Chesapeake Bay Program Partnership's Climate Change Assessment Framework and Programmatic Integration and Response Efforts

STAC Peer Review – Webinar
August 8, 2017

Chesapeake Bay Program
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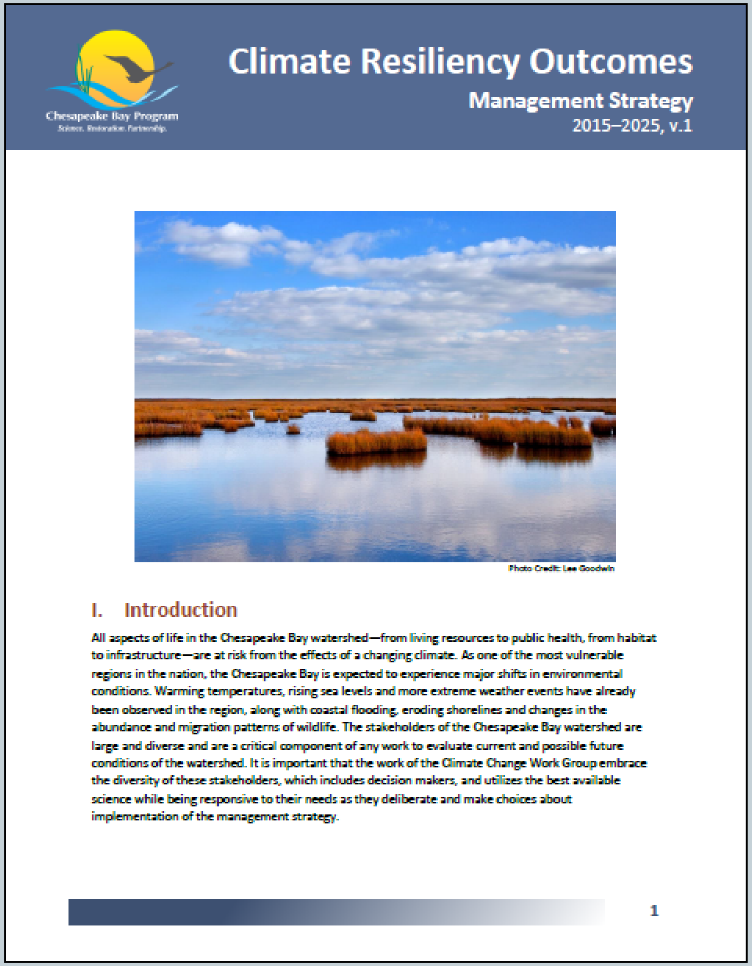
Setting the Stage: Climate Change in the Chesapeake Bay Program Partnership

Zoë Johnson
National Oceanic and Atmospheric Administration
CBP Climate Change Coordinator

Key Partnership Climate Change-Related Commitments and Recommendations

- *2010 Chesapeake Bay TMDL*
- *2010 Executive Order 13058: Strategy for Protecting and Restoring the Chesapeake Bay Watershed*
- *2014 Chesapeake Bay Watershed Agreement*



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Climate Resiliency Outcomes

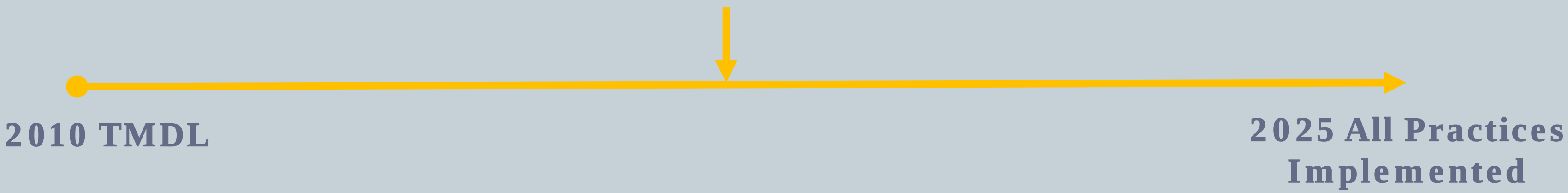
Management Strategy
2015–2025, v.1

Photo Credit: Lee Goodwin

I. Introduction

All aspects of life in the Chesapeake Bay watershed—from living resources to public health, from habitat to infrastructure—are at risk from the effects of a changing climate. As one of the most vulnerable regions in the nation, the Chesapeake Bay is expected to experience major shifts in environmental conditions. Warming temperatures, rising sea levels and more extreme weather events have already been observed in the region, along with coastal flooding, eroding shorelines and changes in the abundance and migration patterns of wildlife. The stakeholders of the Chesapeake Bay watershed are large and diverse and are a critical component of any work to evaluate current and possible future conditions of the watershed. It is important that the work of the Climate Change Work Group embrace the diversity of these stakeholders, which includes decision makers, and utilizes the best available science while being responsive to their needs as they deliberate and make choices about implementation of the management strategy.

Chesapeake Bay TMDL: 2017 Mid-Point Assessment



Goal: Determine whether the implementation the CBP Partnership’s restoration strategies by 2025 will achieve water quality standards in the Bay.

Objective: Make this determination based on the best available science data, tools, Best Management Practices (BMPs), and lessons-learned.

Commitment: Conduct a more complete analysis of climate effects on nitrogen, phosphorus, and sediment loads and allocations in time for the mid-course assessment of Chesapeake Bay TMDL progress in 2017.

2014 Chesapeake Bay Agreement

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CLIMATE RESILIENCY

GOAL: Increase the resiliency of the Chesapeake Bay watershed, including its living resources, habitats, public infrastructure and communities, to withstand adverse impacts from changing environmental and climate conditions.

- **Monitoring and Assessment Outcome:** Continually monitor and assess the trends and likely impacts of changing climatic and sea level conditions on the Chesapeake Bay ecosystem, including the effectiveness of restoration and protection policies, programs and projects.

- **Adaptation Outcome:** Continually pursue, design and construct restoration and protection projects to enhance the resiliency of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms and sea level rise.

Climate Change & the TMDL Mid-Point Assessment

Assessment Procedures (approved)

Assess how climate change may affect current water quality standards (i.e., nutrient and sediment source loads over time and attainment)

- Precipitation change (increased volume and intensity)
- Temperature increase (air and water)
- Sea level rise (hydrodynamics and impacts to beneficial resources (i.e., wetlands)

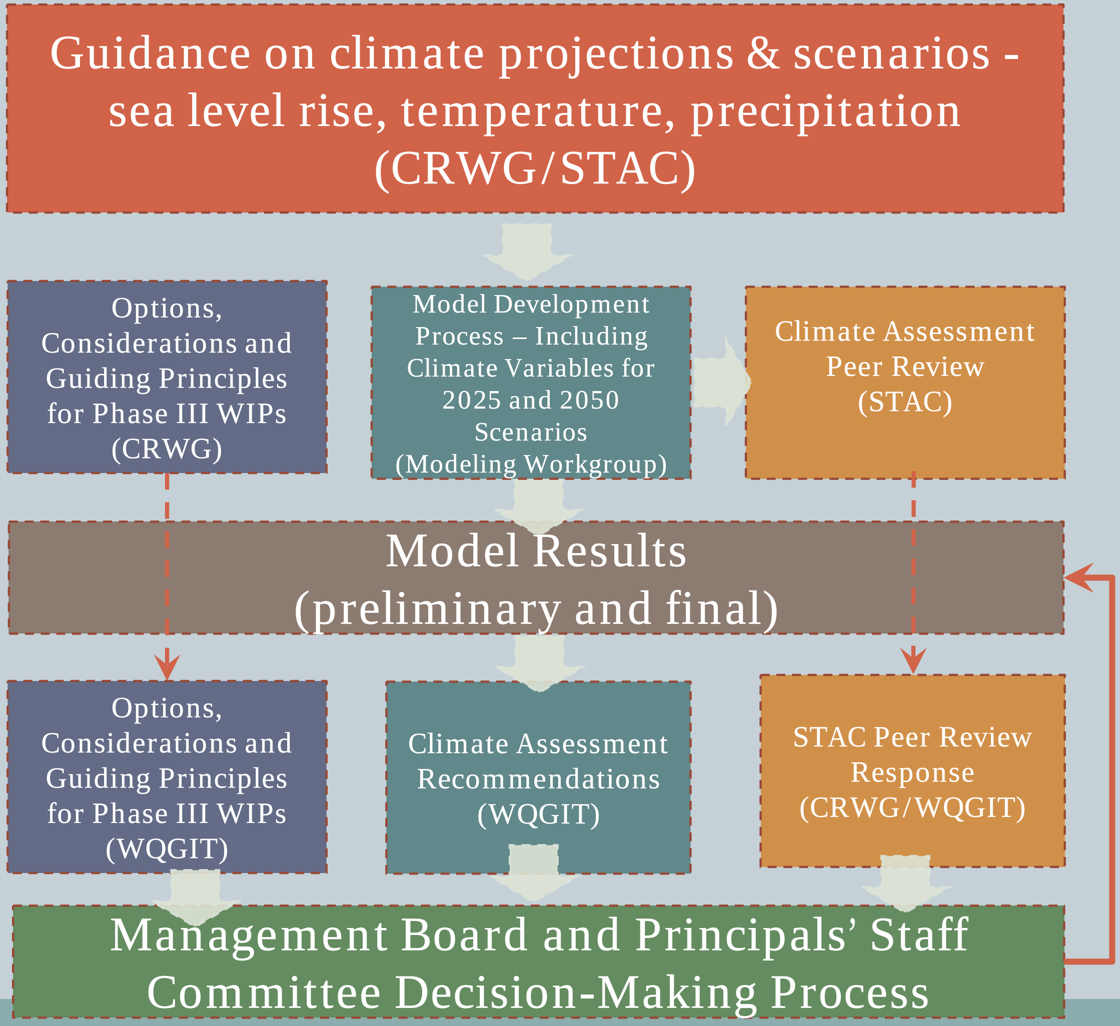
Guiding Principles (approved)

- WIP Development
  - Capitalize on Co-Benefits
  - Reduce vulnerability
- WIP Implementation
  - Monitor performance
  - Adaptability

Policy Options (under consideration)

- Quantitative
  - Factor climate change impacts into Phase III WIP Base Conditions
- Qualitative
  - Optimize WIP Development and Adaptively Manage BMP Implementation

Decision-Making Process



Section I

Guidance on climate projections & scenarios - sea level rise, temperature, precipitation

Zoë Johnson
National Oceanic and Atmospheric Administration
CBP Climate Change Coordinator

The Development of Climate Projections for Use in Chesapeake Bay Program Assessments

Scientific and Technical Advisory Committee (STAC) Workshop

March 7-8 2016

STAC Workshop Goals

1. What climate change variables are of most concern to the CBP partners in the consideration of the 2017 Midpoint Assessment decisions and for longer term climate change management decisions?

2. What are the approaches that can be taken to select climate change scenarios for CBP assessments?

3. What characteristics of those climate variables need to be specified, e.g., temporal, spatial, and other relevant characteristics? In what format are scenarios needed to provide the most utility at the regional, state, and local levels?

4. What climate change scenarios meet CBP decision making needs for the 2017 Midpoint Assessment as well as for longer term climate change management decisions and programmatic assessments?

Workshop Recommendations

- The Partnership should seek agreement on the use of consistent climate scenarios for regional projections of Chesapeake Bay condition and the benefits of an integrated source of climate change projection simulation data that all seven jurisdictions could draw from.
- For the 2017 Midpoint Assessment, use historical (~100 years) trends to project precipitation to 2025 as opposed to utilizing an ensemble of future projections from GCMs. Shorter term climate change projections using GCMs have large uncertainties because climate models are structured to look further out and at much larger scales.
- The Program should carefully consider the representation of evapotranspiration in watershed model calibration and scenarios because the calculation method for evapotranspiration has a strong influence on the strength and direction of future water balance change.
- Looking forward, the 2050 timeframe is more appropriate for selecting and incorporating a suite of global climate scenarios and simulations to provide long-term projections for the management community, and an ongoing adaptive process to incorporate climate change into decision-making as implementation moves forward.

Workshop Recommendations

- Beyond the 2017 Midpoint Assessment, it is recommended that the CBP use 2050 projections for best management practice (BMP) design, efficiencies, effectiveness, selection, and performance – given that many of the BMPs implemented now could be in the ground beyond 2050.
- For any 2050 assessment, use an ensemble or multiple global climate model approach, selecting model outputs that bound the range of key climate variables (e.g., temperature, precipitation) for the Chesapeake Bay region. Use multiple scenarios covering a range of projected emissions (RCP 4.5 and 8.5 are a reasonable range to select and are currently being utilized for Fourth National Climate Assessment). Include the 2 °C emissions reduction pathway (RCP 2.6) as well as more "business as usual" assumptions.
- Select an existing system to access GCM downscaled scenario data (such as 'LASSO' described in more detail in Section II) in lieu of conducting a tailored statistical climate downscaling process for the Chesapeake Bay watershed.

Chesapeake Bay TMDL 2017 Midpoint Assessment

Recommendations on Incorporating Climate-Related Data Inputs and Assessments: Selection of Sea Level Rise Scenarios and Tidal Marsh Change Models

Climate Resiliency Workgroup

August 5, 2016

Climate Resiliency Workgroup Recommendations - SLR

- The CRWG recommends that the CBP leadership consider the application of the plausible range of sea level rise projections for CBWQSTM modeling efforts, with upper and lower limits, for the years 2025 and 2050.

- In selecting the range of scenarios, the upper bound should be consistent with a higher emissions scenario (but not the extreme upper scenario). This would result in the upper bound corresponding with the 99.5% probability, plus 0.1m to account for interannual variability.

- The lower range value should be within the “likely” range, as presented by Dr. Kopp, consistent with a lower emission scenario (RCP 2.6), but not be the extreme lower scenario which depicts historical tide gauge trend.

- Based on the considerations above, the CRWG recommends that the following range of sea level rise projections for 2025 (.2 - .4 m) and 2050 (.3-.8 m) be applied in the CBWQSTM.

CRWG SLR Recommendations: Request for additional analysis

- CRWG Recommendations: Apply a plausible range of sea level rise projections for CBWQSTM modeling efforts, with upper and lower limits, for the years 2025 and 2050. Specifically, the CRWG recommended that the following range of sea level rise projections for 2025 (.2 - .4 m) and 2050 (.3-.8 m) be applied in the CBWQSTM.
- Preliminary modeling results were derived based on a 2025 SLR of .3 meters. Additional scenario runs have not been initiated.
- Given the sensitivity of the CBWQSTM to SLR and the conservative methodology to derive 2025 precipitation inputs (based on linear trends); the CRWG has been asked to provide additional guidance on the lower SLR bound.

Site	Background RSL rate (mm/yr)	Background 1995-2025 RSL Estimate (mm)	1995-2025 GMSL rate (mm/yr)	1995-2025 SLR Estimate (cm)
BALTIMORE	1.4	42.0	3.0	13.2
LEWES	1.7	51.9	3.0	14.2
ANNAPOLIS	1.7	49.8	3.0	14.0
WASHINGTON DC	1.4	40.5	3.0	13.1
PORTSMOUTH	2.3	68.4	3.0	15.8
SOLOMON'S ISLAND	1.9	57.0	3.0	14.7
GLOUCESTER POINT	2.0	61.2	3.0	15.1
KIPTOPEKE BEACH	1.8	53.1	3.0	14.3
CAMBRIDGE II	1.7	52.2	3.0	14.2
CHESAPEAKE BAY BR. TUN.	2.2	67.2	3.0	15.7
SEWELLS POINT	2.5	74.4	3.0	16.4

2025 Estimates of Total Sea Level Rise in the Chesapeake Bay

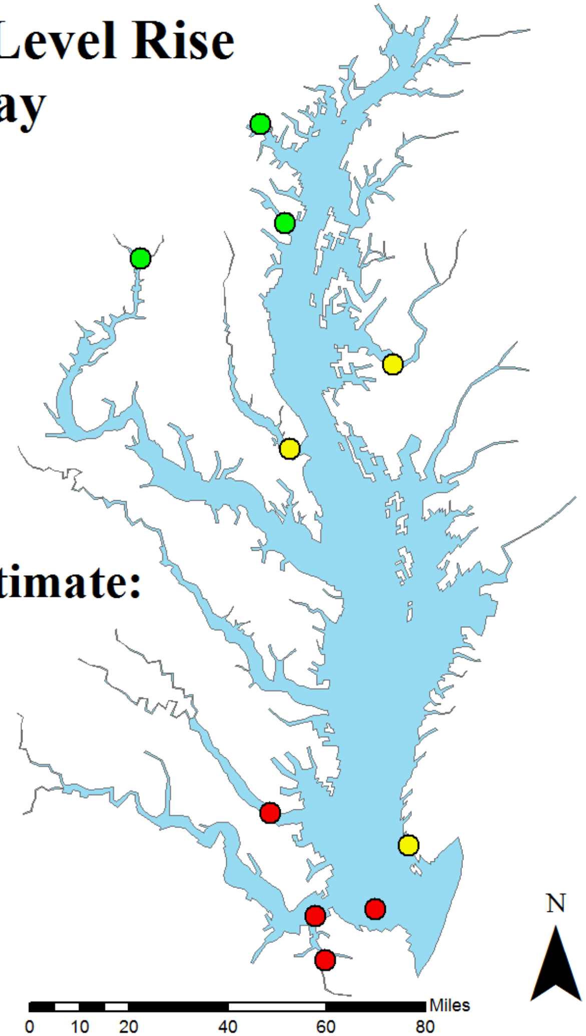
GMSL Scenario: Low

Median Estimates (cm)

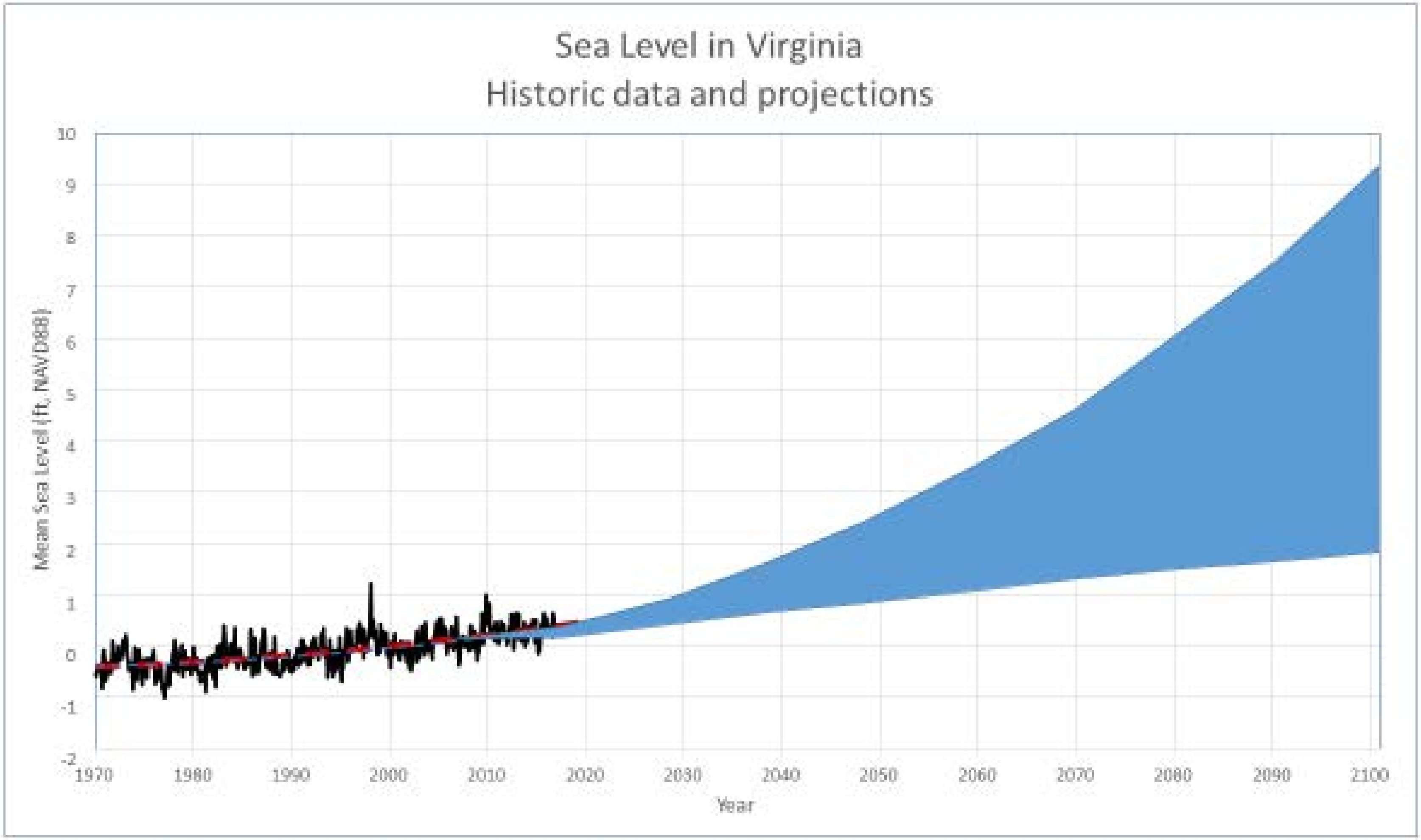
1995 - 2025

- 🟢 13 - 14
- 🟡 14 - 15
- 🔴 15 - 16.5

Average SLR Estimate:
14.7 cm



Coordinate System: NAD 1983 UTM Zone 18N
Projection: Transverse Mercator
Datum: North American 1983
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: -75.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter


Sea Level in Virginia
Historic data and projections
Mean Sea Level (ft, NAVD88)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year

Sewell's Point RMSL scenarios (meters)			Sewell's Pt GMSL scenarios adjusted to MSL and NAVD88 with average 3.1mm/yr subsidence rate							
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
low	0.028	0.089	0.150	0.221	0.282	0.343	0.404	0.465	0.526	0.577
intermediate-lo	0.038	0.109	0.190	0.271	0.362	0.443	0.534	0.615	0.696	0.777
intermediate	0.038	0.129	0.220	0.341	0.462	0.603	0.754	0.925	1.096	1.277
intermediate-hi	0.048	0.129	0.250	0.391	0.562	0.753	0.974	1.215	1.446	1.777
high	0.048	0.139	0.270	0.451	0.662	0.923	1.184	1.515	1.946	2.277
extreme	0.038	0.139	0.300	0.501	0.752	1.053	1.384	1.815	2.246	2.777
	2025 =	0.174		2050 =	0.462					

All the values in this figure are referenced to the elevation benchmark North American Vertical Datum of 1988 (NAVD88) now commonly used for FEMA Flood Insurance Rate Maps, FEMA Elevation Certificates, and many local land surveys. We use this datum because official tidal datums are based on water level observations between 1982 and 2001, and those values no longer represent the reality of water levels in the region. The current tidal datums are subject to revision at some point in the future.

The Sewell's Point water level observations are available from https://tidesandcurrents.noaa.gov/

The forecast of mean sea level for the next 40 years is based on analysis of the water observations over the past 40 years using an exponential trend analysis.

The range of model projections for future sea level through 2100 is based on the analysis reported in NOAA Technical Report NOS CO-OPS 083 titled "Global and regional sea level rise scenarios for the United States" published in January 2017. Available at: https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

The values used in this analysis are found in Table 5 on page 23 of that report. The values in that table are for Global Mean Sea Level rise scenarios (in meters) based on the most recent analyses found in the scientific literature.

After conversion to feet, the GMSL values were adjusted for subsidence using the 3.1mm/yr average regional value computed by the National Geodetic Survey (2013) and reported in USGS Circular 1392 available at: https://pubs.usgs.gov/circ/1392/

There are 6 different sea level rise scenarios developed in the NOAA report. We show only the range between the "low" and the "extreme" scenarios on this figure. Decadal values for all six scenarios (adjusted for subsidence and converted to feet and the NAVD88 datum) are reported in the table below.

Related STAC Peer Review Questions

- Question 11) Please comment on the appropriateness of the methodology to select 2025 and 2050 sea level rise scenarios for application in the WQSTM?

- Question 12) Given limitations on available data sets and modeling products, as well as uncertainty about how wetlands within differing geographies may adapt to changes in sea level over-time, please comment on the appropriateness of the methodology to project 2025 and 2050 tidal wetland change?

Climate Resiliency Workgroup Recommendations - Wetlands

- Use a multi-model approach, tied to the CRWG's recommended range of sea level rise projections for 2025 and 2050, to gain estimates of current wetland area and projected wetland loss/gain. Use these estimates to inform watershed loads in the CBWQSTM modeling effort.

- To estimate project wetland gain/loss, analyze data results available through the National Wildlife Federation, Sea Level Affecting Marsh Model v.5 of the Chesapeake Bay (2008) and data available through NOAA's Office for Coastal Management Sea Level Rise Marsh Impacts and Migration Tool.

- In interpreting the data available through these two products, assess whether the sea level rise projections used for the studies were consistent with the 2025 and 2050 SLR projections (as recommended by the CRWG); or, in the case of the NOAA Marsh Tool, whether data runs could be acquired for a different SLR scenario.

- The USGS/CBP GIS Team, which is working to compile the land use/land cover data set for the Midpoint Assessment, should work with the EPA/CBP Modeling Team to ensure there is consistency among the wetland classifications included in the marsh loss modeling outputs (NWF SLAMM (2008) and the NOAA Marsh Tool) to allow for side by side comparison of results.

Recommended 2025 Modeling Climate Inputs

Variable	Input	Modeling Run Completed	Uncertainty Analysis Component
CO_2	427 ppm	Watershed Model	No
Potential Evapotranspiration	Hargreaves-Samani	Watershed Model	Yes
	Hamon	Watershed Model	Yes
Temperature	RCP 2.6 Ensemble Median		Yes
	RCP 4.5 Ensemble Median	Watershed Model, WQSTM	Yes
	RCP 8.5 Ensemble Median		Yes
Precipitation	Historical Trend (+3.1%) with no Δ Intensity	Watershed Model	Yes
	Historical Trend (+3.1%) with Δ Intensity	Watershed Model	Yes
Sea Level Rise	0.17 meters		Yes
	0.3 meters	WQSTM	Yes
Wetland Loss	NWF SLAMM Model Runs (2008)	WQSTM	Yes
	NOAA SLR Viewer (Marsh Migration)		Yes

Recommended 2050 Modeling Climate Inputs

Variable	Input	Modeling Run Completed	Planned Uncertainty Analysis Component
CO2	487ppm	Watershed Model	No
Potential Evap.	Hargreaves-Samani	Watershed Model	Yes
	Hamon	Watershed Model	Yes
Temperature	Six GCM Analysis: 2040 and 2060	WQSTM (prior methodology but not recommended by CRWG	No
	RCP 2.6 Ensemble Median		Yes
	RCP 4.5 Ensemble Median	Watershed Model	Yes
	RCP 8.5 Ensemble Median		Yes
Precipitation	RCP 2.6 Ensemble Median		
	RCP 4.5 Ensemble Median		Yes
	RCP 8.5 Ensemble Median		Yes
Sea Level Rise	.3 meters	WQSTM	
	0.5 meters	WQSTM	Yes
	0.8 meters		Yes
Wetland Loss	NWF SLAMM Model Runs (2008)	WQSTM	Yes
	NOAA SLR Viewer (Marsh Migration)		Yes

Related Peer Review Questions

- Question 3) Please comment on the appropriateness of the methodology to account for uncertainty in 2025 and 2050 climate projections.

Section II

Developing the Ability to Understand Climate Change Impacts and Implications for CBP Management Actions

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Introduction:

- The Modeling Workgroup 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, 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).

Approved Climate Change Assessment Procedures

- Partition the influence of climate change into separate elements:

Watershed (WSM)

- Increased Precipitation
- Increased temperature
- Increased evapotranspiration
- Storm intensity
- **Modeling Results: Influence on watershed flows and loads**

Estuary (WQSTM)

- Changes in watershed loads
- Increased estuarine temperatures
- Increased sea level rise
- Loss of tidal wetlands
- **Modeling Results: Influence on water quality standards**

- Run climate change scenarios based on estimated 2025 and 2050 conditions
- Run a range of scenarios to bound the range of uncertainty

Section II (A)

Initial Applications of the Draft Phase 6 Watershed Model

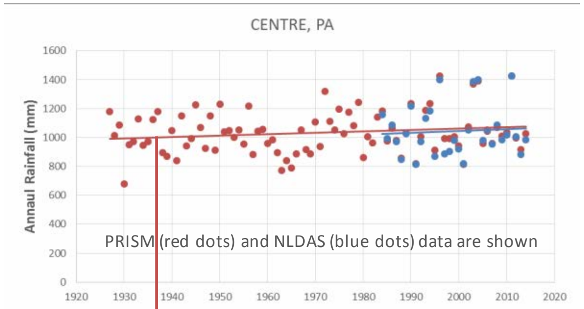
Gopal Bhatt[1] and Gary Shenk[2]

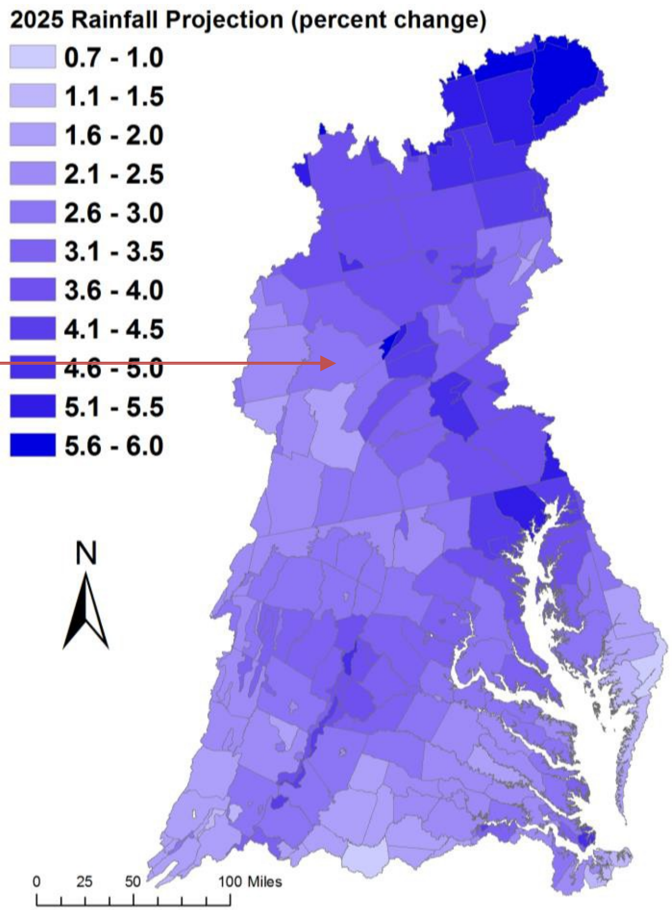
[1] Penn State, [2] USGS

Climate Change

- The Draft Phase 6 watershed model was used to estimate the changes in the 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 of long-term historical trends.
- For the changes in temperature an ensemble analysis of CMIP5 projections was recommended.

Rainfall projections using the trends 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%**

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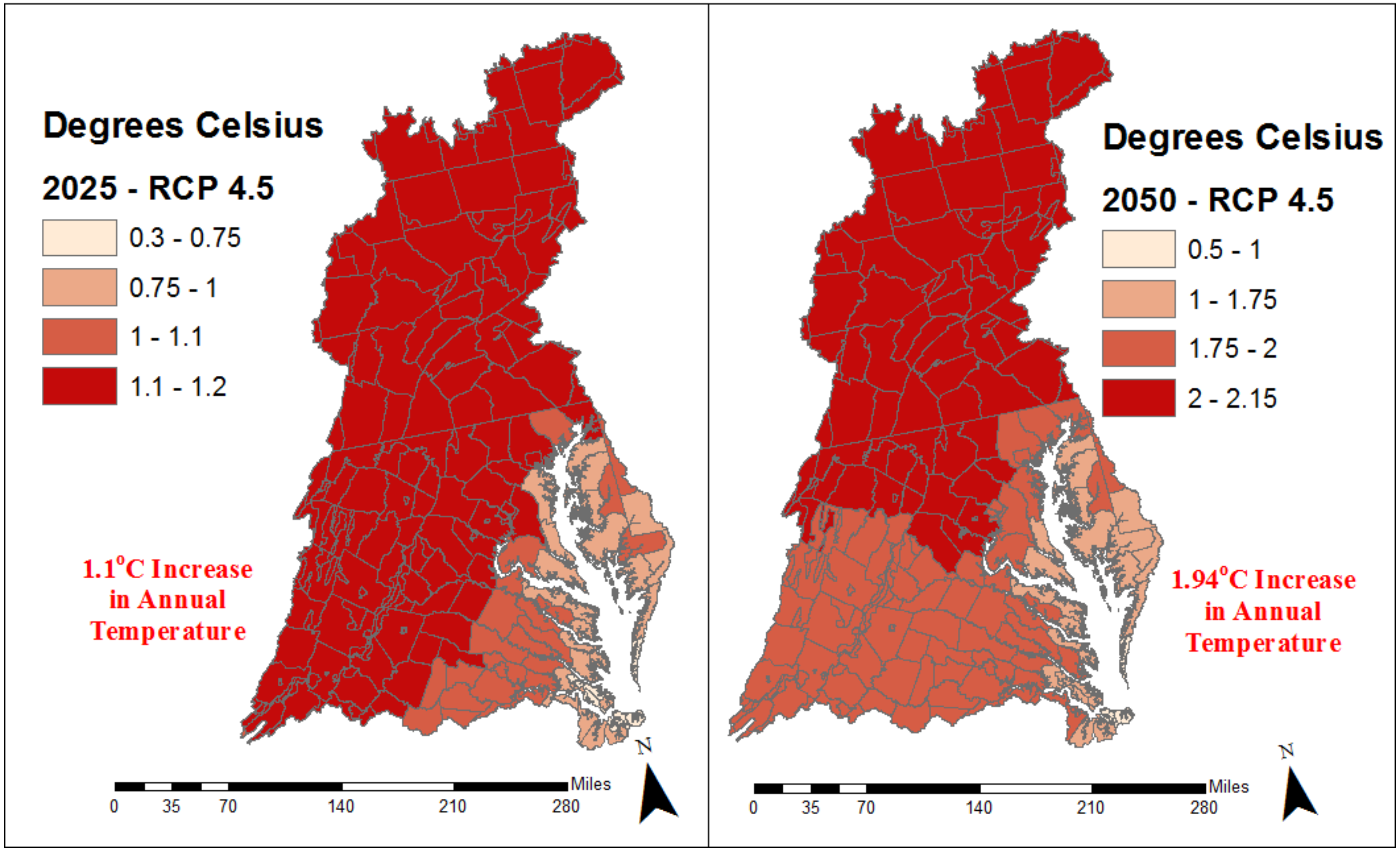
[1] Parameter-elevation Relationships on Independent Slopes Model

Chesapeake Bay Watershed Annual Change in Temperature



An ensemble of GCM projections from BCSD CMIP5[1]

- A minor revision was made to remove inconsistencies in the selection of downscaled GCMs.

Data unavailable
GCM Used
Selection updated

Ensemble members in prior analyses		
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 (1, 2, and 3)
CMCC-CM	HadGEM2-AO	MRI-CGCM3
CNRM-CM5	HadGEM2-CC	NorESM1-M
CSIRO-MK3-6-0	HadGEM2-ES	**32 member ensemble**
EC-EARTH	INMCM4	

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.

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

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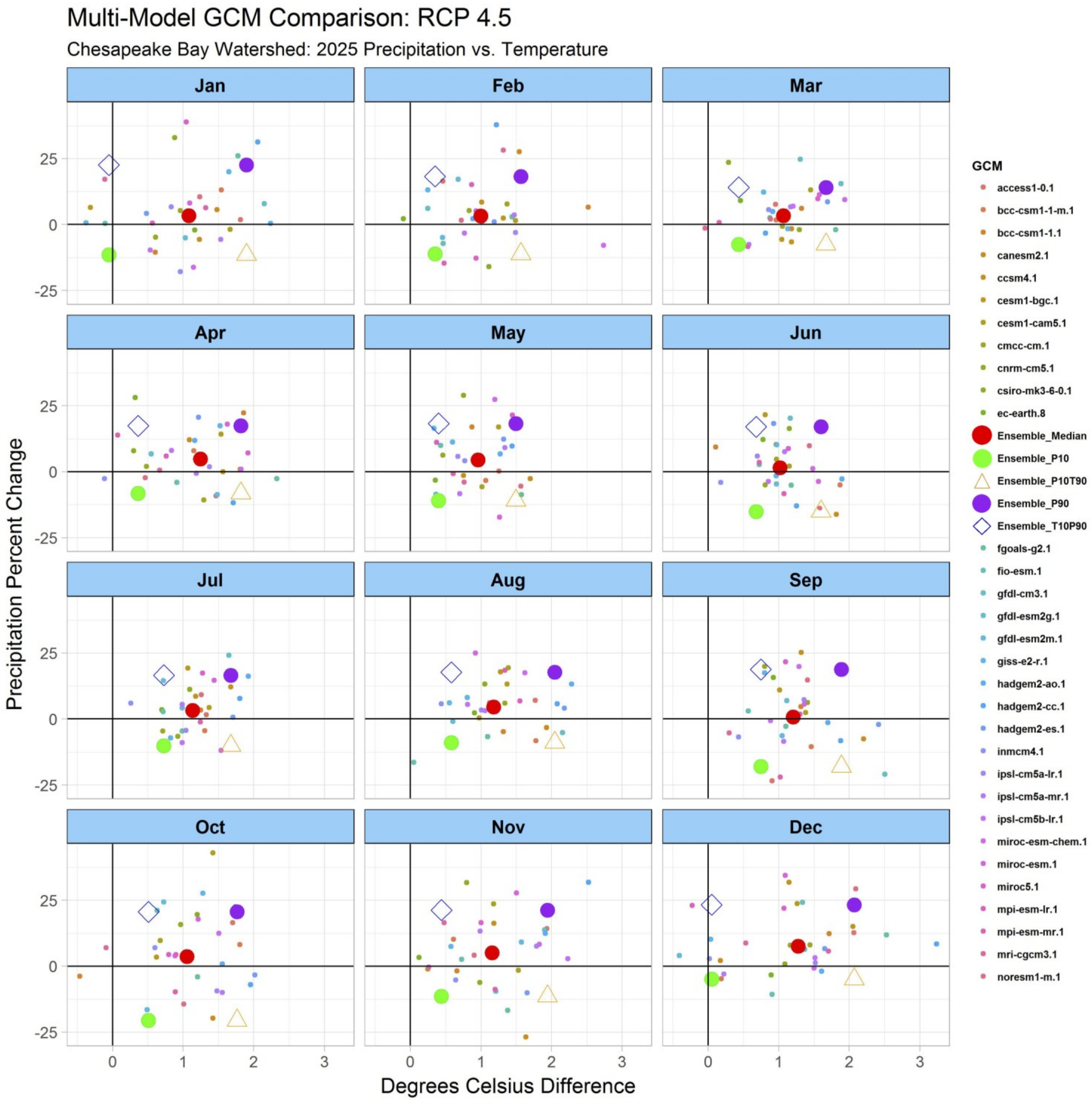
Multi-Model GCM Comparison: RCP 4.5
Chesapeake Bay Watershed: 2025 Precipitation vs. Temperature
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Precipitation Percent Change
Degrees Celsius Difference
25
0
-25
0
1
2
3
GCM
access1-0.1
bcc-csm1-1-m.1
bcc-csm1-1.1
canesm2.1
ccsm4.1
cesm1-bgc.1
cesm1-cam5.1
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

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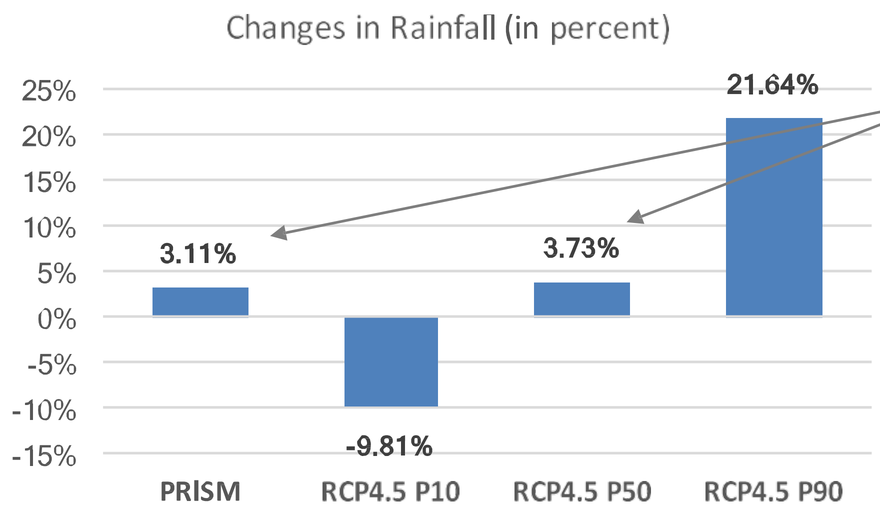
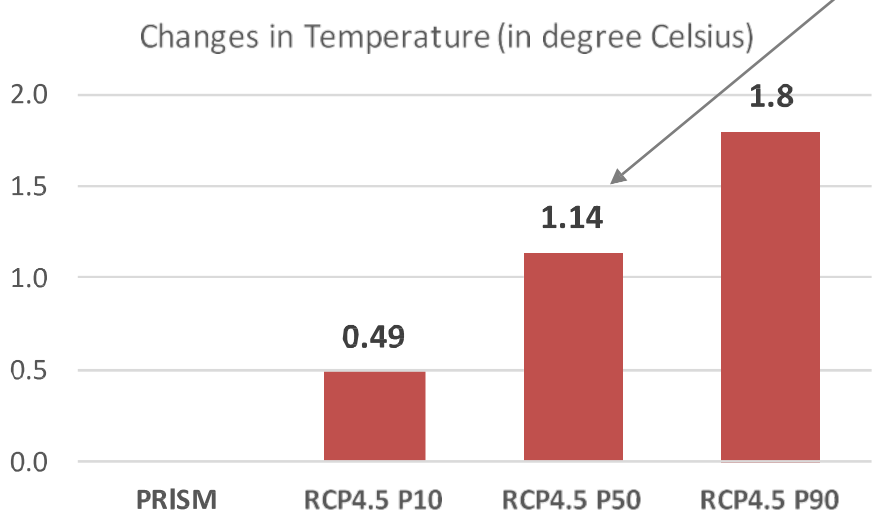
2025 climatic projections summary for Chesapeake Bay Watershed

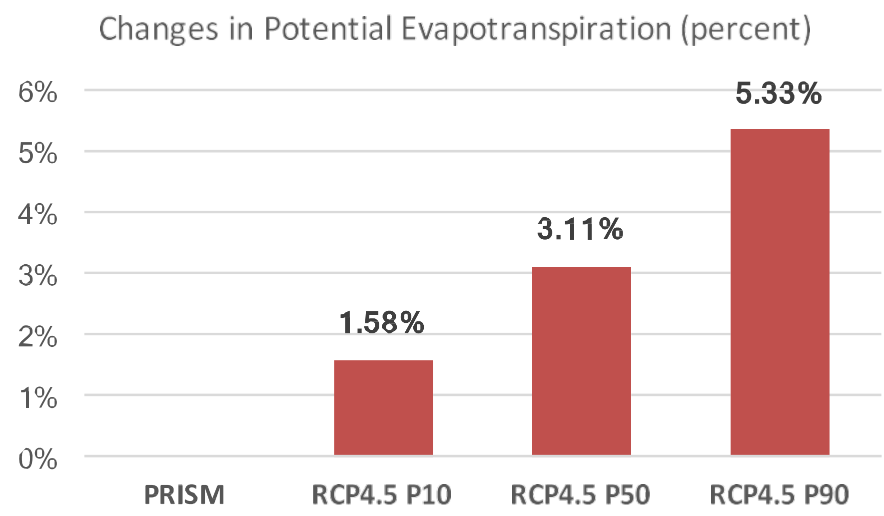


The central tendency of the projections for the changes in rainfall volume based on the 31 member ensemble median, P50, matches well with the extrapolation of PRISM's 88-year trends.

The rainfall uncertainty bounds (P10 and P90) of the ensemble members show wide range.

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





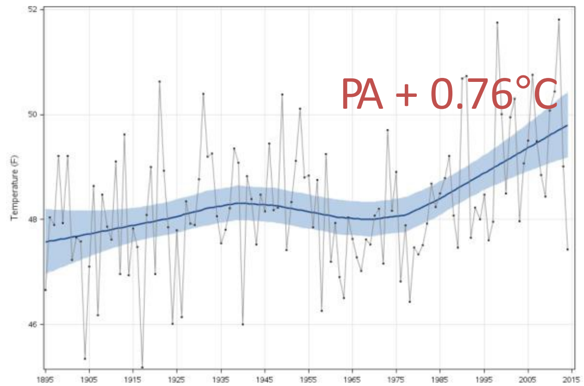
Temperature trends for the six states

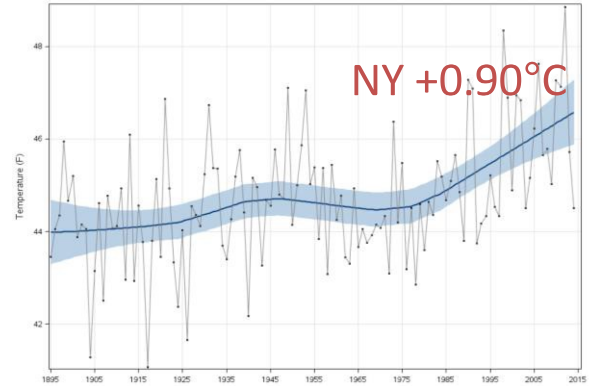
Annual temperature for 1895 to 2015 are shown.

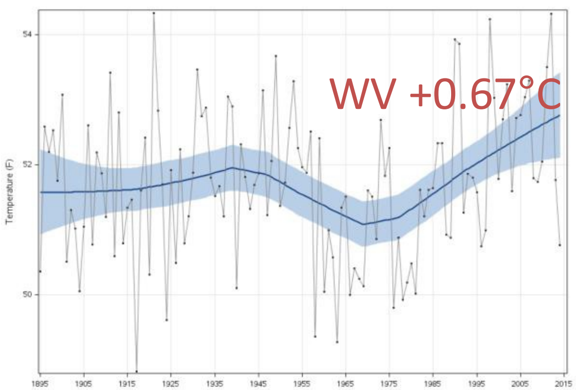
Annual Temperature

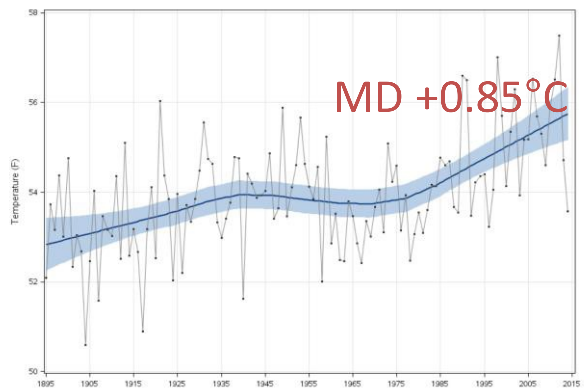
Trend Line

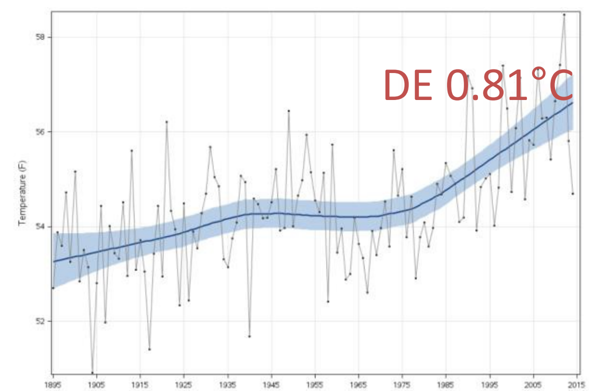
95% Confidence Limits

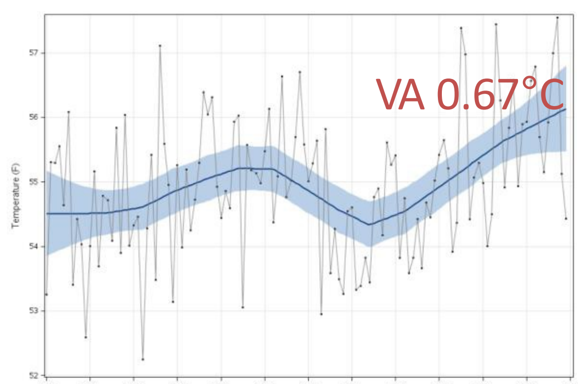










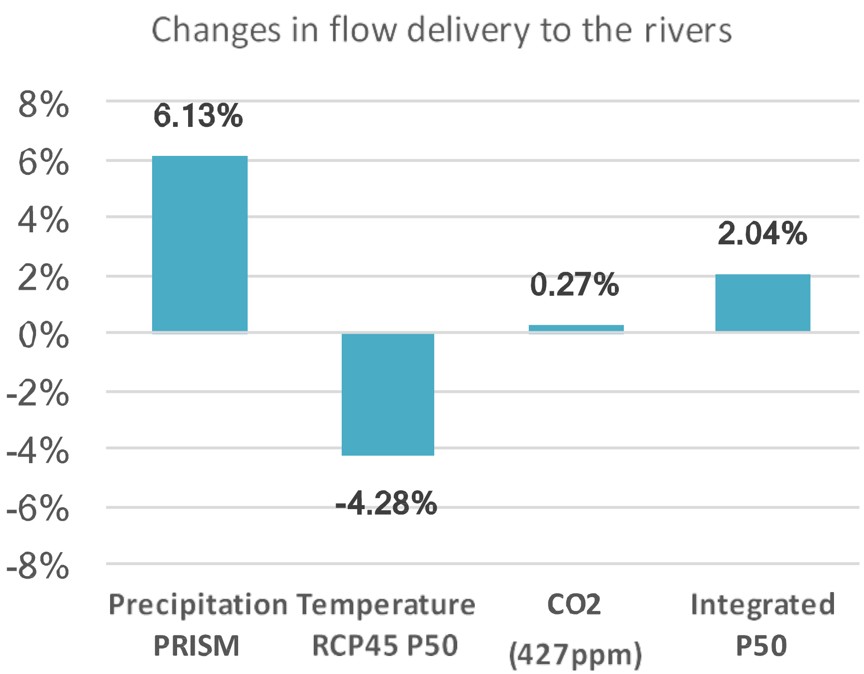


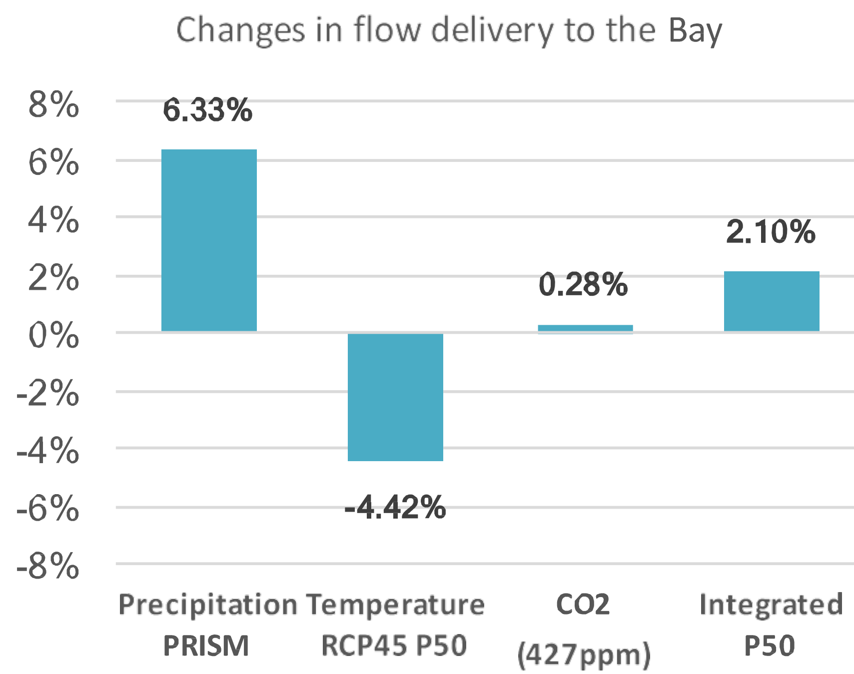
Approx. increases over the last 30 years based on the trend line are shown.

NOAA National Climatic Data Center

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

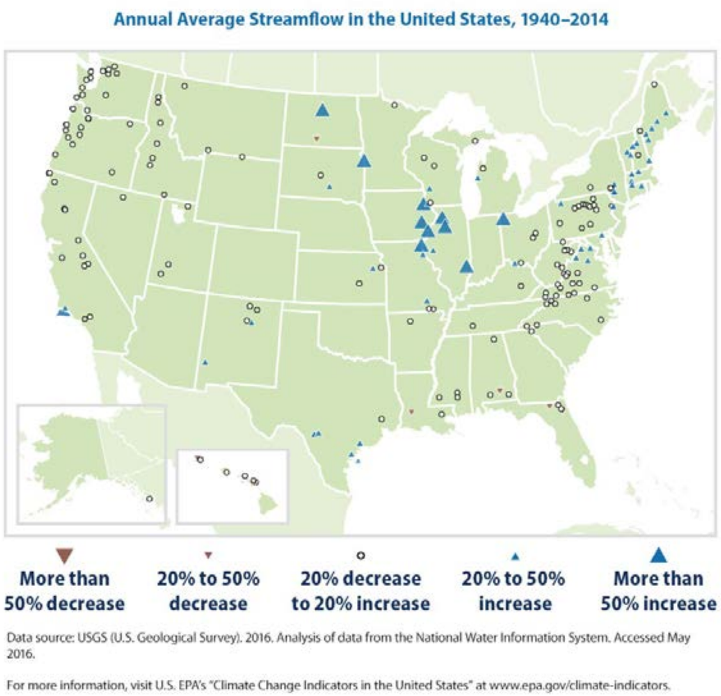
Model results: *flow to rivers and the Bay*

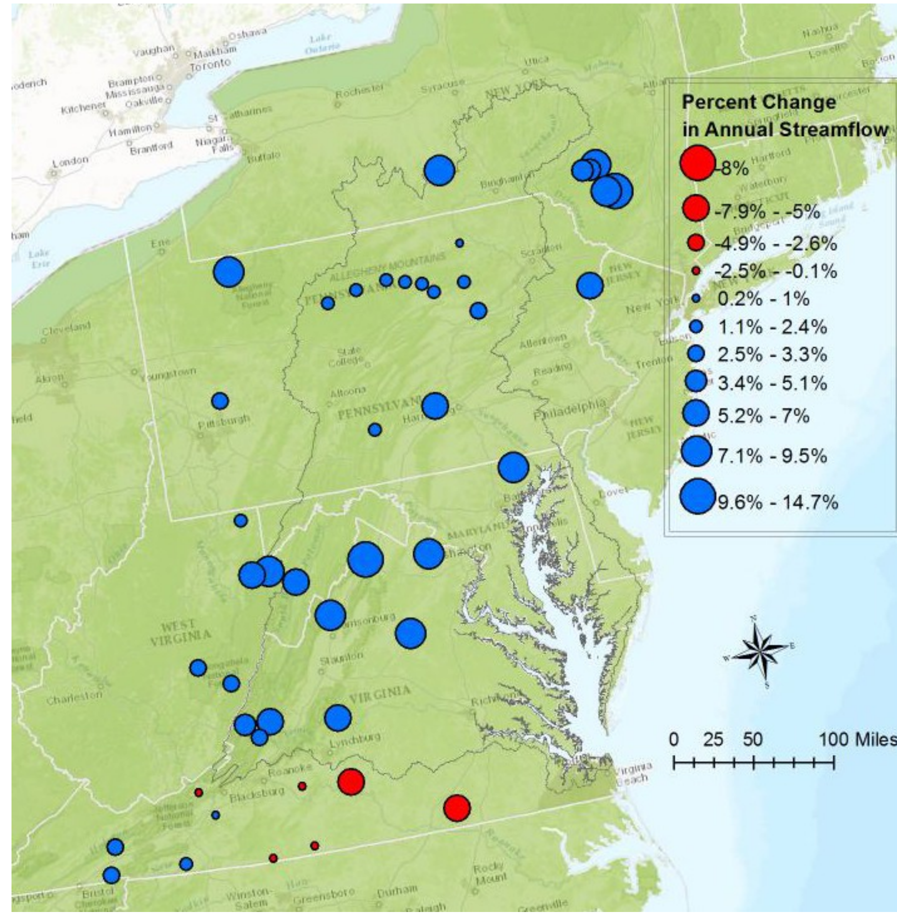




1940-2014 streamflow trends based on observations

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





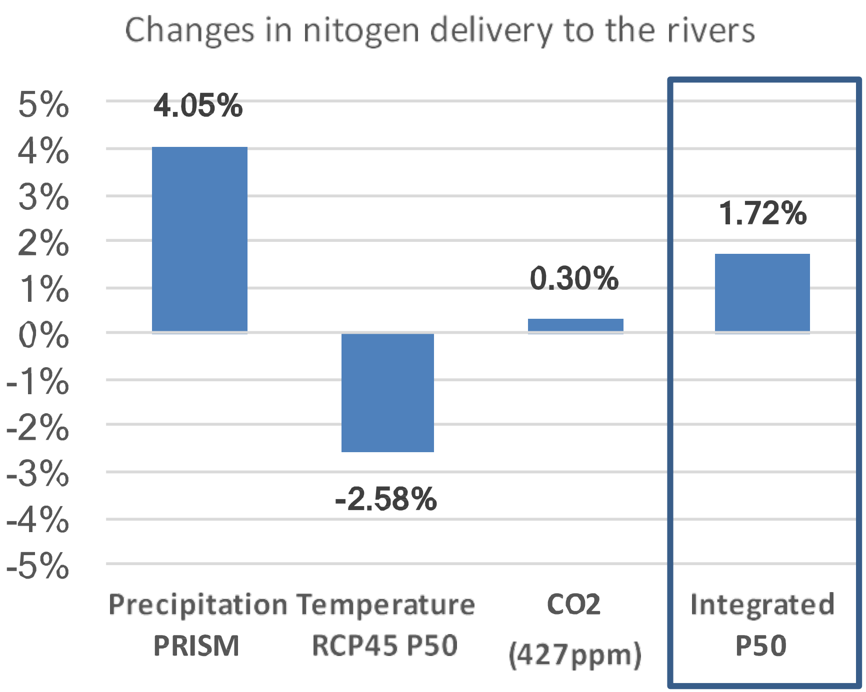
U.S. Environmental Protection Agency. 2016.
Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004. www.epa.gov/climate-indicators.

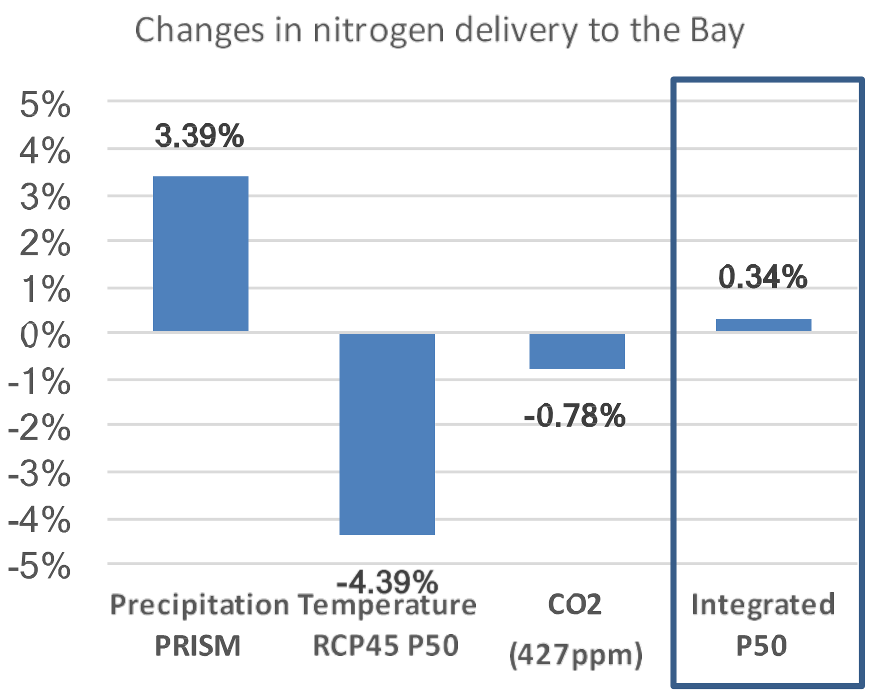
Annual average percent change were calculated using Sen slope (Helsel and Hirsch, 2002).

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.

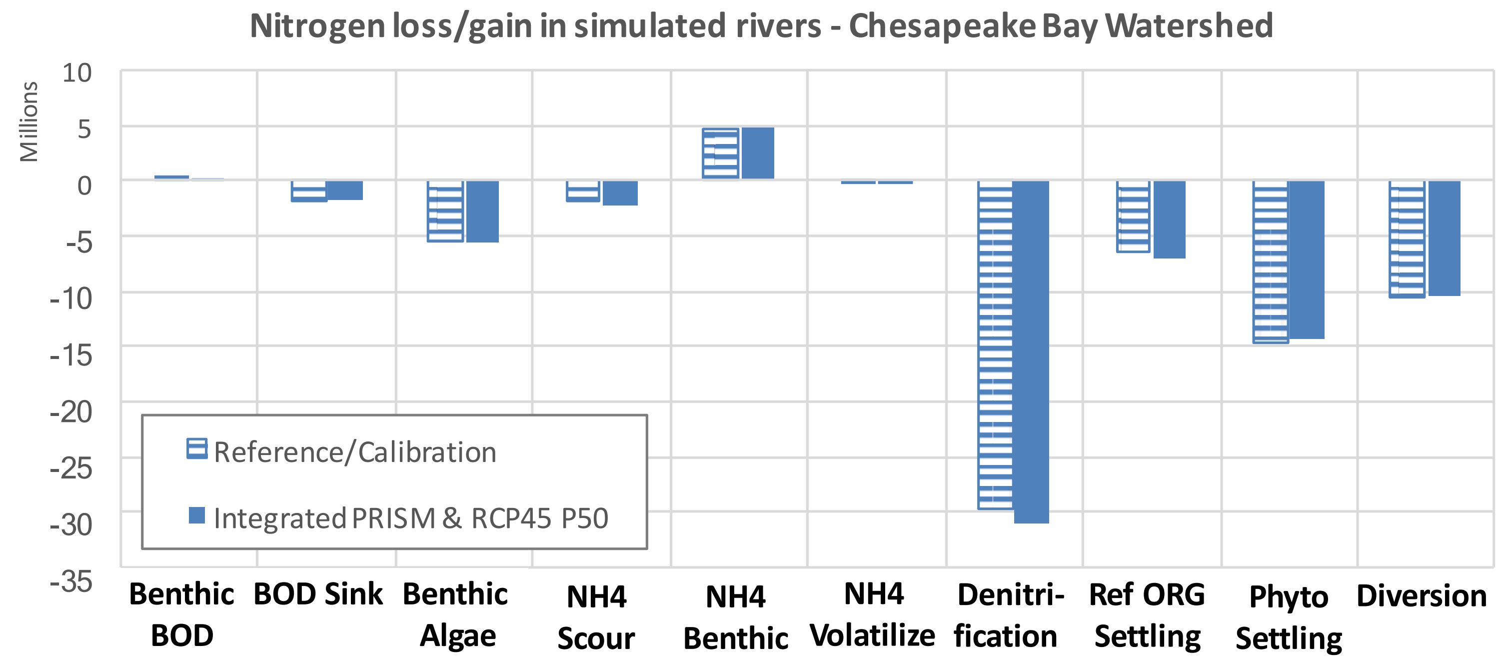
Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources. Techniques of water resources investigations, Book 4. Chap. A3. U.S. Geological Survey. https://pubs.usgs.gov/twri/twri4a3.

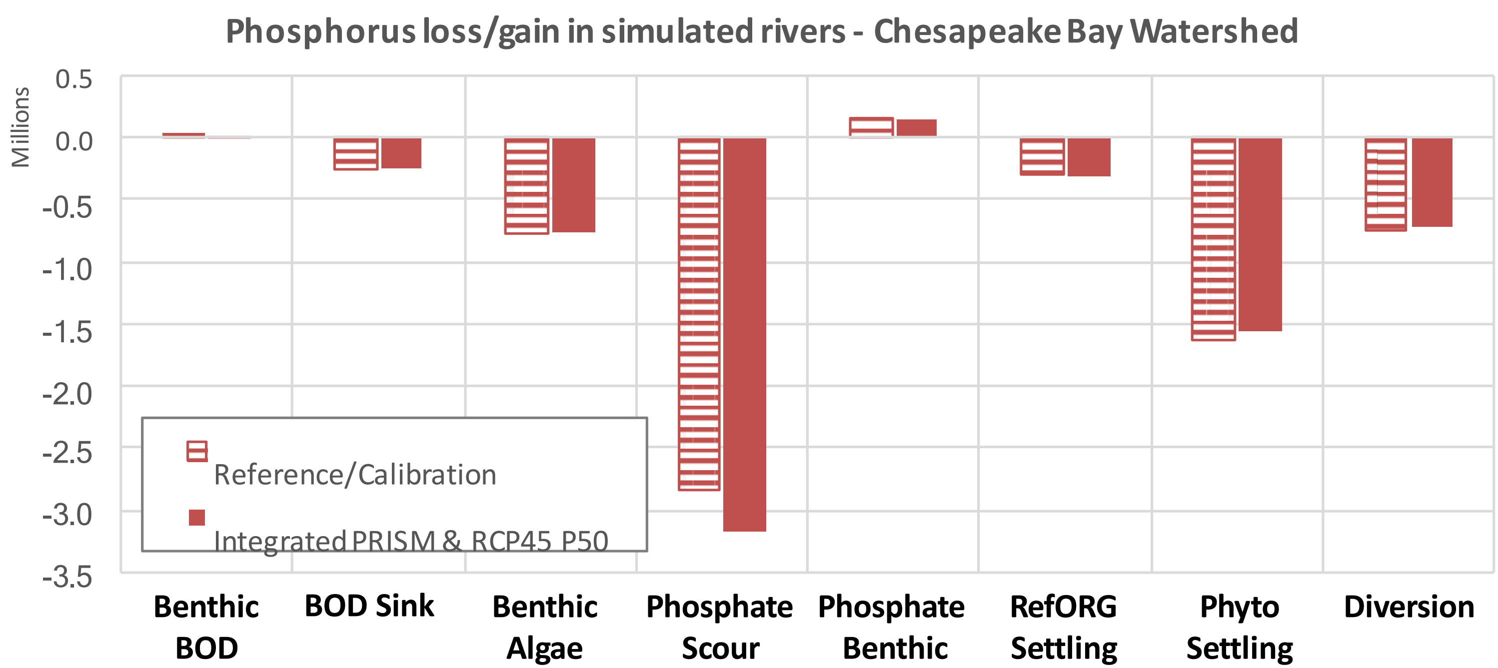
Model results: *nitrogen to rivers and the Bay*



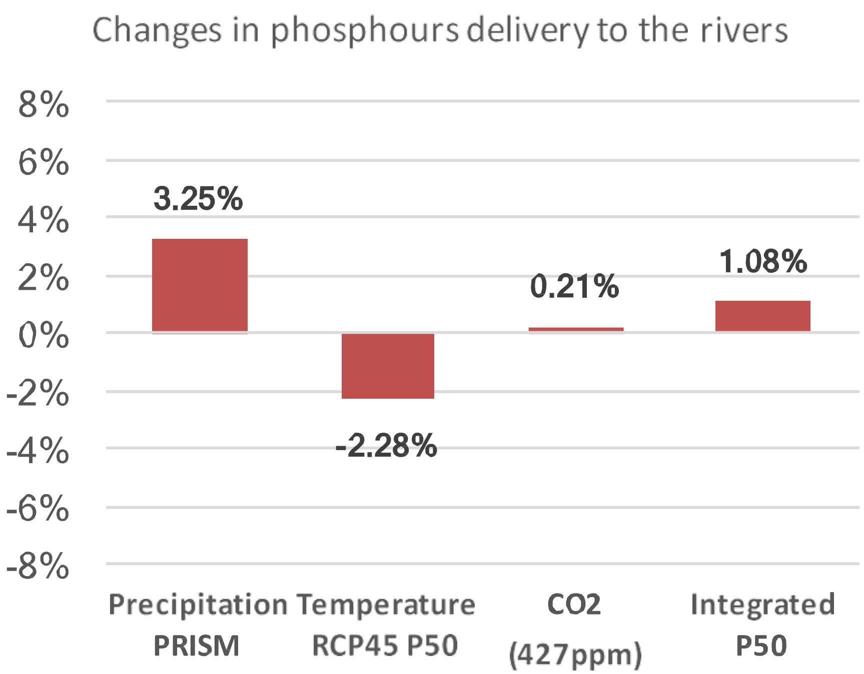


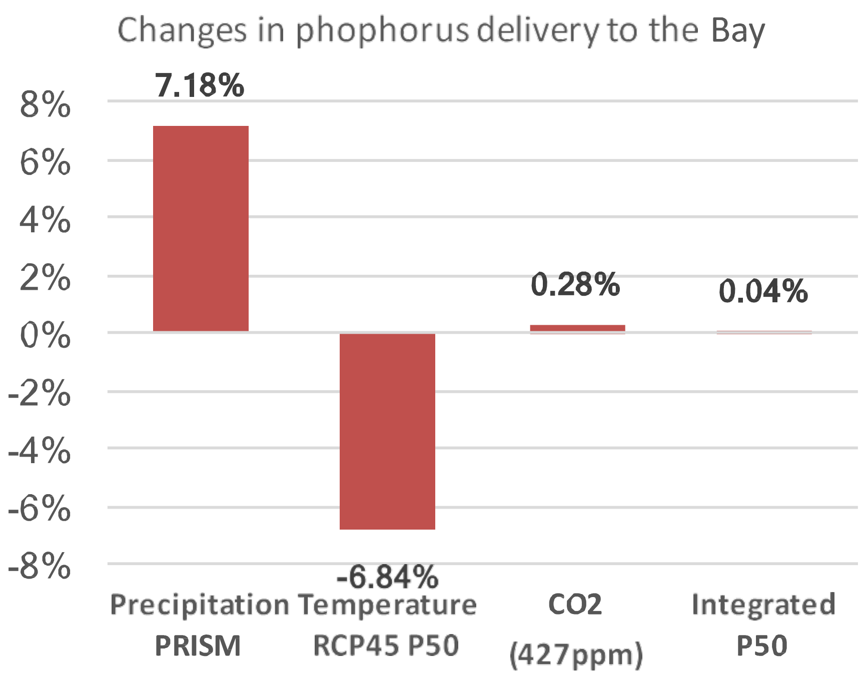
Jessica Rigelman – CAST for the application of Phase 6 sensitivities


Nitrogen loss/gain in simulated rivers - Chesapeake Bay Watershed
Millions
10
5
0
-5
-10
-15
-20
-25
-30
-35
Reference/Calibration
Integrated PRISM & RCP45 P50
Benthic BOD
BOD Sink
Benthic Algae
NH4 Scour
NH4 Benthic
NH4 Volatilize
Denitri-fication
Ref ORG Settling
Phyto Settling
Diversion


Phosphorus loss/gain in simulated rivers - Chesapeake Bay Watershed
Millions
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
Reference/Calibration
Integrated PRISM & RCP45 P50
Benthic BOD
BOD Sink
Benthic Algae
Phosphate Scour
Phosphate Benthic
RefORG Settling
Phyto Settling
Diversion

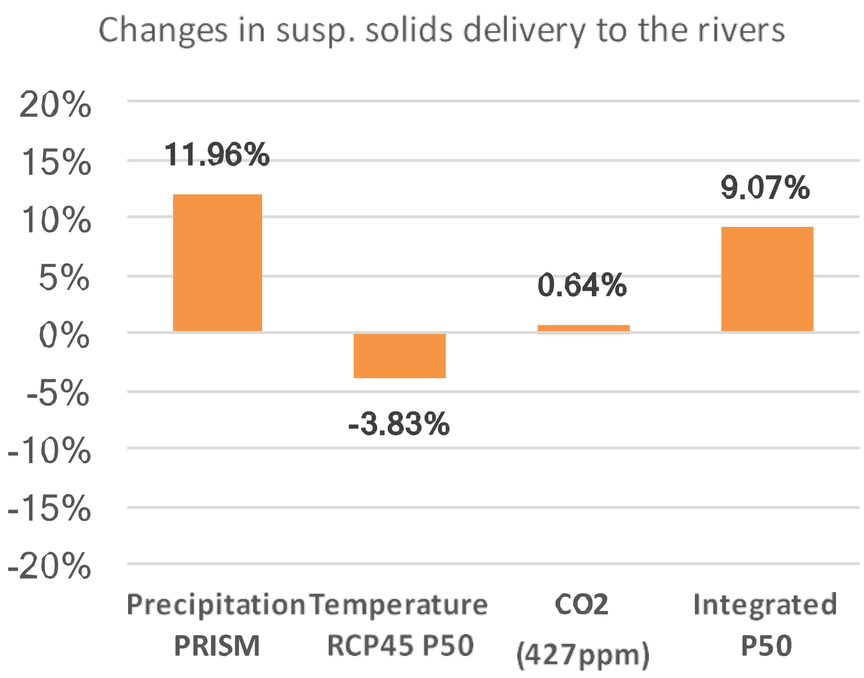
Model results: *phosphorus to rivers and the Bay*

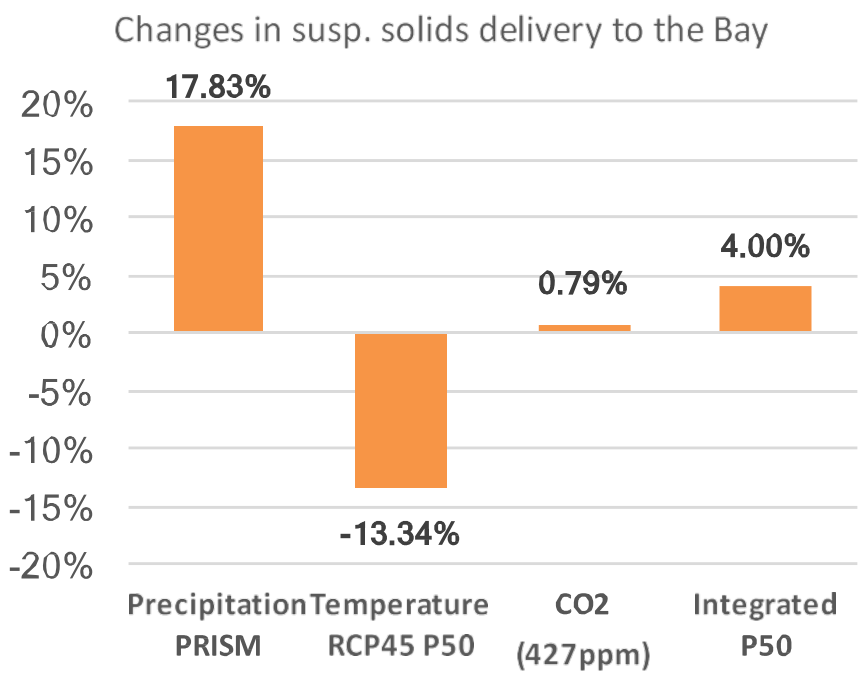




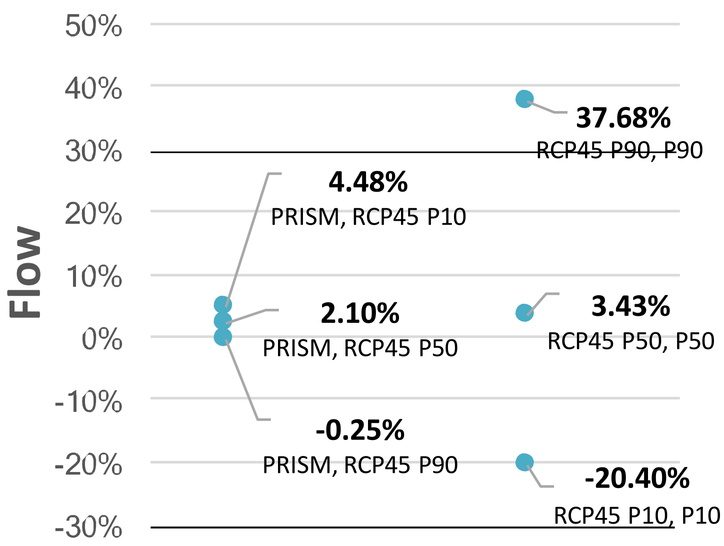
Jessica Rigelman – CAST for the application of Phase 6 sensitivities

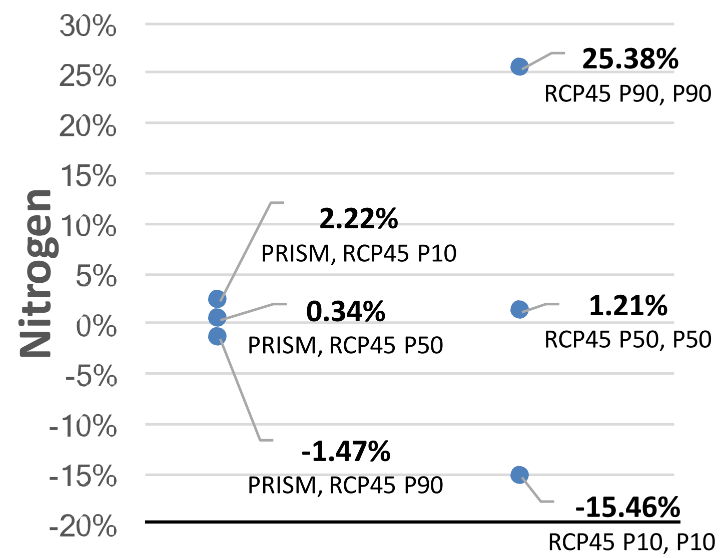
Model results: *suspended solids to rivers and the Bay*

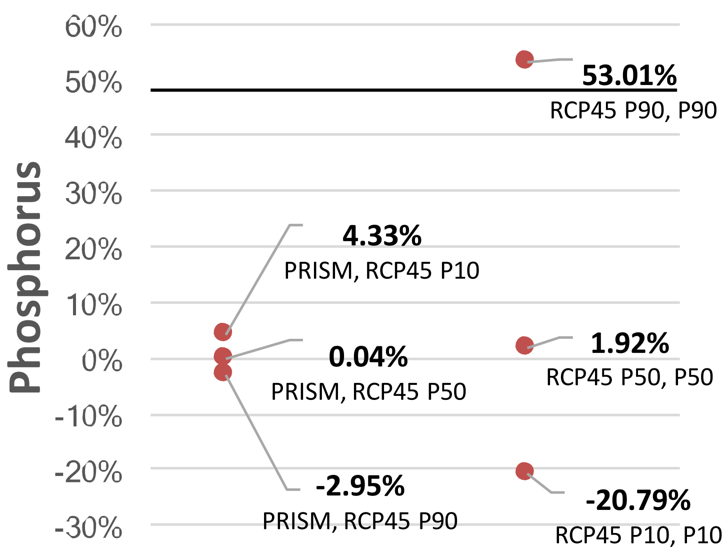


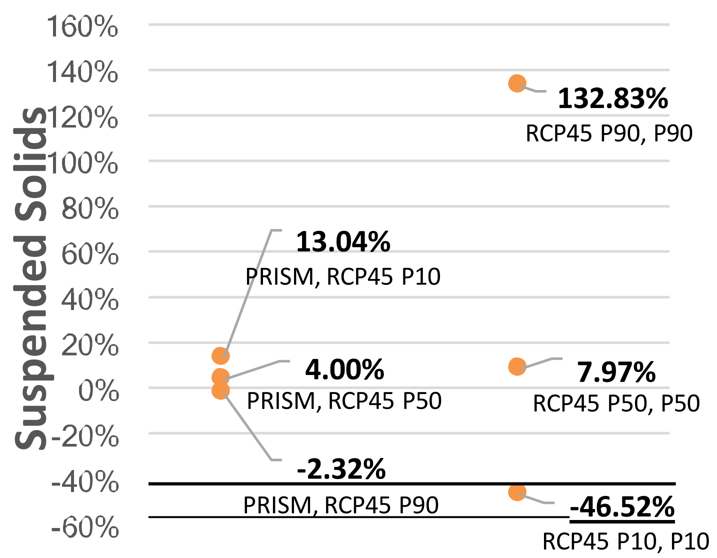


Uncertainty quantification









Summary and Conclusions

- The results shown were based on the Draft Phase 6 Watershed Model.
- Climate change simulations for 2025 were updated, as well as the uncertainty bounds were included in the assessment.
- Nutrient load increases under the estimated 2025 climate change conditions are negligible. Sediment loads are estimated to increase by about 4% under the same condition.

Related Peer Review Questions

- Question 4) Please comment on the CBP's use of multiple Representative Concentration Pathways (RCP's) and their associated 10th, 90th percentiles and the median projections to derive 2025 and 2050 temperature estimates and 2050 precipitation estimates?
- Question 5) Please comment on the CBP's selection of the downscaling approach, Bias Corrected Spatial Disaggregation (BCSD) downscaling methodology to derive 2025 and 2050 temperature estimates and 2050 precipitation estimates?
- Question 6) Is the interpretation of downscaled climate data from a gridded product (⅛° resolution) to a county-scale within the Watershed Model sufficient to represent changing climatic patterns and assess load responses at a larger regional scale?
- Question 7) Given limitations of modeling resources, policy and governance, is the applied Delta Approach for precipitation, temperature and evapotranspiration adequate to represent a range of potential changes in climatic forcing variables? Are there limitations in the ability to capture potential variability of precipitation intensity, temperature swings, or timing of extreme events (e.g., storm occurring early in growing season vs. late fall) that would affect the ability to assess the impact of less probable but higher magnitude events (e.g., Hurricane Isabel)?
- Question 8) Is the use the Karl and Knight (1998) estimates of precipitation intensity appropriate for modifying 2025 precipitation intensity? Is it sufficient to apply these estimates to the entire watershed based on their central Mid-Atlantic derived trends?
- Question 9) The models (both the old P5 and new P6 versions) use a 10-year average hydrology for the simulation. The 10-year period that is used is 1991-2000. The TMDL and planning targets are also based on a hydrologic critical period (1993-1995) for meeting WQ standards. With the latest information we have about climate science and given the methods that being used to incorporate changing temperature, precipitation, and sea-level into the models, are these periods still appropriate, when the hydrologic averaging period is 17 years old and the critical period is 23 years old?
- Question 10) Was the use of a modified Hargreaves-Samani evapotranspiration methodology sufficient to capture expected changes due to projected temperatures? In addition, should other ET methodologies be considered to develop a comparison of ET estimates?

Section II (B)

Preliminary Estimates of Climate Change Influence on Chesapeake Water Quality Attainment

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U.S. EPA Chesapeake Bay Program
410-267-5741
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Science, Restoration, Partnership

Preliminary Estimates of Climate Change Influence On Chesapeake Water Quality Attainment

In the next eight weeks we need to produce for Chesapeake Bay Program decision makers our best estimate of the influence 30 years of climate change (1995 to 2025) has on Chesapeake Bay water quality.

The findings so far:

- On one hand, increased 2025 temperatures ameliorates the estimated increased precipitation in the watershed through evapotranspiration, but also increases stratification and 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 conditions of sea level and watershed flows.

(This work uses the Beta 3 Watershed Model and the Beta 4 WQSTM to provide the best estimate available today of 2025 conditions compared to the 1995 TMDL conditions. We need to run the analysis on the final Watershed and WQSTM models.)

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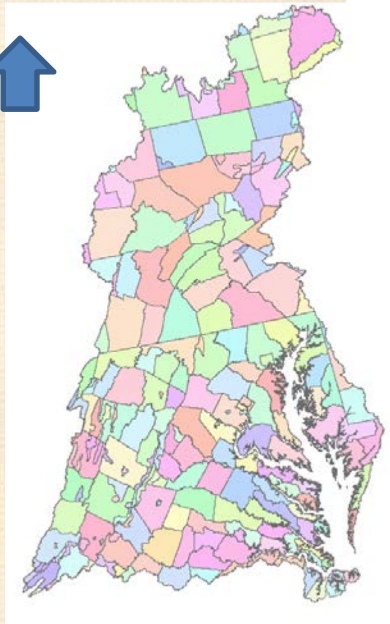
Keeping Score

In the Watershed

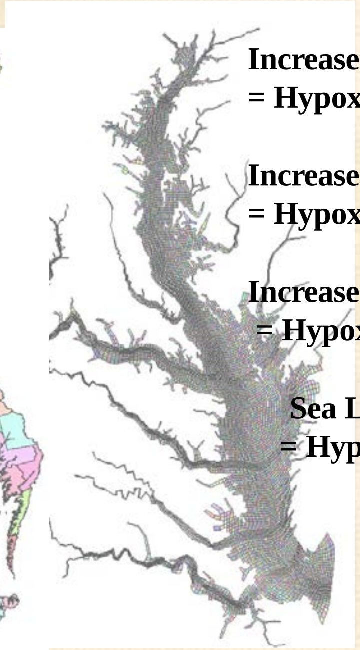
Increased Precipitation Volume = Hypoxia

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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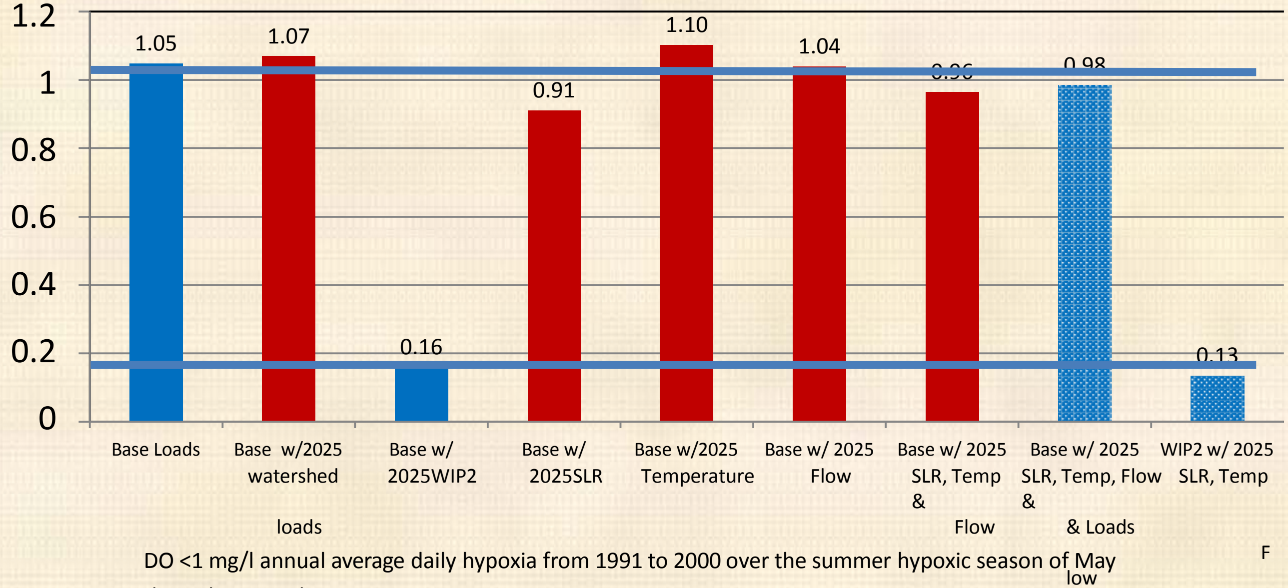

DO <1 mg/l annual average daily hypoxia from 1991 to 2000 over the summer hypoxic season of May through September.

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

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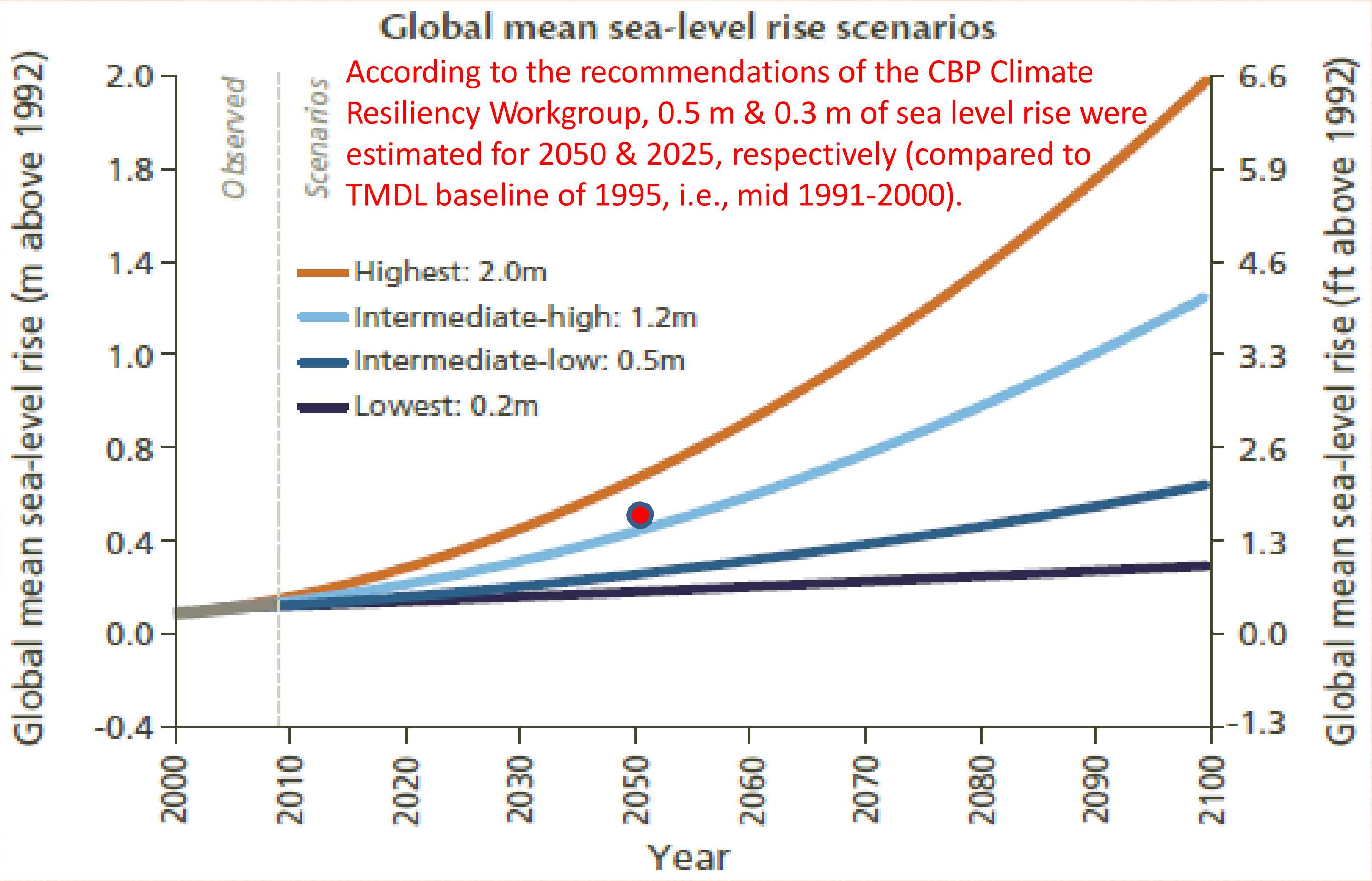
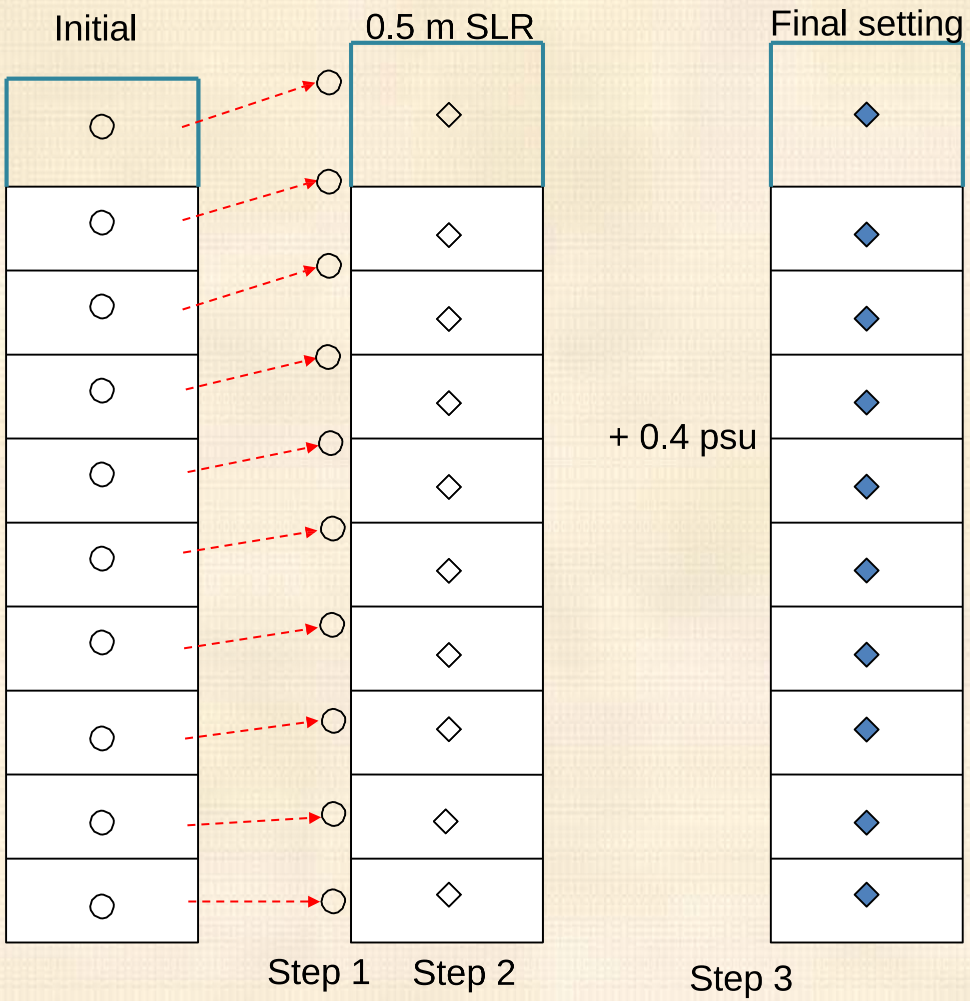
Overview:

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.*

Boundary salinity setting



Does salinity adjustment influence water quality simulation and to what extent?

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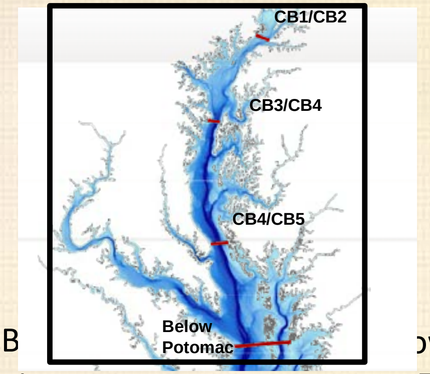
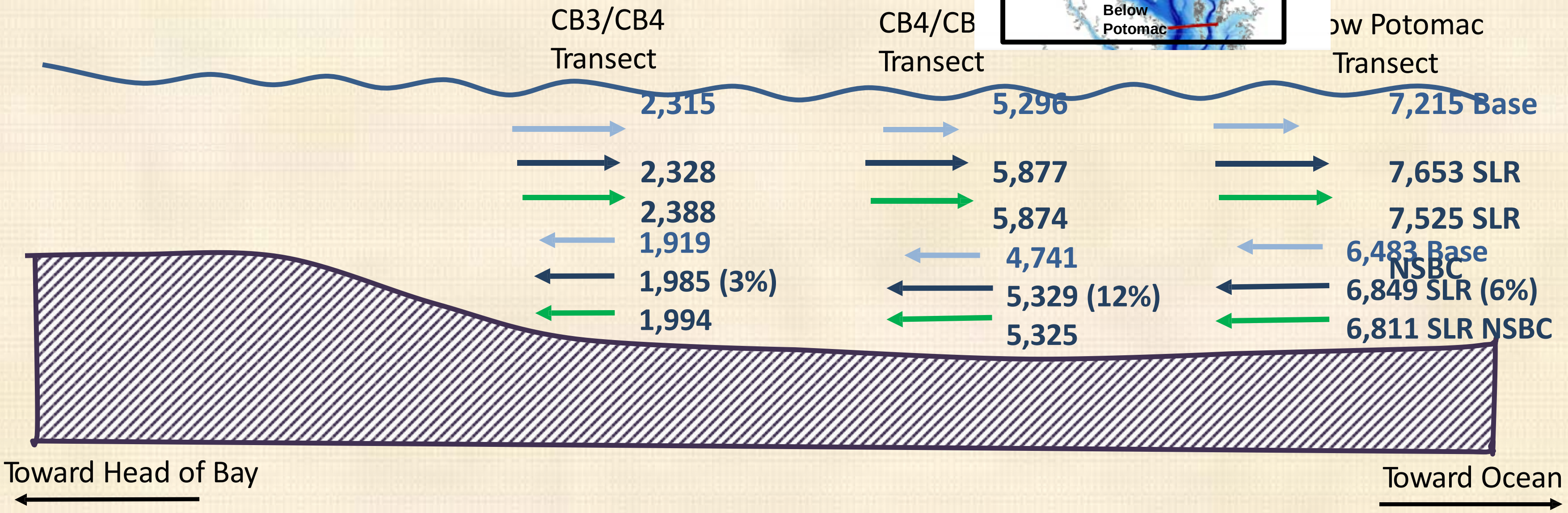
From the Literature: Expectations of the Chesapeake Bay Response to Sea Level Rise:

- 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

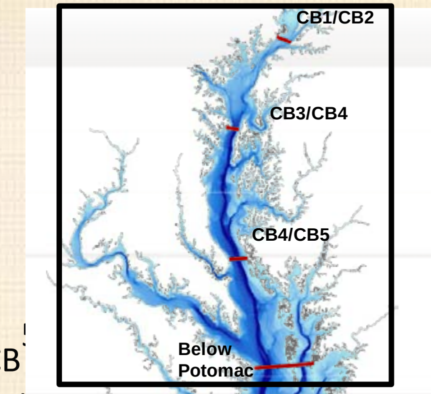
Cross-transect water fluxes (m^3/s) Base case versus sea level rise (SLR) of 0.5m. Summer 1993-1995

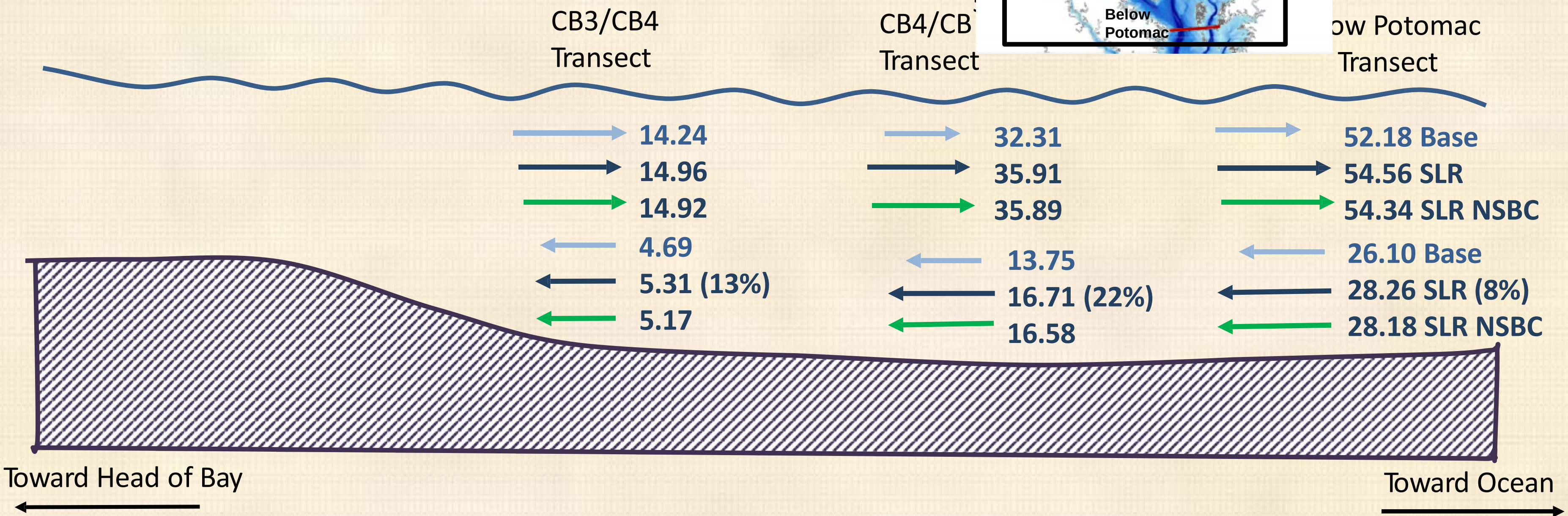




Base = Beta 4 WQSTM, SLR = 0.5m representing relative Chesapeake sea level rise from 1995 to 2050. Units in mean m^3/s for summer (Jun-Sept) 1993 to 1995; NSBC: No Salt Boundary Change.

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 Change.

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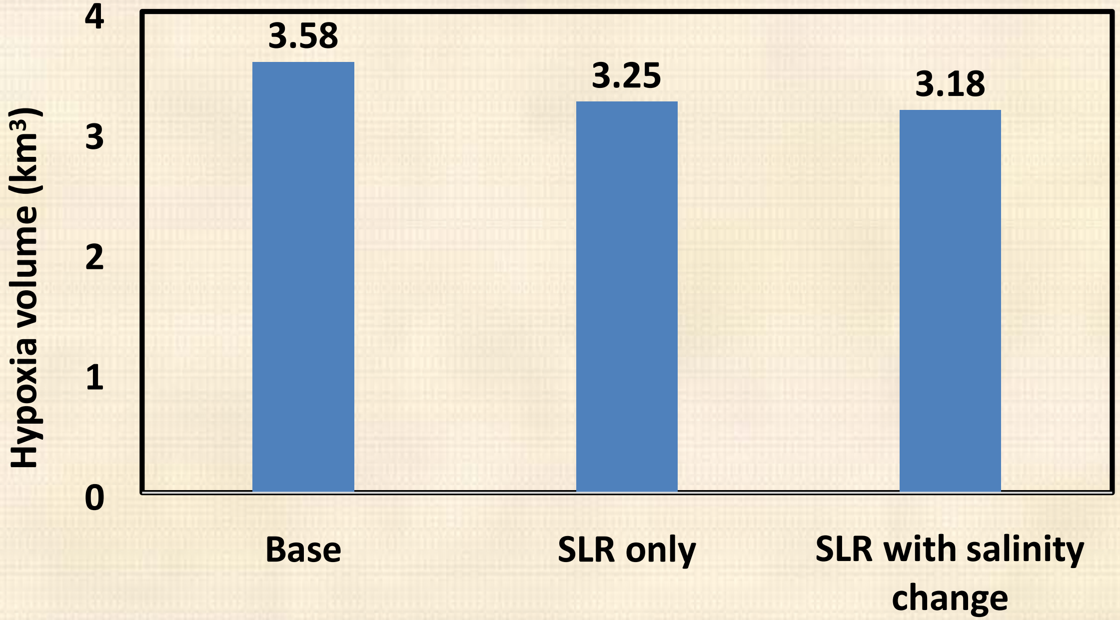
Sea level rise 2050 (0.5m) with open boundary salinity change (SLR) and SRL without open boundary salinity change



Origins of the 0.4 ppt Ocean Boundary Condition

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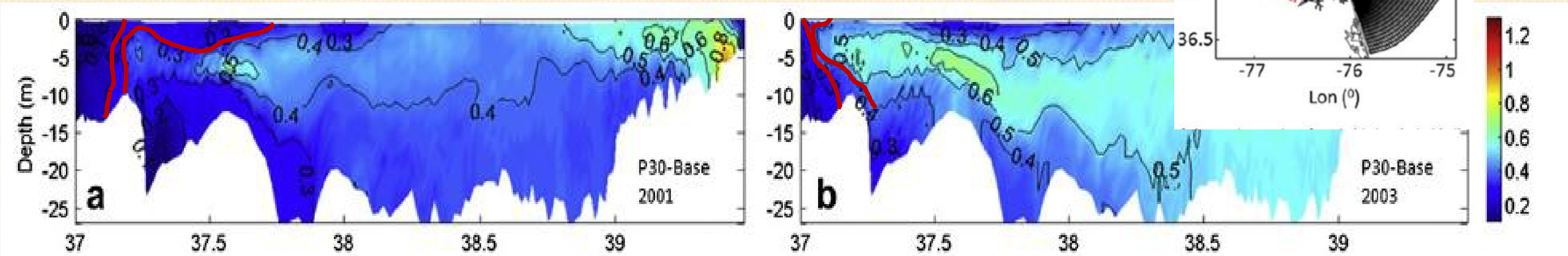
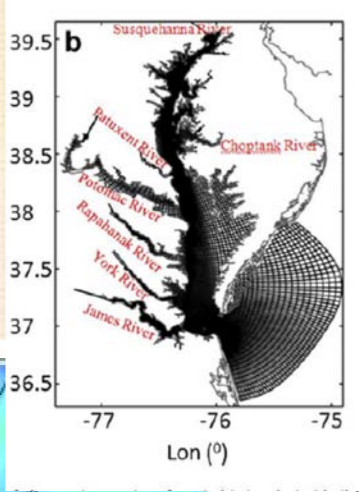
Model estimates of delta June average salinity in 2001 (dry year) and 2003 (wet year) relative to base calibration under conditions of a 0.3 m sea level rise.



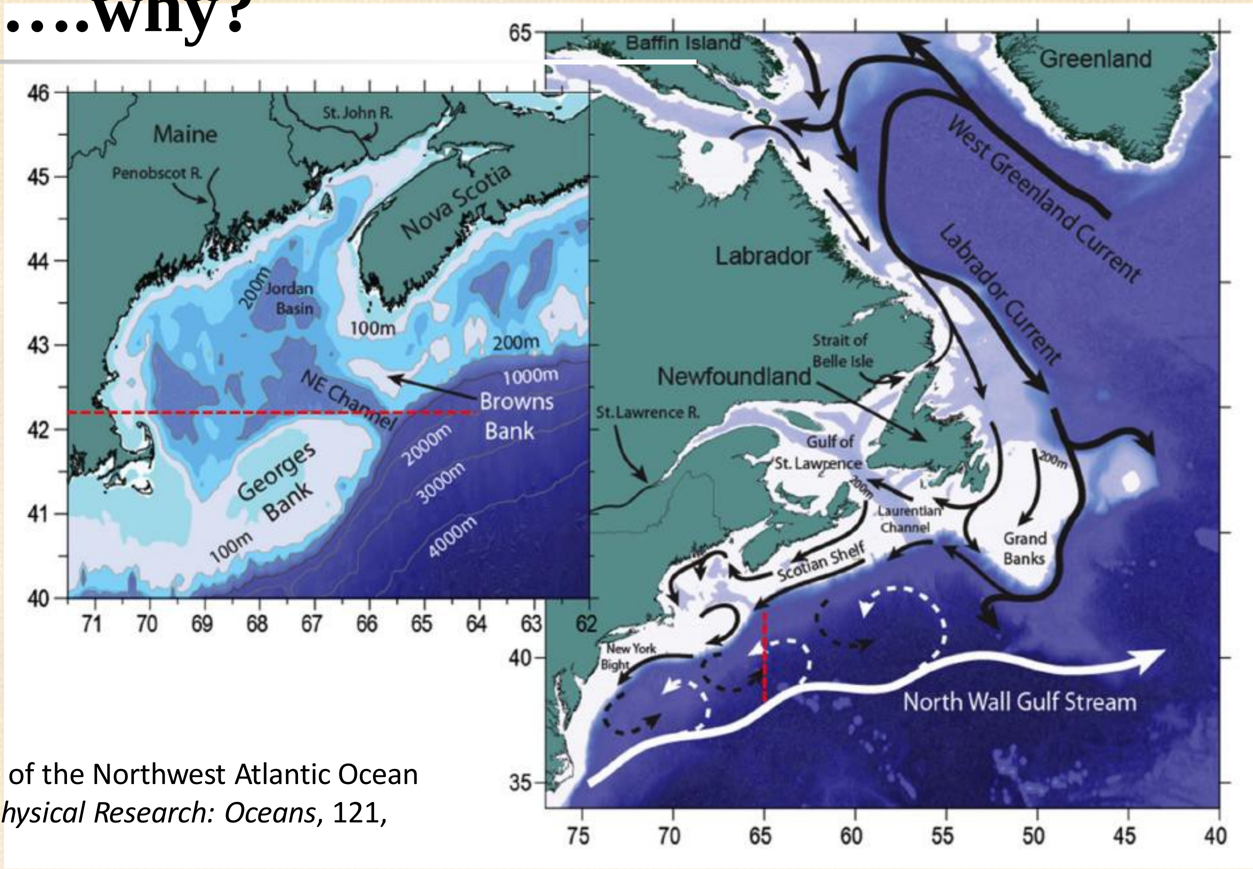


“The mean salinity at the Bay mouth would increase with rising sea level, which could alter the along-Bay pressure gradient. Meanwhile, the water depth in the Bay also increases. These changes will result in the variations of gravitational circulation. According to the classical estuarine circulation theory ….given a sea-level rise of 1.0 m, [in Chesapeake Bay] gravitational circulation will increase by a factor of 1.5.”

Hong and Shen, *Estuarine, Coastal and Shelf Science* 104-105 (2012) 33-45 (page 40)

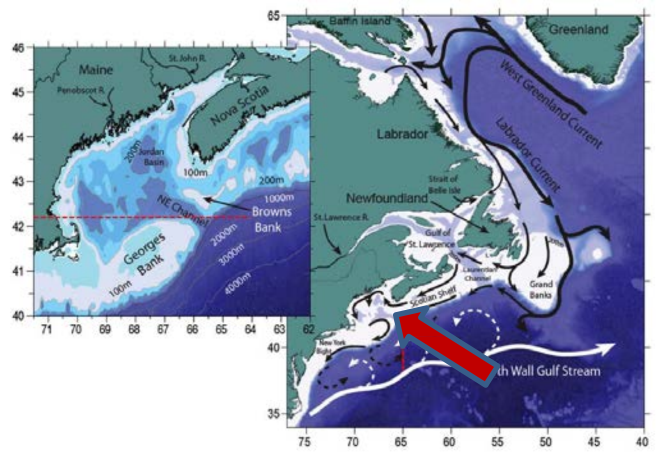
Bringing us to….why?

"Northwest Atlantic Ocean and Labrador Sea bathymetry and major current systems. Black arrows are colder, fresher water associated with the Labrador Current. White arrows are warmer, saltier water associated with the Gulf Stream.
Dashed arrows indicate mixing of waters (not currents) in the Slope sea. Inset shows location of the Northeast Channel (NEC; sill depth ca. 220 m) where a mix of these Slope and Shelf Waters enter the Gulf of Maine."



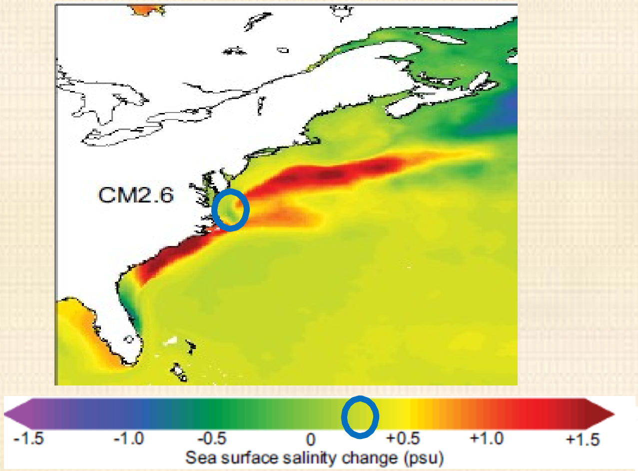
Saba, V. S., et al. (2016), Enhanced warming of the Northwest Atlantic Ocean under climate change, *AGU Journal of Geophysical Research: Oceans*, 121, 118–132, doi:10.1002/2015JC011346.

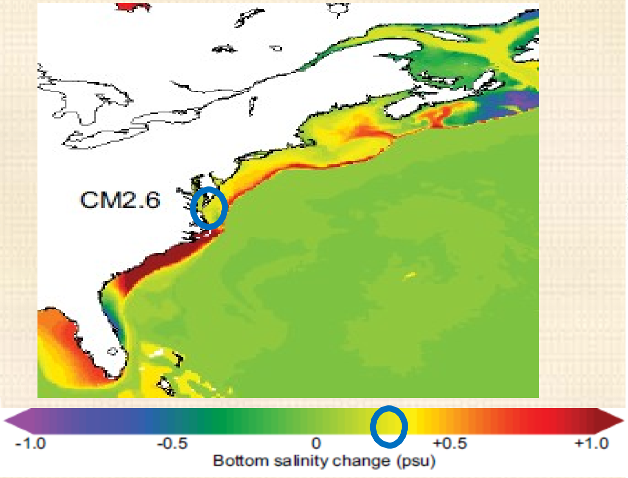
Saba, V. S., et al. (2016), Enhanced warming of the Northwest Atlantic Ocean under climate change, *AGU Journal of Geophysical Research: Oceans*, 121, 118–132, doi:10.1002/2015JC011346.

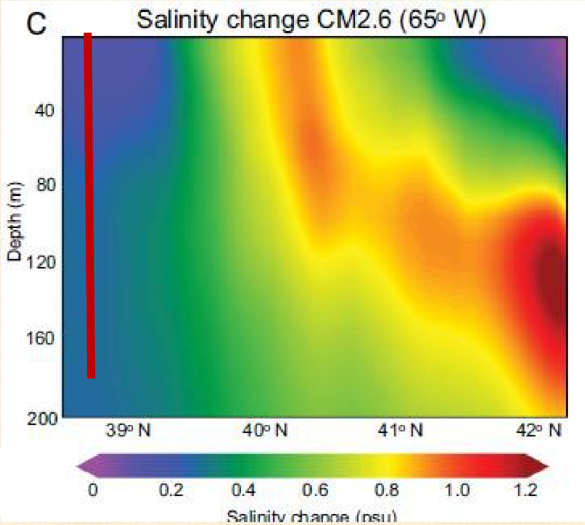


“Examining the ocean change in CM2.6* in more detail, we find an enhanced warming and a more substantial increase in salinity in not only the surface waters of the Northwest Atlantic Ocean but also in the bottom waters of the Northwest Atlantic Shelf. The increase in both temperature and salinity is associated with a northerly shift of the Gulf Stream, a retreat of the Labrador Current, and the replacement of cold Labrador Slope Water by warm Atlantic Temperate Slope Water along the Shelf Slope. This water mass replacement leads to a higher proportion of warmer and saltier Atlantic Temperate Slope Water entering the Shelf via the Northeast Channel.”

CM2.6 is a climate model from NOAA Geophysical Fluid Dynamic Laboratory w/ a highly spatially resolved ocean simulation.



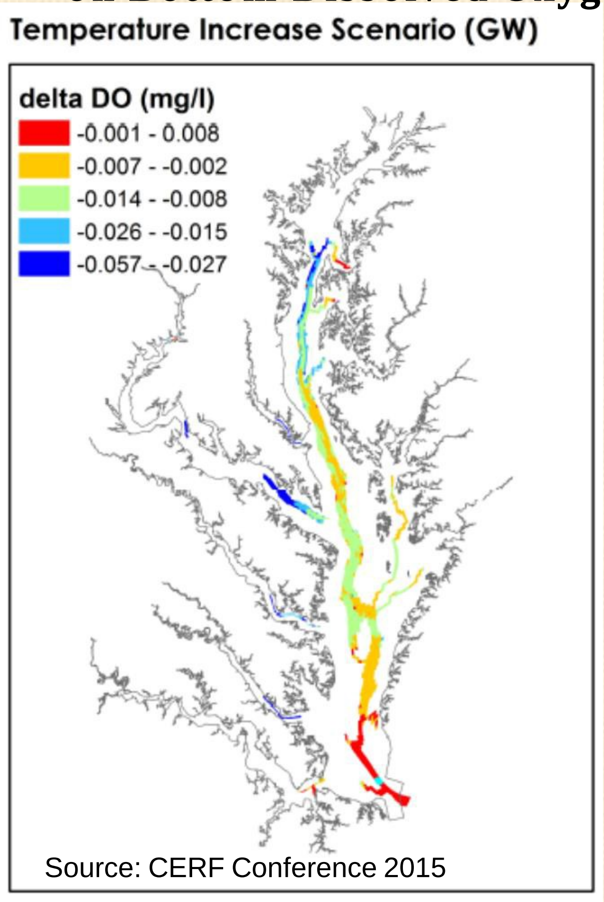




Conclusions:

- **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.**
- **The 0.4 ppt salinity adjustment at the ocean boundary is consistent with literature and provides a better simulation of the salinity distribution within the Chesapeake under estimated 2050 SLR conditions.**

Influence of Estimated 2050 Estuarine Temperature Increases on Bottom Dissolved Oxygen



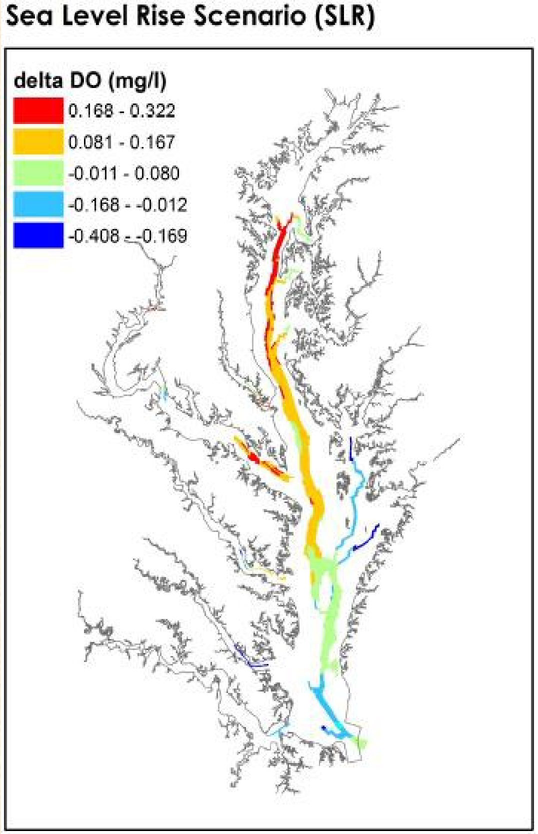
The influence of an 2050 estimated temperature increase on Chesapeake hypoxia is small.

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



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

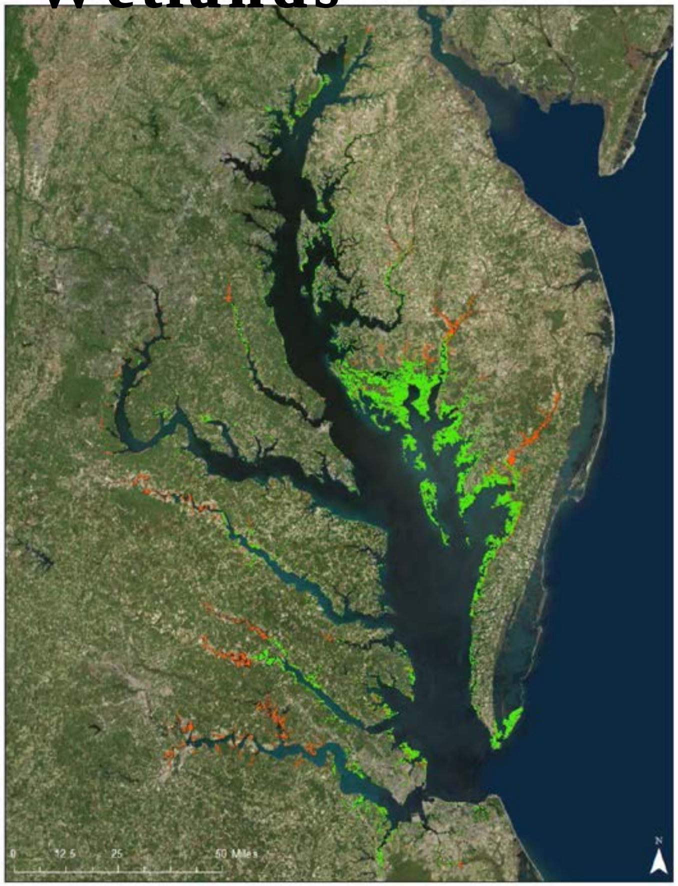
The estimated change from the base (1991 to 2000) condition in Chesapeake hypoxia due to 2050 estimated sea level rise conditions ranges from 0.3 mg/l to -0.4 mg/l.

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.

Source: CERF Conference 2015

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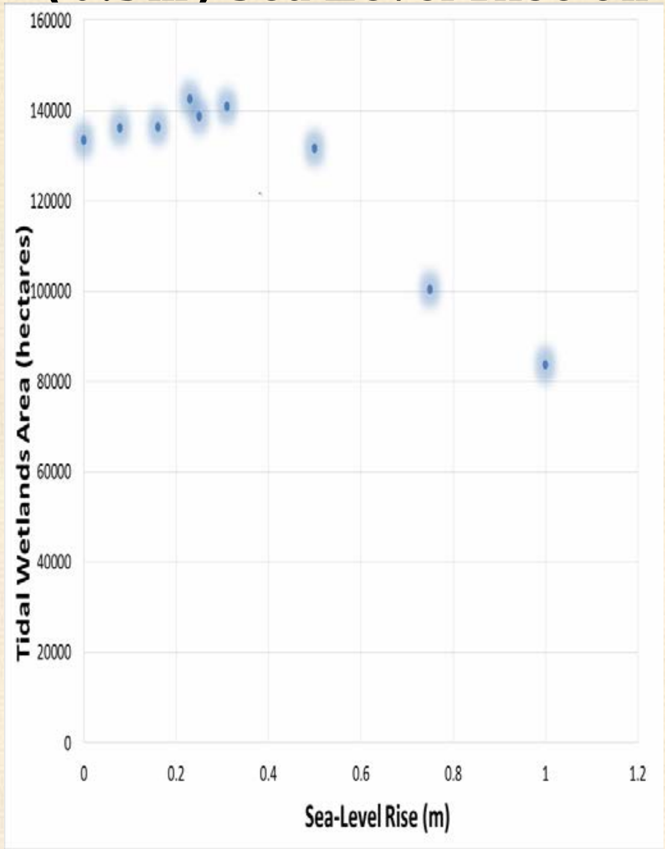
Influence of Estimated 2025 (0.3 m) and 2050 (0.5m) Sea Level Rise on Tidal



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.

Related Peer Review Questions

- Question 13) Does the applied methodology reflect the latest and best scientific understanding of the influence of climate on watershed processes and estuarine responses; is there any additional scientific information that should be included?

Section III

Policy Options for Addressing Climate Change in the Jurisdictions' Phase III WIPs

Zoë Johnson
National Oceanic and Atmospheric Administration
CBP Climate Change Coordinator

Policy Options

Quantitative

- ***Factor Climate Change into Phase III WIP' Base Conditions***:
  - Use either the 2025 or 2050 climate projection scenarios as base conditions (informed by CBWM climate modeling results) in the establishment of the jurisdictions' Phase III WIPs.
  - The climate change projection would be an added load that the jurisdictions would need to address in addition to their Phase III WIP planning targets, thereby increasing the level of effort.

Policy Option Language approved by PSC

Qualitative

- Optimize Phase III WIP Development and Adaptively Manage BMP Implementation:
  - During the development of Phase III WIPs, jurisdictions will prioritize BMPs that are more resilient to future climate impacts over the intended design life of the proposed practices.
  - During each two-year milestone development period, jurisdictions will consider new information on the performance of BMPs and the programs that support them, including the contribution of seasonal, inter-annual climate variability and weather extremes.
    - Jurisdictions will assess this information and adjust plans to implement their Phase III WIPs to better mitigate anticipated increases in nitrogen, phosphorus or sediment due to climate change.
  - Jurisdictions would provide a narrative consistent with the Guiding Principles that describes their programmatic commitments to address climate change in their Phase III WIPs.

Policy Option Language proposed by CRWG

What is a “resilient” BMP?

1) **Assess vulnerability** of BMP’s to projected impacts over intended design life
2) **Incorporate** resilient **siting and design principles**
3) **Monitor performance** over-time and adjust implementation, as necessary
4) **Research changes in BMP efficiencies** in response to extreme events or changing conditions.

STAC Workshop (Fall 2017): Monitoring and Assessing Impacts of Changes in Weather Patterns and Extreme Events on BMP Siting & Design

- What are the general principles of BMP siting and design to reduce the vulnerability of urban, agriculture, and coastal BMP's to future impacts of sea level rise, coastal storms, increased temperature, and extreme events?
- How flexible or adaptable are BMPs to anticipated changes in weather patterns and extreme events and what types of adjustments (e.g., retrofits) in BMP design to maintain structural integrity?
- What suite of BMPs are most robust (e.g., mitigate the anticipated increased nitrogen, phosphorus, and sediment loads) to anticipated changes in weather patterns and extreme events?
- What are the remaining gaps and highest priority needs (i.e., research, monitoring measures, programmatic efforts) to address in order to better inform and improve BMP development and implementation?

Related Peer Review Questions

Question 14) Many of the plans to incorporate climate change into programmatic efforts are using more qualitative information. To what extent is there reliable quantitative information on which land uses and BMPs are going to be impacted by climate change? Is there quantitative information on modification that can be made to land use and BMPs that are effective in addressing climate change?

Section IV

Wrap Up

Zoë Johnson
National Oceanic and Atmospheric Administration
CBP Climate Change Coordinator

Recommended 2025 Modeling Climate Inputs

Variable	Input	Modeling Run Completed	Uncertainty Analysis Component
CO_2	427 ppm	Watershed Model	No
Potential Evapotranspiration	Hargreaves-Samani	Watershed Model	Yes
	Hamon	Watershed Model	Yes
Temperature	RCP 2.6 Ensemble Median		Yes
	RCP 4.5 Ensemble Median	Watershed Model, WQSTM	Yes
	RCP 8.5 Ensemble Median		Yes
Precipitation	Historical Trend (+3.1%) with no Δ Intensity	Watershed Model	Yes
	Historical Trend (+3.1%) with Δ Intensity	Watershed Model	Yes
Sea Level Rise	0.17 meters		Yes
	0.3 meters	WQSTM	Yes
Wetland Loss	NWF SLAMM Model Runs (2008)	WQSTM	Yes
	NOAA SLR Viewer (Marsh Migration)		Yes

Recommended 2050 Modeling Climate Inputs

Variable	Input	Modeling Run Completed	Planned Uncertainty Analysis Component
CO_2	487ppm	Watershed Model	No
Potential Evap.	Hargreaves-Samani	Watershed Model	Yes
	Hamon	Watershed Model	Yes
Temperature	Six GCM Analysis: 2040 and 2060	WQSTM (prior methodology but not recommended by CRWG	No
	RCP 2.6 Ensemble Median		Yes
	RCP 4.5 Ensemble Median	Watershed Model	Yes
	RCP 8.5 Ensemble Median		Yes
Precipitation	RCP 2.6 Ensemble Median		
	RCP 4.5 Ensemble Median		Yes
	RCP 8.5 Ensemble Median		Yes
Sea Level Rise	.3 meters	WQSTM	
	0.5 meters	WQSTM	Yes
	0.8 meters		Yes
Wetland Loss	NWF SLAMM Model Runs (2008)	WQSTM	Yes
	NOAA SLR Viewer (Marsh Migration)		Yes

PSC Decision-Making Timeline

- **December 13, 2016**: Agreement on 1) climate change assessment procedures, 2) guiding principles, and 3) the range of options for how and when to factor climate change considerations into the jurisdictions' Phase III WIPs
- **Late October 2017**: How and when to incorporate climate change considerations into the Phase III WIPs
- **March 2018**: Final Phase III WIP planning targets fully reflecting Partnership decisions regarding how and when to incorporate climate change considerations

CBP Climate Change Resources

- Chesapeake Bay Program, 2016. Climate Resiliency Workgroup. Recommendations on Incorporating Climate-Related Data Inputs and Assessments: Selection of Sea Level Rise Scenarios and Tidal Marsh Change Models to Inform the Chesapeake Bay TMDL 2017 Mid-Point Assessment (August 5, 2016).
- Chesapeake Bay Program, 2016. Climate Resiliency Workgroup. Principal Staff Committee Briefing Document: Guiding Principles and Options for Addressing Climate Change Considerations in the Jurisdictions' Phase III Watershed Implementation Plans (December, 2016)
- Johnson, Z., M. Bennett, L. Linker, S. Julius, R. Najjar, M. Mitchell, D. Montali, R. Dixon, 2016. *The Development of Climate Projections for Use in Chesapeake Bay Program Assessments*.

Related Peer Review Questions

- Question 15) For longer term CBP considerations, how can the overall approach and procedures be improved and what alternative approaches and data would be recommended?

- Question 16) Please comment on the climate change modeling documentation. Is it clear, well organized, concise and complete?

Questions?

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Photo: Lee Goodwin