Storm Water Volume Control – Design vs. Reality
City of St. Paul

Presented by:
Jesse Carlson, WSB & Associates, Inc.
William Alms, WSB & Associates, Inc.
• St. Paul’s goal is to become the most sustainable City in America which is demonstrated by showing their commitment to improve water quality.

• Monitoring will help St. Paul:
  • Quantify water quality improvements made for the purpose of meeting City stormwater management goals and TMDL requirements
  • Evaluate the performance of the systems based on design criteria vs. monitored results
  • Work with organizations who establish stormwater policy to make sure we are constructing systems that can be maximized financially
### Monitoring Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Drainage Area (acres)</th>
<th>Infiltration Rate</th>
<th>Volume Reduction Monitoring</th>
<th>Pollutant Removal Monitoring</th>
<th>Rainfall Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beacon Bluff</td>
<td>136</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Victoria Street</td>
<td>19</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Como Golf Course</td>
<td>128</td>
<td>×</td>
<td></td>
<td></td>
<td>×</td>
</tr>
<tr>
<td>AHUG</td>
<td>55</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>St. Alban’s</td>
<td>22</td>
<td>×</td>
<td>×</td>
<td></td>
<td>×</td>
</tr>
<tr>
<td>Arundel Street</td>
<td>5</td>
<td>×</td>
<td></td>
<td></td>
<td>×</td>
</tr>
<tr>
<td>Ivy-Kennard</td>
<td>5</td>
<td>×</td>
<td></td>
<td></td>
<td>×</td>
</tr>
<tr>
<td>Earl-Mclean</td>
<td>3</td>
<td>×</td>
<td></td>
<td></td>
<td>×</td>
</tr>
</tbody>
</table>
Monitoring Locations

City of St. Paul
2012 Monitoring Program

Site Location Map

Legend:
- Rain gardens/Infiltration Basin
- Infiltration Trench
- Previous Pavement
- Capitol Region Watershed District
- Lower Mississippi River WMG
- Mississippi WMG
- Ramsey/Washington Metro WD
- Proposed Monitoring Locations
- Rain Gauge Locations

[Map showing monitoring locations]
Procedures and Methods – Infiltration Rate

- Infiltration monitoring equipment was placed in PVC enclosures at each site to perform continuous logging.

- Stage/infiltration rate curves were developed
Procedures and Methods – Volume Reduction

- Flow volumes were measured at:
  - Beacon Bluff
  - Victoria Street
  - St. Albans
  - AHUG

- Water level and velocity data was measured using ISCO 2150 Area Velocity Flow Modules

- A water balance was created for each of the systems to determine volume reduction
Procedures and Methods – Water Quality

• ISCO 6712 automatic samplers were installed in diversion structures at:
  • Beacon Bluff
  • Victoria Street

• Grab sampling was done to monitor water discharging from the Victoria Street pervious paver system

• Flow pacing was set up to capture
  • > 6 samples during a 0.25-in storm
  • <120 samples during the 3-in storm.
## Water Quality Testing Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Sample Type</th>
<th>Reporting Limit</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids (TSS)</td>
<td>SM 2540D</td>
<td>Composite</td>
<td>5</td>
<td>mg/L</td>
</tr>
<tr>
<td>Suspended Sediment Concentration (SSC)</td>
<td>ASTM D3977-97</td>
<td>Composite</td>
<td>10</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>SM 2540C</td>
<td>Composite</td>
<td>10</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Phosphorus (TP)</td>
<td>EPA 365.2</td>
<td>Composite</td>
<td>0.01</td>
<td>mg/L</td>
</tr>
<tr>
<td>Ortho-Phosphorus (Ortho-P)</td>
<td>EPA 365.3</td>
<td>Composite</td>
<td>0.006</td>
<td>mg/L</td>
</tr>
<tr>
<td>Chlorides</td>
<td>SM 4500-CI</td>
<td>Composite</td>
<td>1</td>
<td>mg/L</td>
</tr>
<tr>
<td>E. coli</td>
<td>COLI-Q 1</td>
<td>Grab</td>
<td>1</td>
<td>mpn/100/mL</td>
</tr>
</tbody>
</table>
• Maintenance inspections were conducted at:
  • Beacon Bluff
  • Victoria Street
  • St. Alban’s Street
  • Arundel Street

• Pretreatment structure were evaluated for accumulated sediment depth and floatable debris collection efficiency

• Underground chambers were observed for sediment depth accumulation
Victoria Infiltration System

Flow is diverted to the system until it reaches its storage capacity and at that point water will bypass the system and continue through the storm sewer.

1) Year Constructed: 2010

2) Drainage Area to BMP: 19 acres

2) Total Construction Cost: $174,000

3) Storage Volume: 16,700 cu-ft

4) Volume Reduction Credit Received by St. Paul: 16,700 cu-ft
Victoria Infiltration System

60” HDPE Pipe

Permeable pavers over underground system
Located at Orchard Recreation Center
875 Orchard Ave, Saint Paul, MN 55103

Victoria Infiltration System - Infiltration Chambers

Legend:
- Red: Upstream Flow Meter
- Blue: Downstream Flow Meter
- Green: Rain Gauge Tipping Bucket
- Purple: Water Level Logger
- Black Star: Water Quality Sampler
### Volume Reduction Results

<table>
<thead>
<tr>
<th>Monitoring Period</th>
<th>10/14/11 thru 9/28/12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rainfall</td>
<td>20.5 in.</td>
</tr>
<tr>
<td>Total Runoff Volume*:</td>
<td>387,000 cu-ft</td>
</tr>
<tr>
<td>Total Runoff Volume Captured:</td>
<td>378,000 cu-ft</td>
</tr>
<tr>
<td>Percent of Runoff Volume Captured:</td>
<td>98%</td>
</tr>
<tr>
<td>Peak Percentage of System Used:</td>
<td>100%</td>
</tr>
</tbody>
</table>

* This volume includes runoff from snowmelt; however our water quality monitoring was only done during the summer months.
## Victoria Infiltration System

### May 5-6, 2012 Storm

<table>
<thead>
<tr>
<th>Rainfall Amount (in)</th>
<th>Storm Duration (hr)</th>
<th>Volume Captured (cu-ft)</th>
<th>Percent of Volume Captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.61</td>
<td>17</td>
<td>31,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

### May 23-24, 2012 Storm

<table>
<thead>
<tr>
<th>Rainfall Amount (in)</th>
<th>Storm Duration (hr)</th>
<th>Volume Captured (cu-ft)</th>
<th>Percent of Volume Captured</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.02</td>
<td>19</td>
<td>53,000</td>
<td>94%</td>
</tr>
</tbody>
</table>

### System Volume (cu-ft)

<table>
<thead>
<tr>
<th>System Volume (cu-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16,700</td>
</tr>
</tbody>
</table>
## Water Quality Testing Results

<table>
<thead>
<tr>
<th>Monitoring Period</th>
<th>4/25/12 thru 7/18/12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rainfall</td>
<td>15.0 in.</td>
</tr>
<tr>
<td>Number of Events Sampled</td>
<td>21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing Parameter</th>
<th>Total Pollutant Load Conveyed to BMP* (lb.)</th>
<th>Pollutant Load Captured by BMP* (lb.)</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>1,690</td>
<td>1,610</td>
<td>96%</td>
</tr>
<tr>
<td>TDS</td>
<td>710</td>
<td>700</td>
<td>99%</td>
</tr>
<tr>
<td>SSC</td>
<td>11,900</td>
<td>11,600</td>
<td>97%</td>
</tr>
<tr>
<td>TP</td>
<td>9.4</td>
<td>9.1</td>
<td>96%</td>
</tr>
<tr>
<td>Ortho-P</td>
<td>0.75</td>
<td>0.74</td>
<td>99%</td>
</tr>
<tr>
<td>Chloride</td>
<td>111</td>
<td>109</td>
<td>98%</td>
</tr>
</tbody>
</table>

* Event Mean Concentrations (EMCs) were used to determine pollutant loading.
Beacon Bluff Infiltration System

Flow is diverted to the system at an upstream diversion structure. Flow bypasses the system prior to it reaching its storage capacity.

1) Year Constructed: 2011
2) Drainage Area to BMP: 143.6 acres
3) Total Construction Cost: $980,000
4) Storage Volume: 160,000 cu-ft
4) Volume Reduction Credit Received by St. Paul: 116,000 cu-ft*

*Remaining credit was given to the St. Paul Port Authority
Beacon Bluff Infiltration System

120” CMP Underground Chamber

East Infiltration Basin
Beacon Bluff Infiltration System

Located at Wilder Recreation Center
958 Jessie St. Saint Paul, MN 55101

Level Loggers Installed and Operated by American Engineering Testing, Inc. (AET)

LEGEND
- Upstream Flow Meter
- Downstream Flow Meter
- Rain Gauge Tipping Bucket
- Water Level Logger
- Water Quality Sampler
### Volume Reduction Results

<table>
<thead>
<tr>
<th>Monitoring Period</th>
<th>10/14/11 thru 9/28/12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rainfall</td>
<td>20.1 in.</td>
</tr>
<tr>
<td>Total Runoff Volume*</td>
<td>3.3 mil. cu-ft</td>
</tr>
<tr>
<td>Total Runoff Volume Captured</td>
<td>2.0 mil. cu-ft</td>
</tr>
<tr>
<td>Percent of Runoff Volume Captured</td>
<td>60%</td>
</tr>
<tr>
<td>Peak Percentage of System Used</td>
<td>31%</td>
</tr>
</tbody>
</table>

* This volume includes runoff from snowmelt; however our water quality monitoring was only done during the summer months.
<table>
<thead>
<tr>
<th></th>
<th>Rainfall Amount (in)</th>
<th>Storm Duration (hr)</th>
<th>Volume Captured (cu-ft)</th>
<th>Percent of Volume Captured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>May 5-6, 2012 Storm</strong></td>
<td>1.7</td>
<td>18</td>
<td>47,000</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>2.40</td>
<td>19</td>
<td>139,000</td>
<td>45%</td>
</tr>
</tbody>
</table>

**System Volume (cu-ft)**

160,000
### Water Quality Testing Results

**Monitoring Period**: 3/29/12 thru 7/18/12

<table>
<thead>
<tr>
<th>Total Rainfall</th>
<th>14.5 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Events Sampled</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing Parameter</th>
<th>Total Pollutant Load Conveyed to BMP* (lb.)</th>
<th>Pollutant Load Captured by BMP* (lb.)</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>16,700</td>
<td>8,700</td>
<td>52%</td>
</tr>
<tr>
<td>TDS</td>
<td>7,200</td>
<td>3,300</td>
<td>46%</td>
</tr>
<tr>
<td>SSC</td>
<td>72,500</td>
<td>40,500</td>
<td>56%</td>
</tr>
<tr>
<td>TP</td>
<td>68</td>
<td>38</td>
<td>55%</td>
</tr>
<tr>
<td>Ortho-P</td>
<td>8.0</td>
<td>4.7</td>
<td>58%</td>
</tr>
<tr>
<td>Chloride</td>
<td>282</td>
<td>156</td>
<td>55%</td>
</tr>
</tbody>
</table>

*Event Mean Concentrations (EMCs) were used to determine pollutant loading.*
Saint Albans Infiltration System

Flow is diverted to the system until it reaches its storage capacity and at that point water will bypass the system and continue through the storm sewer.

1) Year Constructed: 2010

2) Drainage Area to BMP: 22.2 acres

3) Total Construction Cost: $382,000

4) Storage Volume: 31,200 cu-ft

4) Volume Reduction Credit Received by St. Paul: 31,200 cu-ft
48” perforated HDPE storage chambers during construction

Saint Albans infiltration system after clean out
ST. ALBANS STREET - IMPROVEMENTS

OPTIONS INCLUDE:
1. CORE DRILL
2. BREAK INTO BLOCK
3. NEW MANHOLE

INSTALL 8LF-48”HOLE RISER, 48” CONCRETE COVER, FRAME CASTING “A” - STD. PL. 2201D, COVER CASTING "D" STD. PL. 2202C.

RIM-102.66 (VERIFY) 192.30

CORE DRILL EX. STMH

INV. 185.14

EXWH

LEGEND
- Upstream Flow Meter
- Downstream Flow Meter
- Water Level Logger
## Volume Reduction Results

<table>
<thead>
<tr>
<th>Monitoring Period</th>
<th>3/29/12 thru 8/13/12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rainfall</td>
<td>17.5 in.</td>
</tr>
<tr>
<td>Total Runoff Volume:</td>
<td>384,000 cu-ft</td>
</tr>
<tr>
<td>Total Runoff Volume Captured:</td>
<td>10,800 cu-ft</td>
</tr>
<tr>
<td>Percent of Runoff Volume Captured:</td>
<td>97%</td>
</tr>
<tr>
<td>Peak Percentage of System Used:</td>
<td>100%</td>
</tr>
<tr>
<td>Storm Duration (hr)</td>
<td>Volume Captured (cu-ft)</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>May 5-6, 2012 Storm</td>
<td>46,700</td>
</tr>
<tr>
<td>May 23-24, 2012 Storm</td>
<td>70,100</td>
</tr>
</tbody>
</table>

System Volume (cu-ft)

31,200
• Simple Method
  • The size of the storage area is equal to the runoff volume from the targeted storm.

Simple method for sizing Volume Reduction BMPs requires the largest storage volume
• **Dynamic Method**
  • The size of the storage area depends on how fast the stormwater infiltrates.
  • Rapid infiltration rates would require much less storage area than a system that has low infiltration rates.
## Simple vs. Dynamic Method for Design

<table>
<thead>
<tr>
<th>Site:</th>
<th>Hydraulic Soil Group (USCS)</th>
<th>MSWM Infil. Rate (in/hr)</th>
<th>Kozeny-Carman (in/hr)</th>
<th>Double Ring Infiltrometer (in/hr)</th>
<th>Design Infil. Rate (in/hr)</th>
<th>Measured Draw Down Rate (in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria Street</td>
<td>A(SP)</td>
<td>0.8</td>
<td>32&lt;sup&gt;1&lt;/sup&gt;</td>
<td>95.9</td>
<td>12.8</td>
<td>52.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>101.8&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saint Albans Street</td>
<td>A(SP)</td>
<td>0.8</td>
<td>65&lt;sup&gt;1&lt;/sup&gt;</td>
<td>141.8</td>
<td>26.0</td>
<td>39.1</td>
</tr>
<tr>
<td>Arundel Street</td>
<td>A(SP)</td>
<td>0.8</td>
<td>44&lt;sup&gt;1&lt;/sup&gt;</td>
<td>71.1</td>
<td>17.6</td>
<td>5.1*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>78.5&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earl-Mclean No. 1</td>
<td>B (SM)</td>
<td>0.6</td>
<td>4.8</td>
<td>NA</td>
<td>0.6</td>
<td>9.4*</td>
</tr>
<tr>
<td>Ivy-Kennard No. 1</td>
<td>B (SM)</td>
<td>0.6</td>
<td>ND</td>
<td>NA</td>
<td>0.6</td>
<td>2.3*</td>
</tr>
<tr>
<td>Hillcrest Knoll</td>
<td>A (SP)</td>
<td>0.8</td>
<td>8.5</td>
<td>TBD</td>
<td>2.0</td>
<td>TBD</td>
</tr>
</tbody>
</table>

1 – Infiltration rates from pre-construction well borings were used for the system design

2 – Infiltration rates were from Double Ring Infiltrometer test at the excavated underground system floor.

*Uncorrected for Inflow Volume
### Simple vs. Dynamic Method for Design

<table>
<thead>
<tr>
<th>Site:</th>
<th>BMP Storage Volume (cu-ft)</th>
<th>Volume Reduction Credits Allocated (cu-ft)</th>
<th>Max Volume Reduction Allowed (cu-ft)</th>
<th>Max Volume Reduction Achieved (cu-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria Street</td>
<td>16,700</td>
<td>16,700</td>
<td>48,800</td>
<td>53,100</td>
</tr>
<tr>
<td>Beacon Bluff</td>
<td>160,000</td>
<td>160,000</td>
<td>392,000</td>
<td>135,000*</td>
</tr>
<tr>
<td>St. Albans Street</td>
<td>31,200</td>
<td>31,200</td>
<td>75,700</td>
<td>70,100</td>
</tr>
</tbody>
</table>

* Volume Reduction can be enhanced by modifying diversion structure (estimate 250,000 cu-ft)
## Simple vs. Dynamic Method for Design

<table>
<thead>
<tr>
<th>Site:</th>
<th>Total Construction Cost</th>
<th>Cost per Credit (Simple Method)</th>
<th>Cost per Credit (Dynamic Method)</th>
<th>Cost for Over Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria Street</td>
<td>$174,000</td>
<td>$10.41/cu-ft</td>
<td>$3.56/cu-ft</td>
<td>2.9 x</td>
</tr>
<tr>
<td>Beacon Bluff</td>
<td>$980,000</td>
<td>$6.15/cu-ft</td>
<td>$3.92/cu-ft*</td>
<td>1.6 x</td>
</tr>
<tr>
<td>St. Albans Street</td>
<td>$381,900</td>
<td>$12.24/cu-ft</td>
<td>$5.05/cu-ft</td>
<td>2.4 x</td>
</tr>
</tbody>
</table>

* Dynamic Cost based on estimated volume reduction with modified diversion structure
**Simple Method:**
Volume: 48,800 cu-ft
Infiltration Rate: 0 in/hr
Cost: $508,700

**Dynamic Method:**
Volume: 16,700 cu-ft
Infiltration Rate: 12.8 in/hr
Cost: $174,100

Volume: 11,700 cu-ft
Infiltration Rate: 38.4 in/hr
Cost: $122,100

BMP Storage Volume = 10,339 cubic-feet
2012 monitoring data shows an average infiltration rate of 52.5 in/hr.
Cost = $107,698
Municipal Volume Reduction Budget: $500,000

**Static Method**

- Volume Reduction from **20 acres**
- No hydraulic consideration of performance

**Annual Stormwater Reductions**
- Runoff - 224,000 cu-ft
- TSS - 9,000 lb
- TP - 39 lb

**Dynamic Method**

- Volume Reduction from **58 acres**

**Annual Stormwater Reductions**
- Runoff - 654,000 cu-ft
- TSS - 26,300 lb
- TP - 114 lb
• Monitoring showed that the Cities infiltration systems are performing at or above design goals

• Simple method results in systems that are 2 to 3 times greater than needed for volume reduction as compared to dynamic method

• Simple method does not require a hydraulic analysis to be conducted account for

• In order for these volume reduction practices to be sustainable, they need to be maximized financially
QUESTIONS?

Contacts:
Jesse Carlson - jcarlson@wsbeng.com
William Alms – walms@wsbeng.com
BMP Modeling and Optimization
Duluth Case Study

Jennifer Olson and Bruce Cleland
Tetra Tech, Inc.

MN Water Resources Conference
October 16-17, 2012
Project Overview

- Eight pilot projects funded by US EPA Region 5
- Share information about BMP optimization/planning tools with Great Lakes states, communities, and watershed groups
- Work with Great Lakes states, communities, and watershed groups to plan and implement pilot projects
- Capture lessons learned from interactions with local partners
- Develop specific recommendations on how models can effectively be used by communities and watershed organizations
- Develop technical guidance
BMP Optimization/Planning Tools

► BMP Decision Support System (BMPDSS)
  ▪ Developed for Prince George’s County
  ▪ Precursor to US EPA’s SUSTAIN model
  ▪ ArcGIS interface, simulates multiple BMPs, optimization routine
  ▪ Requires rainfall/runoff time series input

► BMPDSS Navigator
  ▪ Developed for Griffin, Georgia
  ▪ PG County’s BMPDSS with an Excel wrapper
BMP Optimization/Planning Tools

► **SUSTAIN** – System for Urban Stormwater Treatment and Analysis Integration
  - Original release in 2009
  - Version 1.2 released by US EPA in 2012
  - BMPDSS forms the basis of the BMP Module
  - Requires rainfall/runoff time series input

► Long-term Hydrologic Impact Analysis (L-THIA)
  - Developed by Purdue University
  - Web-based tool
  - Average annual runoff, pollutant loads, and BMP effectiveness
  - Pre-processed weather data, uses a modified curve number approach to model low impact development
What is **SUSTAIN**?

**SUSTAIN** – **S**ystem for **U**rban **S**tormwater **T**reatment, and **A**nalysis **IN**tegration

A GIS-based framework designed to support decision-making

- How effective are BMPs or green infrastructure in reducing runoff and pollutant loadings?
- What are the most **cost-effective** BMP options meeting the water quantity and quality objectives?
  - Where, what type, and how large?

See Poster Presentation for more information
SUSTAIN Components

Framework Manager (ArcGIS)

- Watershed Module
- BMP Module
- BMP Siting Tool
- Cost Database
- Optimization
- Interpretation (Post Processor)
Potential BMPs

Generic Treatment Train

On-Site Interception → On-Site Treatment → Routing Attenuation → Regional Storage/Treatment → Outlet
BMP Optimization

**Cost Effectiveness (CE) Curve**

- **Effectiveness (% Reduction)**
- **Cost ($ Million)**

- POROUSPAVEMENT
- RAINBARREL
- BIORETENTION
- DRYPOND

- Cost Effectiveness (CE) Curve
- Selected Simulation
- All Solutions

- Selected Simulation

- $0.0 $0.5 $1.0 $1.5 $2.0 $2.5 $3.0 $3.5 $4.0 $4.5

- $0% $5% $10% $15% $20% $25% $30% $35%

- $0.0
- $0.5
- $1.0
- $1.5
- $2.0
- $2.5
- $3.0
- $3.5
- $4.0
- $4.5

Technical Approach for Pilots

- Developed a **5 Step Process** through early interactions with pilot project stakeholders
  - First identify goals/expectations for the project
  - Step 1 – Establish Baseline Conditions/Characterization
  - Step 2 – Identify BMPs to Consider
  - Step 3 – Opportunities and Constraints
  - Step 4 – Estimate Costs
  - Step 5 – Build Management Strategies

- **Watershed specific goals** developed for each pilot
  - Water quality/TMDL targets
  - Focused watershed plan implementation
  - Flood mitigation planning
Duluth Case Study
Pilot Watershed

- Pilot watershed tributary to Amity Creek and Lake Superior in Lakeside neighborhood
- 700 acres
- 70% developed, 30% forested steep slopes
- Representative slopes (7.6%) and soils
- Turbidity impaired stream
Project Goals

► Develop a cost-effectiveness curve that shows the tradeoffs between cost and sediment load reduction
► Prioritize BMP selection
► Evaluate the sensitivity of pollutant removal parameters in the modeled BMPs to quantify model sensitivity
► Summarize cost, modeled TSS reduction, and modeled flow volume reduction for five select points along the cost-effectiveness curve
Watershed Issues

- Untreated developed watershed, direct drainage to Lake Superior and Amity Creek
- Turbidity impairment in Amity Creek
- Bank failures and erosion
- Sediment loading to Lake Superior
- Watershed and in-stream sediment sources
  - Gravel roads
  - Impervious surfaces
  - Bank and channel erosion
  - Upstream sources
Baseline Model Approach

► Evaluated water quality data in Amity Creek to derive a TSS goal
► Used existing, calibrated Miller Creek SWMM model to derive unit area time series for each land use/soils combination
► Next Generation Radar (NEXRAD) derived weather data
  ▪ Watershed location, slope, and location of weather data
Water Quality and BMPs
Amity Creek Load Duration Curve
Modeled BMPs

- Rain garden
- Rain barrel
- Cistern
- Bioretention
- Porous pavement
- Green roof
- **Stormwater trees**
- **Street sweeping**
Model Results: Cost-Effectiveness Curve
Model Results: Cost-Effectiveness Curve
Key Findings

► As TSS reduction exceeds 50%, cost per unit benefit increase.
► At 50% threshold, in-stream turbidity standard is met under the mid-range and low flow conditions and BMPs contribute to flow reductions needed to minimize erosive flows in-stream during high flow conditions.
► Porous pavement = most cost-effective BMP
► Rain barrel and rain garden installations by homeowners are recommended.
► Cisterns were seldom selected although they are still viable for runoff and peak flow reduction
► Additional TSS load reductions could be achieved by paving gravel roads
Next Steps

► Complete three more pilots (Plaster Creek, Peoria Area, and Lake County)

► Update Final Contract Report with new findings, recommendations, technical notes

► Develop new technical documentation and post-processing tools

► Project complete at end of 2012
Questions/Comments?

jennifer.olson@tetratech.com
Swale Infiltration Capacity

By Farzana Ahmed, John S. Gulliver, and John L. Nieber
University of Minnesota
October 16th, 2012
Overview

• Swale Opportunities
• Background
• Measurement Method
• Measurement Results
• Forensic Infiltration Measurements
• Swale Infiltration Rates
• Conclusions
Swale Opportunities

• What is a swale?
  – Drainage ditch that treats water quality.
  – Typically 10-20% of impervious area.

• Treatment?
  – Particle Sedimentation
  – Infiltration
  – Filtration

• Swales => Excellent Opportunity for Stormwater Treatment
Background on Swale Infiltration

• Prior Research
  – Yousef, Hvitvedjacobson, Wanielista, and Harper (1987)- Swales infiltrated between 9% and 100% of road runoff.
  – Barrett (1997, 2004)- Most of the infiltration occurred along the side slope.
  – Jensen (2004)- Measured infiltration rates of 5.8 to 6.8 cm/hr
  – Abida and Sabourin (2006)- Ks = 1 – 3 cm/hr
  – Gregory, Dukes, Jones and Miller (2006)- Infiltration capacity will be greatly reduced if subject to heavy equipment loads
  – Ahearn and Tveten (2008)- 41 year old, unimproved roadside embankments- 71% to 94% infiltrated

• Groundswell for Swales
Background on Swale Infiltration

- Saturated Hydraulic Conductivity, Ksat
  - The most important soil parameter for infiltration rates
  - Sets the minimum infiltration rate

Graph:
- Infiltration Rate (cm/hr) vs. Time (hr)
- Comparison between High Initial Moisture, Low Initial Moisture, and Ksat
Purpose of this Presentation: Modified Philip-Dunne Infiltrrometer

- Falling head device
- Record W.S. elevation and time
- Measure initial and final soil moisture
- Put data into spread sheet
- Determine saturated hydraulic conductivity
- Can perform multiple measurements simultaneously
- Indicate spatial variability and measure mean Ksat and uncertainty of mean Ksat.
Ksat Measurement Method: MPD Theory

- Green-Ampt Assumptions
- Semi-circular Wetting Front
- Head (H) varies with time
Ksat Measurement Method: Application

Taking measurements in Chaska, MN  Taking measurements in Madison, WI
Measurement Results: Spatial Variation in Ksat

Spatial variation of saturated hydraulic conductivity (Ksat) of a swale located in Hwy 212
Ksat Measurement Results: Different Soil Moisture and Times ~20 measurements each

<table>
<thead>
<tr>
<th>Location</th>
<th>Moisture content (%)</th>
<th>Ksat Geometric mean (cm/hr)</th>
<th>Upper 95% confidence interval (cm/hr)</th>
<th>Lower 95% confidence interval (cm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hwy 47 (center)</td>
<td>31</td>
<td>1.5</td>
<td>4.0</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>2.9</td>
<td>7.9</td>
<td>1.0</td>
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<td>45</td>
<td>0.7</td>
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<td>0.2</td>
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<tr>
<td>Hwy 47 (north)</td>
<td>19</td>
<td>4.3</td>
<td>10.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>5.4</td>
<td>9.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Hwy 47 (south)</td>
<td>23</td>
<td>13.1</td>
<td>25.4</td>
<td>6.8</td>
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## Ksat Measurement Results:
### Different Soil Moisture and Times

~20 Measurements each

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<tbody>
<tr>
<td>Hwy 51 (center)</td>
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<td>2.0</td>
<td>5.3</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>1.9</td>
<td>4.5</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5.0</td>
<td>8.9</td>
<td>2.8</td>
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<tr>
<td>Hwy 51 (north)</td>
<td>27</td>
<td>7.9</td>
<td>16.8</td>
<td>3.8</td>
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<tr>
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<td>31</td>
<td>2.6</td>
<td>6.5</td>
<td>1.0</td>
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<td></td>
<td>30</td>
<td>7.2</td>
<td>15.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Hwy 51 (south)</td>
<td>29</td>
<td>2.4</td>
<td>6.23</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>4.2</td>
<td>10.4</td>
<td>1.7</td>
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Ksat Measurement Results: Different Soil Moisture and Times
~20 measurements each

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<th>Lower 95% confidence interval (cm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hwy 212 (center)</td>
<td>19</td>
<td>0.5</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>1.2</td>
<td>2.8</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>0.2</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Hwy 212 (east)</td>
<td>24</td>
<td>1.3</td>
<td>3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Hwy 212 (west)</td>
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<td>9.5</td>
<td>23.4</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>2.4</td>
<td>6.7</td>
<td>0.9</td>
</tr>
</tbody>
</table>
How Many Measurements?

Relationship between # of measurement and Ksat
Madison, WI Hwy 51 swale

- Geometric mean
- Upper 95% Confidence interval
- Lower 95% Confidence interval
Application of Ksat measurements to swale infiltration

- Green Ampt assumptions were used.
- 1yr 24hr storm.
- Dry soil (initial soil moisture = 20%) and wet soil (initial soil moisture = 39%)
- Swale Area = 10% of the impervious area.
- A horizontal x-section of the swale was chosen.
Estimating total infiltration
Hwy 212-1inch 24hr storm
Dry condition

11.3 cm runoff
16.6 cm runoff
12 cm runoff
16 cm runoff
Estimating total infiltration
Hwy 212- 1 inch 24hr storm
Wet condition

3.8 cm runoff
24.2 cm runoff
16.3 cm runoff
0.6 cm runoff
11 cm runoff
Forensic Infiltration:
Three swales with wetland plants

- Investigate the reason for low infiltration
  - High groundwater table or low Ksat?
- Geometric mean = 13 cm/hr
- Groundwater table was high

• Low infiltrating swale in Fridley, MN
Acknowledgements

• Minnesota Pollution Control Agency (MPCA)
  – Bruce C. Wilson, Project Manager
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  – Barbara Loida, Technical Liaison
• Minnesota Department of Transportation
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• Undergraduate researchers Anne Haws, Brad Weiss and Anthony Vecchi
Conclusions

• Spatial variation of Ksat is high
  – ~20 measurements will result in a mean Ksat within a factor of ~3.
  – ~ 6 measurements will result in a mean Ksat within a factor of ~8

• As of yet, a low Ksat at a swale has not been found in the Twin Cities Metropolitan Area
  – Low: Will not infiltrate the 1 in- 24 hr storm

• So far, swales that do not infiltrate are due to high groundwater table.
Thank you

Questions?

Duck family in a low infiltrating swale
Measurement Results

Some features:

- Five swales were selected among eighteen swales depending on soil types.
- At each swale ~20 measurements were taken.
- $K_{\text{sat}}$ values at some swales were measured for three different soil moisture contents.

Taking measurement in Hwy 212
Purpose of this Presentation

- Spatial variation of infiltration rates
- Use of Ksat for infiltration rate

Taking measurements in Hwy 51