A Power Analysis Tool in R to Enhance Monitoring Studies

Restoration Research Question

What are the cumulative effects of watershed restoration activities within a watershed?

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What do we mean by monitoring?

- Monitoring means different things
  - Part of a hypothesis driven research project.
  - Requirement on a project, e.g. stream restoration.
  - Requirement for the MS4 permit.

- Monitoring designs
  - Paired watershed with control.
    - Combining these “one site monitoring” over time
  - Single watershed without control.
    - Monitoring for a long time.
Research effort: Optimizing Water Quality Monitoring

- Restoration Research Awards:
  - 13973: UMCES
  - 16925: Exponent
  - 20582: UMCES
- STAC 2023 Workshop

The State of the Science and Practice of Stream Restoration in the Chesapeake: Lessons Learned to Inform Better Implementation, Assessment and Outcome
Project #13973 Objectives

- What is the optimal temporal frequency for sampling of pollutant loads within a watershed?
  - Assessed using high quality SERC weekly composite sampling data

- What is the optimal spatial design and scale of monitoring to detect a signal in water quality improvement within a watershed?
  - Leveraging Baltimore LTER data and Bayesian statistical tools to evaluate spatiotemporal sampling frequencies
Lesson 1: Monitor at the Right Spatial Scale

- Moderate load reduction from concentration changes (20%) was detected at project scale, but not at watershed scale.
- Highlighting the challenges in matching the monitoring with the scales of restoration.
Lesson 2: Select Good Controls

- Moderate load reduction from concentration changes (20%) was not detected.
- Highlighting the challenges in designing a BACI monitoring using non-BACI data.
Lesson 3: Value of Coordinated Assessments

- Pseudo-controls provide the biggest reduction in sample size for determining pollutant loads.

<table>
<thead>
<tr>
<th>Site</th>
<th>Scenario</th>
<th>BA SRS</th>
<th>BA STS</th>
<th>BACI SRS</th>
<th>BACI STS</th>
<th>BACI (n=2) SRS</th>
<th>BACI (n=2) STS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glyndon (TN)</td>
<td>20%</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>1075(92)</td>
<td>823(63)</td>
<td>1216(101)</td>
<td>1001(72)</td>
<td>664(61)</td>
<td>582(49)</td>
</tr>
<tr>
<td></td>
<td>80%</td>
<td>71(2)</td>
<td>69(1)</td>
<td>82(2)</td>
<td>83(2)</td>
<td>42(1)</td>
<td>47(1)</td>
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</tbody>
</table>
Project #16925 Objectives

• What are the cumulative effects of restoration activities within a watershed?
  • Assessing Maryland MS4 monitoring data

• What degree of representative temporal sampling is required to determine accurate pollutant discharges?
  • Leveraging high-frequency data and surrogate parameters to evaluate temporal sampling frequencies
Lesson 4: Determining the effect of stormwater restoration from existing monitoring programs is challenging.
Lesson 5: Sampling frequency and watershed characteristics influence load uncertainty
Lesson 5: Sampling frequency and watershed characteristics influence load uncertainty

Table 1. Results of stepwise linear regression models for suspended sediment concentrations

<table>
<thead>
<tr>
<th>Model Fit</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Weekly+Storm</th>
<th>Seven-Hour</th>
<th>Flow-Paced</th>
<th>MDE MS4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIC</td>
<td>-12.19</td>
<td>28.76</td>
<td>125.78</td>
<td>111.72</td>
<td>98.28</td>
<td>77.91</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>62.7%</td>
<td>69.3%</td>
<td>13.0%</td>
<td>35.7%</td>
<td>23.6%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Overall p-value</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.0094</td>
<td>&lt;0.0001</td>
<td>0.0005</td>
<td>0.1168</td>
</tr>
<tr>
<td>Residual standard error (df)</td>
<td>0.1972 (40)</td>
<td>0.3110 (39)</td>
<td>0.9661 (42)</td>
<td>0.8146 (41)</td>
<td>0.7067 (42)</td>
<td>0.5607 (42)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model Terms</th>
<th>Coef.</th>
<th>P-value</th>
<th>Coef.</th>
<th>P-value</th>
<th>Coef.</th>
<th>P-value</th>
<th>Coef.</th>
<th>P-value</th>
<th>Coef.</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.08140</td>
<td>0.4594</td>
<td>-0.9875</td>
<td>0.0038</td>
<td>-2.265</td>
<td>0.0003</td>
<td>-0.7647</td>
<td>0.0054</td>
<td>1.148</td>
<td>0.1670</td>
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<tr>
<td>Log Watershed Size</td>
<td>-0.06871</td>
<td>0.0002</td>
<td>-0.1657</td>
<td>&lt;0.0001</td>
<td>--</td>
<td>--</td>
<td>-0.2140</td>
<td>0.0002</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Log Discharge</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Baseflow Index</td>
<td>--</td>
<td>--</td>
<td>2.253</td>
<td>0.0028</td>
<td>4.499</td>
<td>0.0094</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Flashiness Index</td>
<td>--</td>
<td>--</td>
<td>0.0203</td>
<td>0.0362</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>% Developed Low Intensity</td>
<td>-0.5668</td>
<td>0.0858</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>% Woody Wetlands</td>
<td>-14.30</td>
<td>&lt;0.0001</td>
<td>-18.00</td>
<td>&lt;0.0001</td>
<td>--</td>
<td>--</td>
<td>-16.98</td>
<td>0.0773</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

• Watershed characteristics influence the accuracy and precision of load estimates from different temporal sampling frequencies.
Lesson 6: Decision support tools can help optimize monitoring programs

- **Suspended Sediment**
  - Predictions
  - Parameters
  - Summary
  - Dashed line = expected annual load reduction

- **Total Phosphorus**
  - Predictions
  - Parameters
  - Summary
  - Sampling methods are ordered with the best choice on top
  - Detectable = always; estimated error is always less than expected reduction
  - Detectable = sometimes; estimated error is sometimes less than expected reduction
  - Detectable = never; estimated error is never less than expected reduction
  - Annual Cost = cost per sample * number of samples analyzed per year

<table>
<thead>
<tr>
<th>Sampling Method</th>
<th>Load Reduction Detectable</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow-Paced</td>
<td>sometimes</td>
<td>$2,600.00</td>
</tr>
<tr>
<td>Weekly+Storm</td>
<td>sometimes</td>
<td>$2,600.00</td>
</tr>
<tr>
<td>Weekly</td>
<td>sometimes</td>
<td>$3,000.00</td>
</tr>
<tr>
<td>Seven-Hour</td>
<td>sometimes</td>
<td>$62,400.00</td>
</tr>
<tr>
<td>Monthly</td>
<td>never</td>
<td>$600.00</td>
</tr>
</tbody>
</table>
Project #20582 Objective

- To co-develop a software tool to help plan BMP monitoring studies and enhance restoration research.
  - Co-developed by practitioners and researchers, and data experts.
  - Informed by high frequency data.
  - Deployed in an open source and web-enabled cyberinfrastructure.
Co-Development Process

- Meeting with MDE State Regulatory Staff
- Target: County Scientists/Staff
  - Site visit to Anne Arundel County
  - Virtual meeting with Baltimore County
  - Site visit to Carroll County
- STAC workshop
Acknowledgements

- Janis Markusic, Chris Victoria (Anne Arundel County)
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- Bel Martinez da Matta (MDE), Shannon McKenrick (MDE), Jeff White (MDE).
Translation Slides
Experimental design can make or break a monitoring program. The choice of monitoring scale, BACI based-frameworks and controls, sampling size and frequency should be carefully considered before designing a monitoring study.

Evolving from broader regulatory monitoring to hypothesis-driven monitoring, with greater coordination between researchers, practitioners, state, and local agencies, will help maximize the scientific value of monitoring dollars and better audit implementation dollars.
What do I take from this if I am a practitioner?

- The smaller the pollutant reductions from a project, the larger the investment needed in high-resolution monitoring and greater consideration of experimental designs able to detect expected water quality benefits.

- Decision support tools developed from these projects (current and forthcoming) can be beneficial when deciding whether monitoring will be a worthwhile component of a project, given the required resources.
What do I take from this if I am a regulator?

• Inadequate experimental designs and temporally coarse monitoring will likely be ineffective at evaluating a restoration program’s success. The financial burden of a such a monitoring program can often outweigh the benefits of the information gained.

• Evolving from broader regulatory monitoring to hypothesis-driven monitoring, with greater coordination between researchers, practitioners, state, and local agencies, will help maximize the scientific value of monitoring dollars and better audit implementation dollars.
Monitoring Discussion
Questions for County Scientists/Staff

• What is the goal of your stream monitoring?
• Within your department, what incentivize you to do monitoring?
• What resources are available “in-house” in county government?
• How have you designed your monitoring efforts in the past?
Questions for County Scientists/Staff (Cont.)

- **What kind of stream restoration monitoring are you carrying out?**
- **Does it include automated flow-weighted composite sampling, hierarchical sampling of baseflow and storms....?**
Questions for County Scientists/Staff (Cont.)

- **How as the monitoring supported financially?**
- **Can you estimate the costs for supporting a station?**
  - **If possible, please break into analyte chemistry cost versus labor for data collection versus labor for interpretation and administration.**
Data Requirements?

• How can we get more “perfect” data?
  • Data format is “uniform”, and available for access/re-use?

• Open-source software development and sharing
  • R-Shiny based light-weight applications.

• Web-enabled cyberinfrastructure
  • Facilitate data sharing, visualization and modeling