Chesapeake Bay Program Phase 6 Climate Change Model Initial Findings

Agriculture Workgroup – February 2020

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PENNSTATE 1855

Chesapeake Bay Program
Science. Restoration. Partnership.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

USGS
science for a changing world

Presentation Outline

- Management Decisions
- Summary of Climate Effects
- Climate Assessment Results – Initial Findings
- Initial Load Adjustment Estimates

Principals' Staff Committee Decisions in 2017 and 2018

- No change in the WIPIII target loads until 2025, unless PSC decides to do otherwise.
- Adjust the 2022-2023 milestones for climate change which could mean:
  - Lower the load target
  - Keep the same WIPIII targets and designate an additional climate reduction, perhaps with a different goal date
  - Something else

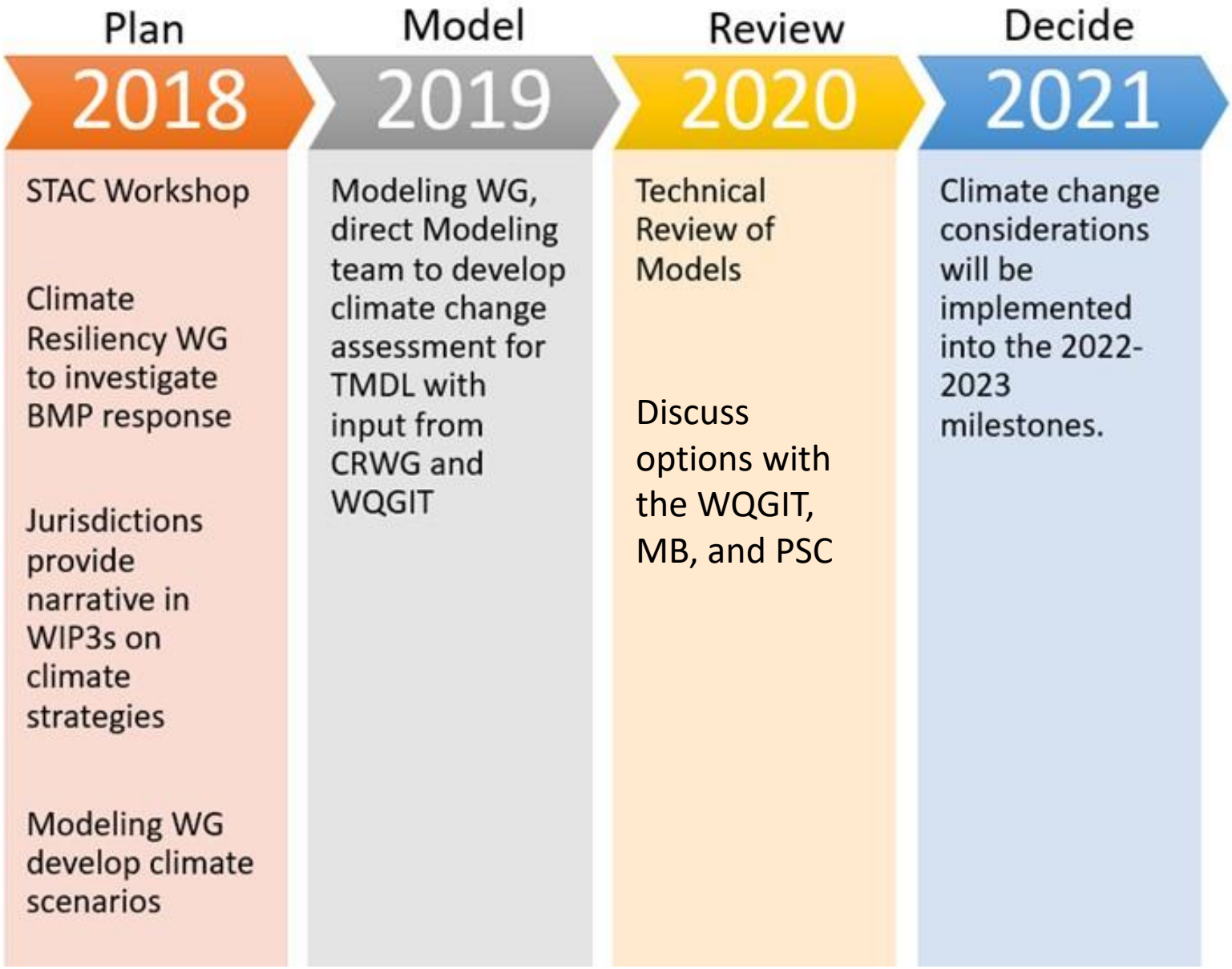
Climate is a moving target

- TMDL is based on hydrology centered on 1995
- TMDL end date is 2025

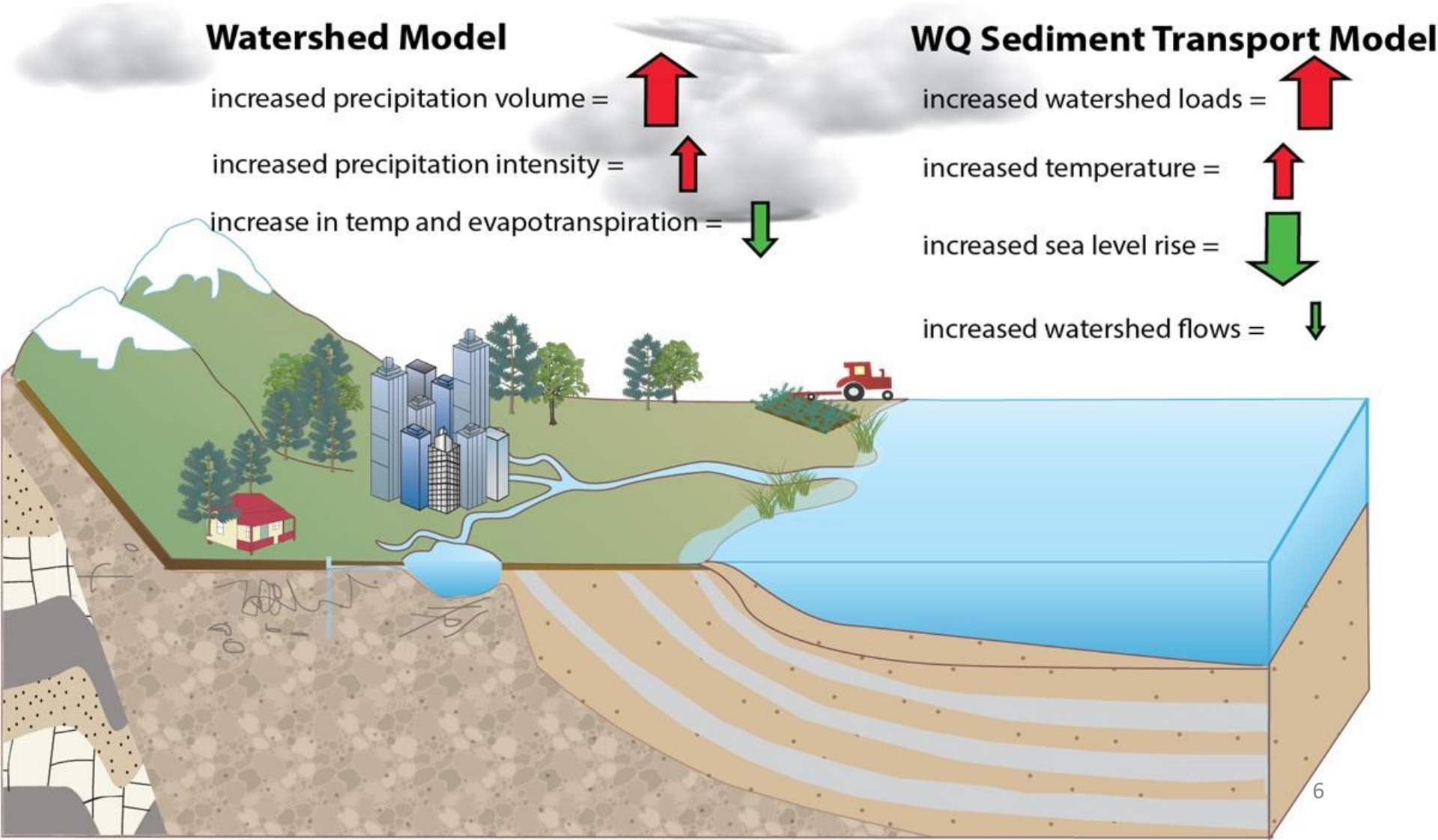
- **How has an ‘average hydrologic condition’ changed between 1995 and 2025**

- Look at 2035, 2045, and 2055

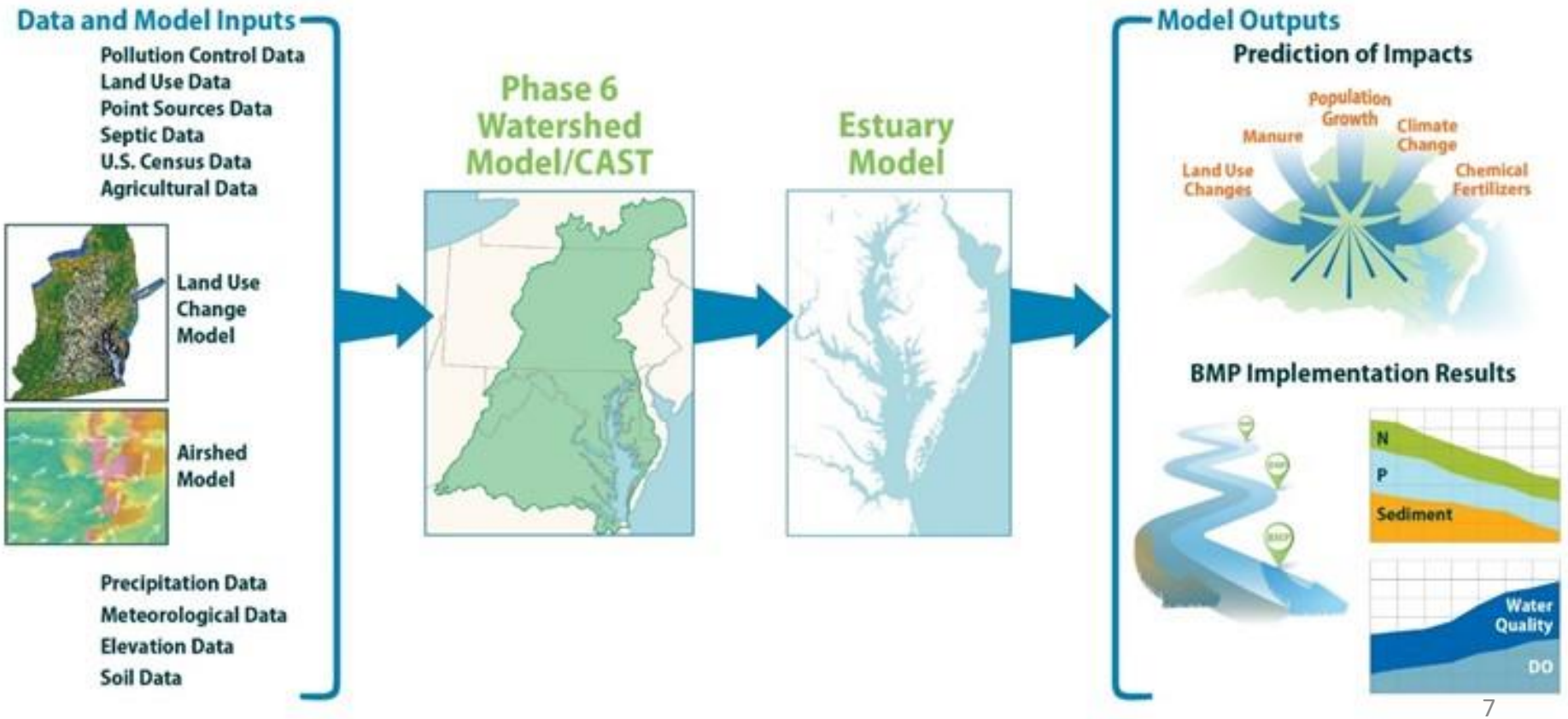
CBP Climate Work Plan



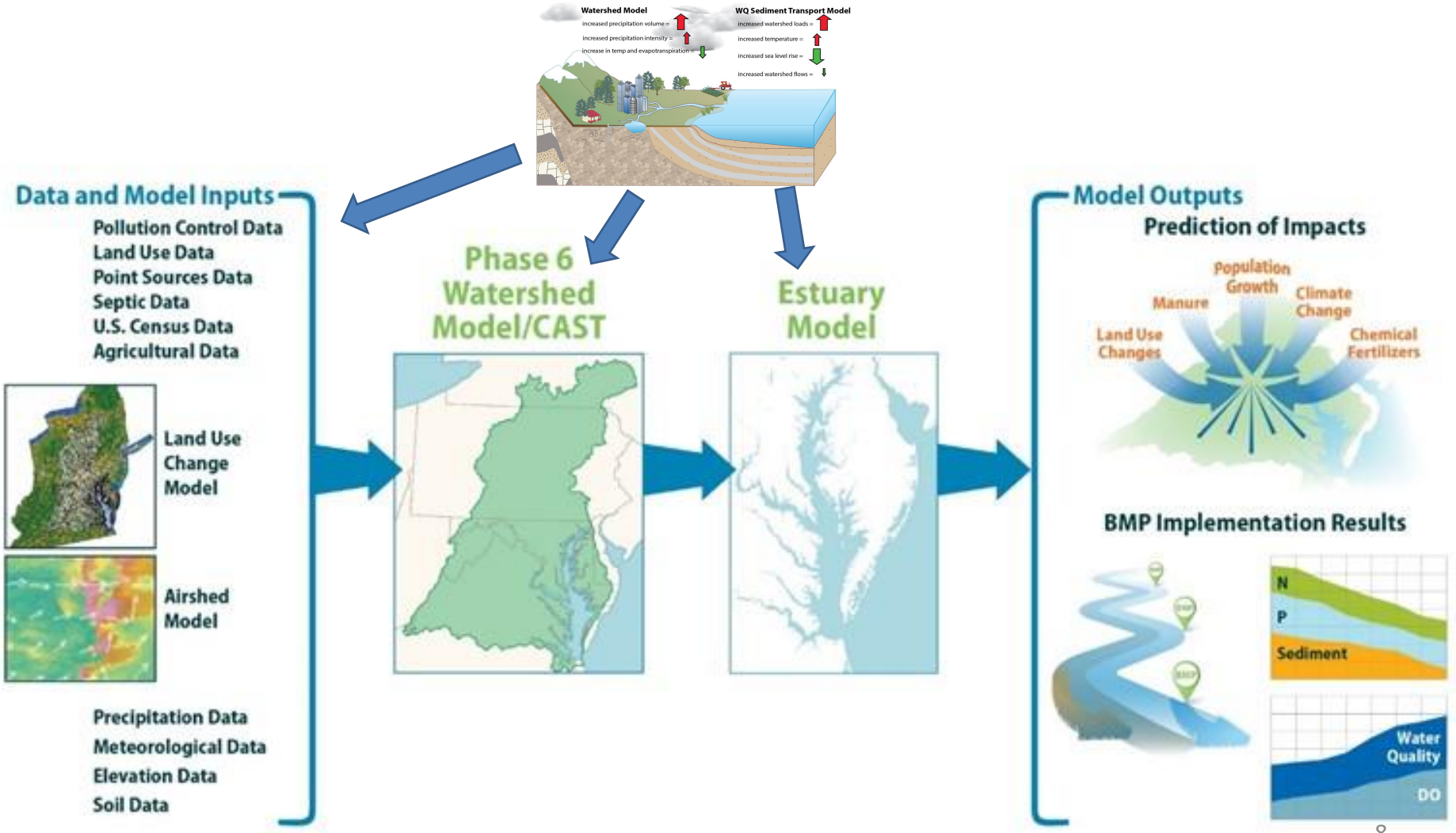
Components of Climate Change



CBP Models


Data and Model Inputs
Pollution Control Data
Land Use Data
Point Sources Data
Septic Data
U.S. Census Data
Agricultural Data
Land Use Change Model
Airshed Model
Precipitation Data
Meteorological Data
Elevation Data
Soil Data
Phase 6 Watershed Model/CAST
Estuary Model
Model Outputs
Prediction of Impacts
Population Growth
Manure
Climate Change
Land Use Changes
Chemical Fertilizers
BMP Implementation Results
N
P
Sediment
Water Quality
DO

CBP Models


Watershed Model
increased precipitation volume =
increased precipitation intensity =
increase in temp and evapotranspiration =
WQ Sediment Transport Model
increased watershed loads =
increased temperature =
increased sea level rise =
increased watershed flows =
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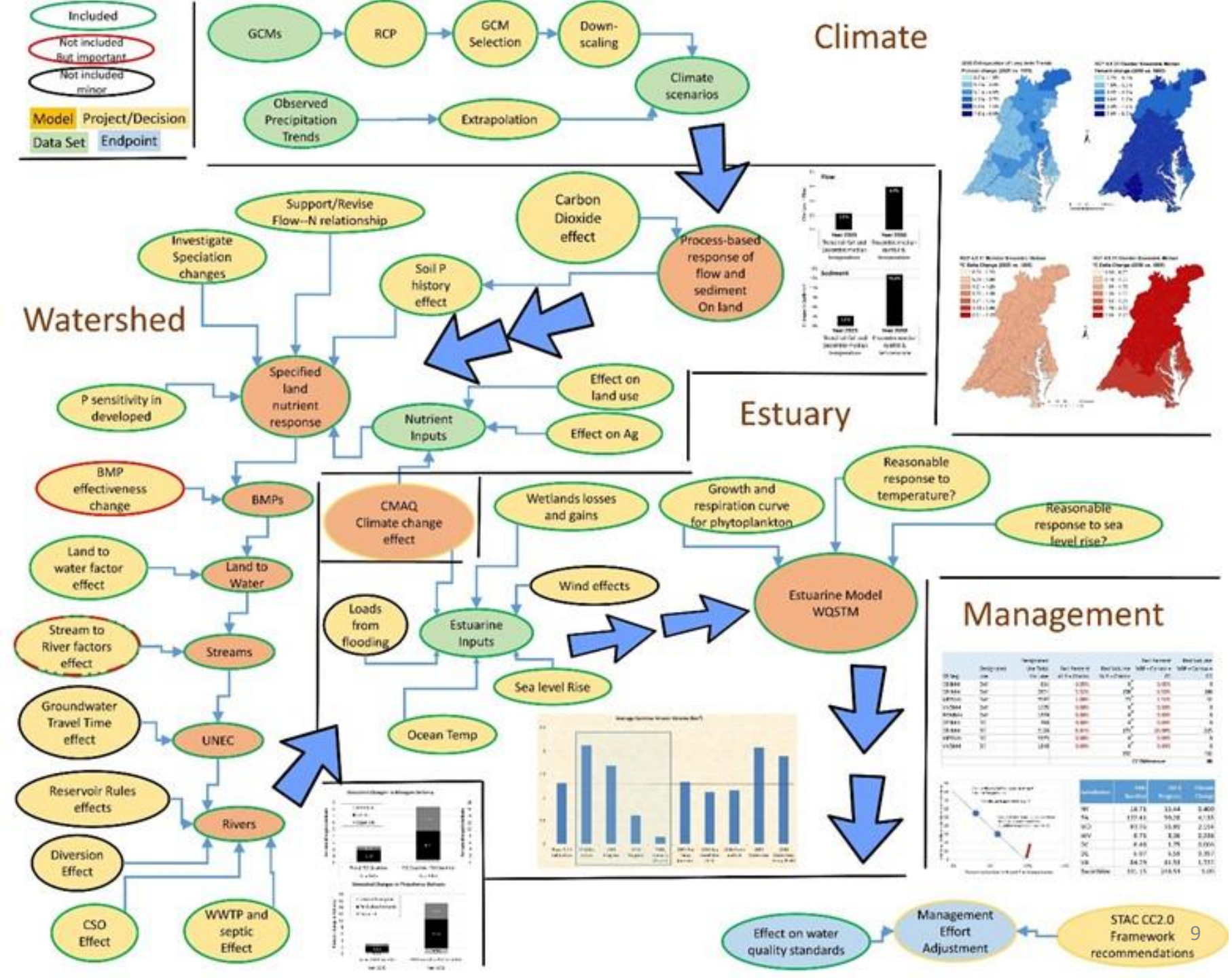
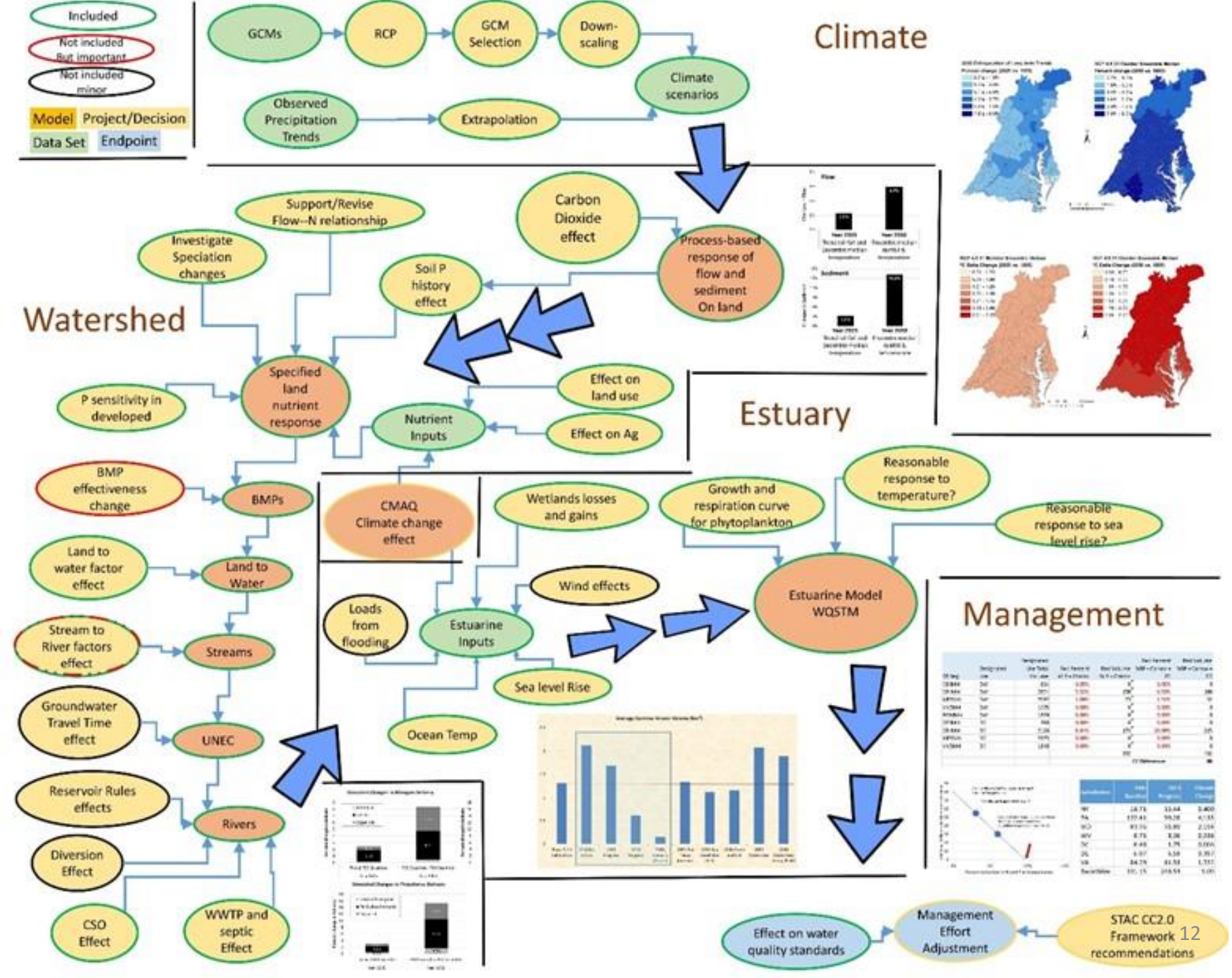

Included
Not included But important
Not included minor
Model
Project/Decision
Data Set
Endpoint
GCMs
RCP
GCM Selection
Down-scaling
Climate scenarios
Observed Precipitation Trends
Extrapolation
Climate
Support/Revise Flow--N relationship
Carbon Dioxide effect
Investigate Speciation changes
Process-based response of flow and sediment On land
Soil P history effect
Watershed
Specified land nutrient response
Effect on land use
P sensitivity in developed
Nutrient Inputs
Effect on Ag
Estuary
BMP effectiveness change
BMPs
CMAQ Climate change effect
Wetlands losses and gains
Growth and respiration curve for phytoplankton
Reasonable response to temperature?
Reasonable response to sea level rise?
Land to water factor effect
Land to Water
Wind effects
Estuarine Model WQSTM
Loads from flooding
Estuarine Inputs
Management
Stream to River factors effect
Streams
Sea level Rise
Groundwater Travel Time effect
UNEC
Ocean Temp
Reservoir Rules effects
Rivers
Diversion Effect
CSO Effect
WWTP and septic Effect
Effect on water quality standards
Management Effort Adjustment
STAC CC2.0 Framework recommendations

CBP 2019 MWG Climate Work Plan

Climate Modeling Approval

Section	Topic	July Approval	October Approval	November Approval	Does Not Require Approval
1	Introduction				X
2	Meteorology and precipitation	X			
3.1	Atmospheric deposition		X		
3.2	Land use	X			
3.3	Agricultural inputs	X			
3.4	Direct loads	X			
4.1	CO2 concentration response	X			
4.2	Hydrology simulation	X			
4.3	Sediment loss simulation	X			
4.4	Nitrogen loss sensitivity		X		
4.5	Phosphorus loss sensitivity		X		
4.6	BMP effectiveness		X		
4.7.1	Nitrogen speciation		X		
4.7.2	Groundwater lag	X			
4.7.3	Delivery effects		X		
4.8	Watershed simulation results			X	
5.1.1	Wetlands losses and gains		X		
5.1.2	Wind effects	X			
5.1.3	Sea level rise	X			
5.1.4	Ocean boundary	X			
5.1.5	Tidal flooding loads		X		
5.2	Growth curve modification	X			
5.3	Validation of model response		X		
5.4	Estuarine simulation results			X	
6.1	Water quality standards				X
6.2	Management effort adjustment				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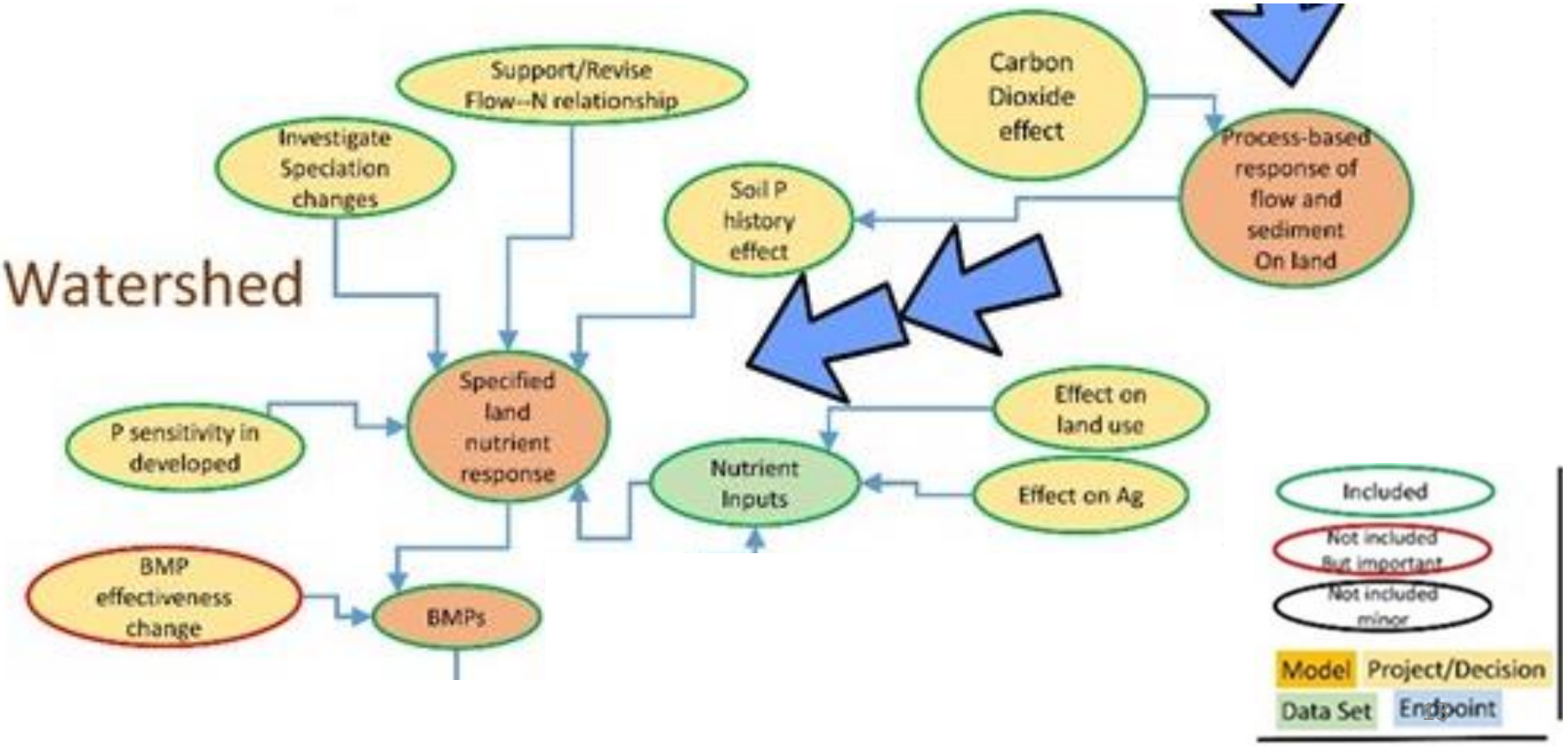
Ag-related topics



Ag Related Topics

Carbon Dioxide effect

- More CO_2 decreases transpiration

Soil P history effect

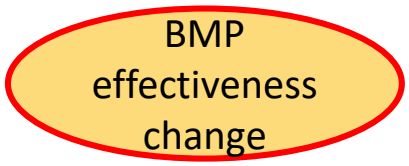
- Greater surface runoff and soil losses
  - higher P loads
  - Faster soil depletion – 10%-20% less of a load increase

Ag Related Topics

Effect on Ag

- Literature points to
  - Increased stress from droughts, extreme precipitation, temperature
  - Beneficial effects of CO2
  - Northward migration of crops
- We already know 1982-2017 trends and project them to 2025
- No methods to 2035, 2045, or 2055

Ag Related Topics



- Literature points to decreased performance, but not enough information
- PSC directed the Management Board to develop a better understanding of BMP effectiveness change by 2025
- The WQGIT and Climate Resiliency Workgroups are working on projects

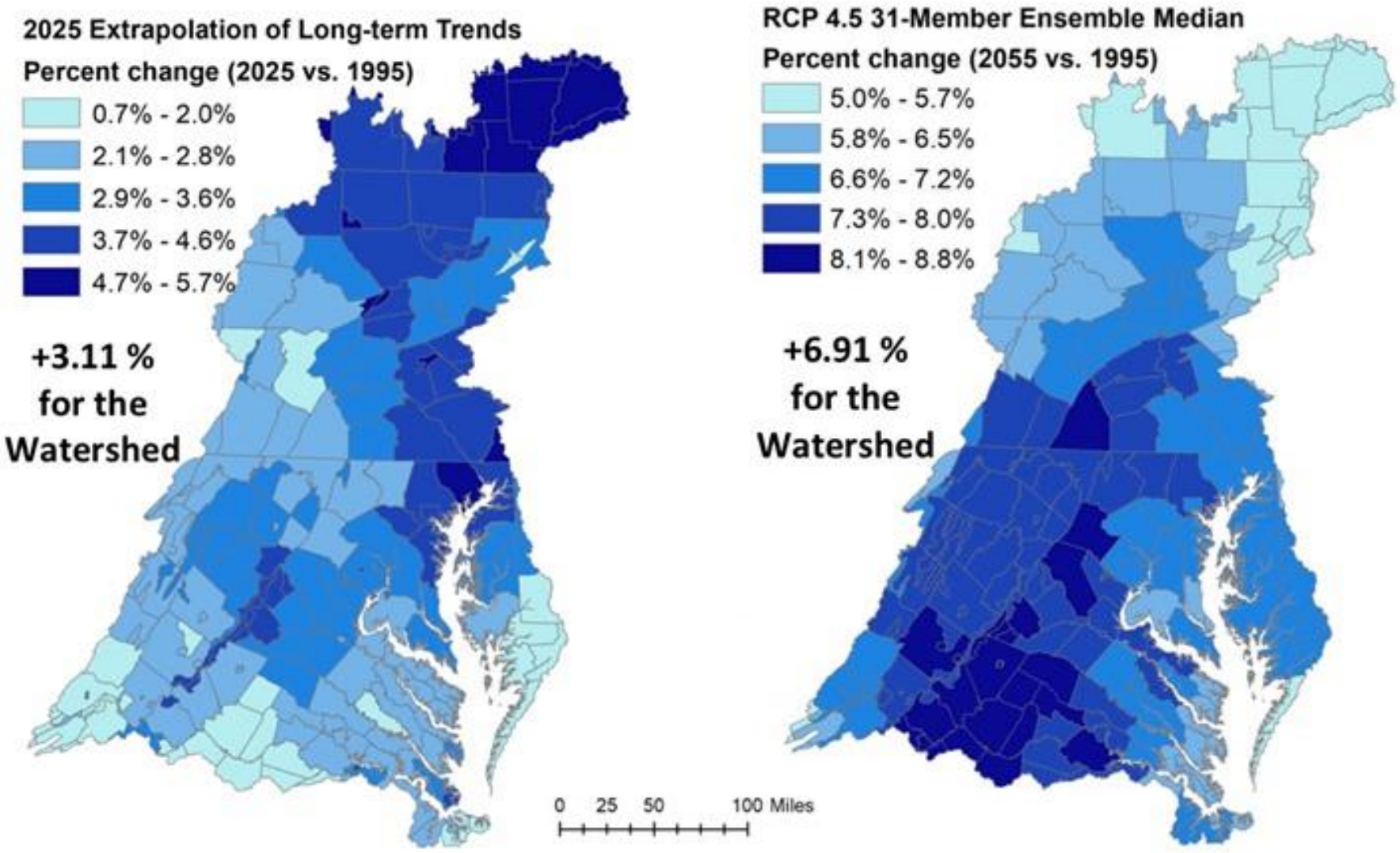
STAC BMP project

- Climate Change and Uncertainty Science Synthesis Kurt Stephenson and Zach Easton;
- (~ Jan 2020 – Dec 2020)
- Awarded to Virginia Tech - Kurt Stephenson and Zach Easton;
- climate change effects on BMP performance (emphasis on ag BMPs, but also evaluating urban and natural)

Urban Stormwater project

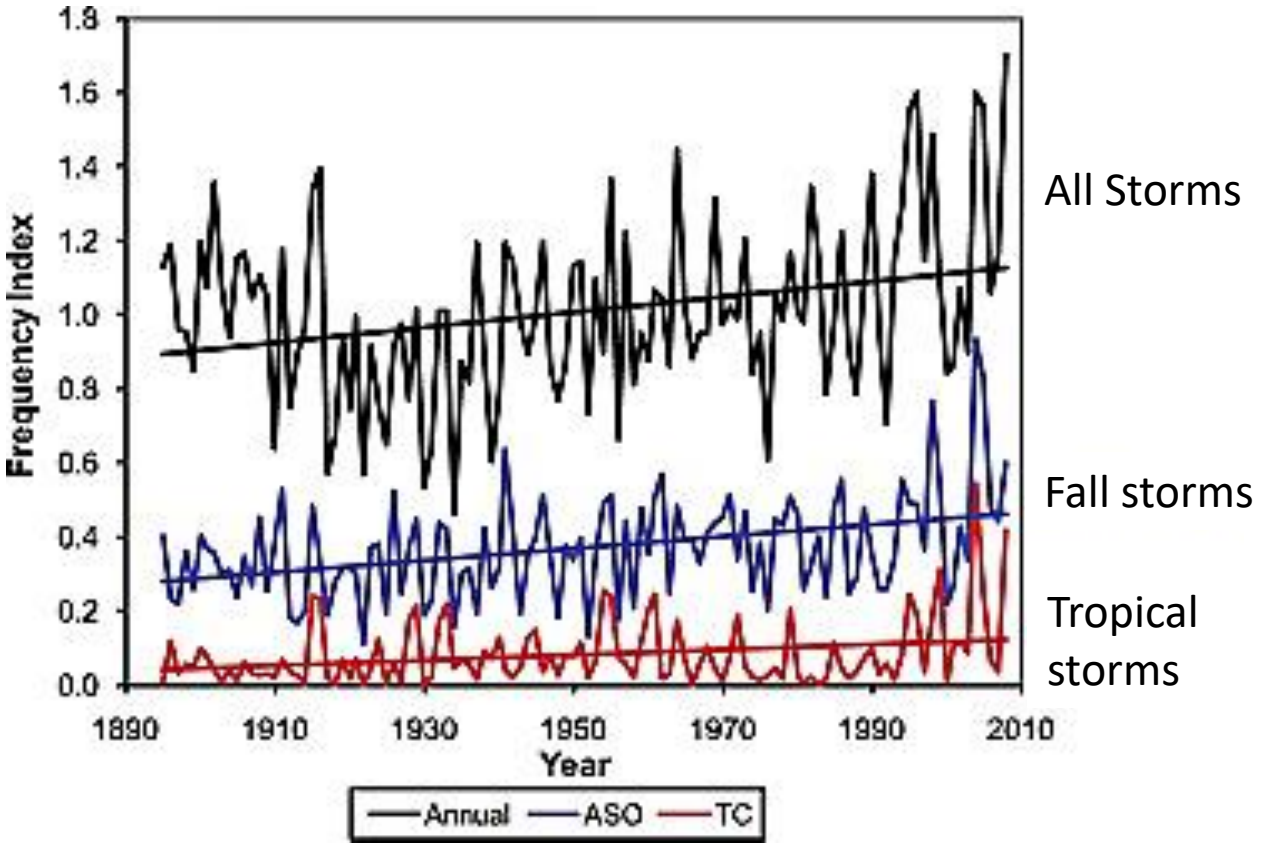
- GIT-Funded – Piloting the Development of Probabilistic Intensity Duration Frequency (IDF) Curves for Chesapeake Bay Watershed
  - (~ March 2020 – March 2021)
- Chesapeake Stormwater Network: Urban stormwater BMP climate vulnerability assessment
  - (~ Jan 2020 – October 2020)

Rainfall


2025 Extrapolation of Long-term Trends
Percent change (2025 vs. 1995)
0.7% - 2.0%
2.1% - 2.8%
2.9% - 3.6%
3.7% - 4.6%
4.7% - 5.7%
+3.11 % for the Watershed
RCP 4.5 31-Member Ensemble Median
Percent change (2055 vs. 1995)
5.0% - 5.7%
5.8% - 6.5%
6.6% - 7.2%
7.3% - 8.0%
8.1% - 8.8%
+6.91 % for the Watershed
0 25 50 100 Miles

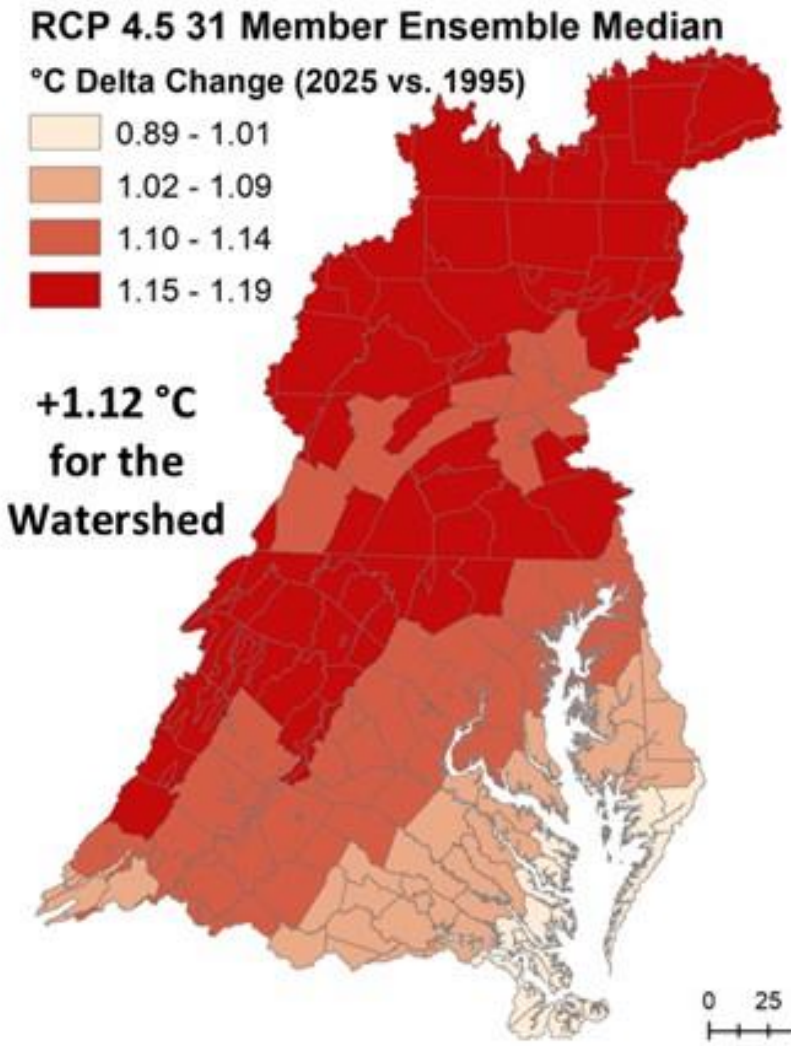
Climate delta change from 1995

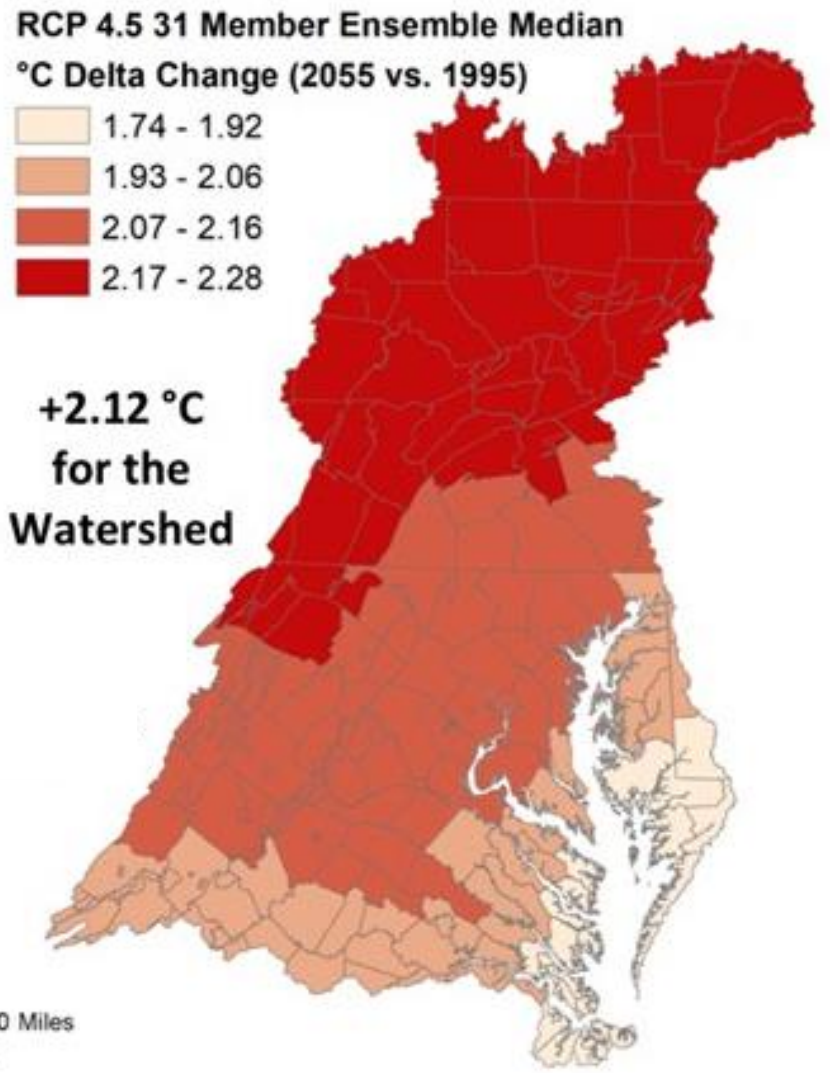
More volume into higher intensity events



National average heavy precipitation event index (HPEI) for the entire year (annual, black), for August through October (ASO, blue), and for heavy events associated with tropical cyclones (TC, red). [Kunkel et al., 2010]

Temperature

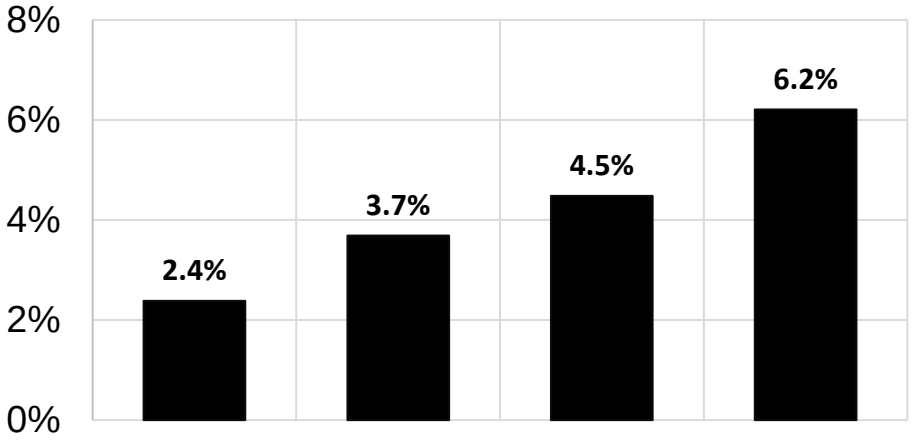




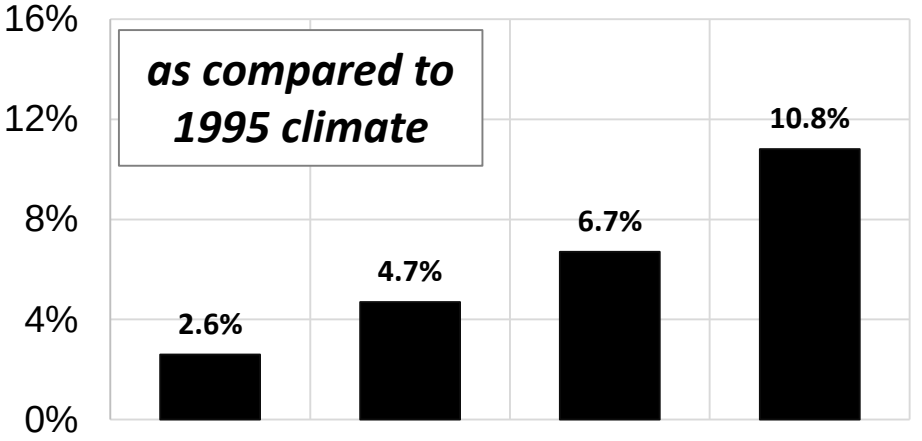
0 25 50 100 Miles

Estimated Water Quality Responses

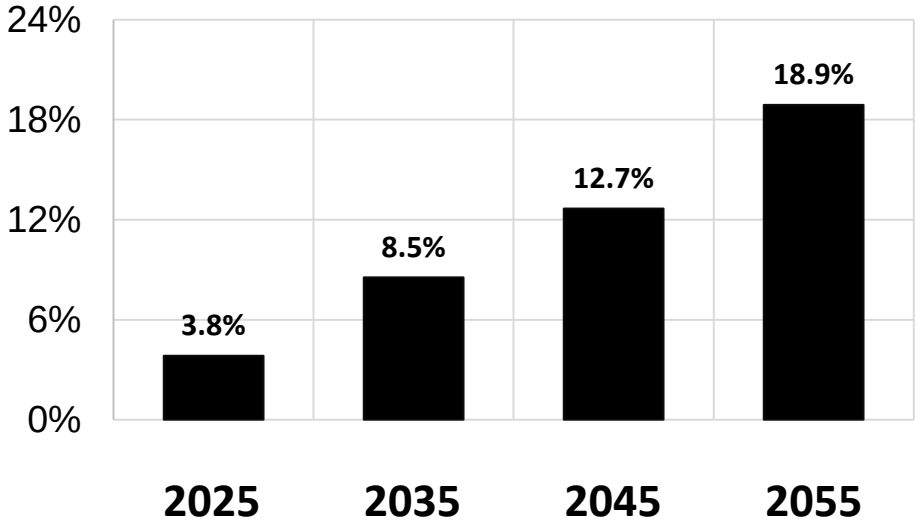
Marginal Differences in **Freshwater** Delivery



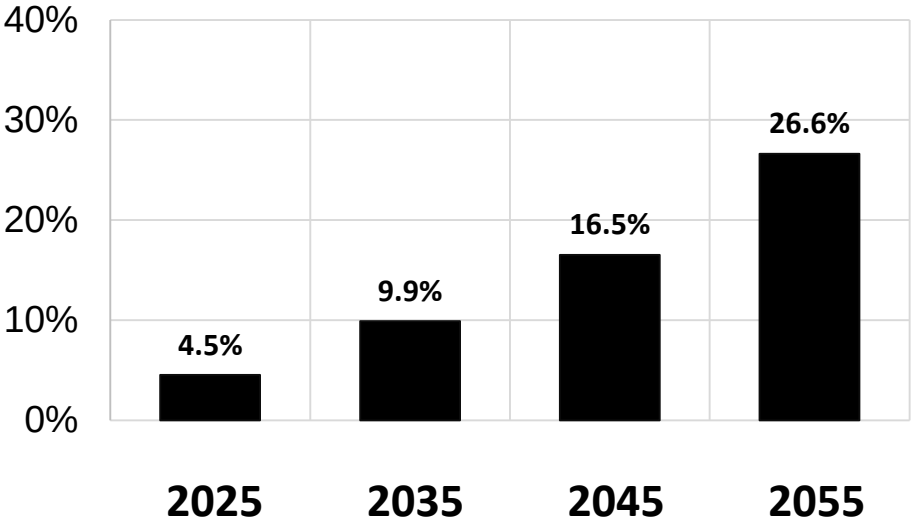
Marginal Differences in **Nitrogen** Delivery



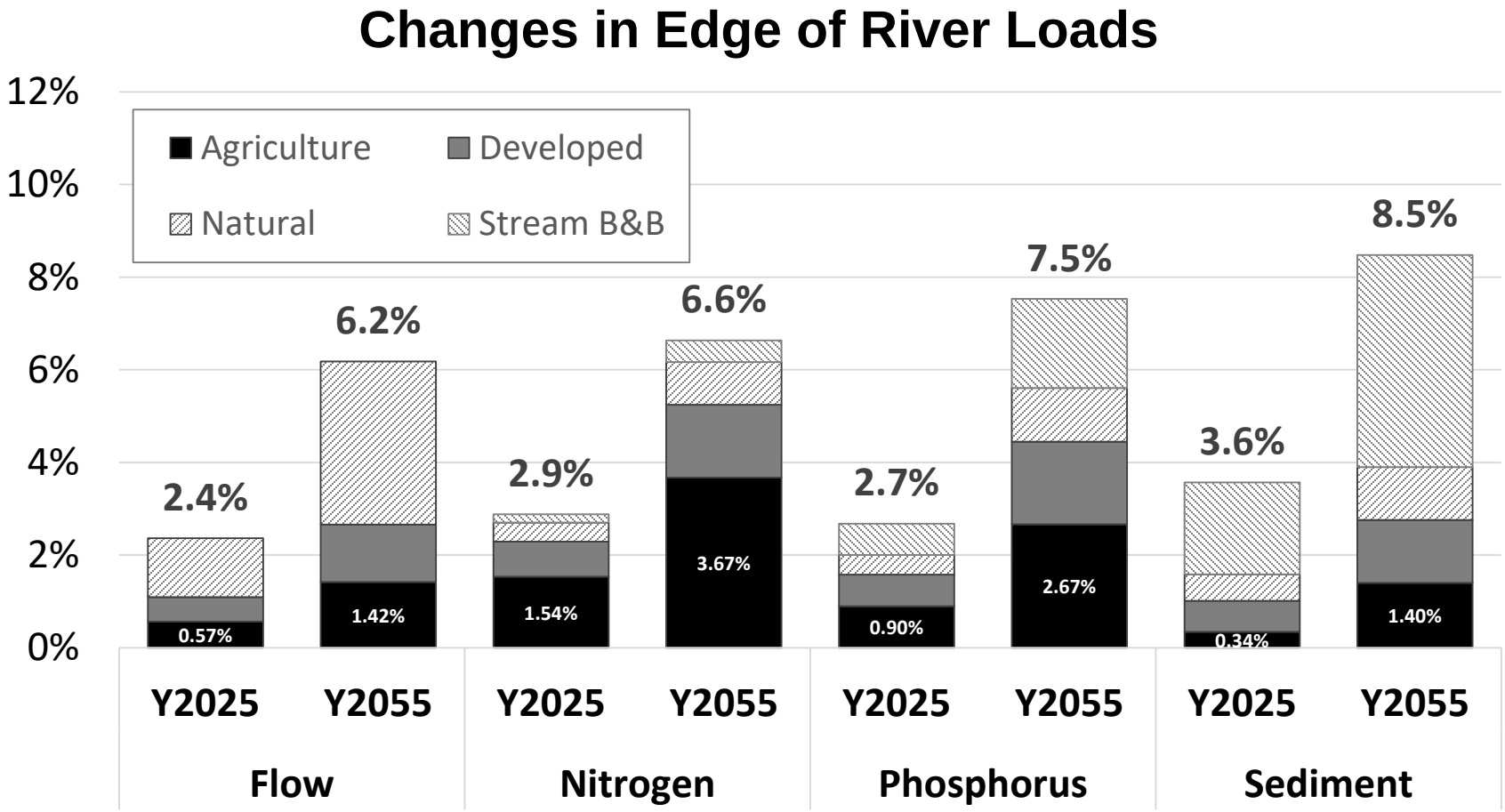
Marginal Differences in **Sediment** Delivery



Marginal Differences in **Phosphorus** Delivery



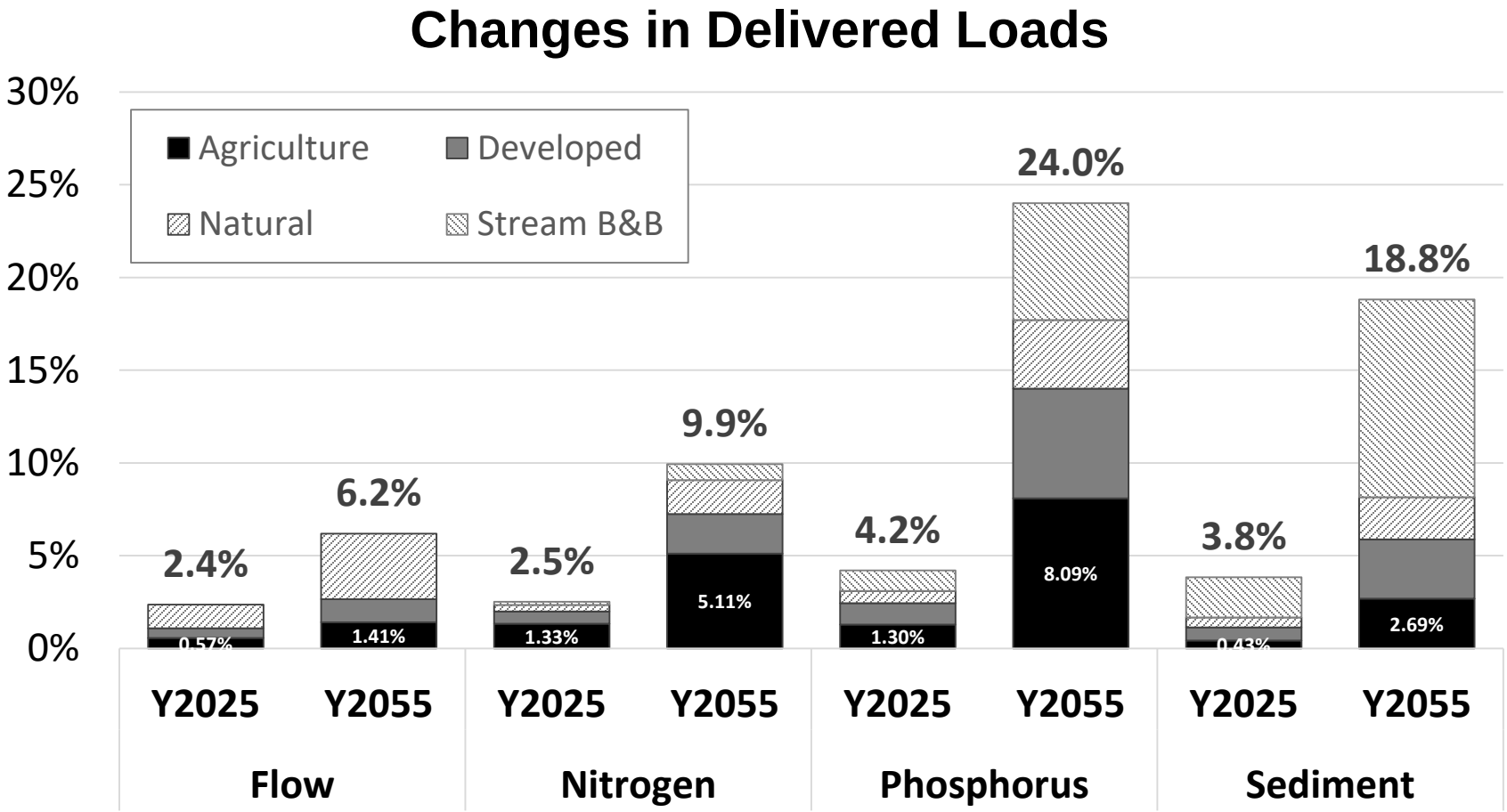
Edge of River Loads



% change with respect to delivered loads under 1995 climate

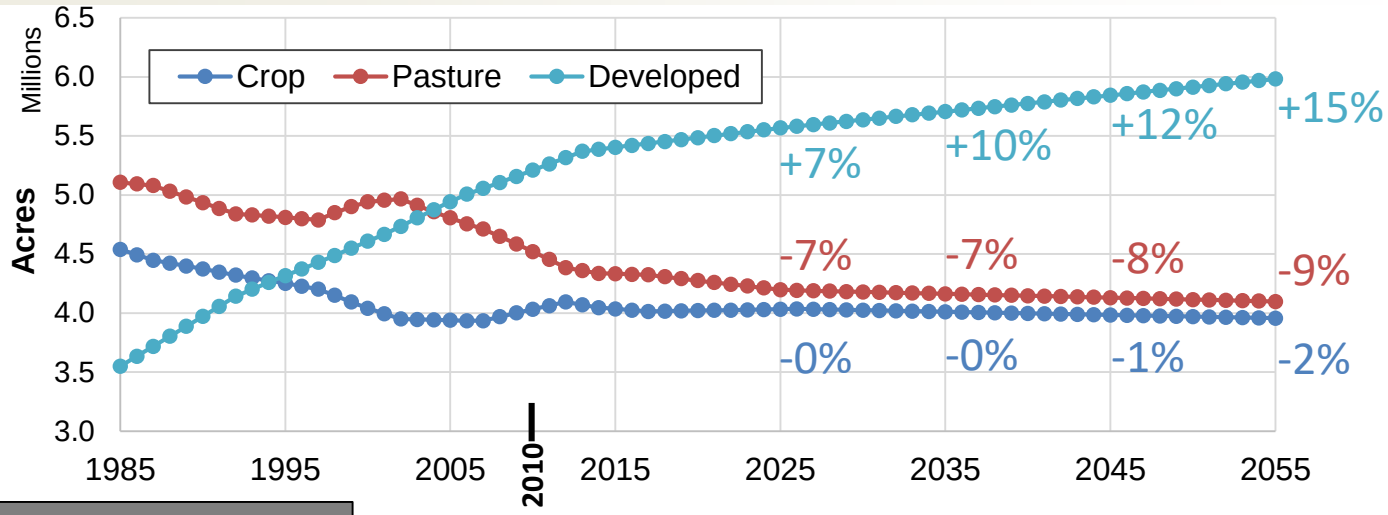
Edge of Tide (Delivered) Loads

- Less retention/losses of nutrients in the rivers



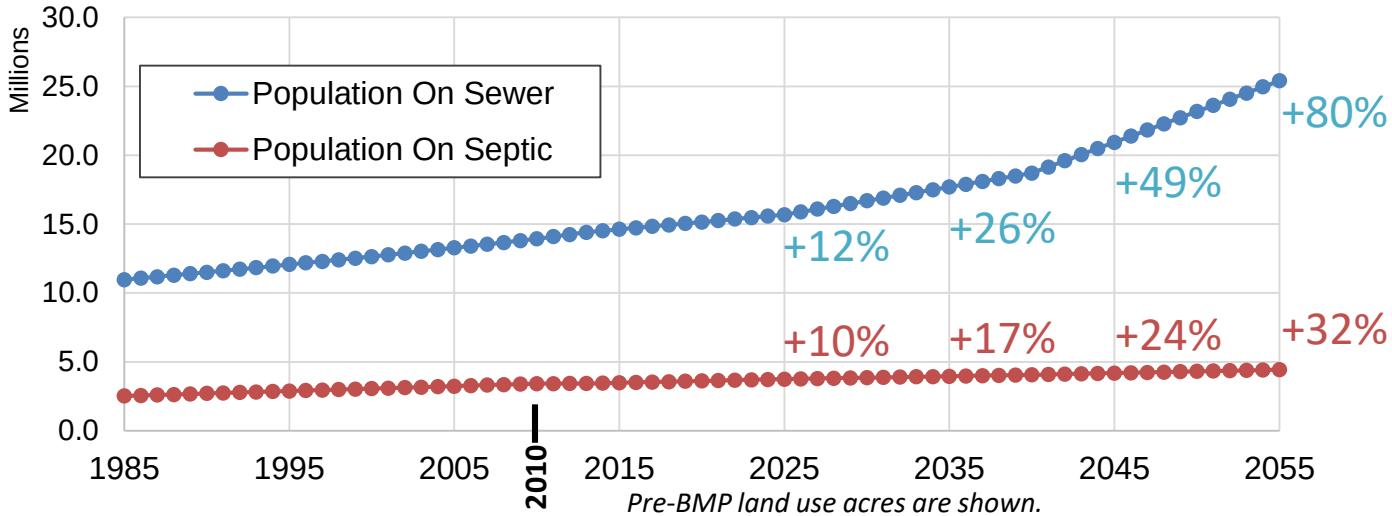
% change with respect to delivered loads under 1995 climate

Land use acres - Chesapeake Bay Watershed



Chesapeake Bay Land Change Model
(CBLCM Version 4 – *Claggett, P., et al.*)

Population - Chesapeake Bay Watershed

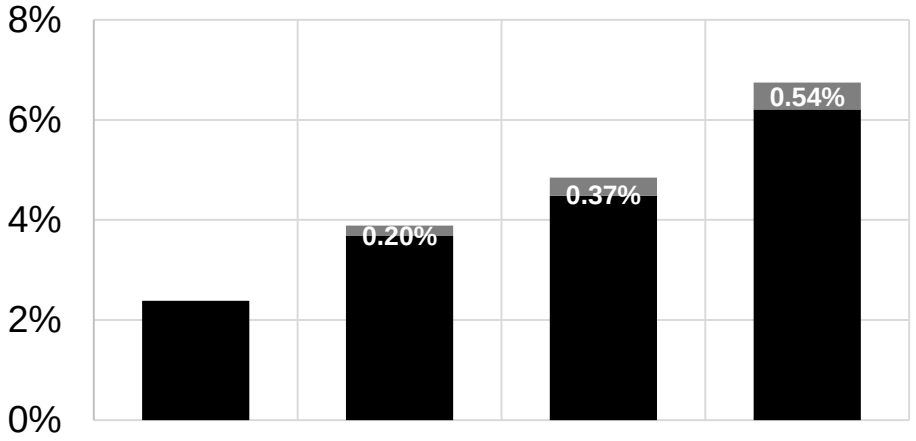


Pre-BMP land use acres are shown.
Percent changes are shown with respect to 2010 (with WIP2 level of effort)

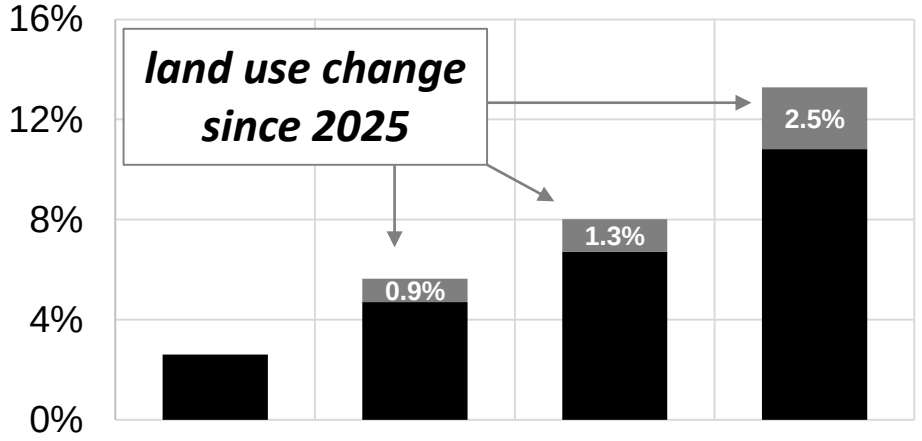
[1] https://www.chesapeakebay.net/channel_files/35723/20190402_-_bhatt_-_mwqm_-_2019_climate_change_assessment.pdf

Estimated Water Quality Responses

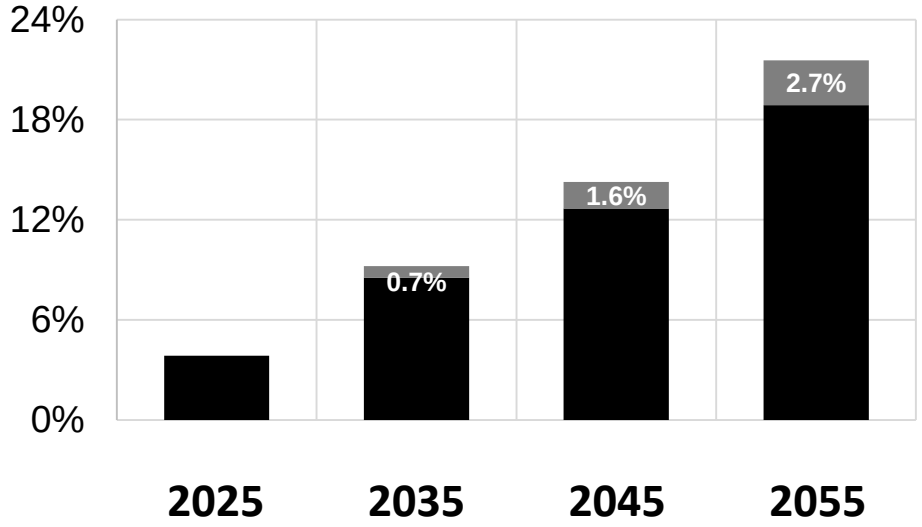
Marginal Differences in **Freshwater** Delivery



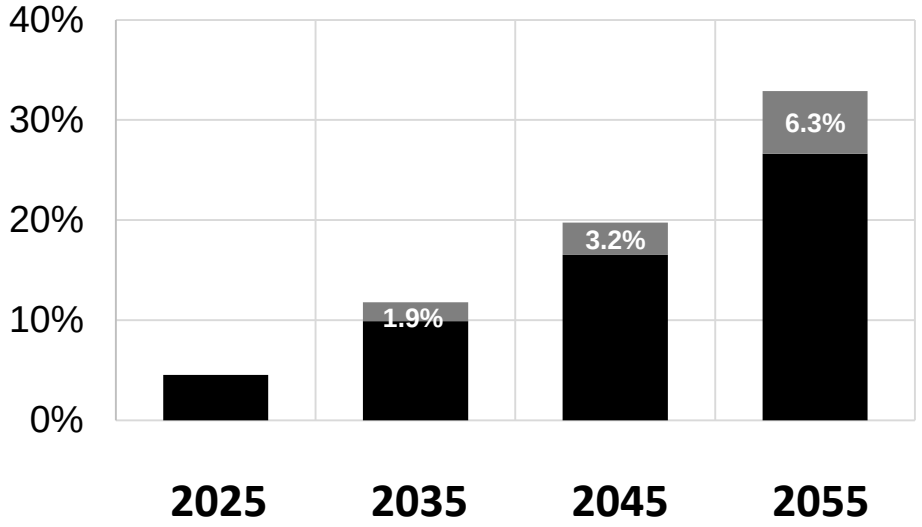
Marginal Differences in **Nitrogen** Delivery



Marginal Differences in **Sediment** Delivery



Marginal Differences in **Phosphorus** Delivery



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Current Climate Change Only Scenarios

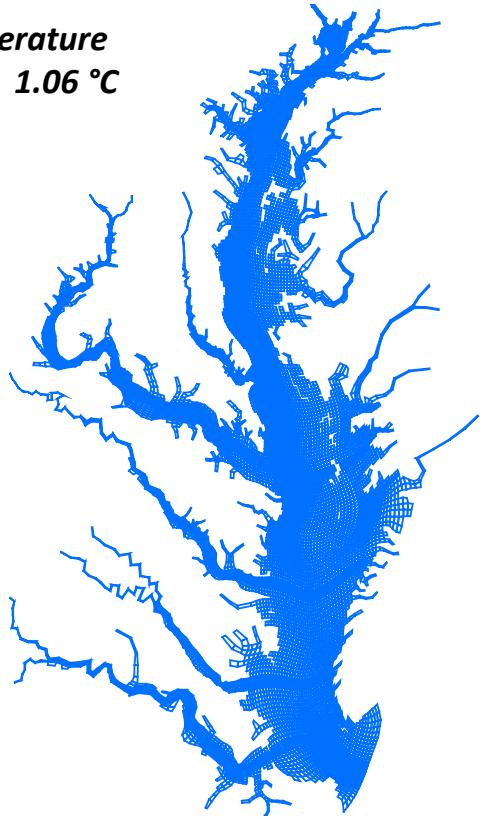
Air-temperature increase: 1.06 °C

Flow
+2.4% est. 2025

TN
+2.6% est. 2025

TP
+4.5% est. 2025

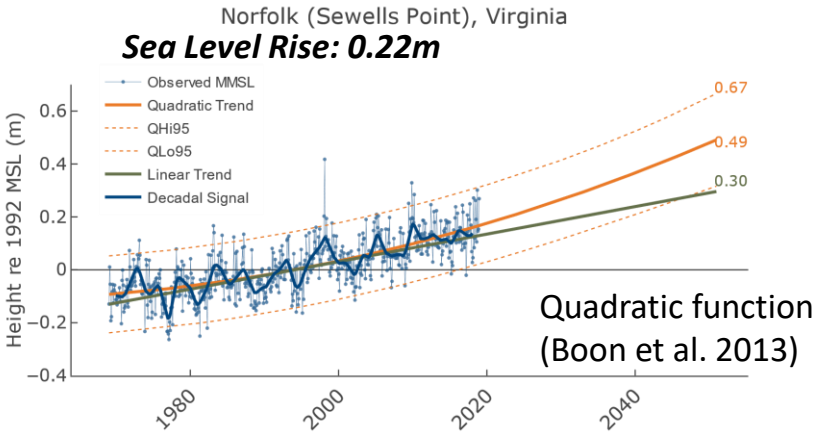
Sediment
+3.8 est. 2025



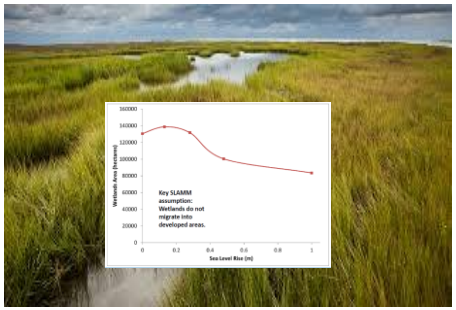
Ocean boundary

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

Sea Level Rise: 0.22m



Quadratic function
(Boon et al. 2013)



Tidal wetland change

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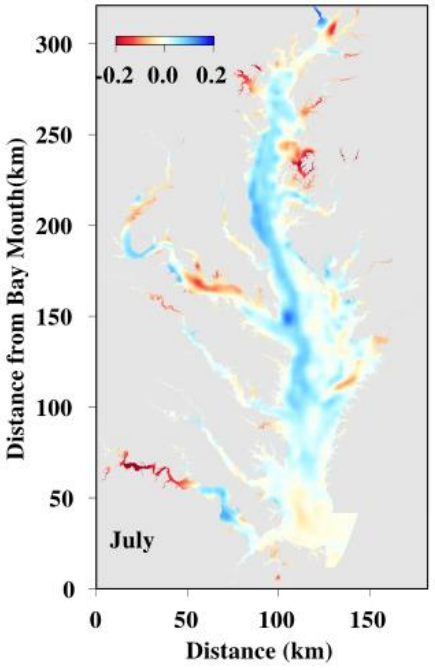
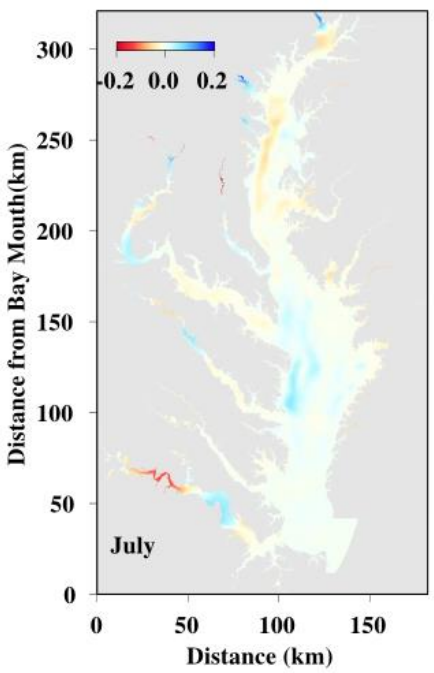
Bottom DO Change: 1995 to 2025

Keeping all other factors constant, sea level rise and increased watershed flow reduce hypoxia in the Bay, but the predominant influence are the negative impacts of increased water column temperature.

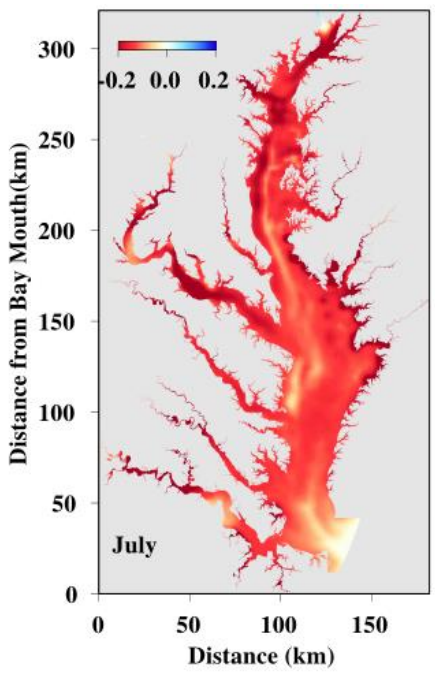
Sea Level Rise



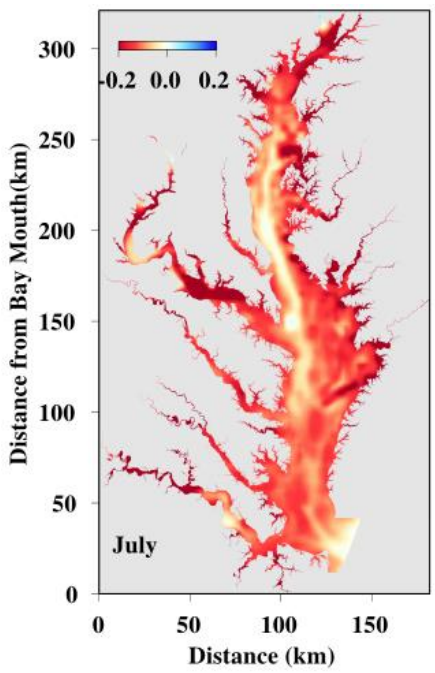
Watershed Flow



Increased Temp.



All Factors



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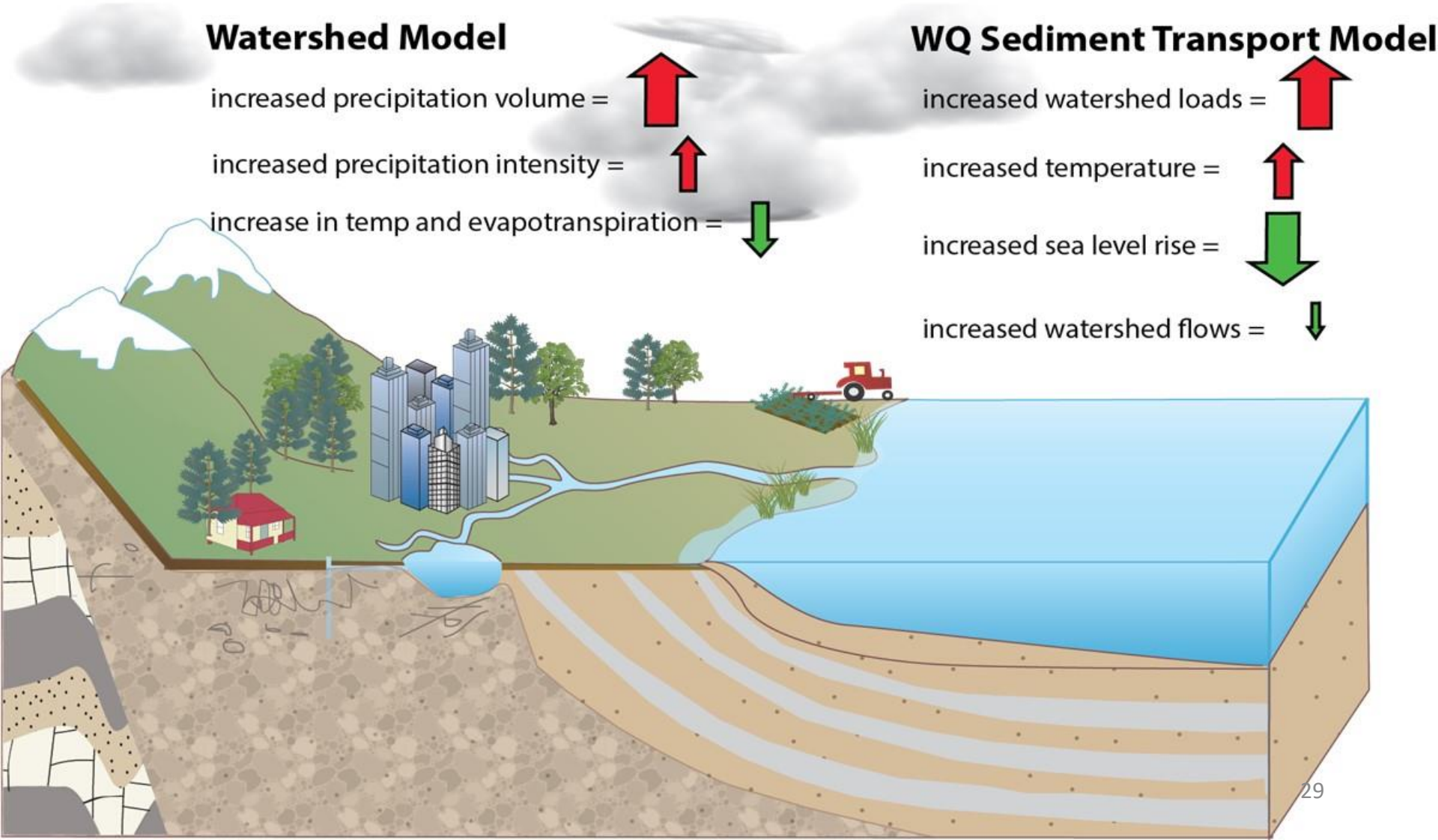


Climate change effort increase

	N	P
DC	0.00	0.001
DE	0.28	0.006
MD	1.56	0.105
NY	0.32	0.017
PA	3.08	0.138
VA	1.28	0.183
WV	0.19	0.016
Total	6.72	0.467

Year	N	P
2025	6.72	0.467
2035	11.95	0.830
2045	18.95	1.316
2055	25.45	1.768

Not final numbers
One of several options presented
WQGIT working on additional options

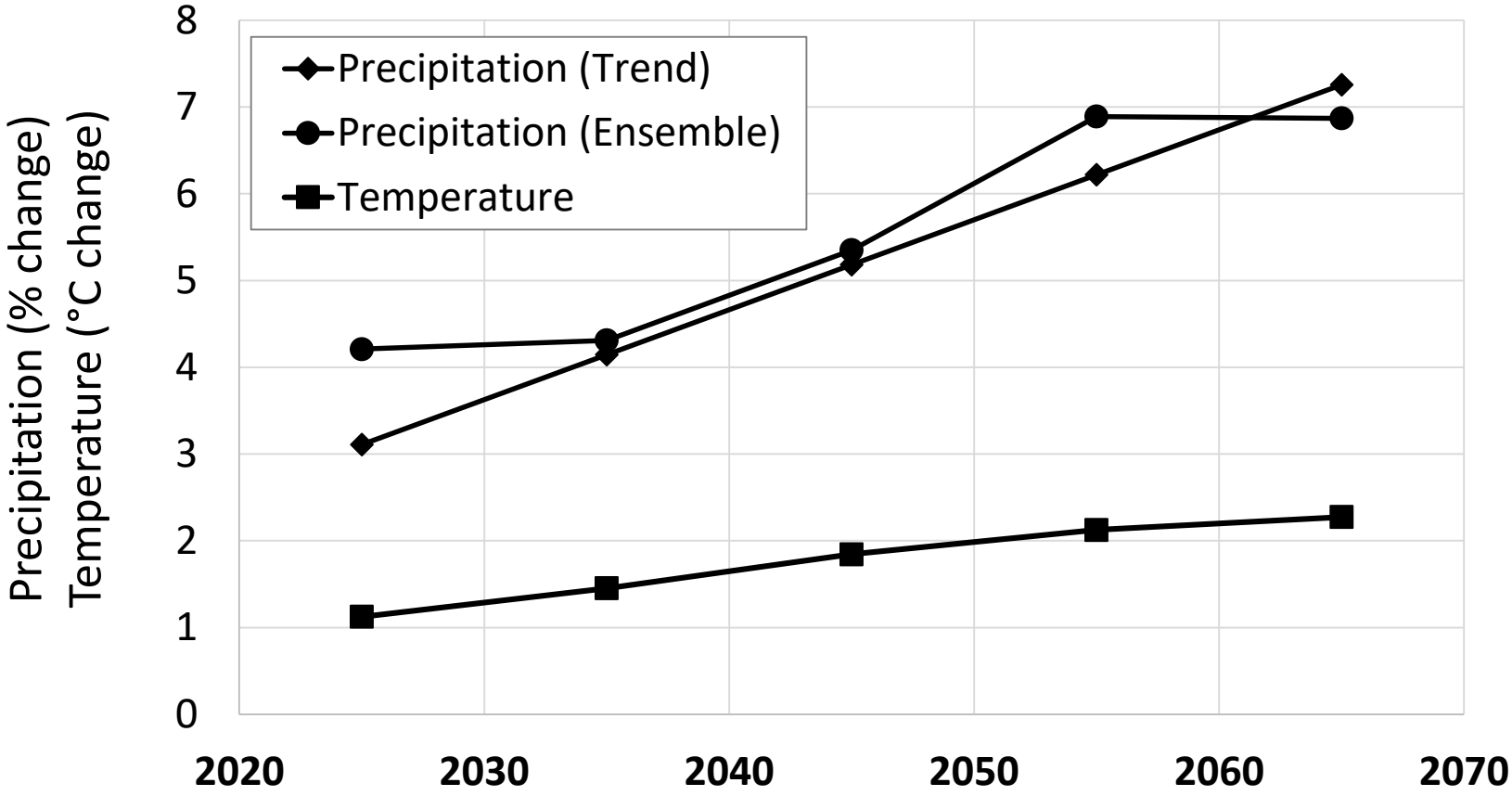
Summary

- The modeling workgroup has completed climate change effect modeling for 2020
  - Higher loads of N, P, and S due to climate change
  - Higher Bay temperatures make oxygen targets more difficult to meet
- The WQGIT will make Recommendations to the Management Board and PSC for how to handle climate change
- The AgWG may decide to start engaging in updating Ag forecasting methods responsive to climate and economic changes

Extra slides

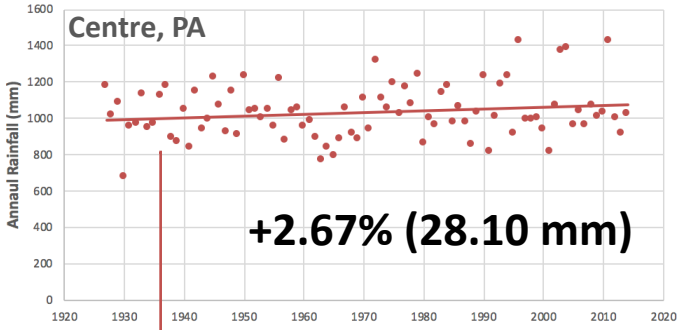
Climate delta change from 1995

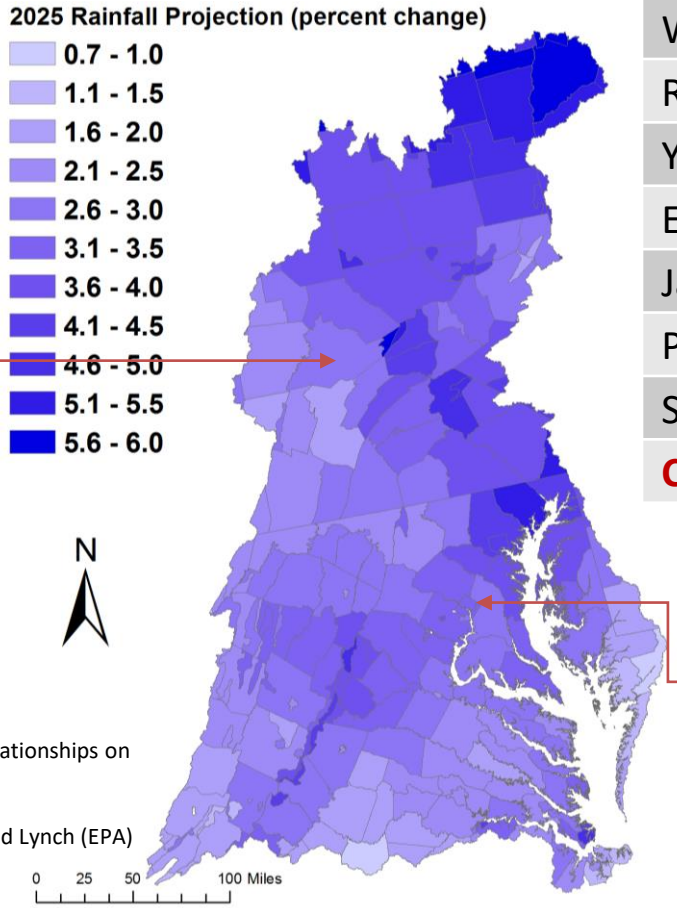
Spatially aggregated over the Chesapeake Bay Watershed



***Trend**: extrapolation of long-term (88-year) linear trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs (BCSD)*

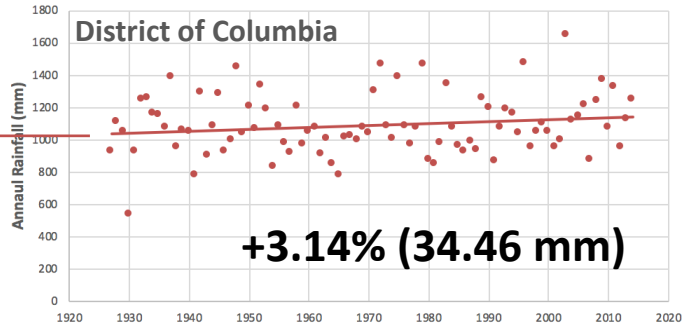
Long term rainfall volume trends





Estimated 30-year change between 2025 and 1995 using 88-year annual PRISM[1] rainfall data

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%**

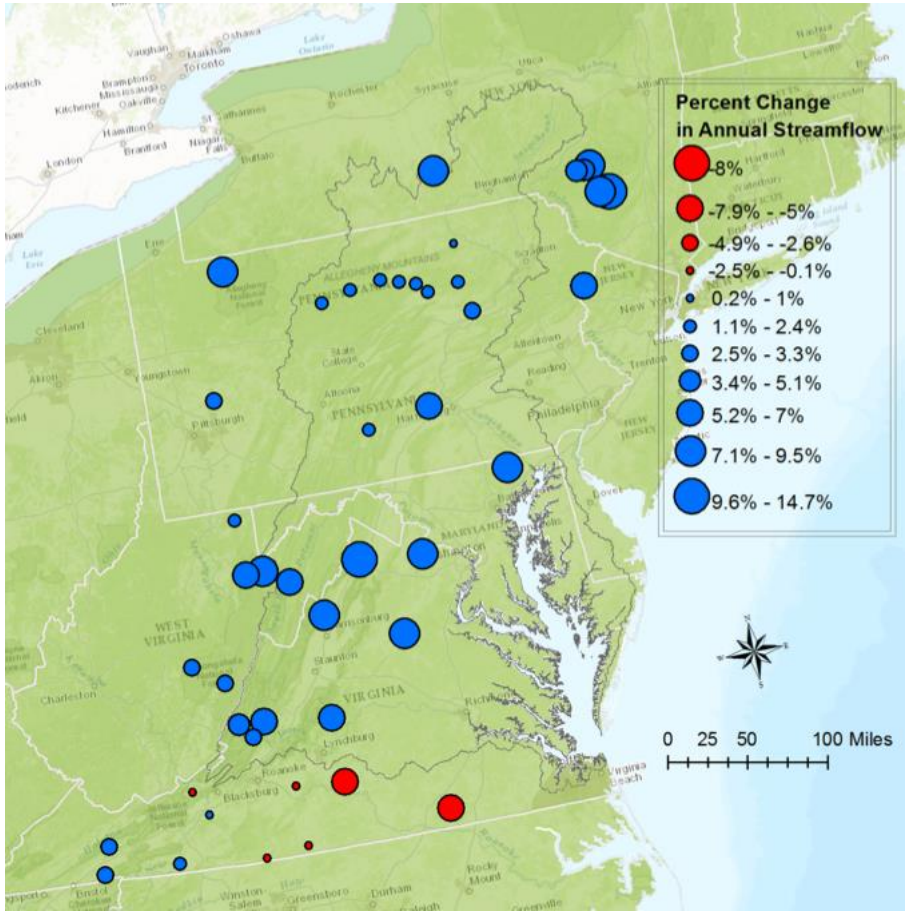


[1] Parameter-elevation Relationships on Independent Slopes Model

Data Source: Rice (USGS) and Lynch (EPA)

Changing Watershed – climate and land use

Annual streamflow has increased between 1 to 17% since 1940



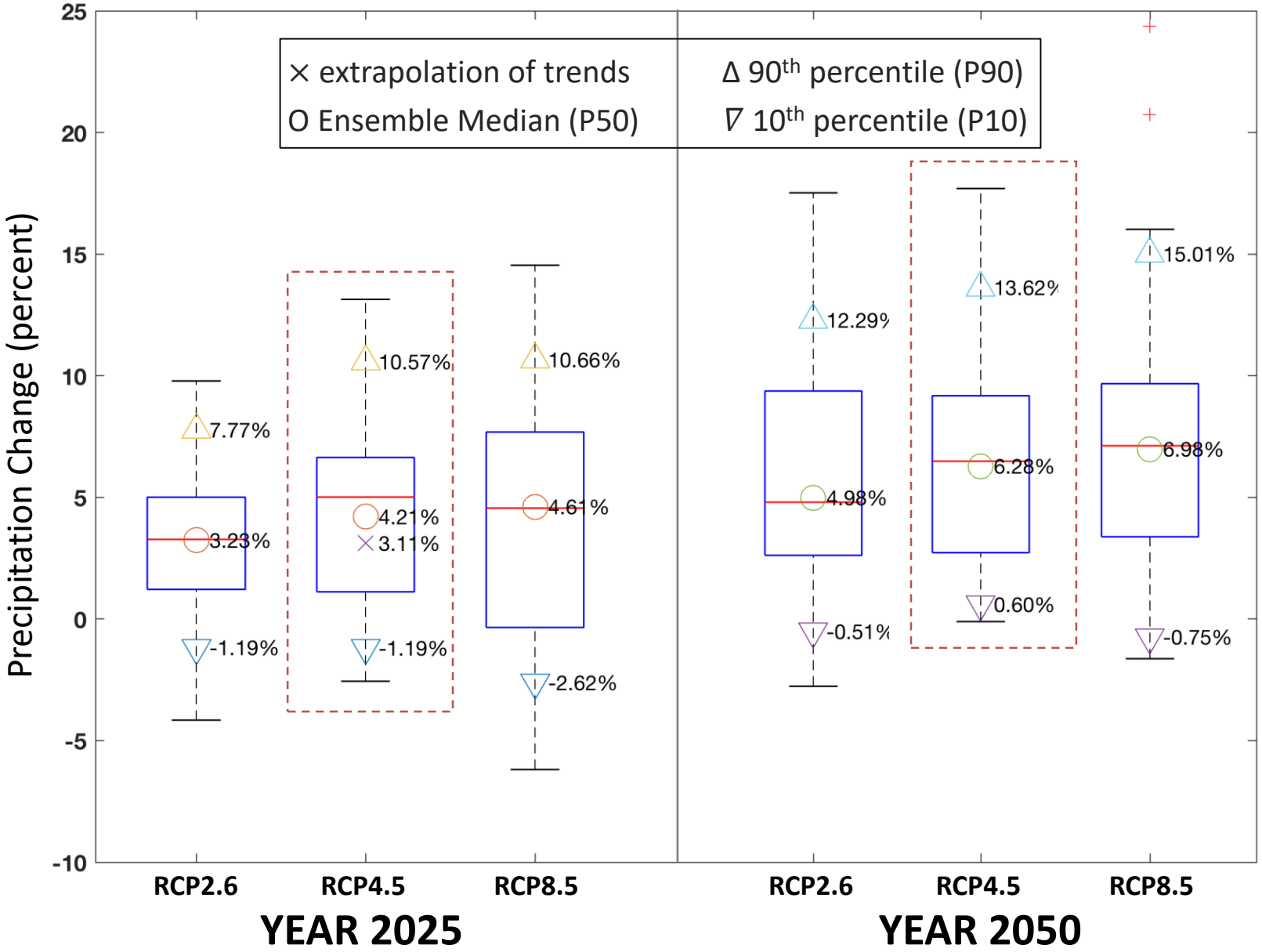
USGS station ID	Precipitation		Discharge	
	Slope	p-value	Slope	p-value
04252500	0.0007	**0.0011**	0.0021	**<0.0001**
01512500	0.0008	**0.0007**	0.0016	**0.0028**
01503000	0.0007	**0.0022**	0.0013	**0.0181**
01531000	0.0006	**0.0219**	0.0018	**0.0030**
01531500	0.0007	**0.0044**	0.0016	**0.0029**
01532000	0.0006	**0.0374**	0.0015	**0.0330**
01534000	0.0005	**0.0497**	0.0015	**0.0120**
01550000	0.0005	**0.0493**	0.0019	**0.0015**
01543000	0.0004	0.1000	0.0018	**0.0058**
01545500	0.0004	0.0953	0.0017	**0.0026**
01536500	0.0006	**0.0078**	0.0016	**0.0027**
01551500	0.0005	0.0612	0.0017	**0.0017**
01439500	0.0005	0.0972	0.0007	0.1661
01541500	0.0003	0.2357	0.0017	**0.0017**
01540500	0.0006	**0.0111**	0.0016	**0.0023**
01541000	0.0004	0.0985	0.0016	**0.0021**
01567000	0.0004	0.1577	0.0011	**0.0250**
01570500	0.0005	**0.0260**	0.0013	**0.0088**
North-South Split				
01562000	0.0004	0.1693	0.0007	0.2082
01638500	0.0004	0.1150	0.0008	0.1026
01608500	0.0004	0.1725	0.0010	0.0833
01636500	0.0005	0.1245	0.0008	0.0624
01606500	0.0003	0.1958	0.0009	0.1108
01668000	0.0006	0.0794	0.0004	0.4727
02035000	0.0003	0.2653	−0.0001	0.8243
02019500	0.0002	0.4333	0.0003	0.4836
03488000	0.0003	0.2480	0.0006	0.2841

The map shows percent changes in the 30-year annual average streamflow for rivers and streams (HCDN,USGS GAGES-II, 1940-2014). U.S. Environmental Protection Agency. 2016. Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004 [2]

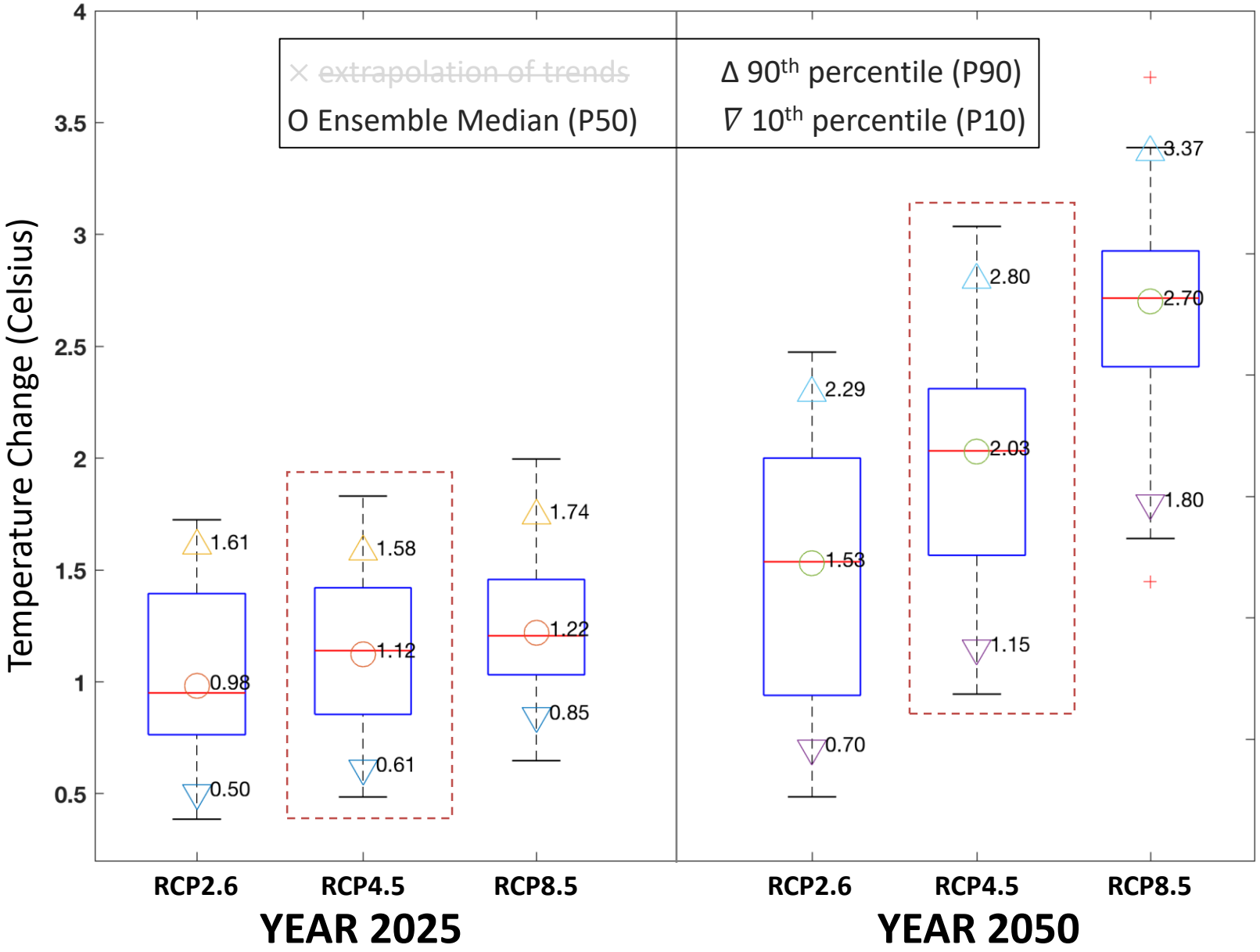
Karen C. Rice, Douglas L. Moyer, and Aaron L. Mills, 2017. Riverine discharges to Chesapeake Bay: Analysis of long-term (1927 - 2014) records and implications for future flows in the Chesapeake Bay basin *JEM* 204 (2017) 246-254

[1] 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.
[2] U.S. EPA. 2016. Climate change indicators in the United States. www.epa.gov/climate-indicators; https://www.epa.gov/sites/production/files/2016-08/documents/climate_indicators_2016.pdf

Summary of precipitation change

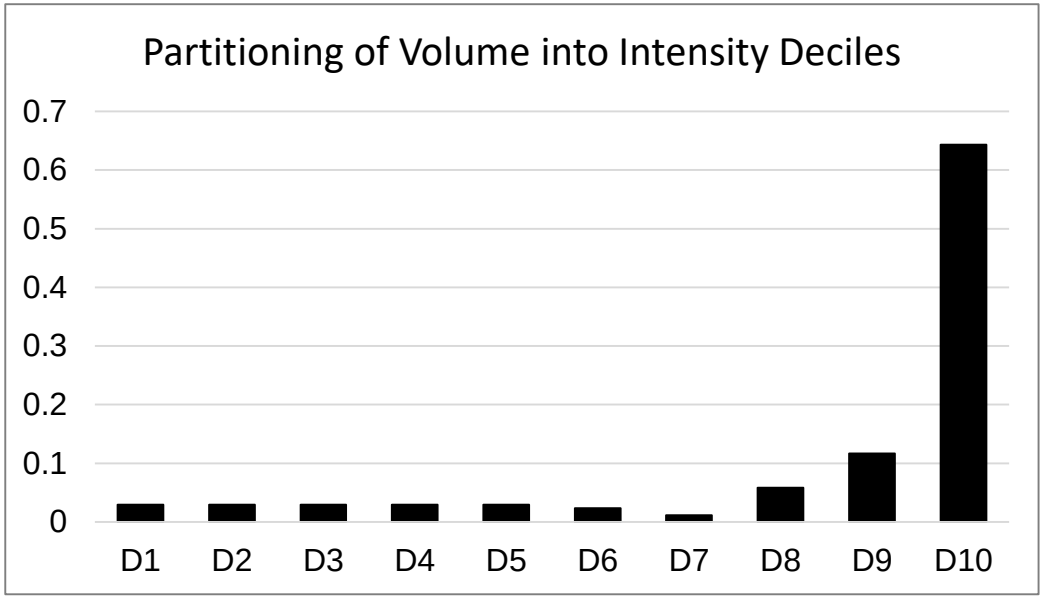


Summary of temperature change

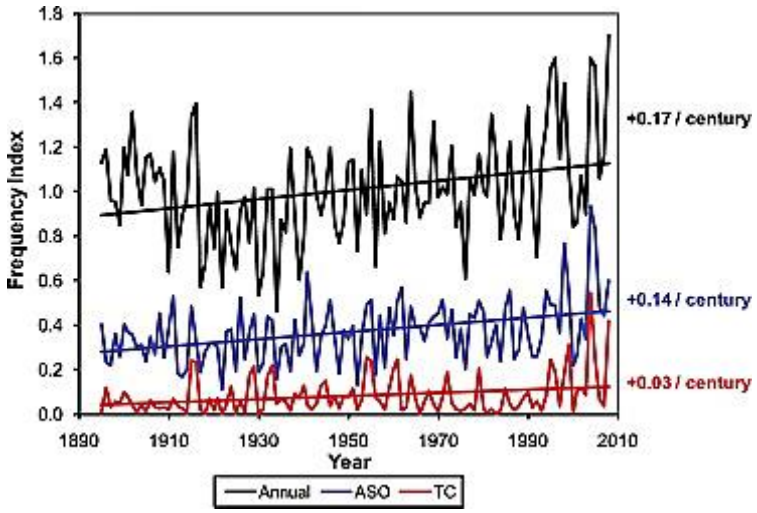


Climate delta change from 1995

More volume into higher intensity events

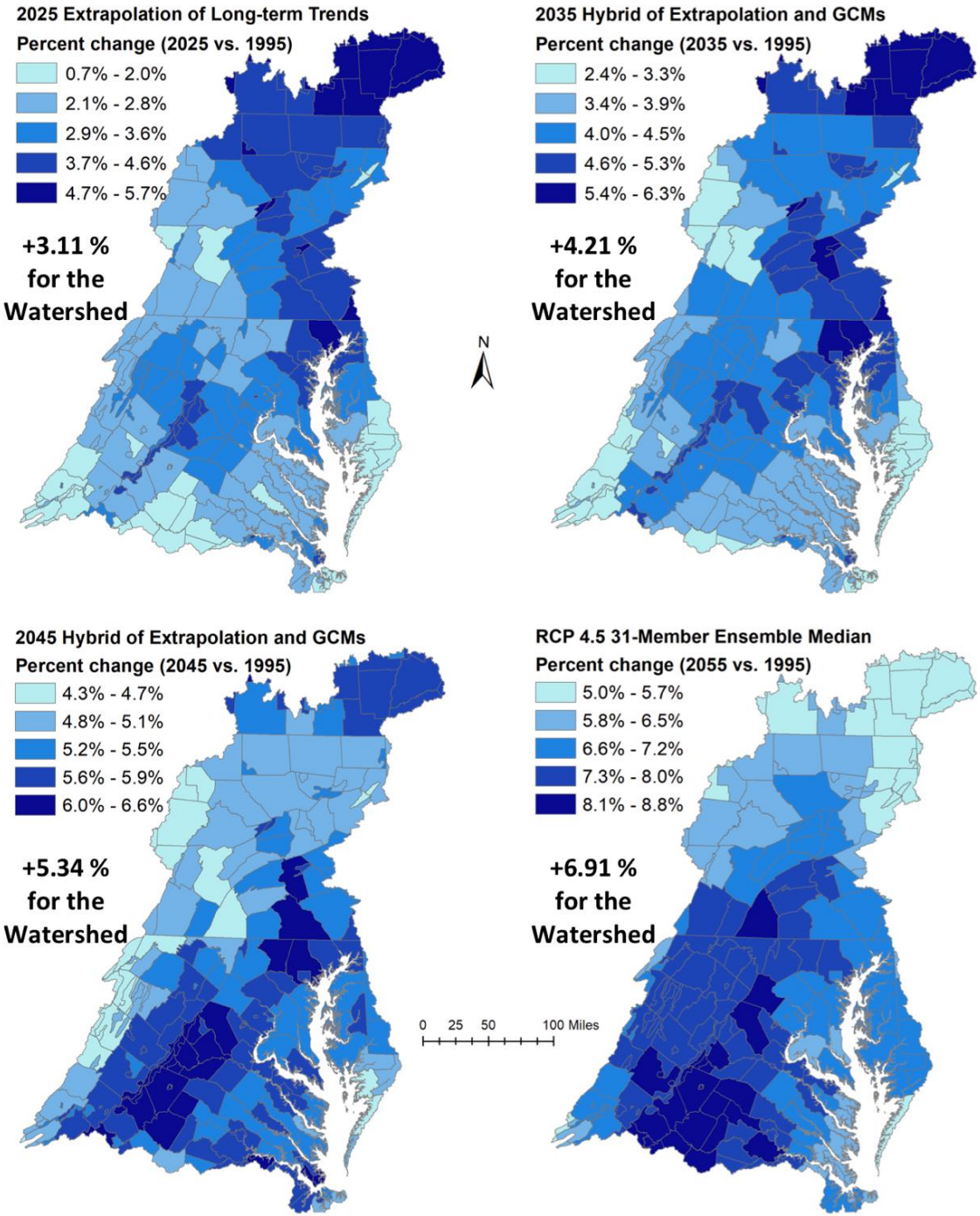


Reproduced from Groisman et al., 2004

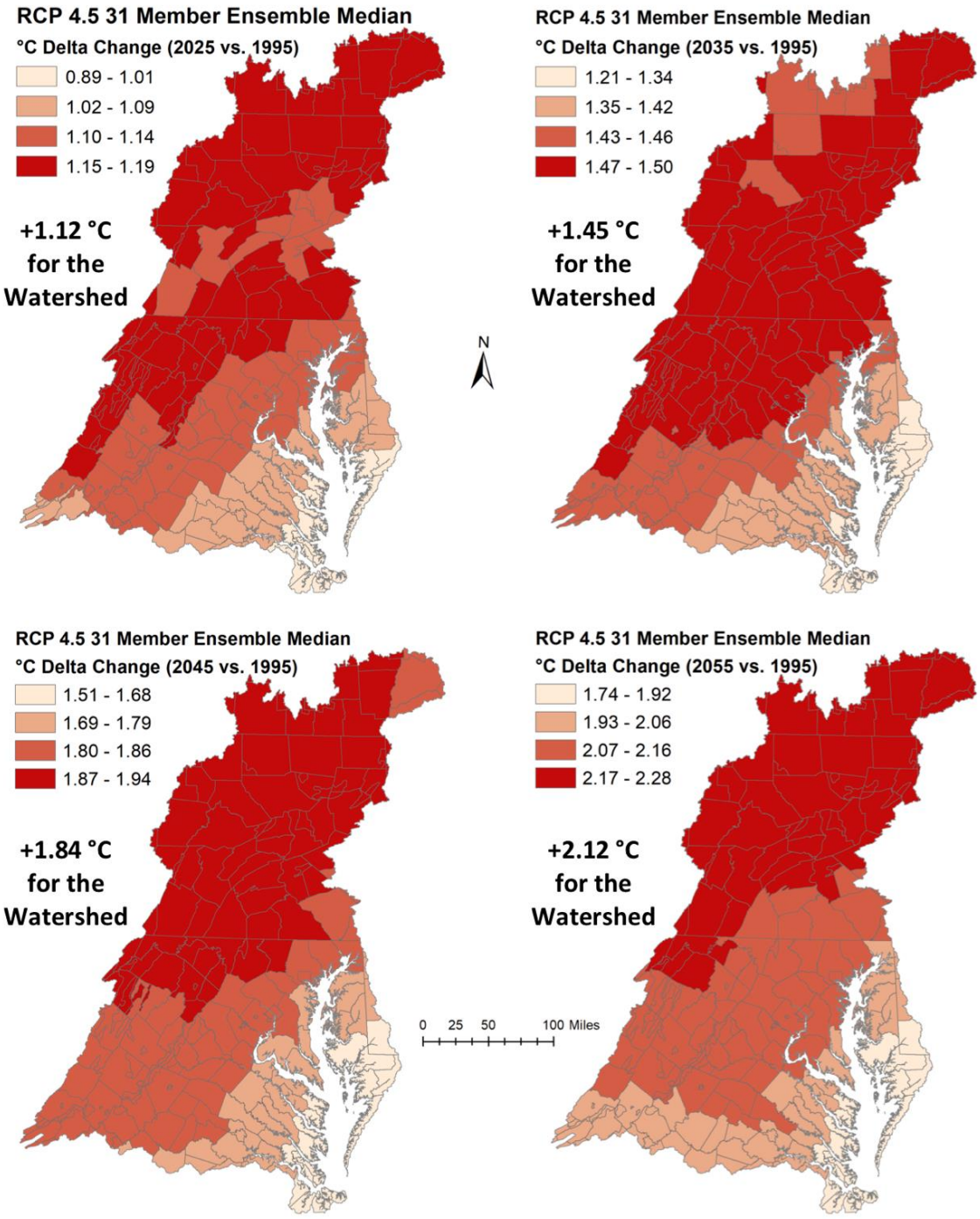


National average heavy precipitation event index (HPEI) for the entire year (annual, black), for August through October (ASO, blue), and for heavy events associated with tropical cyclones (TC, red). [Kunkel et al., 2010]

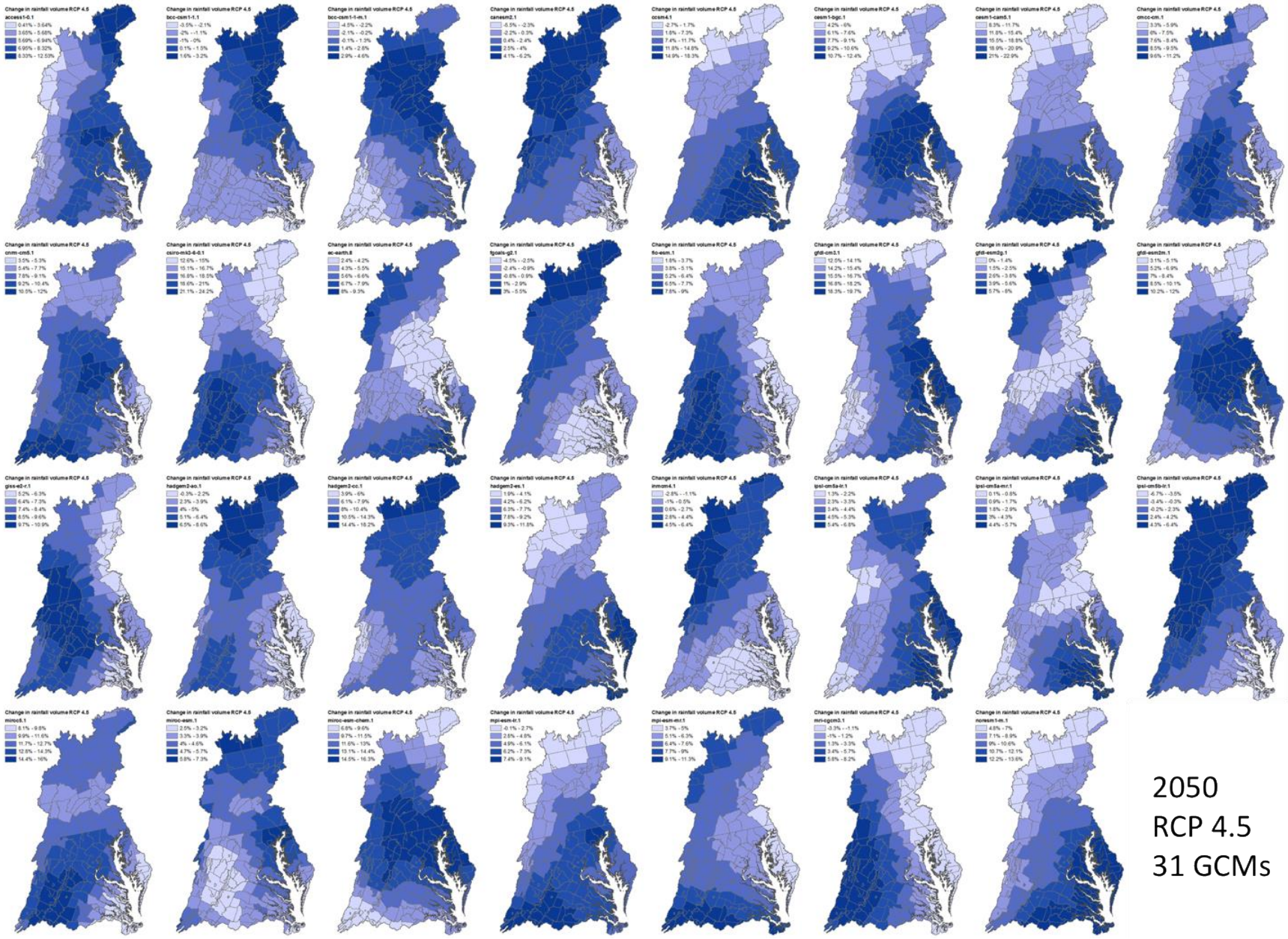
Rainfall


2025 Extrapolation of Long-term Trends
Percent change (2025 vs. 1995)
0.7% - 2.0%
2.1% - 2.8%
2.9% - 3.6%
3.7% - 4.6%
4.7% - 5.7%
+3.11 % for the Watershed
2035 Hybrid of Extrapolation and GCMs
Percent change (2035 vs. 1995)
2.4% - 3.3%
3.4% - 3.9%
4.0% - 4.5%
4.6% - 5.3%
5.4% - 6.3%
+4.21 % for the Watershed
N
2045 Hybrid of Extrapolation and GCMs
Percent change (2045 vs. 1995)
4.3% - 4.7%
4.8% - 5.1%
5.2% - 5.5%
5.6% - 5.9%
6.0% - 6.6%
+5.34 % for the Watershed
RCP 4.5 31-Member Ensemble Median
Percent change (2055 vs. 1995)
5.0% - 5.7%
5.8% - 6.5%
6.6% - 7.2%
7.3% - 8.0%
8.1% - 8.8%
+6.91 % for the Watershed
0 25 50 100 Miles

Temperature

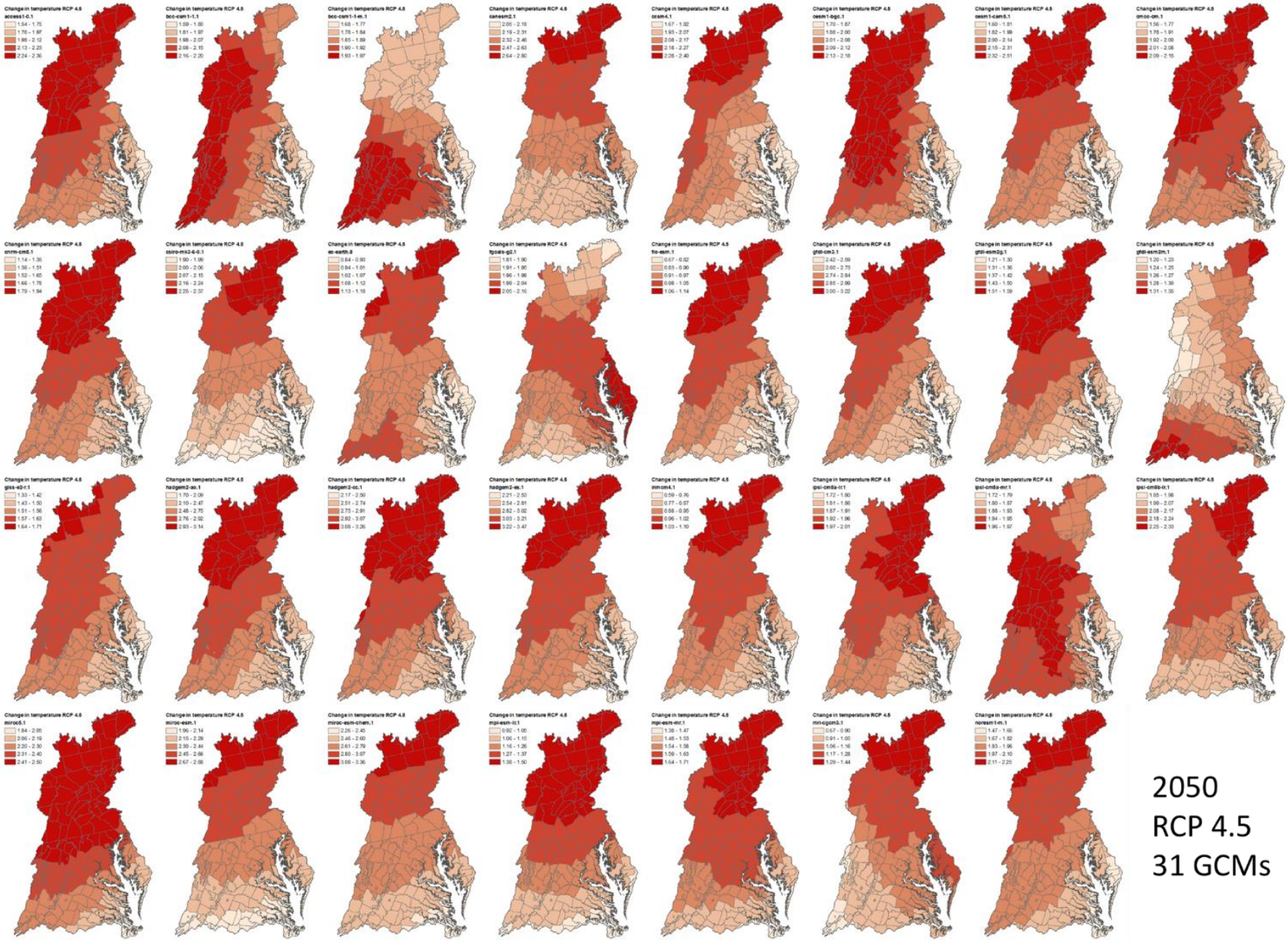


Ensemble of Downscaled Global Climate Models



2050
RCP 4.5
31 GCMs

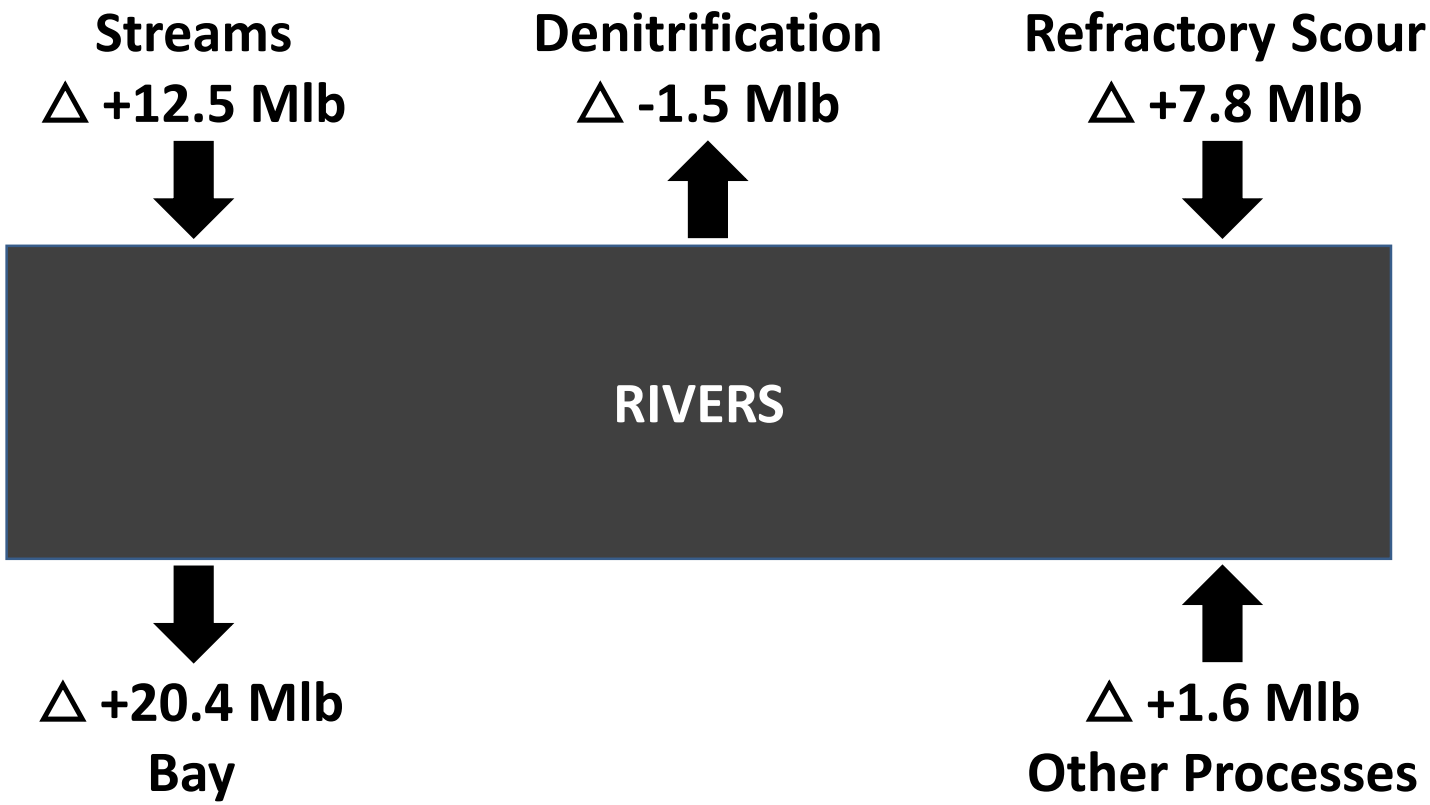
Ensemble of Downscaled Global Climate Models



2050
RCP 4.5
31 GCMs

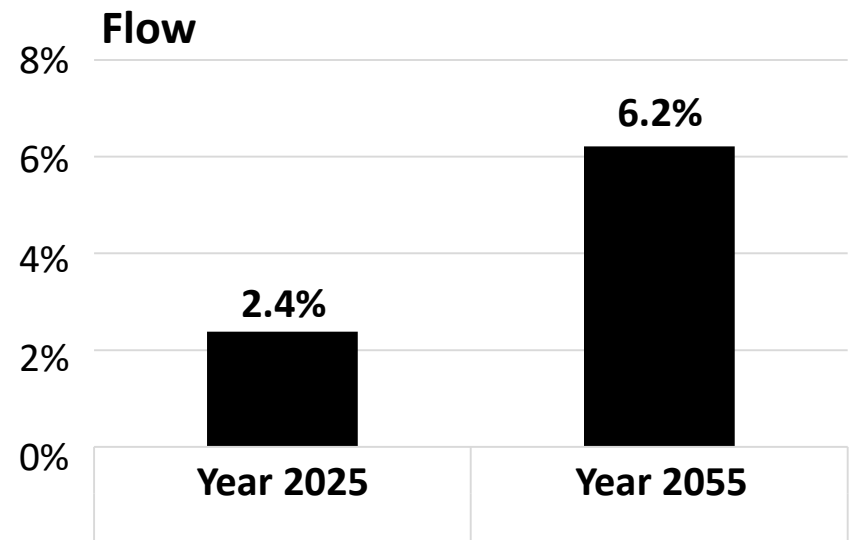
Summary of Nitrogen Budget

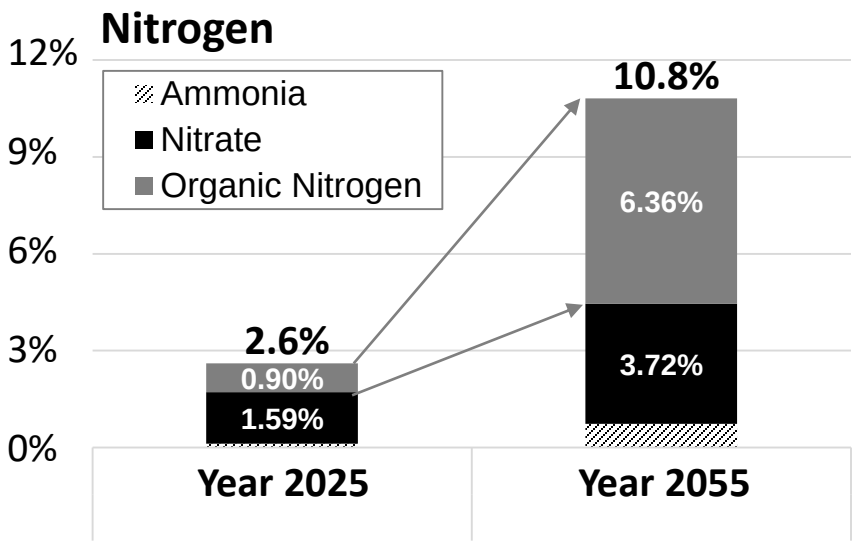
2055 Climate (marginal change in watershed response)

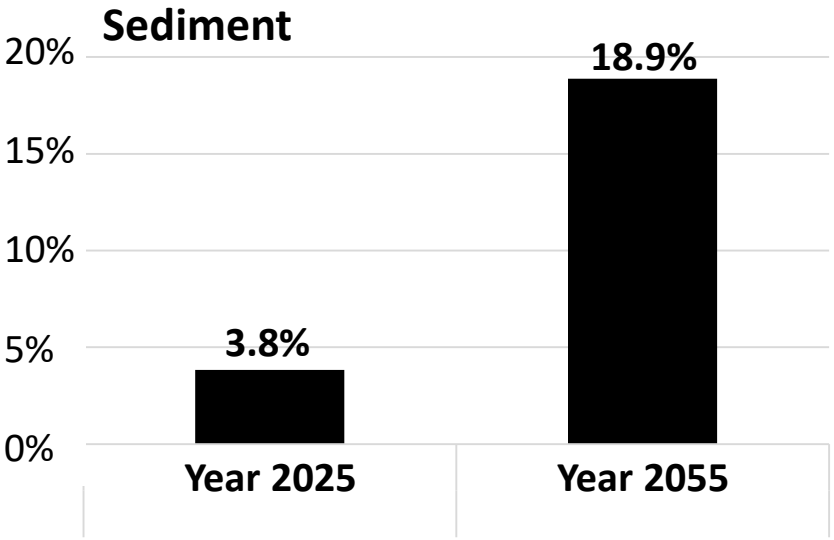


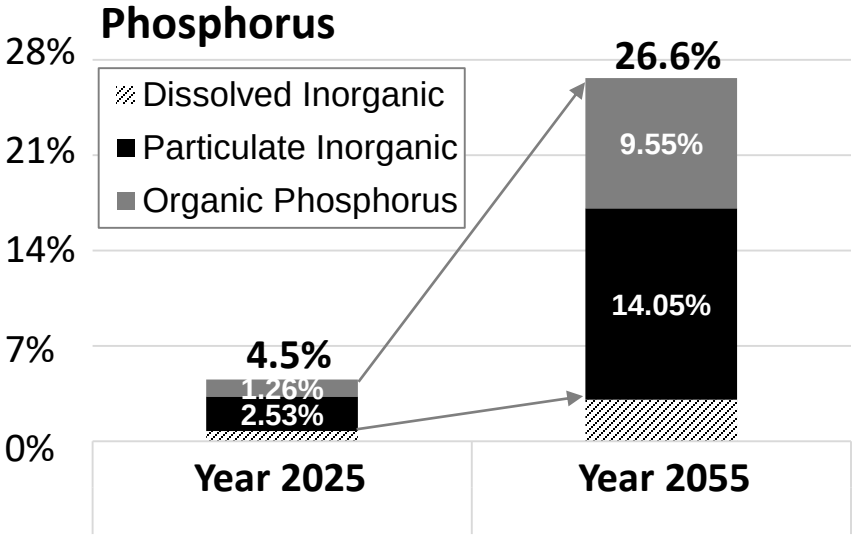
Deltas (△) show change with respect to 1995 climate.

Nutrient Speciation – 2025 and 2055

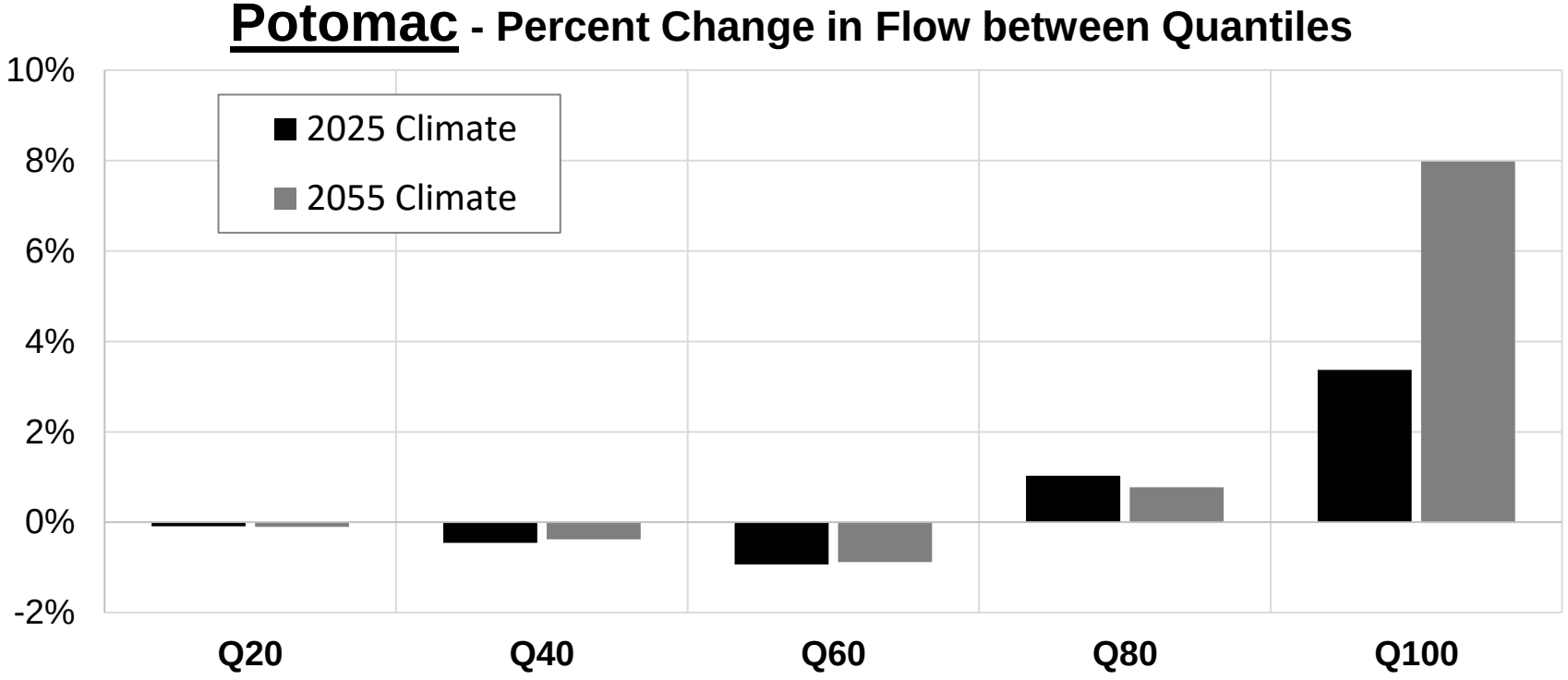






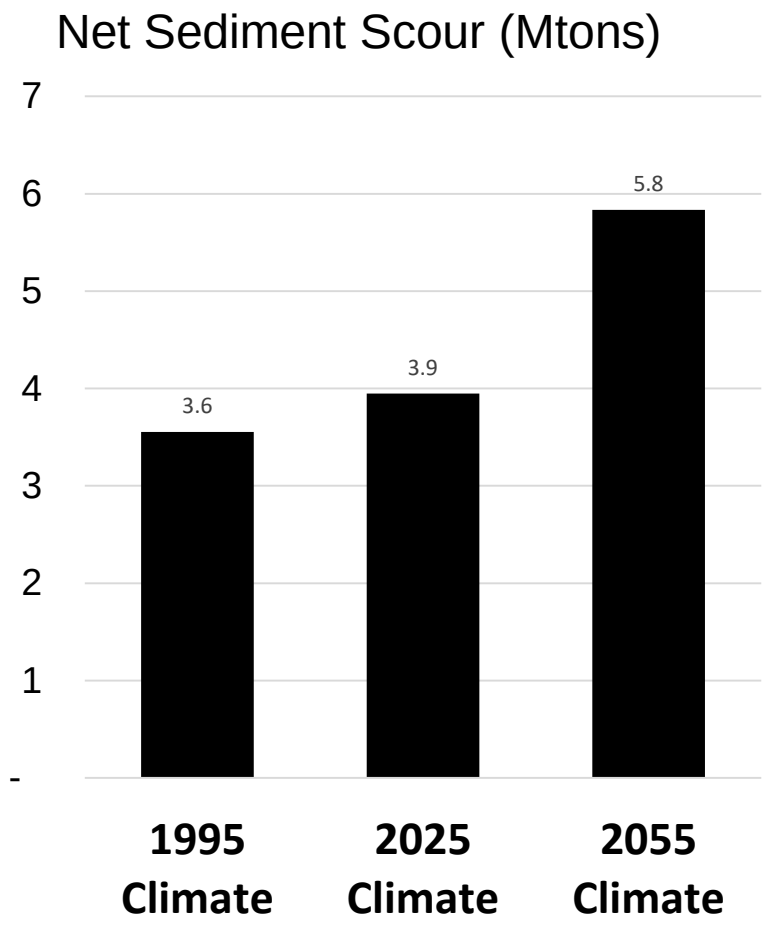


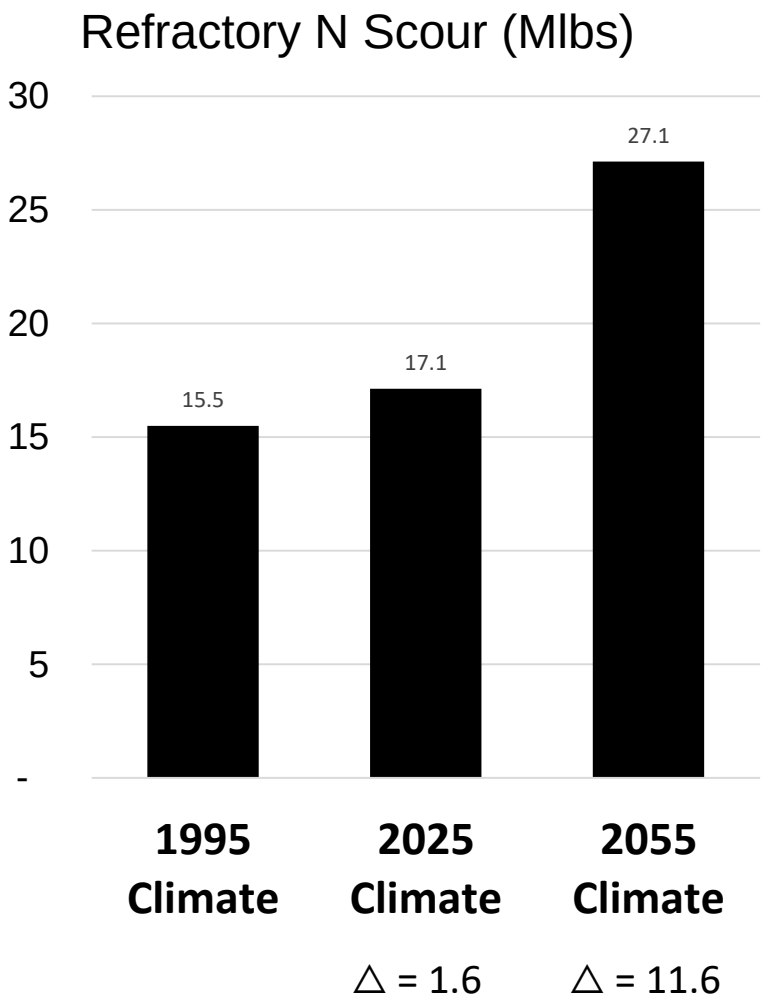
Changes in Flow Regime



Increases in higher flow quantiles impact mobilization and transport of sediment and nutrients (in particulate form) – "*riverine nutrient competency*".

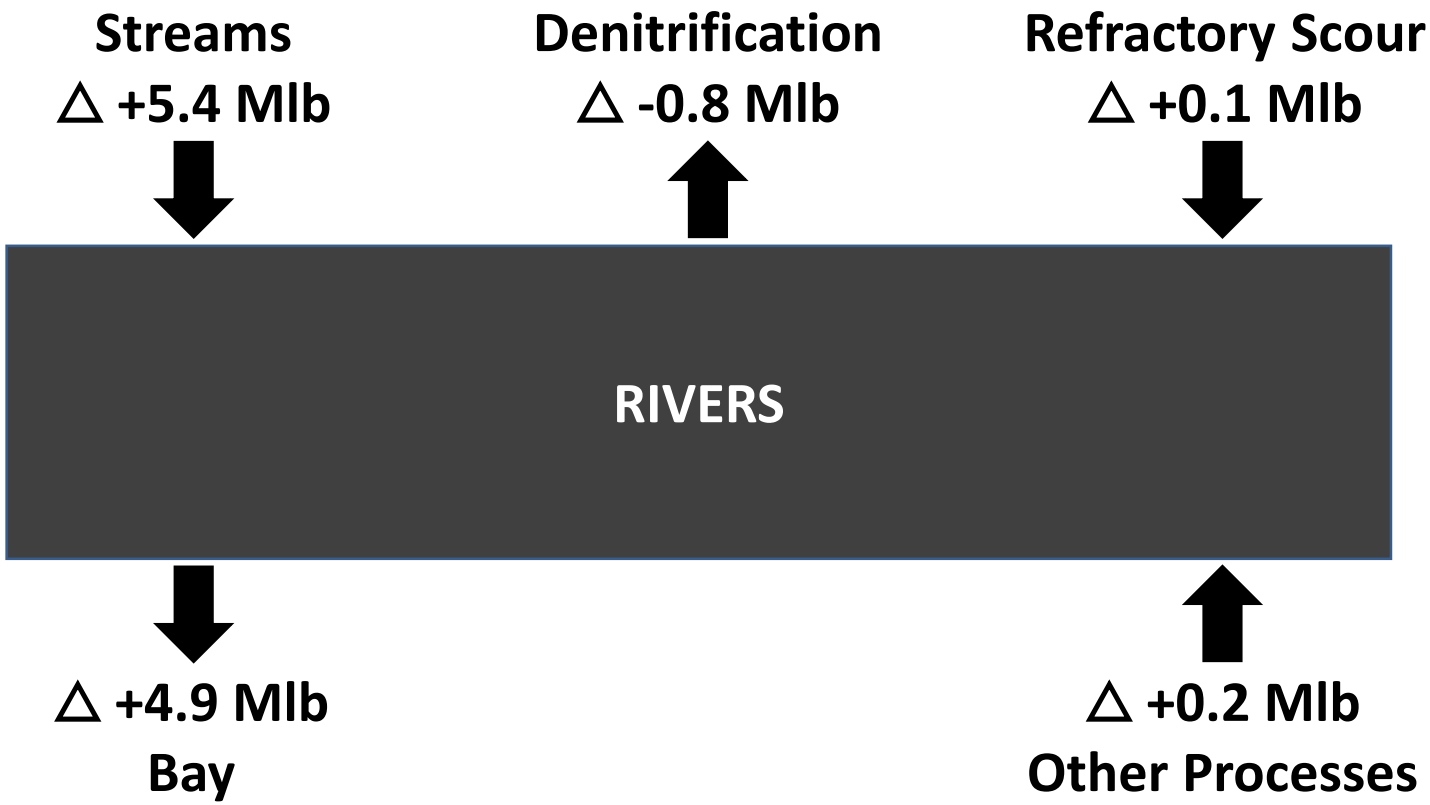
Riverine Processes – refractory organic scour





Summary of Nitrogen Budget

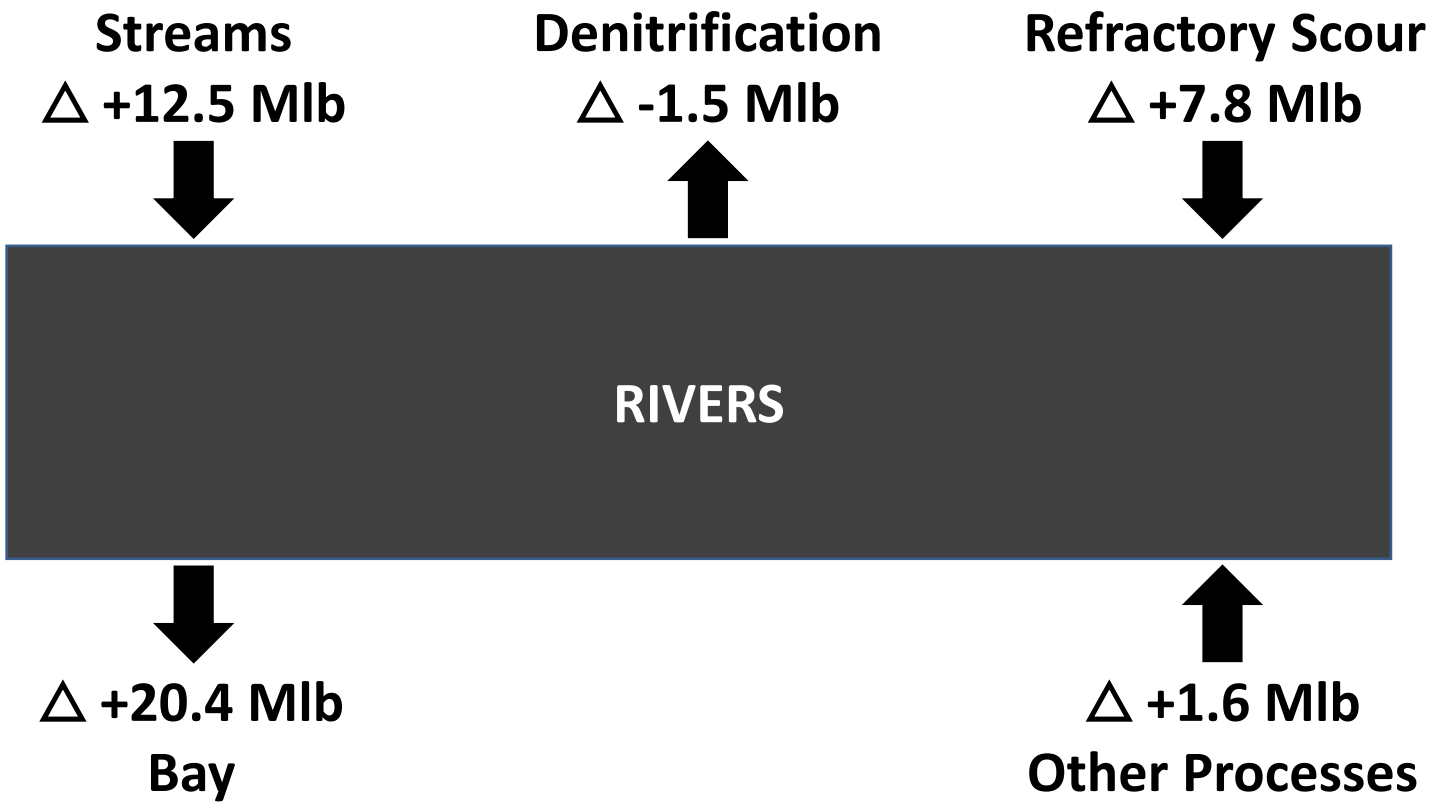
2025 Climate (marginal change in watershed response)



Deltas (△) show change with respect to 1995 climate.

Summary of Nitrogen Budget

2055 Climate (marginal change in watershed response)



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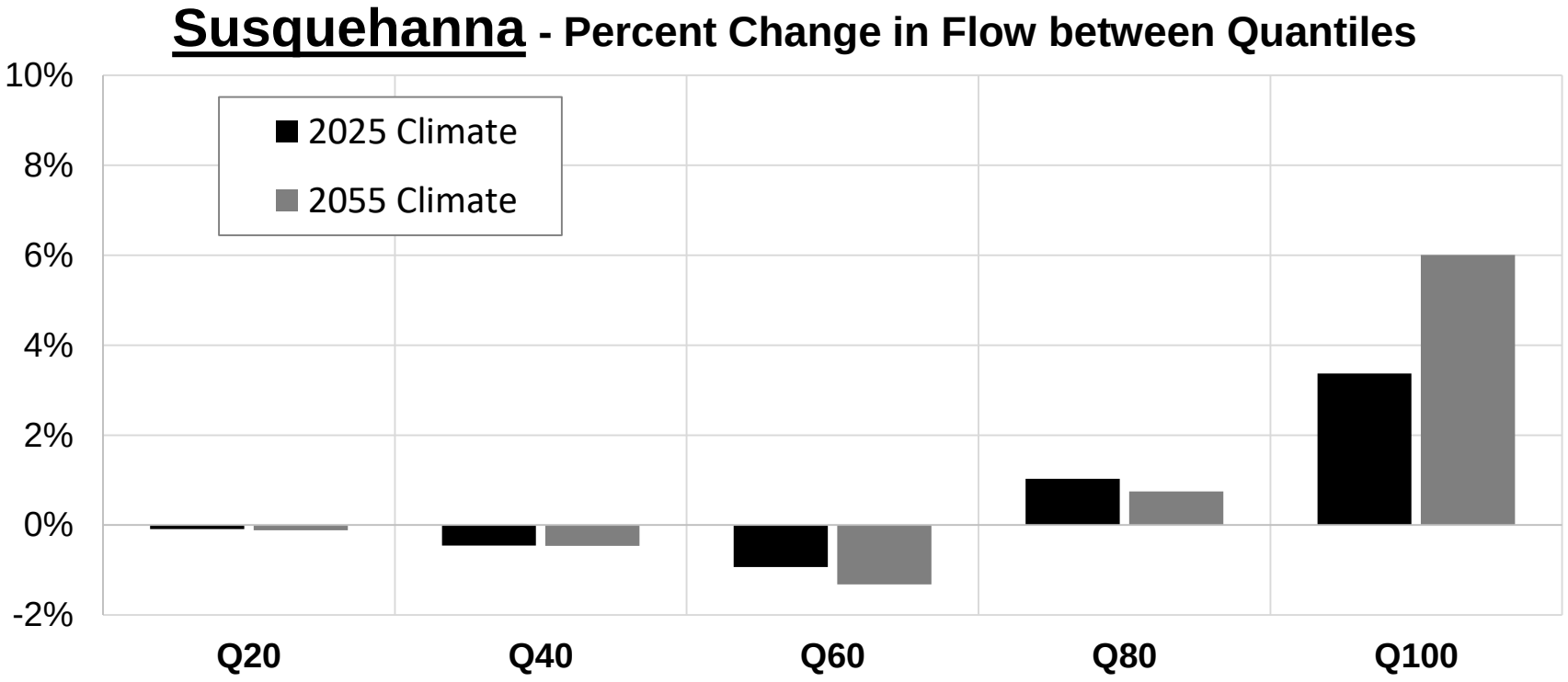
Changes in Flow Regime



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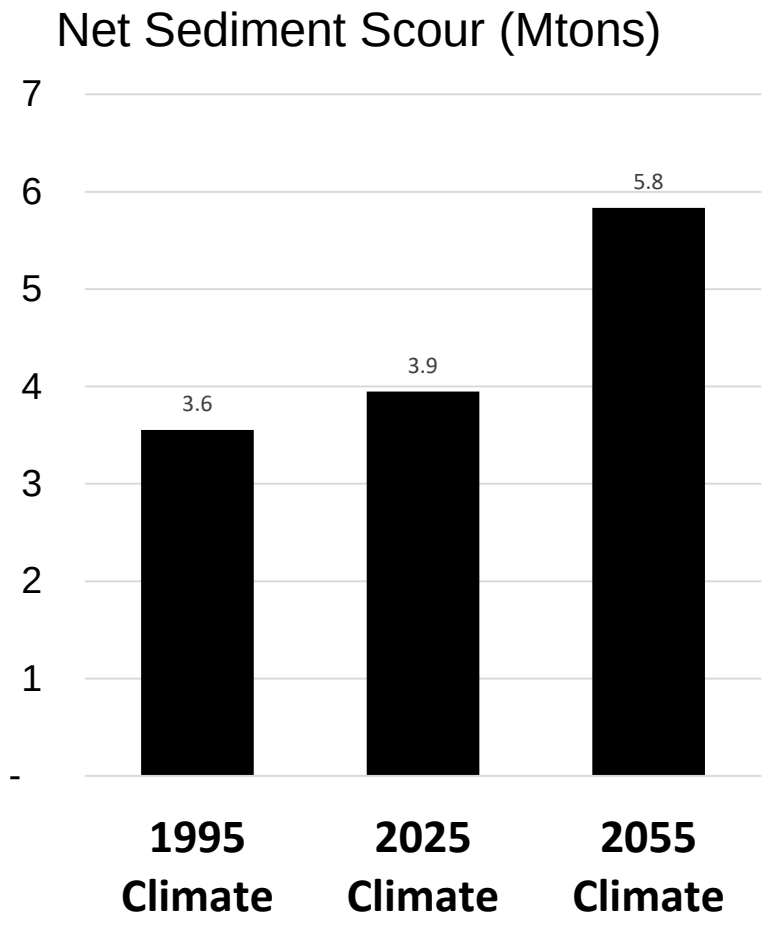
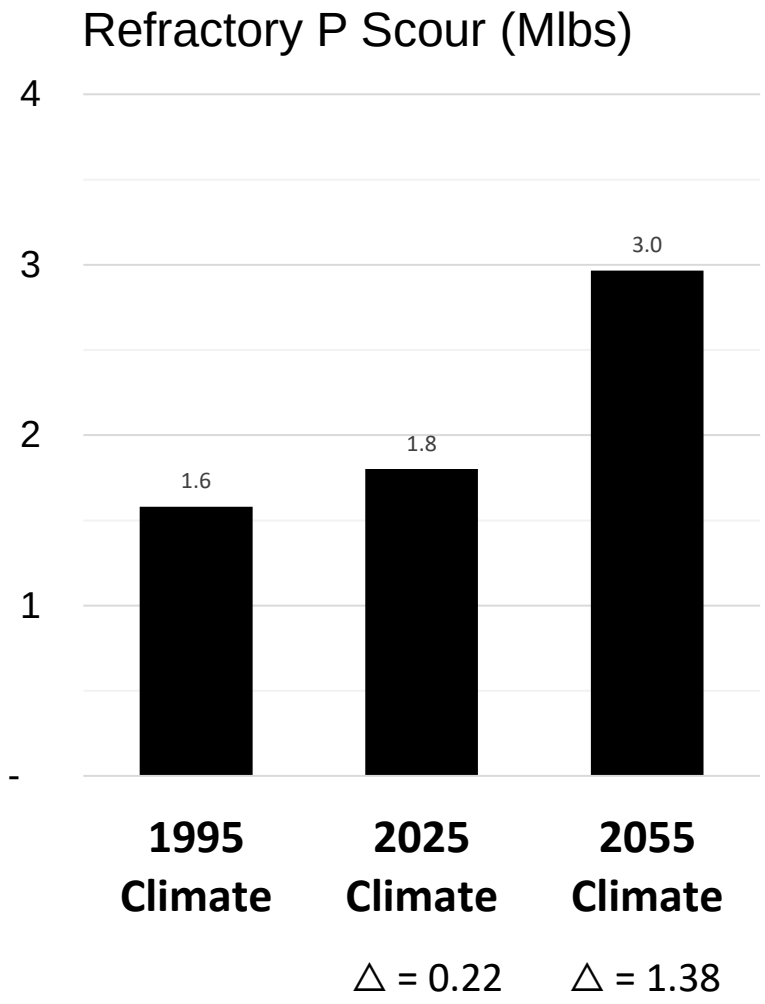
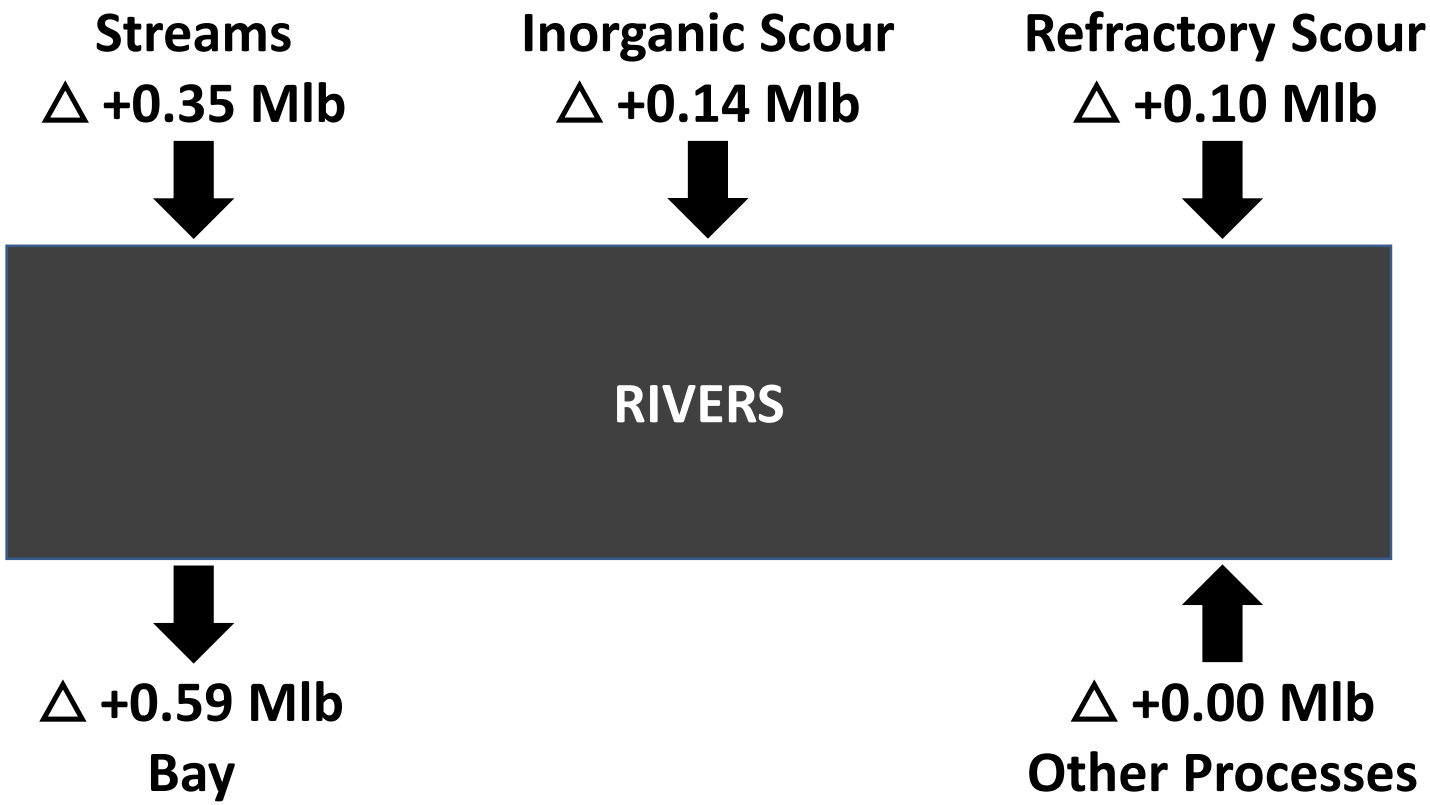




Summary of Phosphorus Budget

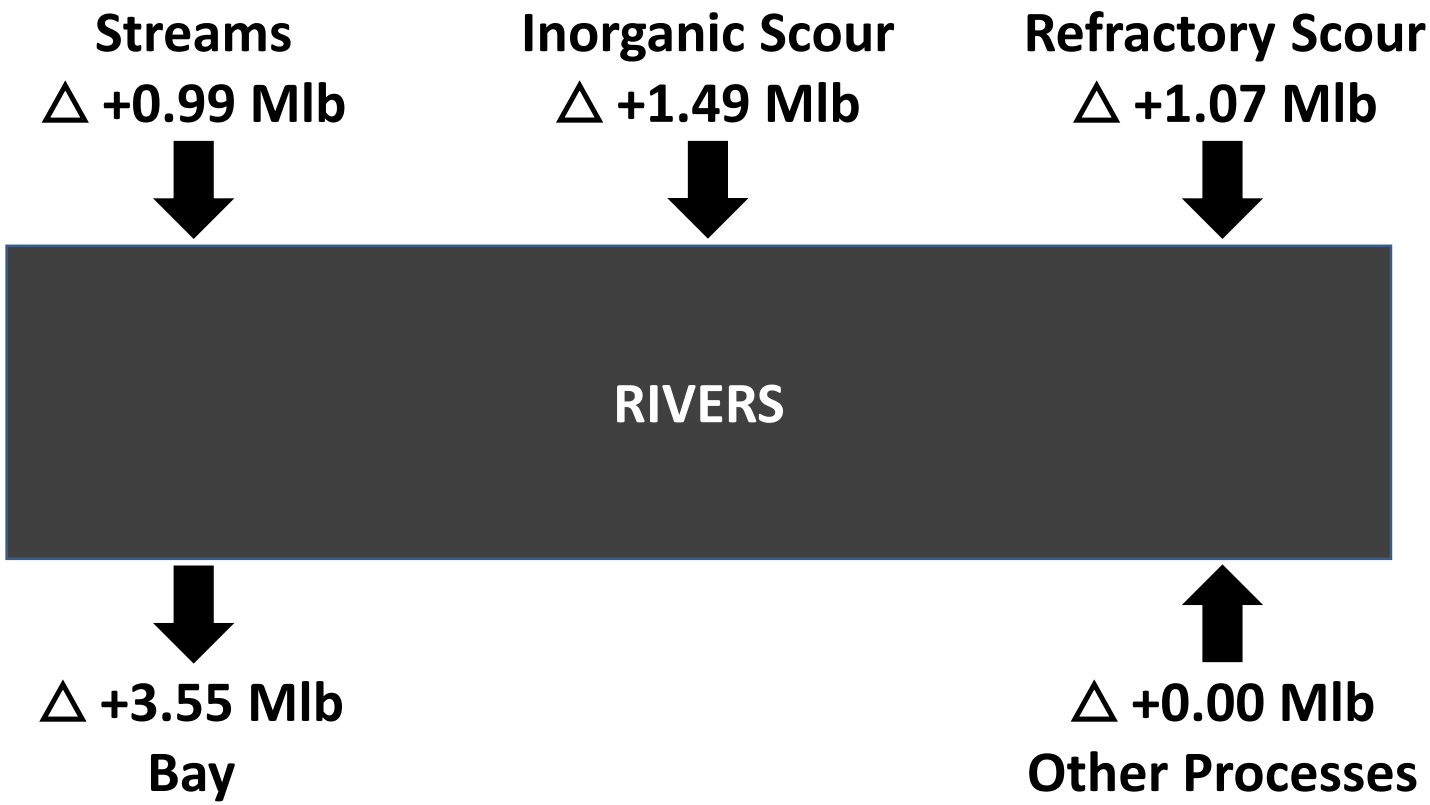
2025 Climate (marginal change in watershed response)



Deltas (△) show change with respect to 1995 climate.

Summary of Phosphorus Budget

2055 Climate (marginal change in watershed response)



Deltas (△) show change with respect to 1995 climate.