Progress on Phase 7 Nutrient Inputs and Sensitivities

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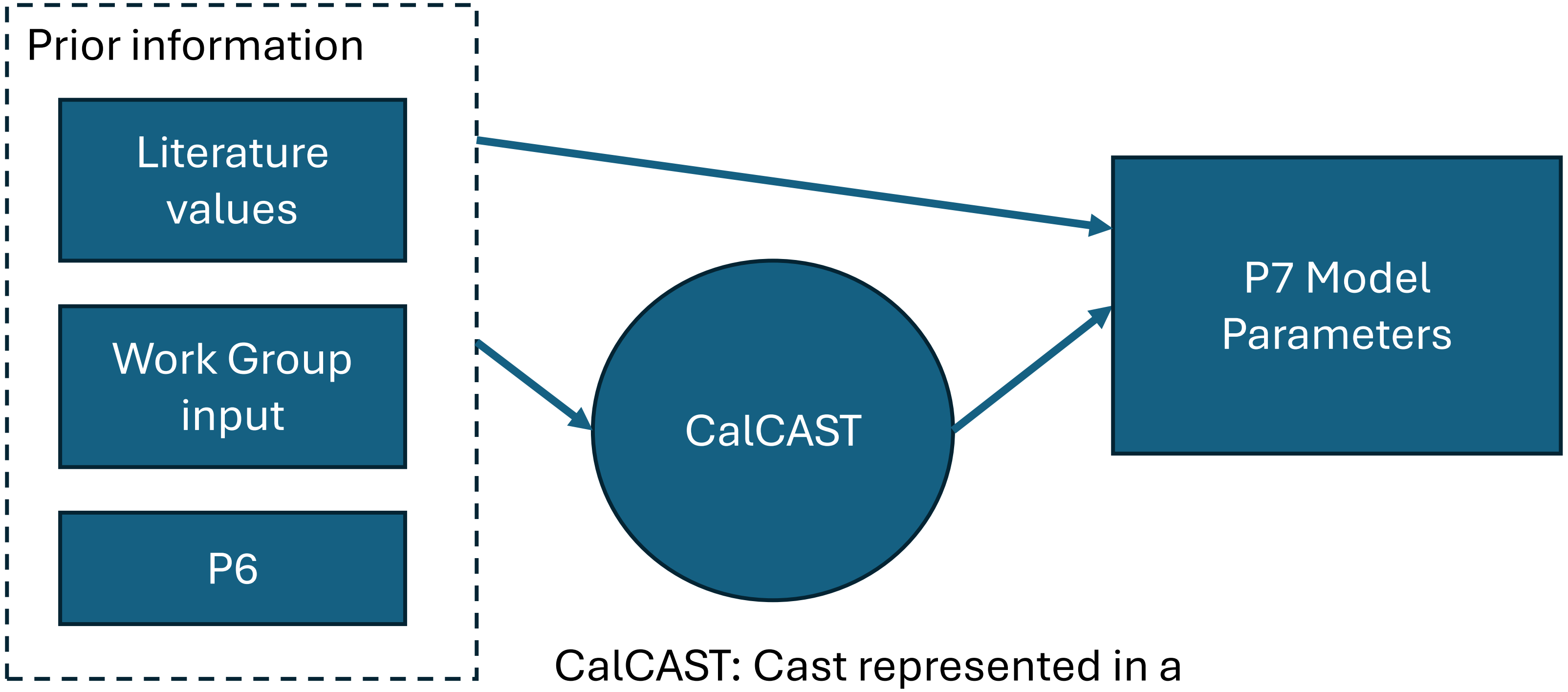
Quantifying P7 model parameters

Incorporate data-driven lines of evidence into modeling approach



CalCAST: Cast represented in a framework for statistical calibration

Prior information

Loading sensitivity to inputs

Cropland sensitivity to fertilizer

Cropland sensitivity to manure

Natural LU sensitivity to atm. deposition

Cropland sensitivity to uptake (ongoing)

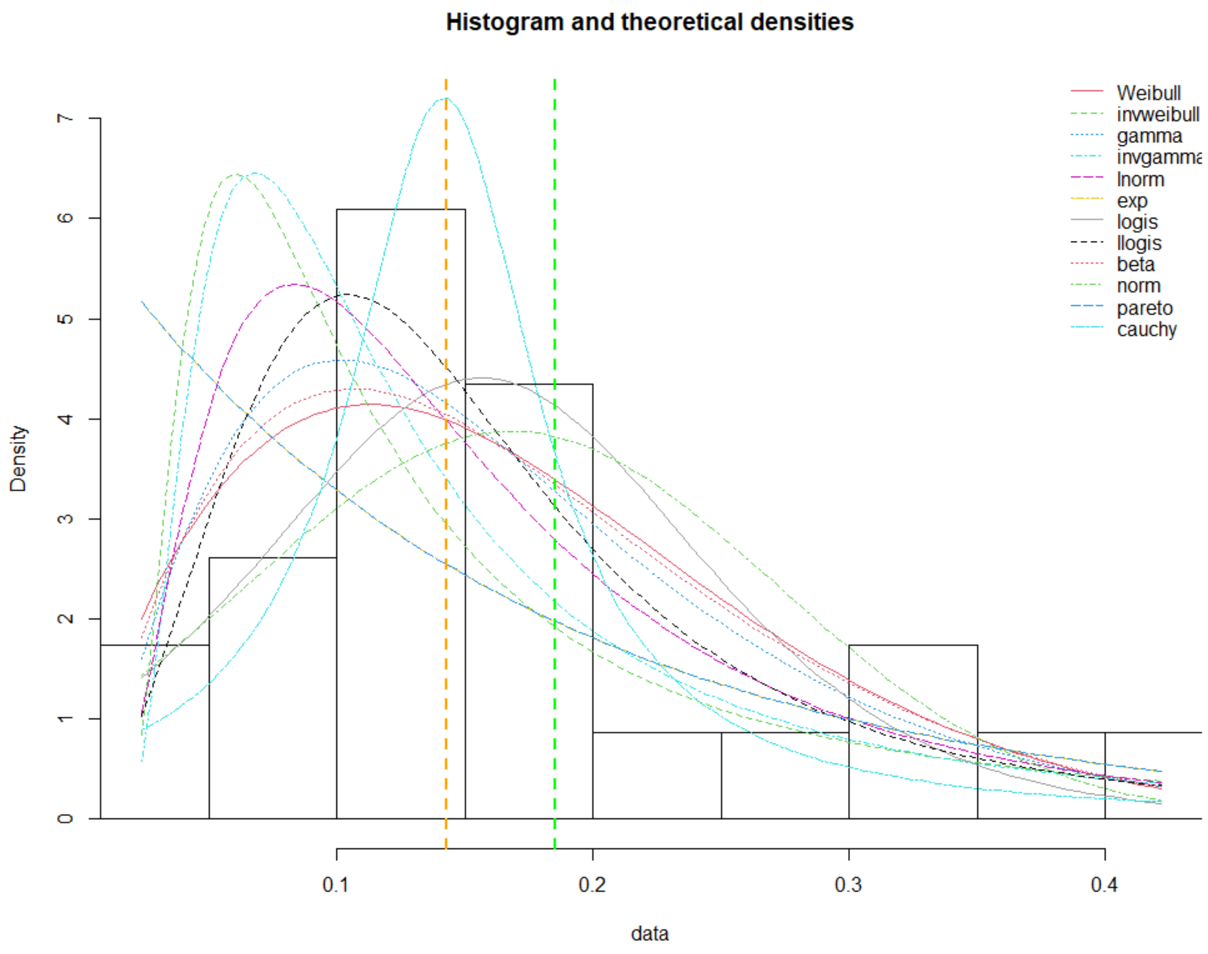
Loading rates

In practice, we've found calibration benefits from strong priors for the highest and lowest loading rates

- Cropland
- Natural

Utilizing prior information

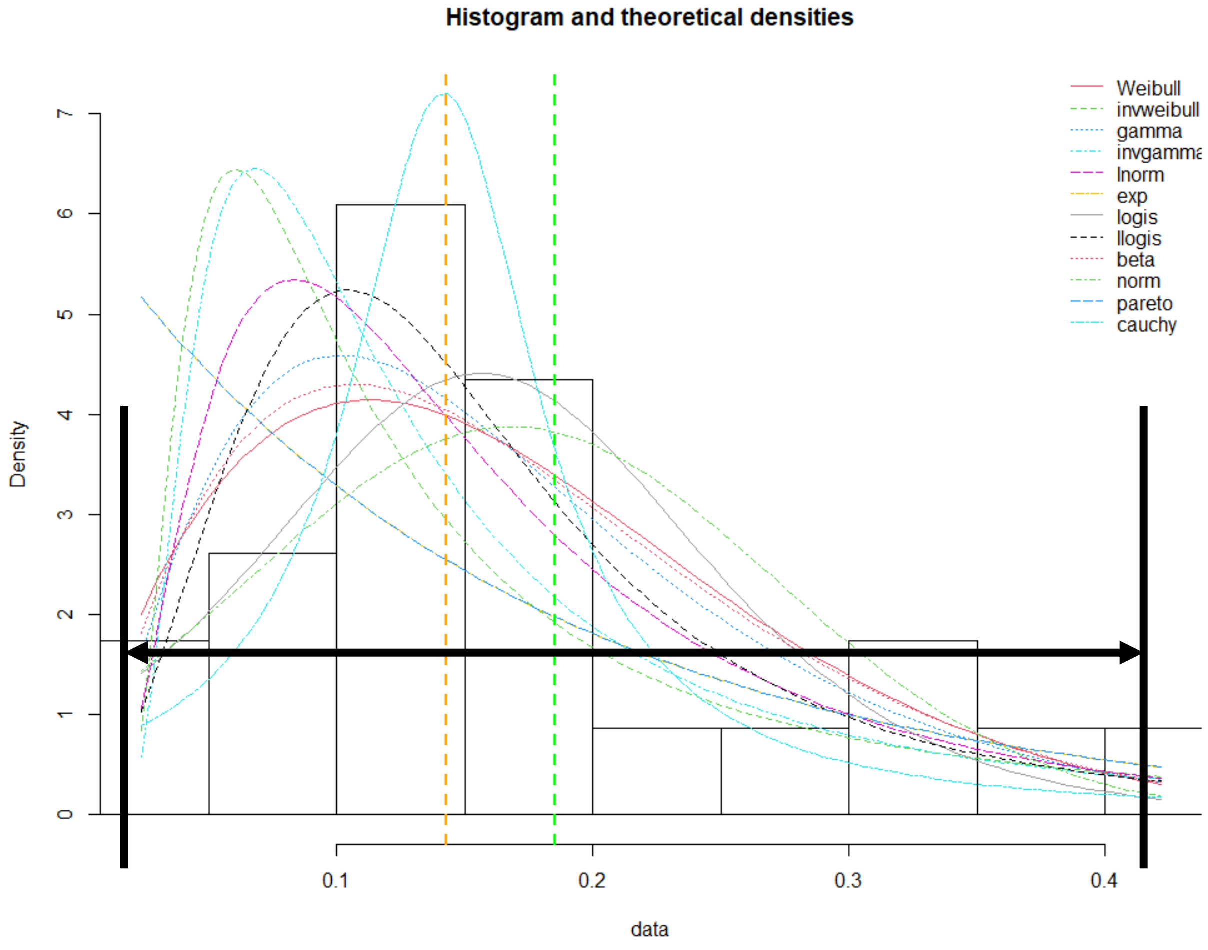
Continuous functions are fit to a distribution of literature values



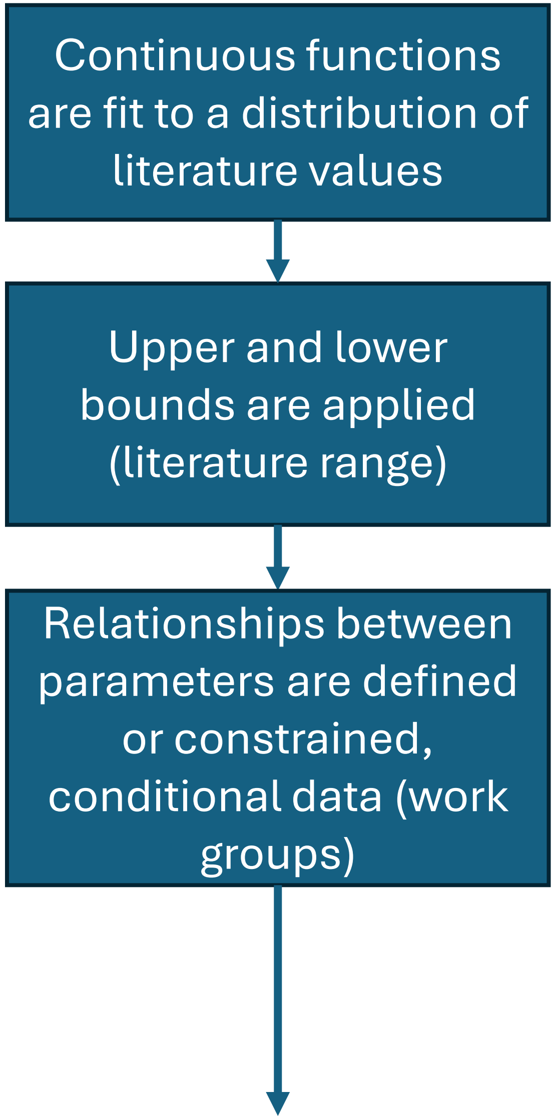
Utilizing prior information

Continuous functions are fit to a distribution of literature values

Upper and lower bounds are applied (literature range)



Utilizing prior information



Example conditional data:

Loading ratios (e.g., grain w/ manure is 1.4* grain w/o manure)

$S_{(\text{harvested forest})} = \min(7*S_{(\text{forest})}, S_{(\text{construction})})$

Total Nitrogen

CLR = Average CROP loading rate (lbs/ac)

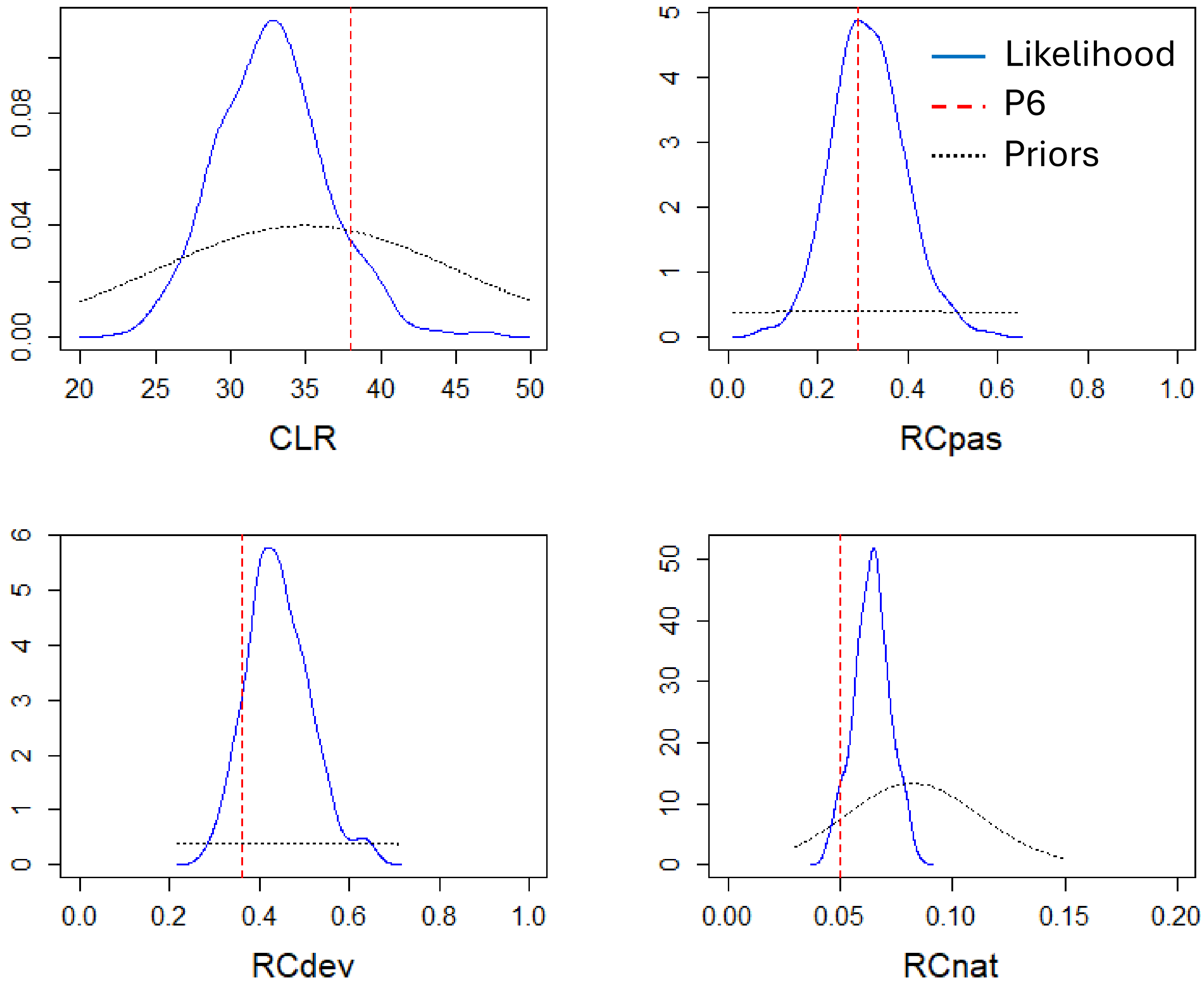
RCpas = Ratio of PASTURE loading rate to CROP loading Rate

RCdev = Ratio of DEVELOPED loading rate to CROP loading Rate

RCnat = Ratio of NATURAL loading rate to CROP loading Rate

Red dashed line = P6
Black dashed lines = P532, SPARROW, CEAP

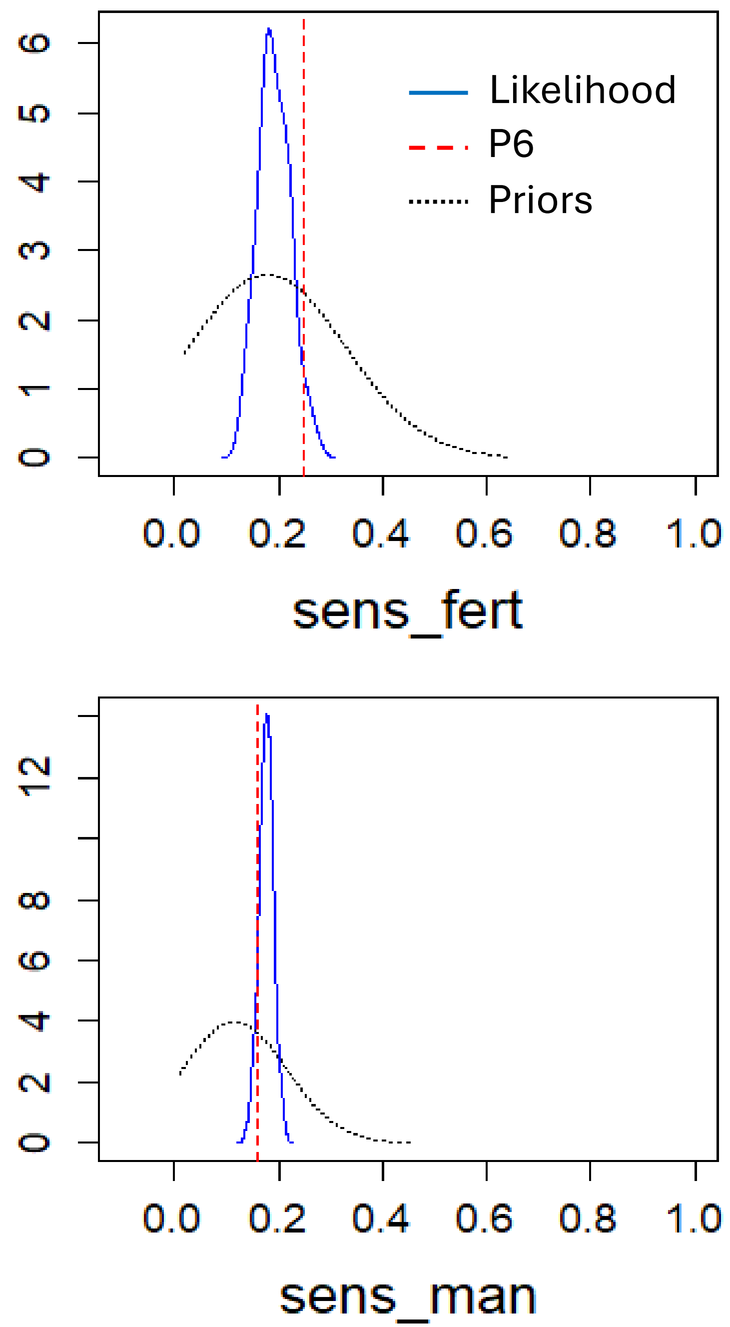
Loading rates with priors



These values will change as CAST and inputs are updated.

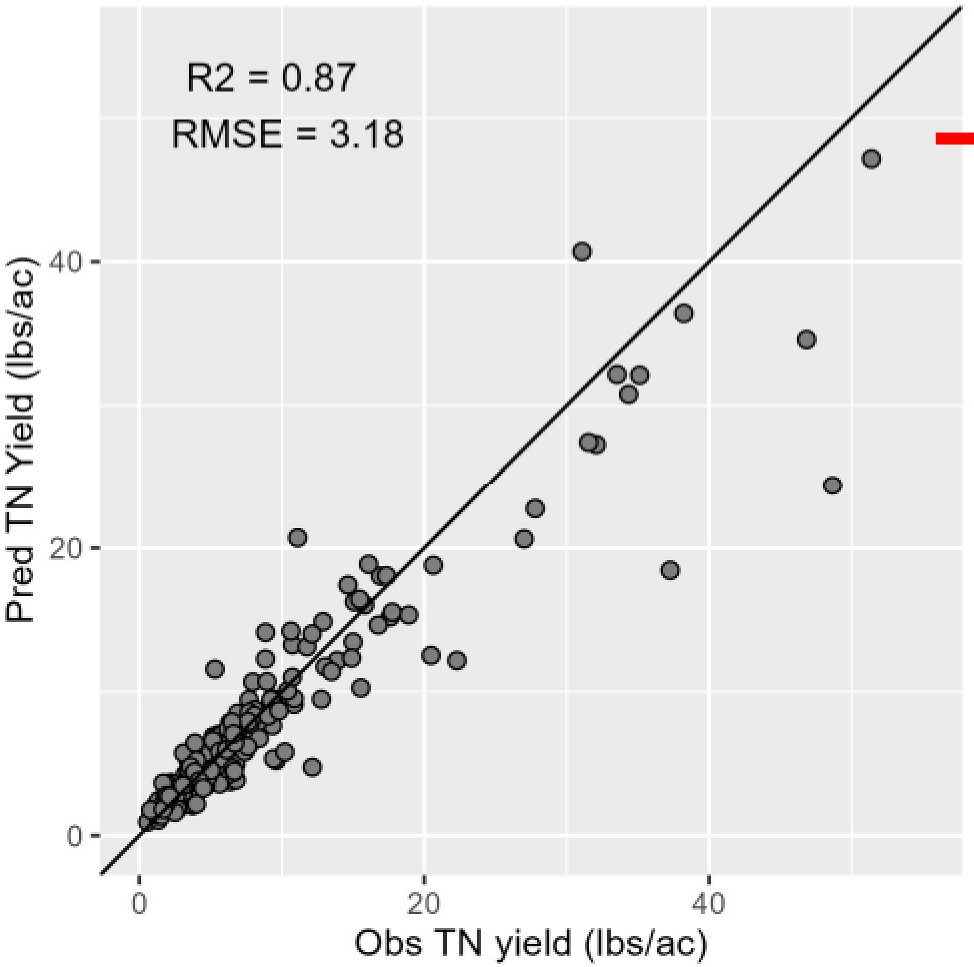
Total Nitrogen

Initial calibration of sensitivity values are reasonable, but manure deviates from the central tendency of the priors.

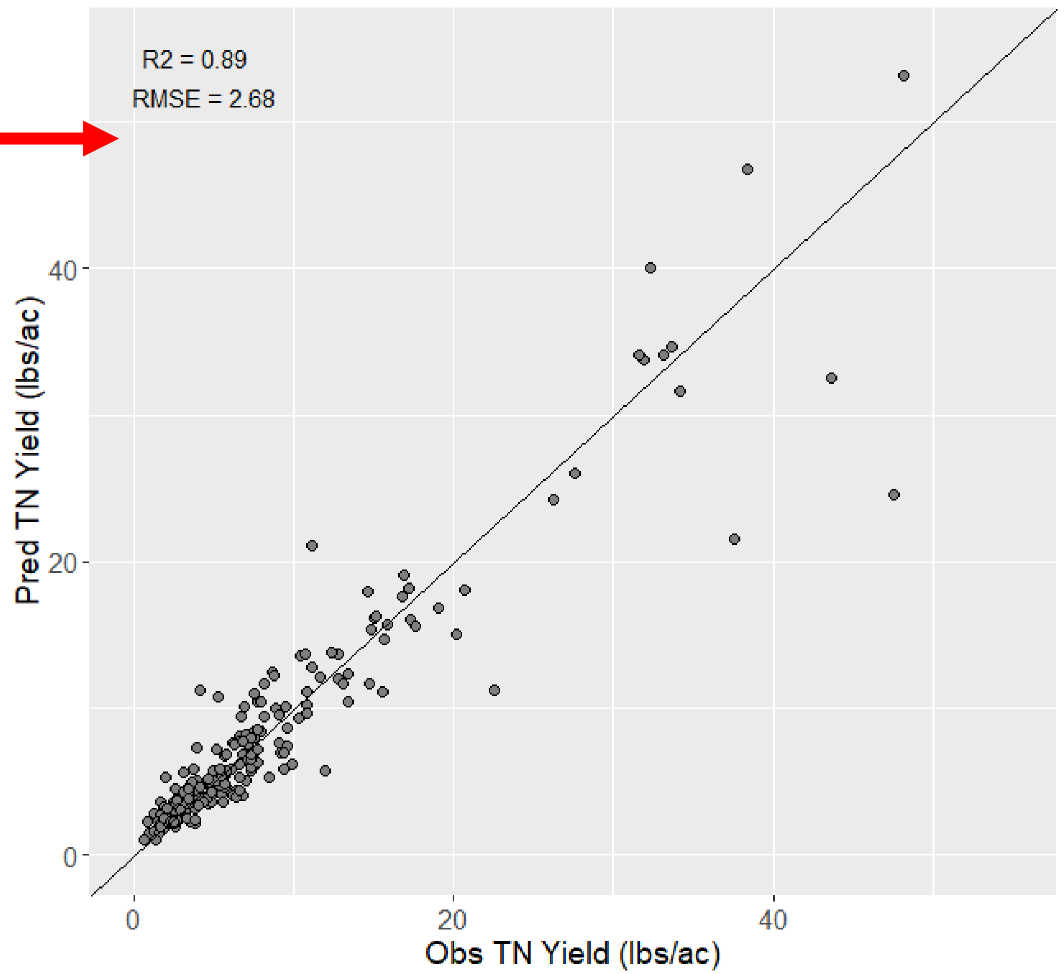


Average annual TN (spatial) model

No Priors

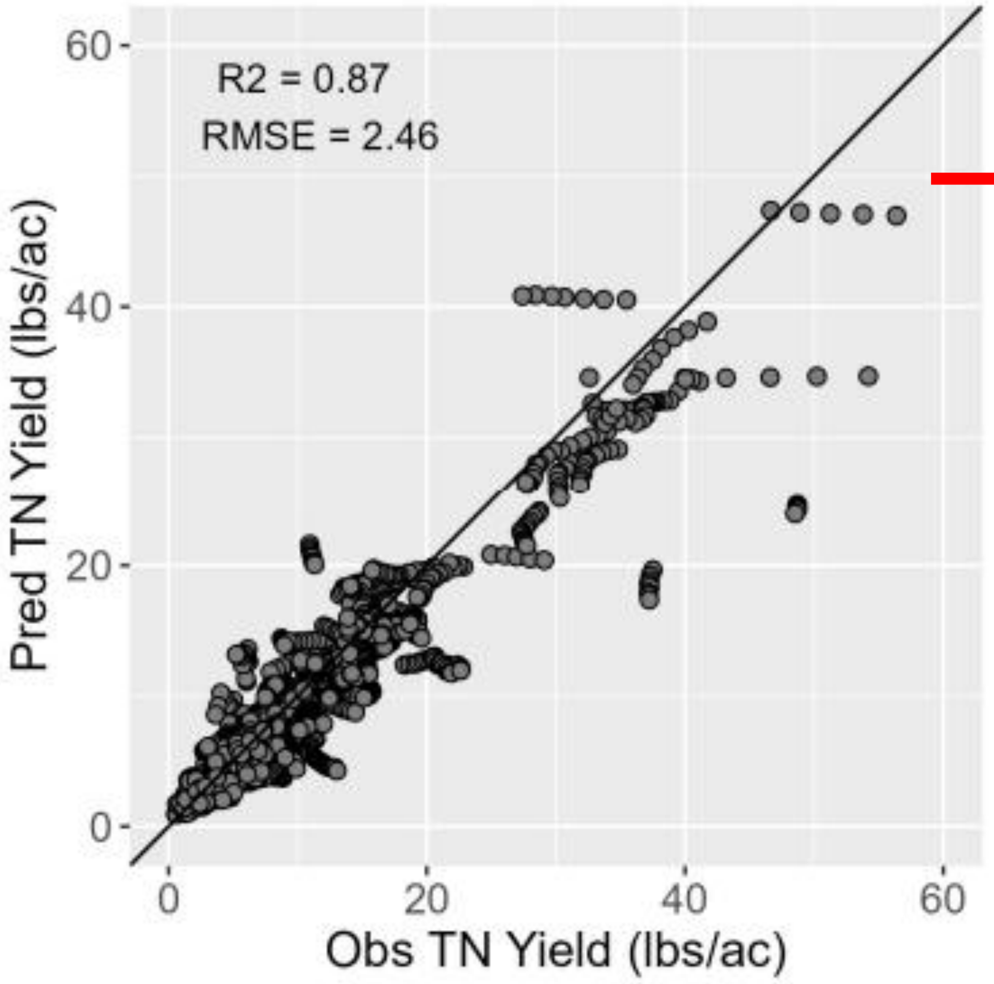


With Priors

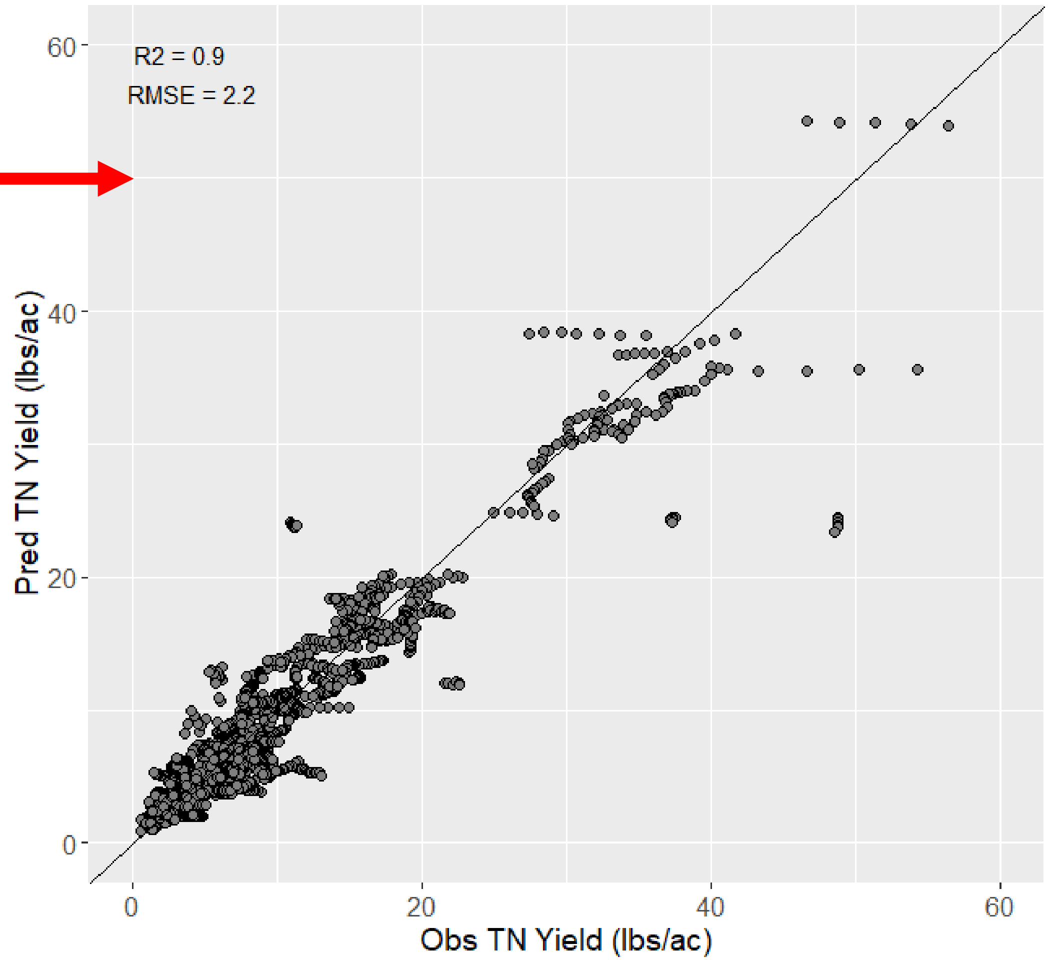


Annual TN (spatial-temporal) model

No Priors

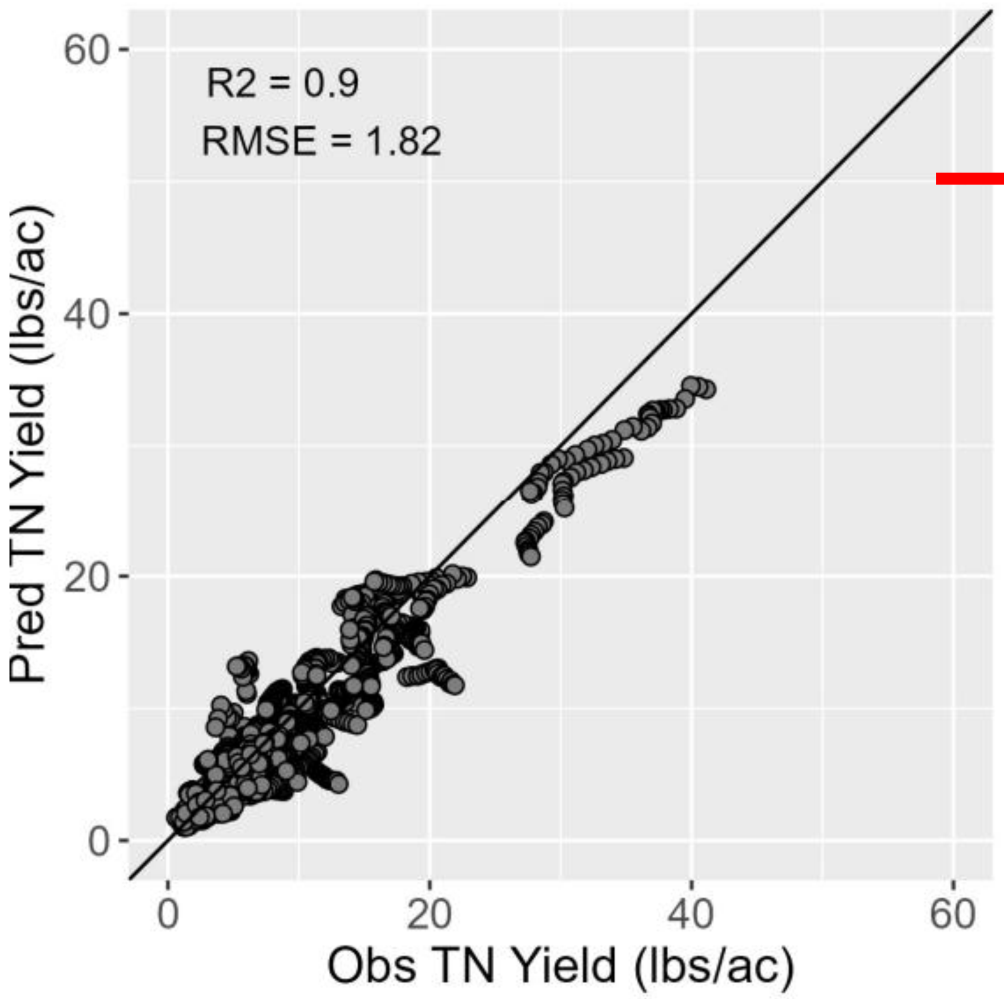


With Priors

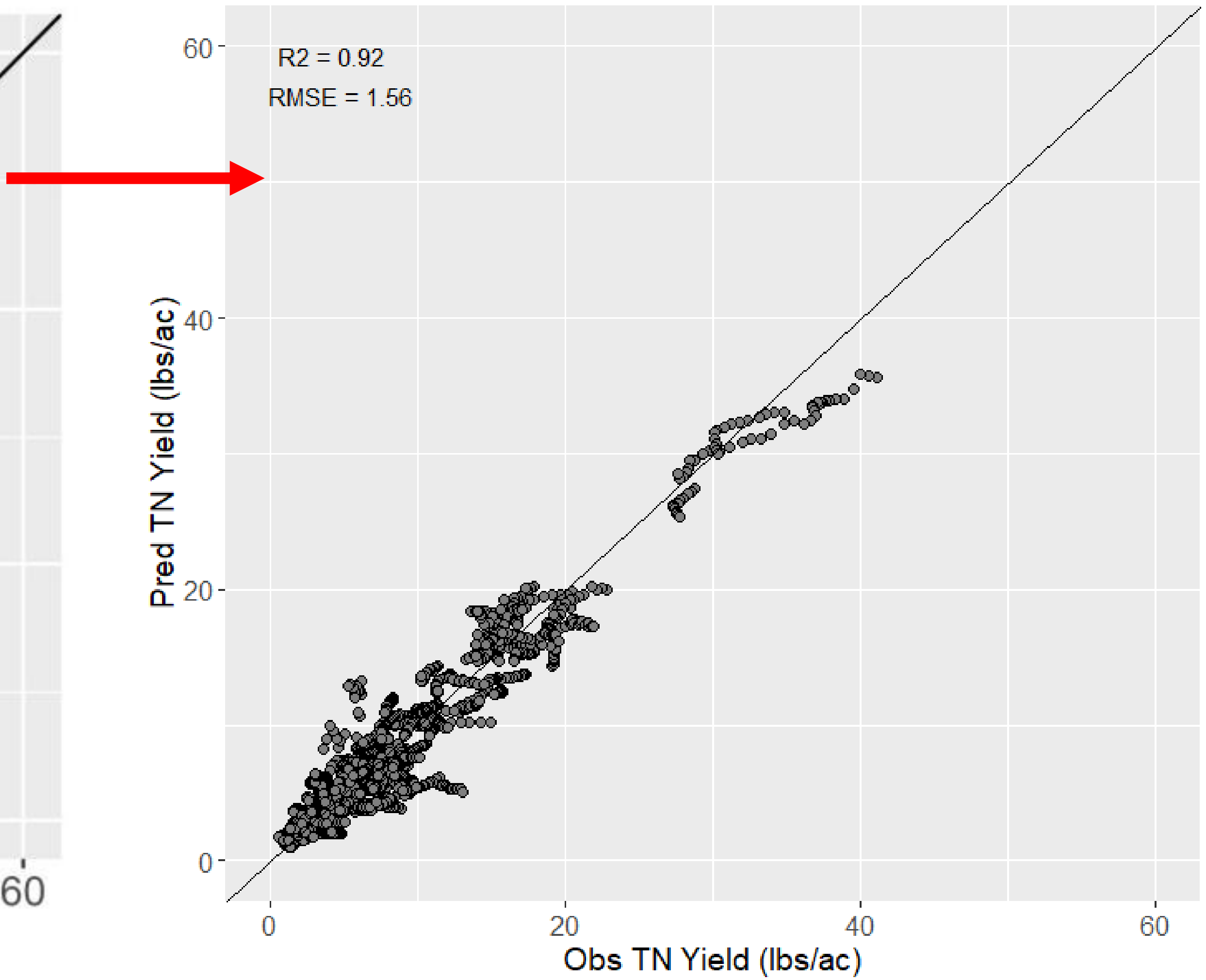


Annual TN model, 10+ yrs obs.

No Priors



With Priors



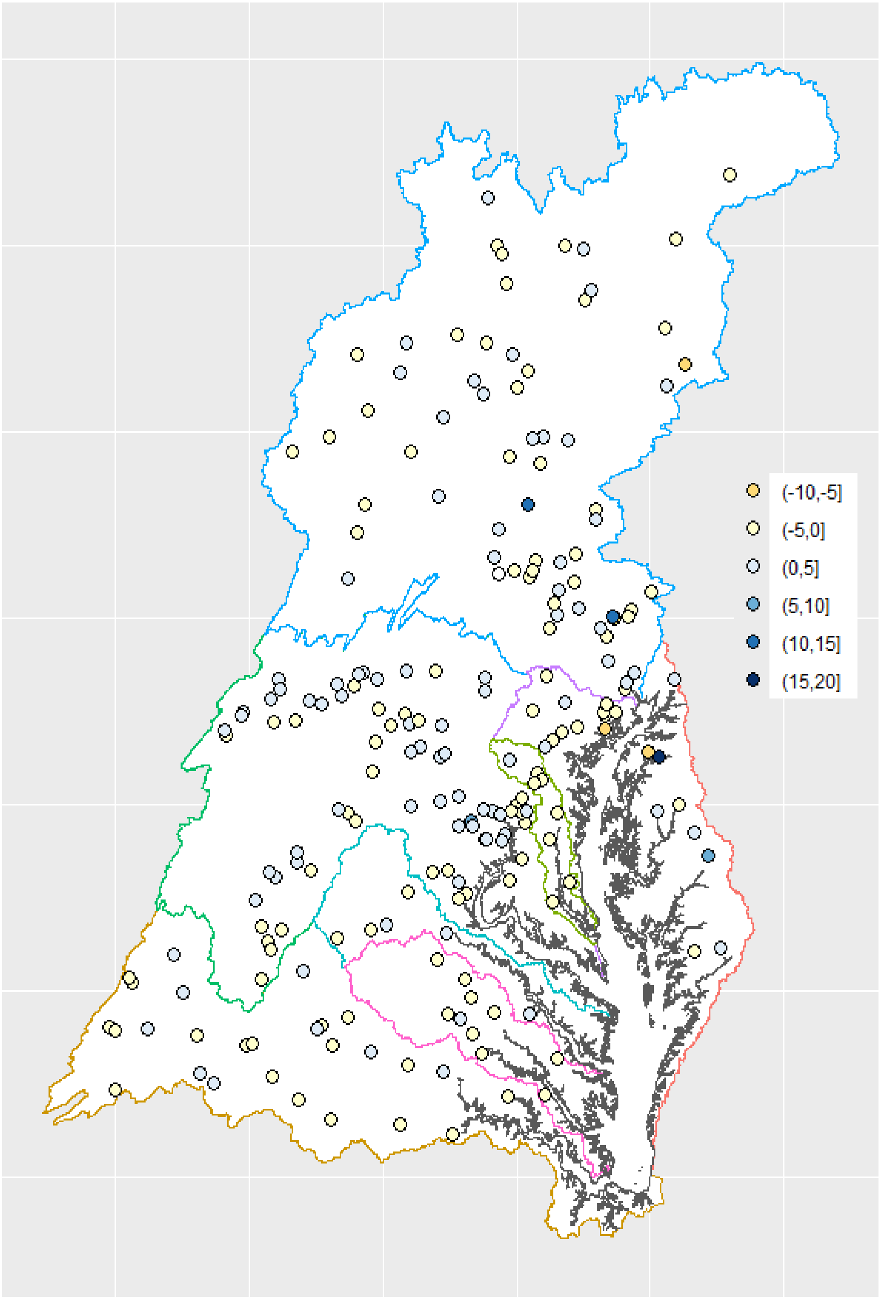
TN residuals and trend analysis

Strongest predictors of TN residuals

- Catchment area and flow
- Number of observations at a station
- Higher inputs
  - However, the relationship is 0.03 lbs residual to 1 lbs input
- Percent open water

Strongest predictors of trend R^2

- Catchment area and flow
- Forest area, including Harvested Forest or forest cover in developed Lus
- Ag. Open Space, Specialty High, Small Grains, Silage



Conclusions

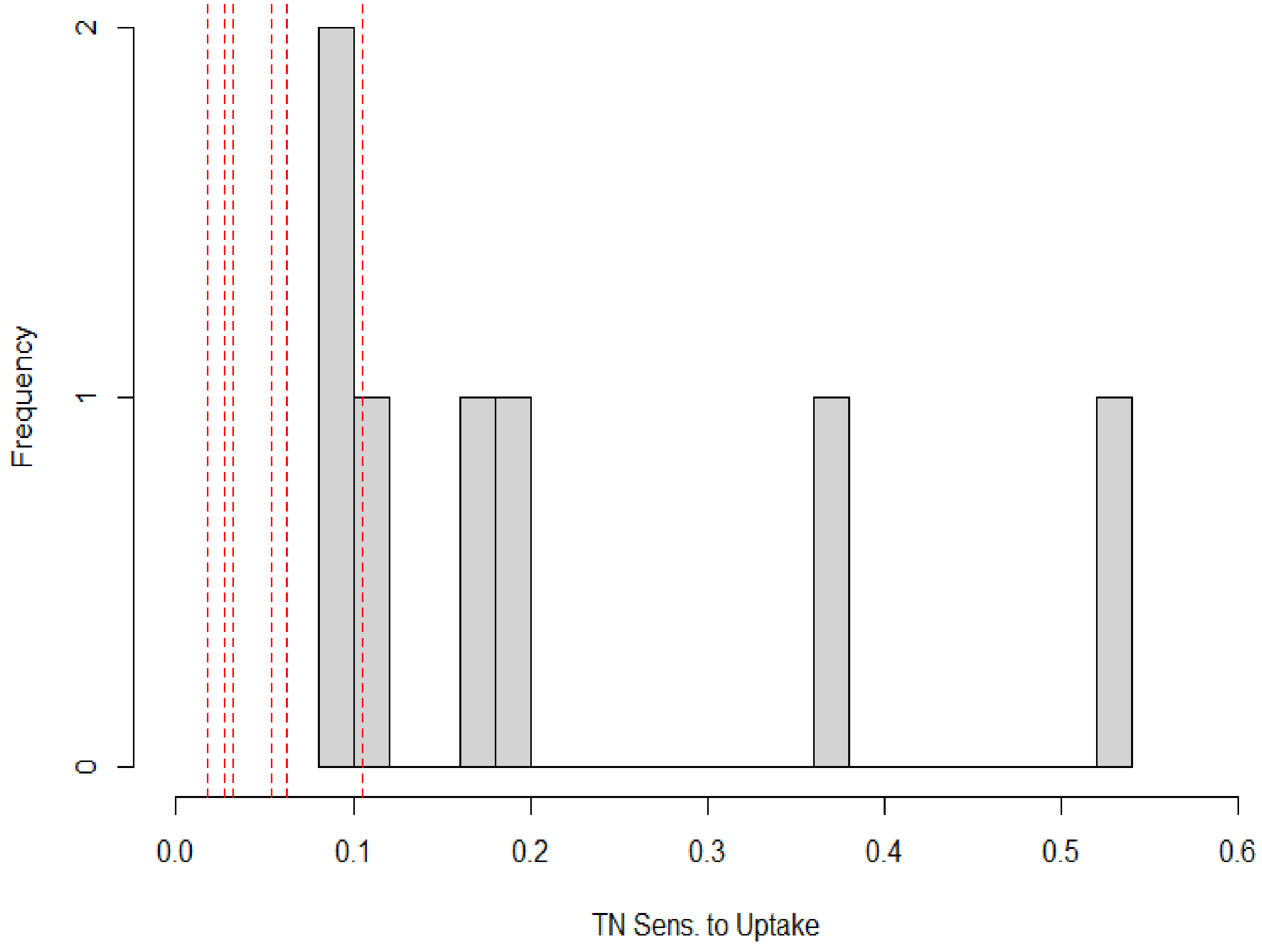
- Priors improve model performance
- We have a clear and validated pathway to model calibration
- TN residuals and leverage analysis do not suggest large issues that can be addressed by the MWG

A lot of work to do…

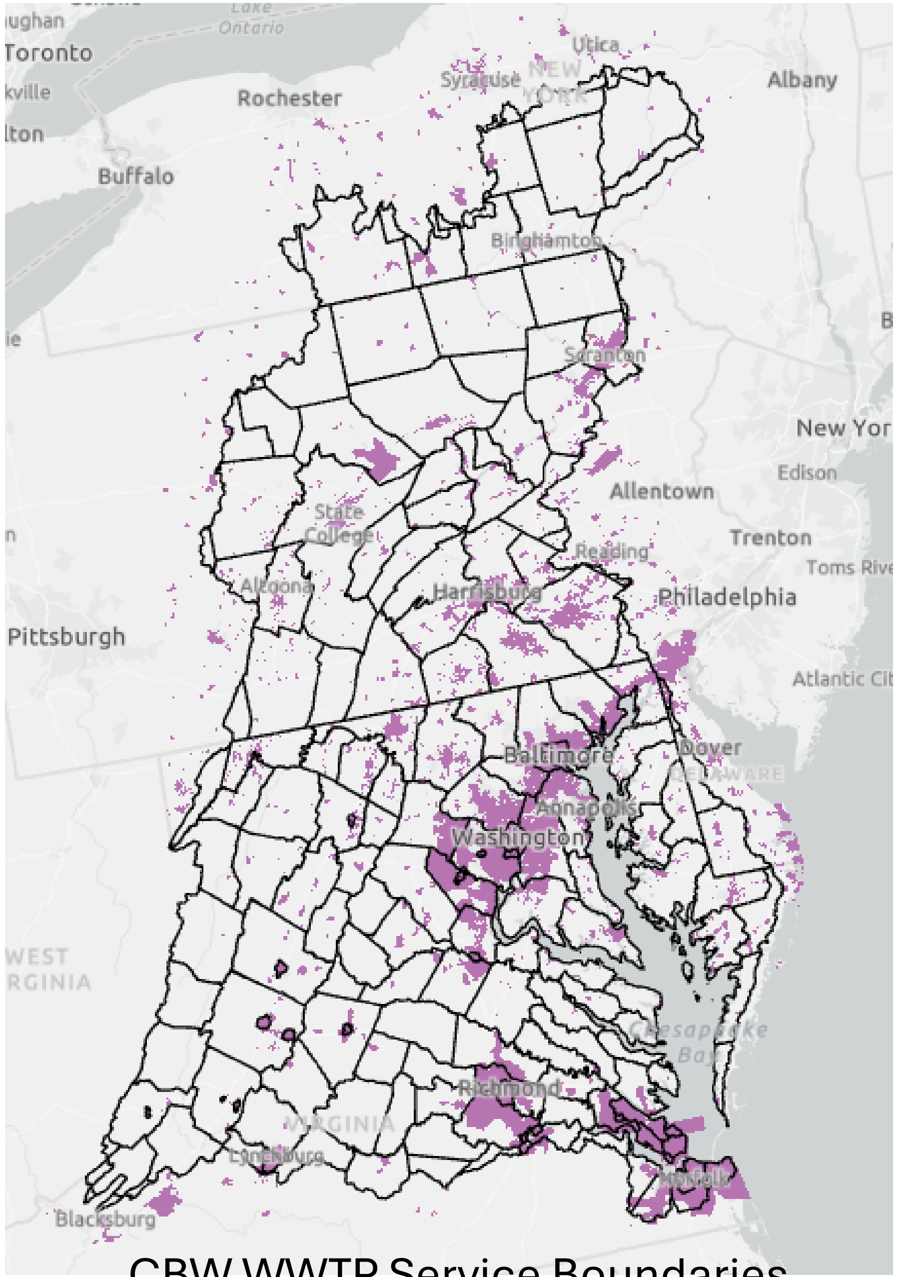
- Represent all P7 updates in CalCAST
- Selection of new L2W and S2R factors…

Sensitivity to crop uptake

- Identified 18 potential sources
- SWAT, APEX, and field studies
- Most studies are optimizing cover crops
- Ongoing…



Sanitary Sewer Exfiltration



CBW WWTP Service Boundaries

"**Sewer pipes are not designed to be watertight.** Sewer design sets a standard for allowable leakage during construction, which averages 125 gallons per 400 feet of pipe, which is the standard distance between sewer manholes (ASTM, 2009), or about 1,650 gallons per mile of standard sewer pipe."

Chesapeake Bay Program, (2014). "Final Expert Panel Report on Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure"

Why does this matter for the model?

★ Proper appropriation of loads
  - Improved calibration
- Improved targeting and crediting of management actions
- Scenario analysis (E.g., remediation, septic/sewer conversion)

This load is in the bay, the load is in the model, but it is currently misappropriated.

Most of the misappropriation is likely to stormwater and lawn fertilizers. These are surface sources, and many of the management practices applied will have little to no impact on subsurface sewer exfiltration.

Model structure

Exfiltration Vol. = Fraction exfiltration * Annual system treatment volume (dry-weather) * Geologic coef. * Fraction gravity line * (Fraction new or rehabbed*Rehabbed coef.)

EOS nutrient load = Exfiltration Vol. * concentration in raw WW (33 mg/L TN, 6 mg/L TP)[1]*Soil Treatment*GW Transmission

Workgroup Defined, Required State Provided Input, Optional State Provided Input

[1]Chesapeake Bay Program, (2014). “Final Expert Panel Report on Removal Rates for the Elimination of Discovered Nutrient Discharges from Grey Infrastructure”

- An initial default exfiltration value as a percent of treated volume will be defined by expert judgement and literature
- Spatially exfiltration will be mediated soils, geology, and by optional factors identified as drivers of exfiltration and transmission by expert judgement and literature.
  - Geologic basin as a metric of water table depth driving exfiltration vs infiltration
  - The proportion of the system which is gravity fed
  - The proportion of the system which is new or recently rehabilitated
  - Soil and groundwater transmission attenuation

Preliminary Results

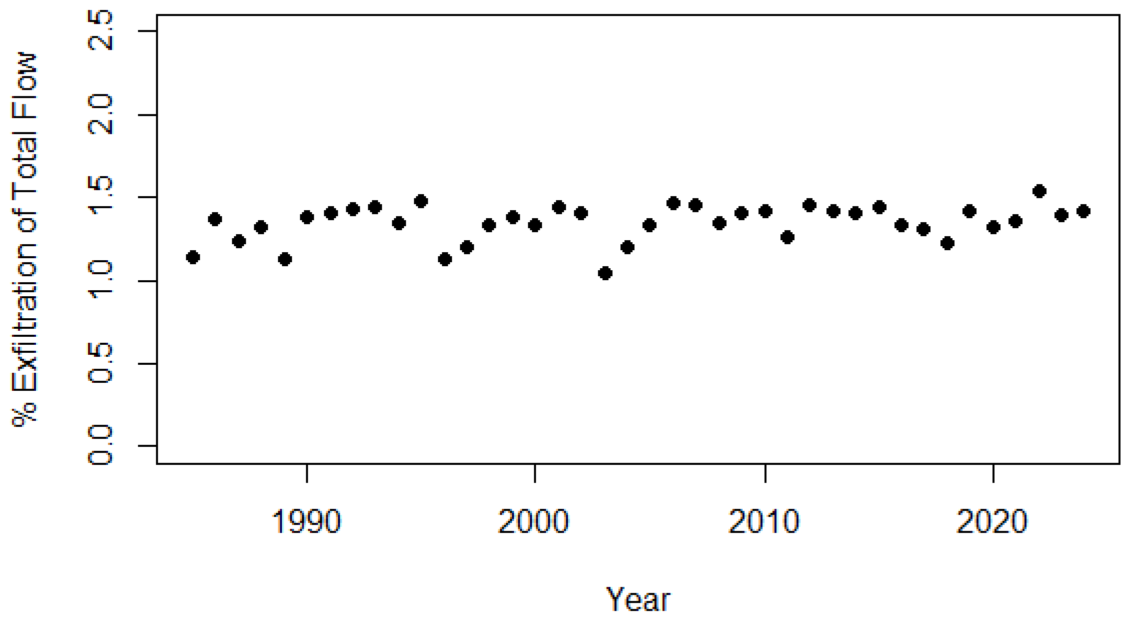
Notes

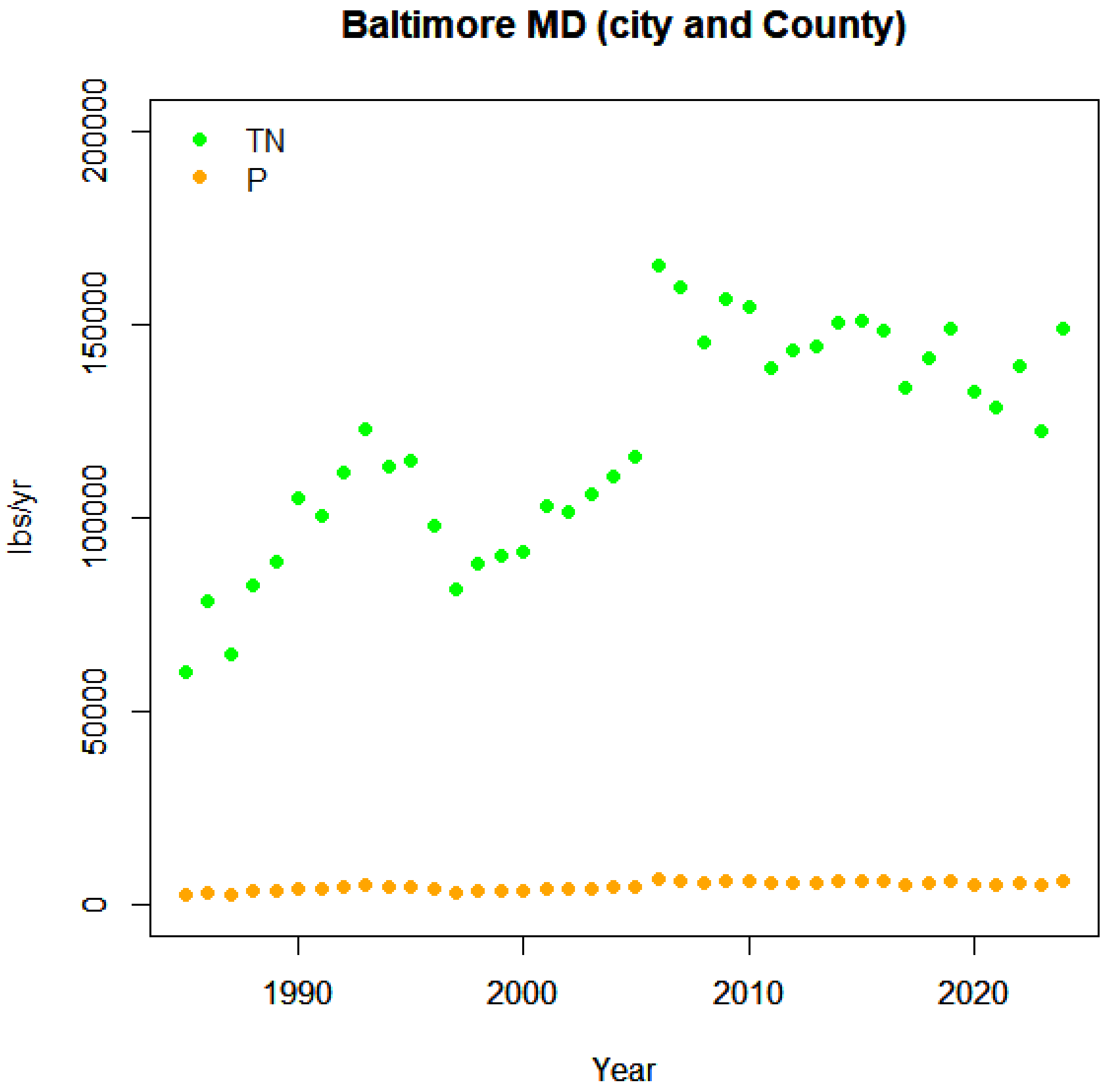
- P6 input datasets are used for testing and development. Final results will vary.
- This testing does not include optional inputs, those have been tested and reported for Baltimore (city and co) and SE VA (HRSD).
- In testing 1.9% of discharges have no associated exfiltration due to NAs which will be resolved for P7.

Watershed wide	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	1010642	1048515	987587	40383	42223	39817
% total EOS load	0.18%	0.20%		0.10%	0.14%	
% EOS developed load	1.35%	1.16%		0.74%	0.81%	

Preliminary Results

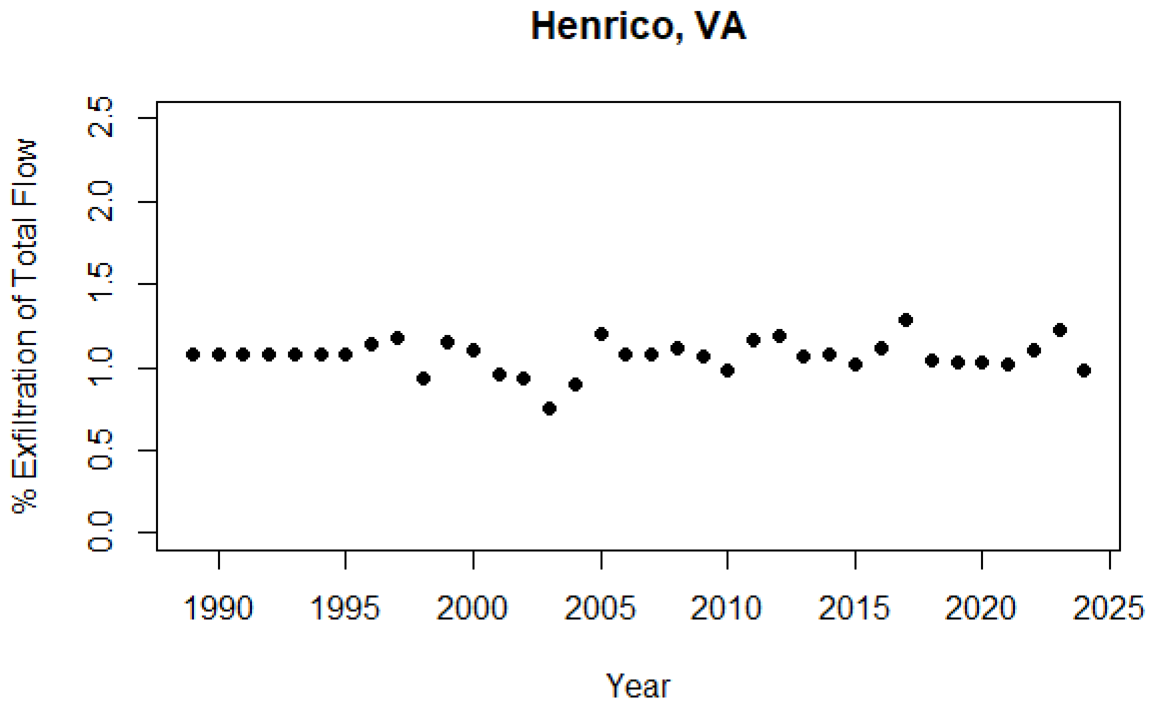
Baltimore (city+county)	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	114785	132735	119597	4549	5223	4730
% of developed load	5.73%	6.35%		2.71%	5.74%	

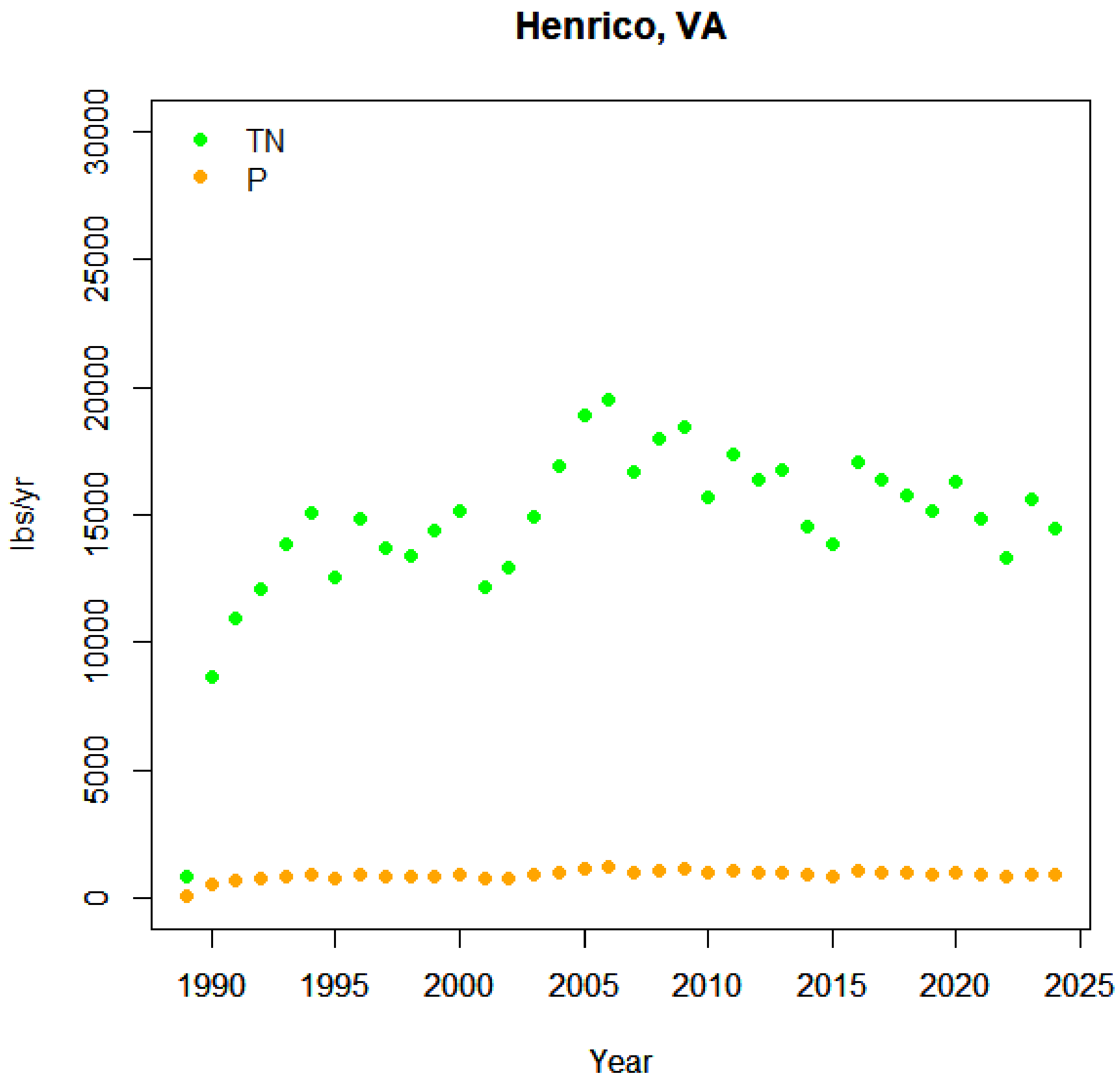




Preliminary Results

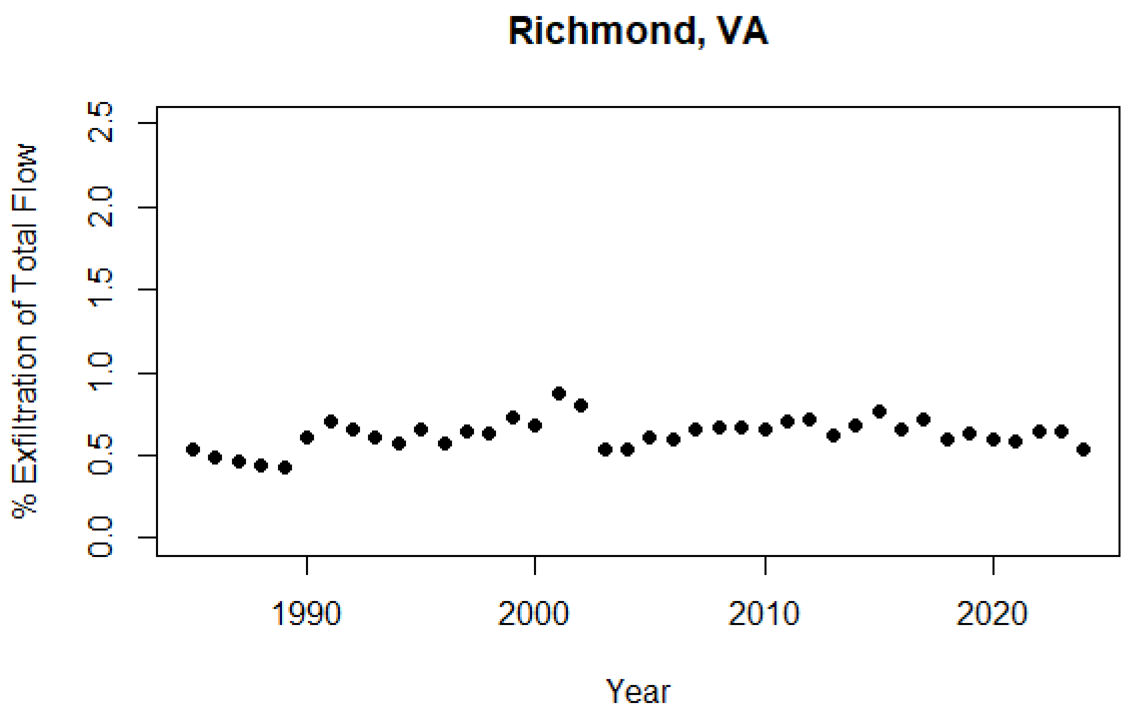
Henrico, VA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	12568	16257	14635	760	984	886
% of developed load	2.51%	2.49%		1.37%	1.72%	

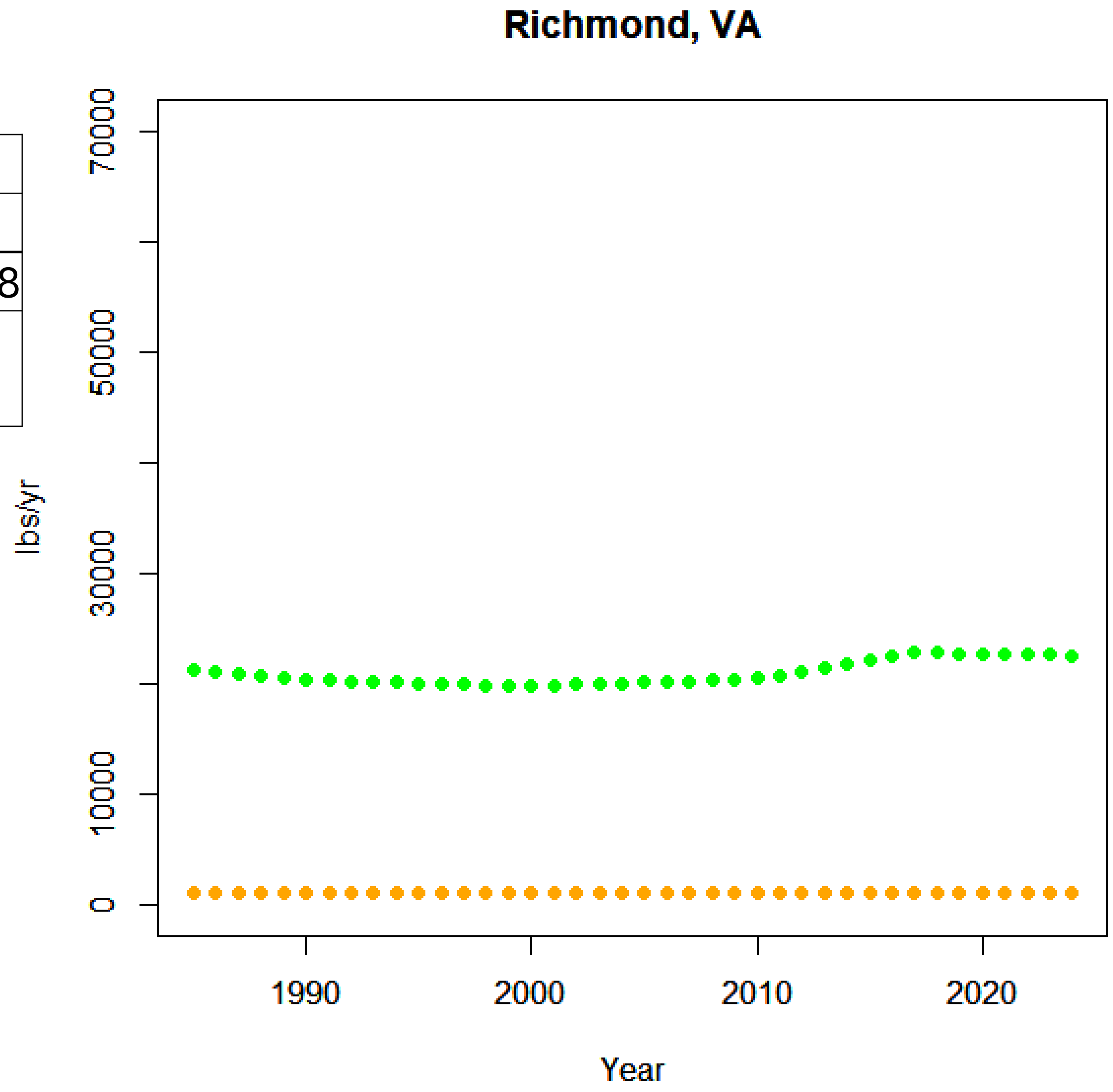




Preliminary Results

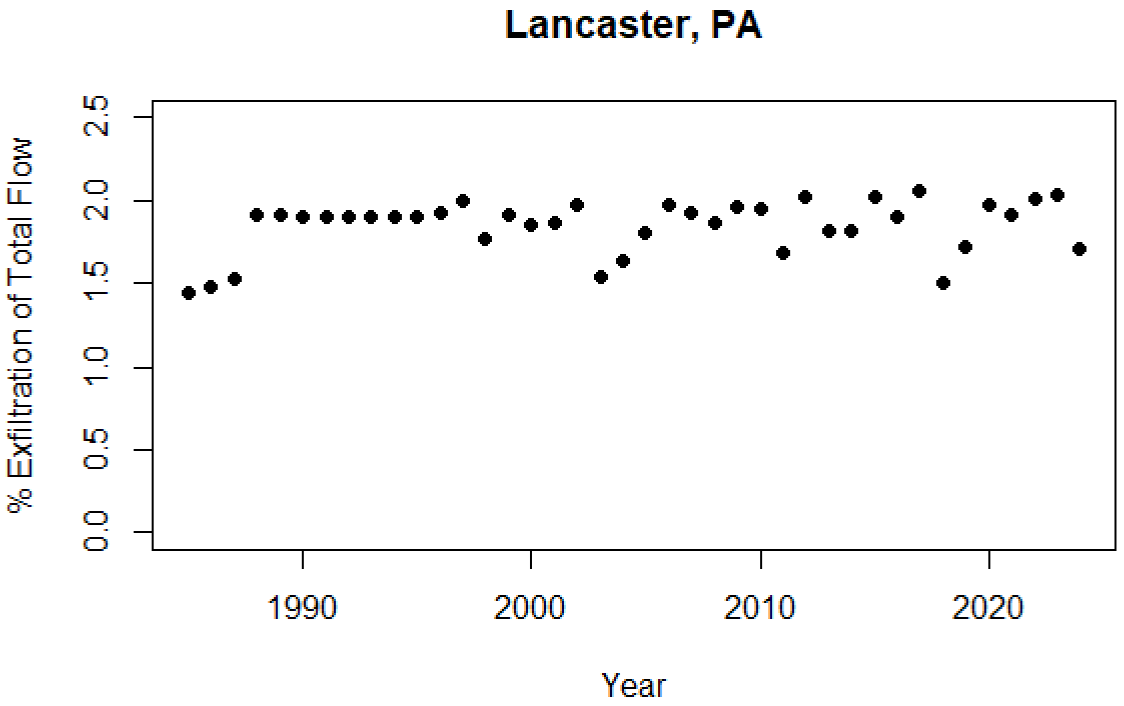
Richmond, VA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	20041	22789	22741	994	1130	1128
% developed load	5.67%	6.27%		2.43%	2.95%	

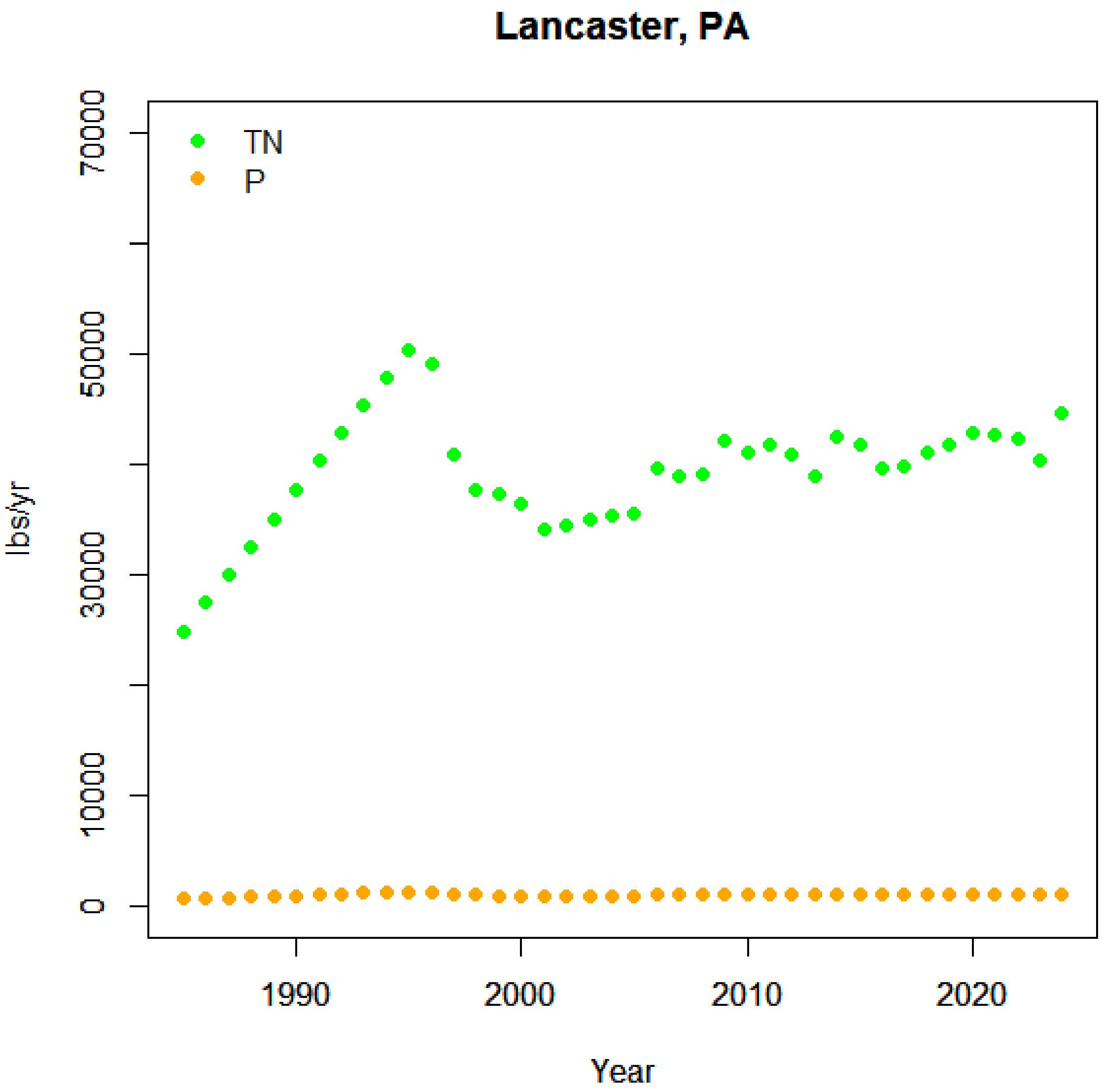




Preliminary Results

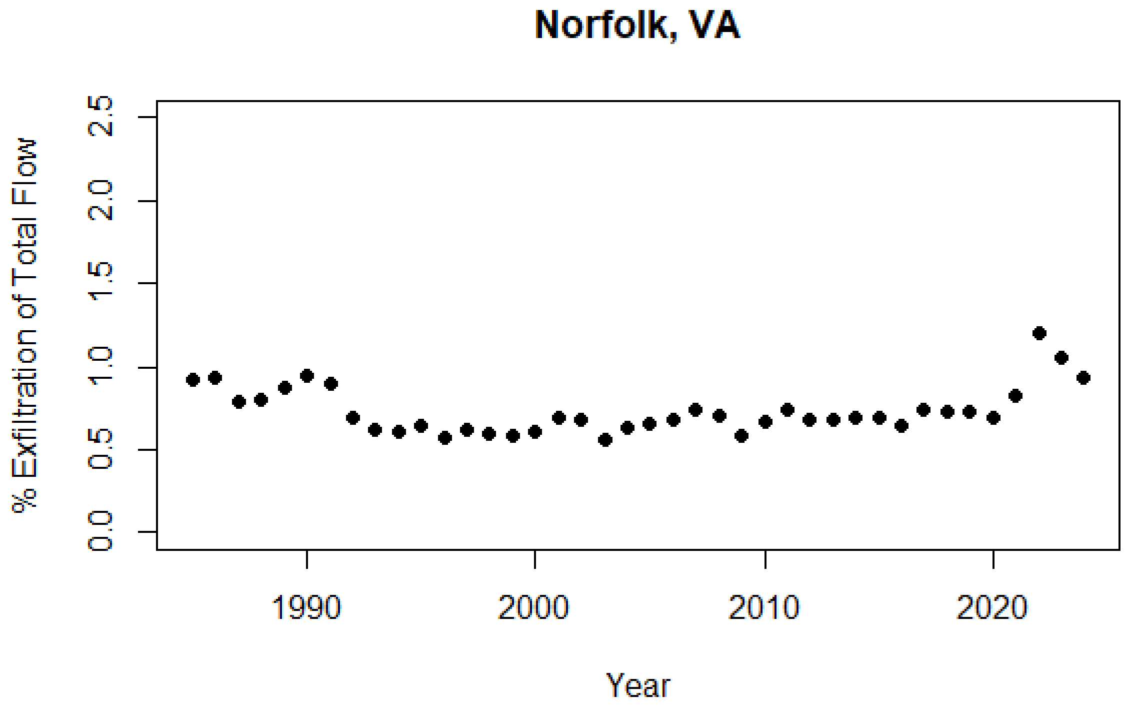
Lancaster, PA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	50334	42858	39285	1283	1084	999
% of developed load	1.69%	1.15%		1.30%	0.97%	

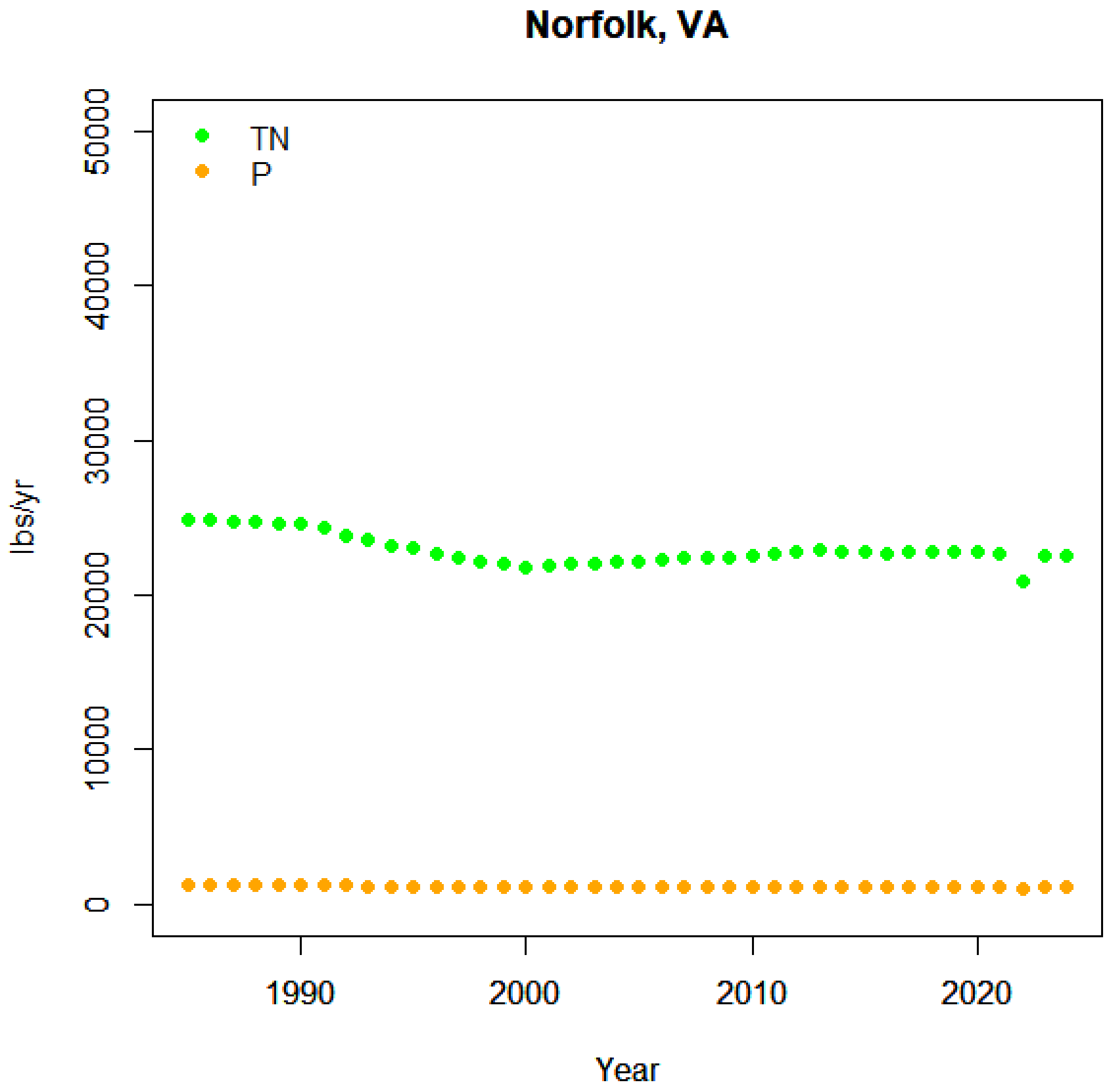




Preliminary Results

Norfolk, VA	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	23015	22862	22814	1160	1150	1148
% developed load	6.86%	6.55%		4.07%	4.64%	

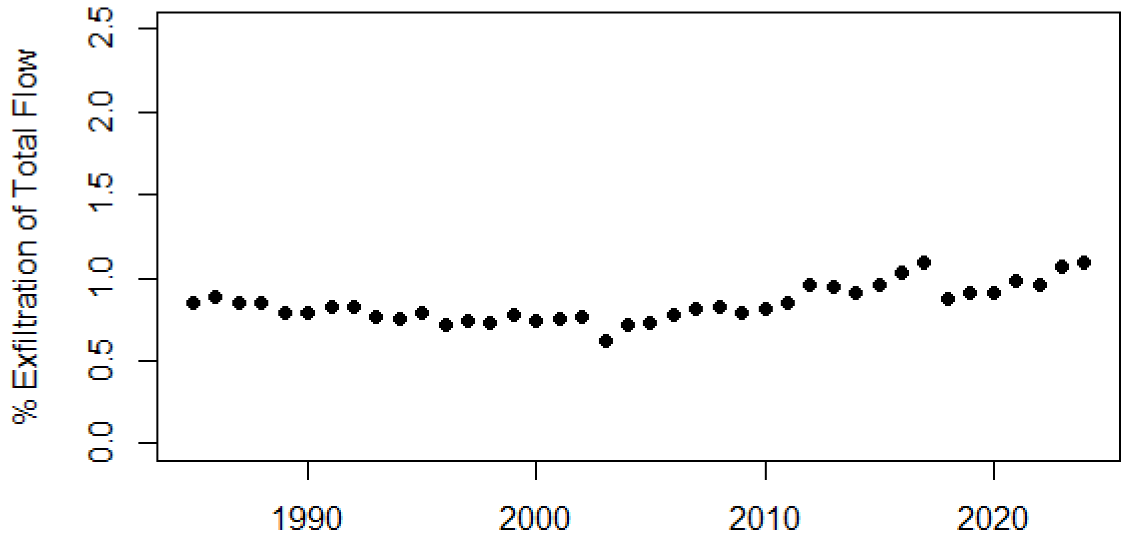


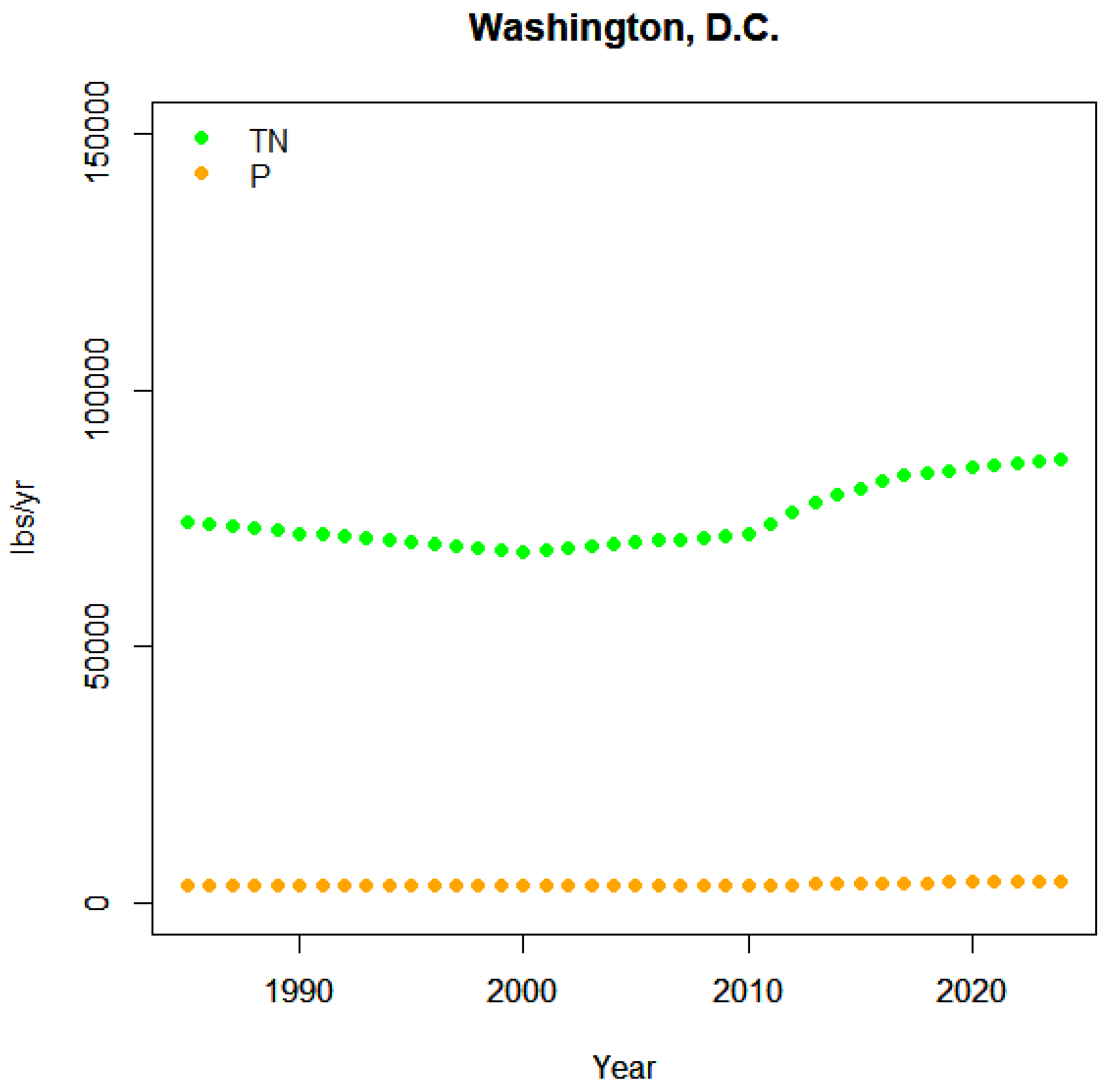


Preliminary Results

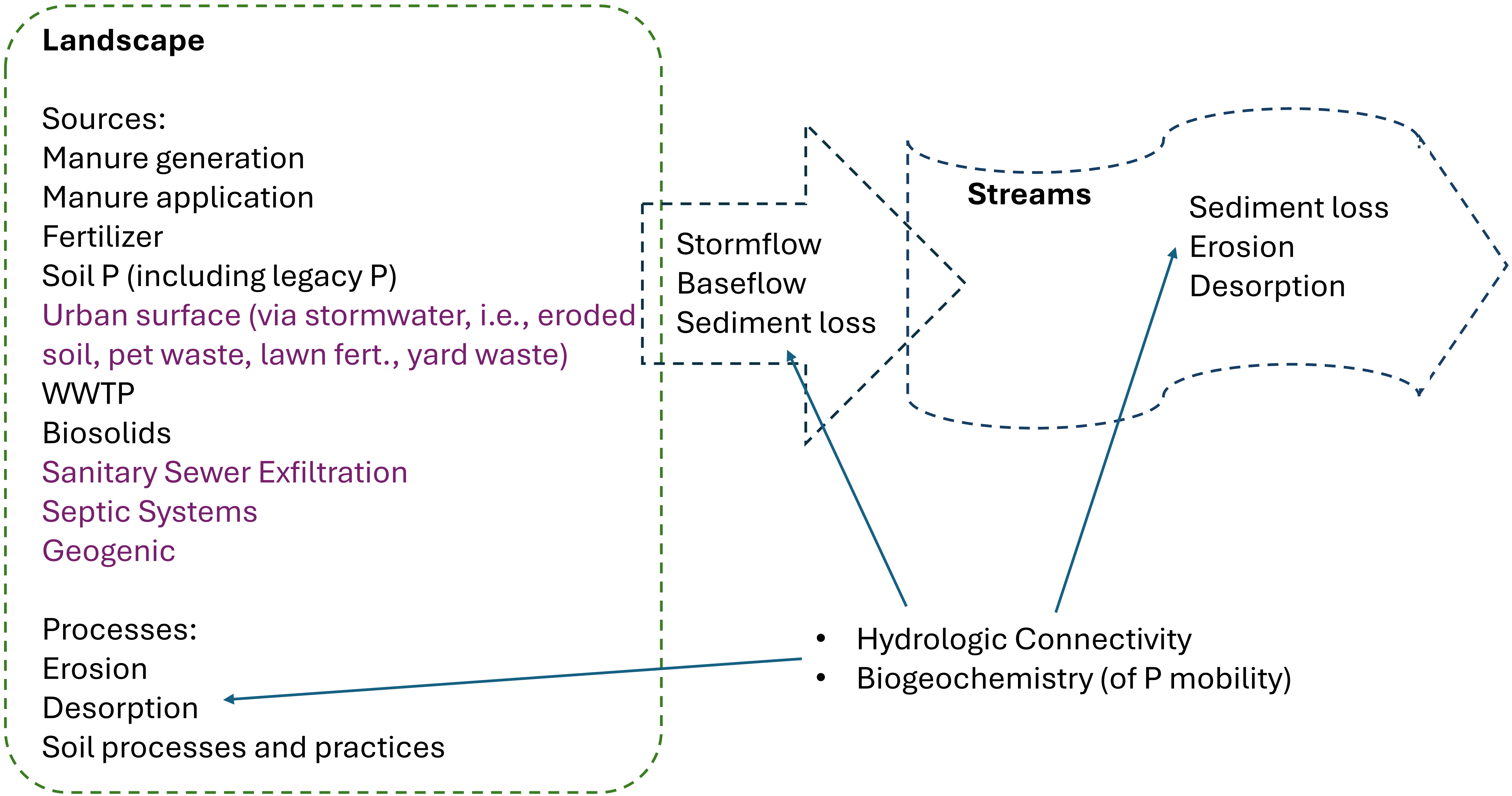
Washington D.C.	TN			P		
	1995	2020	mean	1995	2020	mean
Lbs/yr	70342	84757	74870	3321	4002	3535
% developed load	25.81%	39.00%		9.55%	22.98%	

Note: The SSE load is consistent with similar areas, but the % of developed is high because the CAST estimated dev. load is small.





Addressing the Phosphorus Modeling Gap

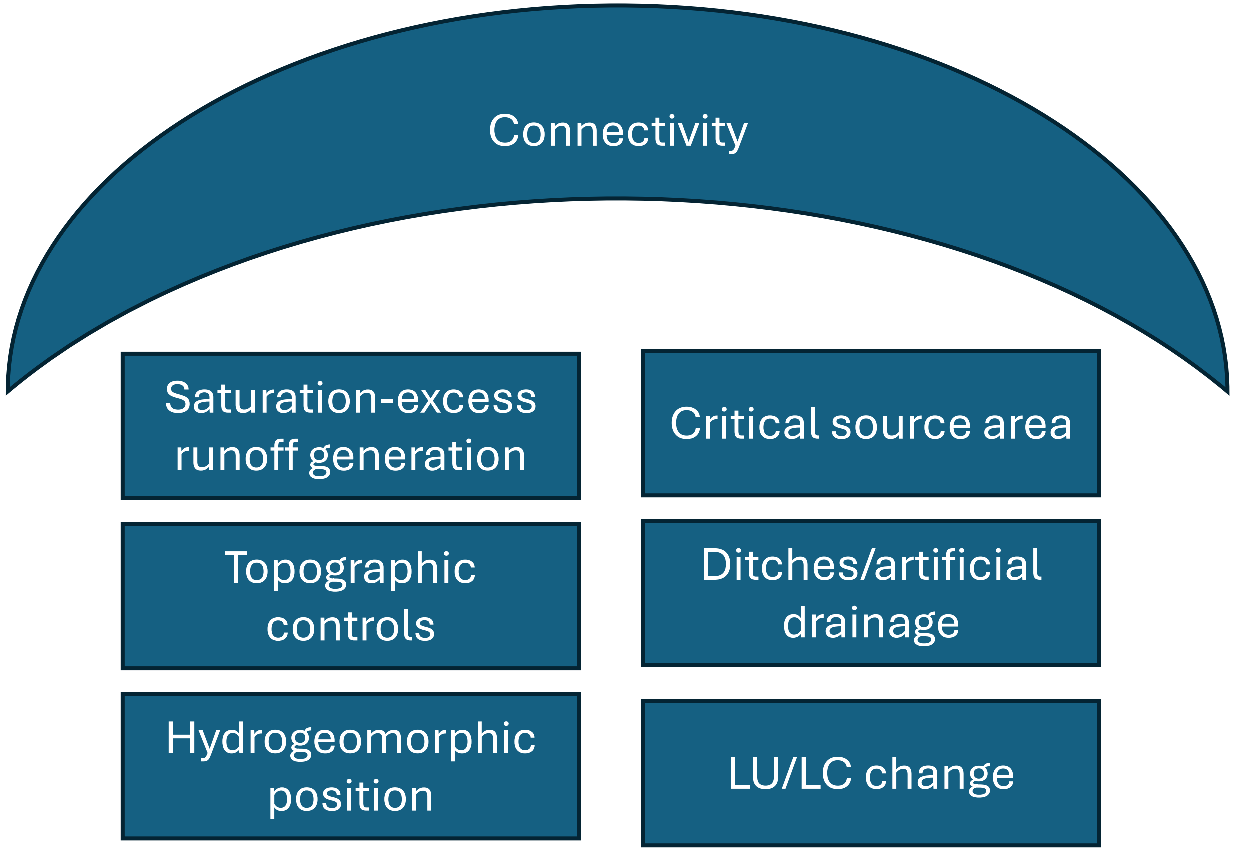


Purple sources are not explicitly accounted for in P6 but are captured to some extent in LU.

Connectivity: Landscape controls

Model review, STAC, and literature review identify several processes related by their influence on landscape connectivity of sources to streams.

We are working with the Geospatial team to better capture connectivity in model Land to Water factors.



Biogeochemical controls on P mobility

- Alkaline desorption
- Saltwater intrusion
- Road salting

These processes potentially control export from the landscape but are also drivers of instream internal loading.

Their effect on loading will then be very sensitive to instream sediment and legacy P.

While these processes are well documented, their potential impact on watershed scale P loading is not.

Alkaline desorption

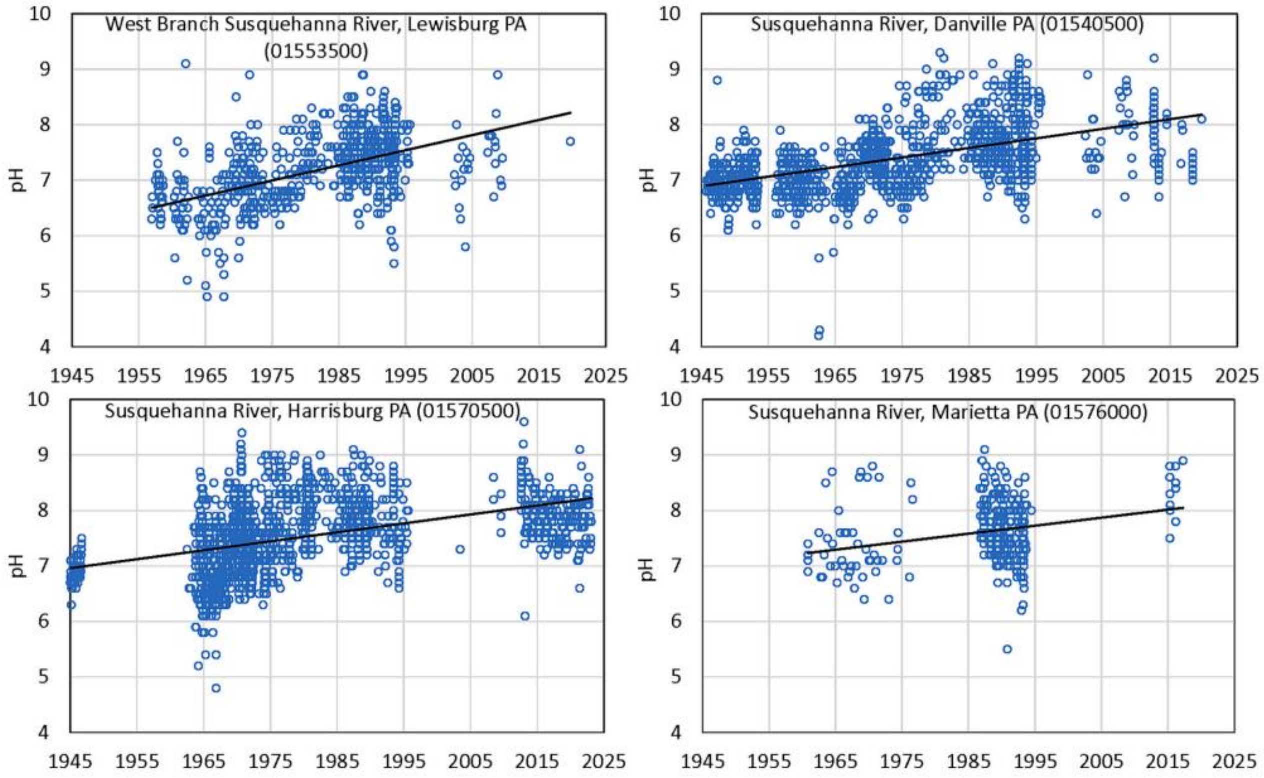


Fig. 5. Time-series showing pH of discrete samples for historical and current conditions on the West Branch Susquehanna River at Lewisburg (USGS station no. 01553500) and the Susquehanna River at Danville (USGS station no. 01540500), which merge downstream to form the lower Susquehanna River, represented by the Susquehanna River at Harrisburg (USGS station no. 01570500) and Marietta (USGS station no. 01576000). A positive trend in pH, with current baseline pH ~8, is indicated for all these stations. For any given year, pH variability by ~3 units reflects variations in flow conditions. Data retrieved from the U.S. Geological Survey (2023a) National Water Information System database; station locations are shown in Fig. 1.

Alkaline desorption and transport of phosphorus from legacy sediments is a potential source of P, but quantifying the export requires addition work.

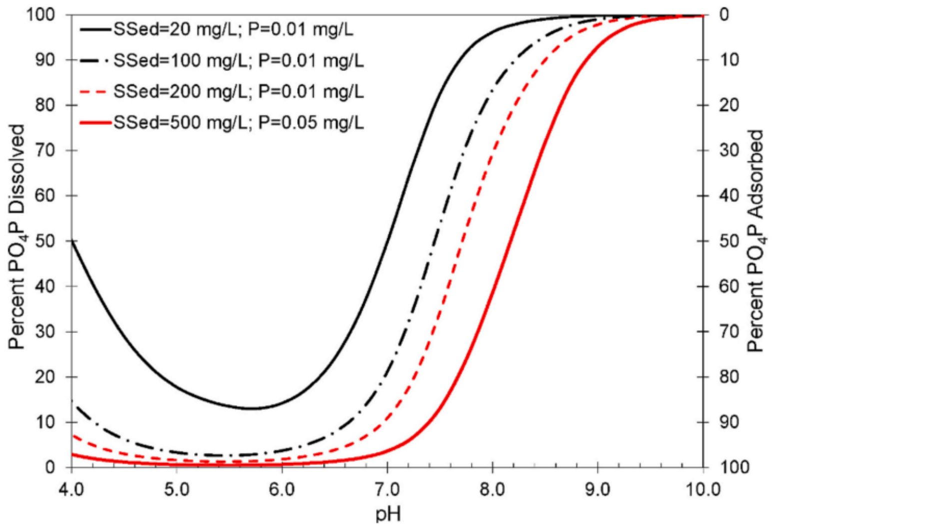


Fig. 4. Equilibrium fractions of initial concentration of phosphate (0.01 or 0.05 mg/L as P) that may be dissolved or adsorbed by suspended sediment (Ssed) composed of 6.7 % Fe (HFO; with a specific surface area (Asp) of 600 m^2/g), 0.5 % Mn (HMO; with Asp of 746 m^2/g), and 2.8 % Al (HAO; with Asp of 68 m^2/g). Upper three curves consider PO_4 = 0.01 mg/L as P and vary sorbent concentration from 20 to 200 mg/L, whereas lower curve considers PO_4 = 0.05 mg/L as P and sorbent concentration of 500 mg/L. Additional details and model results are shown in Figs. S1 and S2.

Legacy sediment as a potential source of orthophosphate: Preliminary conceptual and geochemical models for the Susquehanna River, Chesapeake Bay watershed, USA

Charles A. Cravotta III [a,*], Travis L. Tasker [b], Peter M. Smyntek [c], Joel D. Blomquist [d], John W. Clune [e], Qian Zhang [f], Noah M. Schmadel [g], Natalie K. Schmer [h]

Saltwater intrusion and road salting

- Ions in saltwater and road salting displace bound phosphate and increase P in solution.

Examples of recent literature:

Lucas, E., Kennedy, B., Roswall, T. et al. Climate Change Effects on Phosphorus Loss from Agricultural Land to Water: A Review. Curr Pollution Rep 9, 623–645 (2023). https://doi.org/10.1007/s40726-023-00282-7

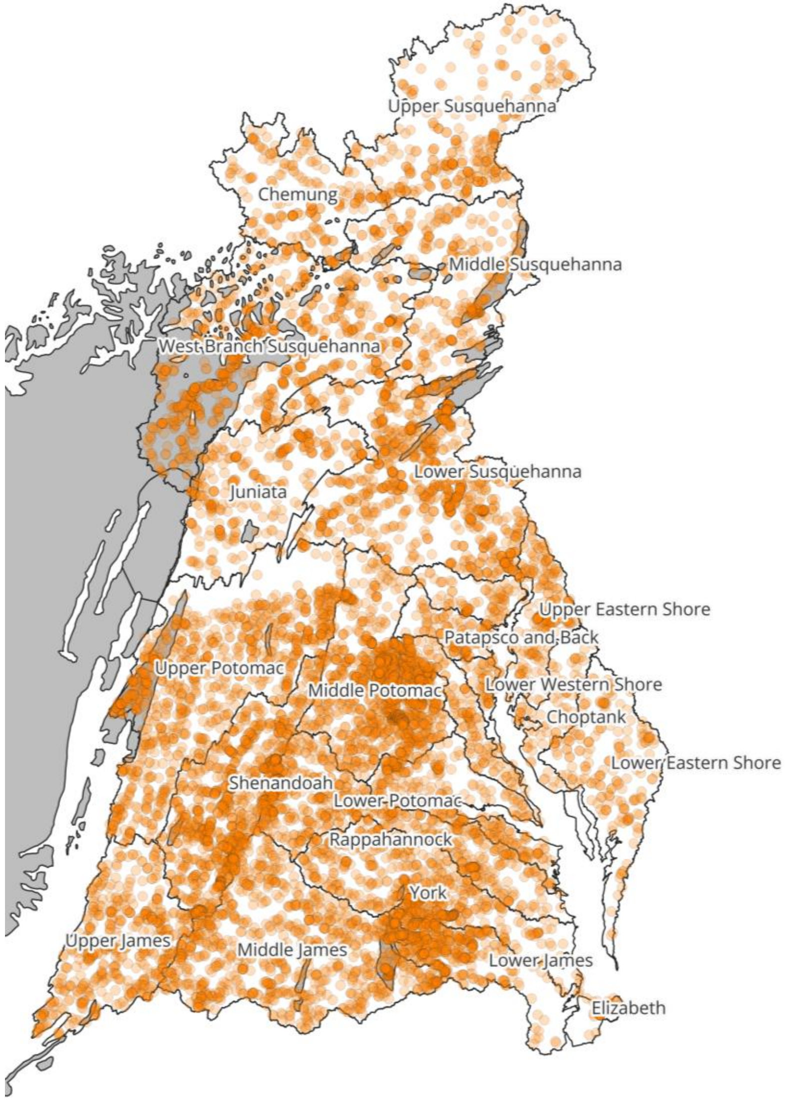
Weissman, D. S., & Tully, K. L. (2020). Saltwater intrusion affects nutrient concentrations in soil porewater and surface waters of coastal habitats. Ecosphere, 11(2), e03041.

Foley, E., & Steinman, A. D. (2023). Urban lake water quality responses to elevated road salt concentrations. Science of the Total Environment, 905, 167139.

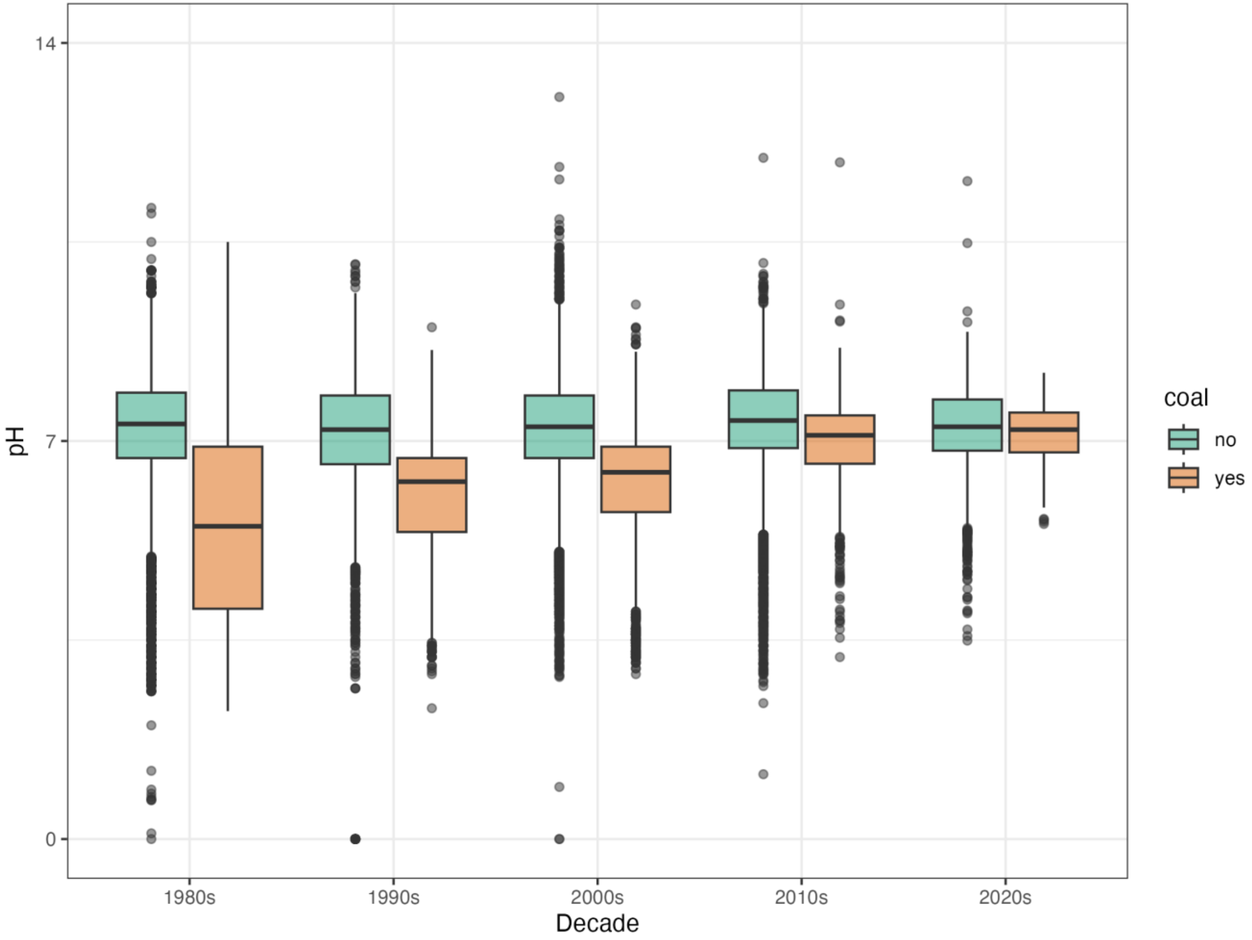
Incorporation into P7

- Represent these processes in time and space and test as land-to-water and stream-to-river factors
- Similarly represent geogenic P, common in SPARROW models

Trends in pH across the watershed, data from the Water Quality Portal

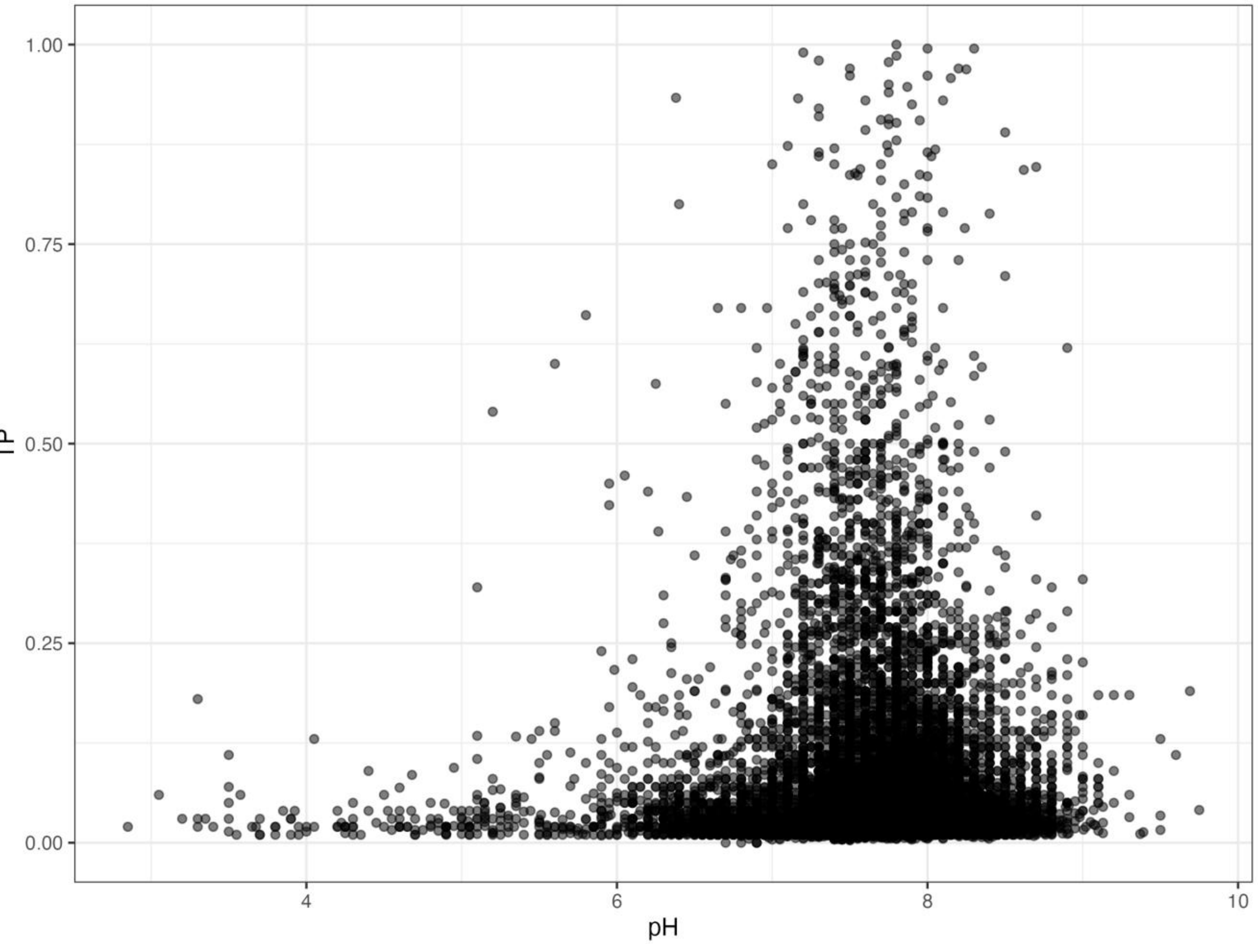


pH observations in coal areas = 6,019
pH observations outside = 208,582

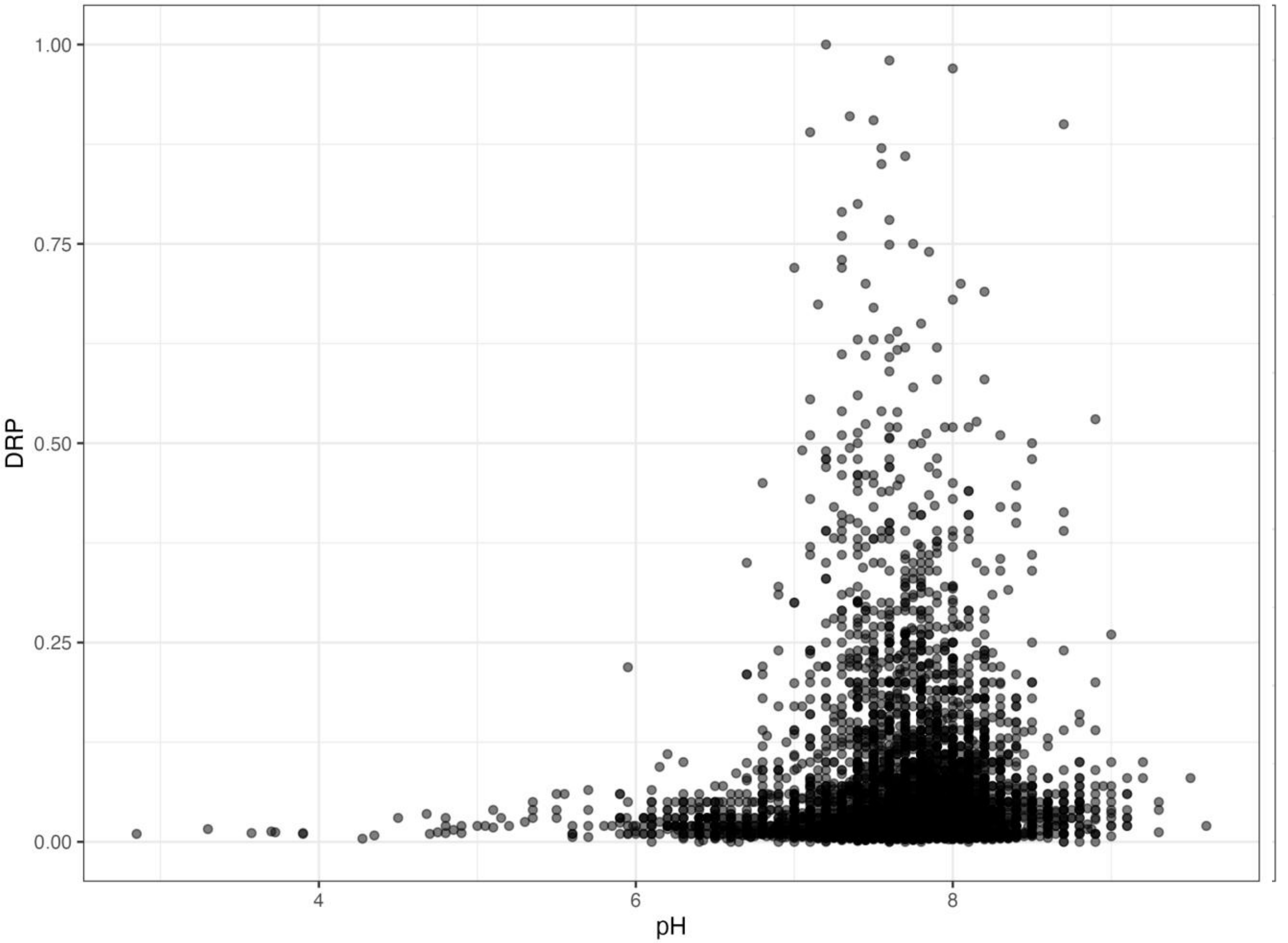


TP and DRP concentrations increase with alkalinity

TP

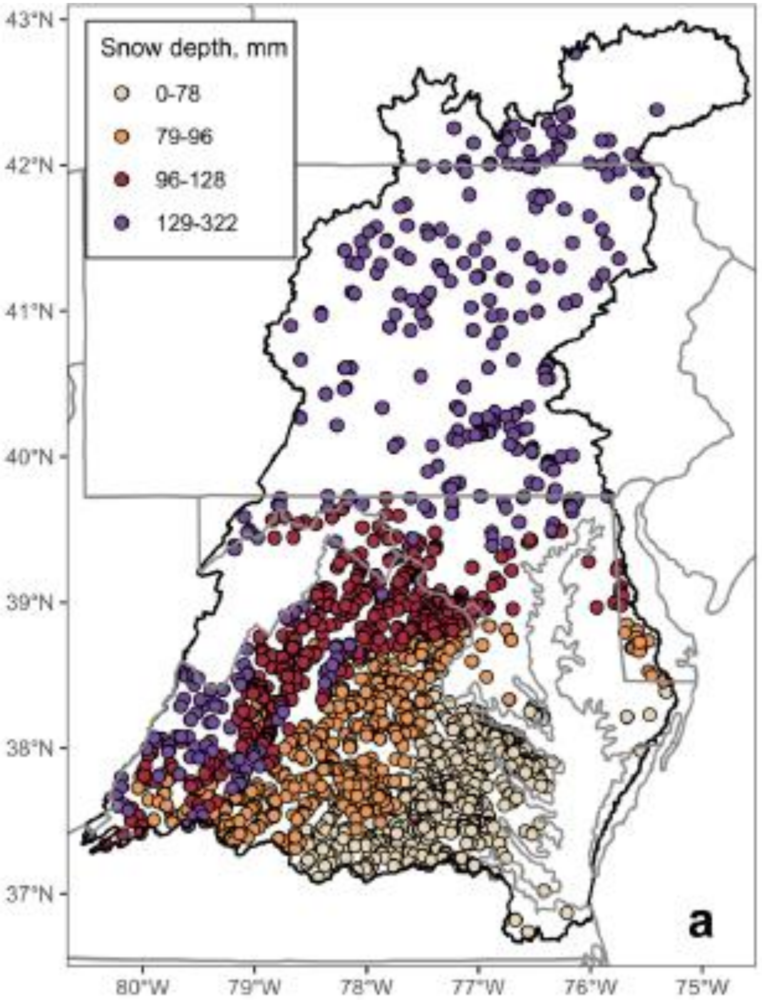


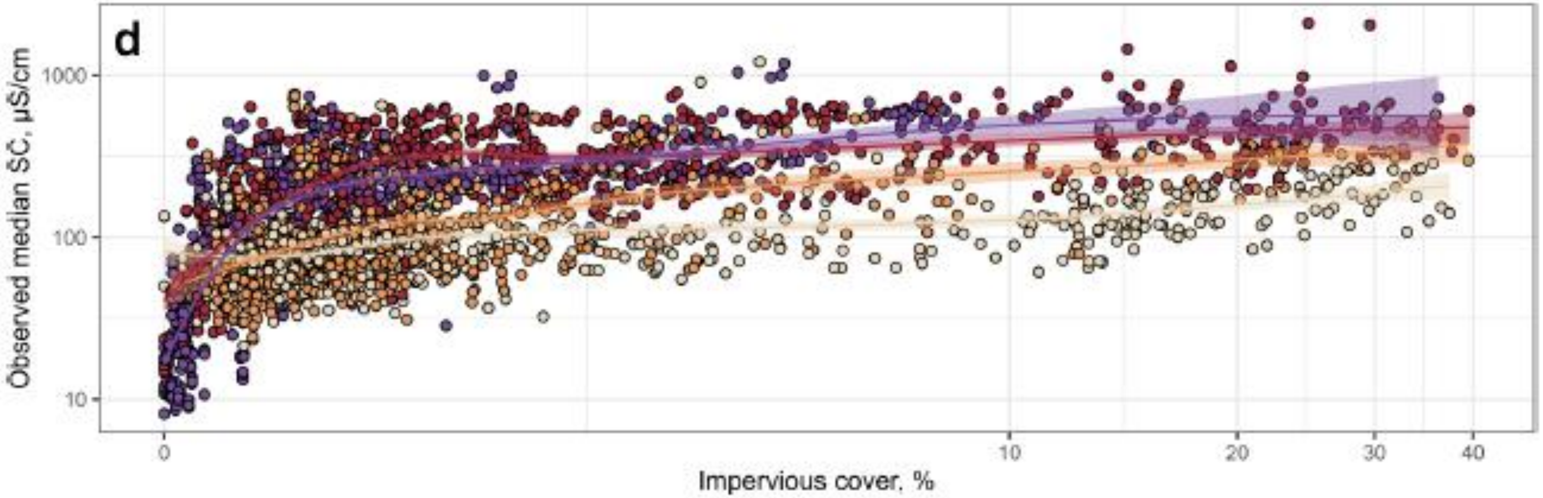
DRP



Review of land use impacts on in-stream salinity levels

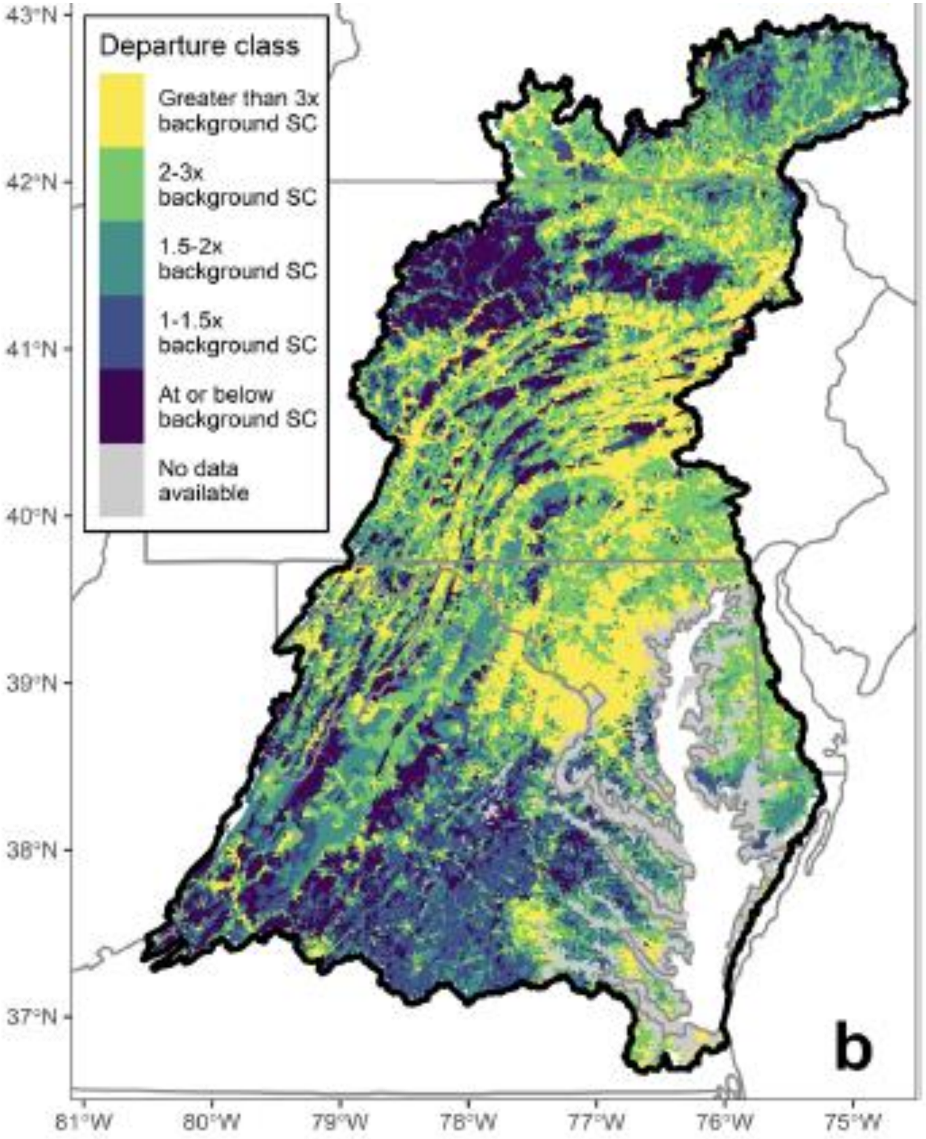
Avg. snow depth (2000-2014)





The amount of snow interacts with impervious cover (Fanelli et al. 2024)

Review of land use impacts on in-stream salinity levels



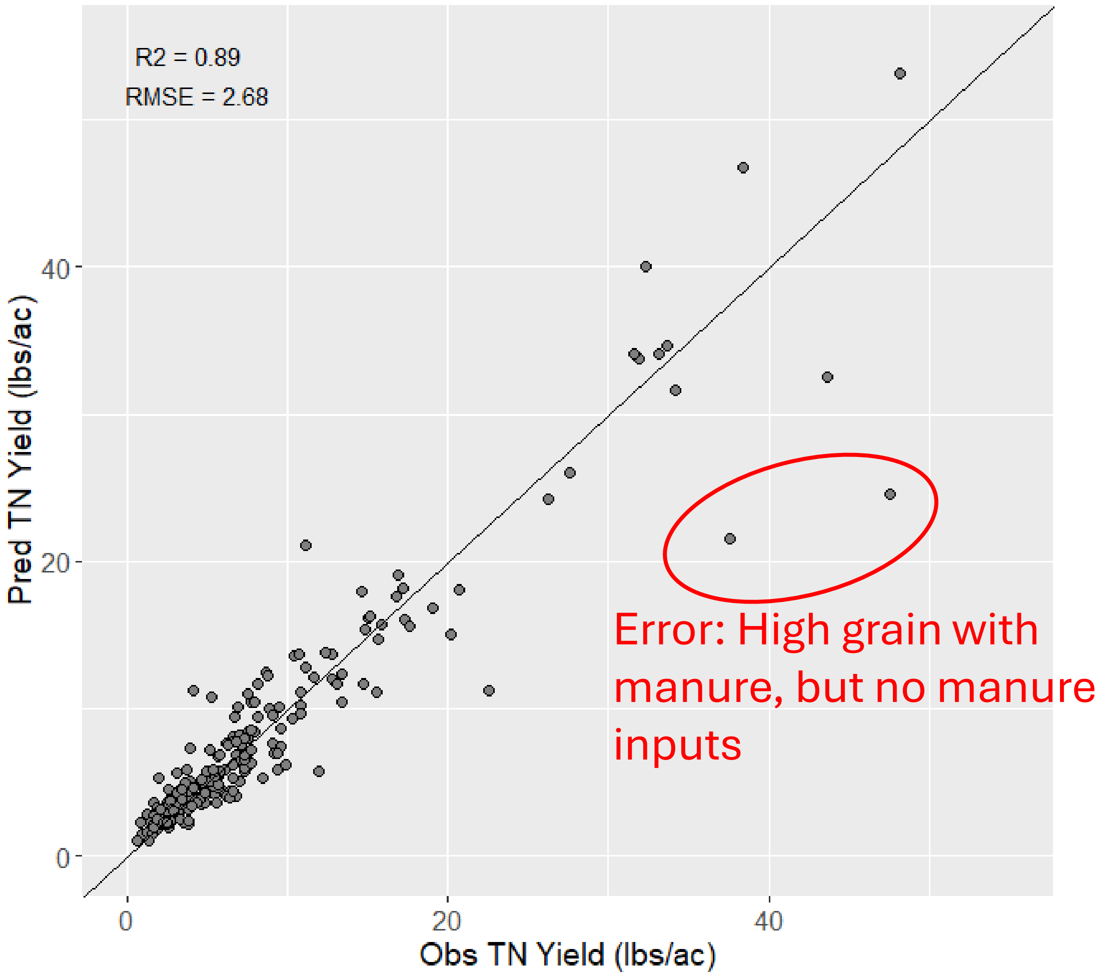
Predictions from a random forest model show that elevated conductivity levels are widespread in the watershed (Fanelli et al. 2024)

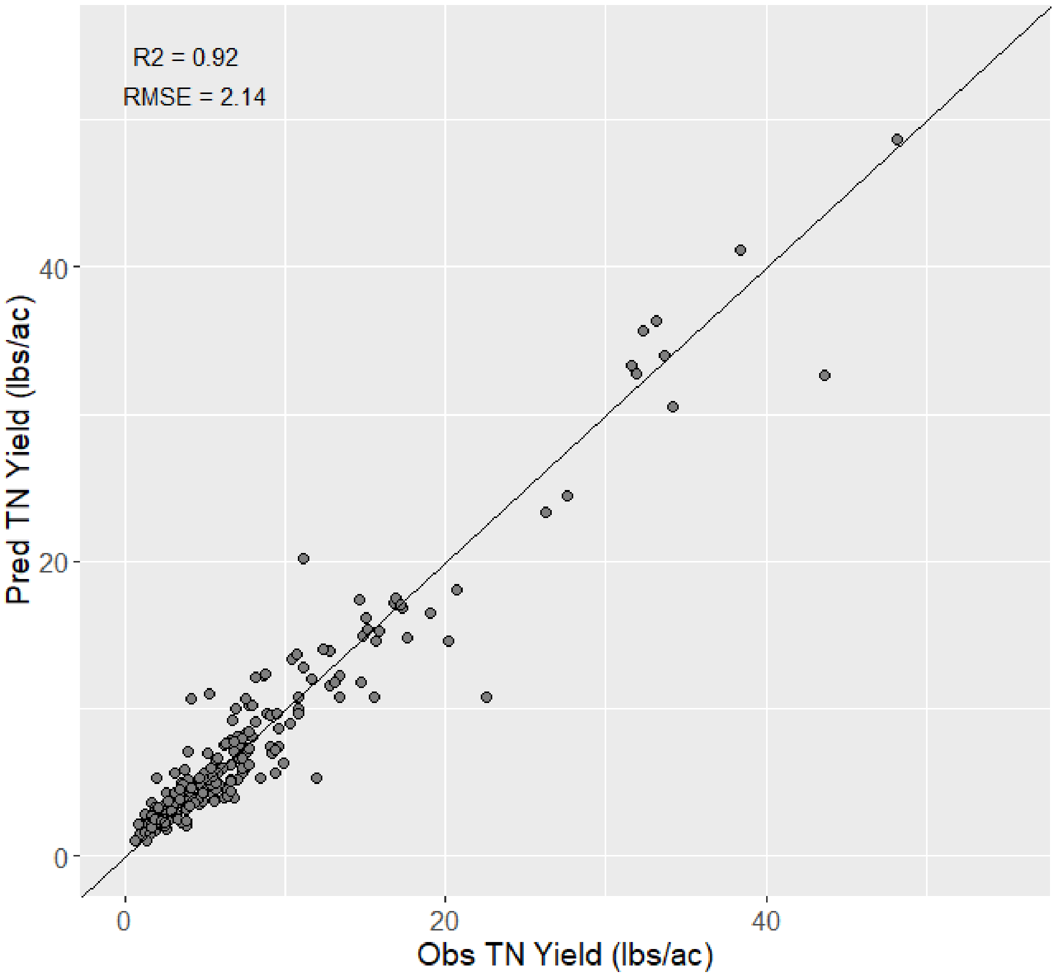
A review of geogenic phosphorus datasets to identify which one is most appropriate is in progress

Discussion

Extra content

Average annual (spatial) model





Total Nitrogen – Loading Rates

No priors

CLR = Average CROP loading rate (lbs/ac)

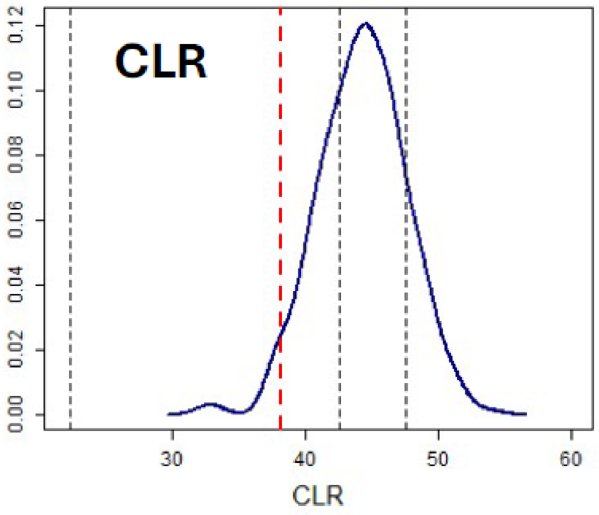
RCpas = Ratio of PASTURE loading rate to CROP loading Rate

RCdev = Ratio of DEVELOPED loading rate to CROP loading Rate

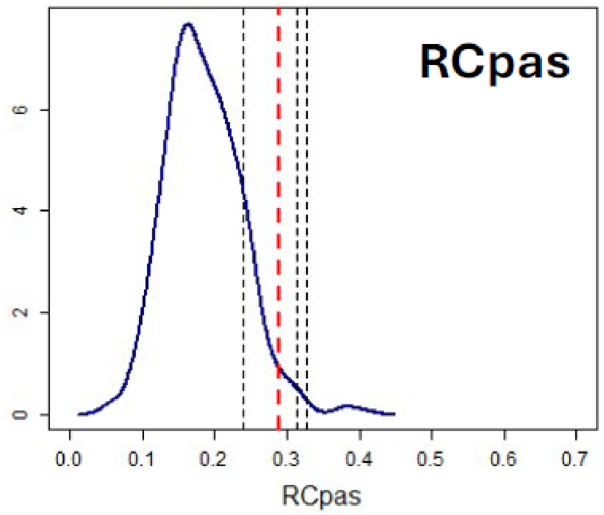
RCnat = Ratio of NATURAL loading rate to CROP loading Rate

Red dashed line = P6
Black dashed lines = P532, SPARROW, CEAP

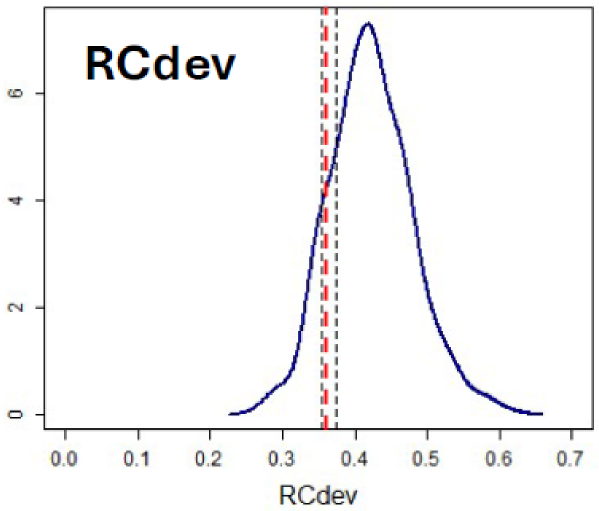
P6 = 38 lbs/ac (22-48)
CalCAST = 44 lbs/ac



P6 = 0.29 (0.24-0.33)
CalCAST = 0.20



P6 = 0.36 (0.35-0.37)
CalCAST = 0.42



P6 = 0.05
CalCAST = 0.03 (0.02-0.09)