Watershed-Scale Hydrologic and Water Quality Improvements due to Green Stormwater Infrastructure Implementation

Ryan Winston, PhD, P.E.
Assistant Professor
Food, Agricultural, and Biological Engineering
Civil, Environmental, and Geodetic Engineering
Sustainability Institute

6th Symposium on Urbanization and Stream Ecology
May 31, 2023 – Brisbane, Australia
Ohio, USA

- 7th largest state in US
  - 11.7M people, 2.5M in Columbus
- Geography
  - Mountains and plains
  - Great Lakes to North
- Climate
  - Approx. 1000 mm / year precipitation
Sanitary & Combined Sewer Overflows

~200 SSO & CSO events in Columbus in an average year
SSO Mitigation: 2 Options

• Blueprint Columbus
  - $1.7B USD capital costs
  - Includes green infrastructure + other infrastructure improvements
  - Reduce infiltration and inflow by 30%

• Grey solutions = no impact on stormwater quality
• Modeling in SWMM showed greater reduction in overall SSOs for green solutions
• Ecosystem and community services
Four Pillars of Blueprint

City Property Retrofits

Private Property Retrofits

Green Stormwater Infrastructure

Downspout Redirection

Sewer Lateral Lining

Sump Pump Installation
Blueprint Objectives & Research 2016-23:

1. Control Stormwater Flows
   - Analyze storm flows
2. Improve water quality
   - Analyze water quality
3. Provide habitat
   - Analyze species in bioretention
4. Improve property values
   - Track home prices
5. Stabilize neighborhoods
   - Survey residents
Study Design

• Beechwold (111 ha)
  – no green infrastructure, control for experiment
• Indian Springs (48 ha)
  – Permeable pavement
  – Moderate density GI
• Cooke-Glenmont (11.5 ha)
  – Low density GI
  – Larger bioretention cells
• Blenheim-Glencoe (61 ha)
  – High density GI
  – Bioretention only
Paired Watershed Design

- Two Watersheds
  - Control
  - Treatment
- Two Monitoring Periods
  - Calibration
  - Treatment
- Accounts for year-to-year and seasonal climate changes
- Changes can be attributed to a treatment
Statistical Methods

- Before / After – Control / Impact
- Analysis of Covariance (ANCOVA)

% Difference: least squares mean/arithmetic

adapted from Page et al. (2015)
Stormwater Monitoring

- Continuous rainfall and flow monitoring (baseflow and stormflow) at stormwater outfalls
- ISCO samplers used to obtain flow proportional, composite samples
- Analyzed for nutrients, sediment, metals, bacteria
Project Timelines and Data Sets

**Pre-GI**
Began July 2016

**Monitored Events:**
- Cooke-Glenmont: 22
- Indian Springs: 56
- Blenheim-Glencoe: 106

**Construction Phase 1:**
GI

**Monitored Events:**
- Cooke-Glenmont: 99
- Indian Springs: 35
- Blenheim-Glencoe: 16

**Post-GI**

**Monitored Events:**
- Cooke-Glenmont: 13
- Indian Springs: 94
- Blenheim-Glencoe: 6

**Construction Phase 2**

**Post-Al²**
All 4 Blueprint Pillars Completed
Runoff Volume Response

- Significant runoff volume reductions (20-40%) at watershed scale following Green Infrastructure retrofits
- Return to pre-GI conditions in Al² period
• Peak Flow Rates were significantly reduced (52-72%) Post-GI.

• Post Al\textsuperscript{2} (four pillars complete) peak flow rates returned to those of Pre-GI.
Water Quality Sampling
TSS Concentrations

- Beechwold: n=124
- Blenheim: n=41
- Cooke-Glenmont: n=23
- Indian Springs: n=34

- 62.1% reduction
- 69.7% reduction

Phase:

- Control
- Pre-GI
- Post-GI

- Baseline
- Post-GI

- Pre-GI
- Post-GI
- Post-Al
Relationship between TSS Concentrations & Imperviousness

% sewershed imperviousness treated by GI \approx  
% TSS concentration reductions (\lt 5\% margin)

• Cooke-Glenmont
  – 66.5\% of the sewershed imperviousness treated by GI
  – 62.1\% reduction in TSS concentration (sig.)

• Indian Springs
  – 69.7\% of the sewershed imperviousness treated by GI
  – 67.7\% reduction in concentration at Indian Springs (sig.)
Observed heavy metal % conc. reductions similar to TSS

<table>
<thead>
<tr>
<th>Location</th>
<th>Phase</th>
<th>Lead (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beechwold</td>
<td>Control</td>
<td>n=125</td>
</tr>
<tr>
<td></td>
<td>Pre-GI</td>
<td>n=45</td>
</tr>
<tr>
<td></td>
<td>Post-GI</td>
<td>n=8</td>
</tr>
<tr>
<td>Blenheim</td>
<td>Pre-GI</td>
<td>n=23</td>
</tr>
<tr>
<td></td>
<td>Post-GI</td>
<td>-49.7%</td>
</tr>
<tr>
<td>Cooke-Glenmont</td>
<td>Pre-GI</td>
<td>n=24</td>
</tr>
<tr>
<td></td>
<td>Post-GI</td>
<td>-67.5%</td>
</tr>
<tr>
<td>Indian Springs</td>
<td>Pre-GI</td>
<td>n=21</td>
</tr>
<tr>
<td></td>
<td>Post-GI</td>
<td>n=34</td>
</tr>
</tbody>
</table>

-49.7% reduction in Cooke-Glenmont after GI installation.
Total Nitrogen

**Beechwold**
- Control: n=120
- Pre-GI: n=45
- Post-GI: n=8

**Blenheim**
- Baseline: n=23
- Post-GI: n=76

**Cooke-Glenmont**
- Pre-GI: n=27
- Post-GI: n=21
- Post-AI²: n=34

**Indian Springs**
- Pre-GI: n=27
- Post-GI: n=21
- Post-AI²: n=34

(TN (mg/L))
Total Phosphorus

- Significant conc. reductions
- Particulate P removal

<table>
<thead>
<tr>
<th>Location</th>
<th>Control</th>
<th>Pre-GI</th>
<th>Post-GI</th>
<th>B</th>
<th>Post-GI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beechwold</td>
<td>126</td>
<td>45</td>
<td>8</td>
<td>A</td>
<td>24</td>
</tr>
<tr>
<td>Blenheim</td>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>79</td>
</tr>
<tr>
<td>Cooke-Glenmont</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Indian Springs</td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34</td>
</tr>
</tbody>
</table>

Phases:
- Control
- Pre-GI
- Post-GI

Significant reductions:
- 35.8% ↓
- 60.0% ↓
- 36.6% ↓
Summary

• Using a paired watershed approach, we observed effects of green infrastructure installation:
  – Runoff reduction at watershed scale (20-40%) following green infrastructure implementation
    • Subsequent return to baseline conditions following other infrastructure improvements
  – TSS, TP, metals reductions above expectations (50-60%)
  – No change in TN concentration

• Questions for the future: Impacts to stream geomorphology / habitat / erosion?