Predicting Natural Background Phosphorus in Wisconsin Streams Using a Geostatistical Model

Shupryt, M.P. and Ruesch A.S.
Background: Numeric Nutrient Criteria

- 6 States with one aquatic media with numeric phosphorus criteria
- 16 additional States have numeric N or P criteria for specific waterbodies
- Criteria are often developed from stressor-response analysis
- Stressor-response relationships do not consider natural background spatial distributions of N or P
Wisconsin Level 3 Ecoregions

- **NLF – Northern lakes and Forests**
- **NCHF – North Central Hardwood Forests**
- **SEWTP – South Eastern Wisconsin Till Plains**
- **DFA – Driftless Area**
Wisconsin Reference Streams TP Concentration Among Ecoregions

Over-protective?

Candidates for UAA/SSC or Not Reference Sites

Level 3 Ecoregions

NLF  NCHF  DFA  SEWTP
Site-Specific Criteria for Phosphorus (SSC)

Use SSC if the statewide phosphorus criteria are over- or under- protective; modify accordingly

- **Range of natural TP concentrations**
- **Range of waterbody responses to TP levels, based on physical/chemical factors**
- Enables more appropriate assessments & permit limits
Developing site-specific nutrient criteria from empirical models

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- Site-specific model to predict natural background TP
- Create Random Forest model at reference watersheds then transfer to all watersheds
  - Use only natural landscape variables
- Poor model performance among Wisconsin streams
- Other model possibilities?
Spatial Stream Networks (SSN)

- Incorporates a linear model and accounts for spatial autocorrelation
- Replaces Euclidean distance with hydrologic network distances
- Accounts for direction and flow within network
- **Ideal for modeling materials transport**

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"A mixed-model moving-average approach to geostatistical modeling in stream networks"

Erin E. Peterson\(^1,3\) and Jay M. Ver Hoef\(^2\)

Ecology, 2010

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SSN & STARS: Tools for Spatial Statistical Modeling on Stream Networks
Sites A-B: closest in Euclidean distance
-Not Flow Connected, no shared watershed
-Low degree of relationship

Sites C & D: farther in Euclidean distance
-Flow Connected, Shared water and nested watersheds
-High degree of relationship
-Flow weighted – Site D
Model Process

- Develop Hydrologic Network with Natural Landscape Variables
  - WI DNR WHDPlus database
- Select Reference Watersheds
- All TP in WI DNR database from 2000-2013
  - May 15th to October 15th
  - Average across time and within WHDPlus catchment
- Develop an linear model with spatial covariance (SSN)
- Apply predictive model to non-reference watersheds
Wisconsin’s Watershed (WHDPPlus) Delineation

- One watershed per REACH ID of 1:24k hydro layer
- Conforms to HUC12 boundaries
  - Black Lines
- Average area 0.9 km²
- 162,651 WHDPlus catchments
WHDPlus Attribute Dimensions

Local Riparian

Local Watershed

60 m on both sides of feature

Riparian Watershed Trace

Watershed Trace
WHDPlus Attribute Dimensions

- Two most important for model development:
Watershed Attributes

Hydrology/Temperature
- Groundwater potential
- Stream discharge (10, 50 & 90% Exceedence flows)
- Stream temperature*
- Watershed Area

Stream Network
- Connectivity to Great Lakes, inland lakes, large rivers
- Stream gradient and sinuosity

Land Cover
- NLCD 2006
- Pre-settlement*

Climate
- Annual precipitation
- Annual, growing season, and monthly temperature

Geology/Soils/Topography
- Soil permeability
- Surficial geology type
- Bedrock depth and type
- Internally drained areas
- Slope
- Runoff curve number*

*Modeled attribute
Percent Land Use Criteria for Reference by Level 3 Ecoregion

<table>
<thead>
<tr>
<th>Watershed</th>
<th>NLF</th>
<th>NCHF</th>
<th>DFA</th>
<th>SEWTP</th>
</tr>
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<tbody>
<tr>
<td>Agriculture</td>
<td>6</td>
<td>8</td>
<td>25</td>
<td>35</td>
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<tr>
<td>Urban</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Local</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td>78</td>
</tr>
<tr>
<td>Urban</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

n= 133 18 12 10

Reference Sites

- Reference Watershed Site Locations
- Reference Watershed Delineations
### Linear Model: Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Response</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Permeability</td>
<td>Negative</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Soil pH</td>
<td>Negative</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Percent Forests (pre-settlement)</td>
<td>Negative</td>
<td>0.07</td>
</tr>
<tr>
<td>Percent Sand Soils</td>
<td>Positive</td>
<td>&lt;0.001</td>
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<tr>
<td>Temp Growing Season</td>
<td>Positive</td>
<td>&lt;0.002</td>
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<tr>
<td>Percent Clay Soils</td>
<td>Positive</td>
<td>0.009</td>
</tr>
<tr>
<td>Depth to Water Table</td>
<td>Positive</td>
<td>0.022</td>
</tr>
<tr>
<td>Soil Erodibility</td>
<td>Positive</td>
<td>0.054</td>
</tr>
</tbody>
</table>

### Model Diagnostics

- Proportion of Error Explained: 0.39
- Modeled Parameters: 0.39
- Tail-Up Spatial Model: 0.39
- Tail-Down Spatial Model: 0.08
- Nugget: 0.14 (unexplained spatial error)
Leave One Out Cross Validation of Reference Sites

Cross Validation Correlation = 0.52
Slope = 0.81
n=178
Prediction Error = 13.0 µg/l
Predicted Background Total Phosphorus

Predicted TP (µg/l)

- 4.0 – 35.0
- 36.0 – 45.0
- 46.0 – 55.0
- 56.0 – 65.0
- 66.0 – 75.0
- 76.0 – 113.0
Predicted Background Total Phosphorus – Prediction Errors

Larger Bubble Size = more confidence

Percentile Prediction Errors (µg/l)
5\text{th} – 14.0
95\text{th} – 17.0

Predicted TP (µg/l)

- 4.0–35.0
- 36.0–45.0
- 46.0–55.0
- 56.0–65.0
- 66.0–75.0
- 76.0–113.0
• Stream network modeling shows promise to predict chemical constituents in streams.

• Median background TP concentration in Wisconsin is ~50 ug/l
  – Range: 27 to 72 ug/l (5th – 95th percentile)

• Model Predicts ~ 3% of streams exceed the WQS (75 ug/l)
  – Strong spatial relationship (SW WI)
  – Highest prediction error among these sites

• Currently, WI is testing the ability of the model to inform TMDL development.
Statewide Predicted Total Phosphorus

Total Phosphorus (mg/l)

75.0 µg/l – Wisconsin’s wadeable stream TP criterion
Predicted Background Total Phosphorus – Probability of Exceeding WQS

Probability of Exceeding TP criterion
- 0.0–0.01
- 0.02–0.05
- 0.06–0.10
- 0.11–0.25
- 0.26–0.50
- 0.51–0.97
Predicted Background Total Phosphorus – By Stream Flow

Larger Bubbles = Watershed Area

Predicted TP (µg/l)
- 4.0 – 35.0
- 36.0 – 45.0
- 46.0 – 55.0
- 56.0 – 65.0
- 66.0 – 75.0
- 76.0 – 113.0
Semivariogram

Nugget Effect: Unexplained Spatial Variance

Semivariance

Hydrologic Network Distance