INSTRUCTORS

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

Chris Webb, PE
Associate Engineer
Key project experience: Specialized expertise in the design and hydrologic/hydraulic analysis of LID.

Scott Kindred
Infiltration Expert
Key project experience: Expertise in stormwater infiltration and subsurface flow

AGENDA

introduction
permeable pavement basics
common siting, design and construction
design and construction by pavement type
wrap-up
LOGISTICS

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

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

LEARNING OBJECTIVES
1. Gain an intermediate level knowledge necessary for proper entry level design and implementation of permeable pavement systems in residential and commercial settings (new and retrofit).
2. Learn skills necessary for basic site assessment and locating permeable pavement areas in residential and commercial settings.
3. Learn practical skills necessary for construction of basic permeable pavement systems.

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/statewide-lid-training-program-plan
• 2014: Training program built from state LID Training Plan.
**Statewide LID Training Program**

**PROGRAM OVERVIEW**

- 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
- Future funding unknown.

---

**Statewide LID Training Program**

**TEAM**

**PROJECT LEAD**

- Herrera

**CORE TEAM**

- Cascadia
- Veda

**ADDITIONAL TRAINING SUPPORT**

- CH2M HILL
- Kindred Hydro
- Learning Program Plan

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**Statewide LID Training Program**

**TRAINING SEQUENCE**

**INTRODUCTORY**

1.0 Introduction to LID for Eastern Washington

2.1 Introduction to LID for Inspectors & Maintenance Staff

2.2 Introduction to LID for Developers & Planning Bylaws

**INTERMEDIATE**

3.1 Intermediate LID — NPDES Phase I & II Requirements

3.2 Intermediate LID Design: Bioretention

3.3 Intermediate LID Design: Permeable Pavement

3.4 Intermediate LID Design: Vegetated Roofs & Vegetative Systems

**ADVANCED**

4.1 Advanced Topics in LID Design: Hydrologic Modelling

5.1 Advanced Topics in LID Design: Bioretention

5.2 Advanced Topics in LID Design: Permeable Pavement

5.3 Advanced Topics for LID Operations: Bioretention

5.4 Advanced Topics for LID Operations: Permeable Pavement

6.1 Advanced Topics in LID Design: Hydrologic Modelling

7.1 Advanced Topics in LID Design, Bioretention, Permeable Pavement & Vegetative Systems

8.1 Advanced Topics in LID Design, Hydrologic Modelling

**TRAIN THE TRainers**

- Introductory Level LID Training
- Intermediate Level LID Training
- Advanced Level LID Training

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**U.S. EPA**
**Statewide LID Training Program**

**TRAINING SEQUENCE**

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**TRAIN THE TRAINERS**

- Service Providers
- LID Topic Experts

**AGENDA**

1. Introduction
2. Permeable Pavement Basics
3. Common Siting, Design and Construction
4. Water Quality Treatment
5. Wrap-Up

**LID REGULATORY STATUS**

- New Permit Requirements for local governments on 3 levels:
  - Building site and subdivision
  - Municipal (codes)
  - Watershed
- New & Redevelopment
  - Site & subdivision - S5.C.4.a.i. & ii. (S5.C.5 in Phase I)
  - Development Codes - S5.C.4.f.
  - Watershed Scale - S5.C.4.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, WSDOT
  - EWA: 18 cities, 6 counties

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

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Statewide LID Training Program

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

---

Statewide LID Training Program

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
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 sf new and replaced hard surface or <7,000 sf land disturbance)

LID REGULATORY STATUS: Definitions

Pollution-Generating Hard Surface (PGHS)
- Pollutant-generating hard surfaces subject to vehicular use, industrial activities, material storage
- Pollution-generating impervious surfaces (PGIS) and pollution-generating permeable pavement

LID REGULATORY STATUS: Infeasibility Criteria

- Erosion, slope failure, or flooding
- Where adjacent impervious pavements compromised
- Threaten below grade basements
- Fill soils that can be unstable when saturated
- Excessively steep slopes meeting certain conditions
- Threaten pre-existing underground utilities tanks, road sub-grades
- Inadequate strength for heavy loads at industrial facilities

Requires site geotech evaluation & written recommendation
Statewide LID Training Program

LID REGULATORY STATUS: Minimum Requirements

Criteria not requiring justification, but possibly professional services

- Area designated as erosion or landslide hazard
- Within 50 feet from top of slopes greater than 20%
- Known soil or ground water contamination
- Fill soils that can be unstable when saturated
- At multi-level parking garages and over culverts & bridges
- Where saturated conditions within 1 foot of bottom of base course

Criteria not requiring justification, but possibly professional services

- On arterial or collector (see state RCW’s)
- Native soils don’t meet soil suitability criteria
- Infiltration less than 0.30 in/hr
- Soils unsuitable for loads when saturated
- Replacing impervious unless NON-PGIS over soil > 4in/hr
- In high use sites
- Areas with “industrial activity”
- Where concentrated spill risk is higher
- Routine heavy sand applications in frequent snow zones

Statewide LID Training Program

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.

Undeveloped - Forest

- During winter months evaporation continues to be active while the transpiration component is minimal
- Storm events moderated by infiltration, evapotranspiration, and interception
- Water is available in substrates to sustain stream base flows during summer months
- As winter progresses, the interflow component of stream flow increases
- During the summer and fall streams are overlain, primarily by seasonal melt water and/or groundwater flow

Developed Conditions

- Overland flow increases and time of concentration decreases
- Less water in substrates available to sustain base stream flows
- Interflow highly variable depending on development
WHAT IS LOW IMPACT DEVELOPMENT

Objectives

- Protect and restore native soils/vegetation.
- Reduce development envelope.
- Reduce impervious surfaces and eliminate effective impervious area.

Objectives

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

Rainwater collection

Low impact foundations

Vegetated roofs

Bioretention

Permeable pavement
Intermediate LID Design:
Permeable Pavement

AGENDA

1. Introduction
2. Permeable pavement basics
   - Common siting, design and construction
   - Design and construction by pavement type
3. Wrap-up

Permeable Pavement Basics

- Wearing course
- Leveling/choker course
- Aggregate storage reservoir/base
- Geosynthetics
- Under- and elevated-drains
- Native underlying soil
- Subsurface berms

Statewide LID Training Program
PERMEABLE PAVEMENT BASICS

TYPES: Porous Asphalt

- Flexible
- Similar to conventional asphalt, but fines < No. 30 sieve reduced
- Typically used for parking and light traffic loads; however, has been used for medium and heavy applications
- ~16 % voids typical (2-3 % for conventional)
- Industry engagement has been limited in this region, but increasing

TYPES: Pervious Concrete

- Rigid
- 1/4 to 5/8 round or crushed aggregate typical, Portland cement, and admixtures (optional) to increase workability and strength
- 15 to 20 % voids typical
- Good experience and industry engagement in western WA.
**Permeable Pavement Basics**

**Types: Permeable Pavers**

- Flexible
- Capable of high vehicle loads. Used for lower speeds
- High-density concrete that interlock and transfer vertical loads to surrounding pavers
- 12% voids typical
- Good experience and industry engagement in western WA.

**Types: Plastic Grids**

- Flexible
- Highest percent voids
- Plastic grid filled with gravel or soil and planted with grass
- Capable of high vehicle loads
- Used for lower speeds/infrequent use (grass)
- Consider Geogrid for additional strength
- Good experience and industry engagement in western WA.
PERMEABLE PAVEMENT BASICS
HOW THE FACILITY WORKS

- Storage
- Infiltration
PERMEABLE PAVEMENT BASICS

HOW THE FACILITY WORKS

- Inlets
- Outlets
- Slopes

APPLICATIONS

- Low-volume residential streets
- Parking
- Public walkways
- Parks
- Plazas and patios
- Bike lanes
- Greenhouse floors
- Sports courts
- Noise barriers/walls

Photos: Kathy Gwilym, SVR

Private parking lot, Seattle
Bellingham bicycle lane
Seattle's Ernst Park

Break
For a successful project, the team needs to carefully assess site, select appropriate materials and plan construction:

- Site selection
- Material specifications
- Design
- Planning & coordination
- Installation
- Construction
- Protection of work
- Operations/use as intended
- Maintenance (covered in Module 5.4)
SITING AND SELECTION OF MATERIALS

**USERS**
- Who will be the users of the facility?
  - Pedestrian
  - Bicycle
  - Parking Lot
  - Low-volume residential streets
  - Aesthetics
- One size does not fit all. Use appropriately.

**PUBLIC VS PRIVATE FACILITIES**
- Design life
- Maintenance effort
- Material selection

**INFILTRATION ASSESSMENTS**
- Site characterization criteria (Volume 3, Section 3.3.5)
- Geology/soil characteristics
- Groundwater conditions
- Infiltration potential
- Mounding analysis
INfiltration Tests

- Exploration
  - Continuous sampling
  - At least 10 ft below base of facility
  - Grain size analyses
- Exploration Approaches
  - Exploration pits
  - Deep exploration borings/wells
  - Vactor explorations (cost effective in developed areas)

INfiltration Assessment

Siting and Selection of Materials

Readily available resources
- USGS and DNR Geologic Maps
- Publicly available logs at DNR Washington State Geologic Information Portal
- Well logs at Ecology
- Streams, lakes, and wetlands generally indicate groundwater elevations

Groundwater Separation
- At least one foot between base of permeable pavement section and seasonal high groundwater table
  - If site assessment shows at least 5 feet of separation, groundwater monitoring not required
  - Separation from both groundwater and hydraulic restriction (perching) layer
  - Ideally, groundwater monitoring occurs between Dec. 21 - Mar 21 during a winter of normal to high precipitation
  - Professional judgment may be sufficient
INFILTRATION TESTS

SITING AND SELECTION OF MATERIALS

Design infiltration rate (3.3.3)

- Special Case Only
  - Grain Size Distribution
- Outdated
  - Small-scale falling head test (EPA)
  - Double Ring Infiltrometer
- Preferred
  - Large-diameter single ring
  - Pilot-scale PIT (large- and small-scale)

INFILTRATION TESTS

SITING AND SELECTION OF MATERIALS

Ecology 2012, Sieve Analysis (USDA/ASTM)

- Recessional Outwash or Holocene only
- Need to assess if deeper layers will limit infiltration (equation 2 in 3.3.6 not recommended)

\[ \log_{10}(K_{s}) = -1.57 + 1.90D_{a} + 0.015D_{m} + 0.013D_{m} - 2.08D_{w} \]

INFILTRATION TESTS

SITING AND SELECTION OF MATERIALS

Old school infiltration testing (not recommended)

- Falling head test (EPA)
  - Scale too small for many applications
- Double Ring Infiltrometer
  - Scale too small for many applications, time consuming and expensive for scale
INFILTRATION TESTS

SITING AND SELECTION OF MATERIALS

Small-scale Pilot Infiltration Test (PIT)

- Difference from Large-Scale: Pit bottom area 12-32 sf

Large-scale Pilot Infiltration Test (PIT)

Modified Pilot Infiltration Test (PIT)
INFILTRATION TESTS

Modified Pilot Infiltration Test (PIT) for finished sub-grade

INFILTRATION ASSESSMENT

Correction factor for permeable pavement design infiltration rates

- Site variability and # test locations
  - CF_v = 0.33-1.0
- Quality of pavement base material
  - CF_m = 0.9-1.0
- \[ K_{design} = K_{measured} \times CF_v \times CF_m \]
  - Total correction ranges from 0.3 to 1.0
  - Personal recommendation: use correction factor of 0.5

INFILTRATION ASSESSMENT

Soil suitability criteria for treatment of runoff from pollution-generating hard surfaces (SSC 6)

- Cation exchange capacity > 5 meq/100 grams dry soil
- Organic content > 1%
- Measured K < 12 inches/hour
- Minimum of one foot of soil with above characteristics
INfiltration Tests

Siting and Selection of Materials

Testing frequency for permeable pavement

• Commercial sites: 1 test per 5,000 sq. ft. of permeable pavement
• Residential sites: 1 test per 200 feet of road and every lot
• Frequency of testing may be reduced based on professional judgment (consistent soil conditions and depth to seasonal high groundwater)
• Over-excavate each test location to look for any restrictive layers or groundwater

Scale of infiltration tests

Mounding analysis required if groundwater is less than 15 feet from base of permeable pavement section

• Depth to water table
• Infiltration rate of native soils
• Thickness and hydraulic conductivity of the saturated zone
• MODFLOW analysis by a qualified hydrogeologist
Detailed Approach

- Use methods for estimating infiltration correction factors with caution
- Infiltration rate is generally not a function of depth to groundwater, facility size, or facility aspect ratio
- Other elements of detailed approach (e.g., mounding analysis) are fine
- MODRET can be unstable, better to use MODFLOW or comparable program for mounding analysis

Summary

- Site characterization
- Infiltration rate testing
- Groundwater separation
- Correction factor
- Mounding analysis
INFILTRATION ASSESSMENT

Summary

• Geologic constraints and opportunities must be fully and correctly incorporated prior to site planning and engineering.

• Geology can help predict the nature of the physical environment.

DESIGN OBJECTIVES

Permeable pavements can be designed to provide one or more of the following:

• Reduce impervious footprint
• Flow control facility via the storage within the gravel sub-base
• Water quality treatment (if subgrade soils are suitable or treatment layer incorporated in pavement section)
• Other
GEOSYNTHETICS

Geosynthetics

- Typically not necessary or advised under most permeable pavement installations
- On sloped applications can address subsurface scour
- Maybe advised in certain situations for material separation
- Can be a clogging surface

SLOPE: Subgrade Slope & Storage Capacity

- Ideal 0% to maximize storage but can increase excavation effort
- Sloped conditions (1% to 5%) reduces the amount of useable storage space but decreases amount of excavation. Use periodic impermeable check dams, or gravel trenches or other measures to allow water to backup & infiltrate
- Consider geosynthetics for scour

SLOPE: Subsurface Overflow

- Install to not compromise section
- Outlet controlled
- Not an underdrain
**DESIGN**

**SLOPE**: Overflow/Back-up System

- Ideal 0% to maximize storage but can increase excavation
- Provide for emergency overflow
- What is the flow path if water does not infiltrate?
- Submerged outlet controlled pipe in base to avoid compromising section

---

**DESIGN**

**SLOPE**: Overflow/Back-up System

- If 100% infiltration facility follow manual guidelines for closed depression infiltration facility
- Subsurface drain pipe as described above (slotted pipe above design water surface level)
PAVEMENT SECTION DESIGN

Section includes:

- Top wearing course
- Leveling course (optional)
- Aggregate sub-base (storage)
- Geotextile (?)

PAVEMENT SECTION DESIGN

- Design conservatively for wearing course section depth
- Follow manufacturer guidelines for proprietary products (e.g. interlocking pavers, rigid and flexible open celled grids)

Consider:

- Design Speed
- Stress/torque on pavement surface (e.g. heavy vehicles making tight radius turns)
- Aesthetics

PAVEMENT SECTION DESIGN: Aggregate Base

- 30% +/- Voids for Gravel Storage Sub-base
  - Consult with Geotechnical Engineer

- Sub-base
  - Key is low fines (% passing 200 sieve), clean and interlocking fracture aggregate

- Sub-base for pedestrian areas:
  - AASHTO #57
  - 3/8” to 3/4” clean crushed gravel
  - OR per manufacturer
PAVEMENT SECTION DESIGN: Aggregate Base

- Sub-base for vehicular areas:
  - Permeable Ballast (WSDOT 9-03.9(2))
  - OR per manufacturer
- Consult with geotech to review subgrade and sub-base preparation
- Scarify existing subgrade to prevent sealing of subgrade
- Geotextile?
  - Consult with Geotechnical Engineer
- Depth depends on structural requirements and flow control objectives (will the installation accept run-on?)

PAVEMENT SECTION DESIGN: Modeling

Performance standards

- On-site Stormwater Management (MR #5) (NEW 2012)
  - Use BMP List (rain garden), 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 50-year peak flow
- Other Flow Control Standards
  - Combined Sewer or Capacity Constrained Basins (peak-based standards)
PAVEMENT SECTION DESIGN: Modeling

Subgrade Slope >2 to 5% (with berms)

- Cannot neglect lateral flow
- Modeled subsurface storage depth = average subsurface ponding depth (water depth before berm overtops or overflows*)

*function of slope, check dam height, and check dam spacing

PAVEMENT SECTION DESIGN: Edge Details

- Transition between impervious and pervious
- Thickened edge
- Transition to landscaping

SITING, DESIGN & CONSTRUCTION

Siting

Construction
PAVEMENT SECTION, TESC AND VERIFICATION

- Specifics to each permeable pavement type to be provided in sections after lunch
- Follow manufacturer guidelines for installation with proprietary products

PAVEMENT SECTION: Subgrade

- Design haul roads and sequence project to eliminate or minimize construction traffic on subgrade
- Rough grade to at least 6" above final grade
- Do not drive directly on finished sub-grade
- Excavator backs out of installation on rough grade while excavating to final grade

PAVEMENT SECTION: Aggregate Base Installation

- To finish sub-grade, excavator pulls back on rough grade 6-12" above finish sub-grade
- Do not drive directly on finished sub-grade
- Install aggregate base by back-dumping and spreading on top aggregate base
CONSTRUCTION

TEMPORARY EROSION & SEDIMENT CONTROL

• Install protection (TESC and Flow Diversion) measures prior to final excavation
• Prime contractor to inform other subs of requirements when working around permeable pavement
• Maintain Erosion Control BEFORE and AFTER construction. Permanently stabilize adjacent areas

POST INSTALLATION INSPECTION AND VERIFICATION

Infiltration Tests
• ASTM C1701 for concrete, asphalt and pavers
• Pavers have specific application guidelines for ASTM C1701
POST INSTALLATION INSPECTION AND VERIFICATION

- Pervious Concrete and Porous Asphalt
  - Check for raveling (pressure washer test or other means)
  - Check for uniform surface and non-sealing at the surface
  - Coring to check for consistent density and design depth

POST INSTALLATION INSPECTION AND VERIFICATION

- Check for sediment contamination from uncontrolled runoff
- Open celled plastic grids, check staking is per manufacturer

MAINTENANCE AND OPERATIONS

- Covered in Module 5.4
- Important: if allowing run-on from adjacent impervious surfaces, additional O&M will be necessary
SITING, DESIGN & CONSTRUCTION

SNOW MANAGEMENT

• Limit sanding material particle size to coarse materials (e.g. #8 stone)
• Raise plow or provide skids for permeable pavers
• Assess salt and sanding needs and adjust snow management program accordingly (permeable pavements may not require as much application)

Photos courtesy of UNH

Lunch
PERVIOUS CONCRETE DESIGN & CONSTRUCTION: General

- Pervious rigid pavement
- Highly durable
- Integral color available
- 15%+ voids

PERVIOUS CONCRETE DESIGN & CONSTRUCTION: Section / Wearing Course

- No fine aggregate reduced fine aggregate (sand)
- Admixtures
- Open Graded Course Aggregate
- Open Graded Course Aggregate
- AASHTO #7 or #8
- AASHTO #67
- Monofiliment Fiber
PERVIOUS CONCRETE DESIGN & CONSTRUCTION:

**SITING, DESIGN & CONSTRUCTION**

**PERVIOUS CONCRETE DESIGN & CONSTRUCTION:**

**Base Material**

- Cast PCCP directly on base material (no need for choker)

- Base for pedestrian areas:
  - AASHTO #57
  - 3/8" to 3/4" clean crushed gravel
  - Permeable Ballast (WSDOT 9-03.9(2))

- Base for vehicular areas:
  - Permeable Ballast (WSDOT 9-03.9(2))

**ACI & ASTM standards**

- ACI 522-10
  - Somewhat limited in specifics
  - Good general resource

- ASTM
  - Many standard concrete tests DON’T work
    - Compressive Strength of Cylinder
    - Flexural Strength Test by Beam

**NRMCA standards**

- NRMCA Contractor Certifications
  - Pervious Concrete Craftsman
  - Pervious Concrete Installer
  - Pervious Concrete Technician

- Contractors need to have a certain number of each level on each crew

- Training offered locally by Washington Aggregates and Concrete Association
  - Bruce Chattin, ED
PERVIOUS CONCRETE DESIGN & CONSTRUCTION:
Testing and Verification

- Test panel
- Unit Weight
  - Dry (cores) & Wet (plastic concrete)
- Thickness
- Uniformity
- Areas sealed with paste
- Infiltration test
  - ASTM C1701

PERVIOUS CONCRETE DESIGN & CONSTRUCTION:
Placing & Finishing

- Can’t pump but conveyor ok
- Minimal handling

PERVIOUS CONCRETE DESIGN & CONSTRUCTION:
Jointing

- Sawcut in cured concrete
- Rolled in plastic concrete (preferred)
PERVIOUS CONCRETE DESIGN & CONSTRUCTION:

Finishing

Cover, secure carefully and protect

- Concrete should remain covered for six days

PERVIOUS CONCRETE DESIGN & CONSTRUCTION:

Mathei Place

- Bellingham, WA
- Built 2006
- 12,000 sf
- Affordable Housing
- “2”/hr. long term
- ¼” pea gravel aggregate
- Less costly than traditional
- LEED-Homes Pilot
PERVIOUS CONCRETE DESIGN & CONSTRUCTION: Firstenberg Comm. Center

- Vancouver, WA
- Built 2005
- 110,000 sf
- Public Community Center
- ~4"/hr. long term
- ¼" pea gravel aggregate
- LEED-Gold

Field Exercise
Infiltration Tests
Equipment Demos
GRID SYSTEM: Types

- Gravel
- Grass

GRID SYSTEM: Gravel Paver: applications

Trails
- Severe rutting prior to installation
- Park estimates an 80% reduction in maintenance time and cost
GRID SYSTEM: Gravel Paver: applications

- Trails
  - Oakdale Nature Preserve, IL
  - Colorado Springs City Building, CO
- Fire lanes
  - Tri Rail Station, Miami Airport, FL
- Utility access

GRID SYSTEM: Gravel Paver

Trade Names
- Grassy Pavers
- TruGrid
- Geoblock
- Gravelpave2
- Agrablock
- Integra 500
- Ground Grid
- Netpave 50

Base course specification
- Sandy gravel material common for road base

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GRID SYSTEM: Gravel Paver: flexible pavers

- Grid colors to match aggregate
- Many systems available
- Many 100% recycled HDPE
- Different structural characteristics

GRID SYSTEM: Gravel Paver: wearing course

Gravel fill examples

Use clean, angular, hard, uniform size: 3/16 inch to 3/8 inch

GRID SYSTEM: Gravel Paver: installation

Refer to manufacturer’s technical specifications for complete installation details

1. Install and compact base
2. Unroll paver, connect and cut as needed
3. Secure to base with anchors*
4. Fill with open graded 3/8” aggregate (gravel)
5. Use and maintain

*Check with specific manufacturer, some do not supply anchors.
GRID SYSTEM: Gravel Paver: ADA access

Americans with Disability Act (ADA)
- Gravelpave2 – tested to meet required standards by Beneficial Designs, Inc. April 1999

GRID SYSTEM: Grass Paver: applications

Primary applications
- Overflow Parking
- Fire/emergency access
- Utility access
- Residential drives and parking
- Pedestrian traffic

GRID SYSTEM: Grass Paver: applications

Fire lanes and emergency access

- 100’ ladder with outrigger
- 70,000 lbs
- Grasspave2 by Invisible Structures

5,720 psi load bearing capacity (filled)
GRID SYSTEM: Grass Pavers

Trade Names
- Grassy Pavers
- TruGrid
- Geoblock
- Grasspave2
- Netpave 50
- GT Interlocking Panels
- MODI Porous Paving Grid
- Salaverde

Base course specification
- Sandy gravel material common for road base

<table>
<thead>
<tr>
<th>Sieve</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td>500</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>90-100</td>
</tr>
<tr>
<td>1/8&quot;</td>
<td>70-80</td>
</tr>
<tr>
<td>#4</td>
<td>55-70</td>
</tr>
<tr>
<td>#10</td>
<td>45-55</td>
</tr>
<tr>
<td>#40</td>
<td>25-35</td>
</tr>
<tr>
<td>#200</td>
<td>3-8</td>
</tr>
</tbody>
</table>

GRID SYSTEM: Grass Paver: flexible pavers
- Exceeds H-20 loading requirements
- Both Grassy Pavers and Invisible Structures recycled HDPE
GRID SYSTEM: Grass Paver: wearing course

- Sand fill
  - Turf (sandy loam) or aggregate (3/16 minus to 3/8) top fill
- Grass

GRID SYSTEM: Grass Paver: installation

Refer to manufacturer’s technical specifications for complete installation details

1. Install and compact base
2. Add soil amendment - fertilizer/polymer*
3. Unroll paver, connect, and cut as needed
4. Fill with sand**
5. Lay sod or hydroseed
6. Use and maintain - irrigate, fertilize, mow. Do Not Aerate

*Check with specific manufacturer for availability (fertilizer, Zeopro, Isolite and Humate soil conditioners).

**Some manufacturers fill with top soil or existing soil. Sand is the preferred method of Prof. Bruce K. Ferguson, author, Porous Pavements: Integrated Studies in Water Management and Land Development
GRID SYSTEM: Grass Paver: applications

Stadium and arena parking lots

Ladd Peebles Stadium, Mobile, AL
Orange Bowl, Miami, FL

St. Louis Rams Stadium, MO
Mitchell Center Arena, Mobile, AL

GRID SYSTEM: Grass Paver: applications

Hybrid grass/gravel fire lane

House of Awakened Culture, Suquamish Tribe Fire lane, Design: Chris Wells

Statewide LID Training Program
PERMEABLE PAVEMENT
INTERMEDIATE LID DESIGN
GRID SYSTEM: Grass and Gravel Paver: snow removal

Seasonal and overflow parking: snow removal

- Raise blade 1 inch above surface and/or attach skids

GRID SYSTEM: Grass Paver: local climate

Urban heat island mitigation

- Grass Albedo 0.40
- Air Conditioning effect through transpiration

GRID SYSTEM: Grass Paver: LEED

LEED™ Points

- Reduced site disturbance
- Stormwater management
- Reduced heat island effect
- Water efficient landscaping
- Innovative wastewater technology
- Water use reduction
- Recycled content
- Erosion and sediment control
Permeable pavements provide several pollutant removal mechanisms inherent to the paving structure:

- Stormwater volume reduction
- Reduced spray and vehicle wash off
- Biological degradation
- Filtration
- Adsorption
- Volatilization

### Typical Stormwater Pollutants

- Hydrocarbons
  - Oil, grease and gasoline
- PAH’s
- Metals
  - Pb, Cu, Zn, Cd, Cr
- Sediment
- Nutrients
- Chloride
- Bacteria

### Characteristics of Paving Pollutants

- PAH’s product of incomplete combustion and sealers. Coal tar emulsions may be 5-600x higher in PAH’s concentrations than asphalt emulsion
- Primary conduit for hydrocarbons (gas and diesel)
- ~344 metric tons/yr of Zn to Puget Sound annually
- Many pollutants associated with fines (particularly metals), many <0.45 microns (dissolved)
WATER QUALITY TREATMENT

MEDIAN OF AVERAGE EFFLUENT CONCENTRATIONS

<table>
<thead>
<tr>
<th></th>
<th>SS (mg/L)</th>
<th>TCu (µg/L)</th>
<th>TPh (µg/L)</th>
<th>TZn (µg/L)</th>
<th>TP (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP (n=6)</td>
<td>16.96</td>
<td>12.78</td>
<td>16.88</td>
<td>16.60</td>
<td>&lt;0.09</td>
</tr>
<tr>
<td>DP (n=25)</td>
<td>20.74</td>
<td>14.91</td>
<td>15.47</td>
<td>18.67</td>
<td>0.18</td>
</tr>
<tr>
<td>WP (n=46)</td>
<td>3.74</td>
<td>5.82</td>
<td>4.30</td>
<td>21.58</td>
<td>0.10</td>
</tr>
<tr>
<td>WB (n=19)</td>
<td>13.38</td>
<td>3.35</td>
<td>2.51</td>
<td>29.21</td>
<td>0.11</td>
</tr>
<tr>
<td>BF (n=57)</td>
<td>17.84</td>
<td>9.63</td>
<td>5.42</td>
<td>27.93</td>
<td>0.27</td>
</tr>
<tr>
<td>MF (n=18)</td>
<td>10.85</td>
<td>7.63</td>
<td>2.62</td>
<td>32.23</td>
<td>0.11</td>
</tr>
<tr>
<td>HD (n=32)</td>
<td>23.48</td>
<td>11.82</td>
<td>5.06</td>
<td>75.12</td>
<td>0.20</td>
</tr>
</tbody>
</table>

PP = permeable paving, DP = detention pond, WP = wet pond, WB = wetland basin, BF = biofilter, MF = media filter, HD = hydrodynamic

WATER QUALITY TREATMENT

MEAN CONCENTRATIONS FOR 9 TEST PARKING STALLS: Renton, WA (2001-2002)

<table>
<thead>
<tr>
<th></th>
<th>Cu (µg/L)</th>
<th>Pb (µg/L)</th>
<th>Zn (µg/L)</th>
<th>Motor Oil (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravelpave</td>
<td>0.89</td>
<td>ND</td>
<td>8.23</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>Grasspave</td>
<td>&lt;MDL</td>
<td>ND</td>
<td>13.2</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>Turfstone</td>
<td>1.33</td>
<td>ND</td>
<td>7.7</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>EcoStone</td>
<td>0.86</td>
<td>ND</td>
<td>6.8</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>Conventional Asphalt</td>
<td>7.98</td>
<td>--</td>
<td>21.6</td>
<td>0.164</td>
</tr>
</tbody>
</table>

- MDL: motor oil <0.10 mg/l, Cu <1.0 (µg/L), Zn <5 (µg/L)
- Permeable paving sections ~10 cm deep, 60-100% occupancy during business hours. Test plots 6 years old. Dissolved metals
- Conventional asphalt section exceeded WA surface flow WQ standards for Zn in all but one sample (acute and chronic)

WATER QUALITY TREATMENT

COMPARISON OF WATER QUALITY PARAMETERS: Permeable vs Conventional

<table>
<thead>
<tr>
<th>Study</th>
<th>TSS (mg/L)</th>
<th>TH/PAHs (mg/L)</th>
<th>Pb (µg/L)</th>
<th>Zn (µg/L)</th>
<th>Cu (µg/L)</th>
<th>Cd (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legret et al (1996) Perm</td>
<td>5.4</td>
<td>15</td>
<td>0.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrett et al (2006) PFC Perm</td>
<td>0.9</td>
<td>26.8</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berbee et al (1999) PFC Perm</td>
<td>7</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berbee et al (1999) PFC Conv</td>
<td>93</td>
<td>121</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Legret: permeable asphalt road France, ~2000 vehicle trip/day. Study estimates that ~97% of stormwater infiltrates in reservoir structure and soil
- Barrett: 4 lane divided highway Austin TX, 20m2 retrofitted with 50mm PFC, ADT 43,000
- Berbee: 2 highways near Amsterdam, 1 conventional (53,000veh/day) and 1 PFC (83,000 veh/day)
CONCENTRATIONS OF DISSOLVED METALS

**Water Quality Treatment**

Concentrations of dissolved metals in 60 cm laboratory rigs with permeable pavers and four different base aggregate materials (simulates 50 yrs of loading)

<table>
<thead>
<tr>
<th>Material</th>
<th>Lead (µg/L)</th>
<th>Cadmium (µg/L)</th>
<th>Copper (µg/L)</th>
<th>Zinc (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic Stormwater</td>
<td>180</td>
<td>30</td>
<td>470</td>
<td>660</td>
</tr>
<tr>
<td>Effluent Gravel</td>
<td>&lt;4</td>
<td>0.7</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Basalt</td>
<td>&lt;4</td>
<td>0.7</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Limestone</td>
<td>&lt;4</td>
<td>3.2</td>
<td>29</td>
<td>85</td>
</tr>
<tr>
<td>Sandstone</td>
<td>&lt;4</td>
<td>51</td>
<td>178</td>
<td></td>
</tr>
</tbody>
</table>

**Percent Retention**

- Gravel: 98% 98% 96% 97%
- Basalt: 98% 98% 96% 98%
- Limestone: 98% 88% 94% 88%
- Sandstone: 98% 74% 89% 72%

---

SOIL POLLUTANT CONCENTRATIONS

Soil pollutant concentrations in soil beneath permeable paving installations

<table>
<thead>
<tr>
<th>Study</th>
<th>Depth</th>
<th>MOH (mg/kg)</th>
<th>PAH's (mg/kg)</th>
<th>Pb (mg/kg)</th>
<th>Zn (mg/kg)</th>
<th>Cu (mg/kg)</th>
<th>Cd (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legret et al (1996)*</td>
<td>surface</td>
<td>--</td>
<td>--</td>
<td>190</td>
<td>383</td>
<td>46</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>60-75 cm</td>
<td>--</td>
<td>--</td>
<td>50</td>
<td>97</td>
<td>15</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>110-150 cm</td>
<td>--</td>
<td>--</td>
<td>29</td>
<td>111</td>
<td>15</td>
<td>0.05</td>
</tr>
<tr>
<td>Dierkes et al (2002)</td>
<td>surface</td>
<td>133</td>
<td>ND(&lt;1.5)</td>
<td>--</td>
<td>--</td>
<td>60</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>0-5 cm</td>
<td>26</td>
<td>ND(&lt;1.5)</td>
<td>--</td>
<td>Background</td>
<td>Background</td>
<td>Background</td>
</tr>
<tr>
<td></td>
<td>5-10 cm</td>
<td>20</td>
<td>ND(&lt;1.5)</td>
<td>--</td>
<td>Background</td>
<td>Background</td>
<td>Background</td>
</tr>
<tr>
<td>MTCA</td>
<td>30/4,000</td>
<td>0.1</td>
<td>250</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Study estimates that ~97% of stormwater infiltrates in reservoir structure and soil
**Gas with benzene/mineral oil

---

**Gas with benzene/mineral oil**
**HYDROCARBON BIODEGRADATION**

- A diversity of microbes (flagelates, amoeba, rotifers) colonize permeable paving immediately
- 97-99% removal capability
- Geotextile primary substrate for microbes... Non-woven perform better than woven
- Nutrient need for microbial population unclear


**DEICING SALTS**

UNH Stormwater Center finding significant reduction of deicing salts for permeable paving compared to conventional paving

- May reduce salt use by 70% by allowing snowmelt and rain to infiltrate

**TYPICAL ROAD AND PARKING POLLUTANTS**

Permeable pavements may be more effective for managing typical road and parking pollutants than conventional practices

- Hydrocarbons, metals and nutrients
- Much of the pollutant capture and transformation happens in the upper few inches of the paving structure...geotextiles
**TYPICAL ROAD AND PARKING POLLUTANTS**

Permeable pavements may be more effective for managing typical road and parking pollutants than conventional practices:

- No significant contamination of soil has been observed in the research
- We currently do not give any water quality treatment credit for standard permeable pavements

**INITIAL INFILTRATION RATES**

Average permeable pavement surface infiltration rates (cm/hr)

<table>
<thead>
<tr>
<th>Date</th>
<th>PC</th>
<th>PICP1</th>
<th>CGP</th>
<th>PICP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/2006</td>
<td>3087</td>
<td>771</td>
<td>91</td>
<td>457</td>
</tr>
<tr>
<td>09/2006</td>
<td>6152</td>
<td>1027</td>
<td>89</td>
<td>171</td>
</tr>
<tr>
<td>03/2007</td>
<td>4466</td>
<td>1299</td>
<td>87</td>
<td>376</td>
</tr>
<tr>
<td>07/2007</td>
<td>4941</td>
<td>1536</td>
<td>101</td>
<td>267</td>
</tr>
</tbody>
</table>

Percent surface runoff reductions from rainfall depth

<table>
<thead>
<tr>
<th></th>
<th>Asphalt (n=44)</th>
<th>PC (n=40)</th>
<th>PICP1 (n=41)</th>
<th>CGP (n=40)</th>
<th>PICP2 (n=40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>34.65</td>
<td>99.86</td>
<td>99.33</td>
<td>98.17</td>
<td>99.51</td>
</tr>
<tr>
<td>Median</td>
<td>29.43</td>
<td>99.94</td>
<td>99.37</td>
<td>98.67</td>
<td>99.68</td>
</tr>
<tr>
<td>Min</td>
<td>-2.73</td>
<td>99.03</td>
<td>97.76</td>
<td>91.11</td>
<td>96.94</td>
</tr>
<tr>
<td>Max</td>
<td>84.80</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**LONG-TERM INFILTRATION RATES**

High initial infiltration rates in permeable paving will diminish over time...important to consider context and maintenance.

Infiltration Rates Over Time

- Most conservative: 10.0 in/hr for 20 yr life span (ICPI)
- 50% of initial infiltration rate typical recommendation.
- Permeable asphalt hwy: 1986 100 in/hr, 1990 28 in/hr
LONG-TERM INFILTRATION RATES

Infiltration Rates Over Time

- Florida permeable concrete field evaluation: 6.5 yrs old: 240 in/hr, 8 yrs old: 42 in/hr
- Borgwardt: reports a long-term infiltration rate for permeable pavers of 4.25 in/hr
- Worst case: 1096 cm/hr reduced to 3.32 cm/hr observed...105 cm/hr after cleaning (Hinman, 2009)

Q&A
Other Course Offerings

Introduction to LID for Eastern Washington
- Introductory LID topics: MPDES Phase 1 & 2 requirements
- Intermediate LID design: bioretention
- Intermediate LID design: permeable pavement
- Intermediate LID design: site assessment, planning & layout
- Intermediate LID design: rainwater collection systems & vegetated roofs

Train the Trainers
- INTRODUCTORY
  - Introductory LID for Service Providers
- INTERMEDIATE
  - Intermediate LID for Inspection & Maintenance Staff
  - Intermediate LID for Developers & Contractors: Make Money be Green
- ADVANCED
  - Advanced Topics in LID Design: Hydrologic Modeling
  - Advanced Topics in LID Design: Bioretention Media

Online Evaluation
- An on-line evaluation will be sent to you within 5 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

Stay tuned!
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

STATEWIDE LID TRAINING PROGRAM

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

STATEWIDE LID TRAINING PROGRAM

QUESTIONS