Measured flow & water quality data from 5 urban karst watersheds compared to standard reference values

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Penn State University
Outline

- Karst and project location
- Data collection
- Results of flow analysis
  - Comparison to EPA NURP data
- Results of water quality analysis
  - Comparison to Simple Method
  - Comparison to NURP data
Karst Topography

- Formed on limestone or dolomite by bedrock dissolution
- Characterized by:
  - sinkholes
  - surface & closed depressions
  - disappearing or losing streams
  - caves
  - high rates of recharge and infiltration
## Study Watersheds

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Total area (ha)</th>
<th>Total impervious area (ha)</th>
<th>% impervious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown</td>
<td>93.45</td>
<td>62.93</td>
<td>67.3%</td>
</tr>
<tr>
<td>Main Campus</td>
<td>155.51</td>
<td>84.42</td>
<td>54.3%</td>
</tr>
<tr>
<td>Big Box</td>
<td>205.07</td>
<td>72.33</td>
<td>35.3%</td>
</tr>
<tr>
<td>Fox Hollow</td>
<td>129.21</td>
<td>41.15</td>
<td>31.8%</td>
</tr>
<tr>
<td>Preserved Drainageways</td>
<td>231.71</td>
<td>54.31</td>
<td>23.4%</td>
</tr>
</tbody>
</table>
Data Collection: Flow

- Continuous flow data
  - Sigma 910
  - Pressure transducers
Data Collection:

Flow

- Study period January 2008 – December 2010
- All events over 12.7 mm (0.5 in) analyzed
- 63 events total
  - Depth range: 12.7 – 96.8 mm
  - Mean depth: 28.7 mm
  - Average intensity range: 0.4 – 21.0 mm/hr
  - Mean average intensity: 3.4 mm/hr
Data Collection: Water Quality

- Study period January 2009 – April 2011
- 13 events
- ISCO samplers set to equal time increment sampling intervals
- Composited based on characteristics of runoff hydrograph
  - 3 to 15 samples per location per event
Results of flow analysis

Comparison to EPA NURP data
Flow Data Analysis:

Runoff Ratio

● Runoff ratio – relationship between runoff and rain fall

● High runoff ratio $\rightarrow$ more rain becomes runoff
  more developed areas

● Low runoff ratio $\rightarrow$ more rain infiltrates
  less developed areas

Runoff ratio = \( \frac{\text{Volume of Runoff}}{\text{Volume of Rain}} \)
0.08 (Big Box) to 0.29 (Downtown)
(0.002 for Preserved Drainageways)
## Overestimation of Runoff in NURP Relationship Used for Estimation

<table>
<thead>
<tr>
<th>Area</th>
<th>Percent Impervious Area</th>
<th>Median Runoff in Karst Study</th>
<th>NURP Predicted Runoff Ratio</th>
<th>Overestimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown</td>
<td>67.3%</td>
<td>0.28</td>
<td>0.62</td>
<td>218%</td>
</tr>
<tr>
<td>Main Campus</td>
<td>54.3%</td>
<td>0.19</td>
<td>0.50</td>
<td>269%</td>
</tr>
<tr>
<td>Big Box</td>
<td>35.5%</td>
<td>0.08</td>
<td>0.28</td>
<td>364%</td>
</tr>
<tr>
<td>Fox Hollow</td>
<td>31.8%</td>
<td>0.13</td>
<td>0.26</td>
<td>203%</td>
</tr>
<tr>
<td>Preserved Drainageways</td>
<td>23.4%</td>
<td>0.002</td>
<td>0.28</td>
<td>14,000%</td>
</tr>
</tbody>
</table>
So what?
Why does it matter that we’re over-estimating runoff in karst watersheds?
Design Implication

- **Volume**
  - Basins bigger than necessary

- **Peak Rate**
  - Determines the size of low flow orifice
  - If pre-development $Q_p$ is over estimated the low flow orifice is oversized
  - Downstream impacts
Results of water quality analysis

Comparison to NURP data
Comparison to Simple Method
Water Quality Data Analysis: Comparing Apples to Apples

- Samples w/ concentrations below detection limit were included in analysis
- **ProUCL V4.1** (Singh et al. 2010)
  - Event loads and mean concentration include substitution values using a distributional method
    - Regression on Order Statistics (ROS) method (Helsel 1990, Helsel 2005)
## Data Comparison: NURP & NPDES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (mg/L)</td>
<td>120.8</td>
<td>54.5</td>
<td>180 - 548</td>
</tr>
<tr>
<td>Total P (mg/L)</td>
<td>0.21</td>
<td>0.259</td>
<td>0.42 - 0.88</td>
</tr>
<tr>
<td>Soluble P (mg/L)</td>
<td>0.05</td>
<td>0.103</td>
<td>0.15 - 0.28</td>
</tr>
<tr>
<td>NO\textsubscript{3} and NO\textsubscript{2} (mg/L)*</td>
<td>0.533</td>
<td>0.86 - 2.2</td>
<td></td>
</tr>
<tr>
<td>NO\textsubscript{3} (mg/L)</td>
<td>1.18</td>
<td></td>
<td>0.043 - 0.118</td>
</tr>
<tr>
<td>Copper (mg/L)</td>
<td>0.02</td>
<td>0.0111</td>
<td>0.182 - 0.443</td>
</tr>
<tr>
<td>Lead (mg/L)</td>
<td>0.01</td>
<td>0.0507</td>
<td>0.202 - 0.633</td>
</tr>
<tr>
<td>Zinc (mg/L)</td>
<td>0.16</td>
<td>0.129</td>
<td></td>
</tr>
</tbody>
</table>
# Data Comparison: NURP & NPDES

<table>
<thead>
<tr>
<th></th>
<th>Median EMC for karst watersheds</th>
<th>NURP EMC</th>
<th>% Difference</th>
<th>Over-estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TSS (mg/L)</strong></td>
<td>120.8</td>
<td>180 - 548</td>
<td>49% - 354%</td>
<td>149% - 454%</td>
</tr>
<tr>
<td><strong>Total P (mg/L)</strong></td>
<td>0.21</td>
<td>0.42 - 0.88</td>
<td>100% - 319%</td>
<td>200% - 419%</td>
</tr>
<tr>
<td><strong>Soluble P (mg/L)</strong></td>
<td>0.05</td>
<td>0.15 - 0.28</td>
<td>200% - 460%</td>
<td>300% - 560%</td>
</tr>
<tr>
<td><strong>NO$_3$ and NO$_2$ (mg/L)</strong>*</td>
<td></td>
<td>0.86 - 2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NO$_3$ (mg/L)</strong></td>
<td></td>
<td>1.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Copper (mg/L)</strong></td>
<td>0.02</td>
<td>0.043 - 0.118</td>
<td>115% - 490%</td>
<td>215% - 590%</td>
</tr>
<tr>
<td><strong>Lead (mg/L)</strong></td>
<td>0.01</td>
<td>0.182 - 0.443</td>
<td>1720% - 4330%</td>
<td>1820% - 4430%</td>
</tr>
<tr>
<td><strong>Zinc (mg/L)</strong></td>
<td>0.16</td>
<td>0.202 - 0.633</td>
<td>26% - 296%</td>
<td>126% - 396%</td>
</tr>
</tbody>
</table>
Data Comparison:
Simple Method to Calculate Urban Stormwater Loads

- Calculate N & P as a function of watershed impervious area

- Center for Watershed Protection
  - Schueler 1994; Schueler 2000
Data Comparison:
Simple Method to Calculate Urban Stormwater Loads

\[ L = 0.226 \times R \times C \times A \]

Where:
- \( L \) = annual load (lbs)
- \( R \) = annual runoff (inches)
- \( C \) = pollutant concentration (mg/L)
- \( A \) = area (acres)
- 0.266 = unit conversion factor
## Data Comparison:
### Simple Method - Phosphorus

<table>
<thead>
<tr>
<th>Location</th>
<th>% Imperv</th>
<th>Measured P lb/acre</th>
<th>Calculated using Simple Method lb/acre</th>
<th>% Difference</th>
<th>Over-estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown</td>
<td>67</td>
<td>0.54</td>
<td>1.39</td>
<td>159%</td>
<td>259%</td>
</tr>
<tr>
<td>Main Campus</td>
<td>54</td>
<td>0.27</td>
<td>1.14</td>
<td>330%</td>
<td>430%</td>
</tr>
<tr>
<td>Manhole</td>
<td>54</td>
<td>0.37</td>
<td>1.14</td>
<td>210%</td>
<td>310%</td>
</tr>
<tr>
<td>Location1</td>
<td>43</td>
<td>0.37</td>
<td>0.93</td>
<td>149%</td>
<td>249%</td>
</tr>
<tr>
<td>Location 2</td>
<td>25</td>
<td>0.34</td>
<td>0.59</td>
<td>71%</td>
<td>171%</td>
</tr>
<tr>
<td>Big Box</td>
<td>35</td>
<td>0.15</td>
<td>0.78</td>
<td>414%</td>
<td>514%</td>
</tr>
</tbody>
</table>
Data Comparison:
Simple Method - Phosphorus

![Graph showing the relationship between annual P load (lbs/ac) and impervious cover (%) for different locations using the simple method.](image-url)
## Data Comparison: Simple Method - Nitrogen

<table>
<thead>
<tr>
<th>Location</th>
<th>% Imperv</th>
<th>Measured N lb/acre</th>
<th>Calculated using Simple Method lb/acre</th>
<th>% Difference</th>
<th>Over-estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown</td>
<td>67</td>
<td>0.35</td>
<td>10.65</td>
<td>2,984%</td>
<td>3,084%</td>
</tr>
<tr>
<td>Main Campus</td>
<td>54</td>
<td>1.05</td>
<td>8.75</td>
<td>731%</td>
<td>831%</td>
</tr>
<tr>
<td>Manhole</td>
<td>54</td>
<td>0.37</td>
<td>8.75</td>
<td>2,239%</td>
<td>2,339%</td>
</tr>
<tr>
<td>Location1</td>
<td>43</td>
<td>0.57</td>
<td>7.15</td>
<td>1,164%</td>
<td>1,264%</td>
</tr>
<tr>
<td>Location 2</td>
<td>25</td>
<td>0.26</td>
<td>4.53</td>
<td>1,648%</td>
<td>1,748%</td>
</tr>
<tr>
<td>Big Box</td>
<td>35</td>
<td>0.19</td>
<td>5.99</td>
<td>3,057%</td>
<td>3,157%</td>
</tr>
</tbody>
</table>
Data Comparison:
Simple Method - Nitrogen

![Graph showing the relationship between Annual N Load (lbs/ac) and Impervious Cover (%). The graph includes different markers for Downtown, Main Campus, Manhole, Location 1, Location 2, Big Box, and the Simple Method line.](image_url)
Design Implications

- Comparison data references are widely used in SCM design
  - NURP data incorporated in WQ models
    - PA DEP Stormwater BMP Manual
    - SWMM (Rossman, 2010)
  - Simple Method is frequently used in the Mid-Atlantic Region to estimate loads for MS4 permits
    \[ L = 0.226 \times R \times C \times A \]
Design Implications

- Using this reference data may assume a higher level of pollutants

- Are we accurately designing/sizing SCMs in karst areas
  - Maybe oversizing?
  - Maybe not meeting removal requirements?
Moving Forward

- Use caution when designing SCMs in karst regions
- Based on comparison between study karst watersheds and standard reference values & commonly used method, more karst-specific data is needed to accurately size treatment SCMs in karst areas
Acknowledgements:
Measured flow & water quality data from 5 urban karst watersheds compared to standard reference values

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