Statewide LID Training Program

INSTRUCTORS

Curtis Hinman
Senior Scientist
Key project experience: research specialist in the performance and design of LID applications.

CHRIS WEBB, PE
LEED FELLOW
Associate Engineer
Key project experience: permeable pavement, bioretention, rainwater harvesting

AGENDA

1. Introduction
2. Water quality treatment
3. Bioretention siting and design
4. Construction, inspection & verification
5. Wrap-up
LEARNING OBJECTIVES

1. Gain an intermediate level knowledge necessary for proper entry level design of bioretention systems.
2. Learn skills necessary for basic site assessment and locating bioretention areas in residential and commercial settings.
3. Learn practical skills necessary for construction of basic bioretention systems.

LOGISTICS

SCHEDULE
8-hour training
Lunch on your own
45 minute site visit

OTHER LOGISTICS
• Restrooms
• Food
• Turn off cell phones
• Sign in and sigh 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.wastormwaterscenter.org/statewide-lid-training-program-plan
• 2014: Training program built from state LID Training Plan.
• Implement first phase of trainings (September 2014 through May 2015)
• 64 trainings offered in first phase
• Three levels: Introductory, Intermediate, and Advanced
• Train the Trainer program for service providers and LID topic experts
• Anticipate two more years of funding.

PROJECT LEAD

CORE TEAM

INTRODUCTORY

INTERMEDIATE

ADVANCED

1.0 Introduction to LID for Eastern Washington
2.1 Introduction to LID for Inspectors & Maintenance Staff
2.2 Introduction to LID for Developers & Contractors for Infill
3.1 Intermediate LID – WPDES Phase I & II Requirements
3.2 Intermediate LID Design: Site, Planning & Layout
3.3 Intermediate LID Design: Sustainable Stormwater Management
4.1 Intermediate LID Design: Rainwater Harvesting & Rain Gardens

5.1 Advanced Topics in LID Design, Maintenance
5.2 Advanced Topics in LID Design, Sustainable Stormwater Management
5.3 Advanced Topics for LID Operations, Maintenance
5.4 Advanced Topics for LID Operations, Sustainable Stormwater Management
6.0 Advanced Topics in LID Design, Maintenance Modeling
7.0 Advanced Topics in LID Design, Sustainable Stormwater Management, Planning & Layout
8.0 Advanced Topics in LID Design, Sustainable Stormwater Management & Operation
9.1 LID Topic Experts

TRAIN THE TRAINERS

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2.1 Introduction to LID for Inspectors & Maintenance Staff
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Introduction to LID for Eastern Washington

Intermediate LID Design - Bioretention

Intermediate LID Design - Permeable Pavement

Intermediate LID Design - Hydrologic Modelling

Train the Trainers

Introduction to LID for Inspection & Maintenance Staff

Introduction to LID for Developers & Contractors: Make Money be Green

Intermediate LID Design: Rainwater Collection Systems & Vegetated Roofs

Intermediate LID Design: NPDES Phase I & II Requirements

Intermediate LID Design: Permeable Pavement

Advanced Topics in LID Design: Hydrologic Modeling

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

Advanced Topics in LID Design: Bioretention Media

Advanced Topics for LID Operations: Bioretention

Advanced Topics for LID Operations: Permeable Pavement

Advanced Topics for LID Operations: Hydrologic Modeling

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

LID Topic Experts

New Permit Requirements for local governments on 3 levels:
- Building site and subdivision
- Municipal (codes)
- Watershed

New & Redevelopment
- Site & subdivision - SS.C.4.a.i. & ii. (SS.C.5 in Phase I)
- Development Codes - SS.C.A.f.
- Watershed Scale - SSC.A.g.
Statewide LID Training Program

LID REGULATORY STATUS

- **Phase I Permittees**
  - Snohomish, King, Pierce, Clark Counties
  - Seattle, Tacoma
  - WSDOT

- **Phase II Permittees**
  - WWA: 80 cities, 5 counties
  - EWA: 18 cities, 6 counties

- **Secondary Permittees:**
  - Approximately 45 such as ports and universities

LID REGULATORY TIMELINE

- **Adopt new site & subdivision stormwater codes**
  - Phase I: June 30, 2015
  - Phase II: December 31, 2016*

- **Review and revise development-related codes, rules & standards**
  - Phase I: June 30, 2015
  - Phase II: December 31, 2016*

* Or GMA update deadline, whichever is later

LID REGULATORY STATUS: New Development Thresholds

- **Min. Requirements #1 - #9:**
  - ≥ 5,000 sq. ft. new and replaced hard surface area, or
  - ≥ 3/4 acre vegetation to lawn/landscape, or
  - ≥ 2.5 acres native vegetation to pasture

- **Min. Requirements #1 - #5:**
  - ≥ 2,000 sq. ft. new and replaced hard surface area, or
  - ≥ 7,000 sq. ft. land disturbance

- **Min. Requirement #2 - Erosion control**
  - All projects (No submittal for projects < 2,000/7,000)
LID REGULATORY STATUS: Minimum Requirements

#1 Preparation of Stormwater Site Plans

#2 Construction Stormwater Pollution Prevention

#3 Source Control of Pollution

#4 Preservation of Natural Drainage Systems and Outfalls

#5 On-site Stormwater Management

#6 Runoff Treatment

#7 Flow Control

#8 Wetlands Protection

#9 Operation and Maintenance

WHAT IS LOW IMPACT DEVELOPMENT

• A land use development strategy that emphasizes protection and use of on-site natural features to manage stormwater.

• Careful assessment of site soils and strategic site planning to best use those soils for stormwater management.

• Integrates engineered and non-engineered, small scale stormwater controls into the site design to closely mimic pre-development hydrologic processes.

WHAT IS LOW IMPACT DEVELOPMENT

• Used at the parcel and subdivision scale. Site scale necessary but not sufficient. Regional land use planning critical for effective stormwater management.

• Primary goal: no measurable impacts to receiving waters by maintaining or approximating pre-development surface flow volumes and durations.
**WHAT IS LOW IMPACT DEVELOPMENT**

Objectives

- Protect and restore native soils/vegetation.
- Reduce development envelope.
- Reduce impervious surfaces and eliminate effective impervious area.
WHAT IS LOW IMPACT DEVELOPMENT

Objectives
- Manage stormwater as close to its origin as possible.
- Integrate stormwater controls into the design—create a multifunctional landscape.

COMPONENTS

- Flow Entrance
- Pre-Settling
- Ponding Area
- Bioretention Soil
- Mulch/Compost
- Vegetation
- Filter Fabric (?)
- Liner (optional)
- Underdrain (optional)
- Overflow
• Bioretention will often include surface and subsurface infrastructure
• Bioretention = designed soil mix
• Bioretention meets requirements for MR 6 and 7 and required for MR 5 if MR 1-9 required

• Rain gardens will usually not include under-drains and may use less restrictive soil mix guidelines (e.g. existing soil augmented with compost and sand). Meets MR 5 requirements.

• Primary functions
  • Hydrologic benefits
  • Water quality treatment
  • Aesthetic amenity

• Bioretention is a "bio-infiltration" BMP
  • Ponding system
  • Treatment via vertical flow through treatment soils while being infiltrated
  • Treatment goal = % volume infiltrated

• Bioretention is NOT a "biofiltration" BMP
  • Flow-through system (ex. biofiltration swale)
  • Treatment via lateral flow through vegetation while being conveyed
  • Treatment goal = hydraulic residence time
BIORETENTION: Definition and Types

- Shallow landscaped depressions that are engineered (bioretention) or non-engineered (rain gardens) to receive stormwater from small contributing areas
- Small scale, dispersed facilities
- Types:
  - Bioretention cells
  - Bioretention swales
  - Bioretention planters
  - Bioretention planter boxes
  - Online and offline

BIORETENTION: Types

Cells
- Shallow vegetated depressions
- Gentle side slopes typical
- Not designed as conveyance system
- Optional underdrains/control structures

Bioretention swales
- Same design features as cells
- Interconnected series of cells
- Provide conveyance (overflow directed to downstream cell)
Bioretention planters
• Vertical walled reservoir (typically concrete)
• Often used in ultra-urban settings
• Open bottom to allow infiltration to native soil
• Optional underdrains/control structures

Bioretention planter boxes
• Same design features as planters
• Closed, impermeable bottom
• Must include underdrain
• Optional control structure
Introduction to course and bioretention

Water Quality Treatment

Bioretention Siting and Design

Construction, Inspection & Verification

Wrap-up

All primary pathways for removing pollutants from storm flows active in bioretention:

- Stormwater volume reduction
- Sedimentation
- Filtration
- Phytoremediation
- Thermal attenuation
- Adsorption
- Volatilization

Note that rain gardens can provide these pollutant capture pathways, but not approved for WQ treatment (MR6) in SWMMWW.

Water Quality Treatment

**Primary Pathways**

Project Completed Infiltration Design Volume Reduction (%)

- Siskiyou Green Street Oct 2003 1.5 - 2.0 in/hr 6% 1/04 – 12/05 83%
- Glencoe Rain Garden Oct 2003 1.8 - 3.0 in/hr 6% 1/04 – 12/05 94%
- Greensboro NC 2001 0.2 – 0.6 in/hr 5% 2002 78%
- Sea Street 2001 variable ~2% 2001 – present 98%
- 110th Cascade 2003 (10/04 – 06) 74%
- Meadow on the Hylebos 2006 0.0 – 0.8 in/hr 15% 10/07 – 5/08 99.99%

Water Quality Treatment

**Volume Reduction**
### SOIL CONTAMINANT LEVELS

<table>
<thead>
<tr>
<th>Project</th>
<th>e. Coli (mpn/g)</th>
<th>Cu (mg/kg)</th>
<th>Pb (mg/kg)</th>
<th>Hg (mg/kg)</th>
<th>Zn (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siskiyou Green Street</td>
<td>0-6*</td>
<td>280</td>
<td>34.4</td>
<td>56.8</td>
<td>0.103</td>
</tr>
<tr>
<td></td>
<td>6-12*</td>
<td>--</td>
<td>17.0</td>
<td>12.2</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>12-18*</td>
<td>--</td>
<td>17.6</td>
<td>10.9</td>
<td>0.054</td>
</tr>
<tr>
<td>SW 12th &amp; Montgomery</td>
<td>0-6*</td>
<td>7</td>
<td>30.1</td>
<td>29.9</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>12-18*</td>
<td>--</td>
<td>22.2</td>
<td>18.9</td>
<td>0.082</td>
</tr>
</tbody>
</table>

MTCA
Pb: 250 mg/kg
Hg: 2 mg/kg

### WATER QUALITY TREATMENT

#### PERCENT REMOVAL OF NUTRIENTS

<table>
<thead>
<tr>
<th></th>
<th>TKN (mg/L)</th>
<th>NO₃ (mg/L)</th>
<th>TP (mg/L)</th>
<th>Hydrocarbons (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davis et al 2006*</td>
<td>38% (u) 68% (l)</td>
<td>-96% (u) 24% (l)</td>
<td>1% (u) 81% (l)</td>
<td></td>
</tr>
<tr>
<td>Greenbelt</td>
<td>57%</td>
<td>16%</td>
<td>65%</td>
<td></td>
</tr>
<tr>
<td>Largo</td>
<td>67%</td>
<td>15%</td>
<td>83%</td>
<td></td>
</tr>
<tr>
<td>Mass removal</td>
<td>97%</td>
<td>97%</td>
<td>99%</td>
<td></td>
</tr>
<tr>
<td>Hunt et al 2006</td>
<td>-4.9%</td>
<td>75%</td>
<td>-240%</td>
<td></td>
</tr>
<tr>
<td>Greensboro</td>
<td>45%</td>
<td>13%</td>
<td>65%</td>
<td></td>
</tr>
<tr>
<td>Chapel Hill</td>
<td>--</td>
<td>18%</td>
<td>-10%</td>
<td></td>
</tr>
<tr>
<td>Hirsh 2005</td>
<td>--</td>
<td>-3%</td>
<td>-88%</td>
<td></td>
</tr>
</tbody>
</table>

Event mean concentrations

* Percent reduction at 18 cm (upper) and 61 cm (lower) depths (lab)

** Herrera from Barrett

### WATER QUALITY TREATMENT

#### PERCENT REMOVAL OF TSS & METALS

<table>
<thead>
<tr>
<th></th>
<th>TSS (mg/L)</th>
<th>Cu (µg/L)</th>
<th>Pb (µg/L)</th>
<th>Zn (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davis et al 2001*</td>
<td>89% (u) 93% (l)</td>
<td>&gt;98% (u) &gt;98 (l)</td>
<td>&gt;98% (u) &gt;98 (l)</td>
<td></td>
</tr>
<tr>
<td>Davis et al 2003**</td>
<td>&gt;99%</td>
<td>&gt;99%</td>
<td>&gt;99%</td>
<td></td>
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<tr>
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<td>97%</td>
<td>&gt;95%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Largo</td>
<td>43%</td>
<td>70%</td>
<td>64%</td>
<td></td>
</tr>
<tr>
<td>Hunt et al 2005</td>
<td>-180%</td>
<td>99%</td>
<td>81%</td>
<td>56%</td>
</tr>
<tr>
<td>Greensboro</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Chapel Hill</td>
<td>91%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hirsh, Davis 2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PNW Bioswales (Herrera 2006)</td>
<td>64%</td>
<td>47%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Bioswales (Herrera from Barrett)</td>
<td>43%</td>
<td>53%</td>
<td></td>
<td></td>
</tr>
</tbody>
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Event mean concentrations

* Percent reduction at 18 cm (upper) and 61 cm (lower) depths (lab)

** Percent mass removal (lab)
### Bioretention Flushing Experiments

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Units</th>
<th>Median Influent</th>
<th>Min</th>
<th>Median Effluent</th>
<th>Max</th>
<th>n</th>
<th>Sand Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>4.9</td>
<td>1</td>
<td>5.3</td>
<td>22.5</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Diss Zn</td>
<td>µg/L</td>
<td>71</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Diss Cu</td>
<td>µg/L</td>
<td>3</td>
<td>1.7</td>
<td>8.6</td>
<td>15.9</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>PO4</td>
<td>mg/L</td>
<td>0.016</td>
<td>0.086</td>
<td>0.236</td>
<td>0.463</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>NO3-N02</td>
<td>mg/L</td>
<td>0.361</td>
<td>0.05</td>
<td>0.145</td>
<td>1.03</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Fecal coliform</td>
<td>CFU/100mL</td>
<td>229</td>
<td>5</td>
<td>22.5</td>
<td>65</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

WSU large-scale lysimeter study (unpublished)
Dissolved Copper Capture

Watershed Large-Scale Lysimeter Study (unpublished)

Filtration: Bioretention provides excellent sediment filtration...

Does not appear to be concentration dependent.

TSS Capture

Watershed Large-Scale Lysimeter Study (unpublished)

SUMMARY

- Initial flushing of nitrogen, phosphorus and low levels of copper at low influent concentrations.
- Excellent zinc at installation and very good copper capture at typical influent concentrations after initial flushing.
- Reasonable TN capture at typical influent concentrations.
- Very good TSS capture
- TP and PO4 remain challenges
- Overall, very good performance in relation to other treatment technologies
All bioretention facilities infiltrate water through bioretention soil for treatment.

Infiltration siting considerations apply to facilities that ALSO:
infiltrate water into underlying native soils.
INFEASIBILITY CRITERIA: Infiltration

Restrictions

- Insufficient vertical separation from bottom of facility to hydraulic restriction layer (water table, bedrock, compacted soil layer)
  - 1 foot clearance if the contributing area is less than:
    - 5,000 square feet of pollution-generating impervious surface
    - 10,000 square feet of impervious area
    - ¼ acres of lawn and landscaped area
  - 3 foot clearance for larger contributing areas

Restrictions (source: SWMMWW Volume II, Section 3.4)

BIORETENTION SITING, DESIGN & CONSTRUCTION

INFEASIBILITY CRITERIA: Infiltration

Restrictions

Infiltration not required in:

- Areas that geotechnical evaluation deems imprudent
  - Erosion, slope failure, flooding
- Erosion/landslide hazard areas
- Groundwater protection area

Restrictions (source: SWMMWW Infeasibility Criteria)

INFEASIBILITY CRITERIA: Infiltration Setbacks

<table>
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<th>Feature</th>
<th>Setback</th>
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<tr>
<td>Drinking water well</td>
<td>100 feet</td>
</tr>
<tr>
<td>Spring used for drinking water</td>
<td>100 feet</td>
</tr>
<tr>
<td>Known deep soil contamination</td>
<td>100 feet</td>
</tr>
<tr>
<td>Closed or active landfill</td>
<td>100 feet</td>
</tr>
<tr>
<td>Small on-site septic drainfield</td>
<td>10 feet</td>
</tr>
</tbody>
</table>

Setbacks (source: SWMMWW Infeasibility Criteria)
INFEASIBILITY CRITERIA: Infiltration Setbacks

<table>
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<th>Feature</th>
<th>Setback</th>
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<tr>
<td>Native Growth Protection Easement</td>
<td>≥ 20 feet</td>
</tr>
<tr>
<td>Top of slopes &gt;20% and over 10 feet of relief</td>
<td>≥ 50 feet</td>
</tr>
<tr>
<td>Underground storage tanks</td>
<td>10-100 feet</td>
</tr>
<tr>
<td>Wellheads, basements, foundations, utilities, slopes, contaminated areas, and property lines</td>
<td>Consult local jurisdiction guidelines</td>
</tr>
</tbody>
</table>

Setbacks (source: SWMWW Infeasibility Criteria)

BIORETENTION SITING, DESIGN & CONSTRUCTION

SITING CONSIDERATIONS

- Understand fate of infiltrated water
  - Intent is to infiltrate to native underlying soil
  - Arterial ROW with dense underground infrastructure (preferential pathway → utility trenches)
  - Potential for excessive shallow interflow emerging at slopes, development cuts, or in basements
  - Use engineering controls
    - Ex. trench water stops to prevent re-infiltration to pipes
    - Ex. liners to protect adjacent infrastructure

- Native soil and vegetation preservation
- Site Slopes
- Cross & Longitudinal Slopes
- Positive Drainage from drainage area to BR to overflow
- Setbacks (e.g., utilities & other infrastructure, wetland and streams)
- Public acceptance/participation (retrofits)
- Transportation/pedestrian safety
SITING CONSIDERATIONS: Soils

- Why soils affect siting
- Soil variability
- Initial infiltration rates
- Design infiltration rates

SITING CONSIDERATIONS: Native Soils

- Important for Infiltrating facilities ONLY
- Infiltrating facilities sized based on infiltration rates
- Minimum “feasible” initial infiltration rate of 0.3 in/hr
- Locate infiltrating BMPs in areas with best soils

SITING CONSIDERATIONS: Soil Variability

- Broadview Green Grid, Seattle, WA
SITING CONSIDERATIONS: Soil Variability

Site 1: Loam

Site 2: Sand

Site 3: Glacial till
INfiltration Rates: Overview

Measure or estimate initial saturated hydraulic conductivity

Apply correction factor

Long-term (design) infiltration rate

INfiltration Rates: Bioretention Methods

- Estimate based on soil properties
  - USDA Soil Textural Classification
  - Soil Grain Analysis

- In-situ field measurements
  - EPA Falling Head
  - Double ring infiltrometer test
  - Small Scale Pilot Infiltration Test (PIT)
  - Large Scale PIT

Bioretention Methods

- Estimate based on soil properties
  - USDA Soil Textural Classification
  - Soil Grain Analysis

- In-situ field measurements
  - EPA Falling Head
  - Double ring infiltrometer test
  - Small Scale Pilot Infiltration Test (PIT)
  - Large Scale PIT

Note: Eliminated in 2012 SWMMWW

Allowed for soils unconsolidated by glacial advance (in-situ soil investigation may still be advised)

Use for all other soils

SWMMWW allowed for soils unconsolidated by glacial advance (in-situ soil investigation may still be advised).
**ECOLOGY SMALL-SCALE PIT METHOD**

- **Excavate pit**
  - Depth ~ surface elevation of native soil (before BSM placement)
  - Horizontal bottom area ~ 12 to 32 sf
  - Side slopes laid back, but vertical to test ponding depth (6 – 12 in)
- **Install vertical measuring rod**
- **Install splash plate**
  - Reduce side wall erosion and disturbance of bottom (clogging)

- **Fill pit for pre-soak period**
  - Standing water (at least 12 inches) for 6 hours
- **Adjust flow rate for steady state period**
  - Constant water depth (6 – 12 inches) for 1 hour
- **Turn off water and record rate of infiltration every 30 - 60 minutes until one hour after the flow has stabilized**
  - Lowest hourly flow rate is the initial (measured) infiltration rate

- **Depth to groundwater**
  - Over excavate 3 feet below pit bottom to check for hydraulic restrictive layers (e.g., bed rock, till/clay lenses) or groundwater
  - Alternatively, monitor groundwater through wet season
ECOLOGY SMALL-SCALE PIT METHOD

- **PIT Timing**
  - Test between December 1 and April 1

- **Number of PITs**
  - Recommend one PIT at each bioretention site
  - For larger site, one PIT every 5,000 sf
  - For long narrow facilities, one PIT every 200 linear feet (unless borings indicate consistent soil characteristics)

Hydrant

Regulate flow (Ex. Ball Valve)

Flow Meter

Fire Hose

Garden Hose

To Pit

Vertical Measuring Rod

Pit (lay back side slopes)

5 gal. Bucket (energy dissipation)

Water level recorded every 15 minutes
**BIORETENTION SITING, DESIGN & CONSTRUCTION**

**ECOLOGY SMALL-SCALE PIT METHOD**

- Initial rate = 0.25 in/hr
- 1.5 in/hr

**DESIGN INFILTRATION RATES**

- Correction factors applied to initial rate to estimate long-term rate for design
  - Partial Correction factors:
    - CFv (Site variability and number of locations tested) = 0.33 to 1
    - CFt (Test method) = 0.4 to 0.75
    - CFm (Degree of influent control to prevent siltation and bio-buildup) = 1 (overlying BSM provides excellent protection)
  - Total Correction Factor (CF) = CFv x CFt x CFm
  - Design rate = Initial Rate x CF
**BIORETENTION SITING, DESIGN & CONSTRUCTION**

**INFILTRATION RATES: Rain Garden Methods**

Small-scale test hole

- Dig hole 1 to 2 ft in diameter
- Bottom should be depth of rain garden sub-grade
- Examine soil texture
- Place measuring rod and fill to design ponding depth
- Time how long it takes to drain down
- Repeat 3 time if in dry season
- Best to perform test in wet season

**APPLICABILITY**

- Residential Parcels
  - Landscaped areas
  - Planters
- Right-of-Way
  - Planting strip
  - Curb bulbs
  - Medians
- Commercial Parcels
  - Landscaped areas
  - Planters
  - Parking Lots

**SINGLE FAMILY: Rain Gardens/Bioretention**

Note that rain gardens meet requirements for MR 1-5, but not for MR 6 or 7.
BIORETENTION SITING, DESIGN & CONSTRUCTION

RIGHT OF WAY: Curb Bulbs

NE Siskiyou Green Street Portland, OR
23rd Ave SE & 171st Pl SE

Photos courtesy of Portland BES

Statewide LID Training Program

BIORETENTION
INTERMEDIATE LID DESIGN

BIORETENTION SITING, DESIGN & CONSTRUCTION

RIGHT OF WAY: Planters

New Seasons Market, Portland
SW 12th Avenue Green St

Photos courtesy of Portland BES

Statewide LID Training Program

BIORETENTION
INTERMEDIATE LID DESIGN

BIORETENTION SITING, DESIGN & CONSTRUCTION

MULTI-FAMILY DEVELOPMENTS

High Point Seattle, WA

Statewide LID Training Program

BIORETENTION
INTERMEDIATE LID DESIGN
BIORETENTION SITING, DESIGN & CONSTRUCTION
COMMERCIAL PARCELS: Conveyance
Downtown CSO Demand Management, Seattle, WA

BIORETENTION SITING, DESIGN & CONSTRUCTION
COMMERCIAL PARCELS: Parking Lots
Northgate Mall, Seattle, WA

BIORETENTION SITING, DESIGN & CONSTRUCTION
COMMERCIAL PARCELS: Parking Lots
Northgate Mall, Seattle, WA
Lunch

Field Exercise
Infiltration Tests

BIORETENTION SITING, DESIGN & CONSTRUCTION

Statewide LID Training Program
INTERMEDIATE LID DESIGN
**PERFORMANCE STANDARDS**

- **On-site Stormwater Management (MR #5)**
  - Use BMP List 1 or
  - Meet LID Performance Standard (match flow durations to pre-developed condition from 8% to 50% of the 2-year peak flow)

- **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 flow durations to pre-developed condition from 50% of the 2-year to the full 50-year peak flow

- **Other Flow Control Standards**
  - Combined Sewer or Capacity Constrained Basins (peak-based standards)

**COMPONENTS**

- Flow Entrance
- Pre-Settling
- Ponding Area
- Bioretention Soil
- Mulch/Compost
- Vegetation
- Filter Fabric (?)
- Liner (optional)
- Underdrain (optional)
- Overflow

**FLOW ENTRANCE: Design Criteria**

- Flow entering should be non-erosive
  - Velocity less than 1.0 fps
- Dispersed flow entrance → Preferred
  - Vegetated buffer strip
  - Sheet flow across pavement/gravel
  - Sheet flow b/t wide wheel stops
- Concentrated flow entrance → Requires erosion protection (e.g., rock)
  - Piped flow
  - Curb cuts
  - Trench drains
Wheel stops prevent vehicle entry and restrict vehicle loading at edge while allowing sheet flow to bioretention.

Depressed gutter at inlet

Finish grade should be 2-3" lower than curb line to allow for unobstructed inflow. Armor flow entrance with concrete pad or stone.
Do not use woody plants at inlet (can restrict or concentrate flows)

Trench Drain Curb Cut

Portland BES

For higher/surface elevation inlets

Armored flow entrance with curb cut

• Finish grade is 2-3” lower than curb line to allow for settling.
• Armored flow entrance with concrete pad and stone.

Chris Webb & Associates, Inc.
FLOW ENTRANCE

Seattle Standard Details

- Curb cut
- Channel with grate

PRE-SETTLING

- To capture debris/sediment and reduce potential for clogging of BSM
- May be required for:
  - For concentrated flow entrances
  - For larger drainage areas
  - Where sediment loading is expected (e.g., high-use parking lots and roadways)

PRE-SETTLING methods:
- Vegetated filter strip
- Fore bay
- Catch basin

Photo from alice
PONDING AREA: Design/Performance

Without underdrain
- Earthen depression (w/o liner) or open-bottomed planter
- Relies on infiltration to native soil
- Can provide effective on-site stormwater management, flow control and WQ treatment

With underdrain
- Some infiltration to native soil
- Can provide effective WQ treatment for some pollutants
- Cannot meet forest duration flow control alone, but can contribute as part of a system to achieve flow control goals (orifice improves performance)
PONDING AREA: Design/Performance

- With underdrain & liner/impermeable container
  - No infiltration to native soil
  - Typically provides minimal flow control (orifice improves performance)
  - Can provide effective WQ treatment

PONDING AREA: Sizing Criteria

- Size to meet performance standards
  - Use hydrologic modeling to size for LID performance (MR#5), flow control (MR#7) or WQ (MR#6) standards
  - For on-site List (MR #5) horizontal projected surface area below overflow = 5% of impervious drainage area
- Max. surface pool drawdown time (24-48 hours)
  - Soil allowed to dry out periodically
  - Restore hydraulic capacity of system
  - Maintain adequate soil oxygen levels
  - Prevent conditions supportive of mosquito breeding

*Example:* 
Surface Pool Drawdown = Ponding Depth ÷ Design Infiltration Rate
PONDING AREA: Footprint Area

- Larger footprint area for:
  - Larger contributing area
  - Higher site precipitation
  - Lower native soil infiltration rate
  - Shallower ponding depth
  - Shallower BSM depth

PONDING AREA: Cross-Section Criteria*

- Max ponding depth (12 inches)
- Min bottom width (1 foot)
- Max planted side slope (2.5:1)

PONDING AREA: Roadway Facility Criteria*

- 2-foot shoulder
- Grade at 3H:1V
- Grade at 4H:1V for intersections (Seattle)
- Compact shoulder to 90 percent standard proctor

*Seattle requirements provided for example design criteria
PONDING AREA: Roadway Facility Criteria*

- Rockery >1’ high, min 10’ from curb/edge of road
- Rockery <1’ high min 5’ from curb/edge of road

*Seattle requirements provided for example design criteria

Max 4’ drop from vehicular lane

*Seattle requirements provided for example design criteria

PONDING AREA: Design Resources

Bioretention with curb

Seattle Standard Details
PONDING AREA: Design Resources

Bioretention without curb

Seattle Standard Details

Rockery wall

Roadside Planter

2012 LID Manual

2014 San Francisco Typical Details
BIORETENTION SITING, DESIGN & CONSTRUCTION

PONDING AREA: Design Resources

Roadside Planter

2014 San Francisco Typical Details

FILTER FABRIC

- Typically NOT recommended between existing soil and BSM because of clogging potential
- Gradation difference between existing soil and BSM is typically small so no migration of fines

HYDRAULIC RESTRICTION LAYER

- Geomembranes on vertical walls
- For facilities adjacent to roads, foundations, etc.
HYDRAULIC RESTRICTION LAYER

- Where infiltration is prohibited or not prudent
- Must use underdrain

2009 Seattle Stormwater Manual

Clay (bentonite) or geomembrane
Impermeable reservoir (concrete, metal)

UNDERDRAINS: Purpose

- Where liner is used
- Where infiltration is prohibited or not prudent
- Near sensitive infrastructure with high flood potential
- Soil infiltration rates not adequate to meet pool and system drawdown time

Broadview Green Grid, Seattle, WA

UNDERDRAINS: Types of Pipes

- Slotted, thick-walled plastic pipe
  - Minimum 4” diameter Schedule 40 PVC
- Slot openings
  - Smaller than smallest aggregate gradation of filter material
  - Slots perpendicular to long axis of pipe
UNDERDRAINS: Types of Pipes

- Slotted PVC Pipe with Aggregate Filter/bedding material
- Aggregate filter/bedding material
  - Prevent migration of fine material into drain
  - City of Seattle Mineral Aggregate Type 26 (sandy gravel)
- Do not wrap in filter fabric

Note: If using City of Seattle Mineral Agg 26, slots shall be 0.069 inches by 1-inch long, spaced 0.25 inches apart. Slots arranged in four rows spaced on 45-degree centers.

UNDERDRAINS: Slotted Pipe Placement

- Slotted pipe placement within aggregate filter/bedding material (Seattle)
  - 6” under pipe
  - 12” on top of pipe
  - 12” each side

UNDERDRAINS: Slotted Pipe Benefits

- Increased media area provides better filtering
  - Reduced potential for clogging (versus perforated pipe wrapped in filter fabric)
- More durable and easier to clean (rotary root cutter or water jet)
  - Versus perforated PVC or flexible slotted HDPE
UNDERDRAINS: Slotted Pipe Guidance

- Observation pipe/clean out
  - Rigid non-perforated
  - Every 250 to 300 feet
  - Clean out port
  - Observation well for dewatering rates

- Raised under-drain
  - Maximize infiltration
  - Fluctuating aerobic/anaerobic conditions → Denitrification

- Minimum underdrain slope = 0.5%

- Orifice/control structures
  - Improve flow control performance
  - Minimum 0.5” orifice diameter
  - Maintenance access to orifice required

- Design with access for future modification
  - “Adaptive management”
  - Cap drain pipe
  - Throttle flows with orifice

Photo courtesy of Seattle Public Utilities

Seattle Standard Details

Bioretention with curb
OVERFLOW: Design Criteria/Types

- Necessary to safely convey flows that exceed capacity
  - Protect downstream property and resources
  - Overflow configuration depends on design objectives
- Overflow elevation set at max. ponding depth
- Directed to downstream BMP or approved discharge point

Sizing
- Conveyance sized for local jurisdiction level of service
- Consider larger overflows (e.g., grade so overflows to ROW)

Surface overflow
- Sheet flow
- Gravel level spreader
- Exit curb cut/trench drain

Catch basin
- Vertical stand pipe
- Horizontal pipe
- Can be connected to underdrain system
BIORETENTION SITING, DESIGN & CONSTRUCTION

ELEVATIONS AND GRADE: Considerations

- Cross Slope
- Longitudinal Slope
- Positive Grade
- Series of Cells
- Check Dams

ELEVATIONS AND GRADE: Cross Slope

- Larger footprint area and berming or wall(s) to achieve ponding area
ELEVATIONS AND GRADE: Cross Slope

- Required width on slope
- Berm

Cross Slope

ELEVATIONS AND GRADE: Longitudinal Slope

- For long, linear configurations, create series of flat-bottomed cells
- Optimum slope is 2%
  Maximum slope = 8%
- Steep slopes: control gradient with intermittent weirs or berms or standpipe overflow to provide ponding and dissipate energy
- Flat slopes: may need weir to create ponding

ELEVATIONS AND GRADE: Series of Cells

- Check dams / weirs or vertical stand pipe overflow
- Reduce flow velocities & erosion potential/dissipates energy
- Create ponding to promote infiltration

Photo courtesy of Seattle Public Utilities
ELEVATIONS AND GRADE: Series of Cells

- Types of check dams/weirs
  - Compacted earthen berms covered with vegetation
  - Vegetated hedgerows
  - Rock
  - Wood
  - Concrete

- Optimum spacing determined by longitudinal slope, performance goals and cost

Photo courtesy of Seattle Public Utilities
ELEVATIONS AND GRADE: Moderate Longitudinal Slope

Concrete weirs

Portland, OR. Photo: Curtis Hinman

ELEVATIONS AND GRADE: Steeper Longitudinal Slope

Concrete weirs for longitudinal slopes

Walls for cross slopes

110th Street Cascade, Seattle, WA

107th Street Cascade, Seattle, WA

ELEVATIONS AND GRADE: Steeper Longitudinal Slope

Beehive grate over vertical pipe/structure

Broadview Green Grid, Seattle, WA
Check Dams

2014 San Francisco Typical Details

Q&A

Bioretention Media
MEDIA: Media for Optimum Performance

- High enough infiltration rates to meet desired surface water drawdown and system dewatering
- Infiltration rates that are not too high in order to optimize pollutant removal capability
- A growth media to support long-term plant and soil health and water quality treatment capability
- Balance nutrient availability and retention and copper retention at low effluent levels

MEDIA: Common Soil Media Guidelines

- 40% topsoil, 30% sand, 30% compost common recommendation nationally and in this region
- Issues with this and other guidelines
  - Fines (< 5% passing the #200 sieve)
  - Minimum organic matter content 10% by dry weight per ASTM D 2974
  - Material control
  - Contaminant flushing

MEDIA: Developing New Soil Media Guidelines

Driver:
- Top soil specifications can be difficult to apply consistently.
- The need for relatively consistent materials that are readily available, affordable and meet necessary criteria.
Hydraulic conductivity strongly related to percent fines (passing #200 sieve)

Hydraulic conductivity strongly related to coefficient of uniformity

• Current guideline in SWMMWW and LID manual 60% sand and 40% compost (this will likely be changing)
• For default media blend use 6”/hr initial infiltration rate (this may be changing with the 2014 SWMMWW update)
• 18” minimum soil depth for enhanced treatment. Minimum of 24” for improved nitrogen or phosphorus removal (2014 manual may eliminate 24” guideline)
**MEDIA: Mineral Aggregate Specification**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot;</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>95-100</td>
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<tr>
<td>#10</td>
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<tr>
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<td>25-40</td>
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<tr>
<td>#100</td>
<td>4-10</td>
</tr>
<tr>
<td>#200</td>
<td>2-5</td>
</tr>
</tbody>
</table>

The following gradation provides a relatively consistent Ksat and coefficient of uniformity for bioretention soil mixes. This is the primary mineral aggregate spec in 2012 LID manual and prescribed by SWMM/WW.

**MEDIA: Infiltration Rates**

**If not using the default media blend determine long-term infiltration rate for sizing and flow control capacity**

- 1 in/hr minimum for acceptable ponding and system de-watering in typical setting (long-term hydraulic conductivity per ASTM D 2434 at 85% compaction per ASTM D 1557)
- If contributing area has <5,000 sf of PGS; and <10,000 sf TIA; and < ¾ acre landscaping then use correction factor of 2
- If over the above thresholds use correction factor of 4

**MEDIA: Infiltration Rates**

**If not using the default media blend determine sizing and water quality treatment flow**

- 2.4 in/hr was maximum rate...guideline likely established for existing native soils not designed soil mixes
- Research indicates that higher infiltration rates provide performance necessary to meet Ecology's enhanced treatment
- DOE now accepts maximum measured (initial) WQ treatment rate of 12 in/hr with an OM content of 5-8% by weight, CEC ≥ 5 milliequivalents/100 grams dry soil, 2-5% mineral fines content, and 18” minimum soil depth
- Apply same correction factor as for flow control capacity
MEDIA: Recent Media Guideline Updates

- Recommended modifications to permeability testing (ASTM 2434) for bioretention soil media.
- If 60% aggregate/40% compost specification in LID and SWMMWW manuals followed then use a measured Ksat of 6"/hr (1.4" to 3"/hr depending on correction factor).
- Previous recommendation of 10% OM content too high. Current recommendation 4% or 5% to 8% max.

MEDIA SUMMARY: What Do We Think We Know

- Sandy bioretention soil mixes should provide excellent water quality performance for Zn, hydrocarbon and bacteria removal. Design with caution for systems with under-drains in P and N sensitive basins.
- 2 to 4 percent passing the 200 sieve ideal. Fines should not be above 5 percent for a proper functioning specification.
- Also important: coefficient of Uniformity (Cu) ≥ 4. Cu is the measure of variation in particle sizes of mineral aggregate (D_{60}/D_{10}).
- Small variations in grain size distributions and uniformity can result in large variations in K values.

MEDIA SUMMARY: What Do We Think We Know

- Monitor carefully if topsoil used for mineral component.
- Sandy soil mixes are very well drained...select plants carefully.
- Question of best soil mixes for bio-available P retention unresolved. Increasing depth likely improves nutrient removal.
- Saturated zone improves nitrate removal.
- More work needed on Cu capture and retention.
- Likely that current compost guidelines in WAC did not consider use in stormwater filters. More research needed.
**Plants: Selection**

- Soil moisture conditions
- Sun exposure
- Above and below ground infrastructure
- Site distances and setbacks along roadways

**BIORETMTION SITING, DESIGN & CONSTRUCTION**

- Pedestrian use
- Adjacent plant communities and potential invasive species control
- Visual buffering
- Aesthetics
Agricultural literature documents well the role of plants for building soil structure (Buckman and Brady 1969, Angers and Caron 1998)

City of Portland OR documents increasing infiltration rates in 12-year old commercial parking bioretention areas. 1999~8”/hr, 2005~13”/hr (BES 2006)

Lucas observes increased phosphate removal in vegetated vs non-vegetated bioretention... removal more than plant uptake
**PLANTS: Mulch**

Mulch reduces weed establishment, regulates soil temperature and moisture, and adds OM to soil. Mulch should be:
- 2-3 inches thick
- Chipped or shredded softwood or hardwood
- Coarse compost for bottom of facility
- Fine beauty bark not preferable

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**Q&A**

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CONSTRUCTION CONSIDERATIONS: Minimize Site Disturbance

- Stream biota significantly reduced at SS levels of 50-80 mg/L (Corish 1995).
- Schueler reported median TSS concentrations of 4,145 mg/L leaving construction sites with no TESC and 283 mg/L with TESC.

CONSTRUCTION CONSIDERATIONS

Through improved site design, construction planning and sequencing, operator training and proper equipment:

- Minimize site disturbance
- Protect trees
- Prevent over compaction of sub-grade and BSM
- Effective erosion and sediment control
CONSTRUCTION CONSIDERATIONS: Minimize Site Disturbance

- Site design
- Construction Planning
- Training
- Equipment

CONSTRUCTION CONSIDERATIONS: Native Soil Variability

- Do cells look like test pit?
- If lower permeability:
  - Increase size
  - Over-ex and add more BR soil
  - Increase ponding depth (if drawdown can be maintained)
  - Add underdrain

CONSTRUCTION CONSIDERATIONS: Over-compaction

- Practical compaction techniques
- Prevent over compaction (CRITICAL FOR PERFORMANCE)
- No excavation, soil placement, or soil amendment during wet or saturated conditions
- Operate equipment adjacent to (not in) the facility
- If machinery must operate in the facility, use light weight, low ground-contact pressure equipment
CONSTRUCTION CONSIDERATIONS: Over-compaction

Vehicular loading prism – some compaction is necessary

For road or parking lot stability, need heavy compaction from road prism-2H:1V from edge

CONSTRUCTION CONSIDERATIONS: Subgrade Preparation

Scarify subgrade to re-fracture soil and till in BSM at interface

Smeared and sealed by bucket

CONSTRUCTION OVERSIGHT

• Inspection and verification timing and processes fall into three general phases of project:
  • Pre-construction reviews
  • Construction
  • Verification/repair and final permit
CONSTRUCTION OVERSIGHT: Pre-Construction Reviews

- Set guidelines, expectations and timing for inspections
- Discuss construction sequencing
- Review checklists
- Determine training needs

CONSTRUCTION OVERSIGHT: Pre-Construction Reviews

- Include developer, builder, utilities, plan review, inspectors in pre-construction
- Make sure everyone knows where and what the requirements are...for an LID project, there may be stormwater requirements in landscaping guidelines

CONSTRUCTION OVERSIGHT: Construction

First Visit: Pre-bioretention soil media (BSM) placement

- Certify native/existing soils comparable to design specs
- Temporary erosion and sediment control (TESC) correctly installed
- Rough grading to plans
- Under-drain(s) and overflow
- Field changes...process should have been covered at pre-construction
- Photo documentation?
CONSTRUCTION OVERSIGHT: Construction

Second Visit: Pre-mulch or planting

- Verify that BSM meets composition guidelines and depth
- For BSM composition: current lab report from physical submittal, truck ticket, visual/texture. If questions on depth, expose to subgrade
- TESC still installed correctly and upslope areas managed properly

CONSTRUCTION OVERSIGHT: Post-Construction

Third Visit: Post-construction

- Verify final grade
- Verify contributing area as designed and stabilized
- Verify BSM not clogged and infiltration rate adequate
- Verify ponding depths, overflow, bottom swale area
- Verify plants (type and density)
- Verify mulch (type and depth)

Third Visit: Post-construction (whole site)

- Final grades
- 30-45 day follow up to remove TESC
- Verify O&M plan in place
INSPECTION & VERIFICATION
CONSTRUCTION SEQUENCING

• Site flat or sloping away from facility likely ok to:
  • Complete bioretention area with roads, utilities and storm infrastructure
  • Install conventional TESC and barriers

CONSTRUCTION SEQUENCING

• Construction activity sloping to bioretention facility
  • Divert flows around facility and treat during construction
  • Partially complete and allow storm flows through facility

CONSTRUCTION SEQUENCING

• Construction activity sloping to bioretention facility (w/o underdrain)
  • Delineate or partially grade to define facility. Keep construction traffic off area
  • Install TESC and stabilize upslope construction area as best as possible
  • Divert flows around facilities
  • If flows allowed through facility, leave at least 6” above final grade. Line or mulch?
  • Keep construction traffic off area
**CONSTRUCTION SEQUENCING**

- Construction activity sloping to bioretention facility (w/underdrain)
  - Place infrastructure
  - If possible leave rest of facility at least 6” above grade
  - Install TESC and stabilize upslope construction area
  - If flows allowed through facility, leave or backfill at least 6” above final grade
  - Cover underdrain with plastic and fabric
  - Line or mulch whole facility?
  - Keep construction traffic off area

**REMEDIES FOR FAILING SITES**

- Poor TESC and sediment to facility
  - Excavate to depth that sediment deposits and potential clogging not present (usually 6”)
  - Replace BSM, mulch, and plants

- Compaction of existing soils
  - Does the facility still infiltrate at design rate?
  - Perform infiltration test or verify pre-construction density
  - Remedy procedures if necessary

**INSPECTION & VERIFICATION**

Partial excavation and completion of facility after homes are finished and landscaping stabilized requires clear agreement among developer, homebuilder and jurisdiction
CONSTRUCTION COSTS

Cost Comparison – bioretention vs. filters for treatment only

CONVENTIONAL

1. 4' wide landscape island between rows of stalls
2. Catch basins @ 150’ o/c
3. 8” CPEP storm pipe continuous
4. Stormwater treatment provided by filter vaults sized @ 10 cartridges per acre

LID

1. 4’ wide bioretention cell between rows of stalls, bioretention cells sized @ +/- 5% of tributary area for treatment only
2. Standpipe overflow with beehive grate in each bioretention cell @ 150’

CONVENTIONAL:
1. $5/ SF x 4’ = $20/ LF
2. $1,000 / 150’ = $6.67/LF
3. $50/LF
4. $1.25/SF x (18’x2 + 22’) = $72.50
TOTAL: ~ $149.17 / LF

LID:
1. $30/ SF x 4’ = $120/ LF
2. $1,000/150’ = $6.67/LF
TOTAL: ~ $126.67 / LF

Notes:
- Reduced detention benefit in addition to the 15% savings shown for treatment only

No formal cost comparison, but contractor found LID project approximately 20% less than conventional.
CONSTRUCTION COSTS

- Present value of O&M + construction costs
- LCC for Pinehurst (47,290 ft²)
  - $1.2M + $5.2M = $6.4M
- Initial estimates
  - $4.8 million construction cost
- Comparable project to retrofit $8.9 million
- Total project cost 453K for 660 ft block
  - Includes all design, project management, construction cost
- Present value of O&M costs compared to traditional systems is significantly less

Q&A

- Introduction to course and bioretention
- Flow control and water quality treatment
- Bioretention siting and design
- Construction, inspection & verification
- Wrap-up
Statewide LID Training Program

OTHER COURSE OFFERINGS

INTRODUCTORY

1.0 Introduction to LID for Eastern Washington

INTERMEDIATE

2.1 Introduction to LID for Inspectors & Maintenance Staff

2.2 Introduction to LID for Developers & Contractors: Meet the Money for Green

3.1 Intermediate LID Topics: MPACT Planning & Design

3.2 Intermediate LID Design: Rainwater Harvesting

3.3 Intermediate LID Design: Permeable Pavement

3.4 Intermediate LID Design: Site Assessment, Planning & Layout

4.1 Intermediate LID Design: Rainwater Collection System & Vegetated Roofs

4.2 Intermediate LID Design: Hydrologic Modelling

ADVANCED

5.1 Advanced Topics in LID Design: Bioretention

5.2 Advanced Topics in LID Design: Permeable Pavement

5.3 Advanced Topics for LID Operations: Maintenance

5.4 Advanced Topics for LID Operations: Permeable Pavement

6.0 Advanced Topics in LID Design: Hydrologic Modelling

7.0 Advanced Topic in LID Design: Site Assessment, Planning & Layout

8.0 Advanced Topic in LID Design: Rainwater Collection System & Vegetated Roofs

8.2 Advanced Topic in LID Design: Long-term LID Operations: Maintenance Media

TRAIN THE TRAINERS

9.1 LID Topic Experts

9.2 LID Topic Experts

ONLINE EVALUATION

• An on-line evaluation will be sent to you within 3 days following this training

• Feedback will help to refine future trainings

• Feedback is also important to pursue funding to support a long-term statewide LID training program

CERTIFICATE

Two certificates:

• LID Design certificate

• Long-term LID Operations certificate

• Stay tuned for developing certificate policies

Sign out!
ONLINE RESOURCES

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

Stay connected through Social Media
• Come "Like" our Page
• Sign up to follow and get Tweets

QUESTIONS

Additional questions contact:
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(206) 449-1163