The 2019 Assessment of Climate Change Influence on Chesapeake Water Quality Standards

STAC Workshop: Chesapeake Bay Program
Climate Change Modeling 2.0

September 24-25, 2018

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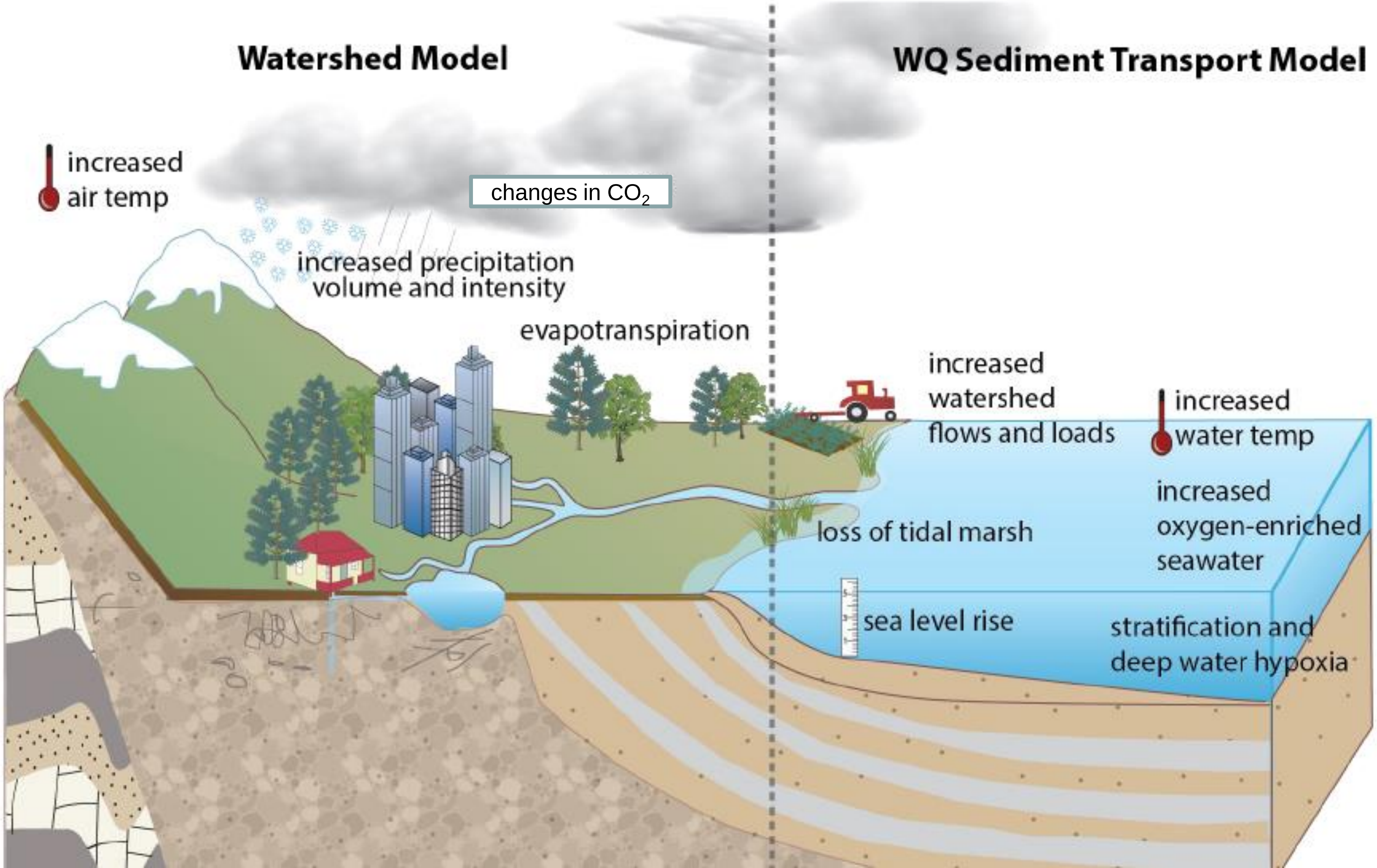
The 2019 CBP Climate Change Assessment

- The CBP is developing 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.
- At the direction of CBP decision makers, the current efforts are to frame initial scenarios of future climate change risk to Chesapeake tidal water quality standards based on estimated 2025 (short term), 2035 (moderate term), and 2050 conditions (long term) by the close of 2019.

The 2019 CBP Climate Change Assessment

- Keep in mind the potential long-term task of developing a 2025 Next Generation Model to support CBP decision making in 2025. The sequence of a 2019 and 2025 build of CBP climate change analysis models allows the consideration of strategic investments in the next generation of CBP climate assessment tools.
- The CBP recognizes that climate change is a multigeneration challenge to the watershed and estuary. The 2019 Assessment is only the first of a reiterative, adaptive, long-term assessment of climate change influence on the Chesapeake living resource based water quality standards.

Accounting for Changing Conditions



Approaches, Methods, and Findings from the Watershed

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Analysis of Climate Change in the Chesapeake Watershed

- For the analysis of climate change in the Chesapeake watershed, the primary components considered were precipitation volume, precipitation intensity, temperature, and evapotranspiration with an additional consideration of CO_2 concentrations
- Overall, increased precipitation volumes and intensity are estimated to increase nutrient and sediment loads from the watershed in 2025, 2035, and 2050 compared to 1995.
- However, increased future temperatures substantially ameliorates the effect of estimated increased precipitation volume in the watershed through evapotranspiration.

For the 2025 Climate Change Estimate:

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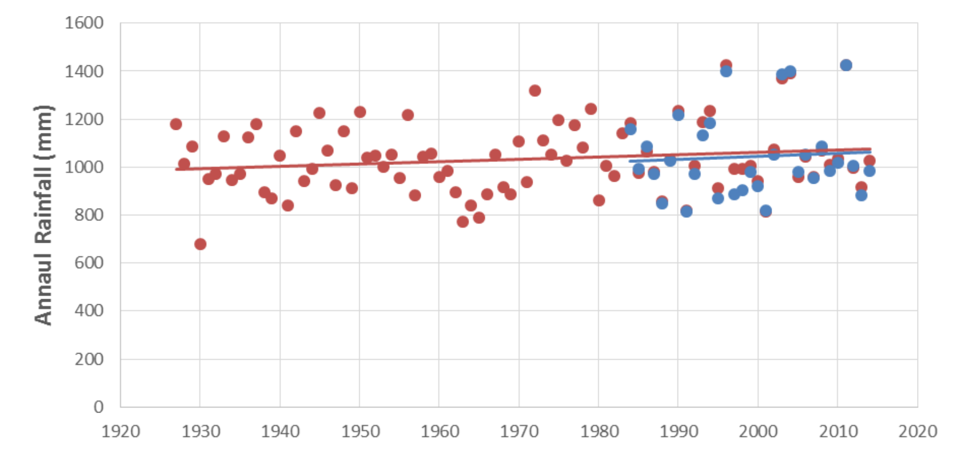
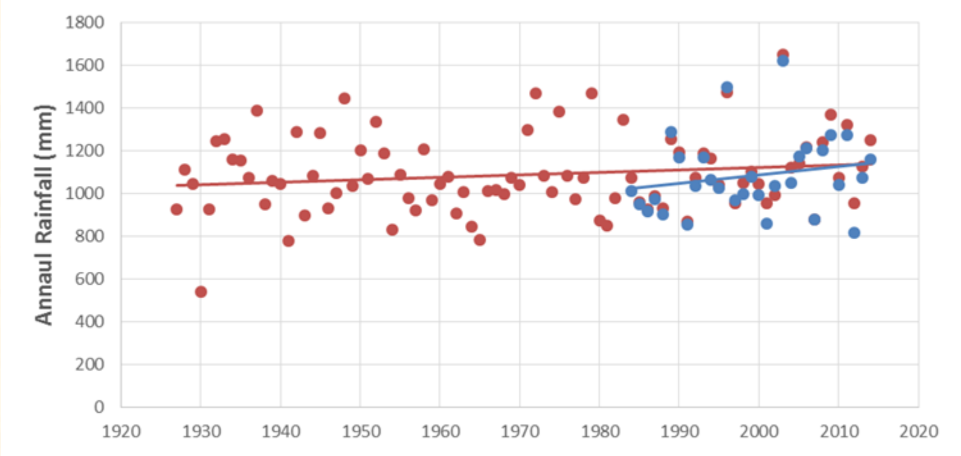
The trends in annual precipitation on a county level were developed through the application of PRISM data and analysis provided and recommended by Jason Lynch, EPA, and Karen Rice, USGS. The annual PRISM dataset for the years 1927 to 2014 (88 years) were used in for the regression trend analysis. The selection of the 87 year period was made because of the easy accessibility of the dataset. 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.

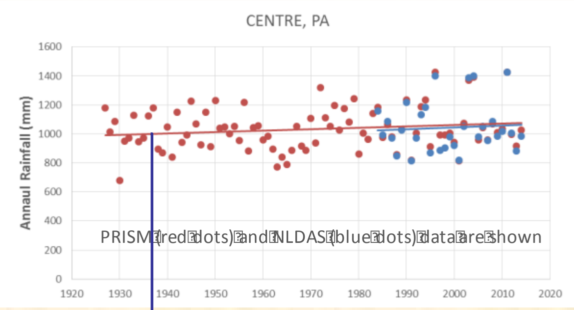




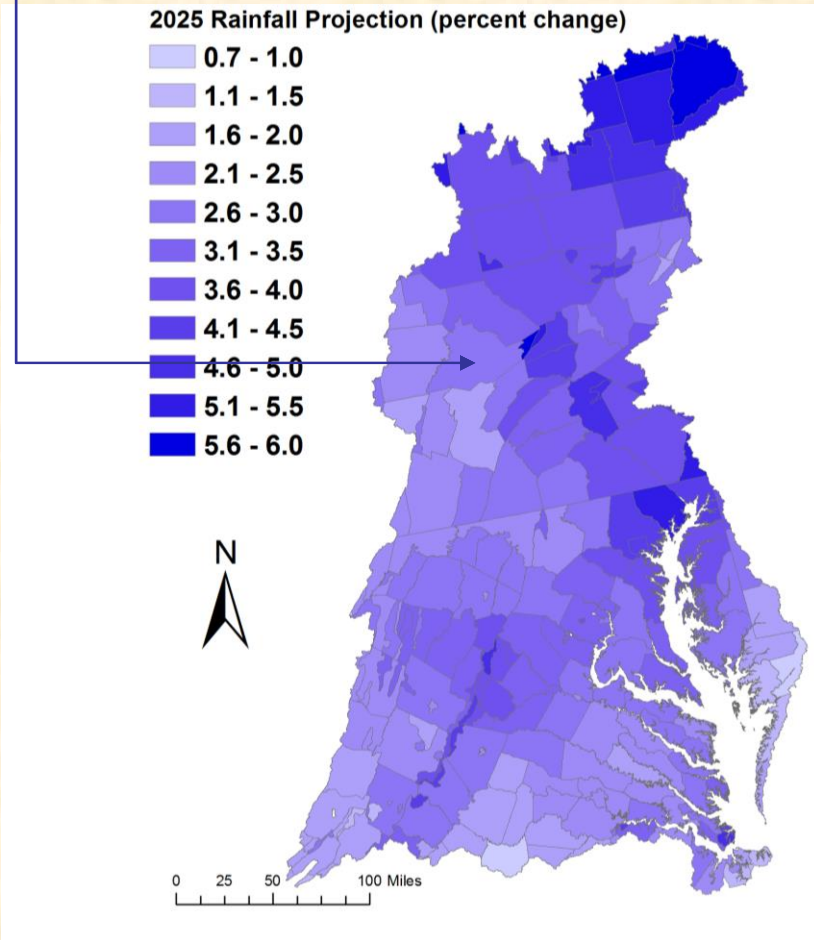
Annual rainfall volumes for the 88-year period linear regression lines are shown in red for the two land segments (counties) – (a) Centre County in Pennsylvania and (b) District of Columbia. The values for the slope of the regression lines, and the corresponding 30-year projections in the rainfall volume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

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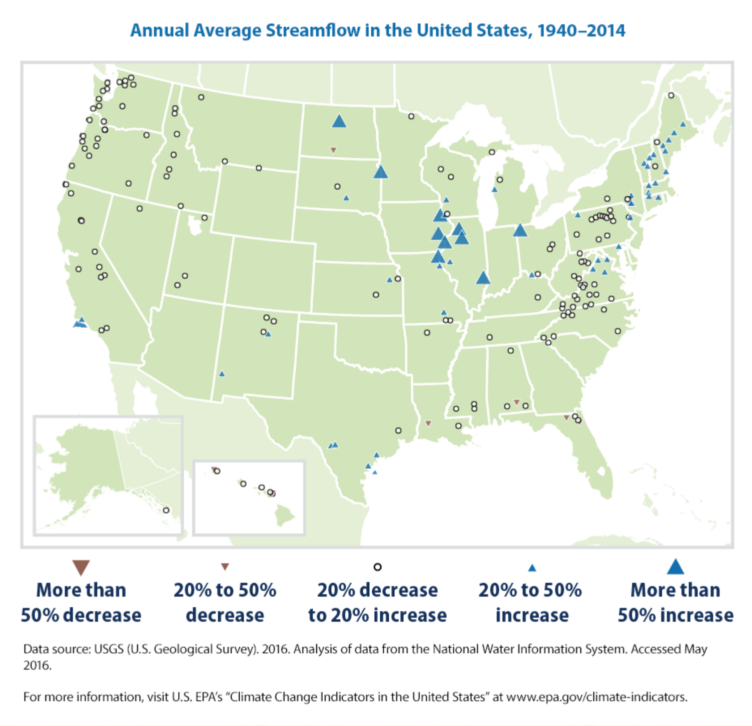
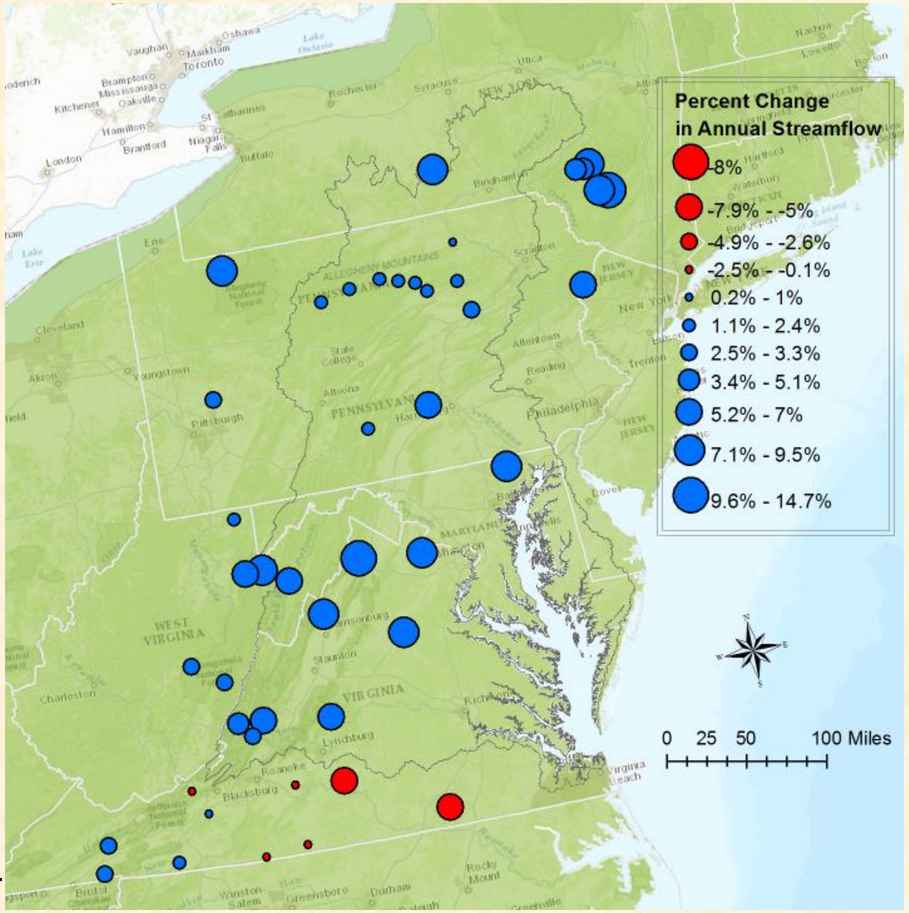
1940-2014 streamflow trends based on observations

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



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.

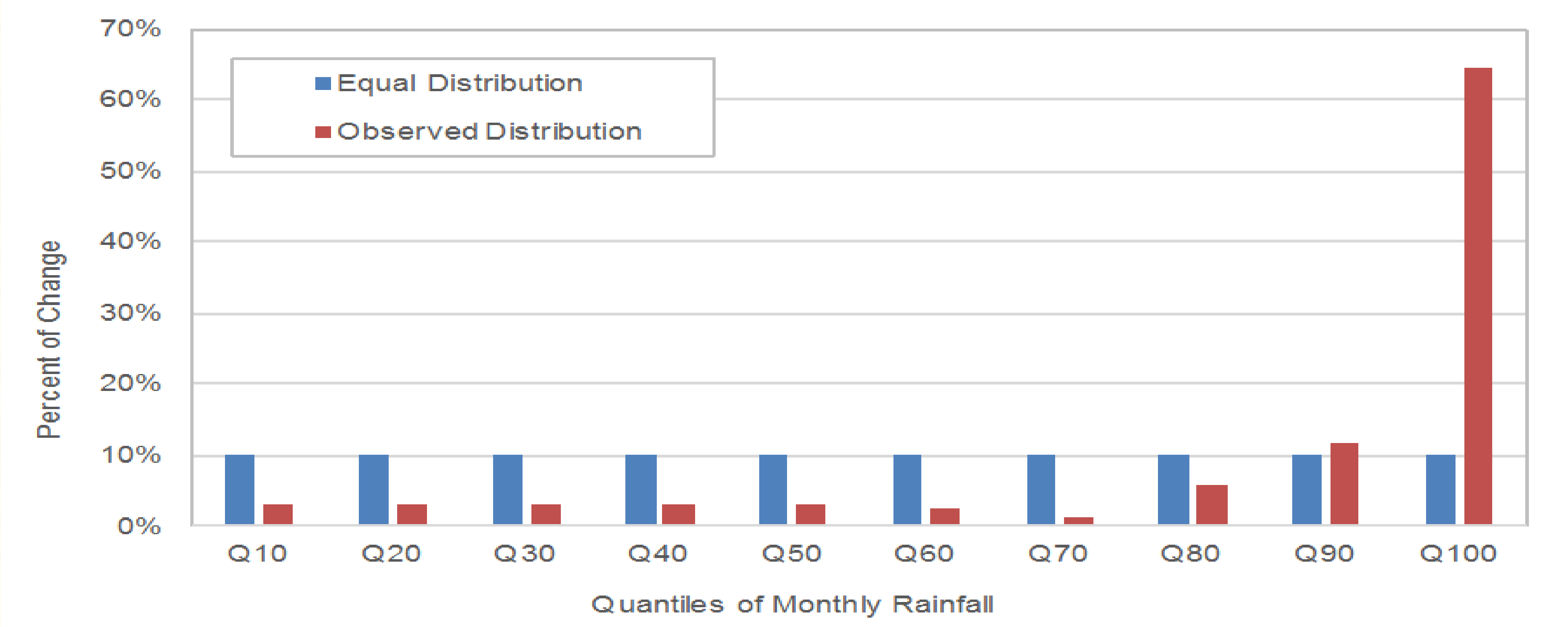


Karen C. Rice, Douglas L. Moyer, and Aaron L. Mills, 2017. Riverine discharges to Chesapeake Bay: Analysis of long-term (1927 - 2014) records and implications for future flows in the Chesapeake Bay basin *JEM* 204 (2017) 246-254

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.

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

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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	
EC-EARTH	INMCM4	

31 member ensemble

[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.

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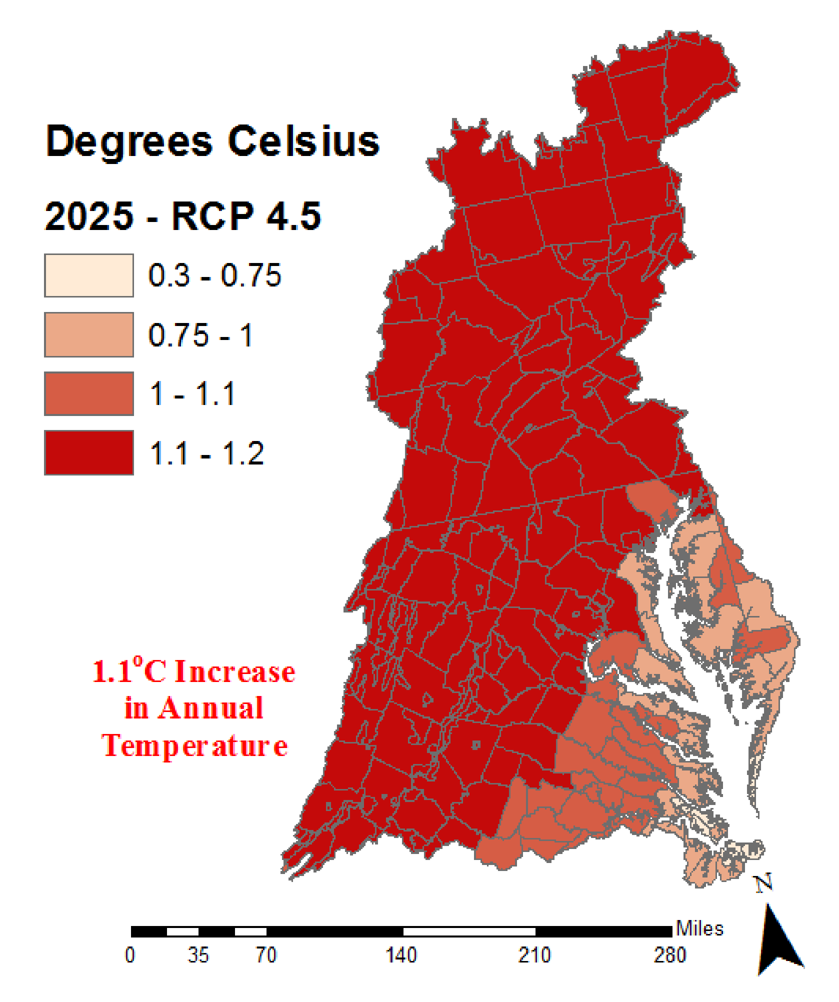
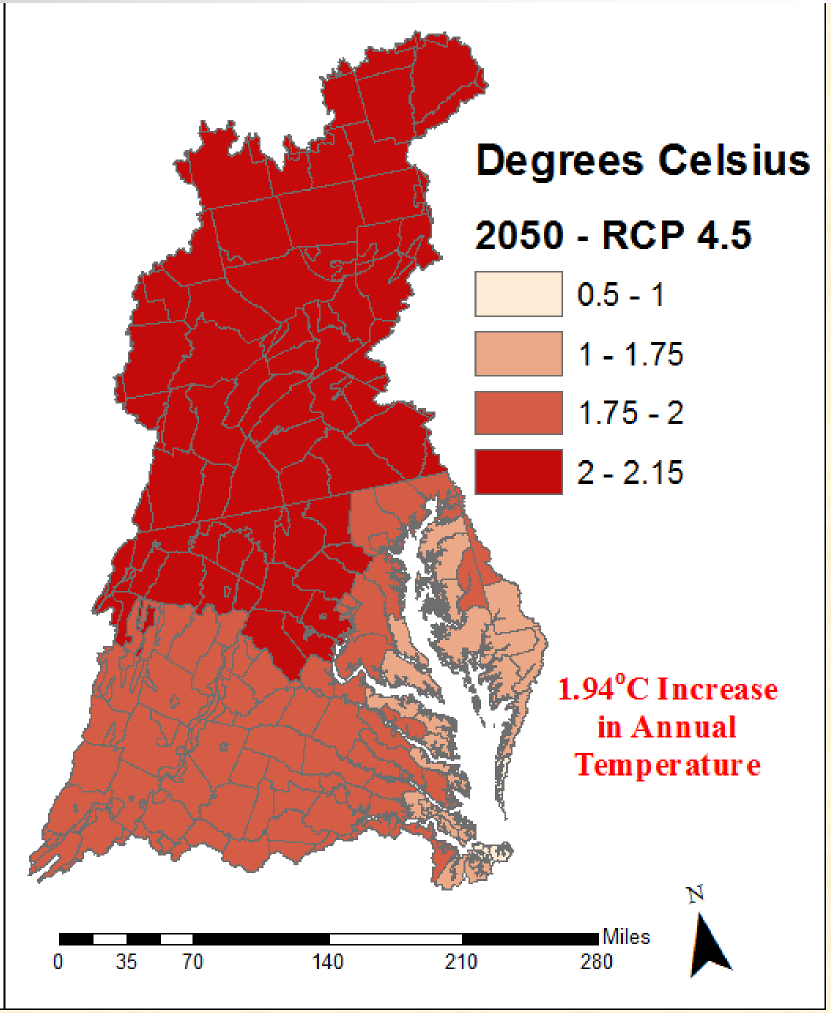
Chesapeake Bay Watershed Annual Change in Temperature





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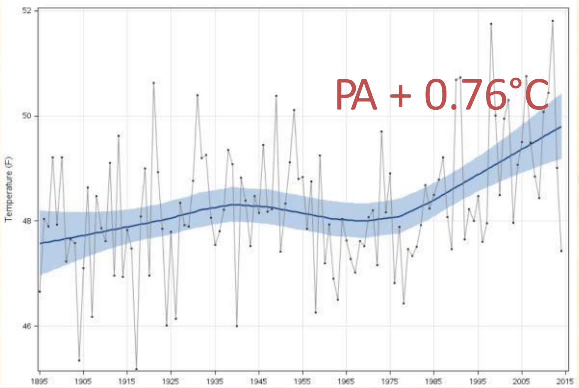
Temperature trends for the six CBP states

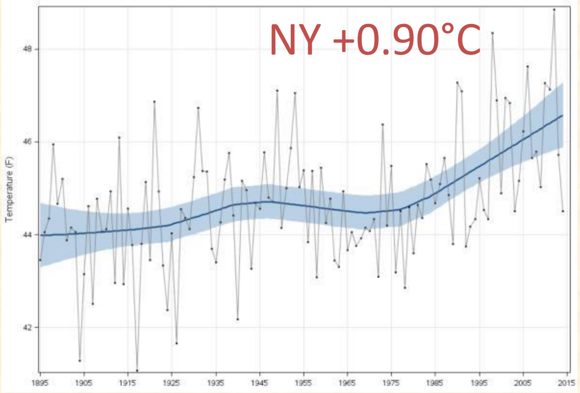
Annual temperature for 1895 to 2015 are shown.

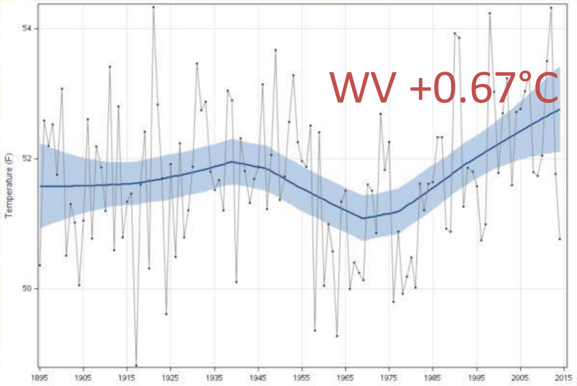
Annual Temperature

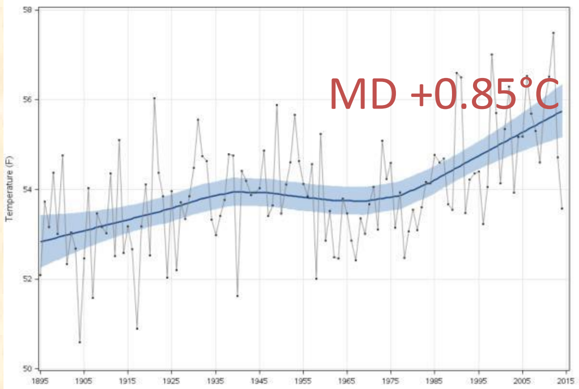
Trend Line

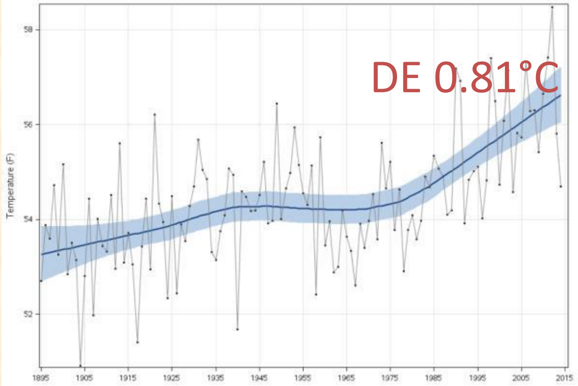
95% Confidence Limits

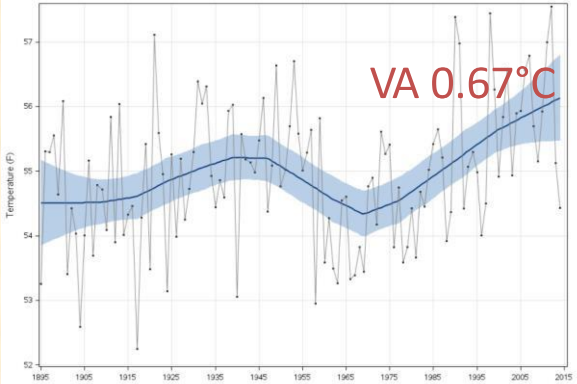












Approx. increases over the last 30 years based on the trend line are shown.

NOAA National Climatic Data Center

https://www.ncdc.noaa.gov/temp-and-precip/state-temps/

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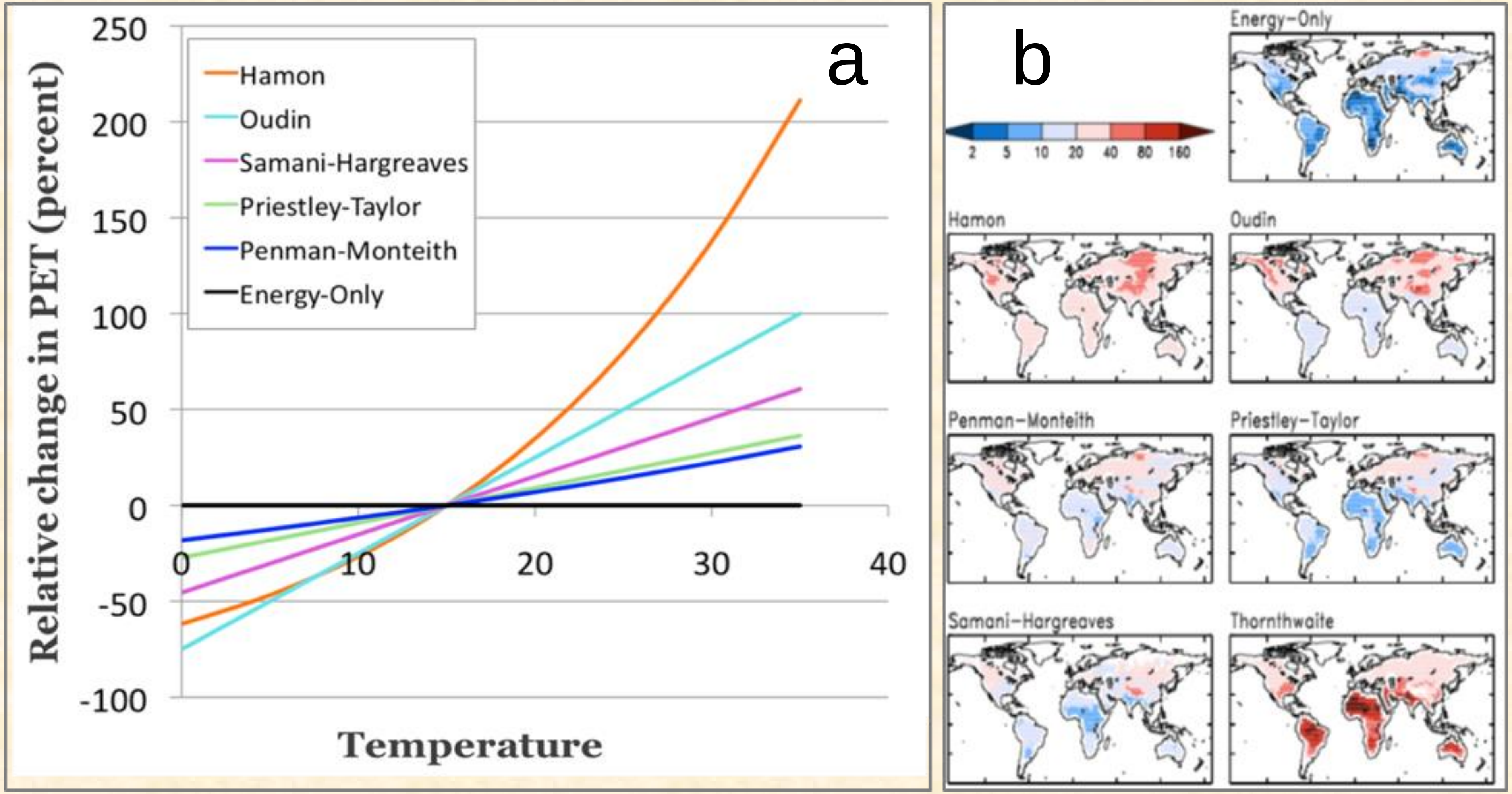
Estimated potential evapotranspiration



(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

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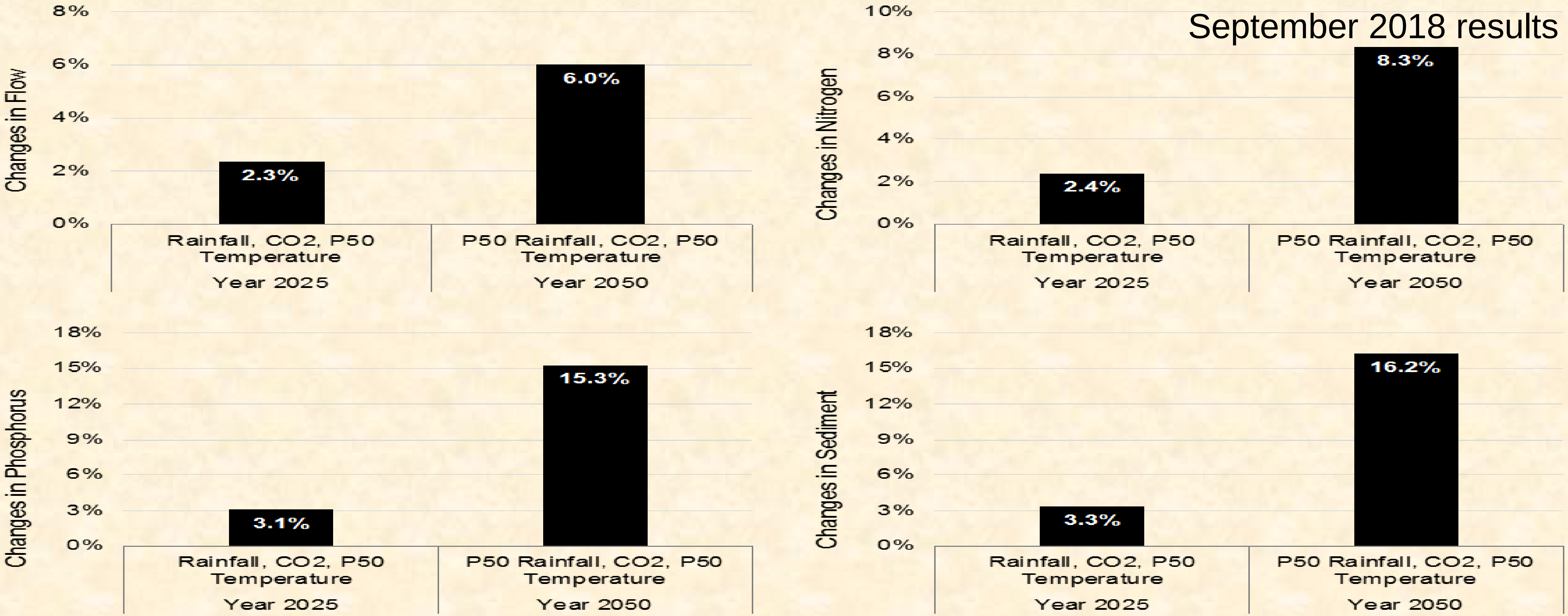
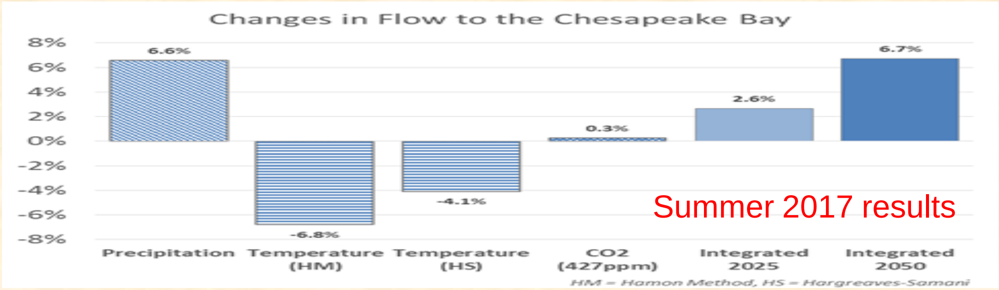
Estimated Flow and Loads from the 2025 and 2050 Climate Change Scenarios



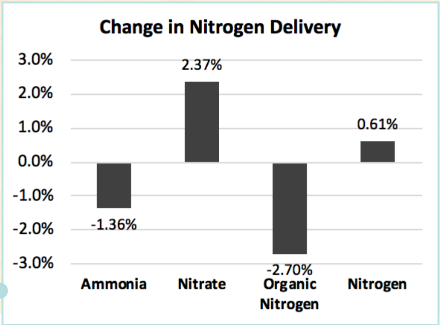
We've had the advantage of being able to sort the various elements of the climate change challenge into "big problems" and "little problems". For example stomatal resistance is a little problem, but evapotranspiration is a big problem.

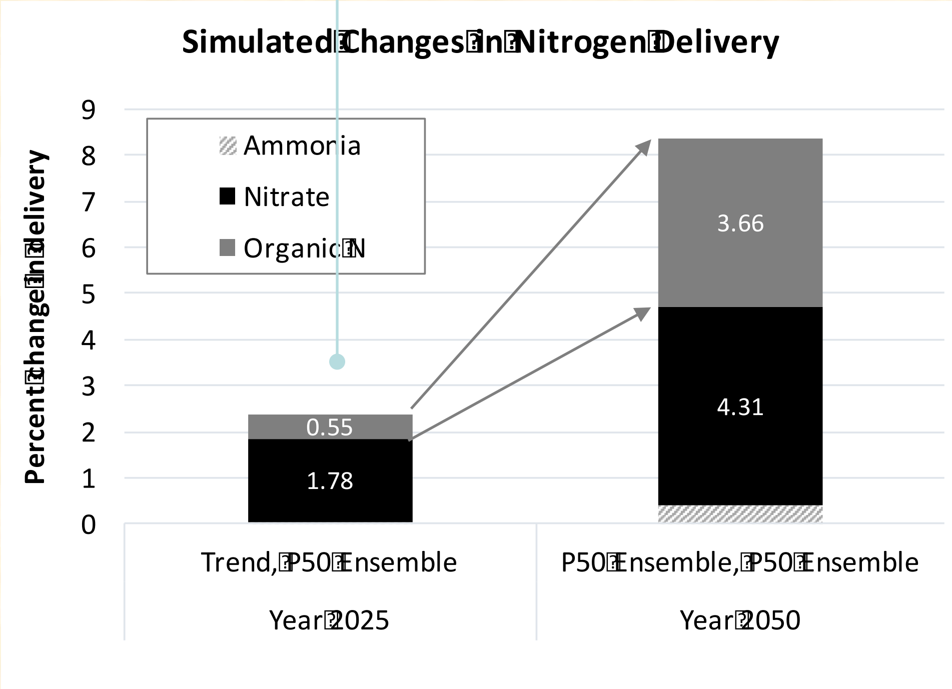


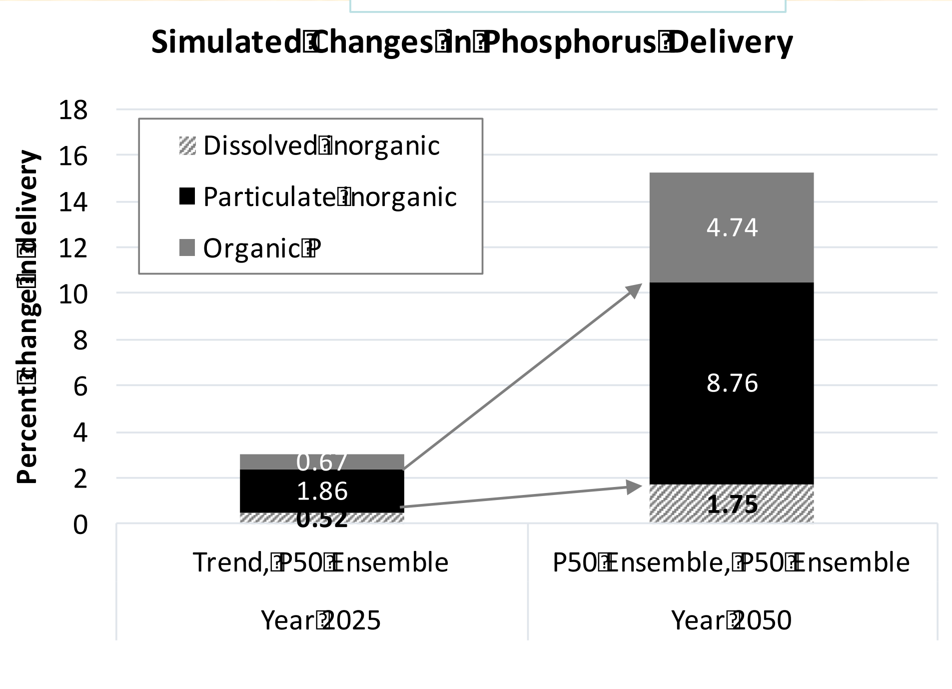
Nitrogen and phosphorus species

September 2018 results

Year 2025 results in December 2017 (with error)







Arrows show relatively more increase in organic nitrogen in 2050 estimates as compared to inorganic DIN.

Arrows show relatively more increase in particulate phosphorus in 2050 estimates as compared to DIP.

Approaches, Methods, and Findings from the Tidal Bay

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Analysis of Climate Change in the Tidal Bay

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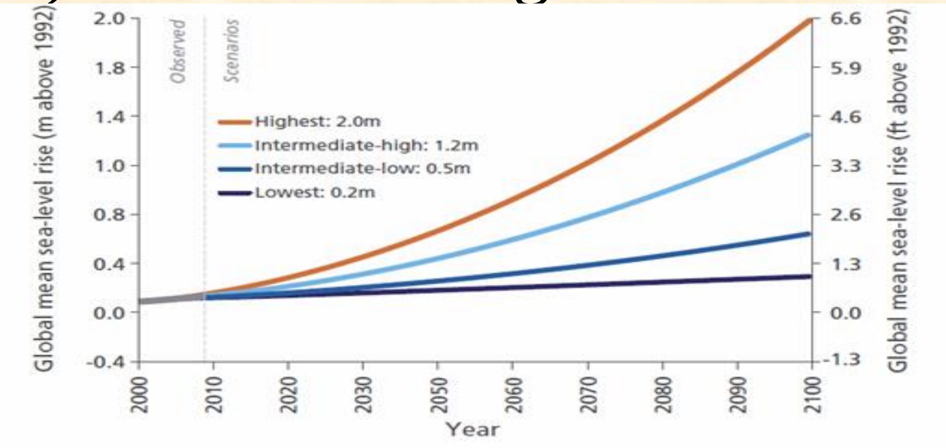
Estimates of the influence of sea level rise, increased temperature of tidal waters, and tidal wetland loss were incorporated into the Water Quality and Sediment Transport Model (WQSTM) of the tidal Bay (Cerco and Noel, 2017). Guidance for increasing levels of regional sea level rise based upon global 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 (0.17 m) and that a range be used for 2050 (0.3 - 0.8 m) be applied in the WQSTM. The approximate median of the 2050 range (0.5 m) was used for initial simulations.



Analysis of Climate Change in the Tidal Bay

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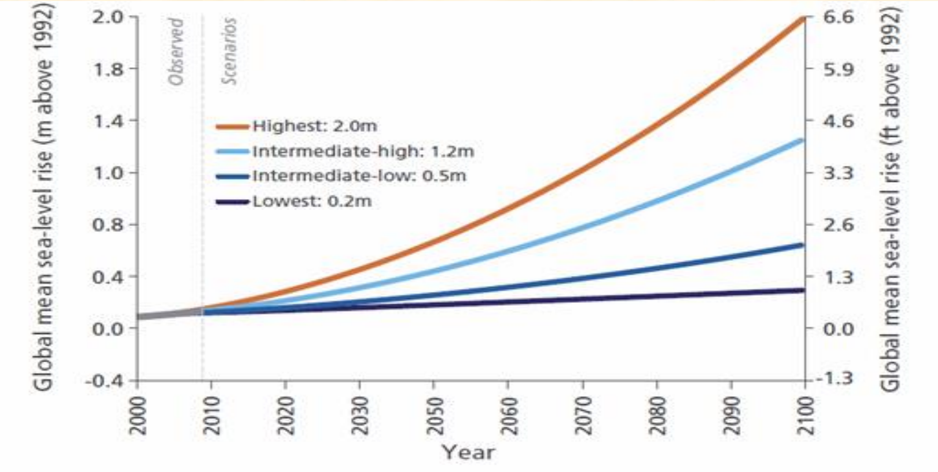
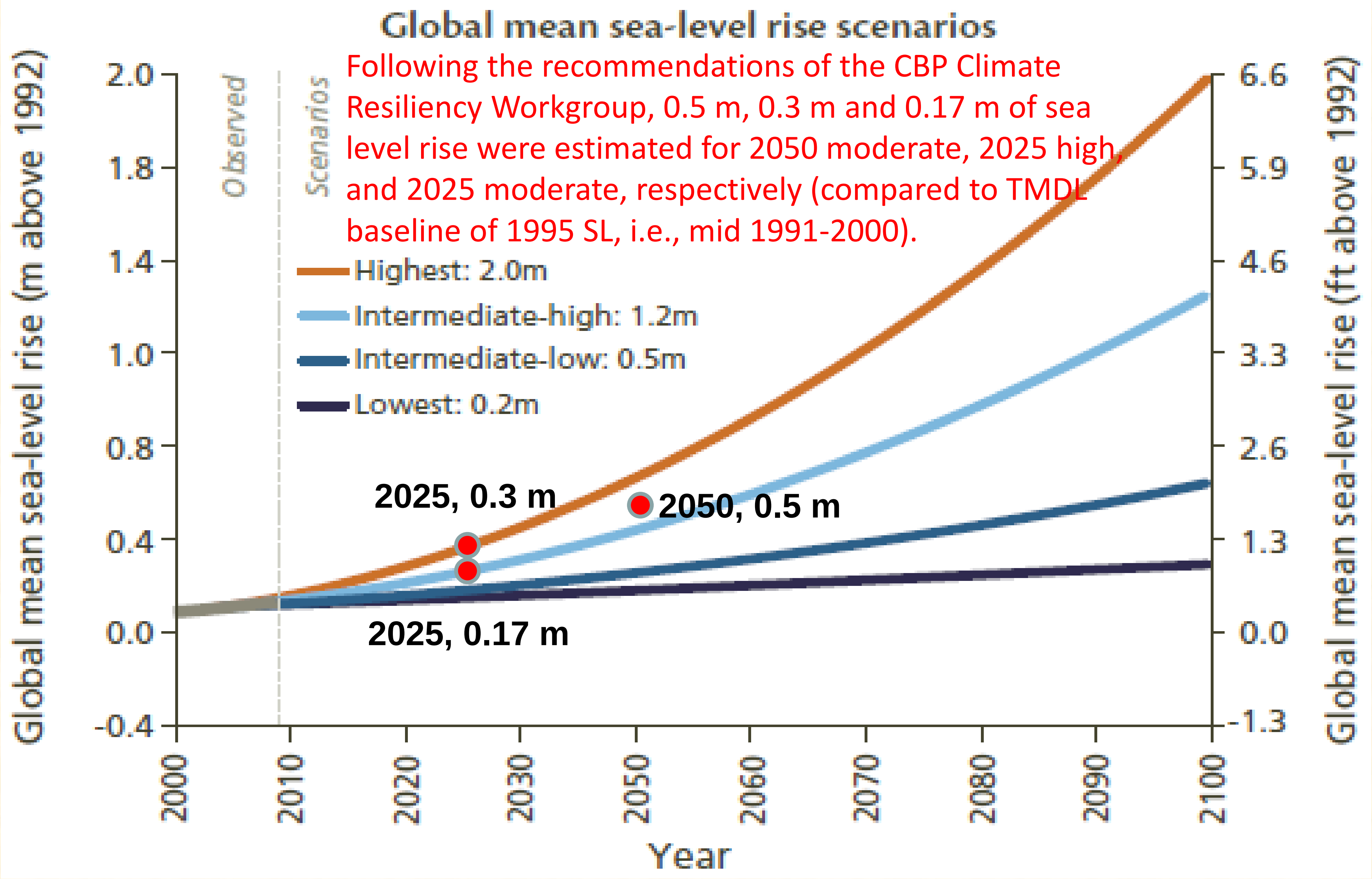
Overall, higher temperatures and loads from the watershed increases hypoxia in the tidal Bay.

However, increases in sea level rise, salinity increases at the Bay mouth, and increased watershed flows all increase estuarine gravitational circulation which in turn decreases estimated hypoxia in the Chesapeake under estimated 2025 and 2050 conditions of sea level rise and watershed flows.





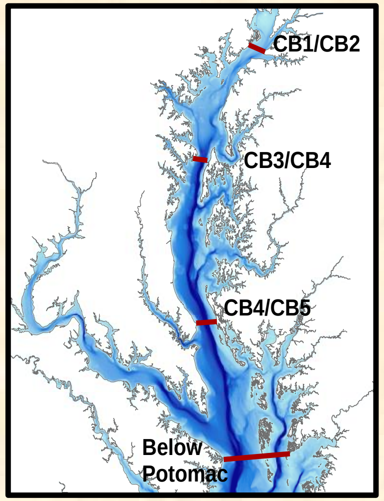
From Parris, A. et al. (2012). *Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Technical Report OAR CPO-1. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.*

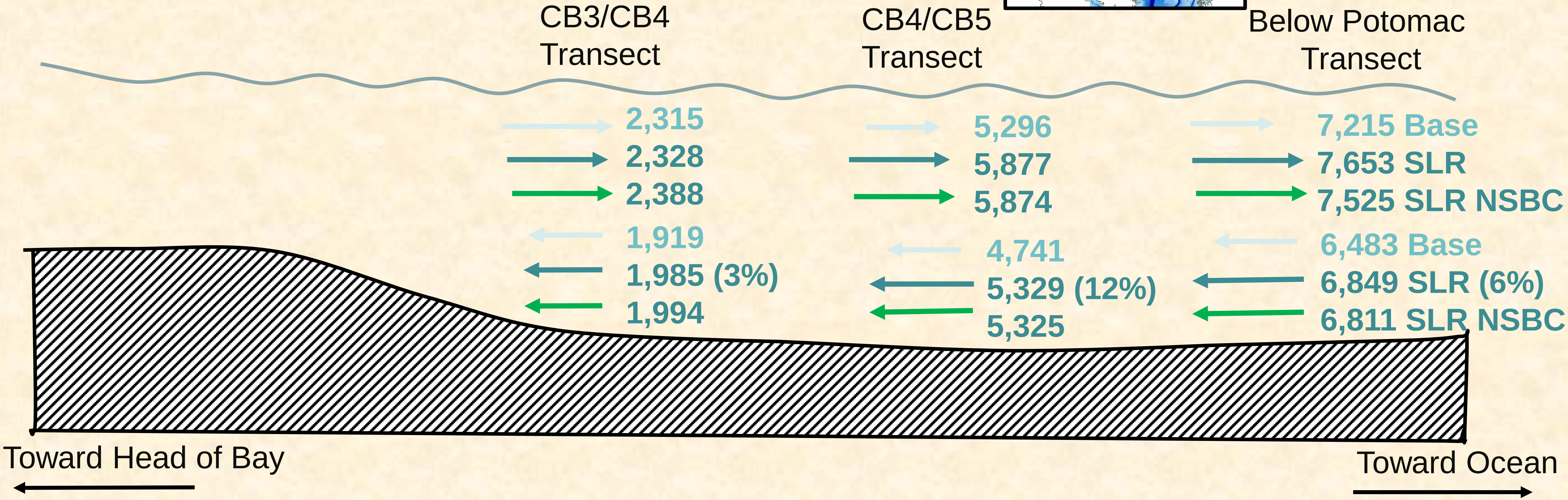
Assessment of Influence of 2025 Climate Change in the Tidal Bay

From the Literature - Responses to Sea Level Rise:

- Increased salinity in Bay
- Increased up-estuary salt intrusion
- Changes in stratification
- Increased gravitational circulation
- Increased salinity at ocean boundary

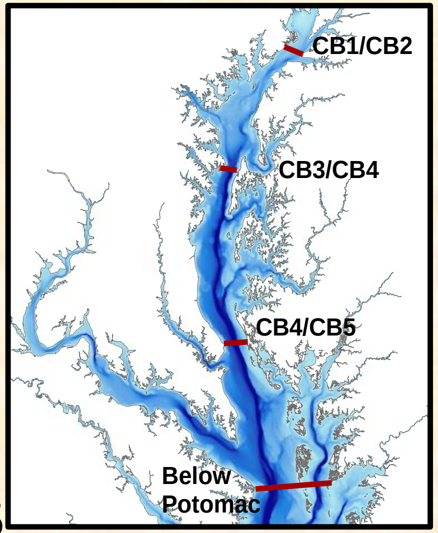
Cross-transect water fluxes (m^3/s) Base case versus sea level rise (SLR) of 0.5m. Summer 1993-1995

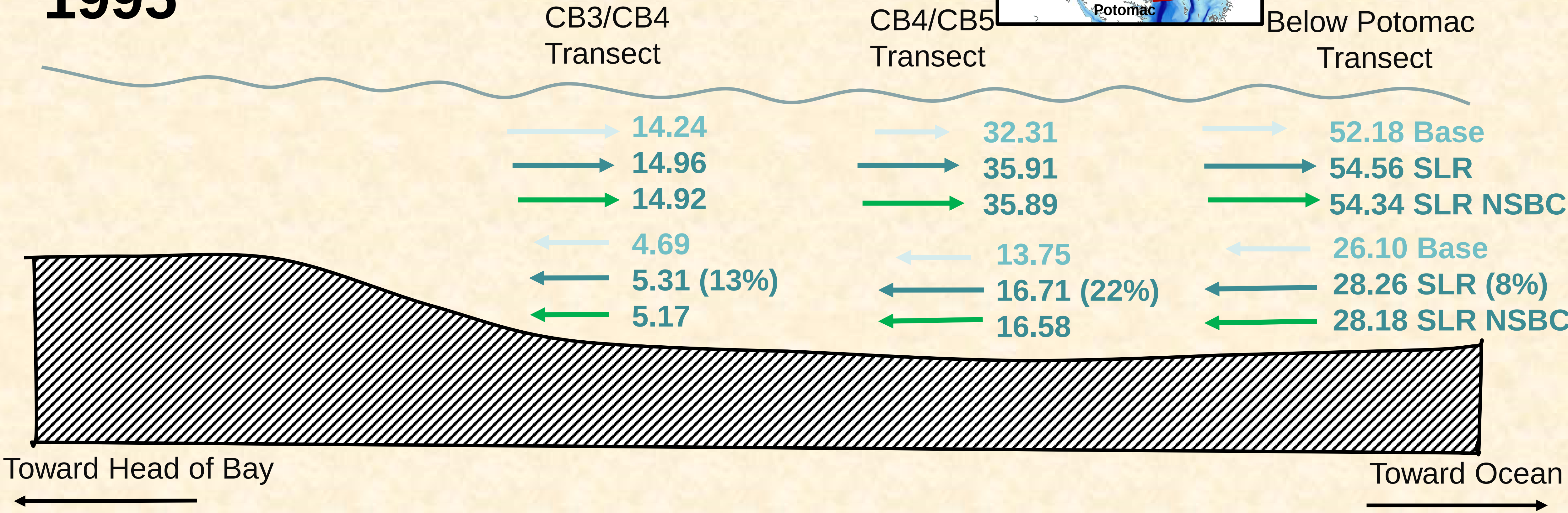




Base = Beta 4 WQSTM, SLR = 0.5m representing relative Chesapeake sea level rise from 1995 to 2050.
Units in mean m^3/s for summer (Jun-Sept) 1993 to 1995; NSBC: No Salt Boundary Change.

Cross-transect DO fluxes (kg/s) Base case versus sea level rise (SLR) of 0.5m. Summer 1993 - 1995





Base = Beta 4 WQSTM, SLR = 0.5m representing relative Chesapeake sea level rise from 1995 to 2050. Units in mean kg DO per second (kg/s) for summer (Jun-Sept) 1993 to 1995; NSBC: No Salt Boundary Change.

Hypoxic volume (DO <1 mg/l) in CB4MH (summer 1991-2000)

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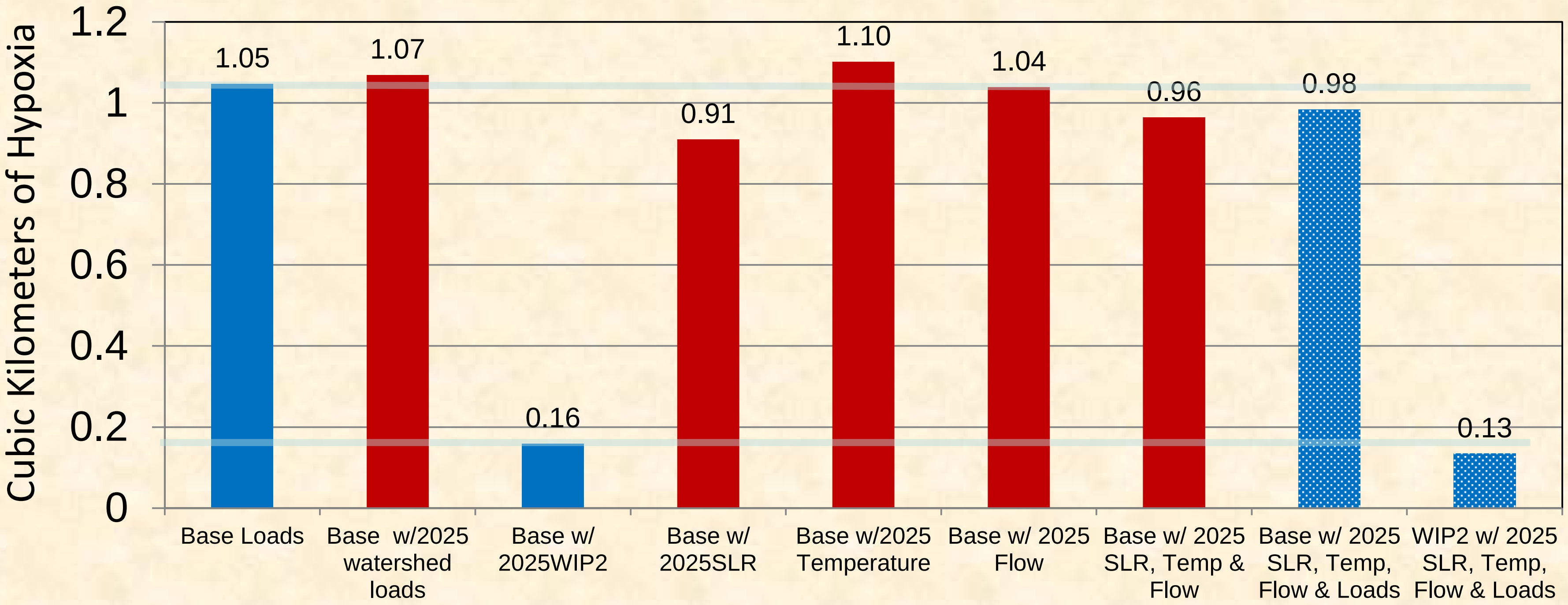
Big problems and little problems: Increased gravitational circulation, watershed loads, and tidal water temperature are big problems, but increased flows into the Bay and changes in atmospheric deposition are little problems.



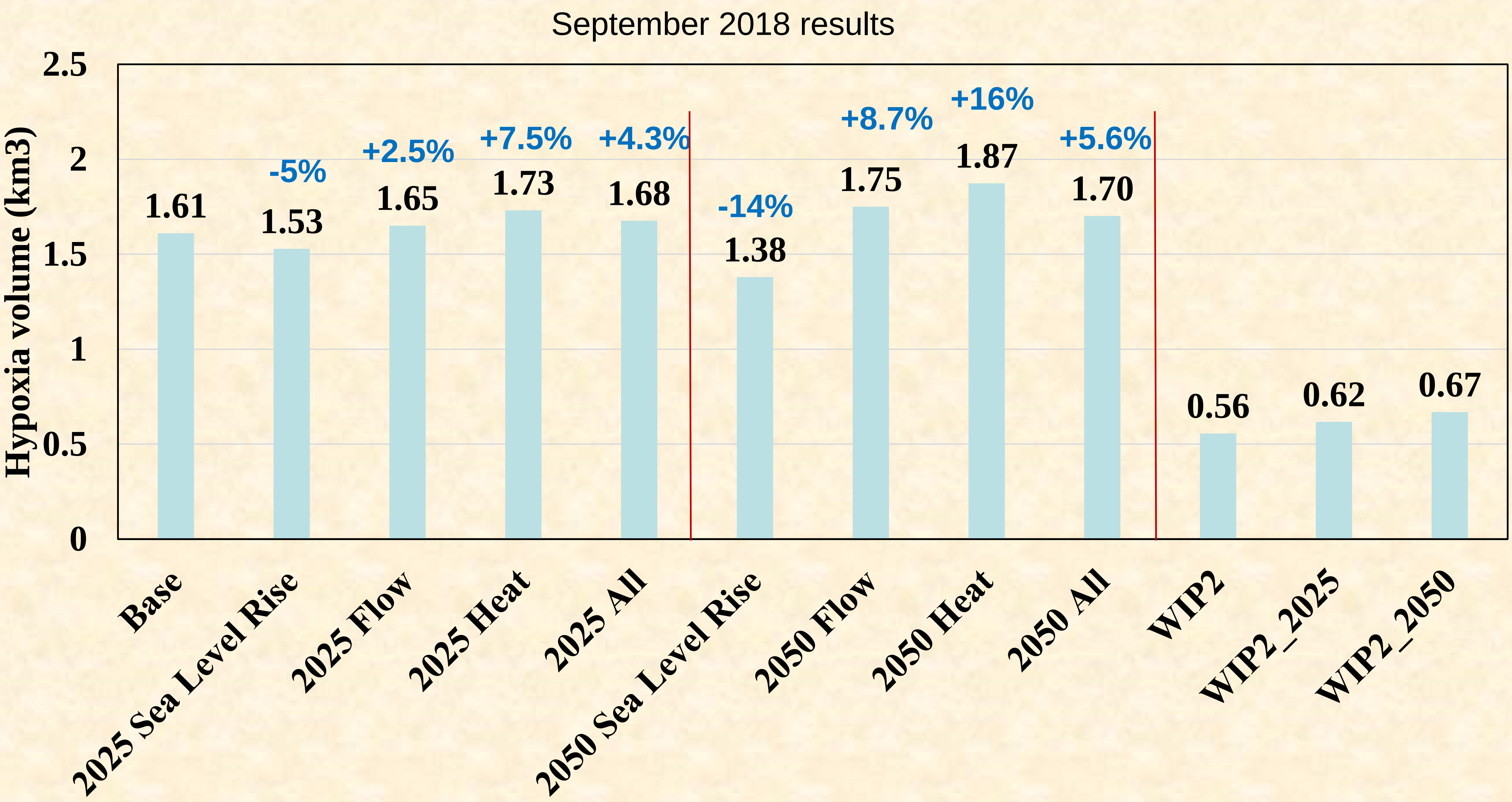
DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September. Sea level rise = 0.3m.

solid blue = key scenario, solid red = sensitivity scenario, stippled blue = 2025 climate scenario

Summer 2017 results

This work used the Draft Phase 6 Watershed Model and WQSTM to provide an initial estimate of relative 2025 and 2050 hypoxia under different temperature, sea level rise, and watershed flow and load conditions. <u>We need to run the analysis on the final Watershed and WQSTM models</u>.

Summer (Jun-Sep) Hypoxia Volume (<1 mg/l) in CB4MH, 1991-2000



Bay Water Quality Responses to 2025 Climate Change Conditions

Changes in estimated 2025 dissolved oxygen criteria attainment for Deep Channel, Deep Water, and Open Water due to observed temperature and precipitation changes since 1991-2000 (years of average Bay hydrology).

Run 223 11/30/17 CAST Loads		WIP2 195TN 13.7TP 1993-1995	WIP2 + Cono Infill 208TN 15.4TP 1993-1995	WIP2 + Cono Infill + CC 210TN 15.3TP 1993-1995
Cbseg	State	Deep Channel	Deep Channel	Deep Channel
CB3MH	MD		0%	0%
CB4MH	MD	6%	8%	10%
CB5MH	MD	0%	0%	0%
CB5MH	VA	0%	0%	0%
POTMH	MD	0%	0%	0%
RPPMH	VA	0%	0%	0%
ELIPH	VA	0%	0%	0%
CHSMH	MD	0%	0%	4%
EASMH	MD	6%	7%	8%

Deep Channel nonattainment increases by 2% in CB4MH

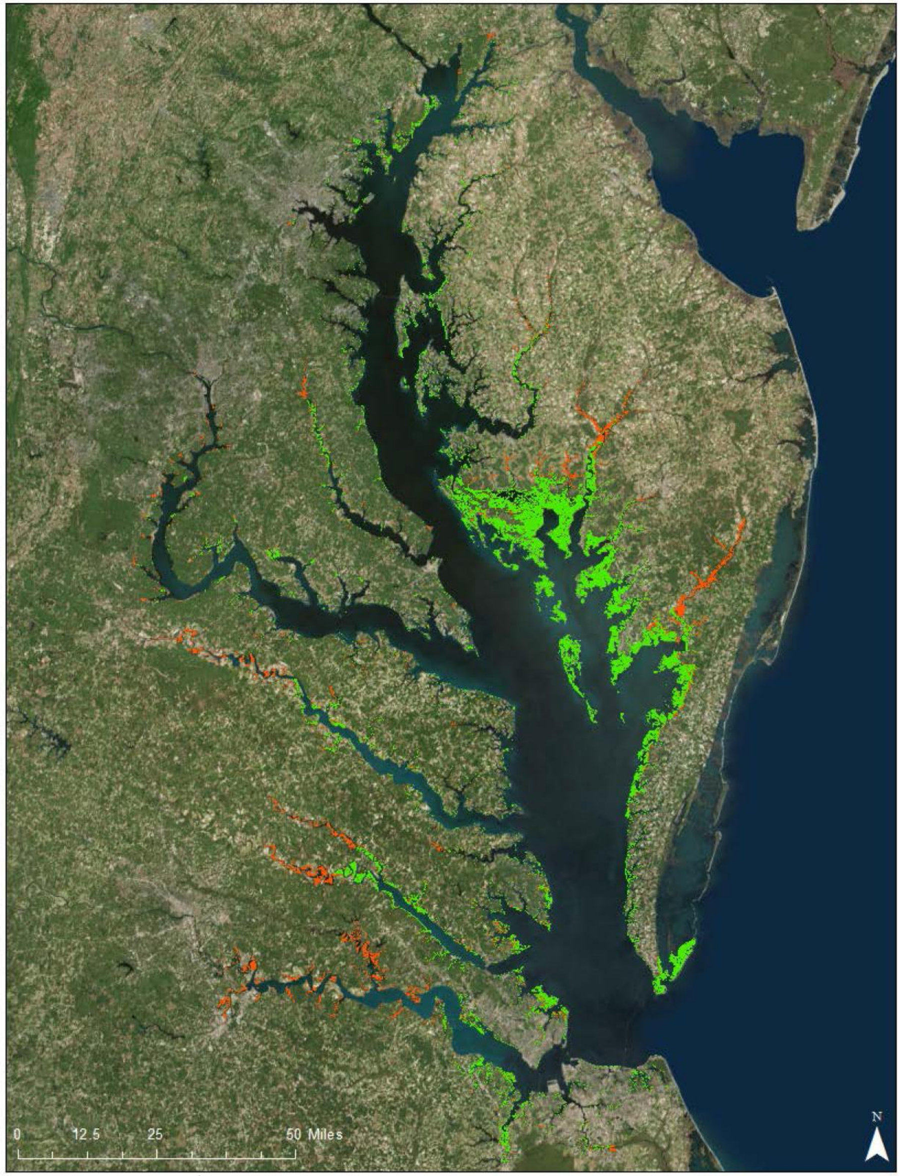
Run 223 11/30/17 CAST Loads		WIP2 195TN 13.7TP 1993-1995	WIP2 + Cono Infill 208TN 15.4TP 1993-1995	WIP2 + Cono Infill + CC 210TN 15.3TP 1993-1995
Cbseg	State	Deep Water	Deep Water	Deep Water
CB4MH	MD	5%	6%	7%
CB5MH	MD	1%	1%	2%
CB5MH	VA	0%	0%	0%
CB6PH	VA	0%	0%	0%
CB7PH	VA	0%	0%	0%
PATMH	MD	1%	2%	3%
MAGMH	MD	1%	5%	5%
SOUMH	MD	3%	8%	7%
SEVMH	MD	0%	0%	0%
PAXMH	MD	0%	0%	0%
POTMH	MD	0%	0%	0%
RPPMH	VA	0%	0%	0%
YRKPH	VA	0%	0%	0%
ELIPH	VA	0%	0%	0%
CHSMH	MD	0%	0%	0%
EASMH	MD	0%	0%	0%

Deep Water nonattainment increases by 1% in CB5MH

Procedures for assessing Open Water attainment under climate change conditions are being developed.

December 2017 results

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.

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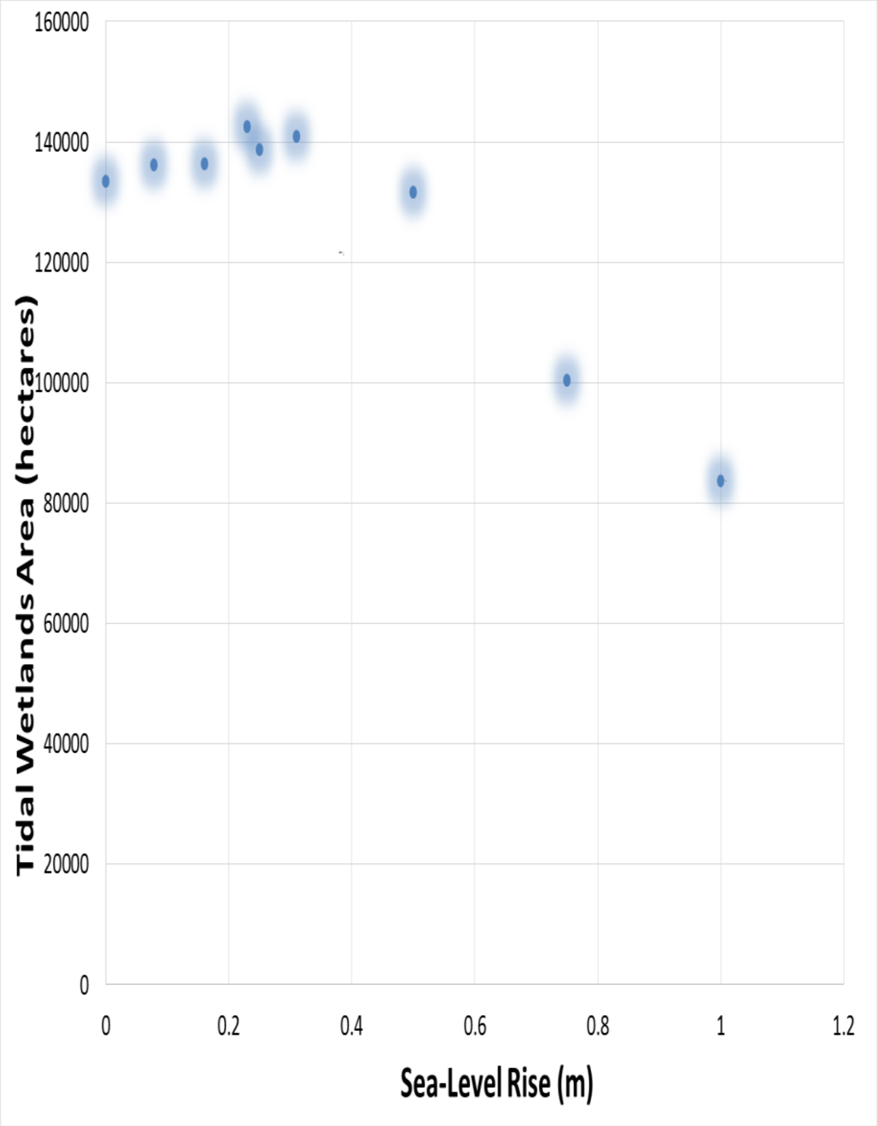
Influence of Estimated 2025 (0.3 m) and 2050 (0.5m) Sea Level Rise on Tidal Wetland Attenuation



There is little change in estimated total tidal wetland area for 2025 (0.3 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.

Uncertainty Analysis

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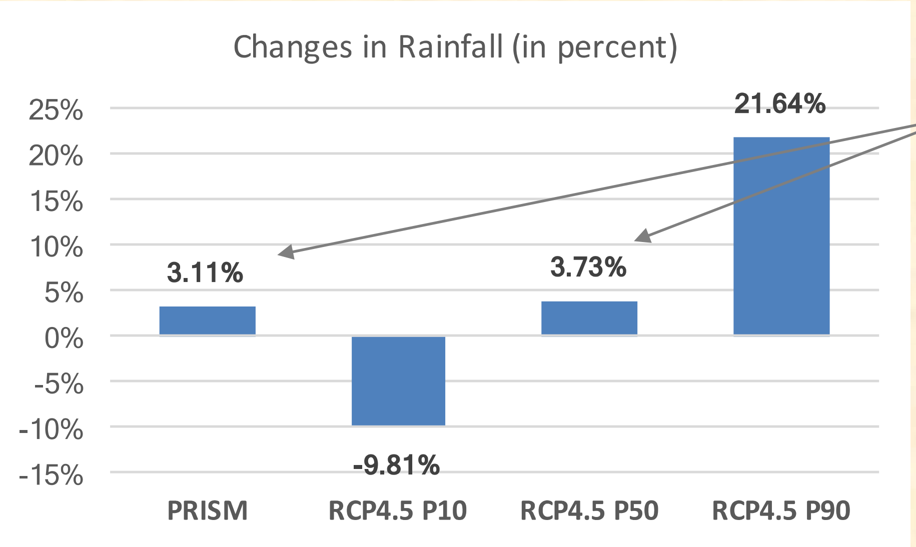
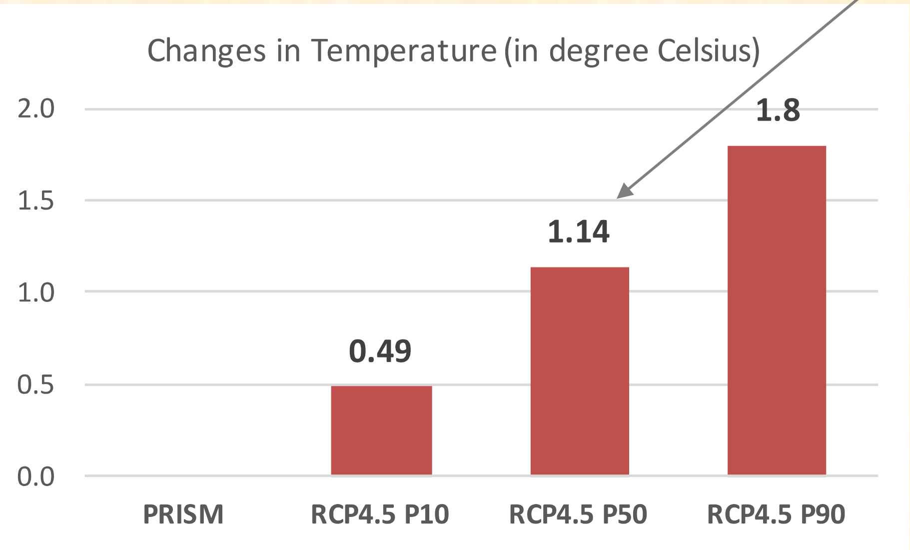
2025 Projections for Chesapeake Bay Watershed

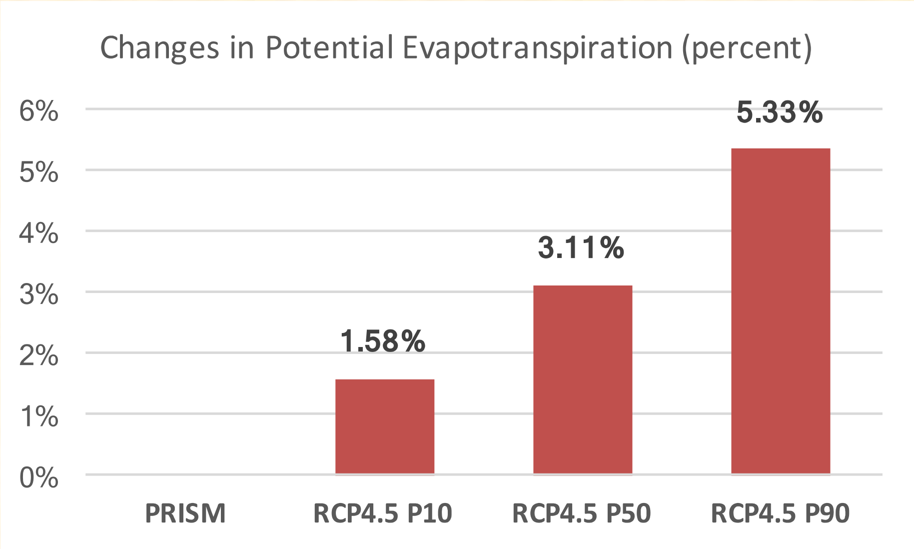


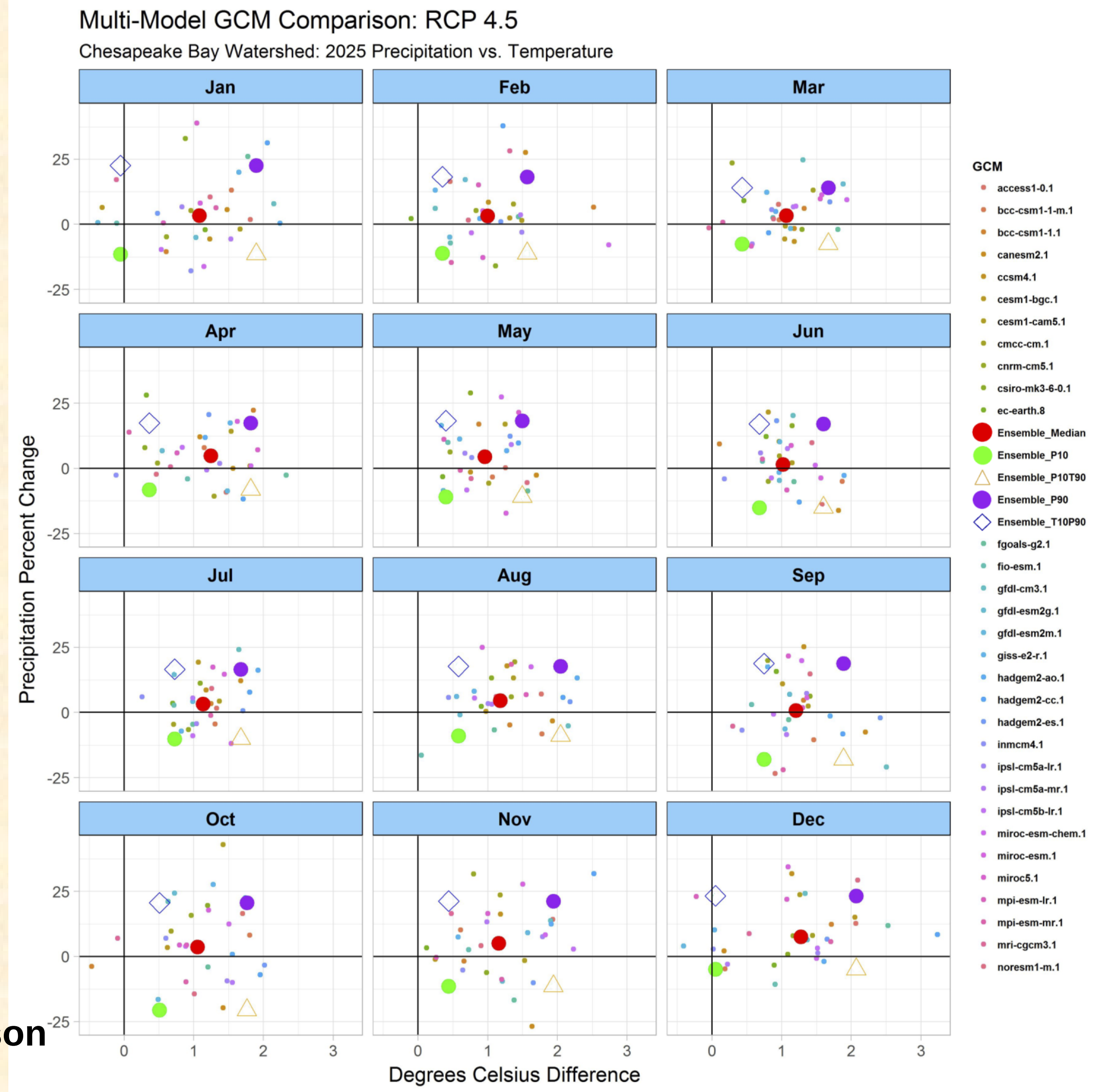
The central tendency of rainfall volume increase projections based on the 31 member ensemble median, P50, matches well with the extrapolation of PRISM's 88-year trends.

The rainfall uncertainty bounds (P10 and P90) of the ensemble members are quite large.

The central tendency of the temperature increase is potentially bit higher.







Multi-Model GCM Comparison: RCP 4.5
Chesapeake Bay Watershed: 2025 Precipitation vs. Temperature
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Precipitation Percent Change
Degrees Celsius Difference
25
0
-25
0
1
2
3
GCM
access1-0.1
bcc-csm1-1-m.1
bcc-csm1-1.1
canesm2.1
ccsm4.1
cesm1-bgc.1
cesm1-cam5.1
cmcc-cm.1
cnrm-cm5.1
csiro-mk3-6-0.1
ec-earth.8
Ensemble_Median
Ensemble_P10
Ensemble_P10T90
Ensemble_P90
Ensemble_T10P90
fgoals-g2.1
fio-esm.1
gfdl-cm3.1
gfdl-esm2g.1
gfdl-esm2m.1
giss-e2-r.1
hadgem2-ao.1
hadgem2-cc.1
hadgem2-es.1
inmcm4.1
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ipsl-cm5a-mr.1
ipsl-cm5b-lr.1
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miroc-esm.1
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mpi-esm-lr.1
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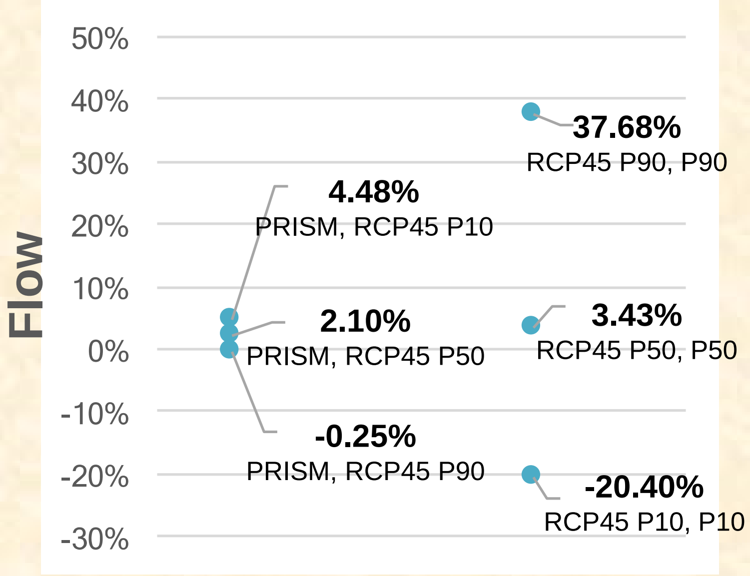
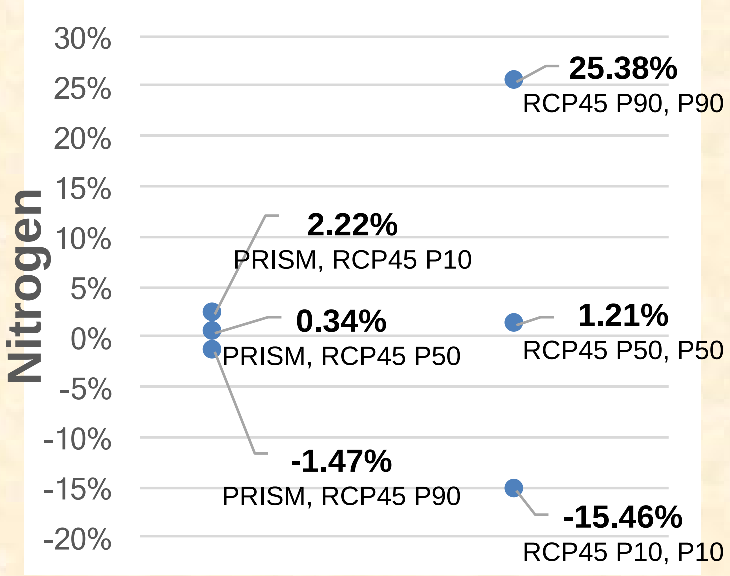
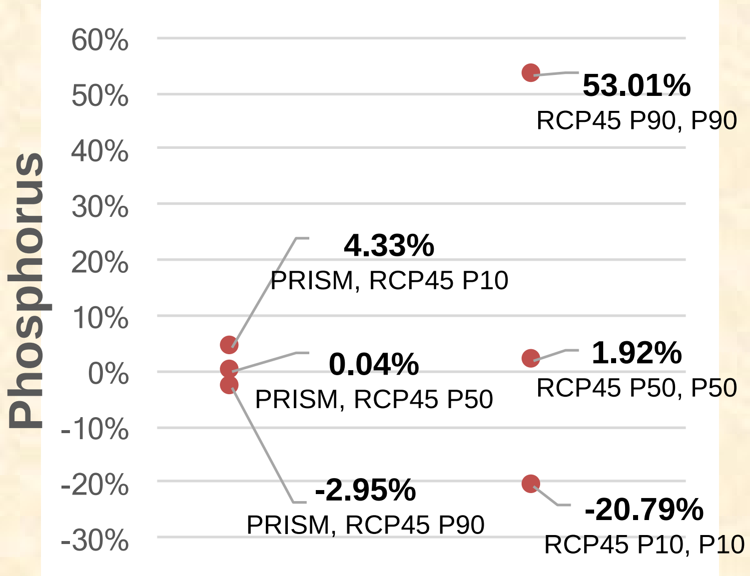
noresm1-m.1

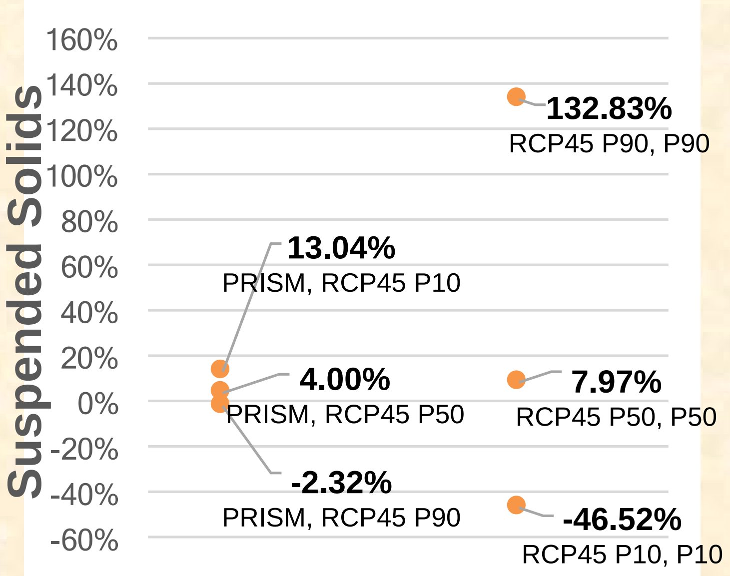
Kyle Hinson

Uncertainty quantification









CBP Management Direction and STAC Guidance

Chesapeake Bay Program

Science, Restoration, Partnership

Recommendations from STAC

The CBP's Scientific and Technical Advisory Committee (STAC) has conducted several assessments of climate science and has recommended processes to integrate consideration of climate change into the Bay Program's management framework (DiPasquale 2014; Johnson et al. 2016; Pyke et al. 2008; Pyke et al. 2012; STAC 2011; Wainger 2016; Benham 2018).

Recommendations from STAC:

STAC's peer reviews and workshops on the assessment of climate change in the Chesapeake watershed and Bay has made a substantial contribution to the CBP as part of STAC's essential ongoing advice on the state of the science in this field, and particularly with respect to watershed and coastal water restoration in the Chesapeake region. Ongoing, long-term, technical and strategic support by STAC for CBP decision making on climate change will provide important guidance going forward.

Management Actions on CB Climate Change:

The Principal Staff Committee (PSC) in December 2017 directed the CBP, through the Modeling and Climate Resiliency Workgroups, to direct immediate efforts toward a more refined analysis of climate change influence on Chesapeake water quality, to be delivered as a complete and fully operational modeling system by the close of 2019.

PSC Decisions of December 2017

The PSC Decisions of December 2017 directed the CBP to work to better understand the science by documenting the current understanding, identifying research gaps and needs, and addressing uncertainty. Specifically, the CBP was to:

"- Develop an estimate of pollutant load changes (N, P, and S) due to climate change conditions [so that] starting with the 2022-2023 milestones, [the CBP will] determine how climate change will impact the BMPs included in the WIPs and address these vulnerabilities in the two-year milestones.

- Develop a better understanding of the BMP responses, including new or other emerging BMPs, to climate change conditions.

- In 2021, the Partnership will consider results of updated methods, techniques, and studies and revisit existing estimated loads due to climate change to determine if any updates to those load estimates are needed.

- Jurisdictions will be expected to account for additional nutrient and sediment pollutant loads due to 2025 climate change conditions in a Phase III WIP addendum and/or 2-year milestones beginning in 2022."

Next Steps Directed by the PSC: Understanding the Science and Refining the Model Estimates

2018

- STAC Workshop to examine current results, assess lessons-learned and recommend next steps.
- Climate Resiliency Workgroup will incorporate actions in its 2018-2020 workplan to develop a better understanding of BMP responses, including new or other emerging BMPs, to climate change conditions.

2019

- Following the direction of the PSC, the Modeling and Climate Resiliency Workgroups, working with other key Chesapeake Bay Program groups, will develop and implement a complete and fully operational climate change modeling and assessment system in 2019.

2020

- In 2020, the CBP partners will complete a technical review and process for approval of the new refined climate change modeling and assessment system as well as the scientific and technical findings from its management applications.

2021

- In 2021, the policy implications for including targets adjusted for the influence of climate change into the 2022-2023 milestones will be considered by the Partnership.
- By the close of 2021, the refined findings on climate change will be implemented into the jurisdictions' 2022-2023 milestones.