Permeable Pavement
Hydrologic Modeling

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Presentation Overview

- Overview of Hydrologic Modeling
- Performance Standards
- Modeling Guidelines, Tools, Concepts
- Permeable Pavement Types
- Applications
  - Flow Control
  - Water Quality Treatment
  - Slope Considerations
  - Peak Flow Reduction
- Advanced Tools

Hydrologic Modeling

- Q: What is hydrologic modeling?
- A: Use of mathematical equations to estimate runoff based on:
  - weather patterns
  - landuse
  - soil
  - topography

Source: http://www.und.nodak.edu/
Hydrologic Modeling

Why do we use hydrologic models?

A1: Characterize hydrologic conditions
- Predeveloped
- Current
- Post-project

A2: Design mitigation

A3: It's fun!

When does hydrologic modeling enter into your project?

A: Start to finish
- Preliminary design (sizing)
- Final design (optimization)
- Demonstrate requirements met (permit submittals)

Performance Standards

Flow Control
- Non Exempt Receiving Water:
  - Ecology requirement to match the flow duration to predeveloped condition (typically forest)
- Combined Sewer or Capacity Constrained Basins:
  - Local requirements are typically peak-control based

Water Quality
- Infiltrate 91 percent of runoff file through soils meeting ecology treatment requirements

Wetland Protection
- Ecology guideline to maintain wetland hydroperiod
- Volume I App 1-D, Guide sheet 2
Hydrologic Modeling
Performance Standards

- **LID (Draft 2012 Ecology Manual)**
  - Match 8% 2-yr to 50% 2-yr pre-developed durations

![Flow Control MR #7](source: Ecology Presentation on Municipal Stormwater General Permit Requirements, May 29, 2011)

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Modeling Tools

- **Single-event models**
  - Appropriate for conveyance sizing

- **Continuous models**
  - Required for sizing flow control (MR7) and treatment (MR6) BMPs

- **Simplified sizing tools**
  - Represent BMP footprint area as % Imp. Area (“sizing factor”)
  - Prescribed design criteria
  - Engineer not needed for small projects (e.g., <10,000sf imp.)
  - GSI Calc available for western WA Lowlands
  - Jurisdiction-specific sizing tools also available (e.g., Seattle, Bellevue, Edmonds, Kitsap County, Pierce County)

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Modeling Tools

**Single-Event Methods**

- Input single storm event
- Output peak flow rates
- Typical methods:
  - SCS
  - SBUH
  - StormShed
  - SWMM
  - HEC-HMS
  - SUSTAIN
  - Rainfall (cfs)
  - Unmit. Runoff (cfs)
  - Mit. Runoff (cfs)
  - Time (hrs)
Modeling Tools

Continuous Models

- Input long-term rain and evaporation
- Output continuous runoff, peak flow, & duration
- Typical programs
  - HSPF
  - WWHM
  - MOSS Flood
  - KCRTS
  - SWMM
  - SUSTAIN

Modeling Tools

Simplified Sizing Tools

Kitsap County: Pavement sized as function of contributing impervious area and precipitation

<table>
<thead>
<tr>
<th>EMP</th>
<th>Design Initial Rate (in/hr)</th>
<th>Forest Standard</th>
<th>Sizing Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeable Pavement Facility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 inch ponding depth</td>
<td>0.25</td>
<td>0.1100</td>
<td>-1.0536</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.0187</td>
<td>+0.4945</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td>0.0048</td>
<td>+0.3511</td>
</tr>
<tr>
<td>Permeable Pavement Surface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope &lt;= 2%</td>
<td>0.13 – 0.249</td>
<td>0.005</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>≥ 0.25</td>
<td>0.01</td>
<td>0</td>
</tr>
</tbody>
</table>

Aggregate Depth (in) = M x Precip. (in) – B

Modeling Tools

Simplified Sizing Tools

Kitsap County Pre-Sized Calculator

GSI-Calc
Current Modeling Guidelines

  - Model as a mix of landscape/impervious on underlying soil type
  - See Section 7.1 of 2005 LID Manual
  - Advantage: simple approach
  - Drawback: greatly underestimates flow control credit

- Explicit Method
  - Model impervious surface area draining to an infiltration trench
    - Infiltration through surface
    - Storage in aggregate discharge subbase
    - Exfiltration to native soil
    - Overflow
  - MGSFlood4 and WWHM4
  - Advantage: better represents design, higher flow control credits
  - Drawback: slightly more time consuming than implicit method

Modeling Tools

HSPF Basics – Model Inputs

- Meteorological Data
  - Rainfall (5-min., 15-min., hourly)
  - Evaporation (daily)

- Land Cover Types
  - Impervious areas
    - Roof
  - Pervious areas
    - Vegetation
    - Soil type (A, B, C, D)
    - Slope
  - Regional calibrated parameters (Dinicola 1990)

- BMP Configurations

Permeable Pavement Types

“Surface” Type:
- Designed to manage rain falling on the permeable pavement area (no inflow from adjacent areas)
Permeable Pavement Types

“Facility” Type:

- May be designed to manage runoff from other areas
- Deeper aggregate subbase
- Measures to create subsurface ponding when subbase is sloped

Model Representation

Gravel Trench Parameters

- Pavement area
- Subsurface ponding depth in storage reservoir controlled by overflow or berms in subbase
- Aggregate layer thickness and porosity
- Subbase infiltration rate

Key:

- Wearing Course
- Aggregate
- Overflow

* May include additional contributing area

Model Representation

Model Configuration

- Precipitation
- Evaporation
- Runoff/Interflow
- Infiltration
- Neglected
- Gravel trench area
- Aggregate courses above overflow invert not modeled
- Void Storage
- Infiltration to native
- Overflow
- Theoretical riser

Where flow control standard must be met

Note: Only aggregate under overflow invert modeled
Model Representation
Gravel Trench Routing

Ex. Cross Sections

Ex. SSD Table

<table>
<thead>
<tr>
<th>Stage (ft)</th>
<th>Area (sf)</th>
<th>Storage (cf)</th>
<th>Infilt. (cfs)</th>
<th>Overflow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>10,000</td>
<td>1,000</td>
<td>0.0579</td>
<td>0</td>
</tr>
<tr>
<td>0.2</td>
<td>10,000</td>
<td>2,000</td>
<td>0.0579</td>
<td>0</td>
</tr>
<tr>
<td>0.3</td>
<td>10,000</td>
<td>3,000</td>
<td>0.0579</td>
<td>0</td>
</tr>
<tr>
<td>0.4</td>
<td>10,000</td>
<td>4,000</td>
<td>0.0579</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>10,000</td>
<td>5,000</td>
<td>0.0579</td>
<td>0</td>
</tr>
<tr>
<td>0.6</td>
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<td>6,000</td>
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<tr>
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<tr>
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<td>10,000</td>
<td>8,000</td>
<td>0.0579</td>
<td>87.1</td>
</tr>
</tbody>
</table>

Ex. SSD Table

0'

Exfiltration

Wearing Course

Subbase

Aggregate

Key:
Overflow

Exfiltration

Wearing Course

Subbase

Aggregate

Key:
Overflow

Exfiltration

Wearing Course

Subbase

Aggregate

Key:
Overflow

Subbase slopes 0 – 2%
→ can neglect lateral flow
→ subsurface storage depth modeled = aggregate thickness

Subbase slopes 2 – 5%
→ cannot neglect lateral flow
→ subsurface storage depth modeled = average water depth before berm
→ overflow

*Function of: slope, check dam height, and check dam spacing
Model Representation
Underlying Soil

- Design Infiltration Rate Requires Correction
- Treatment credits when 91% influent infiltrated through soils meeting Ecology requirements

Ecology Approved Correction Factors for Kitsap County

<table>
<thead>
<tr>
<th>Minimum Correction Factor</th>
<th>Permeable Pavement Surface</th>
<th>Permeable Pavement Facility</th>
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</thead>
<tbody>
<tr>
<td>Not Receiving Run-on</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Receiving Run-on from Area &lt; twice facility size</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Receiving Run-on from Area &gt; twice facility size</td>
<td>NA</td>
<td>4</td>
</tr>
</tbody>
</table>

Applications

- Duration Control (Creek Protection)
- Water Quality Treatment
- Sloped Design Consideration
- Peak Flow Reduction

Flow Control in Creek Basin
WWHM4 Example – Explicit Method

- Site in King County
- Soil is till (0.25 inch/hour design infiltration rate)
- Permeable pavement facility is 10,000 sf
- Receiving run-on from 5,000 sf of additional area
- Design goal = Ecology forest duration standard
- Size aggregate depth (ave. subsurface ponding depth)
- SIZING FOR FLOW CONTROL GOAL → May NEED TO BE THICKER TO SATISFY OTHER DESIGN GOALS (EX. LOADING)
Sizing for Flow Control

Developed Mitigated Basin: Area contributing runoff to permeable pavement...

Sizing for Flow Control

Developed Mitigated Basin Continued: Route to Porous Pavement Module

Sizing for Flow Control

Developed Mitigated Basin Continued: Characterize Porous Pavement

SSD Table

<table>
<thead>
<tr>
<th>Name</th>
<th>Pavement depth + freeboard above surface</th>
<th>Depressions storage before runoff (weir flow over edge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Stage Storage Discharge Table

Overflow Flow Duration Curve - Developed Unmitigated (Impervious)

GOAL

Flow Duration Curve - Developed Mitigated (with Porous Pavement)
Iteratively Sized Storage Aggregate Depth to Meet Duration Standard

Only 2” required to meet goal. Infiltrates almost 100% runoff.

Flow Frequency Results

Use Gringorten or Weibull Method for low annual flows.

Performance & Infiltration Rate

Example: Permeable Pavement in King County designed to achieve DOE forest standard (Facility receiving runoff from 100% of permeable pavement area)
Water Quality Treatment
Same WWHM4 Example

Sizing for Treatment
Percent infiltration: at least 91% of entire runoff infiltrates through soils meeting Ecology treatment soil requirements
Facility sized for flow control infiltrates much more than 91 percent

Further Analysis
WWHM4 Example
Slope Considerations
MGS Flood V4 Example

- Site near WSU Puyallup Extension (Extended Precip. Puget East 40)
- 10,000 sf of till forest converted to 5,000 sf porous pavement receiving runoff from 5,000 sf of impervious area
- 1 in/hour saturated hydraulic conductivity
- Evaluate berm spacing as a function of slope and depth
- Evaluate peak flow reduction
Slope Considerations

Subtract porous pavement area. Rainfall and evapotranspiration applied separately.
Slope Considerations

- Trench bottom too steep: Increase trench depth or add berms.
- First, try adding 1 berm...

Slope Considerations

- Adjust # cells and trench cell length
- 200 ft porous pavement length / 2 cells = 100 ft trench cell length

Slope Considerations

- Beautiful!
Next, let's try removing the berm and increasing the trench depth to 1.5 ft.

That works, too.

For a 3% slope, 5 berms spaced every 40 feet would be needed.
Peak Flow Reduction

Draw Hydrographs

Output Report
Resources

- LID Technical Guidance Manual
  (Draft 2012 Manual does not yet have modeling section developed)

- WWHM
  http://www.clearcreeksolutions.com/

- MGSFlood
  http://www.mgsengr.com/MGSFlood.html

- HSPF
  http://water.usgs.gov/software/HSPF/

- WDMUtils
  http://www.epa.gov/waterscience/basins/b3webdwn.htm

Questions and Answers

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