Phase 7 WSM Development – Water Quality Routing for Small 100K NHDplus Streams

Modeling Workgroup Quarterly Meeting – January 2024

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Presentation Outline

Phase 7 Dynamic Watershed Model (DWM)

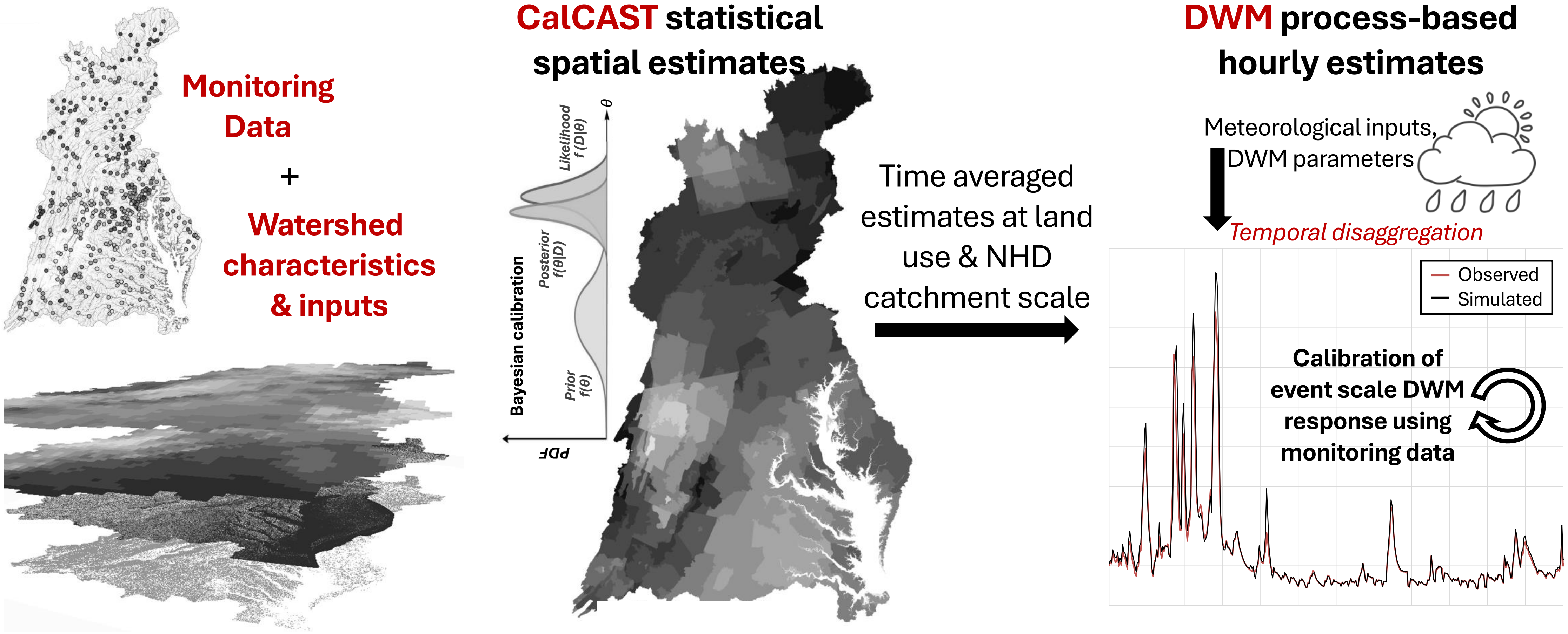
1. **Dynamic Watershed Model Overview**
2. **Review of prior model development progress**
3. **Water quality routing for small streams**
   - Building blocks of water quality routing
   - Structure of water quality routing
   - ~~Model testing and verification~~
4. **Summary and next steps**

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: Spatial Model (CalCAST) → Dynamic Watershed Model (DWM)



- 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

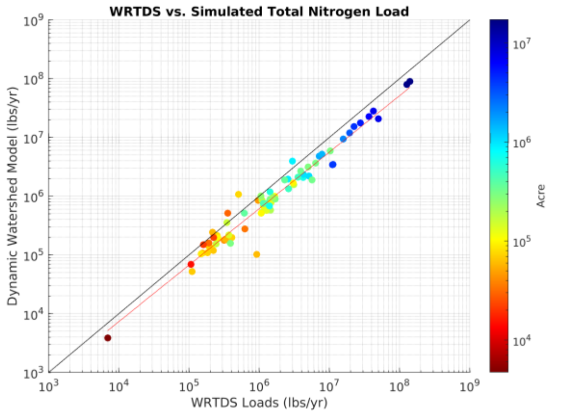
Development Milestones (2022)

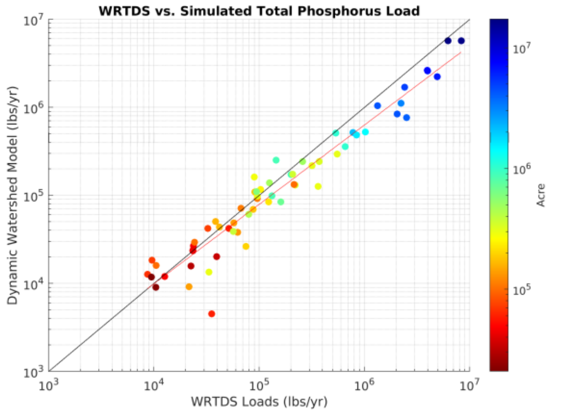
100K NHD	NHD-scale model structure; Hydrology prototype; Expanded simulation period 1985 to 2020; [1][2]
HYDROLOGY	Hydrology calibration (CalCAST→DWM) method updates; initial testing of numerical simplifications for flow routing; [3]
SEDIMENT	Sediment model; Hydrology model calibration updates with respect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

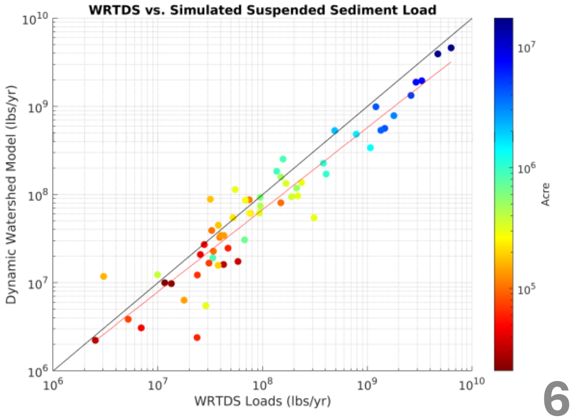
[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress-in-phase-7-wsm-development-1.4.2022-gopal_bhatt_penn_state.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_wsm_development_4.5.2022_-_gopal_bhatt_penn_state.pdf
[3] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/progress_in_phase_7_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

Dynamic Watershed Model (DWM) Development

- **Operational model prototypes**
  - **Reasonable runtime (~16-21 hours)**
  - **Reasonable results out of model prototypes**
- **Need for improving/growing the model on multiple fronts**







Dynamic Watershed Model (DWM) Development

… incremental improvements during 1Q to 3Q - 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
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

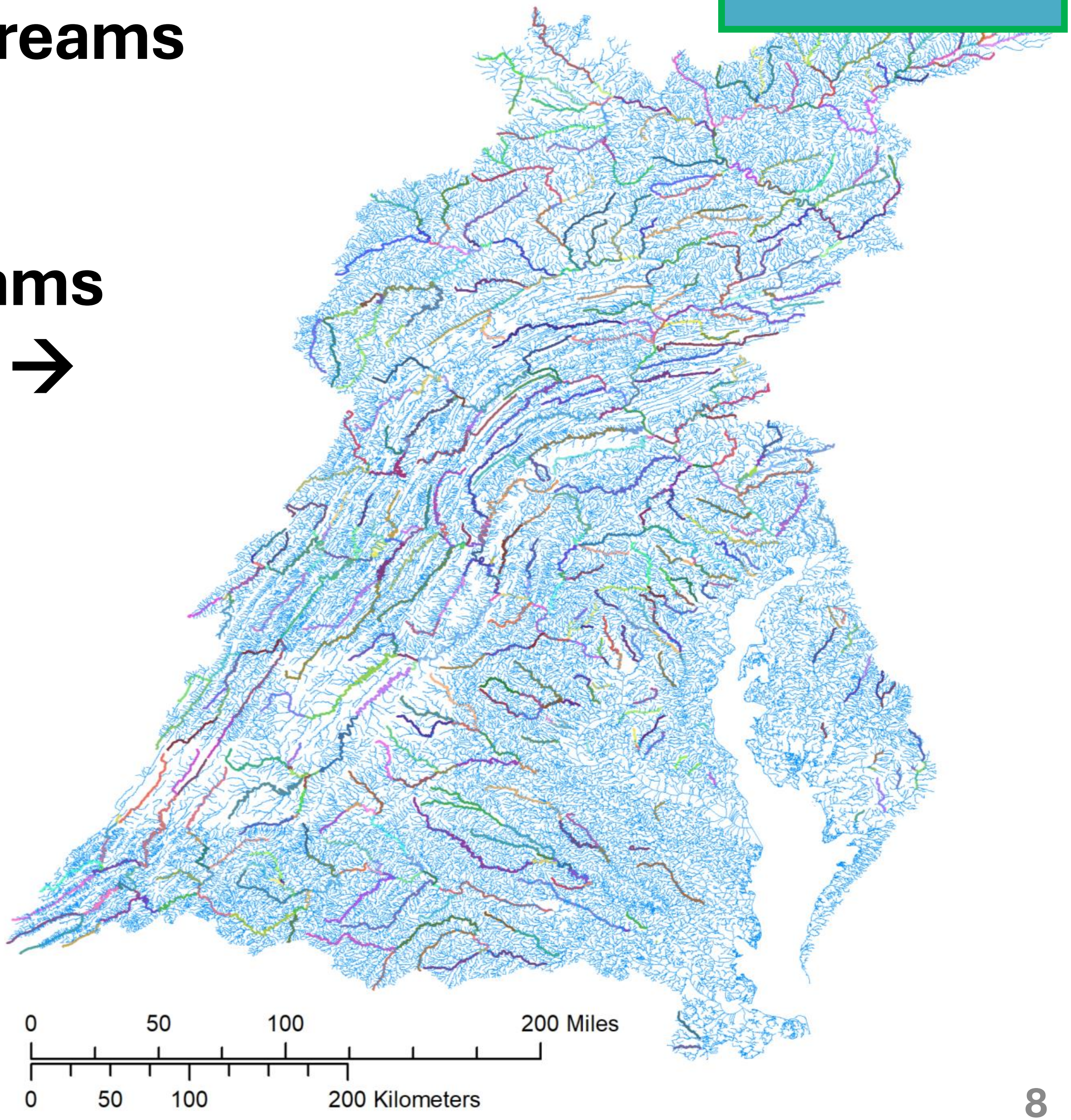
October 2023

Hydraulic Routing for Small Streams

nested model
segmentation of streams
and river mainstems →

100K NHD STREAMS → **Non-iterative Routing**

RIVER MAINSTEM → HSPF

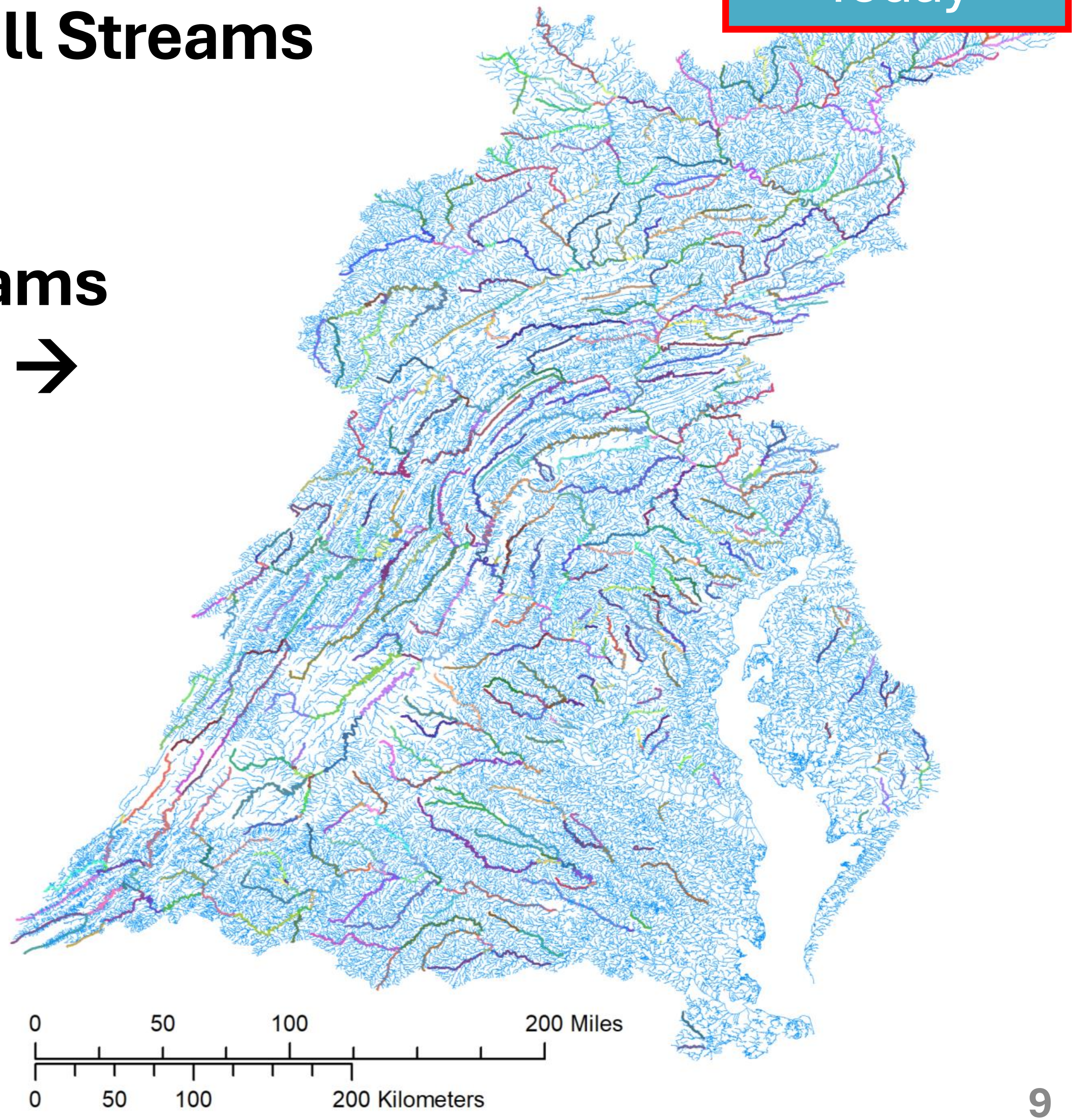


Today

Water Quality Routing for Small Streams

nested model segmentation of streams and river mainstems →

100K NHD STREAMS	→	**WQ Routing**
RIVER MAINSTEM	→	HSPF

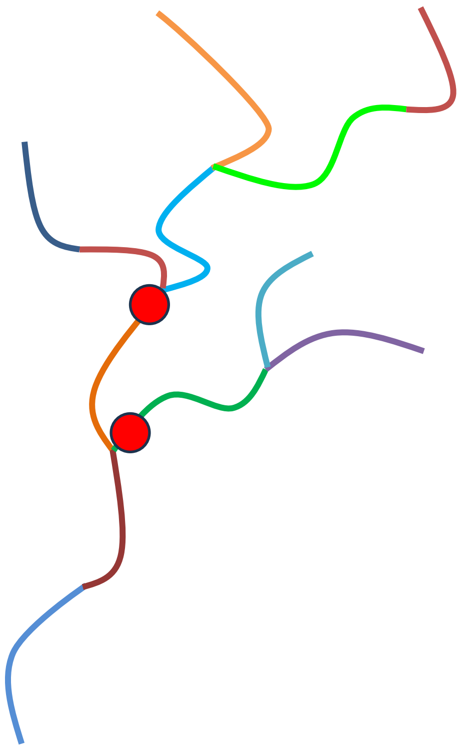


Building blocks of water quality routing for small streams

- Develop model parameters that provide information on ***flow*** and ***seasonal*** variability in concentration for small 100K NHDplus streams
  - parameters rooted in monitoring data and emergent watershed properties
  - improved loadings to the tidal estuary and to HSPF simulations of river mainstems

- Tools such as WRTDS-K and Fluxmaster-K can be useful

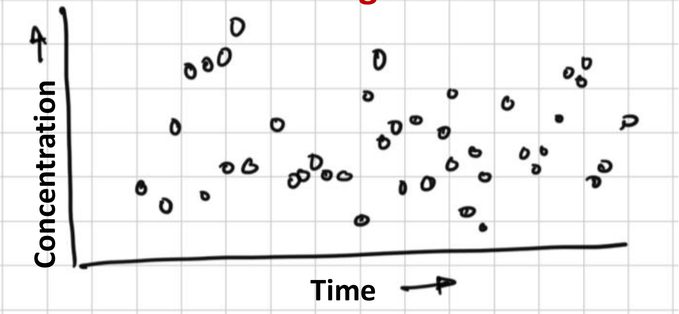
Figure: network of small streams and monitoring stations



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

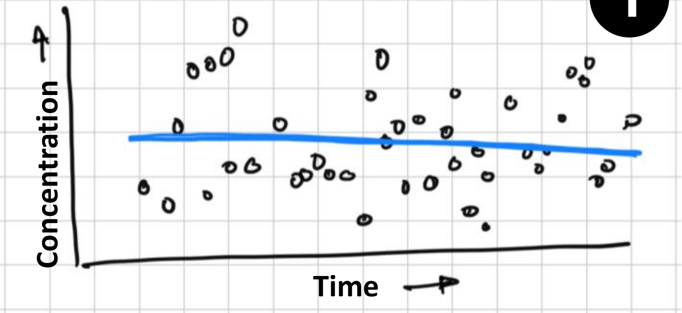
Building blocks of water quality routing for small streams

> data at a monitoring station



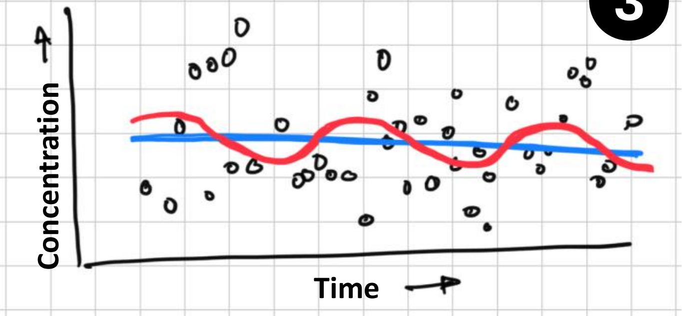
$ln(c_{trend}) = \beta_x + \boldsymbol{\beta_1} t$

1



$ln(c_{season}) = \boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t)$

3



$ln(c_{flow}) = \beta_y + \boldsymbol{\beta_2}\, ln(Q)$

2

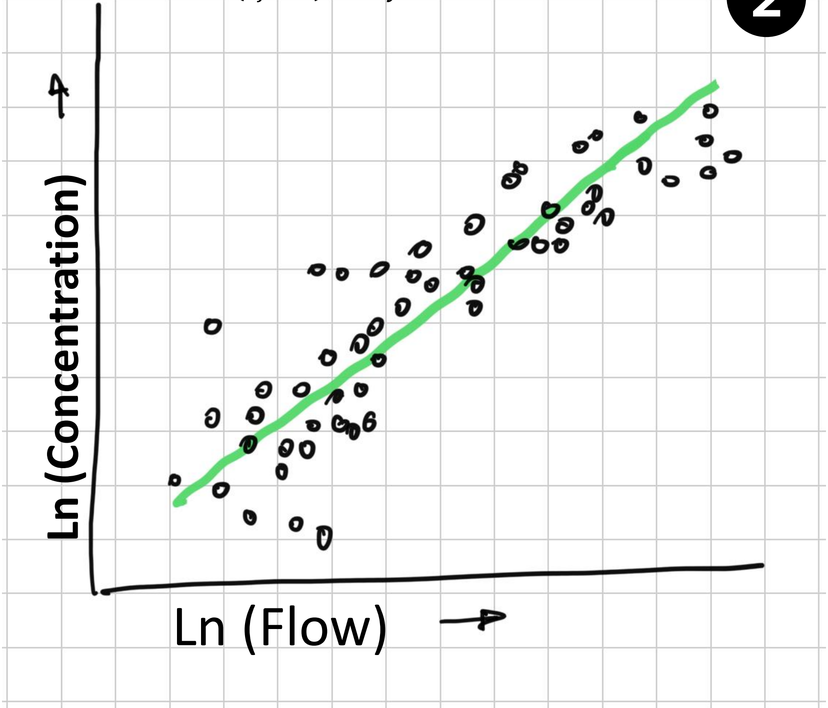
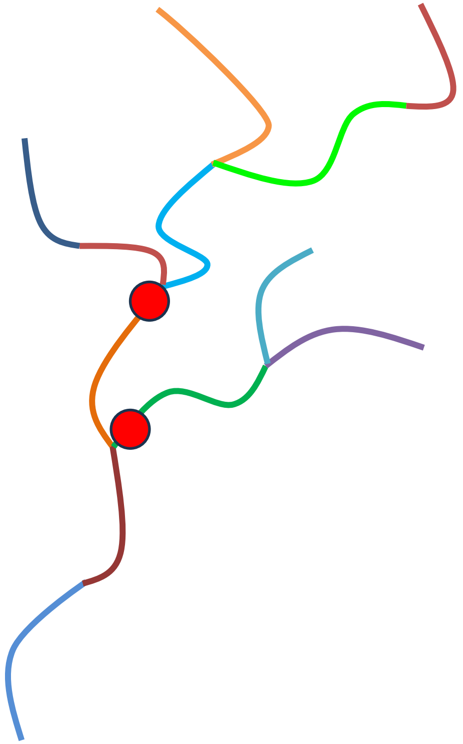


Figure: network of small streams and monitoring stations

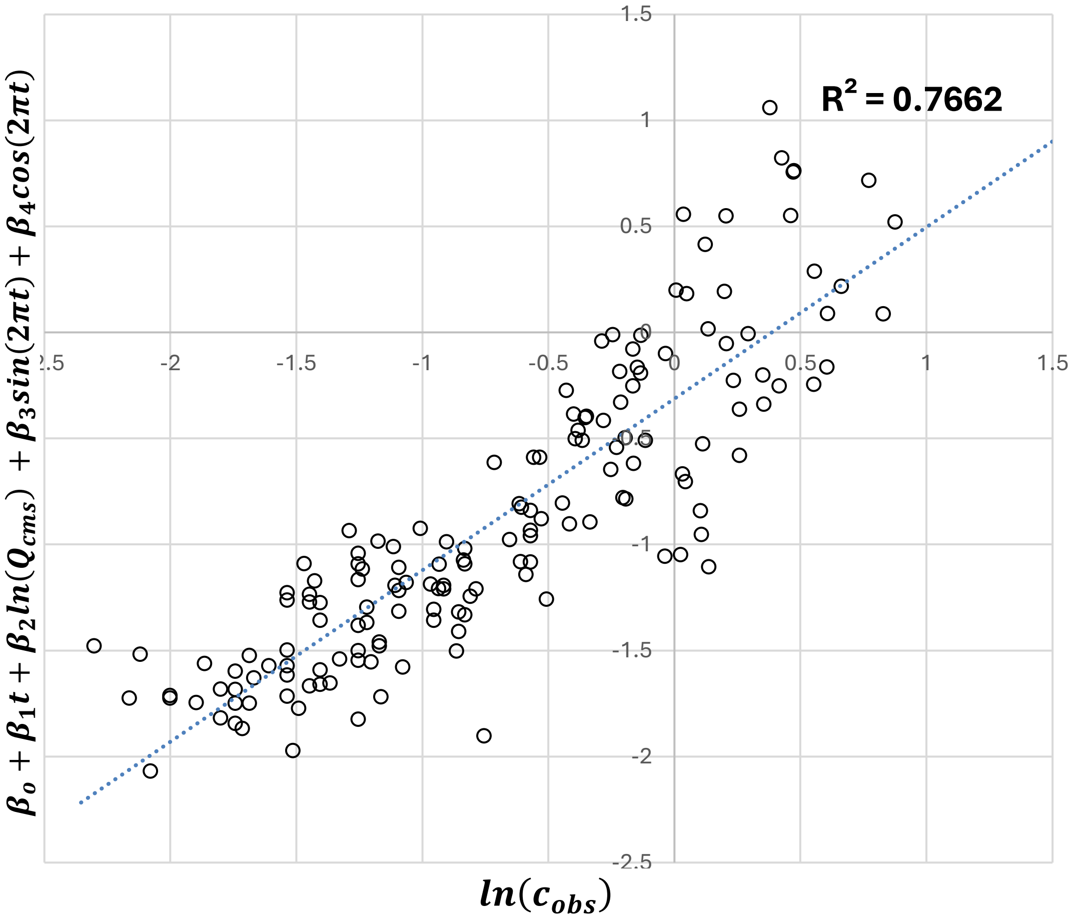


$$ln(c) = \beta_o + \underbrace{\beta_1 t}_{1} + \underbrace{\boldsymbol{\beta_2}\, ln(Q)}_{2} + \underbrace{\boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t)}_{3} + \varepsilon$$

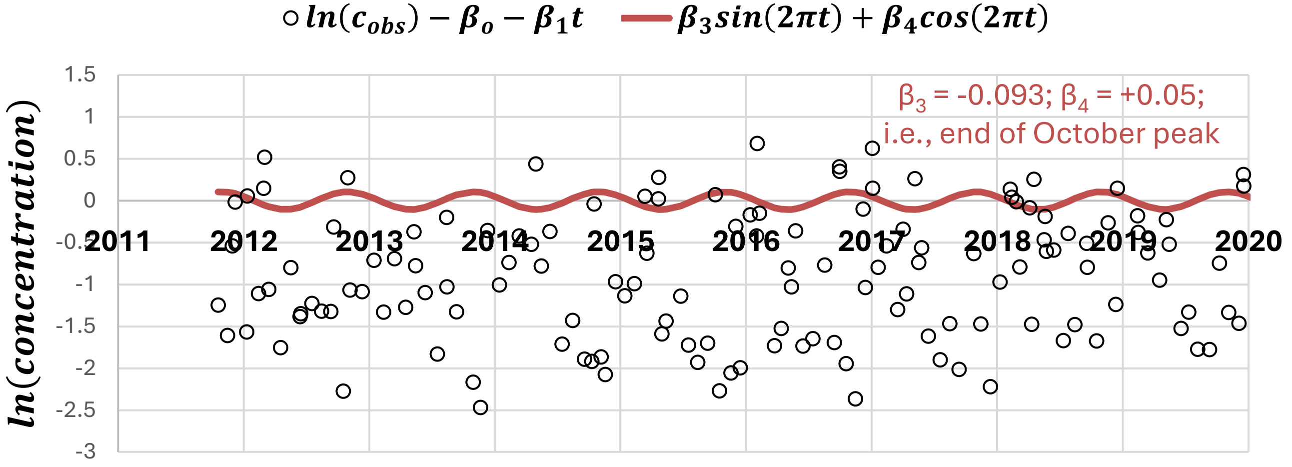
Building blocks of water quality routing for small streams

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

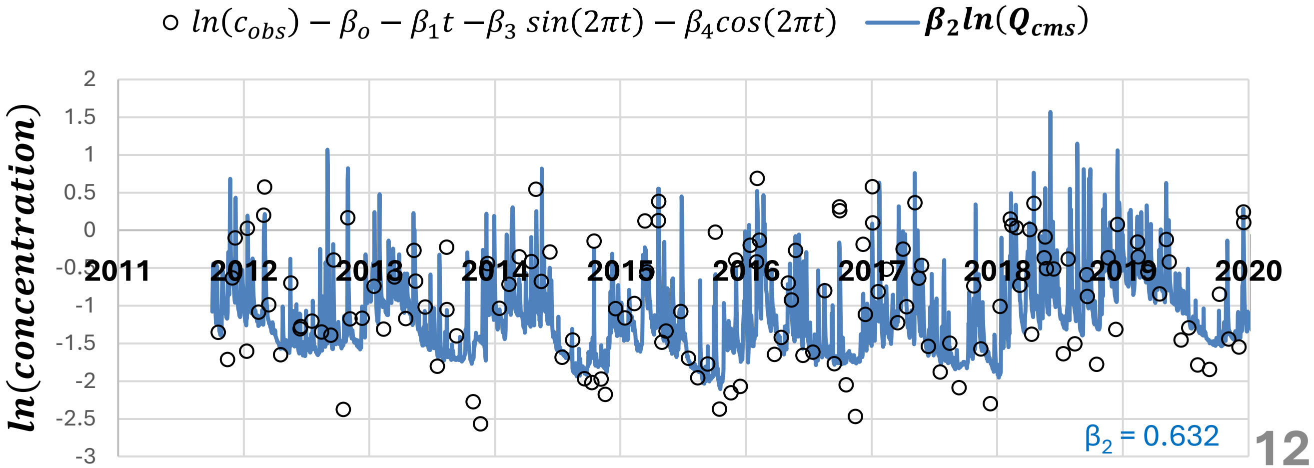
USGS 01613030 - Warm Springs Run Near Berkeley Springs, WV

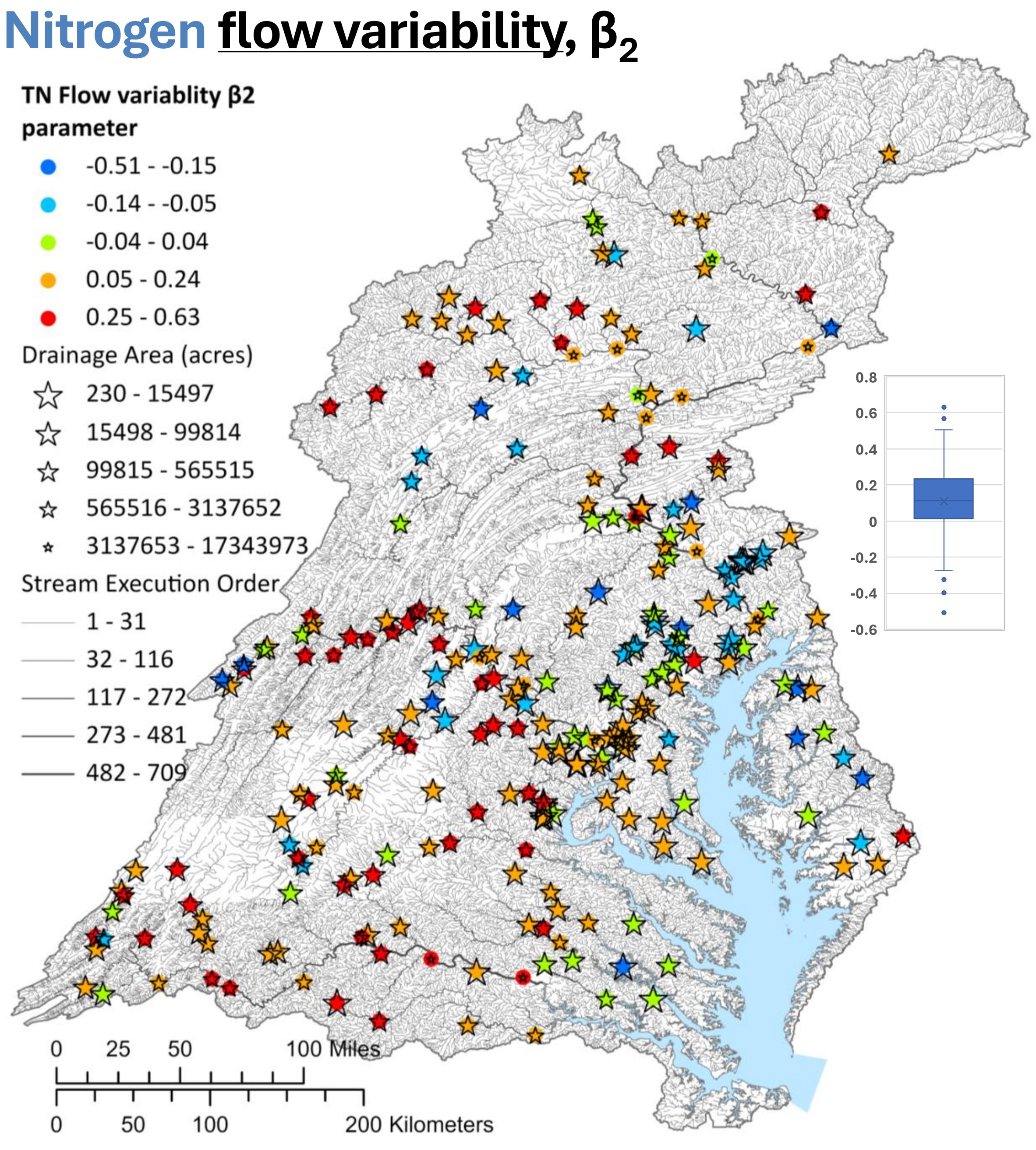


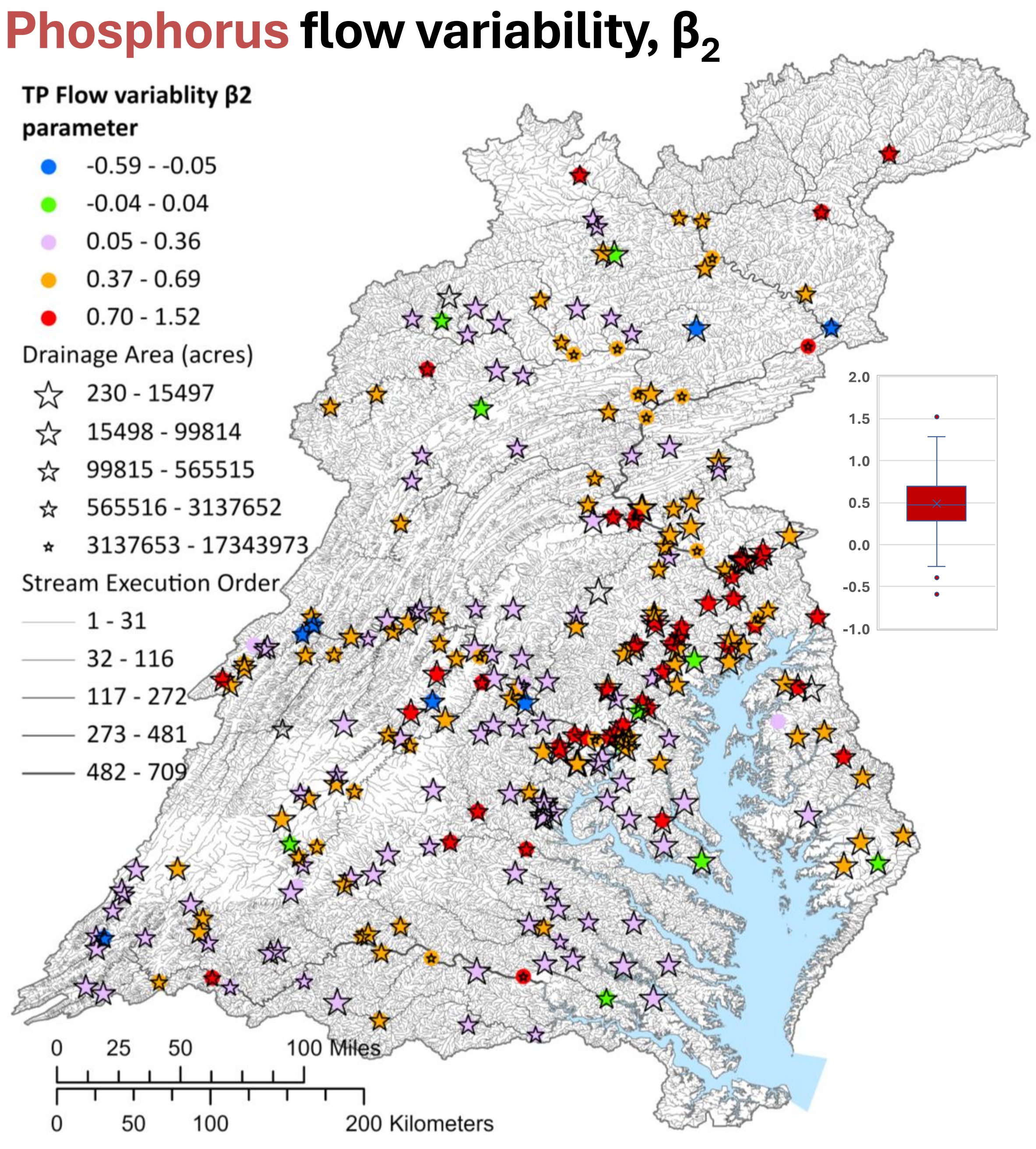
TN Seasonal Variablity



TN Flow Variability

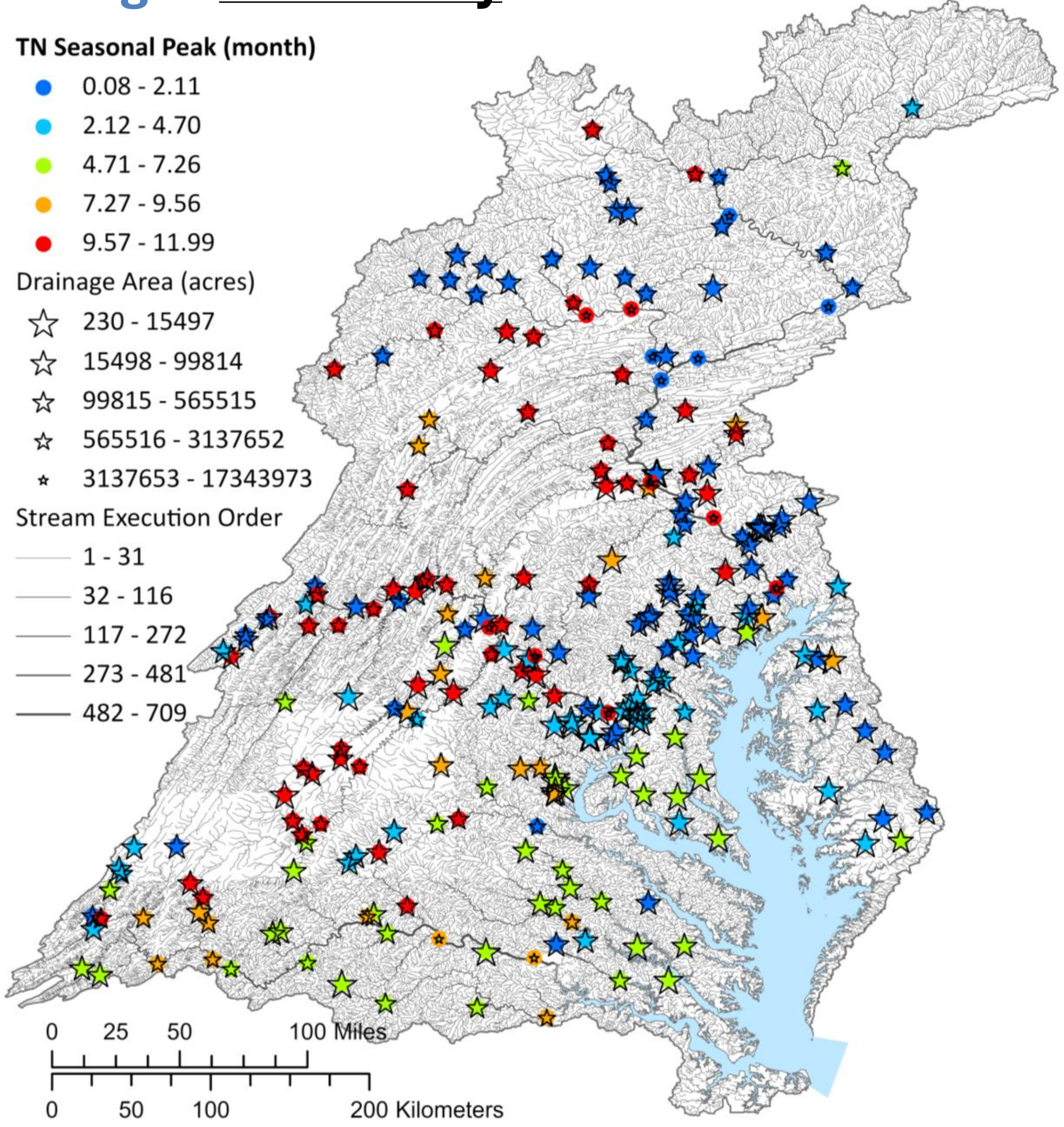




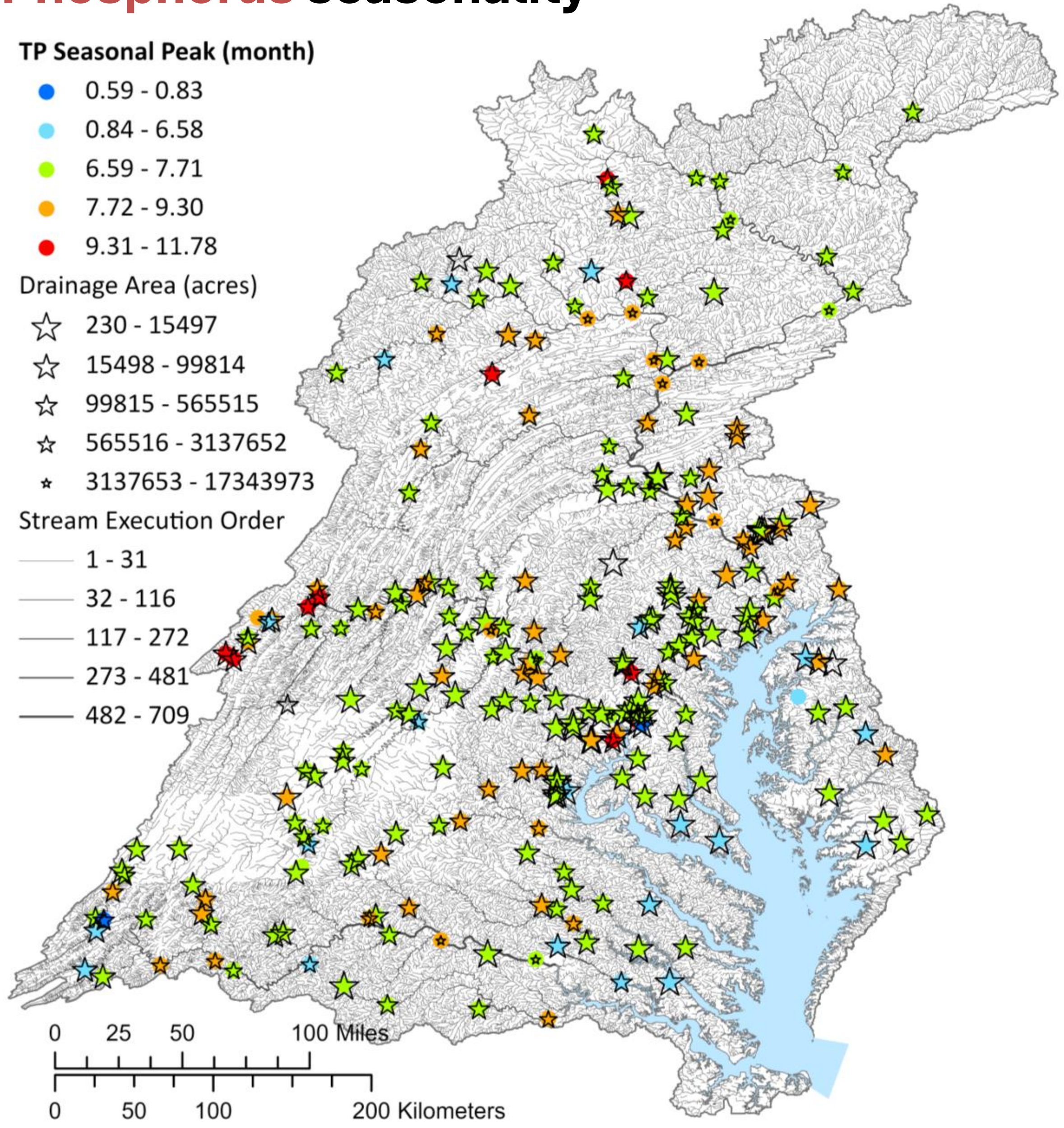


$$ln(c) = \beta_o + \beta_1 t + \boldsymbol{\beta_2}\, ln(Q) + \beta_3 sin(2\pi t) + \beta_4 cos(2\pi t) + \varepsilon$$

Nitrogen seasonality



Phosphorus seasonality

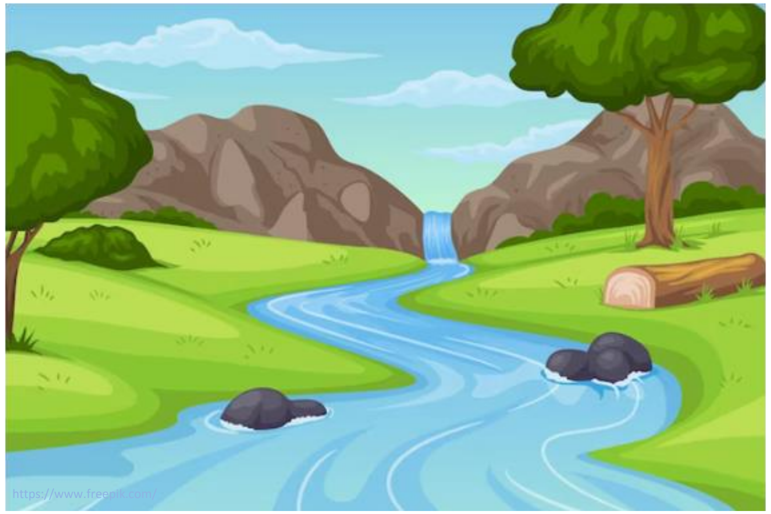


$$ln(c) = \beta_o + \beta_1 t + \beta_2 \, ln(Q) + \boldsymbol{\beta_3} sin(2\pi t) + \boldsymbol{\beta_4} cos(2\pi t) + \varepsilon$$

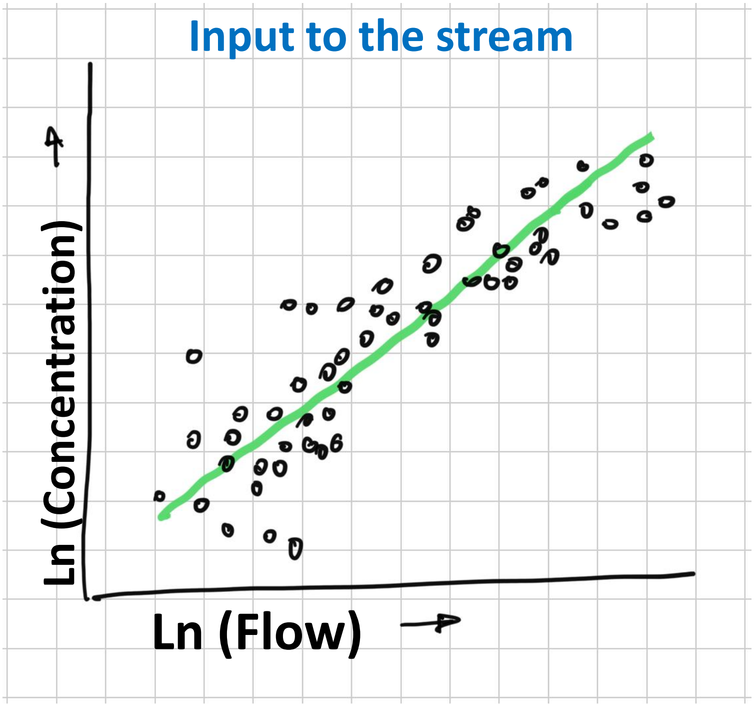
Structure of water quality routing for small streams

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

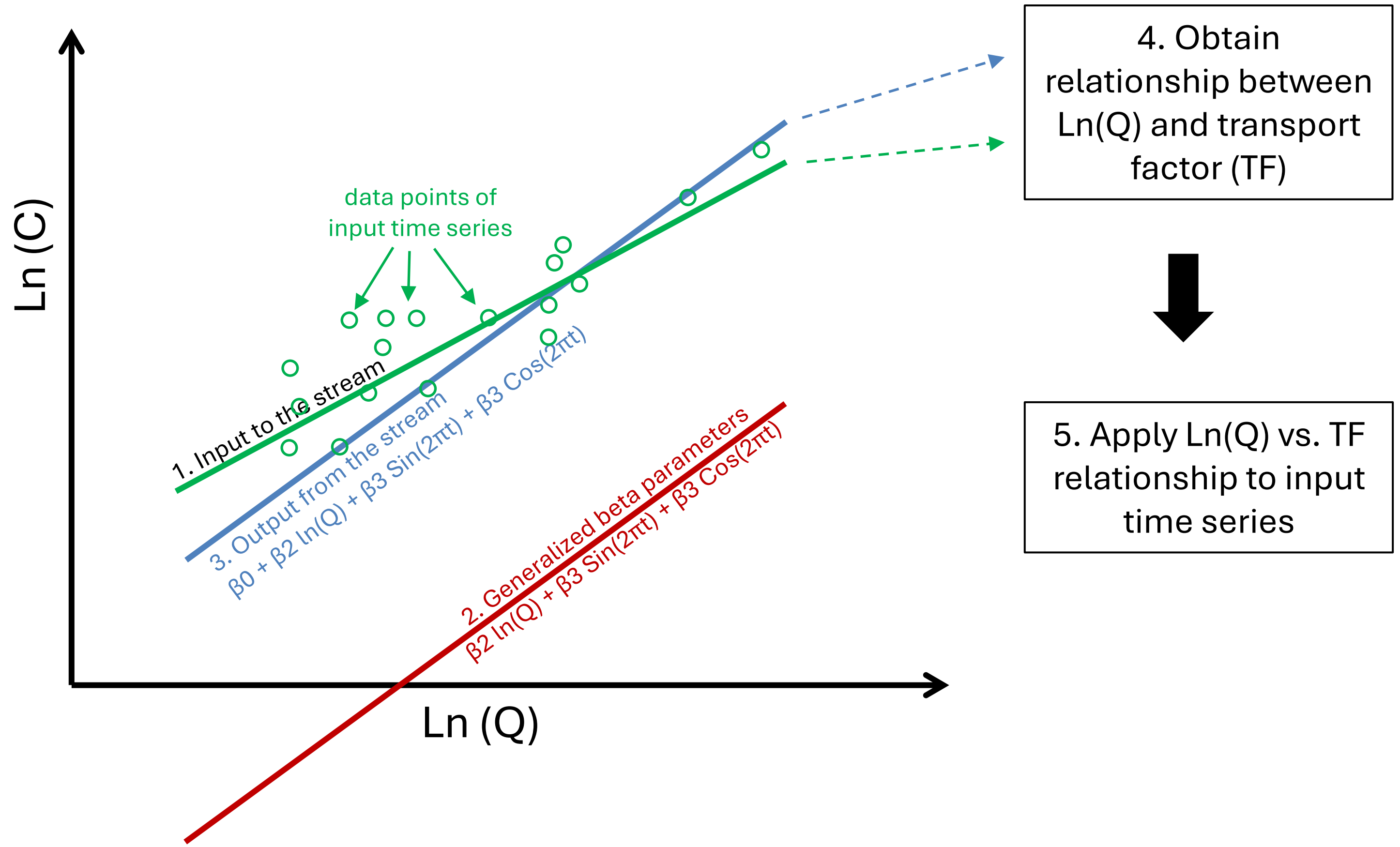


Biogeochemical processing, Storage/deposition, Scour
➔ Fate and Transport



? … emergent behavior

Structure – two good options



Option 1: Concentration time series generated at the end of Step #3

Option 2: Concentration time series generated at the end of Step #5

Summary

1. We implemented water quality routing for small streams and tested it for total nitrogen

- unit water quality response provides trend in delivery from land uses as a function of history of inputs and lag time parameters
- flow and seasonal variabilities are incorporated in the water quality simulation of small streams

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

2. expand water quality routing of small streams to TP, N and P species, and sediment

3. examine surface and groundwater transport in the land simulation

4. Water quality calibration and linkage with the estuarine models