INSTRUCTORS

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

DUSTIN ATCHISON, PE
Water Resources Project Manager
Key project experience: LID design, stormwater master planning, stream and wetland restoration design, hydrologic and hydraulic modeling

AGENDA

1. introduction
2. permeable pavement basics
3. common siting, design and construction
4. design and construction by pavement type
5. 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.wastormwaterscenter.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.

PROJECT LEAD

CORE TEAM

TEAM

ADDITIONAL TRAINING SUPPORT

TRAINING SEQUENCE

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 & Construction Management Teams
3.1 Intermediate LID: NPS2 Phase 1 & 2 Requirements
3.2 Intermediate LID Design: Monitoring
3.3 Intermediate LID Design: Permeable Pavement
3.4 Intermediate LID Design: Rainwater Harvesting Systems & Vegetated Roofs
4.1 Intermediate LID Design: Hydrologic Modeling
4.2 Intermediate LID Design: Permeable Pavement
5.1 Advanced Topics in LID Design: Monitoring
5.2 Advanced Topics in LID Design: Permeable Pavement
5.3 Advanced Topics in LID Design: Maintenance
5.4 Advanced Topics for LID Operations: Permeable Pavement
5.5 Advanced Topics in LID Design: Maintenance
5.6 Advanced Topics in LID Design: Hydrologic Modeling
5.7 Advanced Topics in LID Design: Permeable Pavement
5.8 Advanced Topics in LID Design: Site Assessment, Planning & Layout
6.0 Advanced Topics in LID Design: Maintenance, Monitoring & Assessment
7.0 Advanced Topics in LID Design: Site Assessment, Planning & Layout
8.1 Advanced Topics in LID Design: Maintenance, Monitoring & Assessment
8.2 Advanced Topics in LID Design: Site Assessment, Planning & Layout

TRAIN THE TRainers

9.1 LID Topic Experts
9.2 Version 9.1
Introduction to LID for Eastern Washington

AGENDA

- introduction
- permeable pavement basics
- common siting, design and construction
- water quality treatment
- wrap-up

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.

PREDEVELOPED CONDITION

DEVELOPED CONDITION

Yakima Regional LID Stormwater Design Manual (April 2011)
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.

Statewide LID Training Program

Rainwater collection
Low impact foundations
Vegetated roofs
Bioretention
Permeable pavement
INTRODUCTION

NPDES PERMIT REQUIREMENTS

• Phase I*:
  - Populations ≥ 100,000

• Phase II:
  - Generally populations > 10,000

• Issuance date: August 1, 2012
• Effective date: August 1, 2014
• Permit term: 5 years (through July 31, 2019)

* No Phase I jurisdictions in Eastern WA

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INTRODUCTION

NPDES PERMIT REQUIREMENTS

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INTRODUCTION

NPDES PERMIT REQUIREMENTS: Core Elements

#1 Preparation of a Stormwater Site Plan
#2 Construction Stormwater Pollution Prevention
#3 Source Control of Pollution
#4 Preservation of Natural Drainage Systems and Outfalls
#5 Runoff Treatment
#6 Flow Control
#7 Operations and Maintenance
#8 Local Requirements
INTRODUCTION

NPDES PERMIT REQUIREMENTS:
Core Element 5 and 6 Thresholds

Core Element 5 – Runoff Treatment

• New: ≥ 5,000 sq. ft. pollutant-generating impervious surface (PGIS)
• Redevelopment: ≥ 5,000 sq. ft. PGIS for specific industrial, commercial, high-use, and high traffic sites

Core Element 6 – Flow Control

• New: ≥ 10,000 sq. ft. new impervious surfaces
• Redevelopment: Not required for redevelopment unless required under a basin plan or other federal, state, or local requirement

INTRODUCTION

CORE ELEMENT # 5 (RUNOFF TREATMENT)

• Standards
  • Treat 90% of annual runoff
  • Specific treatment required depending on site type and/or location:
    • Basic (TSS)
    • Metals (dissolved Cu and Zn)
    • Phosphorus
    • Oil

• Basic Treatment Exemptions
  • Satisfies full dispersion
  • Discharges to a qualified UIC facility

• Metals Treatment Exemptions
  • Discharges to non-fish-bearing streams
  • Direct discharges to the main channels of certain rivers and lakes
  • Subsurface discharges
  • Restricted residential and employee-only parking areas
INTRODUCTION

CORE ELEMENT # 6 (FLOW CONTROL)

• Standard
  • Based on a pre-developed condition (prior to settlement) or existing condition

• Exemptions
  • Disperse total 25-year runoff volume without discharge
  • Discharge to irrigation return flow stream reaches
  • Direct discharge to flow control “exempt surface waters” (Large rivers & streams, lakes & reservoirs with > 100 sq. mi. drainage area, reservoirs with outlet controls)

• Exemptions
  • Discharge to a wetland with no surface water outlet
  • Discharge to a stream that flows only during runoff producing event
PERMEABLE PAVEMENT

PERMEABLE PAVEMENT COMPONENTS

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

AGENDA

- Introduction
- Permeable pavement basics
- Common siting, design and construction
- Design and construction by pavement type
- Wrap-up
PERMEABLE PAVEMENT BASICS

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)

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.
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.
PERMEABLE PAVEMENT BASICS

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

Statewide LID Training Program
PERMEABLE PAVEMENT
INTERMEDIATE LID DESIGN
PERMEABLE PAVEMENT BASICS

HOW THE FACILITY WORKS

- Storage
- Infiltration

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
OVERVIEW
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

Photos: Kathy Gwilym, SVR

32nd Ave. SW, Seattle. Pervious Concrete (2005 – 8” PPCC over 18” sub-base)

Grand Central Parking Lot, Vancouver, WA

N. May Ave, Pocatello. Pervious Asphalt Concrete (2005 – 8” porous AC over 6” sub-base)
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

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
INFILTRATION ASSESSMENT

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

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)

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)

\[ \log_{10}(K_{sat}) = 1.57 + 1.90D_10 + 0.015D_{60} + 0.013D_{10} + 2.8K_{sat} \]
SITING AND SELECTION OF MATERIALS

INFILTRATION TESTS

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

SITING AND SELECTION OF MATERIALS

INFILTRATION TESTS

Small-scale Pilot Infiltration Test (PIT)

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

SITING AND SELECTION OF MATERIALS

INFILTRATION TESTS

Large-scale Pilot Infiltration Test (PIT)
SITING AND SELECTION OF MATERIALS

INFILTRATION TESTS

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
  - $C_F_v=0.33-1.0$
- Quality of pavement base material
  - $C_F_m=0.9-1.0$
- $K_{design} = K_{measured} \times C_F_v \times C_F_m$
  - 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

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

INFILTRATION TESTS

Scale of infiltration tests
**INFILTRATION ASSESSMENT**

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

**Groundwater mound development**

**Volume 3, Section 3.3.8 – 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
INFILTRATION ASSESSMENT

Summary

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

- 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 subbase
• 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

**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
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)
  - Frost depth
  - Snow removal
  - Aesthetics
PAVEMENT SECTION DESIGN: Snow

Establish proper snow removal and deicing procedures
Underlying stone bed tends to absorb and retain heat so that freezing rain and snow melt faster on permeable pavement

Source: CWP BMP Design Supplement for Cold Climates

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Consider the soil frost line when developing infiltration bed design.

Recent research has shown permeable pavement to be successful in cold climates when properly installed and maintained, and when sanding is kept to a minimum.

**PAVEMENT SECTION DESIGN: Snow**

- 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

• Runoff Treatment (Core Element #5)
  • Treat 90 percent of the annual runoff volume through soil meeting Ecology treatment criteria (for infiltration BMPs)

• Flow Control (Core Element #6)
  • Match flow durations 50% of the pre-developed 2-year flow
  • Maintain the pre-developed 25-year flow
  • Entire 2-year runoff volume from developed site released at no more than 50% of pre-developed 2-year flow

Note: Only aggregate under overflow invert modeled

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

Photo: courtesy of Curtis Hinman

SITING, DESIGN & CONSTRUCTION

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

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

CONSTRUCTION

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

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)
Lunch

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

Porous Asphalt Guest Speaker:
Mark Palmer, City of Puyallup

Statewide LID Training Program
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
- Monofilament Fiber

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))
PERVIOUS CONCRETE DESIGN & CONSTRUCTION: 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

PERVIOUS CONCRETE DESIGN & CONSTRUCTION: 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

Photos: Kathy Gwilym, SvR
PERVIOUS CONCRETE DESIGN & CONSTRUCTION:
Placing & Finishing

- Can't pump but conveyor ok
- Minimal handling

Bunyan Power Screed

SITING, DESIGN & CONSTRUCTION
PERVIOUS CONCRETE DESIGN & CONSTRUCTION:
Jointing

- Sawcut in cured concrete
- Rolled in plastic concrete (preferred)

SITING, DESIGN & CONSTRUCTION
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
- ¾” pea gravel aggregate
- LEED-Gold
PERVIOUS CONCRETE DESIGN & CONSTRUCTION:
Firstenberg Community Center

SITING, DESIGN & CONSTRUCTION

Photo: Chris Webb, Herrera

Field Exercise
Infiltration Tests
Equipment Demos

PERMEABLE PAVER GUEST SPEAKER:
RICK CROOKS, MUTUAL MATERIALS

Statewide LID Training Program
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

Fire lanes
- Oakdale Nature Preserve, IL
- Colorado Springs City Building, CO

Utility access
- Tri Rail Station, Miami Airport, FL
GRID SYSTEM: Gravel Pavers

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

GRID SYSTEM: Gravel Paver: base material

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

- Crushed Granite 3/16"
- Decomposed Granite 3/8"
- Carbon Cinder 5/16" minus
- Sonora Tan 3/8"

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

SITING, DESIGN & CONSTRUCTION

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: installation

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

World's Fair Park, Knoxville, TN

City Works Yard, Vancouver, BC

GRID SYSTEM: Grass Paver: applications

Fire lanes and emergency access

100' ladder with outriggers
70,000 lbs.
Grasspave2 by Invisible
50-sustains

Dupont Center, Irvine, CA

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
- Salvaverde

Substrate
Compounding porous base course
Polymer/fertilizer
Flexible paver
Sand fill
GRID SYSTEM: Grass Paver: base material

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>100</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>90-100</td>
</tr>
<tr>
<td>3/8&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: Grasss Paver: wearing course

- Sand fill
  - Turf (sandy loam) or aggregate (3/16 minus to 3/8) top fill
  - Grass
GRID SYSTEM: Grass Paver: installation

1. Install and compact base
2. Add soil amendment - fertilizer/polymer*
3. Unroll paver, connect, and cut as needed

SITING, DESIGN & CONSTRUCTION
Refer to manufacturer’s technical specifications for complete installation details

*Check with specific manufacturer for availability (polymer, forms, tools and human squat compliance).

GRID SYSTEM: Grass Paver: installation

4. Fill with sand**
5. Lay sod or hydroseed
6. Use and maintain - irrigate, fertilize, mow.
   Do Not Aerate

**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
GRID SYSTEM: Grass Paver: applications

Stadium and arena parking lots

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 Webb

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

WATER QUALITY TREATMENT
REMOVAL MECHANISMS

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)

MEDIAN OF AVERAGE EFFLUENT CONCENTRATIONS

<table>
<thead>
<tr>
<th>Sample</th>
<th>SS (mg/L)</th>
<th>TCu (µg/L)</th>
<th>TPb (µg/L)</th>
<th>TZn (µg/L)</th>
<th>TP (mg/L)</th>
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<tr>
<td>PP (n=6)</td>
<td>16.96</td>
<td>2.78</td>
<td>7.88</td>
<td>16.60</td>
<td>0.09</td>
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<tr>
<td>DP (n=25)</td>
<td>26.74</td>
<td>15.91</td>
<td>14.57</td>
<td>58.66</td>
<td>0.19</td>
</tr>
<tr>
<td>WP (n=46)</td>
<td>9.74</td>
<td>5.82</td>
<td>3.40</td>
<td>21.58</td>
<td>0.10</td>
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<tr>
<td>WB (n=19)</td>
<td>13.38</td>
<td>3.35</td>
<td>2.57</td>
<td>29.21</td>
<td>0.11</td>
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<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>
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<tr>
<td>MF (n=38)</td>
<td>10.85</td>
<td>7.63</td>
<td>2.62</td>
<td>32.23</td>
<td>0.11</td>
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<tr>
<td>HD (n=32)</td>
<td>23.48</td>
<td>11.82</td>
<td>5.05</td>
<td>75.12</td>
<td>0.20</td>
</tr>
</tbody>
</table>

International BMP Database
PP = permeable paving, DP = detention pond, WP = wet pond, WB = wetland basin, BF = biofilter, MF = media filter, HD = hydrodynamic
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>
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</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 ~60 cm deep, 50-100% 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)

COMPARISON OF WATER QUALITY PARAMETERS: Permeable vs Conventional

<table>
<thead>
<tr>
<th>Study</th>
<th>TSS (mg/L)</th>
<th>TH/PAH's (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>12</td>
<td>TH &lt;0.02</td>
<td>5.4</td>
<td>46</td>
<td>15</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Conv</td>
<td>33</td>
<td>TH &lt;0.02</td>
<td>26.0</td>
<td>165</td>
<td>11</td>
</tr>
<tr>
<td>Barrett et al (2006) PFC Perm</td>
<td>7.6</td>
<td>PAH's &lt;detect&gt;</td>
<td>0.9</td>
<td>40.4</td>
<td>26.8</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Conv</td>
<td>117.8</td>
<td>PAH's &lt;detect&gt;</td>
<td>12.6</td>
<td>167.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Berbee et al (1999) PFC Perm</td>
<td>17</td>
<td>PAH's 5.2-5.8</td>
<td>7</td>
<td>47</td>
<td>40</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Conv</td>
<td>194</td>
<td>PAH's &lt;0.3</td>
<td>93</td>
<td>452</td>
<td>121</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 divide highway Austin TX, 20m2 retrofitted with 50mm PFC, ADT 43,000
- Berbee: 2 highways near Amsterdam, 1 conventional (53,000veh/day) and 1 PFC (81,000 veh/day)

CONCENTRATIONS OF DISSOLVED METALS

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></th>
<th>Lead (µg/L)</th>
<th>Cadmium (µg/L)</th>
<th>Copper (µg/L)</th>
<th>Zinc (µg/L)</th>
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<tbody>
<tr>
<td>Synthetic Stormwater</td>
<td>180</td>
<td>30</td>
<td>470</td>
<td>660</td>
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<tr>
<td>Effluent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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></td>
<td>51</td>
<td>178</td>
</tr>
<tr>
<td>Percent Retention</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td>98%</td>
<td>98%</td>
<td>96%</td>
<td>97%</td>
</tr>
<tr>
<td>Basalt</td>
<td>98%</td>
<td>98%</td>
<td>96%</td>
<td>96%</td>
</tr>
<tr>
<td>Limestone</td>
<td>98%</td>
<td>88%</td>
<td>94%</td>
<td>88%</td>
</tr>
<tr>
<td>Sandstone</td>
<td>98%</td>
<td>74%</td>
<td>89%</td>
<td>72%</td>
</tr>
</tbody>
</table>

Dierkes 2002
CONCENTRATIONS OF DISSOLVED METALS

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</td>
<td>surface</td>
<td>--</td>
<td>--</td>
<td>190</td>
<td>383</td>
<td>46</td>
<td>0.30</td>
</tr>
<tr>
<td>(1996)*</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>28</td>
<td>113</td>
<td>15</td>
<td>0.05</td>
</tr>
<tr>
<td>Dierkes et al</td>
<td>surface</td>
<td>133</td>
<td>ND(&lt;1.5)</td>
<td>~60</td>
<td>~26</td>
<td>~5</td>
<td>~5</td>
</tr>
<tr>
<td>(2002)</td>
<td>0-5 cm</td>
<td>26</td>
<td>ND(&lt;1.5)</td>
<td>Back-ground</td>
<td>Back-ground</td>
<td>Back-ground</td>
<td>Back-ground</td>
</tr>
<tr>
<td></td>
<td>5-10 cm</td>
<td>20</td>
<td>ND(&lt;1.5)</td>
<td>Back-ground</td>
<td>Back-ground</td>
<td>Back-ground</td>
<td>Back-ground</td>
</tr>
<tr>
<td>MTCA</td>
<td>30/4,000</td>
<td>**0.1</td>
<td>250</td>
<td>--</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

HYDROCARBON BIODEGRADATION

- A diversity of microbes (flagellates, 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

Newman 2002 and 2004, Pratt 1999
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

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>-</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

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)
## Statewide LID Training Program

### OTHER COURSE OFFERINGS

<table>
<thead>
<tr>
<th>INTRODUCTORY</th>
<th>INTERMEDIATE</th>
<th>ADVANCED</th>
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<tr>
<td>1.0</td>
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<td>5.1</td>
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<tr>
<td>Introduction to LID for Eastern Washington</td>
<td>Intermediate LID Topics: MP259 Plans &amp; Requirements</td>
<td>Advanced Topics in LID Design, Maintenance</td>
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<tr>
<td>2.1</td>
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<tr>
<td>Introduction to LID for Inspectors &amp; Maintenance Staff</td>
<td>Intermediate LID Design, Bioretention</td>
<td>Advanced Topics in LID Design, Permeable Pavement</td>
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<tr>
<td>2.2</td>
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<tr>
<td>Introduction to LID for Developers &amp; Management Teams: Site Planning &amp; Design</td>
<td>Intermediate LID Design, Permeable Pavement</td>
<td>Advanced Topics for LID Operations, Bioretention Media</td>
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<td>3.4</td>
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<td>Advanced Topics for LID Operations, Bioretention Media</td>
<td>Advanced Topics in LID Design, Rainwater Systems &amp; Vegetated Roofs</td>
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<td>TRAIN THE TRAINERS</td>
<td>Service Providers</td>
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### Q&A
Statewide LID Training Program

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

Statewide LID Training Program

CERTIFICATE

Two certificates:
• LID Design certificate
• Long-term LID Operations certificate
• Stay tuned for developing certificate policies

Sign out!

Statewide LID Training Program

ONLINE RESOURCES

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