Advancing Phosphorus Modeling: Integrating pH and Salinity Predictors in Chesapeake Bay Watershed Modeling

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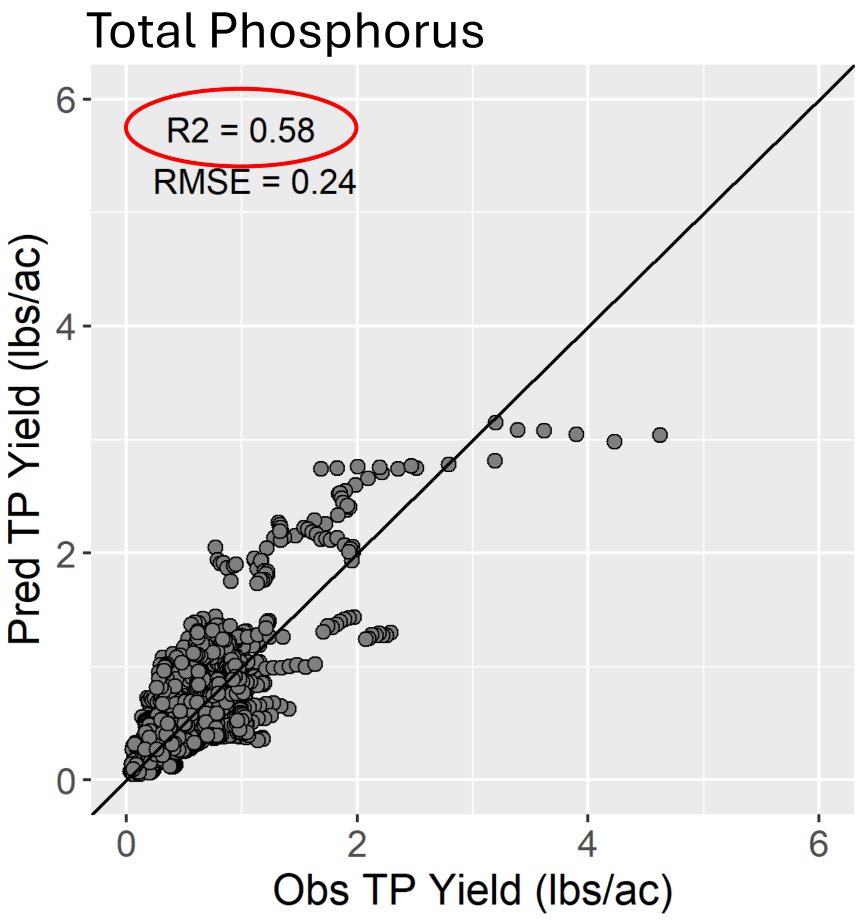
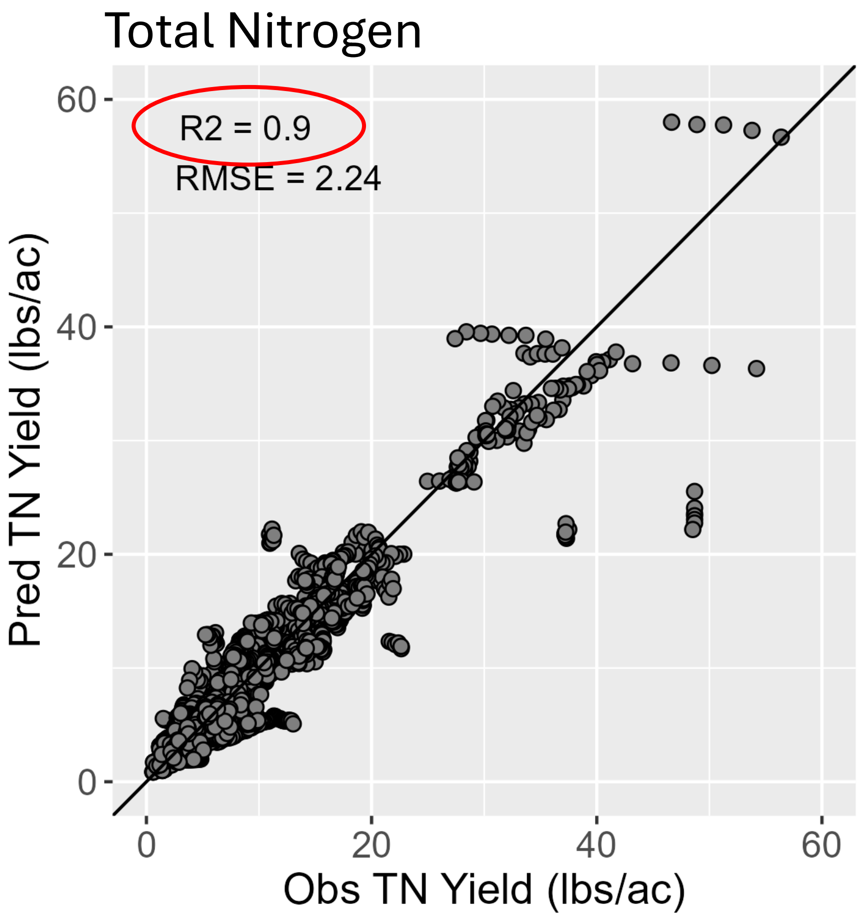
Chesapeake Bay Program

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 hydrologic connectivity
- **Characterizing biogeochemical controls on sorption**
  - **Salinity-driven desorption**
  - **pH-driven desorption**

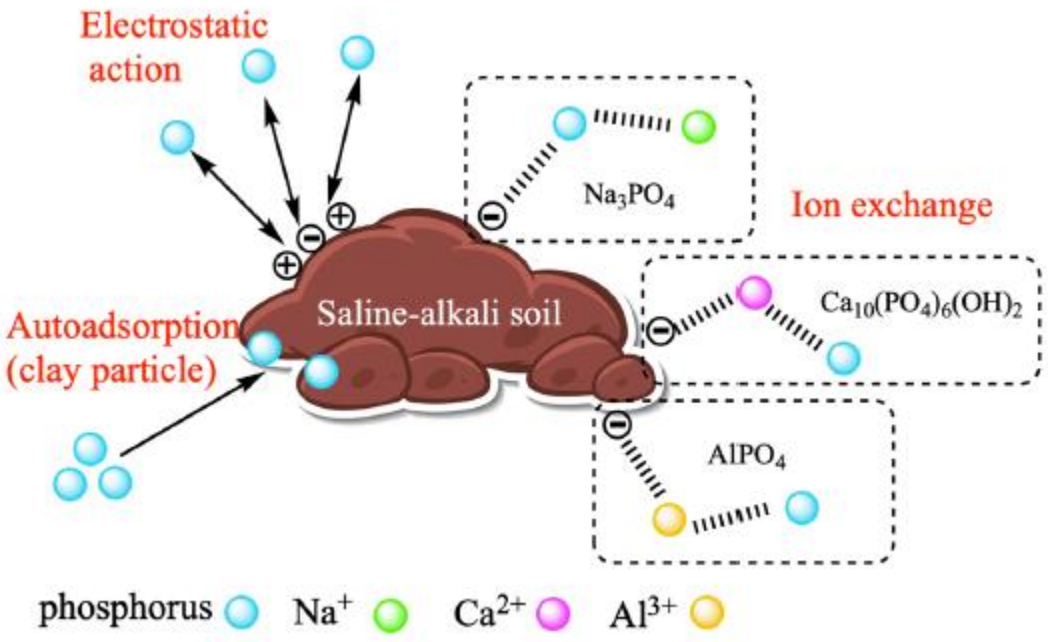


FIGURE 6
Mechanism of phosphorus adsorption in saline soils.

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

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.

pH-Driven Desorption of Legacy P

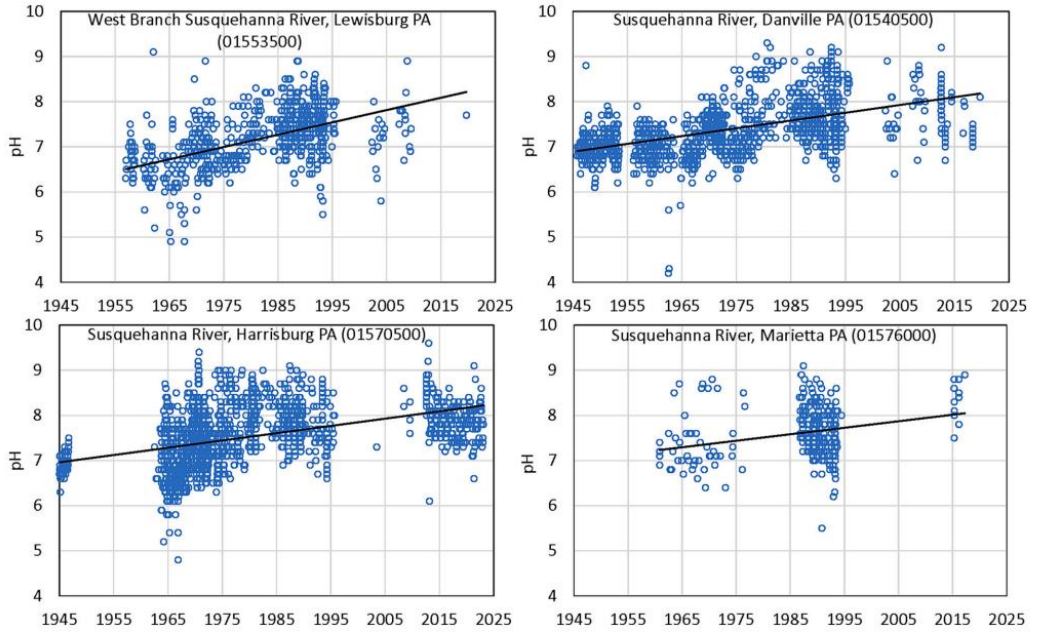


Fig. 5. Time-series showing pH of discrete samples for historical and current conditions on the West Branch Susquehanna River at Lewisburg (USGS station no. 01553500) and the Susquehanna River at Danville (USGS station no. 01540500), which merge downstream to form the lower Susquehanna River, represented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

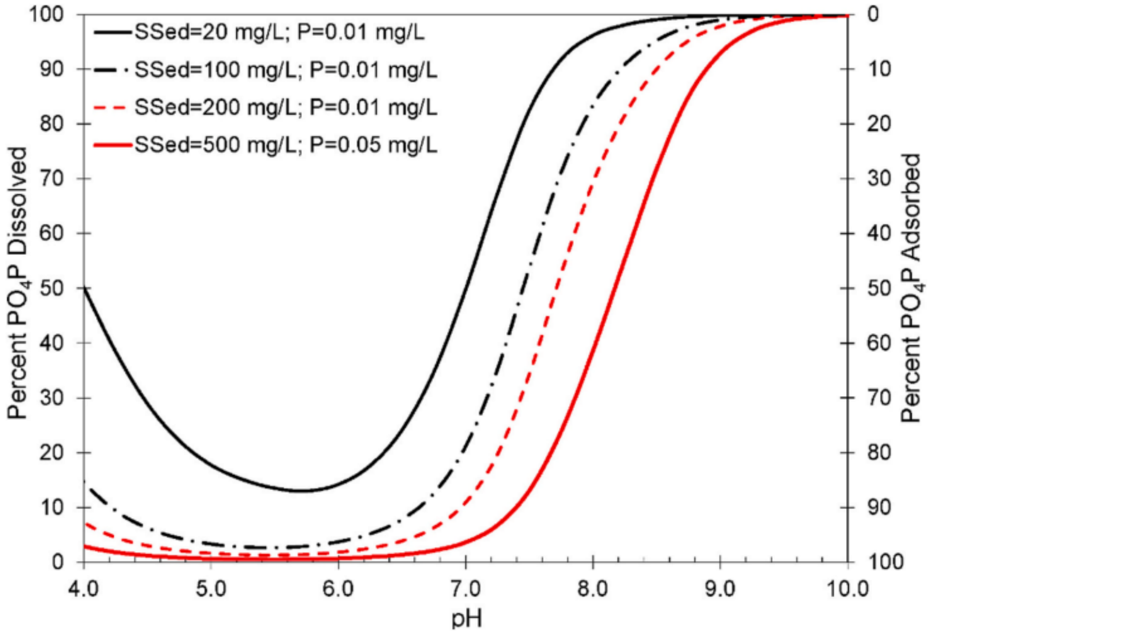


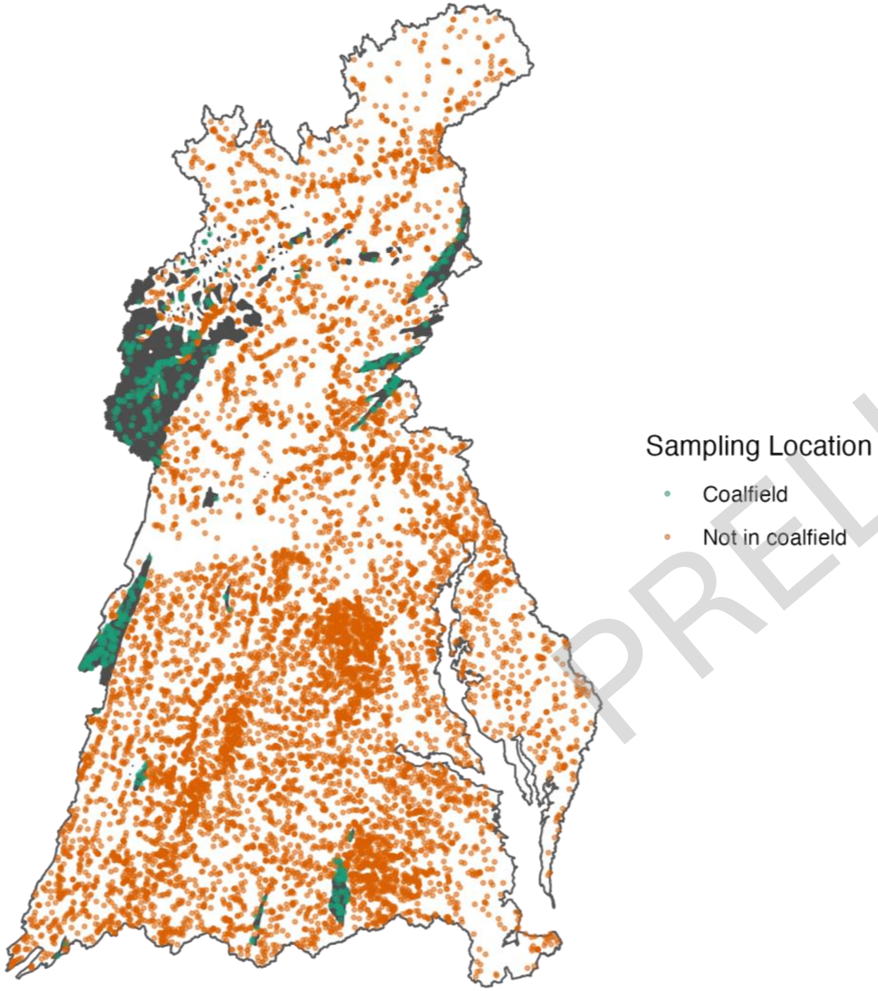
Fig. 4. Equilibrium fractions of initial concentration of phosphate (0.01 or 0.05 mg/L as P) that may be dissolved or adsorbed by suspended sediment (Ssed) composed of 6.7 % Fe (HFO; with a specific surface area (Asp) of 600 m^2/g), 0.5 % Mn (HMO; with Asp of 746 m^2/g), and 2.8 % Al (HAO; with Asp of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

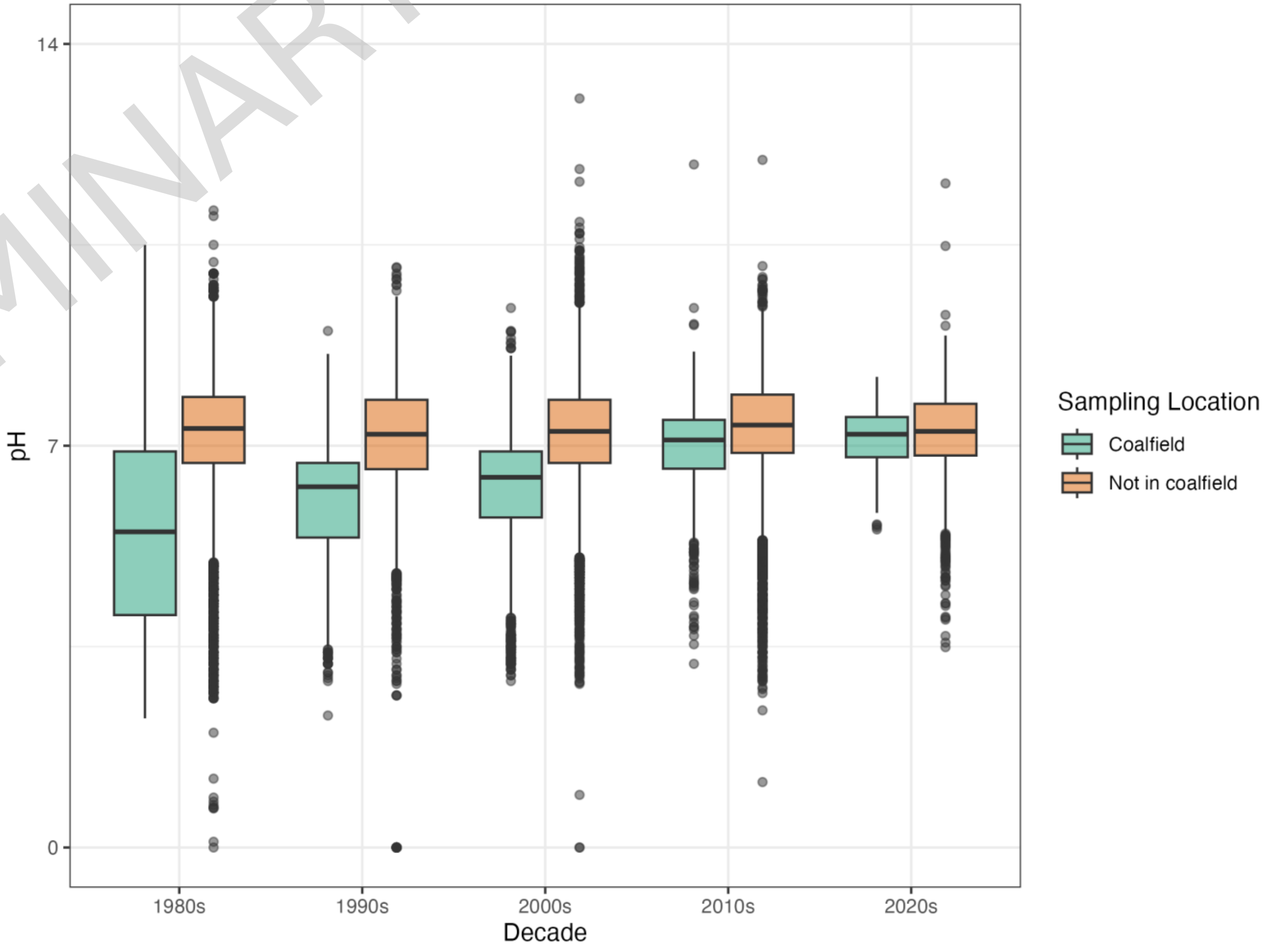
Legacy sediment as a potential source of orthophosphate: Preliminary conceptual and geochemical models for the Susquehanna River, Chesapeake Bay watershed, USA

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]

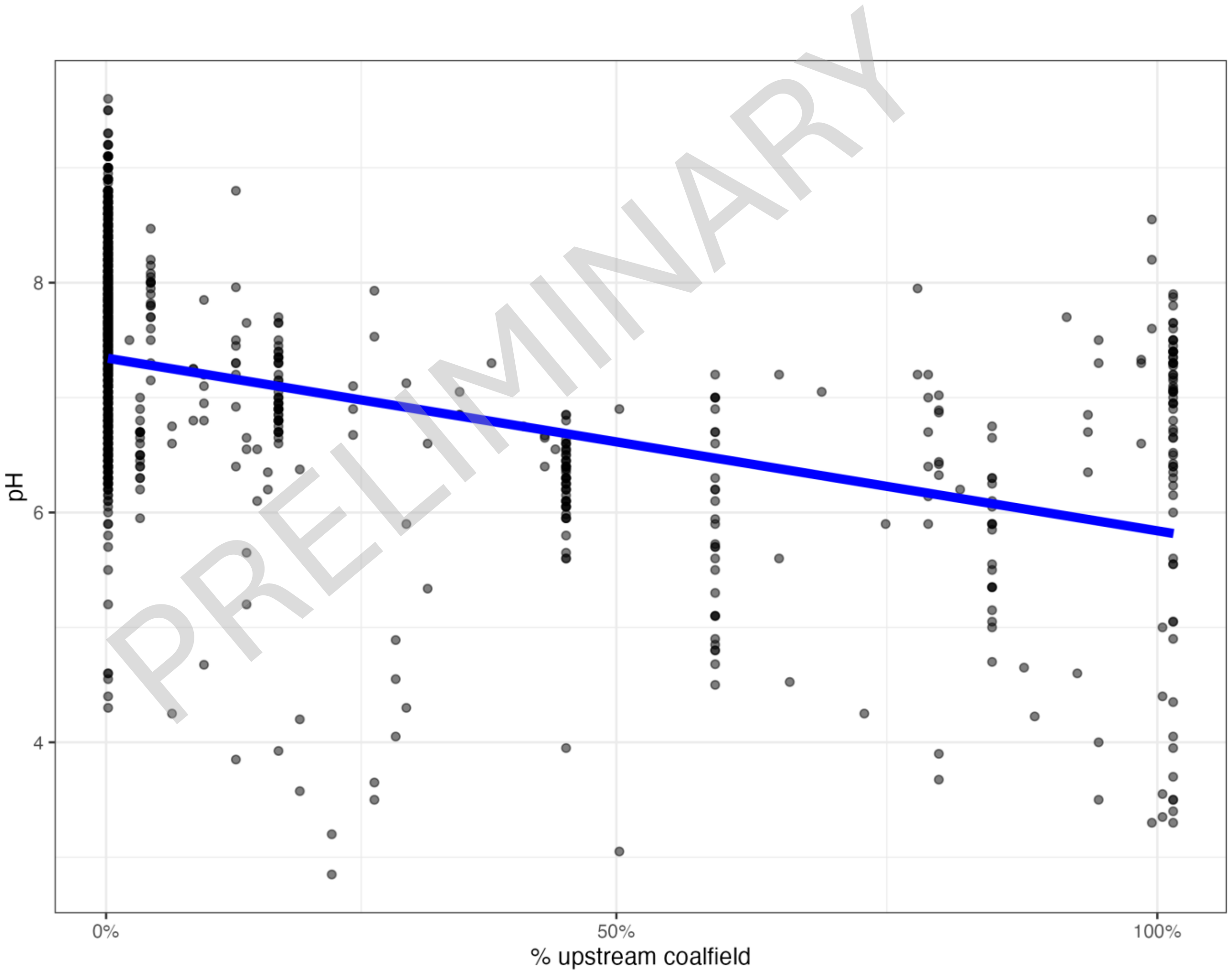
Trends in pH across the watershed, data from the Water Quality Portal

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



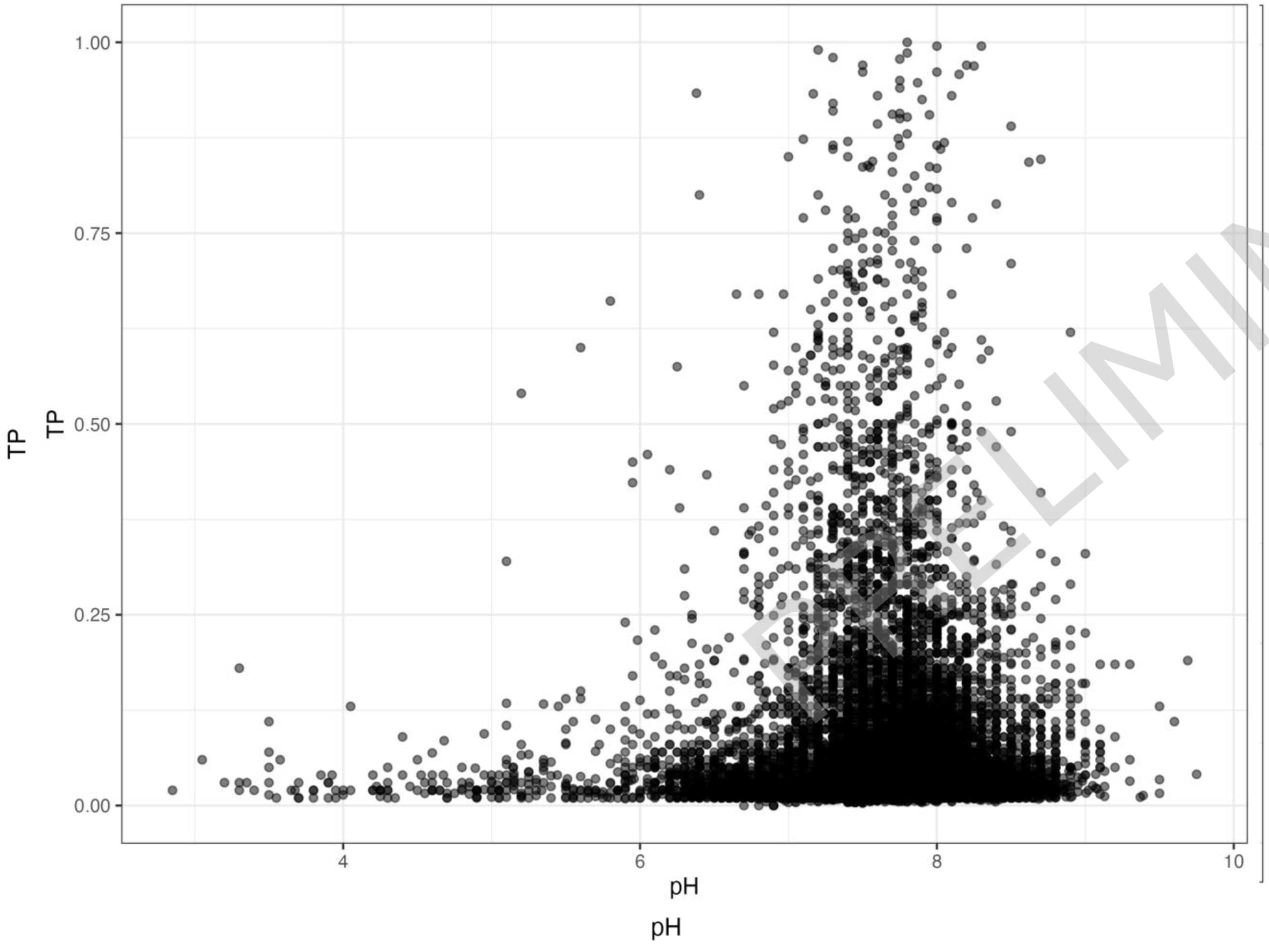


Acidity increases with the amount of upstream watershed area in coal areas

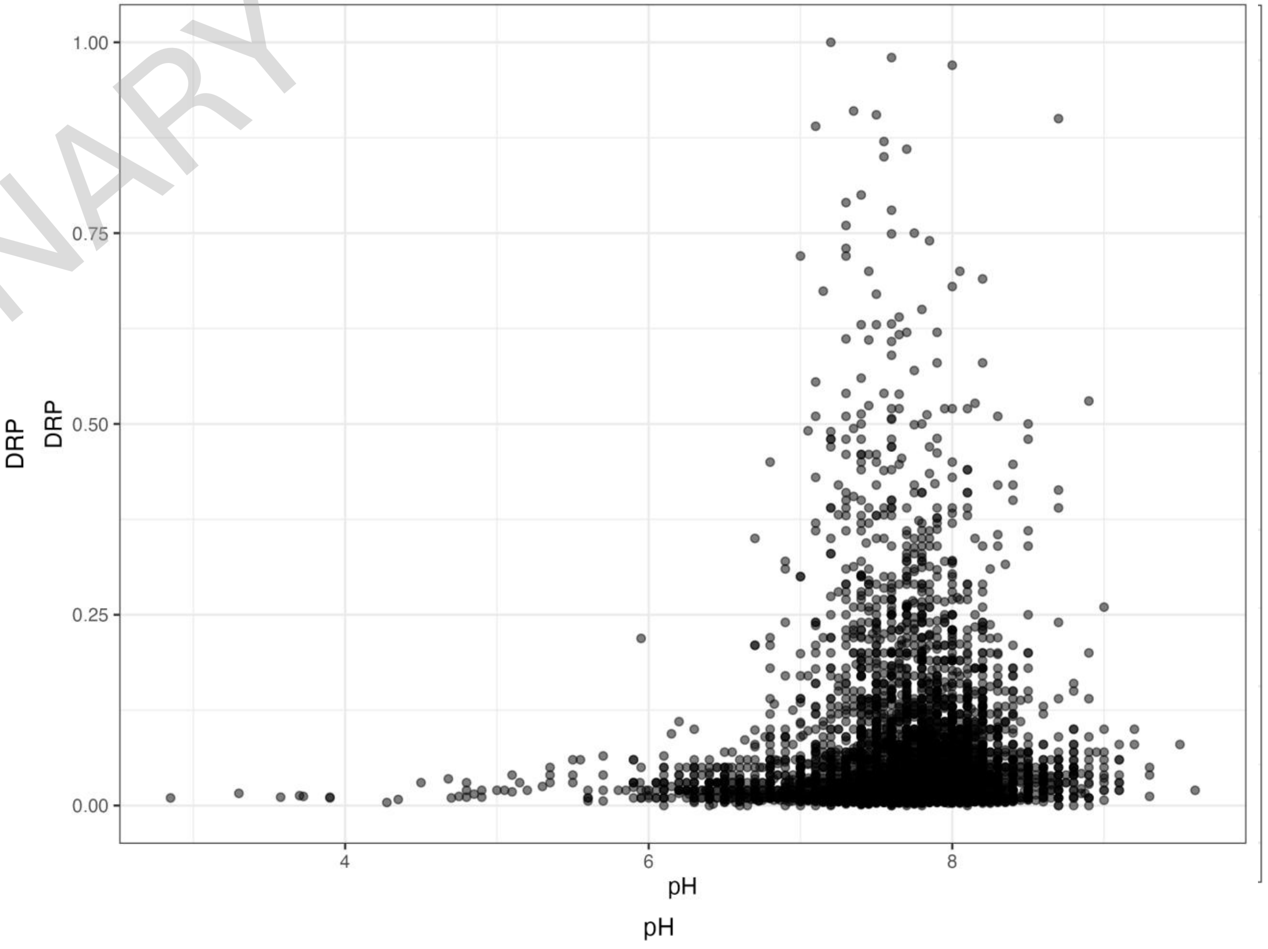


TP and DRP concentrations increase with alkalinity

TP



DRP



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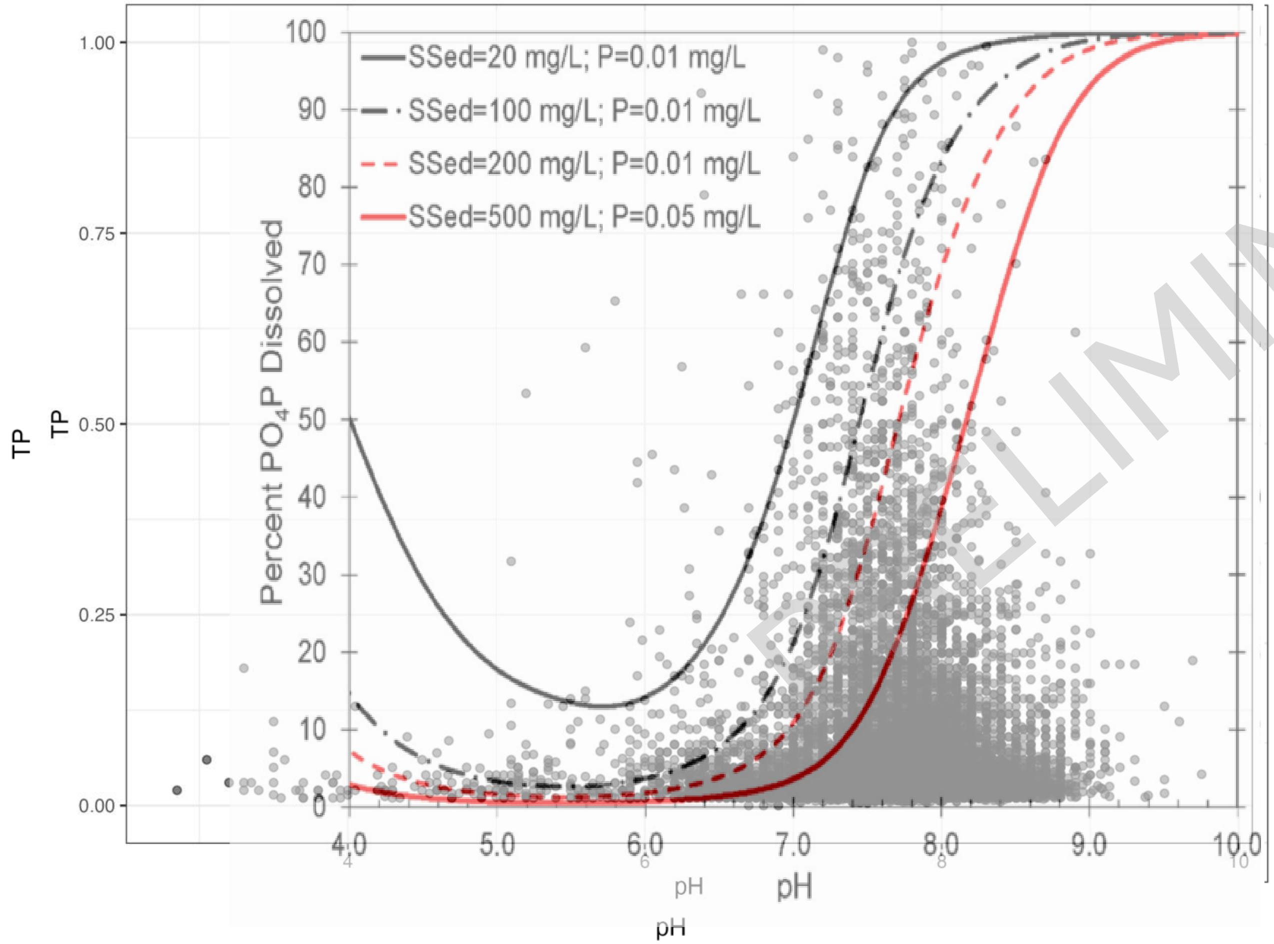
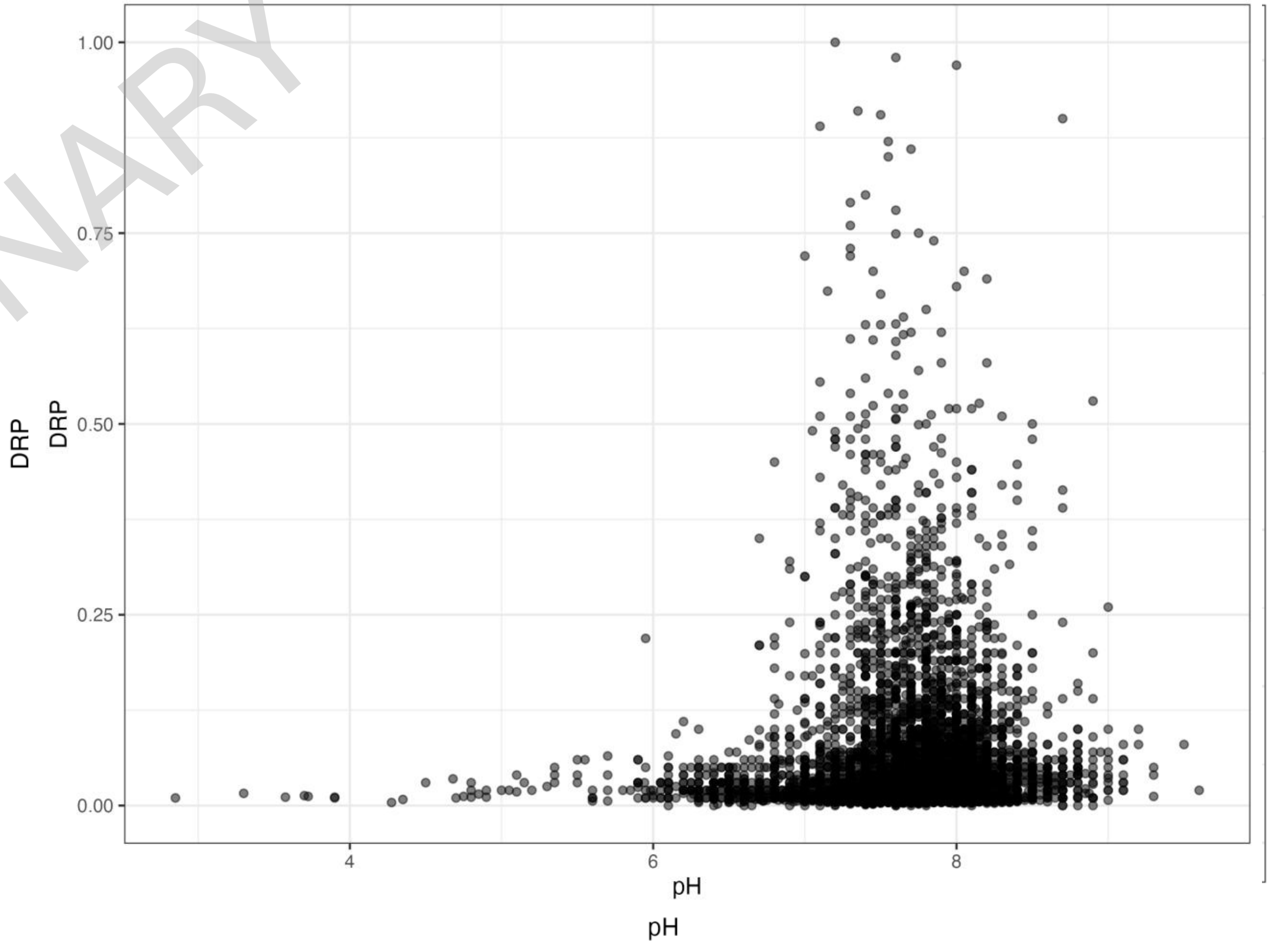
TP



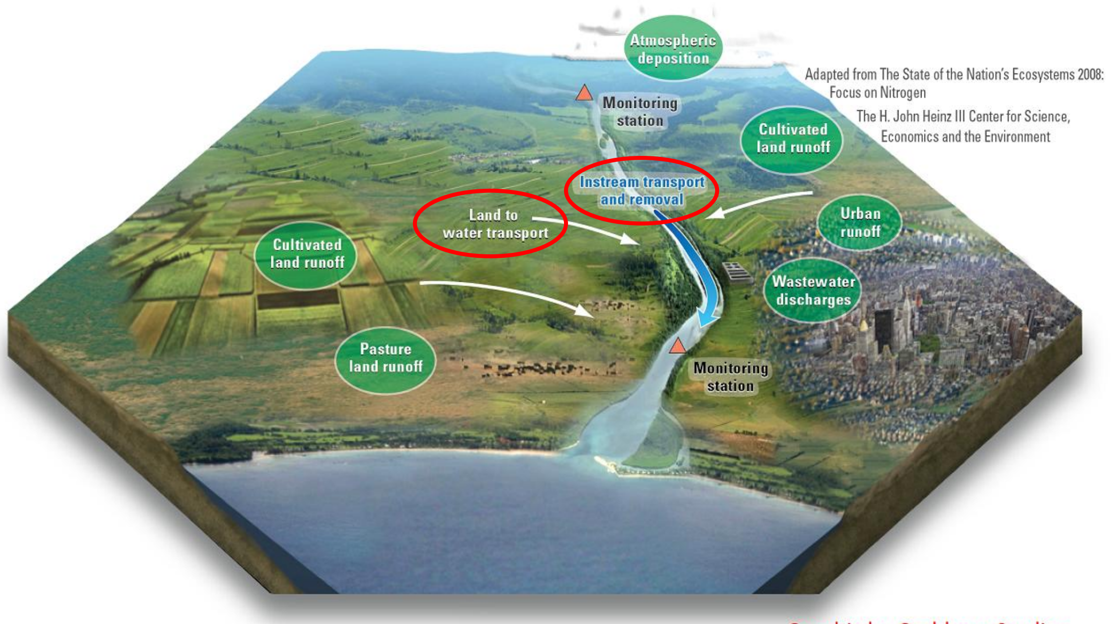
DRP



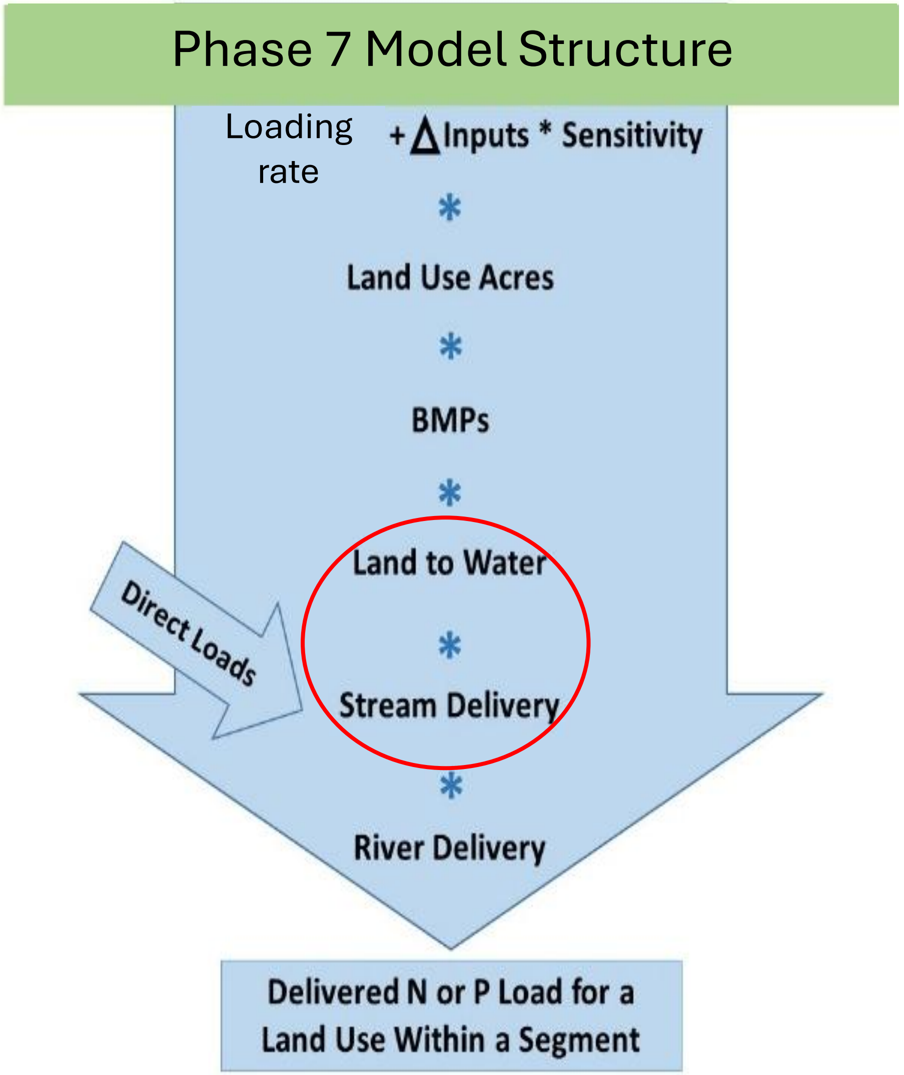
Model Testing and Implementation

- Crude implementation as transport factors
- Capture the emergent behavior at the watershed scale

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



Graphic by Grabhorn Studios



A Spatial-Temporal Index of Coal Field pH Change

Generate an index of the trend from coal areas on pH

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

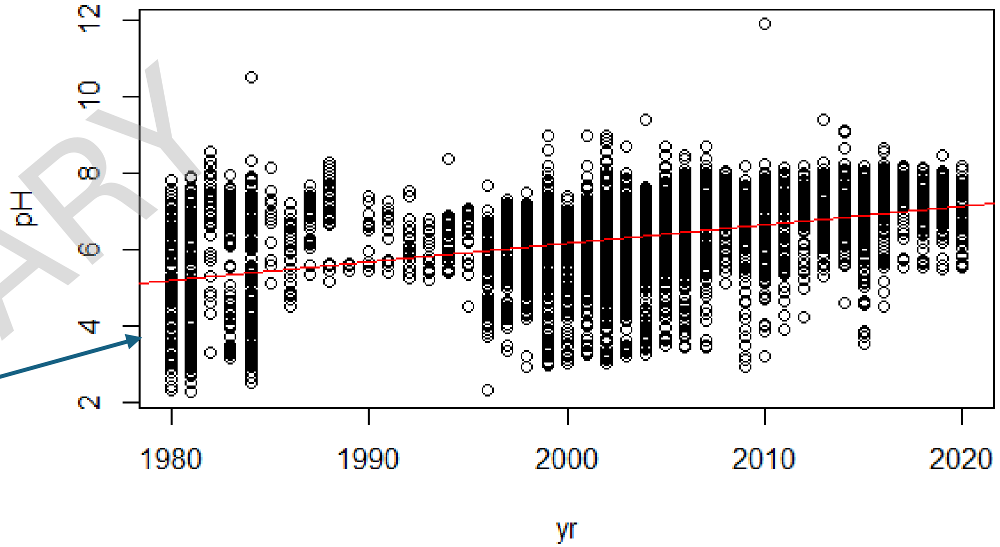
$$pH = 0.049 * t - 91.28$$

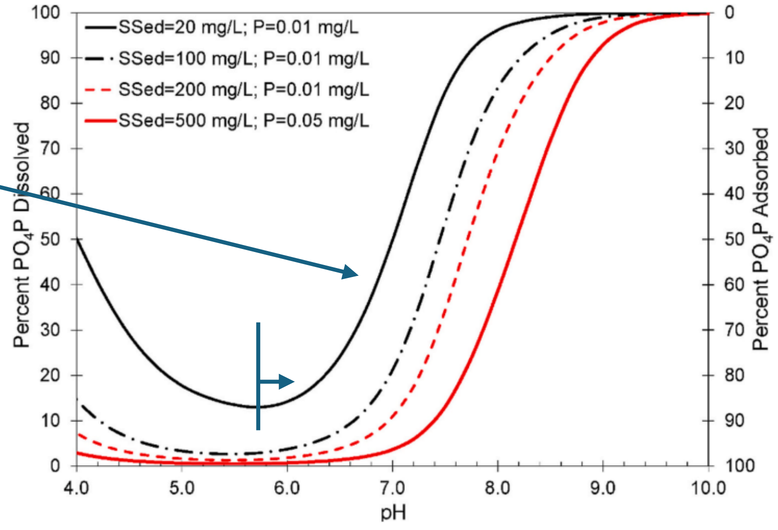
$$Pdissf = \frac{1}{1 + e^{-2.6*(pH-7)}}$$

$$Index = CMAccFrac * Pdissf$$

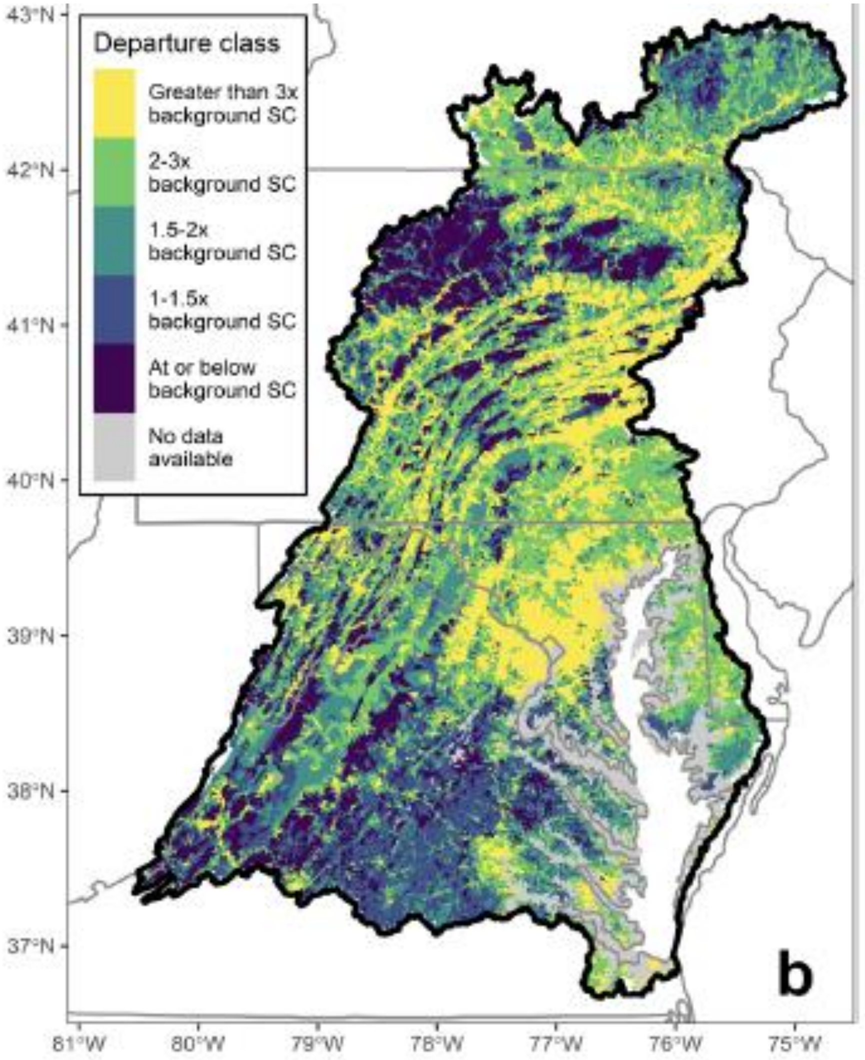
CMAccFrac: Fraction of upslope land area that is coal field land

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





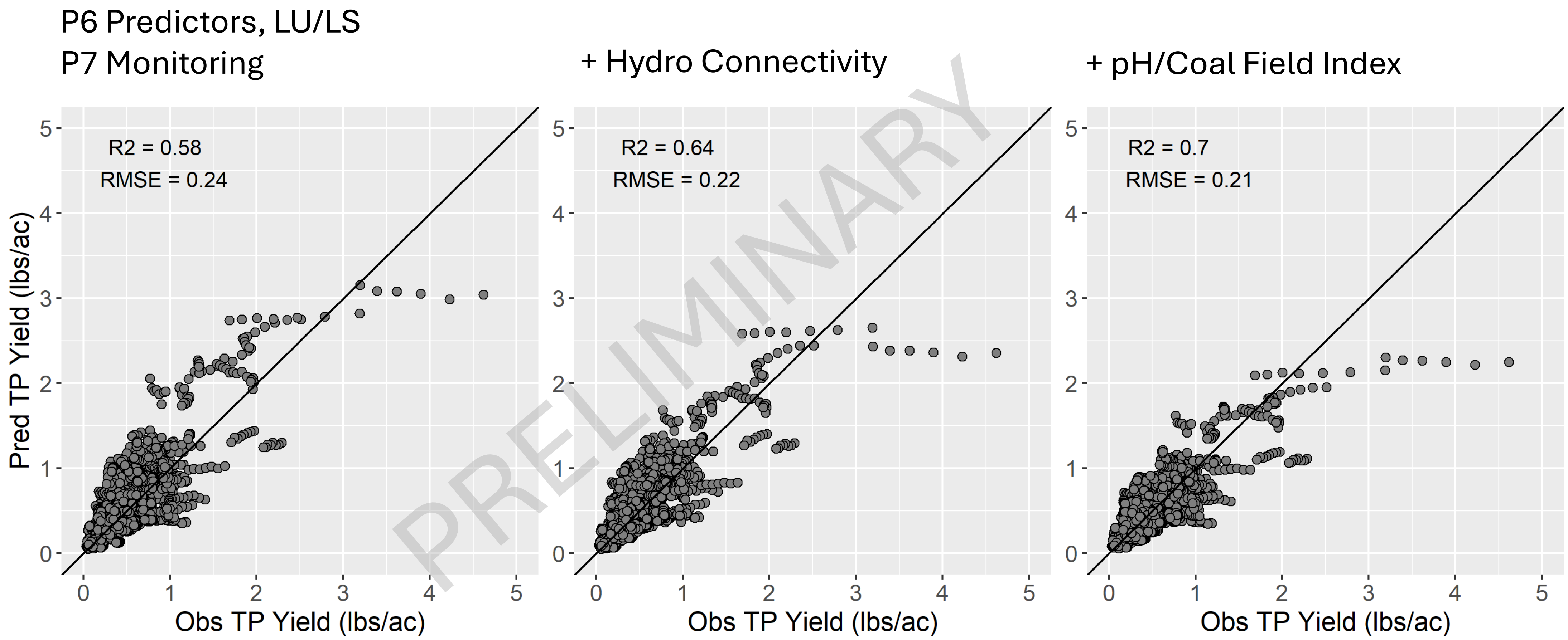
Predicted Salinity from Fanelli et al. 2024



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.

pH Coal Field Index Model Testing

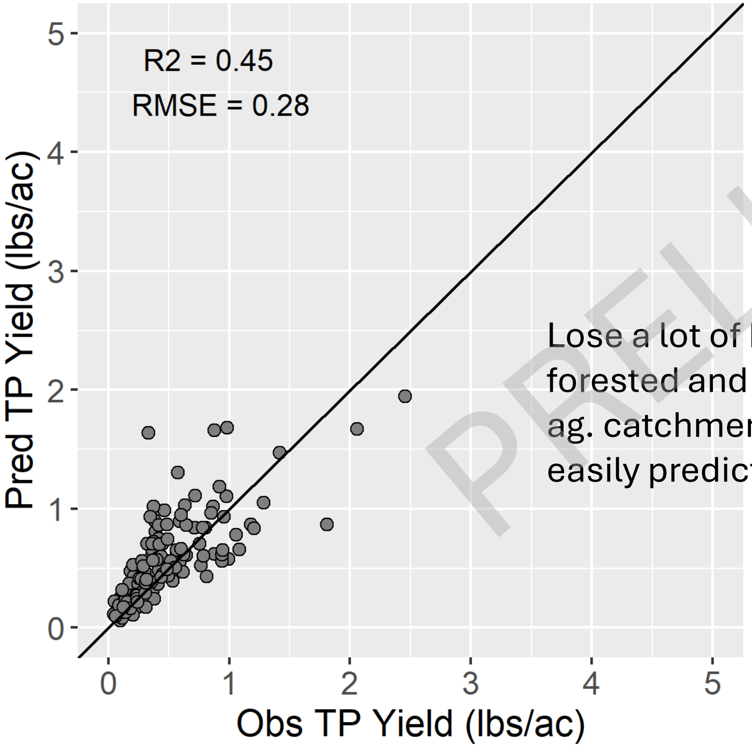


Tested several counterfactuals; the pH/Coal Field index is a significant predictor in both space and time. But we may be seeing the effects of diminishing coal-field-driven legacies rather than pH-driven dissolution?

Predicted Salinity Model Testing

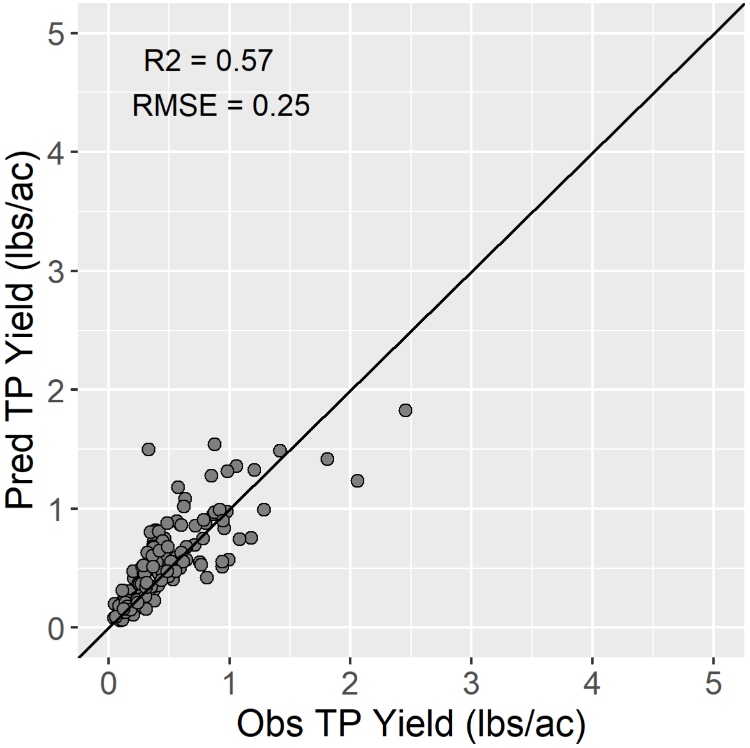
Not a significant predictor in the full model, but…

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



Lose a lot of highly forested and intense ag. catchments with easily predicted loads

+ Predicted Salinity (from Fanelli et al. 2024)



However, predicted salinity is highly correlation to % impervious cover.

Next Steps

Testing indicates significant relationships between pH, salinity, and P transport.

- Try to isolate causal factors.
- Quantify the impacts of salinity and pH on P loads.
- Improve representation of pH and salinity as transport factors for the current modeling phase.
  - Test different configurations as land-to-water and stream-to-river factors
  - Test spatial and temporal influence
  - Investigate model results across different LUs and regions
- Improve representation of processes in future phases of modeling.
  - Estimate legacy pools and parameterize export as functions of pH and salinity.
  - Additional connections to the sediment model.

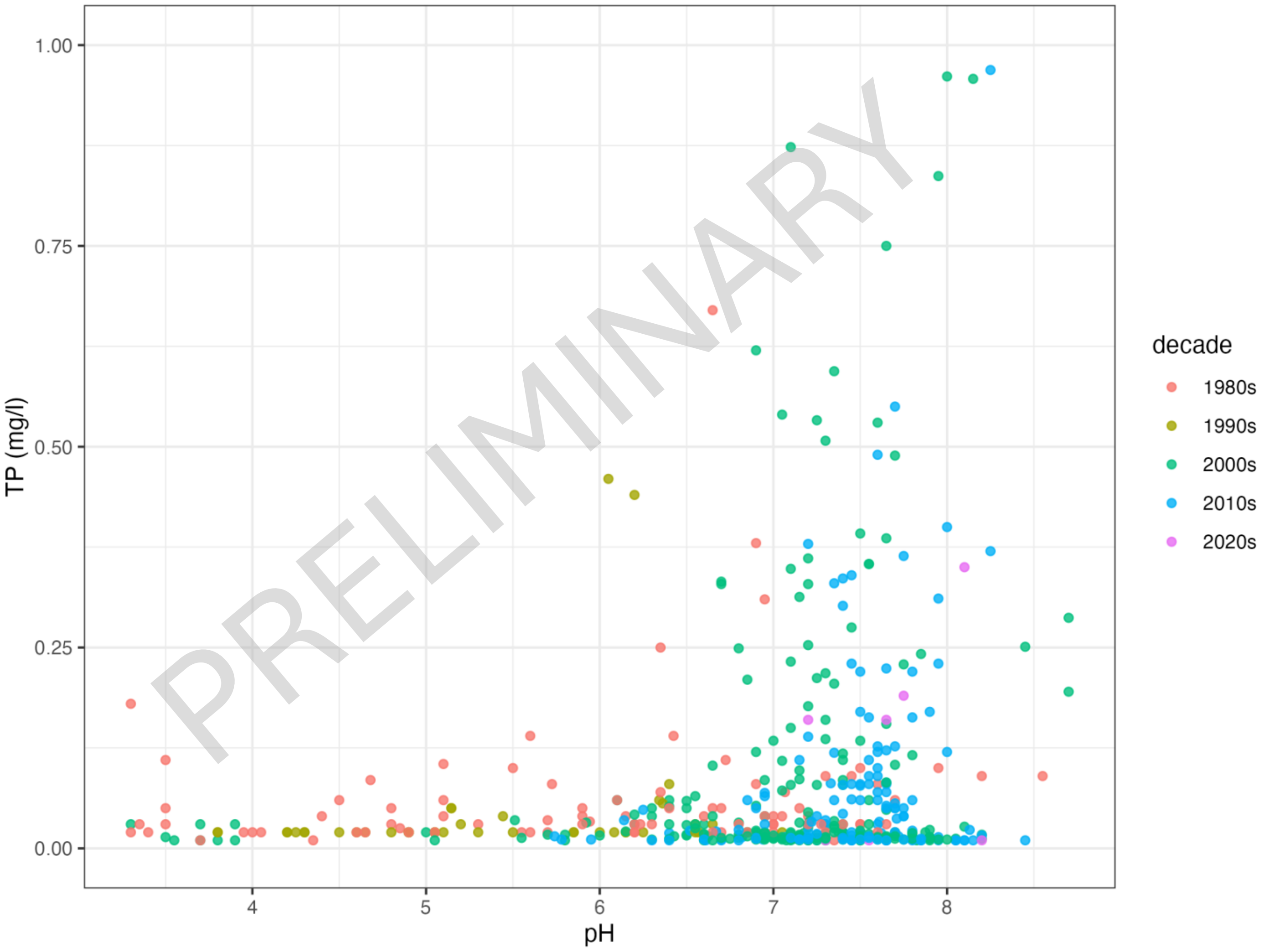
Connections

Wish list:

- Subject matter expertise
- Mapping pH across the watershed
- Consistent salinity mapping across the non-tidal and tidal watershed
- Simplified geochemical and reactive transport models
- Dynamic “pulse” model of winter salt loading and spring freshening export
- DOM???

Contributions:

- Improved model accuracy and projection
- Improved targeting of management
- Quantification of co-benefits



PRELIMINARY
TP (mg/l)
1.00
0.75
0.50
0.25
0.00
4
5
6
7
8
pH
decade
1980s
1990s
2000s
2010s
2020s