Session 3a – SCM - Innovative Tools

VUSP Green Infrastructure Research

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Villanova Urban Stormwater Partnership
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The mission of the Villanova Urban Stormwater Partnership is to advance the evolving field of sustainable stormwater management and to foster the development of public and private partnerships through research.

Research Partners

Nonpoint Source National Monitoring Program
Clean Water Act Section 319

And now... Municipal Partners!
Villanova’s SCM Research and Demonstration Park
Title: Prediction of ET from Vegetated Stormwater Control Measures  
Source of Support: Pennsylvania Department of Environmental Protection  
Starting Date: 03/01/12  Ending Date: 06/30/14

Title: Evaluating SCMs in Series  
Source of Support: Pennsylvania Department of Environmental Protection  
Starting Date: 03/01/11  Ending Date: 06/30/13

Title: VUSP- PADEP Best Management Practice National Monitoring Site  
Source of Support: Pennsylvania EPA 319 NPS Program  
Starting Date: ------- Ending Date: 09/30/15

Title: Rain Garden Configuration to Maximize Hydrologic Performance  
Source of Support: GG-2012  
Starting Date: Now! Ending Date 12/31/2016

Title: WP Transitional Grant  
Source of Support: William Penn Foundation  
End Date: 12/31/2013
Green Cities Clean Water
Bioinfiltration Design

- 1.2 m deep media
- 1:1 in situ soil:sand ratio
  (creating a silty sand, USCS)
- 0.46 m (18”) ponding depth
- Inflow: Rip Rap Channels & Storm Drain
- Outflow: Infiltration, Overflow
Traffic Island Event Average Recession Rate Life-cycle Chart

Average Recession Rate (in/hr)

Water Quantity Results

- Model of inflow & overflow (Heasom et al. 2006)
- 364 storms analyzed
- Overall average reduction – 82%
- Statistically significant reductions (p<0.0001)

<table>
<thead>
<tr>
<th>Storm Size</th>
<th>Sample Size</th>
<th>Average Volume Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (&lt;1.27 cm)</td>
<td>115</td>
<td>100%</td>
</tr>
<tr>
<td>Medium (1.27-2.54 cm)</td>
<td>127</td>
<td>97%</td>
</tr>
<tr>
<td>Large (&gt;2.54 cm)</td>
<td>122</td>
<td>50%</td>
</tr>
</tbody>
</table>
### Water Quantity Results

Ponding durations for different storm sizes:

<table>
<thead>
<tr>
<th>STORM SIZE</th>
<th>N</th>
<th>AVERAGE PONDING DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (&lt;1.27 cm)</td>
<td>115</td>
<td>14 hrs ± 17 hrs</td>
</tr>
<tr>
<td>Medium (1.27 cm – 2.54 cm)</td>
<td>127</td>
<td>29 hrs ± 24 hrs</td>
</tr>
<tr>
<td>Large (&gt; 2.54 cm)</td>
<td>122</td>
<td>52 hrs ± 33 hrs</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>364</td>
<td><strong>32 hrs ± 30 hrs</strong></td>
</tr>
</tbody>
</table>

- Ponding: Beginning of rainfall until pressure transducer records 0.2 m
- Average recession rates: 0.6 cm/hr – 0.8 cm/hr
- Slower than literature values (5 cm/hr – 15 cm/hr)
- Creating longer saturated periods
Inflow vs. Outflow for All Storm Events

Villanova University

Regression
Slope = 0.96
x_intercept = 41.6
95% CI = 2.4
The Nitrogen Cycle

Nitrification

- Organic Nitrogen
- Ammonium (NH₄⁺)
- Nitrite (NO₂⁻)

Plant Uptake

- Nitrite (NO₂⁻)

Denitrification

- N₂ Gas Release
- Nitrous Oxide (N₂O)
- Nitrite (NO₂⁻)

Leaching into surrounding soil
\(\text{NO}_x^-\text{N (NO}_2^-\text{N + NO}_3^-\text{N)}:\)

- Background lysimeters at 0.9 m and 1.8 m (3 ft and 6 ft) had much higher \(\text{NO}_x^-\text{N}\) concentrations than all other samples.
Evapotranspiration

Green Roof
- A large part of annual budget
  - 68% - 88% retention
  - 4 mm/d ET on average
- Credit ET in volume reduction
- Next steps:
  - Comparison between drained and undrained systems
  - Green roof design modifications

Rain Gardens
- A large part of annual budget
  - ~50% direct rainfall goes to ET
  - ET is enhanced by internal water storage layer
- Revamped rain garden lysimeters
  - Engineered media with internal water storage
  - Engineered media with restricted underdrain
  - Native soil with restricted underdrain
- Next steps:
  - Storm simulations
  - Explore hydrologic and soil parameters that affect infiltration and ET

Construct Stormwater Wetland
- Monitored ET in greenhouse lysimeter (standing water), greenhouse flowing system, outside lysimeter (standing water)
- ET varies on season (temperature and plant health) from ~5 - 20 mm/d
Treatment Train

Designed for 1 inch event
Constructed Stormwater Wetland

CSW 2.0 Performance Update

- Average peak flow reduction – 59%
- Average volume reduction (storm) – 25%
- Average volume reduction (baseflow) – 41%
- 17% TN removal (storm)
- 46% TN removal (baseflow)
- 21% TP removal (storm)
- 30% TP removal (baseflow)

Next Steps:

- How much P and N does wild algae remove?
- Can wild algae be suitable for biofuel production?
- Sedimentation analysis
- Using aluminum water treatment residual to amend SCM media for improved P retention (wetland, rain garden and green roof media)
Results from recent work

- Watershed scale effects of rain gardens
  - Link SCM installation to watershed-wide restoration goals by using keystone species
  - Use widely available info (like FEMA flood maps), estimates of geometry of stream, and depth and flow requirements for fish
  - Rain gardens can improve habitat by reducing volume, increasing baseflow (more constant depths), and reducing velocity
• Individual scale

- Our rain garden performs well: infiltration, ET, pollutant removal
- Use of “native” soils
- Rain needs to be 1.1 cm or greater to produce a measurable rise in gwt of 3.6 cm
- Takes about 3 days to dissipate
Future work

• Rain garden
  – Continue work on evaluating soils
  – Transparent spec based on GSD
  – Typical soils here have ~5% organics
  – Lower K = more ET, higher K = more infiltration – goals?
  – Lateral extent of groundwater mounding – relate to foundations

• Long-term evaluation of infiltration SCMs that utilize permeable pavements
  – Infiltration bed that is >10 years old
  – Pervious concrete/porous asphalt site that is >5 years old – still performing well!
  – Depth of clogging
  – Infiltration of base soils
• Data gathering – knowledge transfer via crowd sourcing app
  – Citizens
    • Educational
    • Low-level monitoring via checklists
    • Mapping
  – Citizen-scientists and watershed groups
    • Higher-level data
    • More reliable

• Monitoring of SCMs implemented in the Upstream Philadelphia Watershed
  – A couple at a high-level
  – Several at medium-level
  – All at low-level

http://creekwatch.researchlabs.ibm.com/
Pollutant Removal Mechanisms in SCMs

Results from Recent Work:

• Phosphate mass balance showed that sorption to soil in the Bioinfiltration Rain Garden was the major loss mechanism for the $\text{PO}_4^{3-}$ removal and that infrequent maintenance is needed with respect to $\text{PO}_4^{3-}$ removal.

• Nitrogen load reduction in the infiltration bed is by both volume reduction and attenuation.

• Copper, chromium and lead are removed by the infiltration bed.
Pollutant Removal Mechanisms in SCMs

Current/Future Research:

• Mass Balance of metals in the Bioinfiltration Rain Garden to determine its useful life with respect to metals removal.
• We need a better understanding of the pollutant removal processes if we want to better design SCMs for pollutant removal.
  - Can increased ponding times facilitate pollutant removal?
  - How do redox processes/redox cycling affect pollutant removal?
    • What form of chromium is entering SCMs?
      oxidized form (Cr\textsuperscript{6+}) – toxic and mobile in groundwater
      reduced form (Cr\textsuperscript{3+}) – non-toxic and immobile in groundwater
    • Is chromium being removed by precipitation or through reduction from Cr\textsuperscript{6+} to Cr\textsuperscript{3+}?
    • What can iron redox conditions tell us about the removal of nitrogen (and other pollutants)?
Amendments to Enhance SCM Performance

Results from Recent Work:

- Feasibility Study of Water Treatment Plant Residuals to Improve Pollutant Removal in SCMs (Technical Session 4c3, 8:30-10am tomorrow morning, CEER 205)
Amendments to Enhance SCM Performance

Current/Future Research:
• Field-scale SCM application using modified WTRs.
• Additional WTRs benefits:
  - what other pollutants can be removed?
  - soil media to improve evapotranspiration?
• Other amendments? Biofuel char?
Urban

Temporary Storage in Rock Bed
Above root zone

Flood overflow
To storm sewer