Predicting daily total phosphorus and suspended solids across Wisconsin stream reaches for impairment assessment

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Motivation

• Predict total phosphorus and total suspended solids for Wisconsin streams
  – High-resolution & large spatial scope
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  - High-resolution & large spatial scope

- **Challenge:** 235 USGS gages in WI, but 162,000 stream reaches including many headwaters
  - What to do for ungauged streams without discharge?
Look back in time to see what precipitation was:
- leading up to day of prediction
- for each watershed
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Use *antecedent precipitation* instead of *discharge*
Antecedent precipitation in lieu of discharge
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- Calculated effective precipitation
  - Precipitation + snowmelt – snow
- Sum effective precip on day of interest and 365 preceeding days, where each day is weighted by a decay function
Antecedent precipitation in lieu of discharge

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- Sum effective precip on day of interest and 365 preceding days, where each day is weighted by a decay function
- Lag/Decay function: Calculate a “lag” parameter based on WSA & SLOPE for each reach
  - For TSS: $M = 0.011 + 0.204 \log(WSA)$
  - For TP: $M = 0.528 + 0.203 \log(WSA) - 0.043 \times (\text{SLOPE})$
TP/TSS Model

• Spatio-temporal predictors:
  – Weather (daily temp. and preceding precipitation)

• Fixed spatial predictors:
  – Reach and watershed characteristics (land use, soils, etc.)

• Measured TP (23,028 obs. at 1,473 sites) & TSS (11,859 obs. at 513 sites) for model fitting
Model structure

Predict TP and TSS for stream reach C on day 1

\[ \log(TP_{c,1}) \text{ or } \log(TSS_{c,1}) = \beta X_{c,1} + \gamma_c Z_{c,1} + \epsilon \]

\( X \) (fixed effects)
- \( slope_{ABC} \)
- \( \log(\text{watershed area}_{ABC}) \)
- \( \text{permeability}_{ABC} \)
- \( \text{percent agriculture}_{ABC} \)
- \( \text{percent urban}_{ABC} \)
- \( \sin(2\pi \text{DOY}) \)
- \( \cos(2\pi \text{DOY}) \)
- \( 7\text{-day temp anomaly}_{ABC,1} \)
- \( \text{antecedent precipitation index}_{ABC,1} \)
- \( \text{antecedent precipitation index}^2_{ABC,1} \)

\( Z \) (random effects)
- \( \text{intercept} \)
- \( \sin(2\pi \text{DOY}) \)
- \( \cos(2\pi \text{DOY}) \)
- \( 7\text{-day temp anomaly}_{ABC,1} \)
- \( \text{antecedent precipitation index}_{ABC,1} \)
- \( \text{antecedent precipitation index}^2_{ABC,1} \)

*allowed to interact with antecedent precipitation
Model summary

Relative effects of each predictor

TSS Model

TP Model

...holding other variables constant at their average values
Model summary
Interactions with Precipitation

TP Model

...holding other variables constant at their average values
How do sites’ TP concentrations vary between 10th percentile and 90th percentile of precip?

![Graph showing the distribution of percent change in TP with precip increase.](image-url)
How much does TP increase if antecedent precipitation increases from 10th to 90th percentile?
What causes differences in response to precipitation?
What causes differences in response to precipitation?
Effect of random effects

Kickapoo River

Milwaukee River

Bower Creek
Model summary

TSS Model

TP Model
Overall, TP model performs similarly to LOADEST
Applications

• Incorporate hourly precipitation data
• Incorporate spatial autocorrelation terms
• Provide predictions, reports, and apps to local biologists and stakeholders
• Use AUCs from predicted TSS distributions to test effects on macroinvertebrates and fish
  – Assess impairment due to TSS
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TSS Model
Site-specific responses of TP to precip.
Site-level comparisons to LOADEST: Our model is similar, and sometimes better
Introduction

This report presents results from a model developed by Matt Diefb and Alic Lateika (WDNR Bureau of Water Quality). The model predicts daily total phosphorus (TP) or total suspended solids (TSS) for individual stream reaches throughout Wisconsin. Predictions are made from climatic and hydrologic factors, such as temperature, flow, soil properties, and land use, and climate variability including daily temperature, rainfall, and temperature events as well as temperature variability for each site.

Site reports: Auto-filled & generated for each site
Site-level model outputs

TSS Model (Sugar River)

TP Model (Kickapoo River)
Inferring power to detect change

What is the minimum detectable TP/TSS reduction?
Has TP or TSS changed?

Look at time series of model residuals (after controlling for weather, seasonality, etc.)

- Without any change, these should be randomly distributed along the 0 line
- If there is a change, there will be a shift at some time
- Test for a shift with “segmented regression”
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