Application of SPARROW Modeling to Understanding Water-Quality Trends in the Chesapeake Bay Watershed

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Thanks to:
Silvia Terziotti, Greg Schwarz, Doug Moyer, Joel Blomquist, Jeff Chanat, Andy Sekellick

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Nitrogen and Phosphorus in Chesapeake Bay

- Sources and transport of N and P to Chesapeake Bay have been studied at multiple scales.
- Water-quality trends in selected tributaries are well documented.
- Less clear are the causes of different trends in different areas.

http://cbrim.er.usgs.gov
Sources of Nitrogen

- Agriculture provides the majority of nitrogen inputs to Chesapeake Bay and most major tributaries.

Ator et al., 2011
Nitrogen in Streams

- Nitrogen concentrations have generally decreased in recent years in many tributaries, but increased in others.
Nitrogen Sources

- Atmospheric deposition has generally decreased over time, but varies spatially.

Atmospheric Nitrogen Deposition in 1000’s of Metric Tons (LOESS smooth).

Data from Chesapeake Bay Program
Nitrogen Sources

Research Questions

• How do changes in stream chemistry relate to:
  • changing land use patterns?
  • changing practices within certain land-use settings?
  • changing atmospheric deposition or point sources?

• How can multiple steady-state SPARROW models calibrated for decadal time steps help to improve our understanding of landscape factors driving changes in stream chemistry?
Outline

• Background: What is SPARROW?
• Approach: How might SPARROW models be developed to understand water-quality changes over time?
• Preliminary Results
• Next Steps
The SPARROW Model

- **SPAtially-Referenced Regression On Watershed attributes**
- Developed in the 1990s by USGS (Smith et al., 1997)
- Regression (NLLS) approach to extrapolate estimated mean-annual flux (load) at monitored streams to unmonitored streams on the basis of watershed attributes
- Includes mass-balance and flow-routing
- Steady-state model of mean-annual conditions*
The SPARROW Model

• Regression approach
  – **Dependent variable**: mean annual flux of contaminant in a stream
  – **Explanatory variables**: watershed or stream attributes representing:
    • upland or in-stream sources
    • overland transport
    • in-stream transport

\[
F_{i}^{*} = \sum_{j \in J(i)} F_{j}' \delta_{i} A(Z_{i}^{S}, Z_{i}^{R}; \theta_{S}, \theta_{R}) + \sum_{n=1}^{N_{S}} S_{n,i} \alpha_{n} D_{n}(Z_{i}^{D}; \theta_{D}) A'(Z_{i}^{S}, Z_{i}^{R}; \theta_{S}, \theta_{R}).
\]

Schwarz et al., 2006

- \(i = \text{stream reach}\)
- \(j = \text{upstream reach(es)}\)
- \(n = \text{sources}\)
- \(D = \text{overland delivery function (DVF}_{i}\))
- \(A = \text{fluvial delivery function}\)
- \(\alpha, \theta = \text{estimated coefficients}\)
The SPARROW Model

- **Source Specification:**

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Interpretation of Model-Estimated Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass from a particular source</td>
<td>Mean proportion of that mass reaching local streams</td>
</tr>
<tr>
<td>Area of a particular landscape setting</td>
<td>Mean yield of contaminant from that setting to local streams</td>
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</tbody>
</table>

Flux\_i = Flux delivered from upstream + Flux generated in local catchment

\[ F^{*}_{i} = \left( \sum_{j \in J(i)} F'_{j} \right) \delta_{i} A\left(Z_{i}^{S}, Z_{i}^{R}; \theta_{S}, \theta_{R}\right) + \left( \sum_{n=1}^{N} S_{n,i} \alpha_{n} D_{n}\left(Z_{i}^{D}; \theta_{D}\right)\right) A'\left(Z_{i}^{S}, Z_{i}^{R}; \theta_{S}, \theta_{R}\right). \]

**Schwarz et al., 2006**

- \(i\) = stream reach
- \(j\) = upstream reach(es)
- \(n\) = sources (S)
- \(D\) = overland delivery function (DVF\_i)
- \(A\) = fluvial delivery function
- \(\alpha, \theta\) = estimated coefficients
Approach

- Calibrate individual SPARROW models for 1992, 2002, and 2012 using:
  - A common stream network, land-to-water specification, and aquatic decay specification
  - Flow-normalized annual loads for 1992, 2002, and 2012 at the same group of sites (for calibration)
  - Consistent and comparable land-use and atmospheric and point sources (as source terms)
- Evaluate estimated source coefficients ($\alpha_n$) to understand trends

\[
F_{i}^{*} = \left( \sum_{j \in J(i)} F_{j} \right) \delta_{i} \mathcal{A}'(Z_{i}^{S}, Z_{i}^{R}; \theta_{S}, \theta_{R}) + \left( \sum_{n=1}^{N_{S}} S_{n,i} \alpha_{n} D_{n}(Z_{i}^{D}; \theta_{D}) \right) A'(Z_{i}^{S}, Z_{i}^{R}; \theta_{S}, \theta_{R}).
\]

Schwarz et al., 2006

- $i = $ stream reach
- $j = $ upstream reach(es)
- $n = $ sources
- $D = $ overland delivery function (DVF$_i$)
- $A = $ fluvial delivery function
- $\alpha, \theta = $ estimated coefficients
Inputs: Calibration Data

• Flow-normalized annual loads are estimated and published for sites in the Chesapeake non-tidal monitoring network (NTN)
• With loads for 1992, 2002, and 2012:
  – TN (n=45 sites)
  – TP and SS (n=18 sites)
## Preliminary Nitrogen Models

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<tbody>
<tr>
<td></td>
<td>Coef</td>
<td>p</td>
<td>Coef</td>
<td>p</td>
<td>Coef</td>
<td>p</td>
<td>Coef</td>
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<tr>
<td>Point sources (kg)</td>
<td>1.78</td>
<td>0.0213</td>
<td>1.38</td>
<td>0.0533</td>
<td>0.687</td>
<td>0.1416</td>
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<td>Developed (ha)</td>
<td>17.3</td>
<td>0.0003</td>
<td>13.1</td>
<td>0.0018</td>
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<td>Forest (ha)</td>
<td>0.37</td>
<td>0.3170</td>
<td>0.68</td>
<td>0.2166</td>
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<td>0.3006</td>
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<td>Cropland (ha)</td>
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<td>GW recharge</td>
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<td>Soil AWC</td>
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<td>Pied. carbonate</td>
<td>0.247</td>
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<td>Res Decay (d)</td>
<td>0.004</td>
<td>0.0526</td>
<td>0.004</td>
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<td>Small Str Decay (d)</td>
<td>0.539</td>
<td>0.0102</td>
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<td>Large Str Decay (d)</td>
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<td>0.069</td>
<td>0.1738</td>
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</tbody>
</table>
Next Steps

• Post-processor to:
  – Test $H_0$: source coefficients are not significantly different among time steps
  – Evaluate relative importance of changing sources (ie. land-uses) vs. changing average yield from each source (ie. model coefficients) to observed changes in stream chemistry.

• Look at change in average yields for different hydrogeologic settings
For More Information….


