Estimated Influence of Historical Trends of Precipitation, Temperature, and Sea Level Rise on Chesapeake Tidal Water Quality Standards: Results of the CBP Climate Change Analysis

WQGIT Webinar

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Overview

- Overall findings
- 2025 Watershed estimates
- 2025 Tidal Bay estimates
- Uncertainty estimates
- Conclusions

Overall Findings

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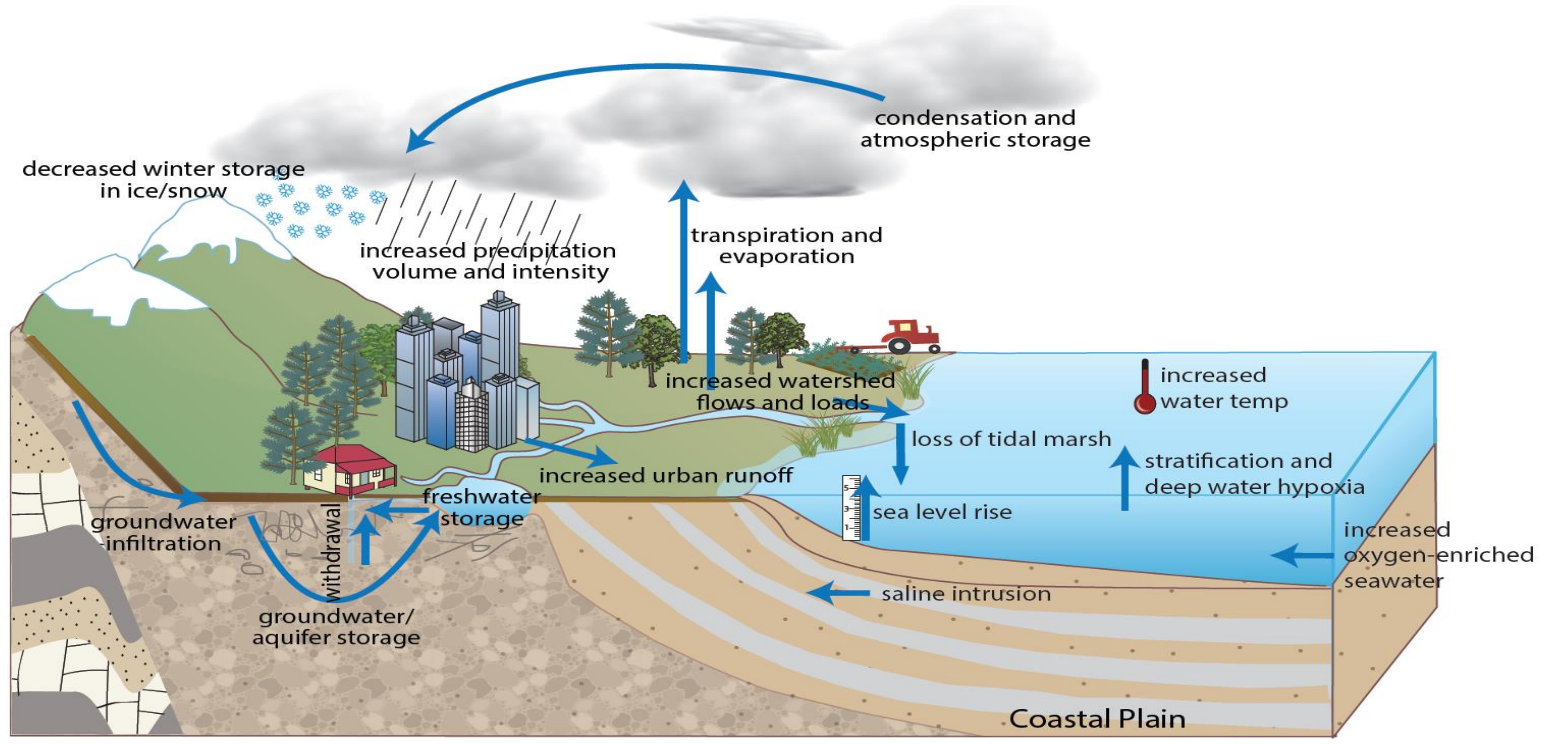
Climate Influence on the CB Watershed



Source: CBP Modified UMCES/ IAN graphic (2011)

Introduction:

- The Modeling Workgroup 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, as well as other ecosystem influences.
- Current efforts are to frame initial future climate change scenarios based on estimated 2025 (short term) and 2050 conditions (long term).

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Estimates of Climate Change Influence On Chesapeake Water Quality Attainment

- Increased precipitation volumes and intensity will increase nutrient and sediment loads from the watershed in 2025 compared to 1995.
- However, increased 2025 temperatures substantially ameliorates the estimated increased precipitation volume in the watershed through evapotranspiration, but temperature increases also increases stratification and hypoxia in the tidal Bay.
- In addition, 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 conditions of sea level and watershed flows.

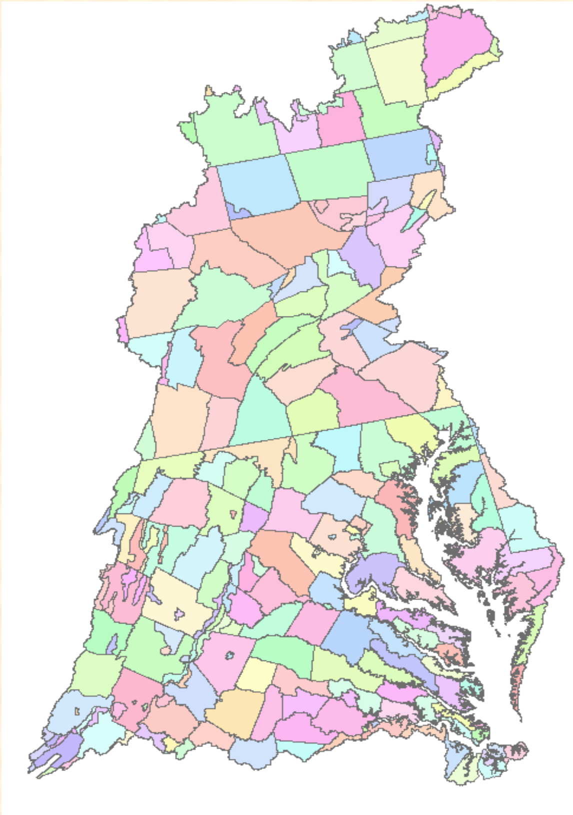
Keeping Score for 2025

In the Watershed

Increased
Precipitation Volume
= Hypoxia ⇧

Increased
Precipitation Intensity
= Hypoxia ⇧

Increase in Temp and
Evapotranspiration
= Hypoxia ⇩



In the Estuary

Increased WS Loads
= Hypoxia ⇧

Increased WS Flows
= Hypoxia ⇩

Increased
Temperature
= Hypoxia ⇧

Sea Level Rise
= Hypoxia ⇩

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

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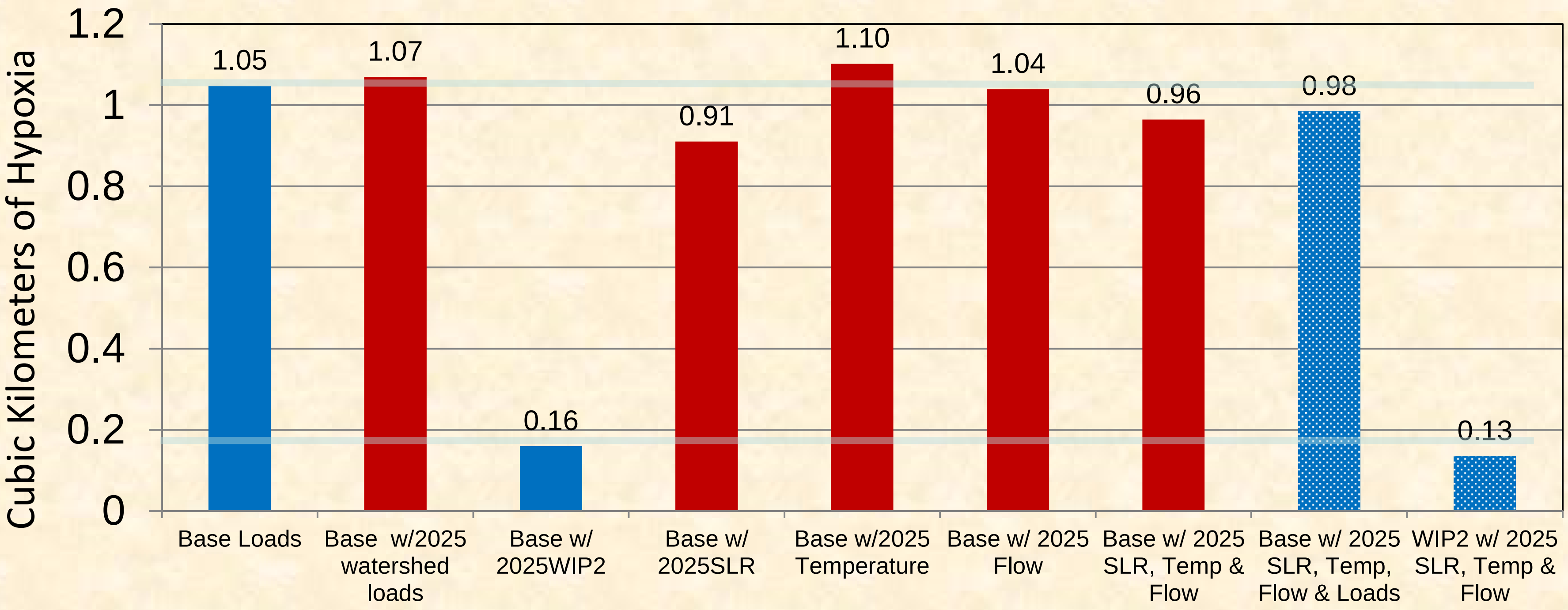

DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

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

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

Findings from the Watershed

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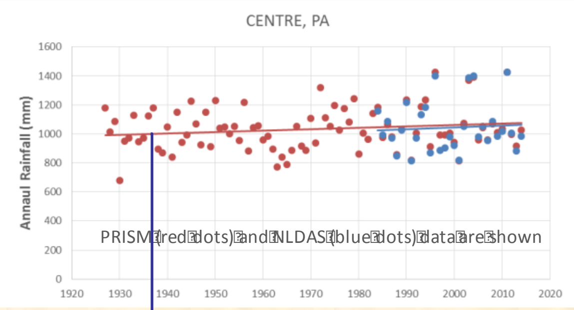
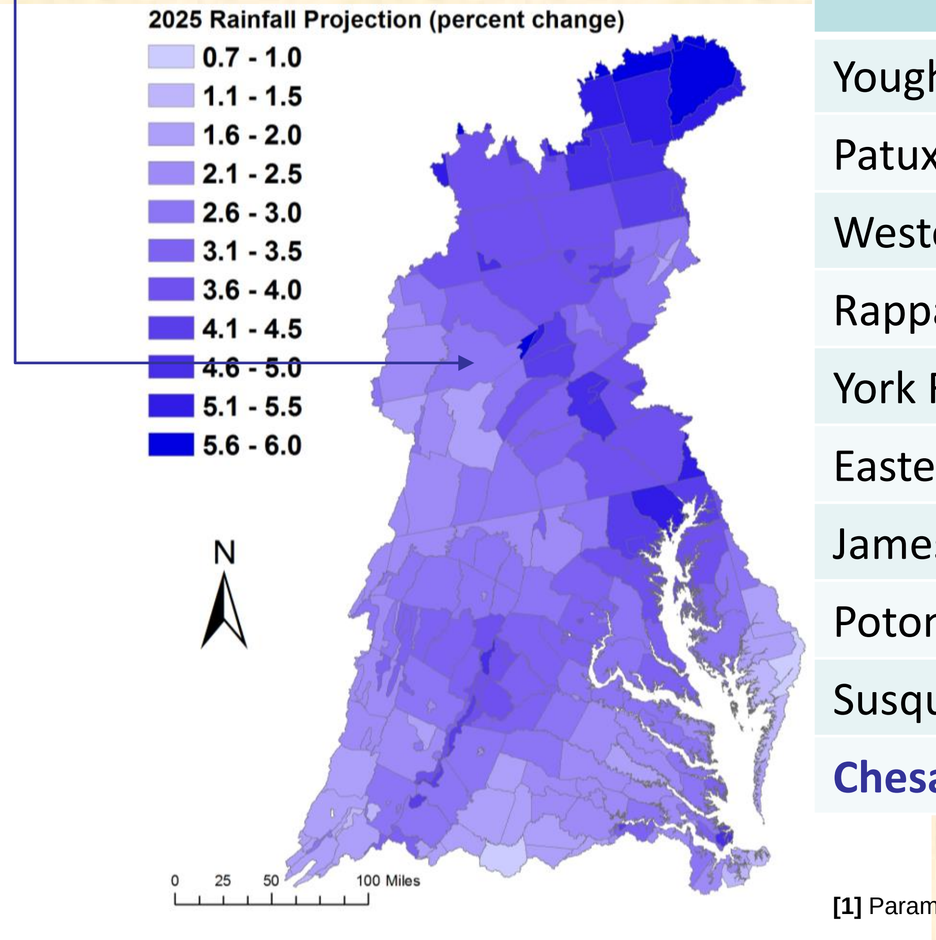
Assessment of Influence of 2025 Climate Change on Tidal Water Quality Standards

- The Draft Phase 6 Watershed Model was used to estimate the changes in delivery of flow, nutrients and sediment with the 2025 projections of rainfall and temperature.
- For the 2025 rainfall projections STAC has recommended the use of extrapolations based on long term observations.
- For the changes in temperature an ensemble analysis of CMIP5 projections was recommended.
- Three separate peer reviews on different aspects of the CBP climate change assessment http://www.chesapeakebay.net/who/group/modeling_team

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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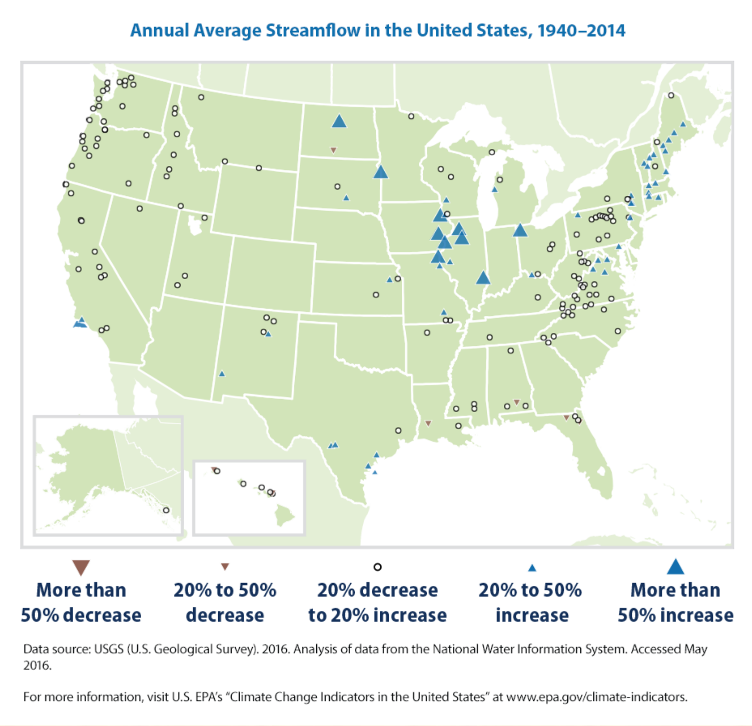
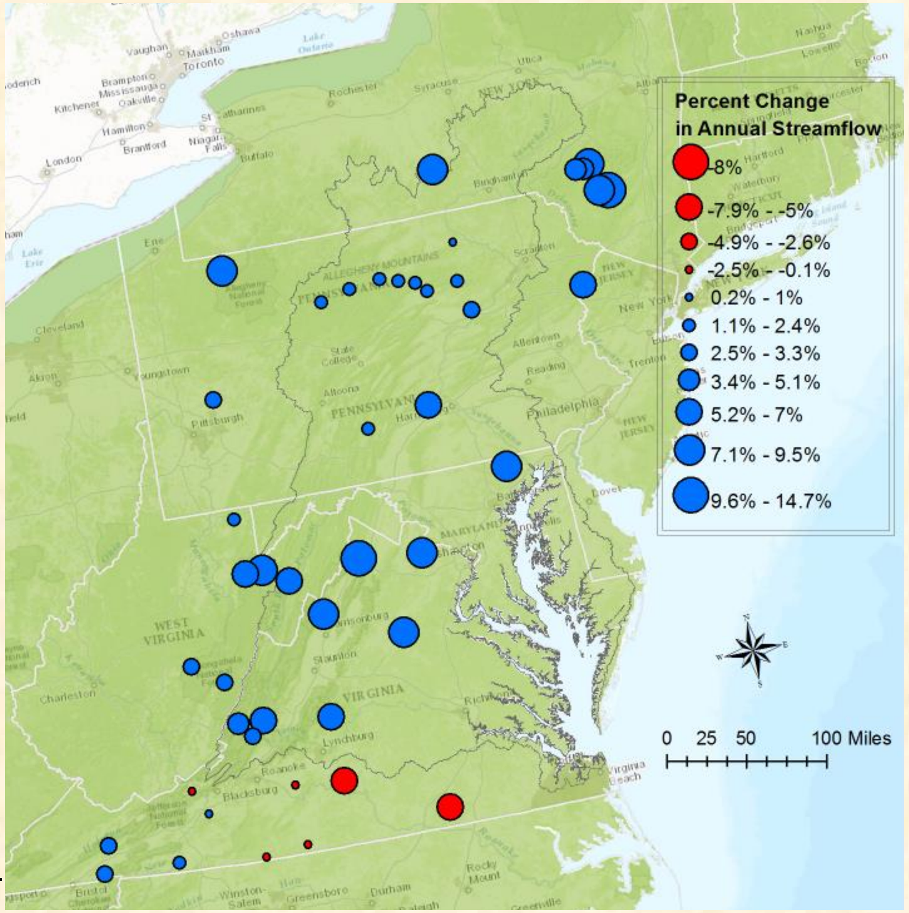
1940-2014 streamflow trends based on observations

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.

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.

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

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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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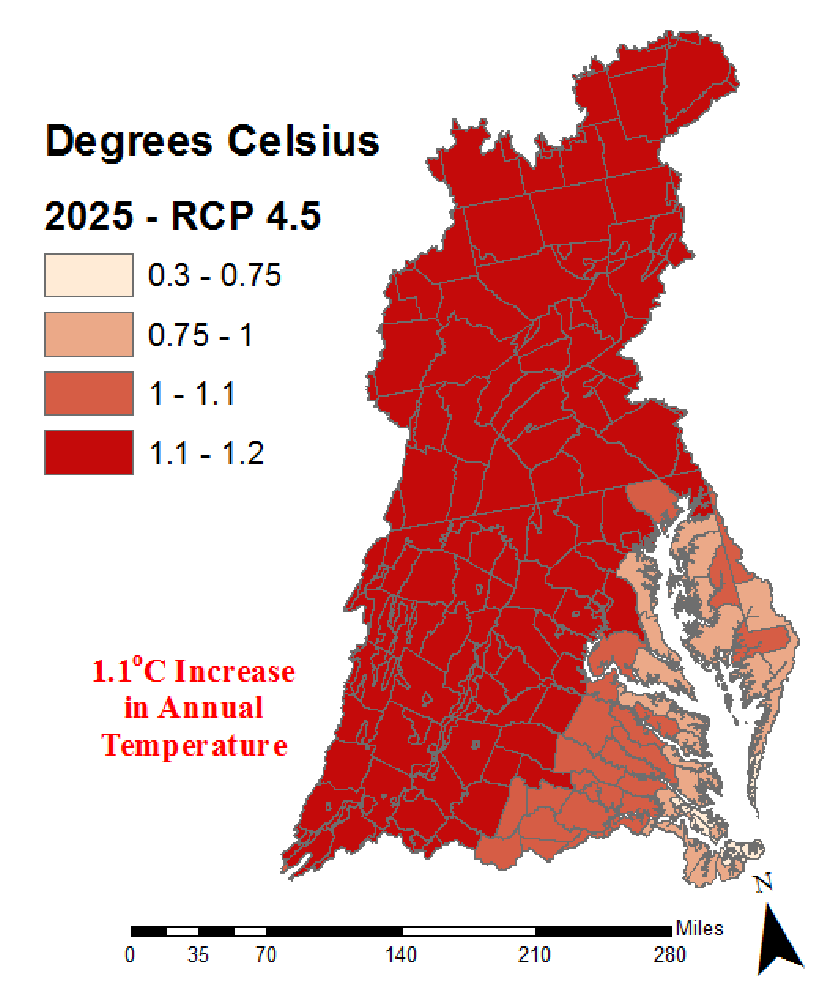
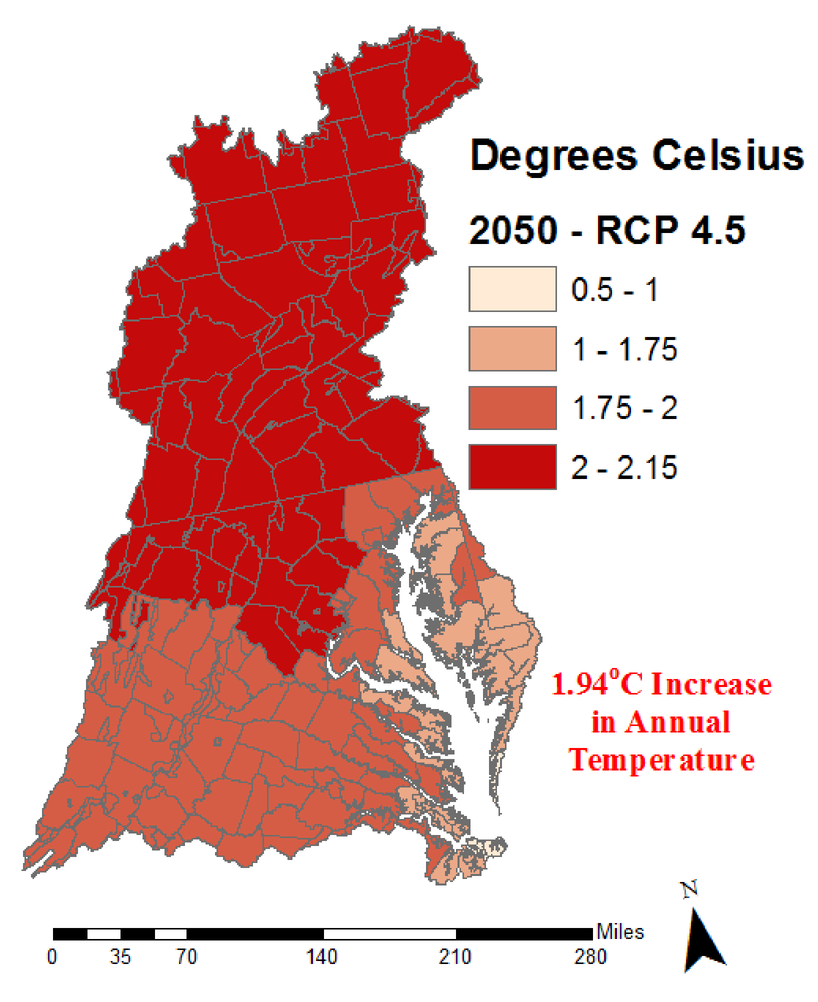
Chesapeake Bay Watershed Annual Change in Temperature





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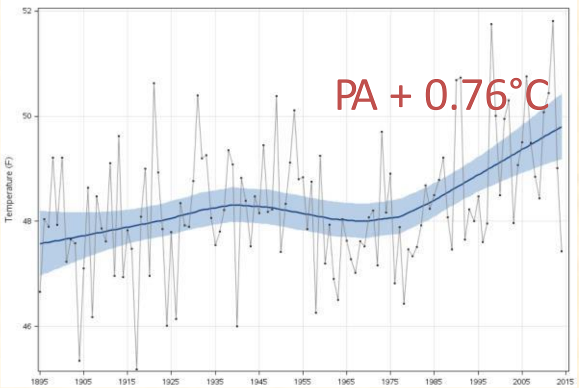
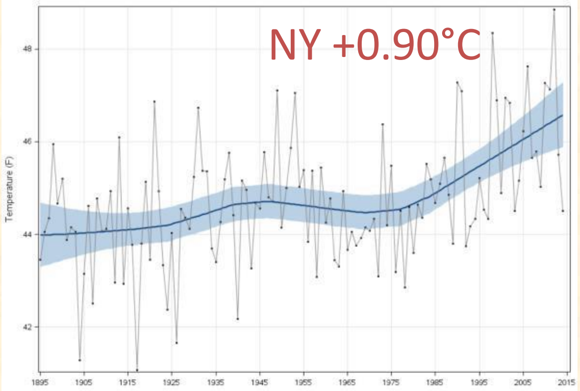
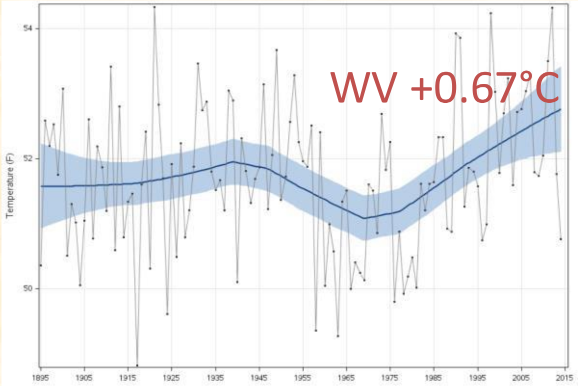
Temperature trends for the six CBP states

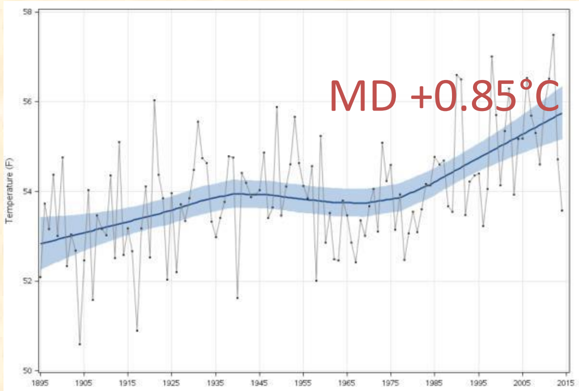
Annual temperature for 1895 to 2015 are shown.

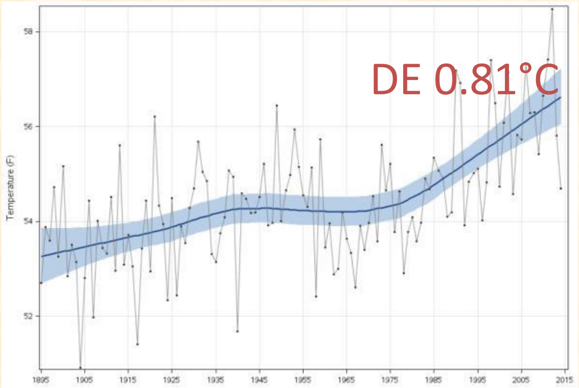
Annual Temperature
Trend Line
95% Confidence Limits

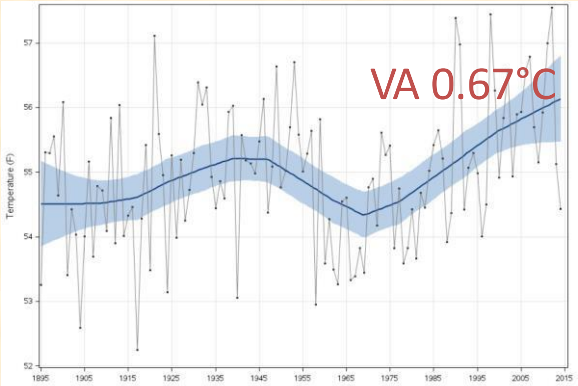








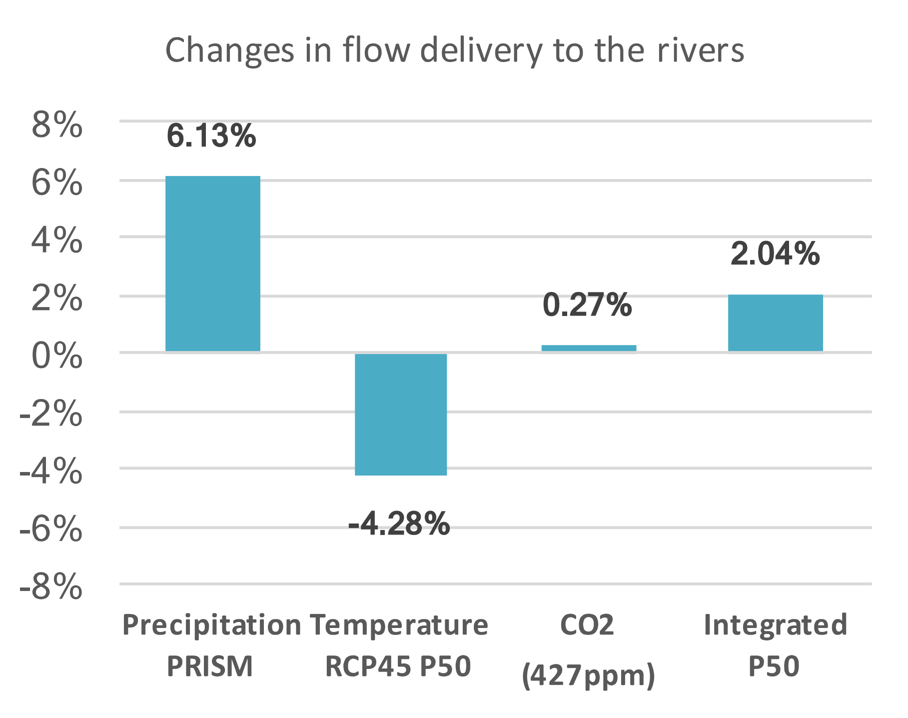


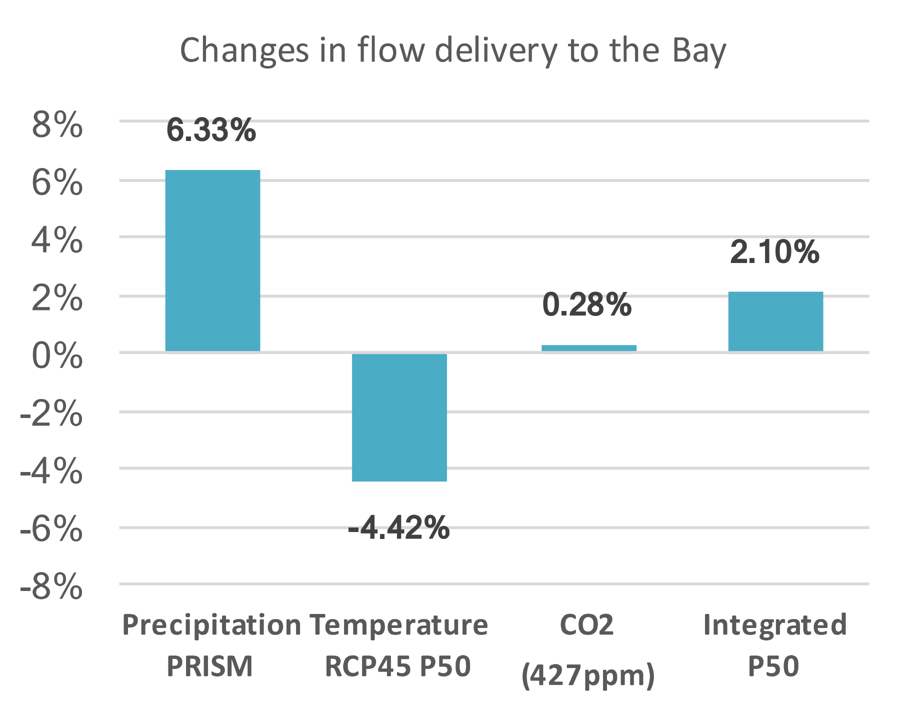


Approx. increases over the last 30 years based on the trend line are shown.

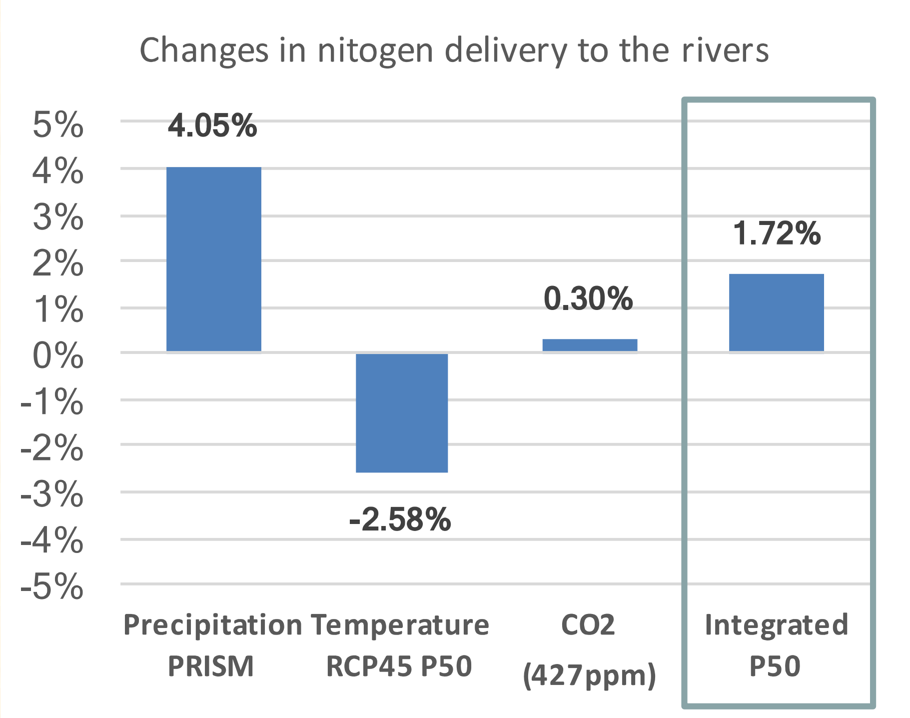
NOAA National Climatic Data Center
https://www.ncdc.noaa.gov/temp-and-precip/state-temps/

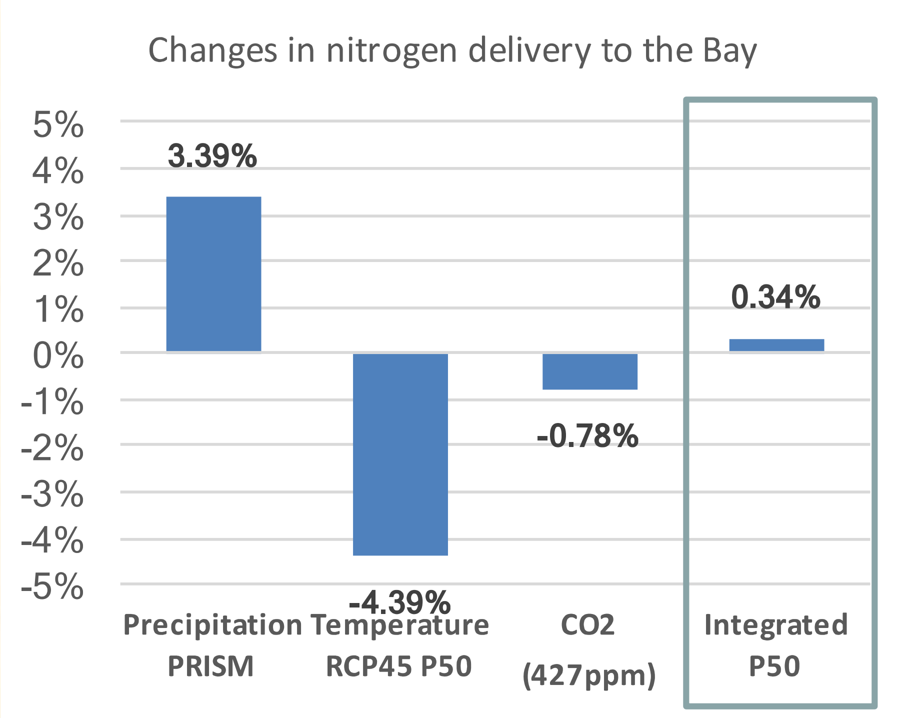
Model results: *flow to rivers and the Bay*



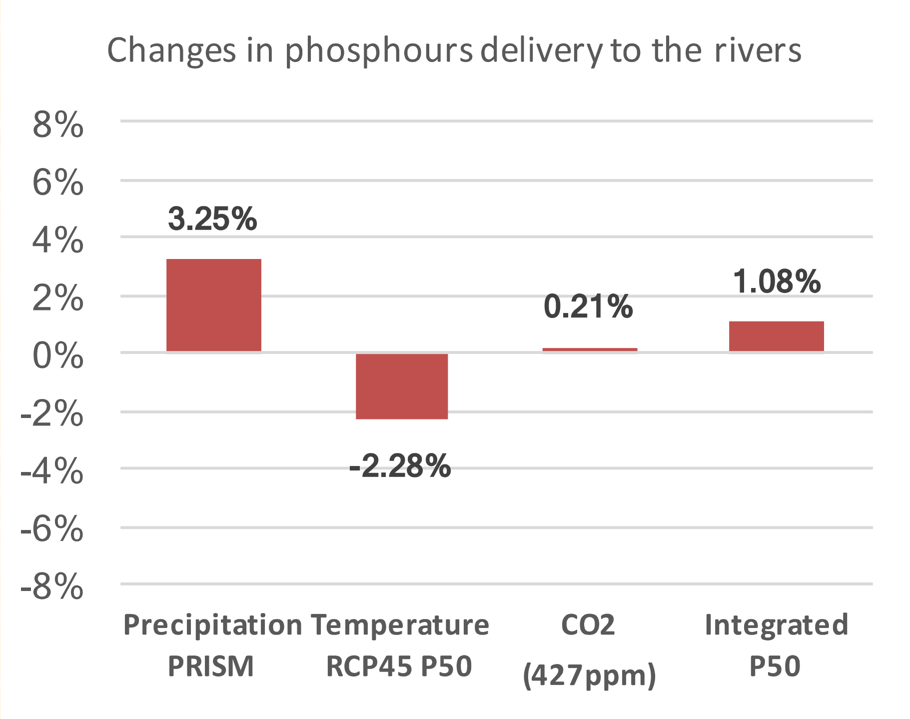


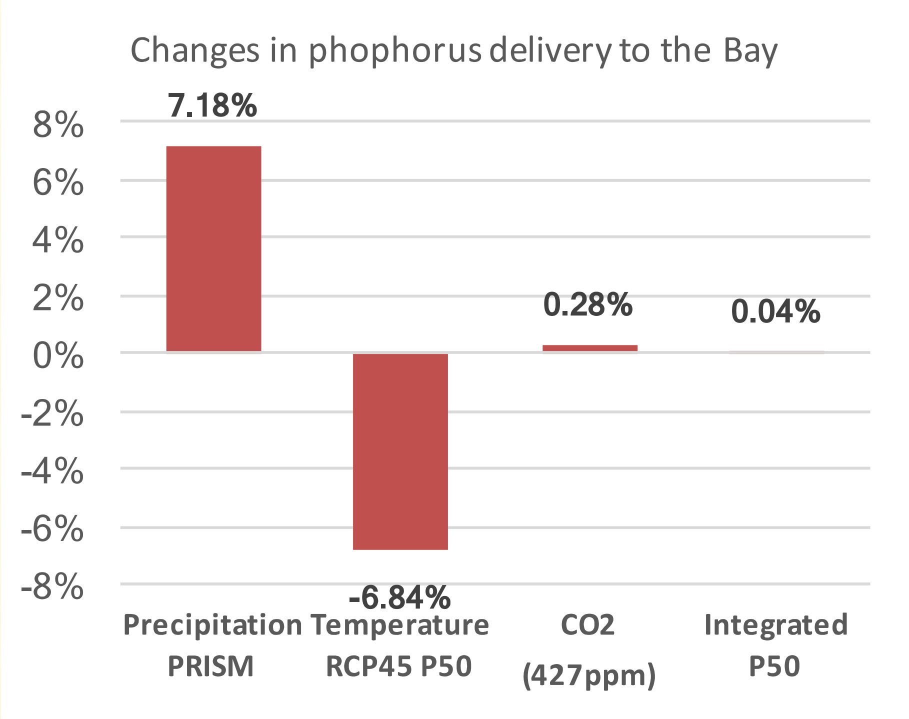
Model results: *nitrogen to rivers and the Bay*



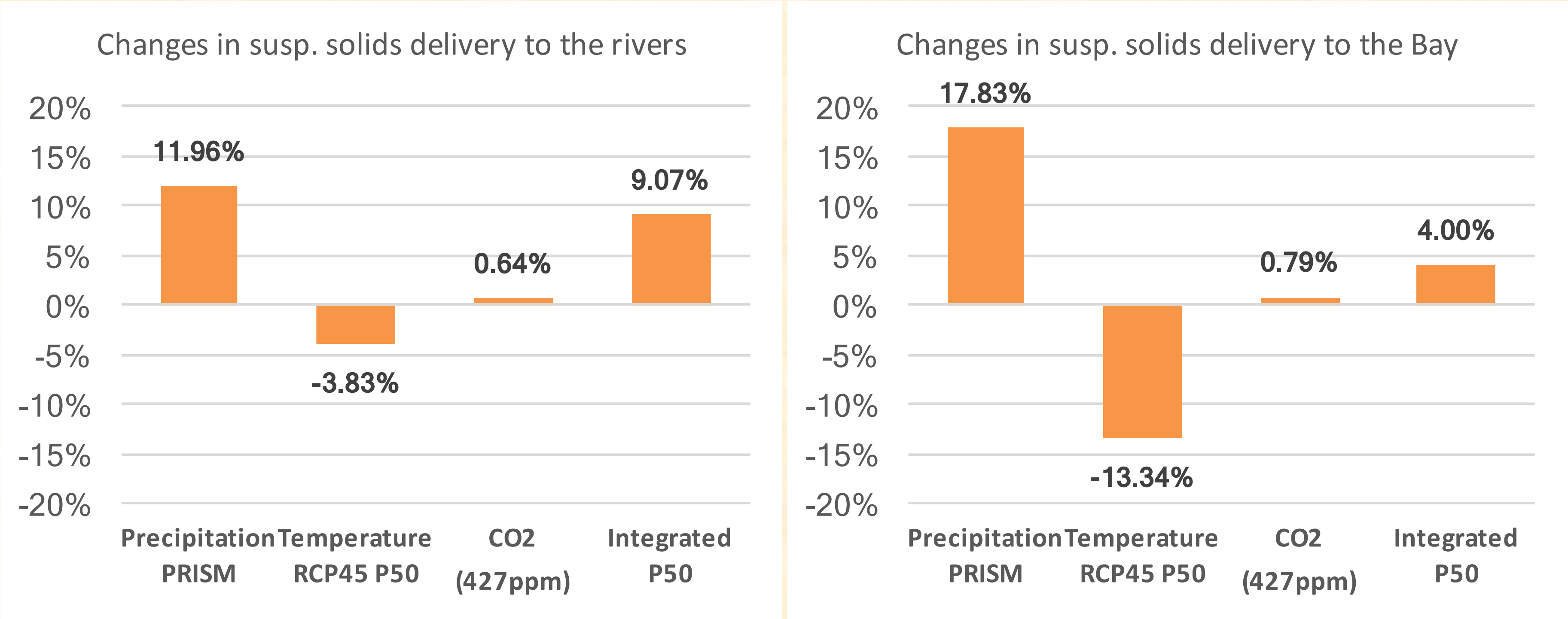


Model results: *phosphorus to rivers and the Bay*





Model results: *suspended solids to rivers and the Bay*



Findings from the Tidal Bay

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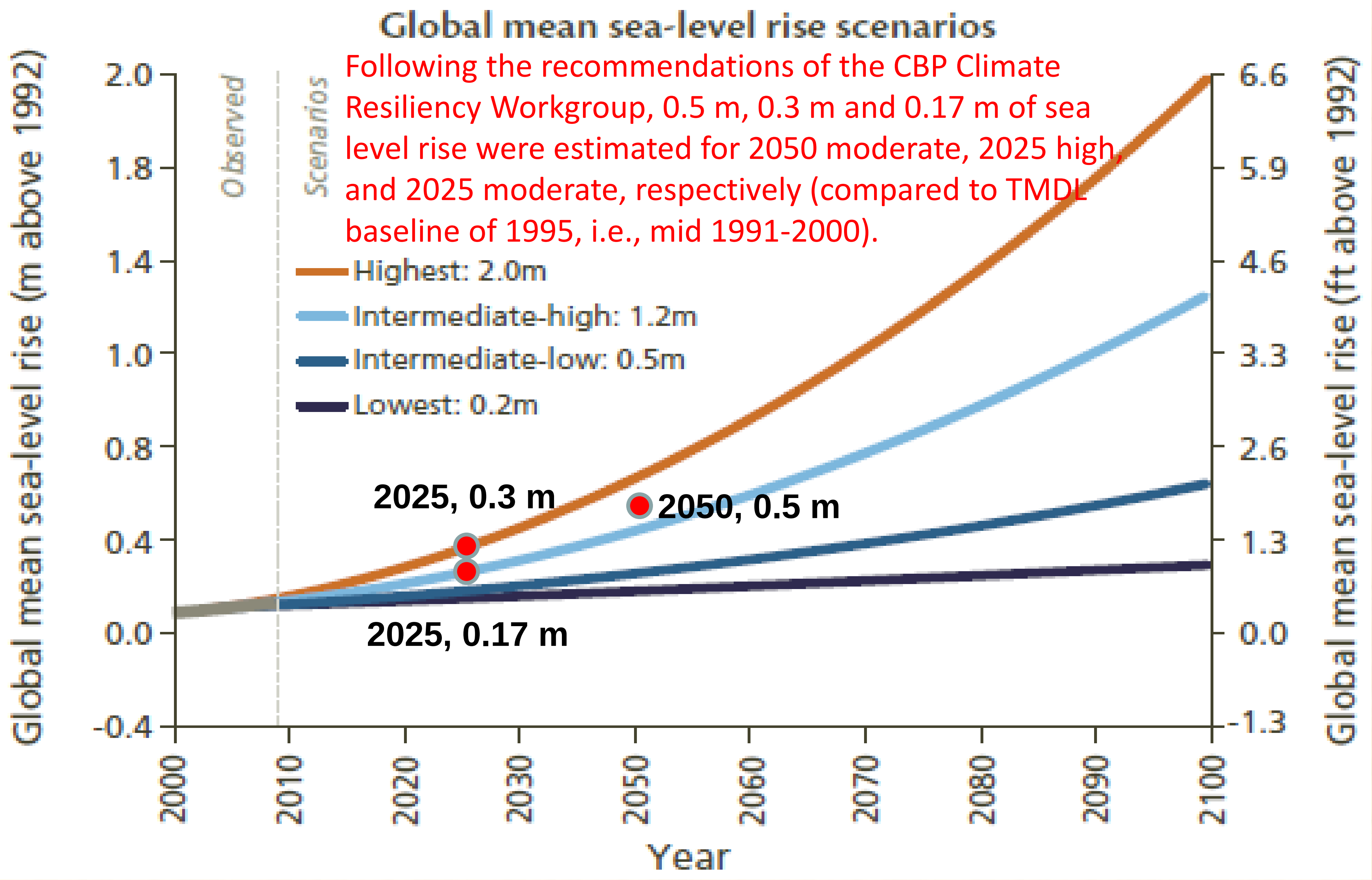
Overview:

Review the sensitivity scenarios of estuarine circulation with estimated 2050 sea level rise (SLR). The sensitivity scenarios used the 1993-1995 WQSTM simulation period to compare scenarios of 1) Base Case w/ out SLR or boundary salinity increase, 2) SLR only w/out salinity boundary increase, and 3) SLR w/ salinity boundary increase. In the case of both (2) and (3) there is an expectation from theory of an increase in gravitational circulation.

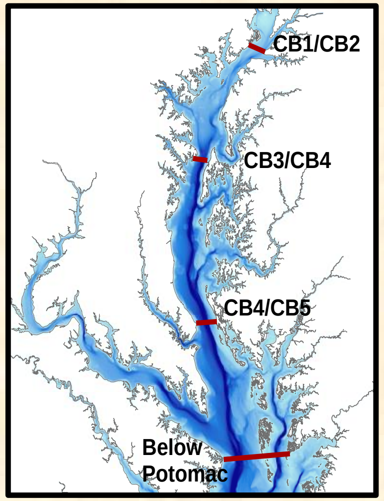


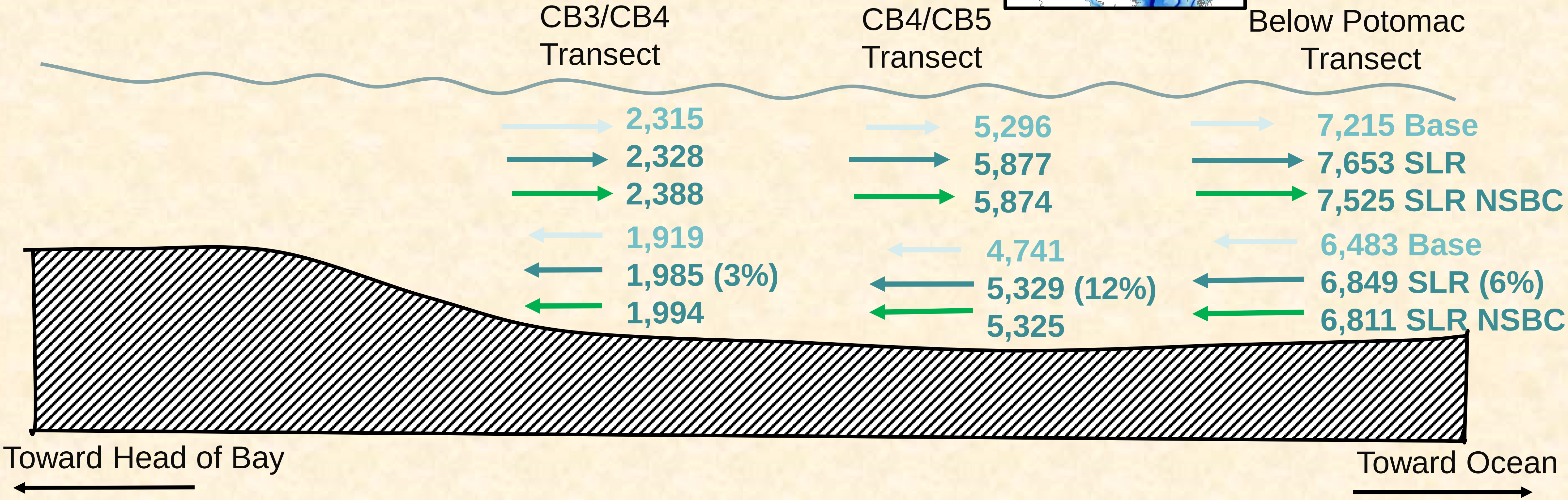
From Parris, A. et al. (2012). *Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Technical Report OAR CPO-1. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.*

From the Literature: Expectations of the Chesapeake Bay Response to Sea Level Rise:

- Increased salinity in Bay
- Increased up-estuary salt intrusion
- Increased vertical mixing (increased tidal currents)
- Changes in stratification
- Increased gravitational circulation
- Increased salinity at ocean boundary

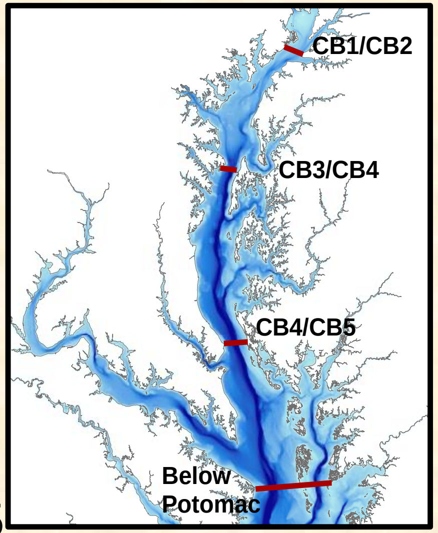
Cross-transect water fluxes (m^3/s) Base case versus sea level rise (SLR) of 0.5m. Summer 1993-1995

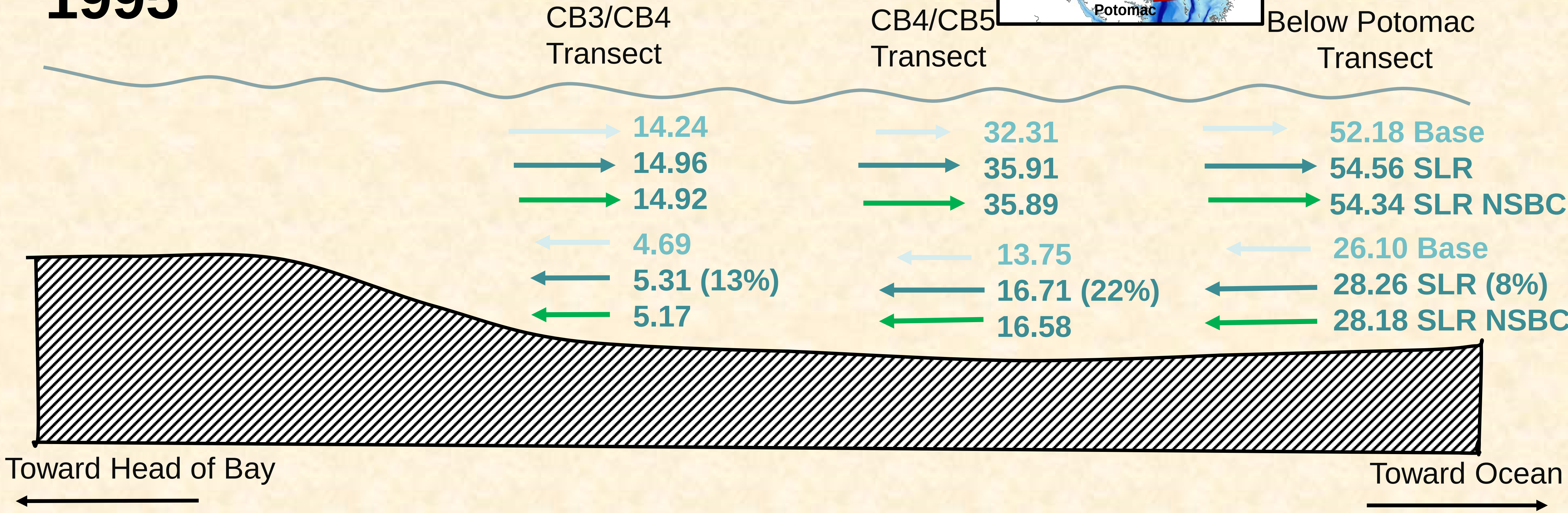




Base = Beta 4 WQSTM, SLR = 0.5m representing relative Chesapeake sea level rise from 1995 to 2050.
Units in mean m^3/s for summer (Jun-Sept) 1993 to 1995; NSBC: No Salt Boundary Change.

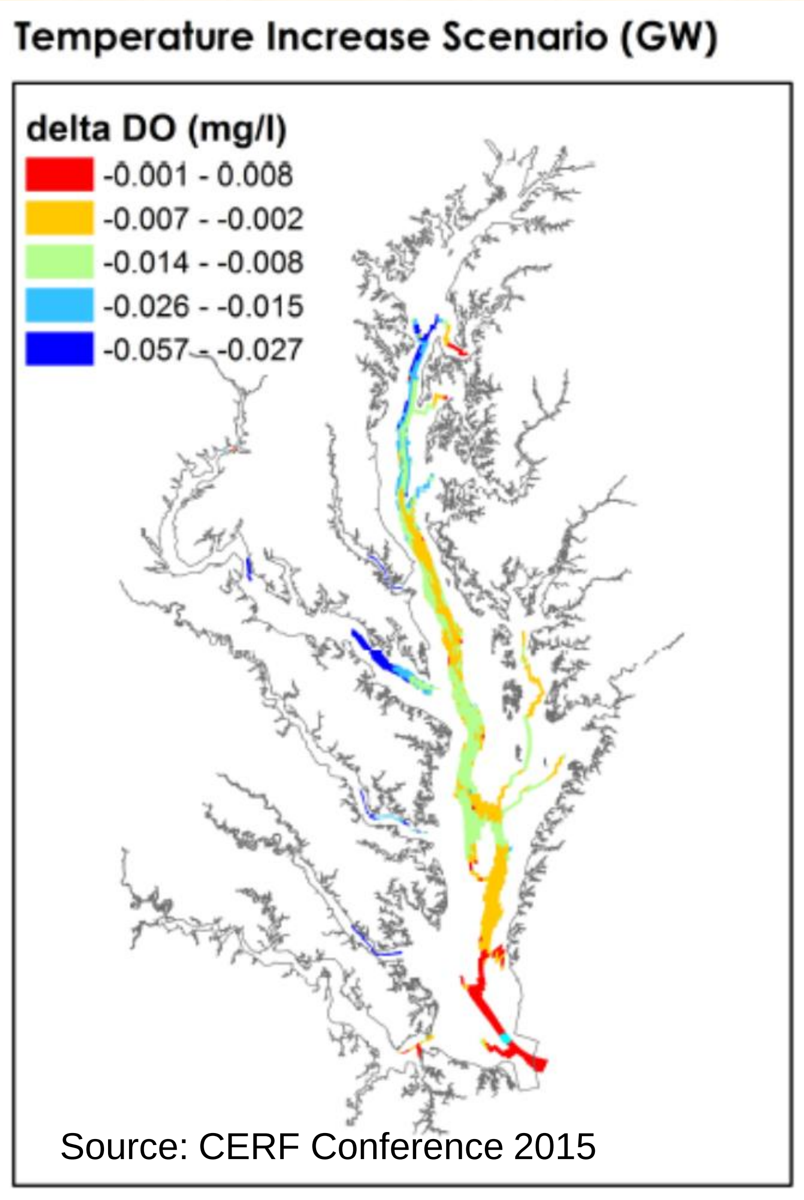
Cross-transect DO fluxes (kg/s) Base case versus sea level rise (SLR) of 0.5m. Summer 1993 - 1995





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

Influence of Estimated 2050 Estuarine Temperature Increases on Bottom Dissolved Oxygen



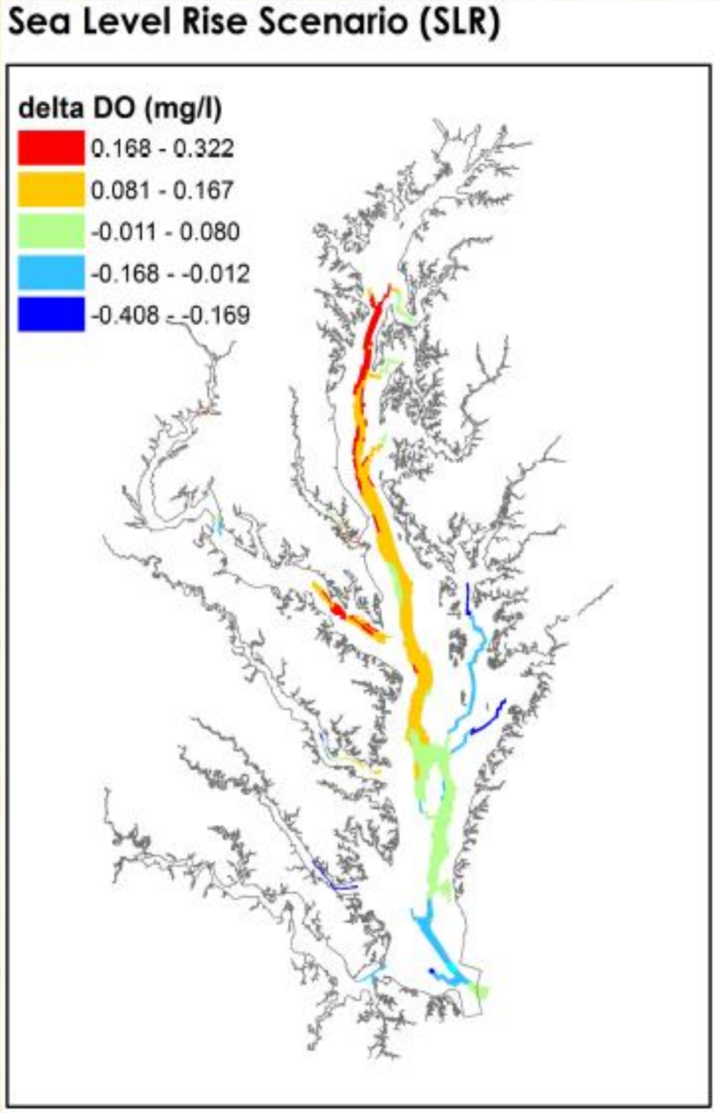
The influence of an 2050 estimated temperature increase on Chesapeake hypoxia is small.

But we can measure in infinitesimal with our models. The estimated increase in Chesapeake hypoxia due to 2050 estimated temperature increases ranges from 0.008 to - 0.06 mg/l.

Hypoxia increases are due to the increase in vertical stratification due to the increased thermocline, reduced oxygen saturation levels, and increased respiration.

By extension, estimated 2025 temperature increases will also have a slight negative influence on water quality standard achievement.

Influence of Estimated 2050 Sea Level Rise (0.5 m) on Bottom Dissolved Oxygen



Source: CERF Conference 2015

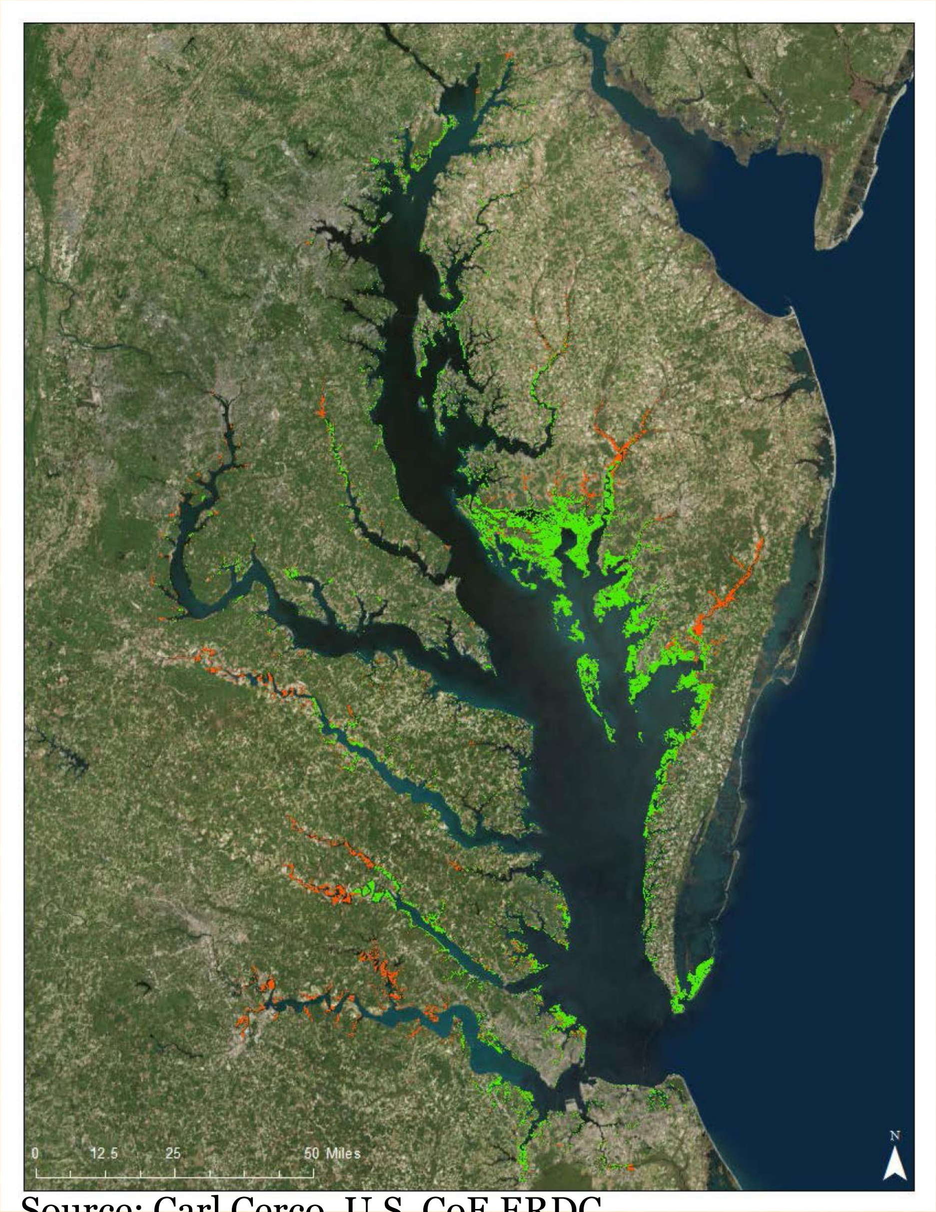
The influence of an 2050 estimated sea level rise on Chesapeake hypoxia is also relatively small.

The estimated change from the base (1991 to 2000) condition in Chesapeake hypoxia due to 2050 estimated sea level rise conditions ranges from 0.3 mg/l to -0.4 mg/l.

Hypoxia decreases in the mid-Bay are due to increased ventilation of deep Chesapeake waters by well oxygenated ocean waters and also because of changes in vertical stratification.

By extension, estimated 2025 (0.3 m or 0.17 m) sea level rise increases will also have slight influence on water quality standard achievement.

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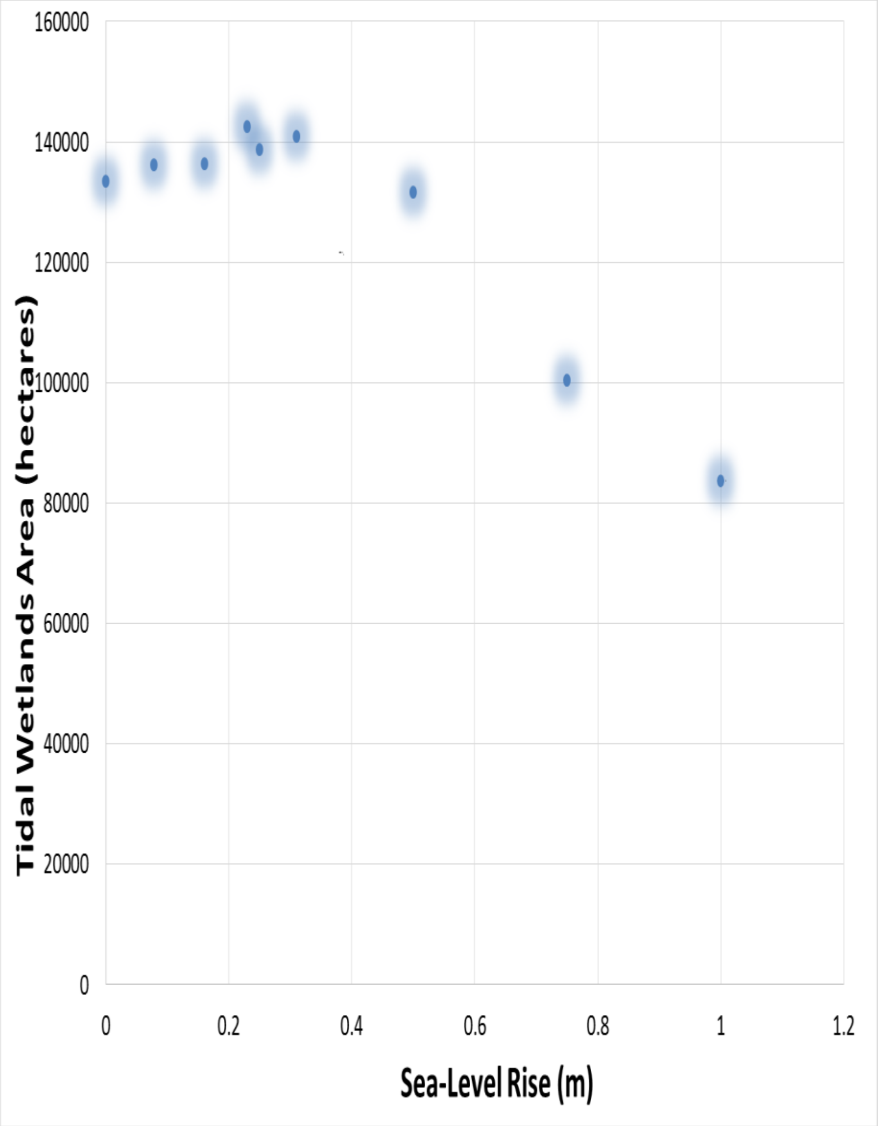
Influence of Estimated 2025 (0.3 m) and 2050 (0.5m) Sea Level Rise on Tidal Wetland Attenuation



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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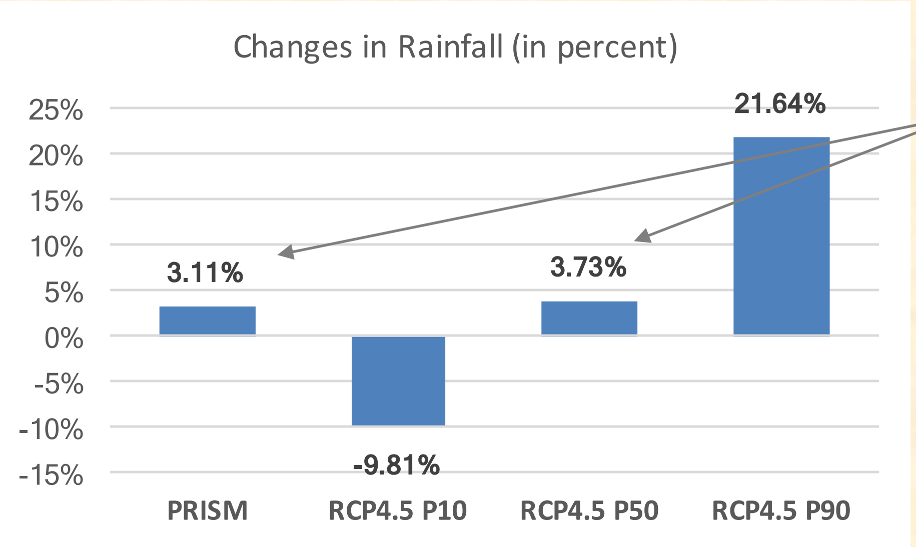
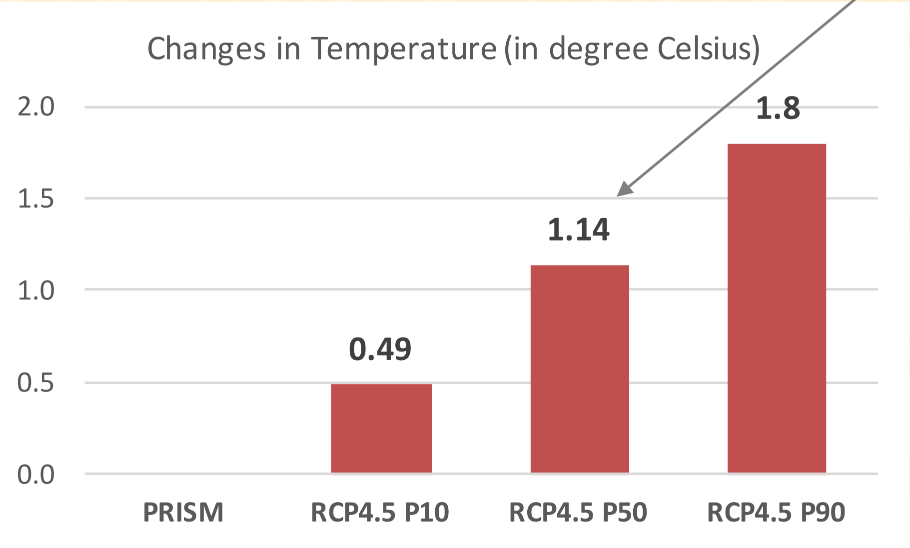
2025 Projections for Chesapeake Bay Watershed

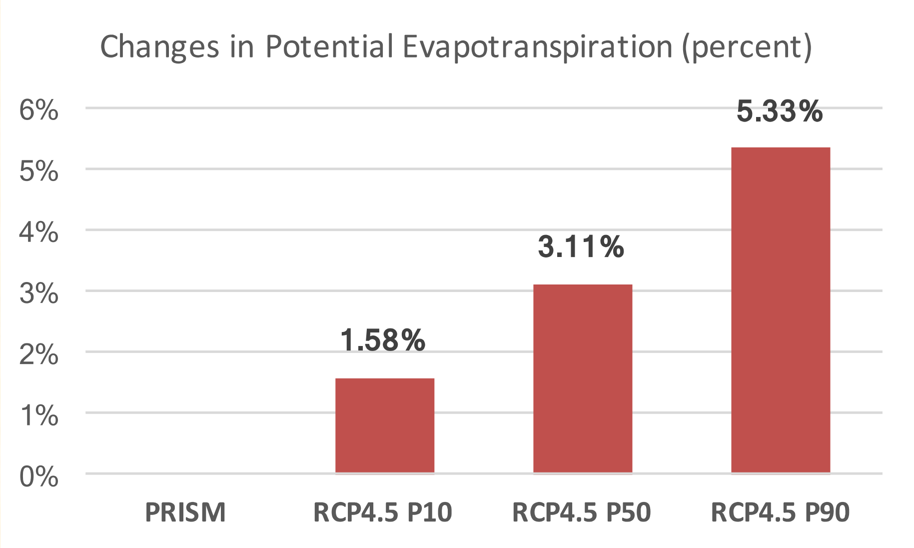


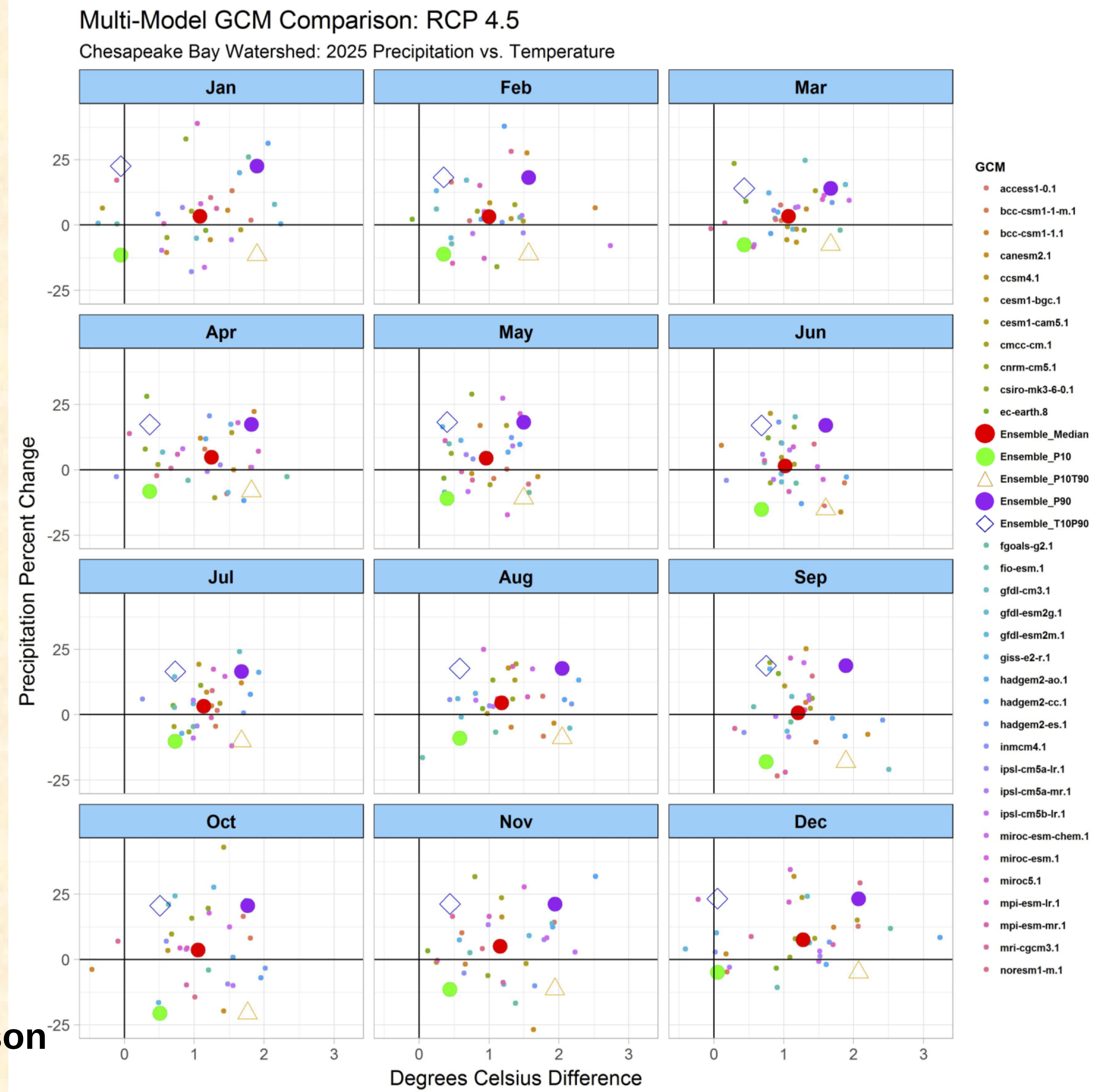
The central tendency of rainfall volume increase projections based on the 31 member ensemble median, P50, matches well with the extrapolation of PRISM's 88-year trends.

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.

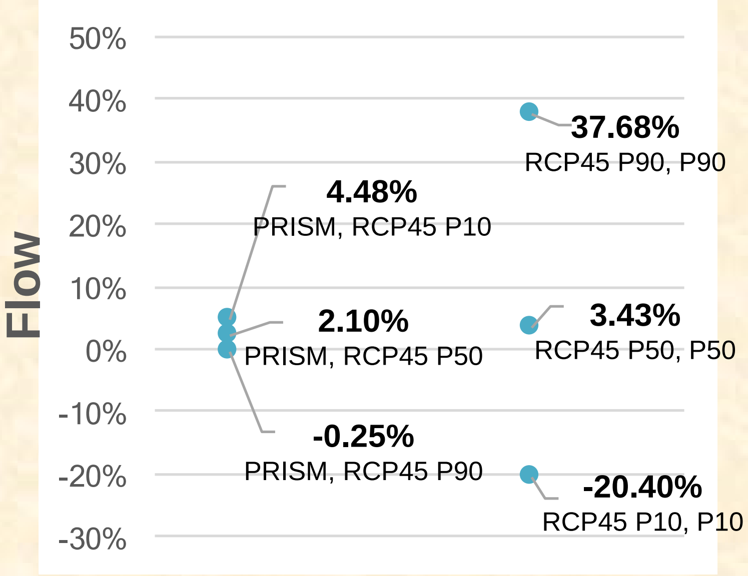


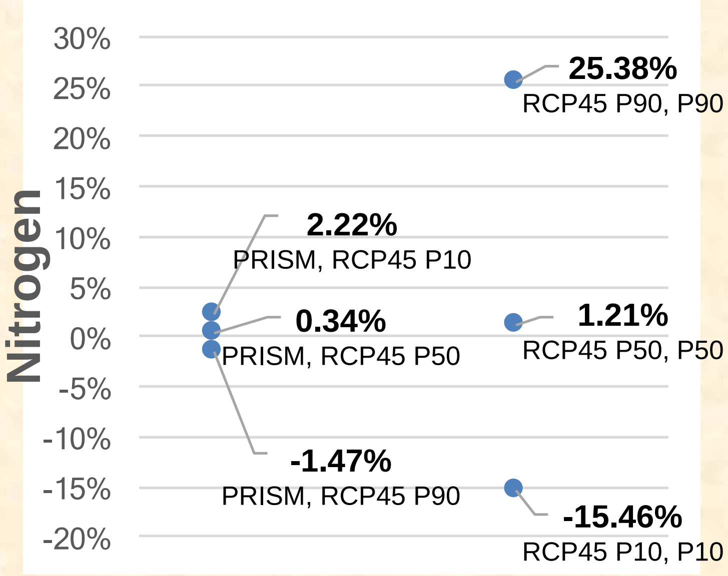


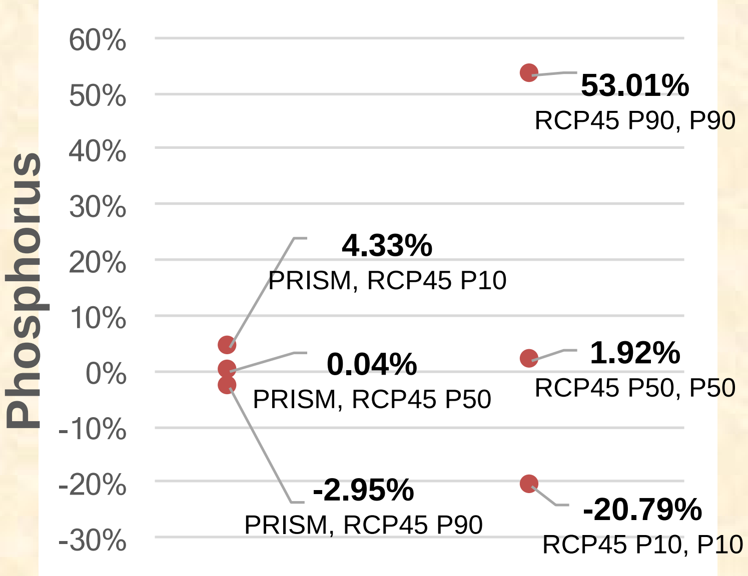

Multi-Model GCM Comparison: RCP 4.5
Chesapeake Bay Watershed: 2025 Precipitation vs. Temperature
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Precipitation Percent Change
Degrees Celsius Difference
25
0
-25
0
1
2
3
GCM
access1-0.1
bcc-csm1-1-m.1
bcc-csm1-1.1
canesm2.1
ccsm4.1
cesm1-bgc.1
cesm1-cam5.1
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
ipsl-cm5a-lr.1
ipsl-cm5a-mr.1
ipsl-cm5b-lr.1
miroc-esm-chem.1
miroc-esm.1
miroc5.1
mpi-esm-lr.1
mpi-esm-mr.1
mri-cgcm3.1
noresm1-m.1

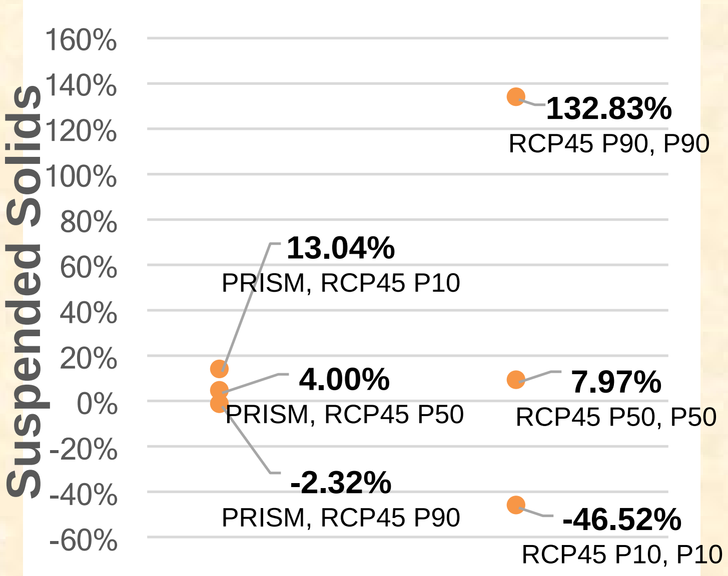
Kyle Hinson

Uncertainty quantification









Conclusions:

- The CBP has the capacity to quantify estimates of a 30 year (1995 to 2025) climate change at the county (land segment) level of resolution based on trends of long term observations.
- Despite increases in precipitation volume and intensity the nutrient load increase from the watershed is slight (< 1%) because of increased evapotranspiration.
- The 2025 estimated increase in sediment load is 4%.

Conclusions:

- Sea level rise (SLR) is estimated to be a major influence in increased gravitational circulation in the Chesapeake.
- Increased salinity at the ocean boundary condition also increases gravitational circulation in the Chesapeake.