Progress on Phase 7 Loading Sensitivities and Transport and Attenuation Factors

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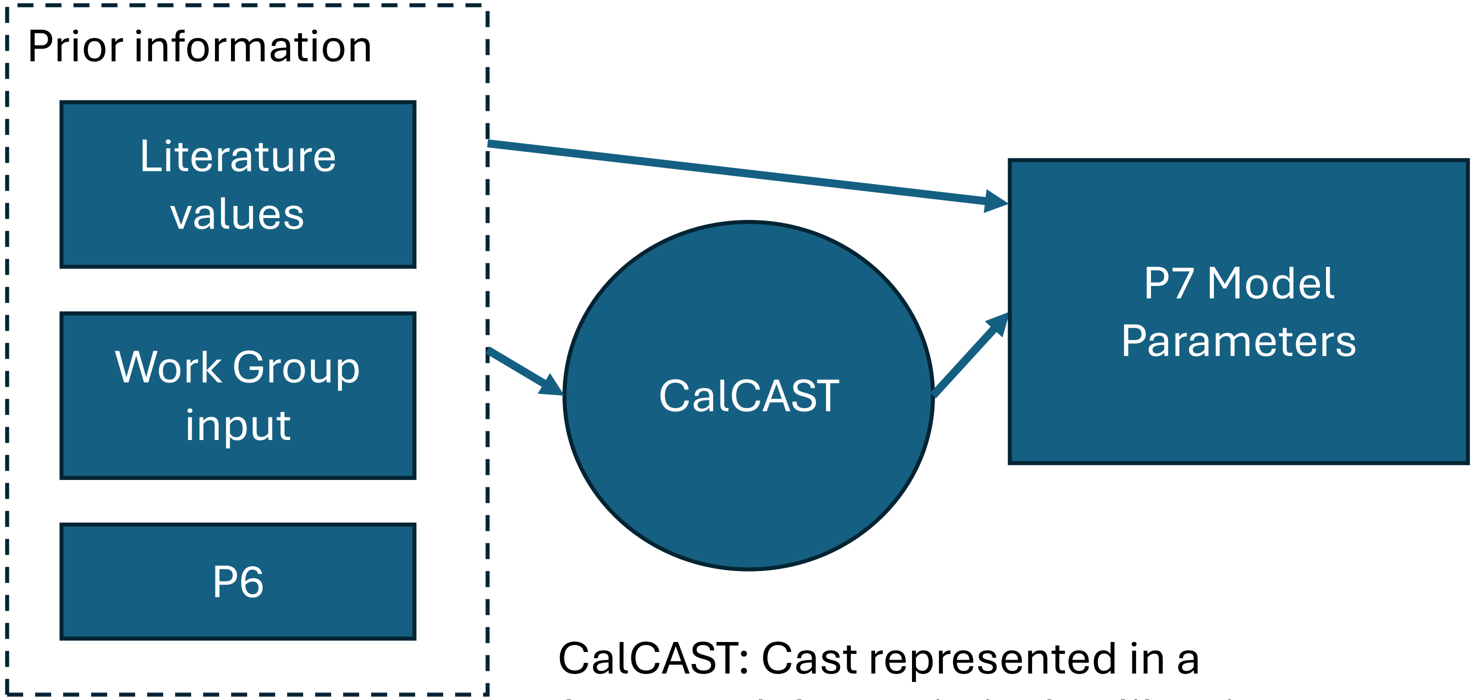
Agenda

- Data-driven quantification of loading sensitivity to inputs

- Transport and attenuation factors
  - Addressing the phosphorus modeling gap
  - Feature selection

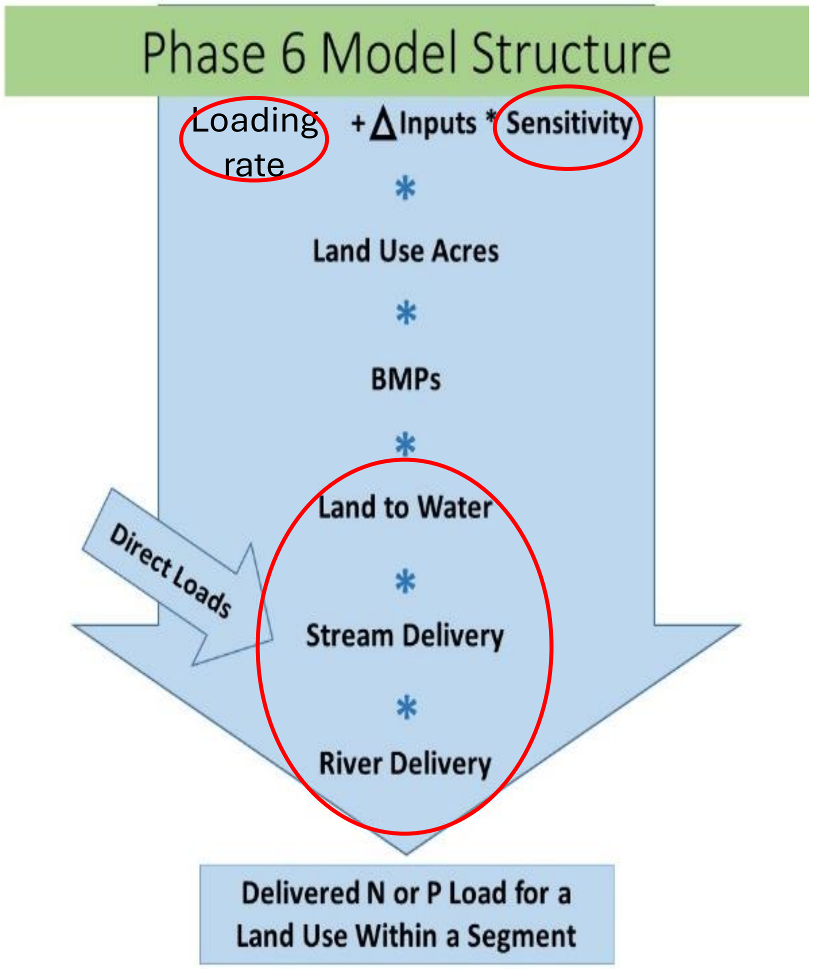
Quantifying P7 model parameters

Incorporate data-driven lines of evidence into modeling approach



CalCAST: Cast represented in a framework for statistical calibration

Calibrate loading rates, select sensitivities, and coefficients of delivery factors.

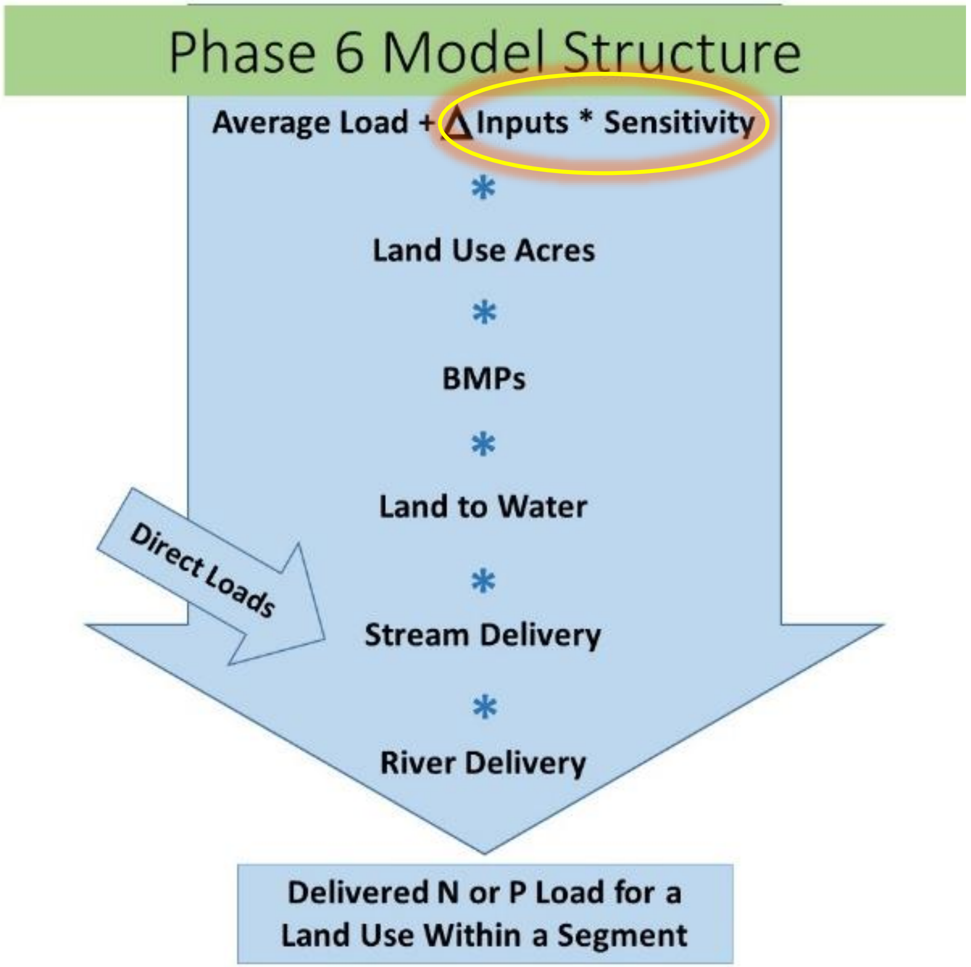


CAST Load Sensitivity to Inputs

Sensitivity (S) is defined as the change in export load per change in input load. If inputs change by Δ, the export will change by S*Δ (S=Δ Export/Δ Input). Δ is defined relative to the mean input.

In other words:

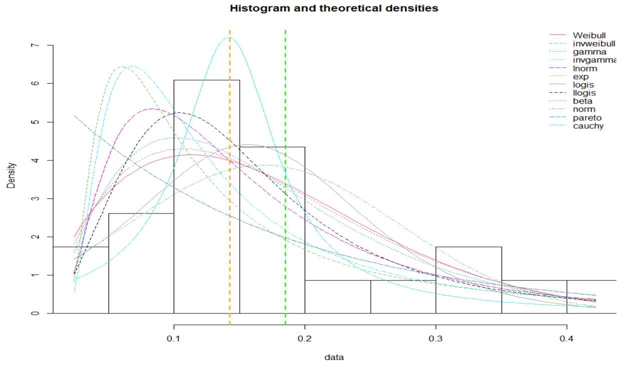
- When added to the land use average load we identify the load, by source (land use and input), which is available for export (edge of field or stream load).
- Sensitivities account for the spatial and temporal variation in the load available for export.
- A lower sensitivity value will result in a more muted loading response to changes in inputs.
    - If there is no sensitivity (0), then the load available for export is constant in space and time for that land use defined by the loading rate.



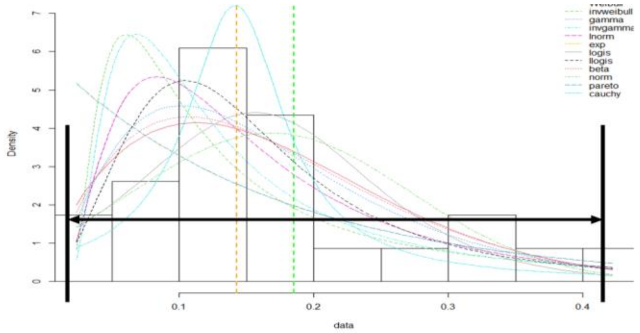
Sensitivity Prior Information

- Cropland sensitivity to fertilizer (N+P)
- Cropland sensitivity to manure (N+P)
- Natural LU sensitivity to atm. deposition (N)
- Cropland sensitivity to uptake (ongoing) (N)

Continuous functions are fit to a **distribution** of literature values



Upper and lower **bounds** are applied (literature range)



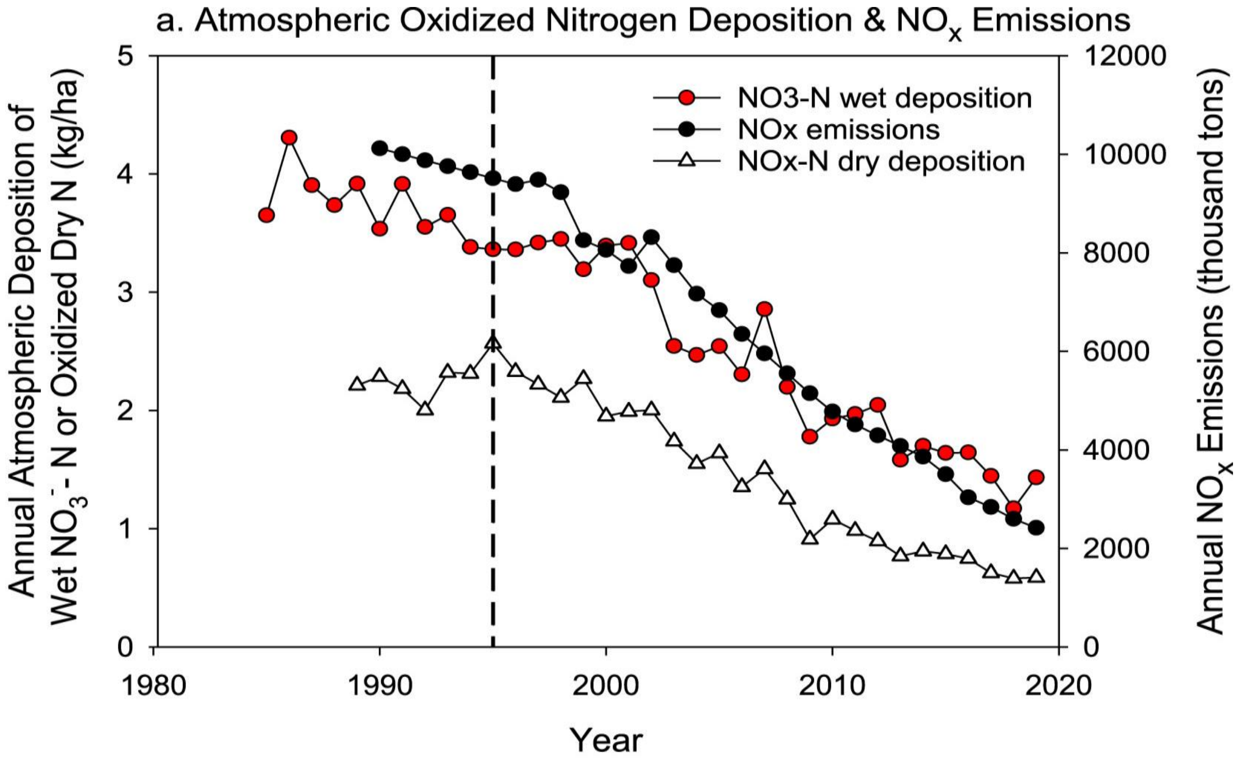
Relationships between parameters are defined or constrained, **conditional data** (work groups)

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

To CalCAST

P6 N Atm. Dep. Sensitivity Values

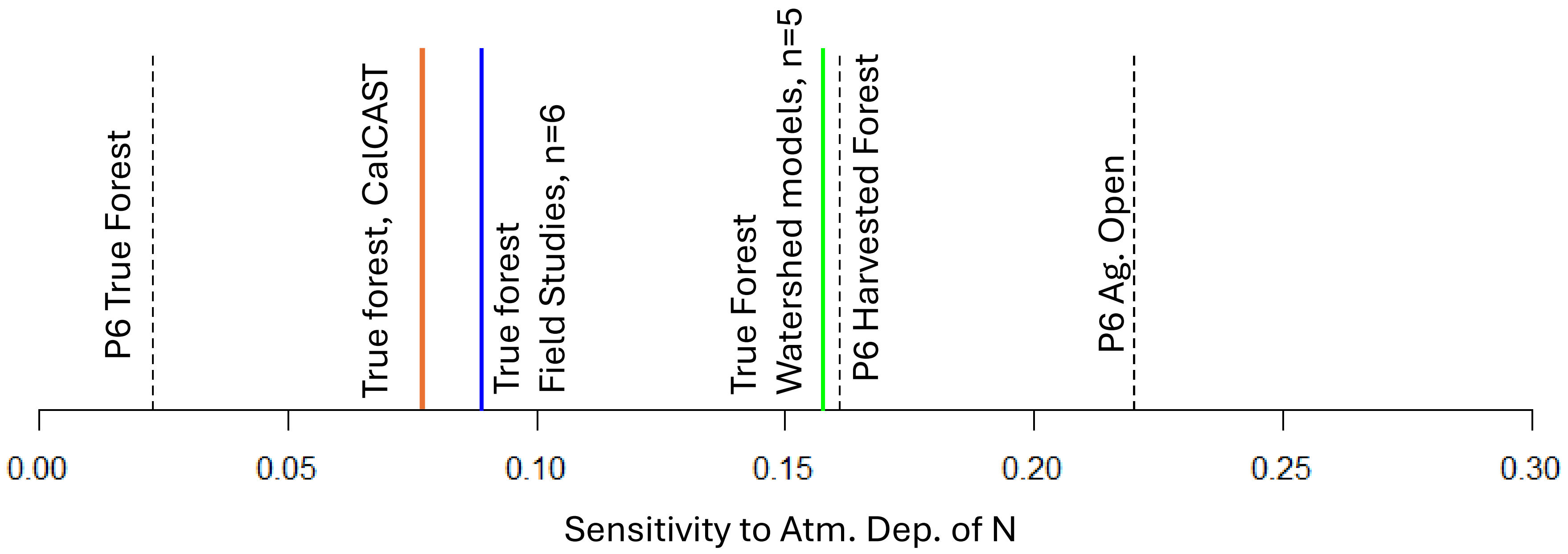
- True Forest: 0.023
- Harvested Forest: 0.161



Burns, D. A., Bhatt, G., Linker, L. C., Bash, J. O., Capel, P. D., & Shenk, G. W. (2021). Atmospheric nitrogen deposition in the Chesapeake Bay watershed: A history of change. *Atmospheric Environment*, *251*, 118277.

Forest Load Sensitivity to N Dep. Literature

- Thanks to Rosh Nair-Gonzalez and Conor Keitzer - UMCES
- While forests are very retentive, most atm. deposition is coincident with rainfall and high flows, elevating sensitivity
- Forestry Work Group suggested a value near that for the field studies was more reasonable (0.089)
- CalCAST values (with literature priors) = 0.077
- Forestry Work Group also suggested adjusting other sensitivities relative to True Forest (next slide)



Sensitivity Conditional Relationships (FWG)

True forest <= Tree canopy over turf

Turf grass

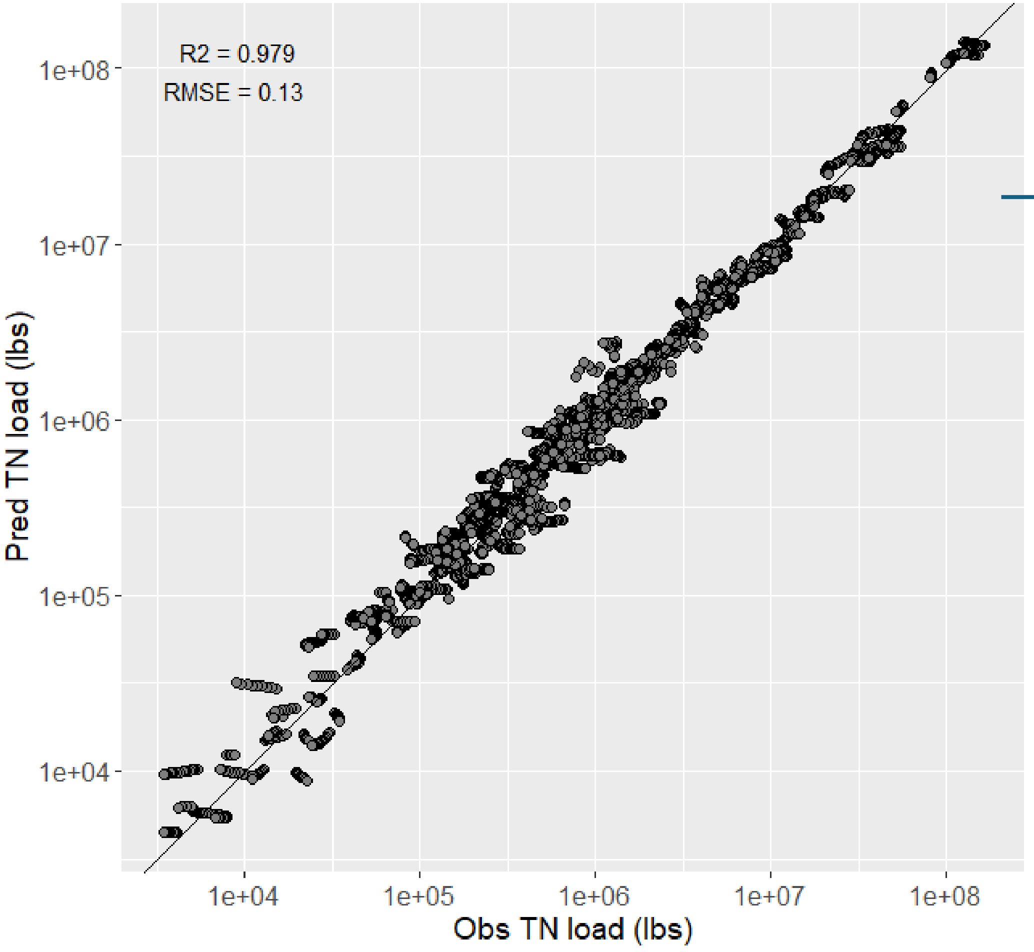
Specialty crops

Other hay

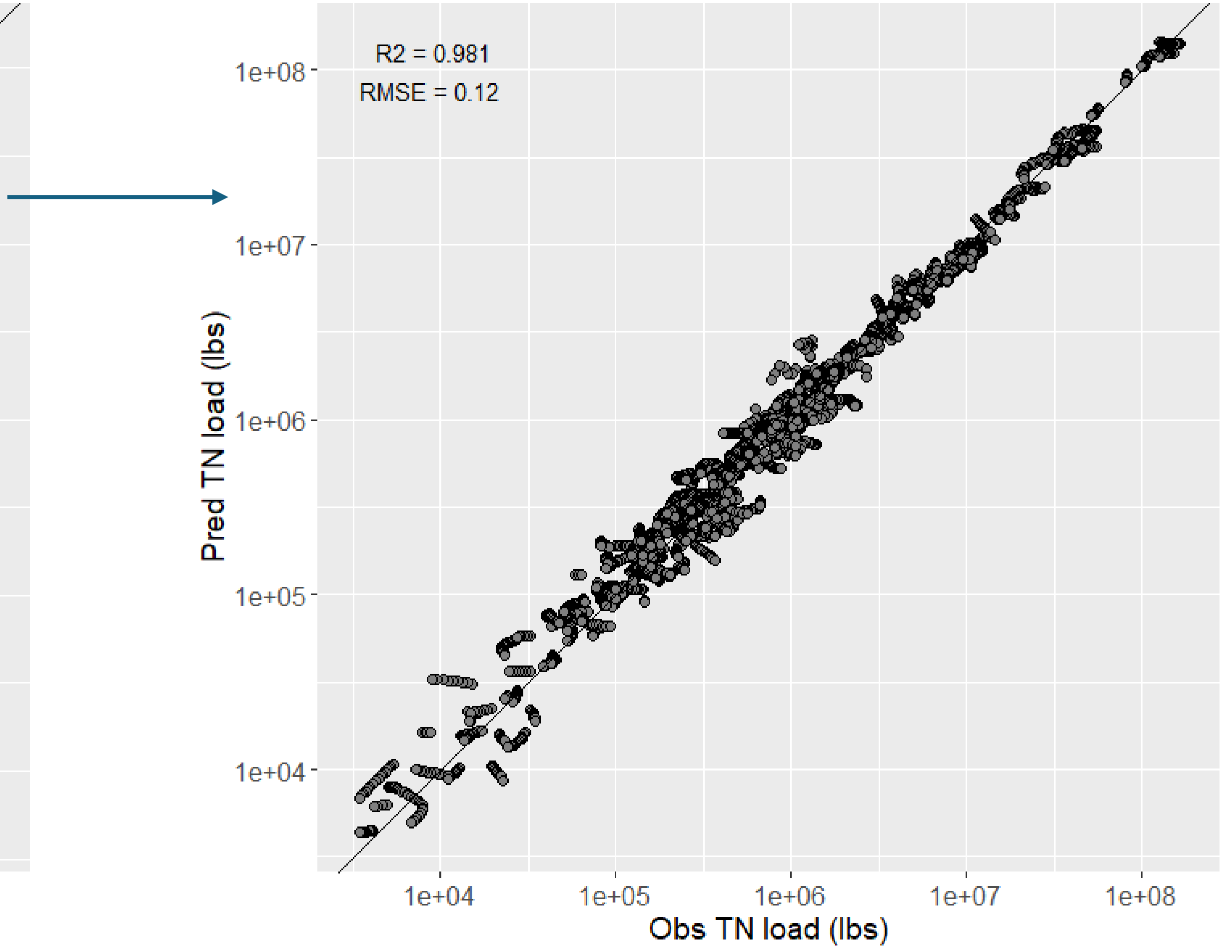
$$S_{(Natural, i)} = \min(LR_{(Natural, i)} * S_{(Forest)}, S_{(Construction)})$$

N Atm. Dep. Sensitivity to Forest

P6 sensitivity value (S=0.023)



Calibrated from lit. priors (S=0.077)



N Atm. Dep. Sensitivity to Forest

Model performance metrics do not capture trend well...

- Model performance is driven largely by spatial variation in loads
- Variation in load from station to station often far exceeds variation from year to year within stations

Within site slope compared to b=1 (sites with 10yr + observations):

P6 sensitivity value (S=0.023)
Slope RMSE = 1.00

Calibrated from lit. priors (S=0.077)
Slope RMSE = 0.85

Mean square error skill score ($1-MSE_{(New)}/MSE_{(Old)}$) = 0.28
(how much better is the model at predicting slope with calibrated atm. dep. to forest s value)

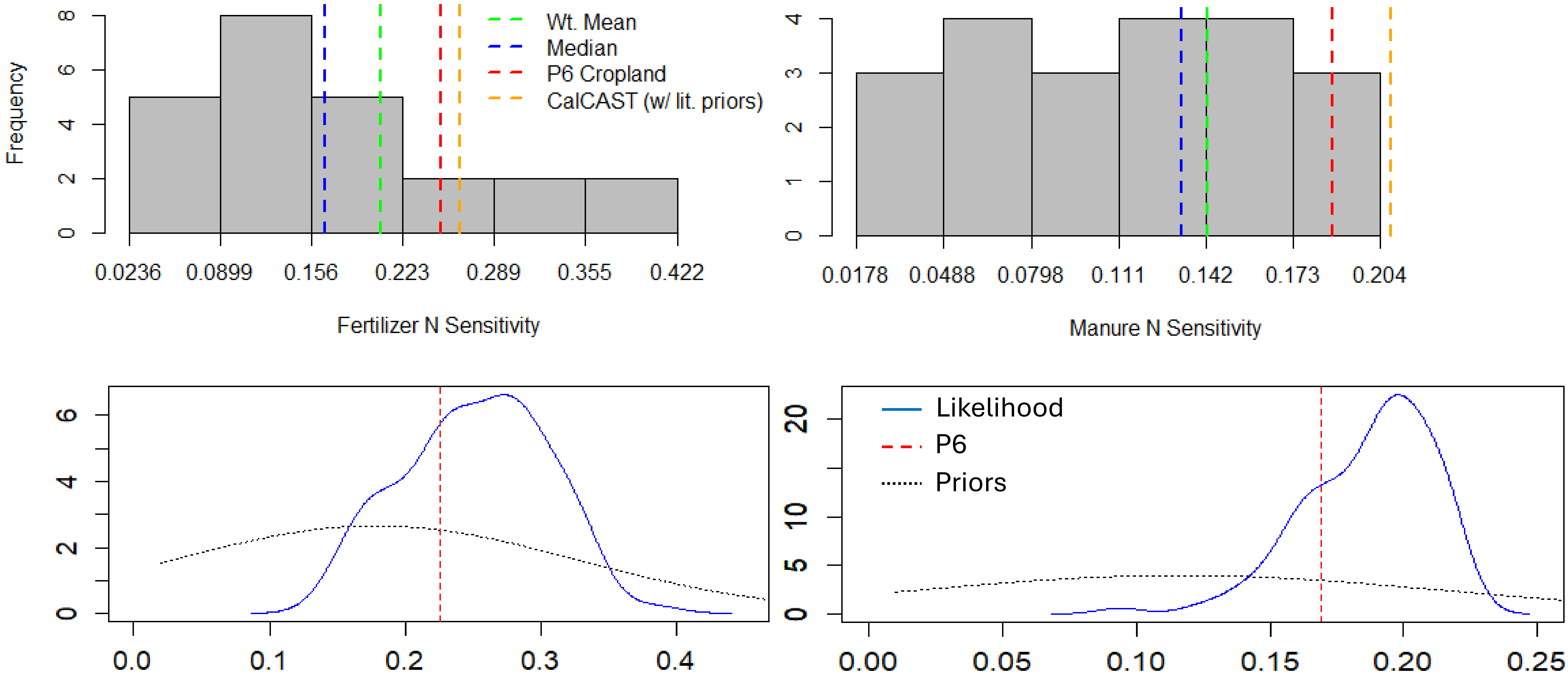
Significant improvement in temporal trend prediction.

Conclusions for Forest Atm. Dep. S

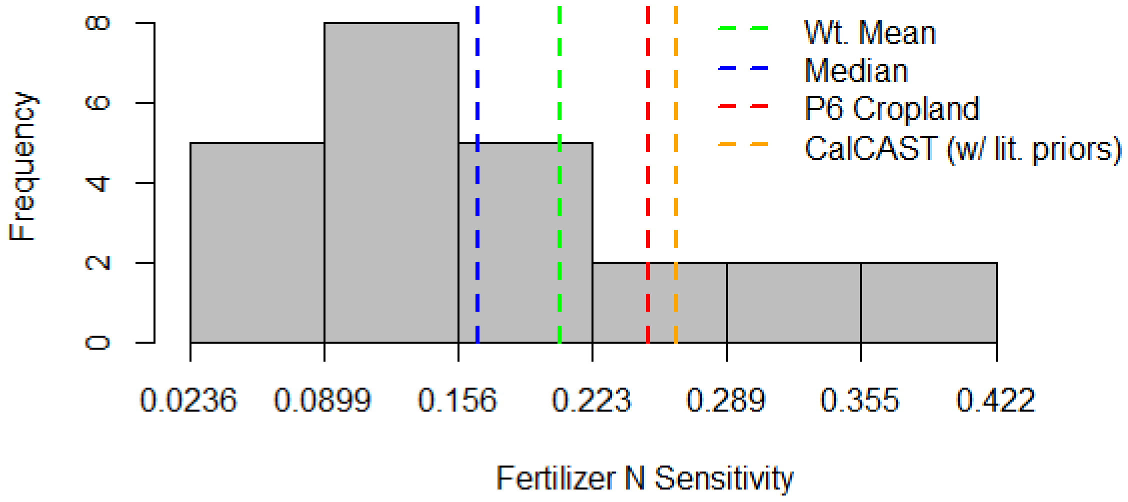
- Solid improvement to trend
- Team effort, thanks everyone

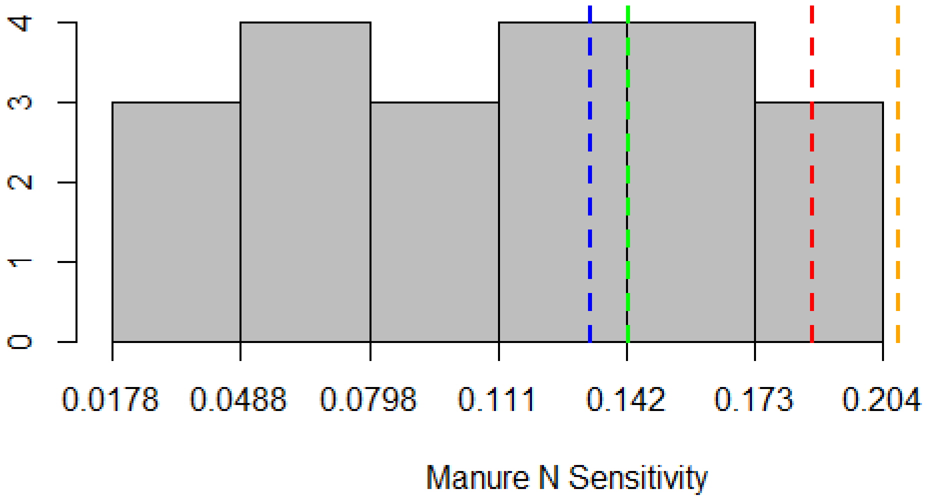
I suggest calibrating the value for P7 with CalCAST, not to exceed the field literature value of 0.089, and imposing the Forestry Work Group's proposed conditional relationships on other values.

Fertilizer and Manure N to Cropland



Fertilizer and Manure N to Cropland





	Base line	Lit. Med.	Lit. Wt. Mean	CalCAST
R2 log(load)	0.979	0.979	0.98	0.98
RMSE log(load)	0.125	0.125	0.125	0.125
R2 yield	0.90	0.90	0.89	0.892
RMSE yield	2.2	2.204	2.201	2.20
RMSE trend	1.004	0.964	0.971	1.002

Conclusions: Fertilizer and Manure N to Cropland

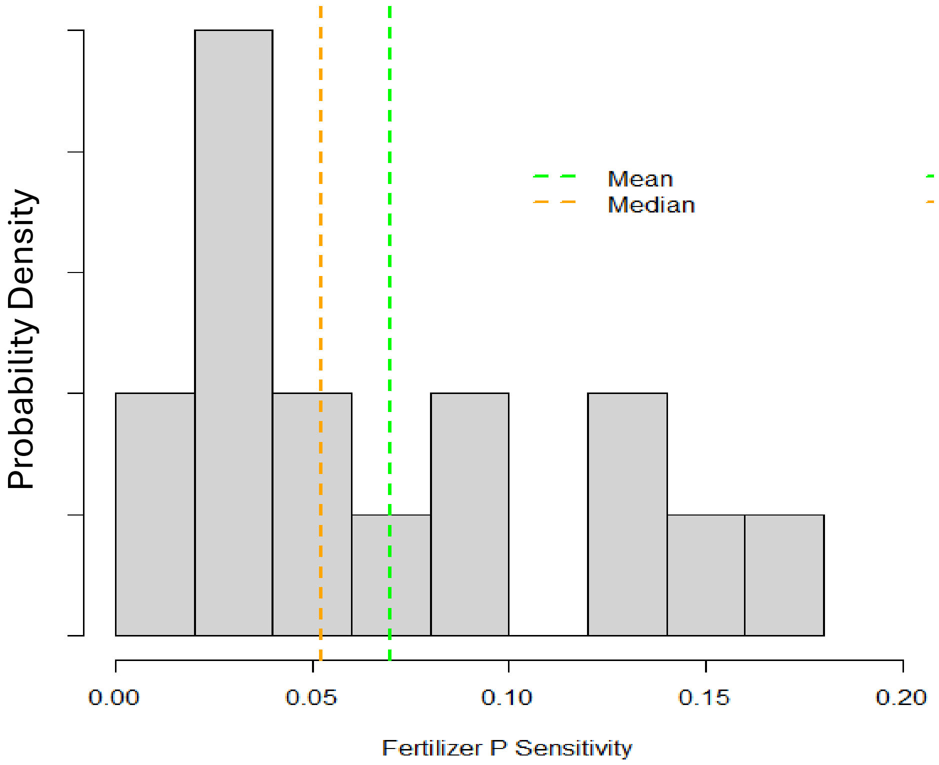
For S values with supporting literature review: If CalCAST calibration of S parameters does not improve model performance, then S should be informed directly from the literature (i.e., a summary statistic of the review literature values).

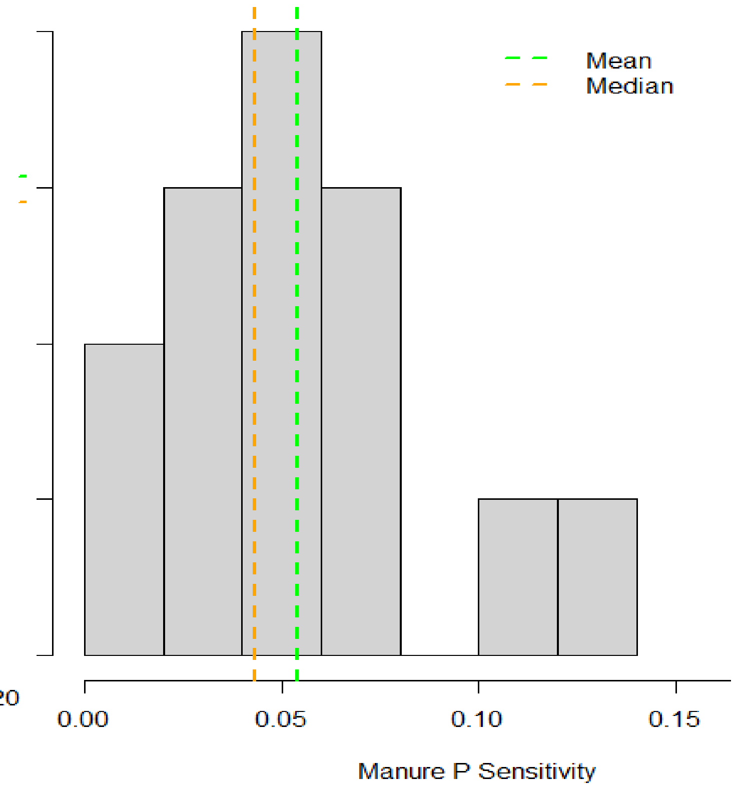
Fertilizer and Manure P Literature Values (Cropland)

- The literature provides fertilizer and manure S values (like N).
- But CAST uses APLE* derived S values:
  - WEP
  - Soil P
  - Sediment
  - Stormwater

Fert. Value	P
Literature Mean	0.07
Literature Median	0.05

Manure Value	P
Literature Mean	0.05
Literature Median	0.04





*APLE (Annual Phosphorus Loss Estimator)

How to compare values?

Both fertilizer and manure contribute to APLE S values

- Calculate the combined fert. and manure S literature values, weighted by CBP applications
  - **Combined Literature Mean = 0.062**
  - **Combined Literature Median = 0.046**

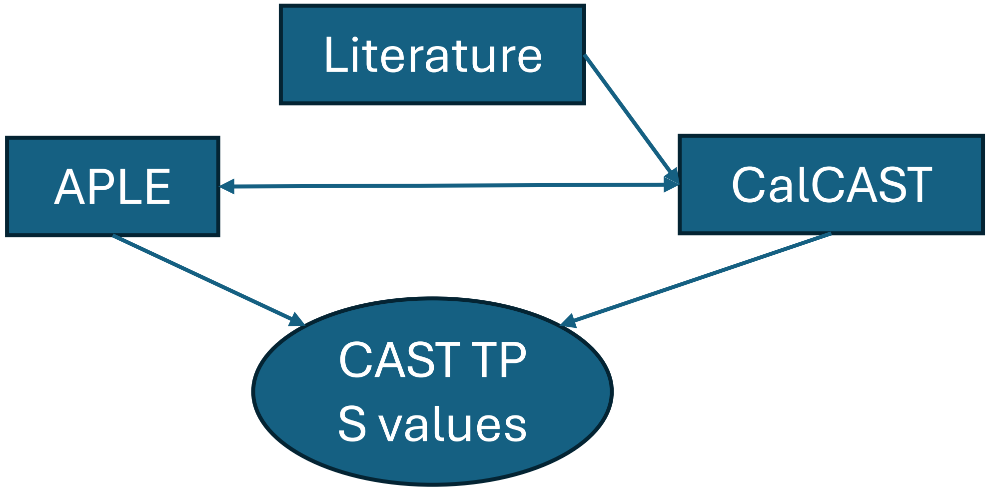
- Calculate the CBP global sensitivity to fert. and manure = **0.045**

- Suggests CBP S values are 35% lower than the literature mean, but close to the median.

Can we improve APLE derived S values?

$\beta * (WEP, Soil\ P, Sediment, Stormwater)$

- APLE defines the relative contribution from each pathway
- CalCAST calibrates the magnitude of the S values (β)
- The literature provides priors to CalCAST



Results

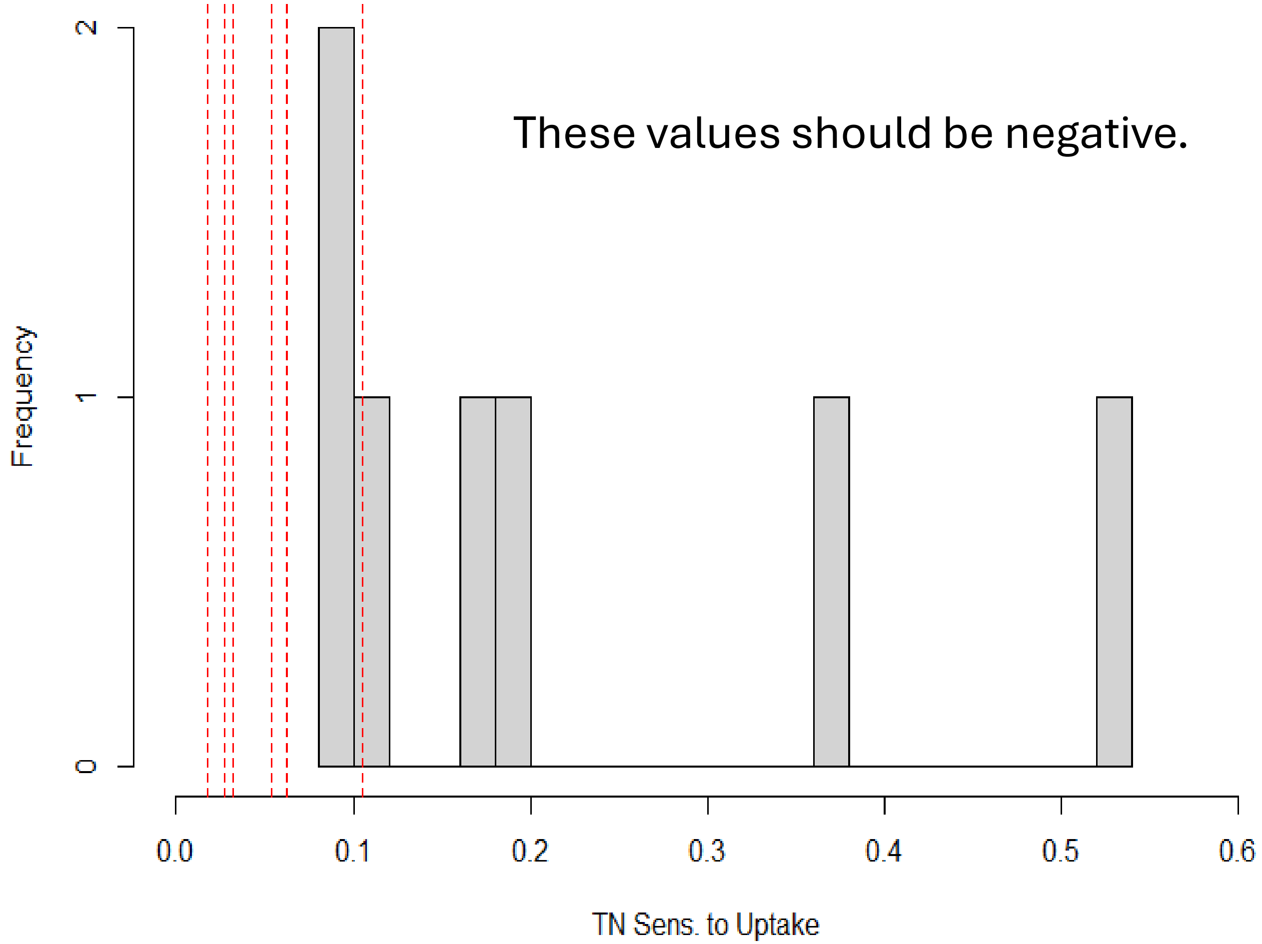
- Preliminary runs on ¼ years
- Small but consistent performance improvement with the calibrated S parameter
- Value is reasonable given the literature
- Need to run on the full time series, but looks promising

	APLE S=0.045	**Lit. Mean Adj. S=0.0615**	**CalCAST S=0.039**
R2 log(load)	0.956	0.952	0.960
RMSE log(load)	0.193	0.202	0.188
R2 yield	0.698	0.660	0.705
RMSE yield	0.238	0.254	0.232

Note: S values shown are effective cropland sensitivity across inputs.

Sensitivity to Crop Uptake

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



Discussion

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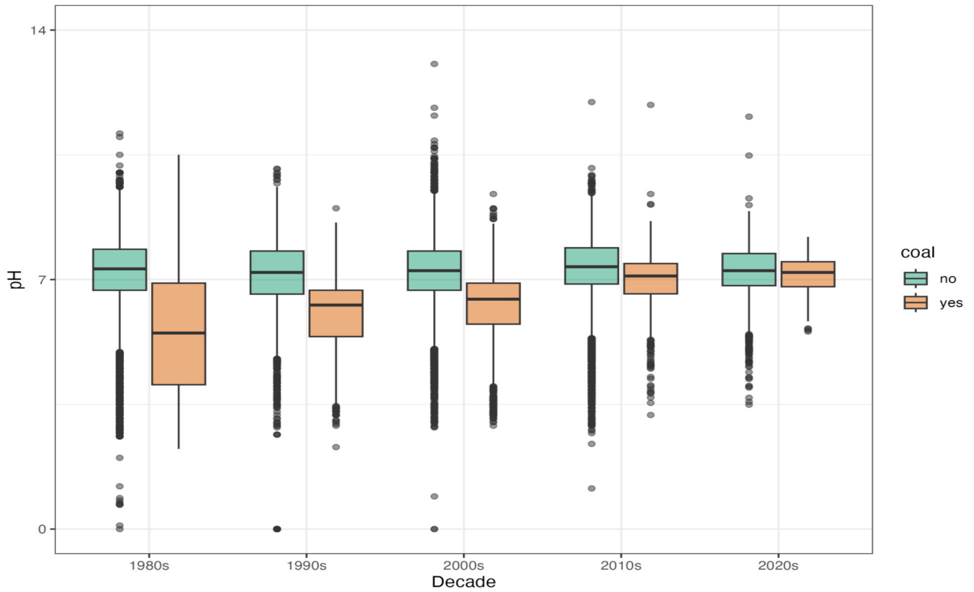
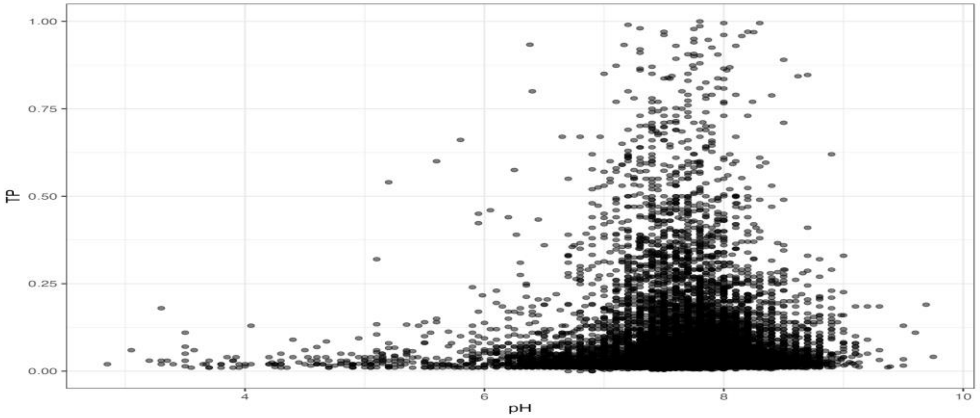
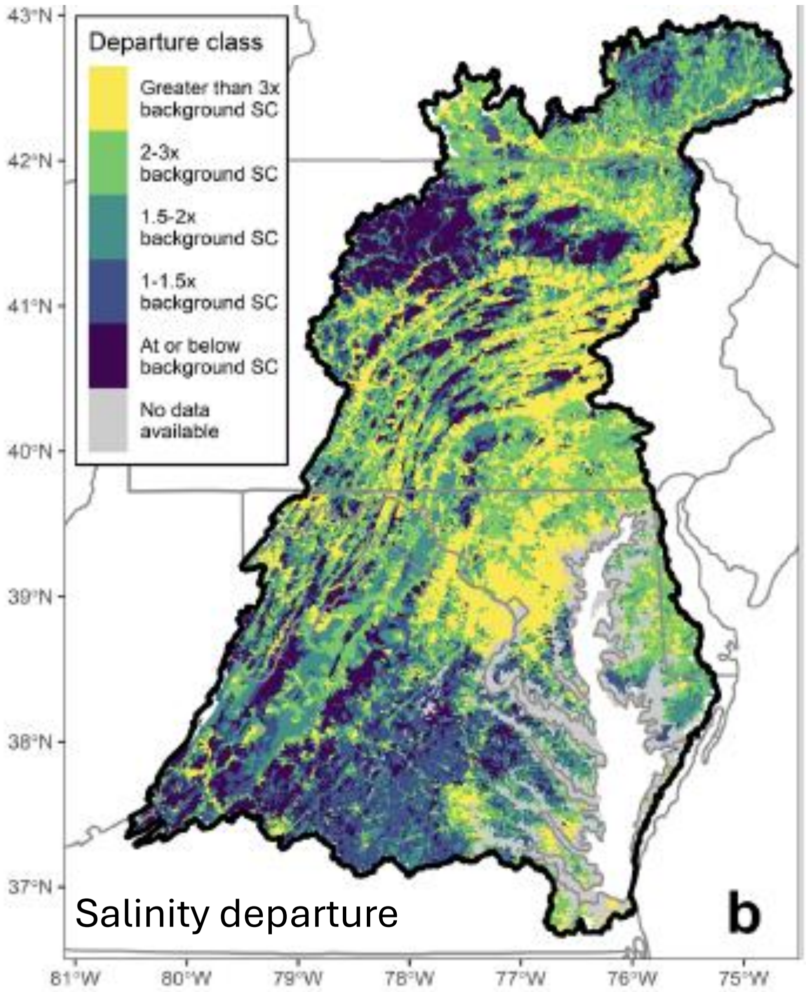
Transport and Attenuation Factors: Addressing the Phosphorus Modeling Gap

Alkaline Desorption and Salinity Impacts on P

Still prepping these datasets.





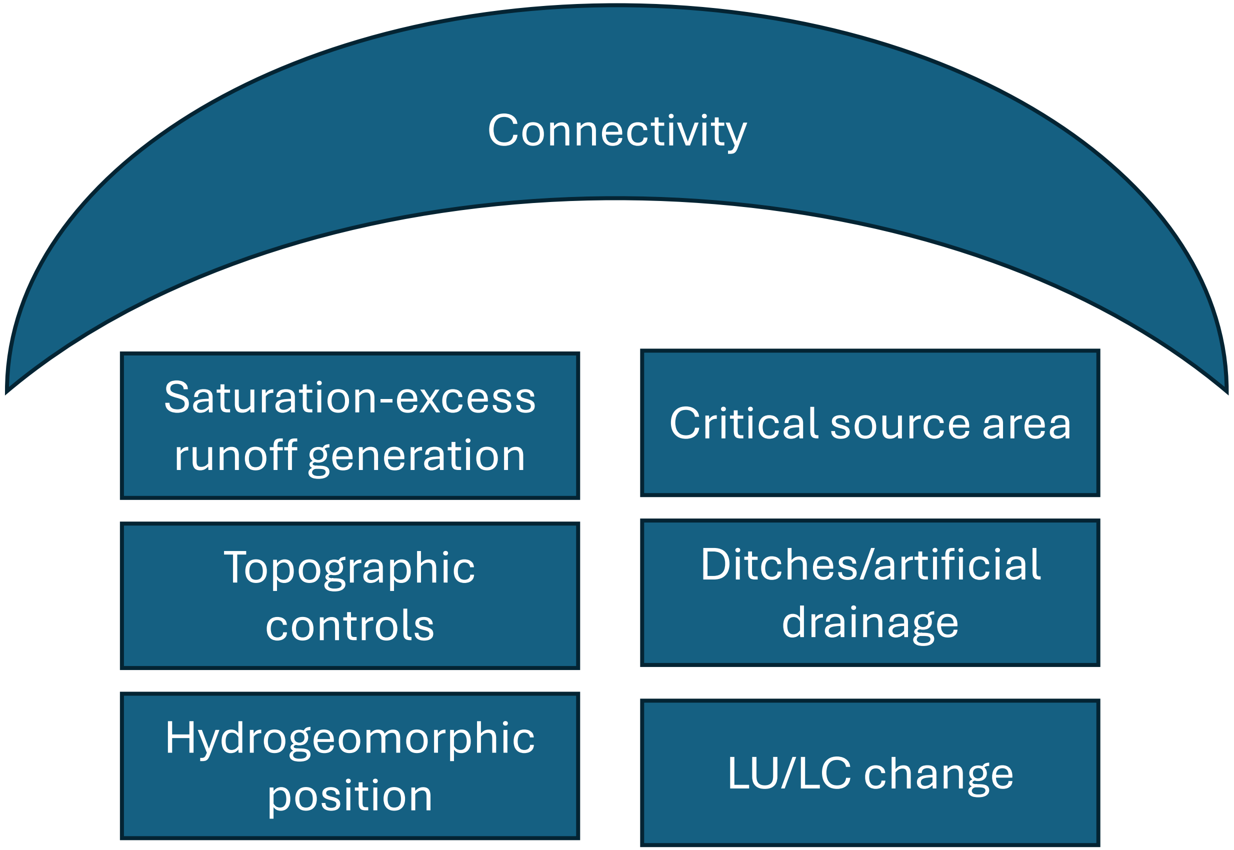


(Fanelli et al. 2024)

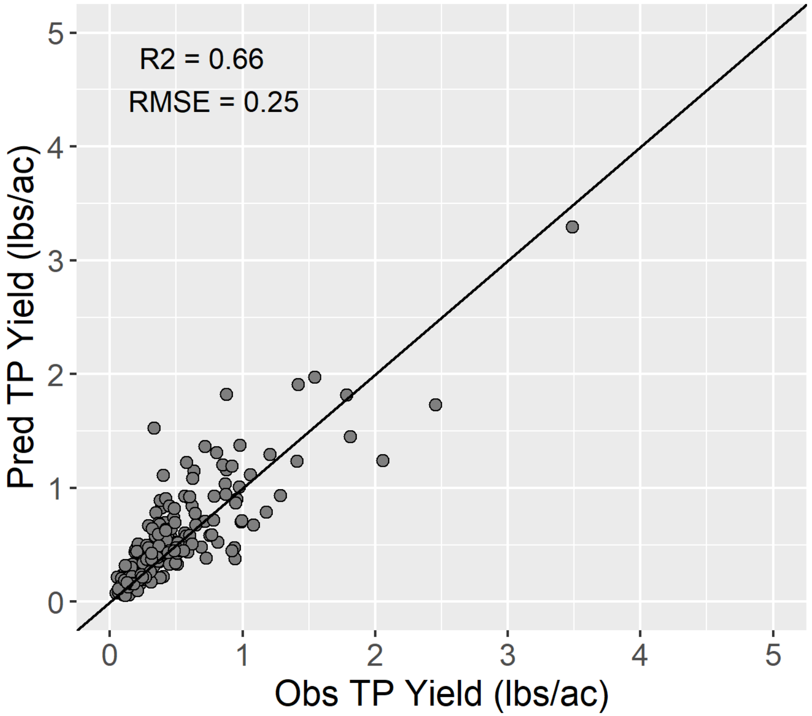
Connectivity: Landscape Controls

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

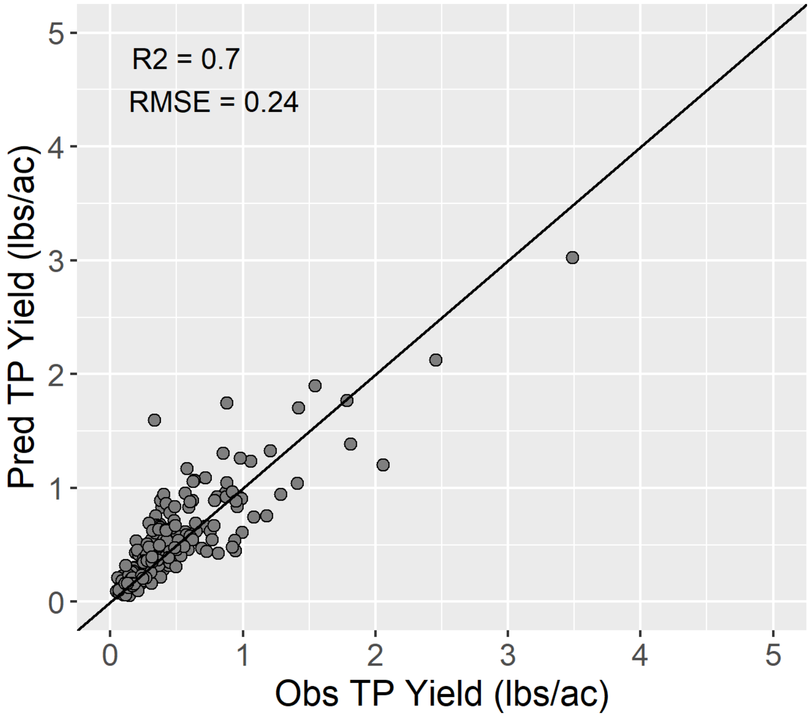
Michelle Katoski has put together a dataset to better capture landscape connectivity in the model.



Connectivity: Landscape Controls



Factor	Coef. sign
K factor	+
Max 1-day precip.	+
Mesozoic Lowland	+
Valley and Ridge	-
Coastal Plain DU	+
Piedmont Carbonate	+
Soil bulk dens.	-
Baseflow index	-



Factor	Coef. sign
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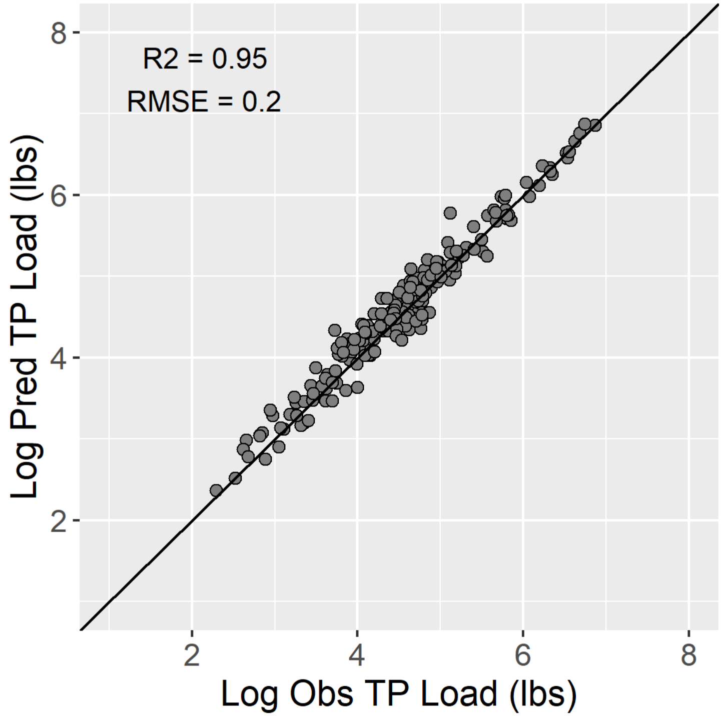
Valley and Ridge	-
Coastal Plain DU	+
Piedmont Carbonate	+
Soil bulk dens.	-
Baseflow index	-
Euclidean distance to stream	+

Connectivity: Landscape Controls



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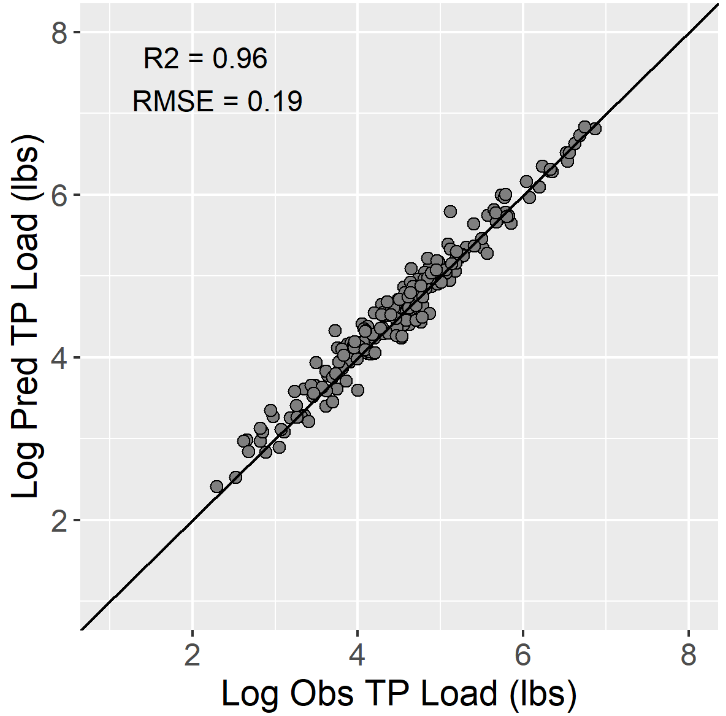
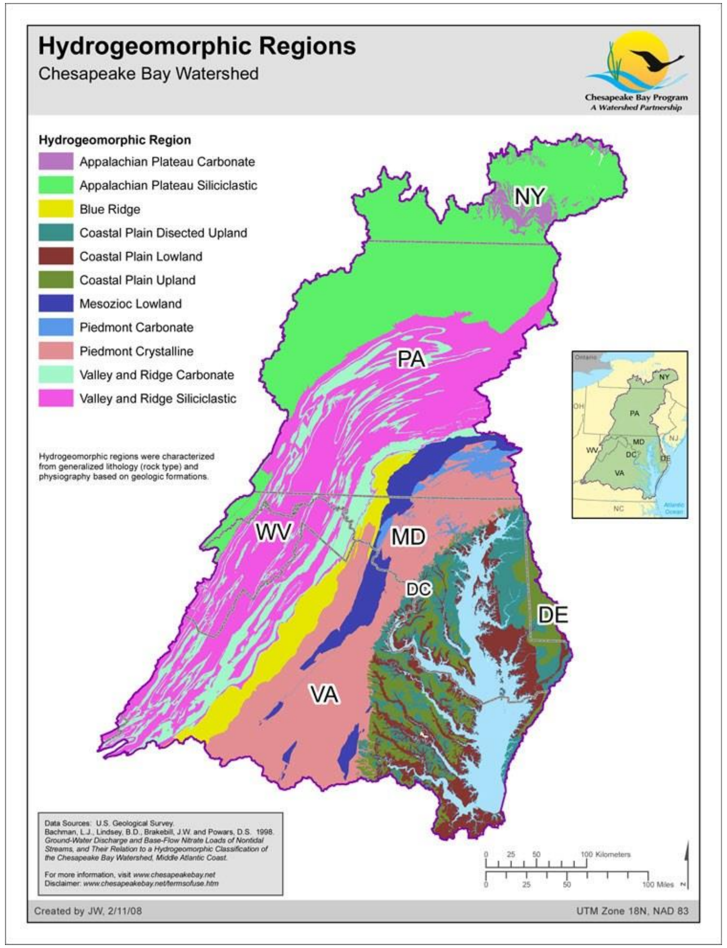


Factor	Coef. sign
K factor	+
Max 1-day precip.	+
Mesozoic Lowland	+
Valley and Ridge	-
Coastal Plain DU	+
Piedmont Carbonate	+
Soil bulk dens.	-
Baseflow index	-
Euclidean distance to stream	+

Two potential approaches for geogenic phosphorus

Hydrogeomorphic Region Approach (Ator et al. 2011 & Ator 2019)

- Erosion of minerals in crystalline and siliciclastic rocks are a natural source of P



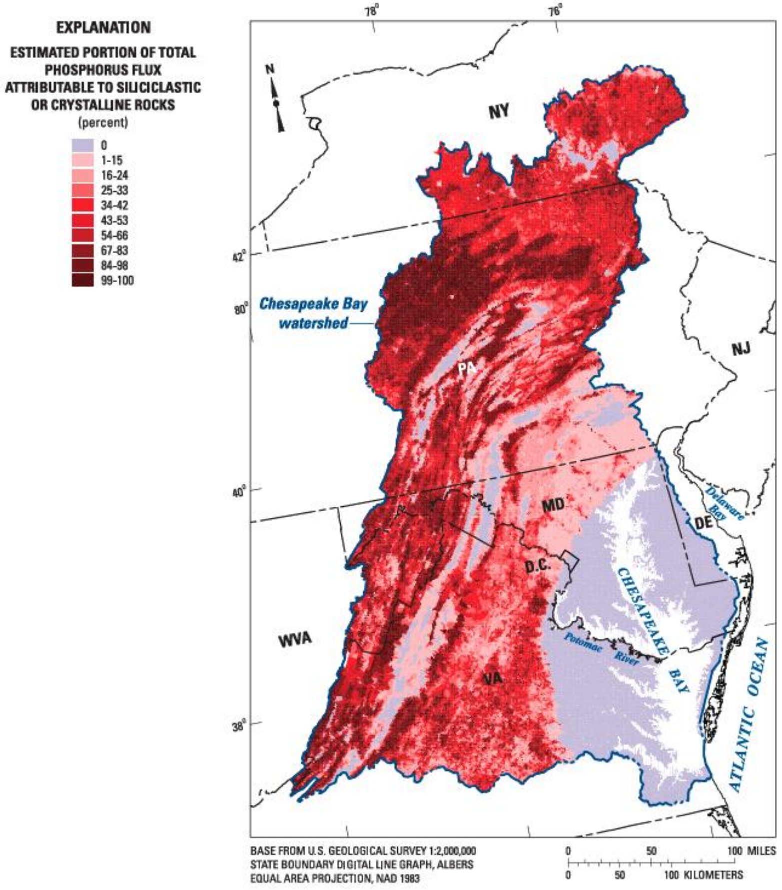
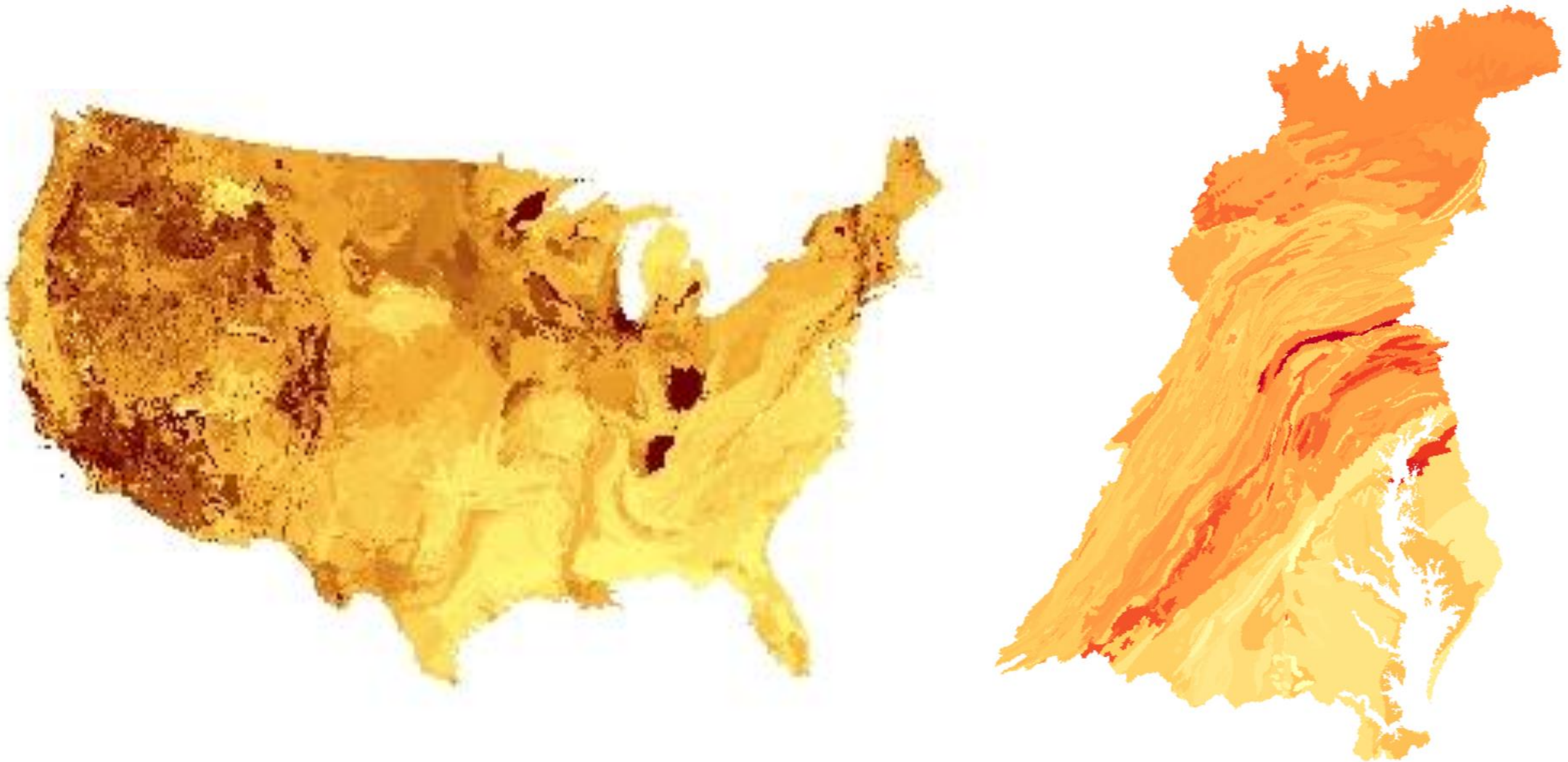


Figure 8. Share of local phosphorus yields attributable to siliciclastic or crystalline rocks.

Two potential approaches for geogenic phosphorus

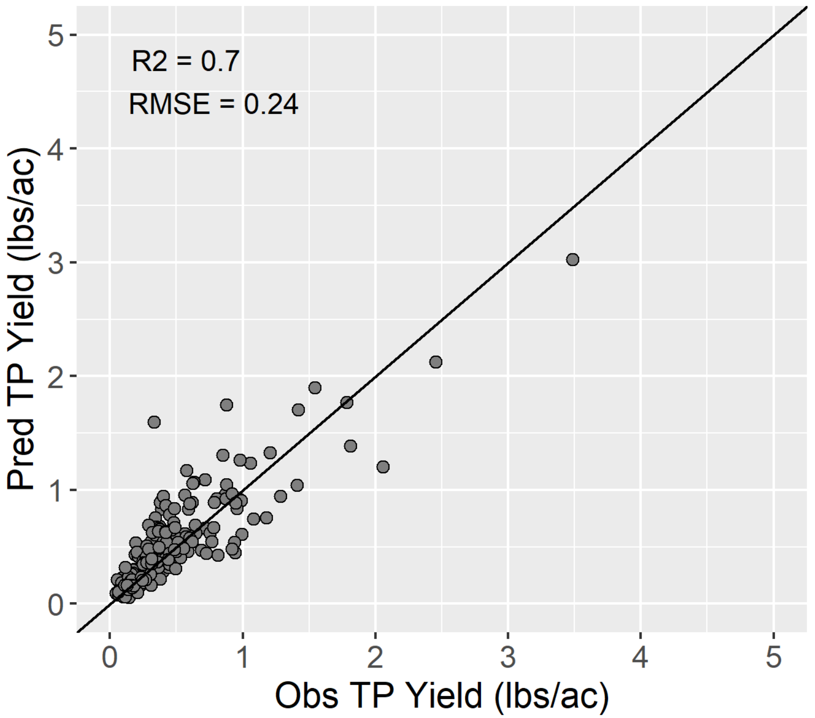
Upland Geologic Approach (Wise 2020, Nardi 2014, Smith 1979)

Geogenic P is characterized by summarizing geochemical data from bed-sediment samples collected from first-order streams in relatively undisturbed watersheds to geologic mapping units.

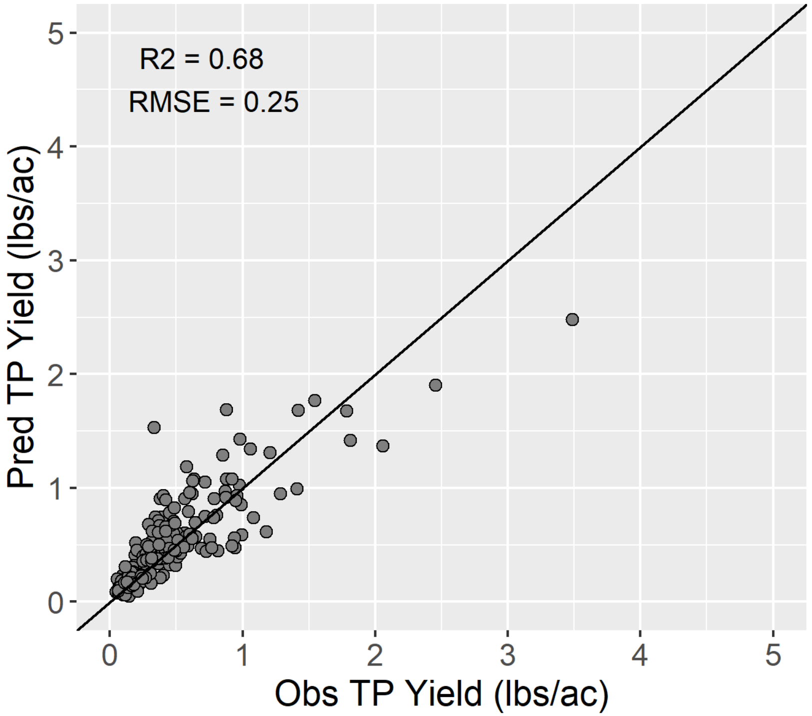


Bed sediment concentrations

Geogenic Phosphorus



Factor	Coef. sign
K factor	+
Max 1-day precip.	+
Mesozoic Lowland	+
Valley and Ridge	-
Coastal Plain DU	+
Piedmont Carbonate	+
Soil bulk dens.	-
Baseflow index	-
Euclidean distance to stream	+



Factor	Coef. sign
K factor	+
Max 1-day precip.	+
Mesozoic Lowland	+
Valley and Ridge	-
Soil bulk dens.	-
Baseflow index	-
Euclidean distance to stream	+
Geo. P	+

Transport and Attenuation Factors: Feature Selection

Feature Selection

Find the combination of factors that provides the best prediction of P transport and attenuation.

Factor	Coef. sign
K factor	+
Max 1-day precip.	+
Mesozoic Lowland	+
Valley and Ridge	-
Soil bulk dens.	-
Baseflow index	-
Euclidean distance to stream	+
Geo. P	+

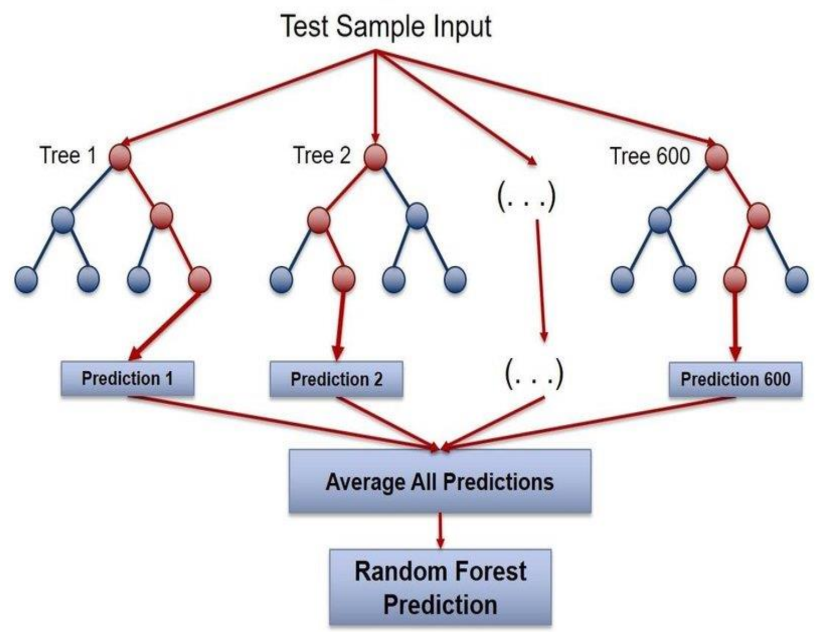
Identifying a limited set of high impact predictors reduces equifinality and allows better prediction with limited observations.

This can be difficult in watersheds, where variables are often correlated.

Feature Selection

Dr. Kim Van Meter (PSU) will apply her Random Forest models (preliminary models presented at Oct. quarterly)

Paired with Partial Dependence Plots (PDP) and Accumulated Local Effects (ALE)



Blakely, Logan & Reno, Matthew & Broderick, Robert. (2018). Evaluation and Comparison of Machine Learning Techniques for Rapid QSTS Simulations.

Feature Selection Methods

Two parallel approaches:

- Predict observed downstream load
  - Mixes loading, source, and transport/attenuation effects.
  - Predictor importance will be skewed by observation station loading magnitude.
- Residual concentration after accounting for inputs
  - Predict a delivery ratio

$$Delivery\ Ratio = \frac{C_{obs}}{C_{eof}}$$

  - Provide estimated CAST edge of field loads (EOF) and predict the change.

Predictor Variable Datasets

Calculated upstream of a station

- Stream execution sequence
- Hi-res LU/LC dataset
- NHD+ Select attributes
- StreamCat properties
- Mean temperature
- Percent LU
- Mined land
- Percent HGMR
- Soil properties (SURGO)
- Prism precipitation metrics
- Soil moisture
- Slope
- Channel gradient
- Hydrologic connectivity metrics (Michelle Katoski)
- Road density
- Hi-res stream density
- Landforms (Geomorphons)
- Geogenic P
- Strean salinity
- Mined land stream alkalinity trend

From CAST

- CAST P6 EOF loads
- CAST Direct loads
- CAST Fertilizer applications
- CAST Manure applications
- CAST Uptake
- CAST P7 Atm. Dep (adding P7)
- CAST BMP eff.

Thanks to Dr. Matt Baker (UMBC) who generated many of these datasets and helped conceptualize this list.

Discussion

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Biogeochemical controls on P mobility

- Alkaline desorption
- 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

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

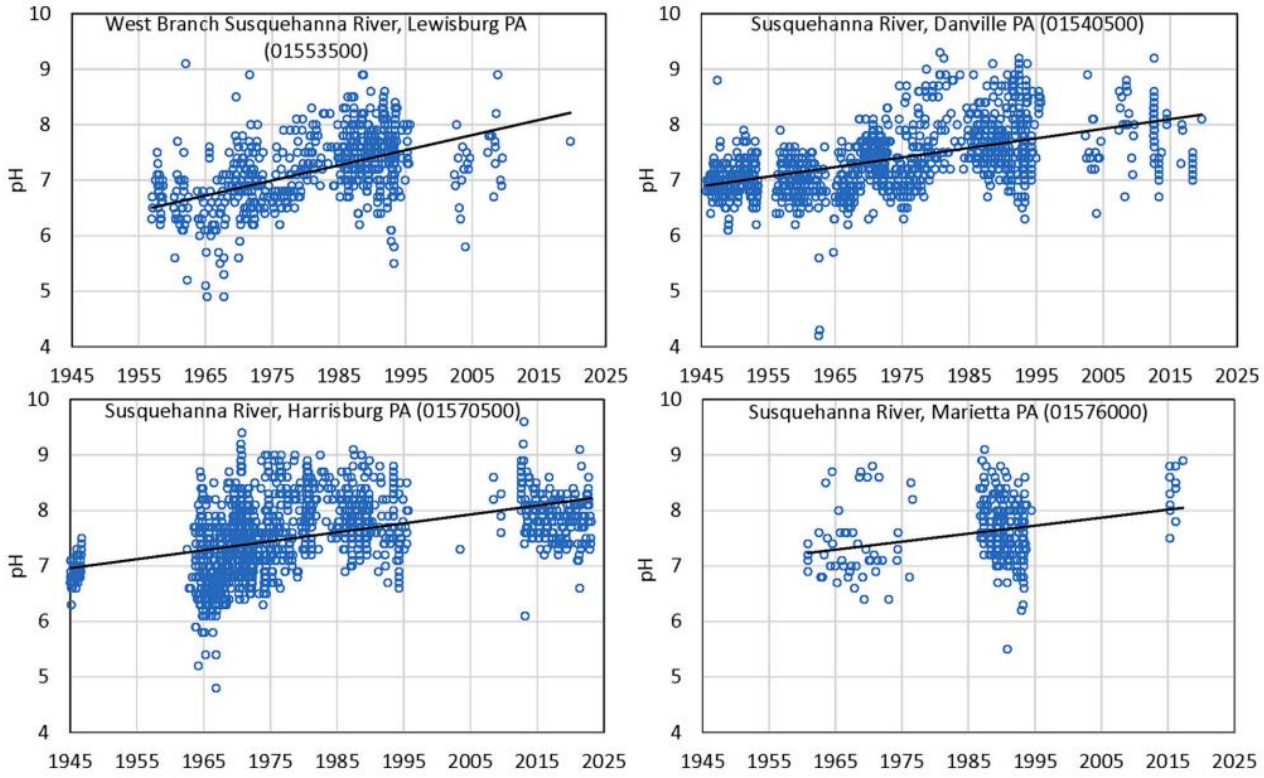


Fig. 5. Time-series showing pH of discrete samples for historical and current conditions on the West Branch Susquehanna River at Lewisburg (USGS station no. 01553500) and the Susquehanna River at Danville (USGS station no. 01540500), which merge downstream to form the lower Susquehanna River, represented 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.

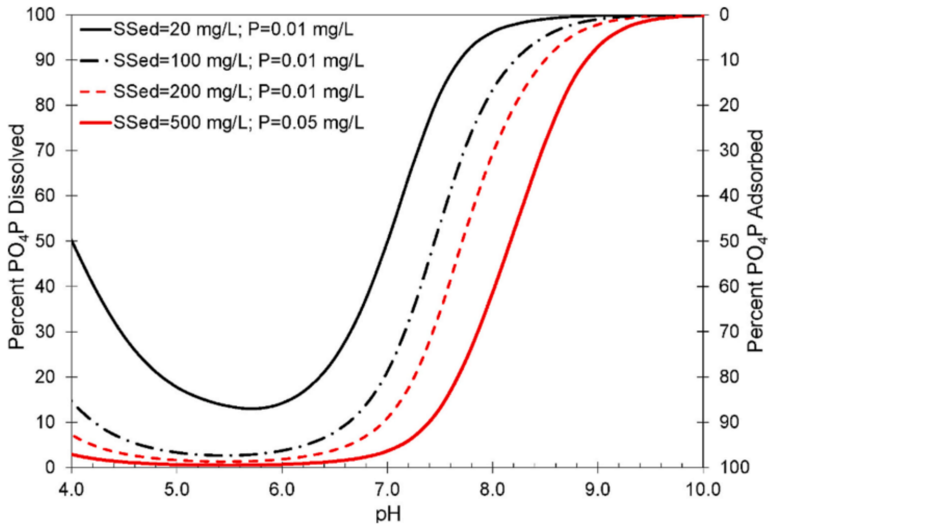
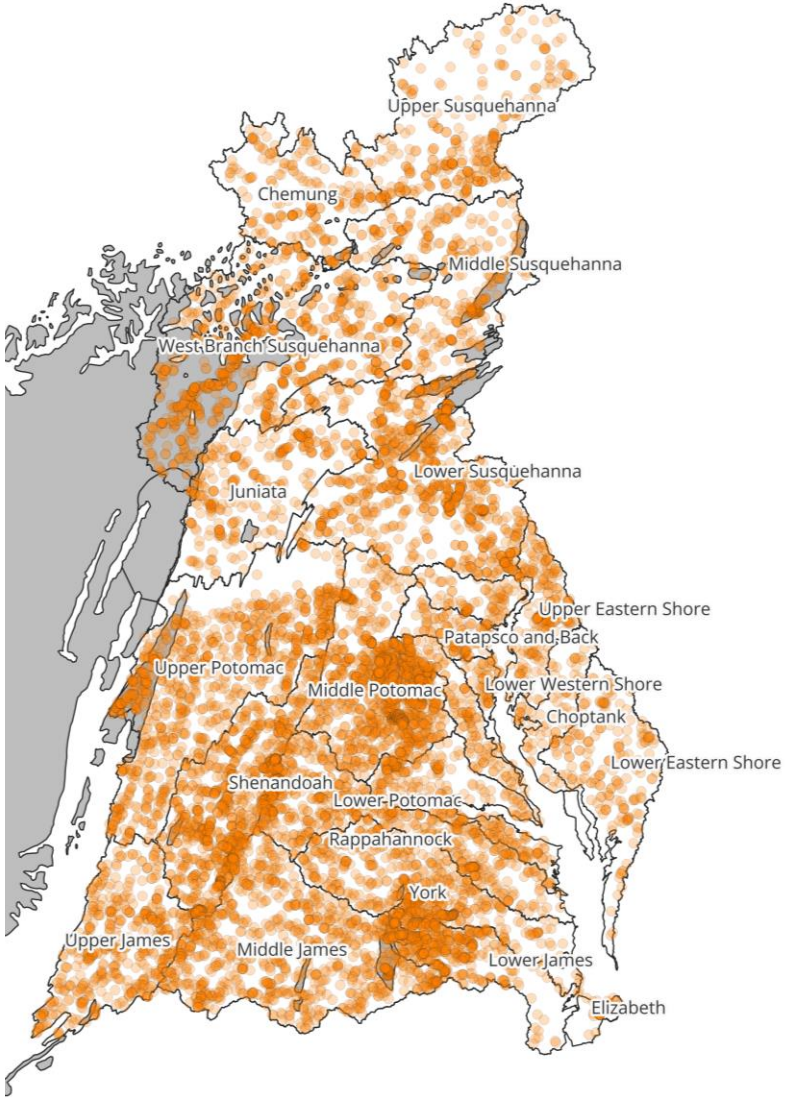


Fig. 4. Equilibrium fractions of initial concentration of phosphate (0.01 or 0.05 mg/L as P) that may be dissolved or adsorbed by suspended sediment (Ssed) composed of 6.7 % Fe (HFO; with a specific surface area (Asp) of 600 m^2/g), 0.5 % Mn (HMO; with Asp of 746 m^2/g), and 2.8 % Al (HAO; with Asp of 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.

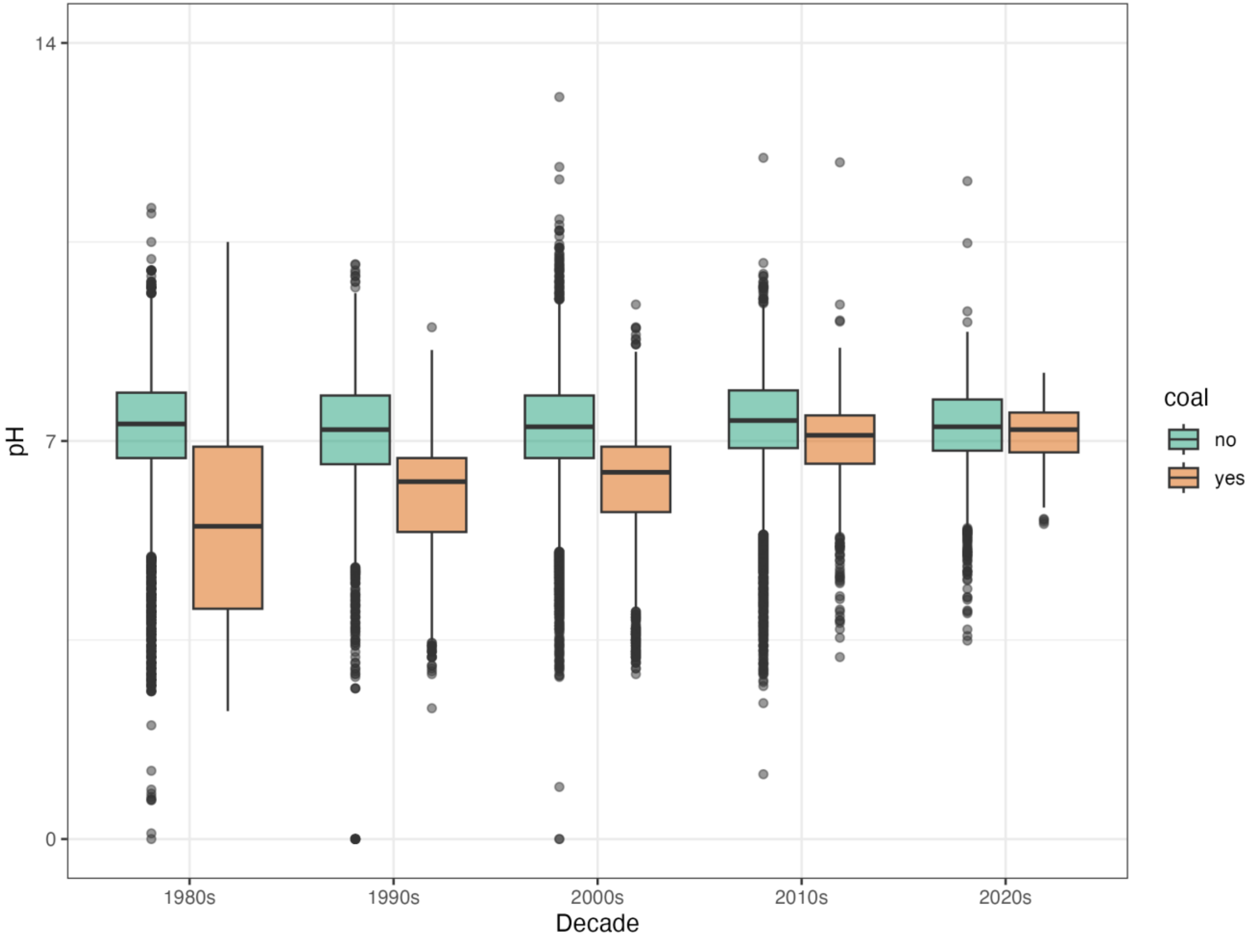
Legacy sediment as a potential source of orthophosphate: Preliminary conceptual and geochemical models for the Susquehanna River, Chesapeake Bay watershed, USA

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]

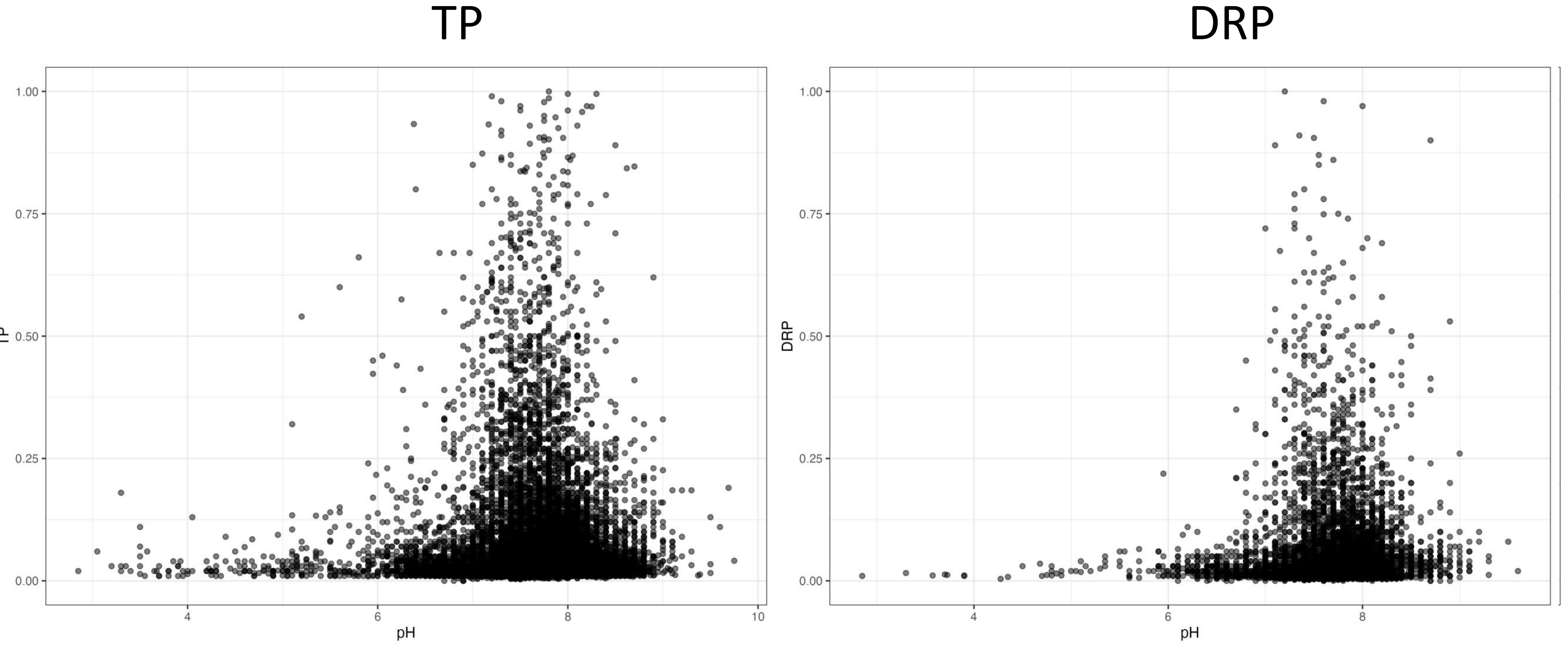
Trends in pH across the watershed, data from the Water Quality Portal



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



TP and DRP concentrations increase with alkalinity



Saltwater intrusion and road salting

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

Examples of recent literature:

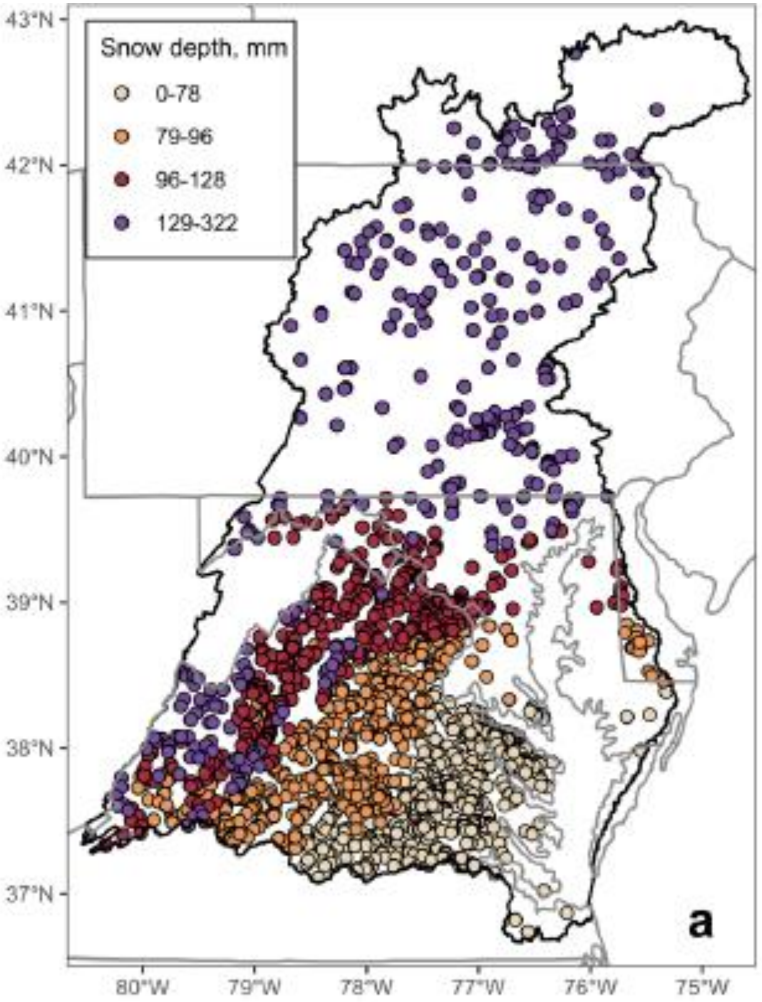
Lucas, E., Kennedy, B., Roswall, T. et al. Climate Change Effects on Phosphorus Loss from Agricultural Land to Water: A Review. Curr Pollution Rep 9, 623–645 (2023). https://doi.org/10.1007/s40726-023-00282-7

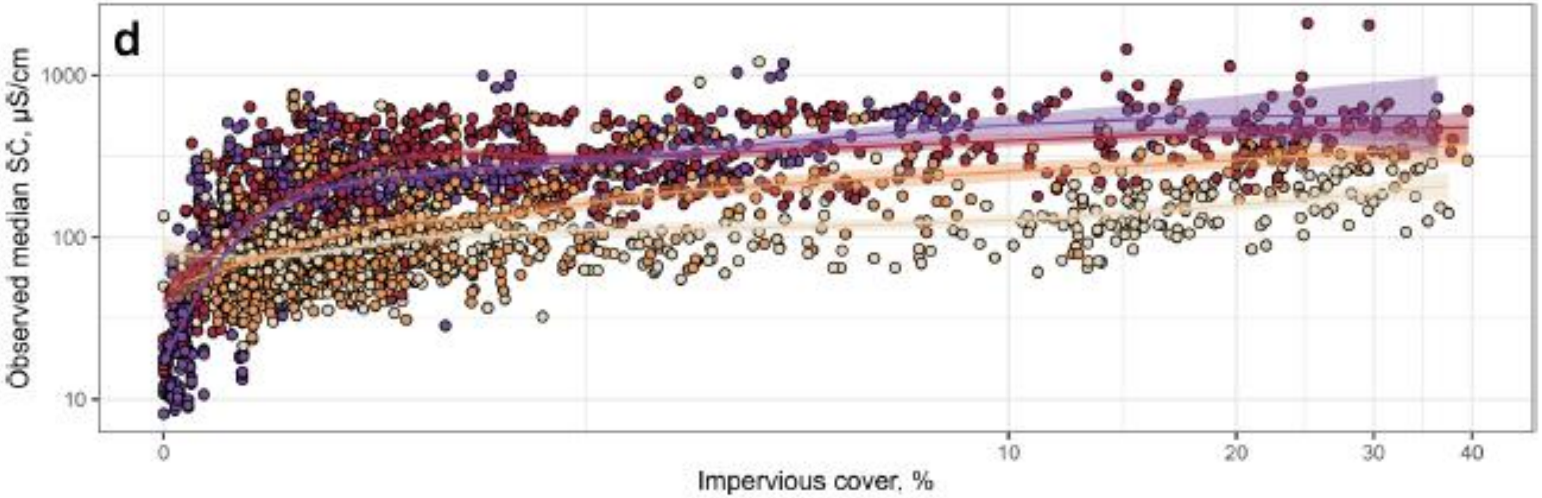
Weissman, D. S., & Tully, K. L. (2020). Saltwater intrusion affects nutrient concentrations in soil porewater and surface waters of coastal habitats. Ecosphere, 11(2), e03041.

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

Review of land use impacts on in-stream salinity levels

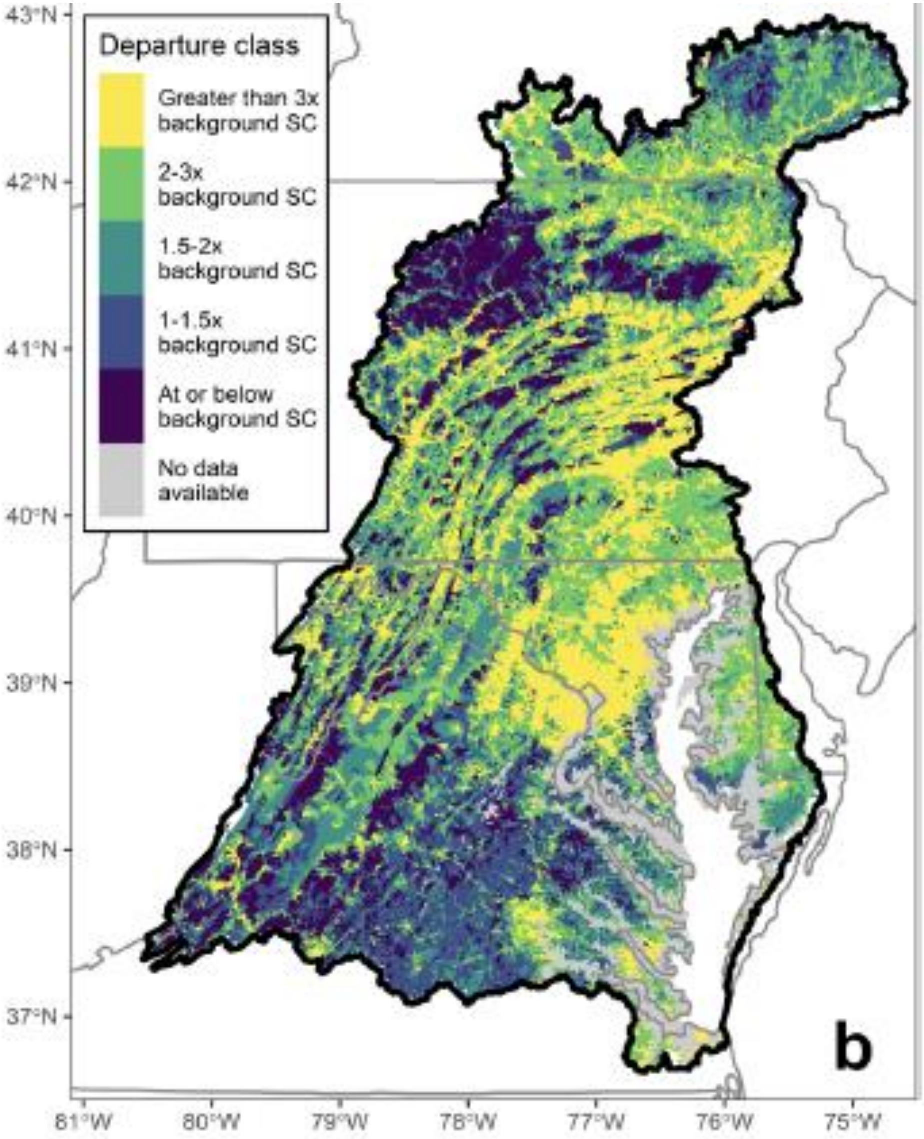
Avg. snow depth (2000-2014)





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)