

Application of Phase 6 Watershed Model to Climate Change Assessment

Modeling Workgroup Conference Call – September 2018

Gopal Bhatt¹ and Lewis Linker²

¹ Penn State, ² US EPA

Presentation outline

- Estimated impacts of 2025 and 2050 climate change on the watershed delivery of nutrients and sediment.

2017 Assessment of climate change

- Decadal series of climate change assessment for the years 2025, 2035, and 2045.

2019 Assessment of climate change

STAC recommendations [1]

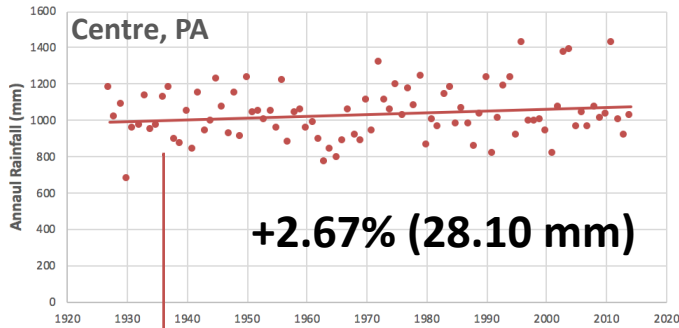
The workshop culminated with the following specific recommendations related to the selection, use, and application of climate projections and forecasts for the 2017 Midpoint Assessment.

1. 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.
2. 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.
3. The Partnership 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.
4. 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.
5. 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 use beyond 2050.
6. 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



[1] Page 8 http://www.chesapeake.org/pubs/360_Johnson2016.pdf

Rainfall projections using 88-years of annual PRISM^[1] data trends



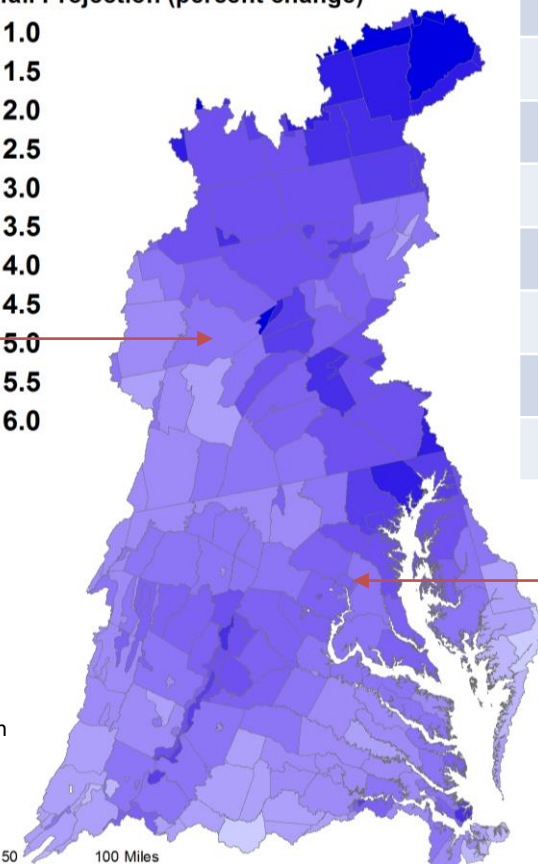
+2.67% (28.10 mm)

2025 Rainfall Projection (percent change)

- 0.7 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- 2.6 - 3.0
- 3.1 - 3.5
- 3.6 - 4.0
- 4.1 - 4.5
- 4.6 - 5.0
- 5.1 - 5.5
- 5.6 - 6.0

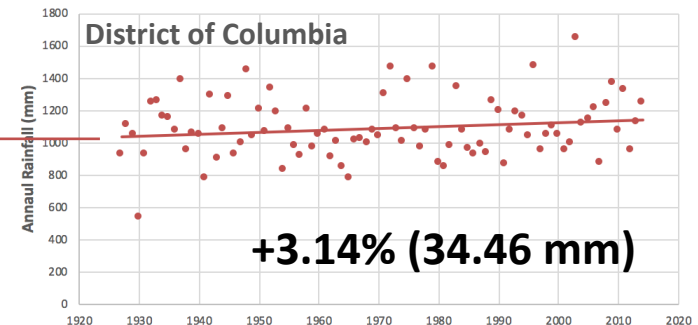


[1] Parameter-elevation Relationships on Independent Slopes Model



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%



+3.14% (34.46 mm)

Ensemble analysis of GCM projections – RCP 4.5

- An ensemble analysis of statistically downscaled projections were used from **BCSD CMIP5^[1]** dataset.
- Change were calculated as differences in 30-year averages.

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] 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.

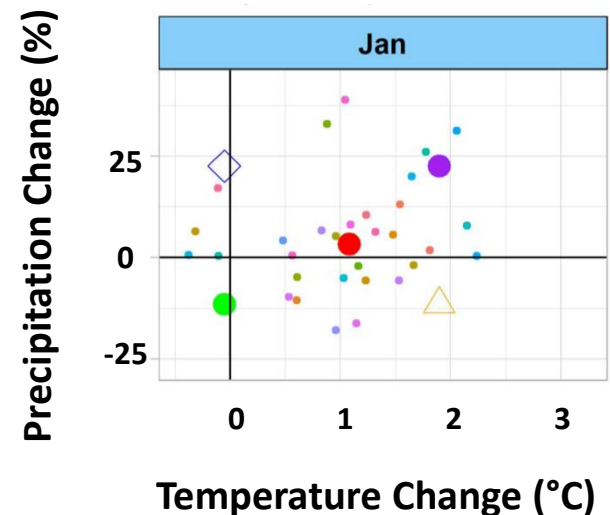
[1] BCSD – Bias Correction Spatial Disaggregation;
 [1] CMIP5 – Coupled Model Intercomparison Project 5

Data unavailable

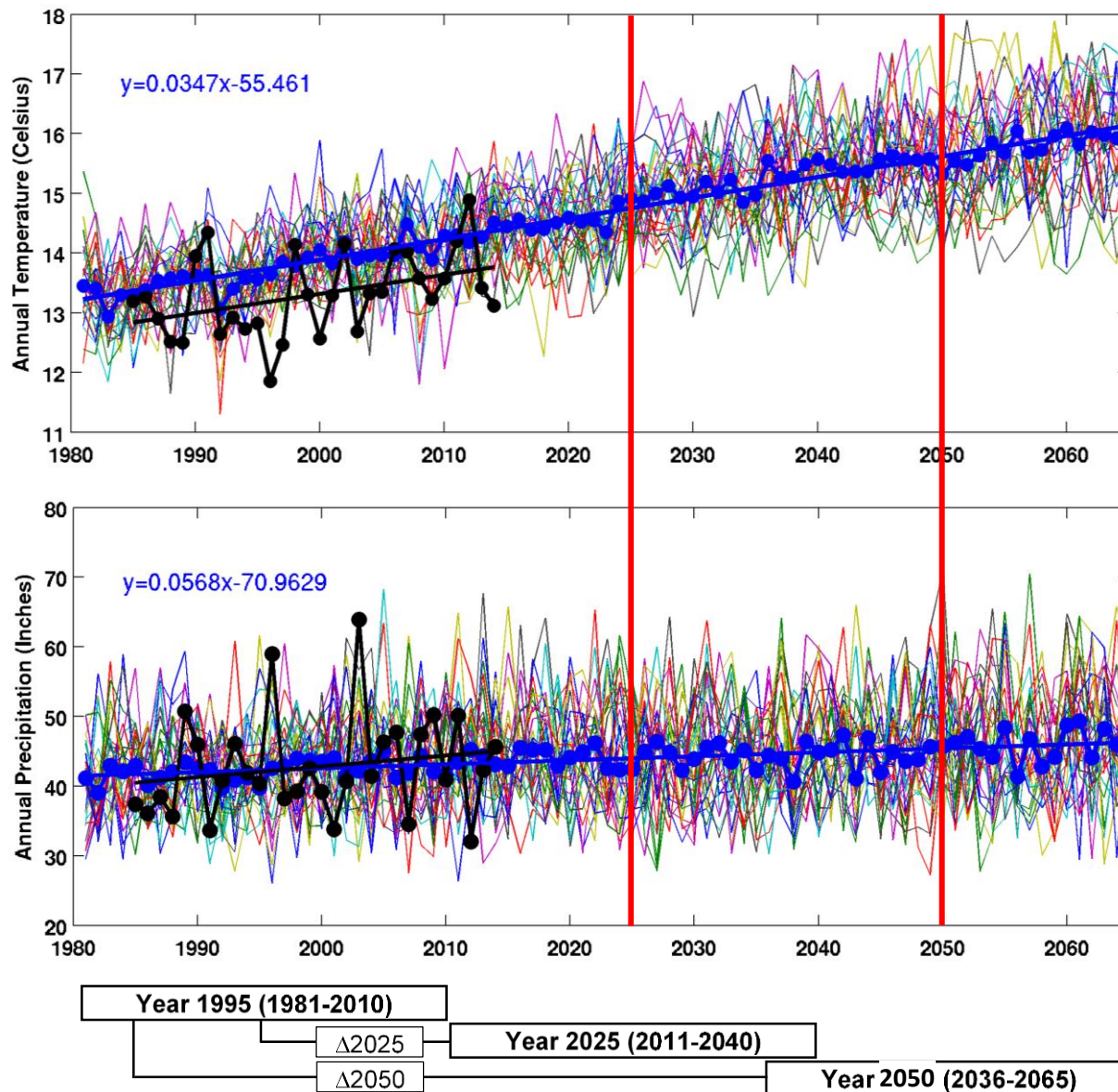
GCM Used

Selection updated

P90 – 90th percentile
 P50 – median ensemble
 P10 – 10th percentile



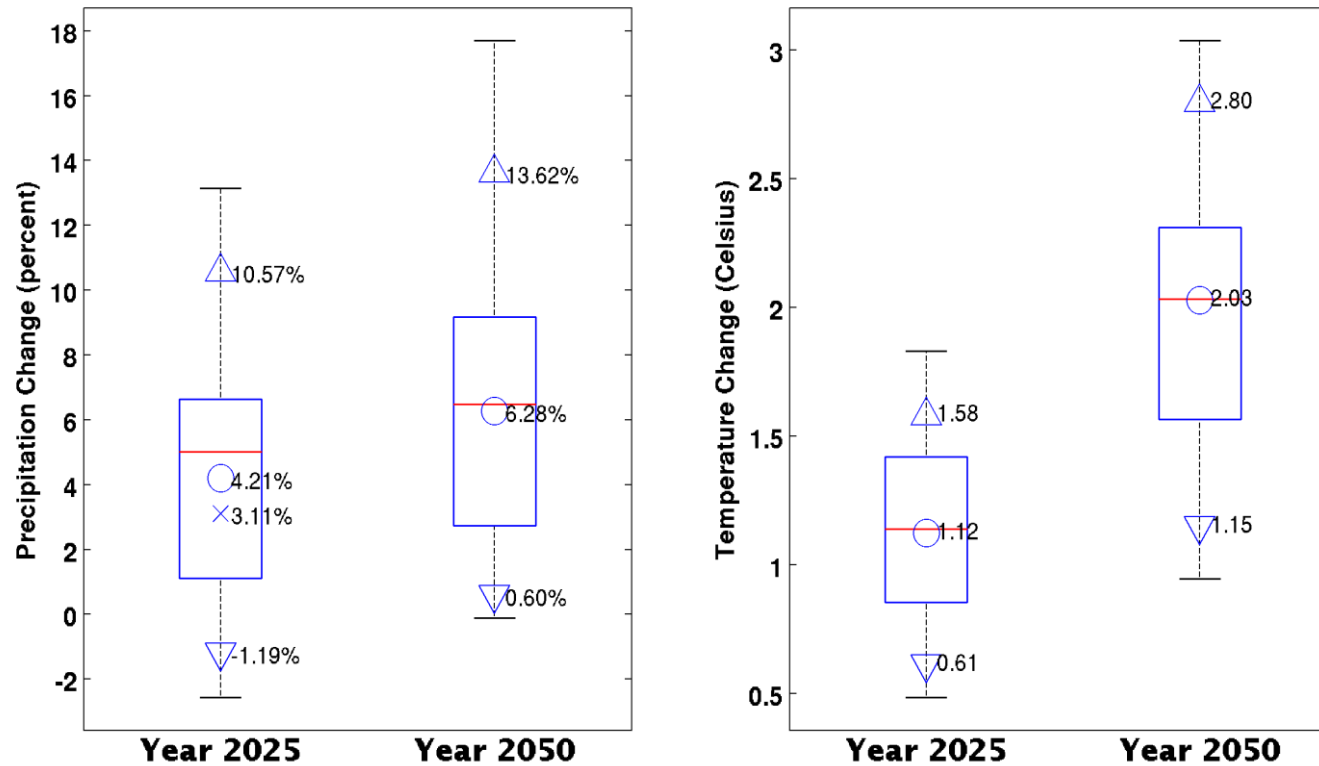
- Ensemble_Median
- Ensemble_P10
- △ Ensemble_P10T90
- Ensemble_P90
- ◇ Ensemble_T10P90



Data shown for the District of Columbia for illustration.

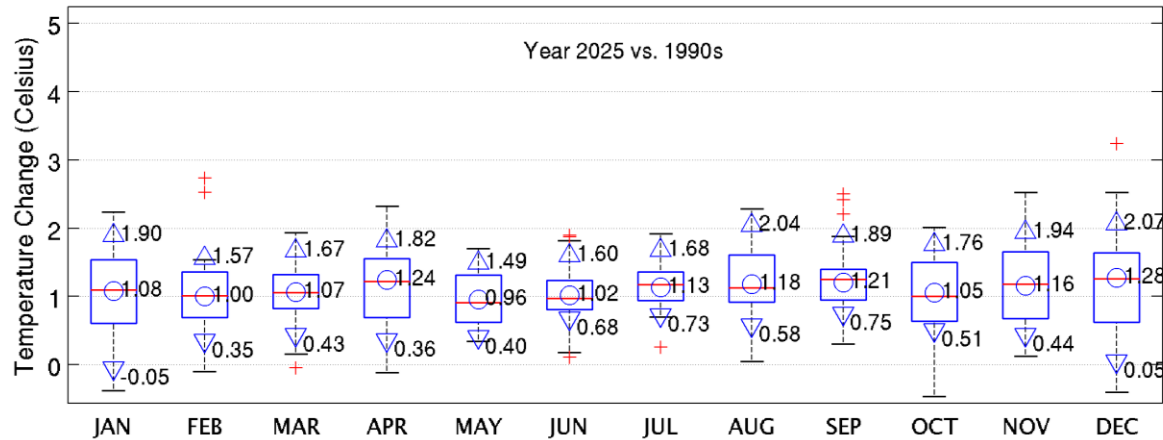
Average annual precipitation and temperature from the 31 bias-corrected downscaled global circulation models are shown for a land segment (N11001). Shown in blue line is the ensemble median. Data used in model calibration from NLDAS-2 are shown in black

Projected changes in precipitation and temperature (RCP 4.5) – *Average Annual*

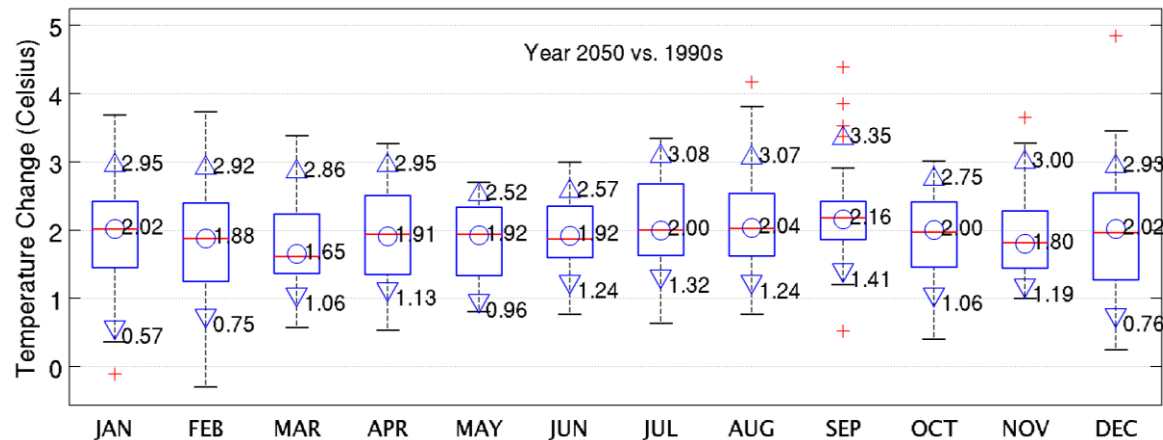


Summary of RCP4.5 average annual rainfall and temperature change for the Chesapeake Bay watershed are shown. Then range for 10th percentile (P10), ensemble median (P50), and 90th percentile (P90) are shown. The estimated change in rainfall volume based on the extrapolation of long-term trends are also shown (with marker symbol x)

Projected changes in temperature (RCP 4.5)



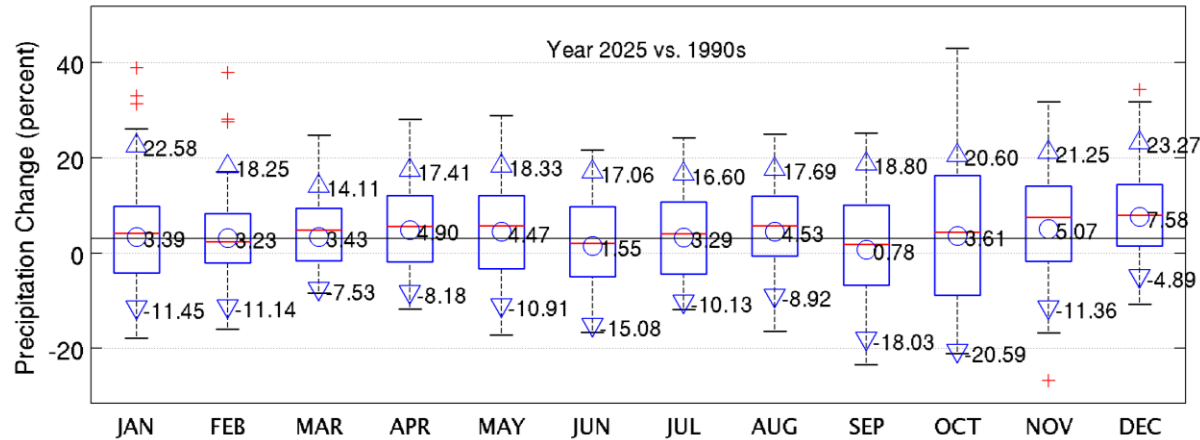
Watershed average of ensemble median is +1.12 °C



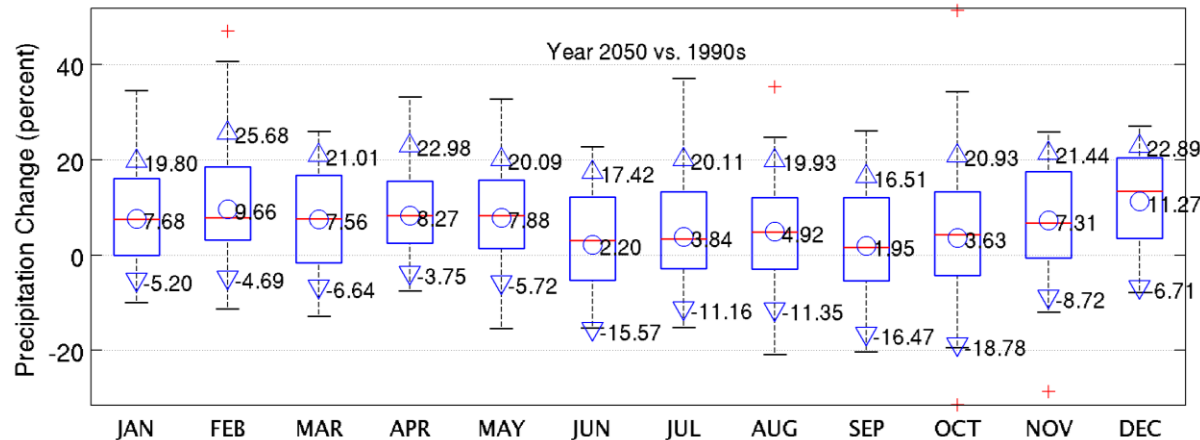
Watershed average of ensemble median is +2.02 °C

Monthly change in temperature for the Chesapeake Bay Watershed is shown. Box plot shows distribution of projected change based on 31-member ensemble of RCP 4.5 for the years 2025 and 2050. Additional three marker keys show 10th percentile (P10), ensemble median (P50), and 90th percentile (P90) bounds.

Projected changes in precipitation (RCP 4.5)



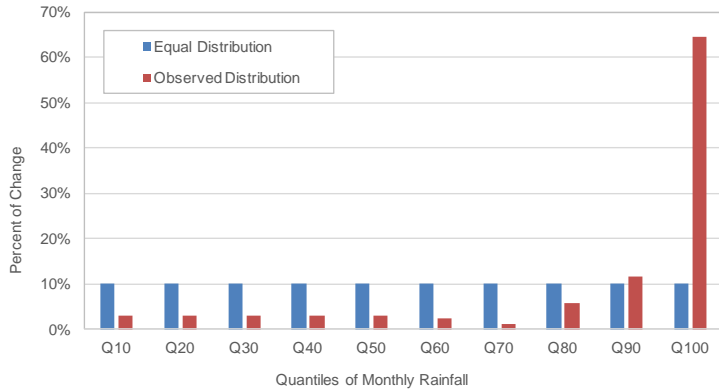
Watershed average of ensemble median is +4.21% (+3.11% estimated using extrapolation of long term trend)



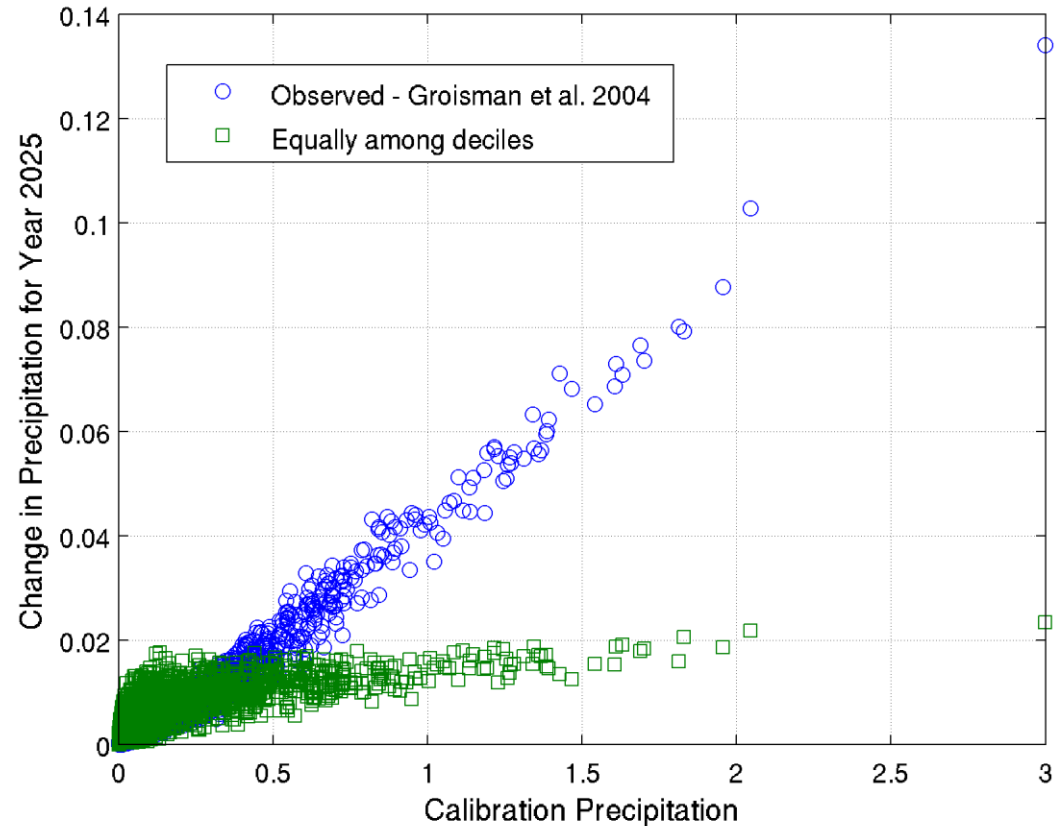
Watershed average of ensemble median is +6.28%

Monthly change in precipitation volume for the Chesapeake Bay Watershed is shown. Box plot shows distribution of projected change based on 31-member ensemble of RCP 4.5 for the years 2025 and 2050. For the year 2025 projected change based on long term trend is shown in black line. Additional three marker keys show 10th percentile (P10), ensemble median (P50), and the 90th percentile (P90) bounds.

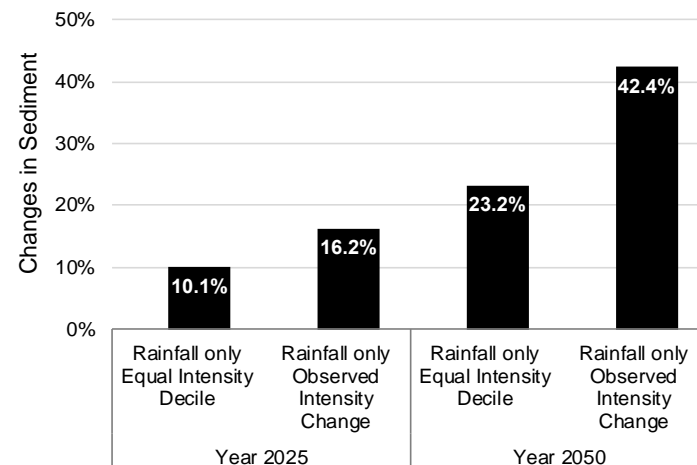
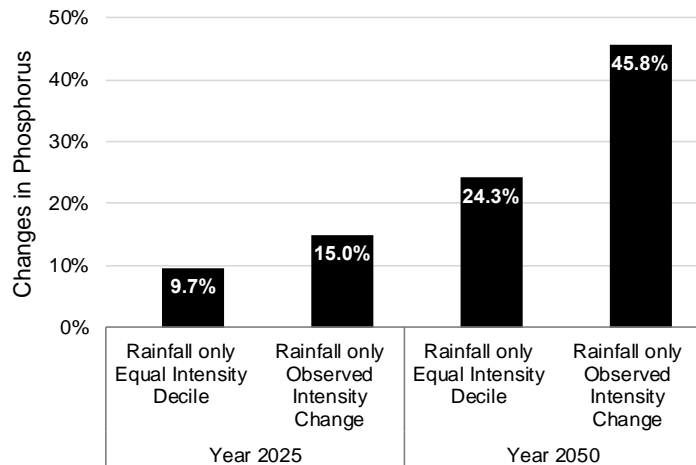
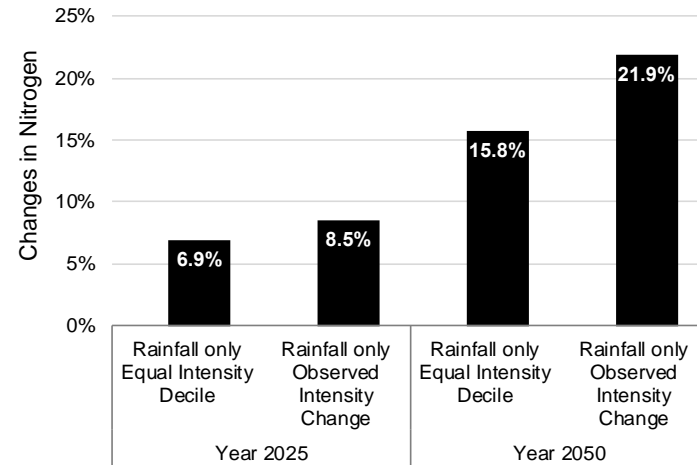
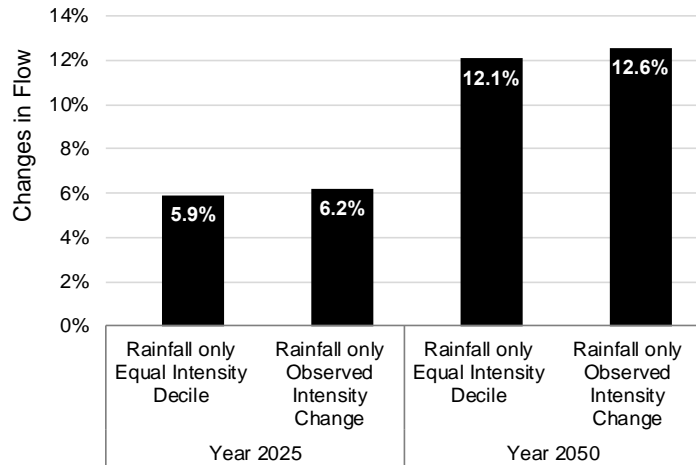
Monthly delta change to hourly events



Observed changes in rainfall intensity over the last century (based on Figure 10 in Groisman et al. 2004). The equal allocation distribution (blue) is contrasted with the distribution obtained based on observed changes (red).

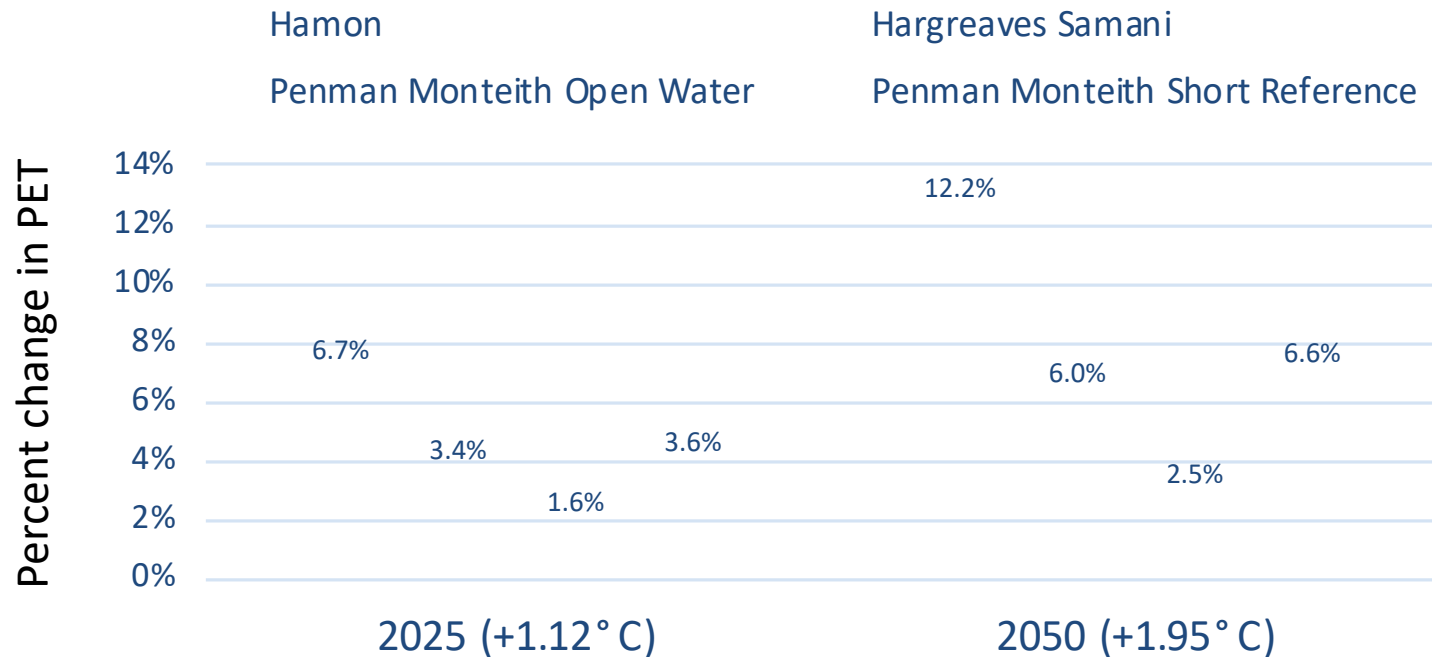


Additional rainfall added to the baseline daily rainfall over the 10-year period for a Phase 6 land segment (Potter, PA) is shown. In the method based on observed intensity trends, (Groisman et al. 2004) more volume is added to 10th decile resulting in higher intensity events become stronger.

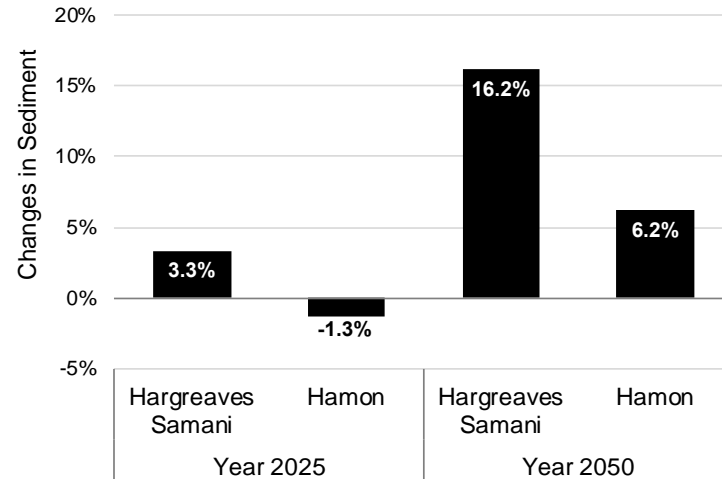
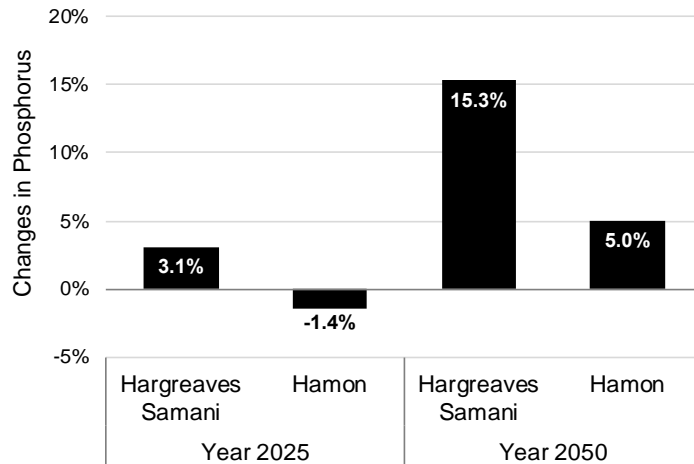
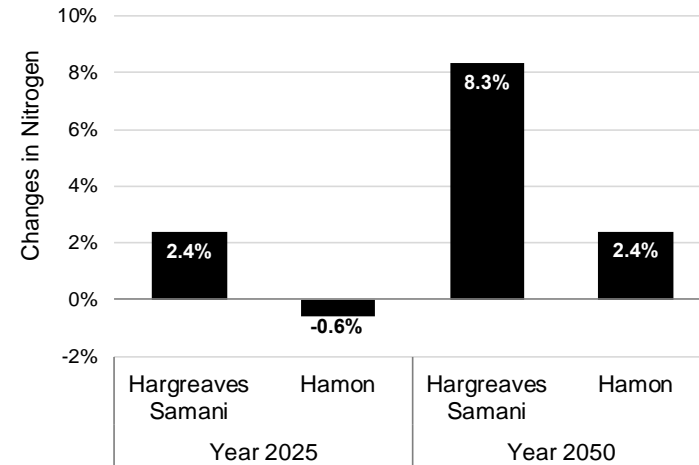
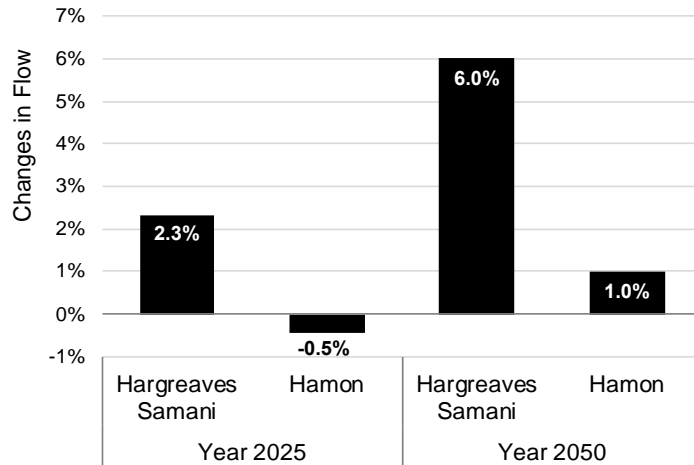


Differences in the watershed delivery of flow, nitrogen, phosphorus, and sediment are shown for the two different methods for downscaling projected changes in monthly rainfall volume for the year 2025 and 2050 to hourly rainfall events.

Estimation of potential evapotranspiration (PET)

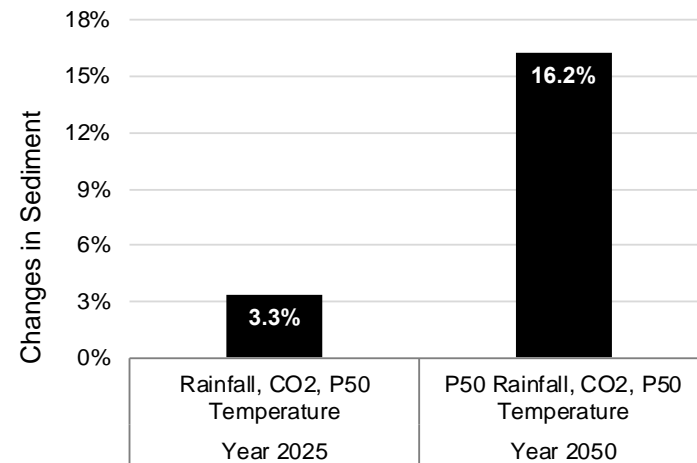
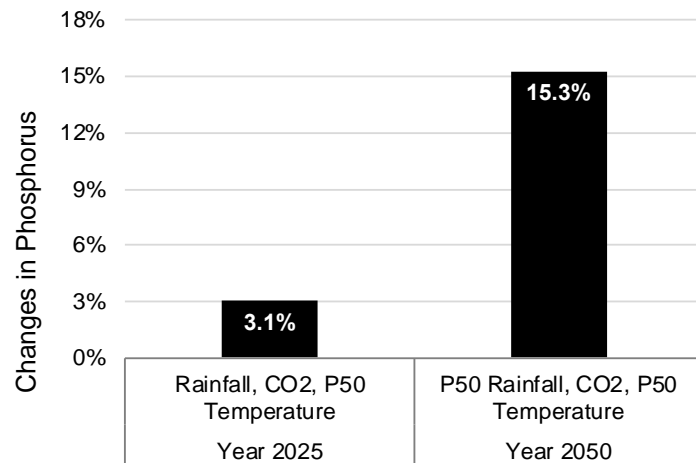
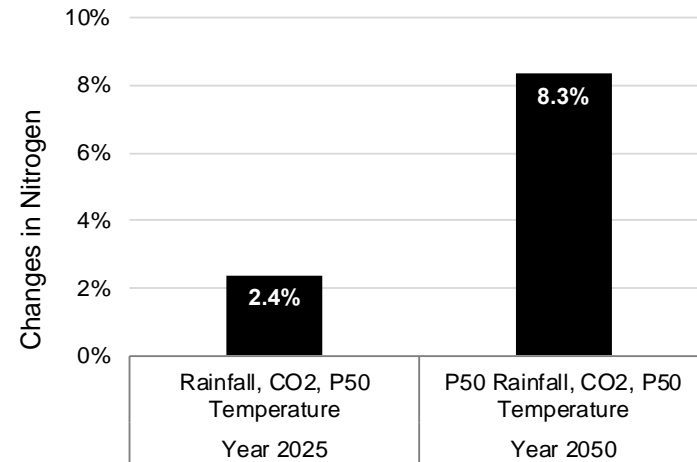
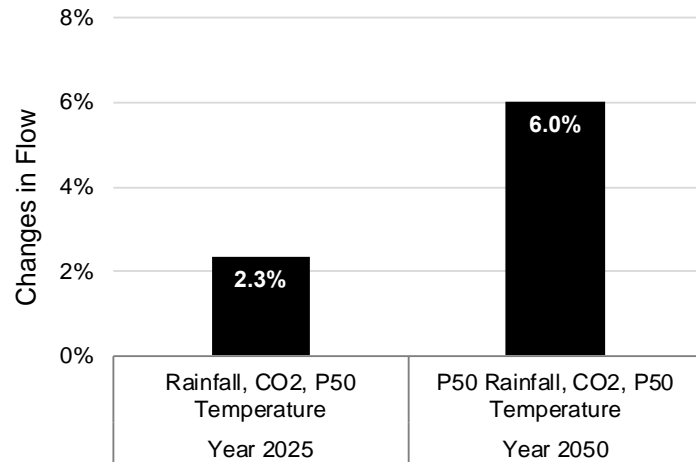


The relative difference in PET produced by using either the Hamon or Hargreaves-Samani methods are shown here. In 2025 projections produced by the WSM, the Hamon method simulated an increase in PET that was 3.36 percent greater than that simulated with the Hargreaves-Samani method. The change was more pronounced in 2050 simulations where the Hamon method outpaced the PET rate of Hargreaves-Samani by 6.26 percent



Differences in estimated delivery due to selection method for estimating potential evapotranspiration for 2025 and 2050 are shown. The differences get higher with increase in temperature

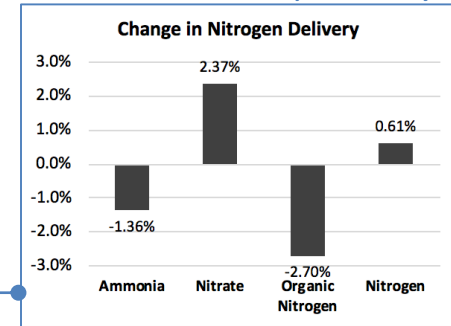
Summary of changes in delivery



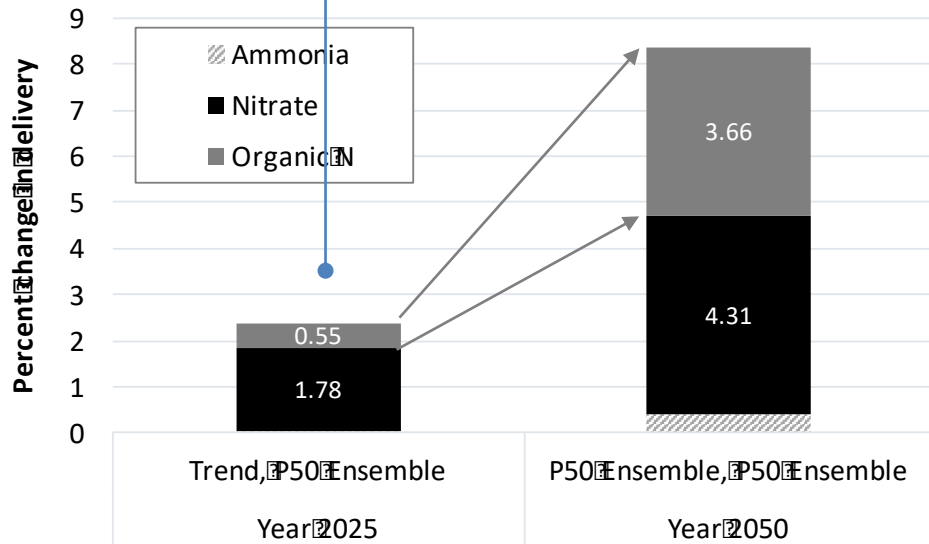
Differences due to selection method for estimating potential evapotranspiration for 2025 and 2050 are shown. The differences get higher with increase in temperature

Nitrogen and phosphorus species

Year 2025 Nov 2017 (with error)

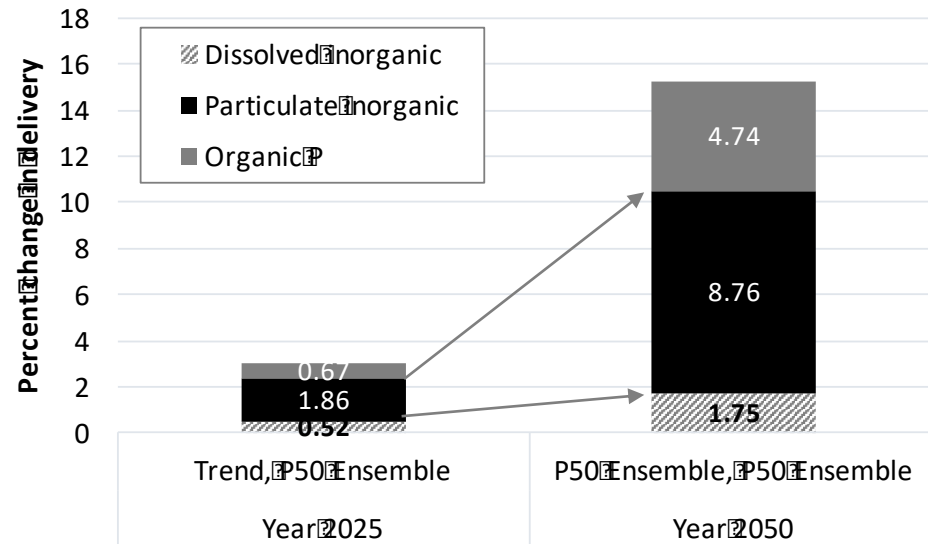


Simulated Changes in Nitrogen Delivery



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

Simulated Changes in Phosphorus Delivery



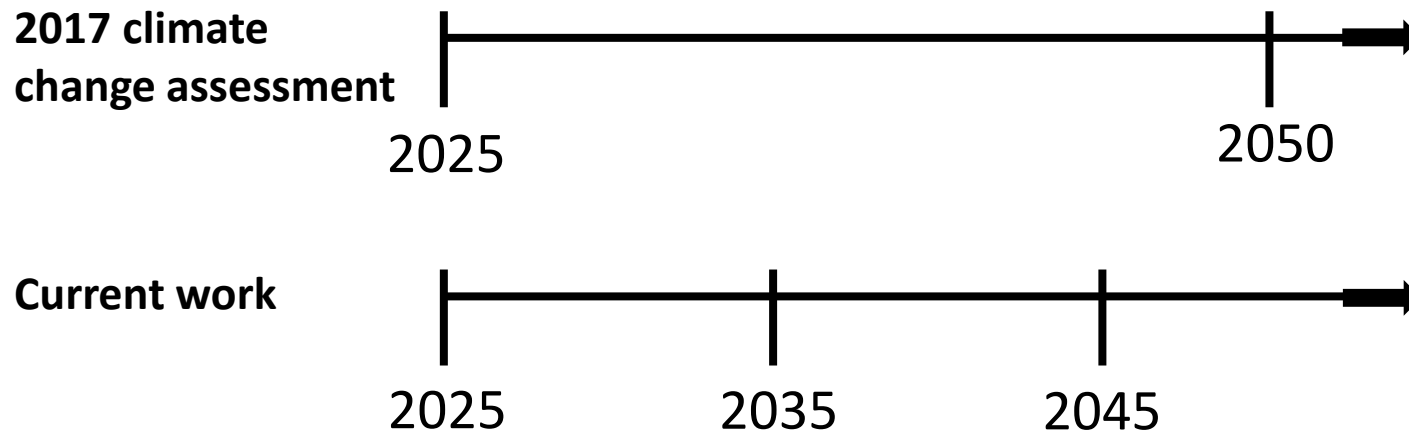
Arrows show relatively more increase in inorganic (particulate) phosphorus as compared to organic.

Uncertainty due to rainfall and temperature inputs

Period	Climate Change Scenario	Flow		Nitrogen		Phosphorus		Sediment	
		B ft3	percent	M lbs	percent	M lbs	percent	M tons	percent
Year 2025	Rainfall, CO2, P10 Temperature	124.78	4.8%	13.55	6.9%	1.61	11.6%	1.10	13.1%
	Rainfall, CO2, P50 Temperature	61.16	2.3%	4.68	2.4%	0.43	3.1%	0.28	3.3%
	Rainfall, CO2, P90 Temperature	-0.44	0.0%	-1.24	-0.6%	-0.22	-1.6%	-0.15	-1.8%
Year 2050	P10 Rainfall, CO2, P10 Temperature	-478.34	-18.3%	-36.01	-18.3%	-3.04	-21.9%	-2.15	-25.6%
	P50 Rainfall, CO2, P50 Temperature	157.25	6.0%	16.44	8.3%	2.13	15.3%	1.36	16.2%
	P90 Rainfall, CO2, P90 Temperature	966.74	36.9%	362.81	183.9%	81.80	588.3%	18.41	219.3%

Presentation outline

- Estimated impacts of 2025 and 2050 climate change on the watershed delivery of nutrients and sediment.
- **Decadal series of climate change assessment for the years 2025, 2035, and 2045.**



STAC recommendations [1]

The workshop culminated with the following specific recommendations related to the selection, use, and application of climate projections and forecasts for the 2017 Midpoint Assessment.

1. 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.
2. 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.
3. The Partnership 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.
4. 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.
5. 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 use beyond 2050.
6. 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



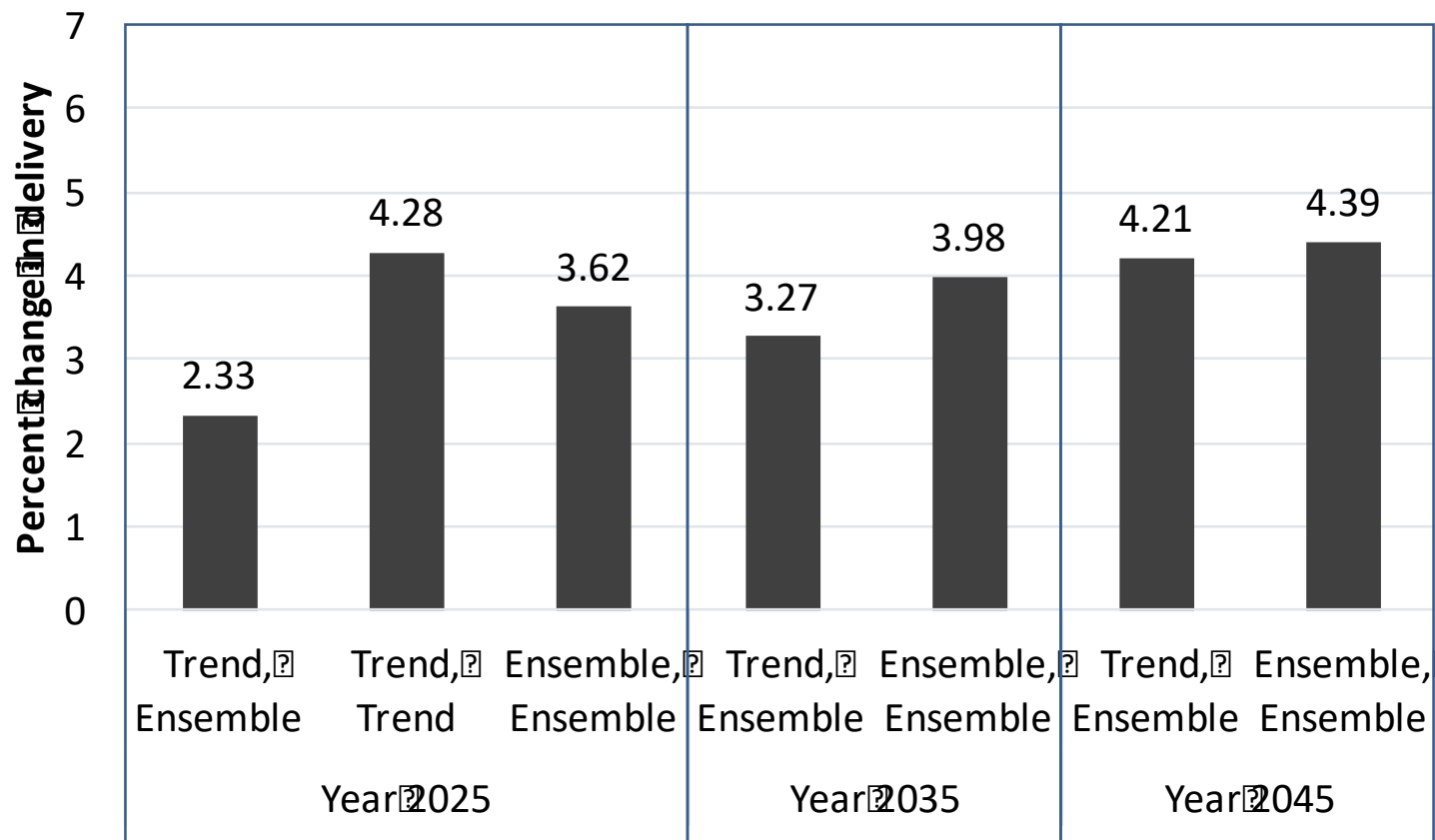
[1] Page 8 http://www.chesapeake.org/pubs/360_Johnson2016.pdf

Year	Precipitation		Temperature	
	Trend	Ensemble	Trend	Ensemble
2025	x	–	–	x
2035	?	?	?	?
2045	?	?	?	?
2050	–	x	–	x

- Highlighted in yellow are the STAC and CBP climate resiliency workgroup recommendations for the 2017 Climate Change assessment, which included years 2025 and 2050.
- For 2035 and 2045 a discussion is needed, leading to perhaps a recommendation for either a specific source or a method for combine the two sources.

Estimated changes in flow

Simulated Changes in Delivery of Flow

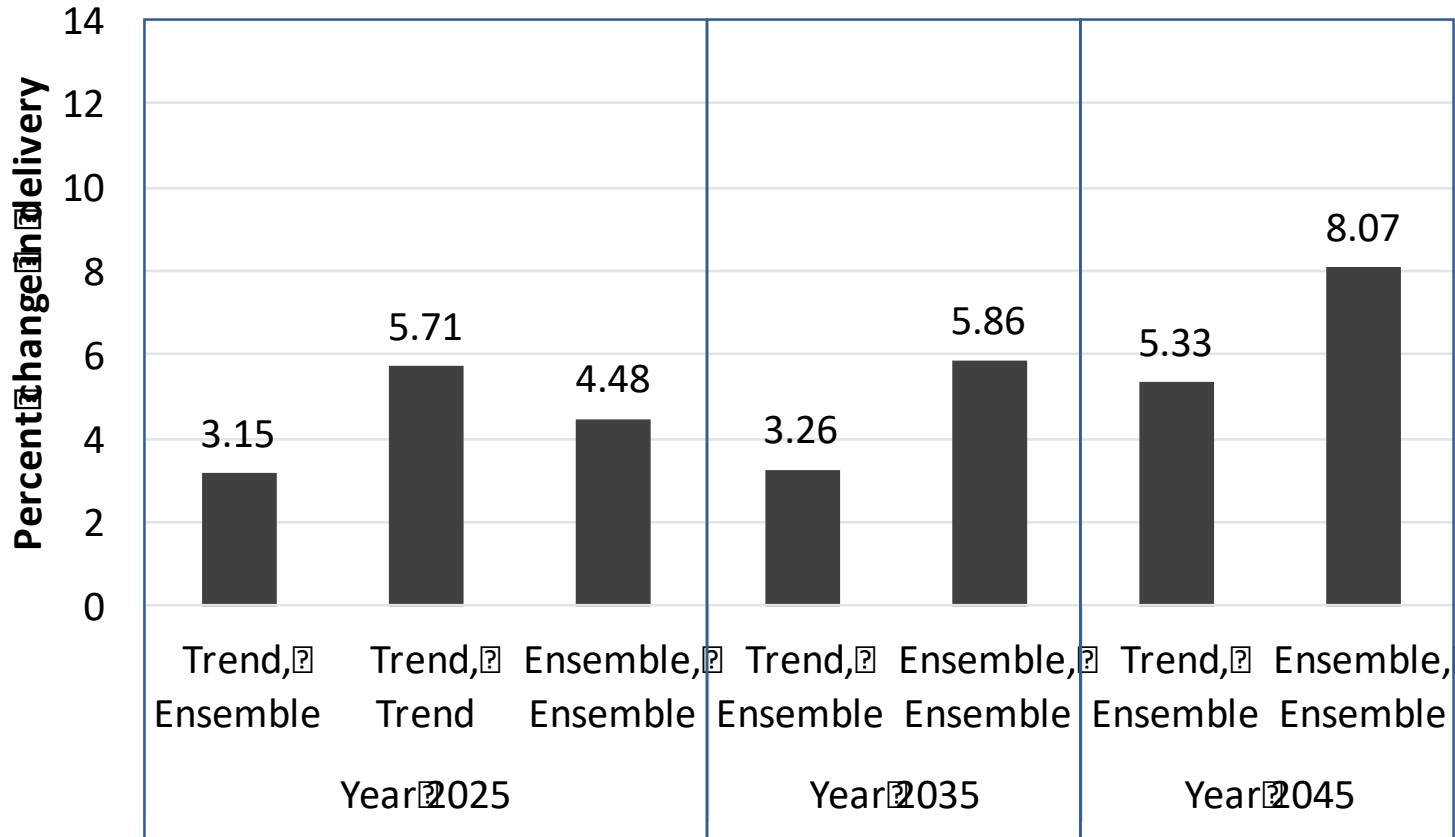


Trend: projection of extrapolation of long-term trends

Ensemble: 31-member ensemble median (P50) of statistically downscaled GCM RCP4.5

Estimated changes in sediment

Simulated Changes in Delivery of Sediment

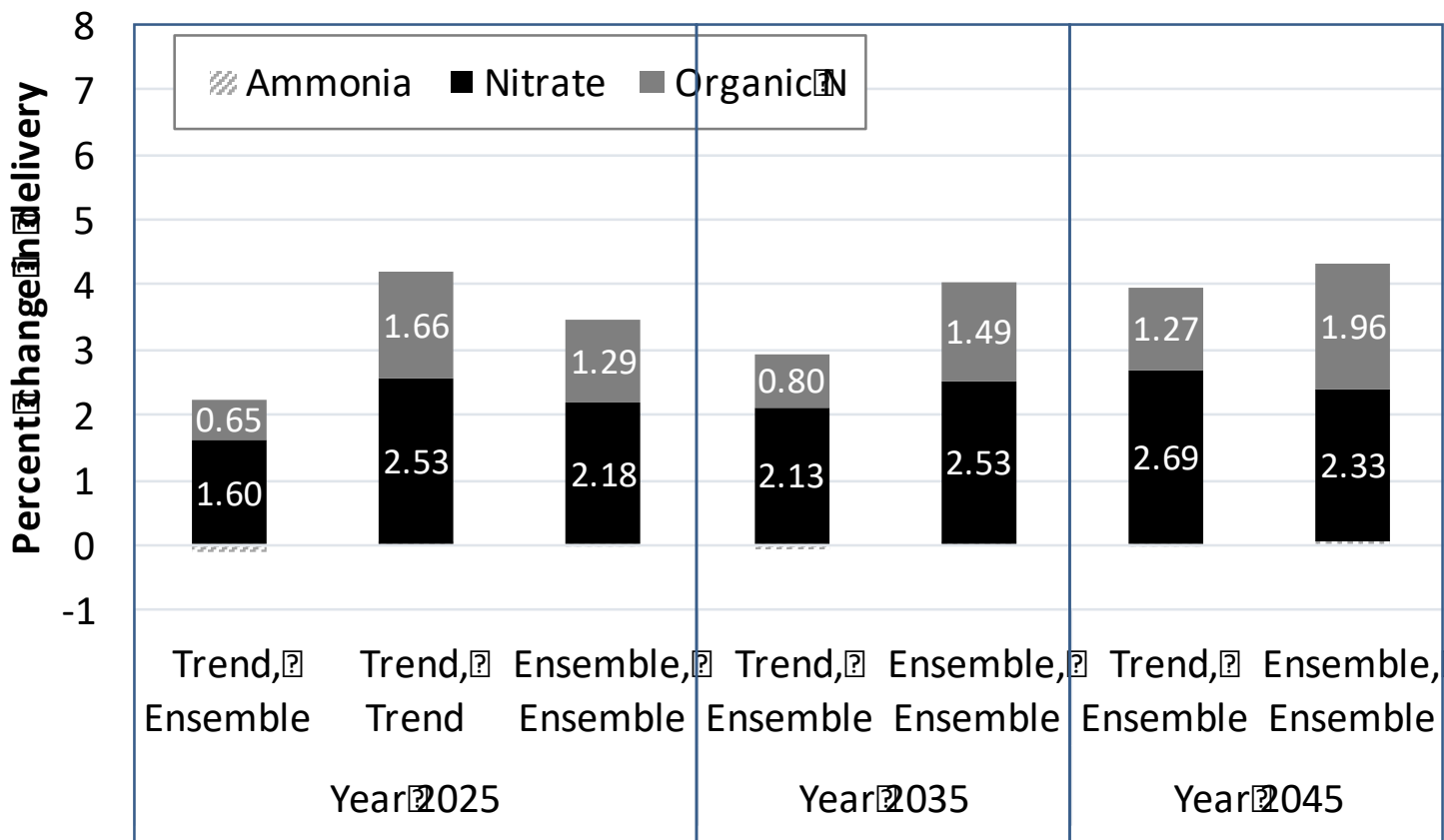


Trend: projection of extrapolation of long-term trends

Ensemble: 31-member ensemble median (P50) of statistically downscaled GCM RCP4.5

Estimated changes in nitrogen

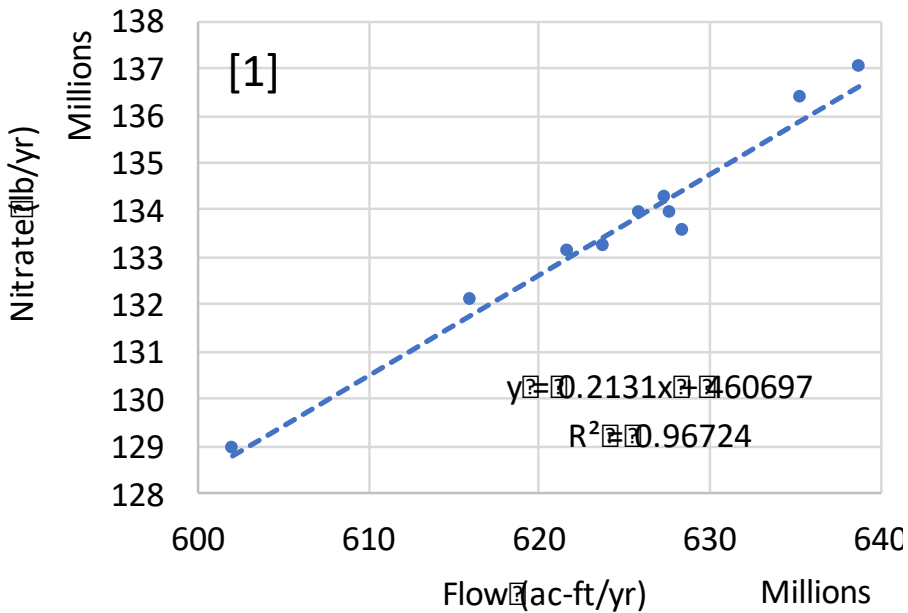
Simulated Changes in Nitrogen Delivery



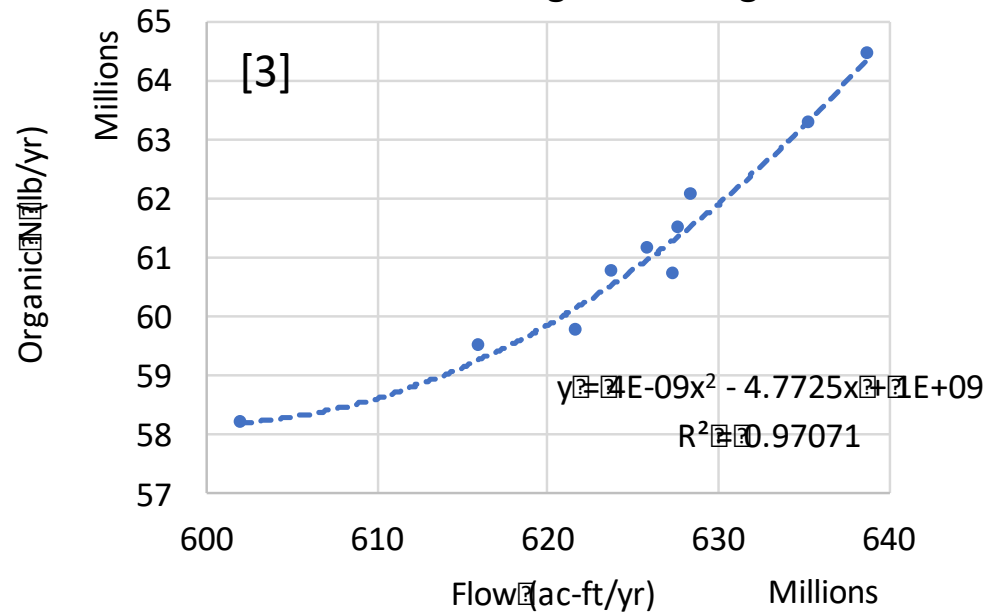
Trend: projection of extrapolation of long-term trends

Ensemble: 31-member ensemble median (P50) of statistically downscaled GCM RCP4.5

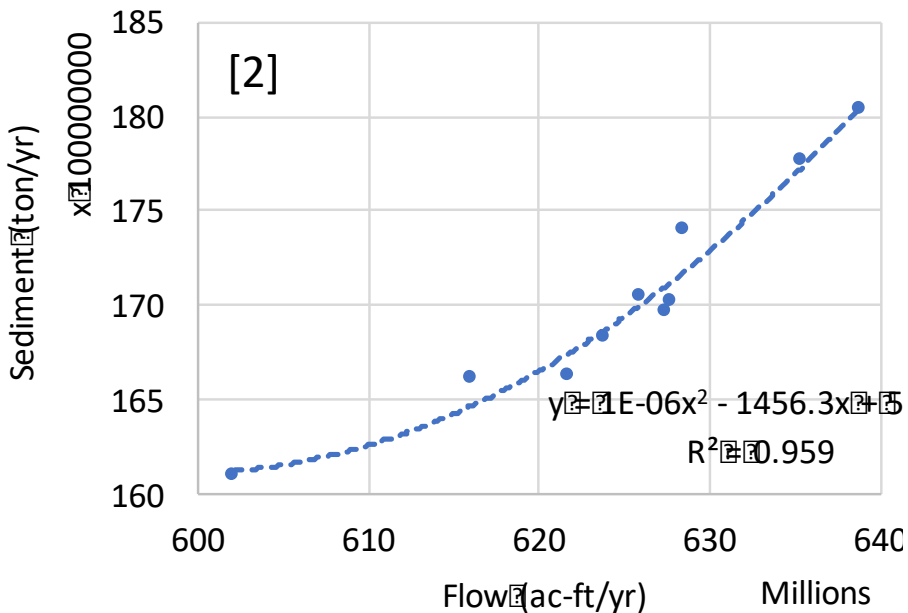
Flow vs. Nitrate



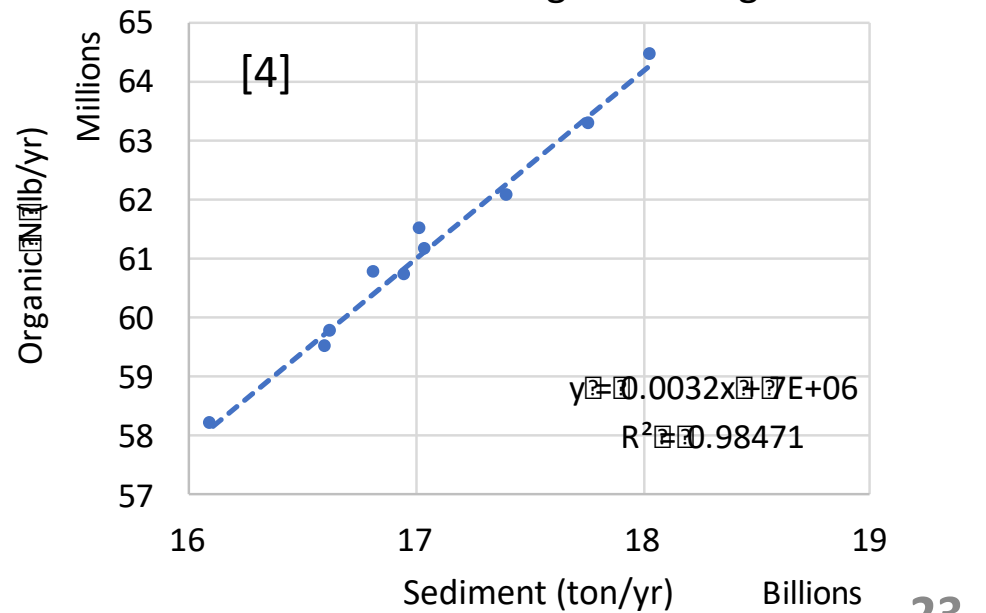
Flow vs. Organic Nitrogen



Flow vs. Sediment

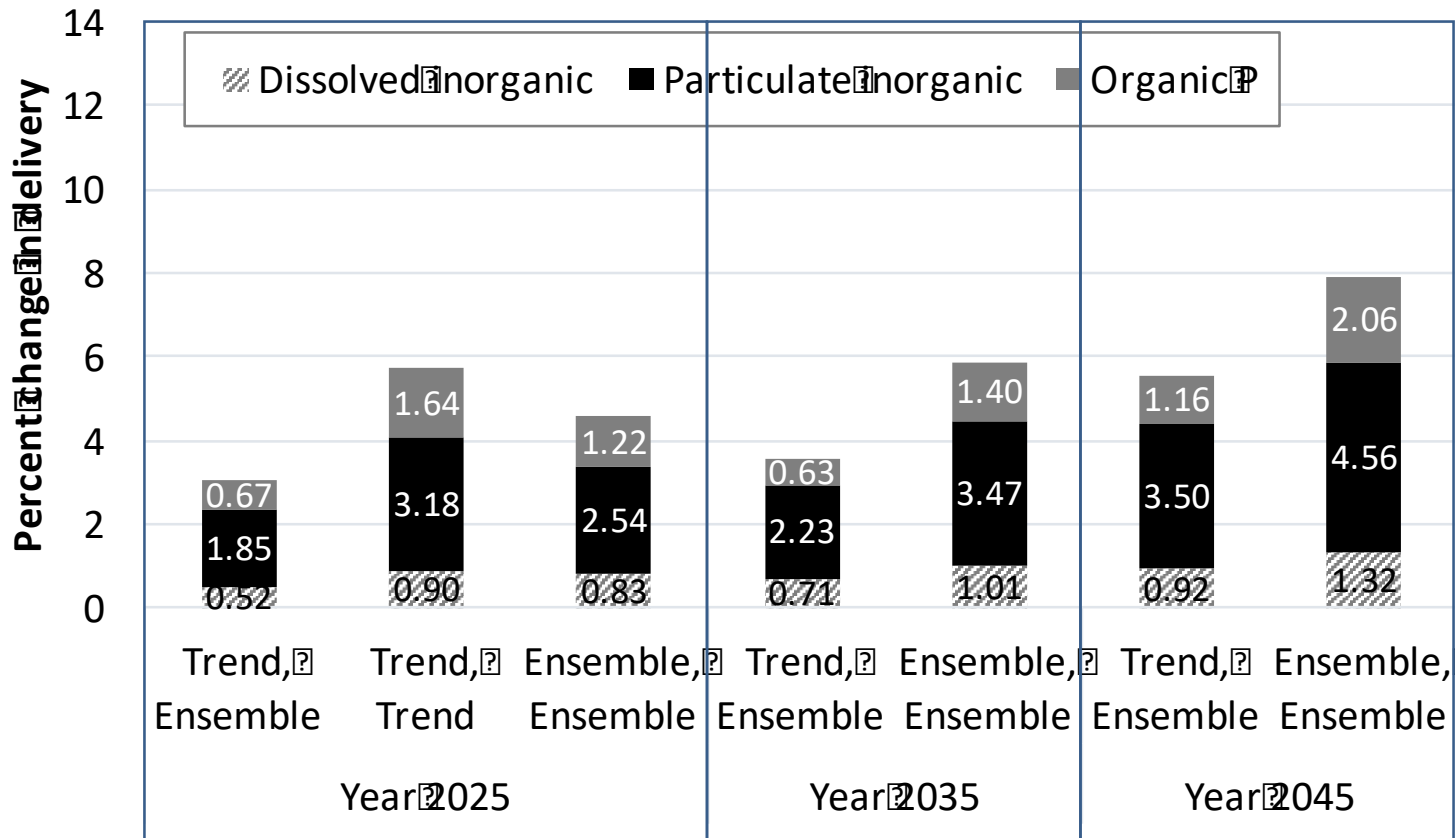


Flow vs. Organic Nitrogen



Estimated changes in phosphorus

Simulated Changes in Phosphorus Delivery



Trend: projection of extrapolation of long-term trends

Ensemble: 31-member ensemble median (P50) of statistically downscaled GCM RCP4.5

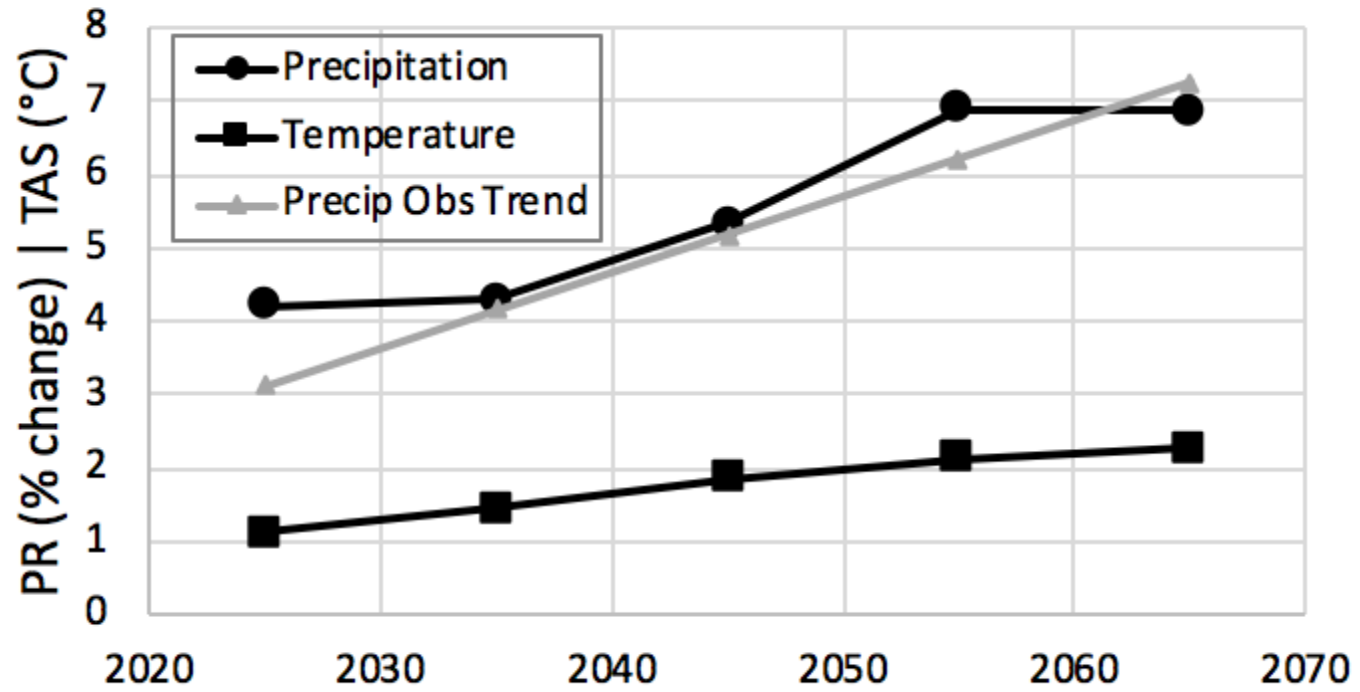
Discussions

- Updated results include:
 - Bug fix for temperature inputs
 - Updated inputs for July PSC
- Analysis did not include any changes in land-use, crop yields, atmospheric deposition, and BMPs.
- Trend based rainfall projection did not have any monthly/seasonal component.

Summary and Conclusions

- Estimated impacts of 2025 and 2050 climate change on the watershed delivery of nutrients and sediment were shown.
- Estimated changes in the delivery of flow, nutrients and sediment were shown for decadal series of climate change assessments for the years 2025, 2035, and 2045.
- For years 2035 and 2045 both extrapolation of long-term trends and 31-member ensemble medians of downscaled GCMs were used.

RCP 4.5 Ensemble Median



RCP 4.5 Ensemble Median

