Permeable Interlocking Concrete Pavement
A Low Impact Development Tool

Training for Design Professionals

Presented by:
Interlocking Concrete Pavement Institute
The Low Impact Development Center, Inc.
North Carolina State University

This program is registered with the AIA/CES and ASLA CPE continuing education professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA or ASLA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Revised Dec. 19, 2008
Program 000008
Learning objectives:
- Identify PICP Components
- Examine cost recovery by reduction/elimination of drainage facilities
- Understand hydrological and structural design principles for the pavement base/subbase
- Work through a PICP sizing example
- Understand basic construction & maintenance requirements of PICPs

Contents
- PICP System & Materials
- PICP Costs
- PICP Benefits
  - Runoff & Pollutant Reduction
  - Green infrastructure
  - Environmental benefits
  - LEED® & Sustainable Design
  - Infrastructure cost savings
  - ADA Compliant
  - improved tax base
- Sizing example
- Construction/Inspection
- Maintenance
- PICP Resources
What is PICP?

Concrete Pavers
Permeable Joint Material
Open-graded Bedding Course
Open-graded Base Reservoir
Open-graded Subbase Reservoir
Underdrain (As required)
Optional Geotextile Under the Subbase
Uncompacted Subgrade Soil

System
Components

Paver Types: Interlocking Shapes/Patterns
Paver Types
Notched Sides

Enlarged Joints: up to ½ in. (13 mm)

Built-In Concrete Joint Spacers

Winter Performance

- Snow melts faster – lower risk of ice hazards
- Surface does not heave when frozen
- Can be snow plowed
- Deicing salts okay
- Sand will clog system

Snow melts faster – lower risk of ice hazards
Surface does not heave when frozen
Can be snow plowed
Deicing salts okay
Sand will clog system
**Assumptions:**
- Paver Thickness: 3 in. (8 cm)
- Bedding Layer: 2 in. (5 cm)
- Base Layer: 8 in. (20 cm)
- Total Area: 15,000-20,000 ft² (1,500 to 2,500 m²)
- Prevailing Wages
- Does NOT include design, concrete curbs, excavation, and pipe costs
- $ 7-12/sf

**Costs**
Autumn Trails, Moline, IL 2006

<table>
<thead>
<tr>
<th></th>
<th>PICP</th>
<th>Concrete</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 39,000 sf</td>
<td>$10.95</td>
<td>$15.00</td>
<td>$11.50</td>
</tr>
<tr>
<td>Cost per sf</td>
<td>No storm sewers</td>
<td>With storm sewers</td>
<td>With storm sewers</td>
</tr>
</tbody>
</table>
Costs

Affordable Housing
PICP reduces CSS loads
High Point
Seattle, WA

PICP Benefits

Green Infrastructure & LID Retrofits
Local Stormwater Regulations
Infrastructure Cost Savings
LEED & Sustainable Design
Improved Tax Base
Environmental Benefits
Durable ADA Compliant Surface
**PICP Benefits**

- Green Infrastructure & LID Retrofits
- Local Stormwater Regulations
- LEED & Sustainable Design
- Infrastructure Cost Savings
- Improved Tax Base
- Environmental Benefits
- Durable ADA Compliant Surface

**The Stormwater Problem**

**Annual Hydrology**

- **Pre-Development**
  - ET: 50%
  - Runoff: 5%
  - Infiltration: 45%

- **Post-Development**
  - ET: 35%
  - Runoff: 50%
  - Infiltration: 15%

---

Stormwater Management Objectives

...Varies with locality...

Water Quantity
• Retain/infiltrate runoff volumes & peak flows
• Imitate pre-development conditions
• Control amount of impervious cover

Water Quality
• Control specific nutrients and metals

PICP addresses these objectives

Integration with Other BMPs

Reduce inbound sediment to PICPs through upstream cover
• Grass swales, bioswales & filter strips
• Sand & organic filters
• Bioretention/ rain garden areas
PICP Hydrology Example

PICP Surface Infiltration Rates

NC State University Research Indicates:

- Not exposed to fines:
  - 800 in./hr (20,000 mm/hr)
- Exposed to fines:
  - 3.1 in./hr (80 mm/hr)
  - PICP infiltration rate similar to surrounding soil

Long term surface infiltration depends on sediment deposition rates + vacuum maintenance

German studies: long term (15+ yr.) surface infiltration is ~15% of initial

How PICP Manages Stormwater

**Water Quantity**
- Reduces volumes & peak flows via infiltration
- Imitates predevelopment conditions: no runoff from common storms
- Reduces or eliminates retention/detention facilities & conserves land
- Reduces stormwater utility fees
- Recharges groundwater
- Helps maintain dry-weather stream flows

**Water Quality**
- Reduced downstream erosion, preserves drainage system
- Filters & reduces nutrients and metals
- Filters oil drippings
- Reduces runoff temperatures

Runoff & Pollutant Reduction

**Case Study**
Jordan Cove Watershed, Glen Brook
Green subdivision, Waterford, CT
EPA Section 319 National Monitoring Program – 10 year program
PICP and No. 8 stone bedding
on *dense-graded* base (*not* typical construction practice!)
Runoff & pollutants compared to
PICP asphalt & gravel driveways in 2002-03

Jordan Cove

Crushed stone

PICP

Asphalt

PICP

Crushed stone

Pollutant Concentrations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Asphalt</th>
<th>PICP</th>
<th>Stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff depth, mm</td>
<td>1.8</td>
<td>0.5</td>
<td>0.04</td>
</tr>
<tr>
<td>TSS, mg/L</td>
<td>47.8</td>
<td>15.8*</td>
<td>33.7</td>
</tr>
<tr>
<td>Nitrate nitrogen, mg/L</td>
<td>0.6</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Ammonia nitrogen, mg/L</td>
<td>0.18</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>Kjeldahl nitrogen, mg/L</td>
<td>8.0</td>
<td>0.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Total Phosphorus, mg/L</td>
<td>0.244</td>
<td>0.162</td>
<td>0.155</td>
</tr>
<tr>
<td>Copper, ug/L</td>
<td>(13/9)</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Lead, ug/L</td>
<td>(65/2.5)</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Zinc, ug/L</td>
<td>(120/120)</td>
<td>87</td>
<td>25</td>
</tr>
</tbody>
</table>

*68% reduction

Mean weekly pollutant concentration in stormwater runoff
Metals: (acute/chronic) toxicity to freshwater aquatic life
### Pollutant Mass Export Reduction

**Clausen (2007) – Residential Driveways**

Pollutant Export kg/ha/year

<table>
<thead>
<tr>
<th>Variable</th>
<th>Asphalt</th>
<th>PICP</th>
<th>Stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>230.1</td>
<td>23.1*</td>
<td>9.6</td>
</tr>
<tr>
<td>Nitrate nitrogen</td>
<td>1.78</td>
<td>1.25</td>
<td>0.15</td>
</tr>
<tr>
<td>Ammonia nitrogen</td>
<td>0.65</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td>Kjeldahl nitrogen</td>
<td>13.06</td>
<td>1.08</td>
<td>0.47</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>0.81</td>
<td>0.25**</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*90% TSS reduction  **69% TP reduction

**Van Seters (TRCA 2007): 81% TSS reduction**

**Hunt (2004): 72% TSS & 63% TP reductions**

**Booth & Leavitt (1999): significant metals reductions compared to asphalt runoff**

### Toronto & Region Conservation Authority – Seneca College Parking Lot
Hydrologic performance for 12 rainfall events in 2006

<table>
<thead>
<tr>
<th>Hydrologic Characteristic</th>
<th>Asphalt</th>
<th>PICP</th>
<th>Bioretention Swale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flow Volume (m³)</td>
<td>37.00</td>
<td>33.50</td>
<td>16.70</td>
</tr>
<tr>
<td>Avg. Peak Flow (L/s)</td>
<td>2.20</td>
<td>0.05</td>
<td>0.40</td>
</tr>
<tr>
<td>Avg. Flow Duration (hrs)</td>
<td>2.00</td>
<td>73.50</td>
<td>0.04</td>
</tr>
<tr>
<td>Avg. Rainfall-runoff Lag (hrs)</td>
<td>Negligible</td>
<td>5.50</td>
<td>2.50</td>
</tr>
</tbody>
</table>

Asphalt compared to LID tools PICP and a bioswale adjacent to an asphalt lot at Seneca College, Ontario by the Toronto & Region Conservation Authority (www.trca.on.ca)

Water Quality Results

- Oils: below lab detection limits
- Lead & zinc significantly lower than asphalt runoff
- Deicing salts
  - Requires less than asphalt
  - Highly mobile regardless of pavement
  - Maintain sufficient separation between PICP bottom & water table

PICP Benefits

Green Infrastructure & LID Retrofits

Local Stormwater Regulations

LEED & Sustainable Design

Improved Tax Base

Environmental Benefits

Durable ADA Compliant Surface

Green Infrastructure & LID Retrofits

Downstream Treatment Train. PICP overflows to grassy swale & rain garden Goldsboro, NC

Retrofit LID Project. Water quality & green infrastructure integration River Front Trails, Payallup, WA
Green Infrastructure

Chicago, IL & Portland, OR
• Reduced combined sewer overflows
• Less expensive than separating storm & sanitary sewers
• Supports tree growth
• Improves neighborhood character

Portland, OR
Chicago Green Alley, Chicago, IL
Two images above courtesy of Chicago DOT

PICP Integrated with LID: a step toward Sustainable Communities

• Stormwater management using natural systems
• Reduced urban heat Island with cooler pavements
• Improved neighborhood character
PICP Benefits

- Local Stormwater Regulations
- LEED & Sustainable Design
- Improved Tax Base
- Durable ADA Compliant Surface
- Green Infrastructure & LID Retrofits
- Infrastructure Cost Savings
- Environmental Benefits

Other Environmental Benefits
Reduce erosion & salt water intrusion, protect water quality

Norfolk, VA

Installed: 2005
1,500 sf (150 m²)
Base: 8 in. (200 mm) thick
Subgrade: sandy

Widely accepted in coastal regions
PICP Structural Soil Supports
PICP and Tree Growth

Pier A Park
Hoboken, N.J., 1998
Image courtesy of Bruce K. Ferguson

Other Environmental Benefits

Antwerp, Belgium
100,000 sf parking of TiO₂ coated pavers to improve air quality

Largest NOx reductions on calm, warm days with no wind

Smog Eaters

The Italian cities of Cagliari, Sassari and Selargius plan this month to begin laying a new sidewalk brick that eats smog. The bricks are made with a titanium-dioxide blend that, when exposed to light, turns carbon monoxide (smog) in the air into water and carbon dioxide—the gas in soda pops. Rossano Araneda, who led tests for the Italian National Research Council, says he was “stunned” by how well the tiles work. Cost: $24 a square meter, 46 percent more than conventional bricks.

— Benjamin Rutherford
PICP Benefits

- Green Infrastructure & LID Retrofits
- LEED & Sustainable Design
- Local Stormwater Regulations
- Infrastructure Cost Savings
- Improved Tax Base
- Environmental Benefits
- Durable ADA Compliant Surface

PICP Contributes to LEED Credits

- Decrease pollution through sustainable sites (SS)
- Increase building water use efficiency (WE)
- Reduce energy and atmospheric pollutants (MR)
- Conserve materials and resources (MR)
- Improve indoor air quality (EQ)
- Offer innovative ideas and designs (ID)
Conservation of Materials and Resources (MR)

Credits - 1 LEED® point each:

3.1 5% reused content (i.e. crushed concrete)
3.2 10% reused content
4.1 5% recycled waste content (i.e. flyash)
4.2 10% recycled waste content
5.1 20% manufactured regionally (<500 mi.)
5.2 50% materials extracted regionally (<500 mi.)

ICPI Tech Spec 16

PICP Contributes to LEED Credits

LEED® Gold Project
Peak flow & pollution reduction,
University of Victoria, BC
PICP Benefits

- Green Infrastructure & LID Retrofits
- Local Stormwater Regulations
- LEED & Sustainable Design
- Durable ADA Compliant Surface
- Infrastructure Cost Savings
- Environmental Benefits
- Improved Tax Base
- PICP Benefits

Infrastructure Cost Savings

Residential Subdivision: Storm sewers eliminated. Savannah, GA
PICP Benefits

- Green Infrastructure & LID Retrofits
- Local Stormwater Regulations
- LEED & Sustainable Design
- Infrastructure Cost Savings
- Improved Tax Base
- Environmental Benefits
- Durable ADA Compliant Surface

PICP Benefits

ADA Compliant

PICP handicapped parking over PICP stormwater detention system, Burnaby, BC
PICP Benefits

- Green Infrastructure & LID Retrofits
- Local Stormwater Regulations
- LEED & Sustainable Design
- Environmental Benefits
- Infrastructure Cost Savings
- Improved Tax Base
- Durable ADA Compliant Surface

Design Basics: Exfiltration Options

- **Full base exfiltration**
  - Sandy soils
  - No perforated drain pipes

- **Partial – detention & infiltration**
  - Silt/clay soils
  - Perforated pipes at bottom of base

- **None – detention only**
  - High rock, water table, poor soils
Full, Partial, or No Exfiltration

 typ. No. 8 aggregate in openings
 curb/edge restraint with cut-outs for overflow drainage
 concrete pavers min. 3 1/8 in. (80 mm) thick
 bedding course 1 1/2 to 2 in. (40 to 50 mm) thick
 (typ. No. 8 aggregate)

 4 in. (100 mm) thick No. 57 stone open-graded base
 no. 2 stone subbase – thickness varies with design
 optional geotextile on bottom and sides of open-graded base
 soil subgrade – zero slope

 Full, Partial, or No Exfiltration

 typ. No. 8 aggregate in openings
 curb/edge restraint with cut-outs for overflow drainage
 concrete pavers min. 3 1/8 in. (80 mm) thick
 bedding course 1 1/2 to 2 in. (40 to 75 mm) thick
 (typ. No. 8 aggregate)
 perforated pipes spaced and sloped to drain all stored water
 outfall pipe(s) sloped to storm sewer or stream
 soil subgrade sloped to drain
Full, Partial, or **NO** Exfiltration

PICP Sizing Steps

**Inputs:**

- 3 1/8 in. thick pavers over 2 in. thick bedding material
- Project location (no-frost or frost region)
- Design storm (in. depth)
- PICP area (sf)
- Contributing area (sf) – if applicable
- Contributing area runoff depth (in.) – if applicable
- Depth to seasonal high water table (ft.)
### PICP Sizing Steps

**Inputs - continued:**

- Soil type (classification)
- Soil infiltration rate (in./hr)
- Soil strength (California Bearing Ratio or R-value)
- Base porosity
- Drainage time typically 24 – 48 hrs
- Traffic (18 kip or 80 kN equivalent single axle loads)
- Traffic design life = 20 years

---

**PICP Sizing Steps**

**Determine:**

1. Water runoff depth from design storm (typically 24-hr 2, 5, 10 or 25 yr event)
2. PICP base & subbase volume to store water
3. PICP base & subbase depth for storage & infiltration
4. Soil infiltration rate vs. water drainage time
5. PICP base & subbase depth to support traffic
6. Thicker of two PICP bases from 3 & 5 for design
7. Total PICP depth & check depth to water table
PICP Sizing Example

**Given:**
- 3 1/8 in. (80 mm) thick pavers over 2 in. (50 mm) thick bedding material
- Project location: no-frost region
- Design storm = 3 in. (typ. 24-hr 2, 5, 10 or 25 yr event)
- PICP area = 30,000 sf
- Contributing area = 10,000 sf asphalt
- Contributing area runoff depth = 2 in.
- Depth to seasonal high water table = 5 ft.
- Soil type: sandy clay
- Soil infiltration rate = 0.25 in./hr
- Soil strength CBR = 7% (R-value = 13)
- Base & subbase porosity = 33%
- Drainage time = 48 hrs
- Traffic load & design life = 300,000 ESALs over 20 years

**PICP Sizing Example**

**Determine:**

1. Water storage volume

   Rainfall on PICP = 3 in. = 0.25 ft x 30,000 sf = 7500 cf
   Runoff from contributing area = 2 in. = 0.17 ft x 10,000 sf = 1700 cf
   Total water volume = 9200 cf
   Total water depth = 9200 cf ÷ 30,000 sf PICP area = 0.3 ft or about 3.7 in.

2. PICP base & subbase volume to store water

   9,200 cf ÷ 0.33 base porosity = 27,879 cf
3. PICP base & subbase depth for storage & infiltration
   Total base volume ÷ PICP area
   27,879 cf ÷ 30,000 sf = 0.93 ft = 11 in. say 12 in.

4. Soil infiltration rate vs. water drainage time
   Drainage time = 48 hours
   Soil infiltration rate = 0.25 in./hr
   Use 2X safety factor for long-term clogging
   0.25 in./hr ÷ 2 = 0.12 in./hr design soil infiltration rate
   Total water depth = 3.7 in. ÷ 48 hrs. = 0.08 in./hr min.
   soil infiltrate rate required
   OK – PICP drains within 48 hrs
   0.08 in./hr required < 0.12 in./hr soil infiltration rate
   Not OK? Design drain pipes to release excess water
   i.e., partial exfiltration design

5. Determine PICP base & subbase depth to support traffic

<table>
<thead>
<tr>
<th>Climate</th>
<th>No Frost</th>
<th>No Frost</th>
<th>No Frost</th>
<th>No Frost</th>
<th>Frost</th>
<th>Frost</th>
<th>Frost</th>
<th>Frost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESALs® Traffic Index</td>
<td>&gt;24</td>
<td>18-23</td>
<td>11-17</td>
<td>5 to 9</td>
<td>CBR 7%</td>
<td>Gravely Soils</td>
<td>Clayey Gravels, Plastic Clays</td>
<td>Silty Gravel, Sand, Sandy Clays</td>
</tr>
<tr>
<td>Pedestrian No. 57</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
</tr>
<tr>
<td>No. 2</td>
<td>6 (150)</td>
<td>6 (150)</td>
<td>6 (150)</td>
<td>6 (150)</td>
<td>6 (150)</td>
<td>6 (150)</td>
<td>6 (150)</td>
<td>6 (150)</td>
</tr>
<tr>
<td>50,000 6</td>
<td>No. 57</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
</tr>
<tr>
<td>No. 2</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
</tr>
<tr>
<td>150,000 7.2</td>
<td>No. 57</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
</tr>
<tr>
<td>300,000</td>
<td>No. 2</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
</tr>
<tr>
<td>600,000 8.5</td>
<td>No. 57</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
<td>4 (100)</td>
</tr>
<tr>
<td>No. 2</td>
<td>8 (200)</td>
<td>8 (200)</td>
<td>10 (250)</td>
<td>8 (200)</td>
<td>14 (350)</td>
<td>18 (450)</td>
<td>8 (200)</td>
<td>18 (450)</td>
</tr>
</tbody>
</table>
6. Select thicker of two PICP bases from steps 3 & 5

*Compare:*
Step 3 base thickness (hydrological) = 12 in.
Step 5 base thickness (structural) = 13 in. from table
Round up to 14 in. for construction expediency
(4 in. thick No. 57 stone + 10 in. thick No. 2 stone)

7. Total PICP depth & check depth to water table

**Full or Partial Exfiltration**

**No exfiltration**

Impermeable liner
PICP Sizing Example

7. Total PICP depth & check depth to water table

Cross section:
3.125 in. thick concrete pavers
2 in. bedding material - chokes into base surface
4 in. thick No. 57 base (or similar) chokes into subbase
8 in. thick No. 2 subbase (or similar)
Optional geotextile per manufacturer’s recommendations

Total cross section thickness
~ 17 in.
+ 24 in. clear to seasonal high water table
41 in. total clearance required

Overflow Drainage

Overflow drain
Drains to bioswale
PICP Design

- Permeable Design Pro
- Software integrates
  - Hydrologic Design
  - Structural Design
- Contact ICPI to obtain software www.icpi.org

Limitations

**Avoid**
- Drinking water wells (100 ft min. distance)
- High water tables (< 2 ft from base bottom)
- High depth to bedrock
- Contributing imp. surfaces max. 5X PICP area
- Industrial sites, fueling stations
- Any threat to groundwater
- Expansive soils
- Increase in impervious cover after PICP
Construction
Subgrade & Base Preparation

Construction
Joint Aggregate Installation
Paver Installation

Mechanical installation reduces construction time
No curing – immediate availability to traffic
Can be reinstated after repairs
Guide construction specs at www.icpi.org

Maintenance

- **Annually**: inspection of observation well after major storm, vacuum and sweep surface – improves infiltration
- Maintenance checklist
- Model maintenance agreement
- Monitor adjacent uses
Sweeper Effectiveness

Best: Vacuum sweeper (no water)

OK: Regenerative air (broom) sweeper (no water)

Vacuum essential as brush bristles clean ~ ¼ in. into surface

PICP Resources

- Fact Sheets
- Design Manual
- Design Software
- Presentations

www.icpi.org
www.ncsu.edu/picp
www.lowimpactdevelopment.org
Questions?