10/08/2024

Phase 7 WSM Development – Water Quality Calibration (~October 2024 version)

Modeling Workgroup Quarterly Meeting – October 2024

Gopal Bhatt[1], Isabella Bertani[2], Lewis Linker[3], Robert Burgholzer[4]

[1] Penn State, [2] UMCES, [3] US EPA, [4] VA DEQ – Chesapeake Bay Program Office

Presentation Outline

Phase 7 Dynamic Watershed Model (DWM)

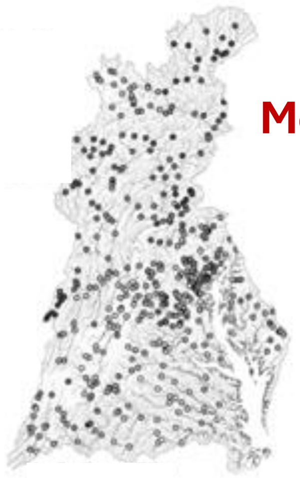
1. **Dynamic Watershed Model Overview**
2. **Review of prior model development progress**
3. **Water quality calibration**
    - Revisions to streamflow simulations
    - Implementations of water temperature module
    - Water quality calibration approaches
    - Review of October 2024 version of the model
4. **Summary and next steps**

Purpose

NHD Scale Dynamic Watershed Model (DWM)

- Inputs for the estuarine models (MBM/MTMs)
- Watershed model calibration and scenario applications
- Support research and collaboration activities

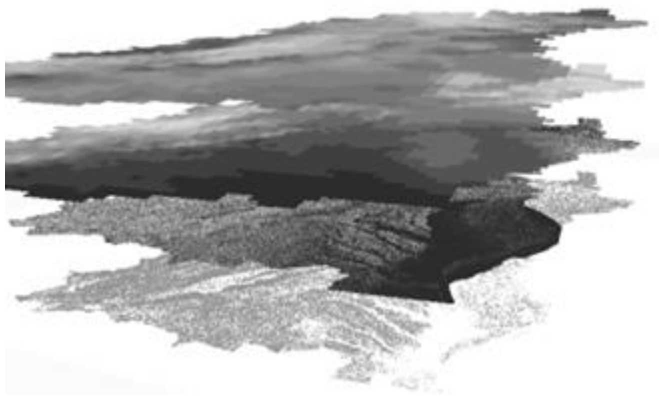
Framework: Statistical Model (CalCAST) → Dynamic Watershed Model (DWM)



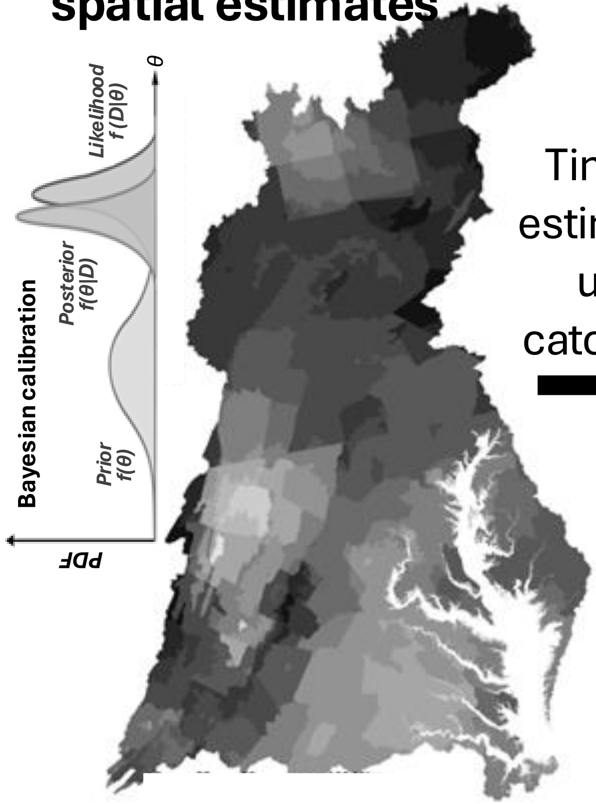
Monitoring Data

+

Watershed characteristics & inputs



CalCAST statistical spatial estimates

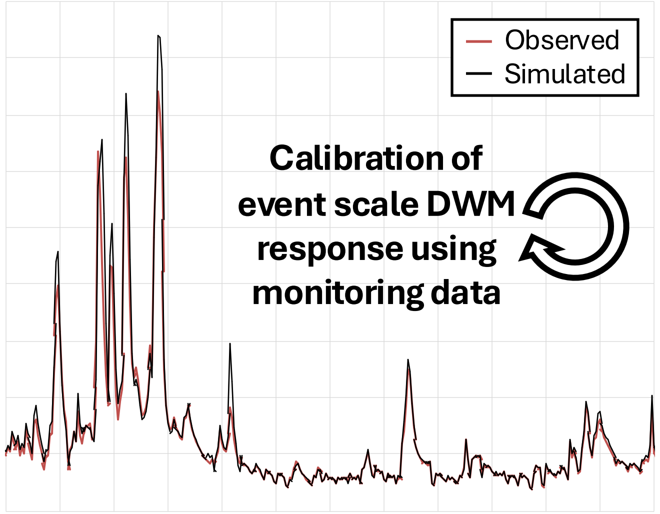


Time averaged estimates at land use & NHD catchment scale

DWM process-based hourly estimates

Meteorological inputs, DWM parameters

Temporal disaggregation



- Data-driven CalCAST informs DWM parameters and responses.
- NHD-scale DWM prototype is now using CalCAST *average annual* (a) total flow, (b) stormflow, (c) sediment erosion and delivery factors, and (d) total nitrogen and total phosphorus loads and delivery factors.

Dynamic Watershed Model (DWM) Development

- Year 2022: NHD-scale model structure and prototypes for hydrology, sediment, and nutrients.
  - Operational prototypes with reasonable runtime and on the graph paper model results.

Development Milestones (2022)

100K NHD	NHD-scale model structure; Hydrology prototype; Expanded simulation period 1985 to 2020; [1][2]
HYDROLOGY	Hydrology calibration (CalCAST→DWM) method updates; initial testing of numerical simplifications for flow routing; [3]
SEDIMENT	Sediment model; Hydrology model calibration updates with respect to stormflow; [4]
NUTRIENTS	Nutrient (Nitrogen and Phosphorus) model; Updated sediment model; [5]

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress-in-phase-7-wsm-development-1.4.2022-gopal_bhatt_penn_state.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_4.5.2022_-_gopal_bhatt_penn_state.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_-_gopal_bhatt_penn_state_7.12.22.pdf
[4] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-10.4.22-v2.pdf
[5] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-1.10.2023.pdf

- Year 2023: Incremental refinements of model prototypes in terms of model segmentation, CalCAST→DWM linkage, and simulation of the small streams.

… incremental improvements during 2023

Segmentation	We performed re-segmentation and tested the revised model. ▪ tidal percent attribute was updated using new shoreline layer ▪ all databases (river mainstem, topology, etc.) were updated ▪ segmentations in the tidal watershed were improved
Model	Improvements on overcoming the 'aggregation effect' in the simulation of river mainstems (CalCAST → DWM) ➢ Non-iterative hydraulic routing for small 100K NHDplus streams ➢ WQ routing (TN) for small 100K NHDplus streams
Simulation	Testing on Amazon AWS and MS Azure cloud HPC environments with various node type and size configurations

[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20230404-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q1.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-6.20.2023.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-10.17.2023.pdf
[4] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20240109-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q4.pdf

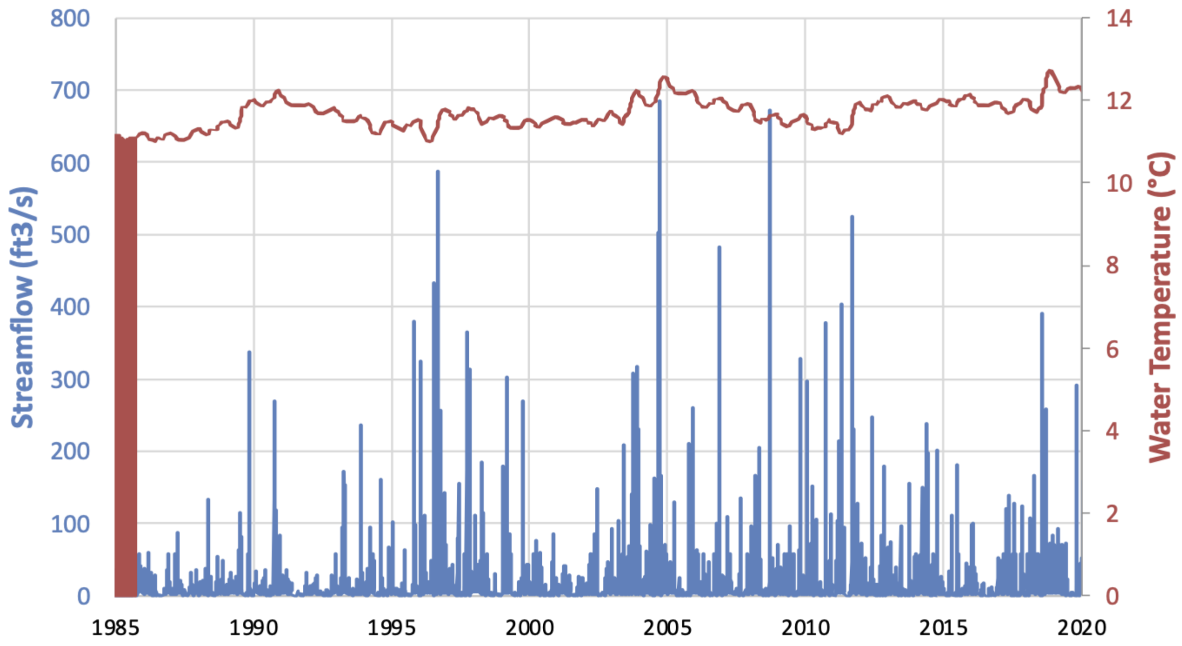
- **Year 2024: (Q1) stream water quality routing based on *β* parameters; (Q2) mechanics of water quality calibrations (step 1 of 2)**

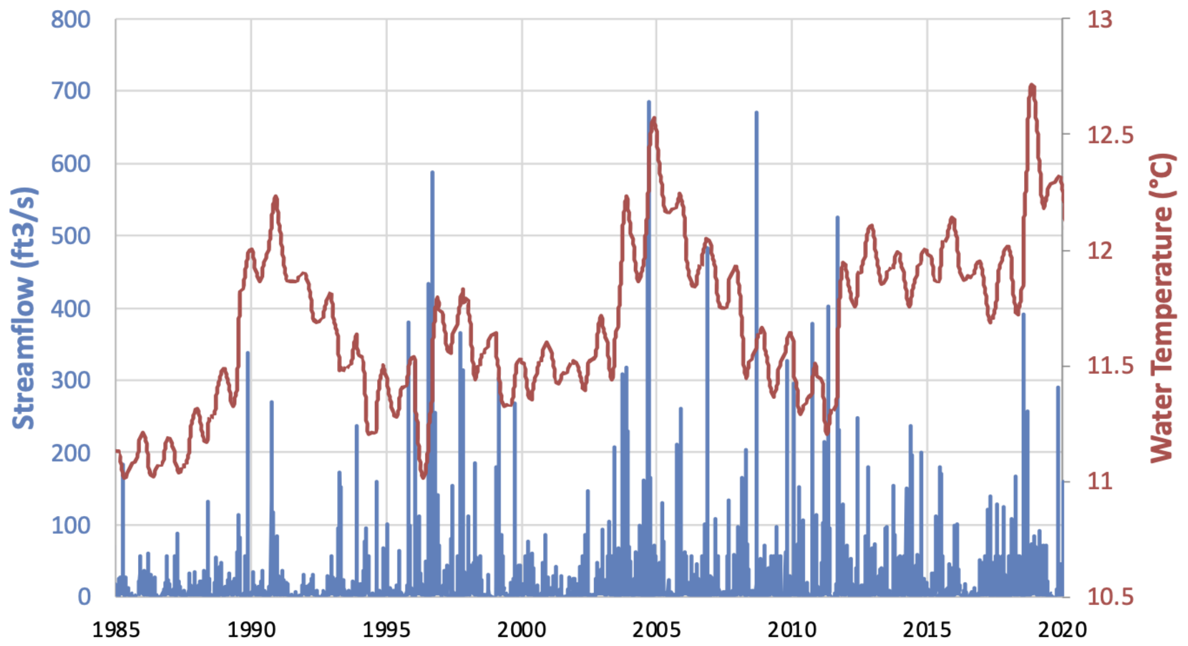
[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-CBPO-4.2.2024.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Phase-7-WSM-Development-Modeling-WG-July-2024.pdf

Flow refinements

- We implemented changes for addressing instability issues
  - A constrain of slow Δstorage when it is greater than the storage
  - A constrain for slow flow release after reaching a low volume threshold
  - A few bug fixes were made

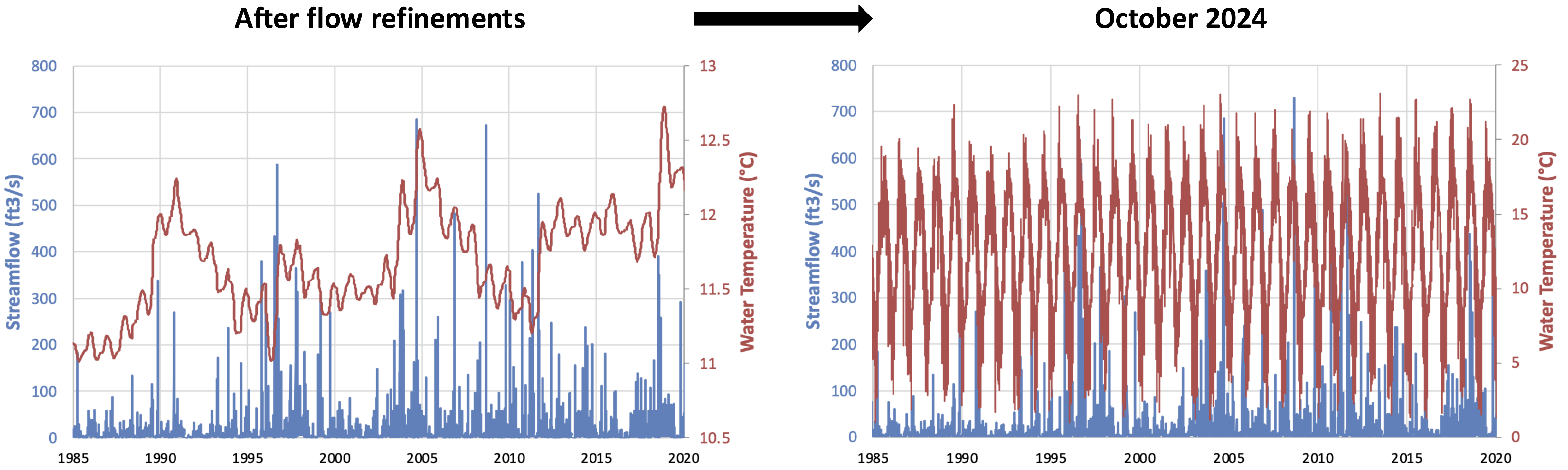
July 2024 → **After flow refinements**





Water temperature

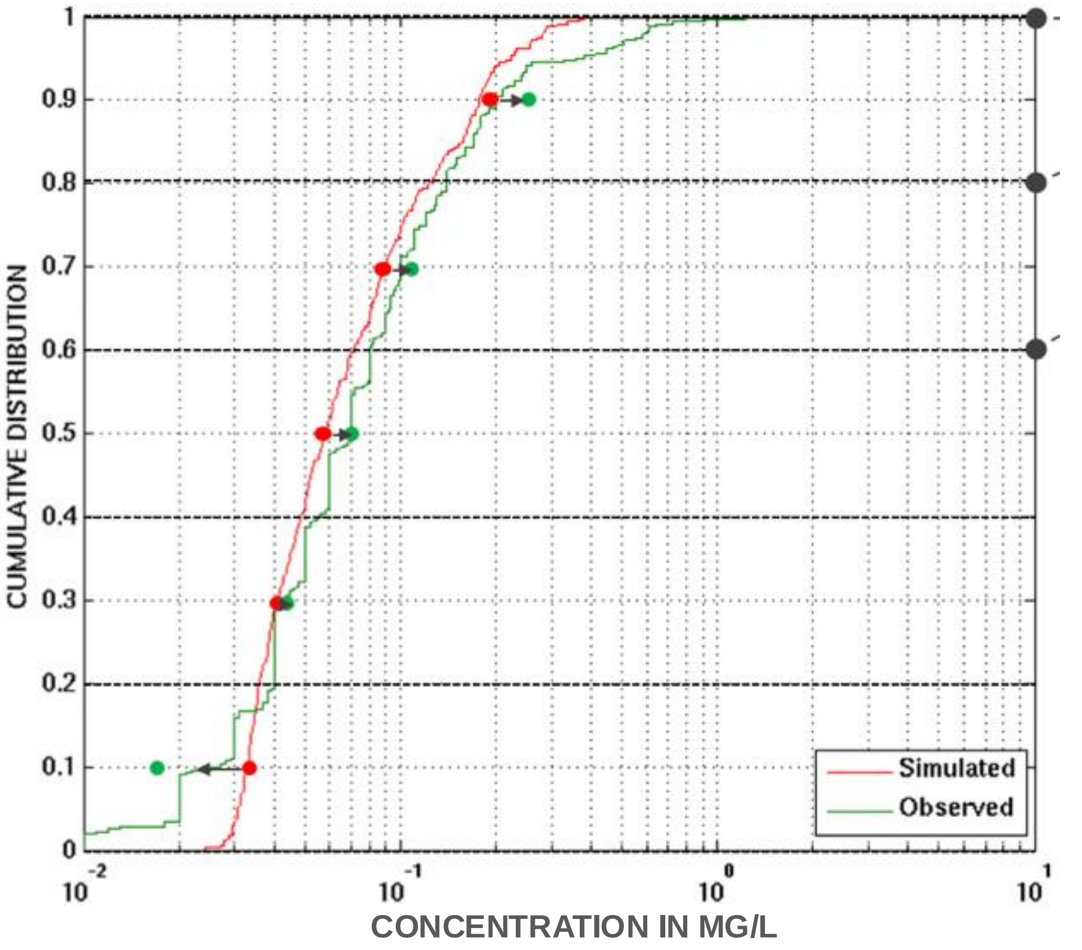
- We implemented a routing module while ensuring heat-balance
  - A constrain for idle water volume was added to overcome precision loss
  - A few bug fixes were made



(1) It offers potential for including emergent behavior of small streams processes, e.g., as a function of shading.
(2) Groundwater temperature currently isn't sensitive to changes in future climate so that could be included in Phase 7 for completeness.

Water quality calibration methods

Figure: Cumulative distribution of concentrations at a monitoring station

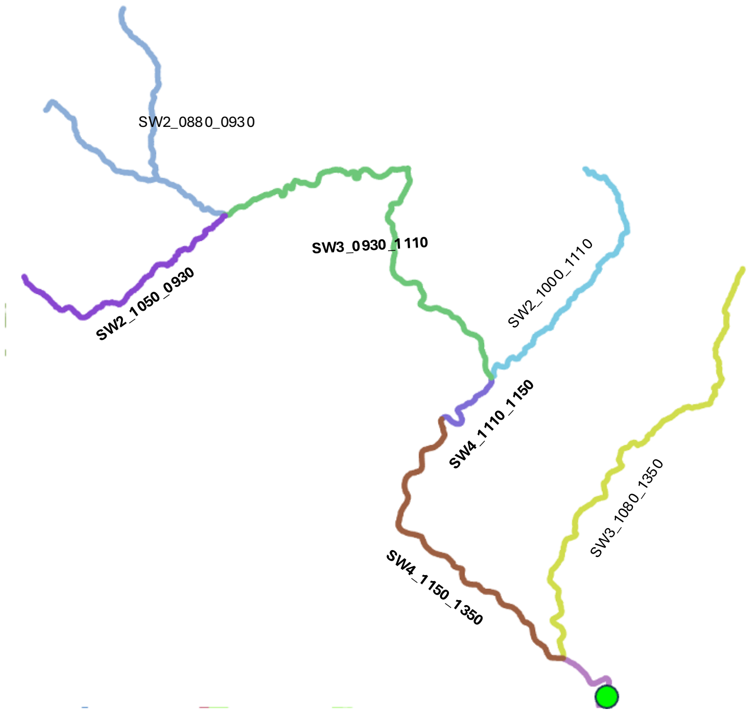


Information available for the calibration dynamic model parameters:

- Observations of daily concentrations for nutrient species at monitoring stations
- Transport factors for TN, TP, and SS for each river mainstems (CalCAST)
- QC relationships (generalized β parameters for river mainstems)

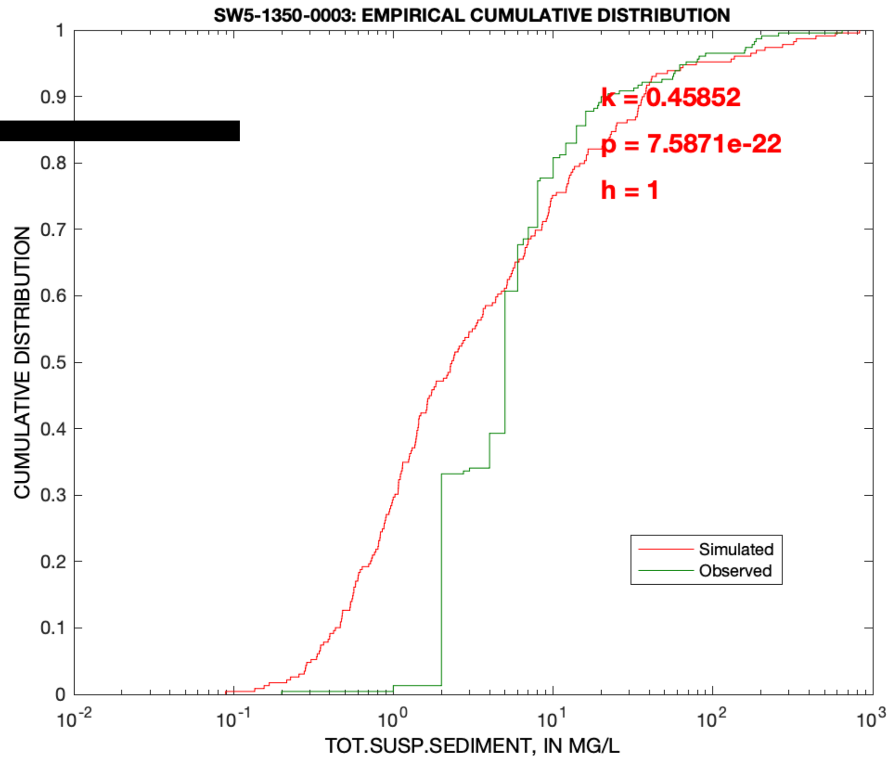
We calibrate model parameters to improve agreement in cumulative frequency distribution (CFD) of observed and simulated concentrations

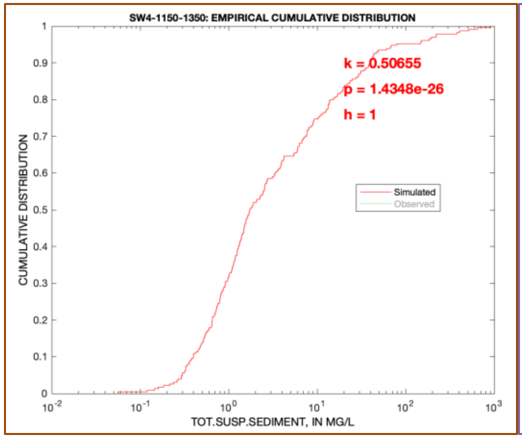
Water quality calibration methods

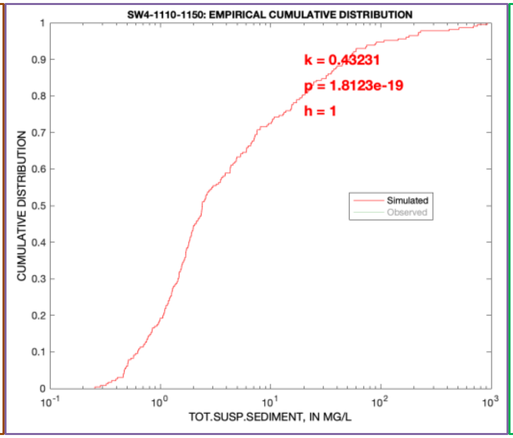


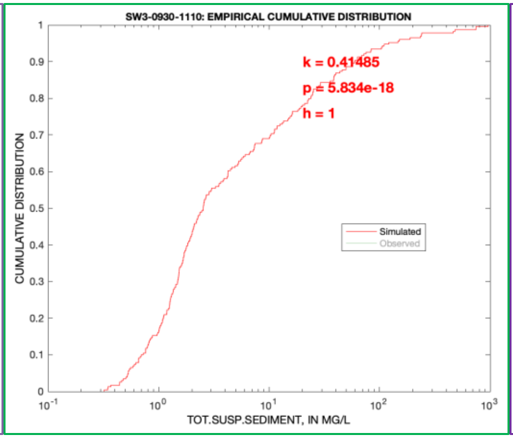
Question: How should the CFDs of unmonitored segments be calibrated?

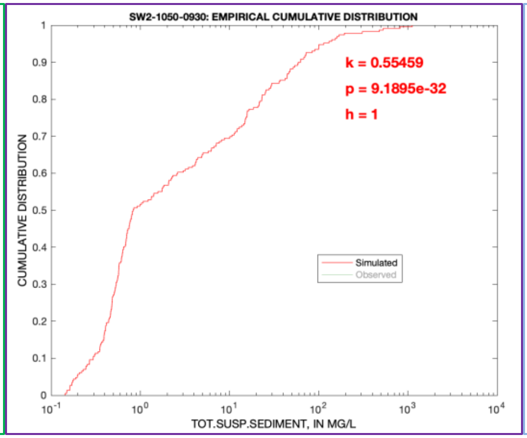
considering 3 options

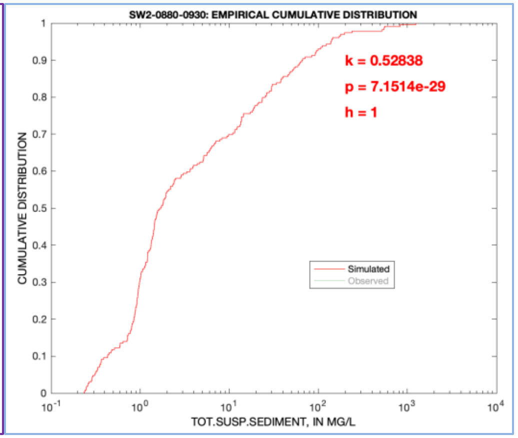




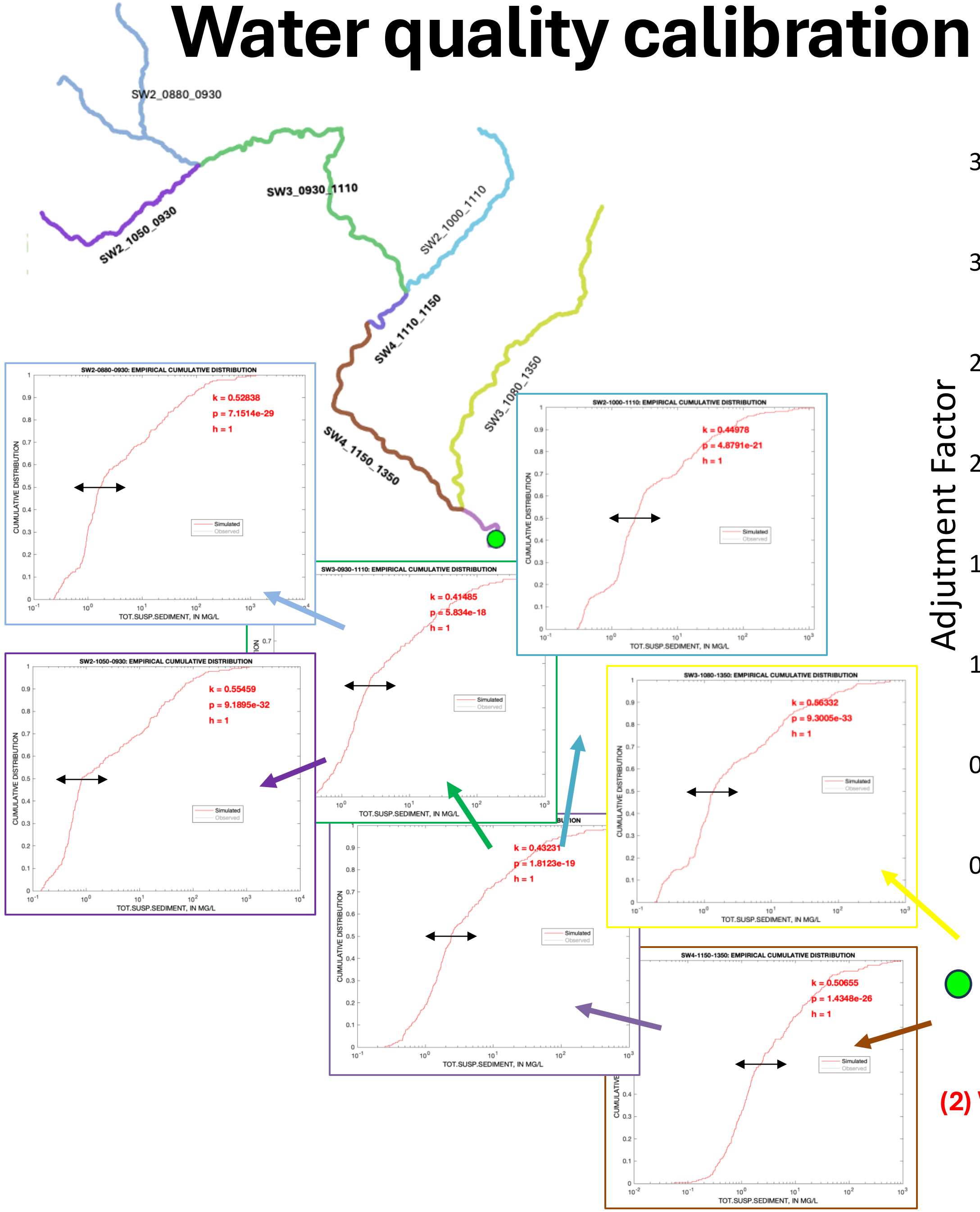


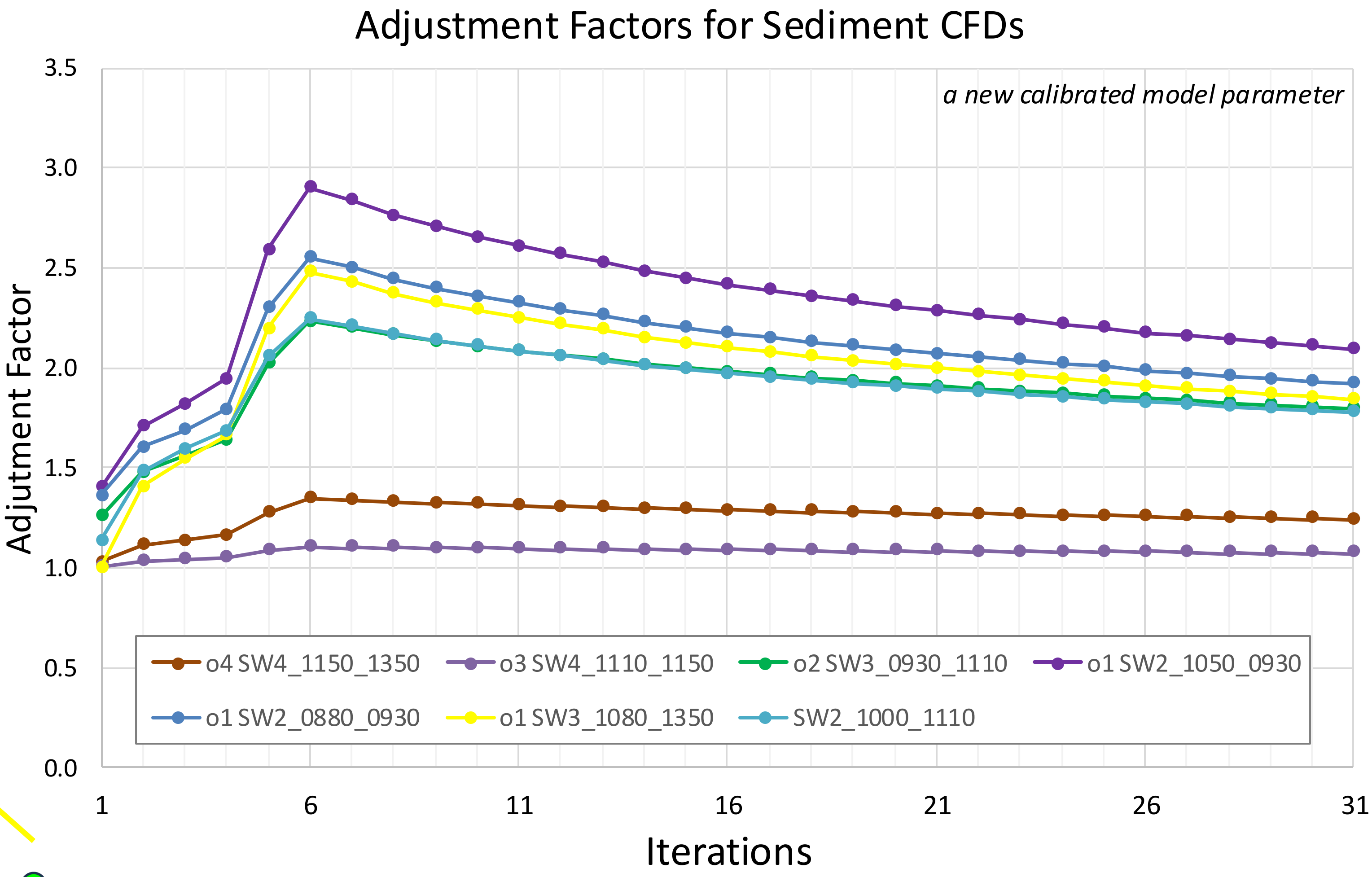






Water quality calibration methods

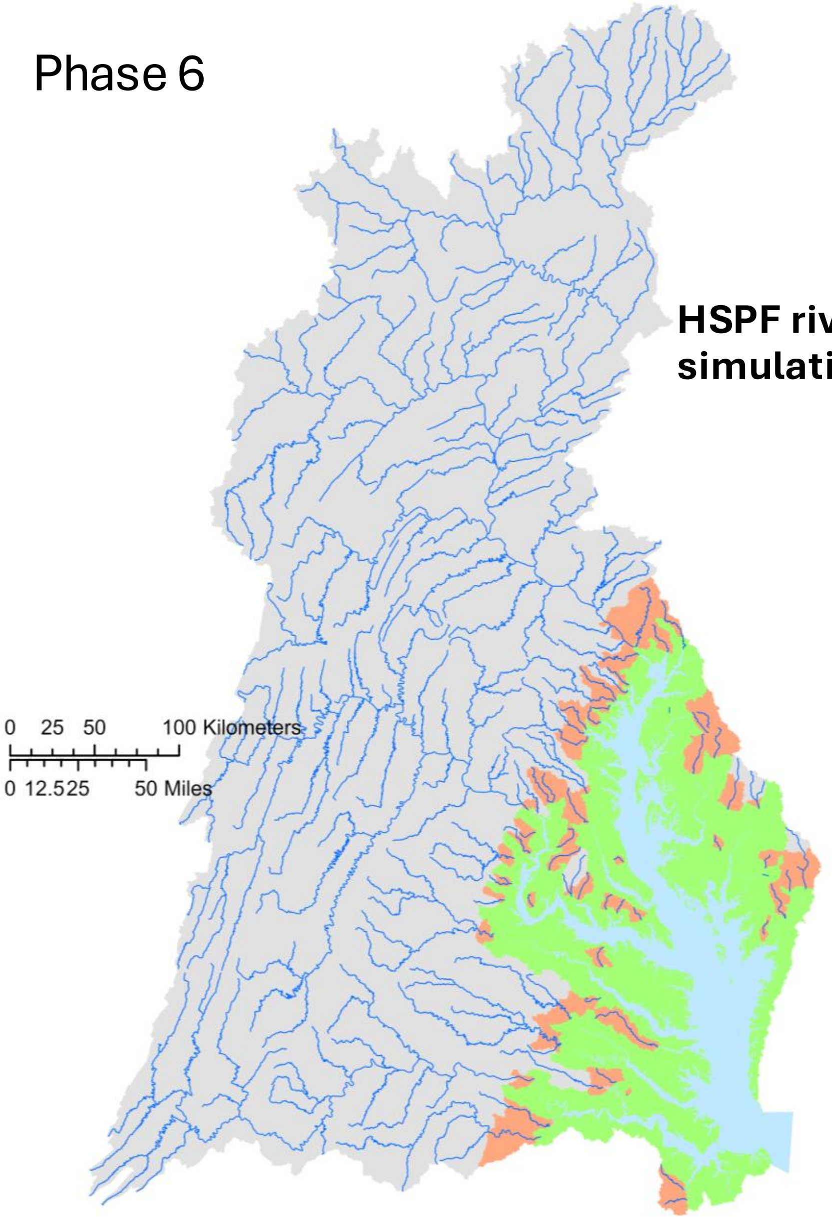




(1) We propagate changes in parameters needed for improving agreement in the shape of the CFDs.
(2) We shift TN|TP|SS CFDs for matching CalCAST average annual delivery potential or transport factors.

Terminal and Tidal loadings

Phase 6



HSPF river simulation

Non Tidal

Terminal

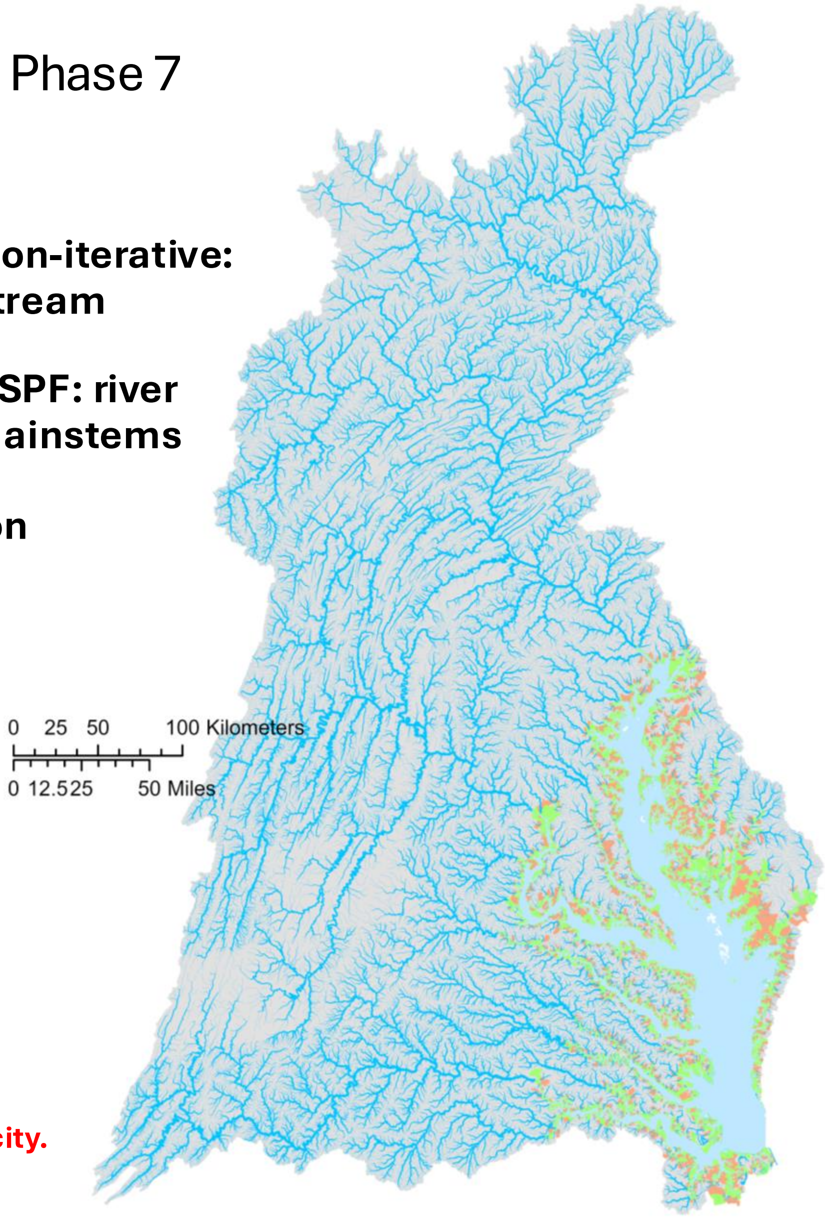
Tidal

no river simulation

Non-iterative: stream

HSPF: river mainstems

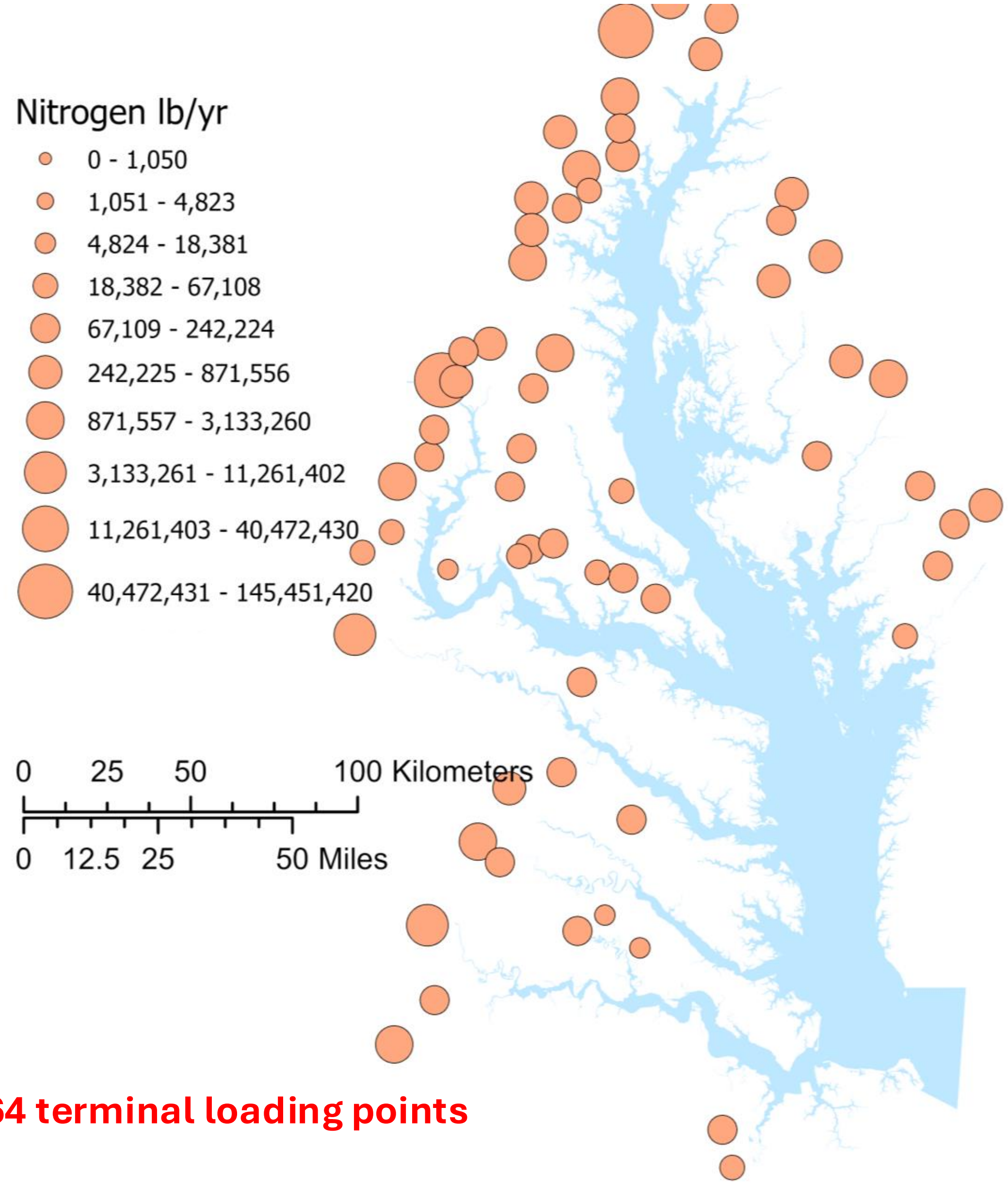
Phase 7



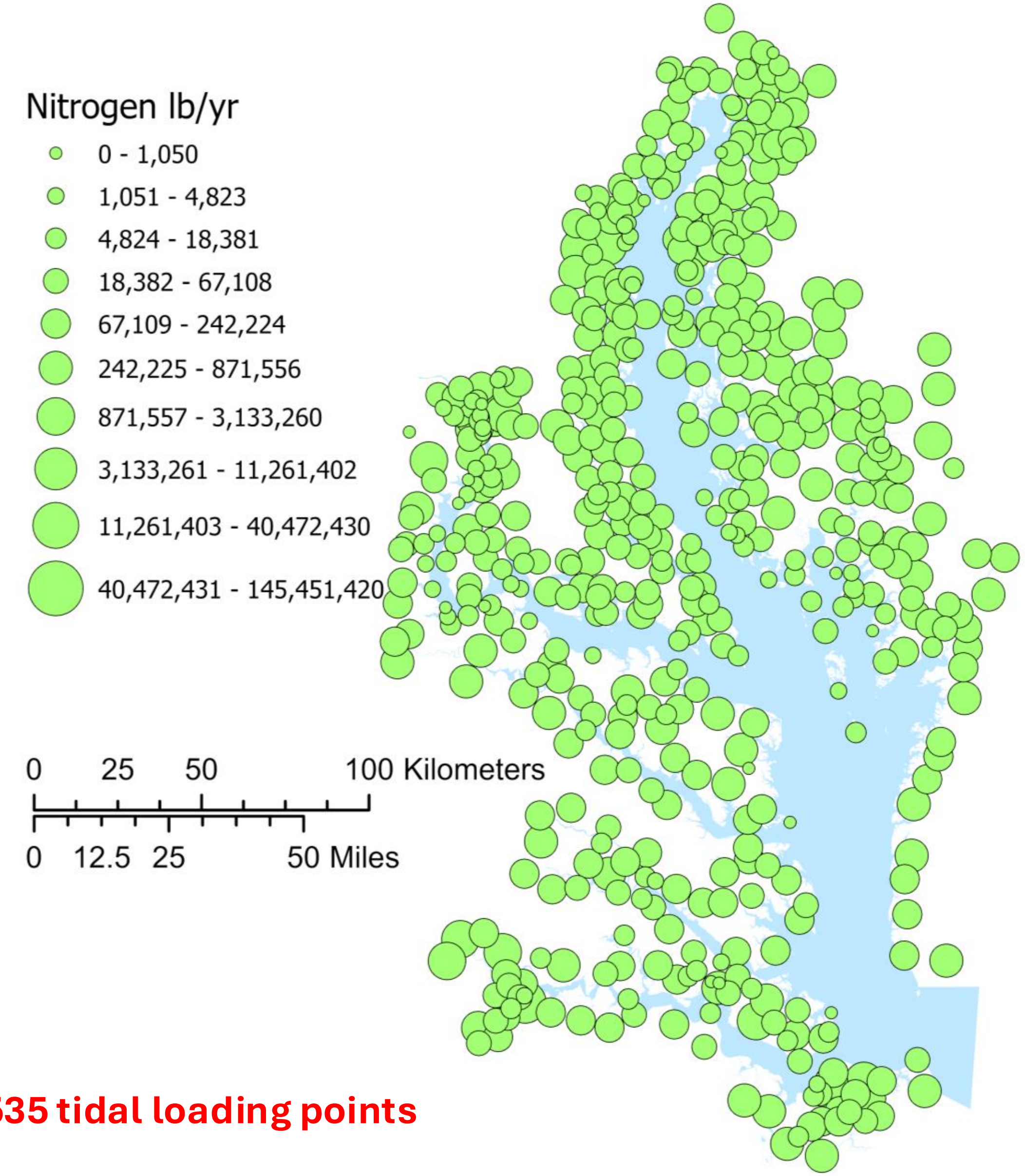
Notice change in the coverage of tidal areas with direct discharge to the Bay.

It translates to greater spatial specificity.

Phase 6: Terminal and Tidal loadings

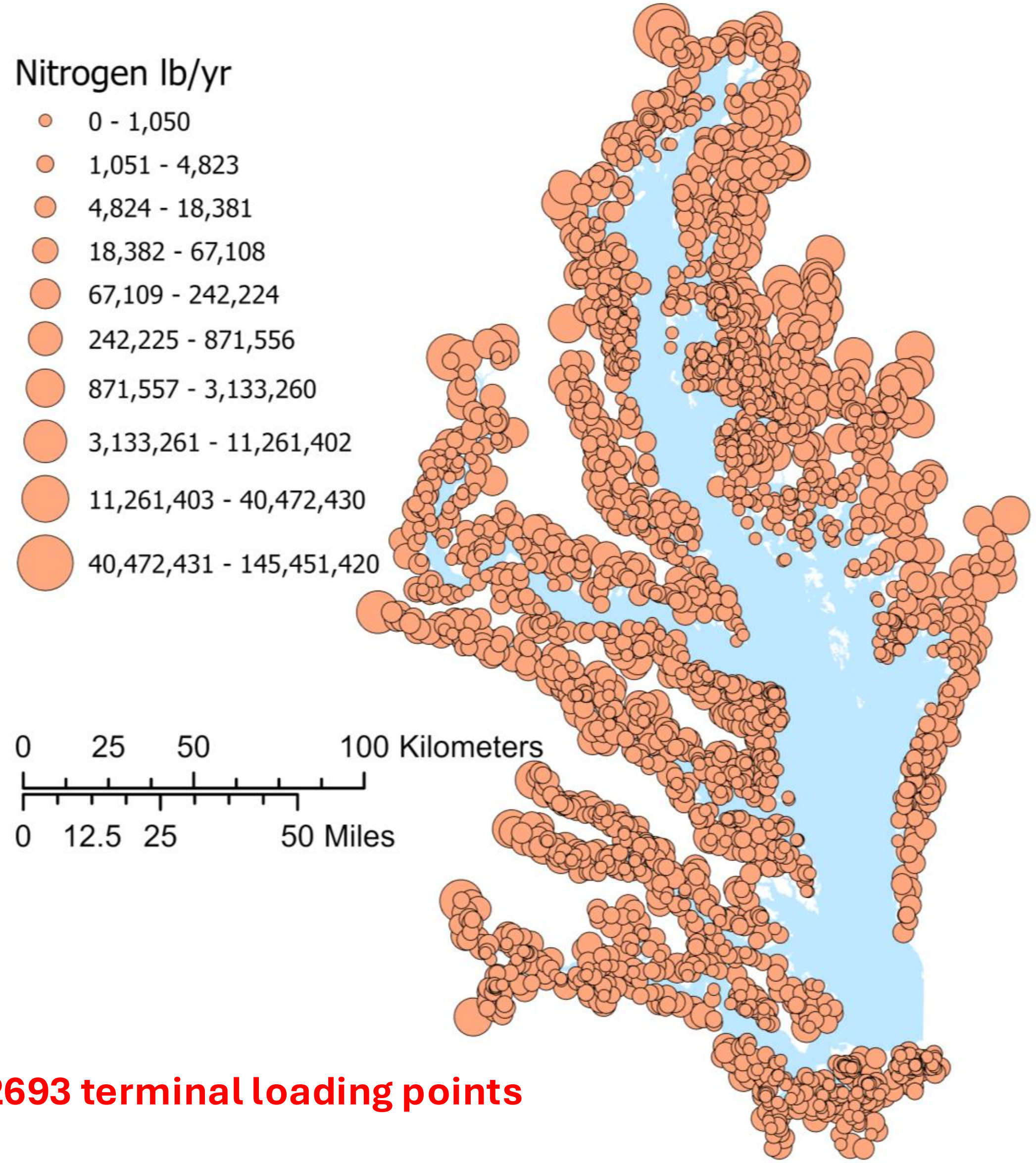


64 terminal loading points

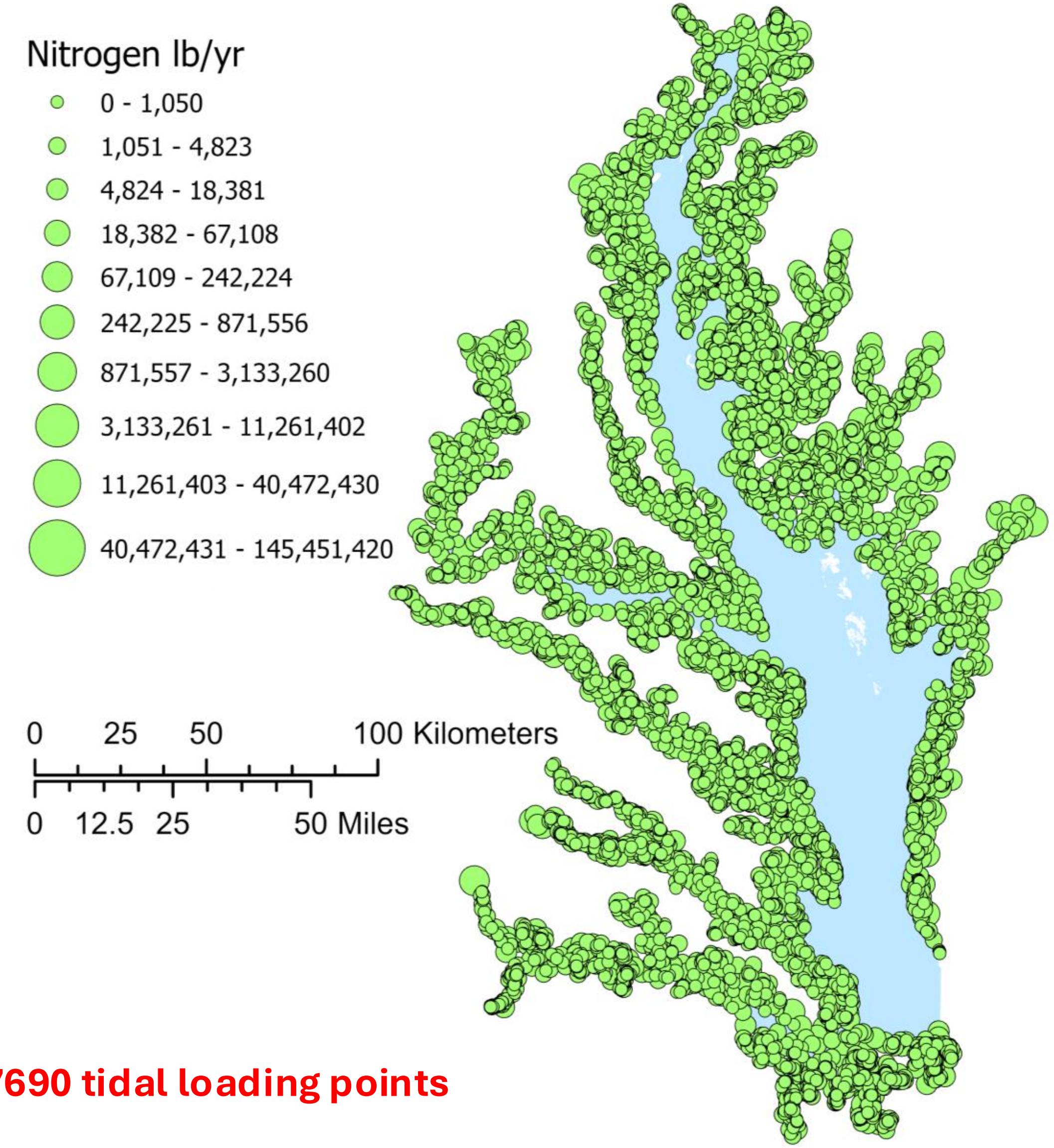


535 tidal loading points

Phase 7: Terminal and Tidal loadings



2693 terminal loading points

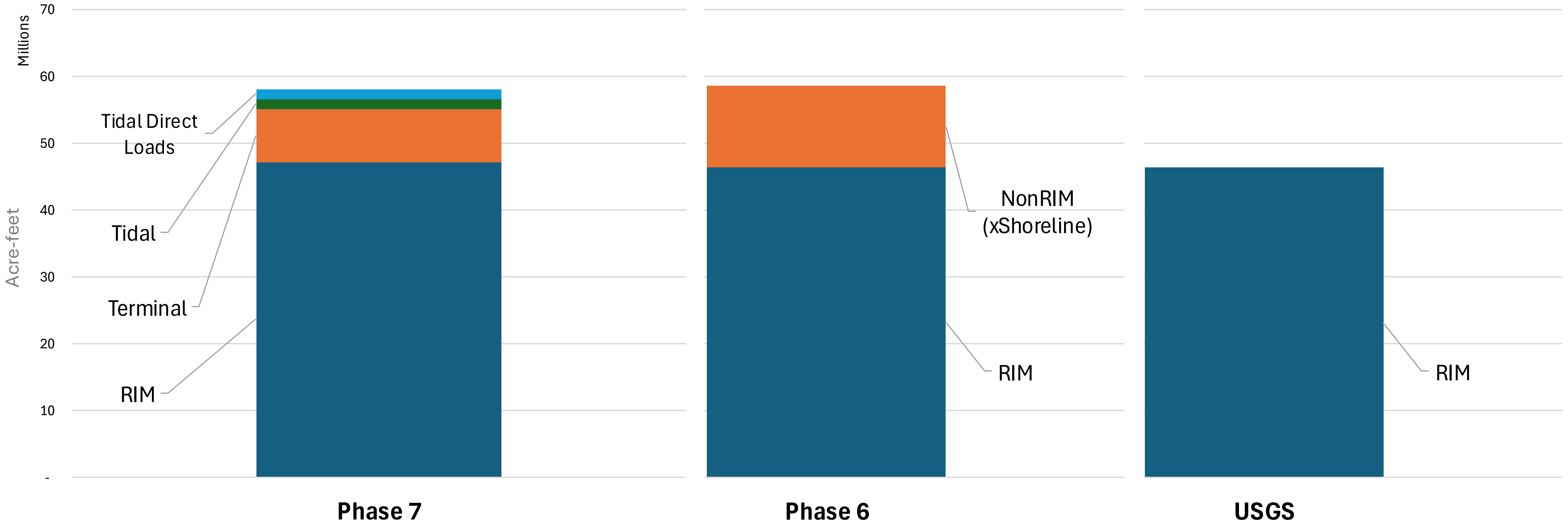


7690 tidal loading points

Summary of Average Annual Loads

- We examined Phase 7 (October 2024 version) as compared to Phase 6 and WRTDS

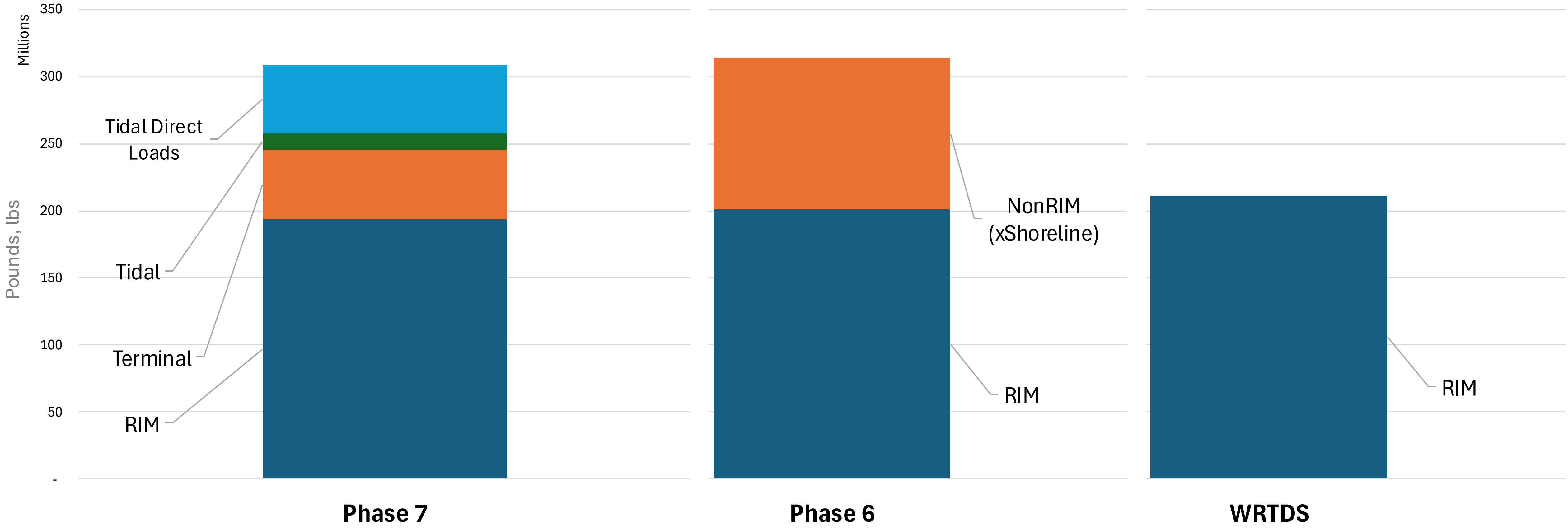
Freshwater Delivery from the Watershed



"Tidal Direct Loads" is currently not included in Phase 7 DWM

Δ total P7 vs. P6 = -1%

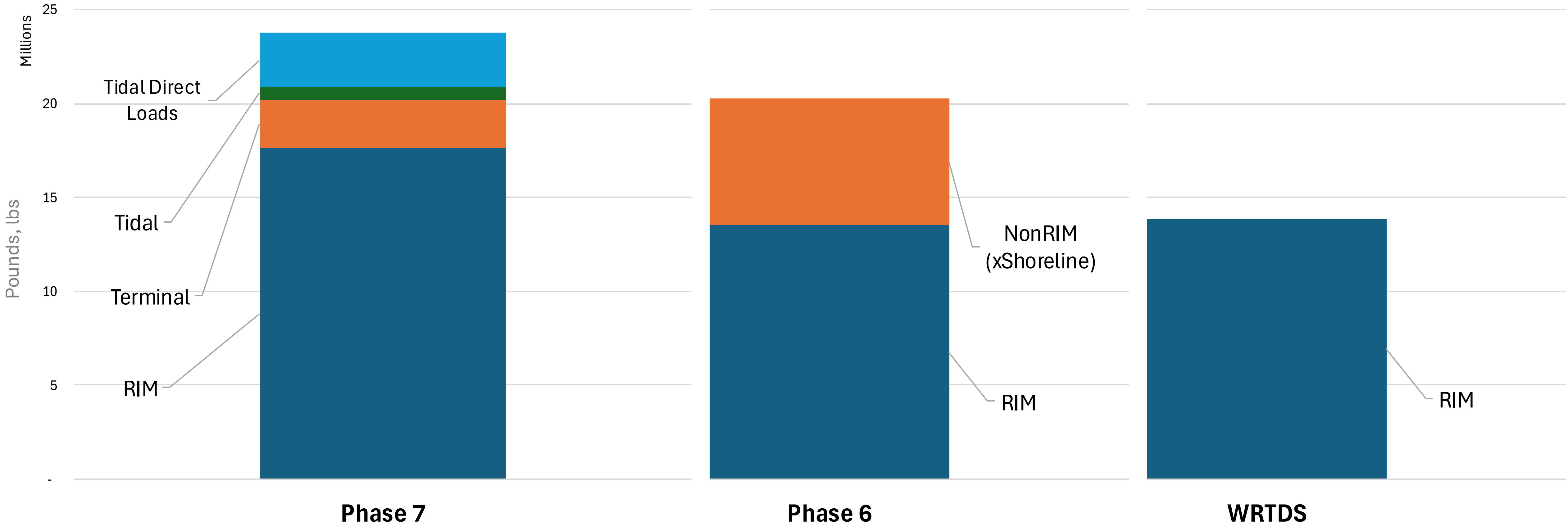
Total Nitrogen Delivery from the Watershed



"Tidal Direct Loads" is currently not included in Phase 7 DWM

Δ total P7 vs. P6 = -2%

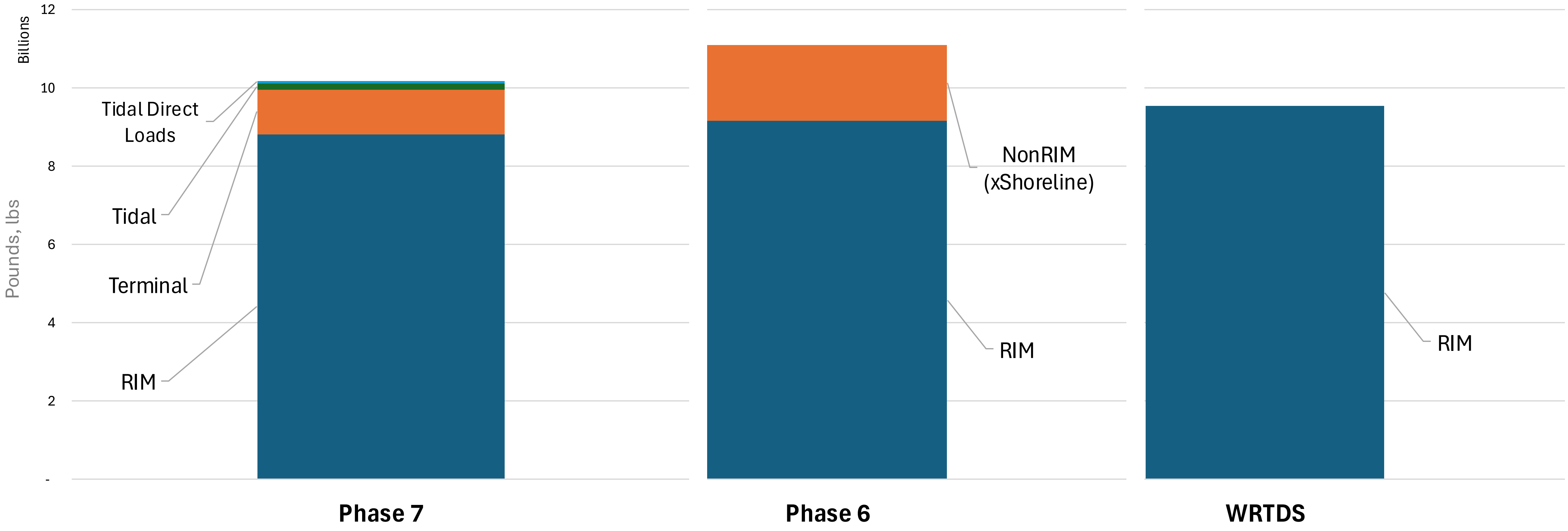
Total Phosphorus Delivery from the Watershed



"Tidal Direct Loads" is currently not included in Phase 7 DWM

Δ total P7 vs. P6 = +17%

Sediment Delivery from the Watershed



"Tidal Direct Loads" is currently not included in Phase 7 DWM

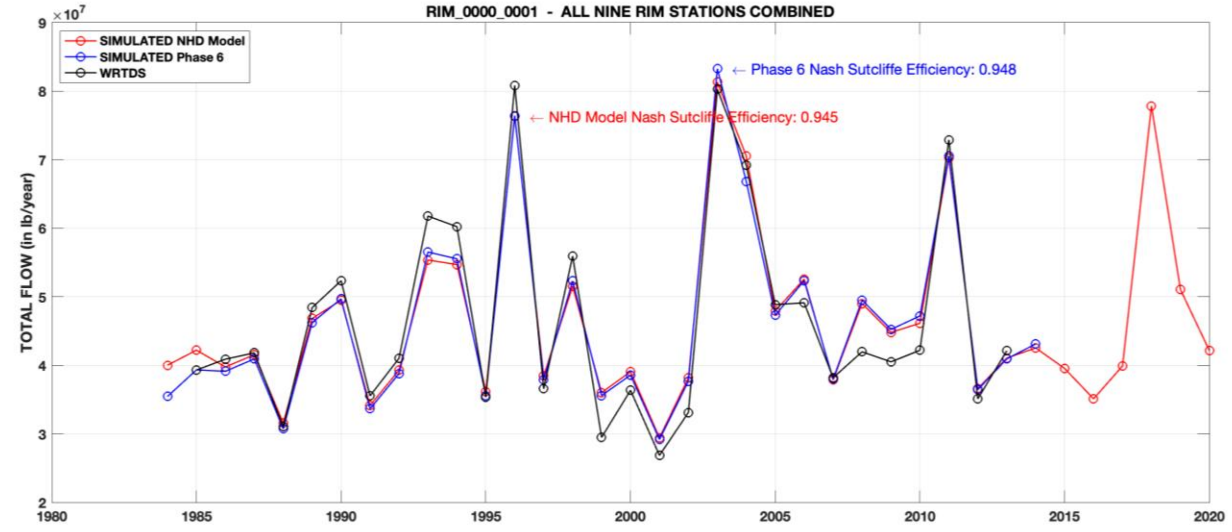
Δ total P7 vs. P6 = -8%

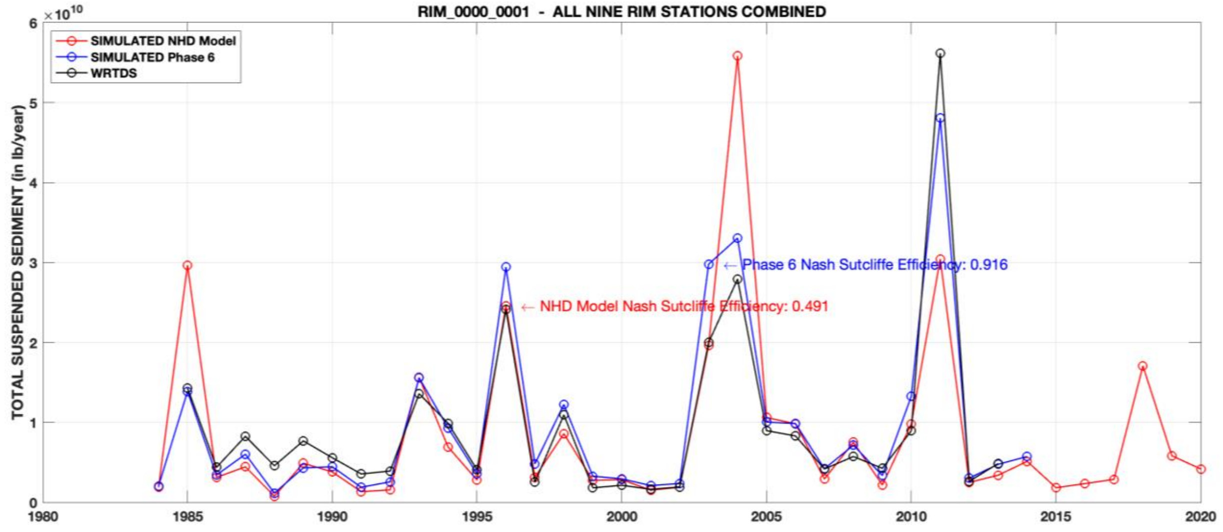
Phase 7 (October 2024) RIM stations loads vs. WRTDS

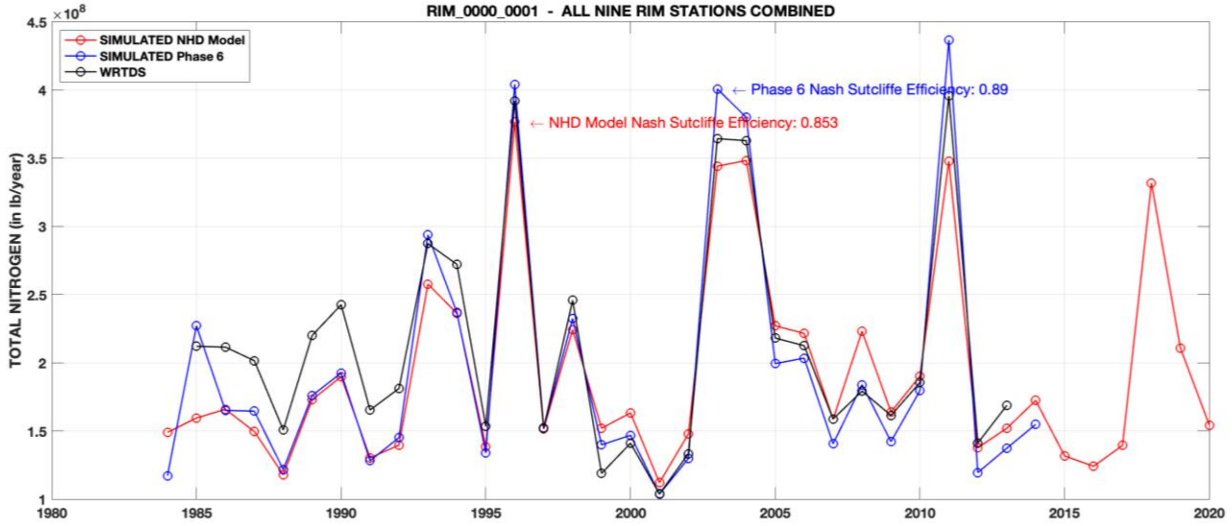
(a) biases in 1985-2014 average loads as compared to WRTDS; (b) NSE of annual loads in parentheses;

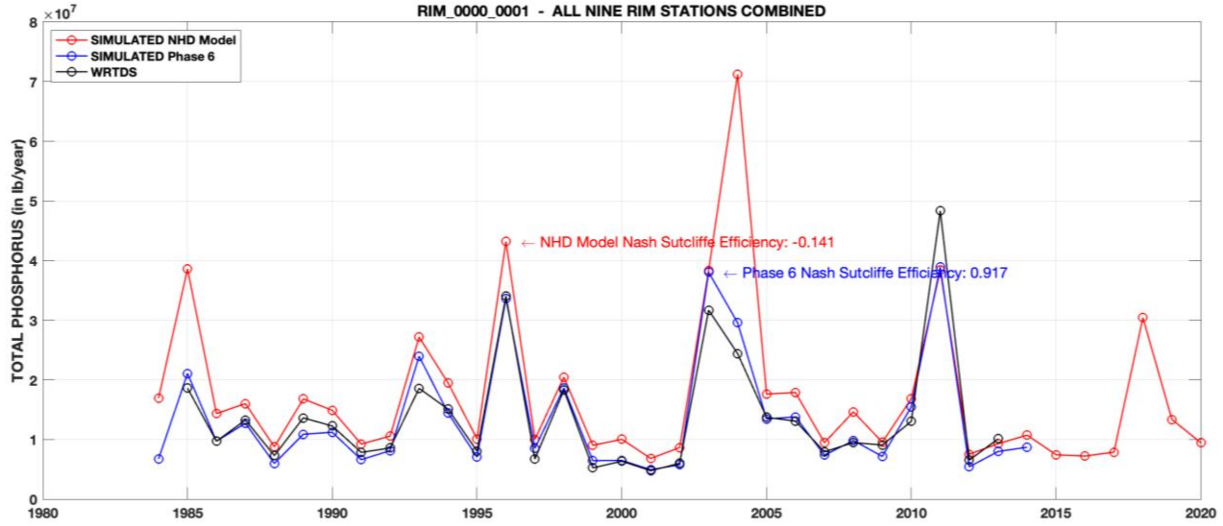
Rivers	Flow	Nitrogen	Phosphorus	Sediment
Susquehanna Conowingo MD	+00.0% (+0.946)	+05.1% (+0.773)	+68.1% (-0.954)	+18.1% (+0.452)
Susquehanna Marietta PA	-01.2% (+0.938)	+04.2% (+0.641)	+26.3% (-0.529)	+02.8% (-0.129)
Potomac Washington, DC	+00.3% (+0.885)	-35.2% (+0.228)	+24.3% (+0.262)	-08.5% (-0.461)
James Cartersville, VA	+03.7% (+0.891)	-39.1% (+0.219)	-06.2% (+0.800)	-36.0% (+0.625)
Rappa. Fredericksburg, VA	-01.3% (+0.903)	-19.0% (+0.673)	-13.8% (-2.679)	-41.9% (-0.737)
Appomattox Matoaca, VA	00.0% (+0.903)	-18.2% (+0.743)	-01.1% (+0.555)	-32.9% (+0.526)
Pamunkey Hanover, VA	+03.6% (+0.815)	-14.1% (+0.684)	-09.4% (+0.020)	-44.2% (+0.229)
Mattaponi Beulahville, VA	+11.0% (+0.714)	+61.6% (-2.501)	+01.8% (+0.272)	+101.7% (-10.449)
Patuxent Bowie, MD	+03.8% (+0.857)	+06.8% (+0.821)	-04.8% (+0.641)	+26.9% (+0.496)
Choptank Greensboro, MD	-05.4% (+0.730)	+103.2% (-6.738)	+11.0% (+0.562)	-19.3% (+0.106)

All 9 RIM Stations Combined

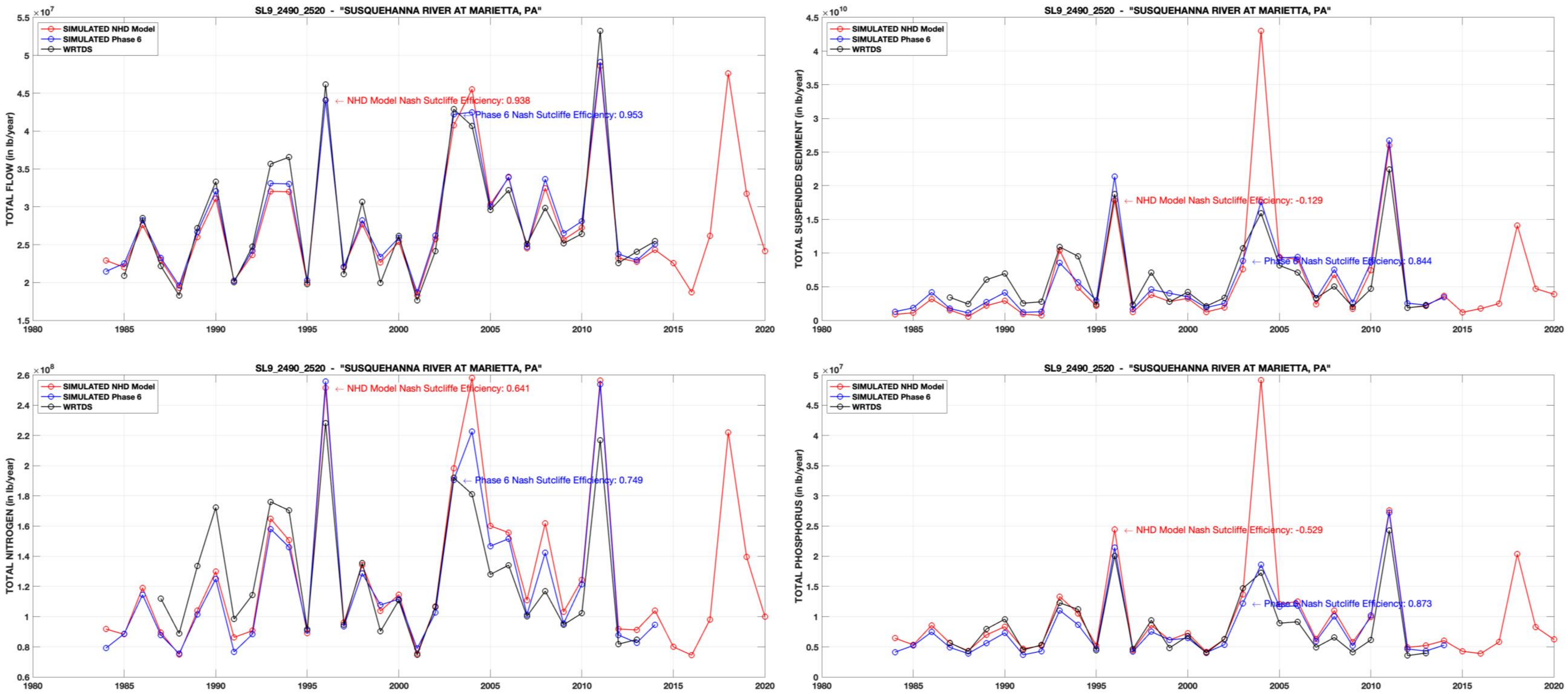




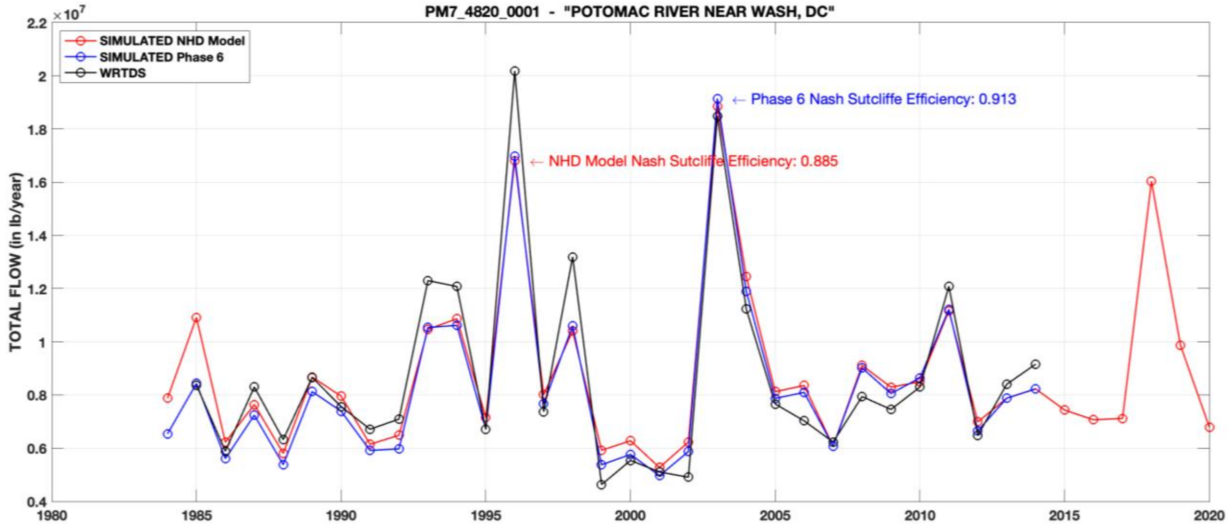


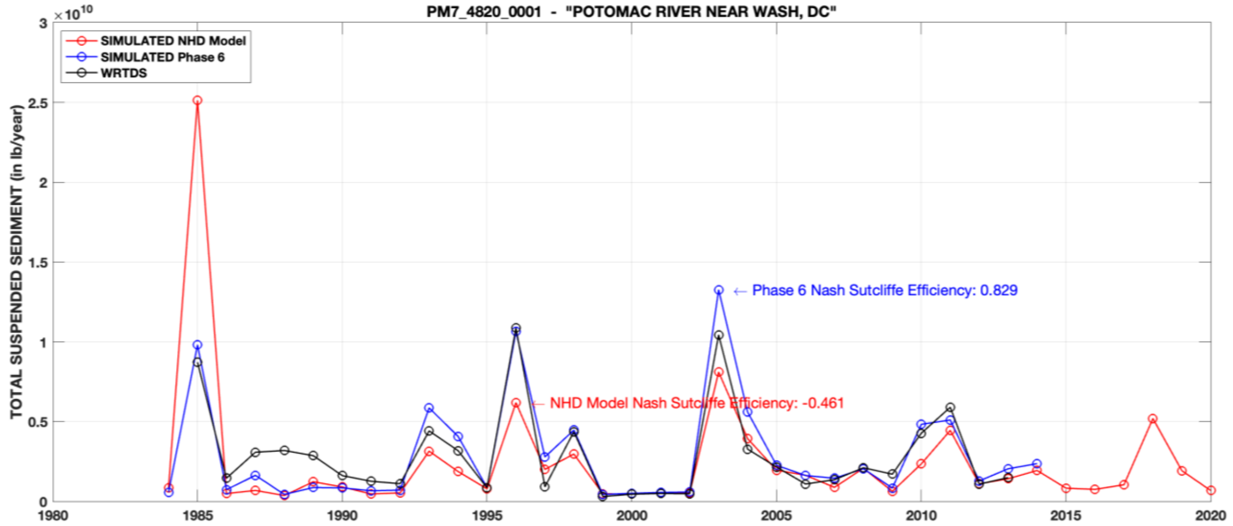


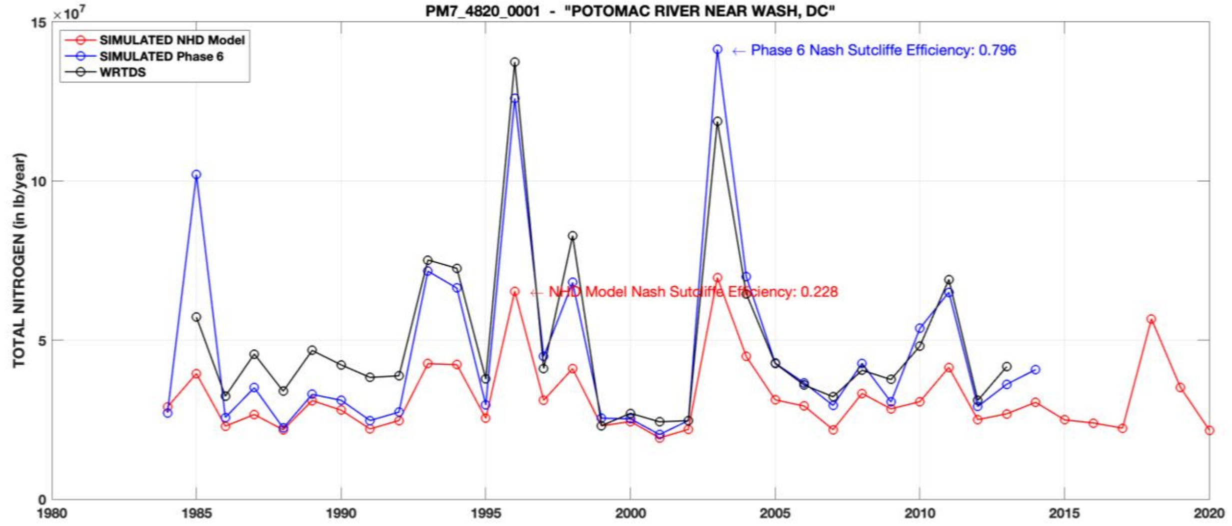
Susquehanna River at Marietta, PA

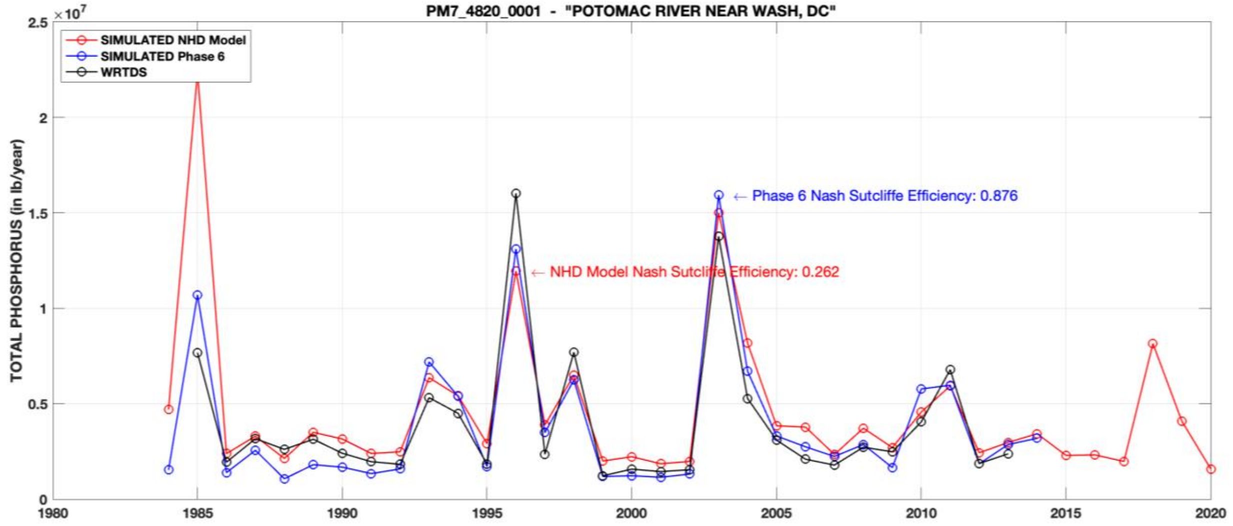


Potomac River at Washington, DC

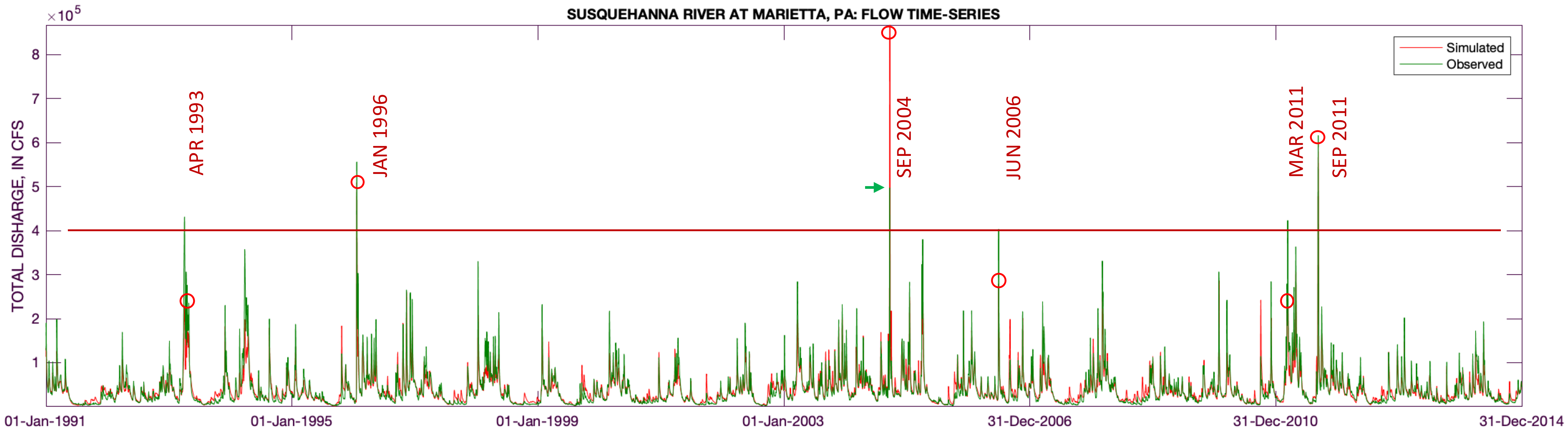




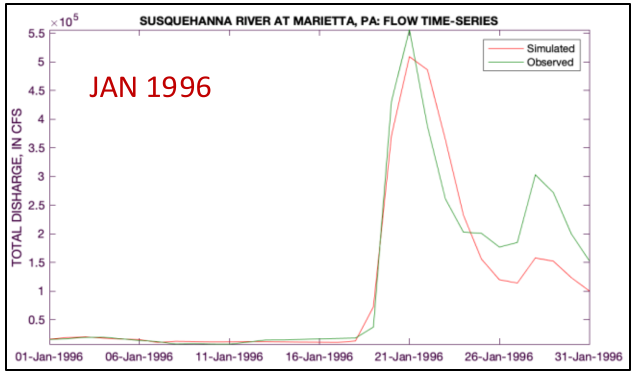


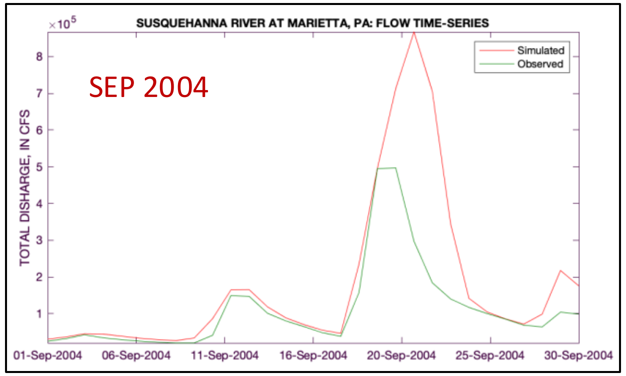


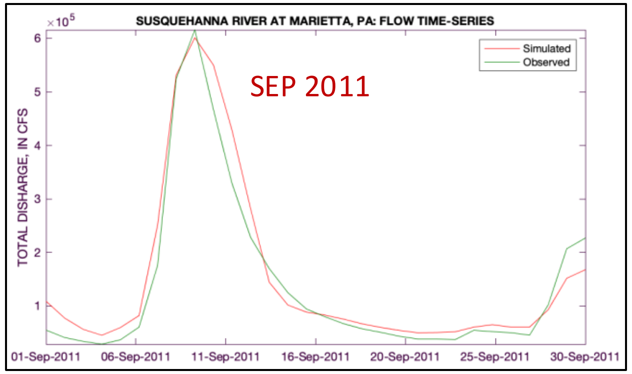
Susquehanna River at Marietta, PA



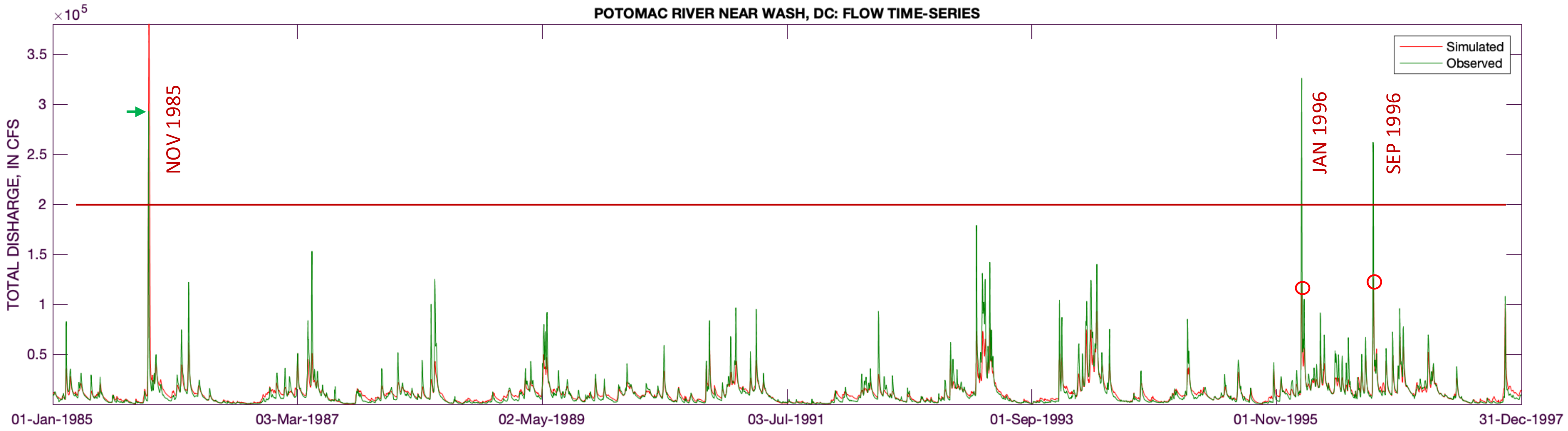
There were 6 events when flow exceeded 400,000 cfs and most of them were under simulated, except for 2004

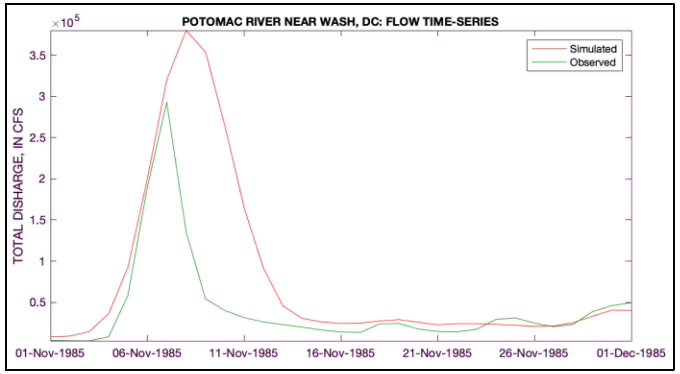






Potomac River near Washington, DC

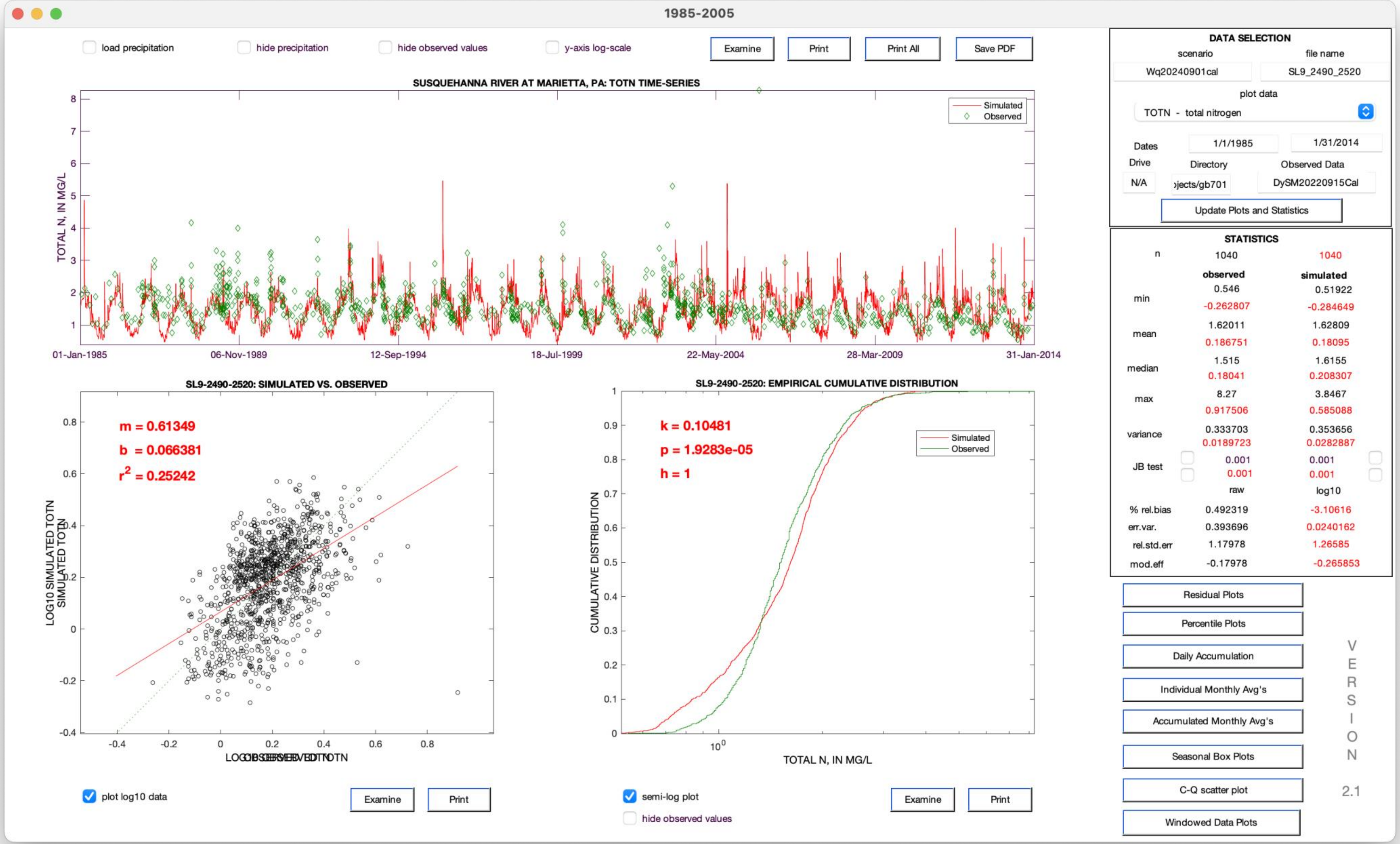




There were 3 events when flow exceeded 200,000 cfs and two in 1996 were under simulated, but one in Nov 1985 is over simulated with flow exceeding 200,000 on 3 consecutive days rather than ~1

Susquehanna at Marietta, PA

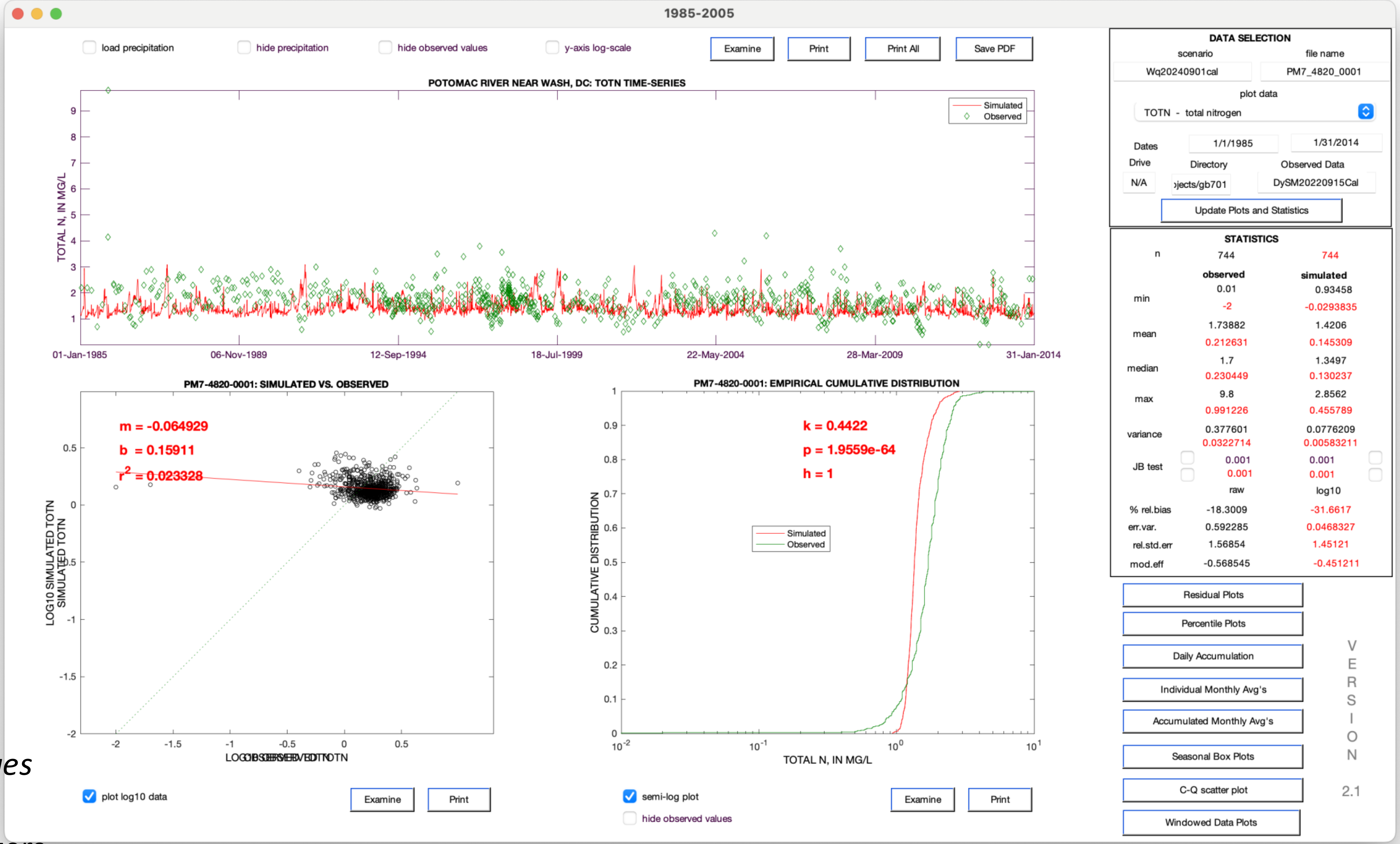
Nitrogen



Δ = +04.2%

Potomac near Washington, DC

Nitrogen



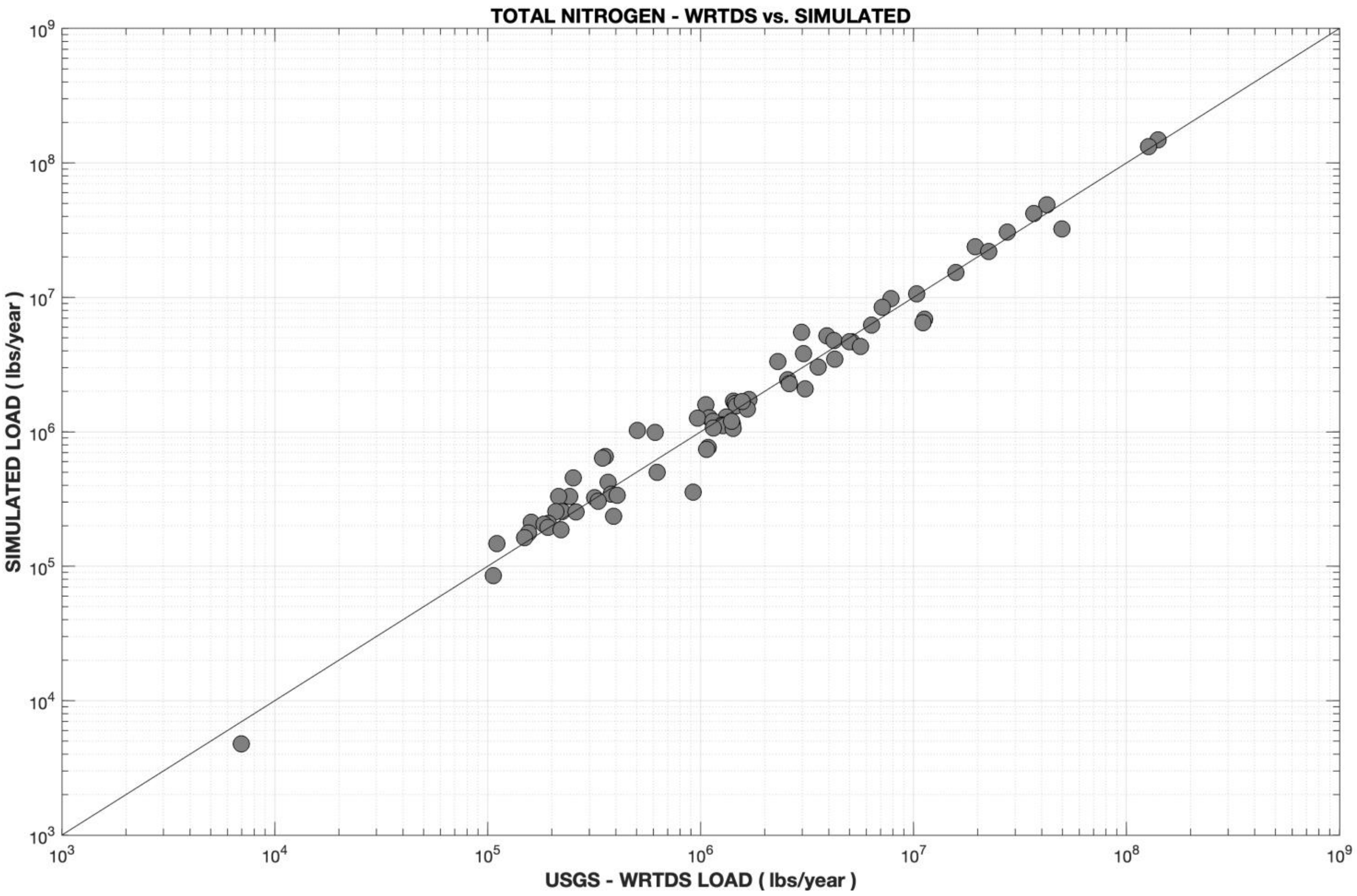
potential issues

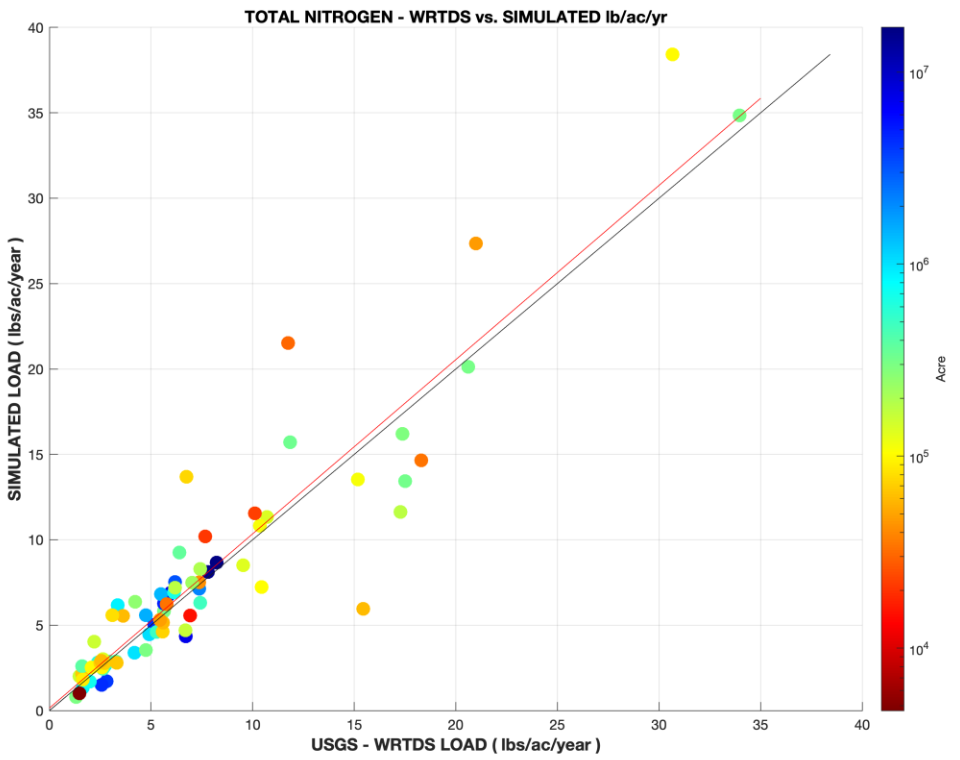
Δ = -35.2%

Beta parameters

Other stations – Simulated vs. WRTDS average loads

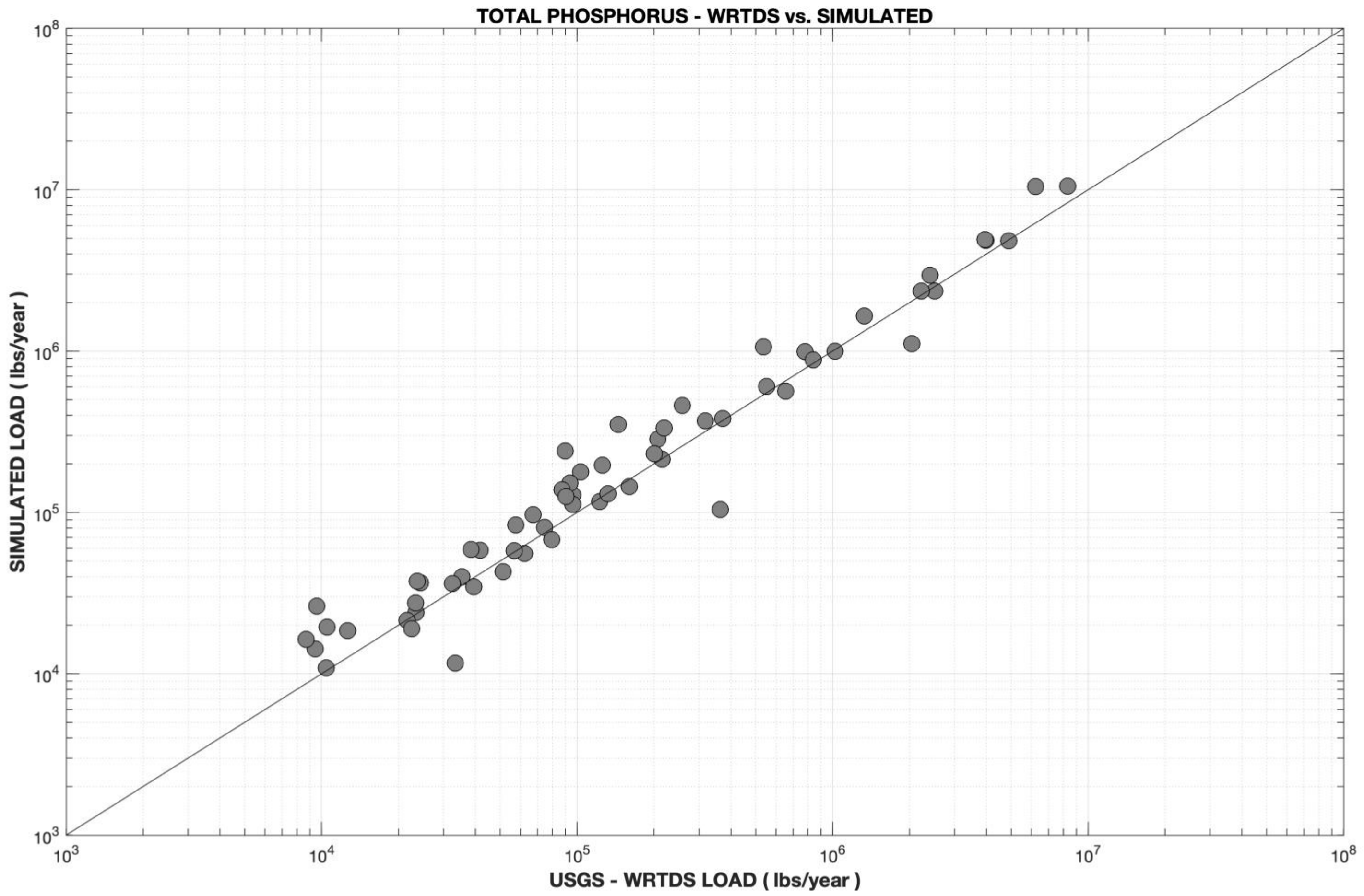
Total Nitrogen

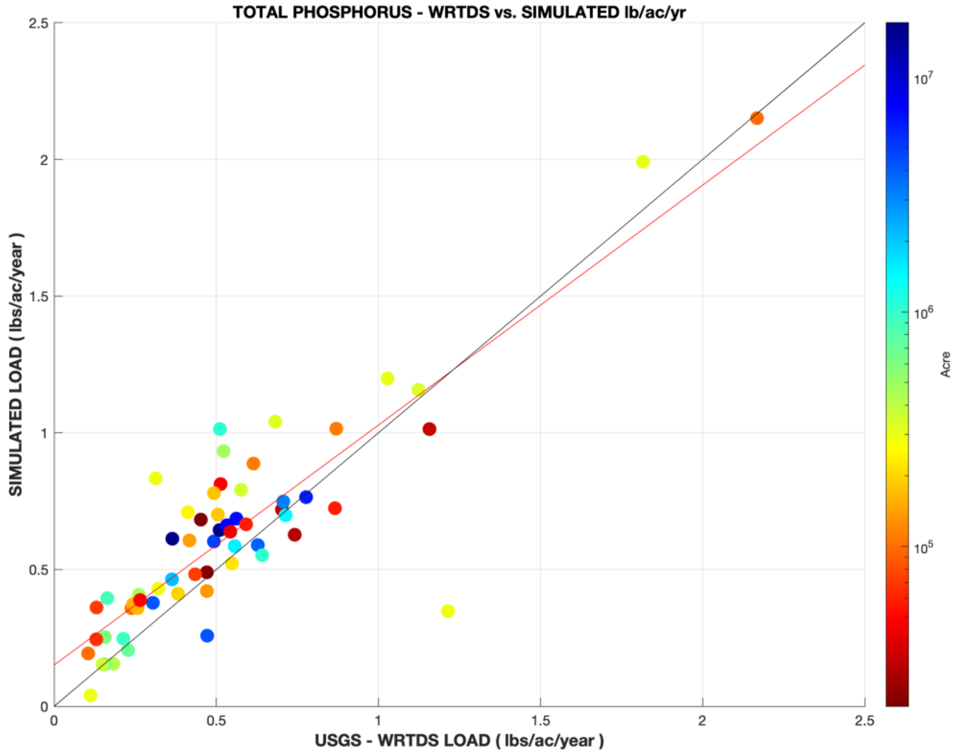




Other stations – Simulated vs. WRTDS average loads

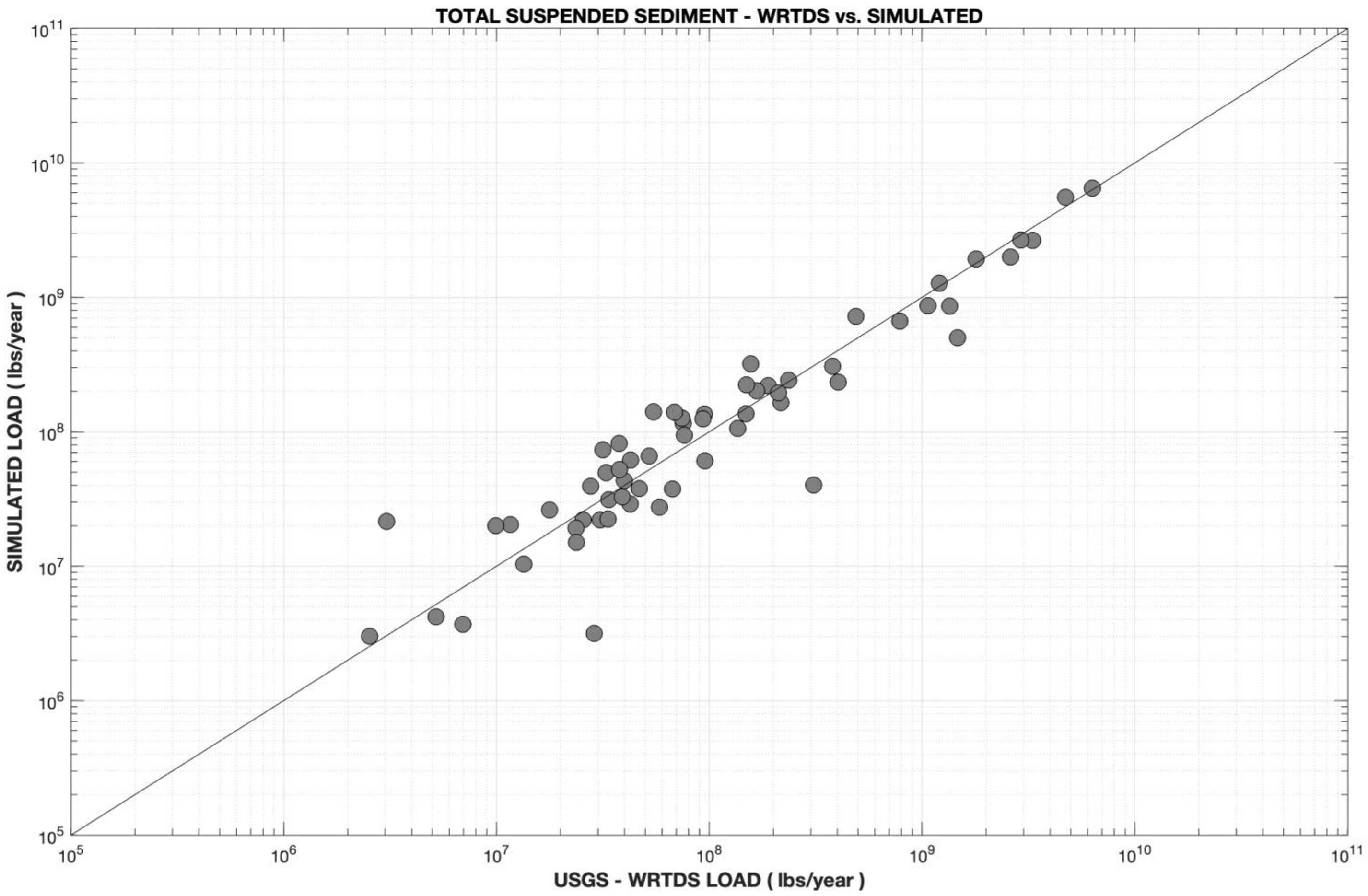
Total Phosphorus

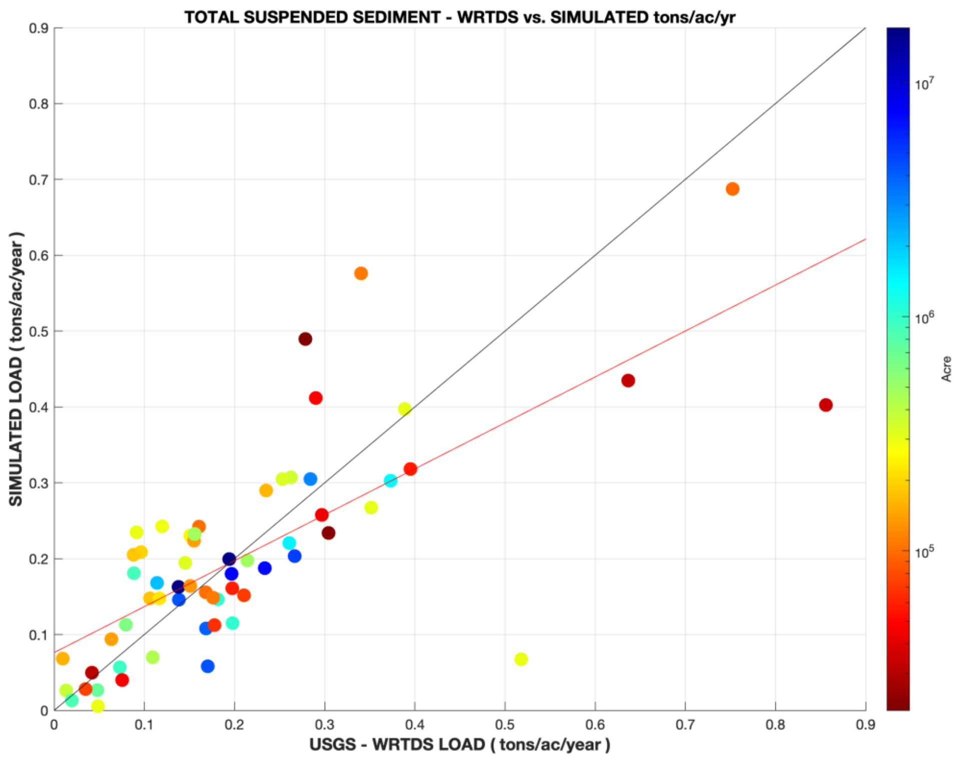




Other stations – Simulated vs. WRTDS average loads

Suspended Sediment





Summary

1. Our model calibration of flow, nutrients, and sediment maybe reasonable for linking watershed model flows and loads with the estuarine model given the stage of our models and inputs.

- we expect to perform a few additional fine tunings
- and collaborate with the MBM team on model linkages

>> Next Steps for the Phase 7 Dynamic Watershed Model (DWM)

2. We need to incrementally improve the model on multiple fronts: (a) incorporation of new inputs where appropriate; (b) model parameters; (c) calibration methods and processes.

>> Next Steps for the Phase 7 Dynamic Watershed Model (DWM)

1. Inputs:

- Direct loads – change point sources, diversions/withdrawals, and septic from P6 river segment scale to NHD (missing tidal direct loads); add flow with septic (load sensitivity to future climate); treatment of withdrawals in small stream modules and tidal areas with direct discharge to the Bay;▪ Effect of best management practices; ▪ Replace use of 12 landcover classes fixed in time (inputs do change over time); ▪ Water quality monitoring data and WRTDS (WRTDS-K);

2. Model parameters:

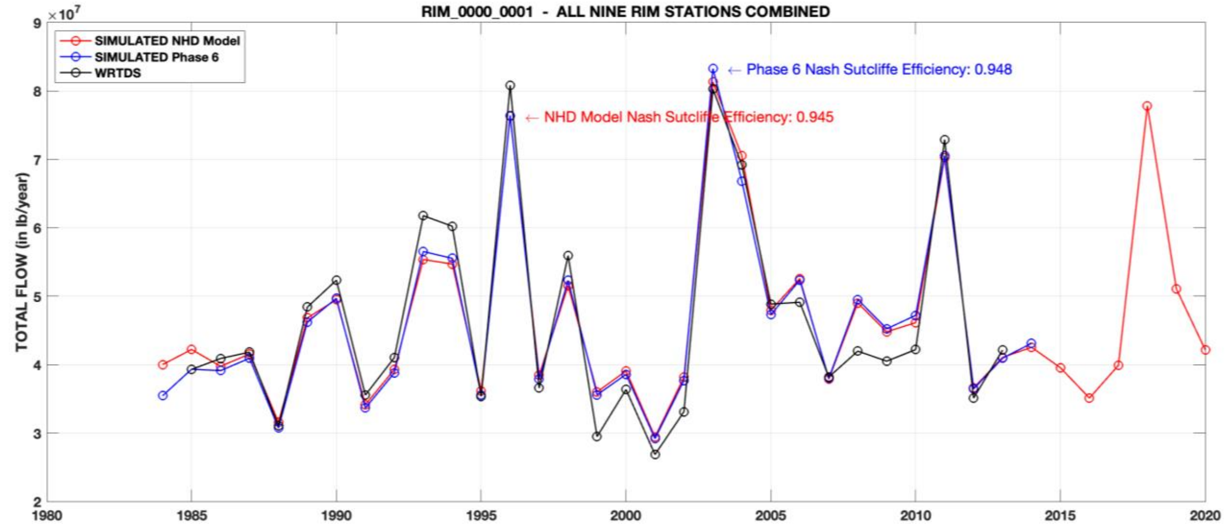
- Beta parameters for flow and seasonal variability; transfer of loading trends from land to stream routing modules; CalCAST parameters;

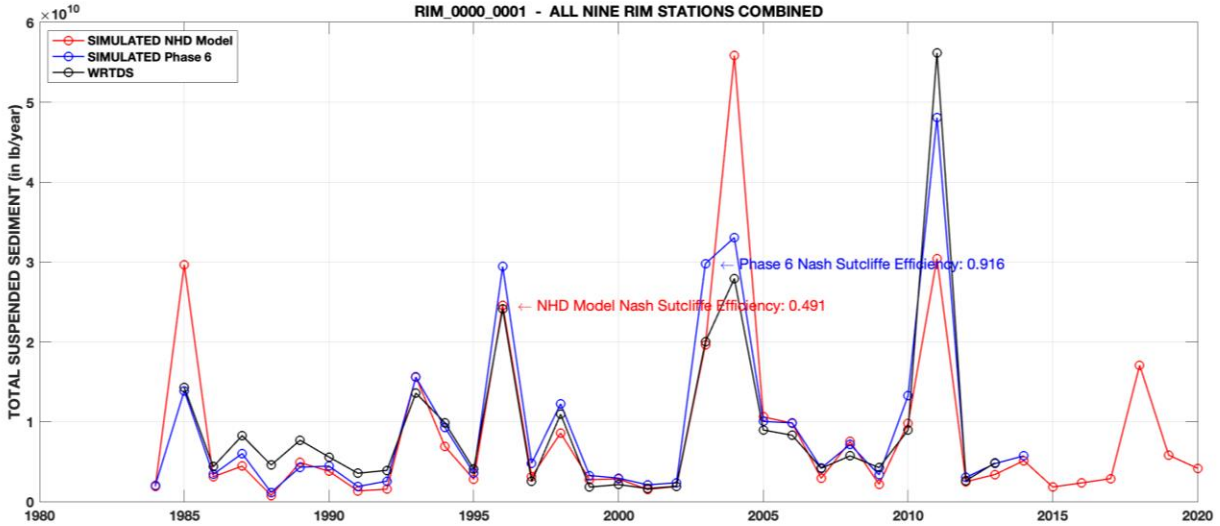
3. Calibration:

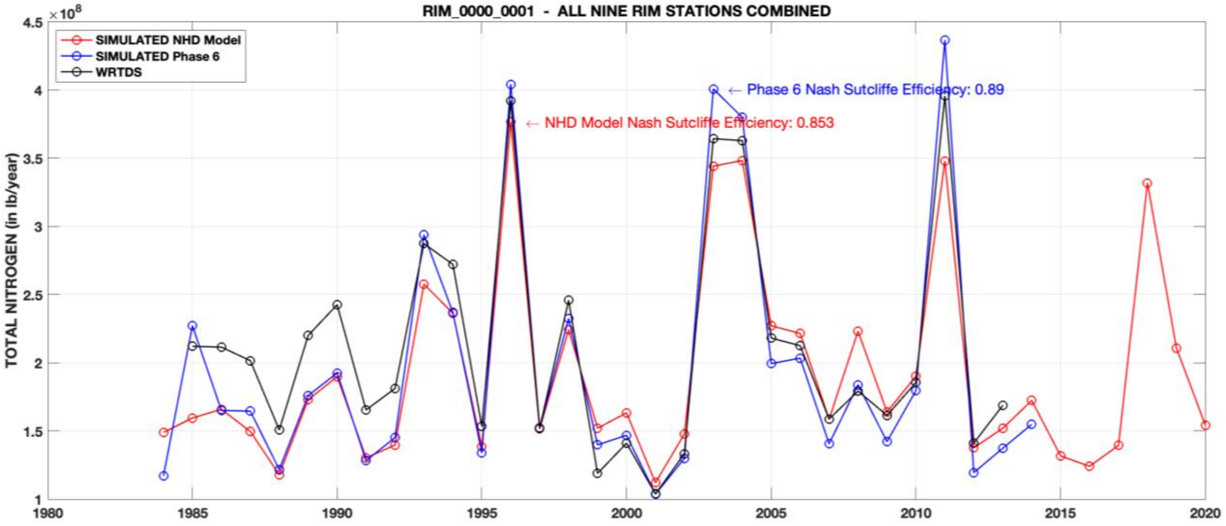
- Calibration methods and watershed processes (e.g., hydrologic simulation anomalies; Conowingo infill; module for source of organic nutrients);

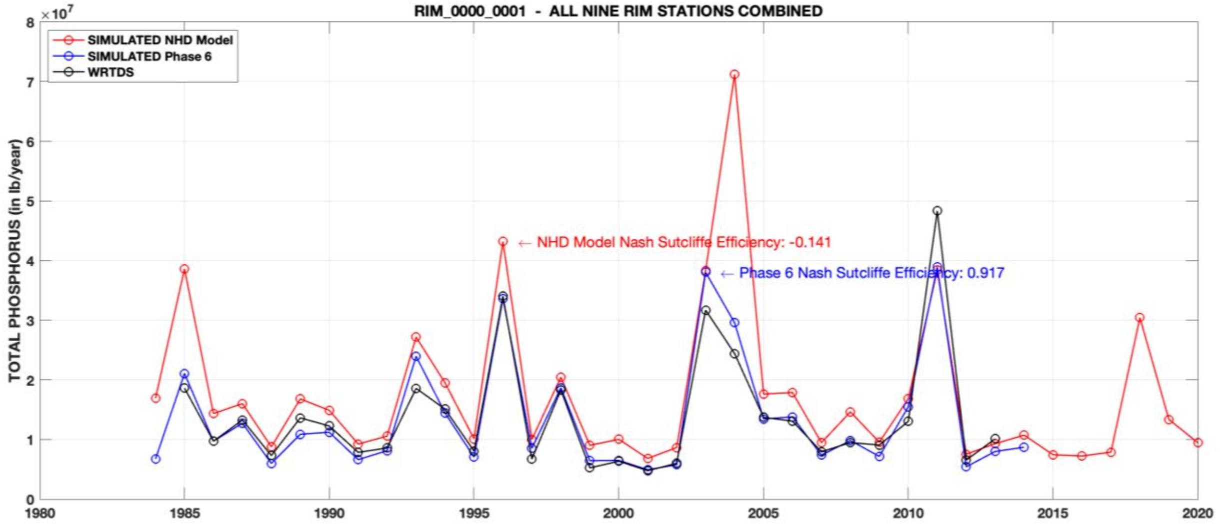
Appendices

All 9 RIM Stations Combined

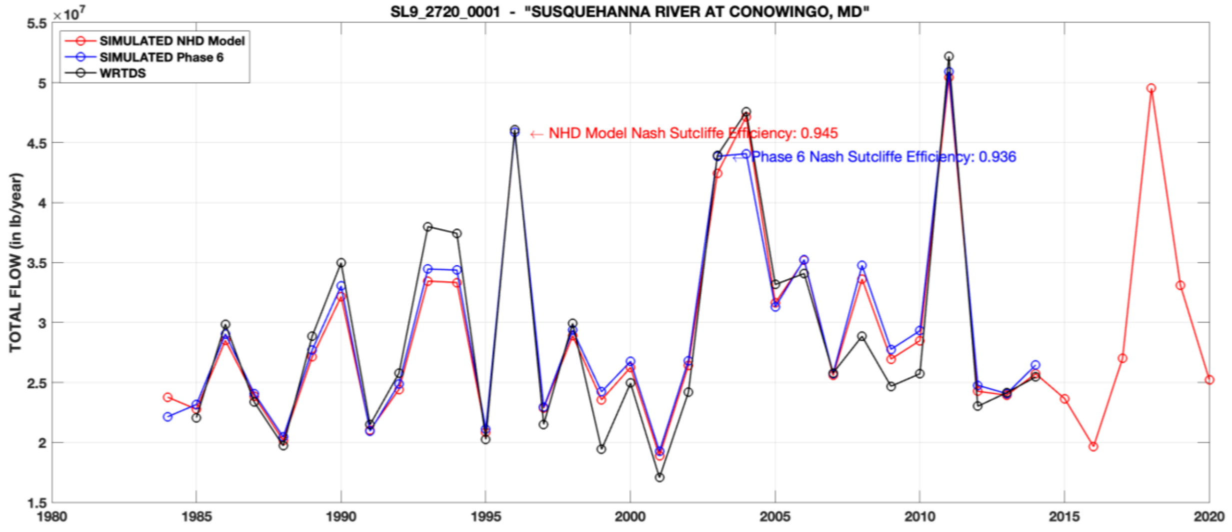


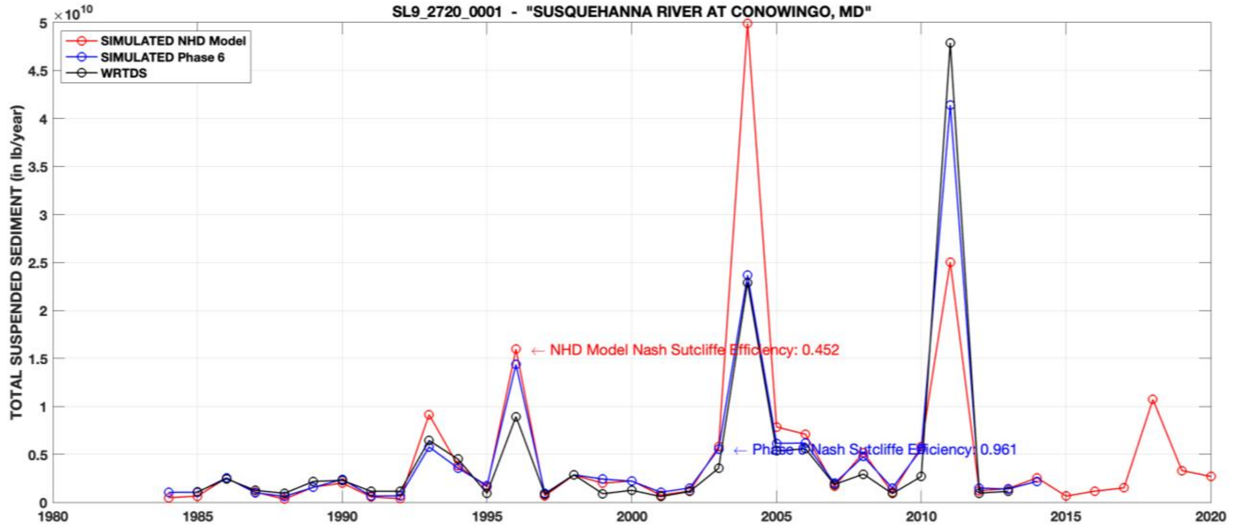


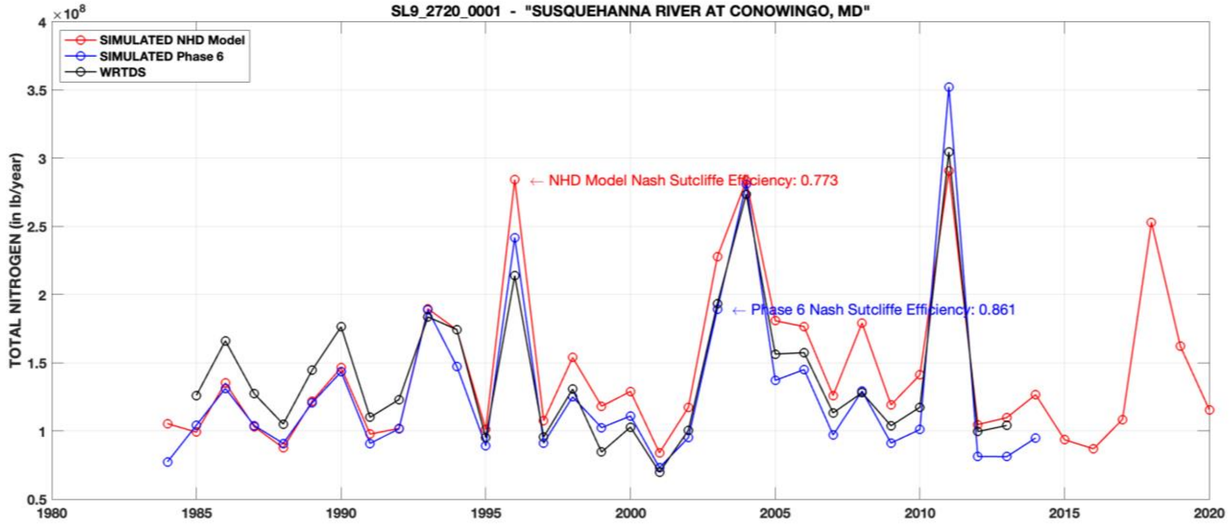


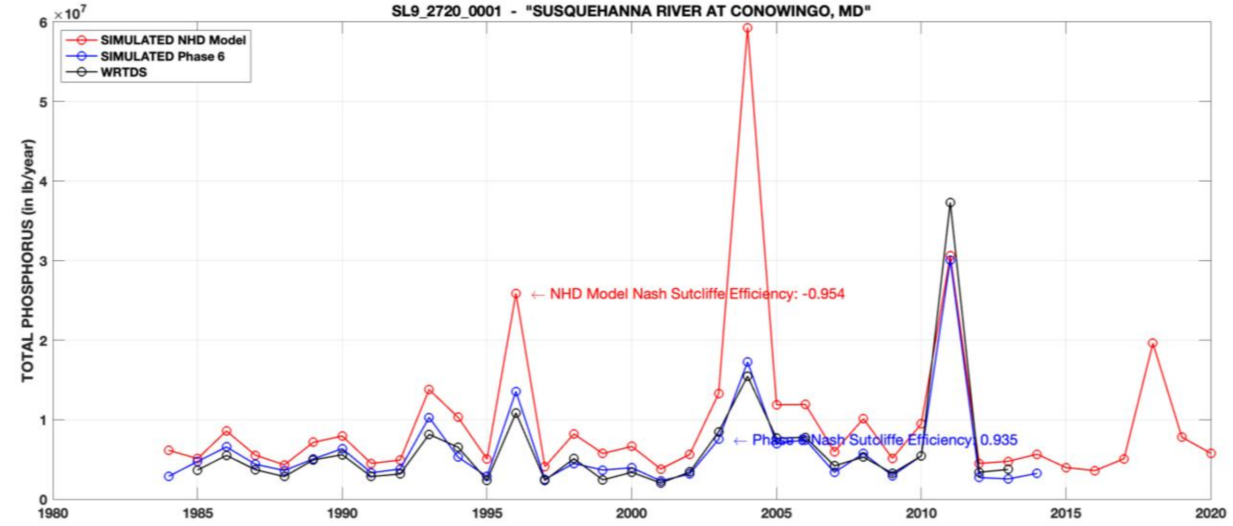


Susquehanna River at Conowingo, MD

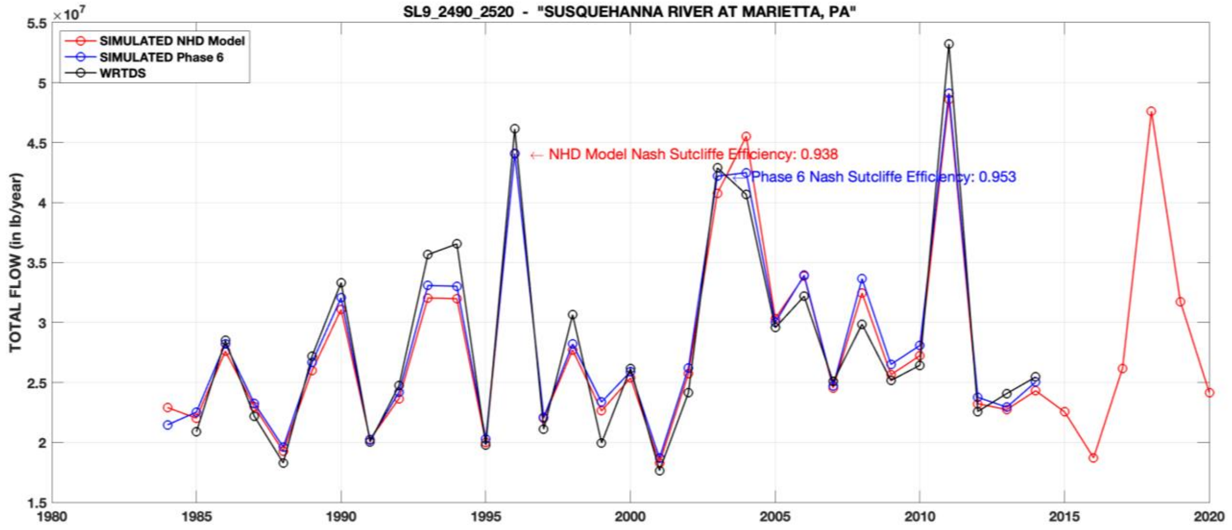


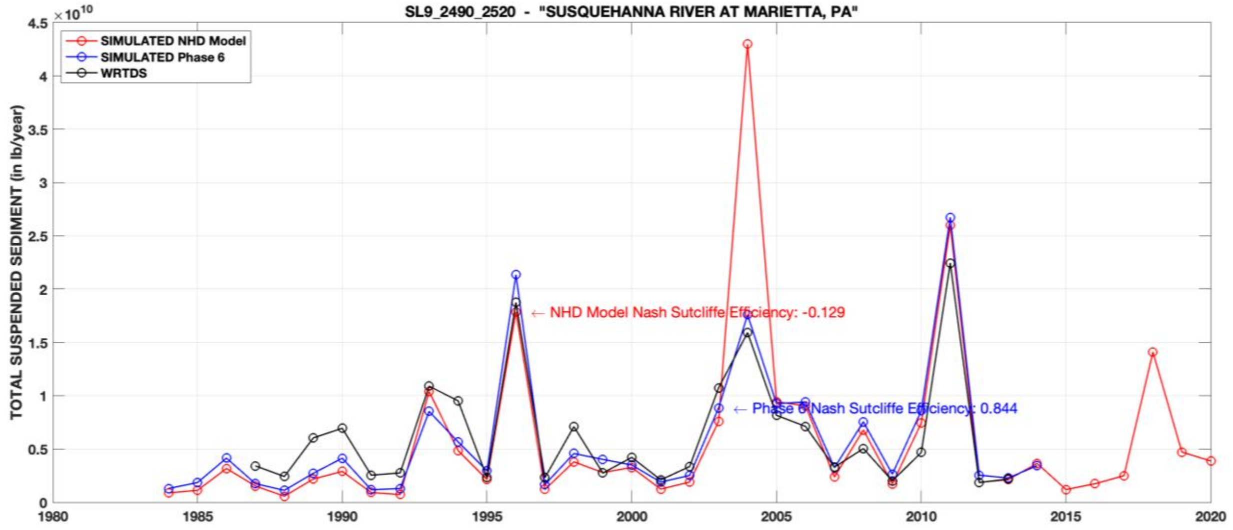


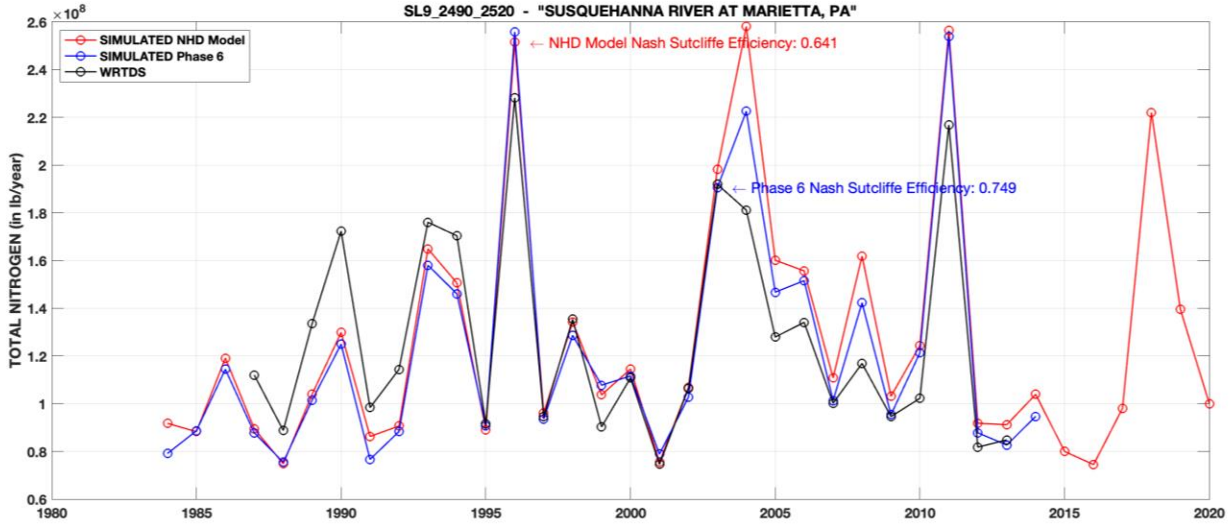


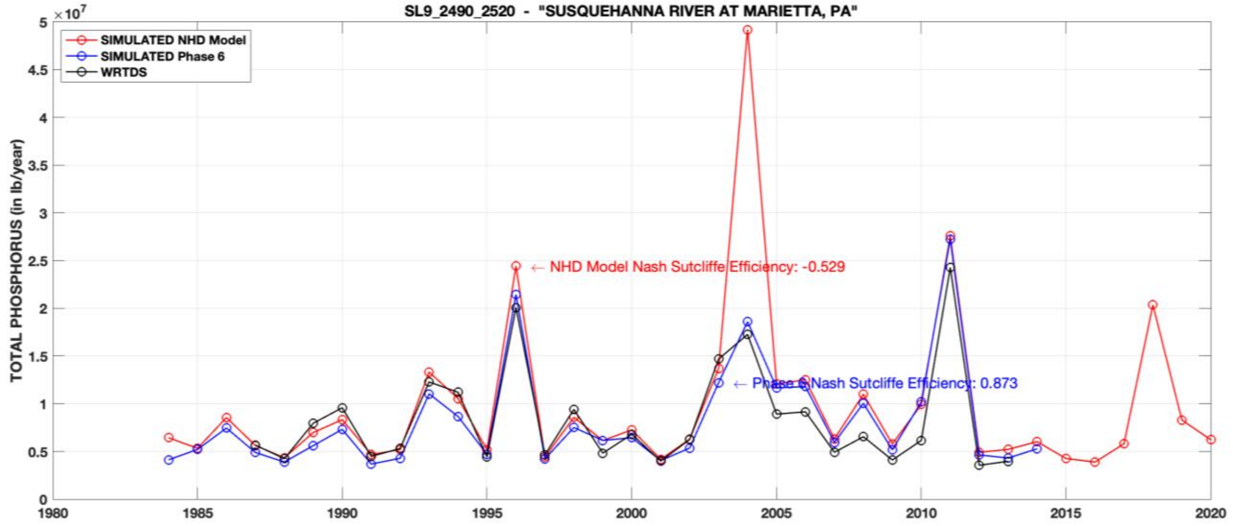


Susquehanna River at Marietta, PA

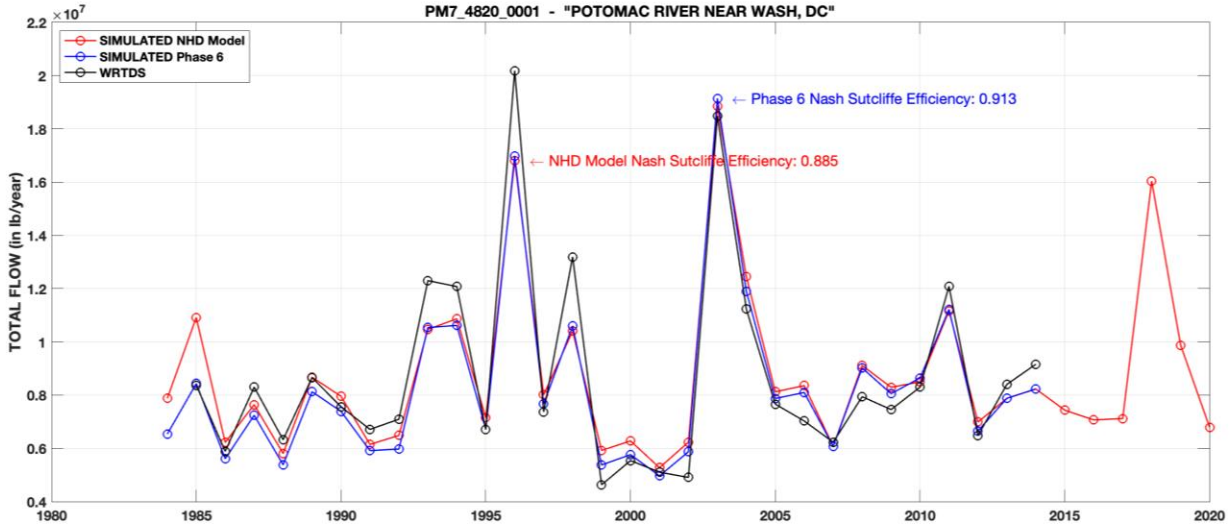


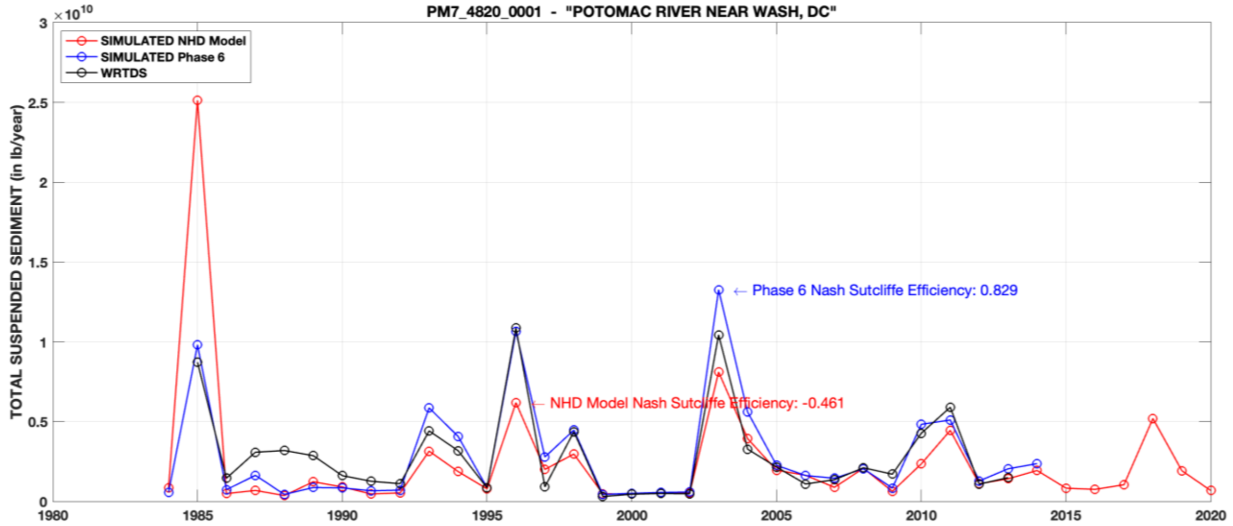


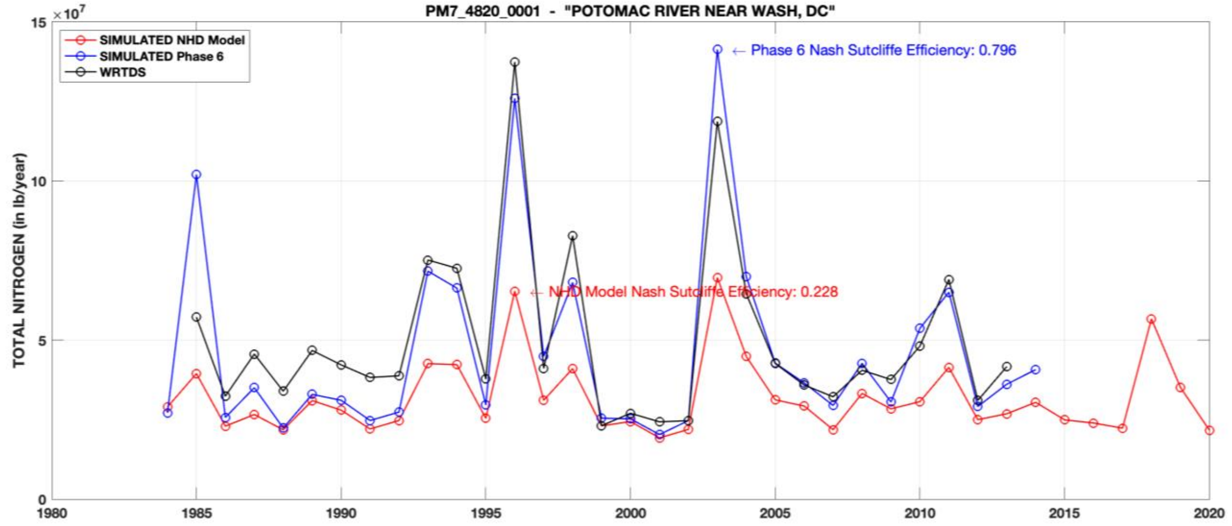


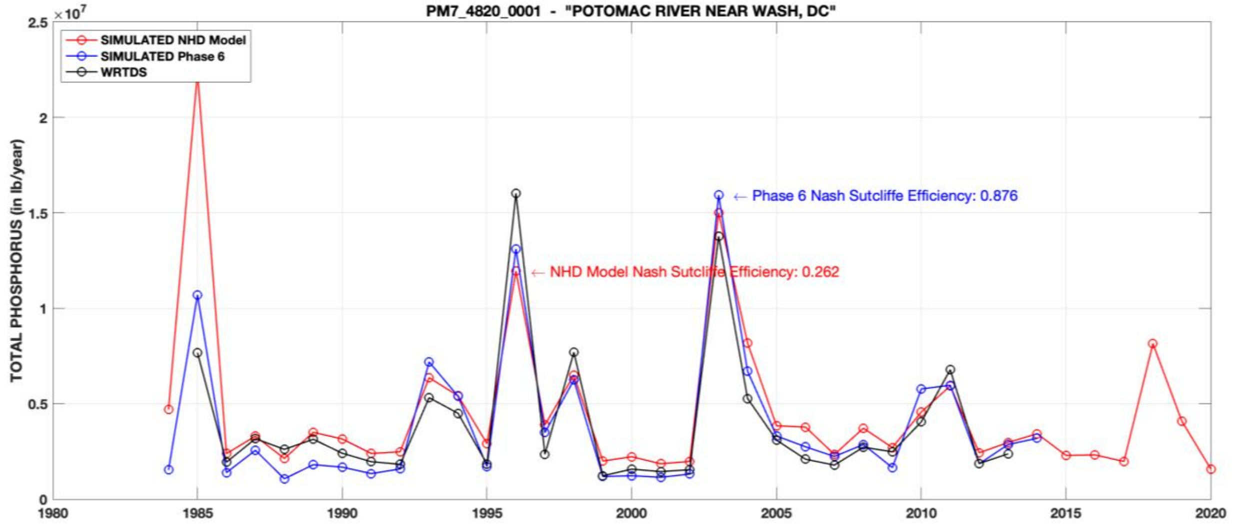


Potomac River at Washington, DC

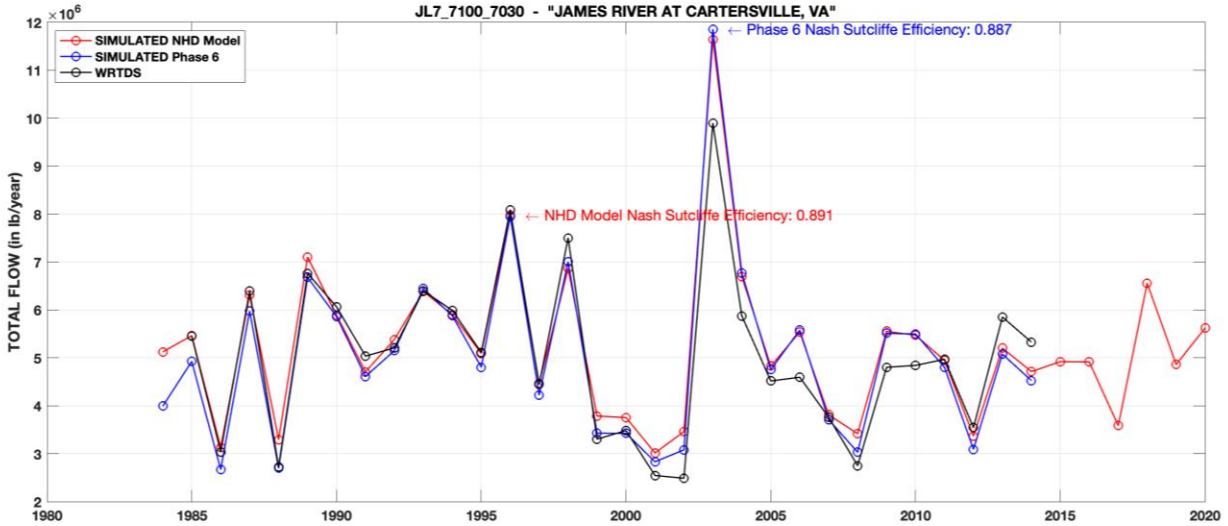


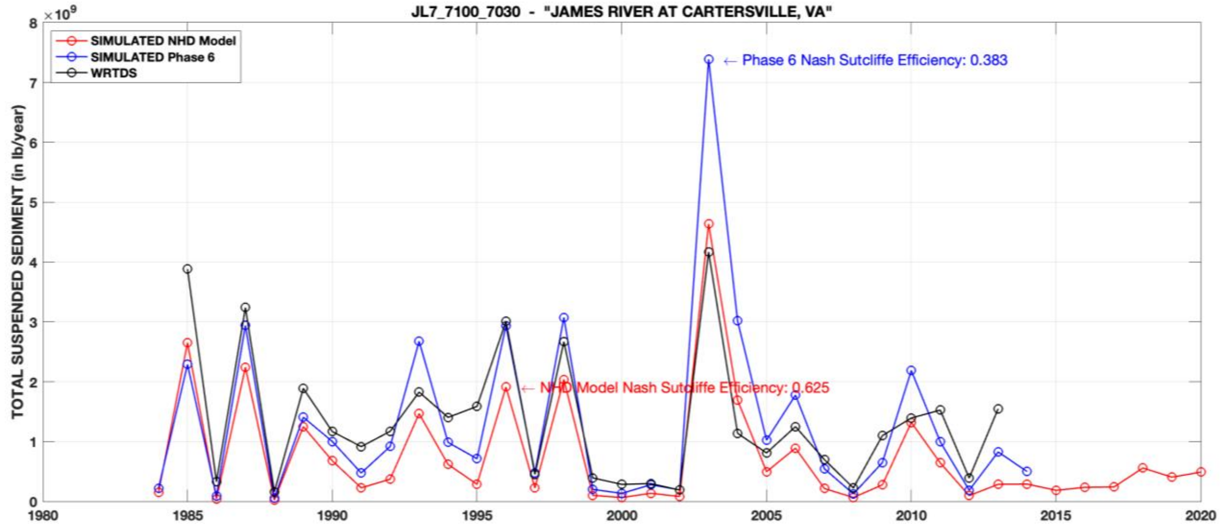


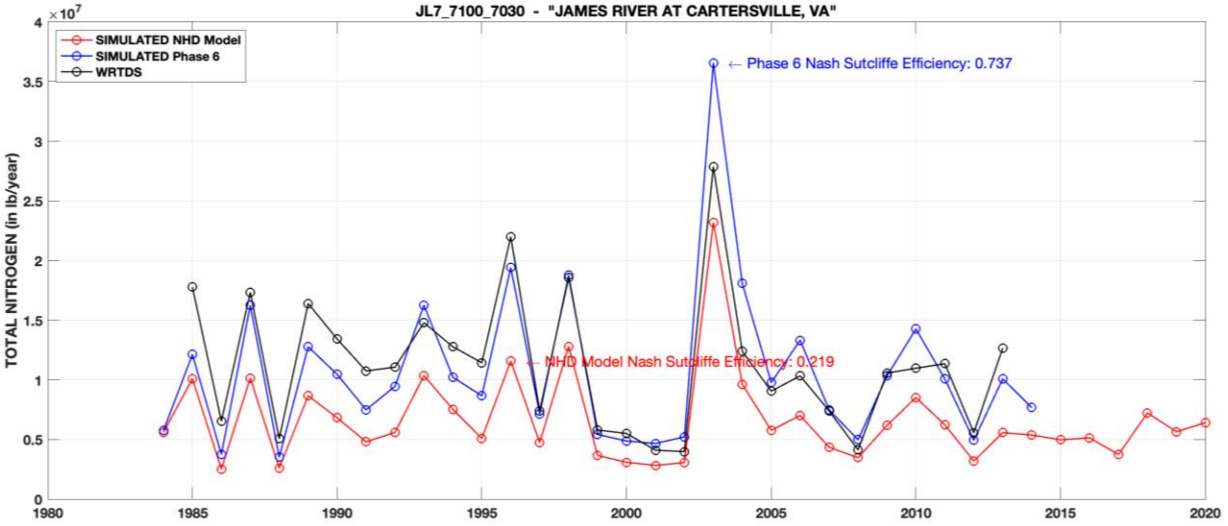


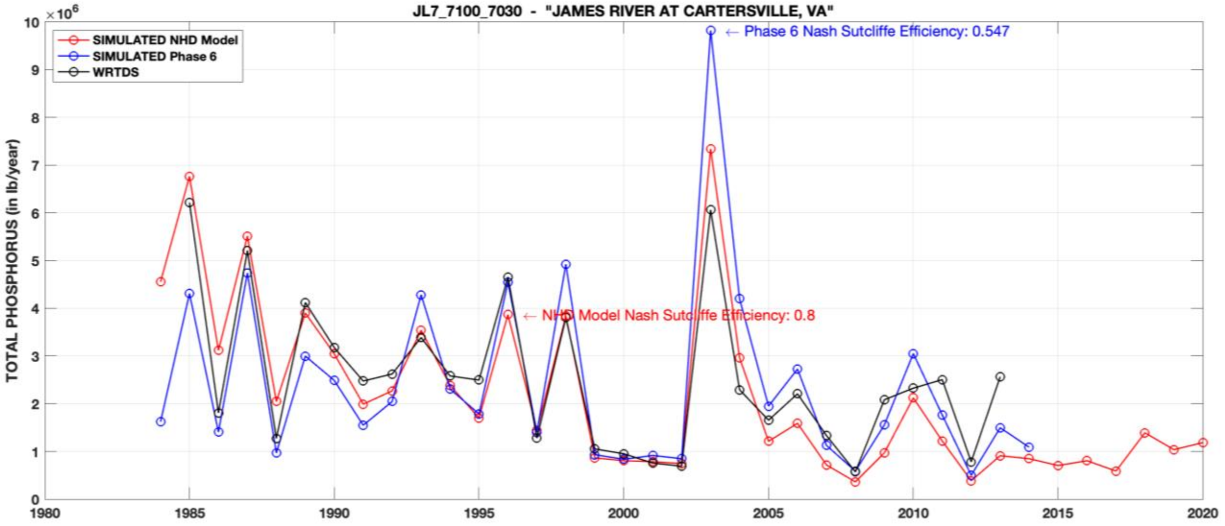


James River at Cartersville, VA

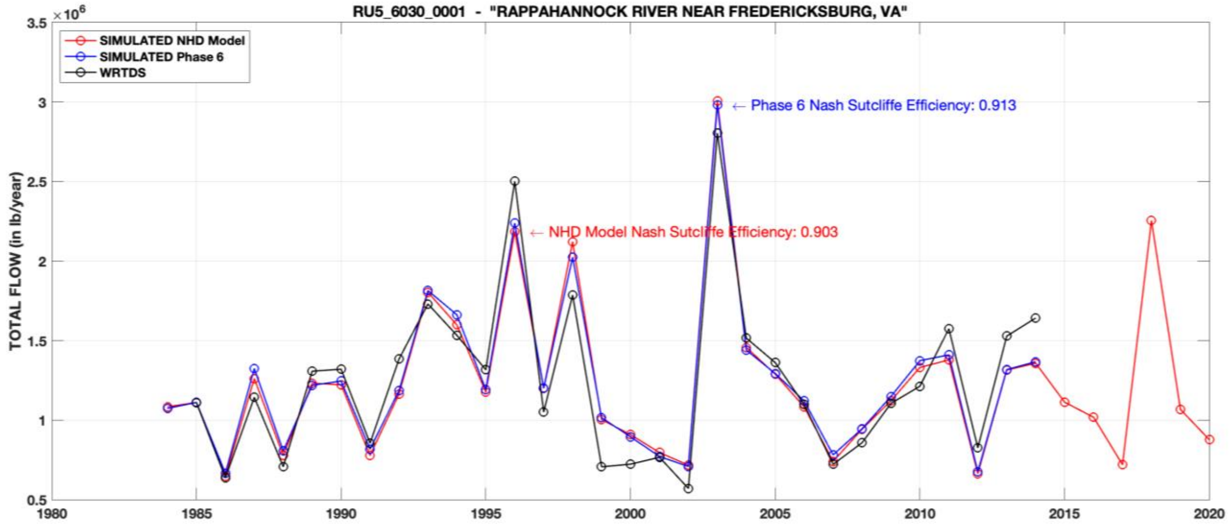


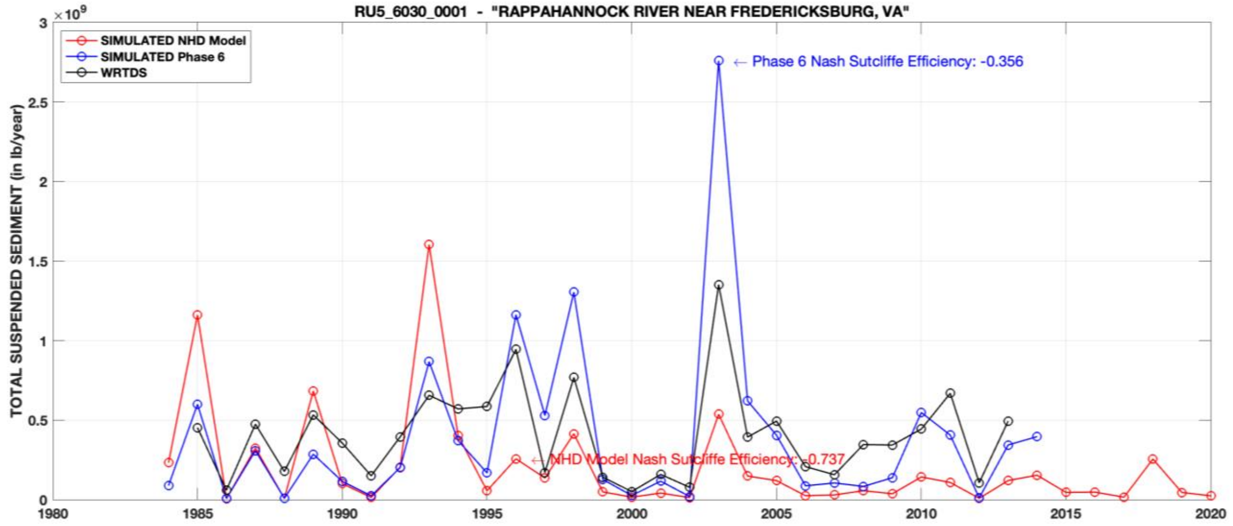


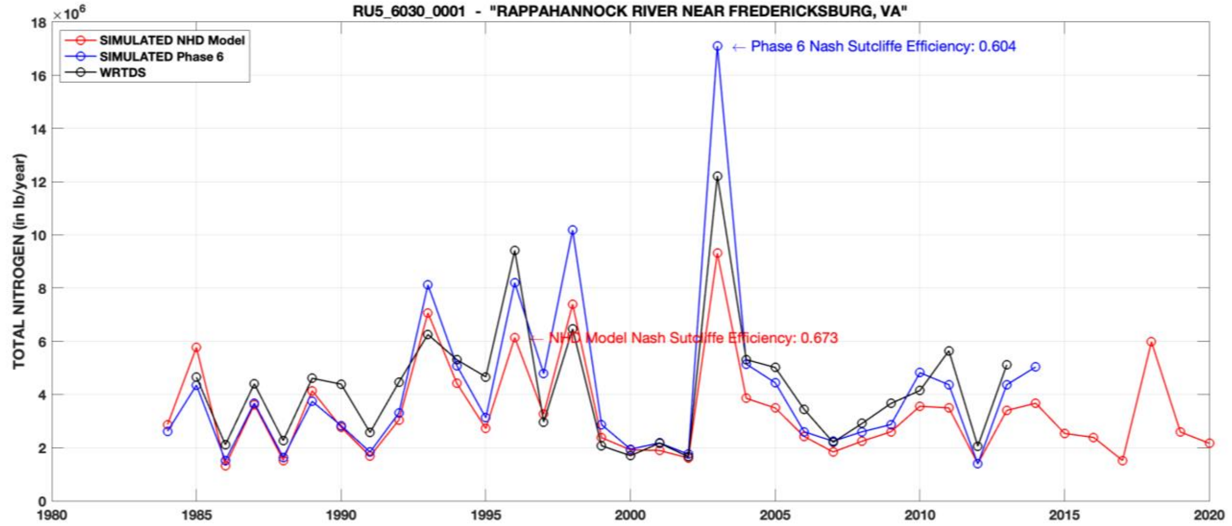


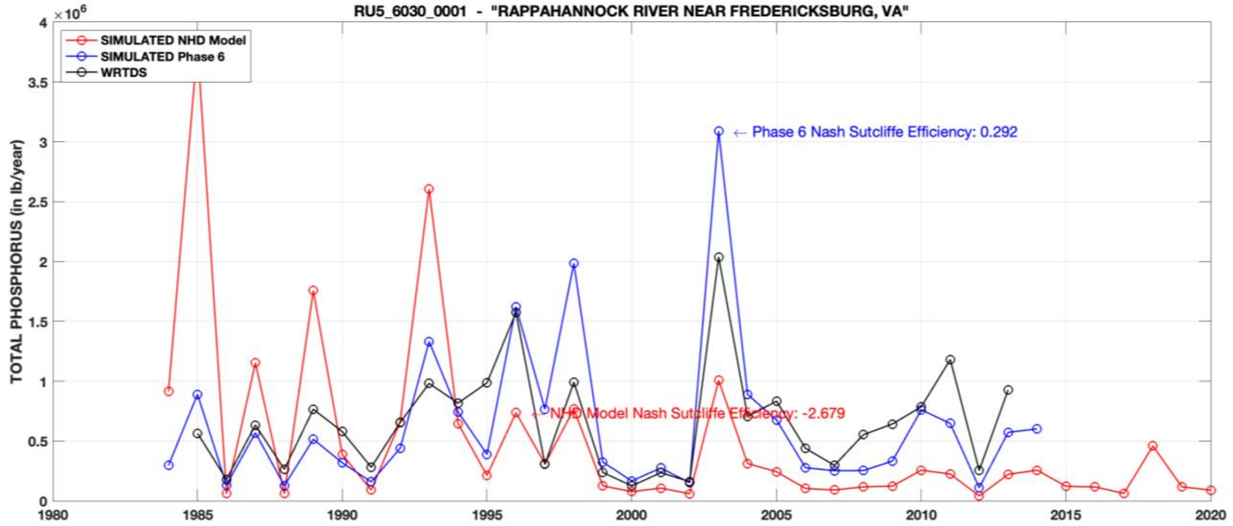


Rappahannock River near Fredericksburg, VA

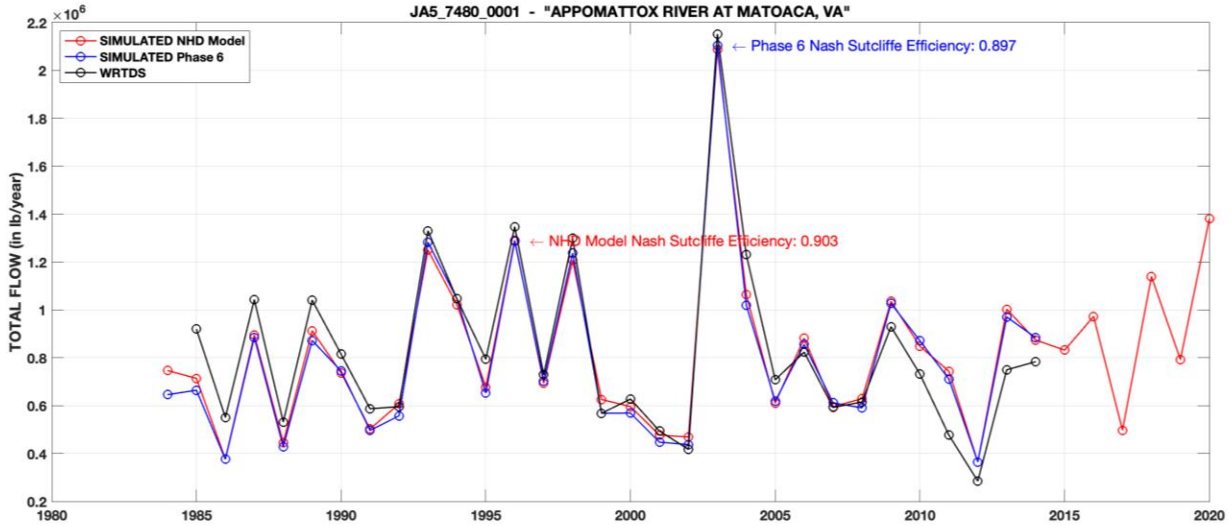


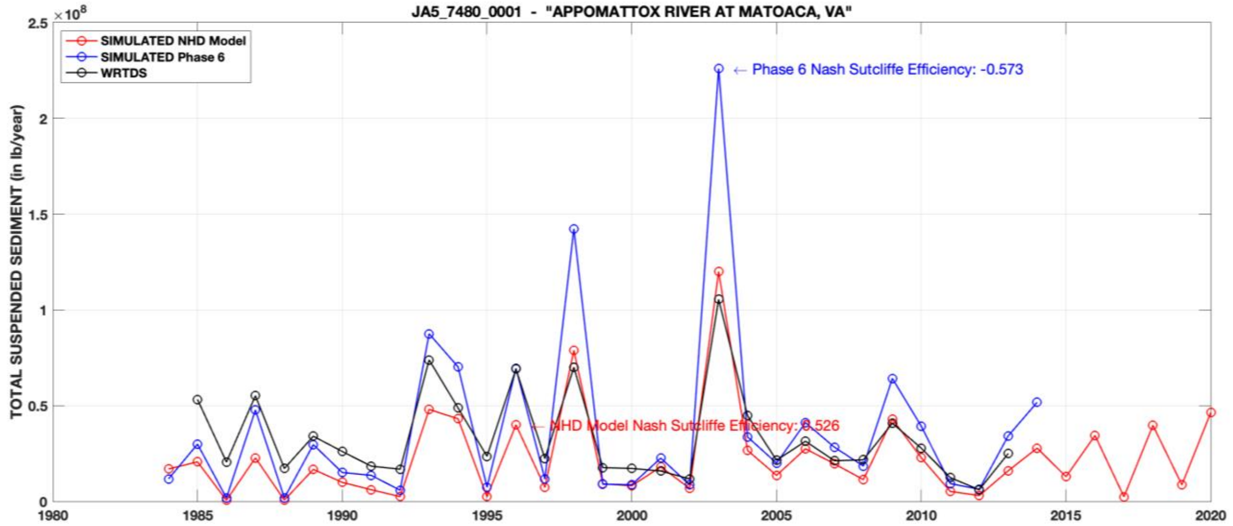


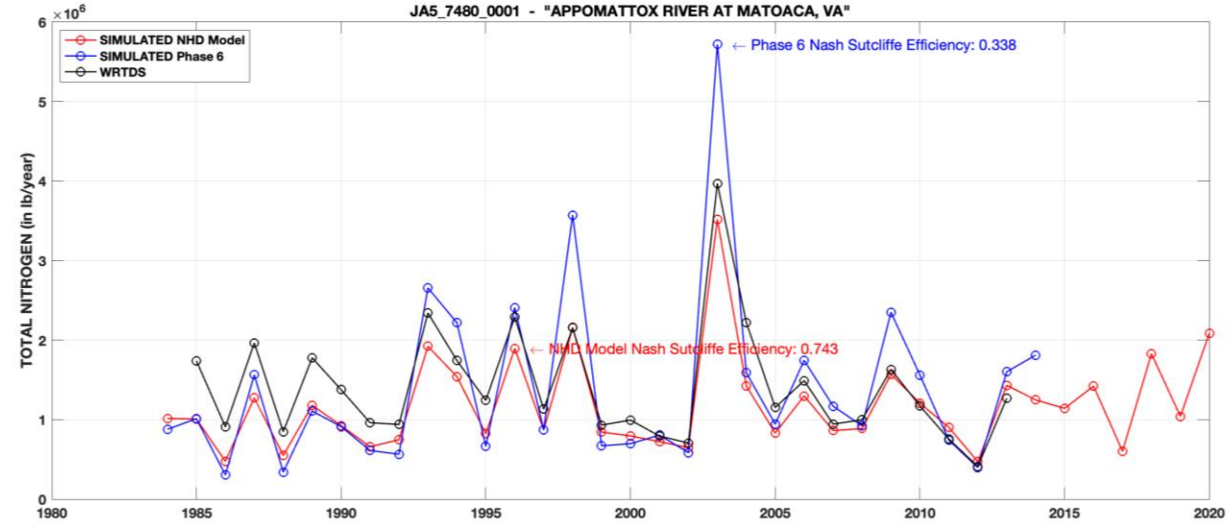


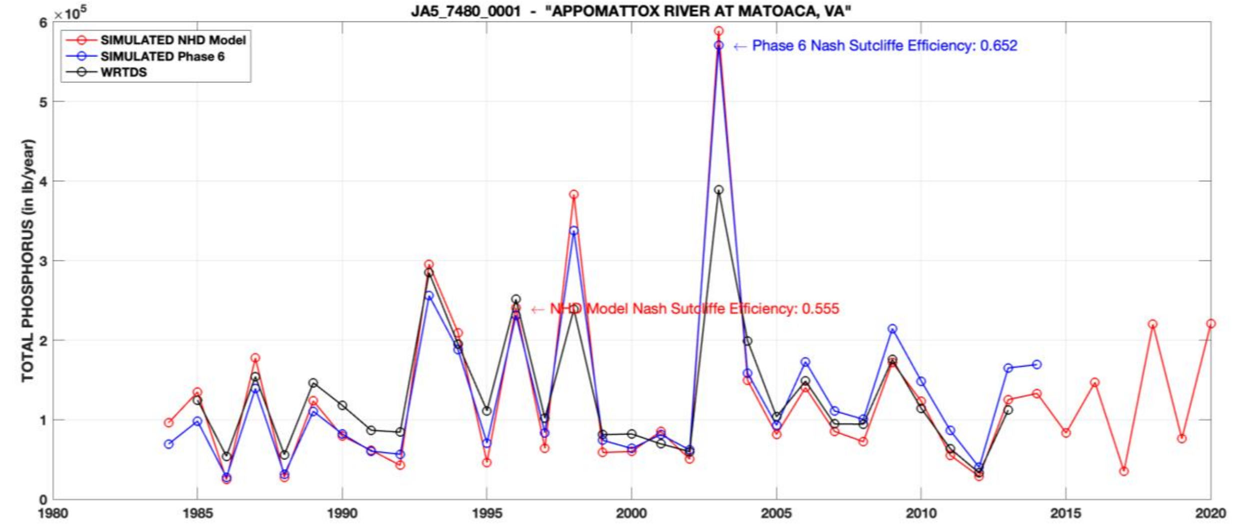


Appomattox River at Matoaca, VA

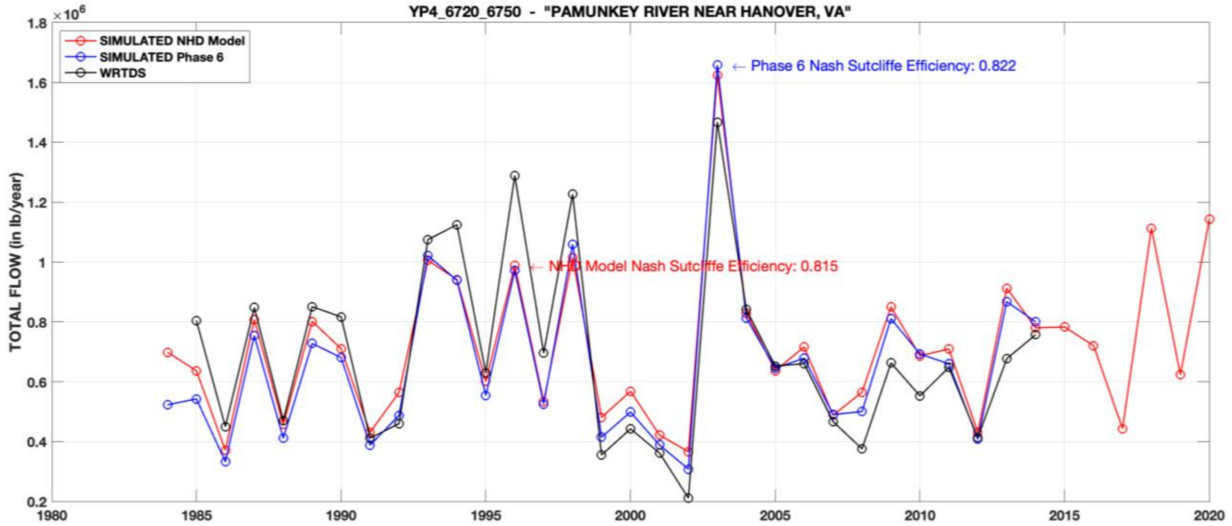


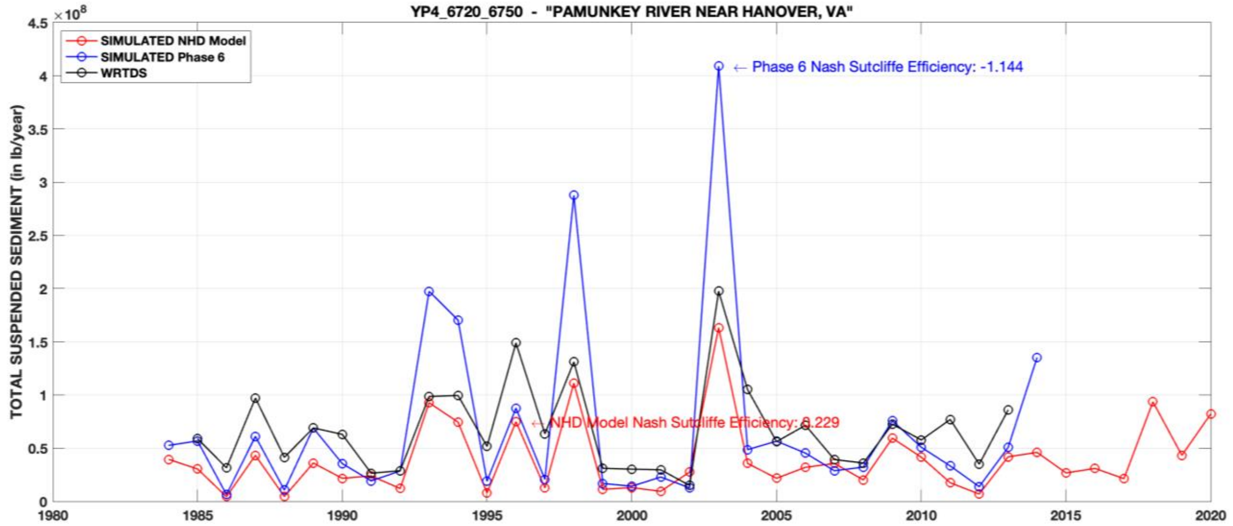


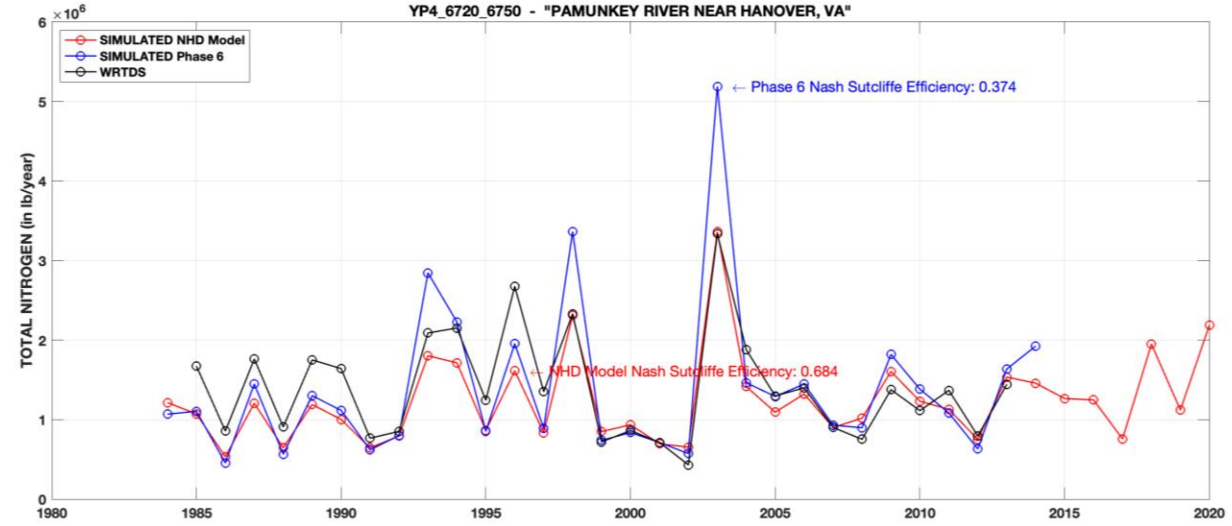


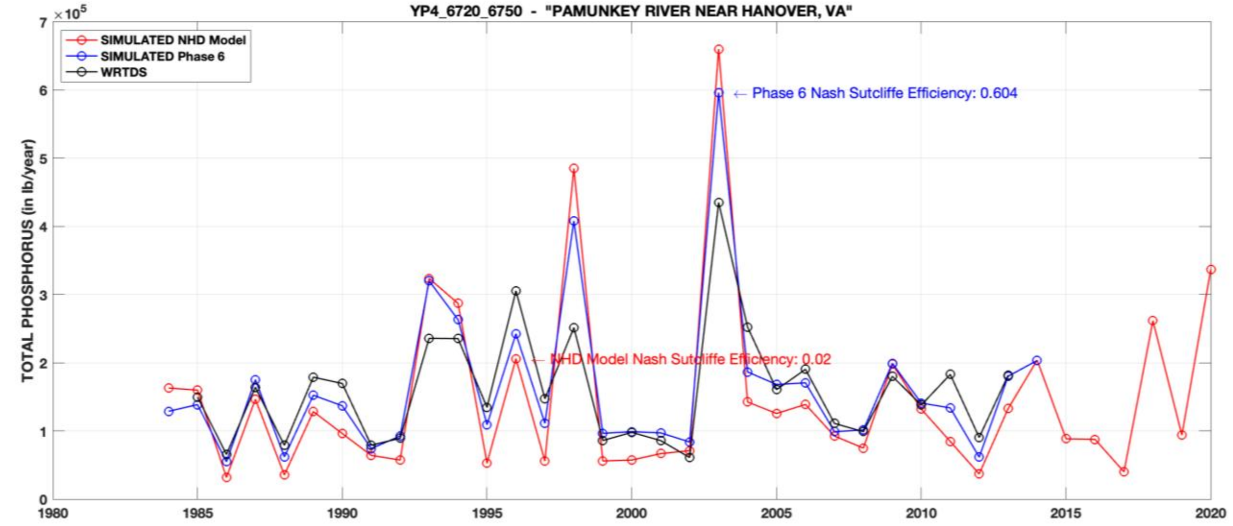


Pamunkey River near Hanover, VA

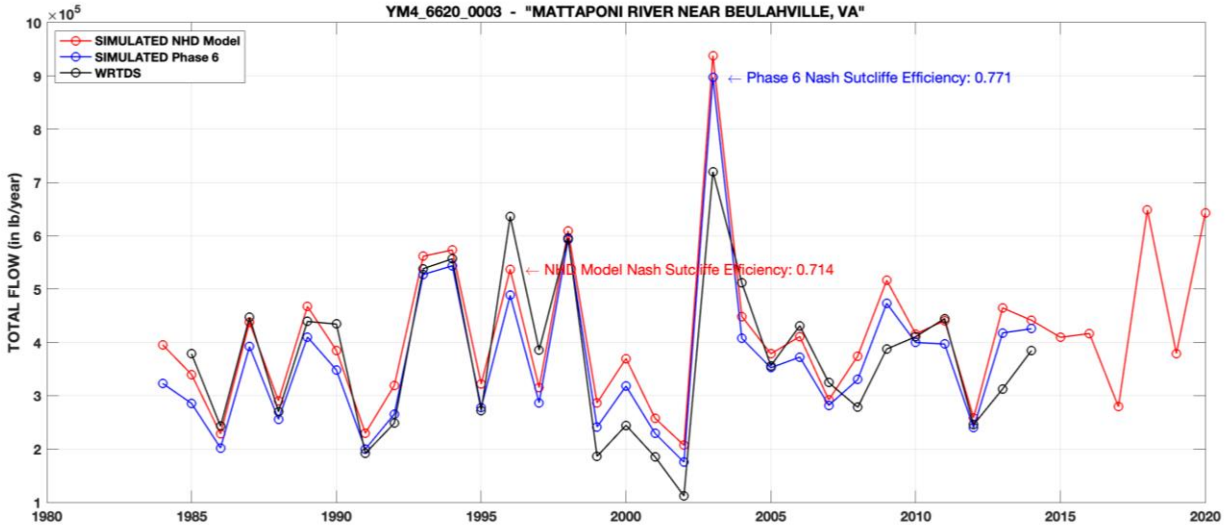


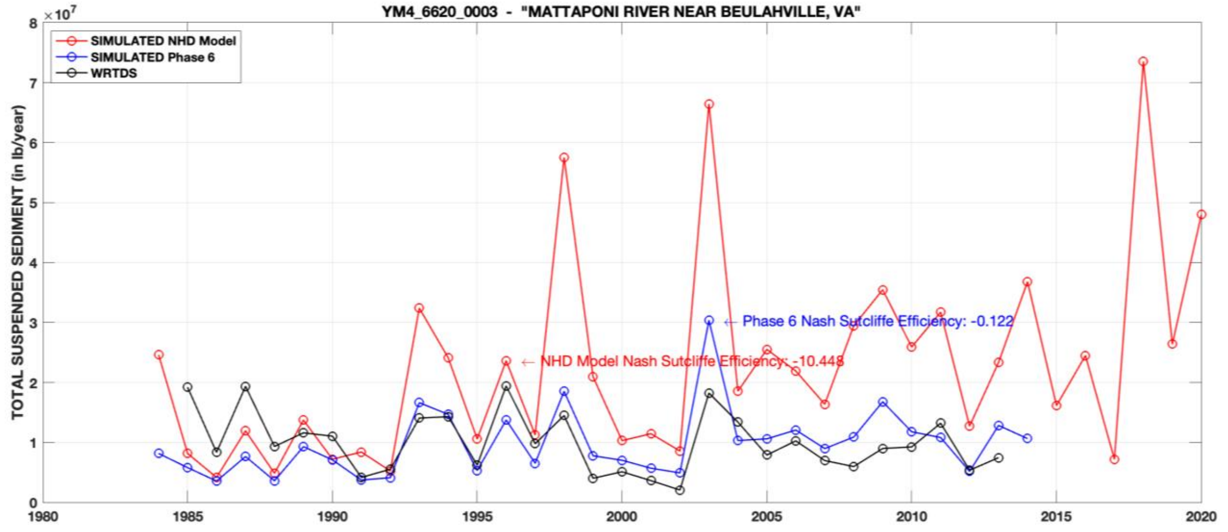


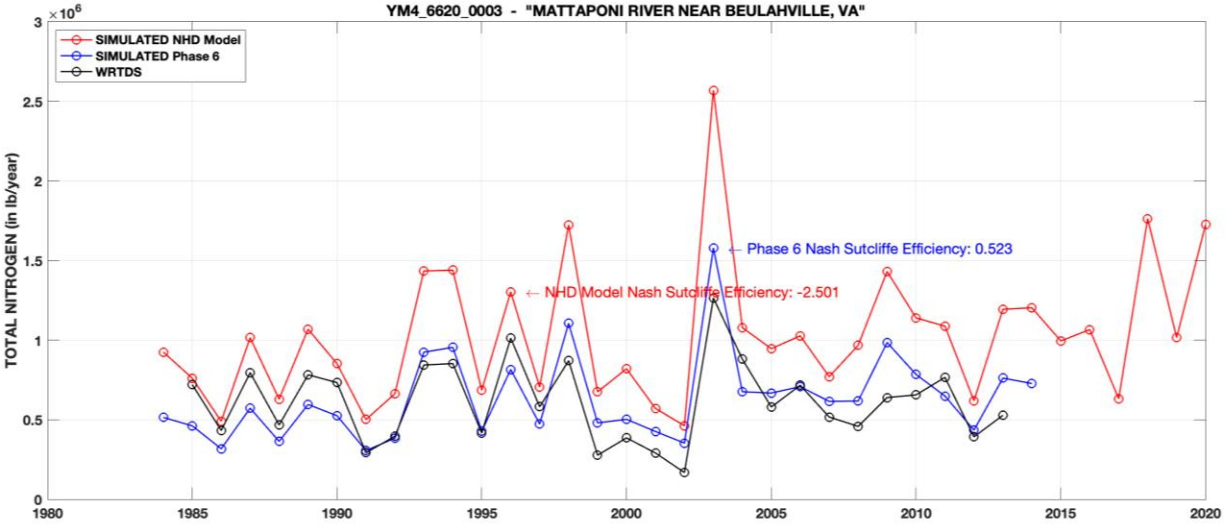


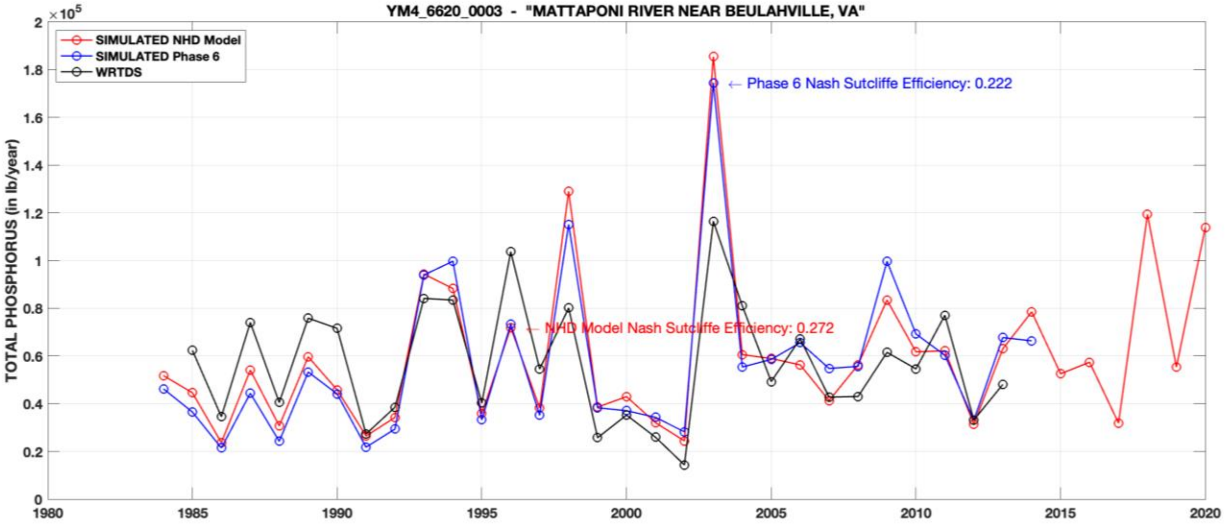


Mattaponi River near Beulahville, VA

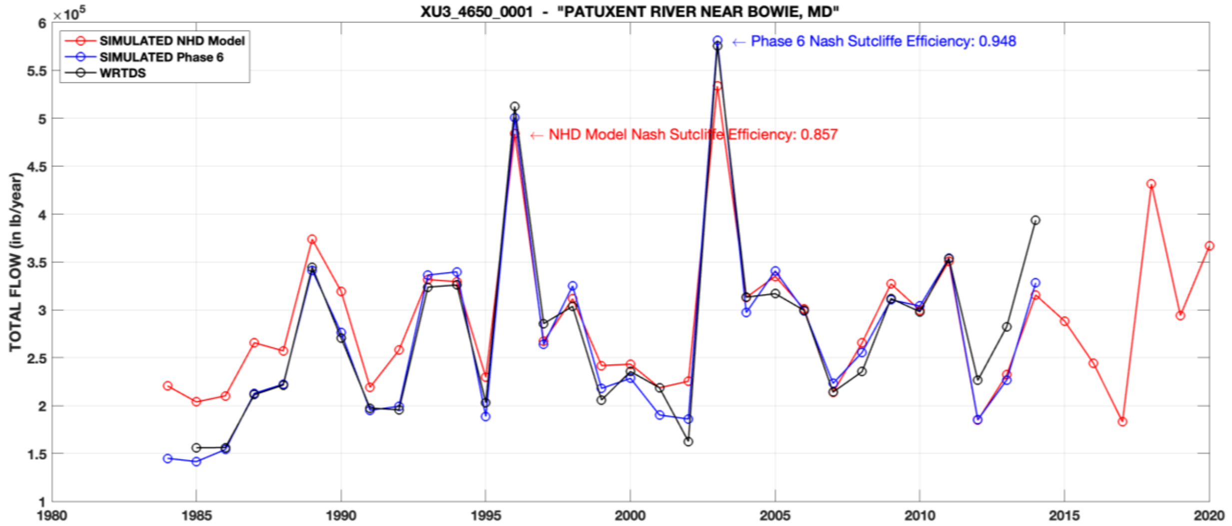


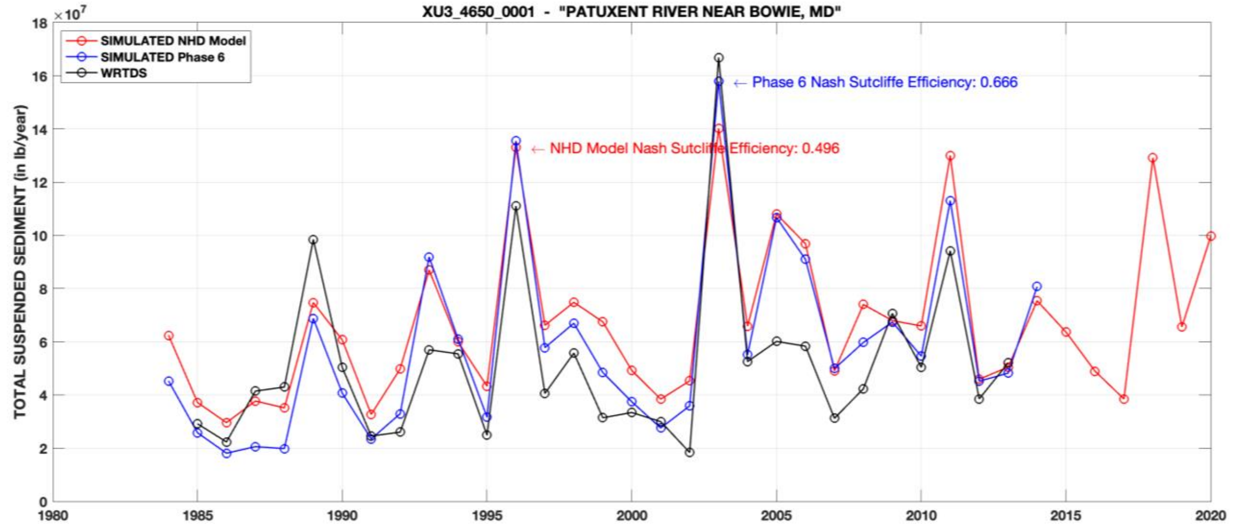


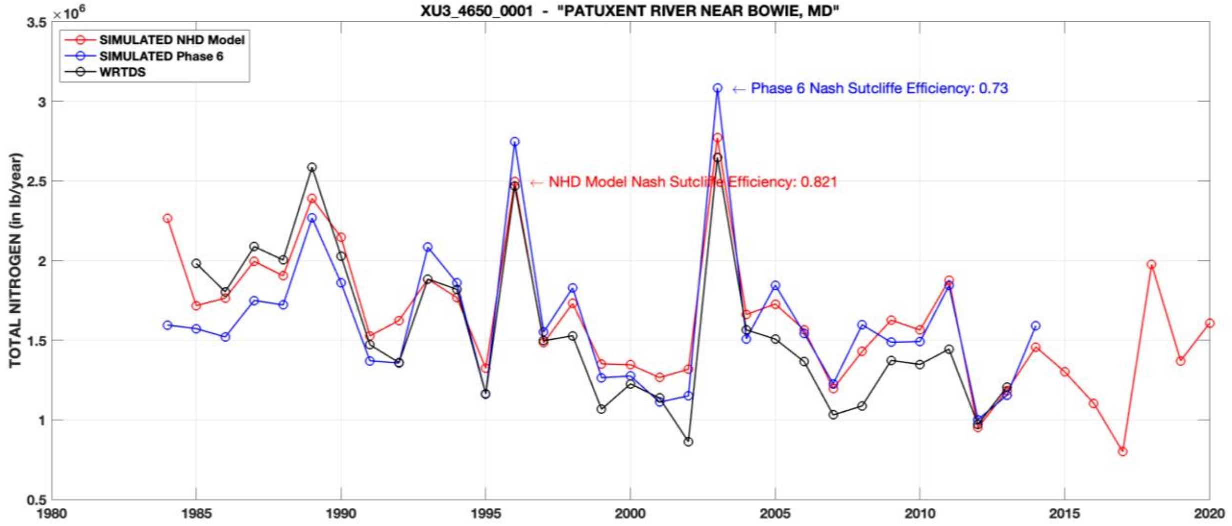


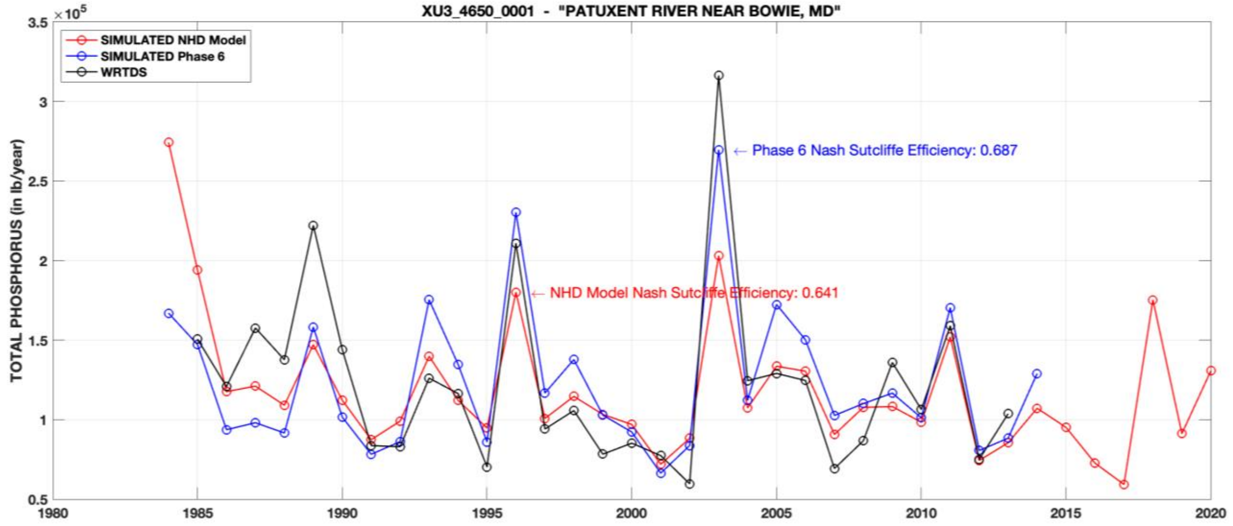


Patuxent River near Bowie, MD

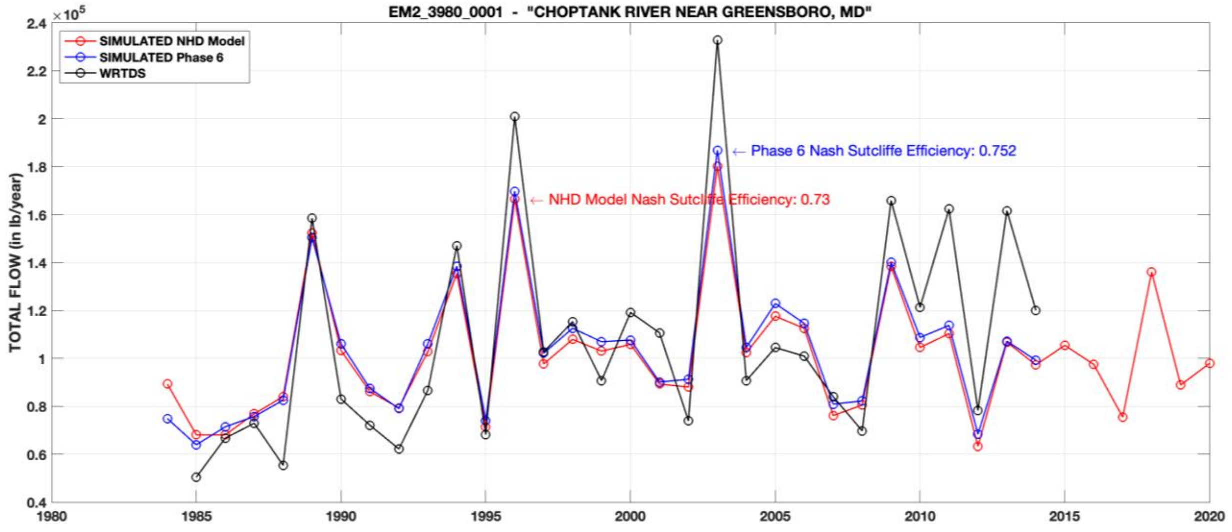


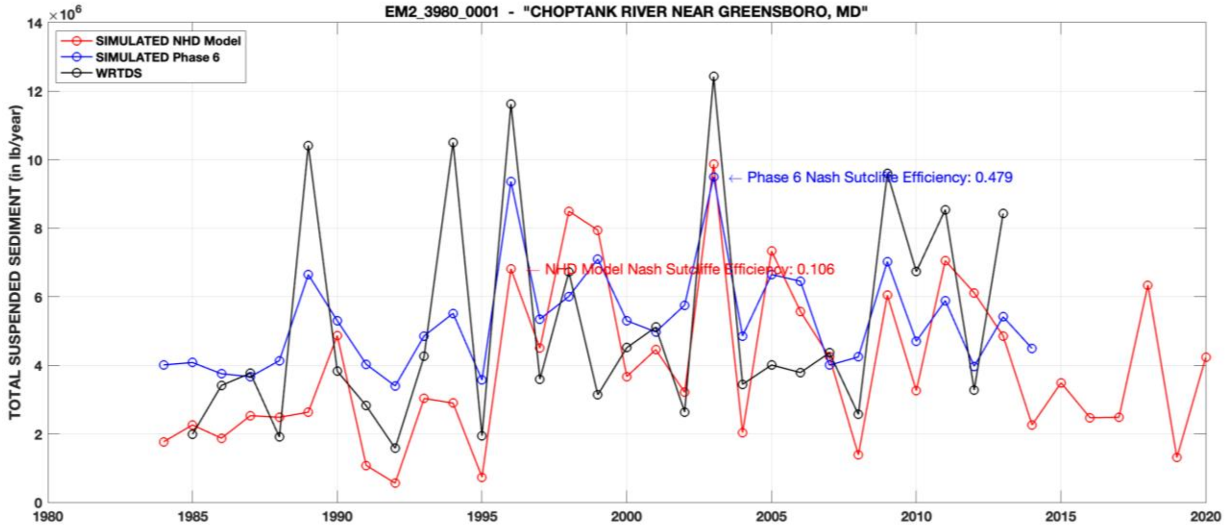


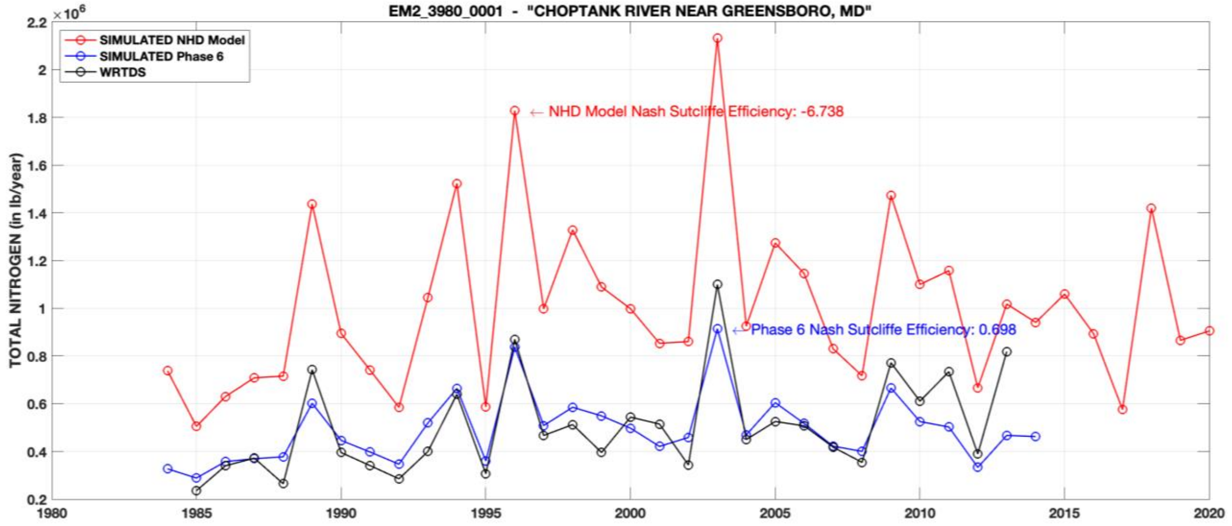


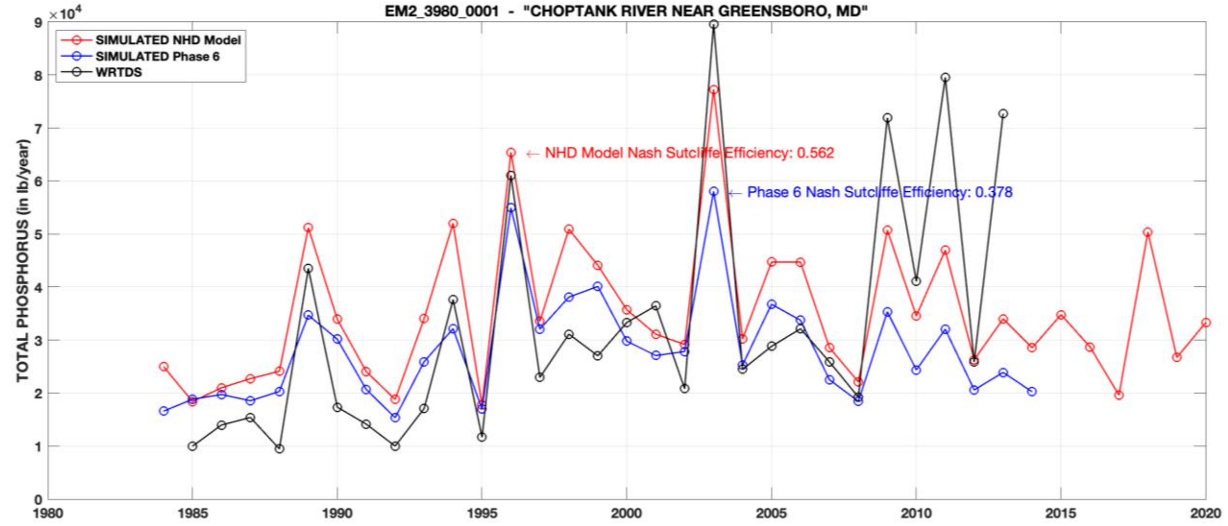


Choptank River near Greensboro, MD





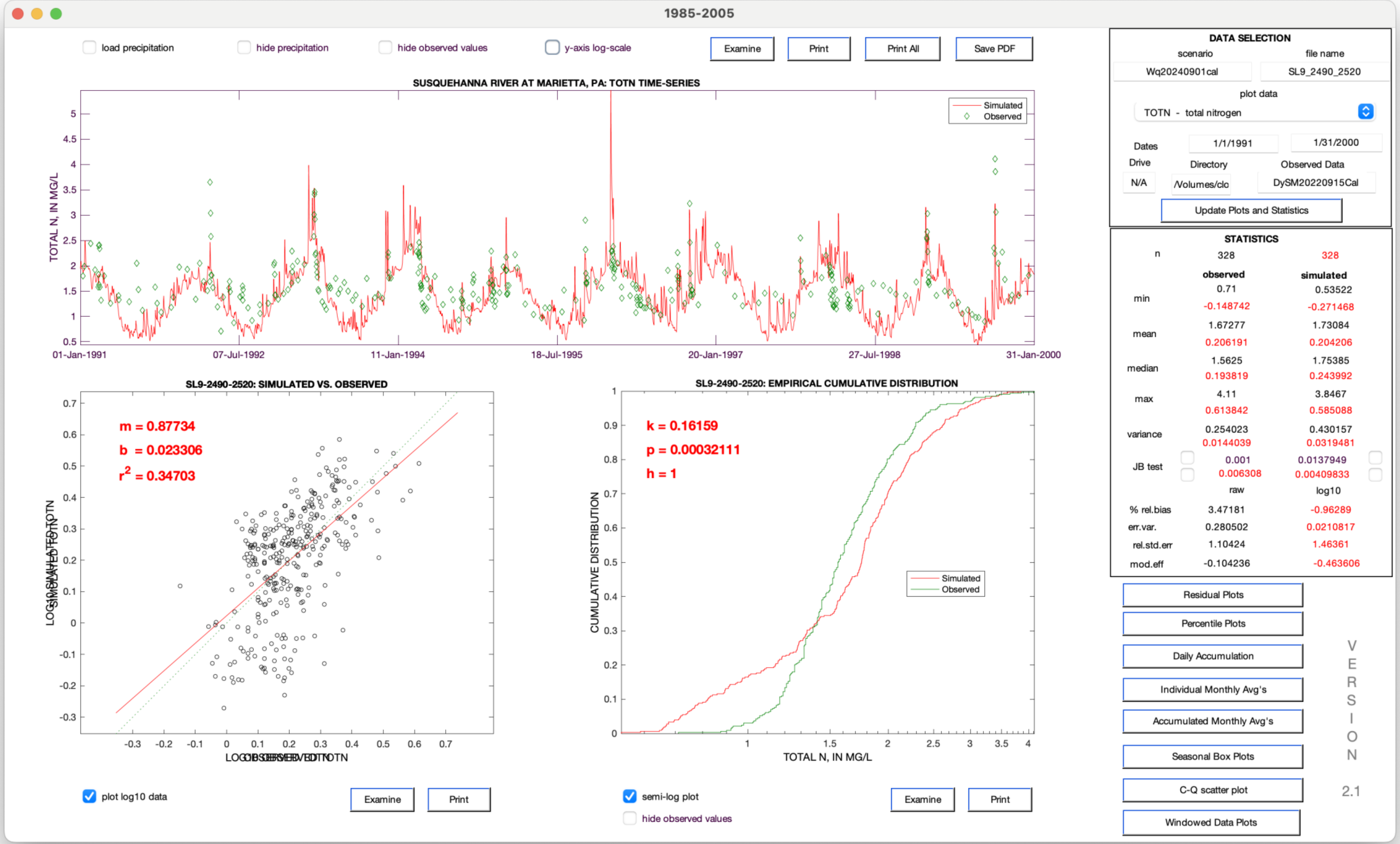




Susquehanna at Marietta, PA

1991-2000

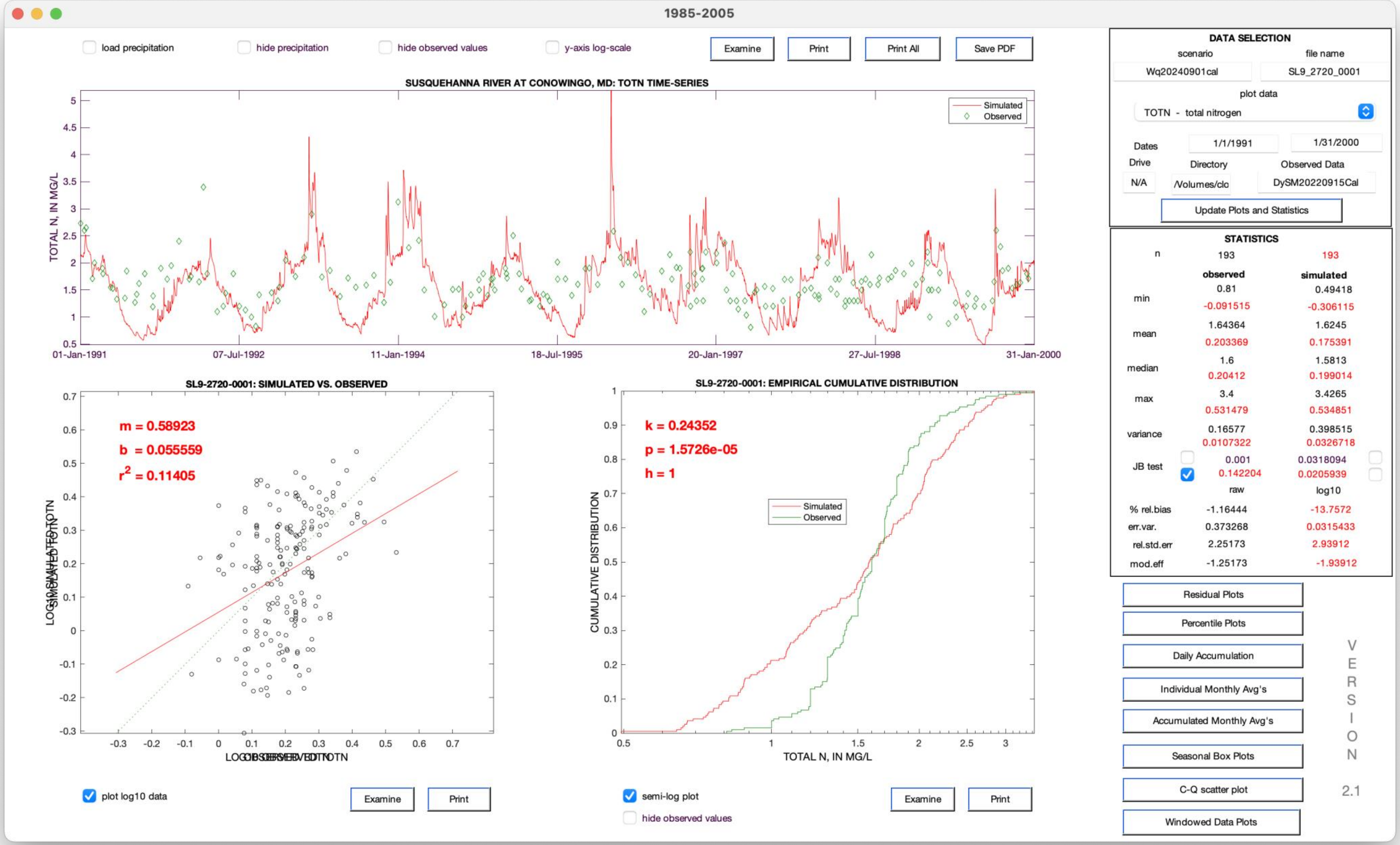
Nitrogen



Susquehanna at Conowingo, MD

1991-2000

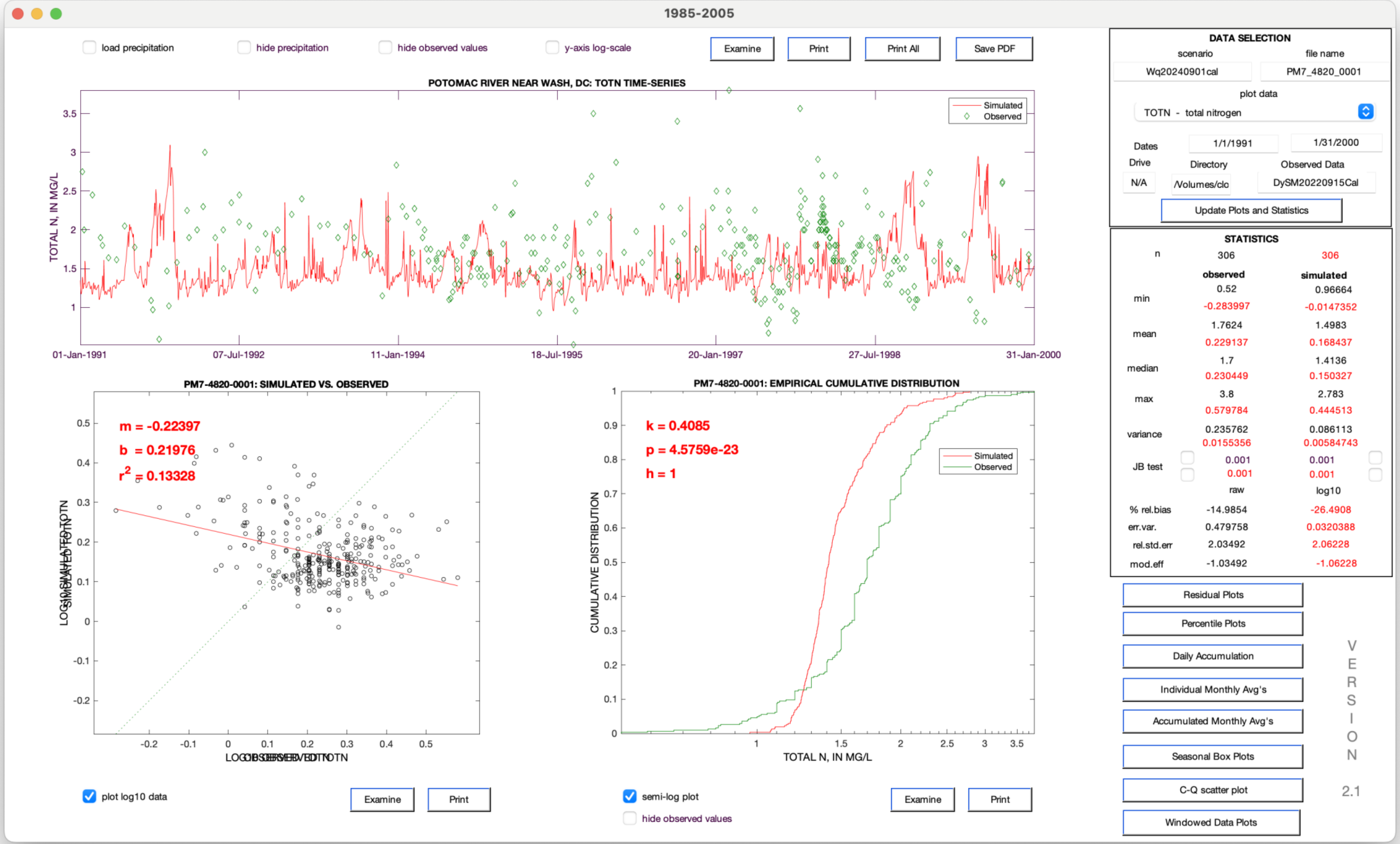
Nitrogen



Potomac near Washington, DC

1991-2000

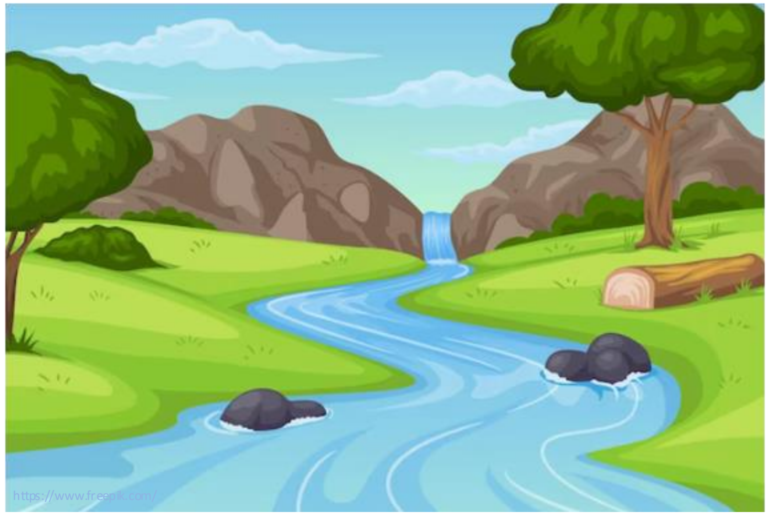
Nitrogen



Small-stream flow and concentration (Q-C) relationship

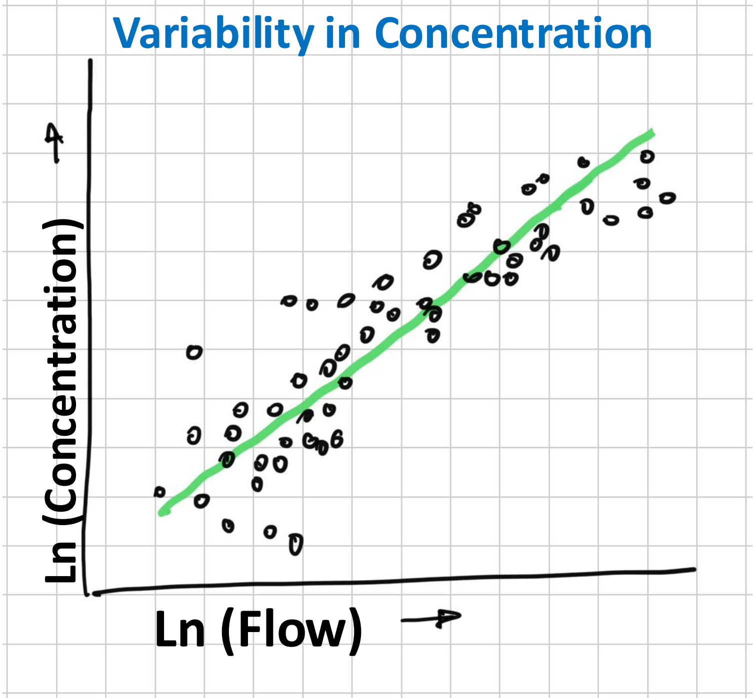
HSPF: hourly surface and groundwater hydrology of land uses

UNEC: annual surface and groundwater concentrations as a function of input history and estimates of lag-times



Biogeochemical processing,
Storage/deposition, Scour
➔ Fate and Transport

Stream Transport Factor (STF)

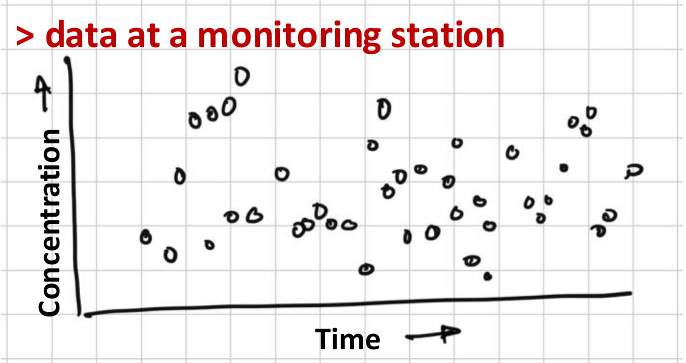


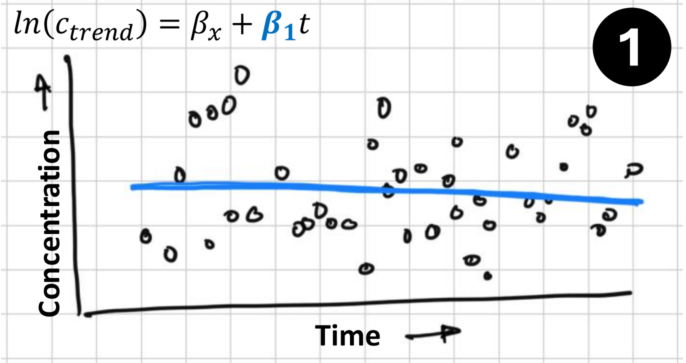
? ... emergent behavior

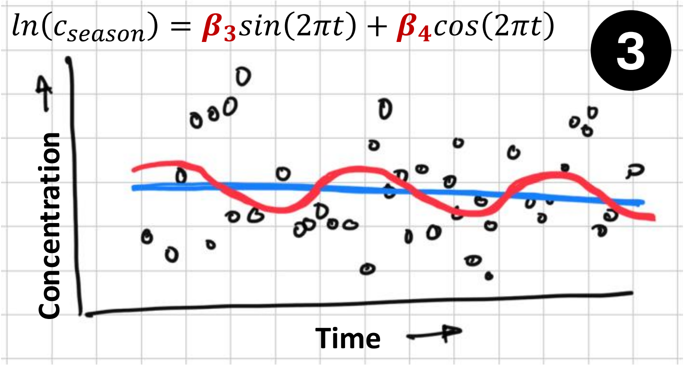
Small-stream flow and concentration (Q-C) relationship

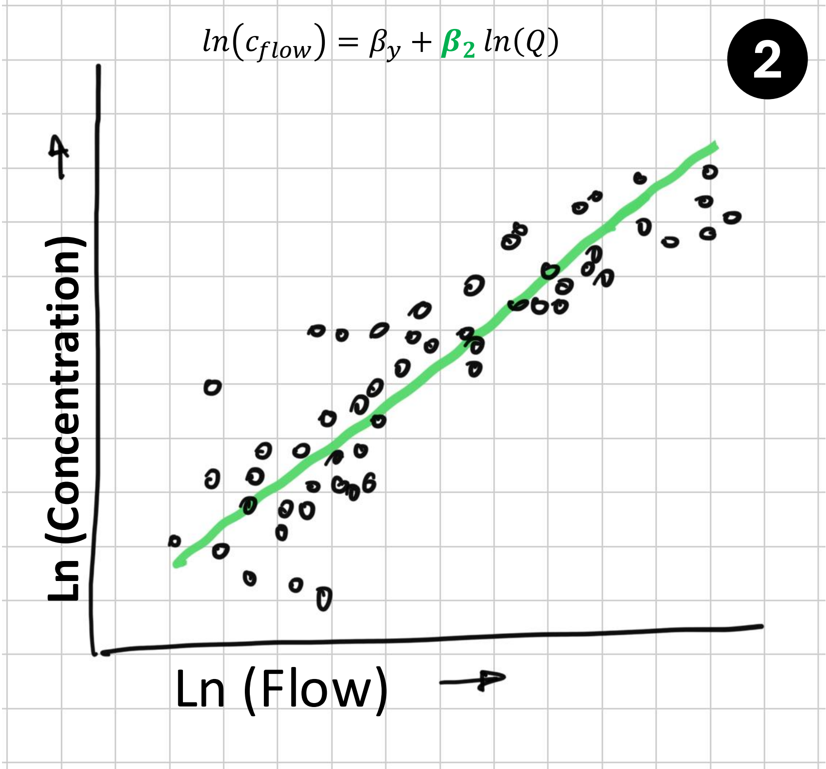
$$ln(c) = \beta_o + \beta_1 t + \boldsymbol{\beta_2}\, ln(Q) + \boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t) + \varepsilon$$

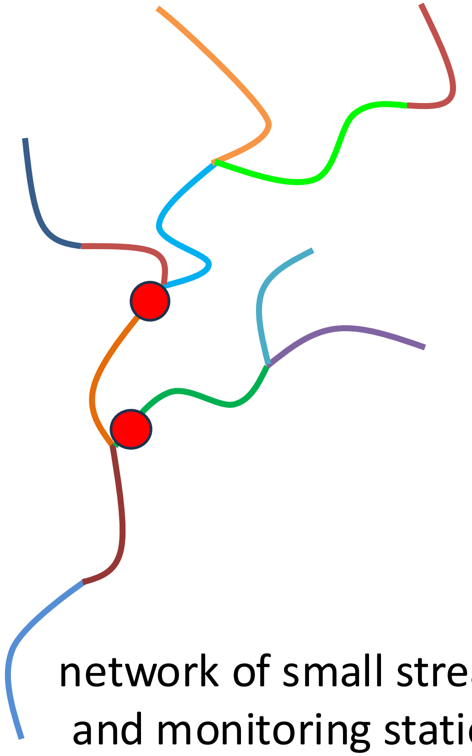
[FluxMaster]





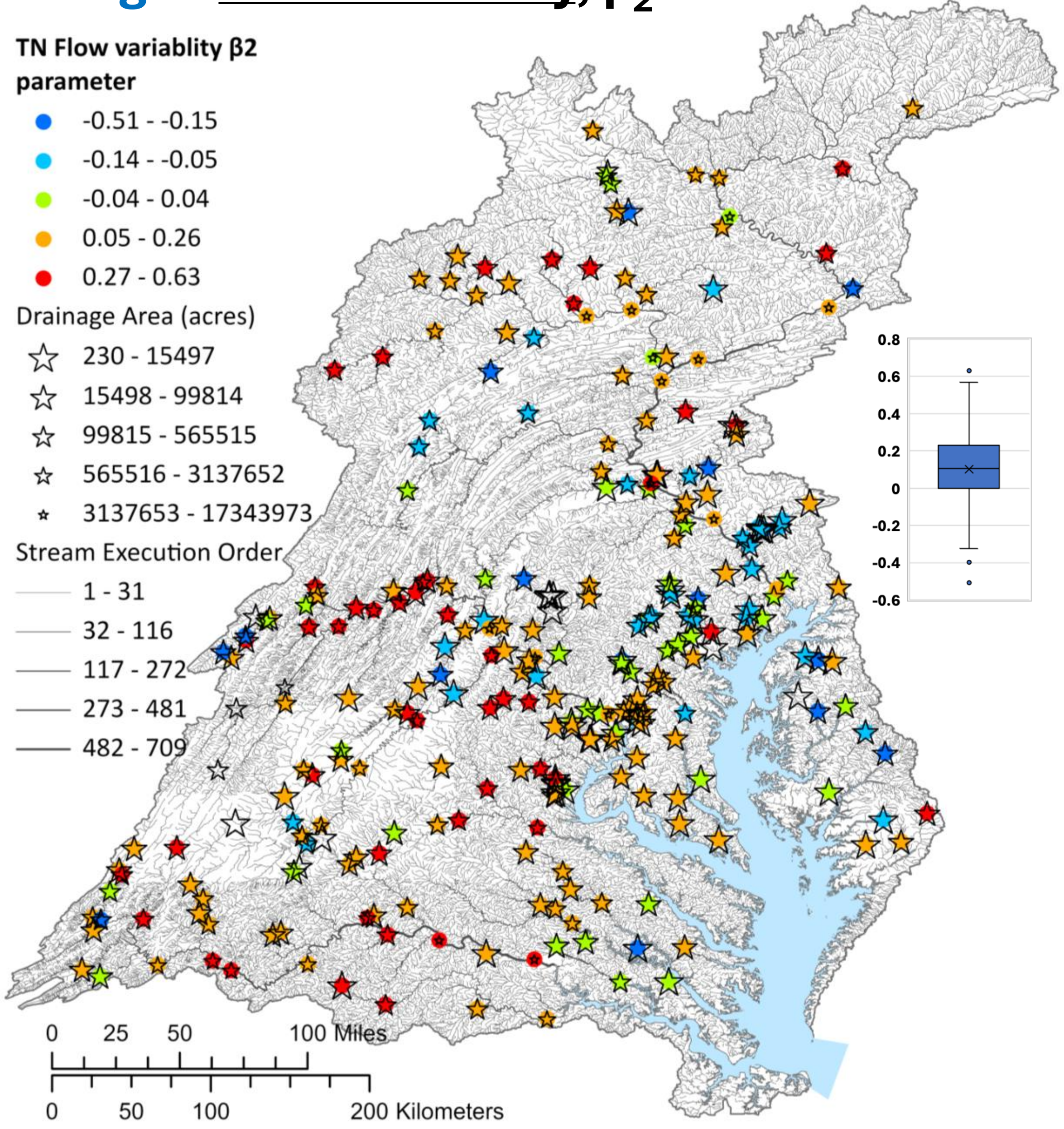




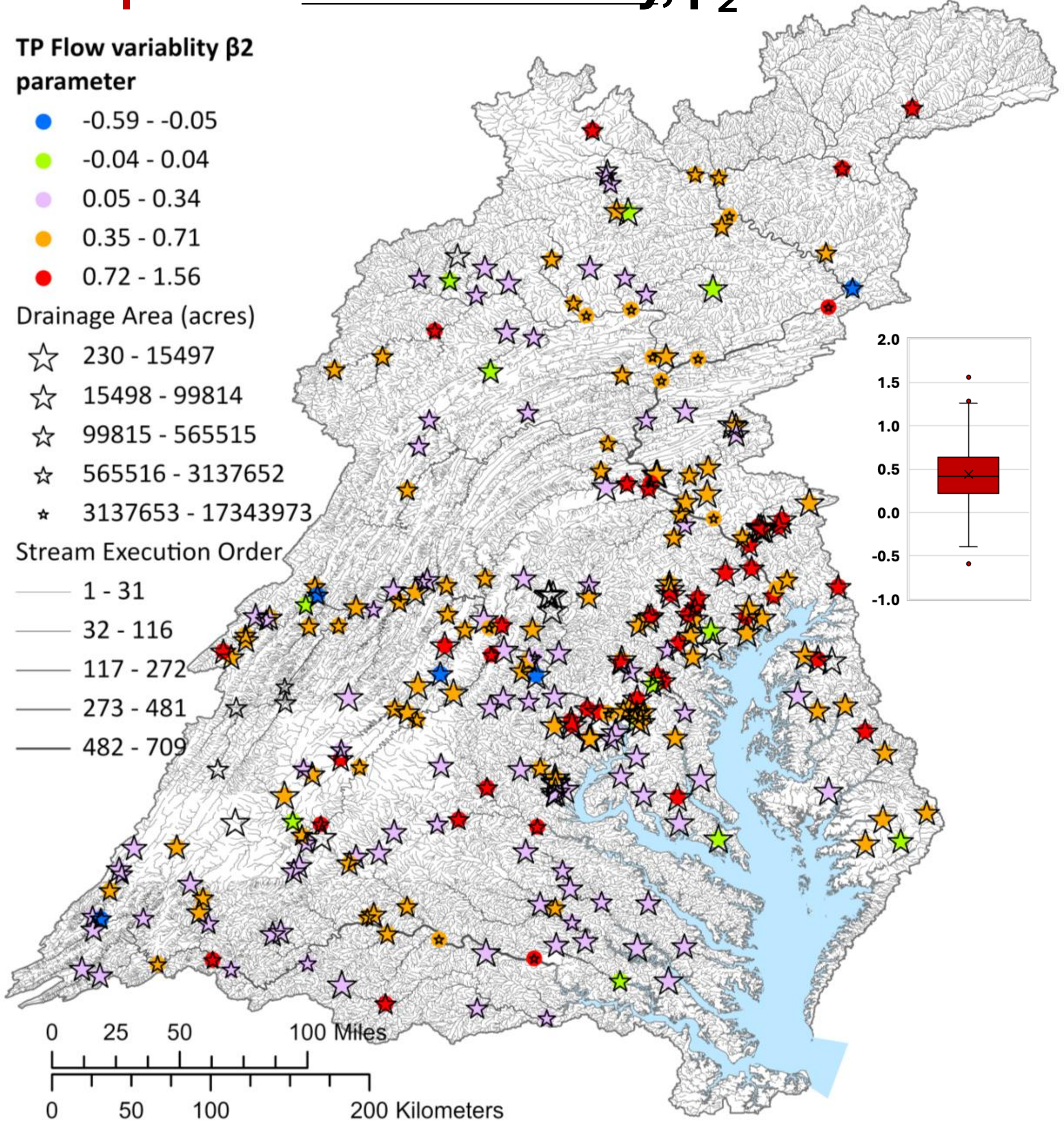


network of small streams and monitoring stations with water quality and streamflow data

Nitrogen flow variability, β_2



Phosphorus flow variability, β_2



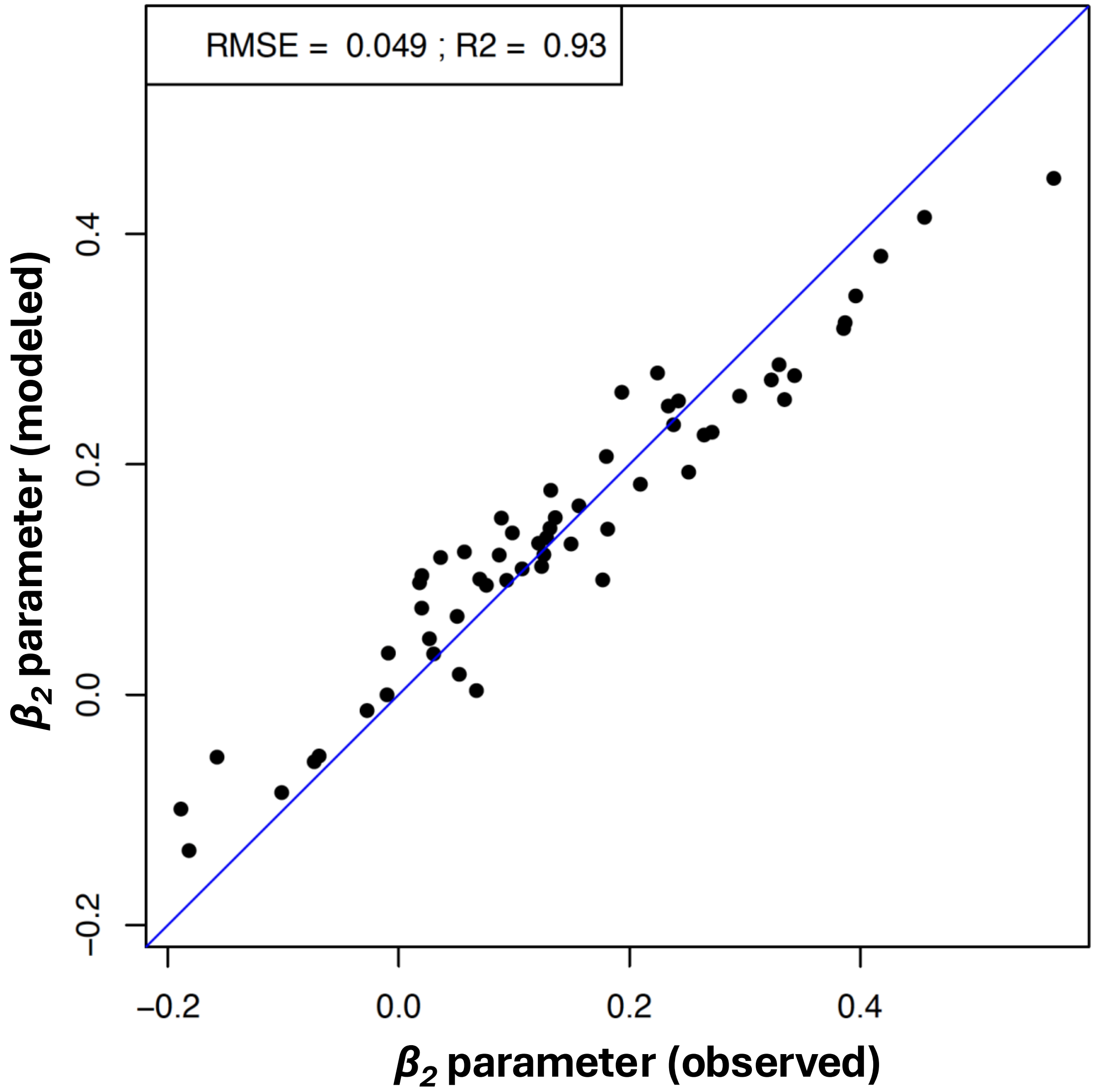
$$ln(c) = \beta_o + \beta_1 t + \boldsymbol{\beta_2}\, ln(Q) + \beta_3 sin(2\pi t) + \beta_4 cos(2\pi t) + \varepsilon$$

Generalization of β parameters – Qian Zhang

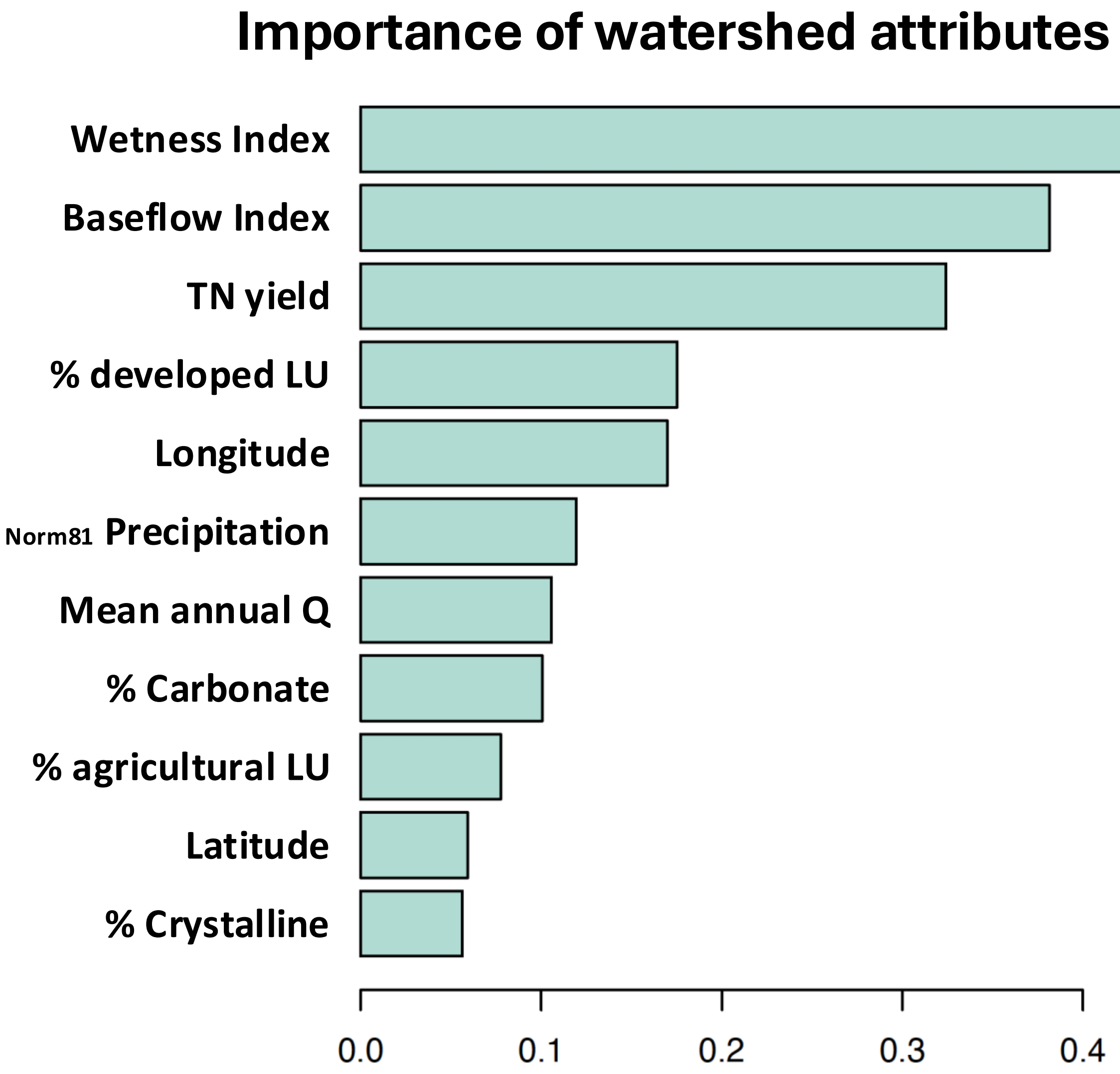
An <u>initial</u> *Random Forest* model was developed:

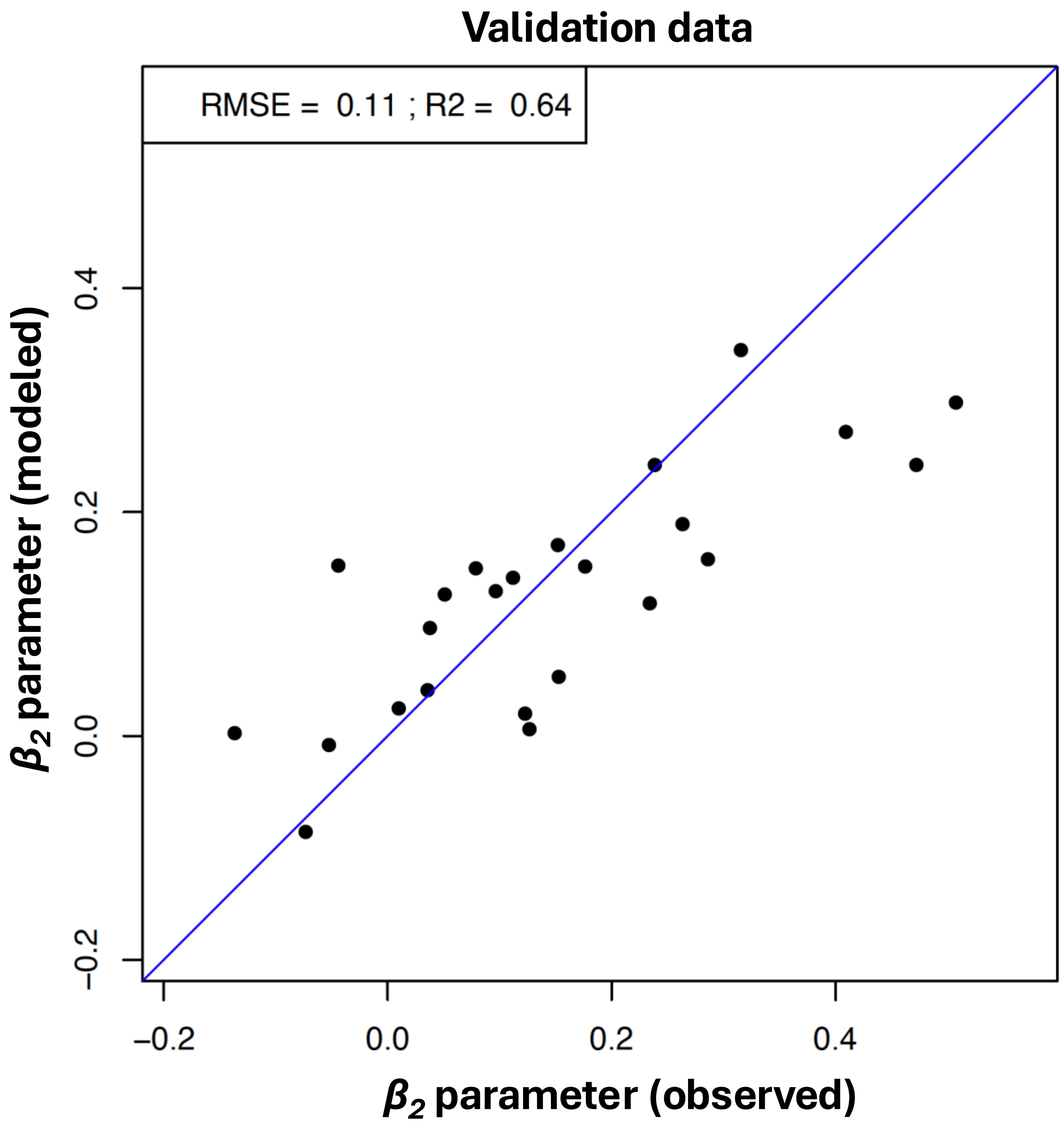
- The model links β_2 parameter with watershed attributes
- Performance of the model for training data is shown in the figure
- Currently using data for NTN stations; an expansion would require watershed attributes for additional stations

Training data



Generalization of β parameters – Qian Zhang



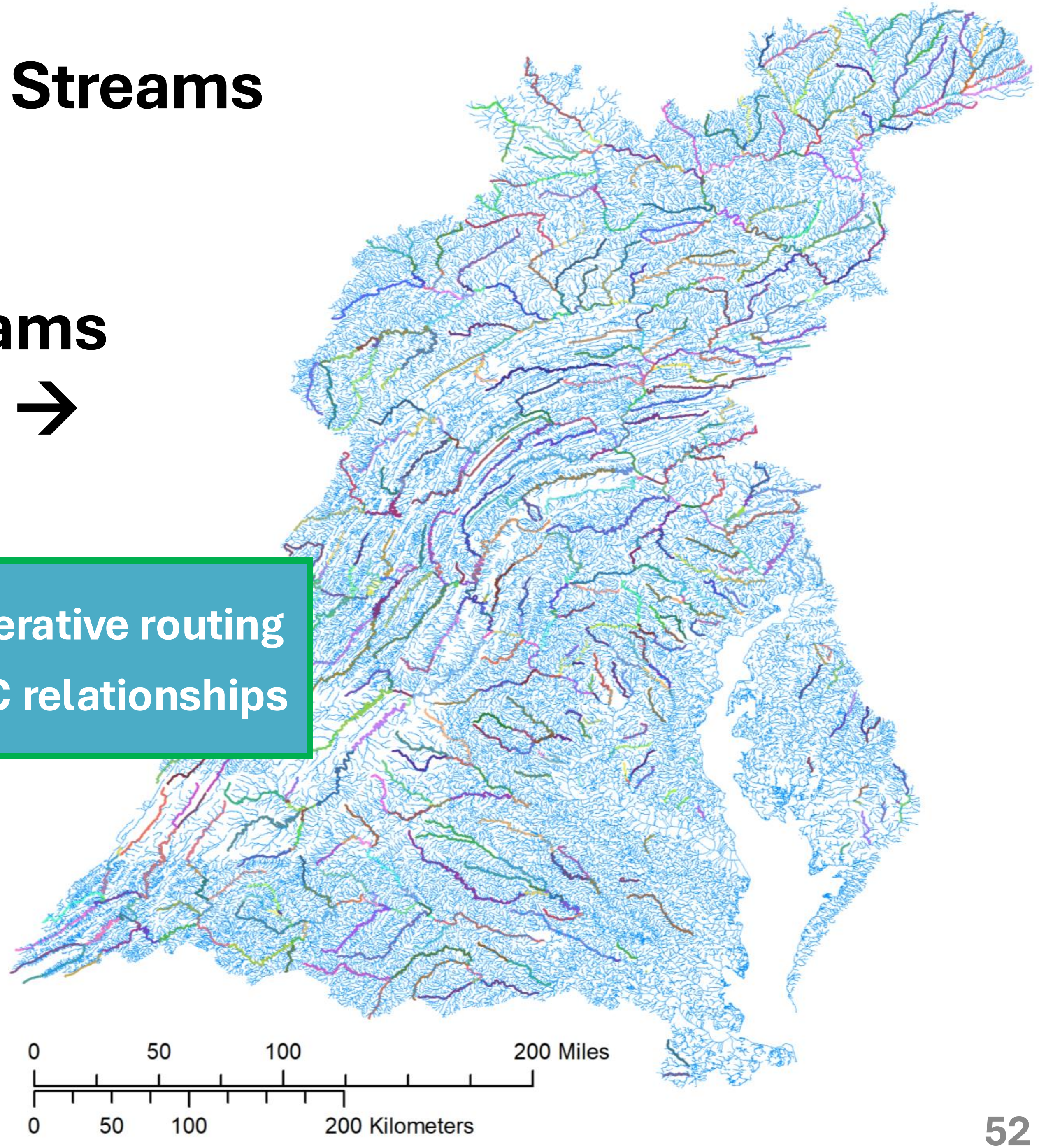


Scale and Simulation of Small Streams

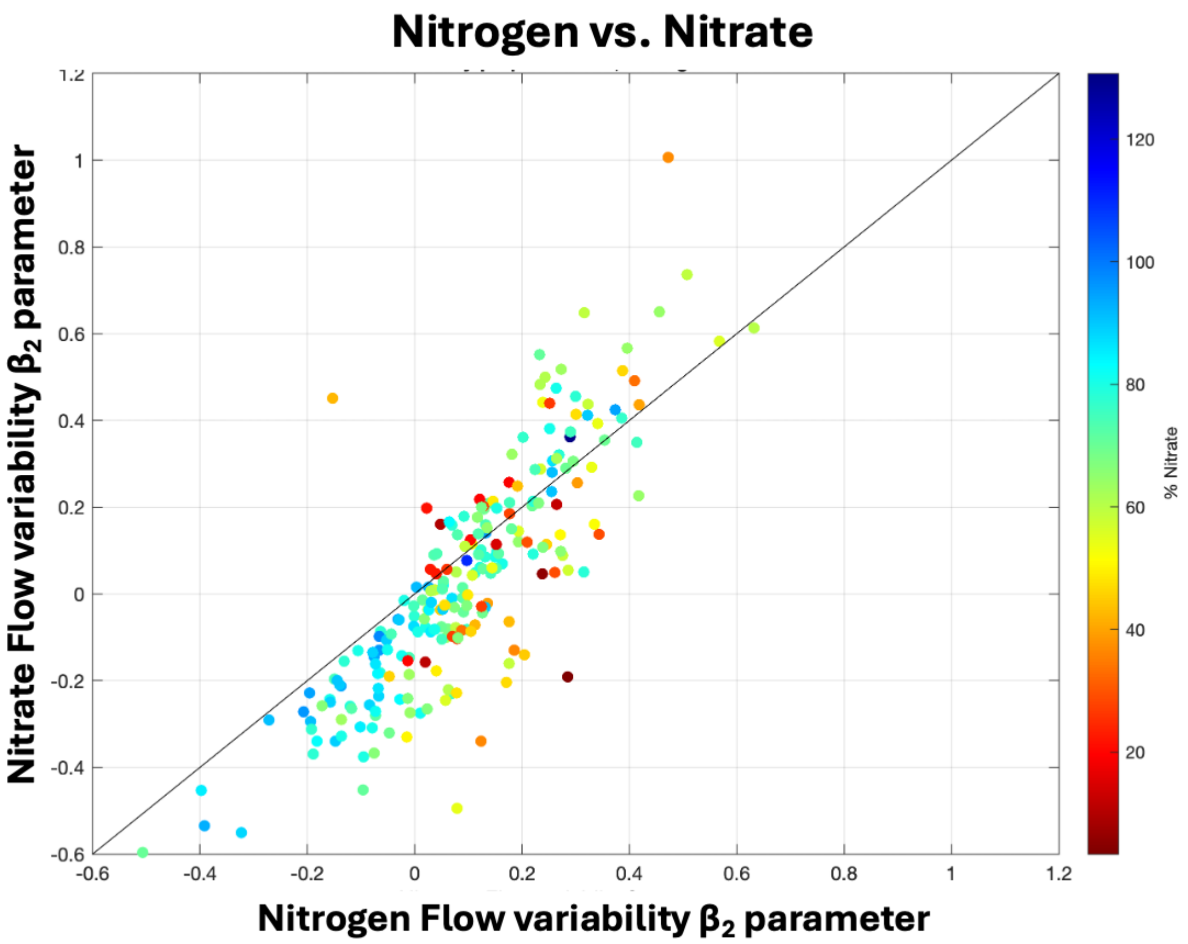
nested model
segmentation of streams
and river mainstems →

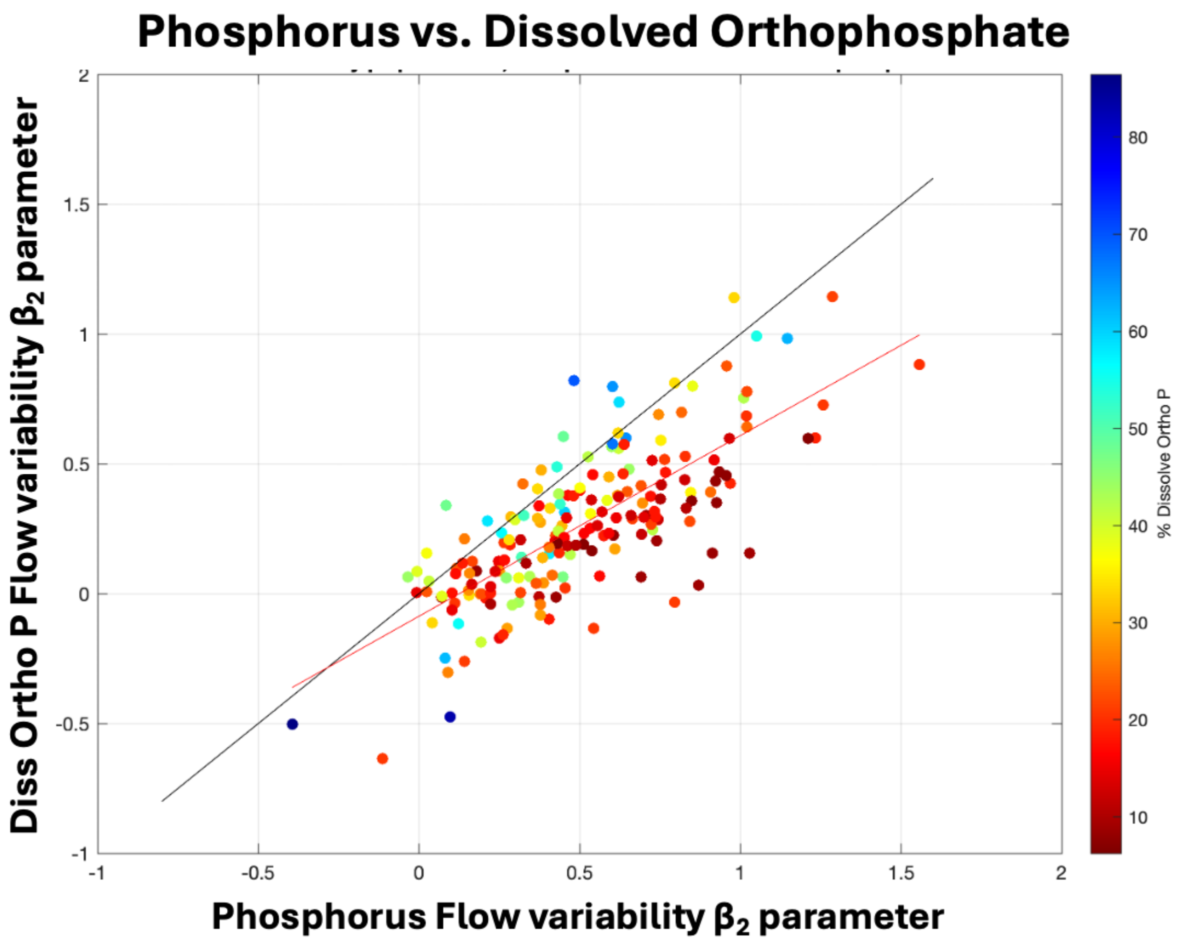
100K NHD STREAMS → <u>Hydrology</u>: Non-iterative routing
<u>Water Quality</u>: Q-C relationships

RIVER MAINSTEM → HSPF

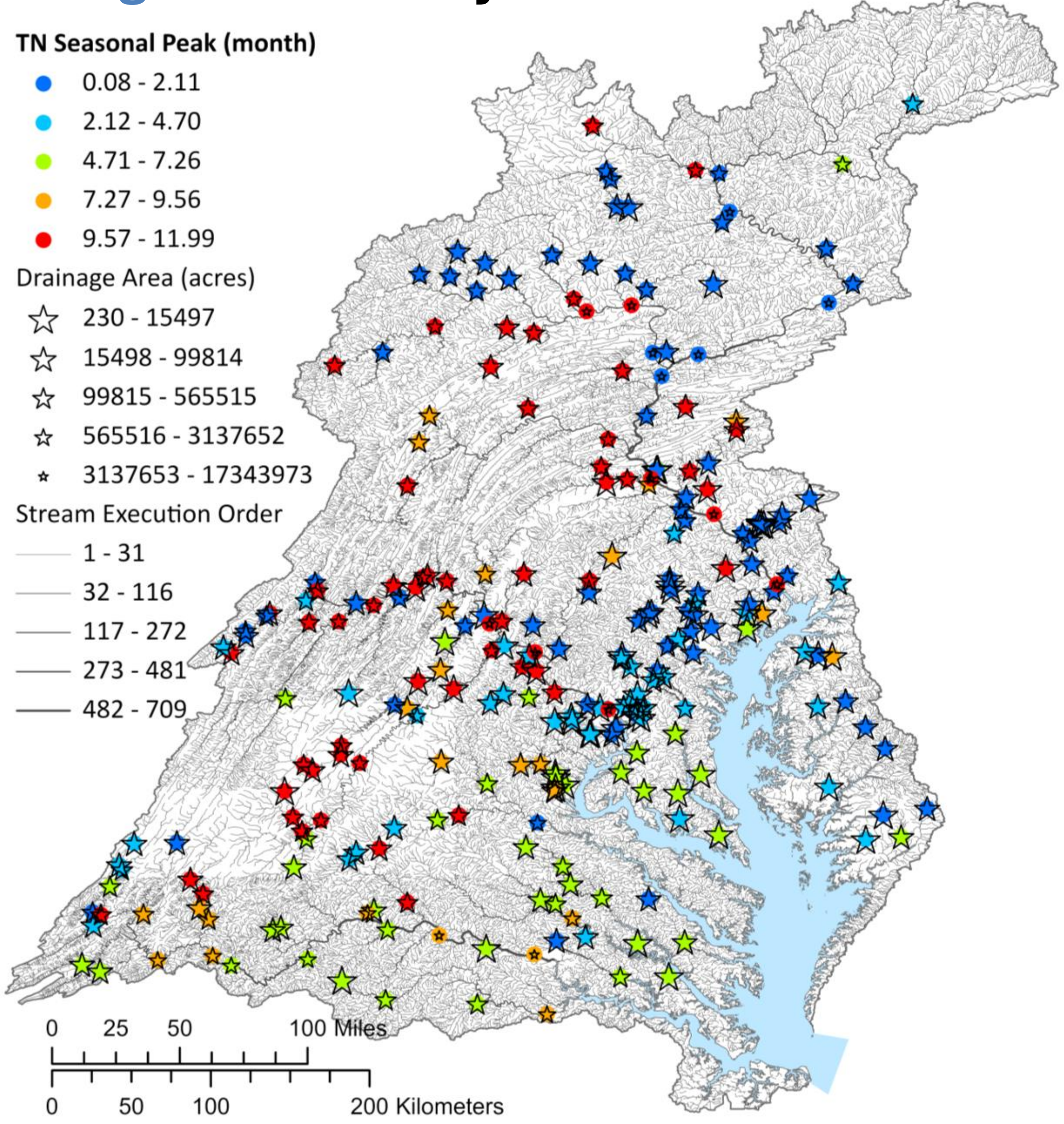


Flow variability, β_2 parameter

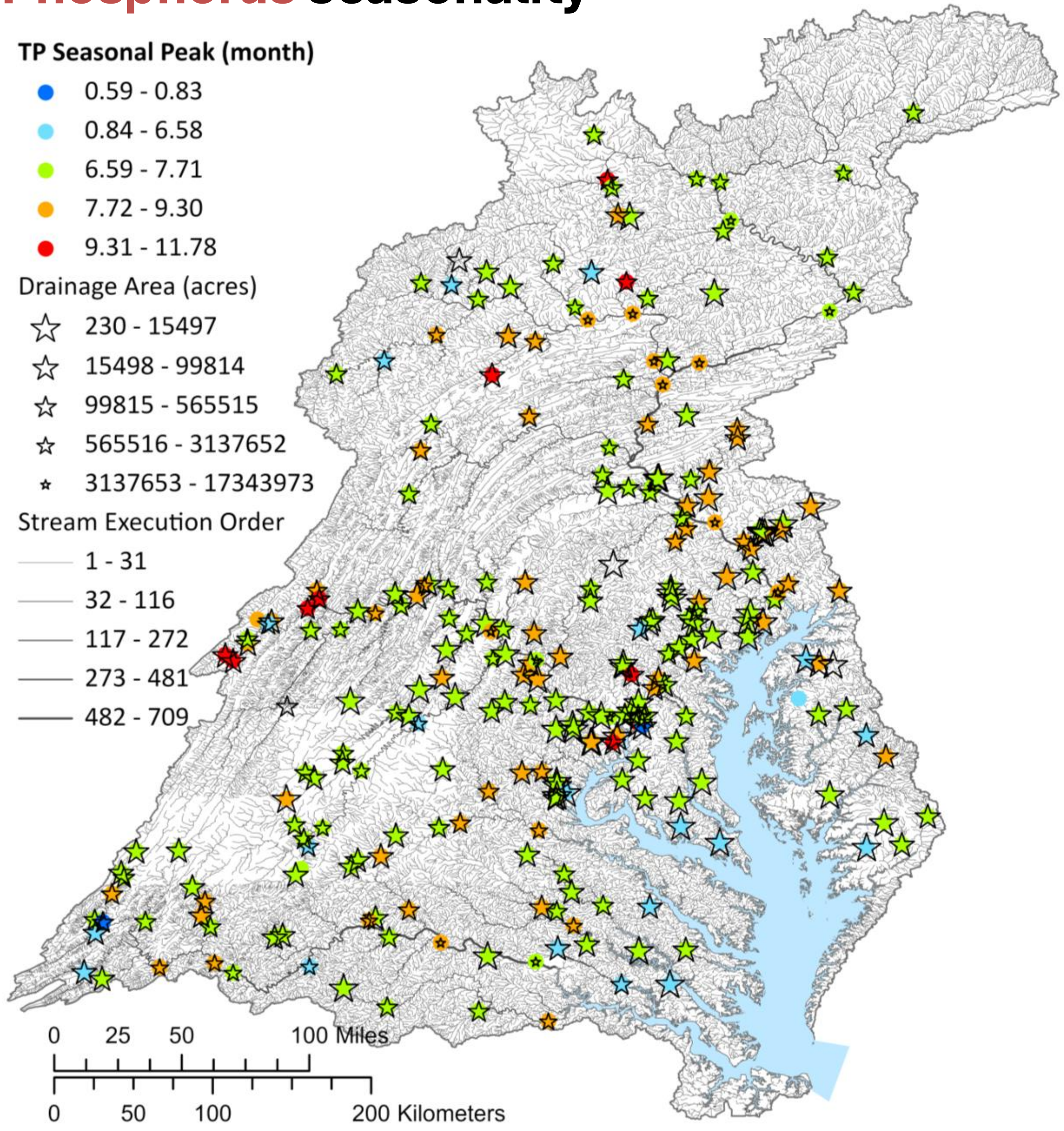




Nitrogen seasonality

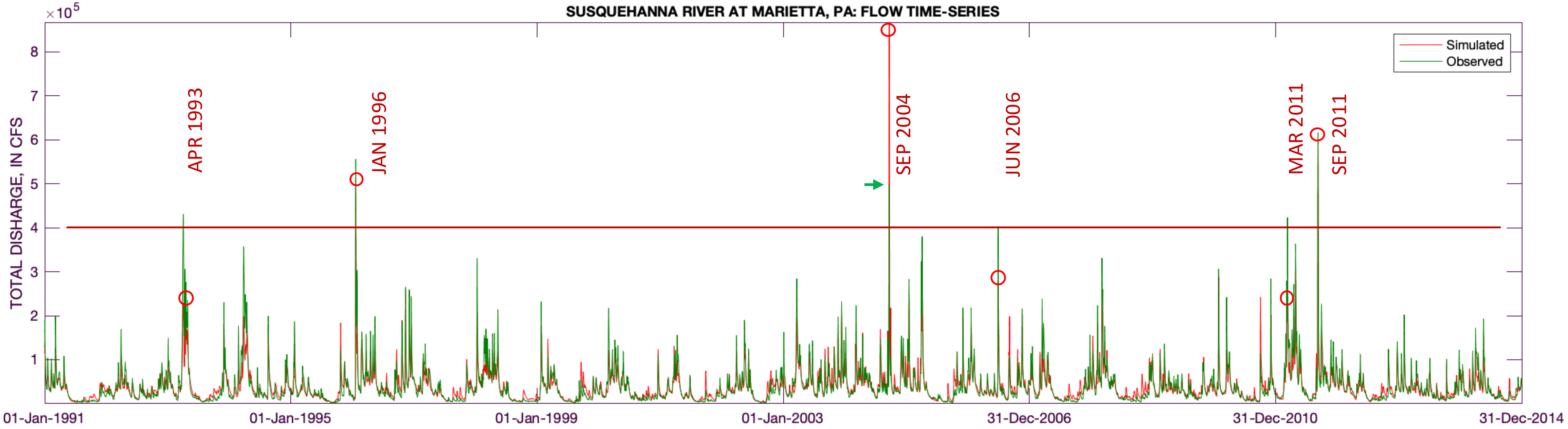


Phosphorus seasonality

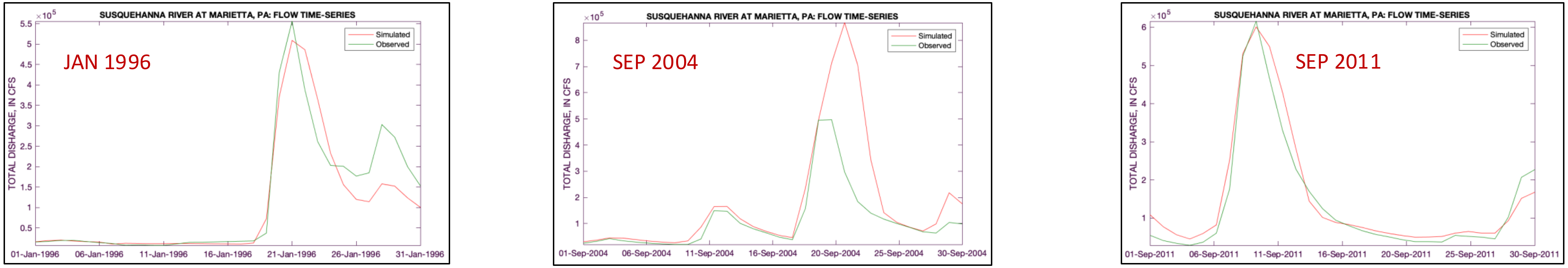


$$ln(c) = \beta_o + \beta_1 t + \beta_2 \, ln(Q) + \boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t) + \varepsilon$$

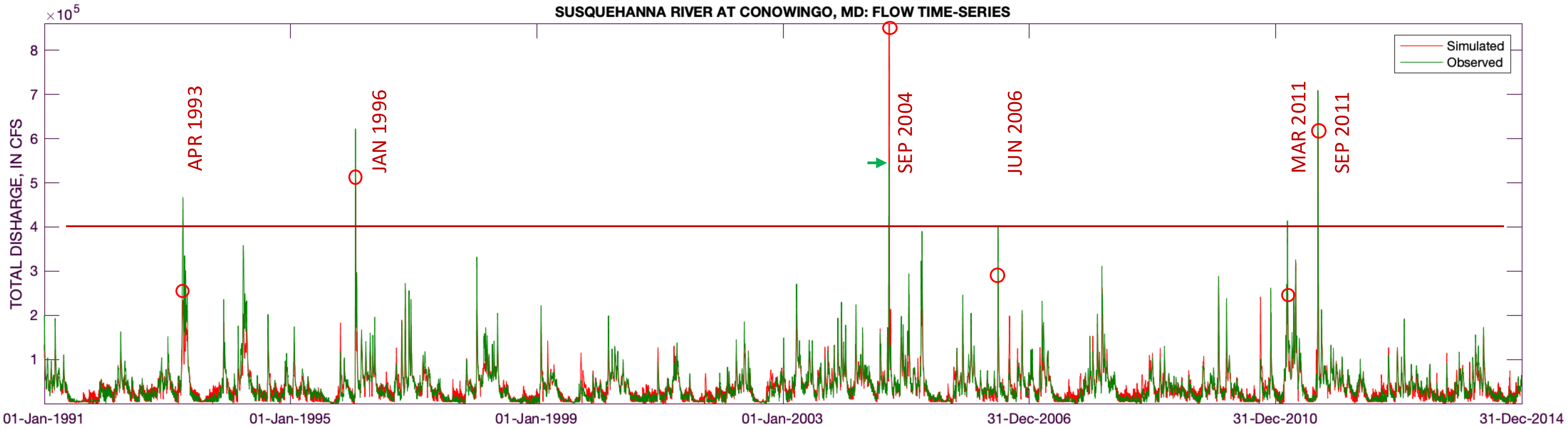
Susquehanna River at Marietta, PA



There were 6 events when flow exceeded 400,000 cfs and most of them were under simulated, except for 2004



Susquehanna River at Conowingo, MD



There were 6 events when flow exceeded 400,000 cfs and most of them were under simulated, except for 2004