INSTRUCTORS

MEGHAN FELLER, PE
Project Engineer
Key project experience: Stormwater planning, design, hydrologic modeling, and NPDES Permit compliance

REBECCA DUGOPOLSKI, PE
Senior Engineer
Key project experience: Stormwater monitoring, design, hydrologic modeling, and NPDES Permit compliance

AGENDA

- Introduction
- Hydrologic modeling basics
- Performance standards
- BMP modeling specifics
- Wrap up
LEARNING OBJECTIVES

1. Gain a basic level of knowledge using WWHM and MGSFlood to predict pre- and post-development flow volumes and durations.
2. Learn basic, entry level skills to size bioretention, permeable pavement, rainwater collection systems, and vegetated roofs in residential and commercial settings using WWHM and MGSFlood.
3. Understand the advantages and limitations of WWHM and MGSFlood and gain an awareness of additional modeling tools for specific predictions.

LOGISTICS

SCHEDULE
6-hour training (5 hours classroom instruction, 1 hour for lunch)
Lunch is provided

OTHER LOGISTICS
• Restrooms
• Food
• Turn off cell phones
• Sign in and sign out

PROGRAM OVERVIEW
• 2012: Public and private partners engage state legislature to fund program
• June 2012: LID Training Steering Committee convened
• 2012-2013: Washington State LID Training Plan developed: www.wastormwatercenter.org/lid-background/
• 2014: Training program built from state LID Training Plan
**Program Overview**

- 42 trainings in western and eastern WA in 2015-2016.
- Three levels: Introductory, Intermediate, and Advanced.
- Statewide LID Certificate now available.

**Core Team**

- Herrera
- Cascadia

**Additional Training Support**

- Ch2m
- M&L
- SR
- Kindred
- Hydro
- Mithun

**Overview of Program**

**Introduction to LID for Inspection & Maintenance Staff**

**Intermediate LID Design: Rainwater Collection Systems & Vegetated Roofs**

**Intermediate LID Design: NPDES Phase I & II Requirements**

**Intermediate LID Design: Permeable Pavement**

**Intermediate LID Design: Hydrologic Modeling**

**Advanced Topics in LID Design: Bioretention Media and Compost Amended Soils**

**Advanced Topics in LID Design: Permeable Pavement**

**Advanced Topics in LID Design: Hydrologic Modeling**

**Advanced Topics in LID Design: Site Assessment, Planning & Layout**

**Advanced Topics for Long-term LID Operations: Bioretention**

**Advanced Topics for Long-term LID Operations: Permeable Pavement**

**Advanced Topics for Long-term LID Operations: Hydrologic Modeling**

**Advanced Topics for Long-term LID Operations: Site Assessment, Planning & Layout**
Introduction to LID for Inspection & Maintenance Staff

Intermediate LID Design:
Rainwater Collection Systems & Vegetated Roofs

Intermediate LID Topics:
NPDES Phase I & II Requirements

Intermediate LID Design: Permeable Pavement

Intermediate LID Design: Hydrologic Modeling

Advanced Topics in LID Design: Bioretention Media and Compost Amended Soils

Advanced Topics in LID Design: Permeable Pavement

Advanced Topics in LID Design: Hydrologic Modeling

Advanced Topics in LID Design: Site Assessment, Planning & Layout

Advanced Topics in LID Design: Rainwater Collection Systems & Vegetated Roofs

Advanced Topics for Long-term LID Operations: Remediation

Overview of Program

Intermediate LID Design:
Hydrologic Modeling

Training Program Statewide LID

Intermediate LID Design:
Hydrologic Modeling

Introduction

Hydrologic Modeling Basics

Performance Standards

BMP Modeling Specifics

Wrap Up
LID PRINCIPLES:

INTRODUCTION

HOW DO WE GET THERE?

• Quantify the effects of development
• Size and evaluate the performance of stormwater management practices
TRADITIONALLY...
• Primarily detention and large scale infiltration
• Detention pond/vault/pipe or infiltration pond/gallery

REGIONAL MANAGEMENT

INTRODUCTION

REGIONAL MANAGEMENT
• Detention hydrograph (single event)

REGIONAL MANAGEMENT
• Match peak flows, increased duration:
  • Ok for piped system with direct discharge to a lake or ocean?
  • Ok for discharge to a creek?
  • Ok for discharge to a wetland?

REGIONAL MANAGEMENT
• May limit erosive flows in stream but we have not mimicked hydrologic cycle (no evaporation, no groundwater recharge, different hydrograph)
INTRODUCTION

FLOW DURATIONS

- Detention (continuous simulation)
- Match peaks and durations
  - Durations \( \rightarrow \) percent of time a particular flow occurs

---

INTRODUCTION

LOW IMPACT DEVELOPMENT (LID):
Stormwater Management Strategy

- Site design & planning techniques emphasizing conservation
- Use of small-scale & distributed engineered controls to closely mimic pre-development hydrologic processes
- Minimizing the concentration of stormwater
- Careful assessment of site soils and strategic site planning to best use those soils for stormwater management

---

INfiltration VS Detention

If not detention, then what?

---

INTRODUCTION

FLOW DURATIONS

\[ \text{Exceedance Probability} \]

\[ \text{Flow (cfs)} \]

Predeveloped
Postdeveloped

---
**LID Principles: Site Design And Planning**

- Minimize disturbance
- Reduce impervious surface
- Protect and restore native soils and vegetation
- Manage stormwater close to the source in a system of distributed practices
- Disconnect impervious surfaces

**Traditional**

**LID**

**LID BMPs: Small-Scale Engineering Controls**

- Infiltration
- Filtration
- Storage
- Evaporation
- Transpiration

Conserve or regain pre-developed hydrologic functions

**Synonyms for LID BMPs:**

Green Stormwater Infrastructure (GSI), Integrated Management Practices (IMP), and On-Site Stormwater Management BMPs
LID PRINCIPLES: Stormwater Impacts

HOW DO WE GET THERE?
• Quantify the effects of development
• Size and evaluate the performance of stormwater management practices

HYDROLOGIC MODELING

PURPOSE OF HYDROLOGIC MODELING

• Q: What is hydrologic modeling?
  • A: Use of mathematical equations to estimate hydrologic cycle components and facility performance based on:
    • Weather patterns
    • Land use
    • Soil
    • Topography

PURPOSE OF HYDROLOGIC MODELING

• Q: Why do we use hydrologic models?
  • A: Characterize hydrologic conditions:
    • Predeveloped
    • Current
    • Post-project
    • Design mitigation
PURPOSE OF HYDROLOGIC MODELING

Q: When does hydrologic modeling enter into your project?

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

MODELING TOOLS

MODELING TOOLS: Single-Event Models

• Input single storm event, typically synthetic
• Output peak flow rates
• Typical methods and models
  - SCS
  - SBUH
  - Rational Method
  - StormShed
  - HydroCAD
  - SWMM
  - HEC-HMS
  - SUSTAIN
MODELING TOOLS: Continuous Models

- Input long-term rain and evaporation
- Output continuous runoff, peak flow, & duration
- Accounts for antecedent conditions
  - Is the soil already saturated?
  - Is your bioretention facility already full of water?
- Common models:
  - HSPF
  - WWHM
  - MGS Flood
  - KCRTS
  - SUSTAIN
  - SWMM
  - InfoWorks

MODELING TOOLS: WWHM/MGSFlood Input

- Meteorological Data
  - Rainfall (5-min, 15-min, hourly)
  - Evaporation (daily)
- Land Cover Types
  - Regional calibrated parameters (Dinicola 1990)
  - Impervious areas
    - Timing: slope, length of flow path, surface roughness
    - Volume: depression storage
  - Pervious areas
    - Timing: slope, length of flow path, surface roughness
    - Volume: depression storage, vegetative cover, soil type
- BMP Configurations
MODELING TOOLS: WWHM/MGSFlood Input

- Meteorological Data
  - Select precipitation region
  - Select mean annual precipitation depth

MODELING TOOLS: WWHM/MGSFlood Input

- Meteorological Data
  - Select precipitation region
  - Select mean annual precipitation depth

MODELING TOOLS: WWHM/MGSFlood Input

- Land Cover

By comparison...
HYDROLOGIC MODELING BASICS

MODELING TOOLS: Simplified Sizing Tools

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

<table>
<thead>
<tr>
<th>BMP</th>
<th>Flow Control Standard (MR #7)</th>
<th>Sizing Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeable Pavement Facility</td>
<td>0.25</td>
<td>0.1000</td>
</tr>
<tr>
<td>6 inch ponding depth</td>
<td>0.5</td>
<td>0.0187</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>0.0048</td>
</tr>
</tbody>
</table>

Area (ft²) = Impervious Area (ft²) x [M x Precip. (in) + B]

Permeable Pavement Surface

Slope <= 2% 0.13 – 0.249
≥ 0.25 0.005 0.01

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

Kitsap County Pre-Sized Calculator

GSI-Calc

**Introduction**

**Hydrologic Modeling Basics**

**Performance Standards**

**BMP Modeling Specifics**

**Wrap Up**
NPDES MUNICIPAL STORMWATER PERMIT:
Minimum Requirements (MRs)

1. Preparation of Stormwater Site Plans
2. Construction Stormwater Pollution Prevention Plan (SWPPP)
3. Source Control of Pollution
4. Preservation of Natural Drainage Systems and Outfalls
5. On-Site Stormwater Management
6. Run-off Treatment
7. Flow Control
8. Wetlands Protection
9. Operations and Maintenance

MINIMUM REQUIREMENT #5

Implementation options:
- List #1
- List #2
- LID Performance Standard

MINIMUM REQUIREMENT #5

MR #5 applies to:
- Projects triggering MR #1-#5 only
  ➔ List #1 or LID Performance Standard Applies
- Projects triggering MR #1-#9
  ➔ List #2 or LID Performance Standard Applies
### PERFORMANCE STANDARDS

#### MINIMUM REQUIREMENT #5: Projects

<table>
<thead>
<tr>
<th>Project Type &amp; Location</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development (new or redevelopment) on any parcel inside the UGA, or development outside the UGA on a parcel less than 5 acres</td>
<td>LID Performance Standard and BMP T5.13 OR List #2 (applicant option)</td>
</tr>
<tr>
<td>Development (new or redevelopment) outside the UGA on a parcel of 5 acres or larger</td>
<td>LID Performance Standard and BMP T5.13</td>
</tr>
</tbody>
</table>

---

#### MINIMUM REQUIREMENT #5: List Option

Consider all the BMPs in the order listed and use the first BMP that is considered feasible.

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#### MINIMUM REQUIREMENT #5: List #1

1. Soil Quality and Depth (BMP T5.13)
2. Rain Gardens or Bioretention (T5.14A or B)
3. Perforated Stub-out Connections (T5.10C)
4. Full Dispersion (T5.30)
5. Permeable Paveiment, Rain Gardens, or Bioretention • (T5.15, T5.14A, T5.14B) • Rain Garden or Bioretention area > 5% of drainage area • Sheet Flow Dispersion, or Concentrated Flow Dispersion (T5.12 or T5.11)

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#### MINIMUM REQUIREMENT #5: List #2

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MINIMUM REQUIREMENT #5: LIST #2

Lawn and Landscaped Areas

1. Soil Quality and Depth (BMP T5.13)

Roofs

1. Full Dispersion or Downspout Full Infiltration (T5.30 or T5.10A)
2. Bioswale (T5.14B)
   • >5% of drainage area
3. Downspout Dispersion Systems (T5.10B)
4. Perforated Stub-out Connections (T5.10C)

Other Hard Surfaces

1. Full Dispersion (T5.30)
2. Permeable Pavement (T5.15)
3. Bioswale (T5.14B)
   • >5% of drainage area
4. Sheet Flow Dispersion, or Concentrated Flow Dispersion (T5.12 or T5.11)

MINIMUM REQUIREMENT #5:
LID PERFORMANCE STANDARD

Match pre-developed durations from 8% of the 2-year peak flow to 50% of the 2-year peak flow

Flow Control Standard addresses lower, more frequent stormwater flows

LID Performance Standard addresses higher, less frequent stormwater flows

PERFORMANCE STANDARDS
MINIMUM REQUIREMENT #6 and #7:

- Runoff treatment (MR #6)
  - Infiltrate 91 percent of the total runoff volume through soil meeting Ecology treatment criteria (for infiltration BMPs)

- Flow Control (MR# 7)
  - Match pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow

- Other flow control standards
  - Combined sewer or capacity constrained basins (peak-based standards): apply only in specific cities with flow control exempt areas with limited conveyance capacity
  - Wetland protection
FLOW DURATION STANDARDS

- LID performance standard (MR #5)
- Flow control (MR #7)

Flow Duration Plot

SIZING COMPARISON EXAMPLE: Bioretention

- Precipitation: 38 inches annually (Seattle)
- Predeveloped condition: Forest on till
- Design Infiltration Rate: 0.25 inch/hour

<table>
<thead>
<tr>
<th>LID Standard</th>
<th>Flow Duration Standard</th>
<th>Treatment Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000 sf</td>
<td>5,000 sf</td>
<td>5,000 sf</td>
</tr>
<tr>
<td>240 sf</td>
<td>1090 sf</td>
<td>1410 sf</td>
</tr>
<tr>
<td>5.1%</td>
<td>27.8%</td>
<td>6.2%</td>
</tr>
</tbody>
</table>

LID COST ANALYSIS: Small Commercial

- Lot 1 Acre
- Total Impervious 35,500 sf
- Roof Area: 5,000 sf
LID COST ANALYSIS: 2012 manual (with LID)

introduction
hydrologic modeling basics
performance standards
BMP modeling specifics
wrap up

BIORETENTION
PERMEABLE PAVEMENT
VEGETATED ROOFS
CISTERNS

DISPERSION
MINIMAL EXCAVATION
FOUNDATIONS
REVERSE SLOPE SIDEWALKS
**BIORETENTION: Definition and Types**

- Shallow landscaped depressions that receive stormwater from small contributing areas
- Small scale, dispersed facilities
- Types:
  - With underdrain
  - Without underdrain
  - With underdrain and liner

**BIORETENTION: Without Underdrain**

- Relies on infiltration to native soil
- Can meet on-site list requirement
- Can provide effective WQ treatment for some pollutants
- Can meet the flow control standard (MR #7) for many soil conditions
**BIORETENTION: With Underdrain**

- Some infiltration to native soil
- Can meet on-site list requirement (List #2 requires the underdrain to be elevated at least 6 inches)
- Can provide effective WQ treatment for some pollutants
- May not be able to meet flow control standard (MR #7) alone, but can help to achieve flow control goals (raised underdrain and orifice improve performance)

**BIORETENTION: With Underdrain and Liner**

- No infiltration to native soil
- Can provide effective WQ treatment for some pollutants
- Cannot meet flow control standard (MR #7) alone, but can help to achieve flow control goals (orifice improves performance)

**BIORETENTION: Current Modeling Guidelines**

- Implicit Method (2012 LID Manual)
  - Lump surface ponding and storage in bioretention soil if
    - Subgrade infiltration rate < long-term bioretention soil infiltration rate
    - Slope ≤ 1%
  - Effective depth = ponding depth + bioretention soil depth x void ratio (%)
  - MGS Flood and WWHM3
  - Neglects movement of water through layers
BIORETENTION: Current Modeling Guidelines

- **Explicit Method**
  - Explicitly represents:
    - Surface ponding
    - Infiltration into bioretention soil and native soil
    - Storage in bioretention soil
    - Overflow
    - Underdrain flow
  - MGSFlood4, WWHM4, WWHM2012

**Key:**
- **Effective subsurface storage**
- **Overflow**
- **Subbase**

**Legend:**
- **Inflow**
- **Side slope**
- **Effective depth**
- **Freeboard**
- **Underdrain**
- **Swale**
BIORETENTION: Model Representation

Explicit Surface Routing

Surface SSD Table

\[
\begin{array}{cccc}
\text{Stage (ft)} & \text{Area (ac)} & \text{Storage (ac-ft)} & \text{Discharge (cfs)} \\
0.0 & 0 & 0 & 0 \\
0.2 & 0.0070 & 0.0056 & 0.0035 \\
0.4 & 0.0075 & 0.0058 & 0.0038 \\
0.6 & 0.0081 & 0.0060 & 0.0041 \\
0.8 & 0.0086 & 0.0063 & 0.0044 \\
0.9 & 0.0089 & 0.0064 & 0.8 & 0.0045 \\
1.0 & 0.0092 & 0.0065 & 1.5 & 0.0046 \\
\end{array}
\]

BIORETENTION: Sizing for LID Performance Standard

- WWHM2012 Example - Explicit Method
  - Site in Seattle
  - Size bioretention cell to meet LID Performance Standard
  - Predeveloped condition = forest on till
  - Native soil is till (0.3 inch/hour design infiltration rate)
  - Bioretention cell (12" ponding depth, no underdrain)
  - Receiving runoff from 2,000 sf of impervious area (0.046 acres)
  - Using bioretention module in WWHM2012
  - 15 minute time-step
BIORETENTION: Sizing for LID Performance Standard

- Precipitation/Evap. Data ➔ Select county and location on map
- Computational Time Step ➔ 15 minutes

Option Menu

Predeveloped Basin ➔ Select area, soil type, land cover and slope

Predeveloped Basin ➔ Point of Compliance
BIORETENTION: Sizing for LID Performance Standard

Developed Mitigated Basin → Impervious with same area and slope...

BMP MODELING SPECIFICS

BIORETENTION: Sizing for LID Performance Standard

Developed Mitigated Basin (continued): Route to Bioretention Module

BMP MODELING SPECIFICS

BIORETENTION: Sizing for LID Performance Standard

Developed Mitigated Basin (continued): Characterize Bioretention

BMP MODELING SPECIFICS
BIORETENTION: Sizing for LID Performance Standard

**Soil Inputs**

- Wilting point (cm³ water/cm³ soil)
- Porosity (fractional)
- Saturated hydraulic conductivity (cm/hr)
- Van Genuchten number (constant)
- Alpha hydraulic parameter constant (constant)
- Hydraulic parameter constant (constant)
- Bubbling pressure head (cm)

*15.24 cm/hr = 6 in/hr (this value will need to be manually updated to 30.48 cm/hr in order to use the 12 in/hr BSM infiltration rate allowed in the 2014 SWMWW)*

**Stage Storage Discharge Table**

**Flow Duration Curve - Developed Unmitigated (Impervious)**

GOAL
BIORETENTION: Sizing for LID Performance Standard

- Iteratively sized Bioretention Area to meet Duration Standard
- Bioretention bottom area = 20 sf (1% of contributing impervious area)
- Footprint area = 65 sf (3.3% of contributing impervious area)
  (given 12” ponding, 6” freeboard, 3:1 side slopes)
- Infiltrates almost 90% runoff

BIORETENTION: Sizing for Flow Control

- Flow Frequency Results

BMP MODELING SPECIFICS

- Hydrologic Modeling
- Intermediate Topics in LID Design
BIORETENTION: Sizing for Flow Control

Flow Frequency Results

Use Gringorten or Weibull Method for low annual flows

Iteratively Sized Bioretention Area to Meet Duration Standard

Bioretention bottom area = 370 sf (18.5% of contributing impervious area)
Footprint area = 550 sf (27.5% of contributing impervious area)
given 12" ponding, 6" freeboard, 3:1 side slopes

Infiltrates almost 100% runoff

BIORETENTION: Water Quality Treatment

Iteratively Size to Infiltrate 95% Runoff File

Bioretention bottom area = 22.8 sf (1.14% of contributing impervious area)
Footprint area = 76.8 sf (3.8% of contributing impervious area)
given 12" ponding, 6" freeboard, 3:1 side slopes

Infiltrates 95%
BIORETENTION: Water Quality Treatment

Check Drawdown Criterion: WQ volume infiltrated through facility in 48 hours

Volume infiltrated in 48 hrs = ponding area at mid-depth x infiltration rate x 48 hrs

= 40.8 sf x 0.3 in/hr x 48 hrs = 49 cf = 0.001124 acre-ft < 0.001 acre-ft

Does not meet Ecology recommendation

BIORETENTION: MGSFlood

GSI-Calc Overview
**GSI-Calc Overview**

- Sizing tool for LID BMPs as a function of:
  - Site precipitation region & mean annual precipitation
  - Contributing impervious area
  - Predominant site soil type (till or outwash)
  - Native soil design infiltration rate
- Assist developers & reviewers to size/design LID without continuous modeling
- Reduce barriers to LID implementation

**GSI-Calc Applicability**

- Lowland areas of Western WA
  - Up to 1,500 feet above sea level
  - Higher elevations impacted by snow accumulation/melt
- Projects subject to selected standards:
  - Ecology flow control standard in MR #7* (match 50% of 2-year to 50-year to forest condition)
  - Ecology treatment standard for infiltration BMPs (infiltration 91% through soil meeting requirements)
  - Kitsap County predeveloped recharge standard* (Kitsap County only)

*Predeveloped forest on till and outwash soil evaluated

**GSI-Calc Applicability**

- Native Soil Infiltration Rates:
  - Predominantly underlain by till: 0.125 to >0.5 in/hr
  - Predominantly underlain by outwash: 0.5 to >3 in/hr
- Contributing Area = Impervious Surface
  - If a drainage area is mix of impervious and pervious (and the pervious area requires mitigation), could use total area for conservative facility size
  - Hope to add pervious surface runoff into future version
LID BMPs

- Bioretention (3H:1V side slopes) with and without underdrain
- Linear Bioretention (3H:1V side slopes) without underdrain
- Bioretention Planter (vertical walls) with underdrain
- Permeable Pavement Surface low slope and higher slope
- Newly Planted and Retained Trees with underdrain

Precipitation Modeled

- Western Coastline: 70 & 90 in/yr
- Vancouver Castle Rock Corridor: 40, 56, & 80 in/yr
- Western Puget Sound: 32, 40, 48, 56, & 80 in/yr
- Eastern Puget Sound: 24, 40, 48, 56, & 80 in/yr

Selected precip/evap timeseries were modeled for each region

GSI-Calc Tour

- Site Precipitation Zone
- Mean Annual Precipitation (in)
- Enter manually or use Google Earth
PERMEABLE PAVEMENT: Definition and Types

- Paved surfaces that allow infiltration, treatment, and storage of stormwater
- Can be designed to accommodate pedestrian, bicycle, and auto traffic
- Types
  - Porous asphalt or warm-mix asphalt pavement (porous asphalt)
  - Pervious Portland cement concrete (pervious concrete)
  - Permeable interlocking concrete pavers (PICPs)
  - Grid systems made of concrete or plastic (reinforced grass and gravel)

PERMEABLE PAVEMENT: 0-2% subgrade slope

- Can neglect lateral flow
- Subsurface storage depth modeled = aggregate thickness

PERMEABLE PAVEMENT: > 2 to 5% subgrade slope without berms

- Cannot neglect lateral flow
- Subsurface storage depth modeled = average subsurface ponding depth (when no berms, may be estimated as = 1/2")
PERMEABLE PAVEMENT: > 2 to 5% subgrade slope with berms

• Cannot neglect lateral flow

Subsurface storage depth modeled = average subsurface ponding depth
  + water depth before berm overtopping* or overflow
  + Function of slope, check dam height, and check dam spacing

PERMEABLE PAVEMENT: Run-on

• Run-on:
  • Always designed to manage rain falling on the permeable pavement area
  • May also be designed to mitigate run-on (flow from other areas)
**PERMEABLE PAVEMENT: Current Modeling Guidelines**

<table>
<thead>
<tr>
<th>Base Material</th>
<th>Underdrain</th>
<th>Subgrade Slope</th>
<th>Model Surface as</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Surrounding Grade</td>
<td></td>
<td></td>
<td>Impervious surface</td>
</tr>
<tr>
<td>Yes – not elevated</td>
<td>Any</td>
<td></td>
<td>Impervious surface</td>
</tr>
<tr>
<td>Yes – elevated</td>
<td>Any</td>
<td></td>
<td>Grass over underlying soil type (silts or outwash)</td>
</tr>
<tr>
<td>No</td>
<td>Any</td>
<td></td>
<td>Impervious surface</td>
</tr>
<tr>
<td>Partially or Below Surrounding Grade</td>
<td></td>
<td></td>
<td>Impervious surface</td>
</tr>
<tr>
<td>Yes – not elevated</td>
<td>Any</td>
<td></td>
<td>Impervious surface</td>
</tr>
<tr>
<td>Yes – elevated</td>
<td>Any</td>
<td></td>
<td>Impervious surface routed to gravel infiltration trench (same size as the pavement area). Trench depth = aggregate depth below surrounding grade</td>
</tr>
<tr>
<td>No</td>
<td>0-2%</td>
<td></td>
<td>Same as &quot;Yes – elevated&quot;</td>
</tr>
<tr>
<td>&gt;2%</td>
<td></td>
<td></td>
<td>Impervious surface routed to gravel infiltration trench (same size as the pavement area). Trench depth = subsurface storage depth if berms (nominal 1/2 inch if no berms)</td>
</tr>
</tbody>
</table>

**PERMEABLE PAVEMENT: Gravel Trench Model Representation**

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

* May include additional contributing area

**BMP MODELING SPECIFICS**

**PERMEABLE PAVEMENT: Gravel Trench Model Representation**

- **Precipitation**
- **Evaporation**
- **Infiltration**
- **Overflow**
- **Pavement area**
- **Gravel trench area**
- **Model Configuration**
- **Only aggregate available for storage is modeled**

- **Where flow control standard must be met**
- **Note:** Only aggregate under overflow invert modeled
PERMEABLE PAVEMENT: Gravel Trench Model Representation

Gravel Trench Routing

Ex. Cross Sections

Stage (ft)

Area (ac)

Storage (ac-ft)

Discharge (cfs)

Infilt. (cfs)

0.0 0 0 0 0

0.1 0.2296 0.0230 0 0.0579

0.2 0.2296 0.0459 0 0.0579

0.3 0.2296 0.0689 0 0.0579

0.4 0.2296 0.0918 0 0.0579

0.5 0.2296 0.1148 0 0.0579

0.6 0.2296 0.1377 0 0.0579

0.7 0.2296 0.1607 31.8 0.0579

0.8 0.2296 0.1837 87.1 0.0579

PERMEABLE PAVEMENT: Sizing for Flow Control

- WWHM2012 Example – Explicit Method
  - Site in King County
  - Soil is till (0.25 inch/hour design infiltration rate)
  - Permeable pavement parking lot is 10,000 sf
  - Receiving run-on from 5,000 sf of additional area
  - Design goal = Ecology Flow Control standard (assuming a predeveloped forest condition)
  - Size aggregate depth (av. subsurface ponding depth)
  - SIZING FOR FLOW CONTROL GOAL → MAY NEED TO BE ThICKER TO SATISFY OTHER DESIGN GOALS (EX. LOADING)
PERMEABLE PAVEMENT: Sizing for Flow Control

Predeveloped Basin → Select area, soil type, land cover and slope

BMP MODELING SPECIFICS

15,000 sf

BMP MODELING SPECIFICS

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

5,000 sf
PERMEABLE PAVEMENT: Sizing for Flow Control
Developed Mitigated Basin (continued): Route to Permeable Pavement Module

PERMEABLE PAVEMENT: Sizing for Flow Control
Developed Mitigated Basin (continued): Characterize Permeable Pavement

PERMEABLE PAVEMENT: Sizing for Flow Control
Stage Storage Discharge Table

BMP MODELING SPECIFICS
Statewide LD Training Program
HYDROLOGIC MODELING
INTERMEDIATE TOPICS IN LD DESIGN
PERMEABLE PAVEMENT: Sizing for Flow Control

Flow Duration Curve - Developed Unmitigated (Impervious)

GOAL

BMP MODELING SPECIFICS

PERMEABLE PAVEMENT: Sizing for Flow Control

Flow Duration Curve - Developed Mitigated (with Permeable Pavement)

ITERATIVELY SIZED STORAGE AGGREGATE DEPTH TO MEET DURATION STANDARD

Infiltrates almost 100% runoff

5.5" required to meet goal
PERMEABLE PAVEMENT: Sizing for Flow Control

Flow Frequency Results

Use Gringorten or Weibull Method for zero annual flows.

PERMEABLE PAVEMENT: Sizing for Flow Control

Example: Permeable Pavement in King County designed to achieve Creek Protection Duration Standard (Forest on Till)

Example Aggregate Storage Reservoir Depth by Infiltration Rate

PERMEABLE PAVEMENT: Sizing for Treatment

Percent Infiltration - at least 91% of entire runoff file
Infiltration through soils meeting Ecology treatment soil requirements

Facility sized for flow control infiltrates much more than 91%.
VEGETATED ROOFS: Definition and Types

- Thin layers of engineered soil and vegetation constructed on top of conventional flat or sloped roofs
- Types:
  - Green roofs
  - Living roofs
  - Eco-.roofs
  - Roof gardens

VEGETATED ROOFS: Current Modeling Guidelines*:

* Implicit method

- 3-8” growing media ➔
  - Model as 50% till landscaped / 50% impervious area

- > 8” growing media ➔
  - Model as 50% till pasture / 50% impervious area

VEGETATED ROOFS: Current Modeling Guidelines: explicit method

Modified PERLND

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<th>Standard SWMM4 Value</th>
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Value for 0% soil cover, fat slope

* Values dependent on depth of material; values shown for Portland east and west roofs: 3 inches and 5 inches of material, respectively.

Source: SWMM3 Eco-Roof Documentation, Memorandum prepared by Clear Creek Solutions to Seattle Public Utilities, December 7, 2005.
VEGETATED ROOFS: Sizing for Flow Control

- 1 acre vegetated roof
- Location: Seattle
- Performance relative to Ecology Flow Control Standard
- Predeveloped condition is till forest

Select Precipitation

Define Predeveloped Condition
VEGETATED ROOFS: Sizing for Flow Control

MGSFlood Module

Vegetated roof reduces downstream BMP size

VEGETATED ROOFS: WWHM

BMP MODELING SPECIFICS

BIODIVERSITY
FLOODWATER MANAGEMENT
VEGETATED ROOFS
CISTERNS
DISPERSION
MINIMAL EXCAVATION
FOUNDATIONS
REVERSE SLOPE SIDEWALKS
CISTERNs: Definition and Types

- Typical in environments where rainfall or other conditions limit water supply
- Collects and stores runoff from roofs, or other surfaces
- Above or below ground cisterns
- Various materials:
  - Fiberglass
  - Polyethylene
  - Concrete

CISTERNs: Types

- Detention
  - Typically below ground
  - Slows runoff entering the stormwater system
- Harvesting
  - Typically above ground
  - Water is reused for irrigation or plumbing

CISTERNs: Current Modeling Guidelines: detention cisterns

- Explicitly Modeled
  - Vault/tank with low flow orifice and overflow
- Orifice Limitations
  - Minimum orifice size typically will not achieve creek protection flow duration standards
- Uses
  - Useful tool for CSO control
  - Upstream of bioretention

Note: No recommendations in 2005 or 2012 LID Manual
CISTERNS: Current Modeling Guidelines:

- Explicitly Model
  - Estimate average annual runoff volume \( V \) using continuous model
  - Size cisterns to provide storage, \( V \)
  - For interior reuse, perform monthly water balance
  - Subtract roof area from site-wide model if sizing flow control or water quality treatment

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DISPERSION: Definition and Types

- Vegetated areas that collect runoff from impervious surfaces
- Restores the natural drainage patterns of sheet flow and infiltration
- Types:
  - Full dispersion
  - Downspout dispersion
  - Concentrated flow dispersion
  - Sheet flow dispersion
DISPERSION: Current Modeling Guidelines

**Full Dispersion**
- Residential developments that implement full dispersion are assumed to fully meet the treatment and flow control requirements and do not have to use approved runoff models to demonstrate compliance.

**Downspout Dispersion**
- Used to disperse runoff onto an undisturbed native landscape area or area that meets BMP T5.13
- Vegetated flow path must be at least 50 feet
- WWHM2012: model connected roof area as a lateral flow impervious area (connect the dispersed impervious area to the lawn/landscape lateral flow soil basin element)
- For multiple downspouts, Ecology may allow the roof area to be modeled as a landscaped area.

**Concentrated Flow Dispersion**
- Used to disperse runoff onto an undisturbed native landscape area or area that meets BMP T5.13
- Vegetated flow path must be at least 50 feet
- WWHM2012: model impervious area as a lateral flow impervious area (connect the dispersed impervious area to the lawn/landscape lateral flow soil basin element)
- For multiple concentrated flow dispersion areas, Ecology may allow the impervious area to be modeled as a landscaped area.
**DISPERSION: Current Modeling Guidelines**

- **Sheet Flow Dispersion**
  - Used to disperse runoff onto an undisturbed native landscape area or area that meets BMP T5.13
  - WWHM2012: model impervious area as a lateral flow impervious area (connect the dispersed impervious area to the lawn/landscape lateral flow soil basin element)
  - For multiple sheet flow dispersion areas, Ecology may allow the impervious area to be modeled as a landscaped area

**MINIMAL EXCAVATION FOUNDATIONS:**

**Definition**

- Limit soil disturbance
- Allow storm flows to more closely approximate natural shallow subsurface interflow paths
MINIMAL EXCAVATION FOUNDATIONS:
Current Modeling Guidelines

• Roof runoff dispersed on up gradient side of structure
  • Dispersion per BMP T5.10 (downspout dispersion)
  • Model roof as pasture on native soil
  • Highest credit available
  • Note: Area receiving credit reduced when step-forming is used on a slope

BMP MODELING SPECIFICS

MINIMAL EXCAVATION FOUNDATIONS:
Current Modeling Guidelines

• Roof runoff dispersed on down gradient side of structure
  • Dispersion per BMP T5.10 (downspout dispersion) AND at least 50 ft of vegetated flow path that meets BMP T5.13
  • Model roof as the connected roof area as a lateral flow impervious area (connect the dispersed impervious area to the lawn/landscape lateral flow soil basin element)
### REVERSE SLOPE SIDEWALKS: Definition

- Sidewalks sloped to drain away from the road and onto adjacent vegetated areas

### Design Criteria

- Greater than 10 feet of vegetated surface downslope that is not directly connected into the storm drainage system
- Vegetated area receiving flow from sidewalk must be native soil or meet guidelines in BMP T5.13

### REVERSE SLOPE SIDEWALKS: Current Modeling Guidelines

- In WWHM3, enter sidewalk as lawn/landscape on native soil
- In WWHM2012, use the lateral flow elements to send the impervious area runoff onto the lawn/landscape that will be used for dispersion

### EXERCISE 2
ONLINE EVALUATION

• An on-line evaluation will be sent to you within 5 days following this training.
• Feedback will help to refine future trainings.

Two certificates:
• LID Design certificate.
• LID Operations and Maintenance certificate.

You will receive an e-mail with login information following relevant courses.

LID Certificate Program Policies Page:
www.wastormwatercenter.org/lid-certificate-policies

Remember to sign in and sign out!

For information on training and other resources, visit the Washington Stormwater Center website:
http://www.wastormwatercenter.org

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Further questions? Contact:
training@cascadiaconsulting.com
(206) 449-1163