SWMM Calibration and Sensitivity Analysis for Bioretention

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Storm Water Management Model (SWMM)

- Produced by the US Environmental Protection Agency
- Dynamic hydrology-hydraulic water quality simulation model
- Low Impact Development Controls were introduced as part of SWMM 5 in 2009
Objective

- Evaluate the accuracy of SWMM’s LID controls using data collected from GI implementations at Stevens
  - Sensitivity analysis
  - Model calibration and validation

- Few published studies have evaluated the accuracy of SWMM with LID

- Accurate models critical to evaluating design alternatives, determining regulatory compliance, etc.
Site Characteristics

Planter acts as a **bioretention cell** to manage roof runoff
Planter Modeling

- Rainfall measured onsite
- Area
- Flow path width
- Slope
- Manning’s n
- % impervious
How SWMM Models LID Controls

**Evapotranspiration**
- from field measured ET rates or estimates from temperature

**Infiltration from ponding zone to media layer**
- Green-Ampt infiltration model

**Inflow**
- SWMM runoff computations for drainage area

**Soil percolation**
- modeled using Darcy’s law

**Drainage**
- Empirical power law
Planter Modeling

**Green** = design/measured data
**Gold** = calculated from sensors
**Red** = assumed values

**Inflow**
Calculated by SWMM using rainfall and drainage area properties

**Evapotranspiration**

- Ponding depth
- Manning’s n
- Media thickness
- Conductivity
- Conductivity slope
- Suction head
- Thickness
- Void ratio
- Flow coefficient
- Flow exponent
- Vegetative volume fraction
- Surface slope
- Porosity
- Field capacity
- Wilting point

**Outflow**
Continuous simulation

- August 8, 2017 to March 14, 2018
- 32 rain events (total P = 14.85 in)

Model efficiency: Nash-Sutcliffe efficiency coefficient (NSE)

- Ranges from $-\infty$ to 1
- $\eta = 1 \rightarrow$ perfect match

Continuous simulation NSE: 0.796

Individual storms NSE: 0.138 to 0.992
Uncalibrated Model Accuracy

Influence of rainfall depth

SWMM Efficiency for Bioretention Modeling

Rainfall depth (inches)

NSE Coefficient
Uncalibrated Model Accuracy

Influence of **average** rainfall intensity

![Graph showing SWMM Efficiency for Bioretention Modeling](image)

- **X-axis**: Average rainfall intensity (inches/hour)
- **Y-axis**: NSE Coefficient

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**Graph Description**

The graph illustrates the relationship between average rainfall intensity and SWMM efficiency for bioretention modeling. The efficiency is measured using the NSE (Nash-Sutcliffe Efficiency) coefficient. As the average rainfall intensity increases, there is a noticeable decrease in the efficiency, indicating a decline in model accuracy with higher rainfall intensity.
Uncalibrated Model Accuracy

Influence of peak rainfall intensity (5-minute peak)

**SWMM Efficiency for Bioretention Modeling**

![Graph showing the relationship between NSE coefficient and peak rainfall intensity.](image)
Uncalibrated Model Accuracy

SWMM vs. Observed Flow (Aug. 18, 2017)
(depth = 0.78 in, $\eta = 0.63$)

SWMM vs. Observed Flow (Feb. 19, 2018)
(depth = 0.16 in, $\eta = 0.26$)
Sensitivity Analysis

Surface Roughness

Conductivity Slope

Suction Head

Vegetative Volume Fraction

Surface Manning’s $n$

<table>
<thead>
<tr>
<th>Range</th>
<th>Std. Dv.</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0018</td>
<td>0.0008</td>
<td>No sensitivity</td>
</tr>
</tbody>
</table>

Media Cond’tvty Slope

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<thead>
<tr>
<th>Range</th>
<th>Std. Dv.</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0085</td>
<td>0.0035</td>
<td>Minor sensitivity</td>
</tr>
</tbody>
</table>

Media Suction Head

<table>
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<th>Range</th>
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Vegetative Volume Fraction

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<td>0.0035</td>
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Sensitivity Analysis

Field Capacity

Porosity

Flow Exponent

Conductivity

<table>
<thead>
<tr>
<th>Media</th>
<th>Range</th>
<th>Std. Dv.</th>
<th>High sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Capacity</td>
<td>0.0579</td>
<td>0.0279</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Media</th>
<th>Range</th>
<th>Std. Dv.</th>
<th>High sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>0.0686</td>
<td>0.0290</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Drain</th>
<th>Range</th>
<th>Std. Dv.</th>
<th>High sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Exponent</td>
<td>0.0387</td>
<td>0.0153</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Media</th>
<th>Range</th>
<th>Std. Dv.</th>
<th>Moderate sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>0.0526</td>
<td>0.0197</td>
<td></td>
</tr>
</tbody>
</table>
Sensitivity Analysis

Differences between parameter values also had an impact…
Model Calibration and Validation

• March 1, 2018 storm selected for calibration
  • NSE improved from 0.72 to 0.91 (27% improvement)
  • Peak flow error improved 12%

• Overall continuous simulation improved by 5% to 0.84.
  • Accuracy for individual storms generally improved, though some got worse
Model Calibration and Validation

- Calibration involved further lowering media porosity and field capacity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity Test Range</th>
<th>Measured Value</th>
<th>Calibrated Value</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media porosity</td>
<td>0.34 to 0.70</td>
<td>0.290</td>
<td>0.110</td>
<td>↓ 0.180 (62%)</td>
</tr>
<tr>
<td>Media field capacity</td>
<td>0.10 to 0.40</td>
<td>0.244</td>
<td>0.100</td>
<td>↓ 0.144 (59%)</td>
</tr>
<tr>
<td>Conductivity (in/hr)</td>
<td>0.03 to 11.78</td>
<td>6.600</td>
<td>8.000</td>
<td>↑ 1.400 (21%)</td>
</tr>
<tr>
<td>Drain flow exponent</td>
<td>0.00 to 1.00</td>
<td>0.500</td>
<td>0.660</td>
<td>↑ 0.160 (32%)</td>
</tr>
<tr>
<td>Storage void ratio</td>
<td>0.25 to 1.00</td>
<td>0.750</td>
<td>0.660</td>
<td>↓ 0.090 (12%)</td>
</tr>
<tr>
<td>Wilting point</td>
<td>0.01 to 0.16</td>
<td>0.105</td>
<td>0.001</td>
<td>↓ 0.104 (99%)</td>
</tr>
<tr>
<td>Storage depth (in)</td>
<td>N/A</td>
<td>6.000</td>
<td>5.000</td>
<td>↓ 1.000 (17%)</td>
</tr>
<tr>
<td>Drain offset height (in)</td>
<td>N/A</td>
<td>3.000</td>
<td>3.500</td>
<td>↑ 0.500 (17%)</td>
</tr>
</tbody>
</table>
Conclusion

- SWMM is a useful tool for continuous simulations over an extended period of time and a range of conditions
- For individual storms, additional evaluation or calibration may be required for reliable results
- Accuracy of simulation highly dependent on measurements for porosity, field capacity, and other media properties
- Seasonal impacts of leaf clogging, snowfall, and snow melt not well accounted for in SWMM
Questions?