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

What is PICP?

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
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
- C$ 95-160 / m²

PICP System Cost Example

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>~ 3,600 m²</td>
<td>C$149 No storm sewers</td>
<td>C$202 With storm sewers</td>
<td>C$156 With storm sewers</td>
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</tbody>
</table>
Costs

Affordable Housing
PICP reduces CSS loads
High Point
Seattle, WA

PICP Benefits

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

Improved Tax Base
PICP Benefits

- Green Infrastructure & LID Retrofits
- Infrastructure Cost Savings
- Local Stormwater Regulations
- LEED & Sustainable Design
- 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
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

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>
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<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>
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<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

Diagram showing permeable pavement and bioretention swale system.
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>
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<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

Infrastructure Cost Savings

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

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

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

Residential Subdivision: Storm sewers eliminated. Savannah, GA
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

ADA Compliant

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

PICP Benefits

- Green Infrastructure & LID Retrofits
- Infrastructure Cost Savings
- Local Stormwater Regulations
- LEED & Sustainable Design
- Improved Tax Base
- Environmental Benefits
- Durable ADA Compliant Surface
Full, Partial, or No Exfiltration

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

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)

Soil subgrade—zero slope
Full, Partial, or **NO** Exfiltration

**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**
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>
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<th>Frost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R-value</td>
<td>18-23</td>
<td>11-17</td>
<td>Gravely Soils</td>
<td>Clayey Gravels, Plastic Sandy Clays</td>
<td>Silty Gravel, Sand, Sandy Clays</td>
<td>Silts, Silty Gravel, Silty Clays</td>
<td></td>
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<tr>
<td></td>
<td>Soaked CBR</td>
<td>&gt;15</td>
<td>0-14</td>
<td>5 to 9 CBR 7%</td>
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<td>4 (100)</td>
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<td>Traffic Index</td>
<td>Subbase</td>
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<td>4 (100)</td>
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<td>8 (200)</td>
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<td>8 (200)</td>
<td>8 (200)</td>
<td>8 (200)</td>
</tr>
</tbody>
</table>

PICP Sizing Example
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**

![Diagram showing PICP Sizing Example](image_url)
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 (30 m min. distance)
- High water tables (< 60 cm 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?