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

Modeling Workgroup Quarterly Meeting – June 2023

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)

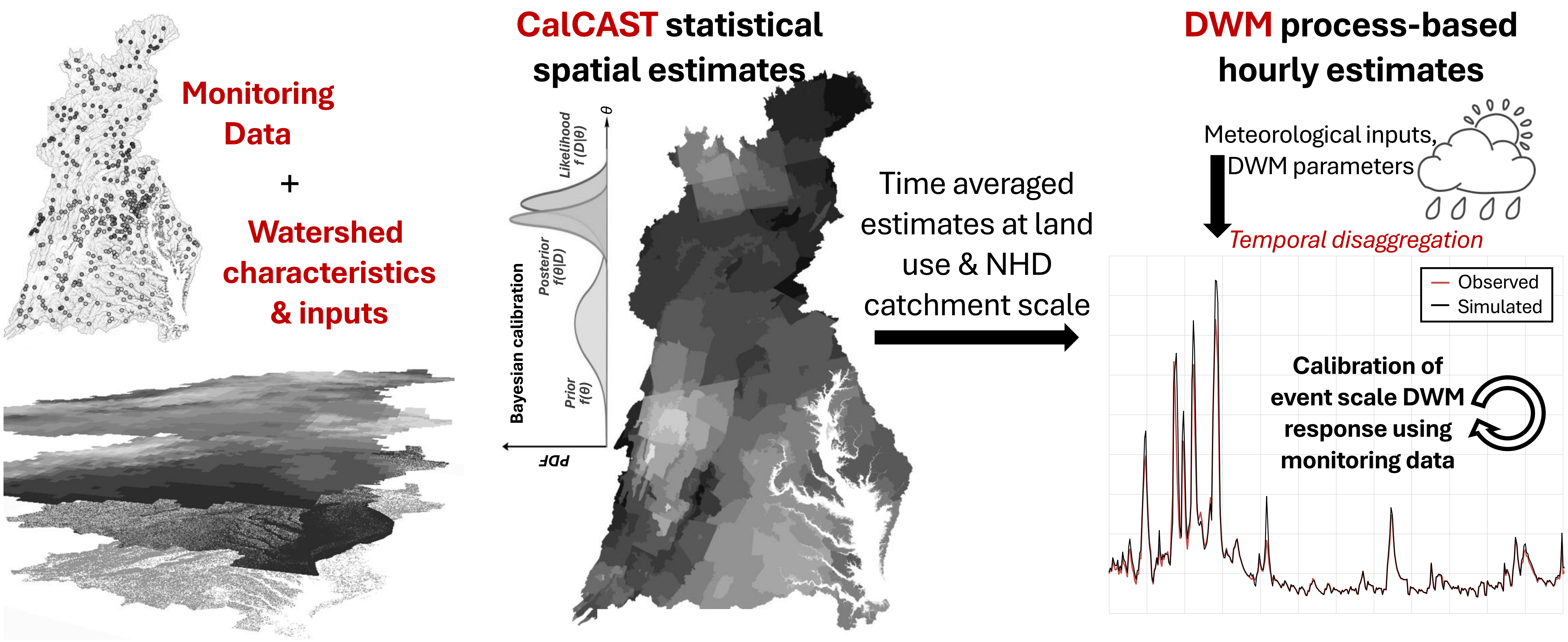
1. **Dynamic Watershed Model Overview**
2. **Summary of prior model development progress**
3. **Hydraulic routing for small streams**
   - Channel hydraulic properties
   - Conceptual model and simplifications
   - Model testing and verification
4. **Summary and next steps**

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.

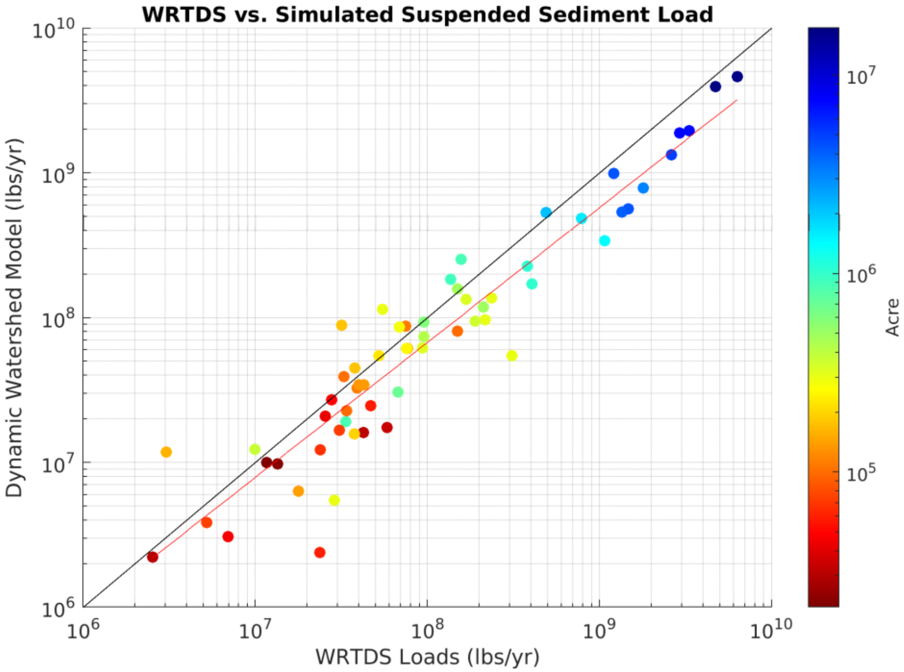
Dynamic Watershed Model (DWM) Development

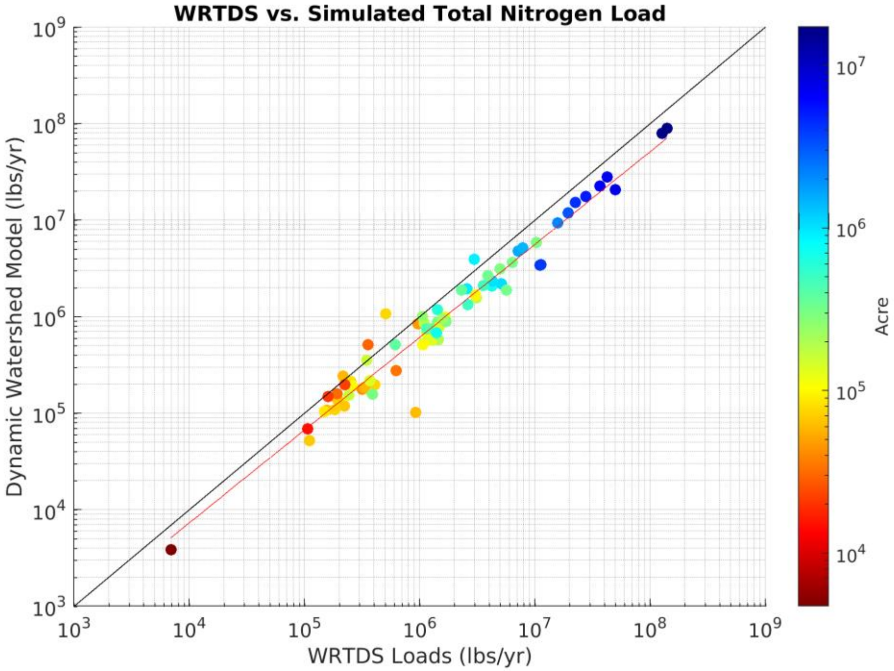
Development Milestones (2022)

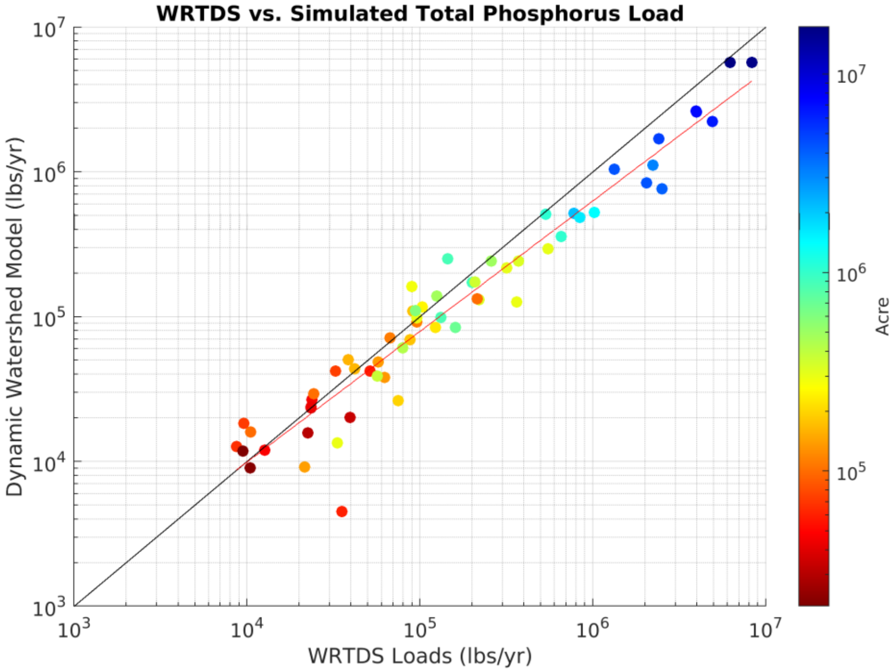
100K NHD	NHD-scale model structure; Hydrology prototype; Expanded simulation period 1985 to 2020; [1][2]
HYDROLOGY	Hydrology calibration (CalCAST→DWM) method updates; Simple routing (initial testing of numerical simplifications); [3]
SEDIMENT	Sediment model; Hydrology model calibration updates with respect 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

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







Dynamic Watershed Model (DWM) Development

… incremental improvements during 1Q and 2Q - 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 ▪ we focused on improving segmentations in the tidal watershed ▪ overall, we have a better prototype than we had previously
Model	Improvements on overcoming the 'aggregation effect' in the simulation of the mainstems (CalCAST → DWM)
Simulation	Testing on Amazon AWS and MS Azure cloud HPC environments with various node type and size configurations

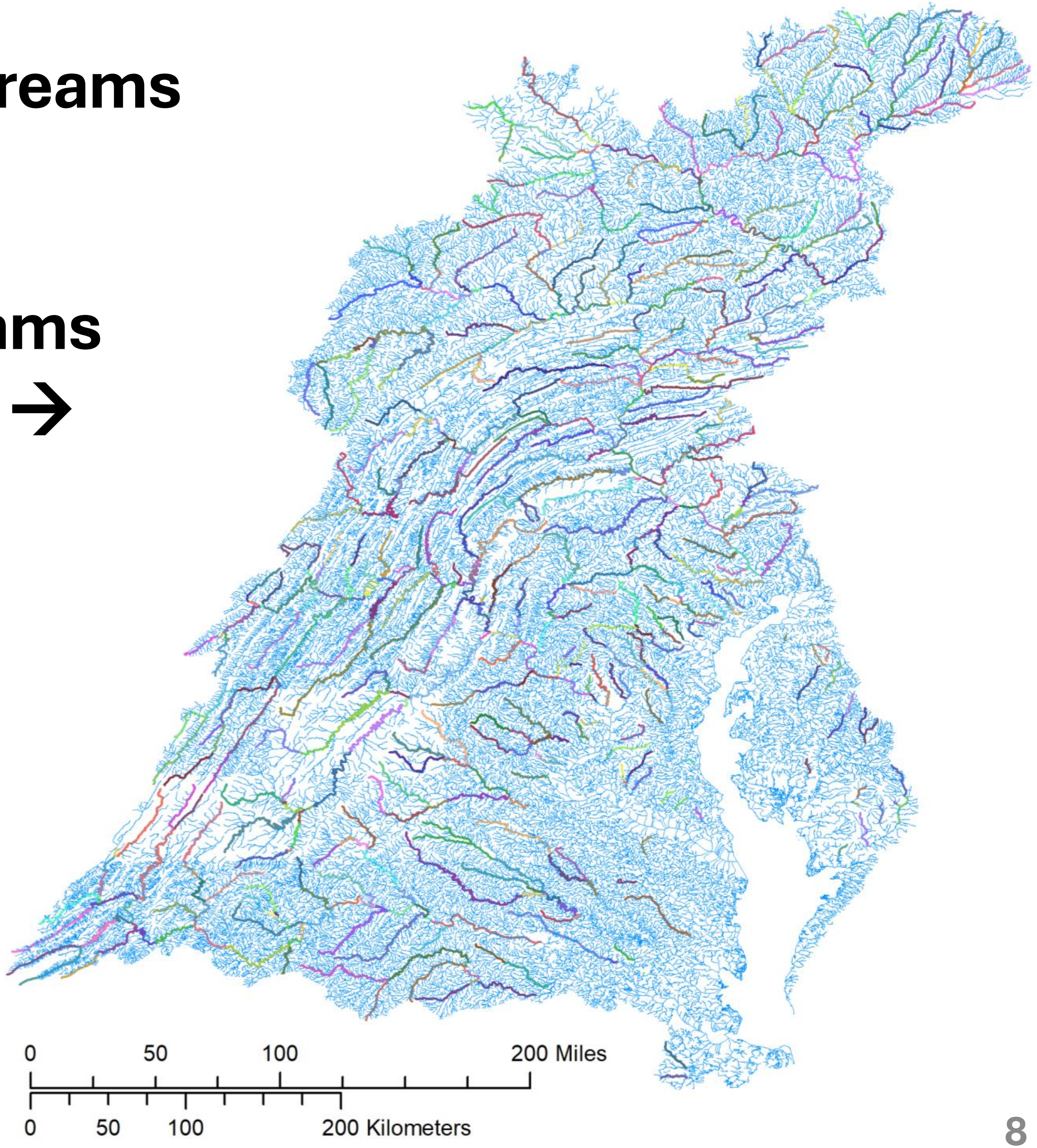
[1] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/20230404-BHATT-Phase-7-WSM-Development-Dynamic-Model-Development-2023Q1.pdf
[2] https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/Progress-in-Phase-7-WSM-Development-Gopal-Bhatt-Penn-State-6.20.2023.pdf

Hydraulic Routing for Small Streams

nested model
segmentation of streams
and river mainstems →

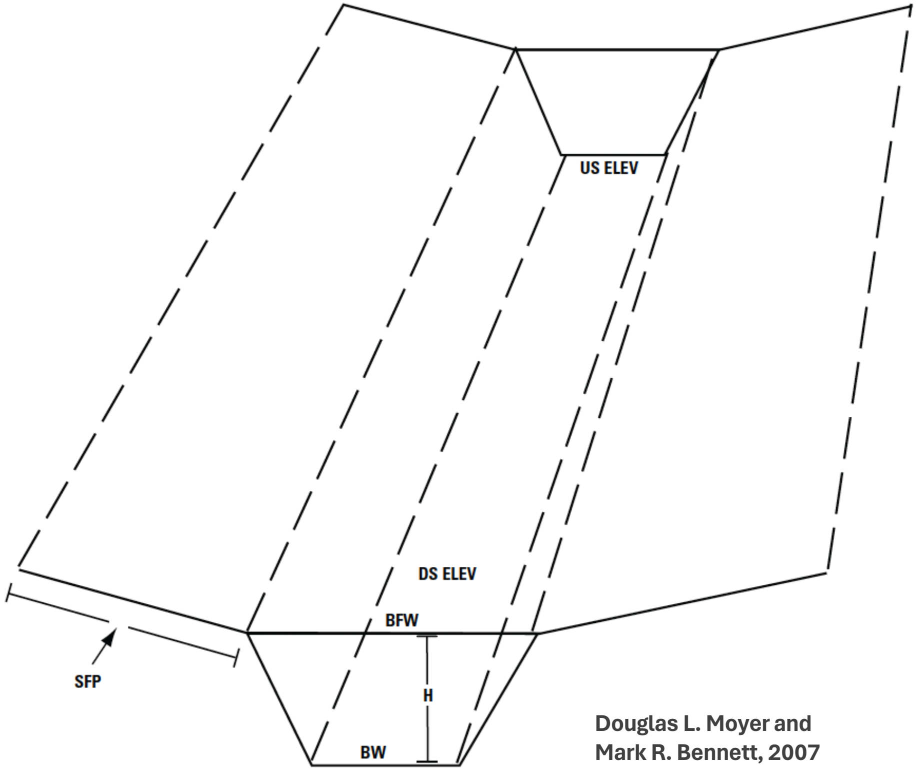
100K NHD STREAMS → **Non-iterative Routing**

RIVER MAINSTEM → HSPF

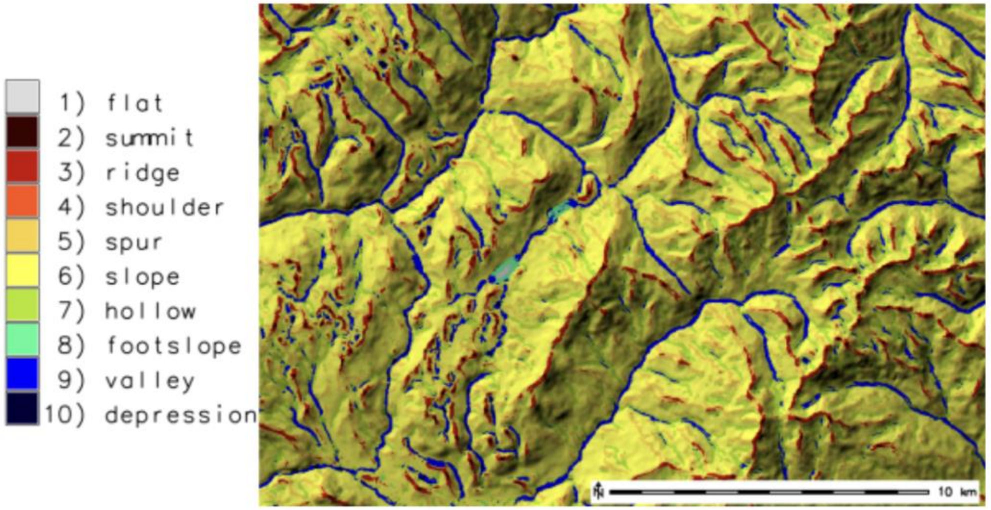


Channel Properties

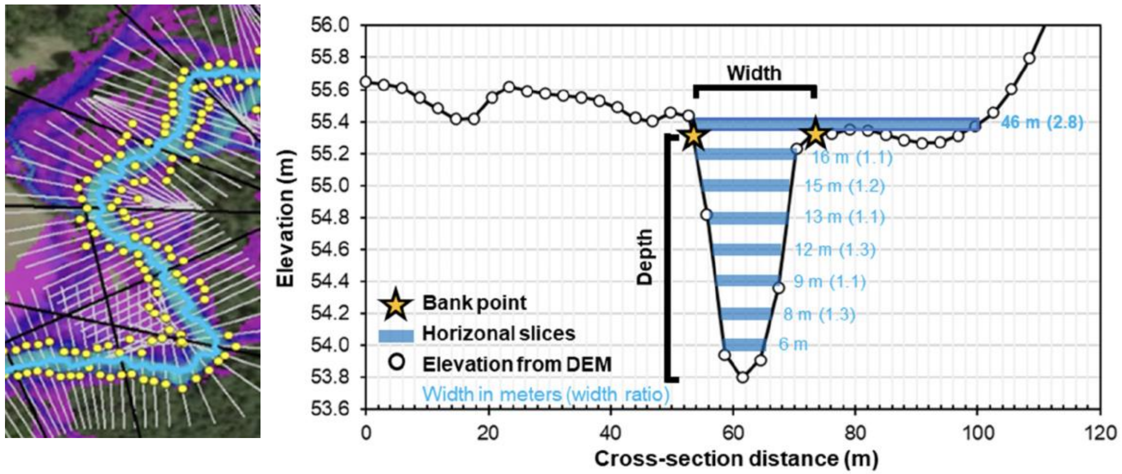
- Bed width, Bank full width, Bank full height, slope, Manning's roughness, etc.



Douglas L. Moyer and Mark R. Bennett, 2007



Baker, Saavedra, Norton (2018) have developed high-resolution stream and associated geometry dataset for the Chesapeake Bay watershed using geomorphons (terrain forms or landforms) classification based on machine vision approach [1][2].



Labeeb Ahmed, Kristina Hopkins, Peter Claggett, and others have developed the Floodplain and Channel Evaluation Tool (FACET) for automated processing of digital elevation models (DEMs) to generate regional-scale estimates of bank height, channel width, floodplain width.

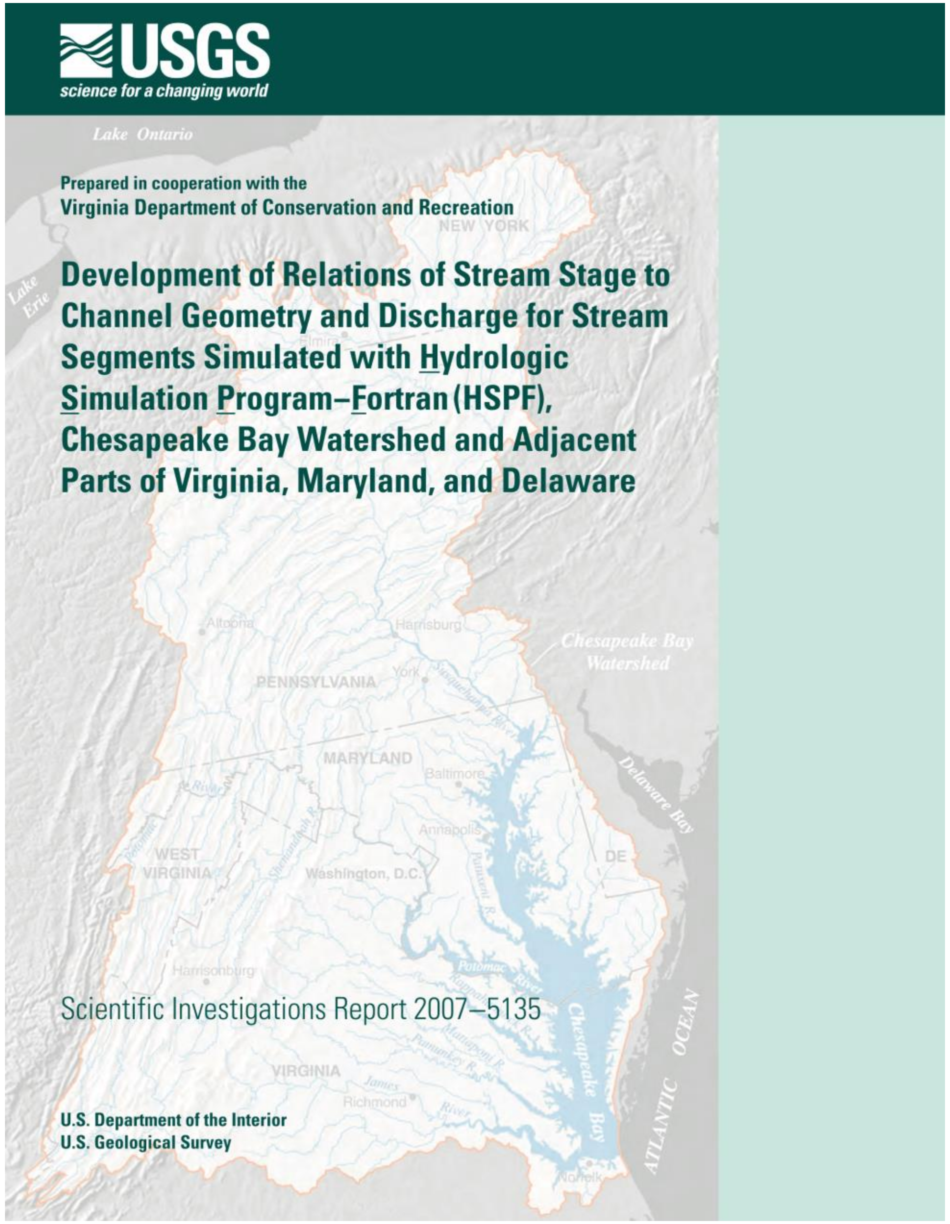
[1] Baker, Saavedra, Norton (2018) Methodology for developing high-resolution stream and waterbody datasets for the Chesapeake Bay watershed
[2] Jasiewicz, J., Stepinski, T., 2013, http://dx.doi.org/10.1016/j.geomorph.2012.11.005 https://grass.osgeo.org/grass83/manuals/r.geomorphon.html

Channel Properties

Table 4. Regional regression equations, relating channel geometry to basin drainage area and associated diagnostic statistics, for streamflow-gaging stations in the Appalachian Plateaus, Valley and Ridge, Piedmont, and Coastal Plain physiographic provinces.

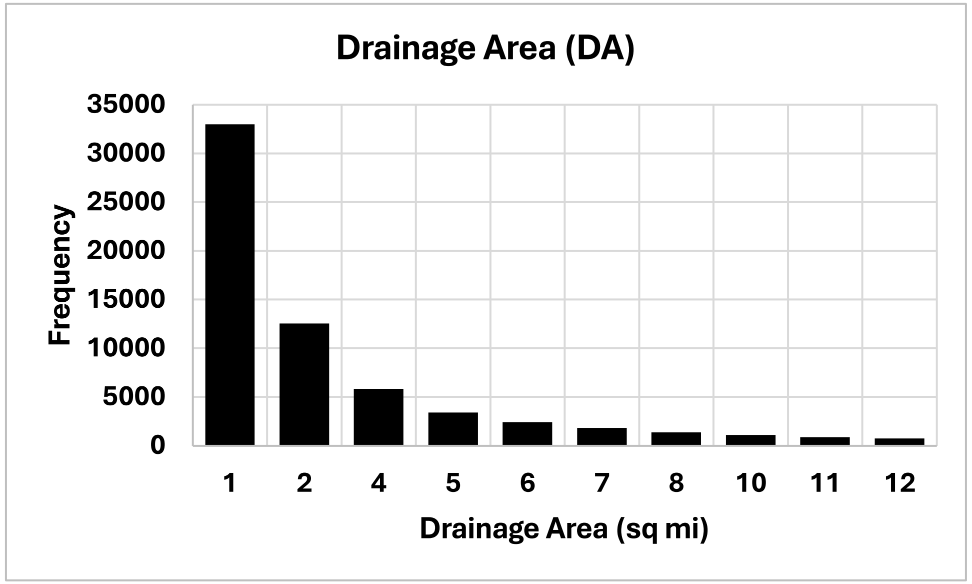
H, bankfull stage; **BFW**, bankfull width; **BW**, bottom width; **DA**, basin drainage area

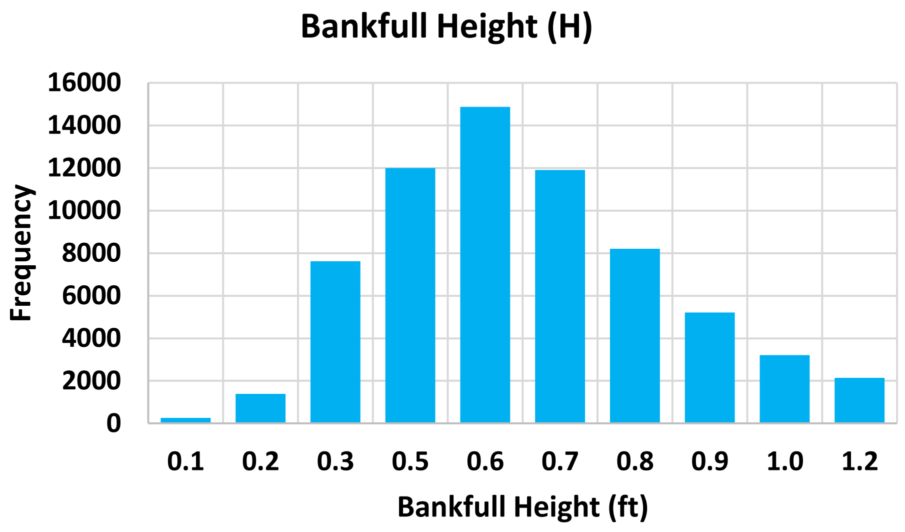
Province	Equation	*p*-value	R^2
		Bankfull stage	
Appalachian Plateaus	$H = 2.030*(DA)^{0.2310}$	0.00	0.633
Valley and Ridge	$H = 1.435*(DA)^{0.2830}$	.00	.718
Piedmont	$H = 2.137*(DA)^{0.2561}$	.00	.735
Coastal Plain	$H = 2.820*(DA)^{0.2000}$	.00	.609
		Bankfull width	
Appalachian Plateaus	$BFW = 12.175*(DA)^{0.4711}$	.00	.882
Valley and Ridge	$BFW = 13.216*(DA)^{0.4532}$	.00	.861
Piedmont	$BFW = 14.135*(DA)^{0.4111}$	.00	.846
Coastal Plain	$BFW = 15.791*(DA)^{0.3758}$	.00	.868
		Bottom width	
Appalachian Plateaus	$BW = 5.389*(DA)^{0.5349}$	.00	.776
Valley and Ridge	$BW = 4.667*(DA)^{0.5489}$	.00	.865
Piedmont	$BW = 6.393*(DA)^{0.4604}$	.00	.827
Coastal Plain	$BW = 6.440*(DA)^{0.4442}$	.00	.830

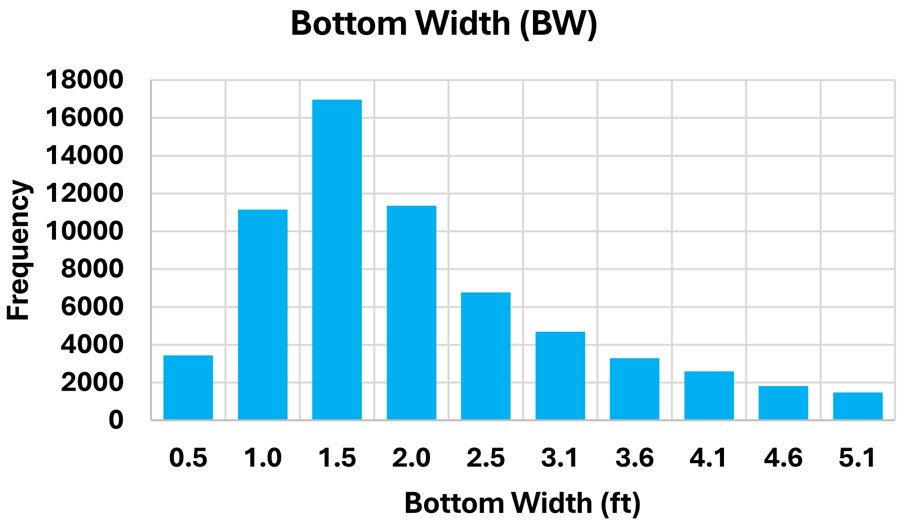


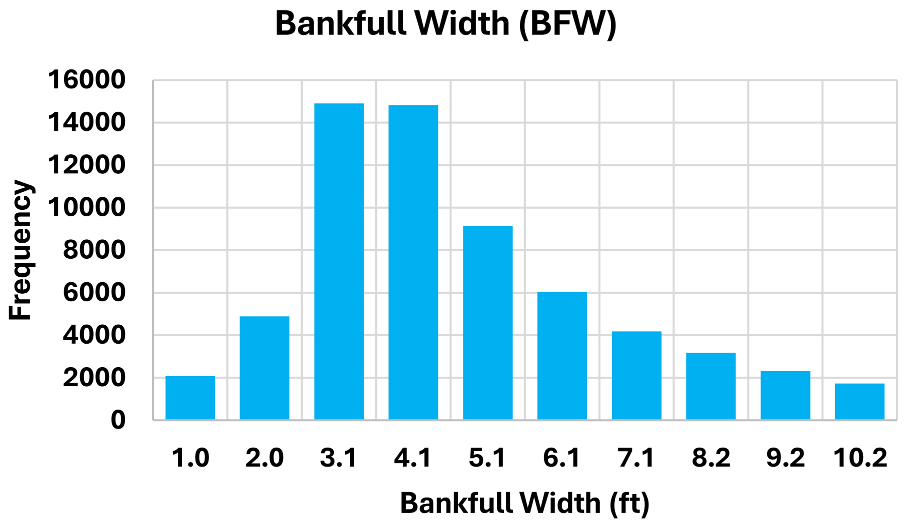
By Douglas L. Moyer and Mark R. Bennett

Estimated Channel Properties





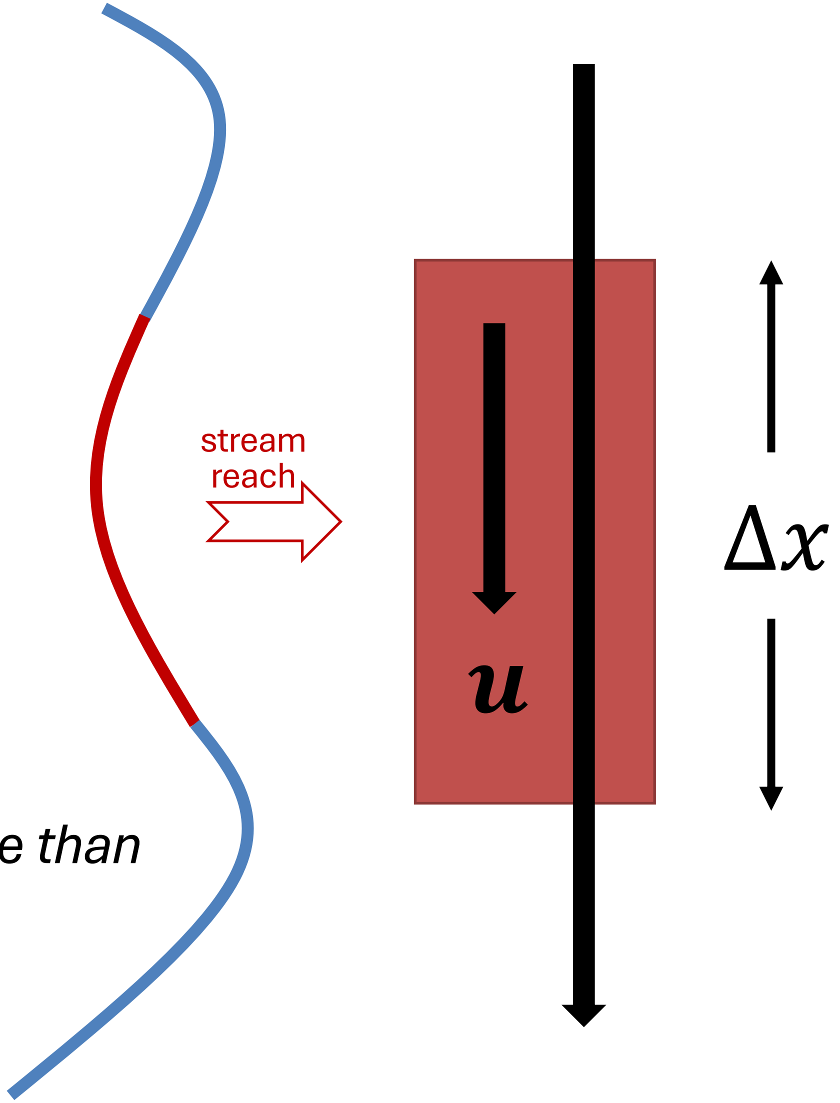




Courant Number

$$\boldsymbol{Cuhrant\ Number}, CN = \frac{u\Delta t}{\Delta x}$$

u *is velocity*;
Δt *is the simulation time step*;
Δx *is the length of the model element*;



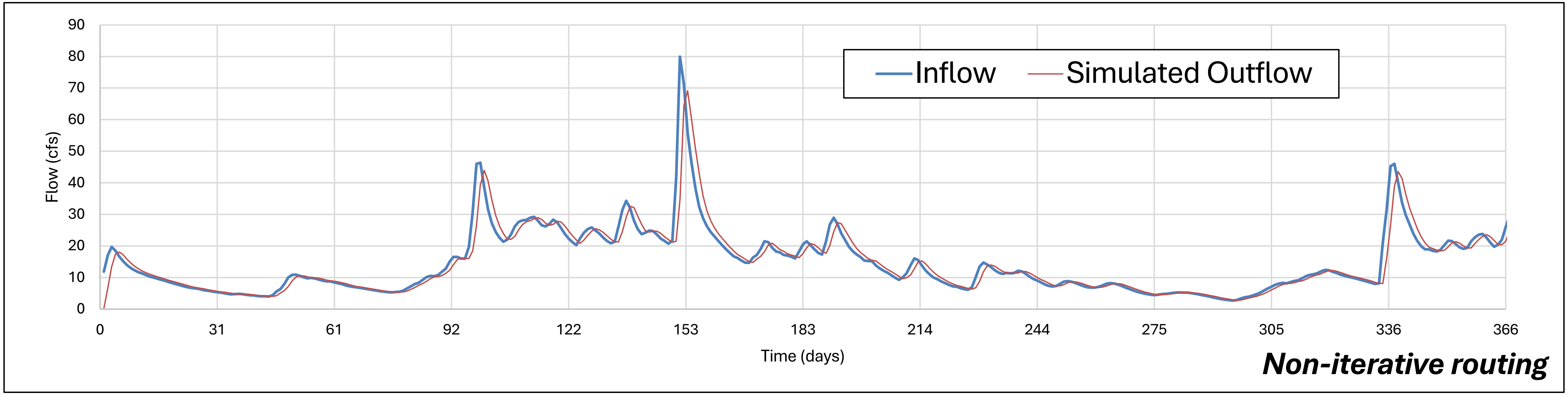
Courant number broadly indicates how much the information travels and is linked to the stability condition of numerical schemes.

Courant number > 1 implies the information propagates through more than one mesh/grid/segment, making the solution inaccurate.

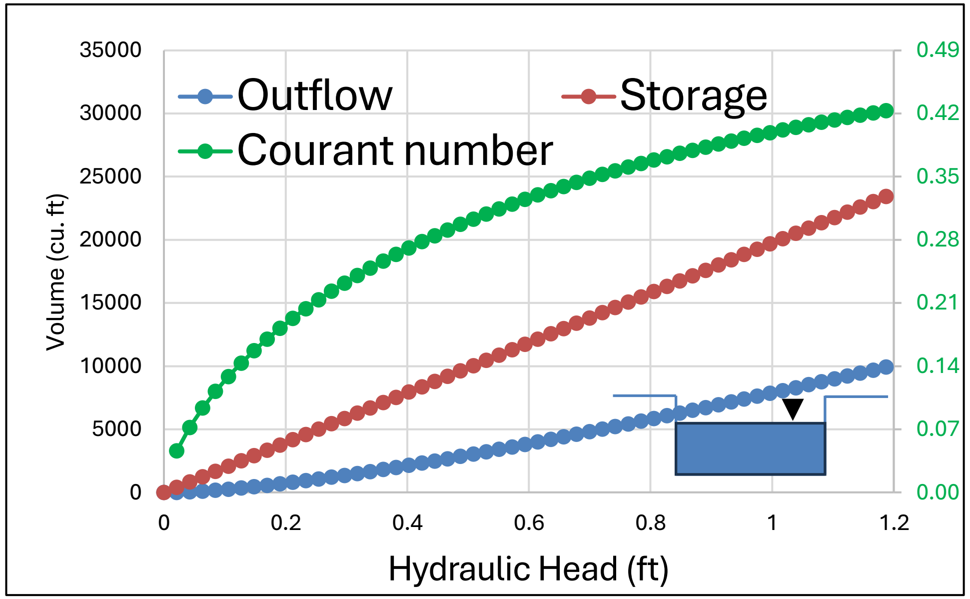
Therefore, the timestep and mesh size should be carefully selected.

So, what are we doing? Are we making the reaches longer? Or the time step smaller? Ans: No.

Open Channel Flow

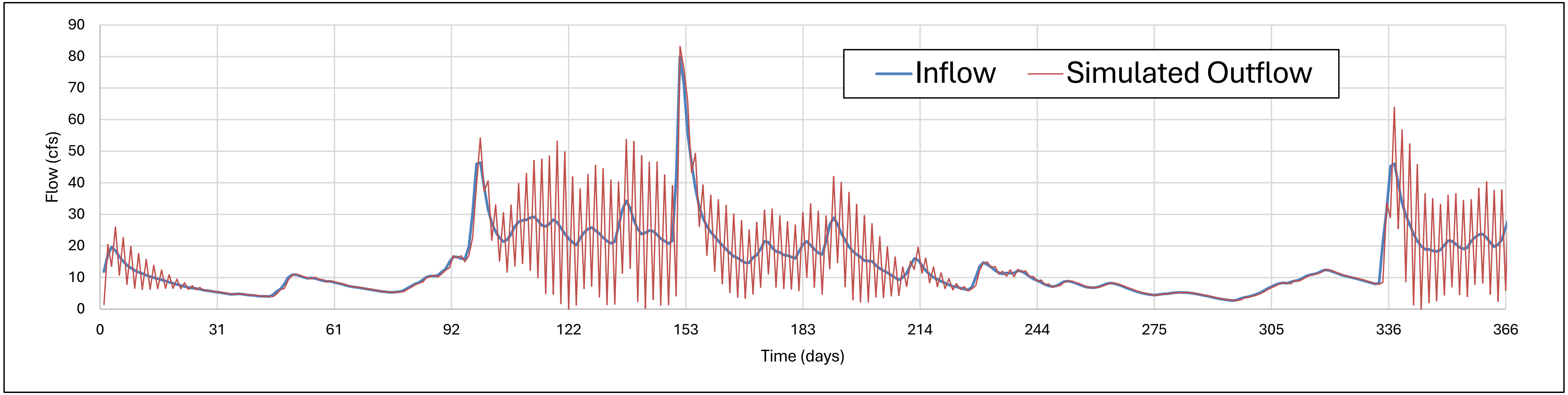


For a given set of channel properties



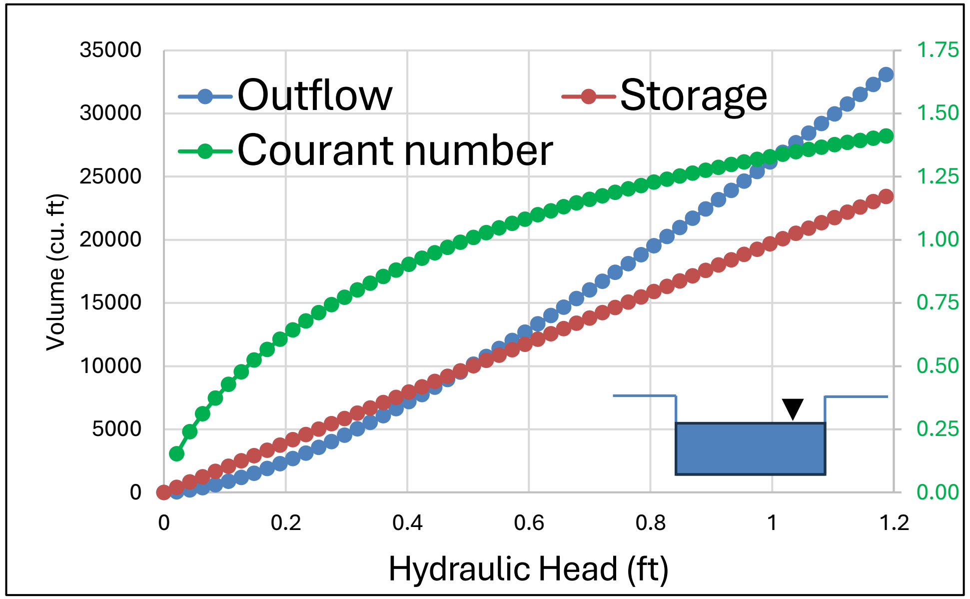
- Using Manning's equation and an explicit numerical scheme (Euler method). $S(t+1) = S(t) + \frac{dS}{dt}\Delta t$

Open Channel Flow

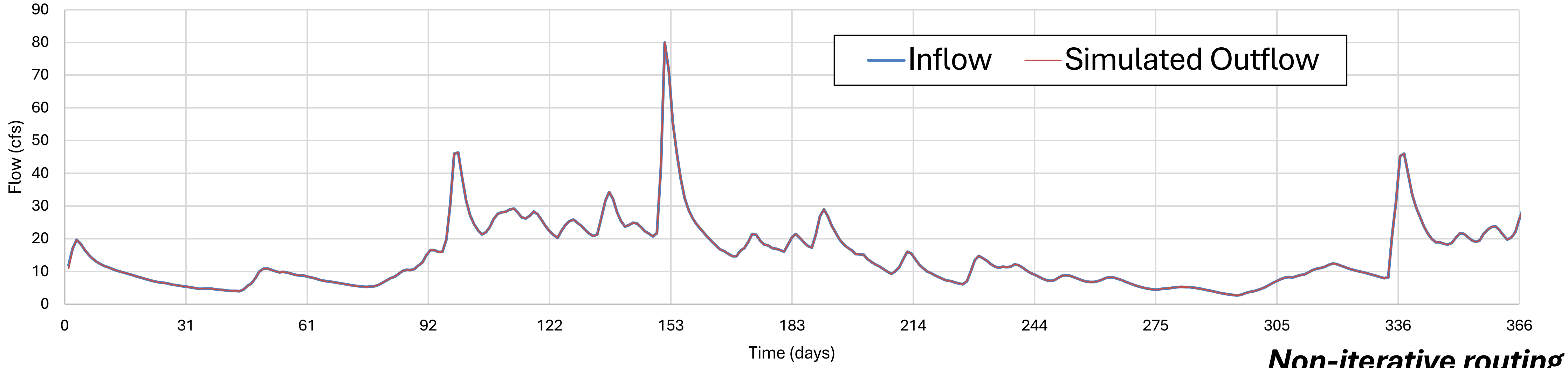


For another set of channel properties

- Using Manning's equation and an explicit numerical scheme (Euler method).

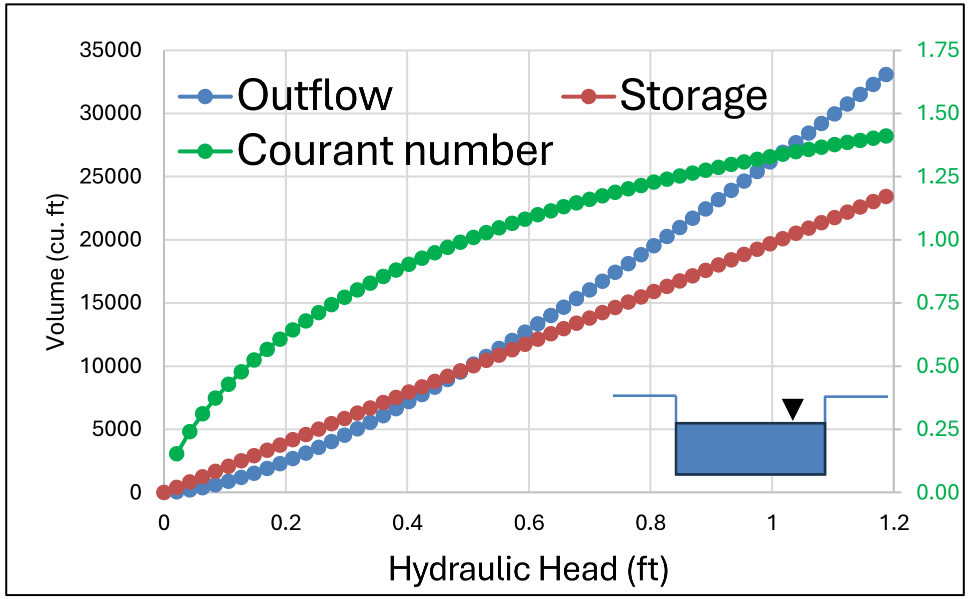


Open Channel Flow



Non-iterative routing

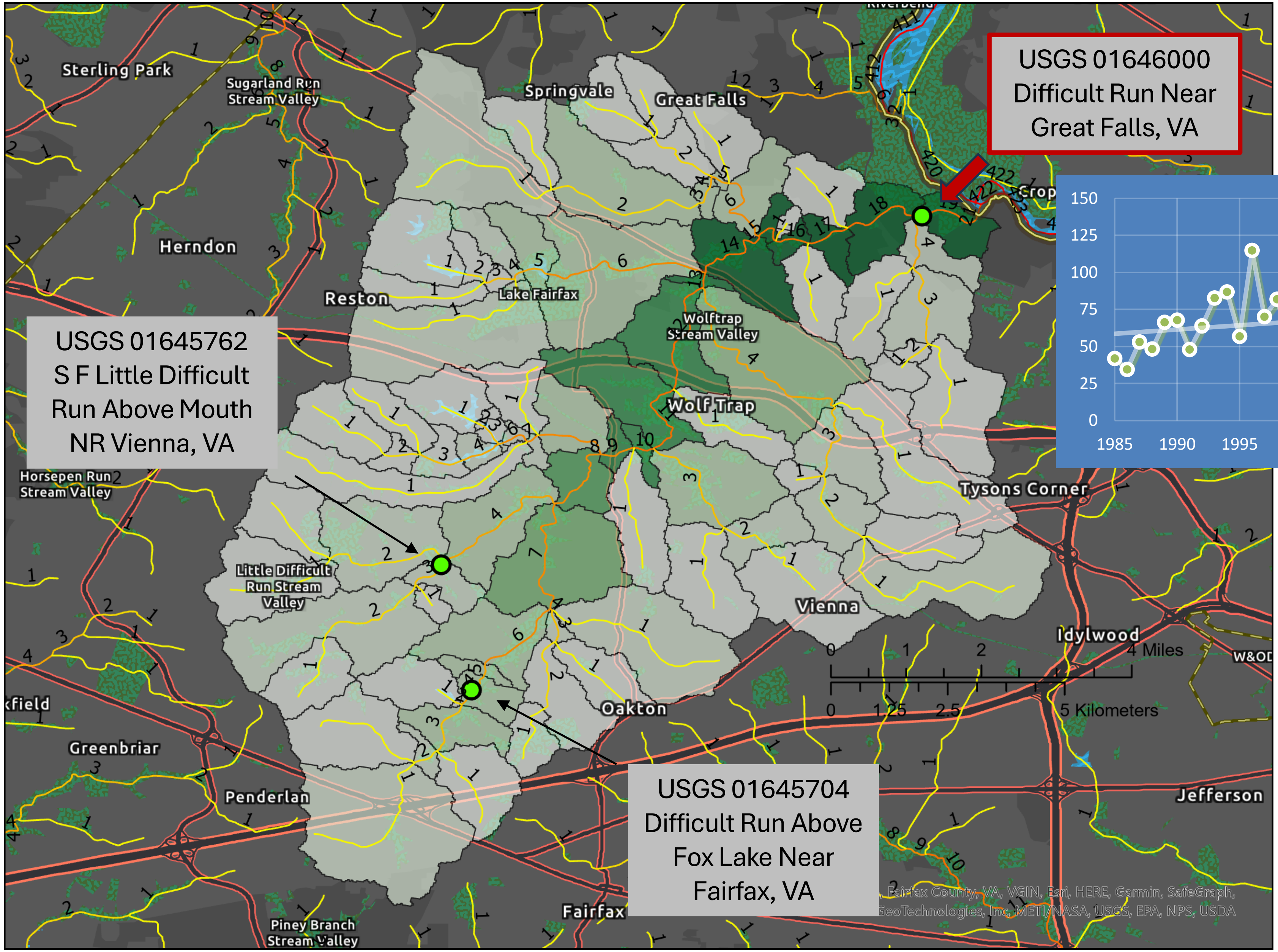
$S(t+1)$ *constrained with* $S_{min} = 0$ *and* S_{max} = *storage when CN is* 0.999

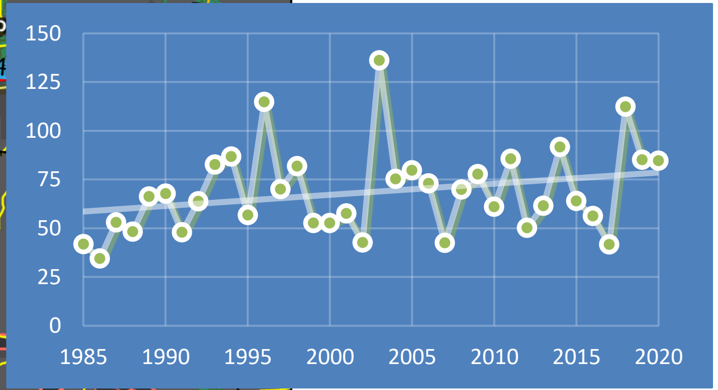


- Using Manning's equation and an explicit numerical scheme (Euler method).

Non-iterative routing vs. HSPF

Difficult Run (~ 58 sq. mi)

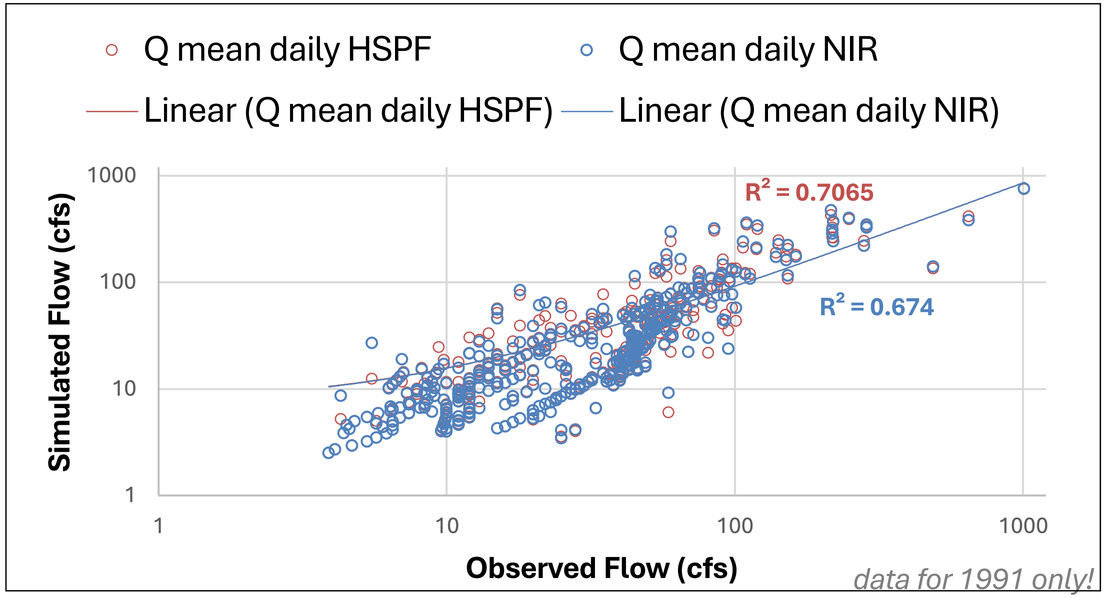


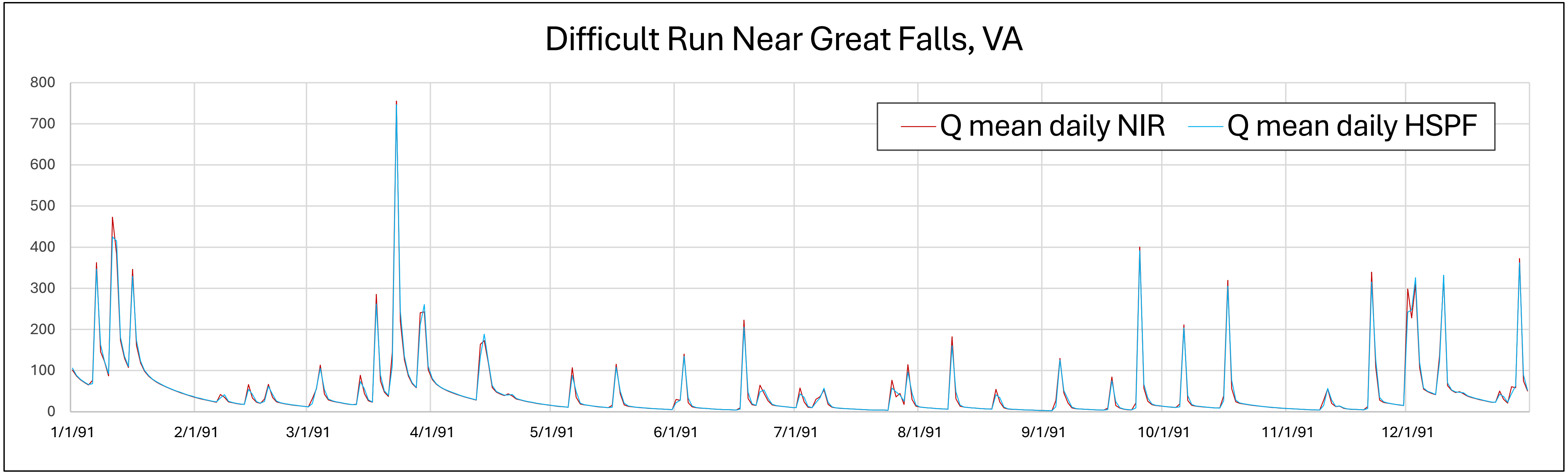


Mean annual flow = 70 cfs

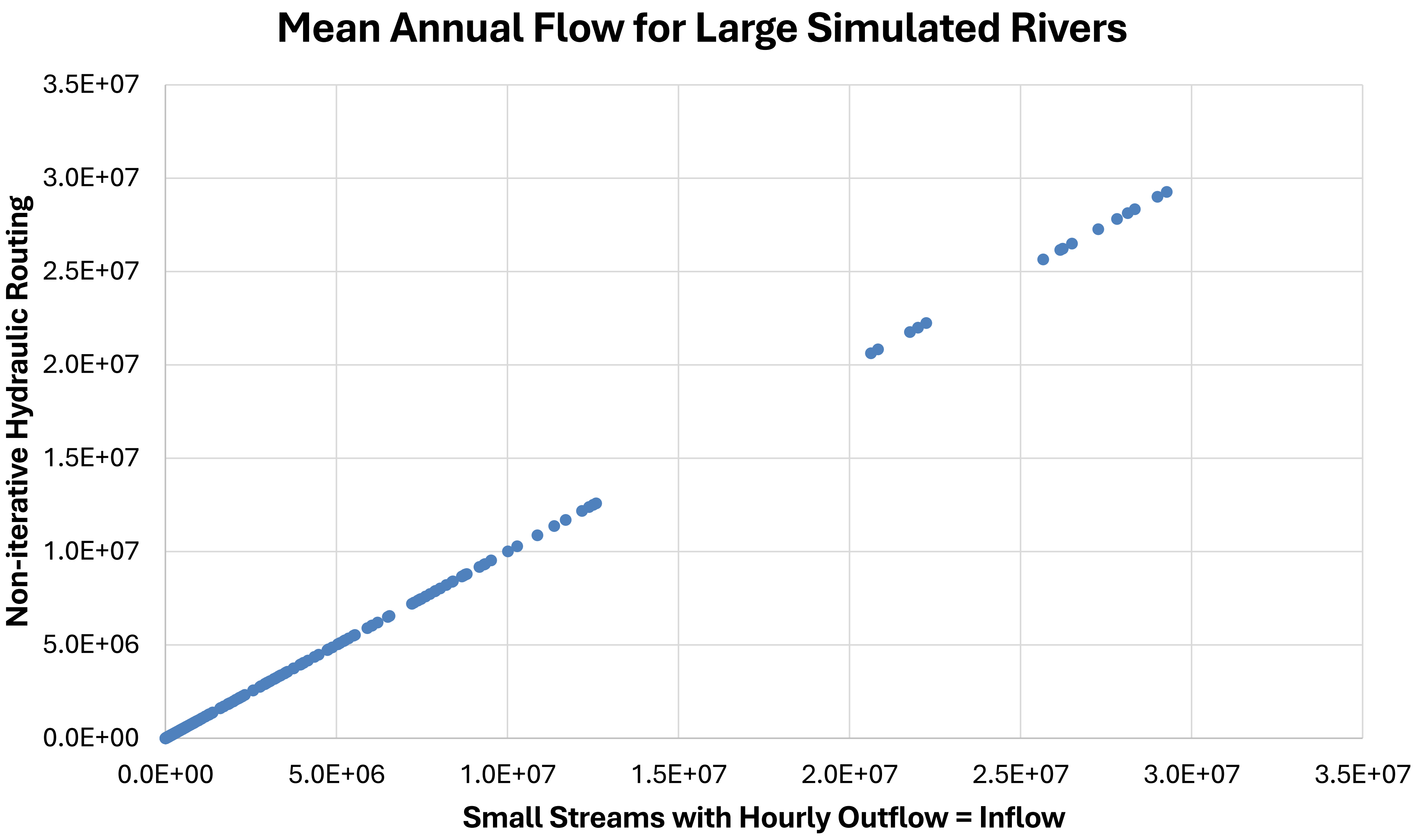
Non-iterative routing vs. HSPF

- Model run time for the entire watershed increased by about 2.5 hours.
- Difficult Run (~ 58 sq. mi) is a 19th NHD sequence order stream.





Watershed scale verification



Summary

1. We implemented and tested a non-iterative hydraulic routing method for small streams.

- channel properties were estimated using Moyer et al. regressions and will be revised going forward as new information become available
- we are assuming rectangular geometry, but we will investigate for potentially revising it with trapezoidal geometry
- overall, we have a better DWM prototype than we had previously

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

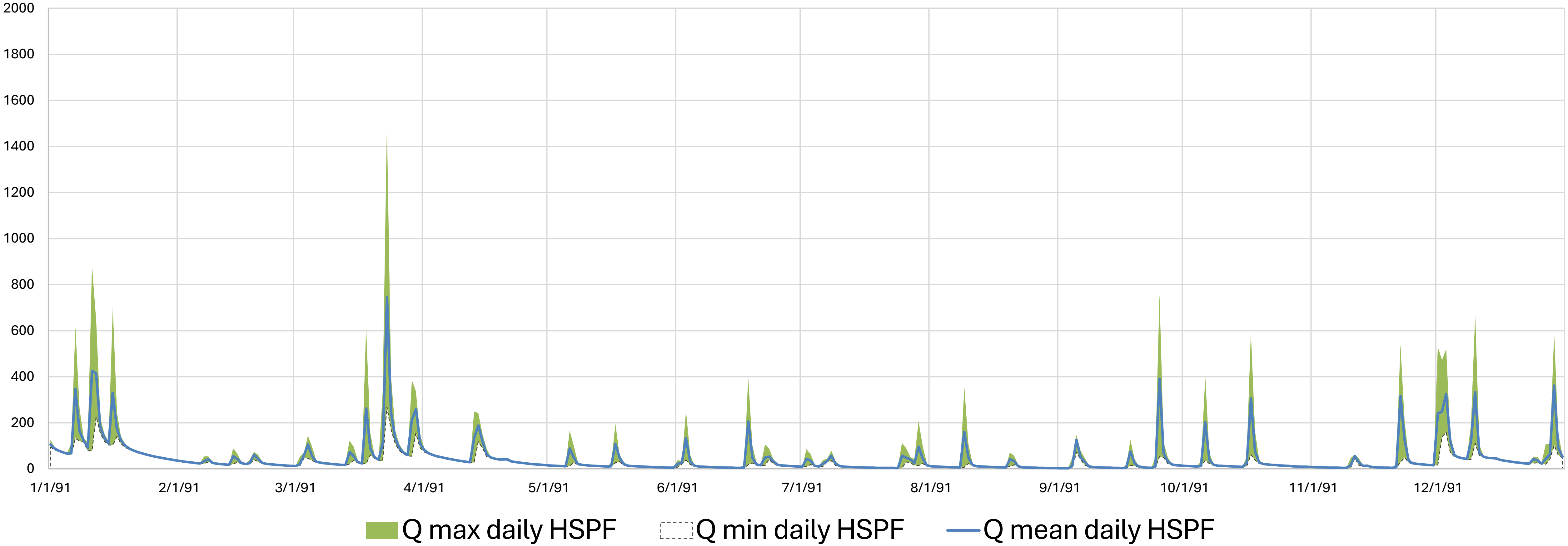
2. Additional QA QC of the non-iterative routing

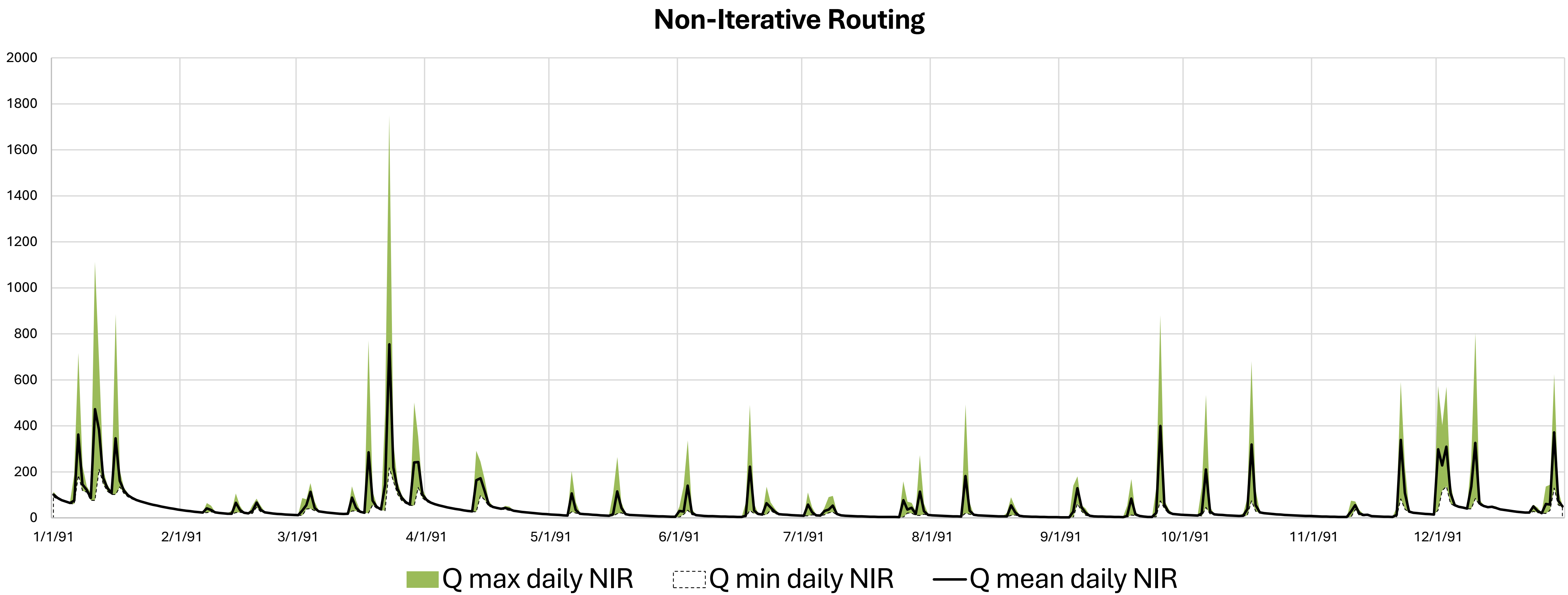
3. Non-iterative routing for water quality (sediment and nutrients)

4. Water quality calibration

- The End.

HSPF Routing





Non-Iterative Routing
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1/1/91
2/1/91
3/1/91
4/1/91
5/1/91
6/1/91
7/1/91
8/1/91
9/1/91
10/1/91
11/1/91
12/1/91
Q max daily NIR
Q min daily NIR
Q mean daily NIR