Application of Phase 6 Watershed Model to Climate Change Assessment

STAC Workshop: Climate Change Modeling 2.0
September 24, 2018

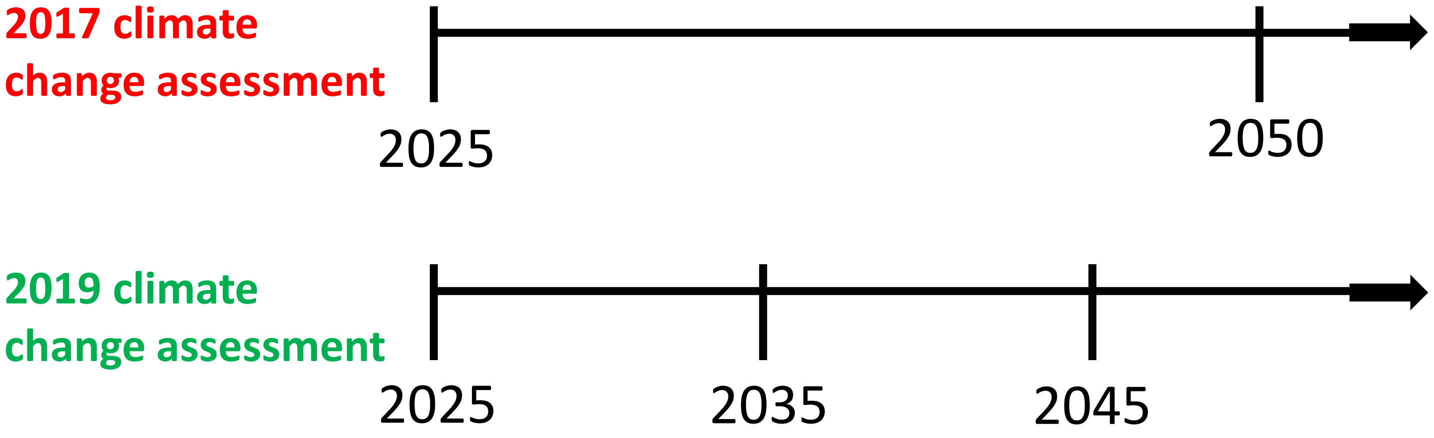
Gopal Bhatt[1] and Lewis Linker[2]

[1] Penn State, [2] US EPA

Chesapeake Bay Program
Science, Restoration, Partnership

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

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

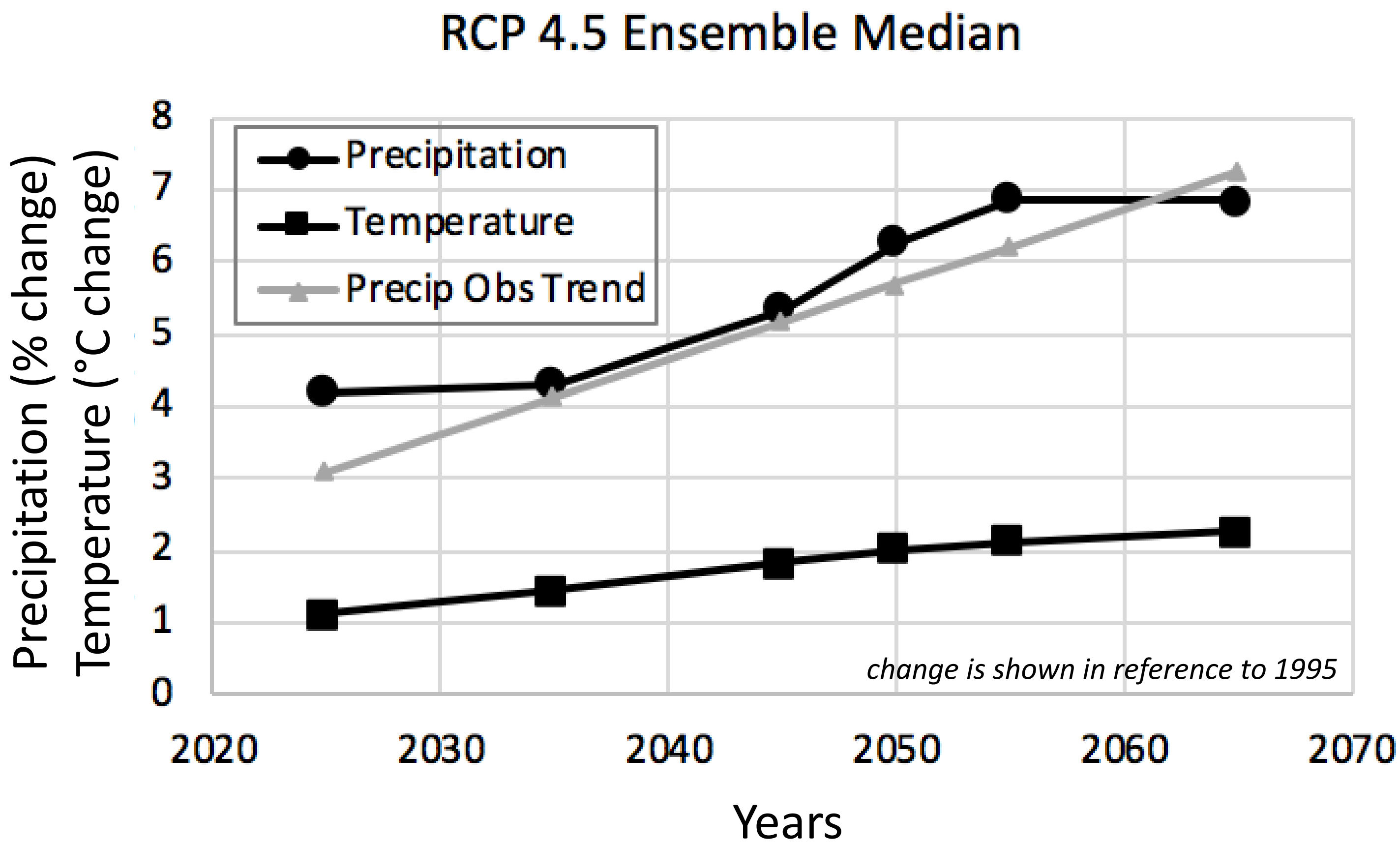
STAC Workshop Report
March 7-8, 2016
Annapolis, MD

stac

STAC Publication 16-006

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

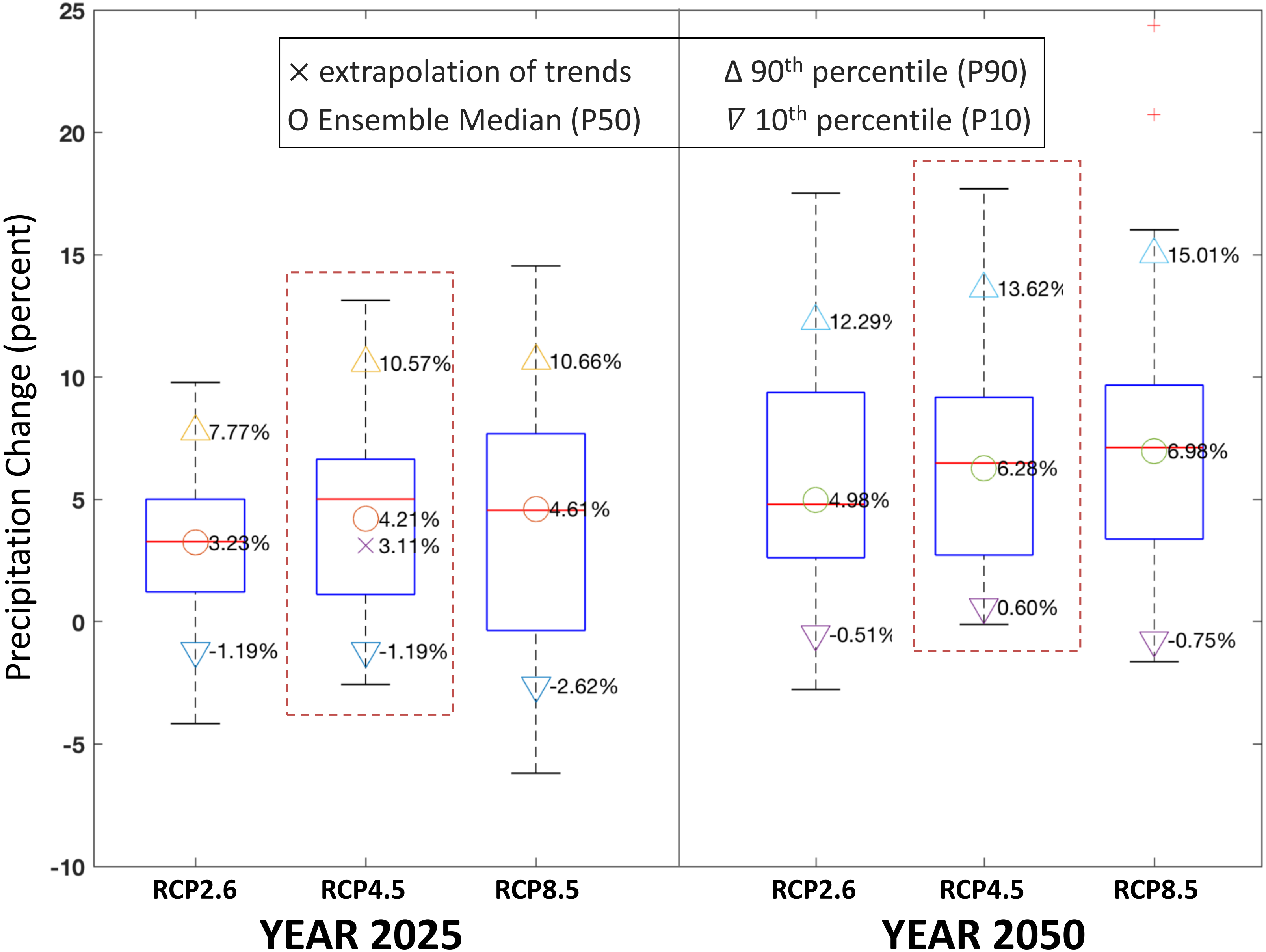
Summary of precipitation and temperature



***Trend**: extrapolation of long-term (88-year) trends*

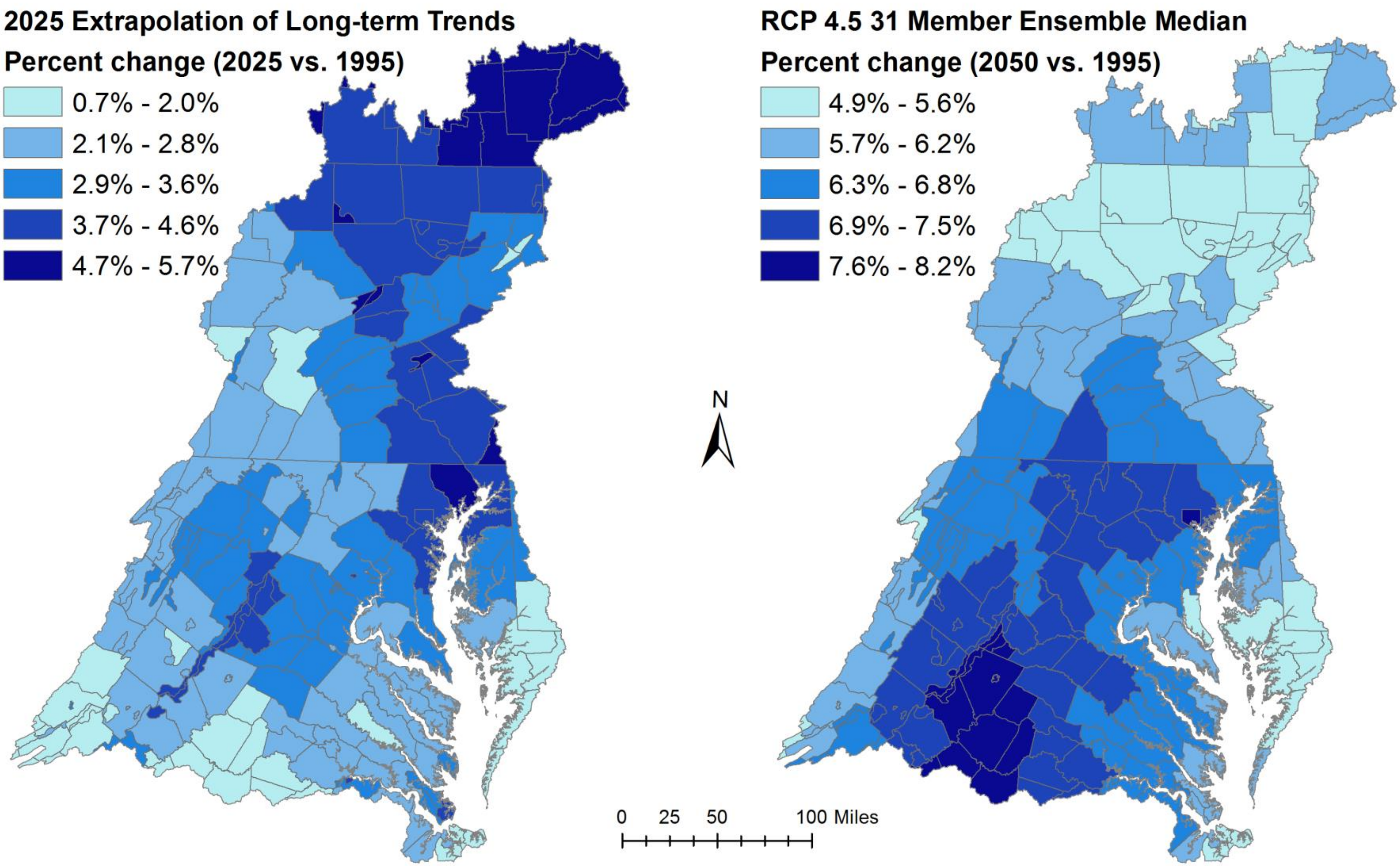
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*

Summary of precipitation change



YEAR 2025

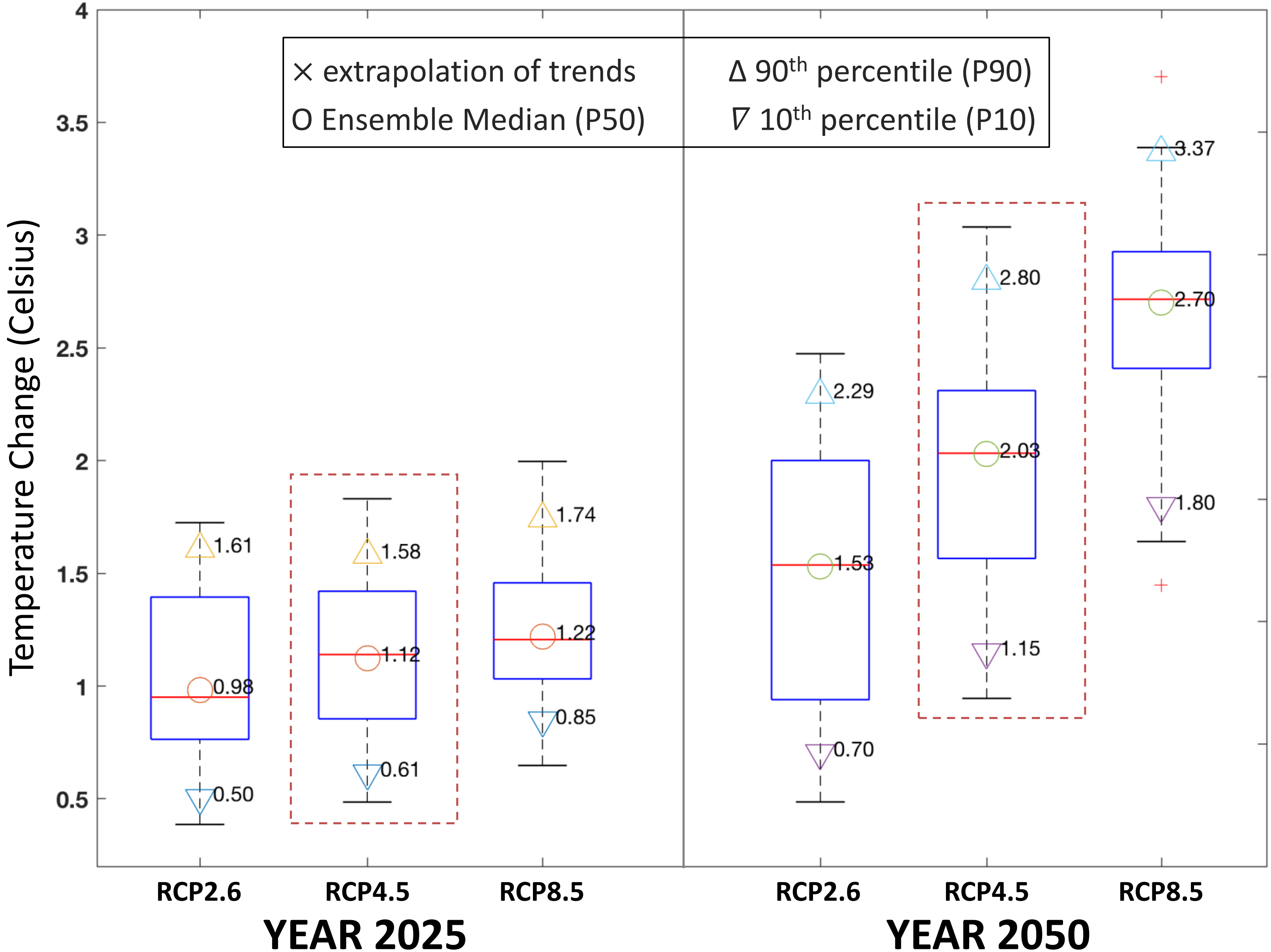
YEAR 2050



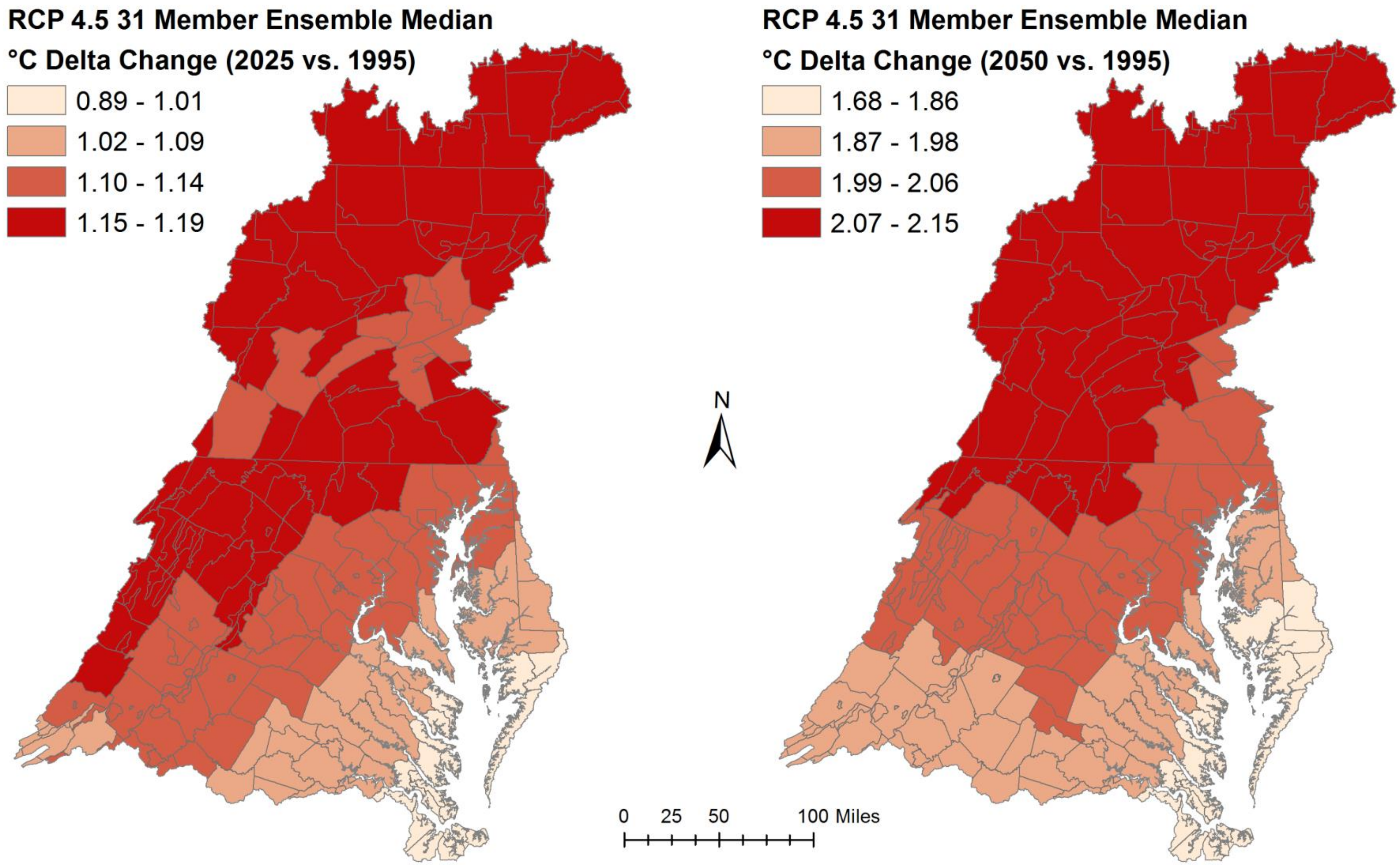
3.11% increase in average annual rainfall volume

6.28% increase in average annual rainfall volume

Summary of temperature change



YEAR 2025 | YEAR 2050

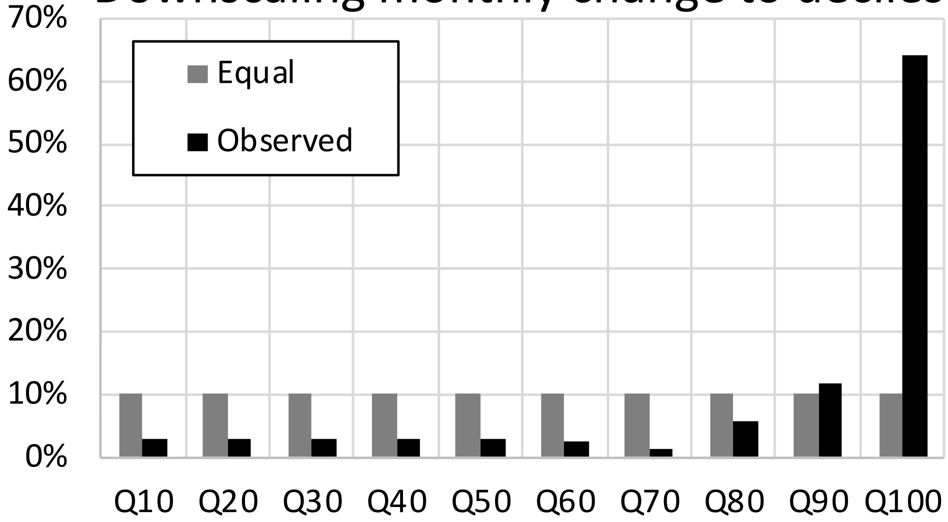


1.12°C increase in average annual temperature

2.03°C increase in average annual temperature

Monthly delta change to hourly events

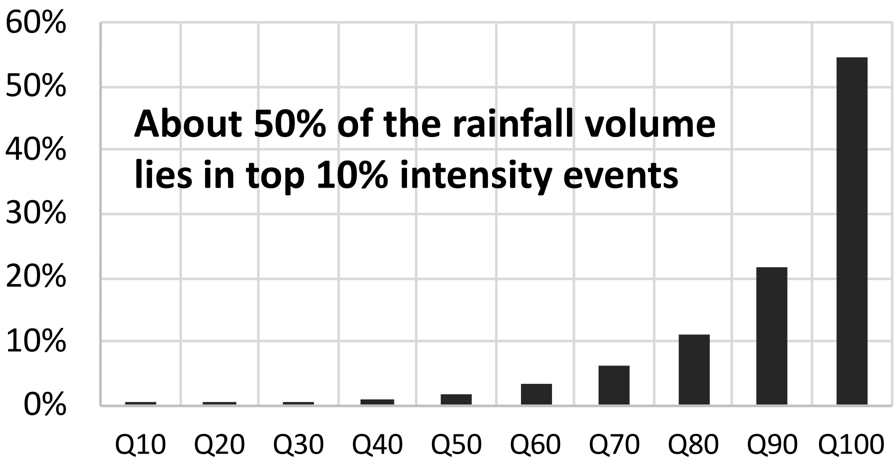
Downscaling monthly change to deciles



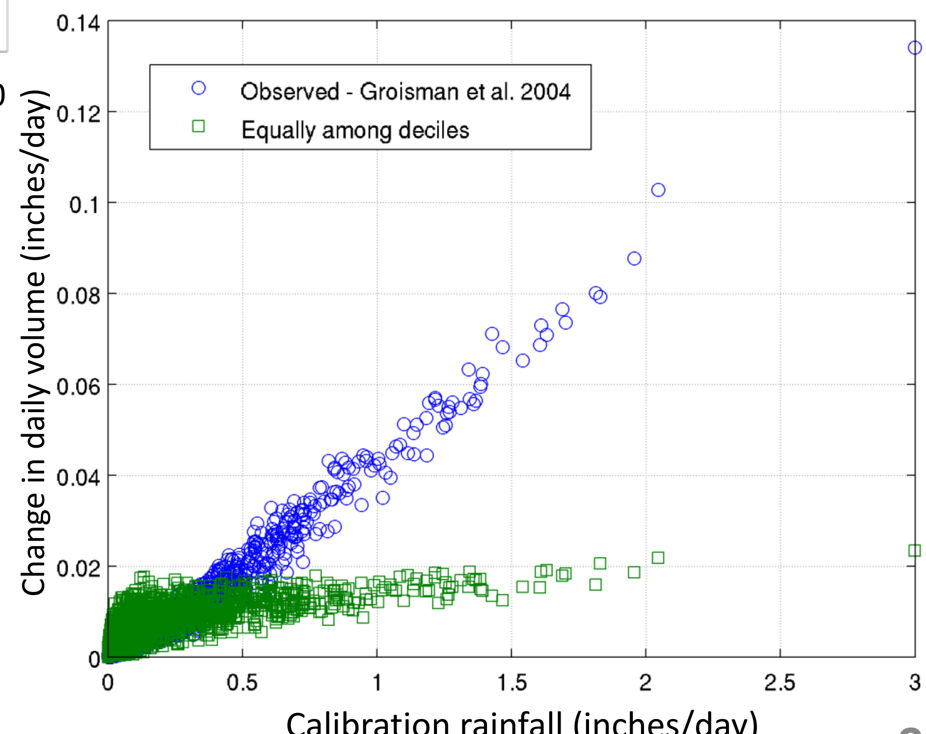
(a) Observed changes in rainfall intensity over the last century (based on Groisman et al. 2004, Figure 10).

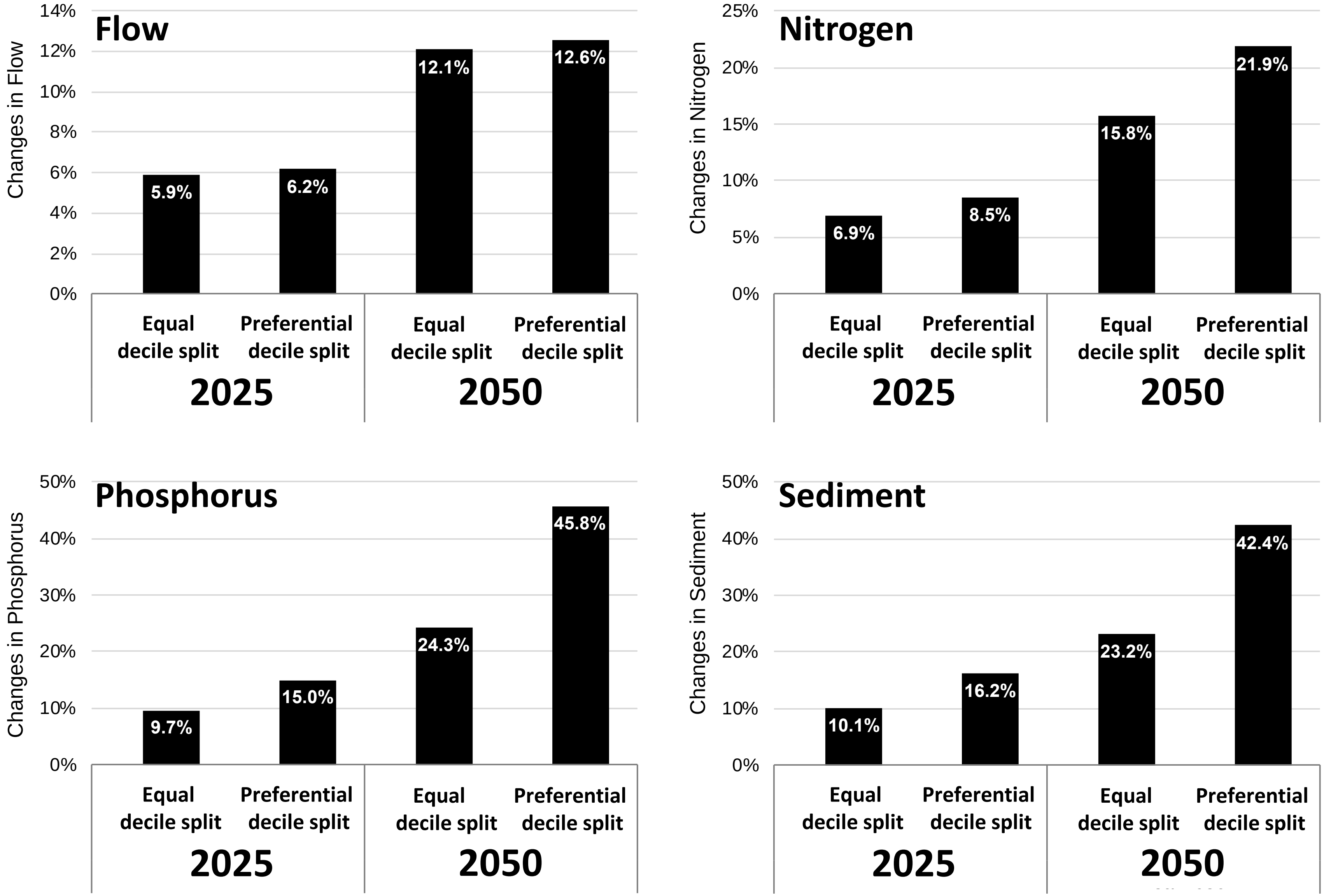
(b) Equal distribution

Deciles vs. Percent volume (Potter, PA)



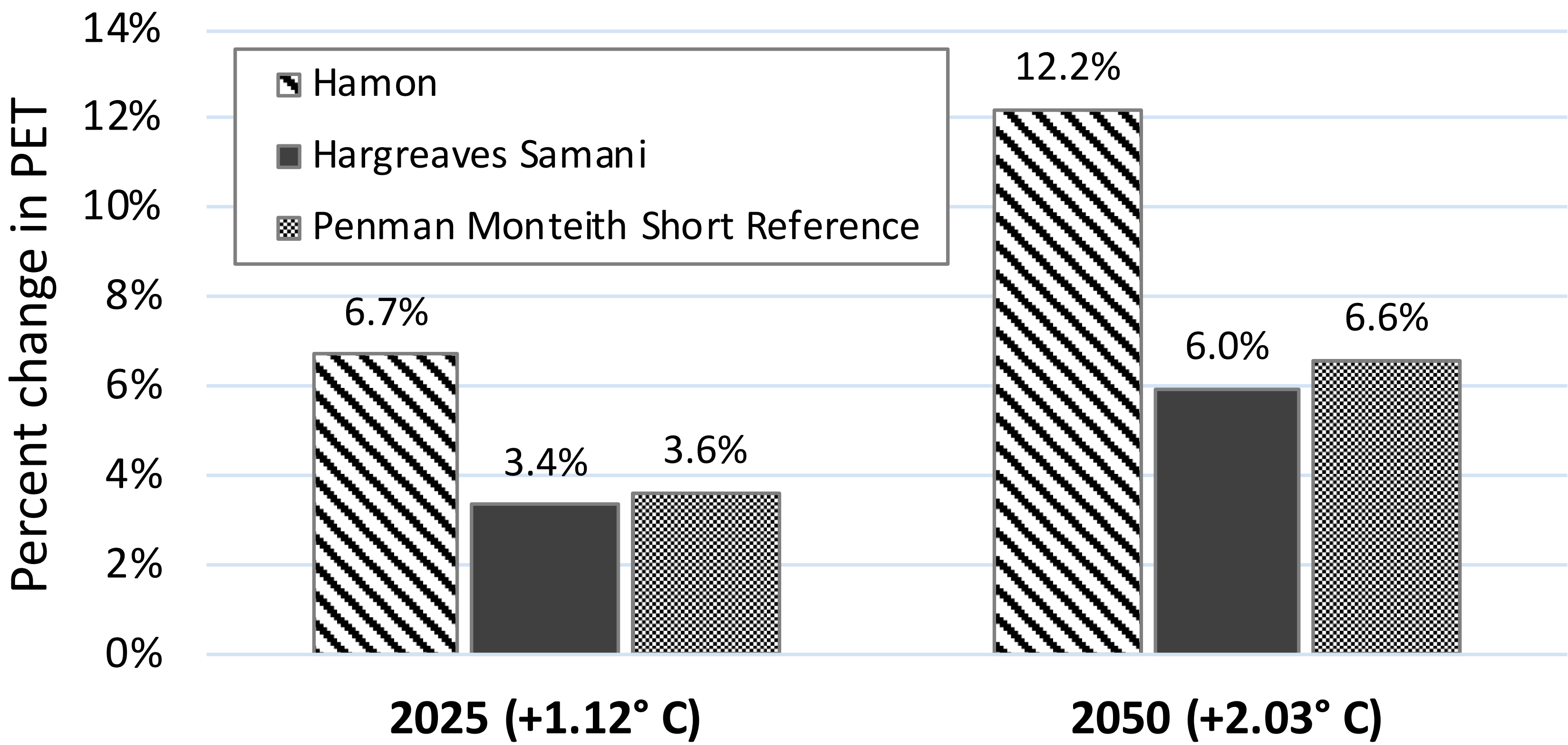
Summary of daily rainfall data



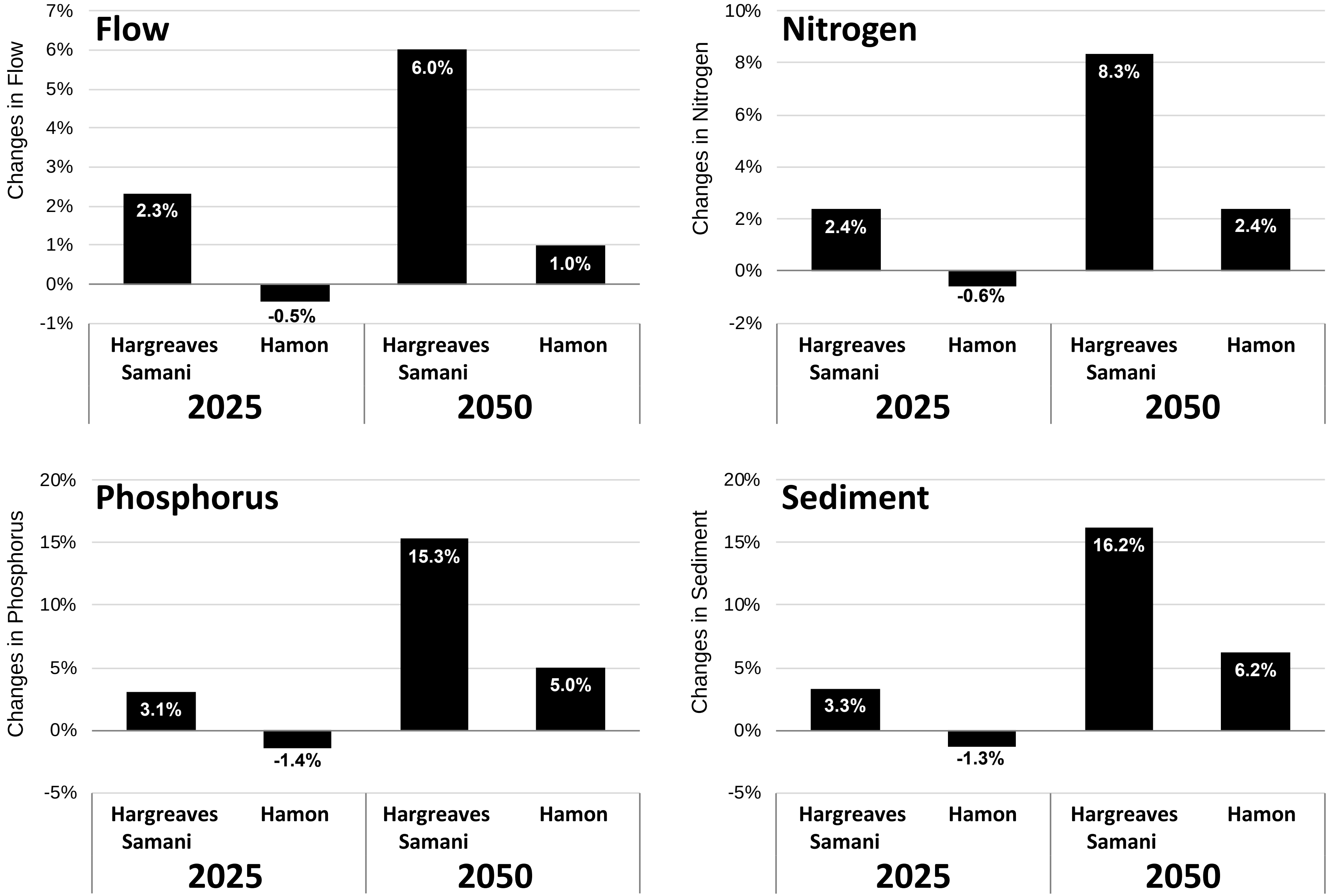


Differences in the watershed delivery of flow, nitrogen, phosphorus, and sediment are shown for the two methods for downscaling changes in monthly rainfall volume for the year 2025 and 2050 to hourly rainfall events.

Estimation of potential evapotranspiration (PET)



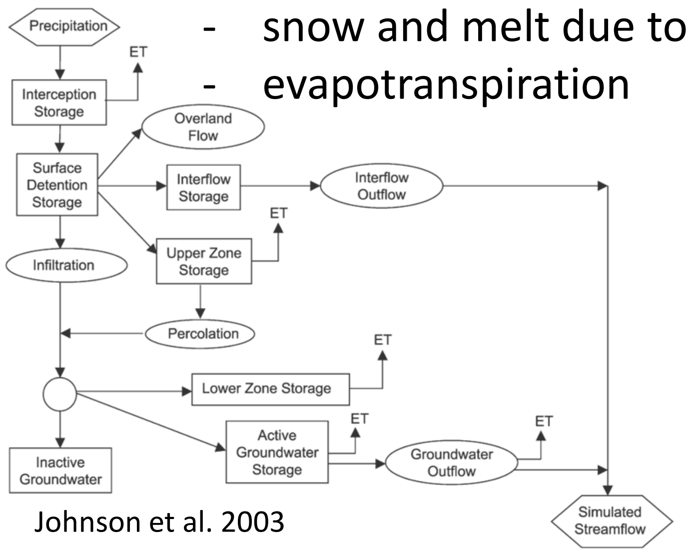
The difference in PET using the Hamon and Hargreaves-Samani methods are shown. For 2025, the Hamon method estimated an increase in PET that was 3.36% greater than that from Hargreaves-Samani method. The change was even more pronounced for 2050, where the Hamon method estimated 6.26 percent additional increase in PET as compared to Hargreaves-Samani. Estimated change in PET using Penman Monteith (short reference) show better alignment with Hargreaves-Samani.



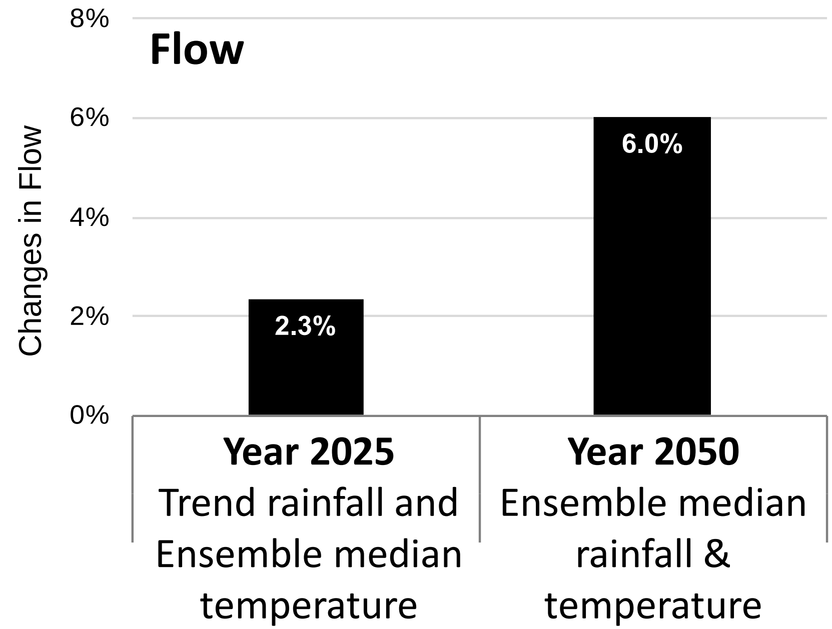
Differences in estimated delivery due to methods for estimating potential evapotranspiration for 2025 and 2050 are shown. The differences are higher with increase in temperature.

Summary of changes in delivery

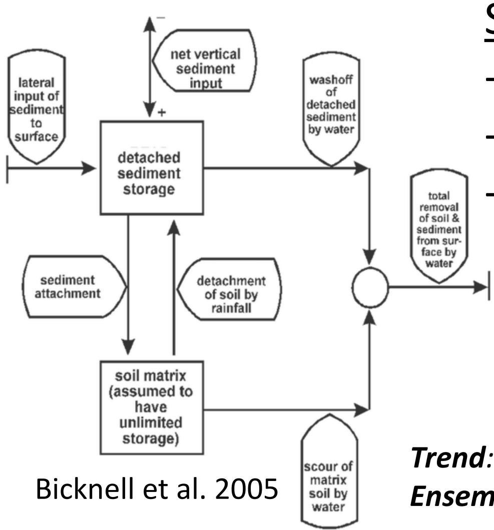
Hydrologic response:
- rainfall volume & intensity
- snow and melt due to temperature
- evapotranspiration



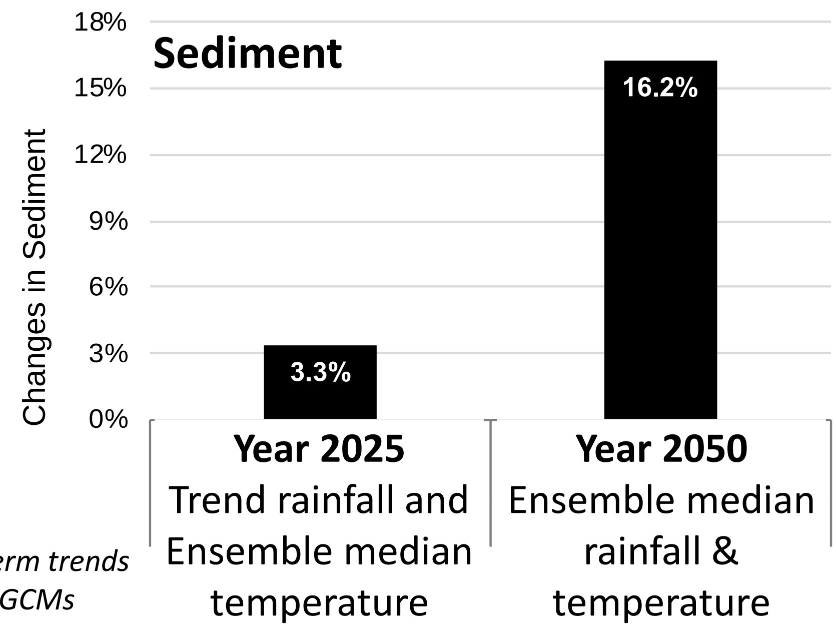
Johnson et al. 2003



Sediment response:
- rainfall intensity
- surface runoff
- riverine scour and deposition



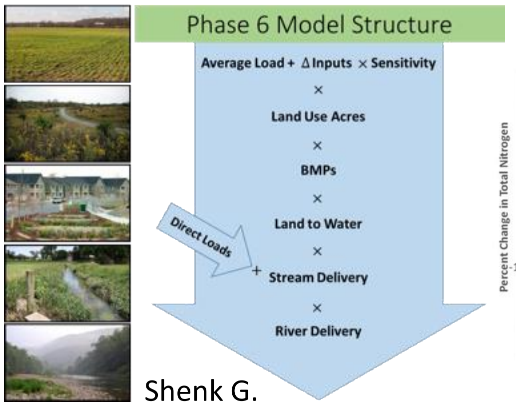
Bicknell et al. 2005

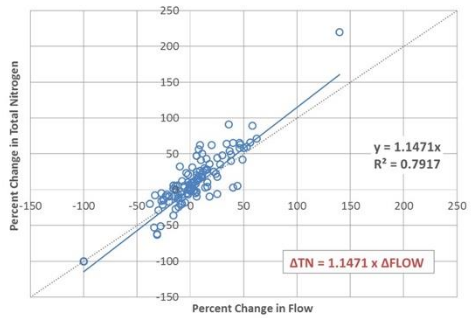


***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*

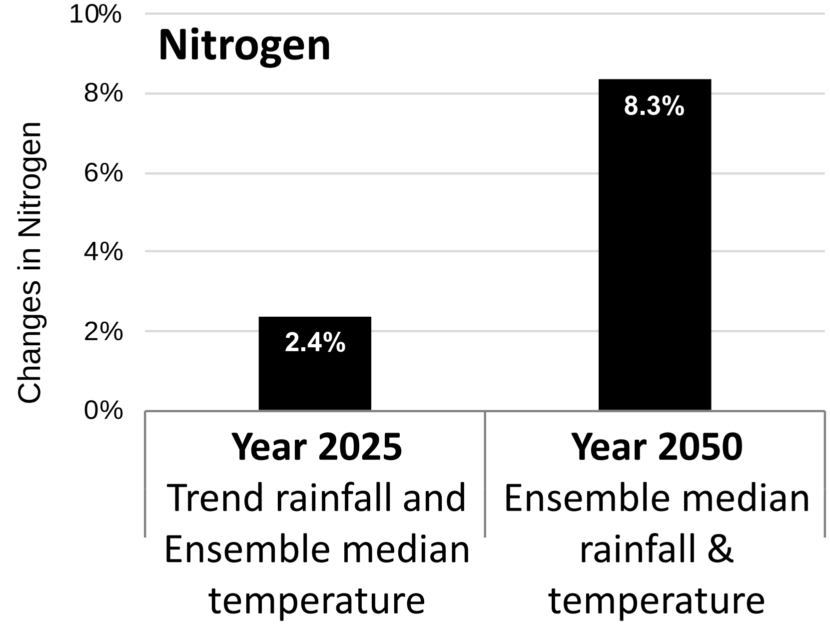
Summary of changes in delivery

Nitrogen response:
- sensitivity to flow
- stream bank erosion
- denitrification, organic scour

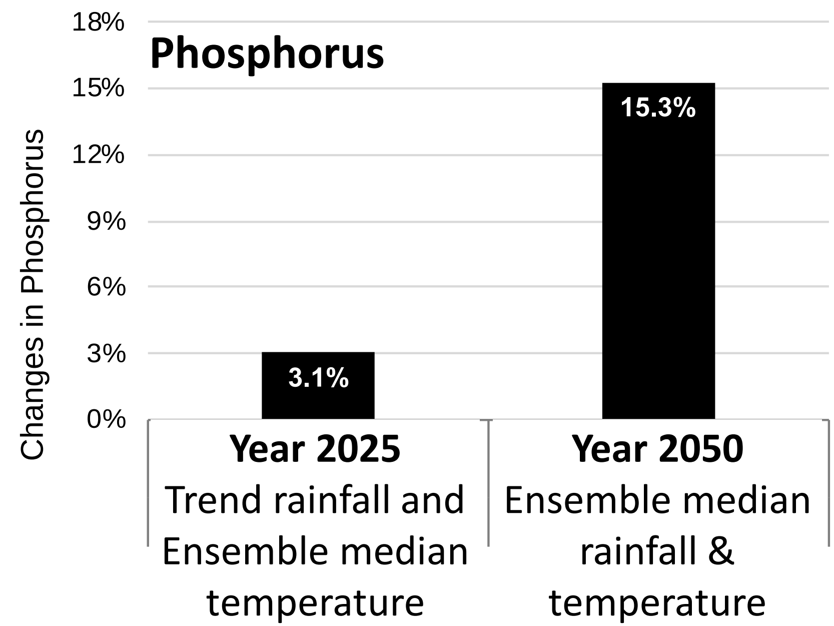




Shenk G.



Phosphorus response:
- sensitivities to flow and sediment (APLE)
- stream bank erosion
- scour/deposition of inorganic and organic (HSPF)

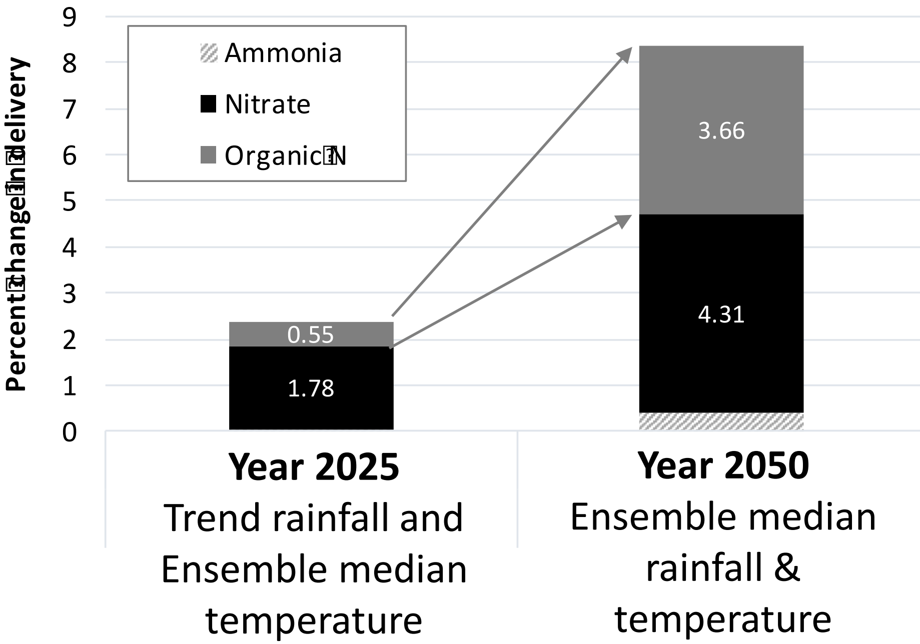


Trend*: projection of extrapolation of long-term trends*

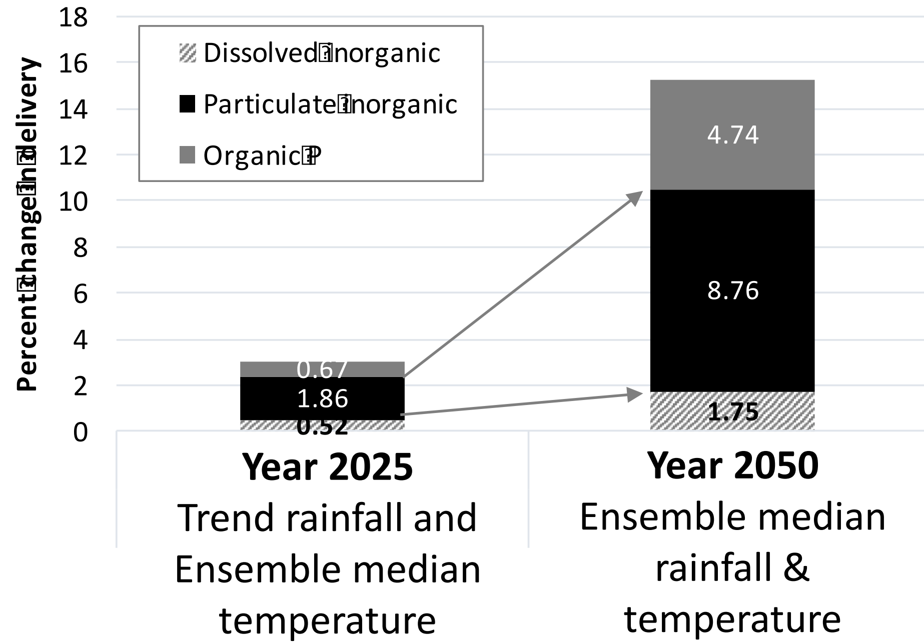
Ensemble*: 31-member ensemble of RCP4.5 GCMs*

Nitrogen and phosphorus species

Simulated changes in nitrogen delivery



Simulated changes in phosphorus delivery

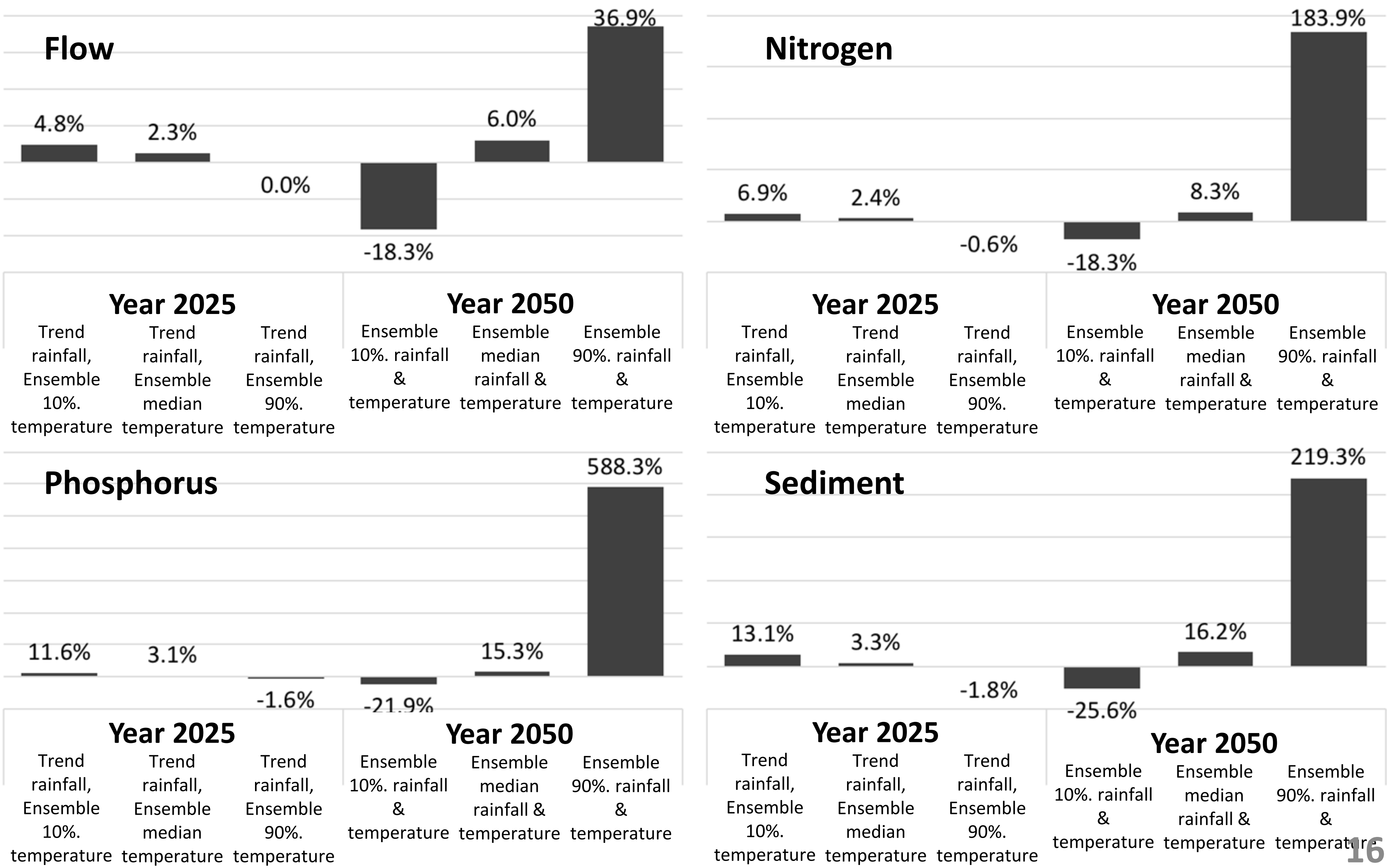


Arrows show relatively more increase in organic nitrogen as compared to inorganic.

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

Trend*: projection of extrapolation of long-term trends*
Ensemble*: 31-member ensemble of RCP4.5 GCMs*

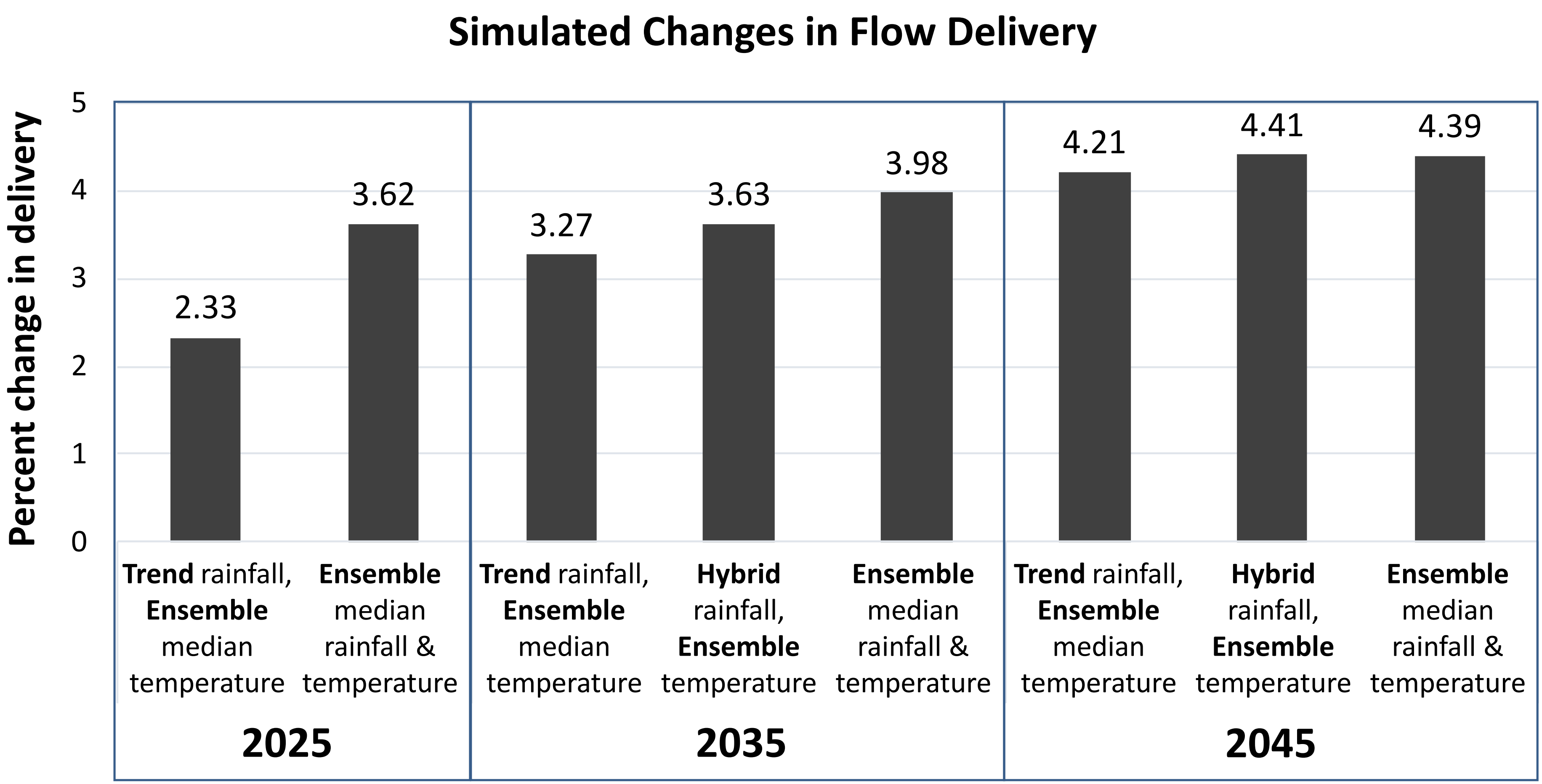
Uncertainty due to climatic inputs



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

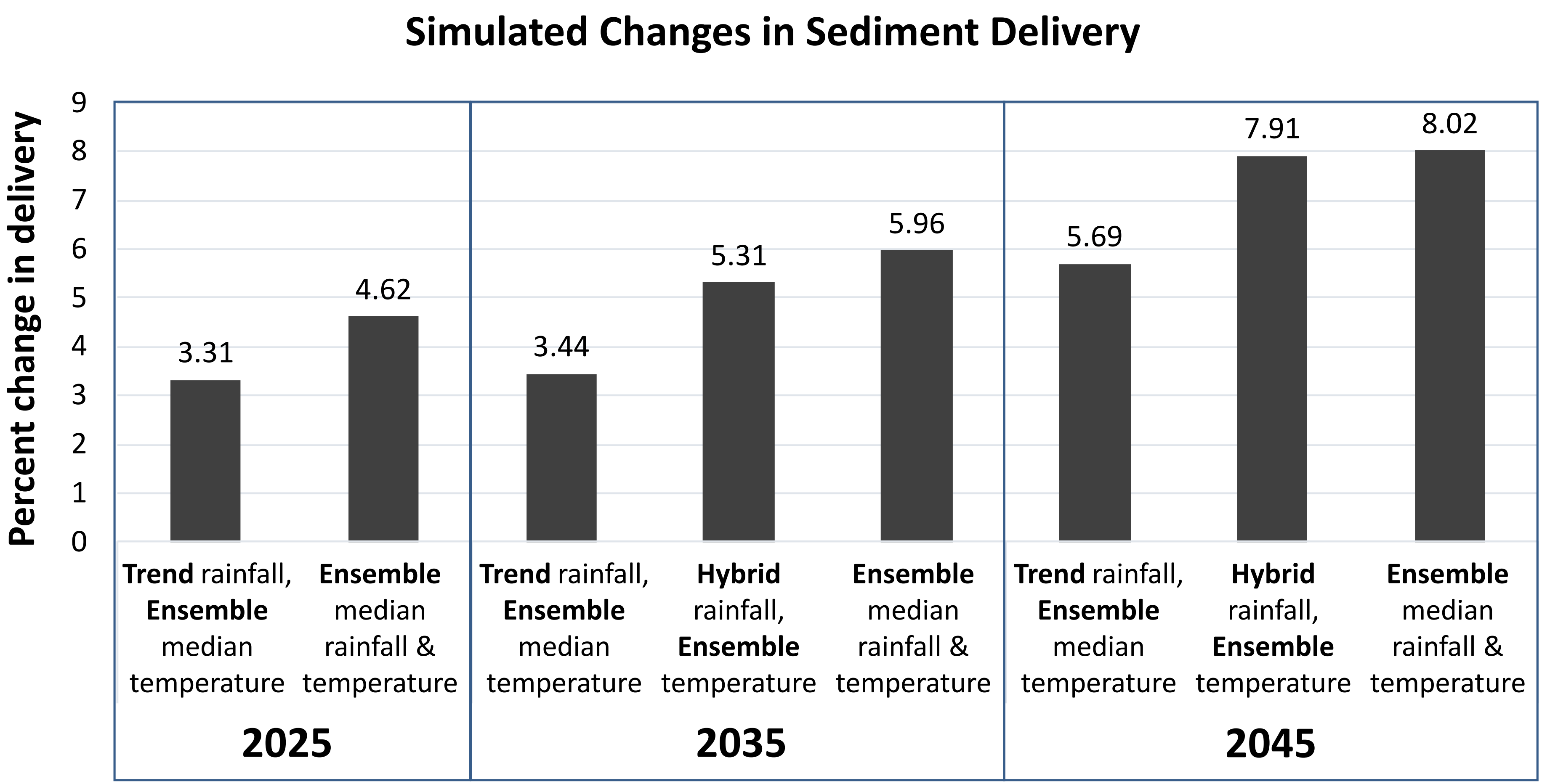
- Selections highlighted in yellow are the STAC and CBP climate resiliency workgroup recommendations and CBP approved approaches for the 2017 Climate Change assessment.
- For 2035 and 2045 the Modeling Workgroup (September 2018) recommended (a) combining the two sources using weighted means for rainfall, (b) using the ensemble for temperature. Both approaches are consistent with the STAC 2016 Climate Change Workshop recommendations of observed precipitation trends for 2025 and ensemble precipitation estimates for 2050.

Flow response



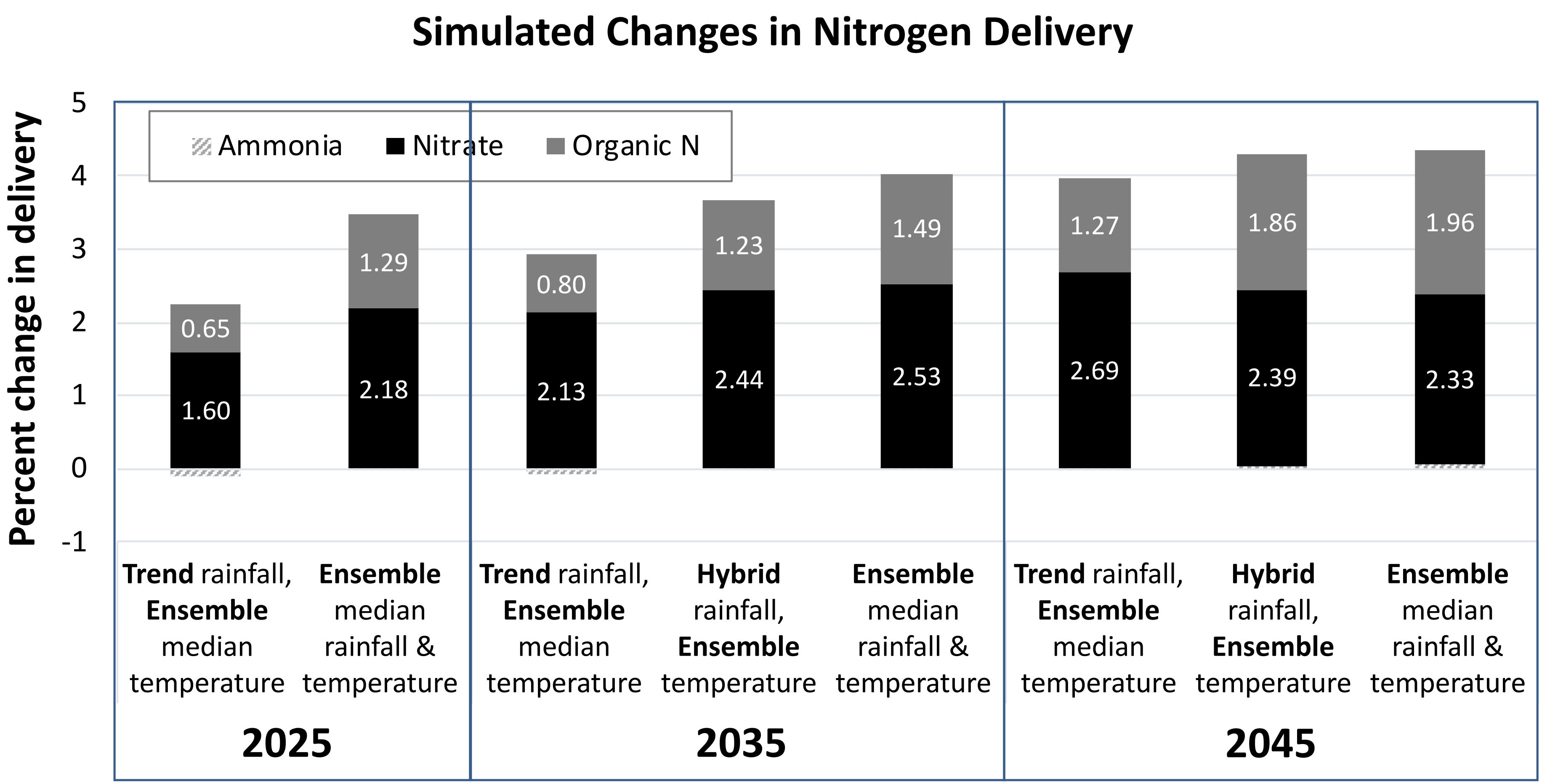
***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*
***Hybrid**: weighted average of trend and ensemble*

Sediment response

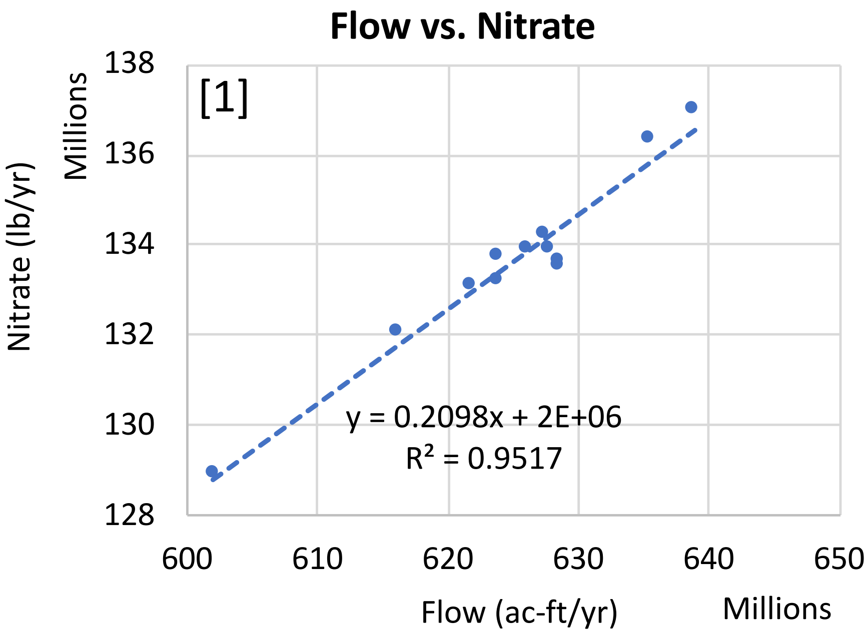


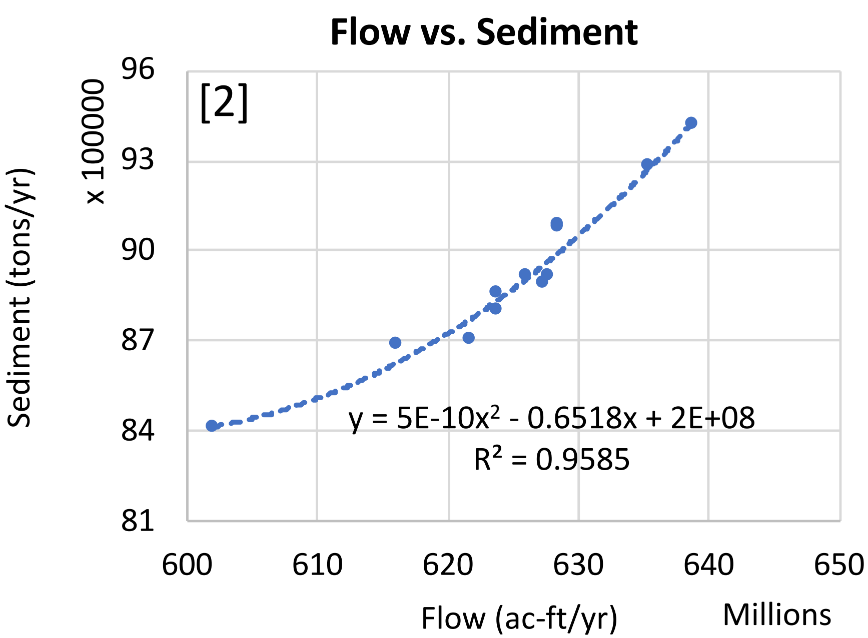
***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*
***Hybrid**: weighted average of trend and ensemble*

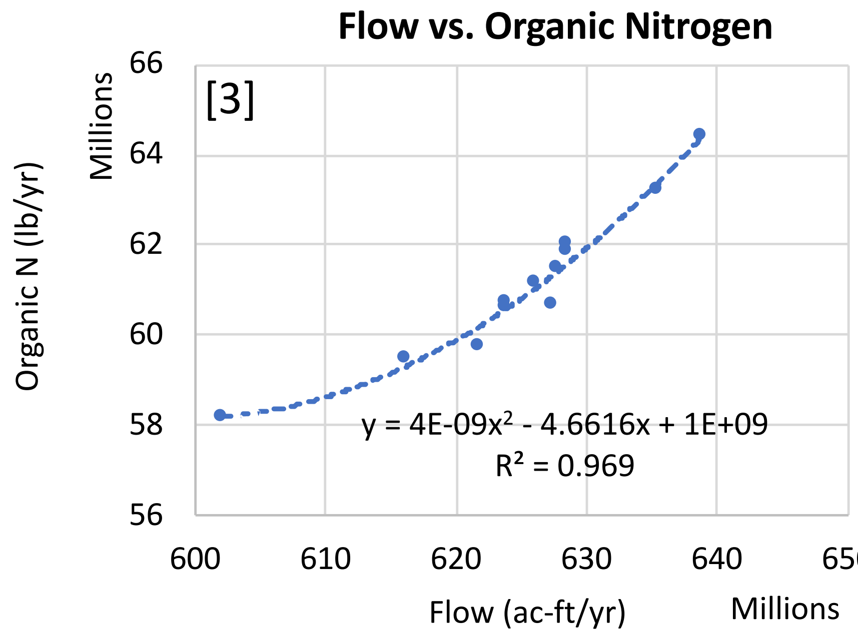
Nitrogen response

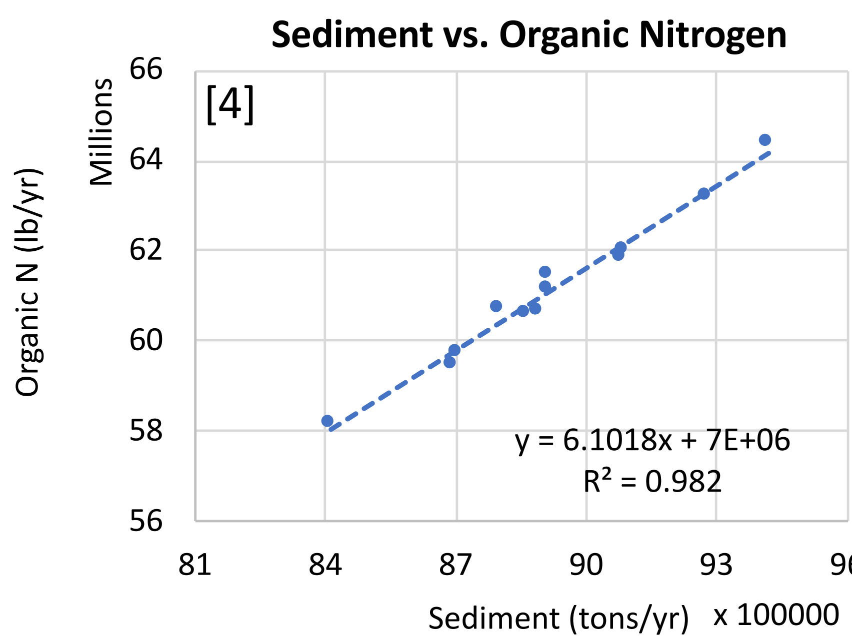


Trend: *projection of extrapolation of long-term trends*
Ensemble: *31-member ensemble of RCP4.5 GCMs*
Hybrid: *weighted average of trend and ensemble*

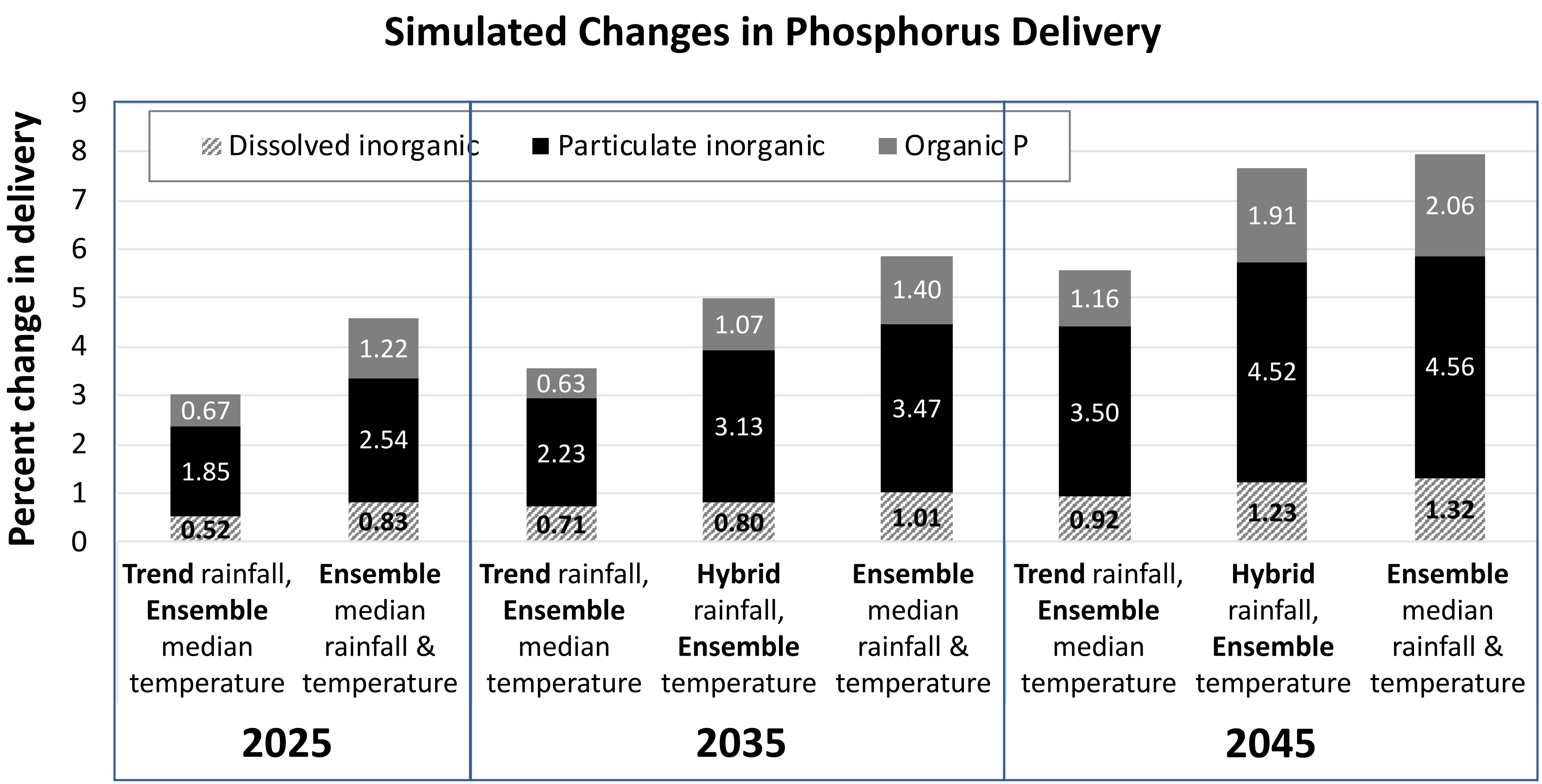

Flow vs. Nitrate
[1]
Nitrate (lb/yr)
Millions
128
130
132
134
136
138
y = 0.2098x + 2E+06
R² = 0.9517
600
610
620
630
640
650
Flow (ac-ft/yr)
Millions


Flow vs. Sediment
[2]
Sediment (tons/yr)
x 100000
81
84
87
90
93
96
y = 5E-10x² - 0.6518x + 2E+08
R² = 0.9585
600
610
620
630
640
650
Flow (ac-ft/yr)
Millions

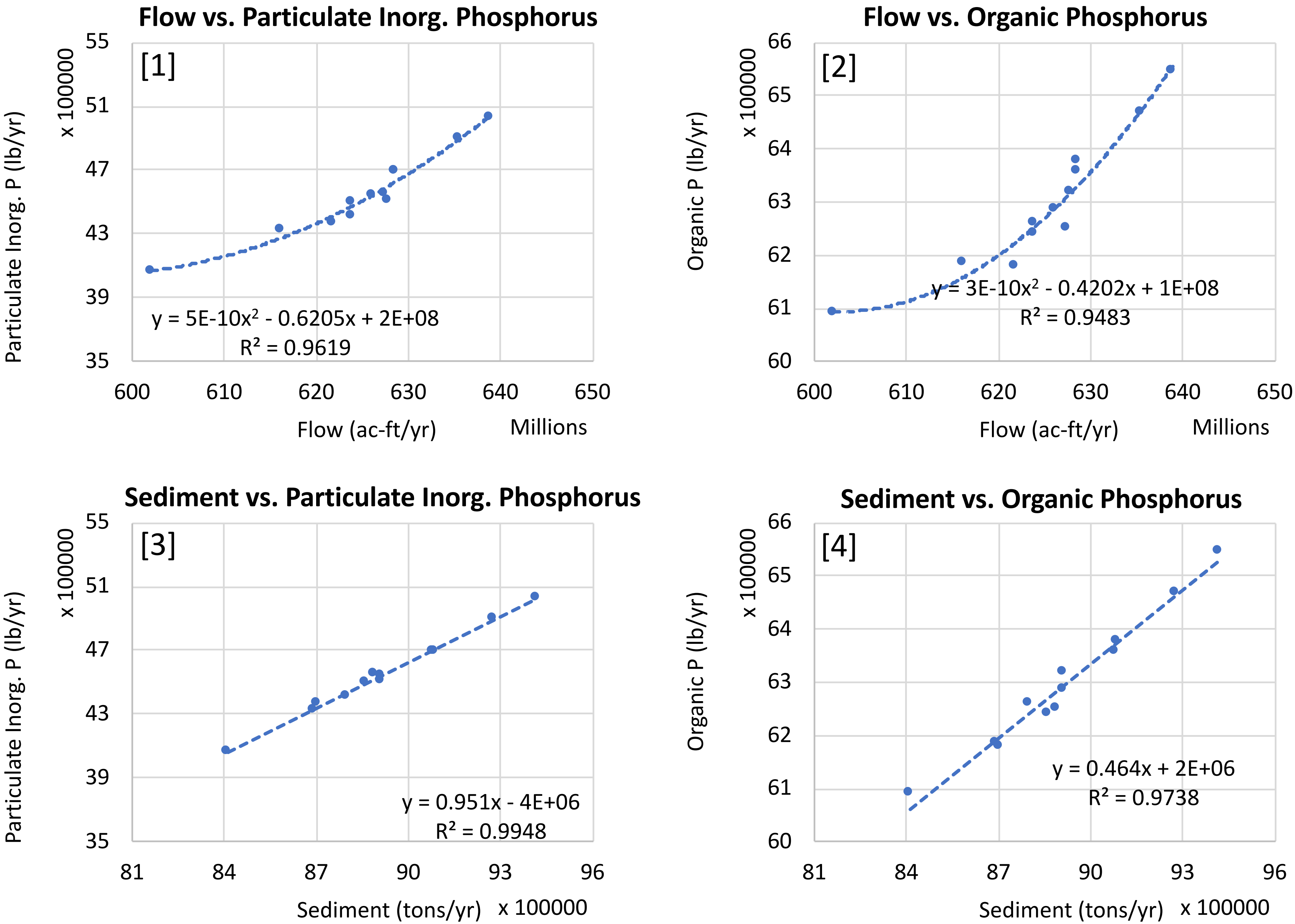

Flow vs. Organic Nitrogen
[3]
Organic N (lb/yr)
Millions
56
58
60
62
64
66
y = 4E-09x² - 4.6616x + 1E+09
R² = 0.969
600
610
620
630
640
650
Flow (ac-ft/yr)
Millions


Sediment vs. Organic Nitrogen
[4]
Organic N (lb/yr)
Millions
56
58
60
62
64
66
y = 6.1018x + 7E+06
R² = 0.982
81
84
87
90
93
96
Sediment (tons/yr)
x 100000

Phosphorus response

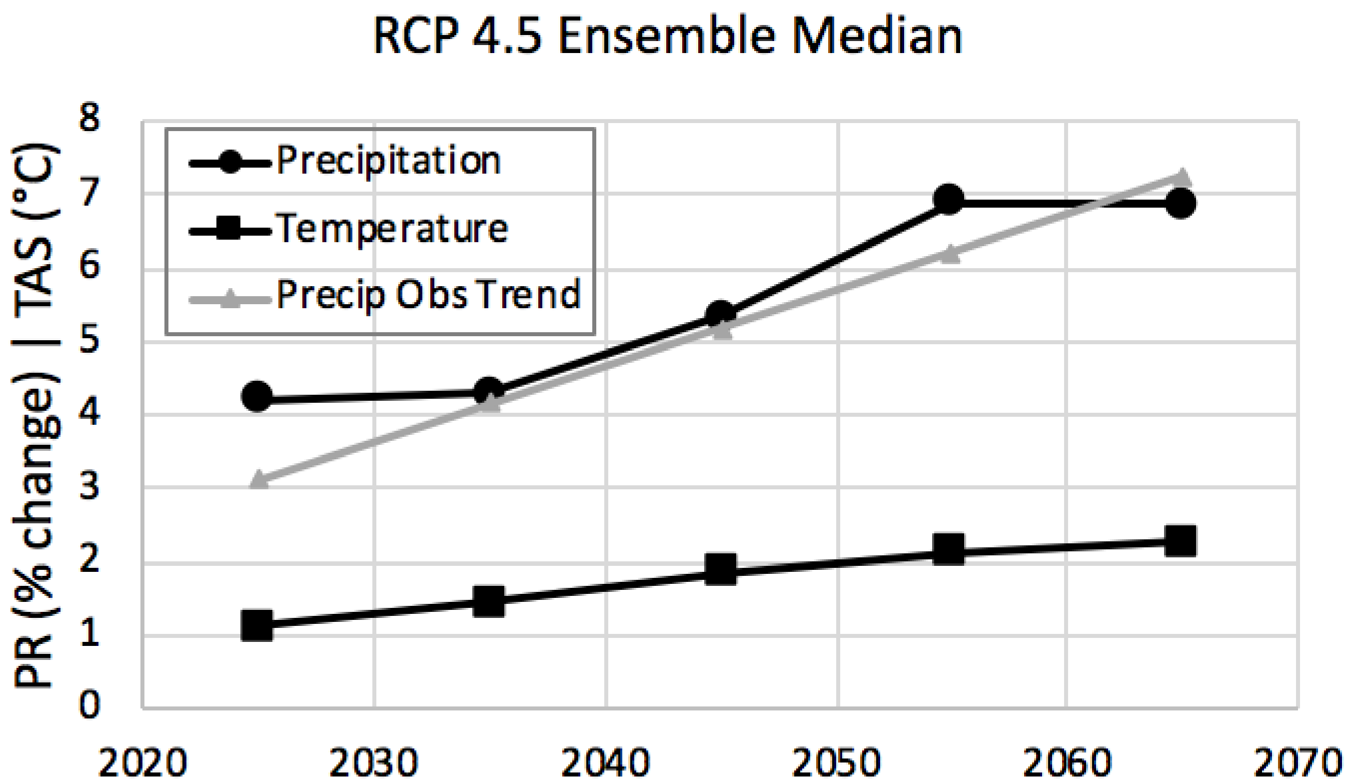


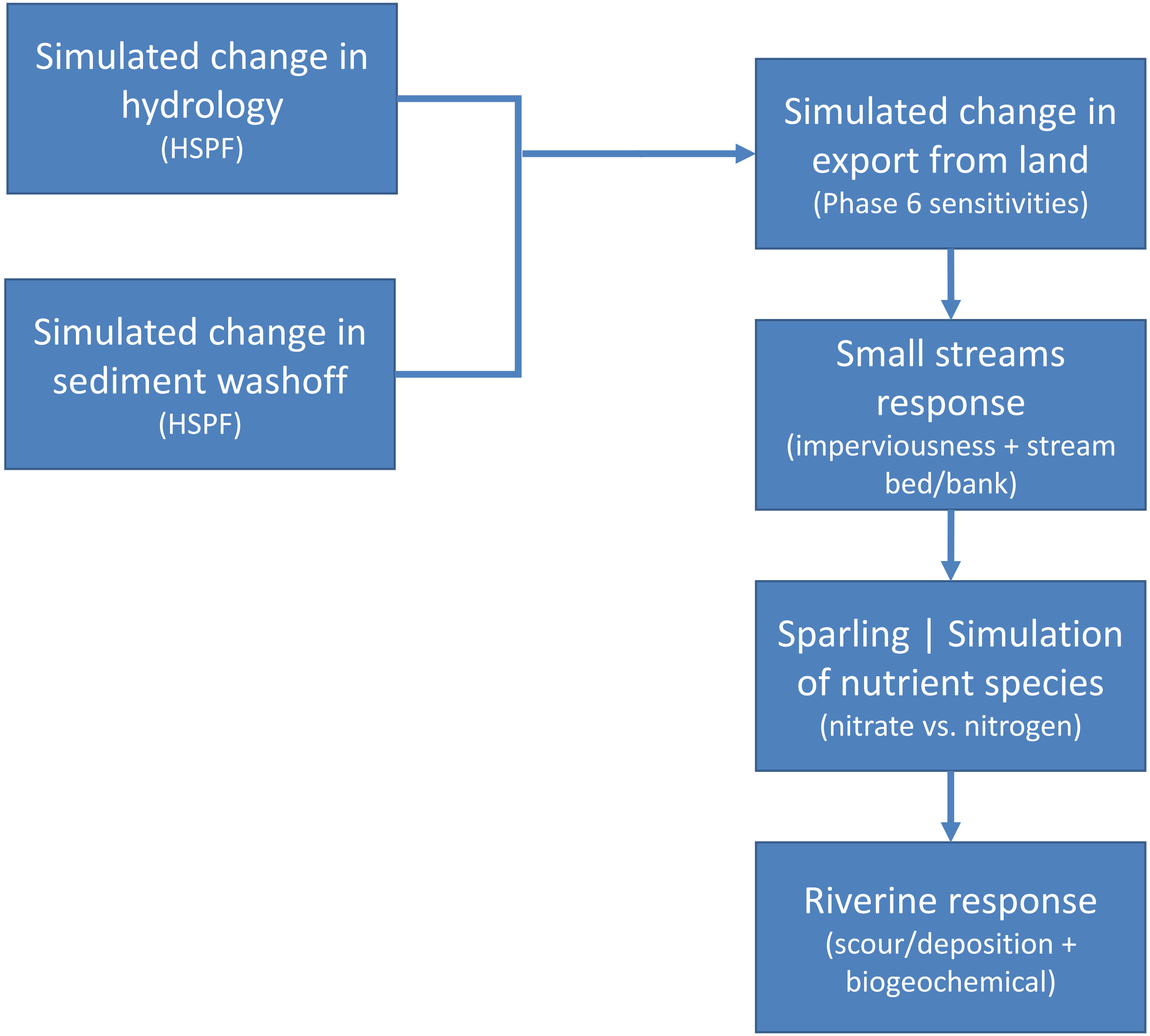
***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*
***Hybrid**: weighted average of trend and ensemble*


Flow vs. Particulate Inorg. Phosphorus
[1]
Particulate Inorg. P (lb/yr) x 100000
35
39
43
47
51
55
600
610
620
630
640
650
Flow (ac-ft/yr) Millions
y = 5E-10x² - 0.6205x + 2E+08
R² = 0.9619
Flow vs. Organic Phosphorus
[2]
Organic P (lb/yr) x 100000
60
61
62
63
64
65
66
Flow (ac-ft/yr) Millions
y = 3E-10x² - 0.4202x + 1E+08
R² = 0.9483
Sediment vs. Particulate Inorg. Phosphorus
[3]
Particulate Inorg. P (lb/yr) x 100000
81
84
87
90
93
96
Sediment (tons/yr) x 100000
y = 0.951x - 4E+06
R² = 0.9948
Sediment vs. Organic Phosphorus
[4]
Organic P (lb/yr) x 100000
Sediment (tons/yr) x 100000
y = 0.464x + 2E+06
R² = 0.9738

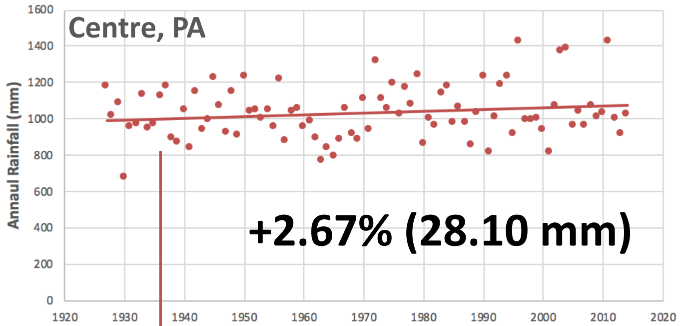
Summary and Conclusions

- 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.
- Synthesis of inputs and model results provided insights into the overall behavior of the model response.
- Analysis did not include changes in land-use, crop yields, atmospheric deposition, and best management practices (BMPs).
- Trend-based rainfall projection (estimated from annual data) did not have any monthly/seasonal component.


RCP 4.5 Ensemble Median
PR (% change) | TAS (°C)
Precipitation
Temperature
Precip Obs Trend
0
1
2
3
4
5
6
7
8
2020
2030
2040
2050
2060
2070

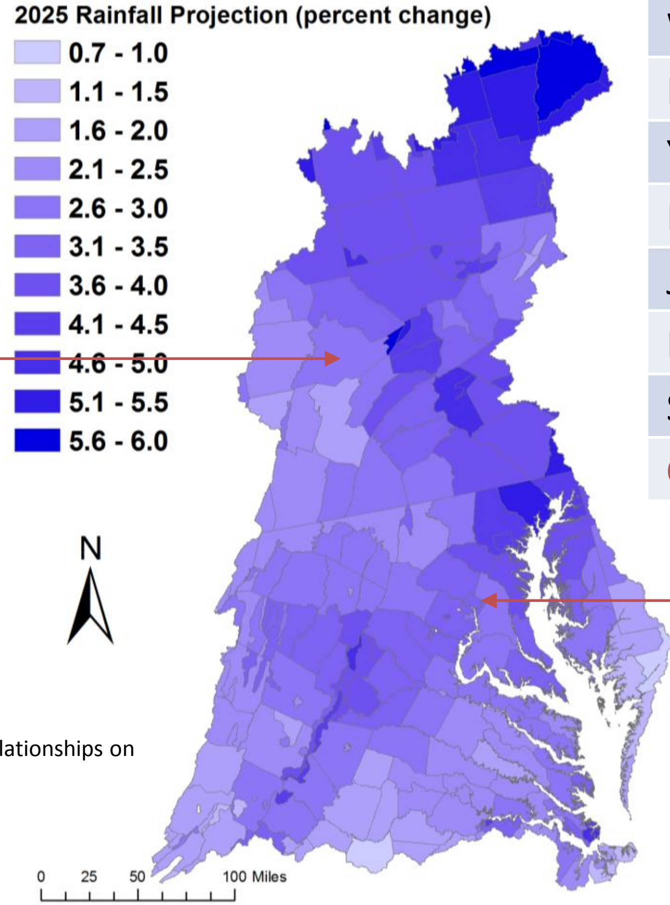

Simulated change in hydrology
(HSPF)
Simulated change in sediment washoff
(HSPF)
Simulated change in export from land
(Phase 6 sensitivities)
Small streams response
(imperviousness + stream bed/bank)
Sparling | Simulation of nutrient species
(nitrate vs. nitrogen)
Riverine response
(scour/deposition + biogeochemical)

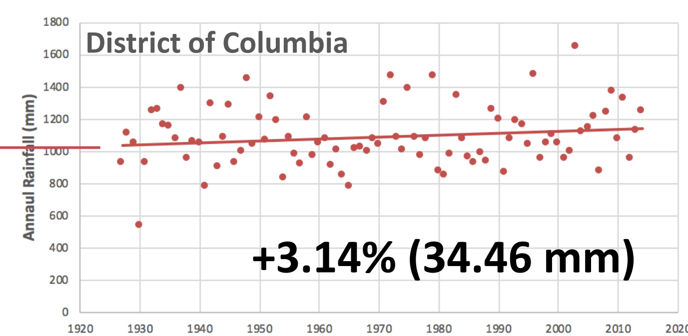
Rainfall projections using 88-years of annual PRISM[1] data trends



Change in Rainfall Volume 2021-2030 vs. 1991-2000

Major Basins	PRISM Trend
Youghiogheny River	2.1%
Patuxent River Basin	3.3%
Western Shore	4.1%
Rappahannock River Basin	3.2%
York River Basin	2.6%
Eastern Shore	2.5%
James River Basin	2.2%
Potomac River Basin	2.8%
Susquehanna River Basin	3.7%
Chesapeake Bay Watershed	3.1%





[1] Parameter-elevation Relationships on Independent Slopes Model

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

Data unavailable

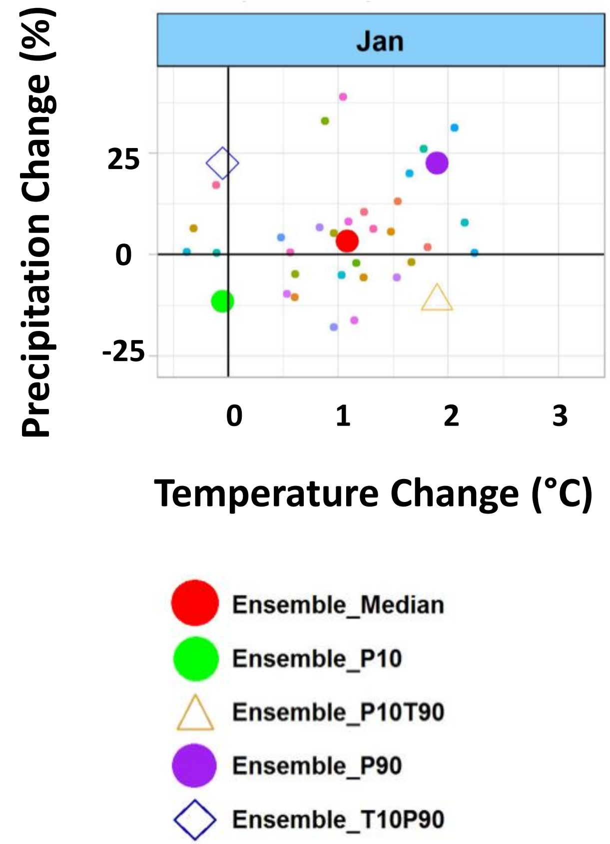
GCM Used

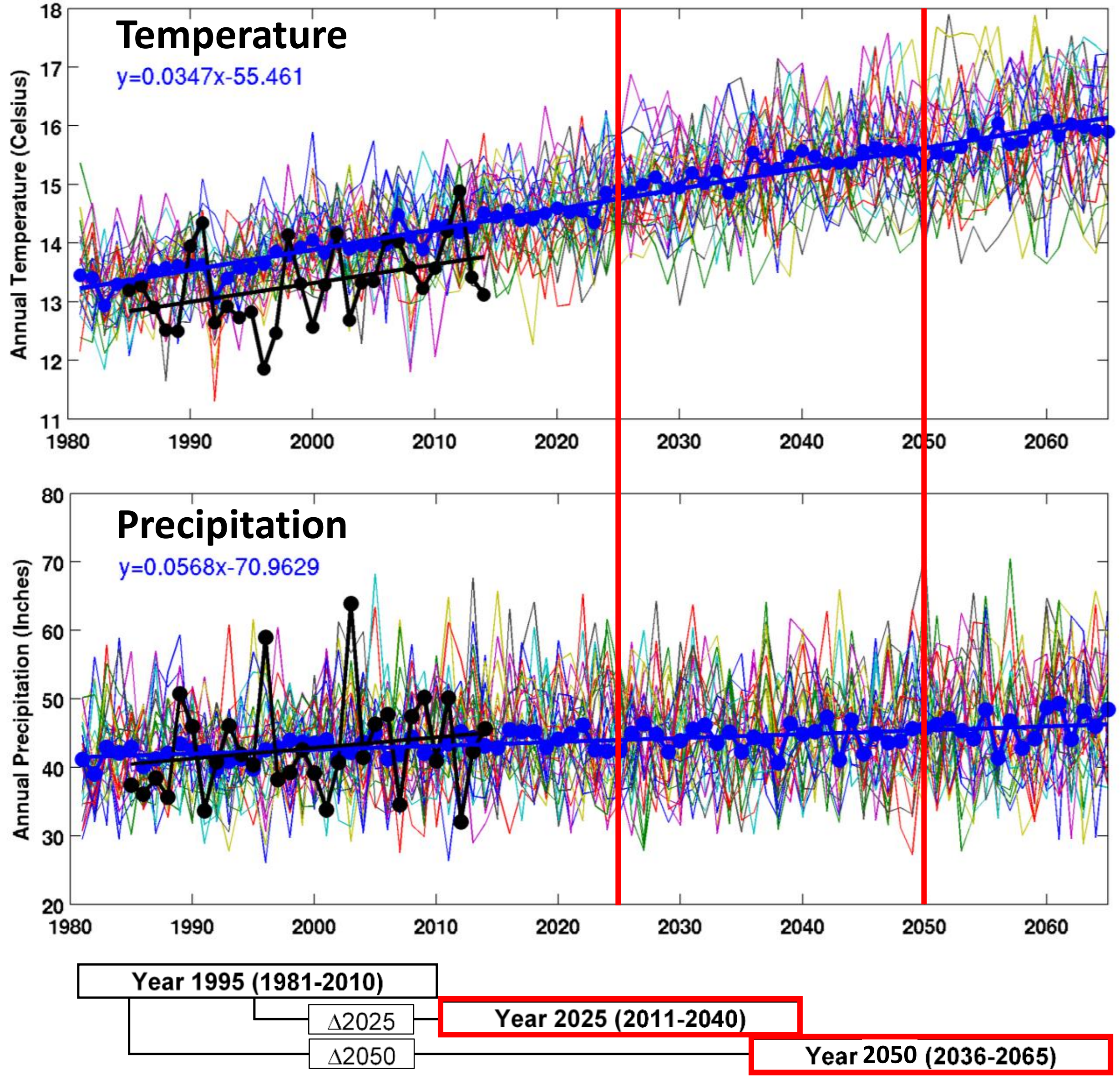
Selection updated

[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

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

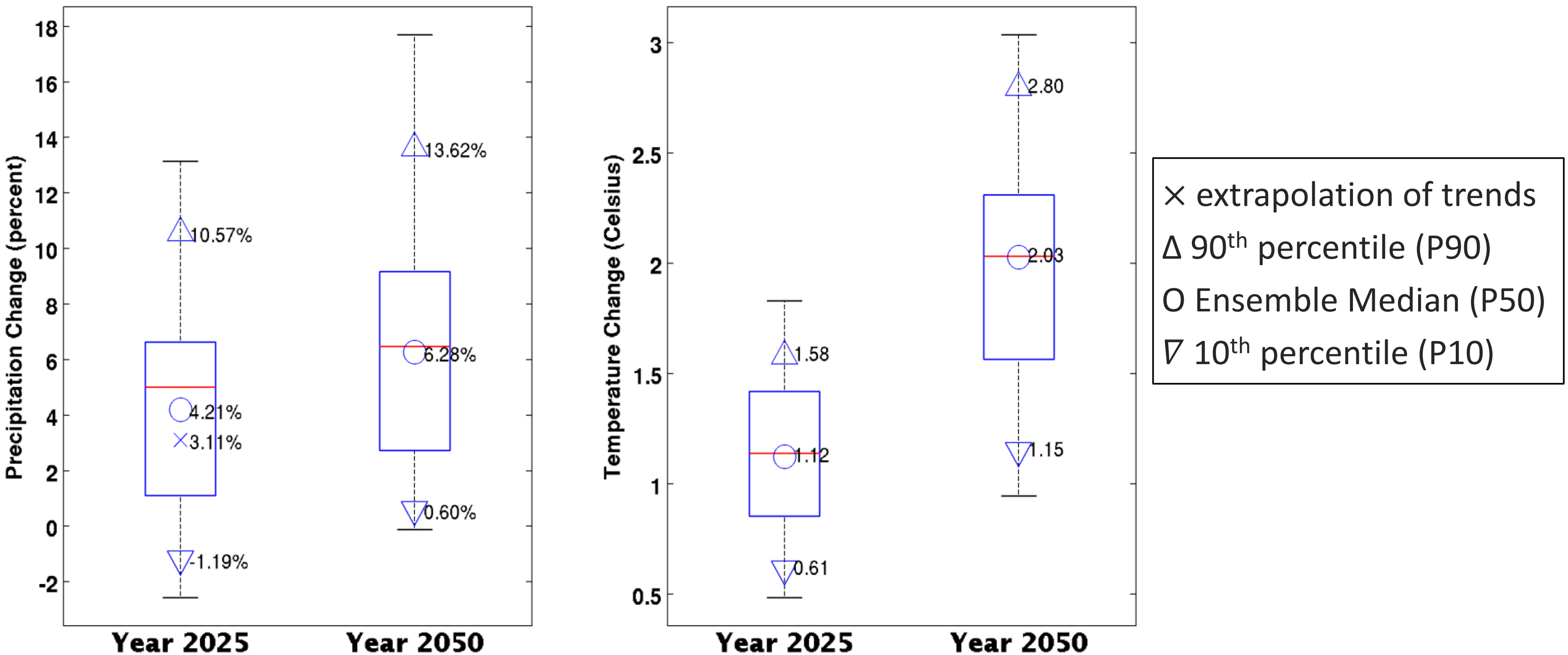




Data shown for the District of Columbia for illustration.

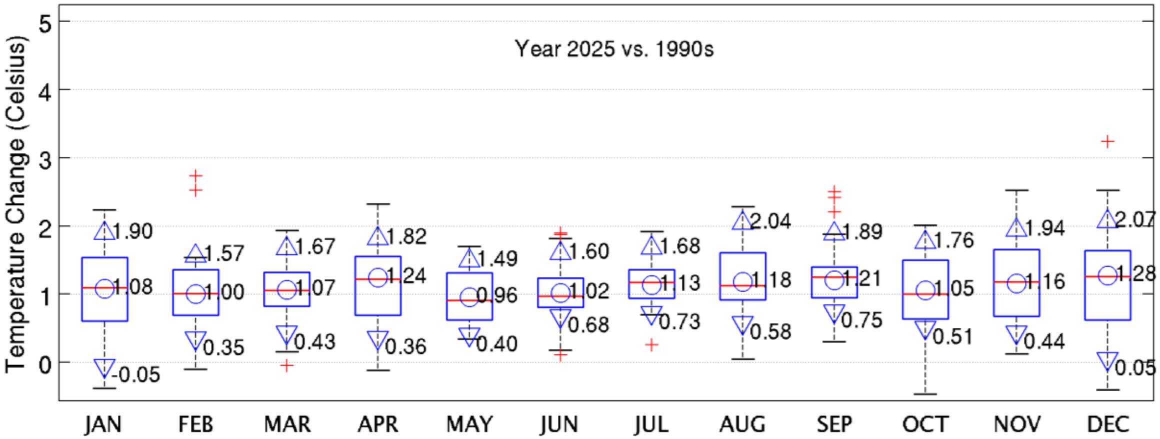
Average annual precipitation and temperature from the 31 bias-corrected downscaled global circulation models are shown for a land segment (N11001). Shown in blue line is the ensemble median. Data used in model calibration from NLDAS-2 are shown in black

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

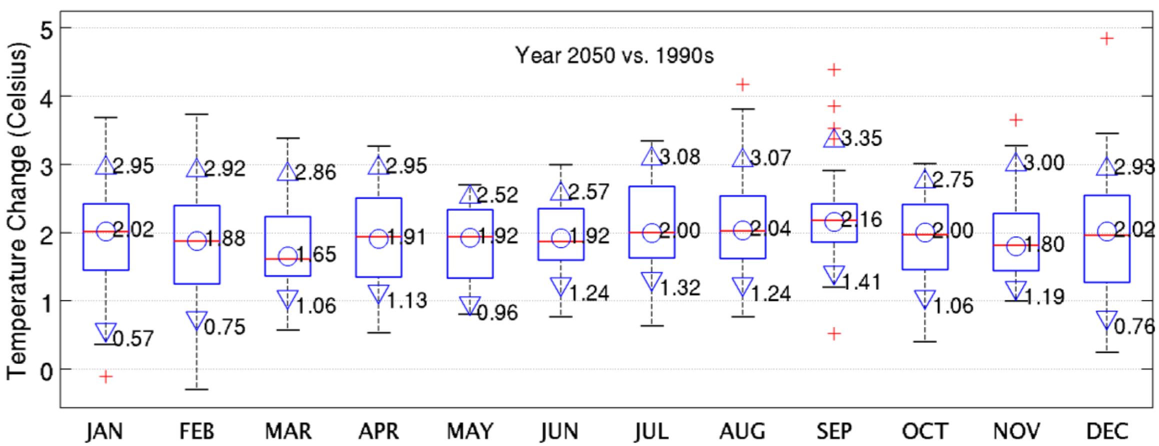


Summary of RCP4.5 average annual rainfall and temperature change for the Chesapeake Bay watershed are shown. Then range for 10th percentile (P10), ensemble median (P50), and 90th percentile (P90) are shown. The estimated change in rainfall volume based on the extrapolation of long-term trends are also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

Projected changes in temperature (RCP 4.5)



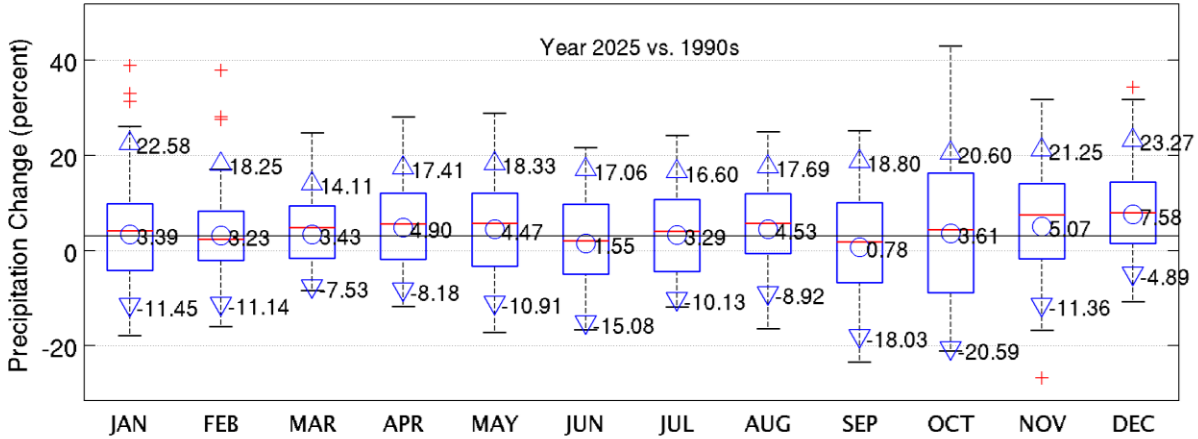
Watershed average of ensemble median is +1.12 ^{O}C



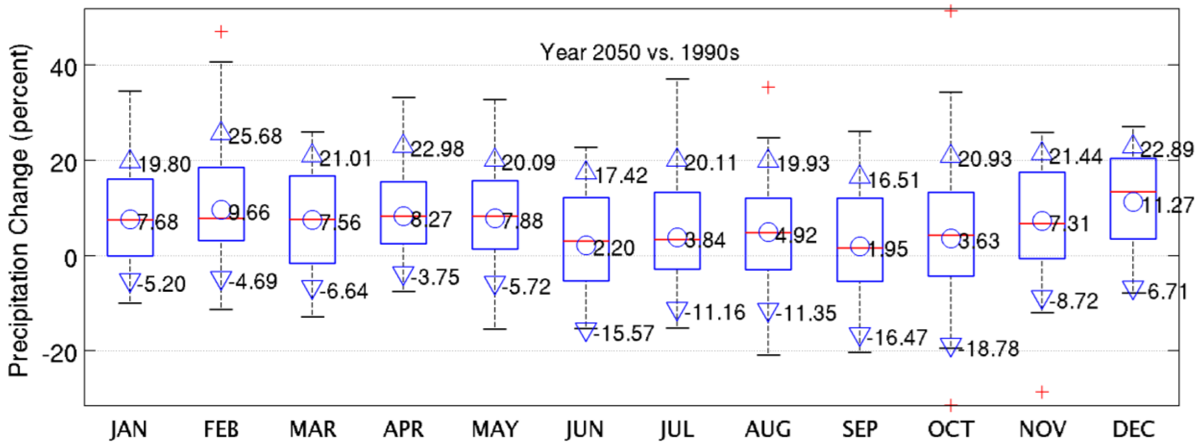
Watershed average of ensemble median is +2.02 ^{O}C

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)



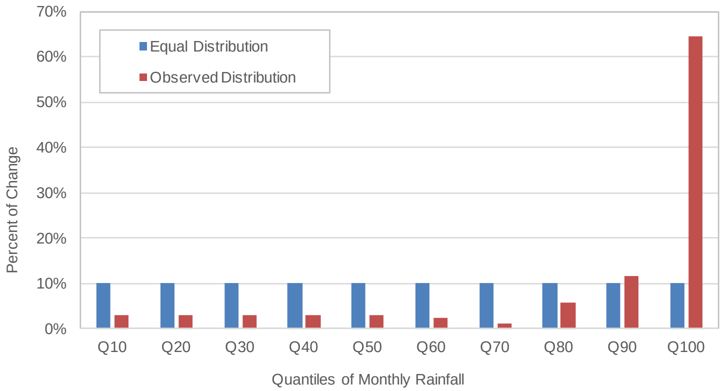
Watershed average of ensemble median is +4.21% *(+3.11% estimated using extrapolation of long term trend)*



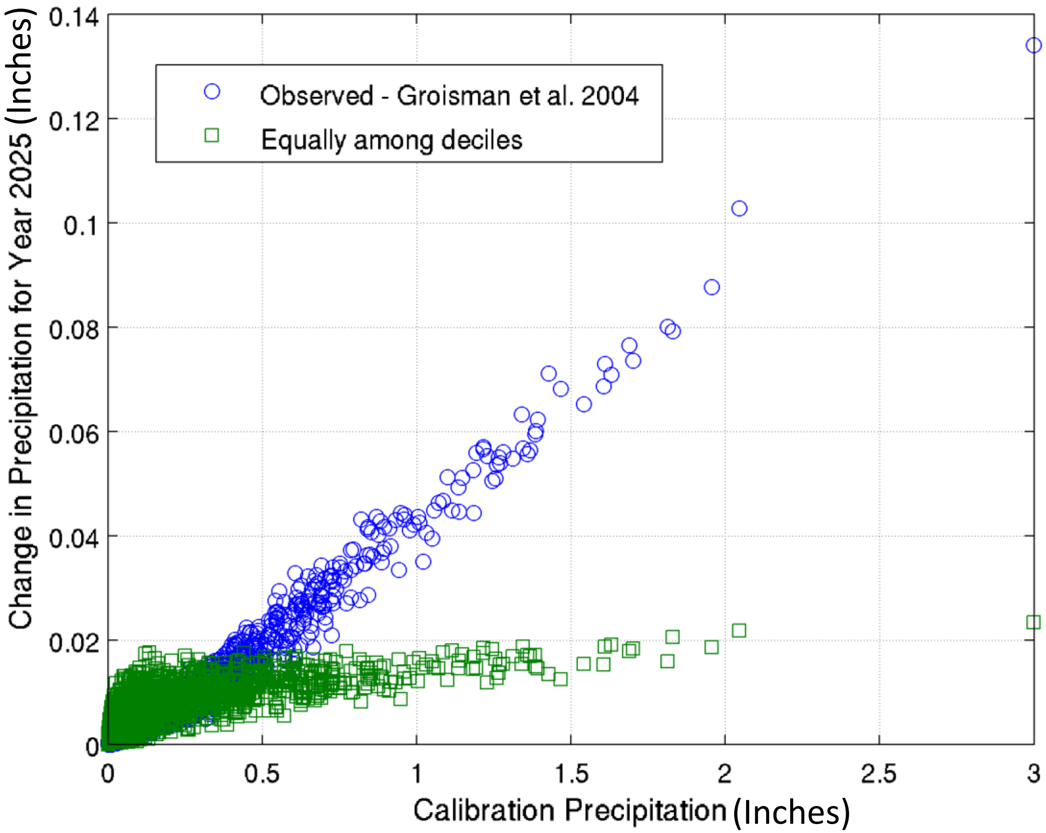
Watershed average of ensemble median is +6.28%

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

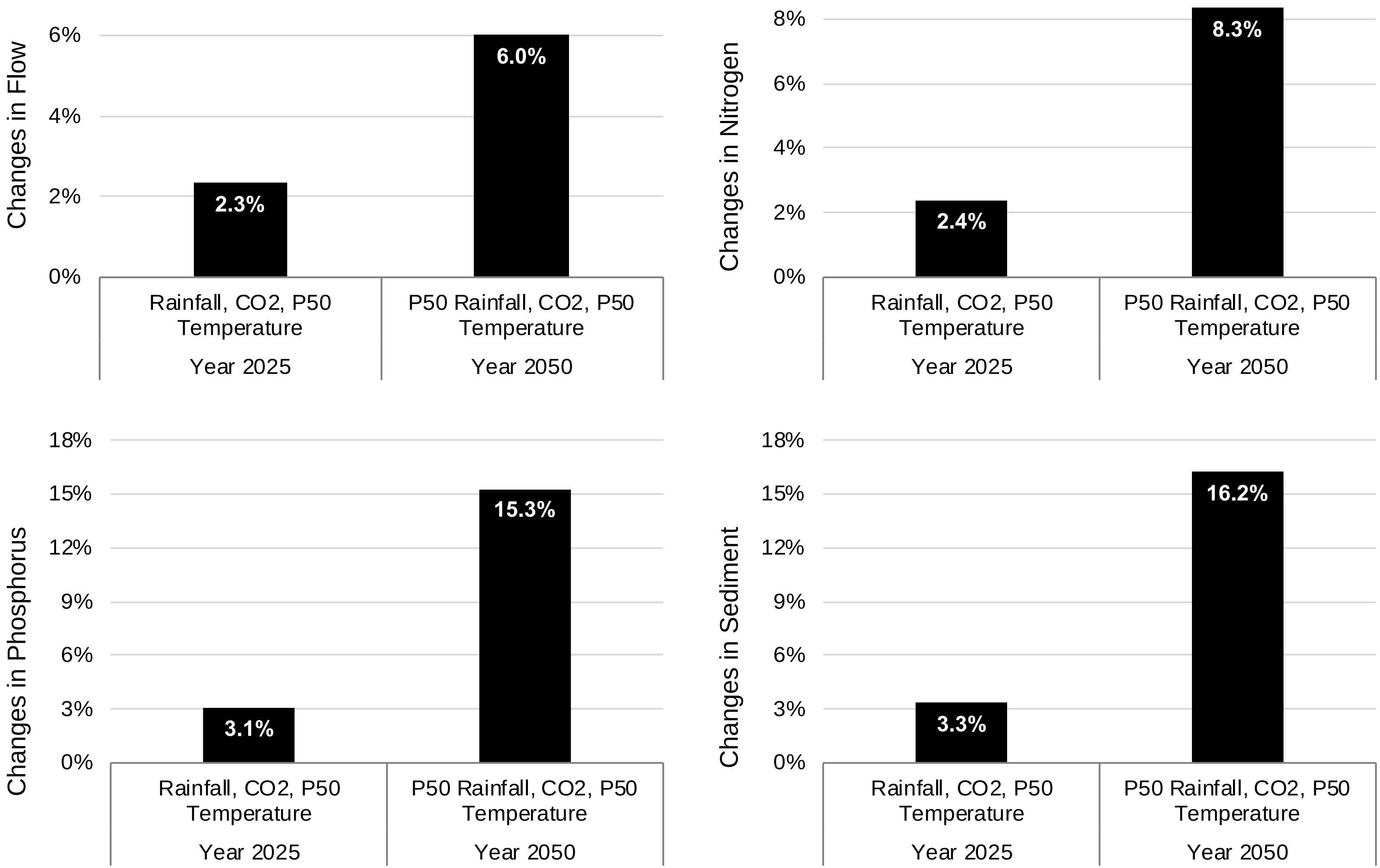


Observed changes in rainfall intensity over the last century (based on Figure 10 in Groisman et al. 2004). The equal allocation distribution (blue) is contrasted with the distribution obtained based on observed changes (red).



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.

Summary of changes in delivery



Simulated changes in the delivery of flow, nutrients, and sediment to the Chesapeake Bay for year 2025 and 2050 climate change scenarios are shown.

Uncertainty due to climatic inputs

Period	Climate Change Scenario	Flow	Nitrogen	Phosphorus	Sediment
		percent	percent	percent	percent
Year 2025	Trend rainfall, Ensemble 10%. temparature	4.8%	6.9%	11.6%	13.1%
	Trend rainfall, Ensemble median Temparature	2.3%	2.4%	3.1%	3.3%
	Trend rainfall, Ensemble 90%. temparature	0.0%	-0.6%	-1.6%	-1.8%
Year 2050	Ensemble 10%. rainfall & temparature	-18.3%	-18.3%	-21.9%	-25.6%
	Ensemble median rainfall & temparature	6.0%	8.3%	15.3%	16.2%
	Ensemble 90%. rainfall & temparature	36.9%	183.9%	588.3%	219.3%

Trend: *projection of extrapolation of long-term trends*
Ensemble: *31-member ensemble of RCP4.5 GCMs*