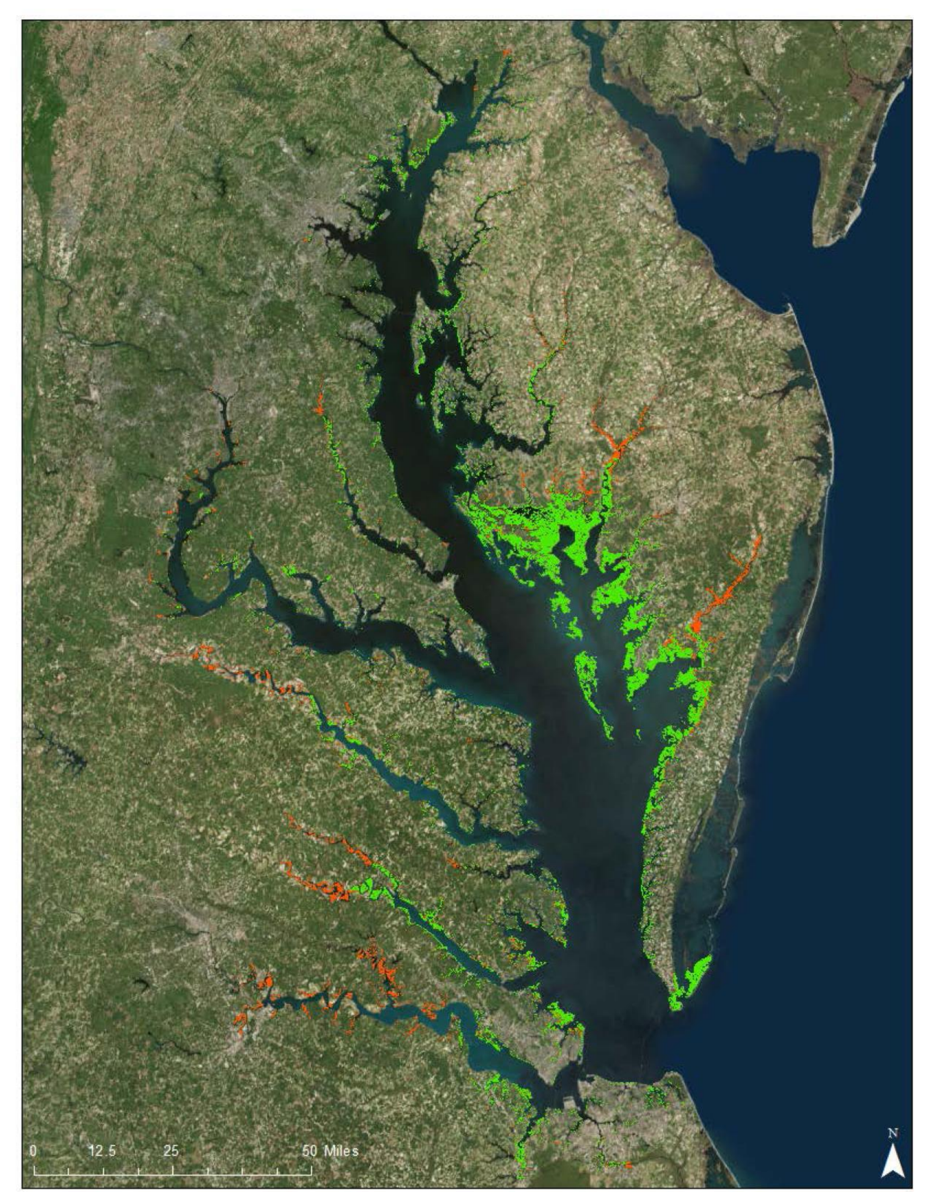


Tidal wetland change



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

Chesapeake Bay Tidal Wetlands

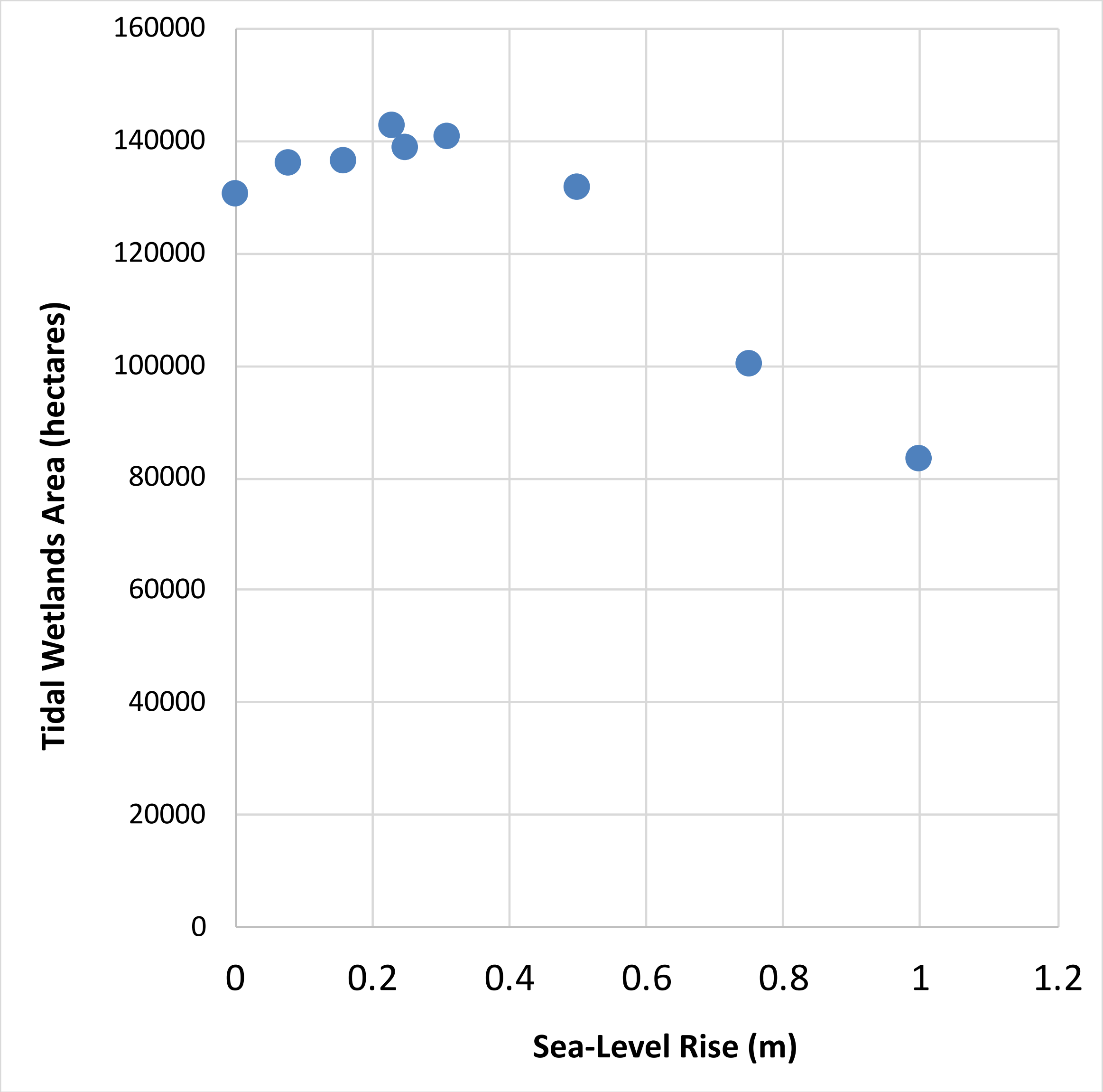


Source: Carl Cerco, U.S. CoE ERDC

- The extent from National Wetlands Inventory is determined largely from vegetation perceived via aerial photography.
- 190,000 hectares of estuarine (green) and tidal fresh (red) wetlands.
- A tidal wetlands module is now fully operational in the WQSTM. The module incorporates functions of sediment and particulate nutrient removal and burial, denitrification, and respiration. The loss of wetland function due to sea level rise and inundation will be accounted for explicitly.

Chesapeake Bay Program
Science, Restoration, Partnership

Influence of Estimated 2025 (0.3 m) and 2050 (0.5m) Sea Level Rise on Tidal Wetland Attenuation



There is little change in estimated total tidal wetland area for 2025 (0.17 - 0.3 m) and 2050 (0.5 m) which equates to negligible changes in tidal wetland attenuation.

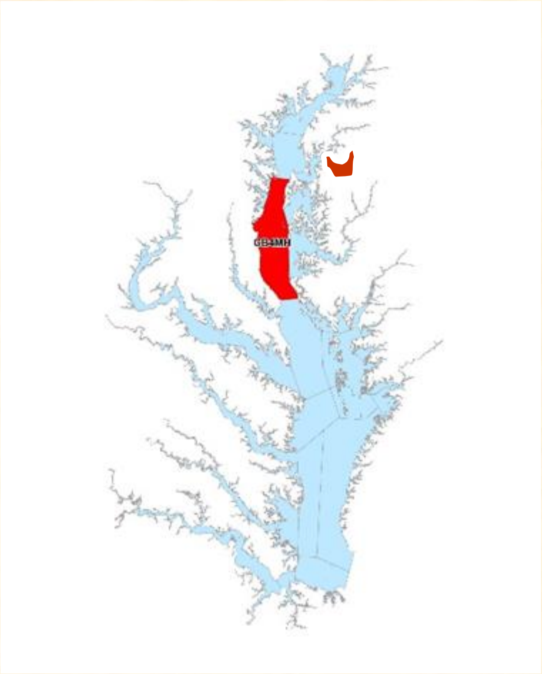
Long range (2100) conditions estimate tidal wetland changes to be on the order of a 40% loss in the Chesapeake which could reduce tidal wetland attenuation on the order of about 10 million pounds nitrogen and 0.6 million pounds phosphorus.

Source: Carl Cerco, CoE ERDC and Lara Harris, UMCES Sea Level Affecting Marshes Model (SLAMM) results.

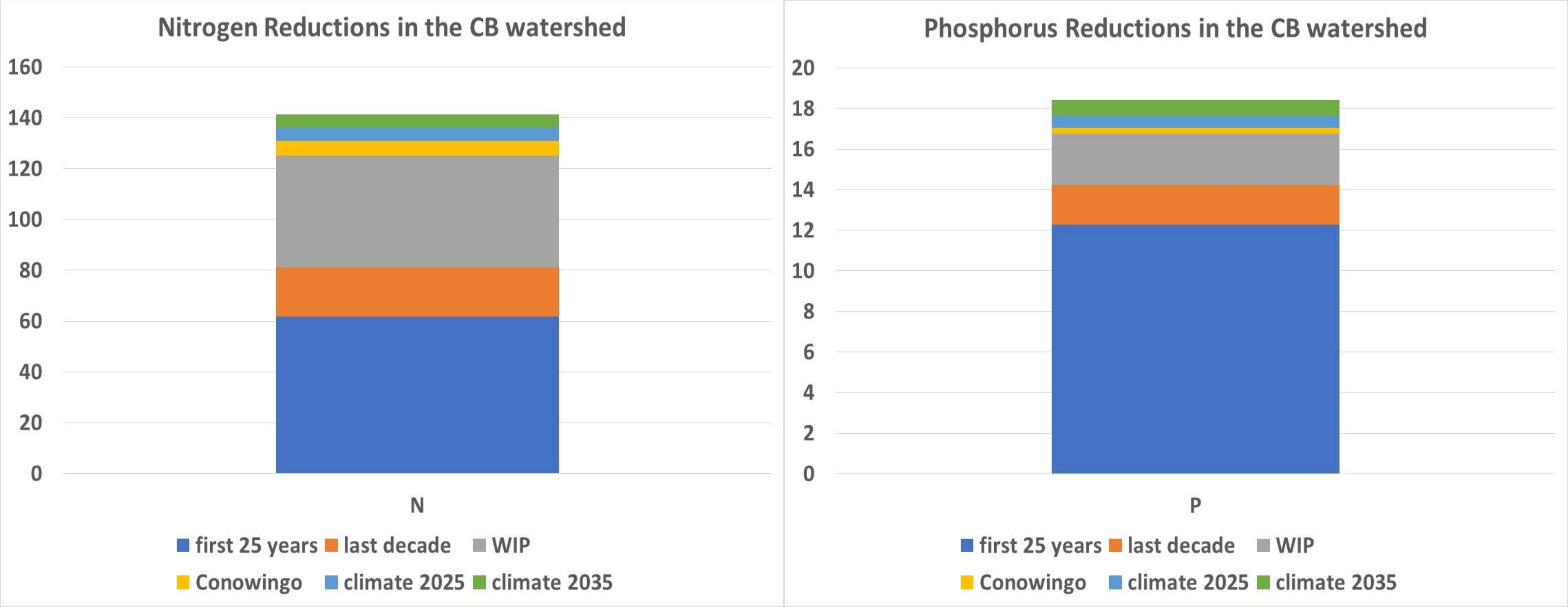
△Achievement of Deep Channel DO Water Quality Standard

Achievement of **Deep Channel DO** water quality standard (1mg/l instantaneous minimum) expressed as ***an incremental increase*** over the PSC agreed to 2025 planning targets

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%



Climate Target Loads in Perspective



Overall, the CBP found that a target load of 5 million pounds nitrogen and 0.6 million pounds phosphorus will be sufficient to offset 30 years of climate change in the Chesapeake Bay.

Model load reduction estimates from CAST-2019 (current version of the CBP watershed model)

Conclusions:

Climate change is a multigenerational challenge for the CBP and is a force multiplier for headwinds to the Chesapeake restoration.

However, the CBP is working on management practices that are effective counters to climate change such as:

- 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 agriculture and urban BMPs that are most vulnerable to future climate risk, with an emphasis on practices that could be adapted to become more resilient to future climate conditions of increased rainfall intensities and volumes.
- A quantification of the co-benefits of BMPs that mitigate future climate risk as they relate to the protection of local infrastructure, public health and safety, green infrastructure, urban floodplain management, riparian buffers, tidal and non-tidal wetlands, cold water fisheries, and other management actions.

The climate change risk to the Chesapeake TMDL can be effectively managed and the CBP is actively addressing the challenge.