07/25/2017

# Initial Applications of the Draft Phase 6 Watershed Model

Modeling Workgroup Quarterly Meeting – July 2017

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[1] Penn State, [2] USGS

# Presentation Outline

1. **Conowingo Infill**: A *draft* assessment of the delivery of nutrients and sediment for different infill conditions, including the dynamic equilibrium, was made using the Draft Phase 6 watershed model.

2. **Climate Change**: The Draft Phase 6 watershed model was used for the assessment of changes in the delivery of flow, nutrients and sediment with the 2025 projections of rainfall and temperature.

# 1. Conowingo Infill

- The modeling workgroup has made four key decisions for the simulation of Conowingo infill:
  - The Lower Susquehanna Reservoirs are now in the state of dynamic equilibrium (no long-term trapping) [1][2][3].
  - The information on changes in the trapping capacity provided by USGS-WRTDS should be used in the the model calibration [1][2][3].
  - Constant delivery factors should be used for scenarios involving both increases or decreases in the sediment and phosphorus inputs [4].
  - Use of a flow dependent dynamic G-series response for the organic- nitrogen, phosphorus, and carbon [5].

**[1]** Hirsch, R.M., 2012, Flux of nitrogen, phosphorus, and suspended sediment from the Susquehanna River Basin to the Chesapeake Bay during Tropical Storm Lee, September 2011, as an indicator of the effects of reservoir sedimentation on water quality: U.S. Geological Survey Scientific Investigations Report 2012–5185, 17 p.
**[2]** Zhang, Q., D.C. Brady, and W.P. Ball, 2013. Long-term Seasonal Trends of Nitrogen, Phosphorus, and Suspended Sediment Load from the Non-tidal Susquehanna River Basin to Chesapeake Bay, Science of the Total Environment, 452–453: 208–221
**[3]** Zhang, Q., R.M. Hirsch, and W. Ball. 2016a. Long-Term Changes in Sediment and Nutrient Delivery from Conowingo Dam to Chesapeake Bay: Effects of Reservoir Sedimentation. Environmental Science & Technology 50(4): 1877-1886
**[4]** HDR Inc. Coupled Sediment Flux Model and Conowingo Pond Mass Balance Model (2017) - http://www.chesapeakebay.net/channel_files/24718/2017-02-14_conowingo_hdr_models_2.pdf
**[5]** HDR Inc. Coupled Sediment Flux Model and Conowingo Pond Mass Balance Model (2017) - http://www.chesapeakebay.net/channel_files/24719/2017-04-04_conowingo_hdr_g1g2g3_2.pdf

# Simulation of Conowingo infill in Phase 6

- In the June modeling workgroup conference call, a detailed presentation was made to describe the elements of Conowingo reservoir calibration [1].

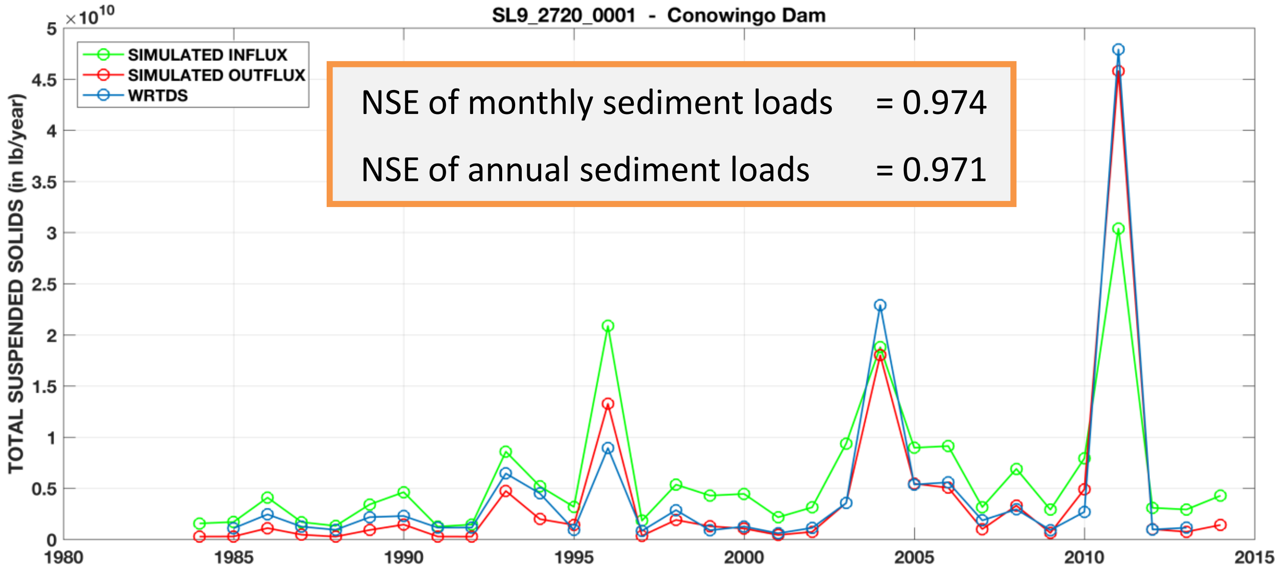
- In this work, an assessment of the delivery of nutrients and sediment under different infill conditions, including the dynamic equilibrium, was made using the Draft Phase 6 watershed model.

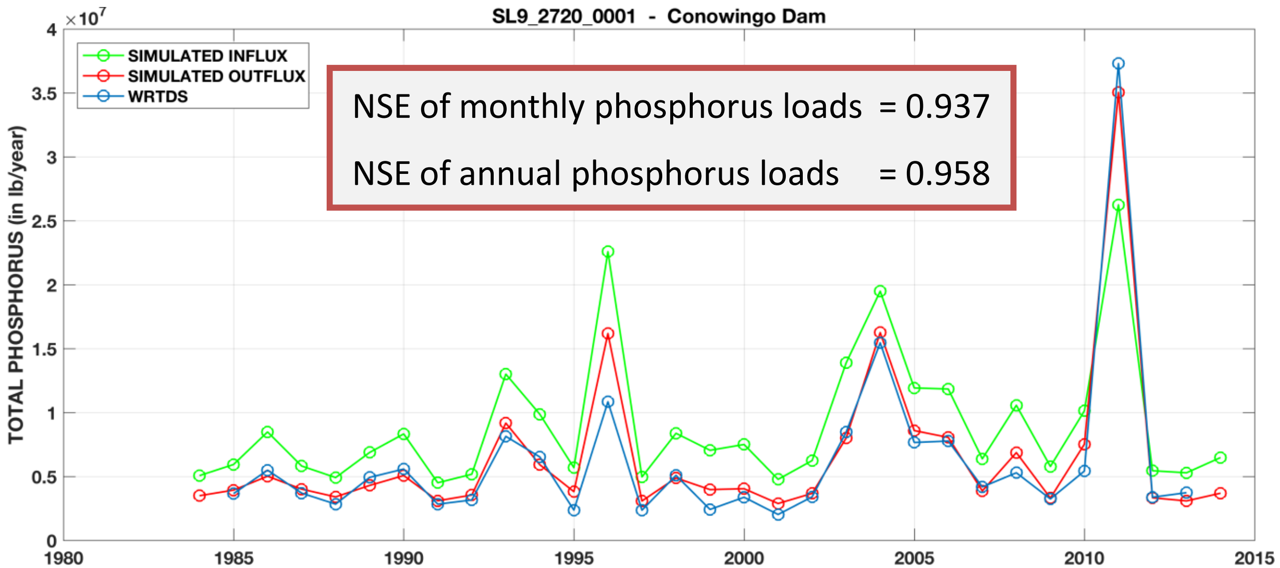
- The model was used for estimating the nutrients and sediment delivery for the following infill states –
  - True-condition (calibration)
  - 1990s infill condition
  - 2010s infill condition
  - Dynamic equilibrium (no net trapping)

- The results are ***preliminary*** as they are based on currently available information that is subject to revisions by the partnership.

**[1]** http://www.chesapeakebay.net/channel_files/25164/20170615_-_bhatt_kh_-_cbp_-_mwcc_-_draft_phase_6.pdf

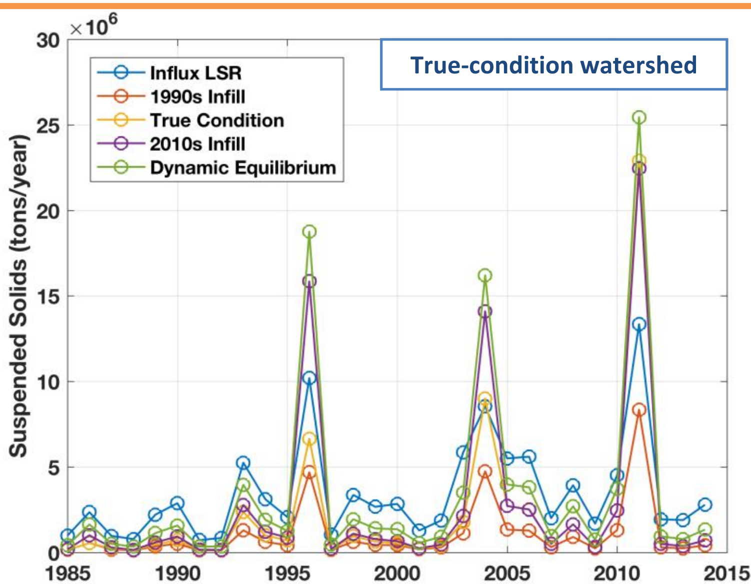
# Phase 6 Calibration and WRTDS estimates

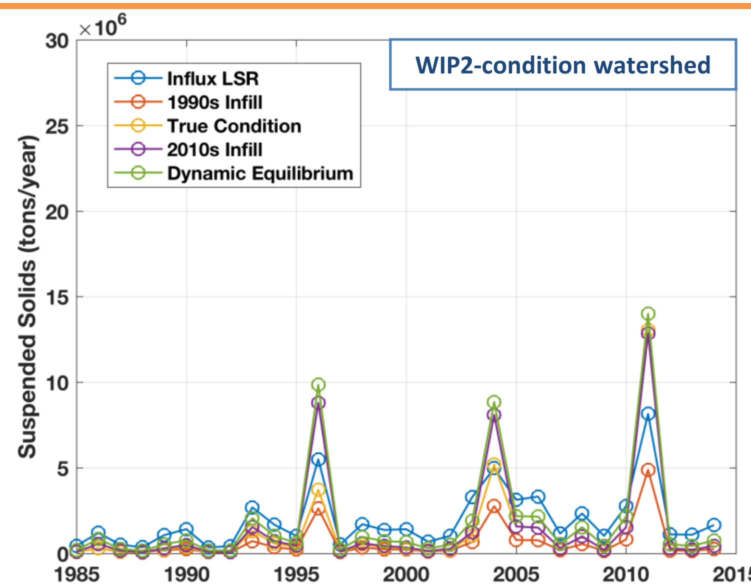


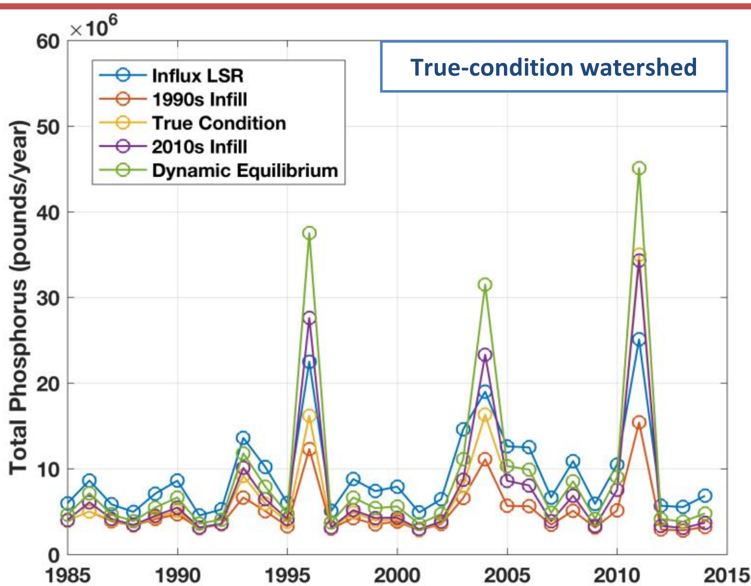



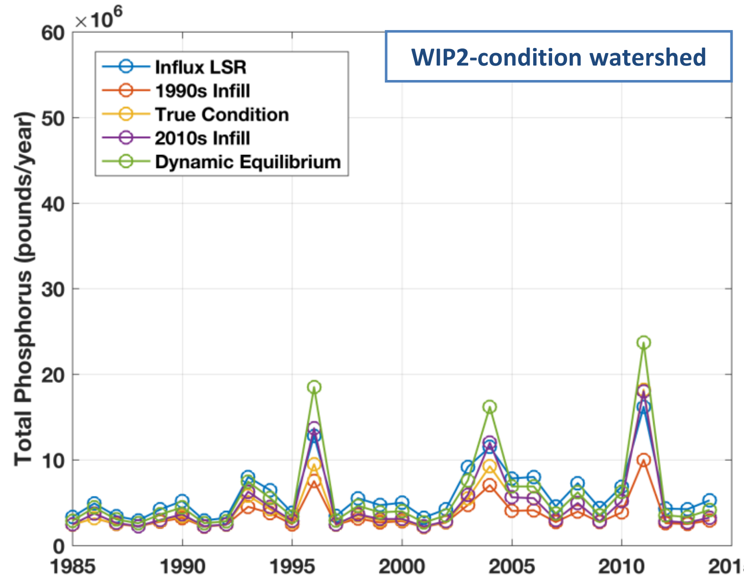

*The annual and monthly Nash-Sutcliffe efficiencies (NSE) for the suspended solids and phosphorus confirm good model performance.*

# Simulated responses for different infill conditions



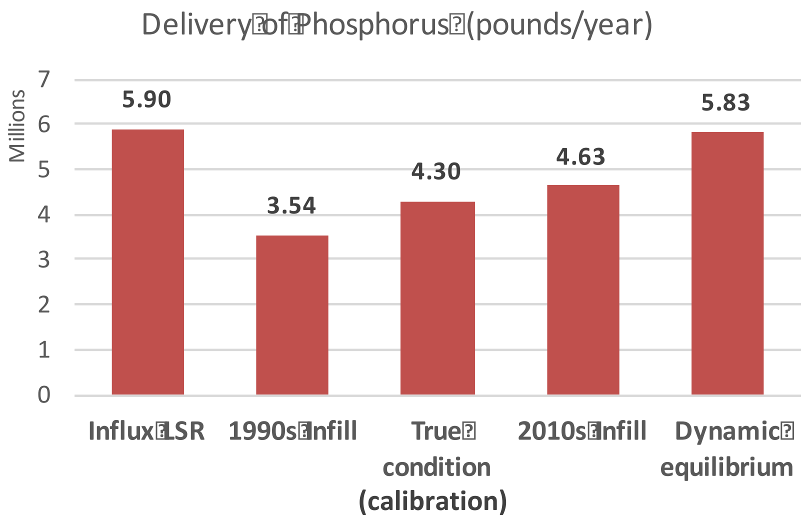



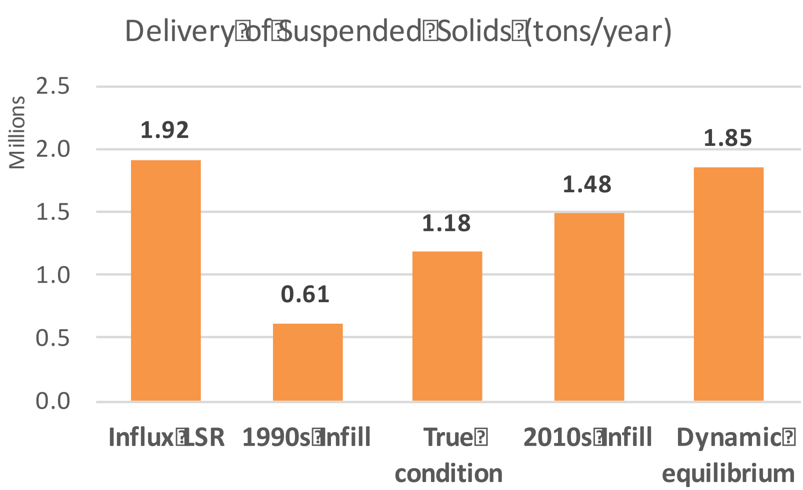



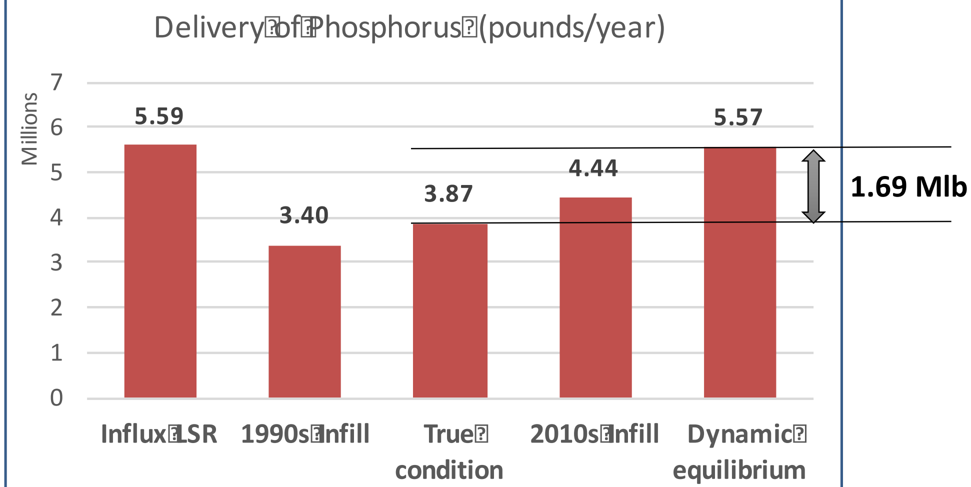
# Lower Susquehanna Reservoirs – 2010 WIP2

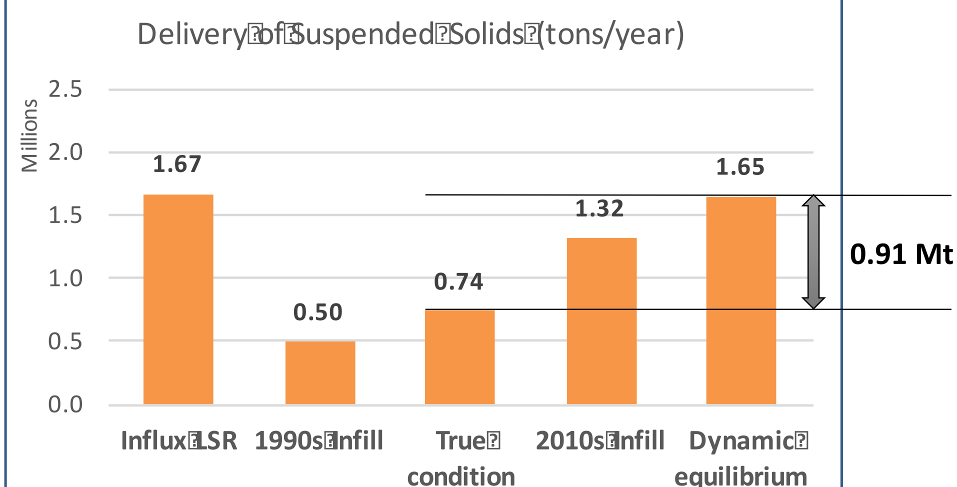
## 1985 – 2014



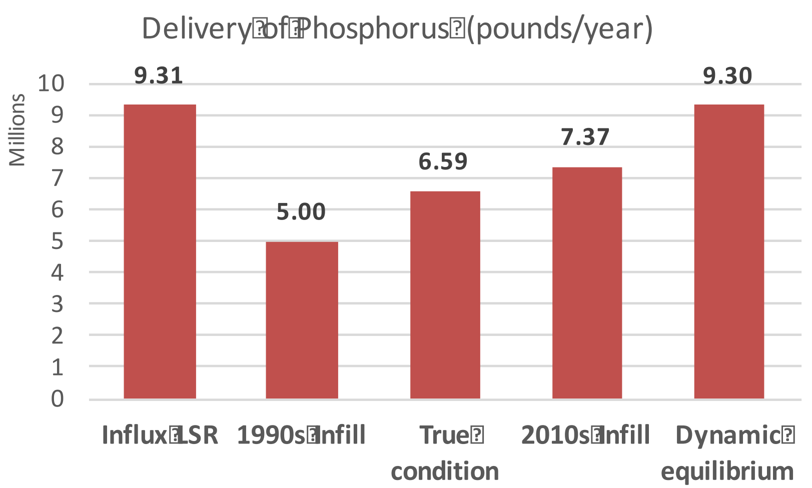

## 1991 – 2000

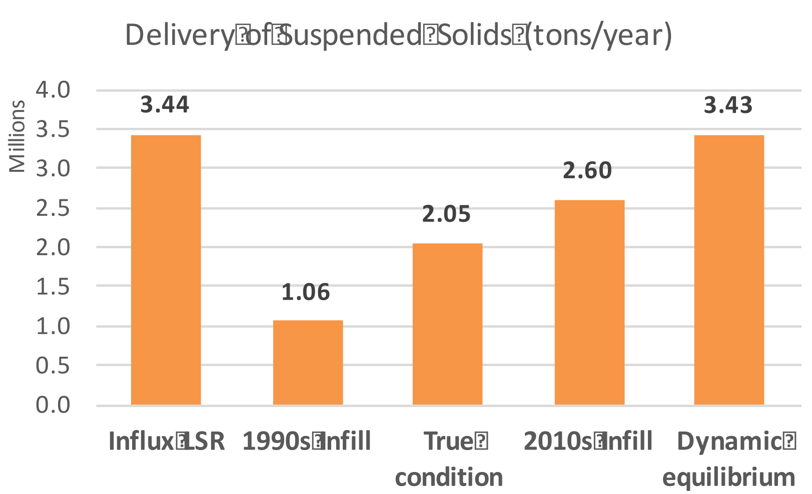


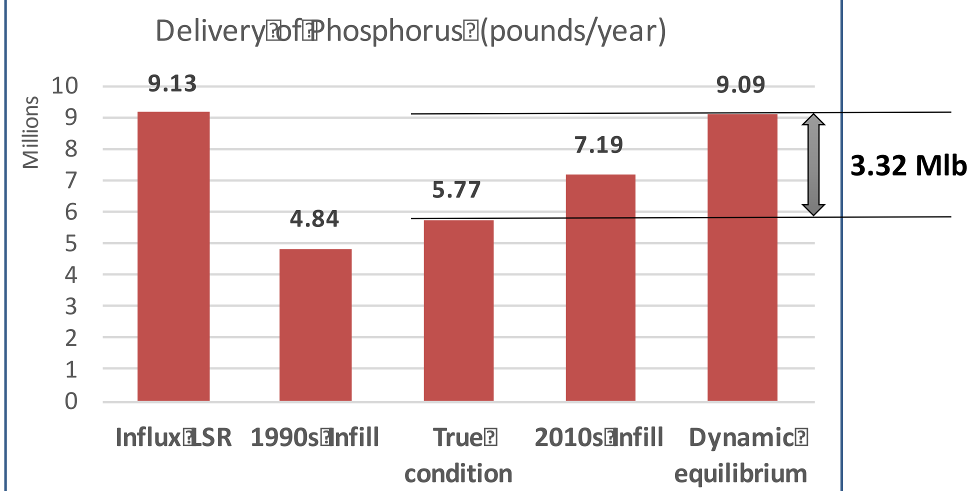
# Lower Susquehanna Reservoirs – True Condition

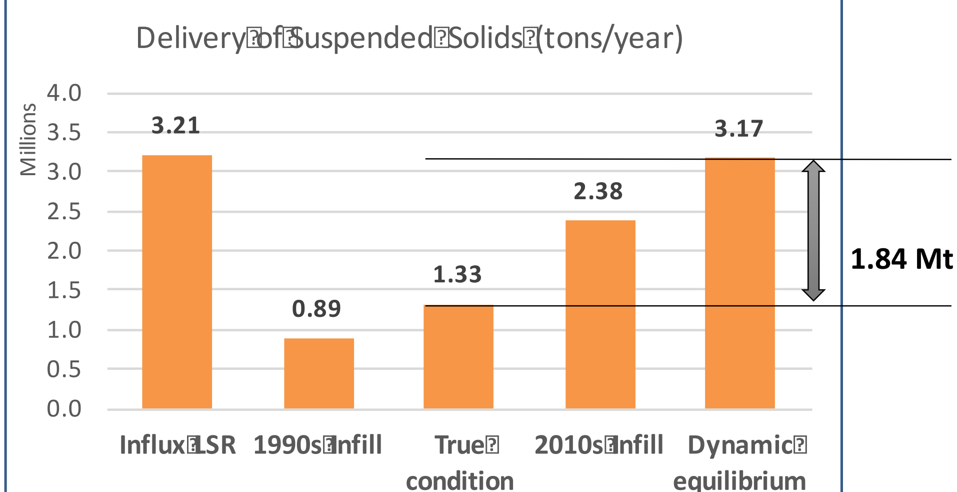
## 1985 – 2014




## 1991 – 2000



# Lower Susquehanna Reservoirs – Transport Factors

$$Transport\ Factor = \frac{Output}{Input}$$

| 1985 – 2014 | 1990s Infill | True Condition | 2010s Infill | Dynamic Equilibrium |
|---|---|---|---|---|
| Suspended Solids | 0.308 | 0.597 | 0.757 | **0.998** |
| Phosphorus | 0.536 | 0.707 | 0.791 | **0.998** |

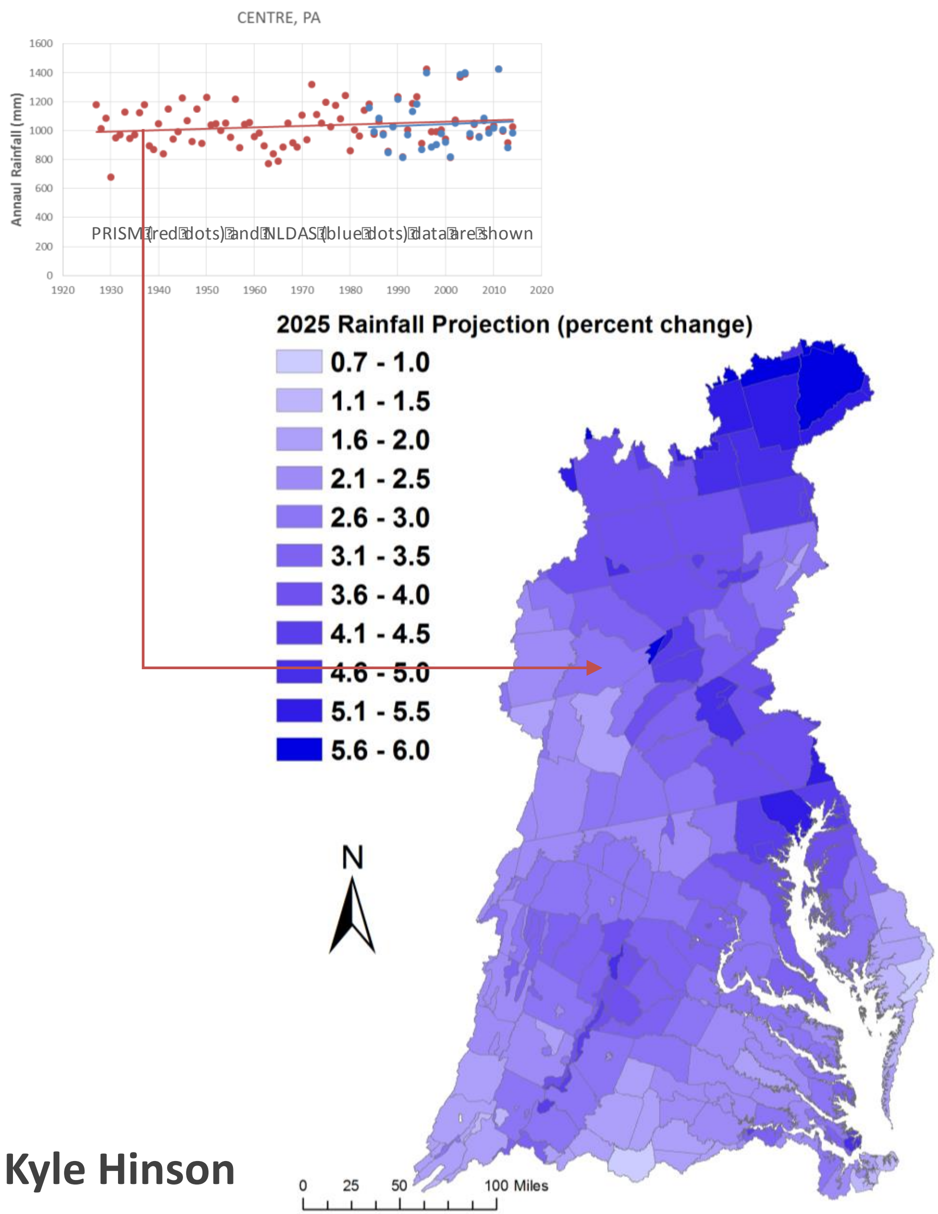
| 1991 – 2000 | 1990s Infill | True Condition | 2010s Infill | Dynamic Equilibrium |
|---|---|---|---|---|
| Suspended Solids | 0.277 | 0.413 | 0.741 | **0.987** |
| Phosphorus | 0.530 | 0.632 | 0.787 | **0.996** |

***The dynamic equilibrium transport factor for the 1991-2000 average hydrology period is slightly lower than that for the 1985-2014 period.***

# 2. 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

# 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 | |
| EC-EARTH | INMCM4 | |

**32 member ensemble**

**Updated Ensemble members**

| | | |
|---|---|---|
| ACCESS1-0 | FGOALS-g2 | IPSL-CM5A-LR |
| BCC-CSM1-1 | FIO-ESM | IPSL-CM5A-MR |
| BCC-CSM1-1-M | GFDL-CM3 | IPSL-CM5B-LR |
| BNU-ESM | GFDL-ESM2G | MIROC-ESM |
| CanESM2 | GFDL-ESM2M | MIROC-ESM-CHEM |
| CCSM4 | GISS-E2-H-CC | MIROC5 |
| CESM1-BGC | GISS-E2-R | MPI-ESM-LR |
| CESM1-CAM5 | GISS-E2-R-CC | **MPI-ESM-MR** |
| CMCC-CM | HadGEM2-AO | MRI-CGCM3 |
| CNRM-CM5 | HadGEM2-CC | NorESM1-M |
| CSIRO-MK3-6-0 | HadGEM2-ES | |
| EC-EARTH | INMCM4 | |

**31 member ensemble**

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

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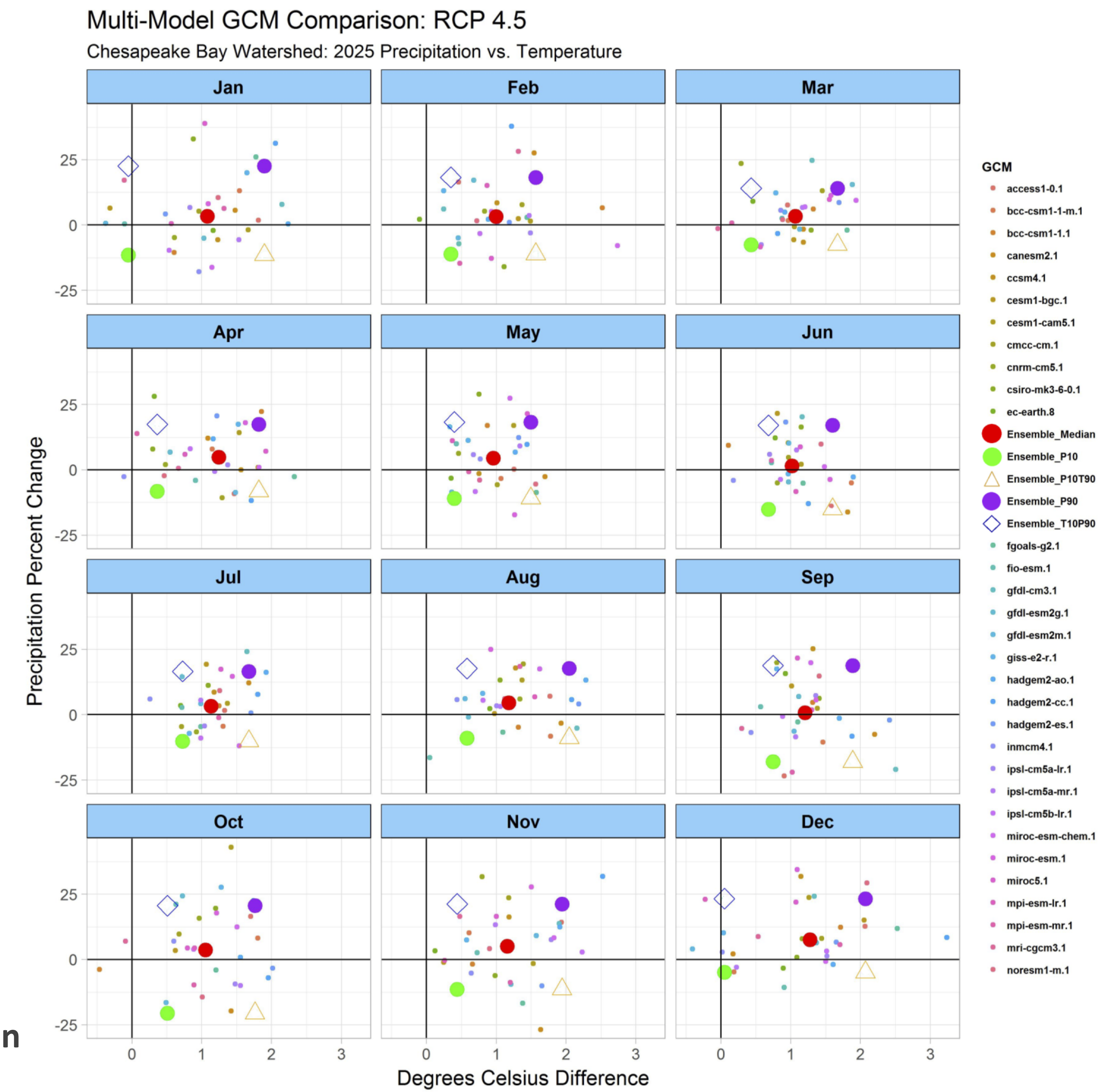

Multi-Model GCM Comparison: RCP 4.5
Chesapeake Bay Watershed: 2025 Precipitation vs. Temperature
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Precipitation Percent Change
Degrees Celsius Difference
GCM
access1-0.1
bcc-csm1-1-m.1
bcc-csm1-1.1
canesm2.1
ccsm4.1
cesm1-bgc.1
cesm1-cam5.1
cmcc-cm.1
cnrm-cm5.1
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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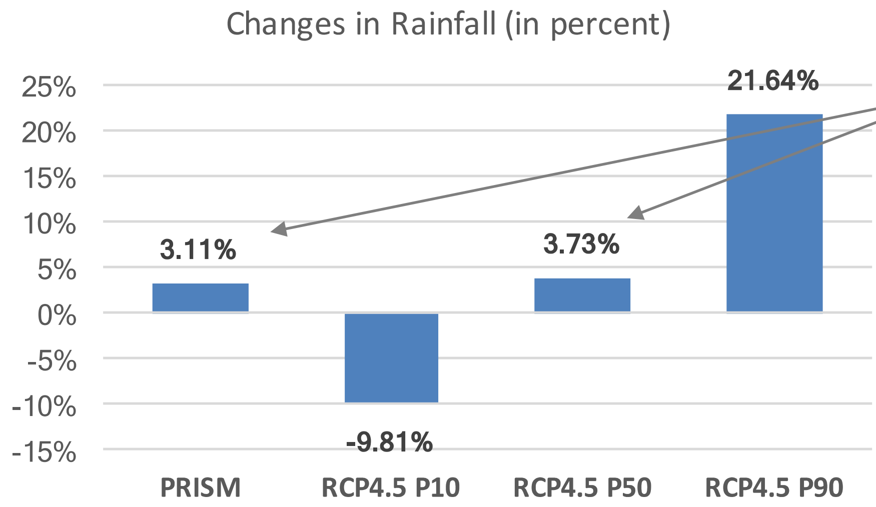
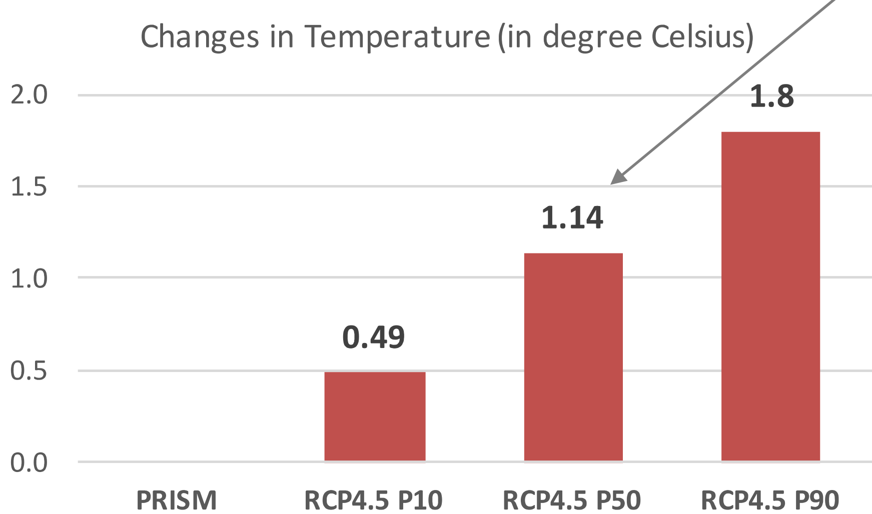
# 2025 climatic projections summary for Chesapeake Bay Watershed

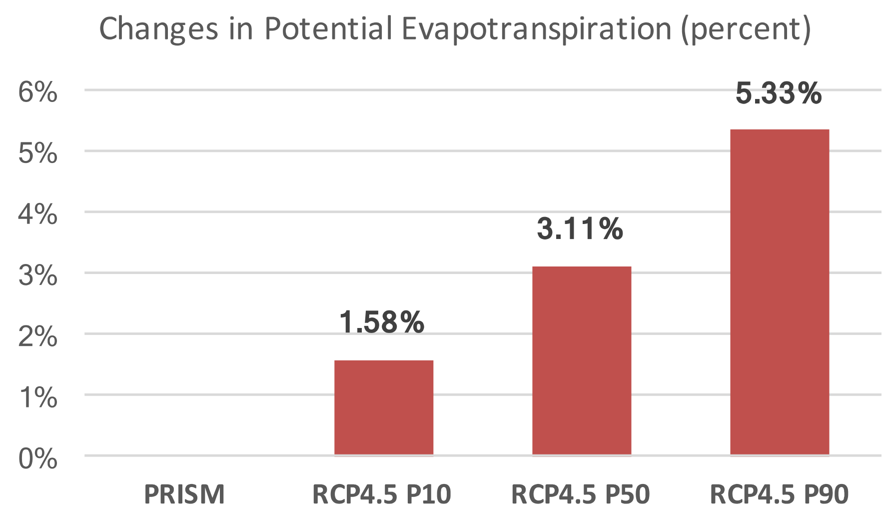



***The central tendency of the projections for the changes in rainfall volume based on the 31 member ensemble median, P50, matches well with the extrapolation of PRISM's 88-year trends.***

***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.***



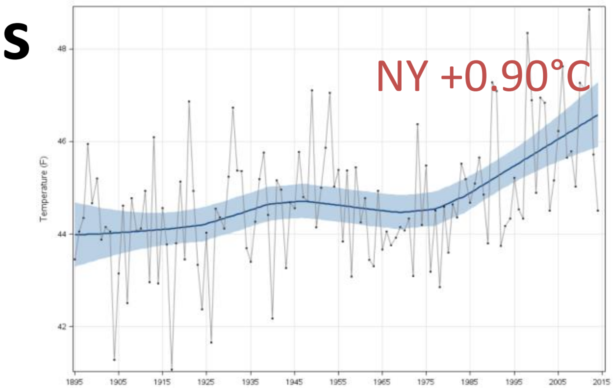
# Temperature trends for the six states

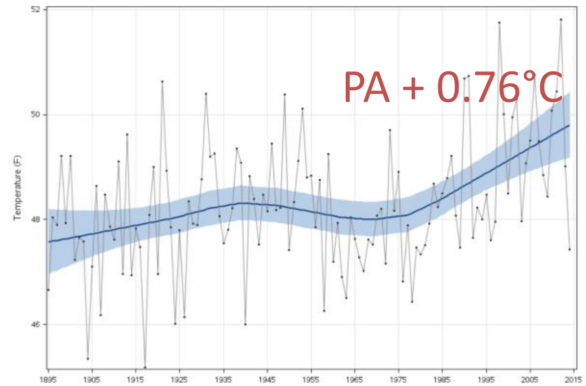
Annual temperature for 1895 to 2015 are shown.

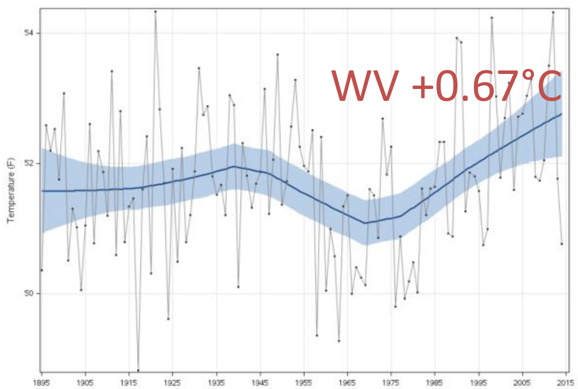
Annual Temperature

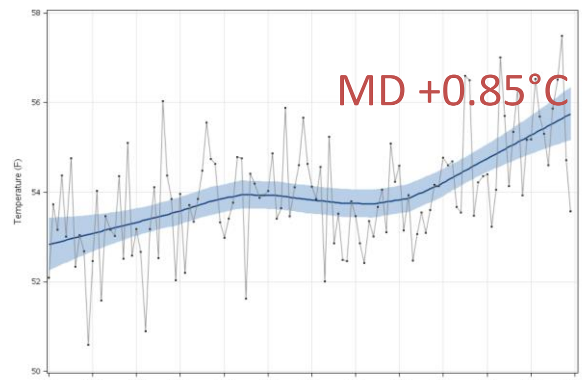
Trend Line

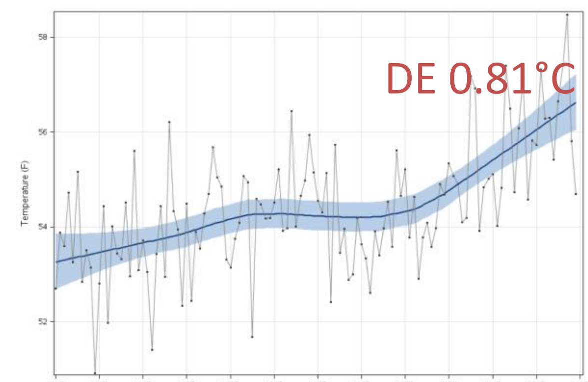
95% Confidence Limits

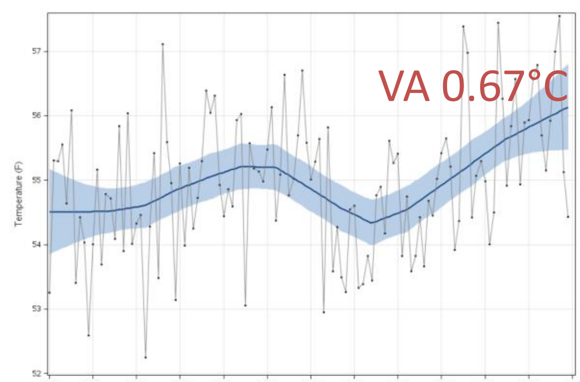


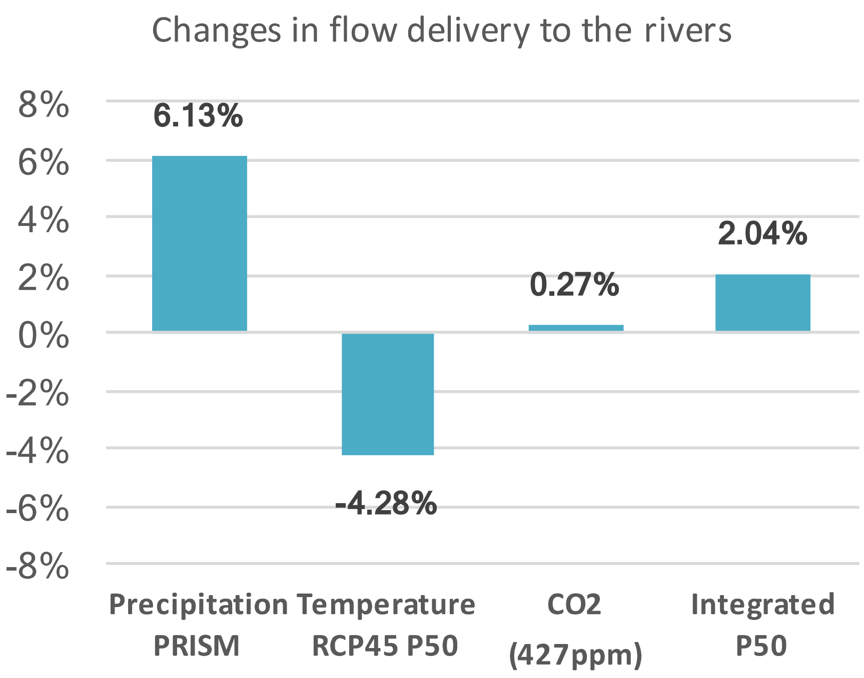



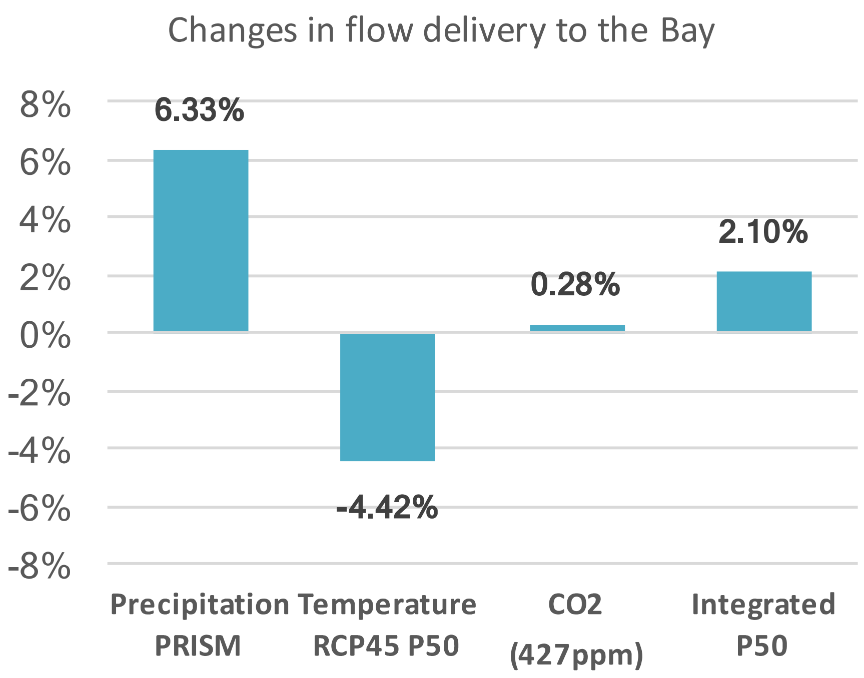




**Approx. increases over the last 30 years based on the trend line are shown.**

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

# Model results: *flow to rivers and the Bay*

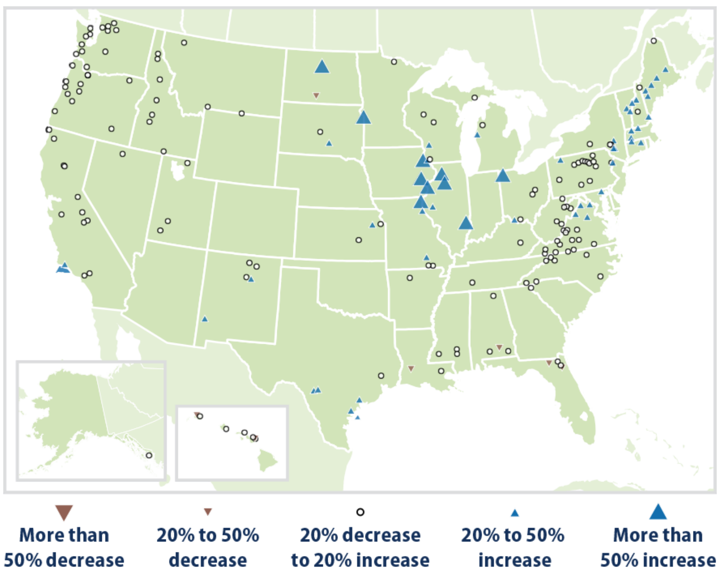


# 1940-2014 streamflow trends based on observations

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

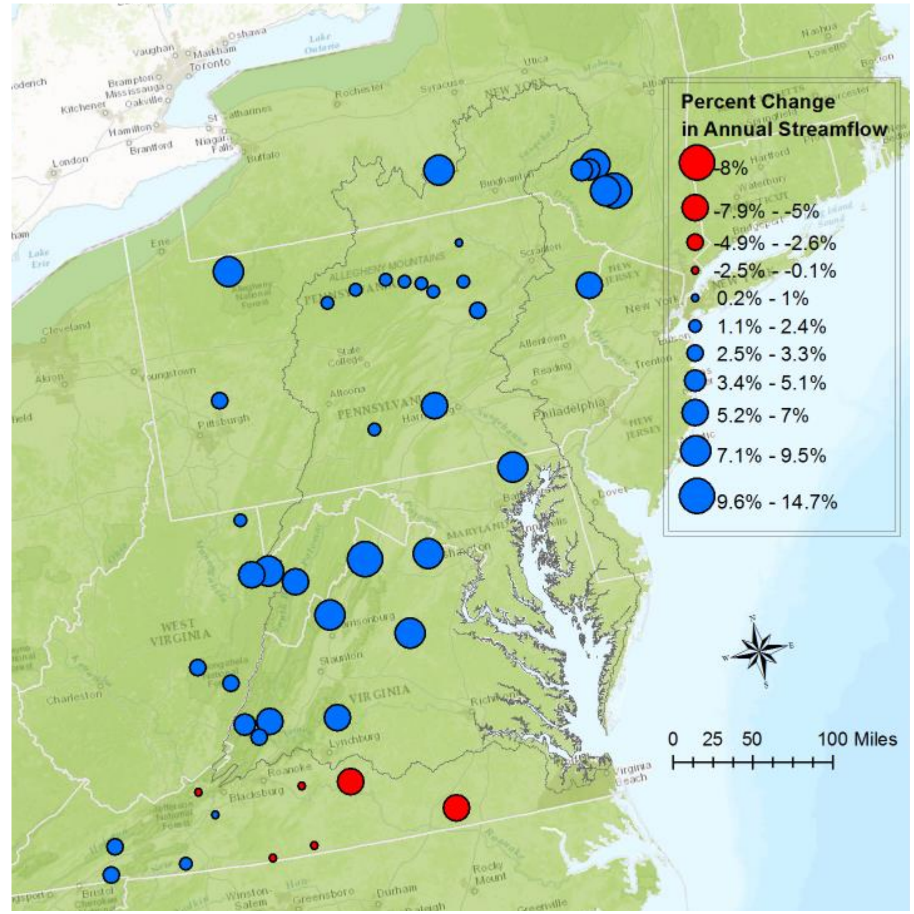
**Annual Average Streamflow in the United States, 1940–2014**




Data source: USGS (U.S. Geological Survey). 2016. Analysis of data from the National Water Information System. Accessed May 2016.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

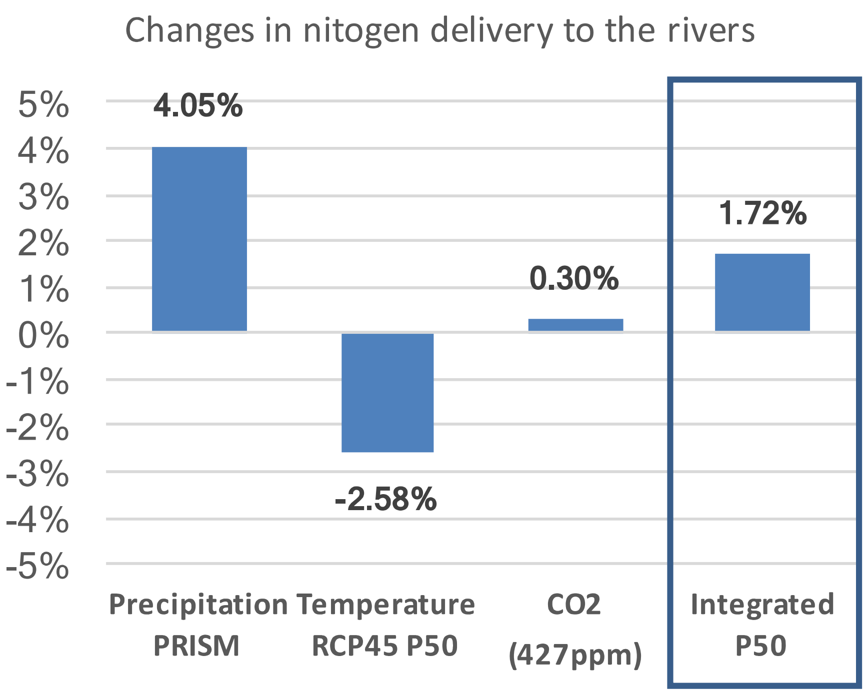
U.S. Environmental Protection Agency. 2016.
Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004. www.epa.gov/climate-indicators.

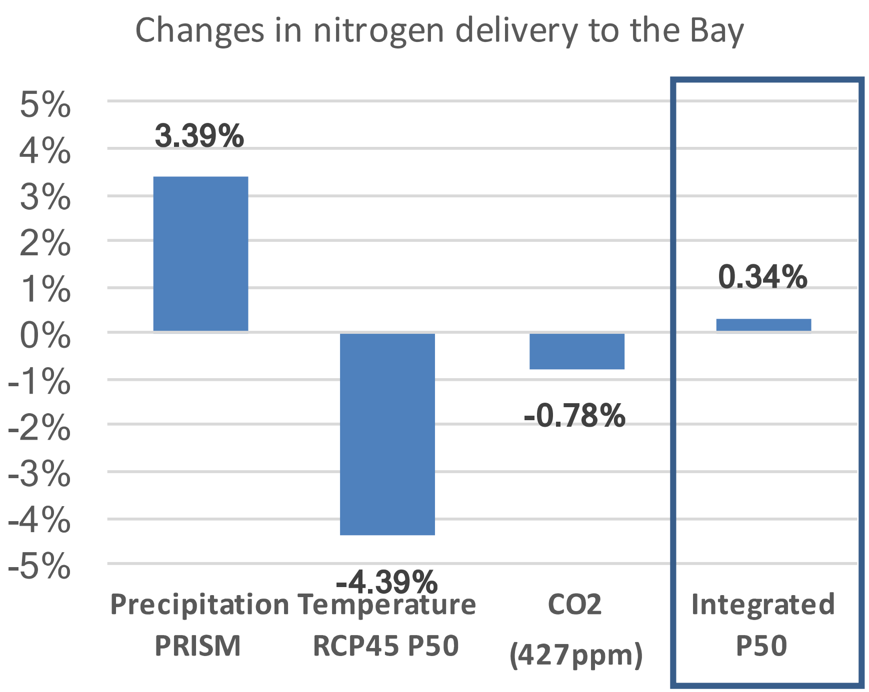



Annual average percent change were calculated using Sen slope (Helsel and Hirsch, 2002).

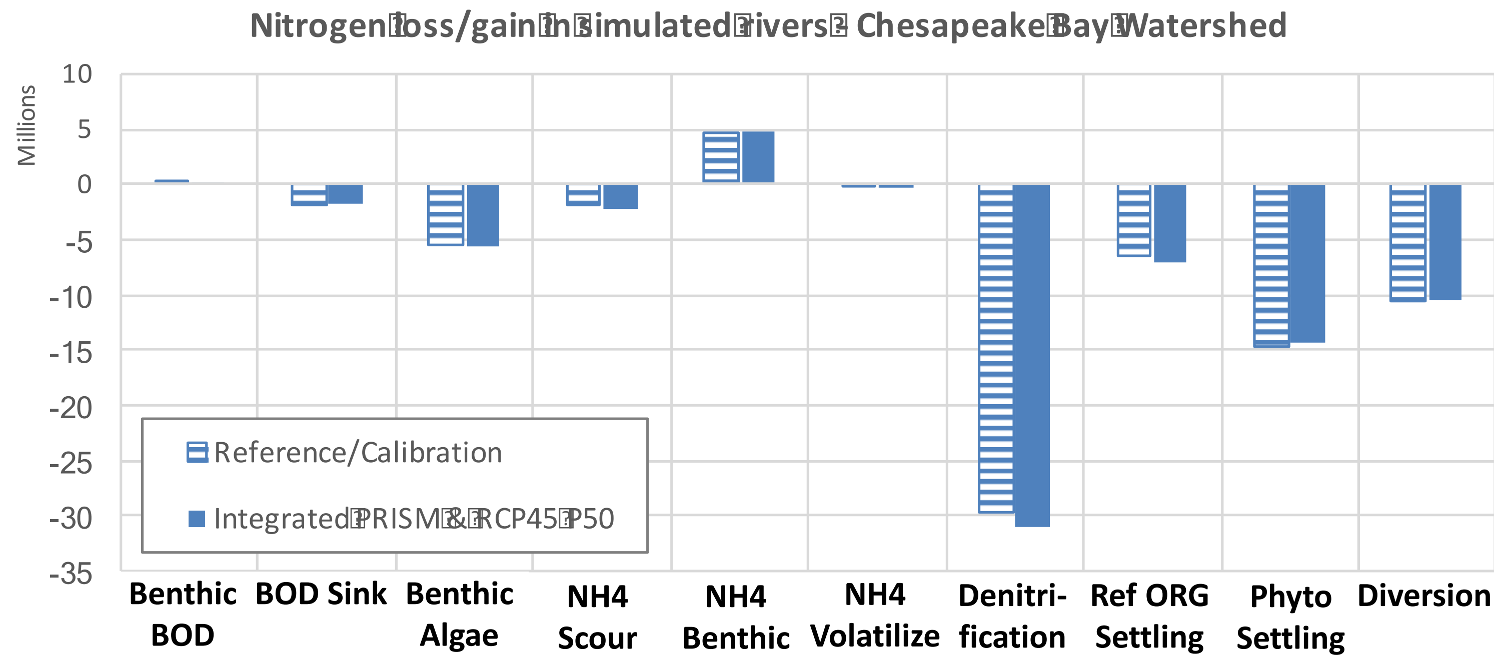

Lins, H.F. 2012. USGS Hydro-Climatic Data Network 2009 (HCDN-2009). U.S. Geological Survey Fact Sheet 2012-3047. https://pubs.usgs.gov/fs/2012/3047.
Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources. Techniques of water resources investigations, Book 4. Chap. A3. U.S. Geological Survey. https://pubs.usgs.gov/twri/twri4a3.

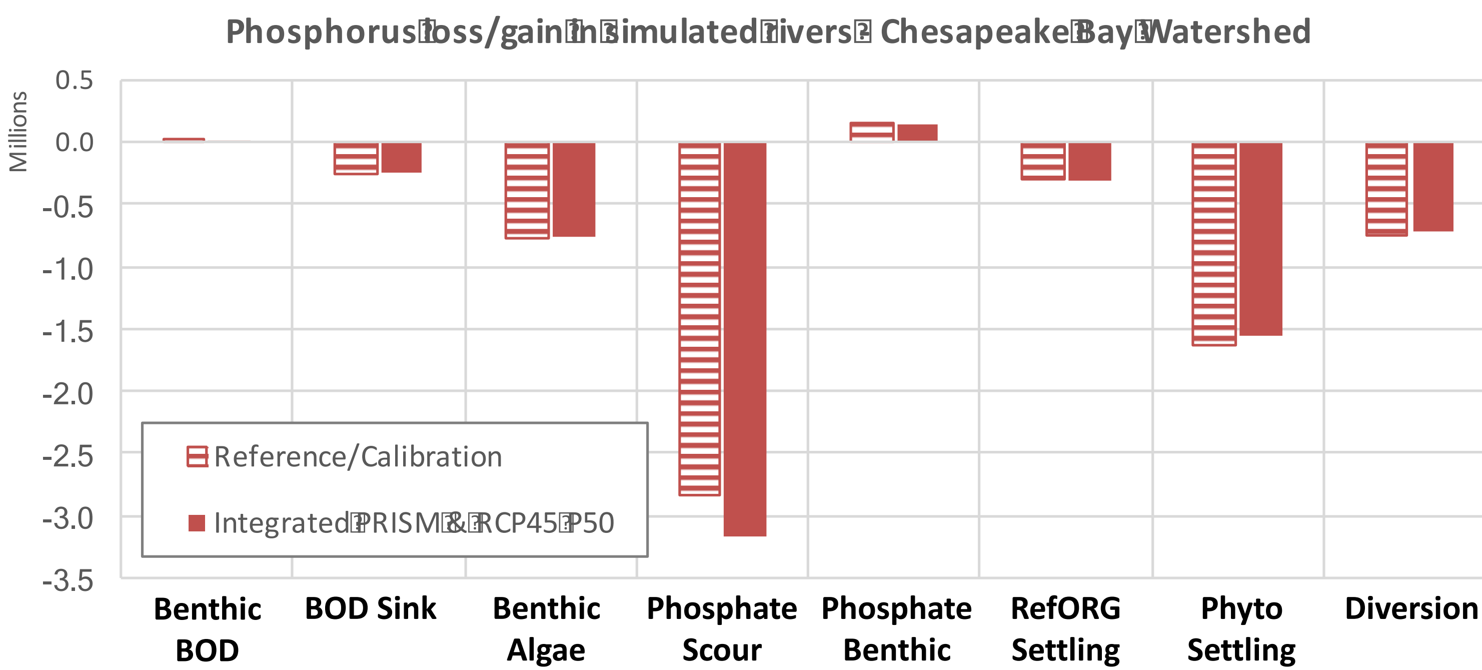
# Model results: *nitrogen to rivers and the Bay*



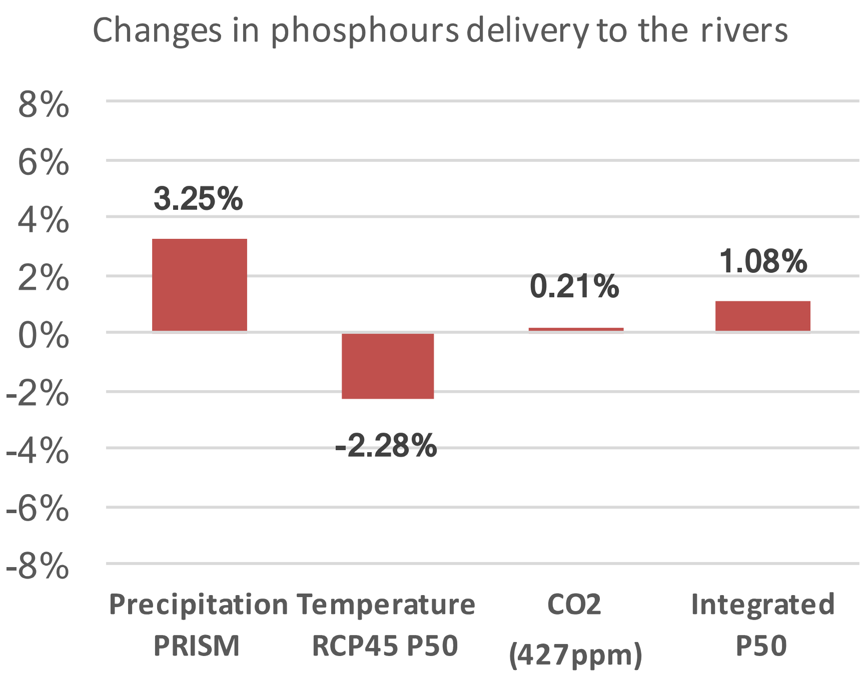



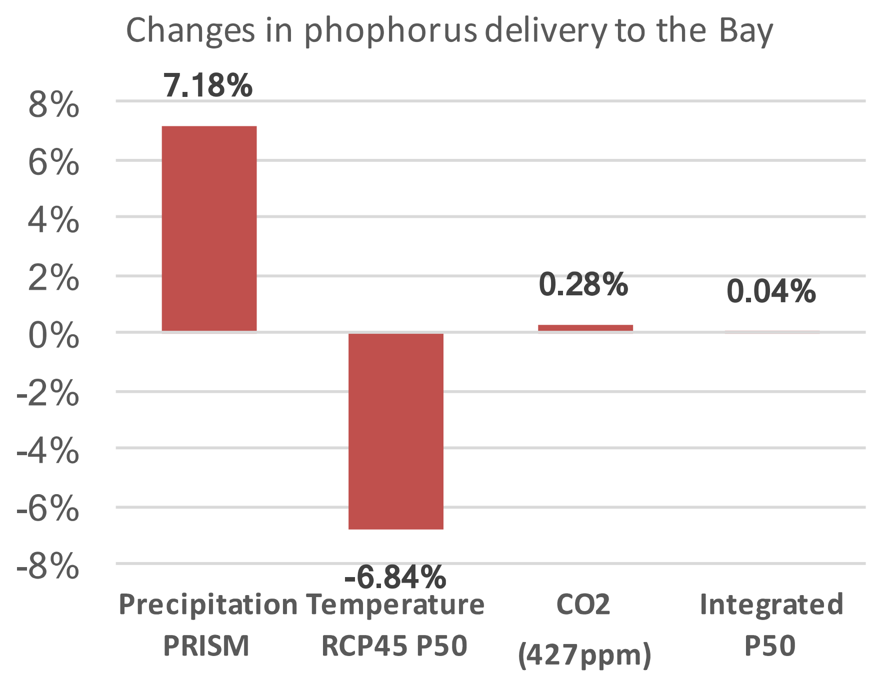

Jessica Rigelman – CAST for the application of Phase 6 sensitivities


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

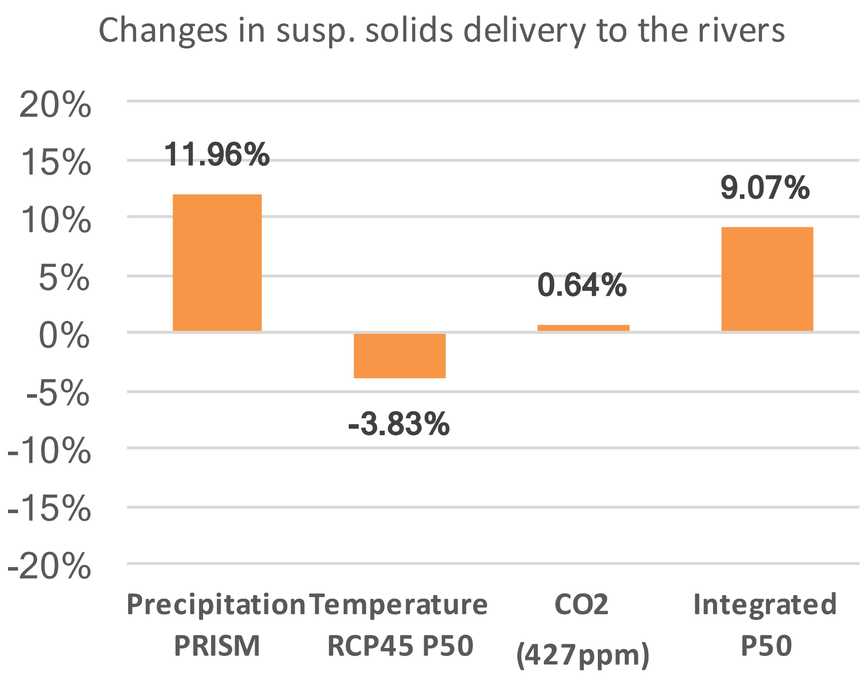
# Model results: *phosphorus to rivers and the Bay*

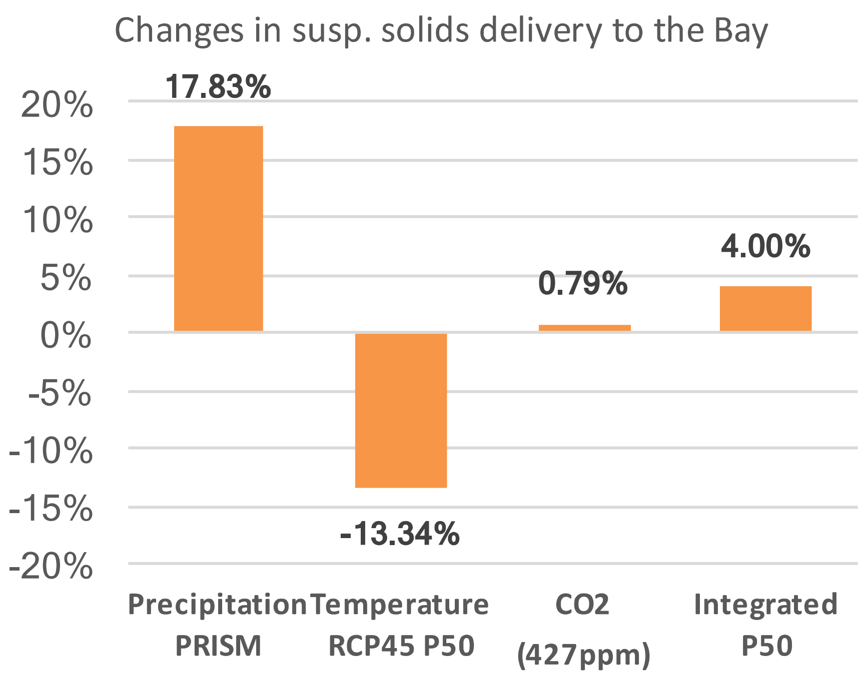


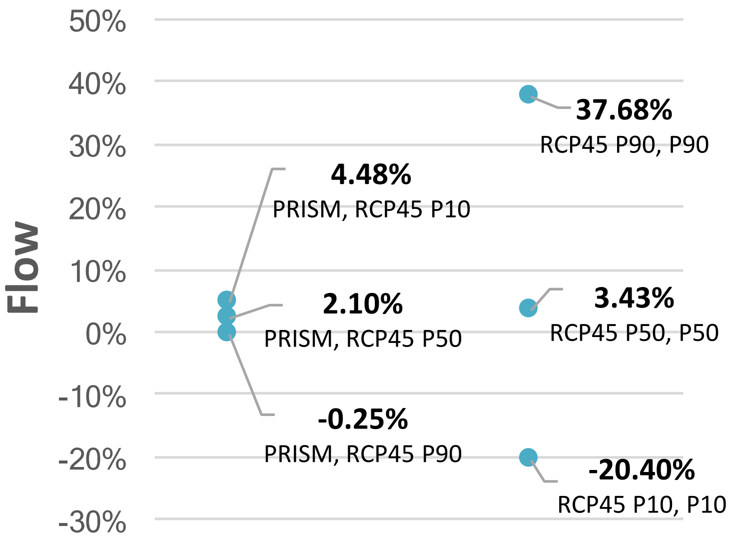

Jessica Rigelman – CAST for the application of Phase 6 sensitivities

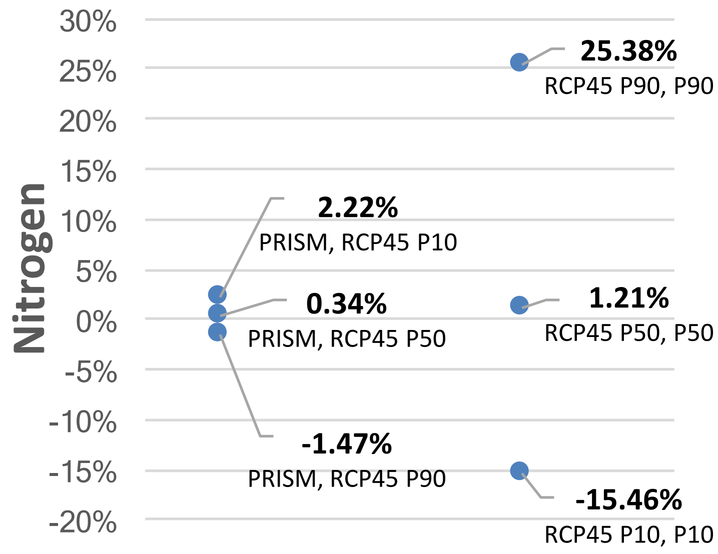
# Model results: *suspended solids to rivers and the Bay*

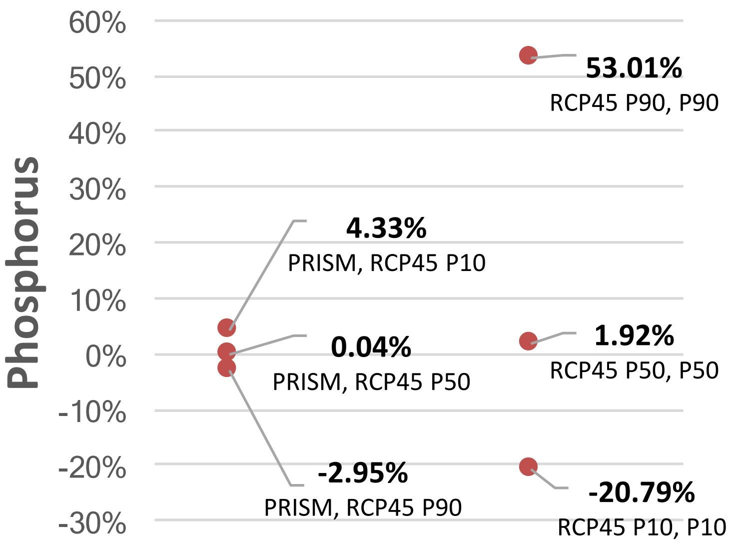


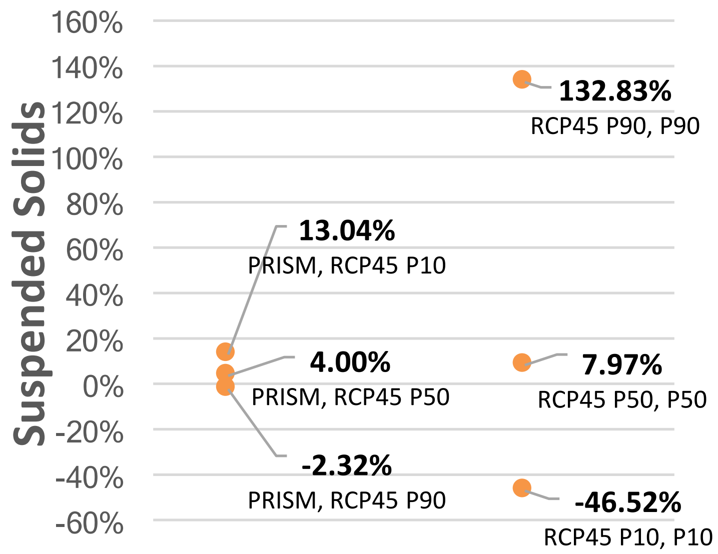



# Uncertainty quantification



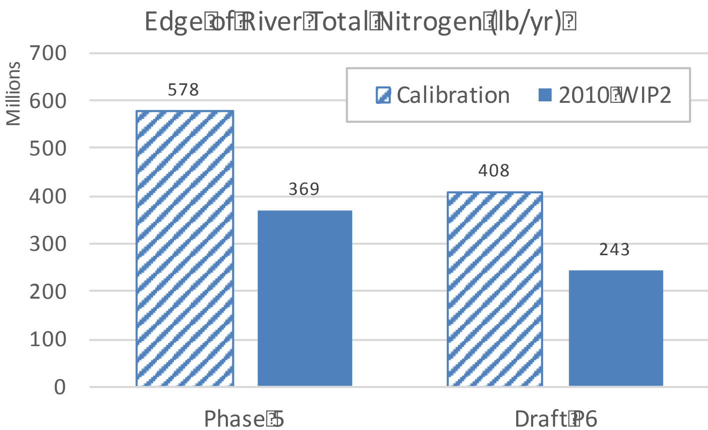
# Summary and Conclusions

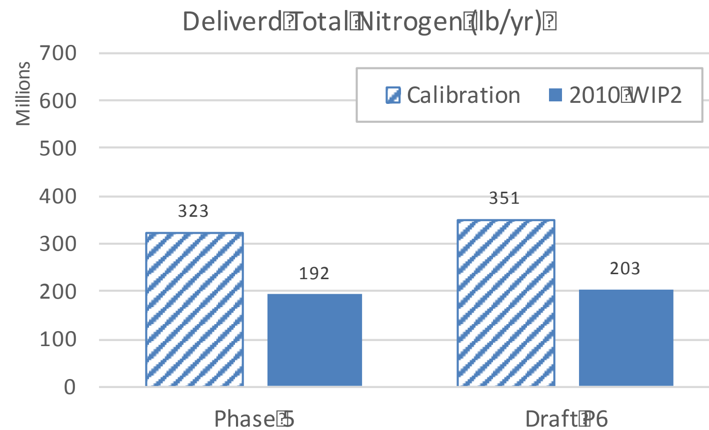
- The results shown were based on the Draft Phase 6 Watershed Model.
- The simulations for a range of Conowingo infill conditions were made, leading to the evaluation of the changes in the delivery of nutrients and sediment, for both true-condition (calibration) and 2010 WIP2.
- The increase of about 1.7 million pounds phosphorus is consistent with the previous analyses (2 million pounds) going back to 2015.
- 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.

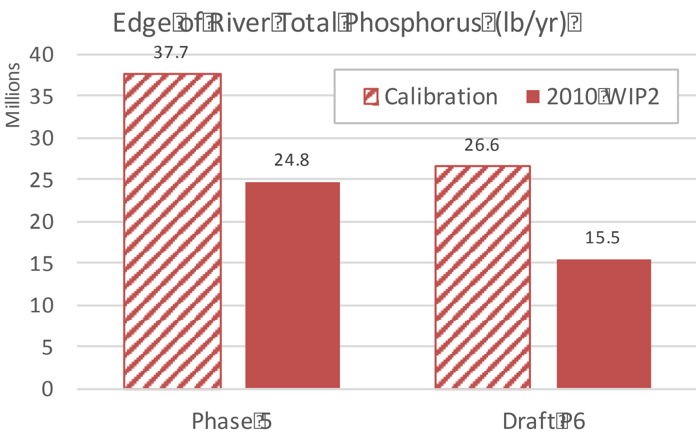
# Appendices

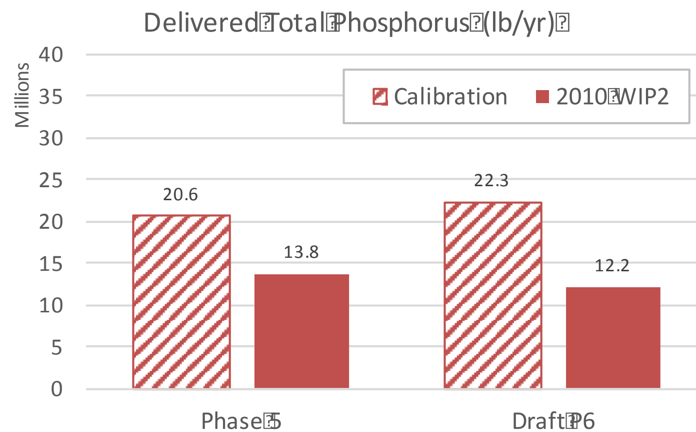
# X. 2010 WIP2 scenario

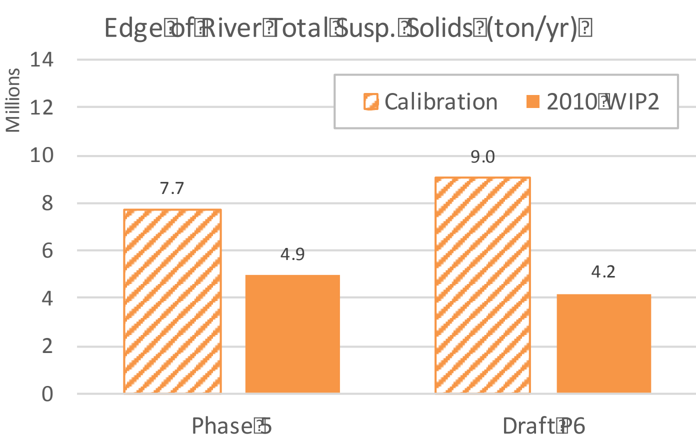
- The Draft Phase 6 watershed model was used for the simulation of 2010 WIP2 scenario.
- 2010 WIP2 scenario results are ***preliminary draft*** as they are based on currently available information that is subject to revisions by the partnership.

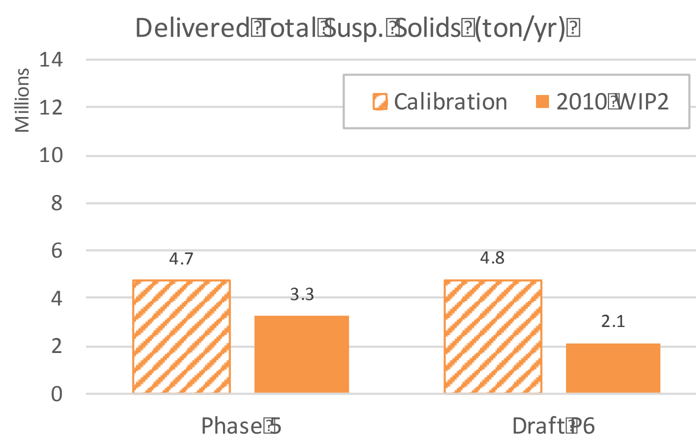

Edge of River Total Nitrogen (lb/yr)
Millions
700
600
500
400
300
200
100
0
Calibration
2010 WIP2
578
369
408
243
Phase 5
Draft P6


Deliverd Total Nitrogen (lb/yr)
Millions
700
600
500
400
300
200
100
0
Calibration
2010 WIP2
323
192
351
203
Phase 5
Draft P6


Edge of River Total Phosphorus (lb/yr)
Millions
40
35
30
25
20
15
10
5
0
Calibration
2010 WIP2
37.7
24.8
26.6
15.5
Phase 5
Draft P6


Delivered Total Phosphorus (lb/yr)
Millions
40
35
30
25
20
15
10
5
0
Calibration
2010 WIP2
20.6
13.8
22.3
12.2
Phase 5
Draft P6


Edge of River Total Susp. Solids (ton/yr)
Millions
14
12
10
8
6
4
2
0
Calibration
2010 WIP2
7.7
4.9
9.0
4.2
Phase 5
Draft P6


Delivered Total Susp. Solids (ton/yr)
Millions
14
12
10
8
6
4
2
0
Calibration
2010 WIP2
4.7
3.3
4.8
2.1
Phase 5
Draft P6