

Closing the Phosphorus Modeling Gap

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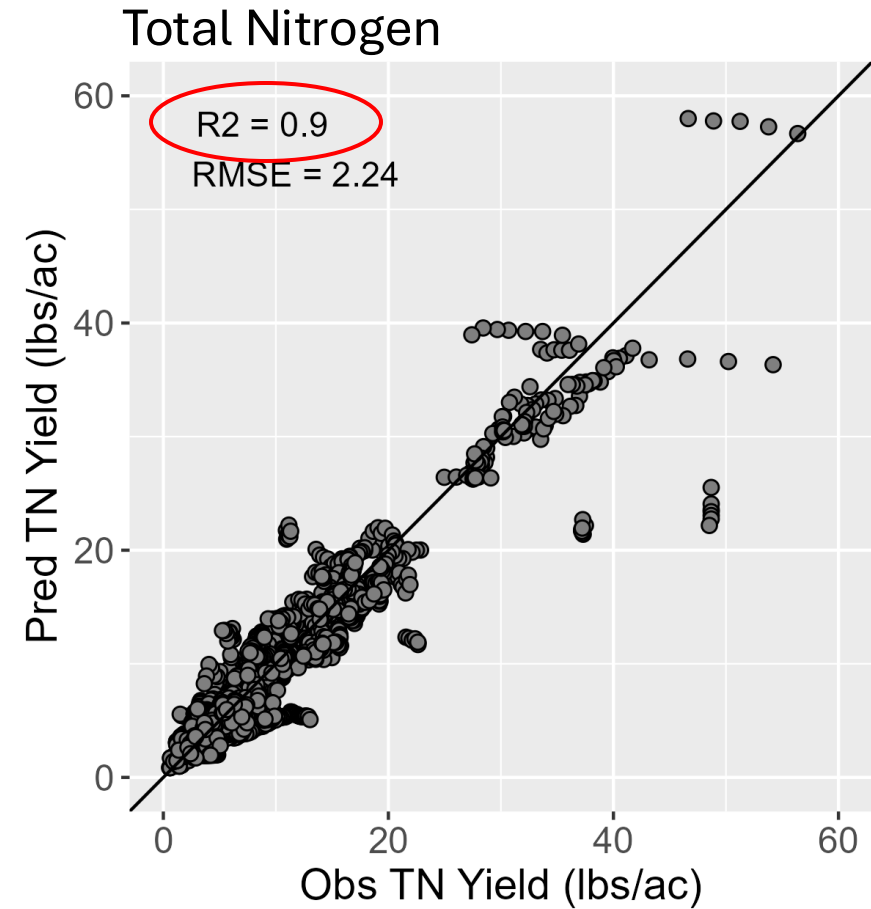
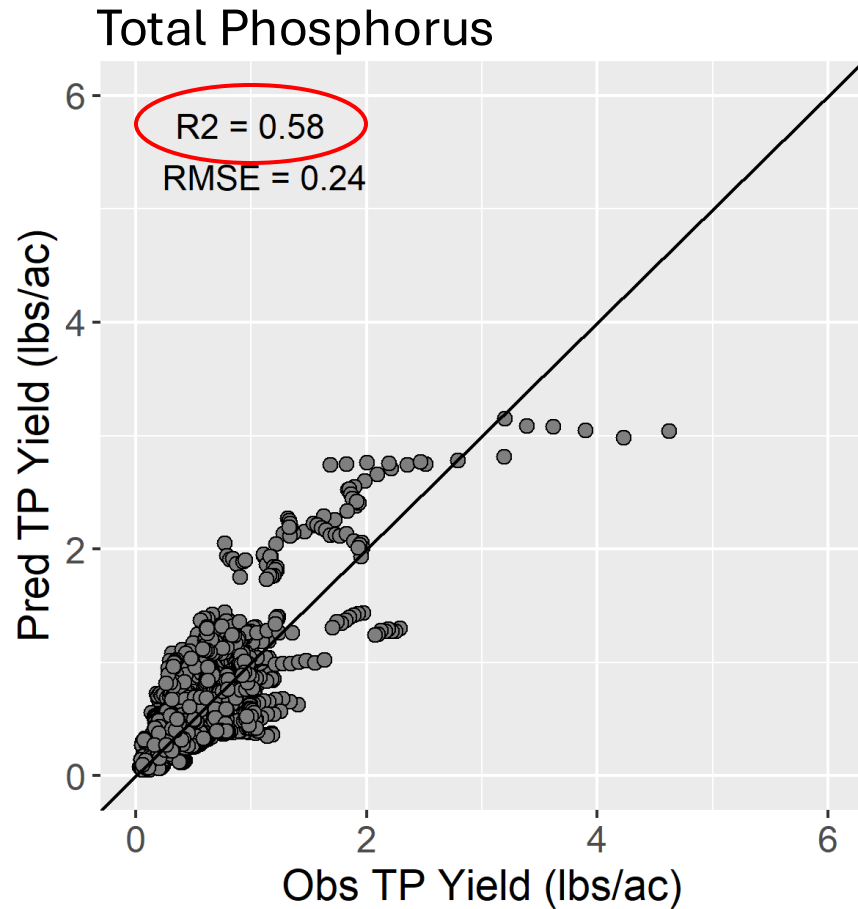


Chesapeake Bay Program

Science, Restoration, Partnership

Contents are preliminary

The Modeling Gap



Results from early CBP development models for P7, largely representing P6 inputs and predictors

Closing the Modeling Gap

- Improving P input data
- Better inclusion of wastewater sources
- **Characterizing geogenic P**
- **Characterizing hydrologic connectivity**
- **Characterizing biogeochemical controls on sorption**
 - **Salinity-driven desorption**
 - **pH-driven desorption**

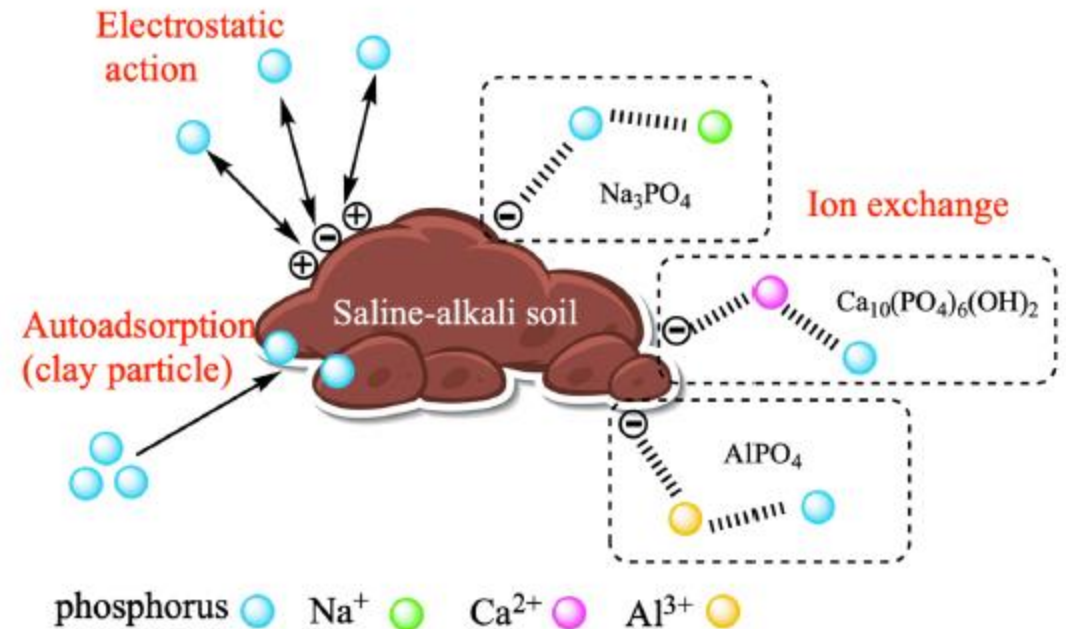


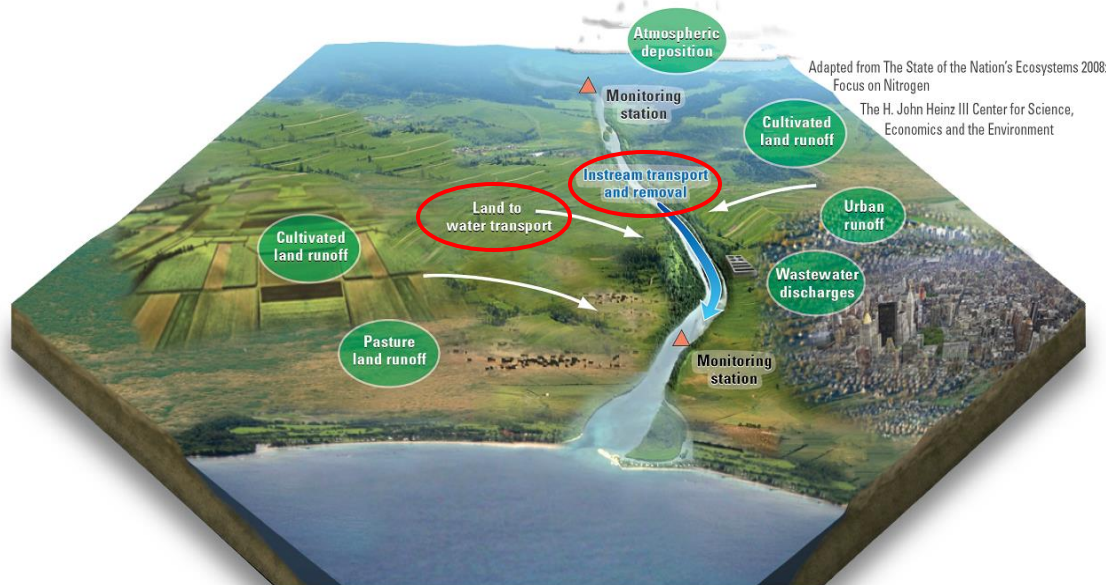
FIGURE 6
Mechanism of phosphorus adsorption in saline soils.

Jiang Y, Yan Q, Liu T, Xu Y, Han X, Ma X and Wang Y (2023) Phosphorus adsorption characteristics and release risk in saline soils: a case study of Songnen Plain, China. *Front. Plant Sci.* 14:1302763. doi: 10.3389/fpls.2023.1302763

Model Testing and Implementation

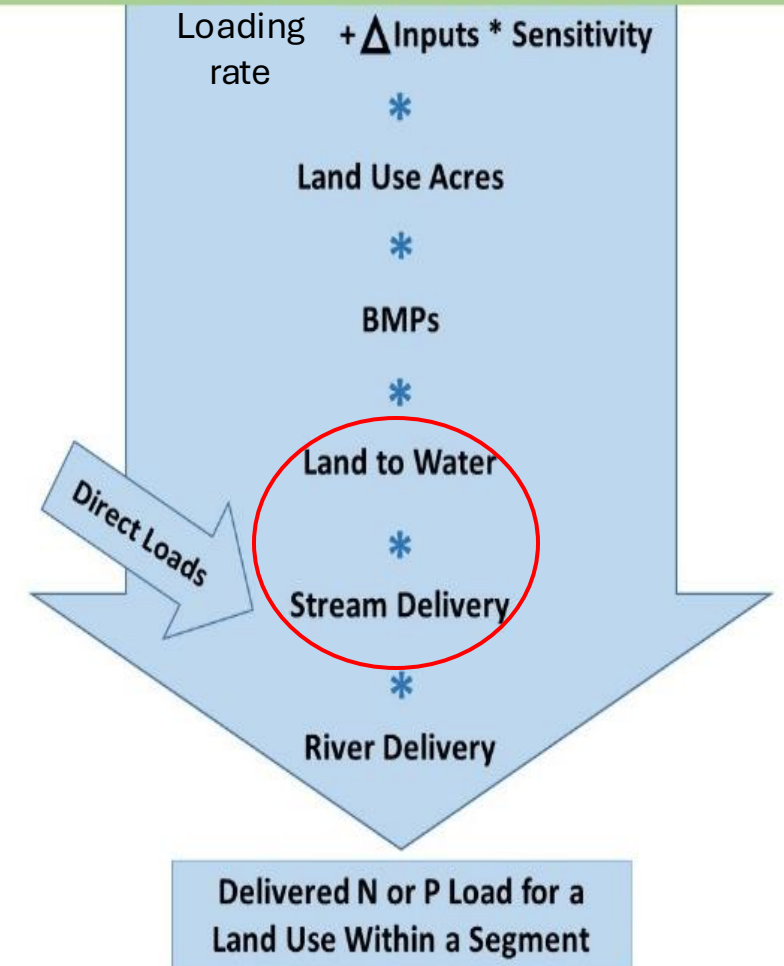
- Implementation as transport factors
- Capture the emergent behavior at the watershed scale

Landscape properties -> pH/salinity/sediment -> sorption behavior -> stream P export



Graphic by Grabbhorn Studios

Phase 7 Model Structure



Two Potential Approaches for Geogenic Phosphorus

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

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

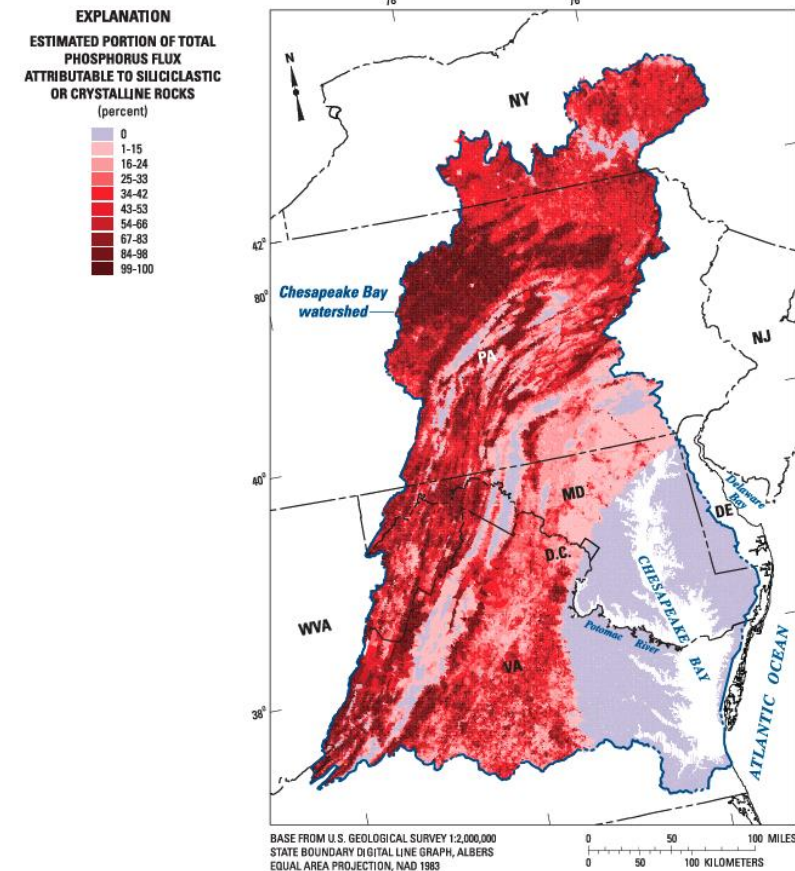
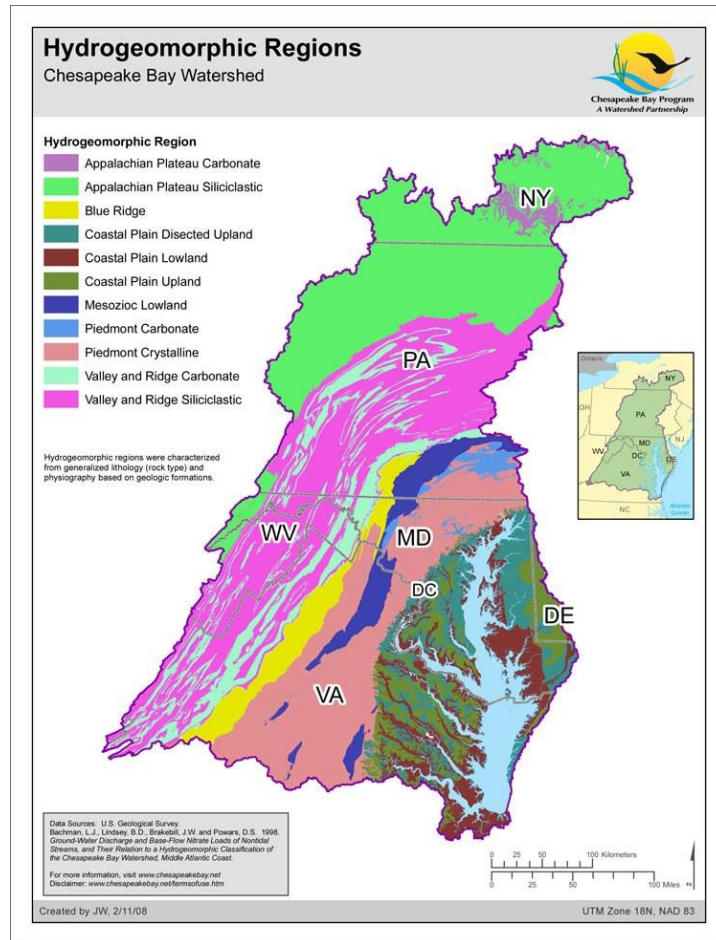
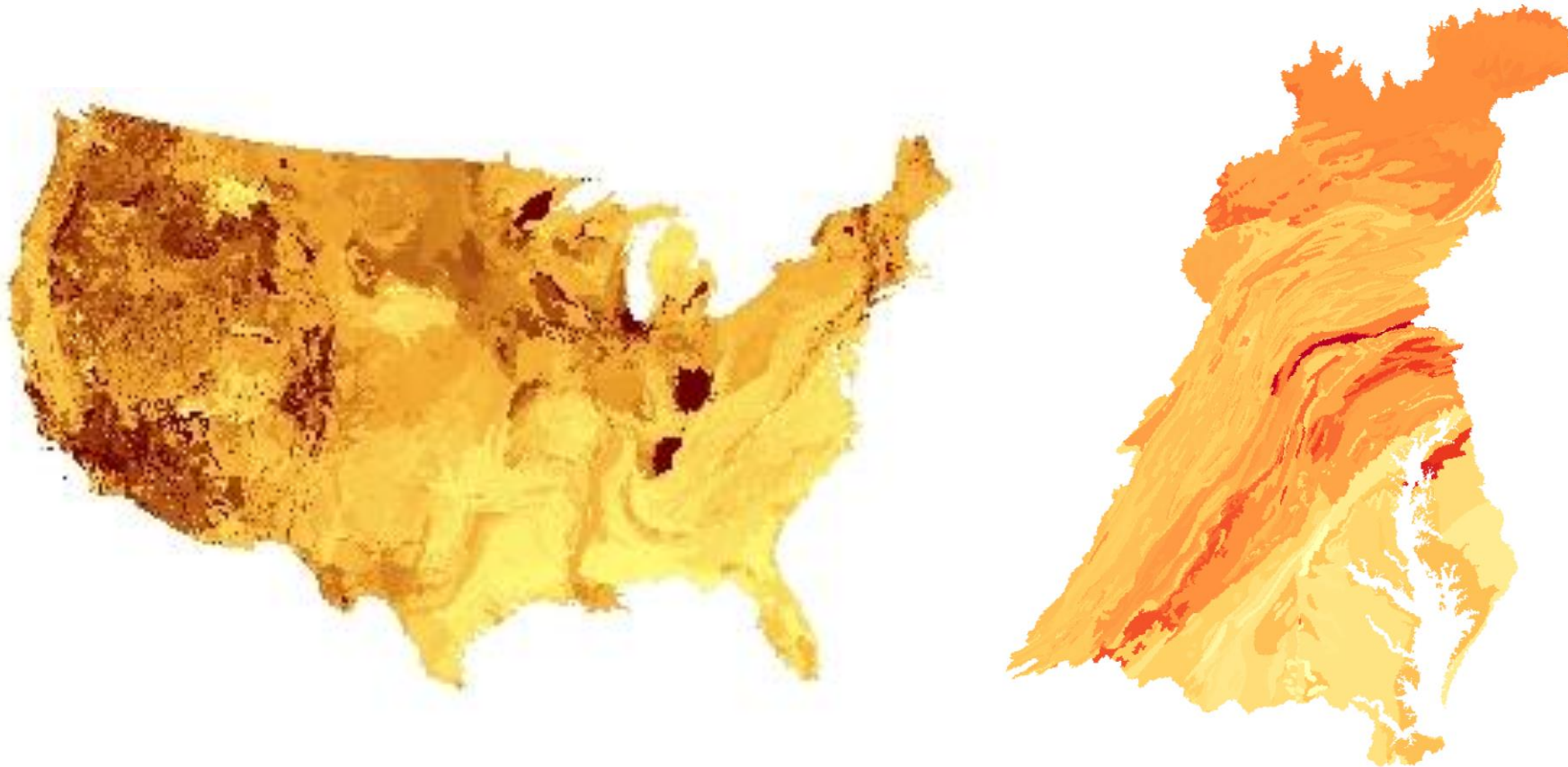


Figure 8. Share of local phosphorus yields attributable to siliciclastic or crystalline rocks.

Two Potential Approaches for Geogenic Phosphorus

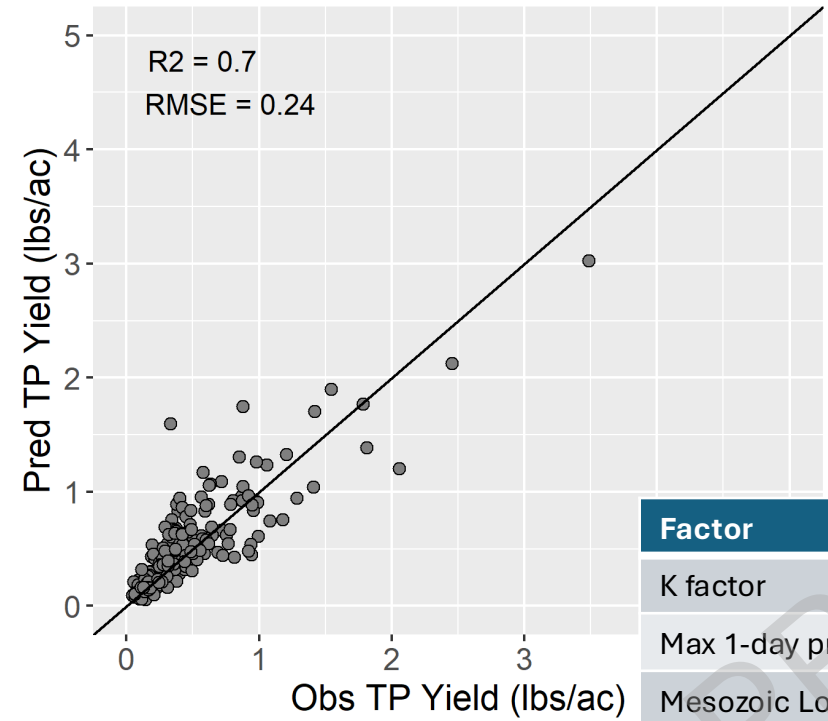
Upland Geologic Approach ([Wise 2020](#), [Nardi 2014](#), [Smith 1979](#))

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.

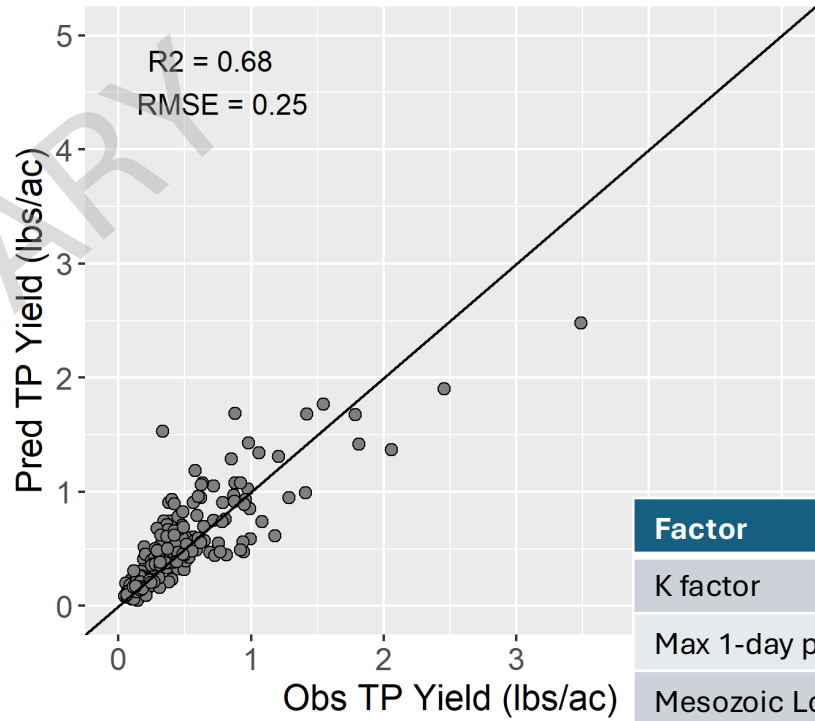


Bed sediment concentrations

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	+

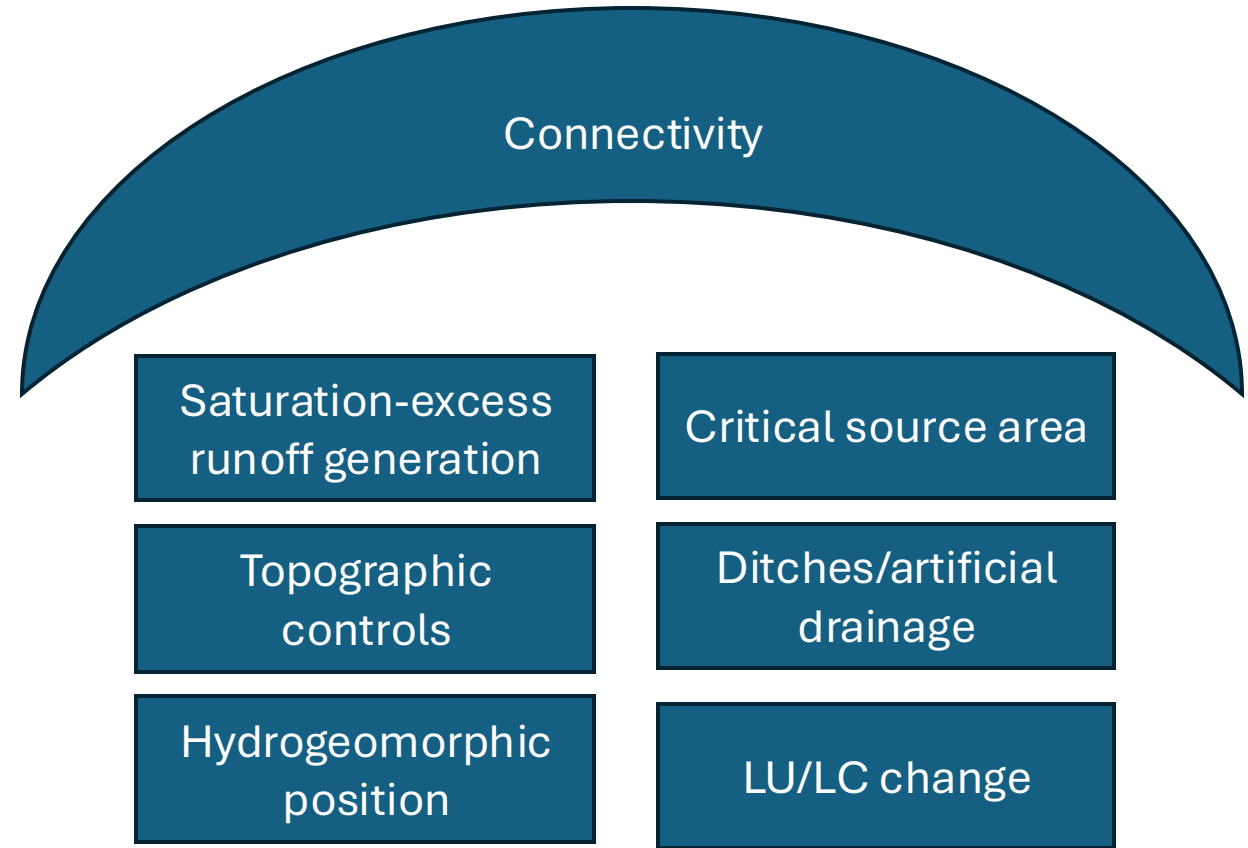


Factor	Coef. sign
K factor	+
Max 1-day precip.	+
Mesozoic Lowland	+
Valley and Ridge	-
Soil bulk dens.	-
Baseflow index	-
Euclidean distance to stream	+
Geo. P	+

Hydrologic Connectivity

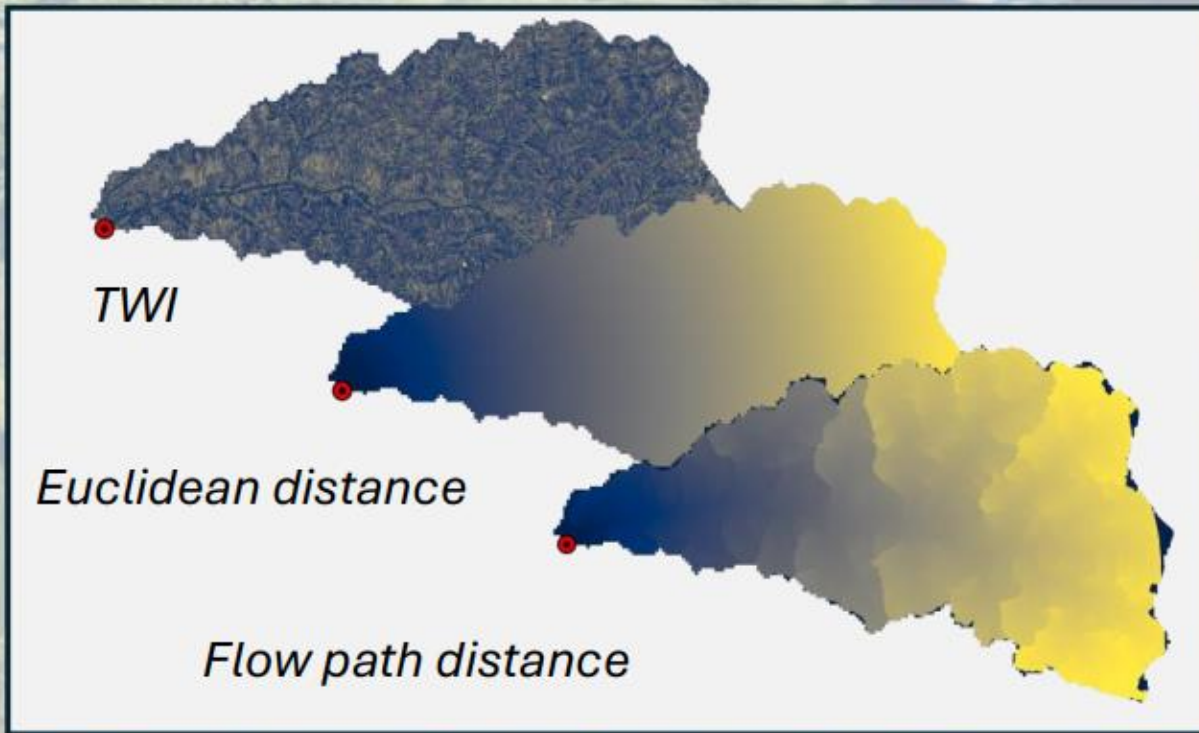
Model review, STAC, and literature review identify several processes related by their influence on landscape connectivity of sources to streams.

Particularly important for P because of high sorption potential.



Hydrologic Connectivity

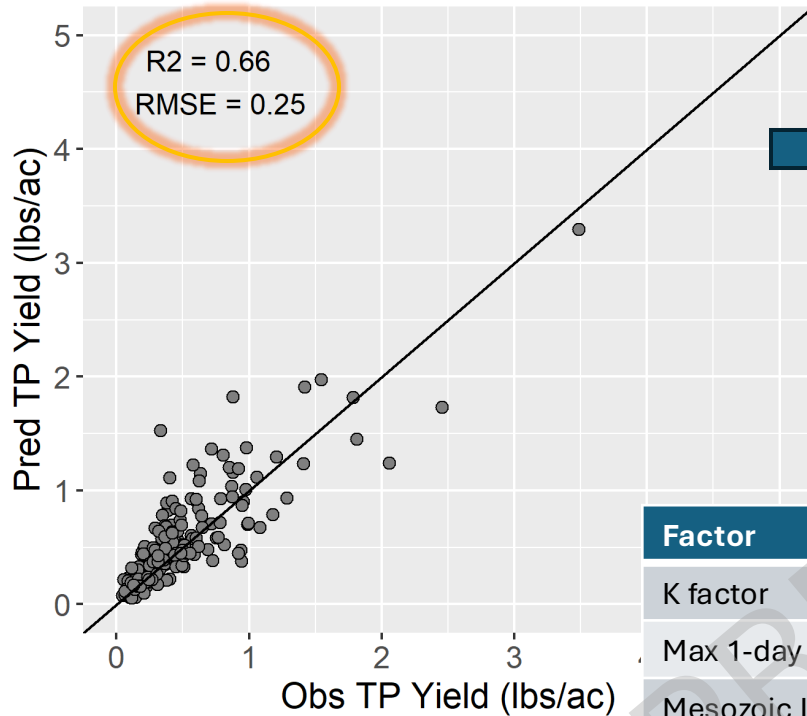
1. Connectivity metrics



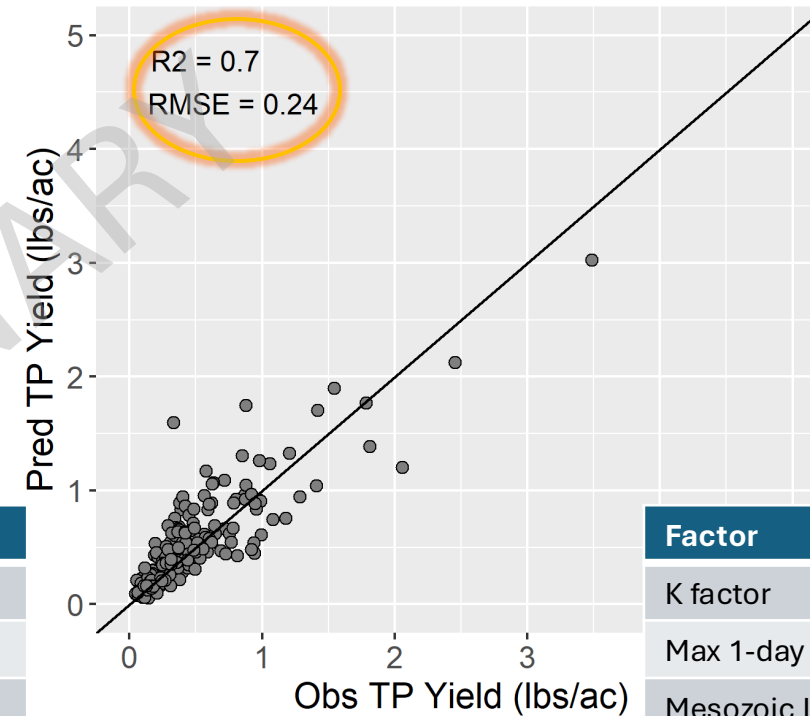
Suite of connectivity metrics (processed at 1m, 10m)

- Index of Sediment Connectivity (SedIC)
- Inverse distance to Stream:
 - Euclidean distance
 - Flow path distance
- Topographic Wetness Index

Hydrologic Connectivity



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



New landscape
connectivity factor

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	+

Salinization Effects on P Desorption

Ions from salty water and road salt displace bound P and increase loading.

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.

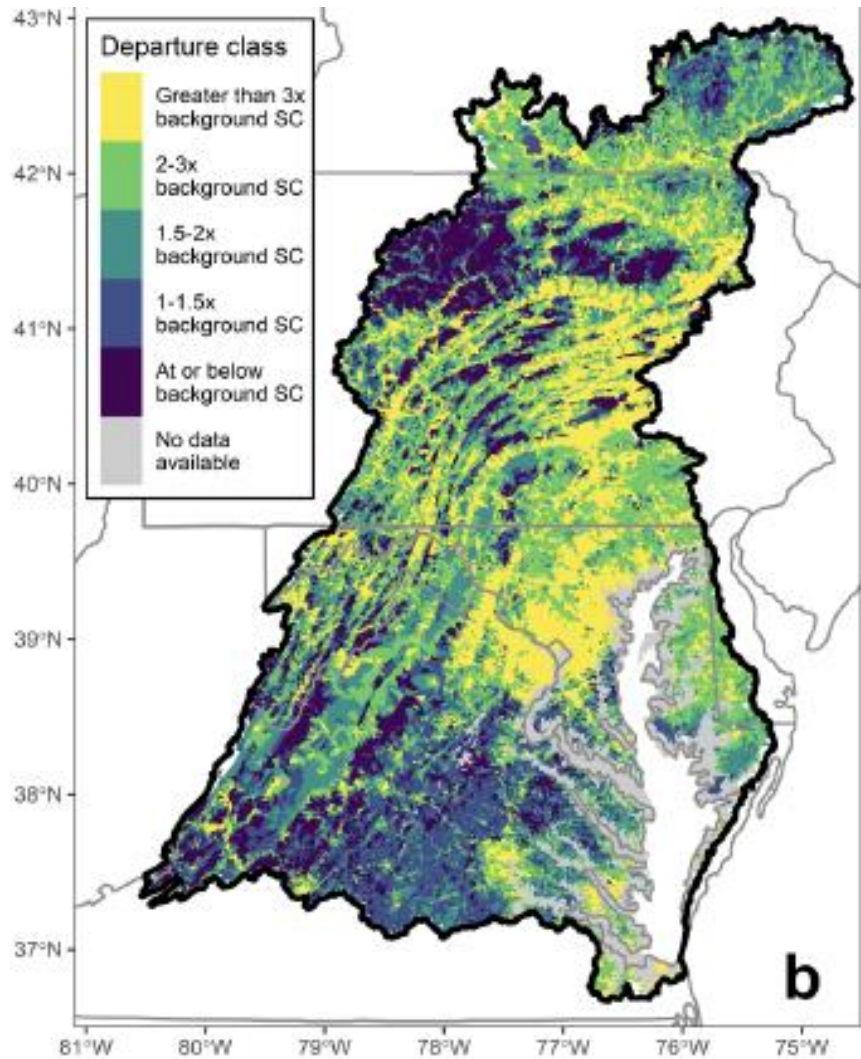
Yin, Yuepeng, et al. "Effect of Ionic Strength and Electrolyte Type on Phosphorus Deposition and Release from the Sediments." *Current Pollution Reports* 11.1 (2025): 56.

Brown, Alexander H., Margaret C. Hoffman, and Lauren Elyse McPhillips. "Impacts of deicer salt on water quality performance of stormwater bioretention systems with varied vegetation and hydrology." *ACS ES&T Water* 4.7 (2024): 2882-2893.

Predicted Salinity from Fanelli et al. 2024

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

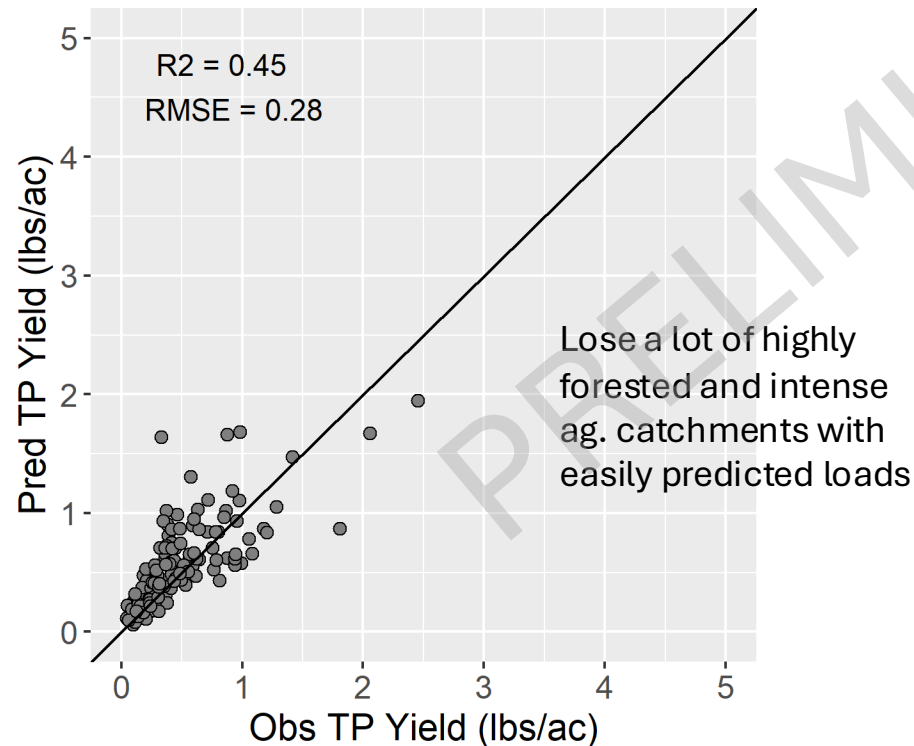
Fanelli, R. M., Moore, J., Stillwell, C. C., Sekellick, A. J., & Walker, R. H. (2024). **Predictive modeling reveals elevated conductivity relative to background levels in freshwater tributaries within the Chesapeake Bay Watershed, USA.** *ACS ES&T Water*, 4(11), 4978-4989.



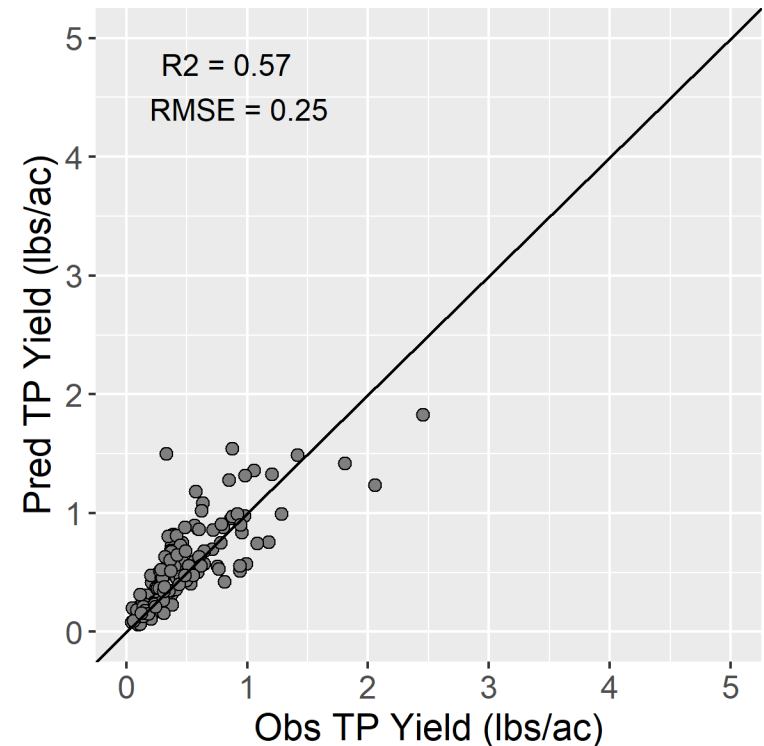
Predicted Salinity Model Testing

Not a significant predictor in the full model, but...

Model subset to the most urbanized 50% of the watershed (134 monitoring stations)



+ Predicted Salinity (from Fanelli et al. 2024)



However, predicted salinity is highly correlated with % impervious cover.

pH-Driven Desorption of Legacy P

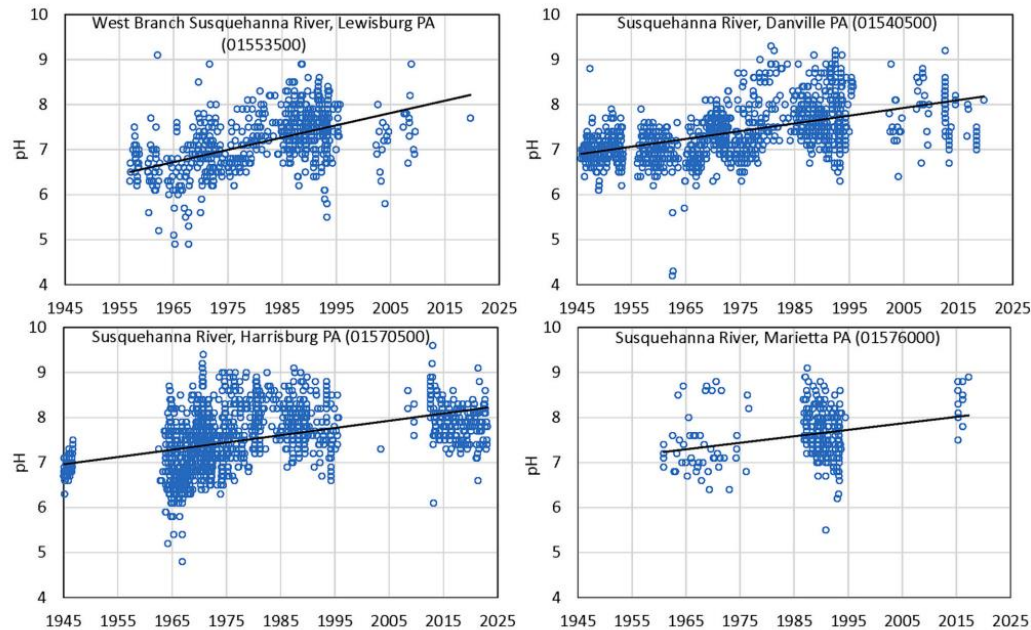


Fig. 5. Time-series showing pH of discrete samples for historical and current conditions on the West Branch Susquehanna River at Lewisburg (USGS station no. 01553500) and the Susquehanna River at Danville (USGS station no. 01540500), which merge downstream to form the lower Susquehanna River, represented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

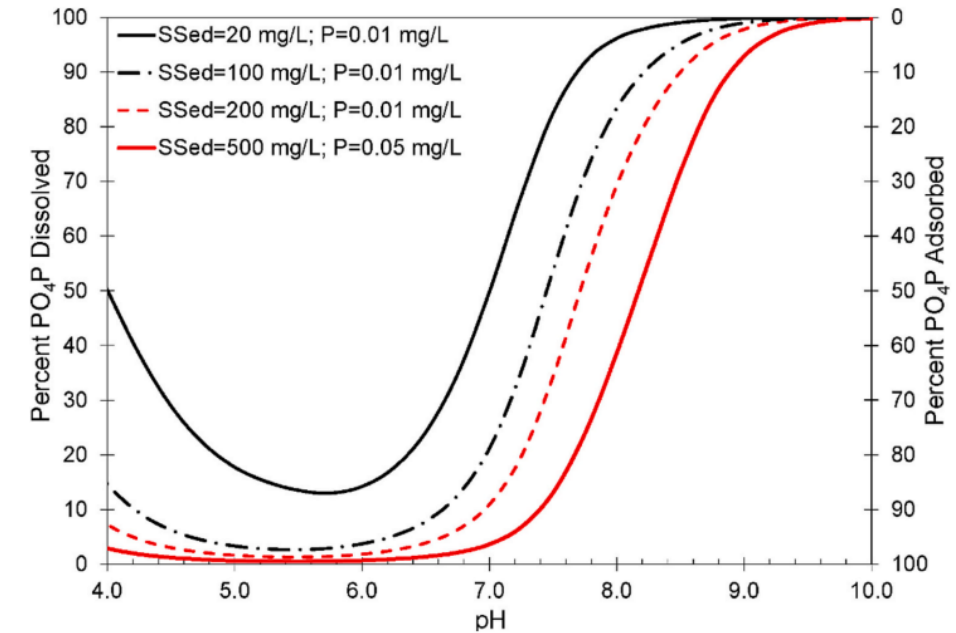


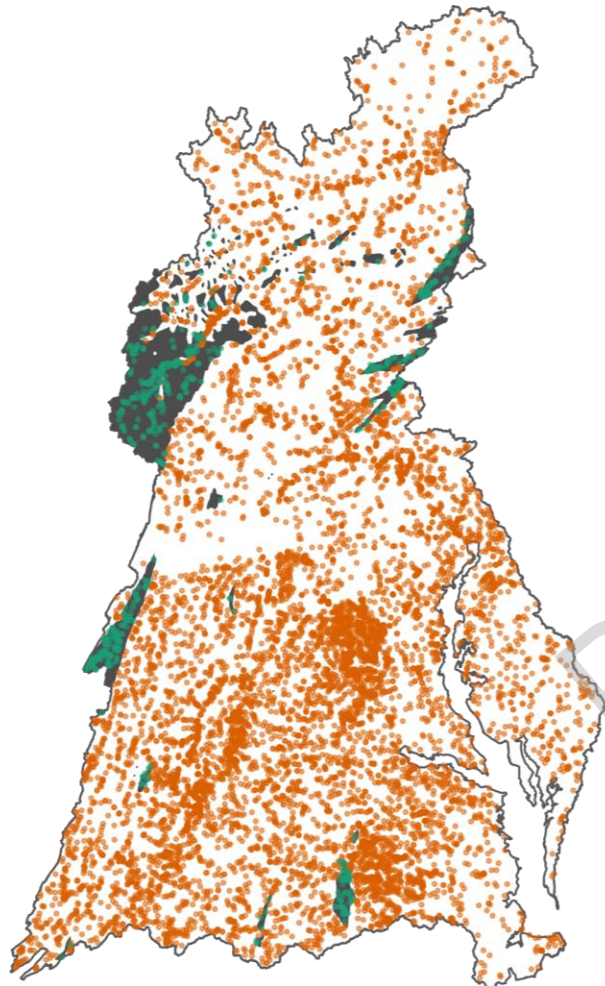
Fig. 4. Equilibrium fractions of initial concentration of phosphate (0.01 or 0.05 mg/L as P) that may be dissolved or adsorbed by suspended sediment (Ssed) composed of 6.7 % Fe (HFO; with a specific surface area (Asp) of 600 m²/g), 0.5 % Mn (HMO; with Asp of 746 m²/g), and 2.8 % Al (HAO; with Asp of 68 m²/g). Upper three curves consider PO₄ = 0.01 mg/L as P and vary sorbent concentration from 20 to 200 mg/L, whereas lower curve considers PO₄ = 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

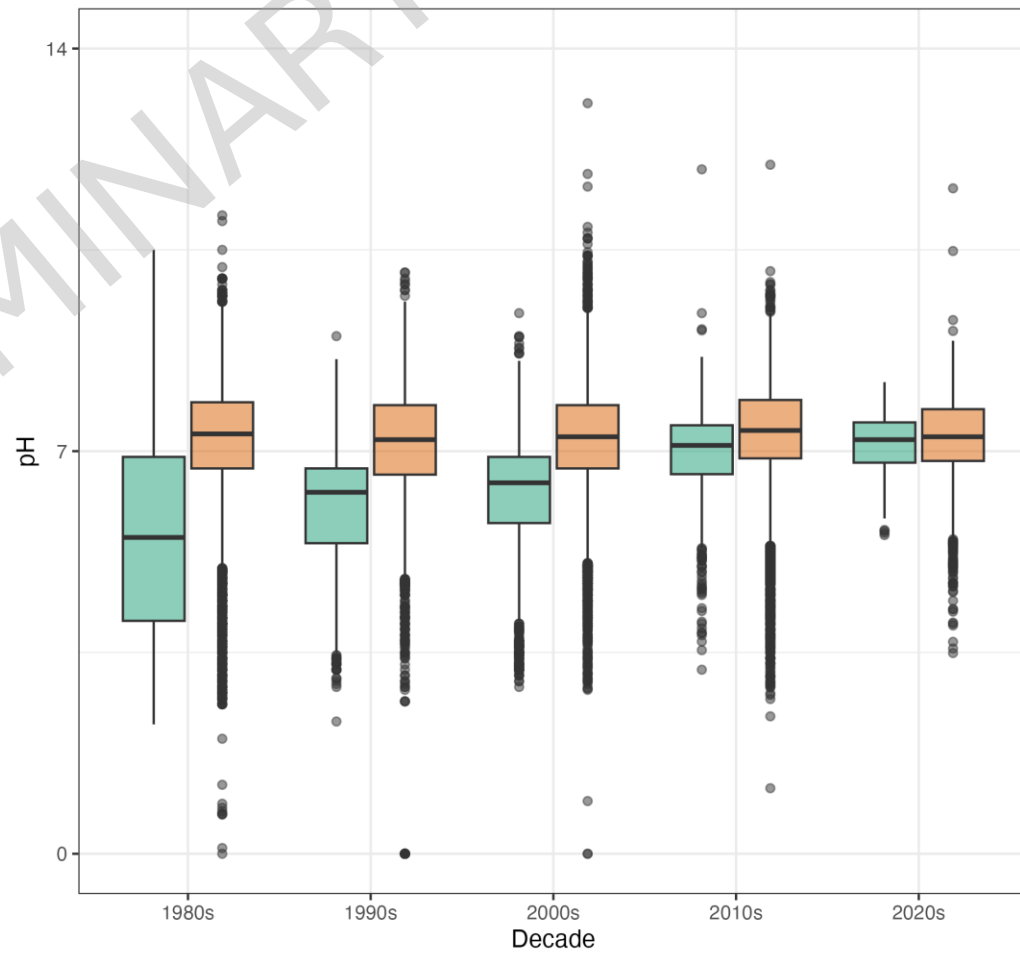
Trends in pH Across the Watershed, Data from the Water Quality Portal

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

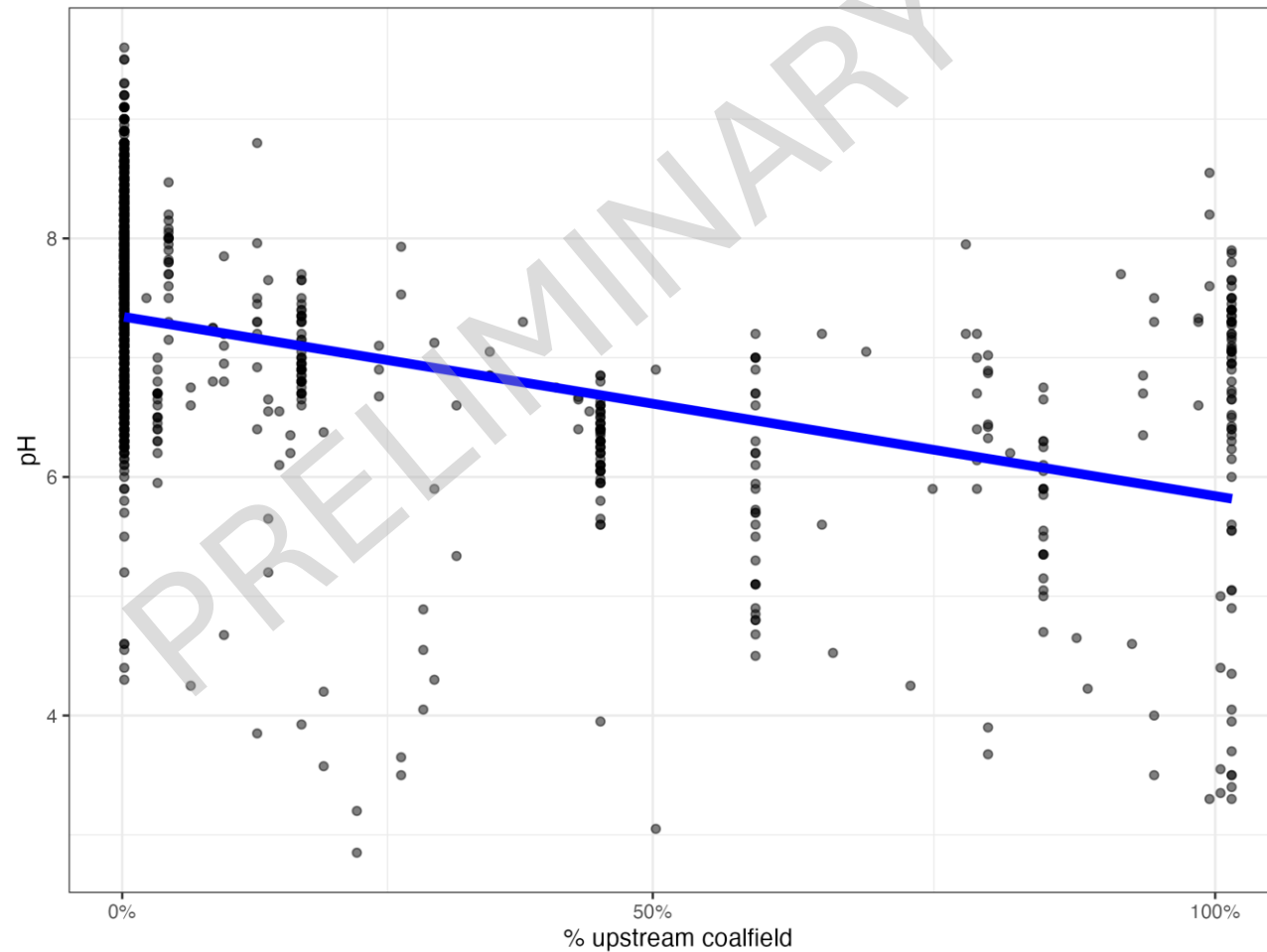


Sampling Location

- Coalfield
- Not in coalfield

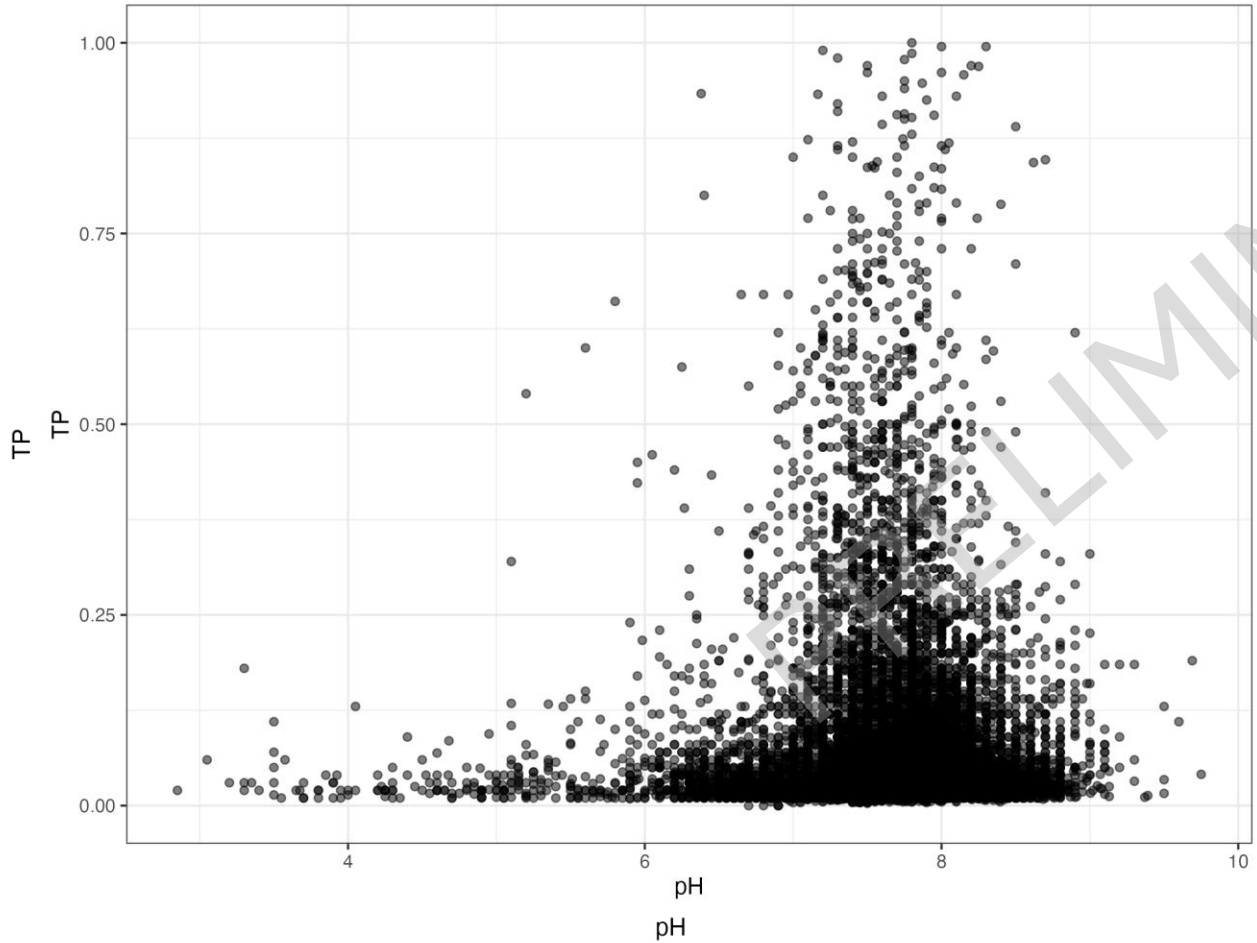


Acidity Increases with the Amount of Upstream Watershed Area in Coal Areas

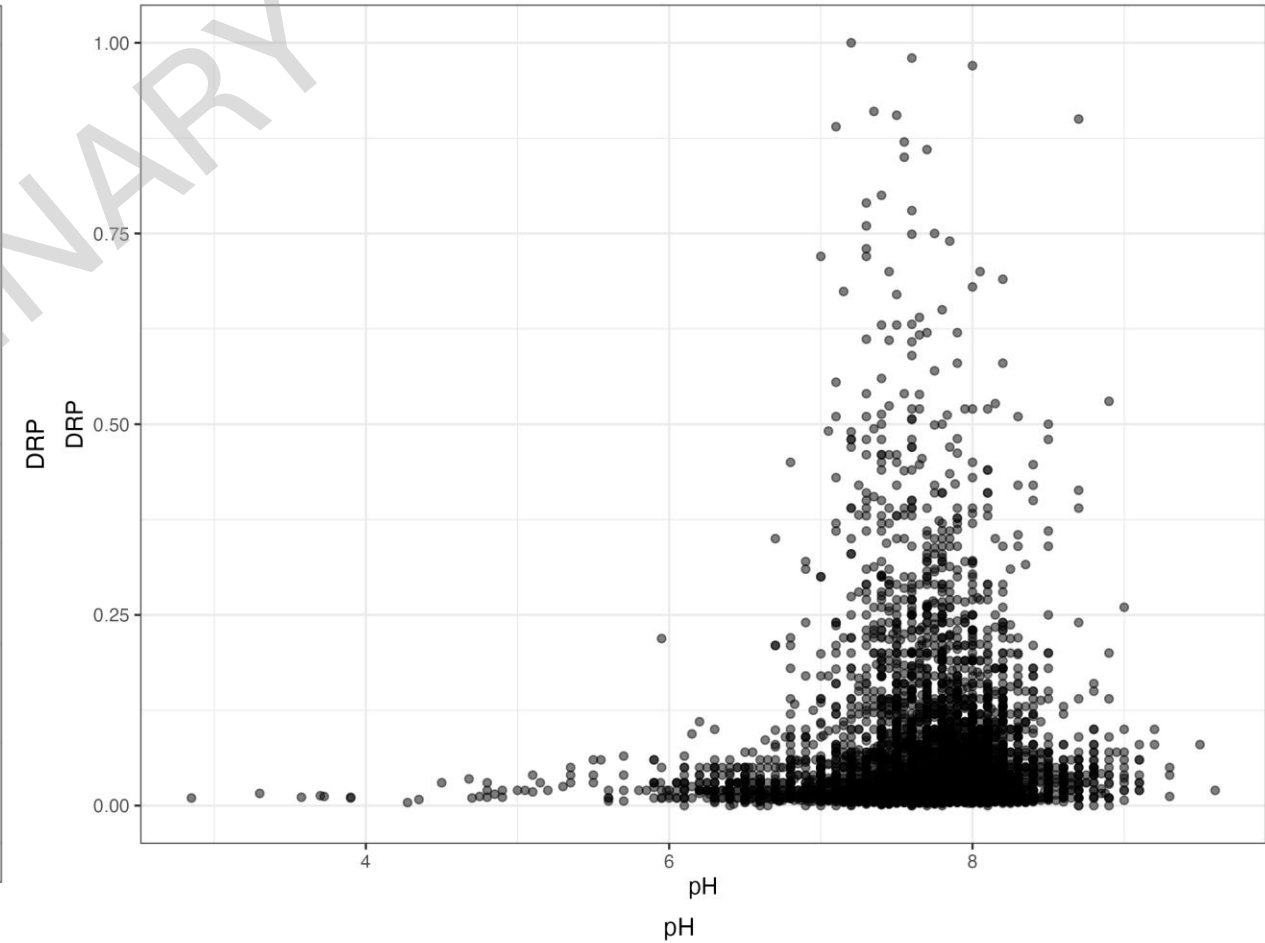


TP and DRP Concentrations Increase with Alkalinity

TP

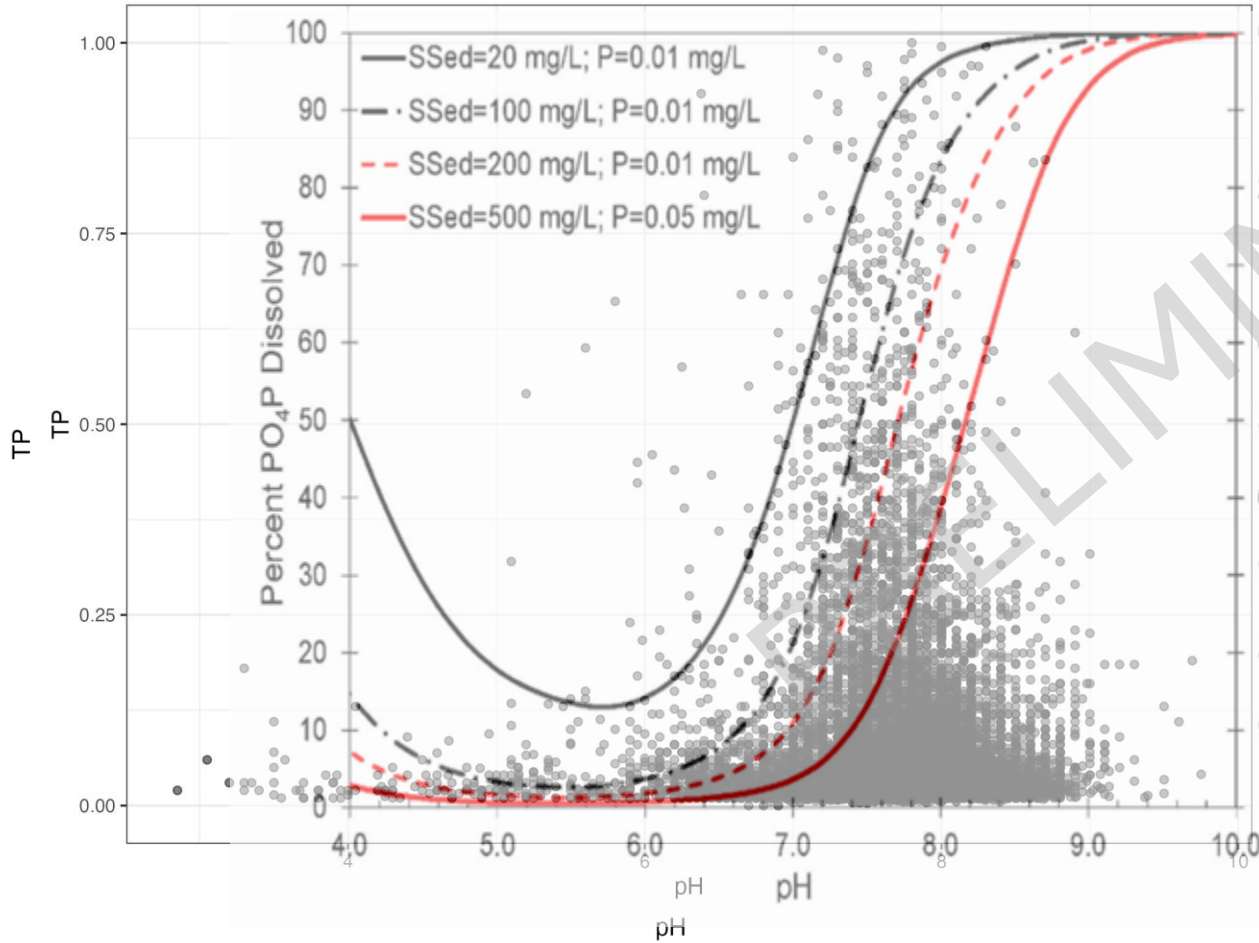


DRP

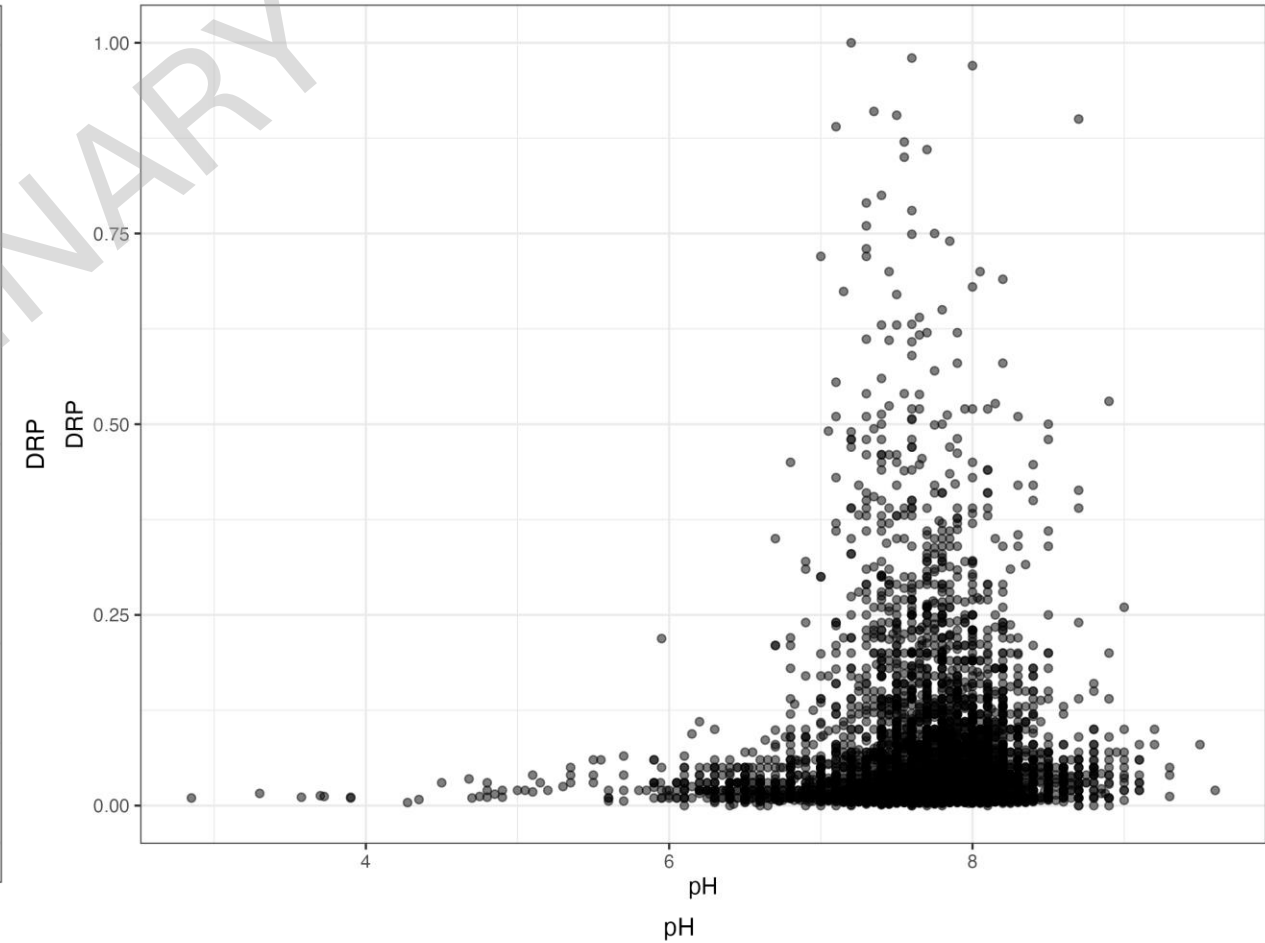


TP and DRP Concentrations Increase with Alkalinity

TP



DRP



A Spatial-Temporal Index of Coal Field pH Change

Generate an index of the trend in pH from coal areas

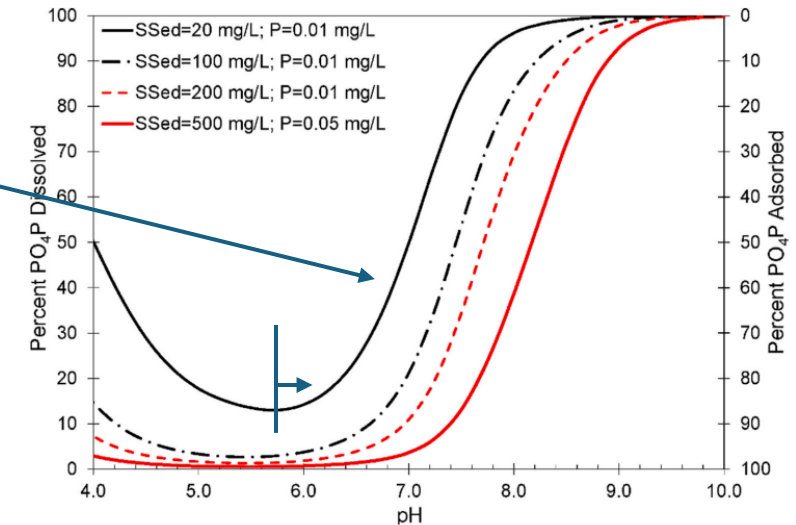
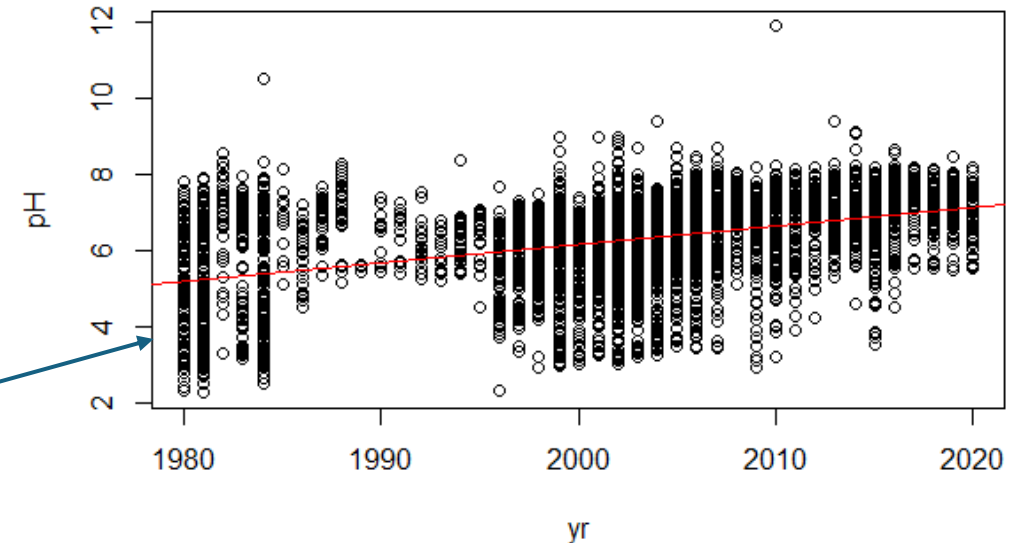
- Captures the effect of trend from changing pH driven by coal-field land and time.

$$pH = 0.049 * t - 91.28$$
$$Pdissf = \frac{1}{1 + e^{-2.6*(pH-7)}}$$

$$Index = CMAccFrac * Pdissf$$

CMAccFrac: Fraction of upslope land area that is coal field land

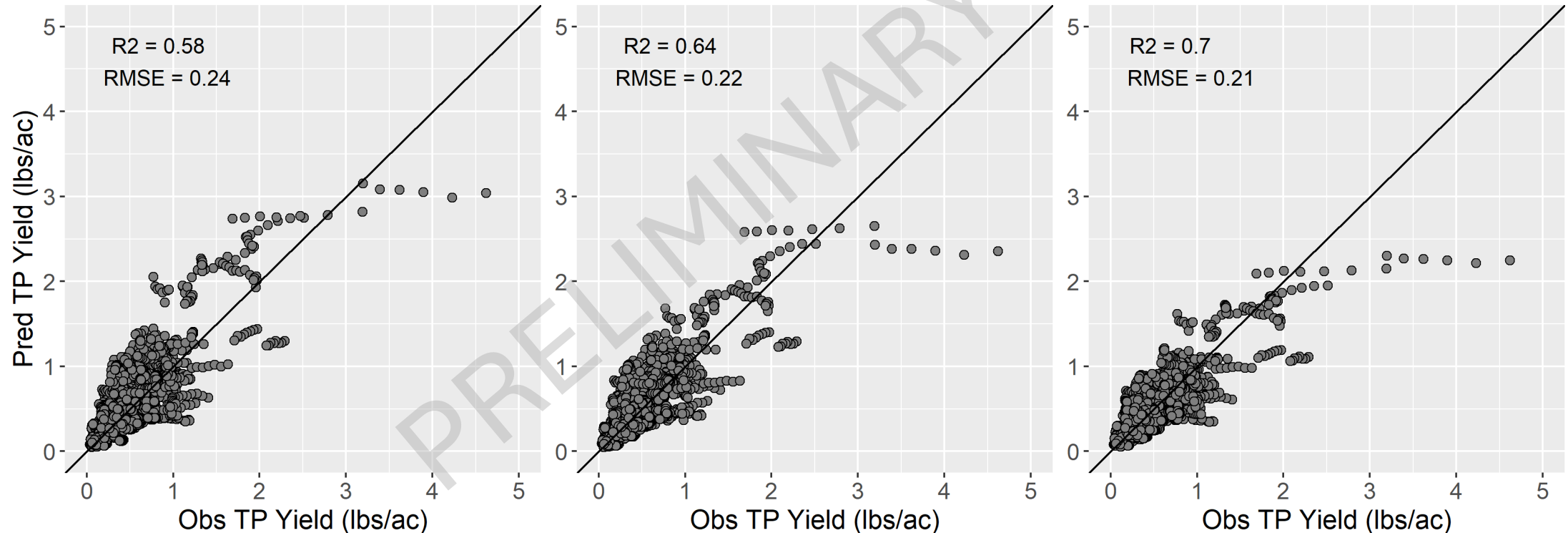
Pdissf: P dissolution fraction, where minimum dissolution is 0 and max dissolution is 1



pH Coal Field Index Model Testing

P6 Predictors, LU/LS

P7 Monitoring



Tested several counterfactuals; the pH/Coal Field index is a significant predictor in both space and time. But we may be seeing the effects of diminishing coal-field-driven legacies rather than pH-driven dissolution?

Next Steps

- Update P CalCAST model with P7 land use, sediment, stormflow, soil P, and direct loads.
- Note: Tillage BMPs have been associated with higher WEP, but they were not found to be a significant predictor of TP.