Permeable Pavements in Cold Climates

Peter T. Weiss, Valparaiso University

John Gulliver, UMN
Masoud Kayhanian, UC-Davis
Lev Khazanovich, Univ. of Pittsburgh

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Outline

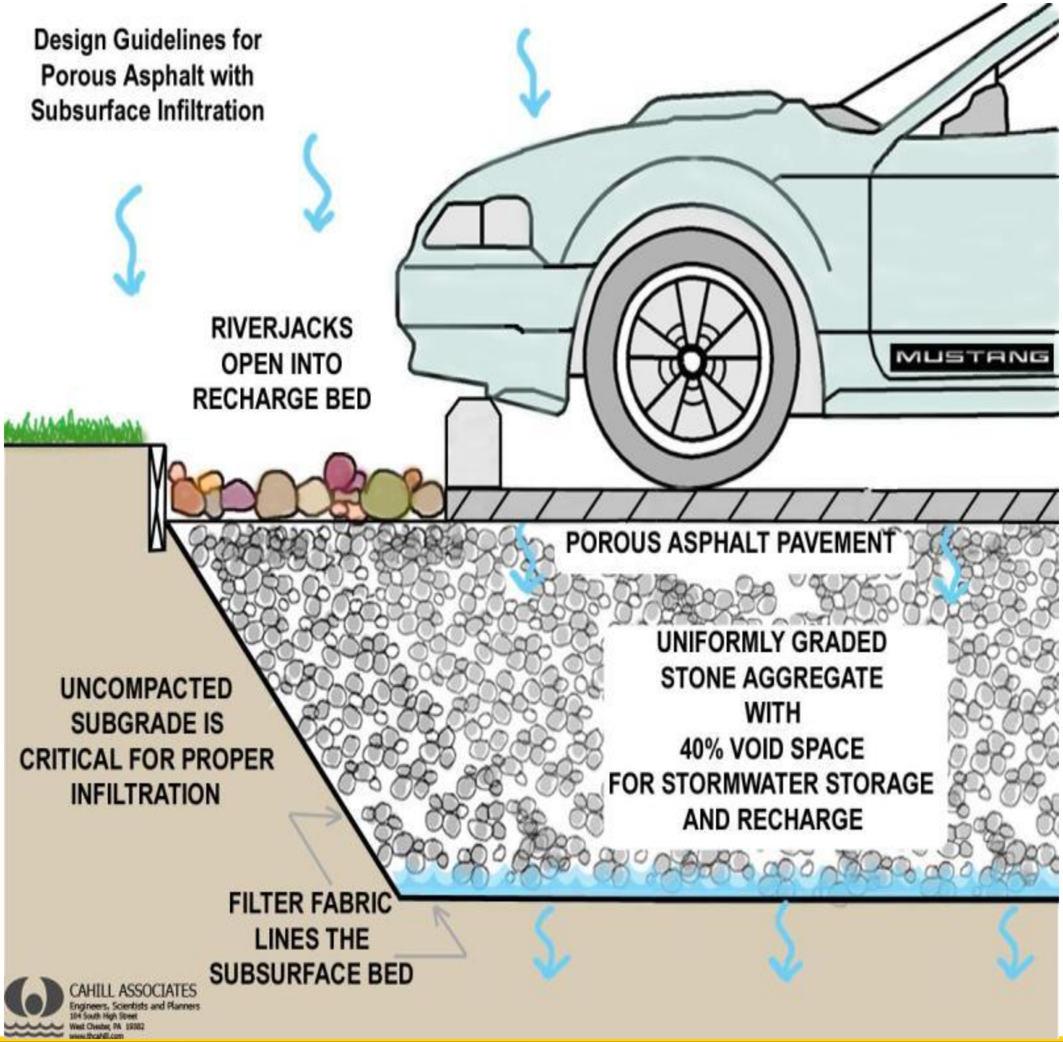
- Introduction and background
- Design methods
- Summary of performance & maintenance
- Case Studies
  - Paired Intersection Study (Minnesota)
  - Porous Asphalt Study (New Hampshire)
  - Woodbridge Neighborhood (Minnesota)
  - Experiences in Colorado
- Summary and Conclusions

Porous pavements developed as early as the 1930s

A sign at a park in Massachusetts.

Image source: MAAPA

Full Depth Permeable Pavement



- Water infiltrates through permeable pavement surface and other layers
- Stored in gravel layer (~40% voids)
- Water infiltrates into soil or is collected by drain tile

Benefits Permeable Pavement

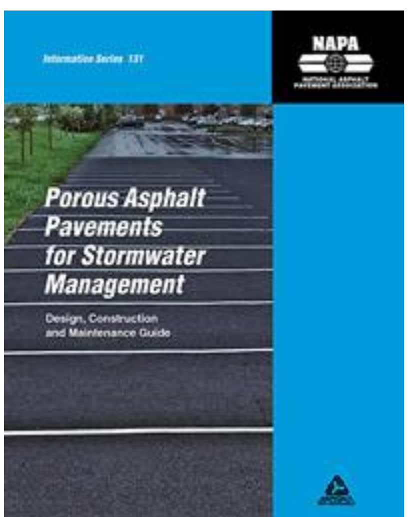
- Volume reduction
- Improved water quality
- Hydroplaning resistance
- Spray reduction
  - Increased visibility
- Smoother ride
- Noise reduction
- Less salt required

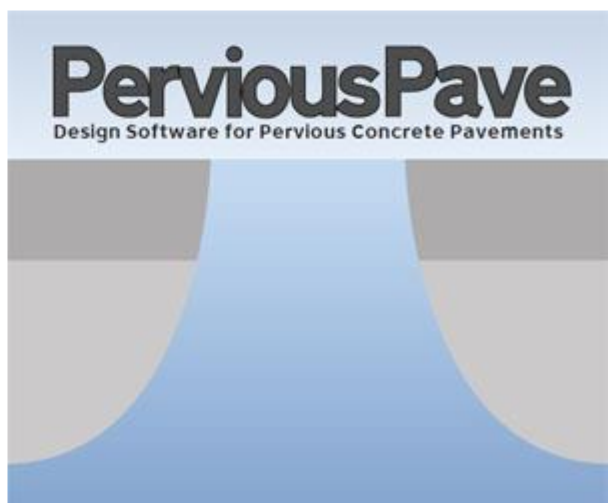
Types of Permeable Pavement

- **Porous Asphalt**
- **Pervious Concrete**
- **Permeable Pavers**
- **Permeable Articulated Concrete Blocks**

Permeable Pavement Design

- No uniform or standard design across industries
- See Weiss et al. (2015) for design recommendations
- Examples of design variations:
  - NAPA: AASHTO design w/ SN. Use non-woven geotextile.
  - ACPA: PerviousPave, uses model developed for StreetPave. Use geotextile liner.
  - ICPI: AASHTO w/ SN. Geotextile fabric is optional





Keys for Success

- **Proper Construction**
  - Mix design
  - Compaction
  - Void ratio
  - Curing
- **Proper and regular maintenance**

Photo courtesy of M. Maloney, Shoreview, MN

Summary of Hydraulic Performance

- Surface infiltration rates decrease but are not rate limiting
- Method needed to determine permeability of sub-base before design
- Geotextile fabrics can reduce/eliminate infiltration
- Infiltration rates are maintained through winter

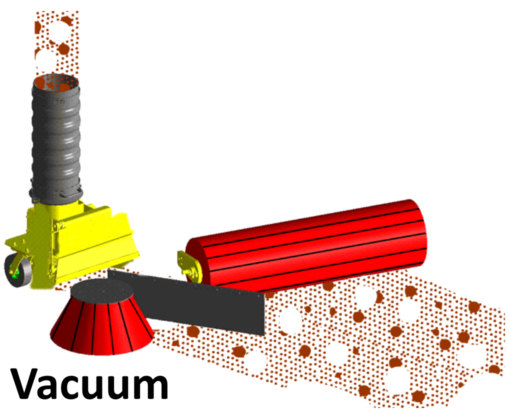
Summary of Water Quality Impact

- Removes solids & solid-bound contaminants
- Mass load reduction often through infiltration
- Nitrification may occur (ammonium to nitrate), but total N removal is low
- Dissolved phosphorus removal is minimal

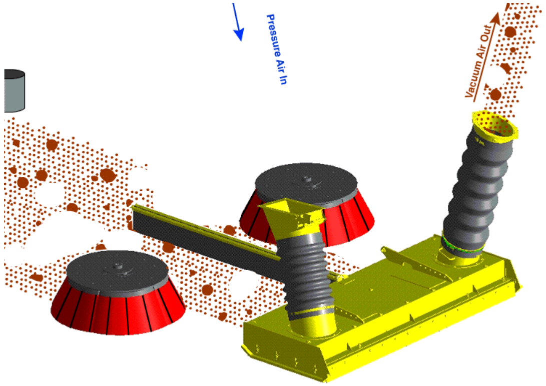
Photo http://switchboard.nrdc.org/

Summary of Maintenance

- Surface cleaning is effective but variable
- Particle removal (top ¼ inch) is major issue
- Pressure washing (45°) and/or vacuuming with regenerative air sweepers is most effective
- Brushes can push material farther into voids
- Clean multiple times per year



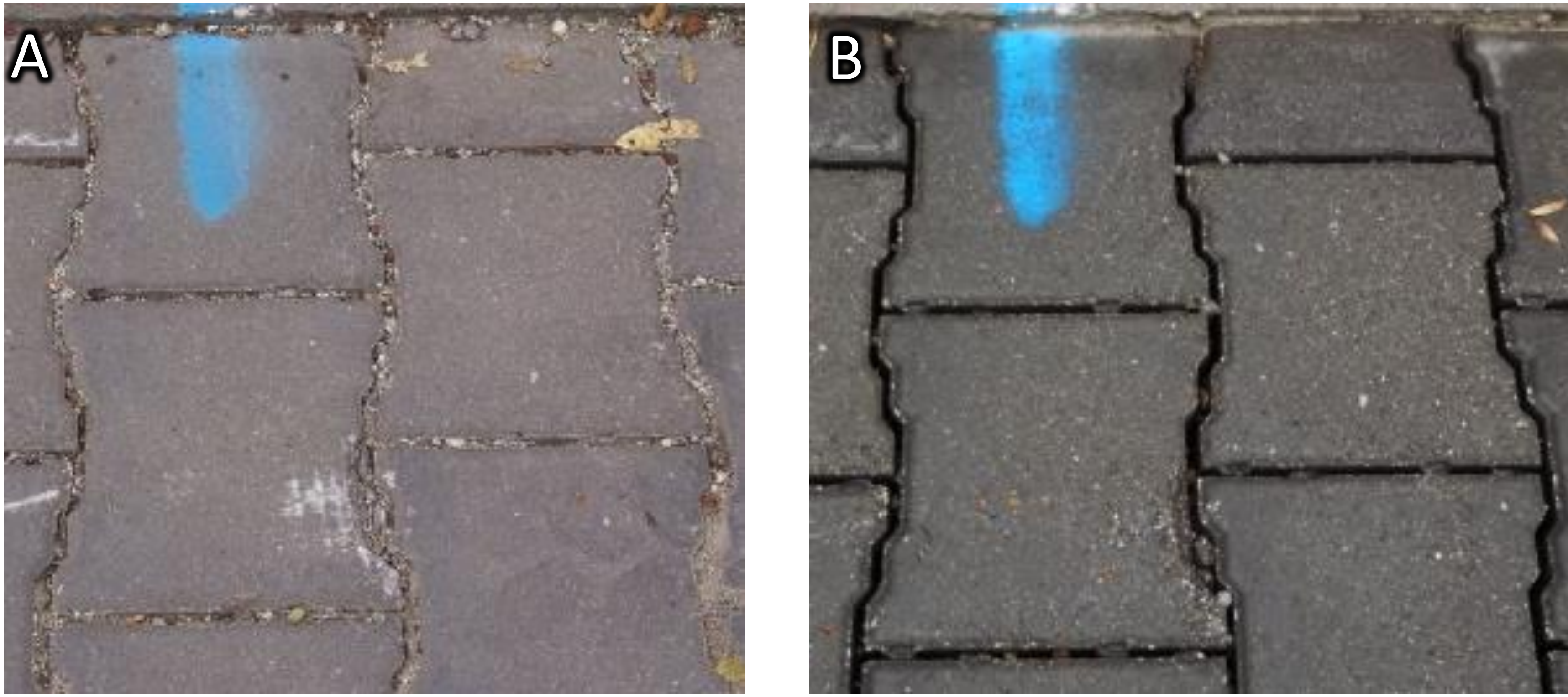
Vacuum



Regenerative Air

Images: Elginsweeper.com

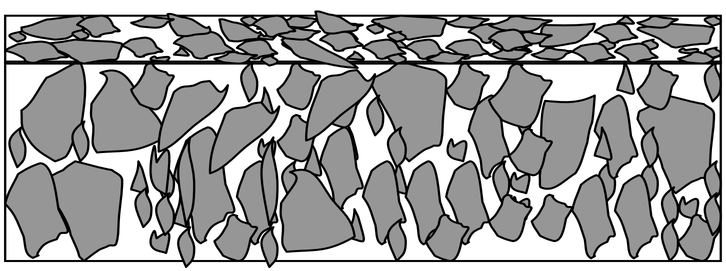
Impact of Vacuuming



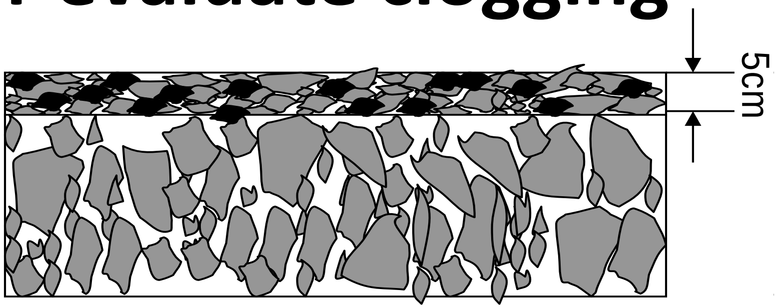
Permeable articulated concrete blocks/mats before (A) and after (B) cleaning with a Vac Head.

Summary of Maintenance

- **Major cause of clogging is reduction of surface pavement void space:**
  - **Heavy loads**
  - **Particles**
  - **Lack of maintenance**
- **No standard to measure or evaluate clogging**



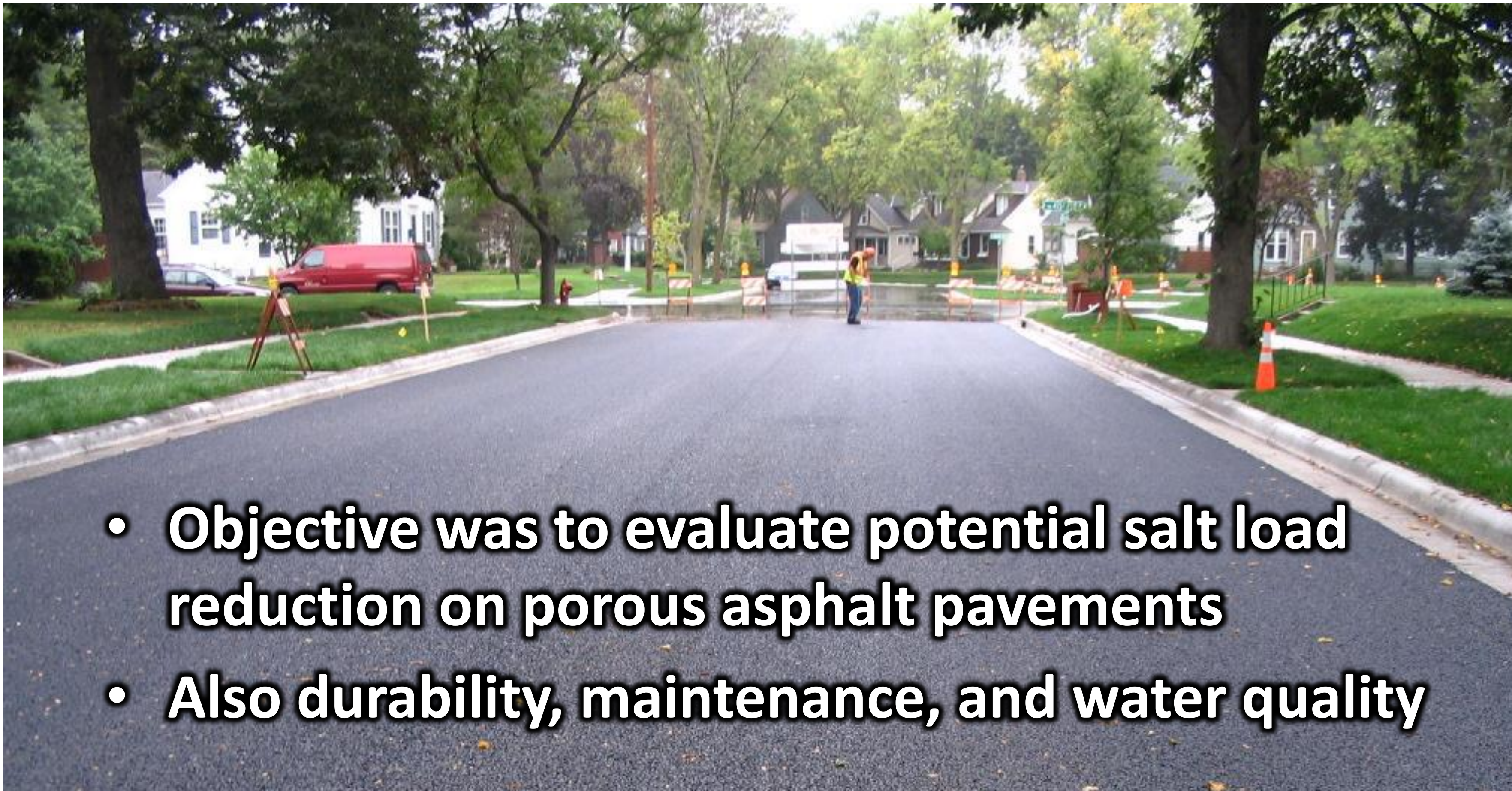
Open voids



Partially clogged voids

Porous Asphalt Paired Intersections – Robbinsdale, MN

Constructed 2009-2010



- **Objective was to evaluate potential salt load reduction on porous asphalt pavements**
- **Also durability, maintenance, and water quality**

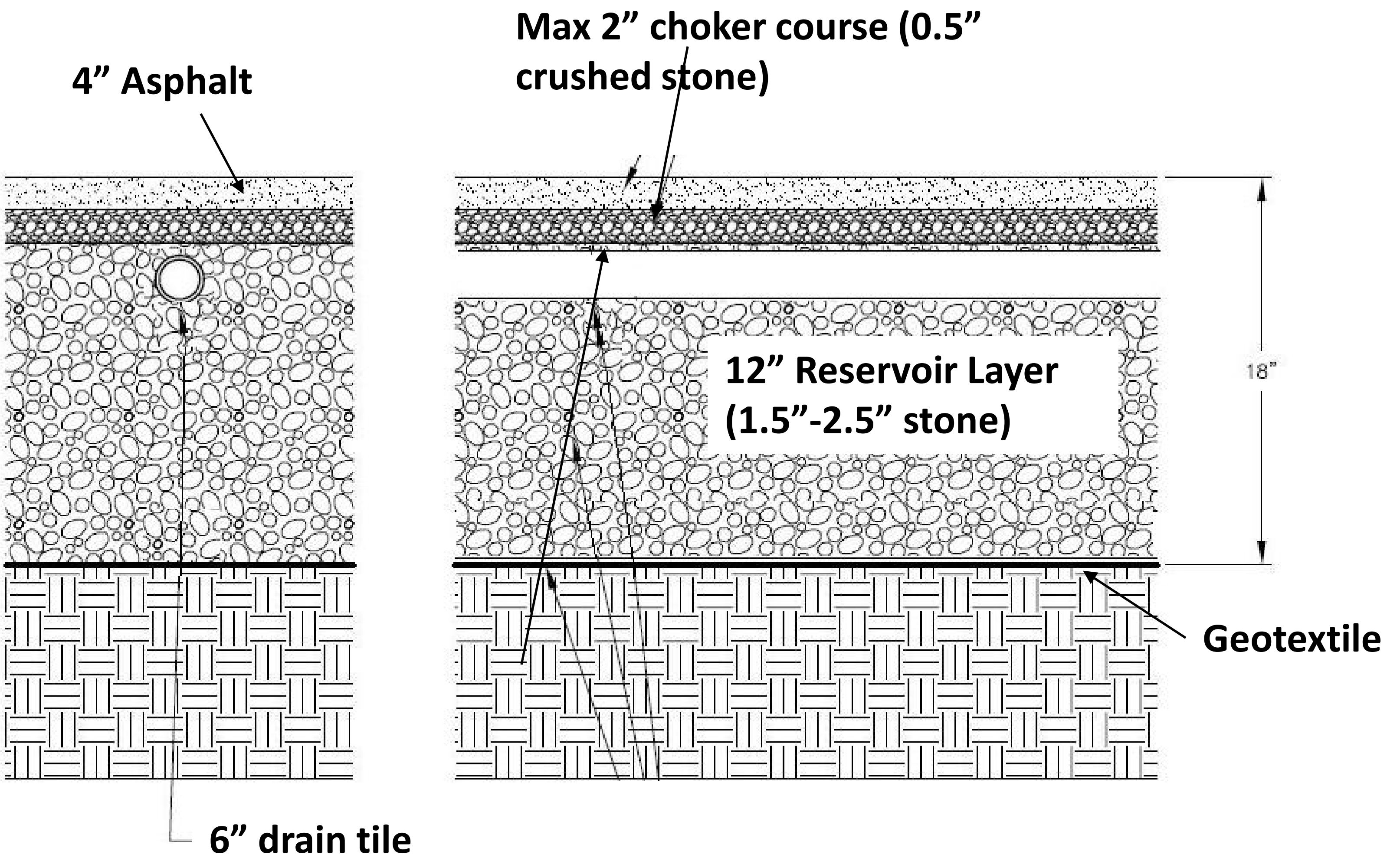
Construction in September 2010 (Wenck 2014)

Paired Intersection Study

- TMDL study for Shingle Creek, MN: Reduce Cl by 81%
- Two porous asphalt pavement intersection constructed: 1) Sand sub-base, 2) Clay sub-base
- Designed for 2-yr storm
- The porous asphalt sections were not salted during the winter
- Conventional asphalt sections were salted

(thenewsherald.com)

Paired Intersection Study



Paired Intersection Study

- **Porous asphalt sections: ~150 feet long by ~28 feet wide (4200 square feet)**
- **Cost: Site 1 was $42,670**

  Site 2 it was $32,200.
- **Site 1 construction was negotiated as part of a change order. Site 2 the contract was awarded to the low bidder.**

Paired Intersection Study

Results

- **Winter reservoir temperatures warmer than the pavement temperature**

- **Reservoir air voids provided insulation**

- **Insulation minimizes winter freezing and keeps reservoir temperatures cooler in spring**

Paired Intersection Study

Results

- **Suggests winter infiltration into subgrade is possible**

- **Conventional pavement sites were slushier than the porous asphalt sites due to infiltration into PP**

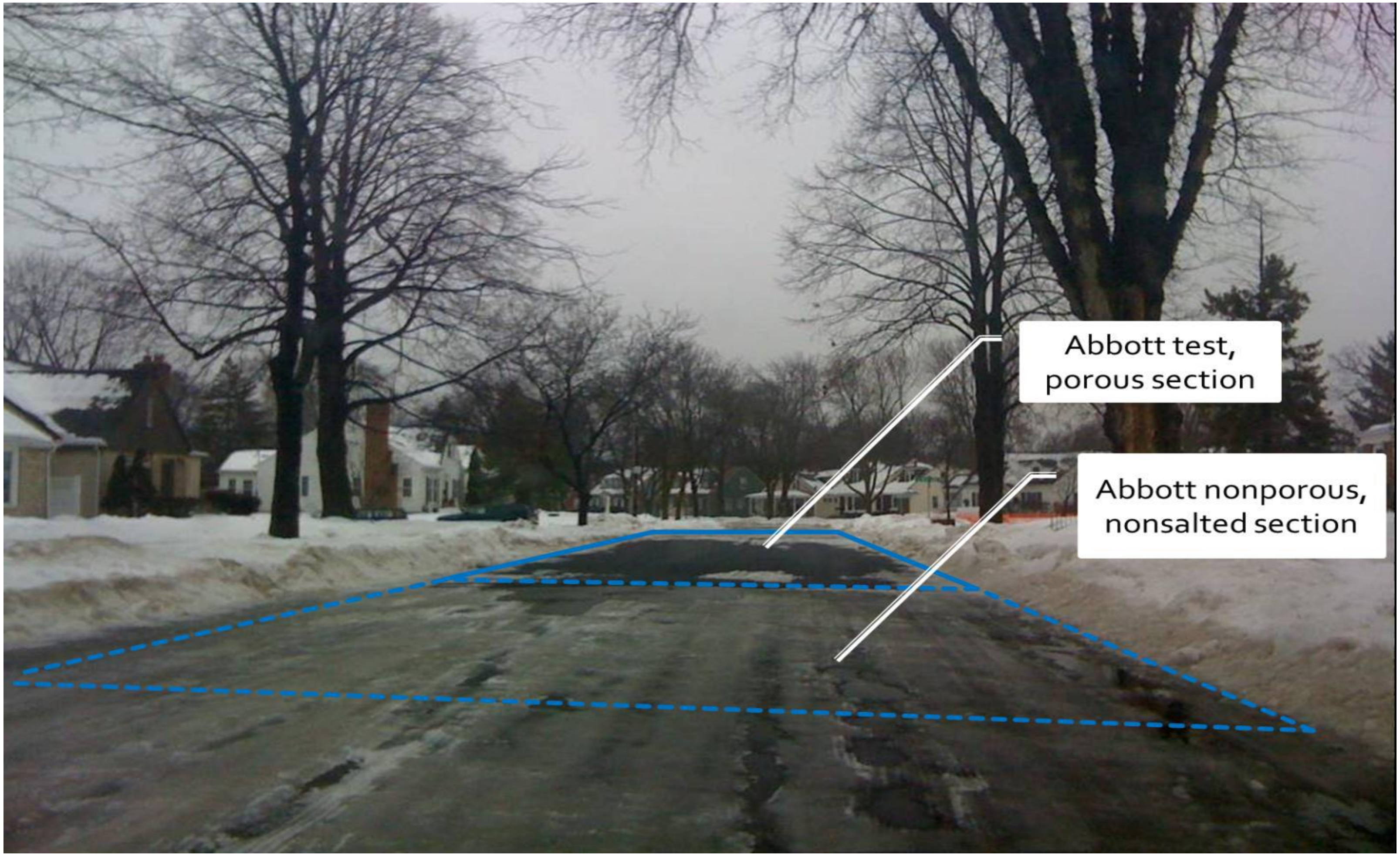
- **Bare pavement on the porous test sections comparable to conventional sections but had a lag**

Paired Intersection Study

Slush gathering and refreezing on the traditional asphalt at Site 1 on January 17, 2010

Slush free porous asphalt on January 17, 2010

Paired Intersection Study



Site 1 Test Section looking south

Paired Intersection Study

Lessons Learned

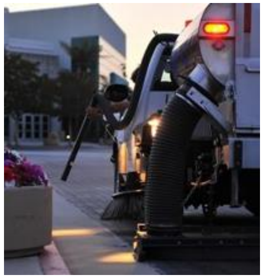
- The unsalted, porous asphalt sections had a similar amount of bare pavement compared to salted, conventional asphalt sections

- The porous pavement over sand subgrade was more effective for ice control compared to the porous pavement on clay subgrade,
  - porous asphalt on sand can infiltrate all or most of the runoff
  - On clay, frequent overflows were observed

- Porous asphalt sections have been durable without any special snow plow equipment or adjustments

Paired Intersection Study

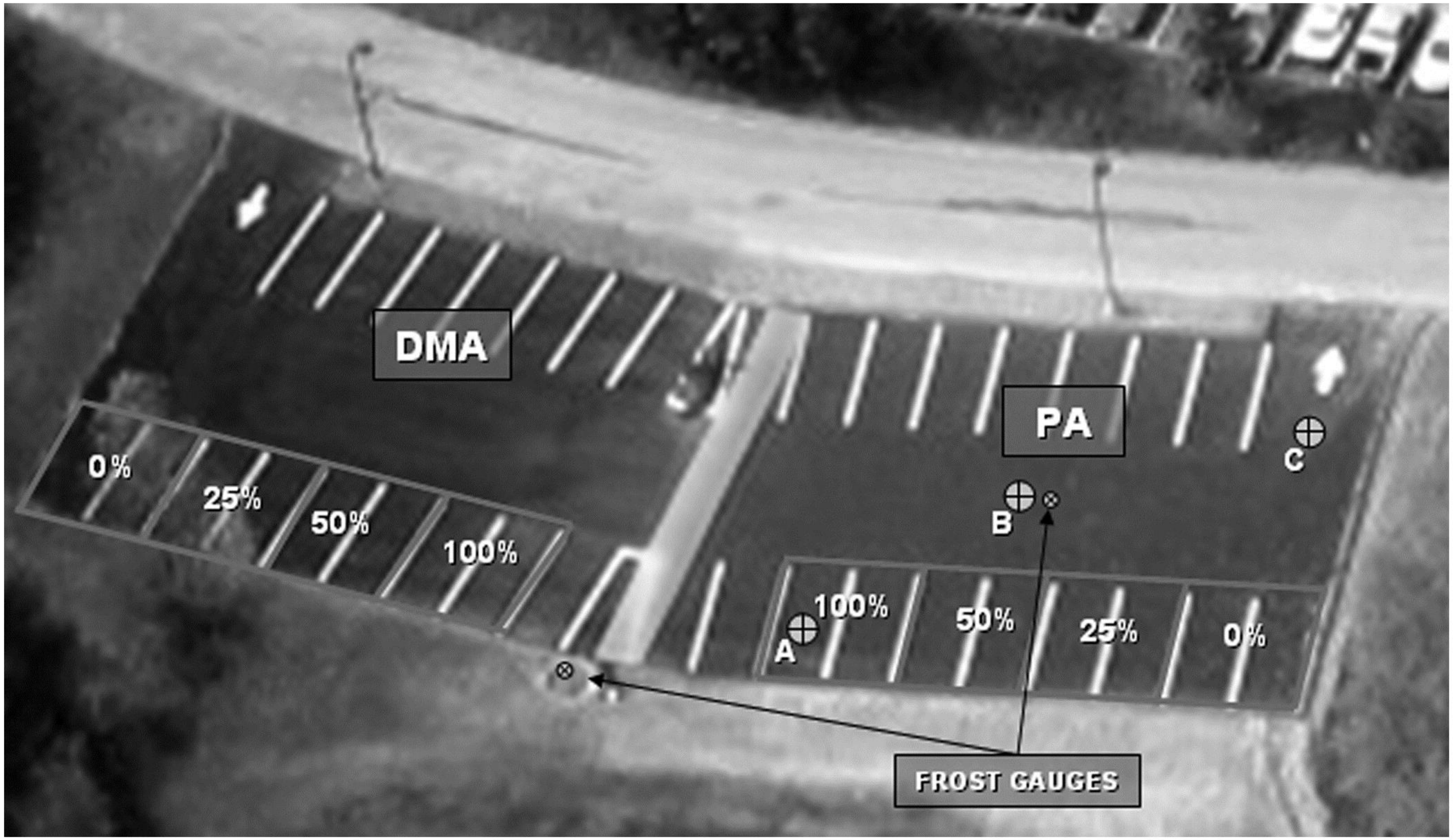
Lessons Learned



- Effective maintenance on the porous asphalt sections appears to be vacuuming twice per year and patching with traditional asphalt, as necessary

- Porous asphalt intersections have potential as an ice-control management practice in certain situations

UNH Porous Asphalt Parking Lot



Winters of 2006-2007, 2007-2008

Photo from Roseen et al. 2014

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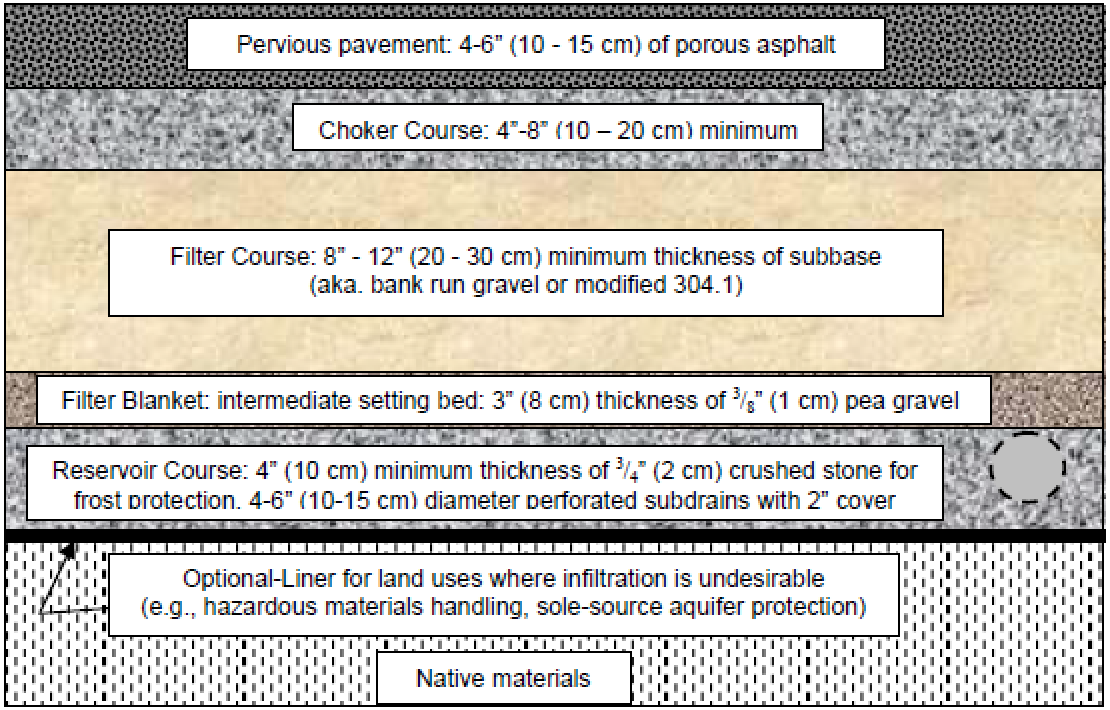
UNH Porous Asphalt Study

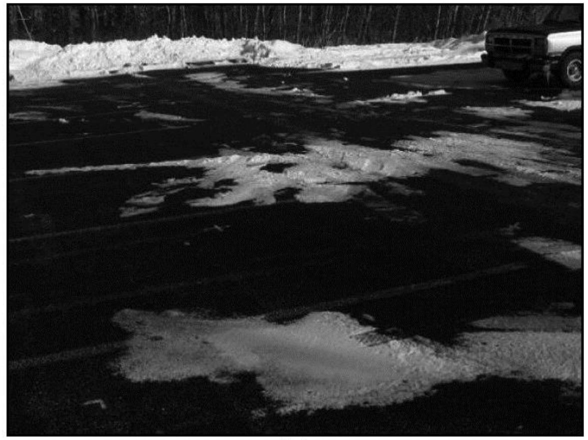


- Each lot = 5000 ft^2
- 4" of porous asphalt
- 18% voids, 5.8% asph.
- Filter Course: K=10-60 ft/day at 95% comp.
- Filter blanket prevents migration of fines
- 21 inch stone reservoir
- Underdrain 12 inches above bottom

Image from Roseen et al. 2014

UNH Porous Asphalt Study

(a)



(b)

(c)

(d)

- PA lot received 25% of typical salt load of 3 lb/1000 sf
- DMA received 100% of typical salt load
- Frost penetration deeper on PA (27” vs. 18”)
- PA lot thawed ~30 days before DMA
- 25% of runoff infiltrated in PA (Type C soils)

a) PA at 11:20 AM; b) PA at 1 PM;
c) DMA at 11:20 AM; d) DMA at 1 Pm

(Roseen et al. 2014)

UNH Porous Asphalt Study

Lots one hour after plowing (-4º C)
(Photo: UNHSC)

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UNH Porous Asphalt Study

- PA exported nitrate;
- PA: no impact on TP;
- PA reduced TPH (1970 μg/L to 166 μg/L
- PA reduced TSS (54 mg/L to 6 mg/L)
- PA mean infiltration rate = 1700 in/hr after 3 yrs & no maintenance

(a)

(b)

Pavement after freezing rain: a) PA, b) DMA

(Roseen et al. 2014)

UNH PA Parking Lot Study-Conclusions

- PA with 25% of salt load had same snow/ice cover as DMA lot
- Salt loads could be reduced by 64% with no compromise in safety
- PA froze but maintained high infiltration capacity
- PA had higher skid resistance (for wet, snow, & compacted snow)
- More salt applications may be necessary
- PA particles were found in voids after winter

Roseen et al. 2014.

Photo: Heather Lynn Peters

Woodbridge Neighborhood-Shoreview, MN

Pervious Concrete, constructed in 2009.

Photo courtesy of M. Maloney

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Woodbridge Neighborhood

<u>Initially:</u>

- **38 ac, fully developed**
- **9000 yd^2 of asphalt**
- **Storm drainage concerns**

<u>Needed to:</u>

- **Replace road, upgrade utility, improve stormwater management**
- **Total cost = $15M**

Photo courtesy of M. Maloney

Woodbridge Neighborhood

<u>Why PC?</u>

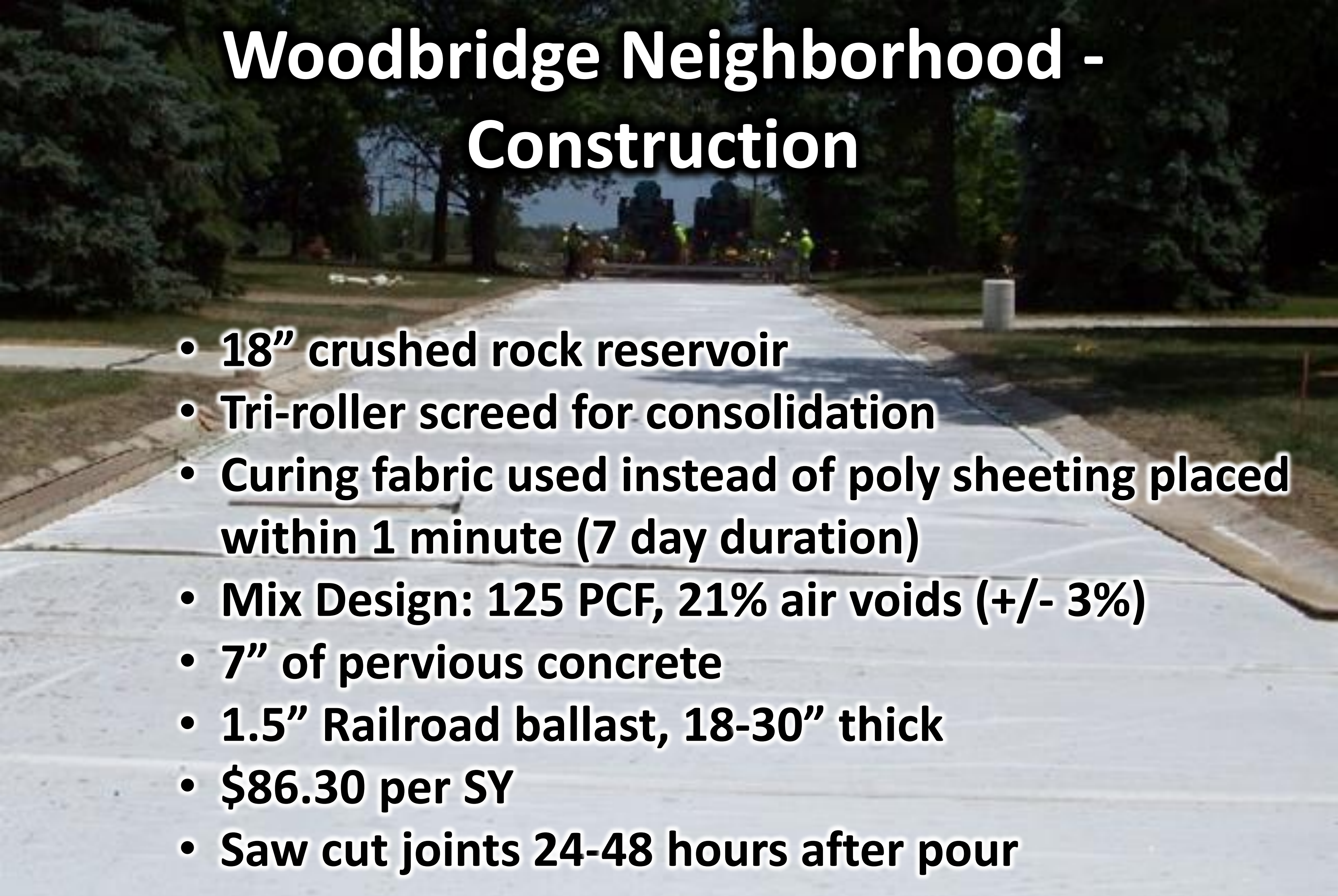
- **Free draining soils**
- **Advances in mix designs and placement techniques**
- **Same cost as conventional asphalt with storm drains**

Project construction.

Photo courtesy of M. Maloney

Woodbridge Neighborhood - Construction

- 18” crushed rock reservoir
- Tri-roller screed for consolidation
- Curing fabric used instead of poly sheeting placed within 1 minute (7 day duration)
- Mix Design: 125 PCF, 21% air voids (+/- 3%)
- 7” of pervious concrete
- 1.5” Railroad ballast, 18-30” thick
- $86.30 per SY
- Saw cut joints 24-48 hours after pour



Curing of Pervious Concrete.

Photo courtesy of M. Maloney

Woodbridge Neighborhood - Maintenance

- Regenerative air sweeper (no brushes); ~ every 6 weeks
- No salt or sand application
- Plowed by one-ton pickup w/ regular plow
- Clogging occurs mostly in top ¼" of pavement
- Maintenance has maintained infiltration rates of 300-500 in/hr in most areas

Project Construction.

Photo courtesy of M. Maloney

Lessons Learned

- **Construction & curing very important**
- **Saturated curing blankets have been successful**
- **Saw cut joints have been successful**

Saw cut joint.
Photo courtesy of M. Maloney

Lessons Learned

- Reservoir aggregate should be large & angular
- Salt and turning traffic have caused isolated failure
- Organics are the main source of clogging
- Do not work PC by hand
- Do not "walk" screed around corners

1.5" Railroad ballast.

Photo: Florence Crushed Stone

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The Denver (UDFCD) Experience

Denver, Colorado.

Photo: PlaneandJane.com

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Aurora Wal-Mart Parking Lot

- Pervious Concrete
- Installed in 2004
- No info on mix design
- Raveling at joints (some saw cut)

Photo courtesy of K. MacKenzie, UDFCD

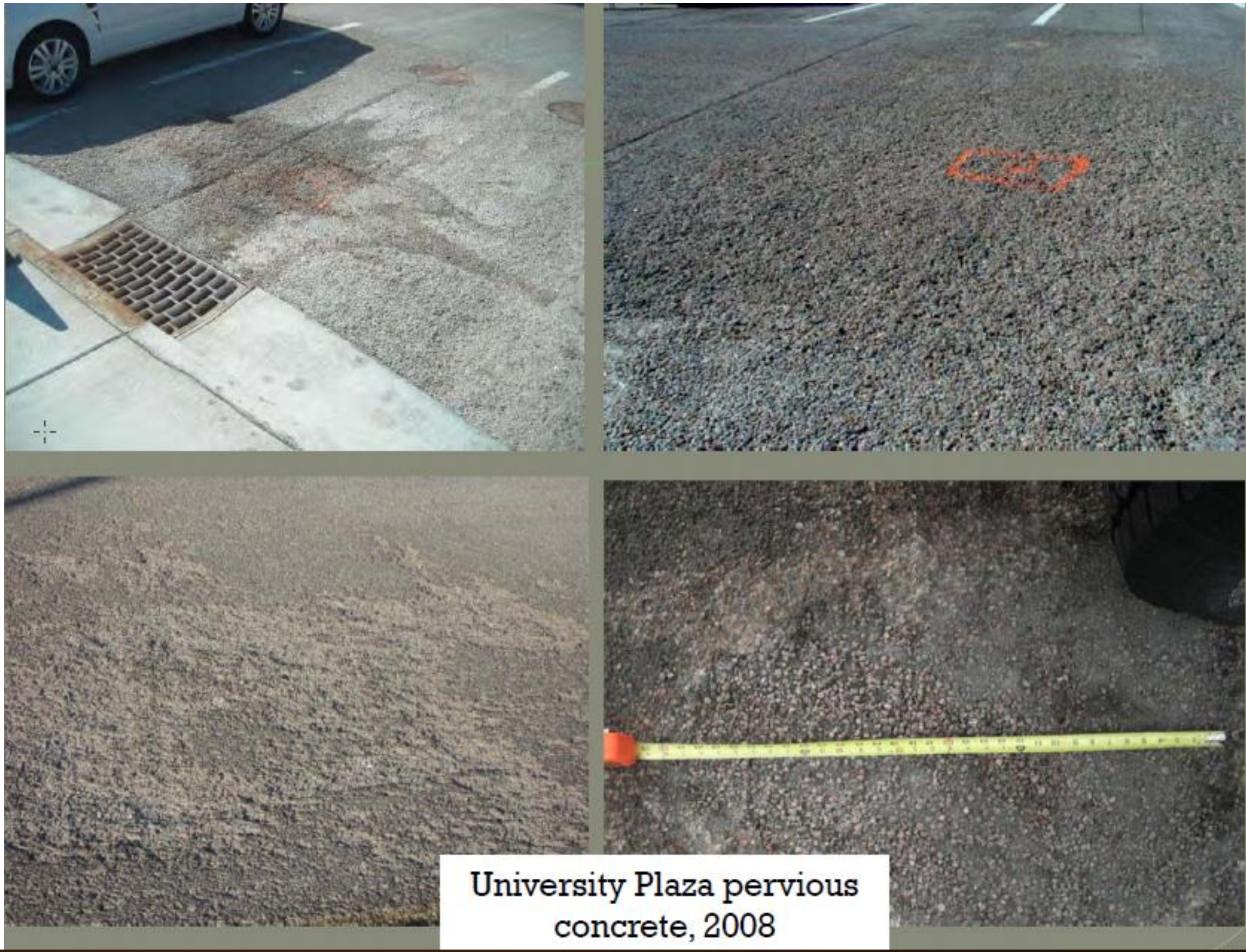
Denver Safeway Parking Lot

- **Pervious Concrete**
- **Installed in 2004**
- **No info on mix design**
- **Surface erosion**

Safeway pervious concrete, 2008

University Plaza Parking Lot

- Pervious Concrete
- Installed in 2005
- No info on mix design
- Surface erosion



University Plaza pervious concrete, 2008

Possible Causes of Failure

- Non-uniform void content
- Poor air entrainment in cement paste
- Chloride (applied/carried in)
- Cement paste consolidation
- Placement during adverse weather
- Loss of hydration water during curing

Close up of parking lot stall.

Photo courtesy of K. MacKenzie, UDFCD

National Renewable Energy Lab Parking Lot

- Pervious Concrete
- Installed in 2009
- Mix design followed new requirements
- PC use in Denver suspended

Photo courtesy of K. MacKenzie, UDFCD

Denver Waste Management Building

- Porous Asphalt
- Installed in 2008
- Surface infiltration < 20 in/hr
- Intensive maintenance was ineffective

Parking lot after light rain.

Photo courtesy of K. MacKenzie, UDFCD

Denver Waste Management Building

- Cores revealed proper construction (17% voids, proper PSD, asphalt content, etc.)
- More than half of other PA sites have infiltration < 20 in/hr
- UDFCD does not recommend use of PA

Parking lot after snowfall.

Photo courtesy of K. MacKenzie, UDFCD

Conclusions

- **Permeable pavements can result in less winter salt application**
- **Permeable pavements can reduce runoff volume and improve water quality (with other benefits)**
- **Permeable pavements are more expensive to construct**
- **Construction & maintenance are critical to success**

Conclusions (Cont'd)

- **Maintenance: pressure washing and/or vacuuming**
- **Permeable pavements can withstand harsh winters**
- **Permeable pavements can maintain infiltration rates throughout the winter**

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Thank you for your attention!

Questions?

Peter.Weiss@valpo.edu

Photo: http://itcontrolsfreak.files.wordpress.com/2012/11/rain1.jpg

References (page 1)

ACI (American Concrete Institute). 2010. *Report on Pervious Concrete*. ACI, Farmington Hills, MI, USA. ACI 522R-10.

Barrett, M.E. 2008. Effects of a Permeable Friction Course on Highway Runoff. Journal of Irrigation and Drainage Engineering, 134(5):646-651.

CRMCA (Colorado Ready Mixed Concrete Association). 2009. *Specifier's guide for pervious concrete pavement design*. CRMCA, Centenial, CO, USA.

Jones D., Harvey J., Li H., Wang T., Wu R. and Campbell B. (2010). *Laboratory testing and Modeling for Structural Performance of Fully Permeable Pavements under Heavy Traffic*. Report number CTSW-RT-10-249.04 prepared for California Department of Transportation, Sacramento, California.

Li, H., Jones, D., Harvey, J. 2012. Development of mechanistic-empirical design procedure for fully permeable pavement under heavy traffic. *Transportation Research Record*, 2305:83-94.

NAPA (National Asphalt Pavement Association). 2008. *Porous asphalt pavements for stormwater management, Design, Construction and maintenance guide*. Information Series 131, NAPA, Lanham, MD, USA.

References (page 2)

Partl, M.N., Momm, F., Bariani, B. 2003. Study of the aggregate for the pervious asphalt concrete performance testing and evaluation of bituminous materials. *Proceedings of the 6th International RILEM Symposium*, 2003/04/14-2003/04/16. Zurich, Switzerland. pp. 237-43.

Roseen, R.M., Ballestero, T.P., Houle, K.M., Heath, D., Houle, J.J. 2014. Assessment of winter maintenance of porous asphalt and its function for chloride source control, *Journal of Transportation Engineering*, 140(2): 04013007, 1-8.

UNHSC (University of New Hampshire Stormwater Center). 2009. *UNHSC Design specifications for porous asphalt pavement and infiltration beds.* University of New Hampshire, Durham, NH, USA.

Weiss, P.T., Kayhanian, M., Khazanovich, L., and J.S. Gulliver, "Permeable Pavements in Cold Climates: State of the Art and Cold Climate Case Studies," Report #: MN/RC 2015-30, Minnesota Department of Transportation, St. Paul, MN, 2015.

Wenck Associates, Inc. 2014. *Porous pavement paired intersection study*, prepared for the Shingle Creek Watershed Management Commission, City of Robbinsdale, MN, and the Minnesota Pollution Control Agency, Maple Plain, MN, USA.

Porous Asphalt Design Recommendations

1. Particle size distribution & binder type are the 2 most important factors in mix selection *(Jones et al. 2010; Li et al. 2012)*
2. Void ratios of 25% & infiltration rates of > 7 cm/s possible by optimizing aggregate *(Partl 2003)*
3. Typical air voids are 16 – 20% *(NAPA 2008)*
4. Depth of aggregate bed to be 65% of frost depth *(UNHSC 2009)*
5. Typical aggregate gradations/specs given in reports *(NAPA 2008)*

Pervious Concrete Design Recommendations

1. Course aggregate: 3/8 - 3/4 inch. All aggregates meet ASTM D448 and C33/C33M *(ACI 2010)*
2. Low water:cement ratios (i.e. 0.26-0.34)
3. Supplementary materials (e.g. fly ash)/admixtures may be used (must meet ASTM requirements)
4. Void content from 15-25%
5. Increase in sand content may increase freeze-thaw resistance *(CRMCA 2009)*

Permeable Paver Design Recommendations

1. Open-graded bases: <2% fines, density: 95-120 lb/ft3, porosities >30%
2. All stone & aggregate: >=90% fractured faces and a minimum Los Angeles abrasion value of less than 40
3. Base and sub-base: porosity >= 32%, CBR >= 80%