Modeling Green Infrastructure Components in a Combined Sewer Area

Robert Pitt, Ph.D., P.E., D.WRE, BCEE
Department of Civil, Construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL, USA 35487

John Voorhees, P.E., P.H.
AECOM, Inc.
Madison, WI
Kansas City’s CSO Challenge

- Combined sewer area: 58 mi$^2$
- Fully developed
- Rainfall: 37 in./yr
- 36 sewer overflows/yr by rain > 0.6 in; reduce frequency by 65%.
- 6.4 billion gal overflow/yr, reduce to 1.4 billion gal/yr
- Aging wastewater infrastructure
- Sewer backups
- Poor receiving-water quality
Kansas City Middle Blue River Outfalls

- 744 acres
- Distributed storage with “green infrastructure” vs. storage tanks
- Need 3 Mgal storage
- Goal: < 6 CSOs/yr
Kansas City’s Original Middle Blue River Plan with CSO Storage Tanks
Adjacent Test and Control Watersheds
KC’s Modeling Connections

- SUSTAIN-SWMM
  - Individual LID
  - Drainage (Transport)
  - Multi-scale
  - Subarea Optimization

- KCMO XP-SWMM
  - Drainage (Transport)
  - Design Objectives

- WinSLAMM
  - Land Surface Characteristics
  - Drainage (Transport)
  - Design Options
  - Stormwater Beneficial Uses
  - Multi-scale

Weight of Evidence
Control Devices Included in WinSLAMM

- Hydrodynamic devices
- Development characteristics
- Wet detention ponds
- Porous pavement
- Street cleaning
- Green roofs
- Catchbasin cleaning
- Grass swales and grass filtering
- Biofiltration and bioretention
- Cisterns and stormwater use
- Media filtration/ion exchange/sorption
# Major Land Use Components in Residential Portion of Study Area (% of area and % of total annual flow contributions)

<table>
<thead>
<tr>
<th></th>
<th>Roofs</th>
<th>Driveways</th>
<th>Side-walks</th>
<th>Parking</th>
<th>Streets</th>
<th>Landscaped</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly connected</td>
<td>2 (6)</td>
<td>4 (9)</td>
<td>1 (3)</td>
<td>2 (5)</td>
<td>9 (21)</td>
<td></td>
<td>18 (44)</td>
</tr>
<tr>
<td>Disconnected</td>
<td>11 (7)</td>
<td>4 (3)</td>
<td>1 (1)</td>
<td></td>
<td></td>
<td></td>
<td>16 (11)</td>
</tr>
<tr>
<td>Landscaped</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66 (45)</td>
<td>66 (45)</td>
</tr>
<tr>
<td>Total area</td>
<td>13</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>66</td>
<td>100</td>
</tr>
</tbody>
</table>

Based on KCMO GIS mapping and detailed site surveys, along with WinSLAMM calculations.
Kansas City 1972 to 1999 Rain Series
Irrigation needs for the landscaped areas surrounding the homes were calculated by subtracting long-term monthly rainfall from the regional evapotranspiration demands for turf grass.
The surface infiltration rates are less than 1 in/hr for rains about 2 hrs duration, but can be greater for shorter duration events. Subsurface measurements have indicated that infiltration rates are lower for most of the area in the drainage zones.

Must consider effects of scaling, location, and uncertainty in measured values.
Modeling of Controls for Directly Connected Roof Runoff

This presentation focuses on the results of recent modeling efforts examining rain barrels/water tanks and rain gardens to control the annual runoff quantity from directly connected roofs. The modeling is being expanded as the curb-cut biofilter designs are finalized.
Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Gardens
(Kansas City CSO Study Area)
Household water use (gallons/day/house) from rain barrels or water tanks for outside irrigation to meet ET requirements:

<table>
<thead>
<tr>
<th>Month</th>
<th>Use (gallons/day/house)</th>
<th>July</th>
<th>Use (gallons/day/house)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>42</td>
<td>357</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>172</td>
<td>August</td>
<td>408</td>
</tr>
<tr>
<td>March</td>
<td>55</td>
<td>September</td>
<td>140</td>
</tr>
<tr>
<td>April</td>
<td>104</td>
<td>October</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>78</td>
<td>November</td>
<td>0</td>
</tr>
<tr>
<td>June</td>
<td>177</td>
<td>December</td>
<td>0</td>
</tr>
</tbody>
</table>
WinSLAMM conducts a continuous water mass balance for every storm in the study period.

For rain barrels/tanks, the model fills the tanks during rains (up to the maximum amount of runoff from the roofs, or to the maximum available volume of the tank).

Between rains, the tank is drained according to the water demand rate. If the tank is almost full from a recent rain (and not enough time was available to use all of the water in the tank), excess water from the event would be discharged to the ground or rain gardens after the tank fills.
Basic Rain Barrel/Water Tank Input Screen in WinSLAMM (same as for biofilters, but no soil infiltration and with water use profile)
Reductions in Annual Flow Quantity from Directly Connected Roofs with the use of Rain Barrels and Water Tanks (Kansas City CSO Study Area)
0.12 ft of storage is needed for use of 75% of the total annual runoff from these roofs for irrigation. With 945 ft² roofs, the total storage is therefore 113 ft³, which would require 25 typical rain barrels, way too many! However, a relatively small water tank (5 ft D and 6 ft H) can also be used.

<table>
<thead>
<tr>
<th>rain barrel storage per house (ft³)</th>
<th># of 35 gallon rain barrels</th>
<th>tank height size required if 5 ft D (ft)</th>
<th>tank height size required if 10 ft D (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.7</td>
<td>1</td>
<td>0.24</td>
<td>0.060</td>
</tr>
<tr>
<td>9.4</td>
<td>2</td>
<td>0.45</td>
<td>0.12</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
<td>0.96</td>
<td>0.24</td>
</tr>
<tr>
<td>47</td>
<td>10</td>
<td>2.4</td>
<td>0.60</td>
</tr>
<tr>
<td>118</td>
<td>25</td>
<td>6.0</td>
<td>1.5</td>
</tr>
<tr>
<td>470</td>
<td>100</td>
<td>24</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Two 35 gal. rain barrels plus one 160 ft² rain garden per house can reduce the total annual runoff quantity from directly connected roofs by about 90%.
Biofilter Design with multiple layers and outlet options

Biofiltration Control Device

- Land Use: Commercial
- Source Area: Small Landscaped Area 1
- Biofilter Number 3

**Device Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Area (sf)</td>
<td>1600</td>
</tr>
<tr>
<td>Bottom Area (sf)</td>
<td>600</td>
</tr>
<tr>
<td>Total Depth (ft)</td>
<td>2.50</td>
</tr>
<tr>
<td>Typical Width (ft) [Cost est. only]</td>
<td>10.00</td>
</tr>
<tr>
<td>Native Soil Infiltration Rate (in/hr)</td>
<td>2.400</td>
</tr>
<tr>
<td>Native Soil Infiltration Rate COV</td>
<td>N/A</td>
</tr>
<tr>
<td>Infiltr. Rate Fraction-Bottom (0-1)</td>
<td>1.00</td>
</tr>
<tr>
<td>Infiltr. Rate Fraction-Sides (0-1)</td>
<td>1.00</td>
</tr>
<tr>
<td>Rock Filled Depth (ft)</td>
<td>1.00</td>
</tr>
<tr>
<td>Rock Fill Void Ratio (0-1)</td>
<td>0.10</td>
</tr>
<tr>
<td>Engineered Soil Type</td>
<td>Peat-Sand</td>
</tr>
<tr>
<td>Engineered Soil Infiltration Rate (in/hr)</td>
<td>2.10</td>
</tr>
<tr>
<td>Engineered Soil Depth (ft)</td>
<td>0.75</td>
</tr>
<tr>
<td>Engineered Soil Void Ratio (0-1)</td>
<td>0.30</td>
</tr>
<tr>
<td>Percent solids reduction due to Engineered Soil (0-100)</td>
<td>83.00</td>
</tr>
<tr>
<td>Inflow Hydrograph Peak to Average Flow Ratio</td>
<td>3.80</td>
</tr>
</tbody>
</table>

**Source Areas from Land Use that Contribute Runoff to Biofiltration Control Device(s)**

- Rooftop 1
- Rooftop 2
- Rooftop 3
- Rooftop 4
- Rooftop 5
- Rooftop Parking/Storage 1
- Rooftop Parking/Storage 2
- Rooftop Parking/Storage 3
- Unpaved Parking/Storage 1
- Unpaved Parking/Storage 2

**Selected Outlets**

1. Vertical Stand Pipe
2. Broad Crested Weir
3. Underdrain Outlet

**Biofilter Geometry Schematic**

Use Random Number Generation to Account for Infiltration Rate Uncertainty

Select Native Soil Infiltration Rate:
- Sand - 8 in/hr
- Loamy sand - 2.5 in/hr
- Sandy loam - 1.0 in/hr
- Loam - 0.5 in/hr
- Silt loam - 0.3 in/hr
- Sandy silt loam - 0.2 in/hr
- Clay loam - 0.1 in/hr
- Silty clay loam - 0.05 in/hr
- Sandy clay - 0.05 in/hr
- Silty clay - 0.04 in/hr
- Clay - 0.02 in/hr
- Rain Barrel/Cistern - 0.00 in/hr

Select Particle Size File: C:\Program Files\WinSLAMM\HIGH.CFZ

Refresh Schematic
Examples from “65%” plans prepared by URS for project streets. Plans reviewed and modeled by project team, and construction will occur in spring and summer of 2011.
Swale and grass filter hydraulic characteristics can be predicted on the basis of flow rate, cross sectional geometry, slope, and vegetation type.
Annual Runoff Reductions from Paved Areas or Roofs for Different Sized Rain Gardens for Various Soils

Reduction in Annual Impervious Area Runoff (%)

Rain Garden Size (% of drainage area)
Clogging Potential for Different Sized Rain Gardens Receiving Roof Runoff

Clogging not likely a problem with rain gardens from roofs
Rain gardens should be at least 10% of the paved drainage area, or receive significant pre-treatment (such as with long grass filters or swales, or media filters) to prevent premature clogging.
Conclusions

• Extensive use of biofilters and other practices is needed in order to provide significant benefits to the combined sewer system.

• Placement and design of these controls is very critical. Roof runoff rain gardens located at disconnected roofs are less than 10% as effective compared to directly connected roofs.

• Critical hydrologic and hydraulic processes for small flows and small areas are not the same compared to large events and large systems.

• Detailed site surveys are needed to determine actual flow paths; remote sensing is limited for these details.

• The weight-of-evidence provided by independent evaluations decreases the uncertainty of complex decisions.