Continuous Surrogate Monitoring for Pollutant Load Estimation in Urban Water Systems

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Background and Introduction

- USEPA Phase I stormwater regulations (1990)
- USEPA Phase II stormwater regulations (2000)
- Phase II MS4s are required to include SCMs in stormwater management program
- Quantifying pollutant loads and identifying sources can be difficult for most MS4s
Problem Statement– Challenges with Estimating Pollutant Loads in Urban Stormwater

- Existing monitoring programs do not capture spatial and temporal variability
- Impervious surfaces change runoff hydrograph characteristics
- Grab sampling does not consider seasonal and within storm variability
- Stormwater often received in conveyances with multiple uses

Problem Statement - Temporal Variability of Pollutant Loads

- Urban catchments often experience a concentration based first flush
- Pollutant loading in urban waterways experience seasonal variation
Problem Statement – Load Estimation Using Surrogates

- Sample collection and laboratory analysis throughout the year is infeasible.
- Regression relationships allow us to use surrogate indicators to estimate pollutant concentrations.
- Surrogate relationships vary between base flows and runoff.

\[
TP = 0.0209 + 0.000798 \times \text{Turb} + 0.0386 \times Z
\]

Problem Statement - Spatial Variability of Pollutant Loads

- Pollutant loading varies greatly based on land use coverage and imperviousness.
- “End-of-pipe” sampling does not provide information on spatial variability.
Motivating Research Questions

1. What are the instrumentation and data collection needs for assessing the effects of stormwater inputs on urban water systems?
2. What methods can be implemented to optimize the information content and accuracy of measurements (e.g., sensor selection and programming, deployments and housings, maintenance, sampling methods, etc.)?
3. How can a coordinated, adaptive sampling scheme aid in understanding the spatial and temporal scales of phosphorus and suspended solids loading in an urban environment?

- Middle Bear River and Cutler Reservoir TMDL

Study Area – Northwest Field Canal (NWFC) Drainage Area

- Open canal whose base flows represent diverted Logan River water
- Canal receives stormwater runoff from multiple land uses during storm events
- Base flows and the stormwater flows allow us to compare and contrast the two water quality/quantity signals
Design – Required Infrastructure

- Required ability to distinguish between base flows and stormwater runoff
- Required ability to communicate detections of stormwater flows to other monitoring sites
- Required ability to adapt our data observation and automated sampling frequencies

Design – Network Design

- Two types of sites designed: Continuous Canal and Continuous Outfall
- Locations for 6 monitoring sites selected (4 active at a time)
- Monitoring sites equipped with telemetry for communication with base station
- Base station equipped with network link connection
### Design – Site Design

<table>
<thead>
<tr>
<th>Site Type</th>
<th>Variable Measured</th>
<th>Instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuously Monitored</td>
<td>Water Depth</td>
<td>Teledyne ISCO 2150</td>
</tr>
<tr>
<td>Stormwater Outfall Site</td>
<td>Water Velocity</td>
<td>Teledyne ISCO 2150</td>
</tr>
<tr>
<td></td>
<td>Water Flow</td>
<td>Teledyne ISCO 2150 (calculated)</td>
</tr>
<tr>
<td></td>
<td>Water Volume</td>
<td>Teledyne ISCO 2150 (calculated)</td>
</tr>
<tr>
<td></td>
<td>Water Temperature</td>
<td>Teledyne ISCO 2150</td>
</tr>
<tr>
<td></td>
<td>Automated sample collection Rain</td>
<td>Teledyne ISCO 3700 automated sampler</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Campbell Scientific</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T3525WS rain gage</td>
</tr>
<tr>
<td>Continuously Monitored</td>
<td>Turbidity</td>
<td>FTS DTS-12</td>
</tr>
<tr>
<td>Canal Site</td>
<td>Dissolved Oxygen</td>
<td>YSI EXO2 Multiparameter Sonde</td>
</tr>
<tr>
<td></td>
<td>Conductivity</td>
<td>YSI EXO2 Multiparameter Sonde</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>YSI EXO2 Multiparameter Sonde</td>
</tr>
<tr>
<td></td>
<td>IDOM</td>
<td>YSI EXO2 Multiparameter Sonde</td>
</tr>
<tr>
<td></td>
<td>Water Temperature</td>
<td>YSI EXO2 Multiparameter Sonde</td>
</tr>
<tr>
<td></td>
<td>Gage Height</td>
<td>Campbell Scientific C5451 Pressure transducer</td>
</tr>
<tr>
<td></td>
<td>Automated sample collection Rain</td>
<td>Teledyne ISCO 3700 automated sampler</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Campbell Scientific</td>
</tr>
<tr>
<td></td>
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<td>T3525WS rain gage</td>
</tr>
<tr>
<td></td>
<td>Rain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water Flow (Upstream Canal Site)</td>
<td>Sontek SL3000 Side looking ADVM</td>
</tr>
</tbody>
</table>

**Continuous Outfall Site Design**

**Continuous Canal Site Design**

**Upstream Continuous Canal Site (200 South)**

**Continuous Outfall Site at 1250 North**
Design – Catchment Characteristics

- Continuous canal sites were located at upstream and downstream ends of canal
- Continuous outfall sites were located based on catchment size, land use variability, and imperviousness

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Catchment Area (km²)</th>
<th>Land Use (percent coverage)</th>
<th>Percent Impervious</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 North</td>
<td>0.041</td>
<td>Residential: 29.5 Commercial: 39.0 Street: 31.5</td>
<td>62.3</td>
</tr>
<tr>
<td>1250 North</td>
<td>0.205</td>
<td>Residential: 11.1 Commercial: 76.3 Street: 12.5</td>
<td>69.5</td>
</tr>
<tr>
<td>800 North</td>
<td>0.359</td>
<td>Residential: 45.5 Commercial: 36.1 Street: 18.4</td>
<td>43.5</td>
</tr>
<tr>
<td>1300 North</td>
<td>0.065</td>
<td>Residential: 18.0 Commercial: 78.9 Street: 3.1</td>
<td>84.6</td>
</tr>
</tbody>
</table>

Adaptive Sampling and Communication

- Continuous Outfall Sites
  - Scan at 1-minute intervals
  - Determine if it’s raining and flowing
  - Sends a flag to the canal sites at the start of an event and at the end of an event
  - Writes data every minute during events and every 15 minutes otherwise
  - Pumps a physical sample every 3-minutes during the first flush and every 15 minutes otherwise
Adaptive Sampling and Communication

- Continuous Canal Sites
  - Scans at 5-minute intervals
  - Records values at 5-minute intervals during storms and 15-minute intervals during base flows
  - Pumps physical samples during storm events based on Turbidity Threshold Sampling scheme

Turbidity Threshold Sampling

- Series of rising and falling thresholds calculated once flag is received from outfall site
- Sample is pumped as turbidity passes a threshold
- Samples are pumped at peaks and valleys of turbidity
Results – Base flow conditions vs Storm Event Conditions

- Box plot shows TSS concentrations at canal sites
- Little change is observed at upstream site between base flows and storm flows
- A much greater change is seen at the downstream site. Can be attributed to stormwater runoff

Results – Spatial Variability of Export Coefficients

- TSS, TP, and TDP export coefficients at 300 North and 1250 North catchments
- ECs vary by orders of magnitude
- EC at 300 North is greater 53, 60, and 87 percent of the 15 events for TSS, TP, and TDP respectively.
Results – Temporal Variability

- Shows results for analysis of TSS first flush based on 30/80 and 25/50 definitions (Bertrand-Krajewski 1998; Wanielista and Yousef 1993)
- Only 300 North experienced a 30/80 first flush
- Results seem to show that smaller catchments experience first flush. This supports findings in literature

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Monitoring Period</th>
<th>Number of Storms</th>
<th>Catchment Area (km²)</th>
<th>First Flush (TSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 North</td>
<td>April – October 2015</td>
<td>15</td>
<td>0.041</td>
<td>13.3% 33.3%</td>
</tr>
<tr>
<td>1250 North</td>
<td>April – October 2015</td>
<td>18</td>
<td>0.205</td>
<td>0.0% 11.1%</td>
</tr>
<tr>
<td>800 North</td>
<td>March – May 2016</td>
<td>13</td>
<td>0.359</td>
<td>0.0% 30.8%</td>
</tr>
<tr>
<td>1300 North</td>
<td>March – May 2016</td>
<td>13</td>
<td>0.065</td>
<td>0.0% 46.2%</td>
</tr>
</tbody>
</table>

Results – Adaptive Sampling

- Plot of sampling event on April 10, 2016
- Intense storm has rising hydrograph limb of ~10 min
- First flush sampling able to capture pollutograph peak
Results – Inter-Site Communication

- Shows network’s ability to synchronize sampling at four different monitoring sites
- Runoff detected at outfall sites communicated to canal sites
- Upstream canal site observes little change in turbidity

Conclusions

- The urban stormwater network created for this research allowed us to capture the short-duration runoff events using the high-frequency data collection
- Multiple monitoring sites allowed us to assess how TSS, TP, and TDP loading events varied across multiple land uses and catchment sizes
- Adaptive sampling algorithm allowed us to automate collection of physical samples based on flow or turbidity and to increase frequency of sensor observations during events
- Inter-site communications permitted the synchronization of sampling across multiple monitoring sites, thus ensuring that TSS, TP, and TDP inputs due to stormwater runoff are adequately sampled
Questions?

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