Advancements and Challenges of Stormwater Management Along Highways

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Highway Stormwater Management

US 30 in Merrillville, IN (Photo courtesy of Joey B. Lax-Salinas)

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Stormwater Management Goals

- Volume Reduction
- Rate Control
- Contaminant Retention
  - Sediment (or TSS)
  - Nutrients (N & P)
  - Metals (Cd, Cu, Pb, Zn, etc.)
  - Oils & Greases
  - Chloride

Contaminant Sources

- Vehicles
  - Motor oil: Phosphorus, oils
  - Batteries: Lead, nickel
  - Brakes: Cd, Cu, Pb, Zn
  - Tires: TSS, Cd, Cu, Pb, Zn
  - Electronics: Copper
- Buildings
  - Metal roofs, flashing, siding, gutters
- Atmospheric Deposition


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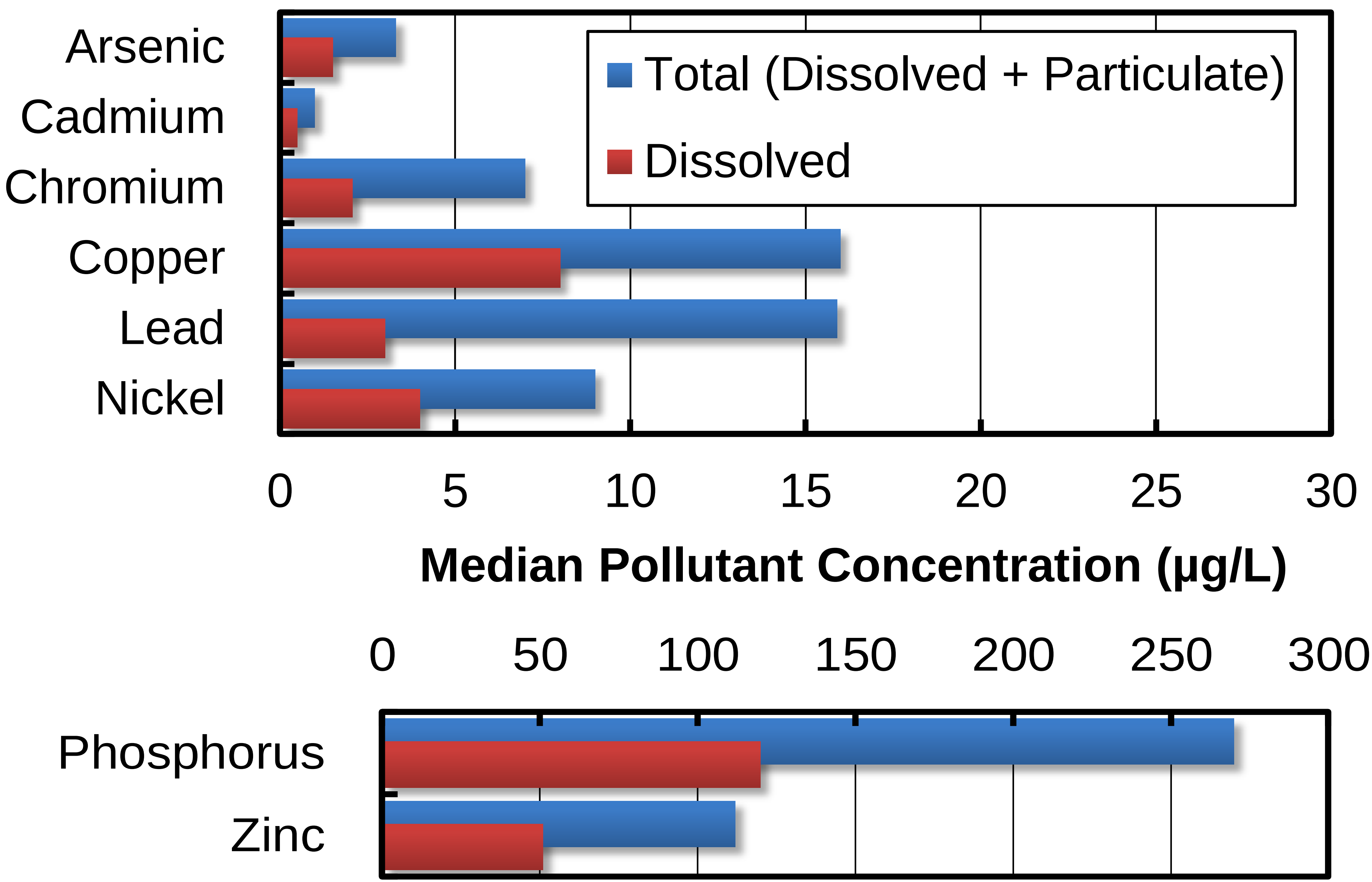
Dissolved & Particulate Fractions



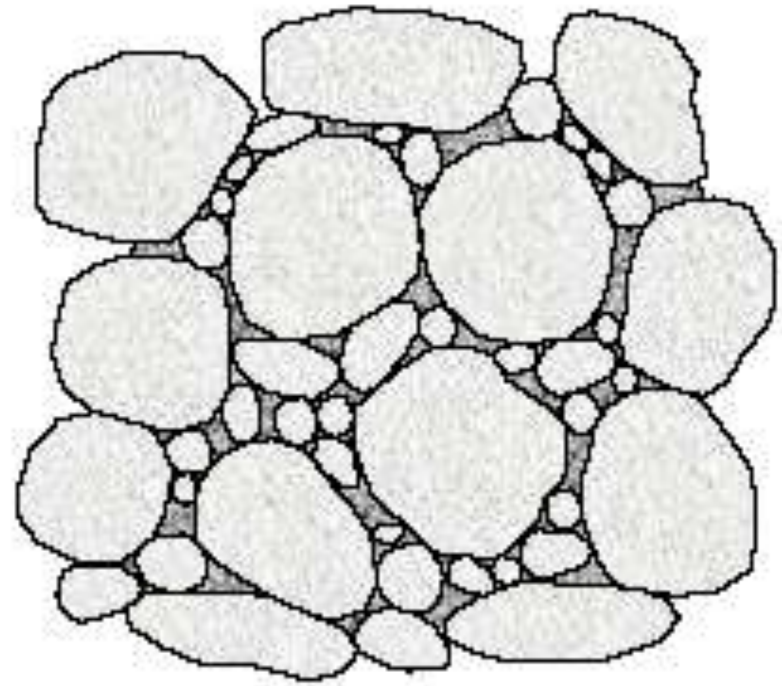
Adapted from Pitt et al. 2005. Image courtesy of Andy Erickson

Stormwater Management Options

- Permeable Pavements
  - Permeable Pavement Shoulders
  - Open Graded Friction Course
- Drainage Swales
- Iron Enhanced Sand Filter Check Dams

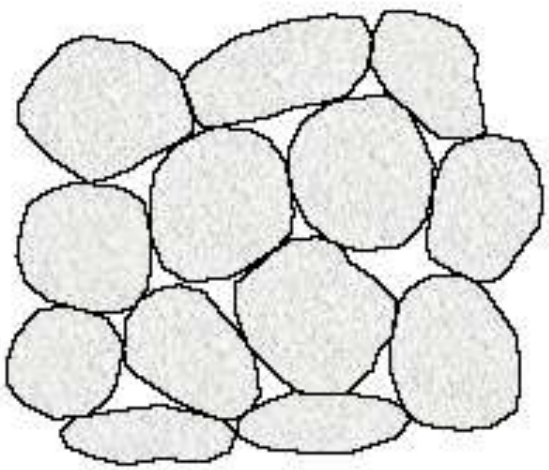
Conventional Pavement

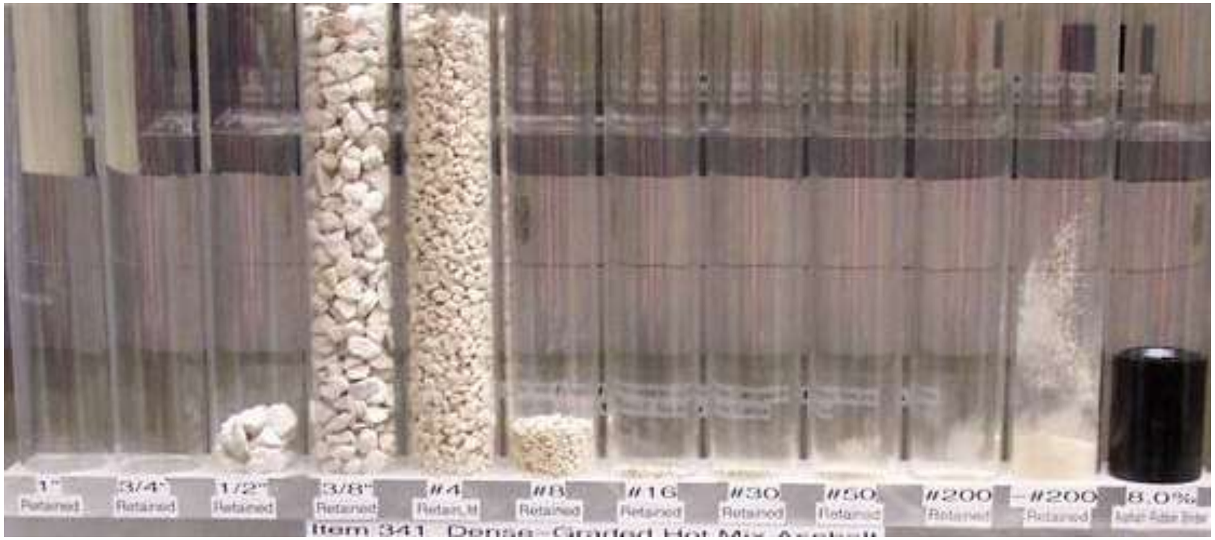
- Agg-Agg Contact
- Low void content
- High Stability



Permeable Pavement

- Agg-Agg Contact
- High void content (15-25%)





Photos courtesy of M. Barrett and perviouspavement.org

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Full-Depth Permeable Pavement

- Stone reservoir under permeable pavement
- Underdrains, if necessary
- Infiltration into soil subgrade

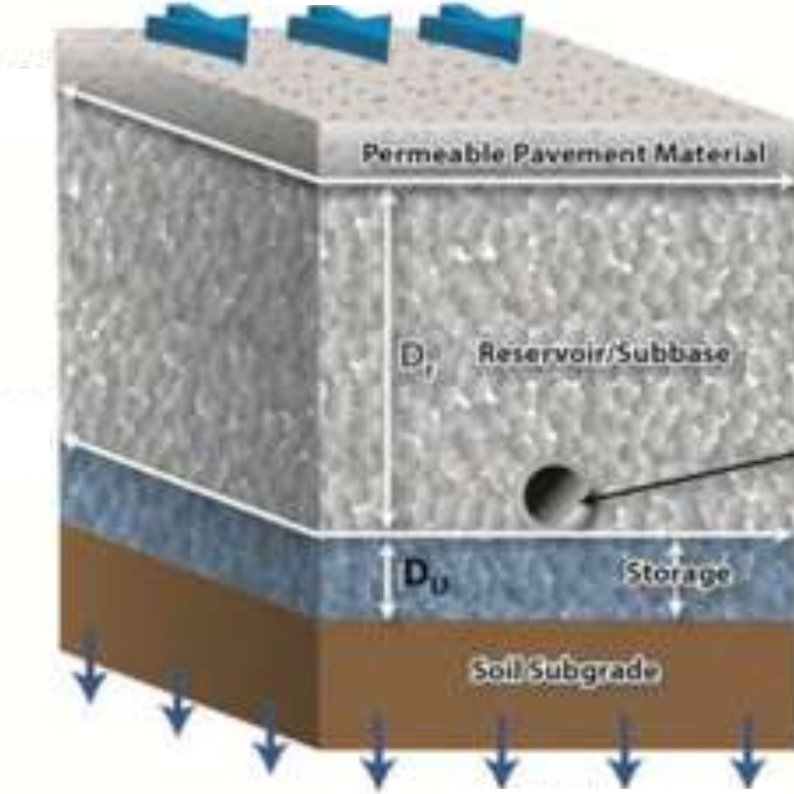
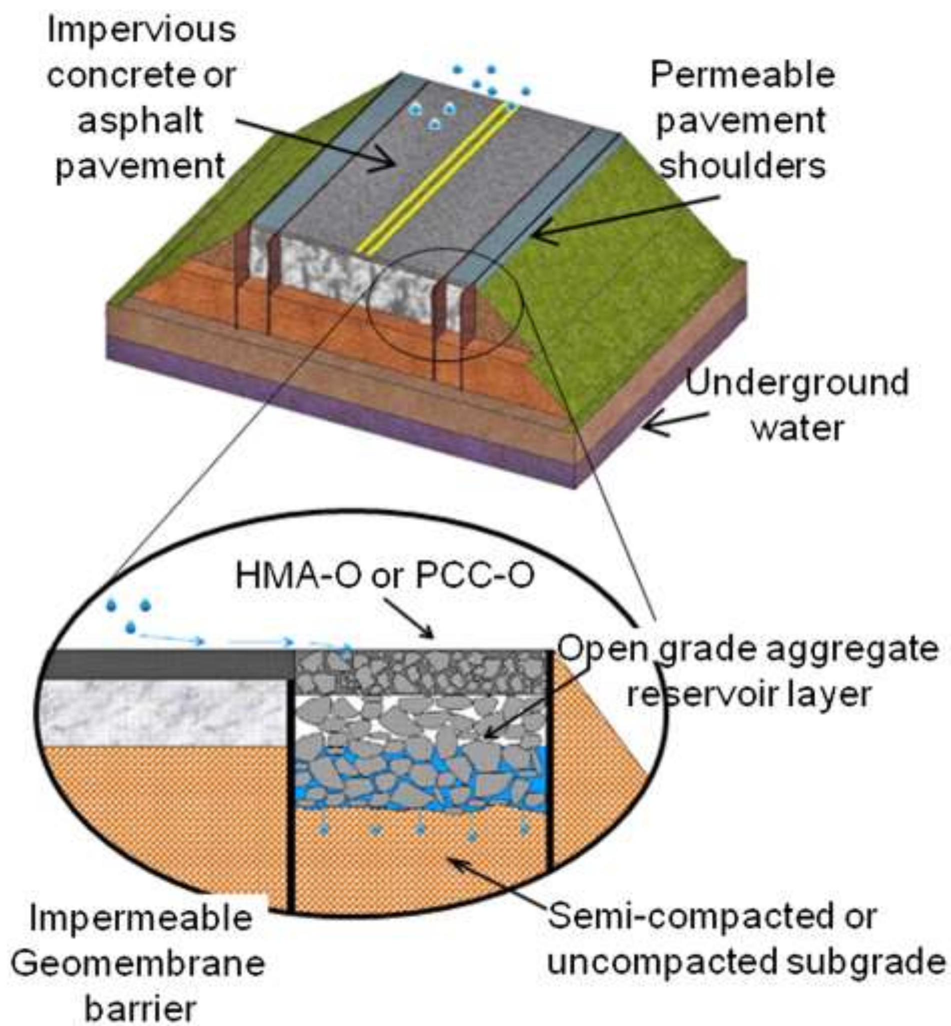


Image source: MPCA

Permeable Pavement Shoulders

- Full depth
- Must separate permeable reservoir from road subbase
- Found viable by Caltrans and NCHRP



Permeable Pavement Shoulders

South Bend, Indiana (Photo courtesy of Brian Lutey, Ozinga)

Maintenance of PP Shoulders

- Do not sand
- Remove snow (no raised blades)
- Regular visual inspection: Clogging & durability
- Measure infiltration: ASTM C1701-09/ASTM C1781-13
- Vacuum sweeping: High risk areas 2x/year
- Inspection ports: Monitor reservoir drainage

Hein et al. 2013.

Image source: ABC 10 – San Diego

Performance of PP Shoulders

- Initial Infiltration rates > 200 cm/hr
- May achieve up to 40% volume reduction in low permeable soils
- Typical contaminant retention:
  - 85% Total Suspended Solids
  - 35% Total Phosphorus
  - 30% Total Nitrogen

Source: Drake 2013, Hein 2013, NCDENR 2012

Image source: Delaware Free News

Construction Cost of Full depth Permeable Pavement

- Pavement Costs ($\$/yd^2$):

ASPHALT

– Conventional Asphalt:	$23.00 - $24.50
– Porous Asphalt:	$31.00 - $48.40

CONCRETE

– Conventional Concrete:	$29.25 - $47.25
– Pervious Concrete:	$60.75 - $71.21

Source: Rowe 2010, UMD, Concrete Network.

Image: NY DEC

Open Graded Friction Course (OGFC)

- Placed over conventional pavement
- 25-50 mm thick
- ~20% voids
- Vertical then lateral infiltration
- 8-10 year life

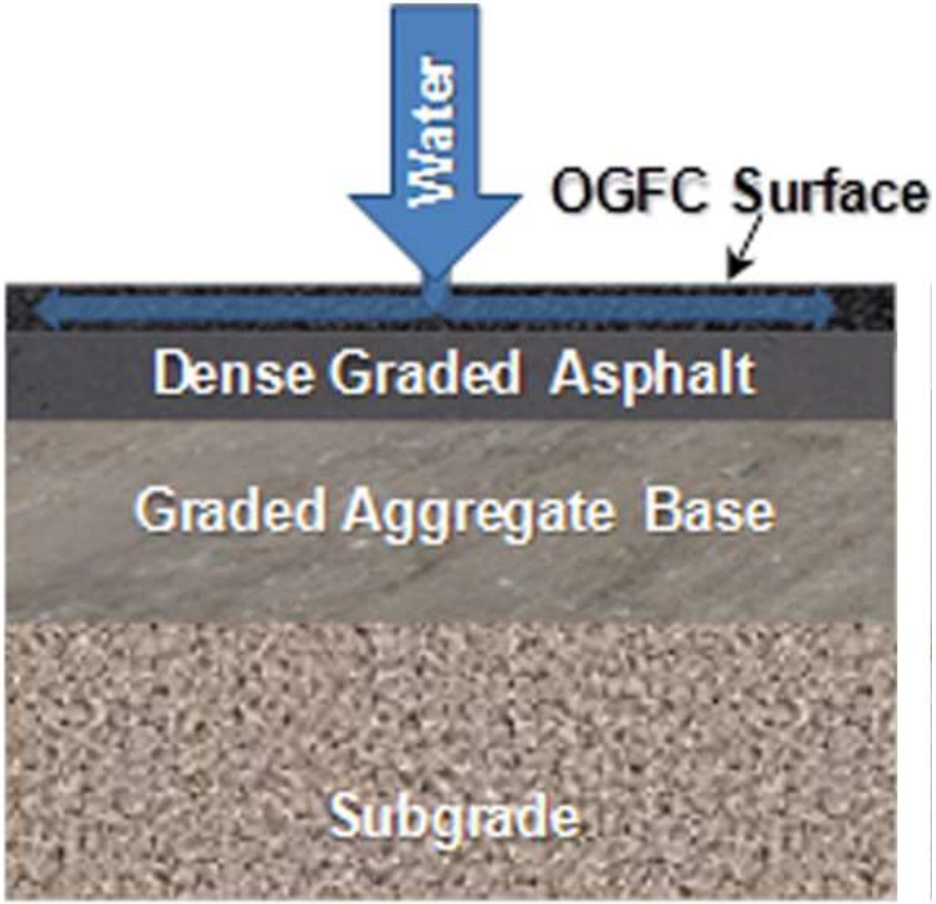


Image source: Putman and Kline 2012

Open Graded Friction Course

Image source: Barrett 2008

Open Graded Friction Course

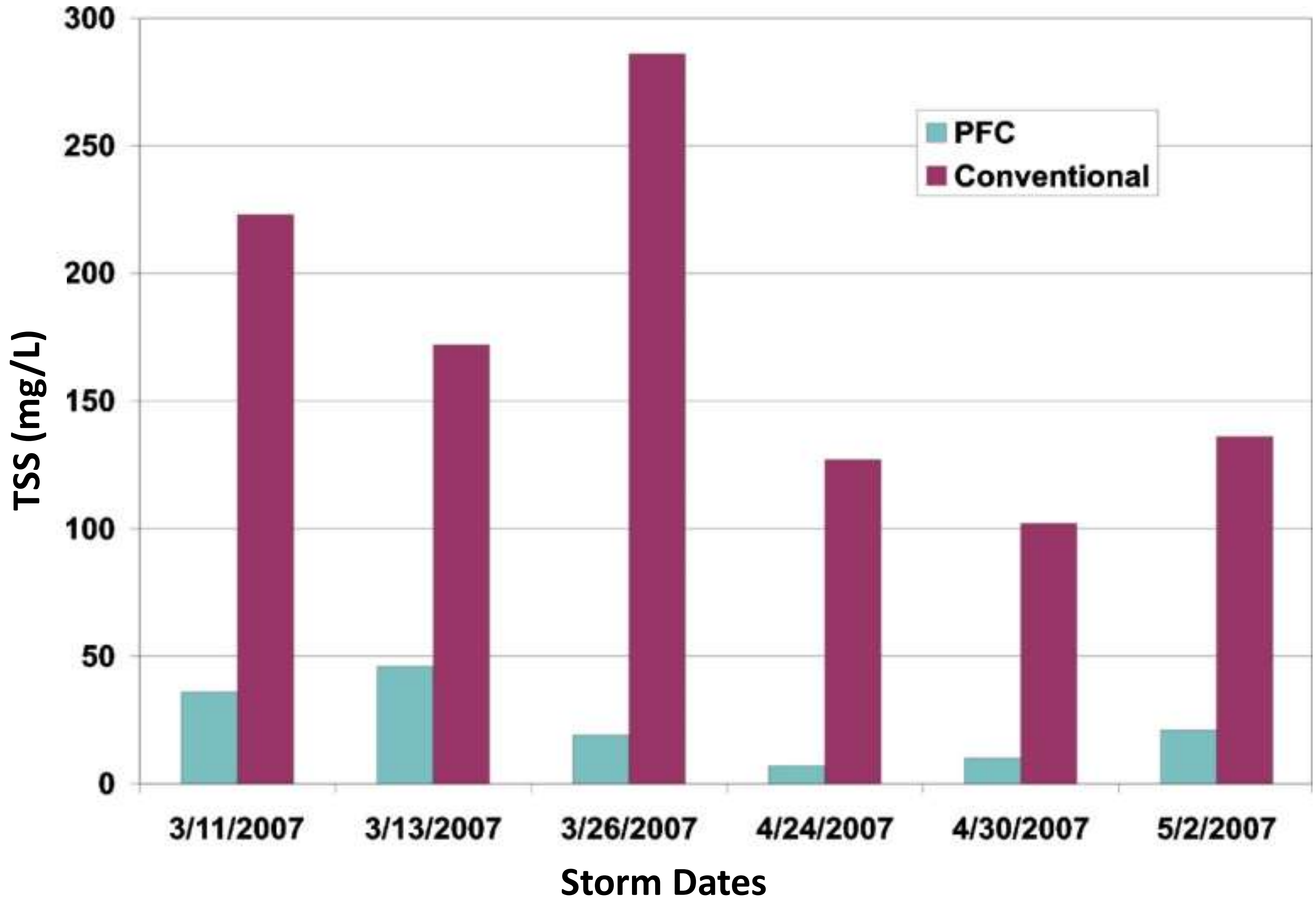
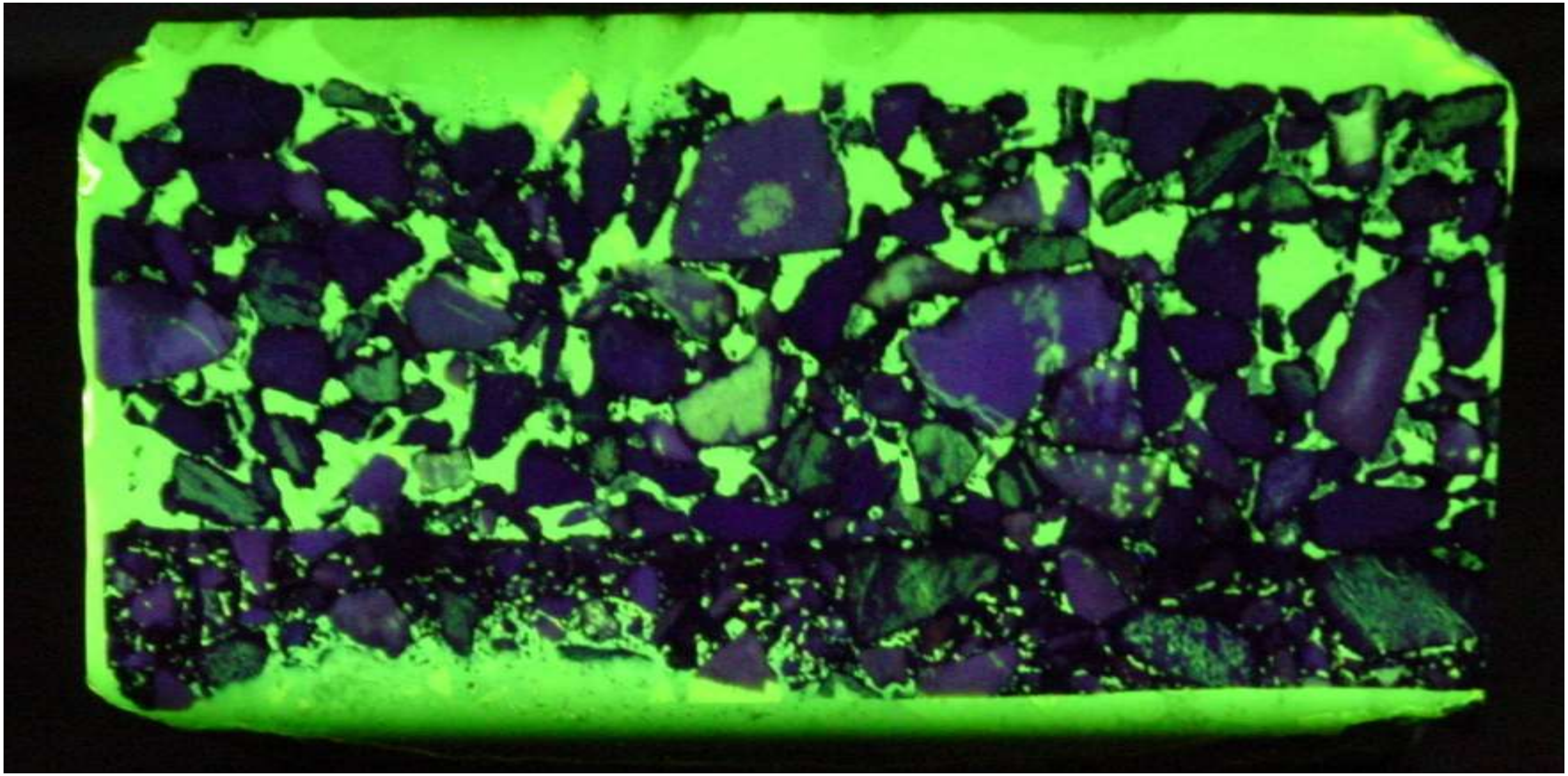


Image source: Barrett 2008

Open Graded Friction Course



OGFC core impregnated with fluorescent epoxy after > 2.5 years of service

Open Graded Friction Course

Spray reduction may mean less TSS on road surface

(Video source: Plantmix Asphalt Industry of KY)

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OGFC Test on I74 - Indianapolis

- Test section of OGFC east of Indianapolis in 2003
- Monitored for 4 years (until 5 years old)
- OGFC can “perform well under Indiana conditions”

- “Voids did not clog over the life of the study”
- “INDOT now has a new tool…”

McDaniel et al. 2010

OGFC Test on I74 - Indianapolis

- Not recommended for slower traffic
- OGFC was colder, retained snow and ice longer
- Required 1-2 additional salt applications

I74 OGFC after 5 years of service (McDaniel et al. 2010).

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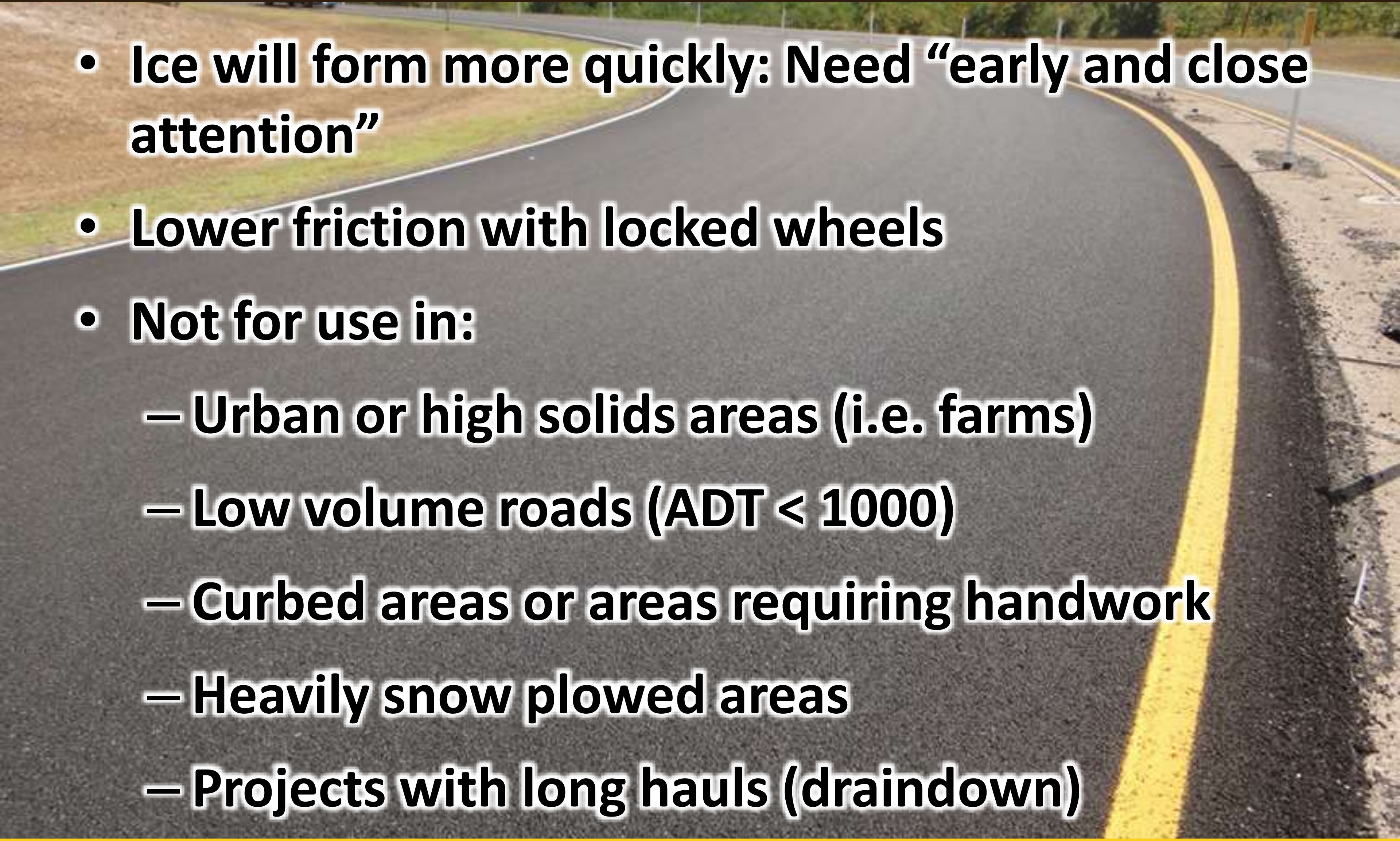
Winter Maintenance of OGFC

- Winter infiltration may decrease 90-100%
- Use pre-wetted salts & increase frequency
  - More anti-icing agent (50 – 300% increase)
- Do not use with frequent snowplowing
- OGFC no worse than conventional pavements in Switzerland winter

Backstrom & Bergstrom 2002, Camomilla et al. 1990, FHWA 2005, Isenring et al. 1990, Moore et al. 2001

Limitations of OGFC

- **Ice will form more quickly: Need "early and close attention"**
- **Lower friction with locked wheels**
- **Not for use in:**
  - **Urban or high solids areas (i.e. farms)**
  - **Low volume roads (ADT < 1000)**
  - **Curbed areas or areas requiring handwork**
  - **Heavily snow plowed areas**
  - **Projects with long hauls (draindown)**



OGFC on US 59 in TX (from Texas A&M Transportation Institute)

NCHRP 2009

Highway Drainage Swales

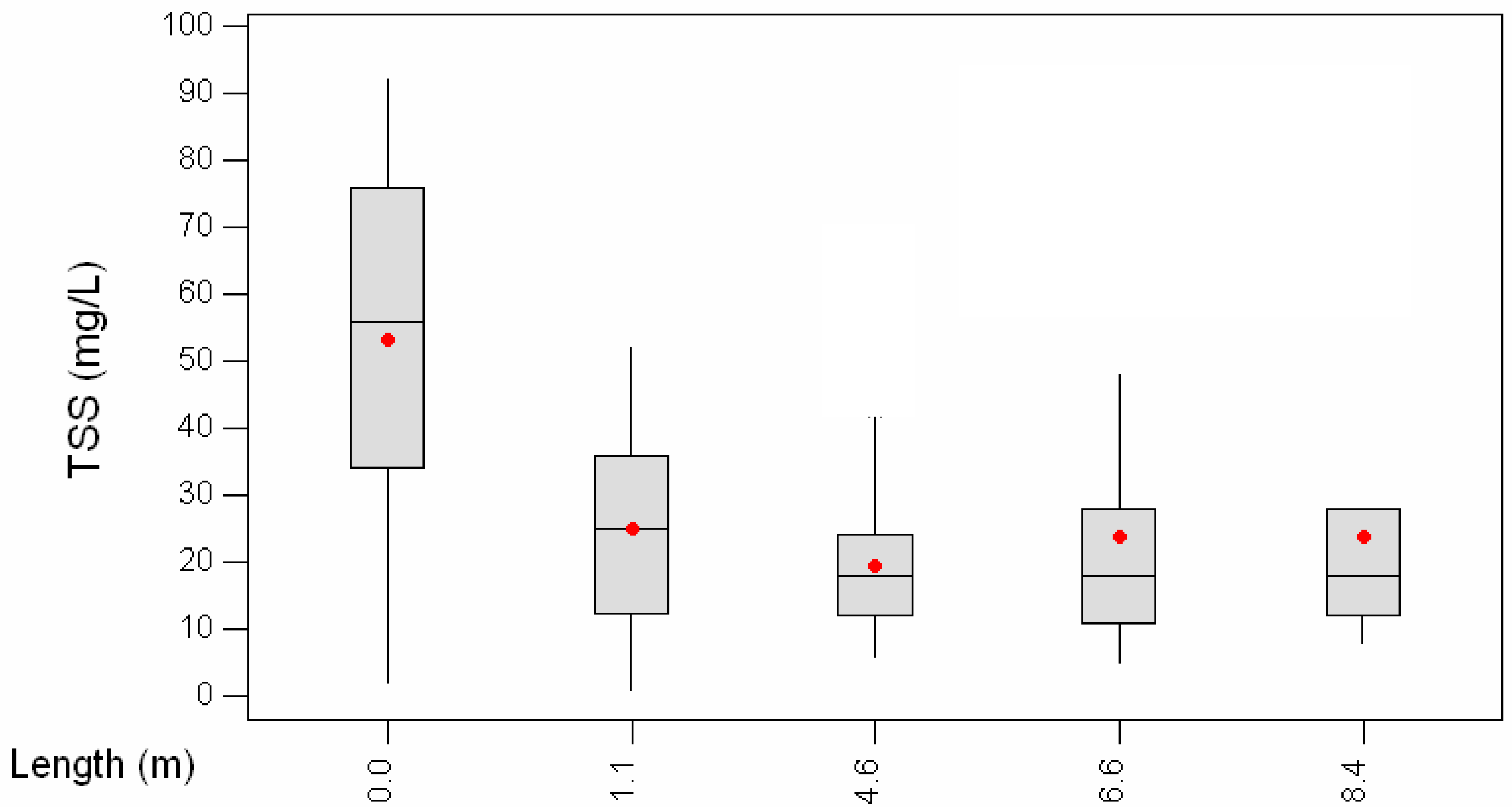
Monitoring of a swale in California. Image : Barrett 2004

Swale Retention Performance

- TSS Removal typically > 70%
- TSS Removal on side slope or embankment
  - 59 - 82%, 2 m from EOP
  - 93 - 96%, 4 m from EOP
- No N or P removal (may increase)
- Total metals reduced

Barrett 2008
Image source: sdstate.edu

Impact of Median Width



Performance of highway swale in Sacramento, CA. Slope = 33%

Recommendations

- Vegetative type, height, width, residence time have little or no impact on performance
- Maintain healthy vegetation over >90% area
- Substantial removal for slopes up to 30%
- Maximize length of slide slope (up to 4.6m)
- Avoid sediment lip at edge of pavement
- Remove grass clippings and sediment

Monitoring of a highway median in Washington. (Ahmed et al. 2014, Barrett et al. 1998, Barrett 2004, Lancaster 2009, Li et al. 2008. Image: Cory Lancaster.)

Drainage Swale Maintenance Costs

Maintenance Activity	Cost (2013)
Annual O&M*	5-6% of total construction $
Swale: Mow & sediment removal	$6-$13 per foot
Concrete end aprons: Sediment removal	$285 per apron
Break up soil to 16-20 inches	$420 per acre

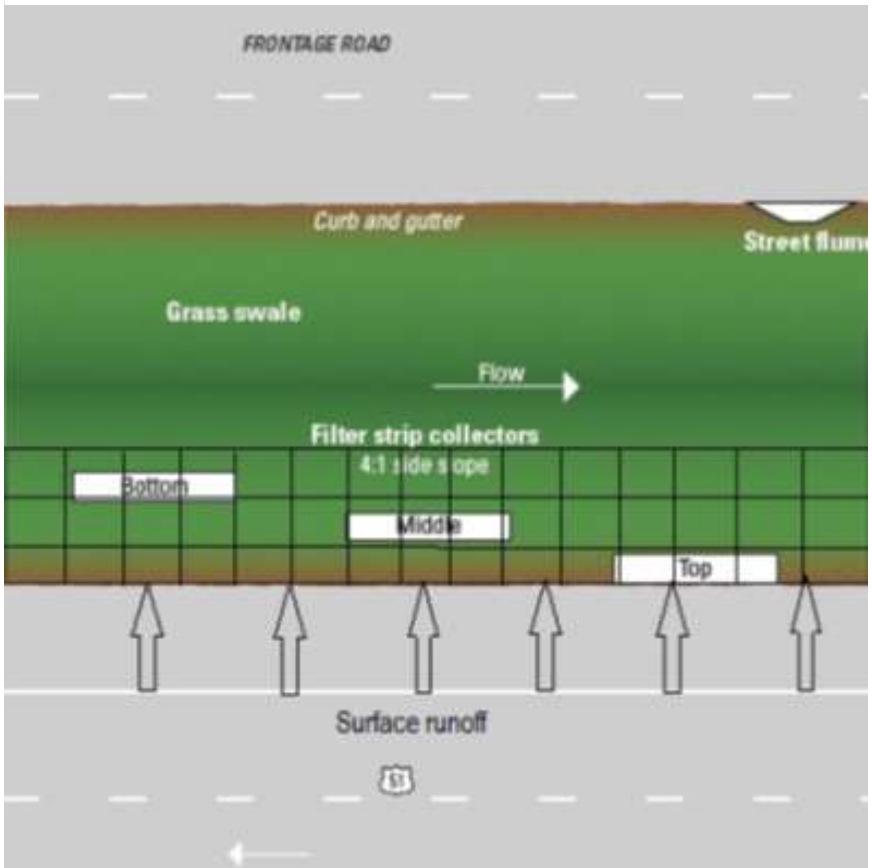
Maintenance Activity	Person-hours
Swale: Mow & sediment removal	0.22 - 0.28 per foot
Concrete end aprons: Sediment removal	5.7 per apron

Source: Ahmed et al. 2014, US EPA 1999, MnDOT personal communication except as noted. * US EPA 1999.

Photo: roads.Maryland.gov

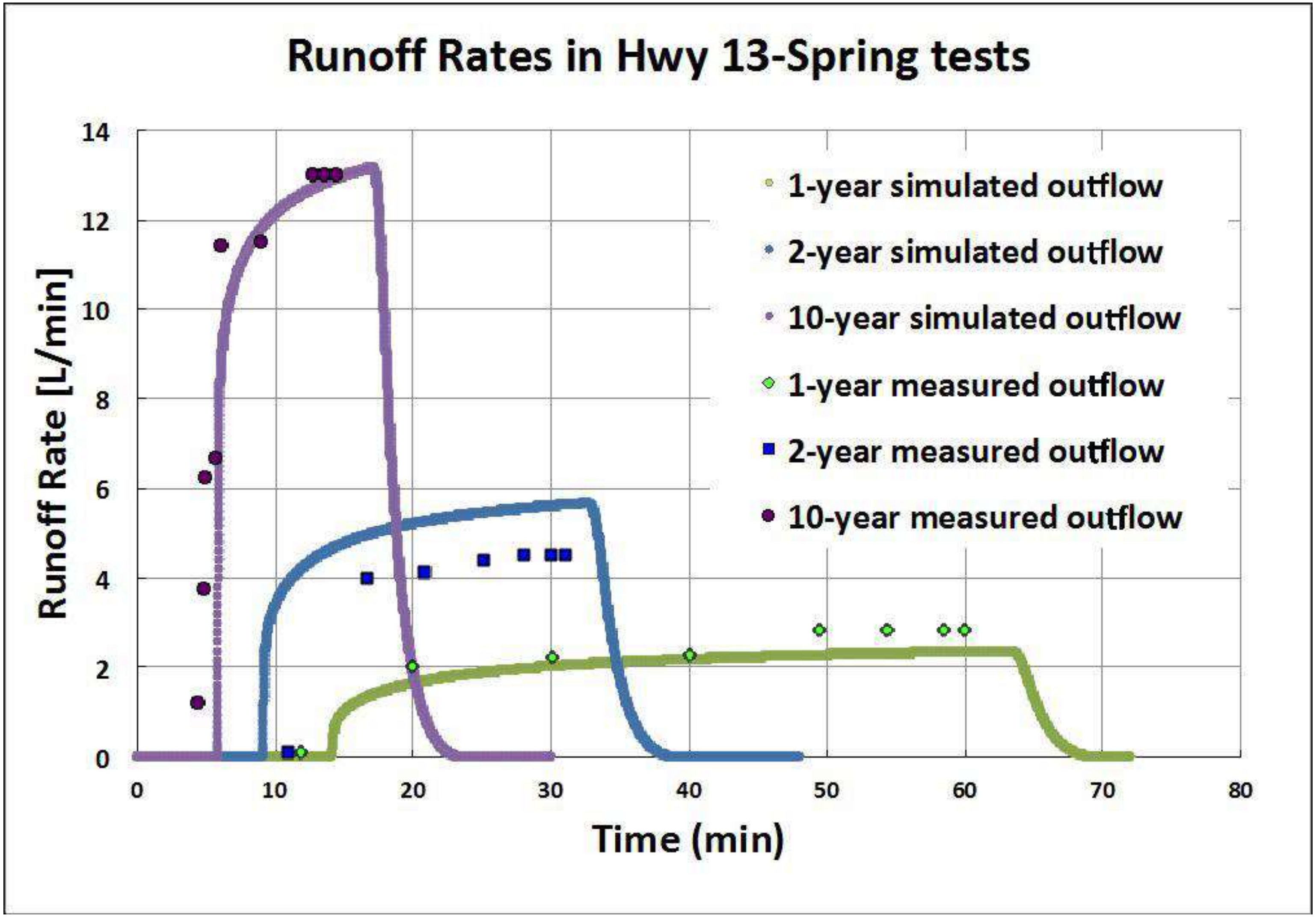
Swale Hydraulic Model

Schematic of modeling grid



- **Grid established over entire channel**
- **Model infiltration: Green-Ampt eq.**
- **Model flow: Kinematic Wave eq.**
- **Calculate volume & fraction of runoff**

Field Verification of Hydraulic Model



Garcia-Serrana et al. 2016

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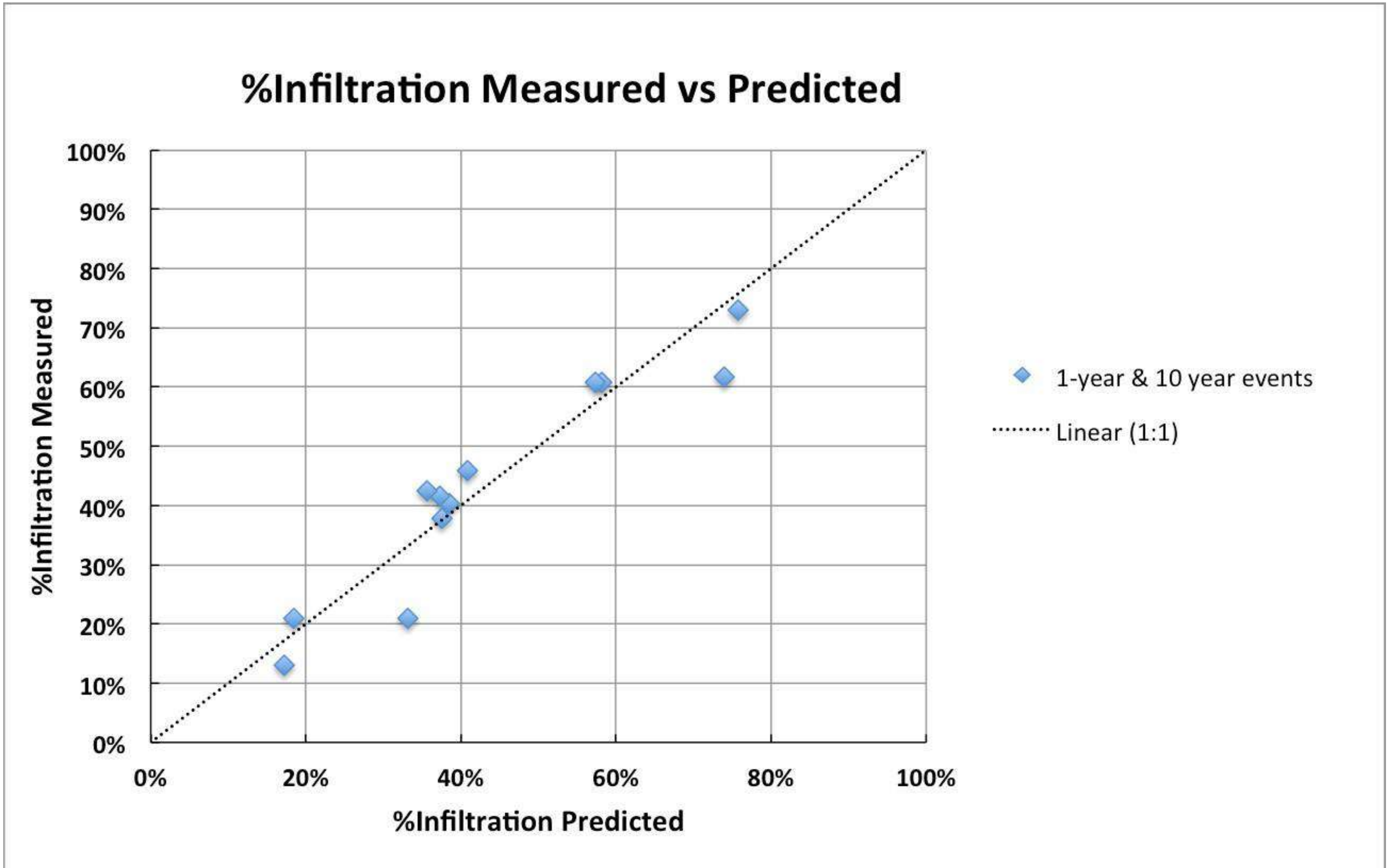
Field Verification of Hydraulic Model



Garcia-Serrana et al. 2016

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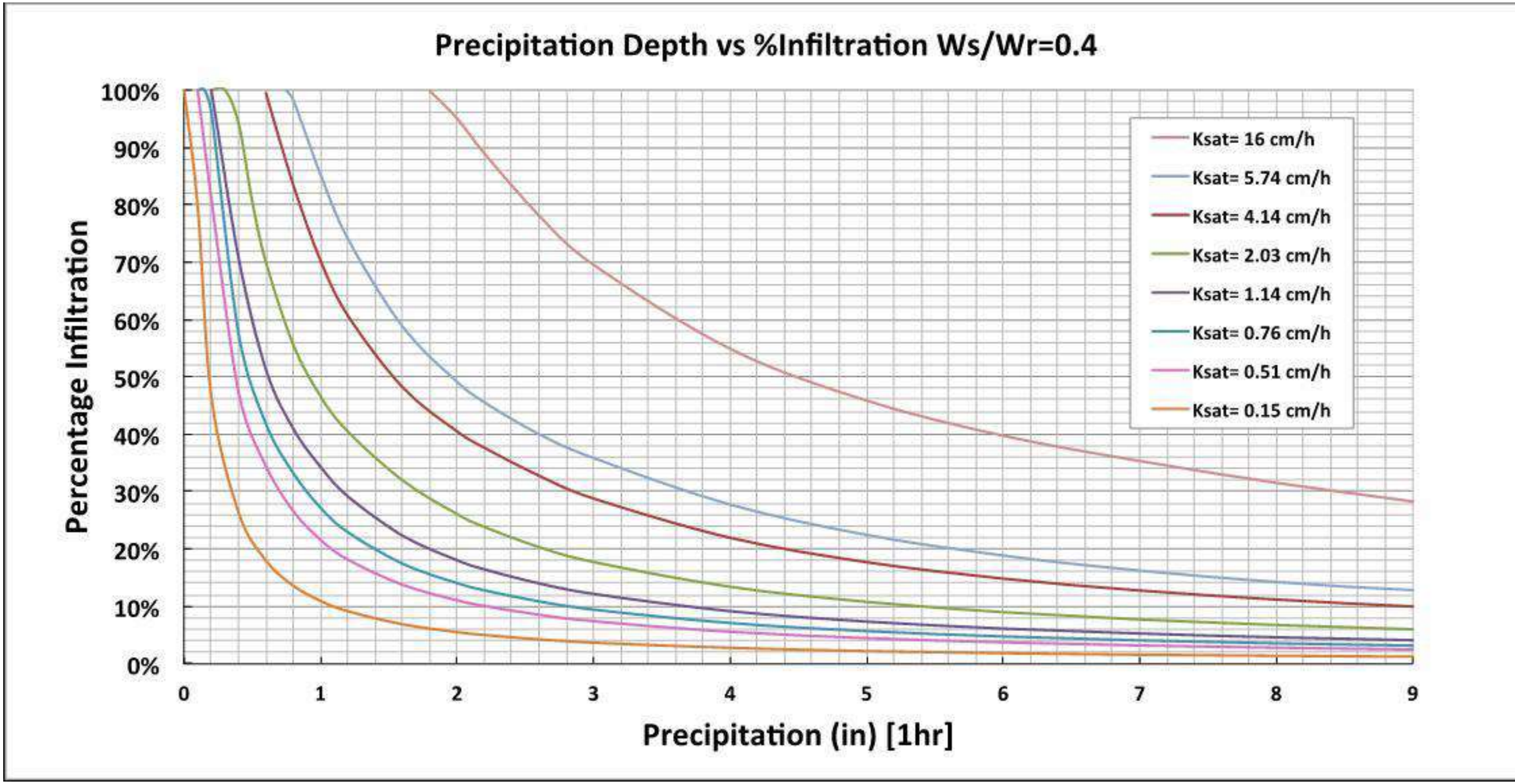
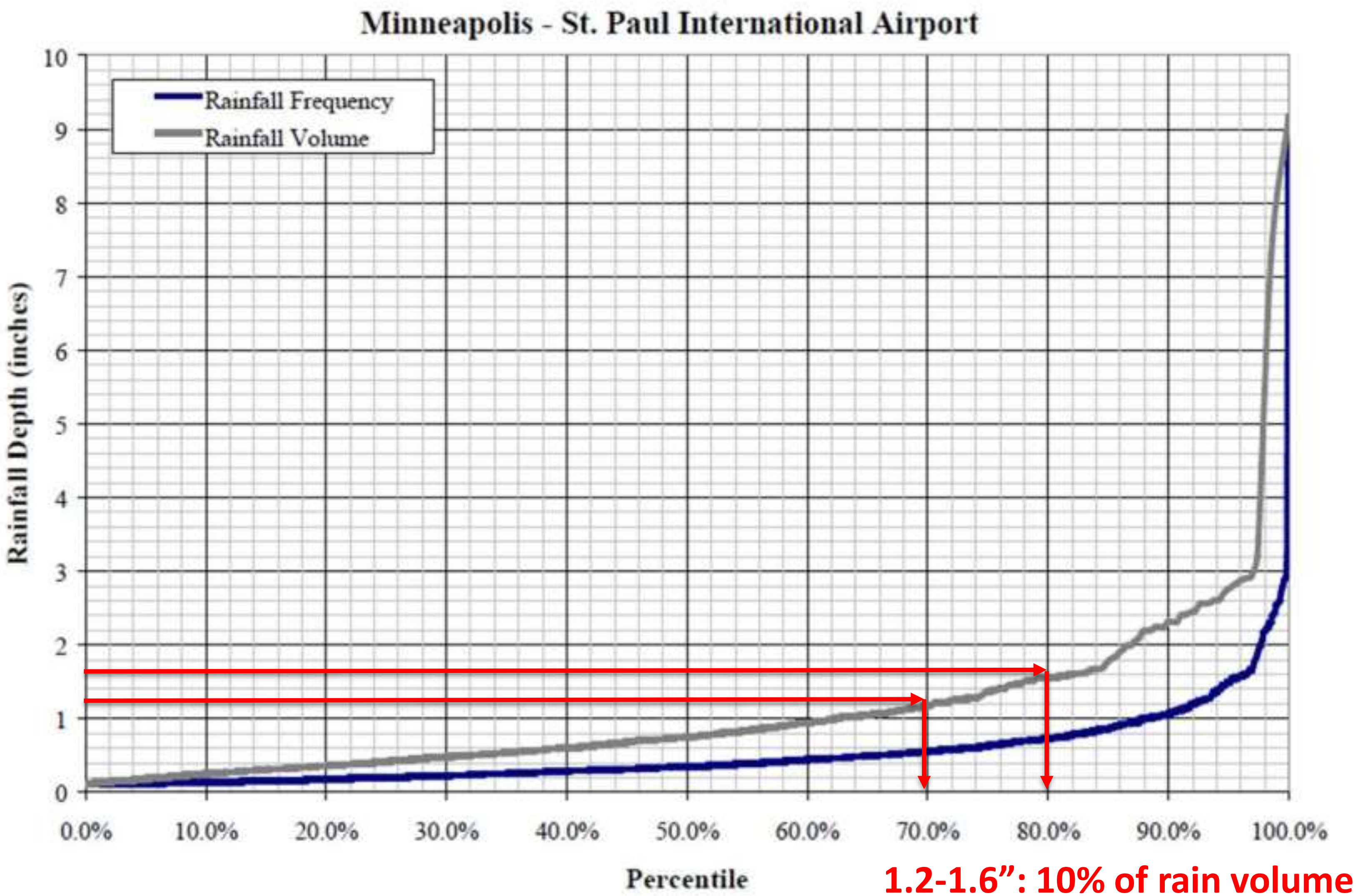
Estimating Annual Performance



Estimating Annual Performance



Percent rainfall volume and frequency graph

(Garcia-Serrana et al. 2016)

Estimating Annual Performance

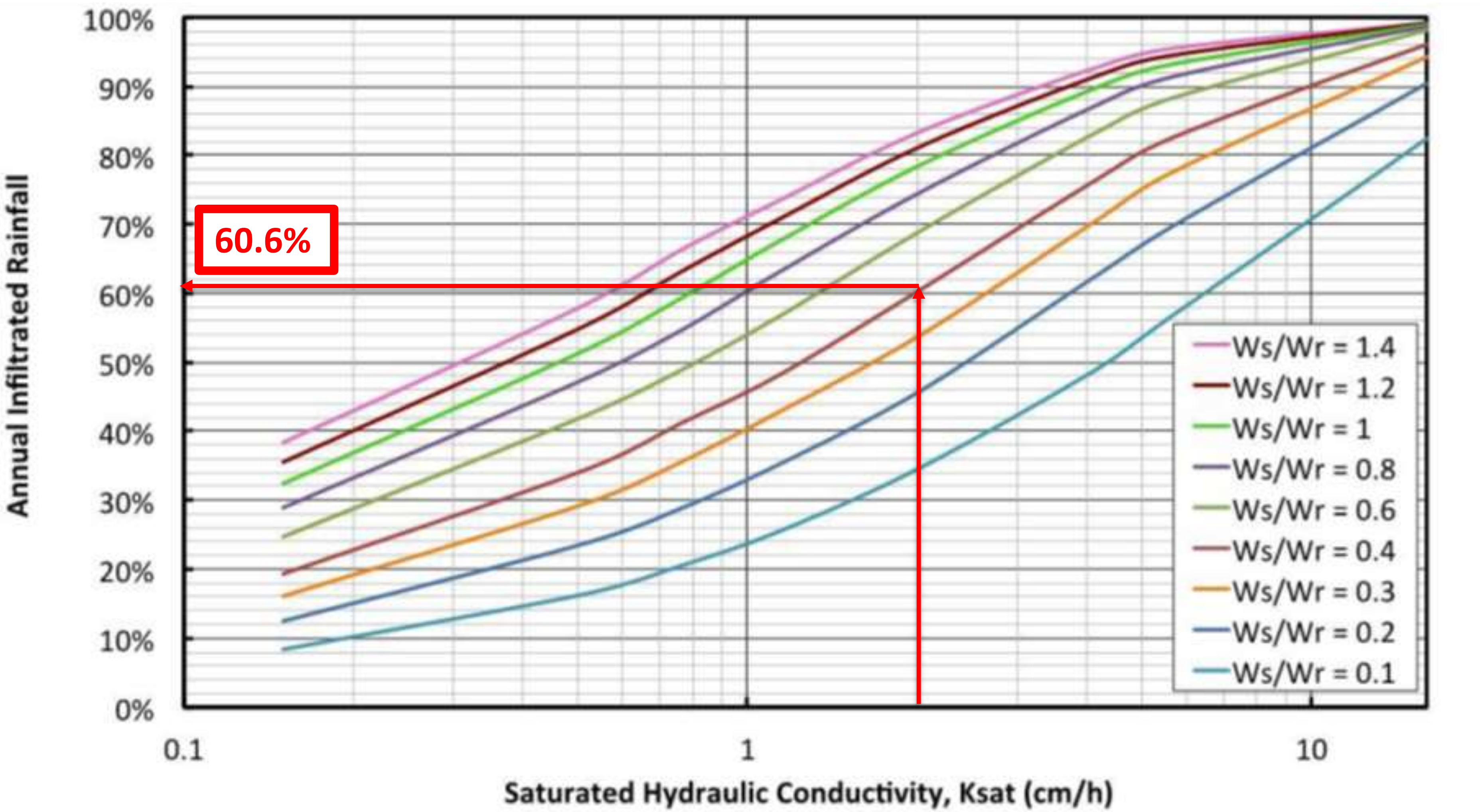
Rainfall Depth (in)	PRV (Annual Rainfall)	PDF (Annual Rainfall)	Infiltration (%)	Annual Performance
9	100.0%		6.0%	
8	99.0%	1.0%	6.8%	0.1%
7	98.3%	0.7%	7.7%	0.1%
6	98.0%	0.3%	9.0%	0.03%
5	97.8%	0.2%	10.8%	0.02%
4	97.6%	0.2%	13.4%	0.02%
3	97.0%	0.6%	17.7%	0.1%
2.6	94.0%	3.0%	20.4%	0.6%
2.2	88.0%	6.0%	23.9%	1.3%
2	87.0%	1.0%	26.1%	0.2%
1.6	80.0%	7.0%	Avg = 36%	2.0%
1.2	70.0%	10.0%		3.6%
1	63.0%	7.0%	46.6%	3.0%
0.8	52.0%	11.0%	55.6%	5.6%
0.6	40.0%	12.0%	70.0%	7.5%
0.4	22.0%	18.0%	94.1%	14.8%
0.2	6.0%	16.0%	100.0%	15.5%
0.1	0.0%	6.0%	100.0%	6.0%

$\Sigma = 60.6\%$

Example: Ws/Wr = 0.4, Ksat = 2.03 cm/hr

(Garcia-Serrana et al. 2016)

Estimating Annual Performance



Annual Infiltration Performance using MSP historic rainfall data. (Garcia-Serrana et al. 2016)

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Drainage Swales Infiltration Capacity

Modified Philip Dunne (MPD) Infiltrometer & In field measurements

(Ahmed et al. 2014)

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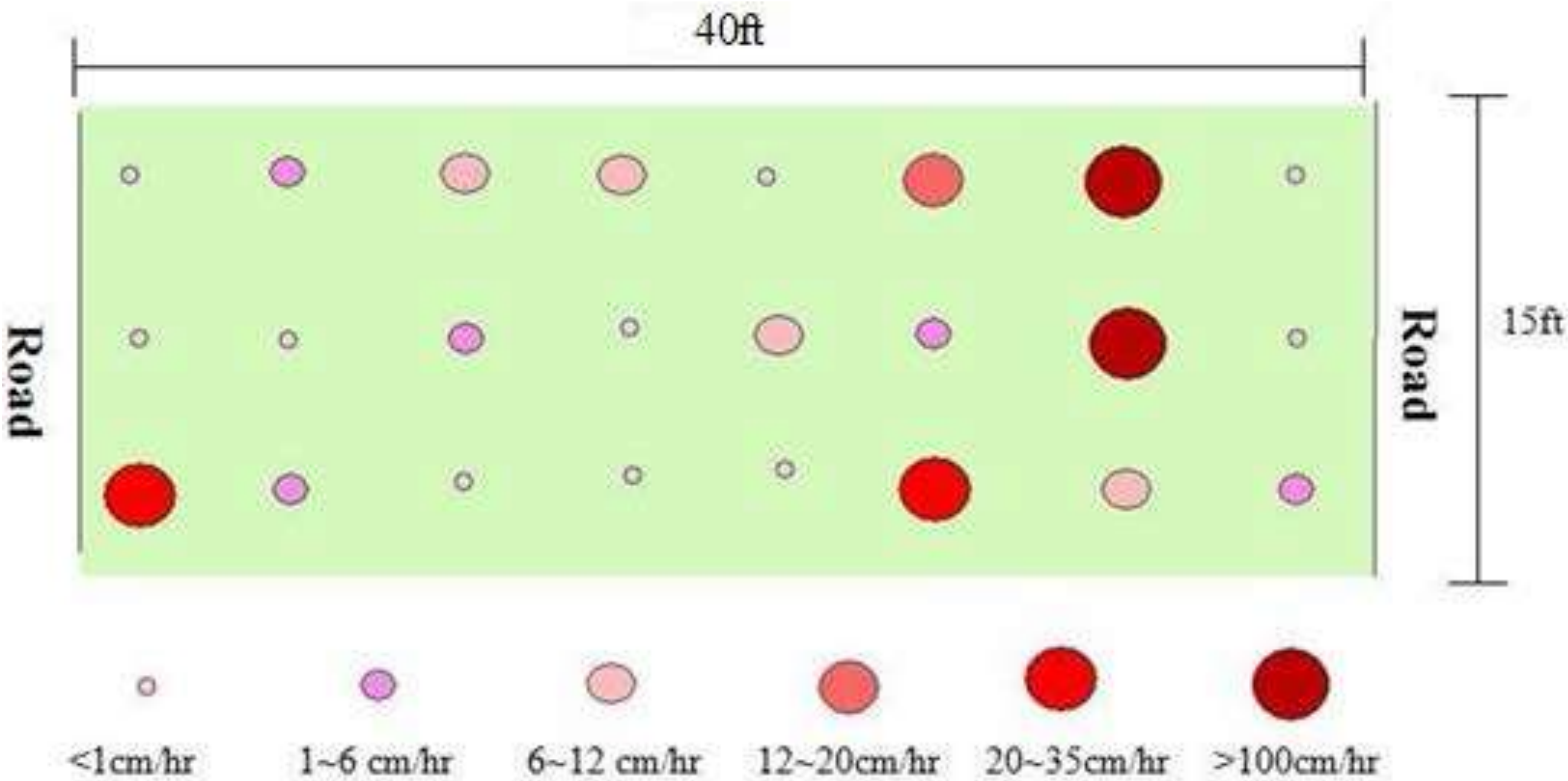
Wide Variation in Permeability



$$K_{sat\text{-}eff} = 0.32(K_{avg}) + 0.68(K_{geomean})$$

~20 measurements in 350 m long swale

Spatial variation of K_{sat} adjacent to HWY 212 near Twin Cities (Ahmed et al. 2014, 2015; Weiss & Gulliver 2015)

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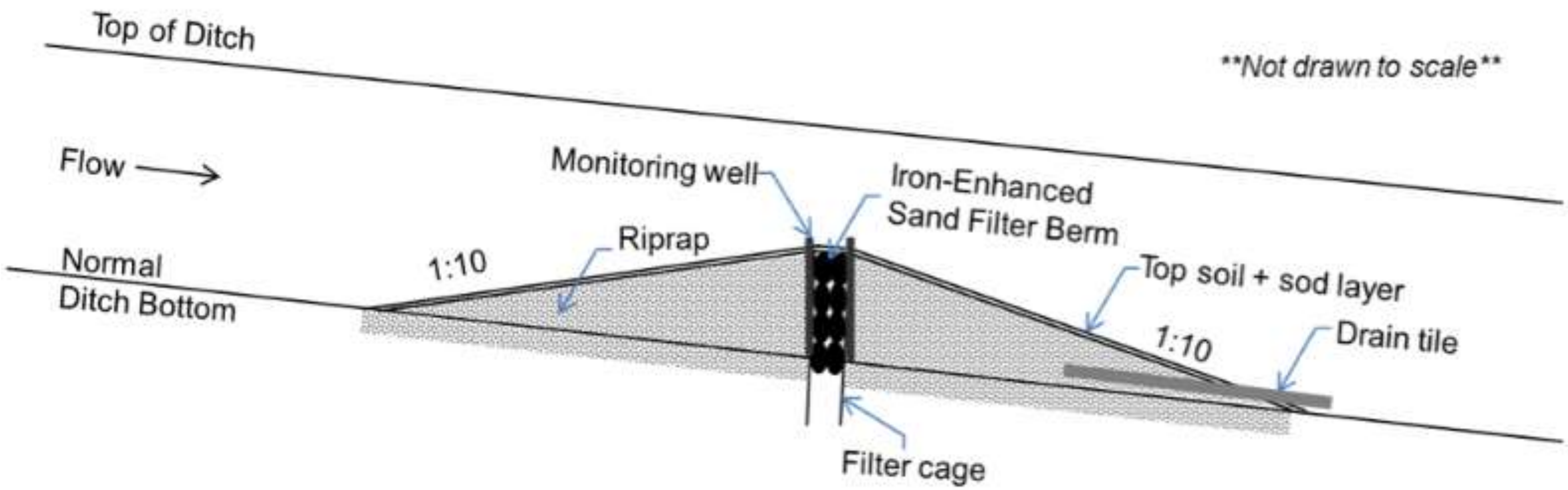
Iron-Enhanced Sand Filtration (IESF)

Maplewood, MN Iron-enhanced surface sand filter

- Targets dissolved P
- 5-7% Fe w/ C33 sand
- Iron rusts (+ charge)
- Phosphate (- charge)
- P adsorbs to Fe
- Up to 70-90% dissolved P retained
- Used in surface sand filters in Minnesota

IESF for Highway Swales



- Check dam w/ filter
- Iron-sand mix socks
- Supported by cage

- 7% iron by weight
- Sand d_{50} = 1.2 mm
- Larger than C33 (d_{50} = 0.7 mm)

Schematic of IESF Check Dam (Natarajan & Gulliver 2015)

IESF for Highway Swales

IESF Check Dam, TH5 in Stillwater, MN

(Natarajan & Gulliver 2015)

Testing of IESF Check Dam

Water truck testing, TH 5 in Stillwater, MN

(Natarajan & Gulliver 2015)

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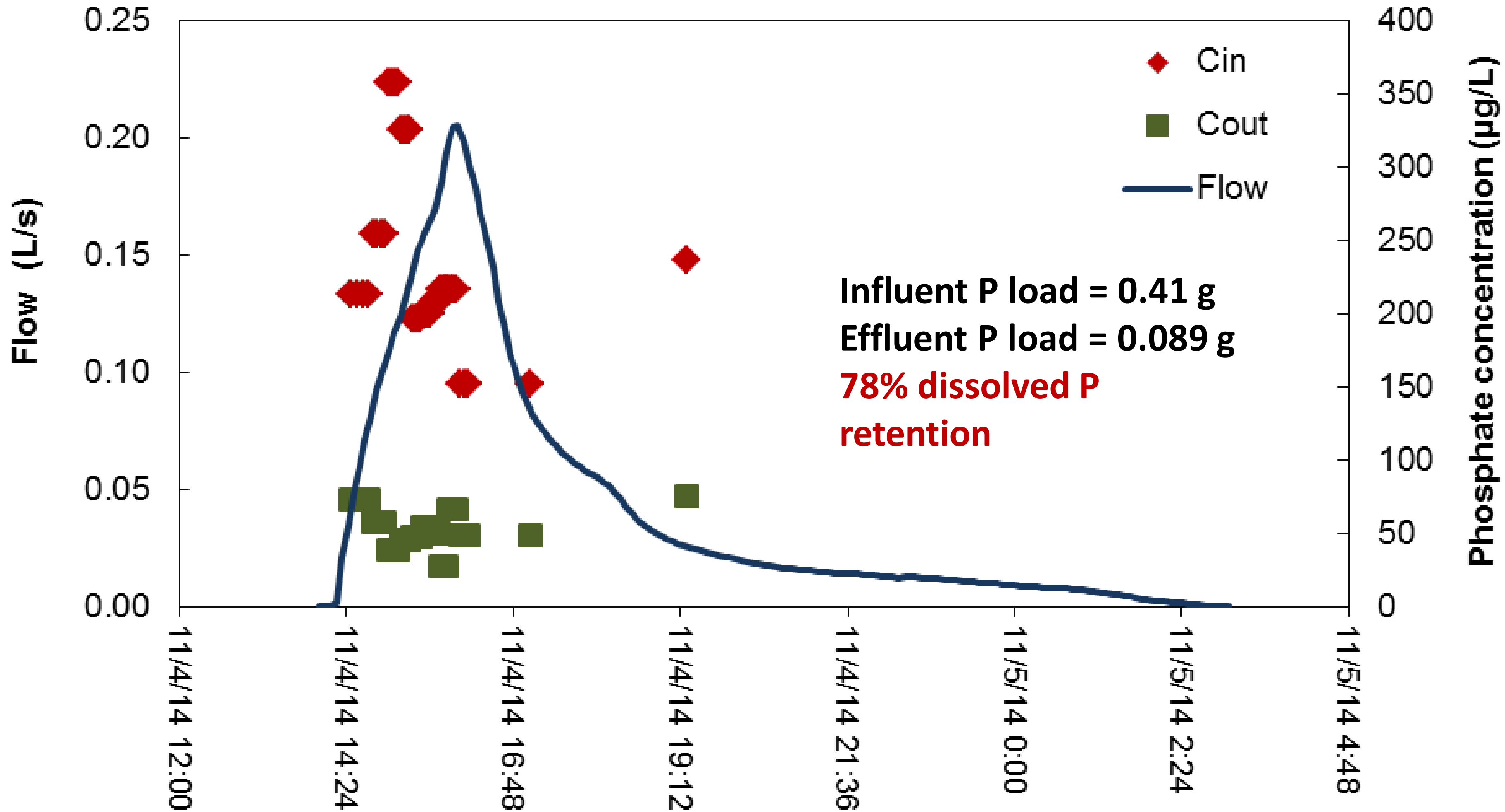
Test Results

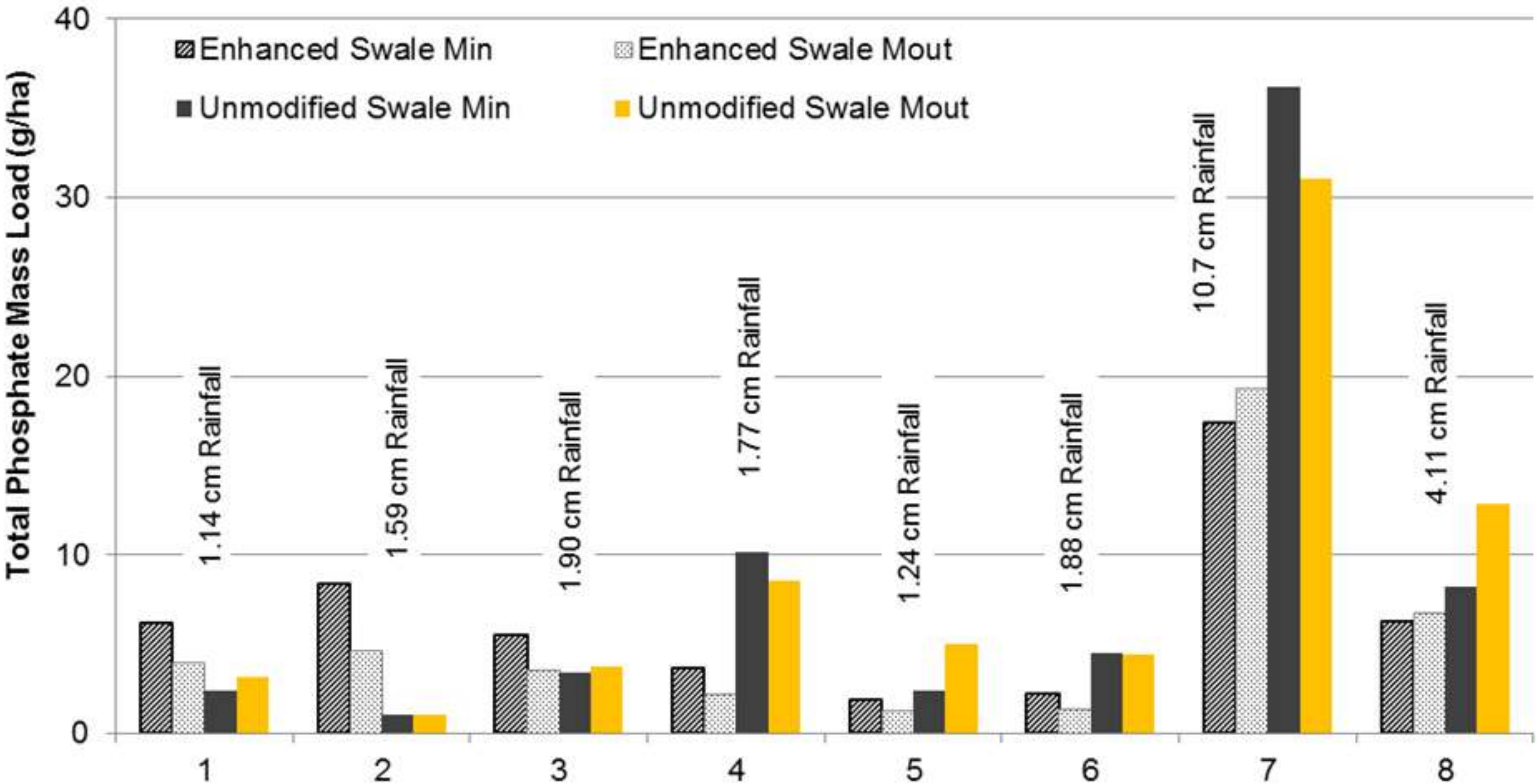


Each data point is average concentration of 20 L synthetic runoff volume

Water truck synthetic runoff test results.

(Natarajan & Gulliver 2015)

Natural Rainstorm Monitoring



IESF Check Dam: 35% P retention. Unmodified Check Dam: 14% P increase.

Rainstorm monitoring results, TH 5 in Stillwater, MN.

(Natarajan & Gulliver 2015)

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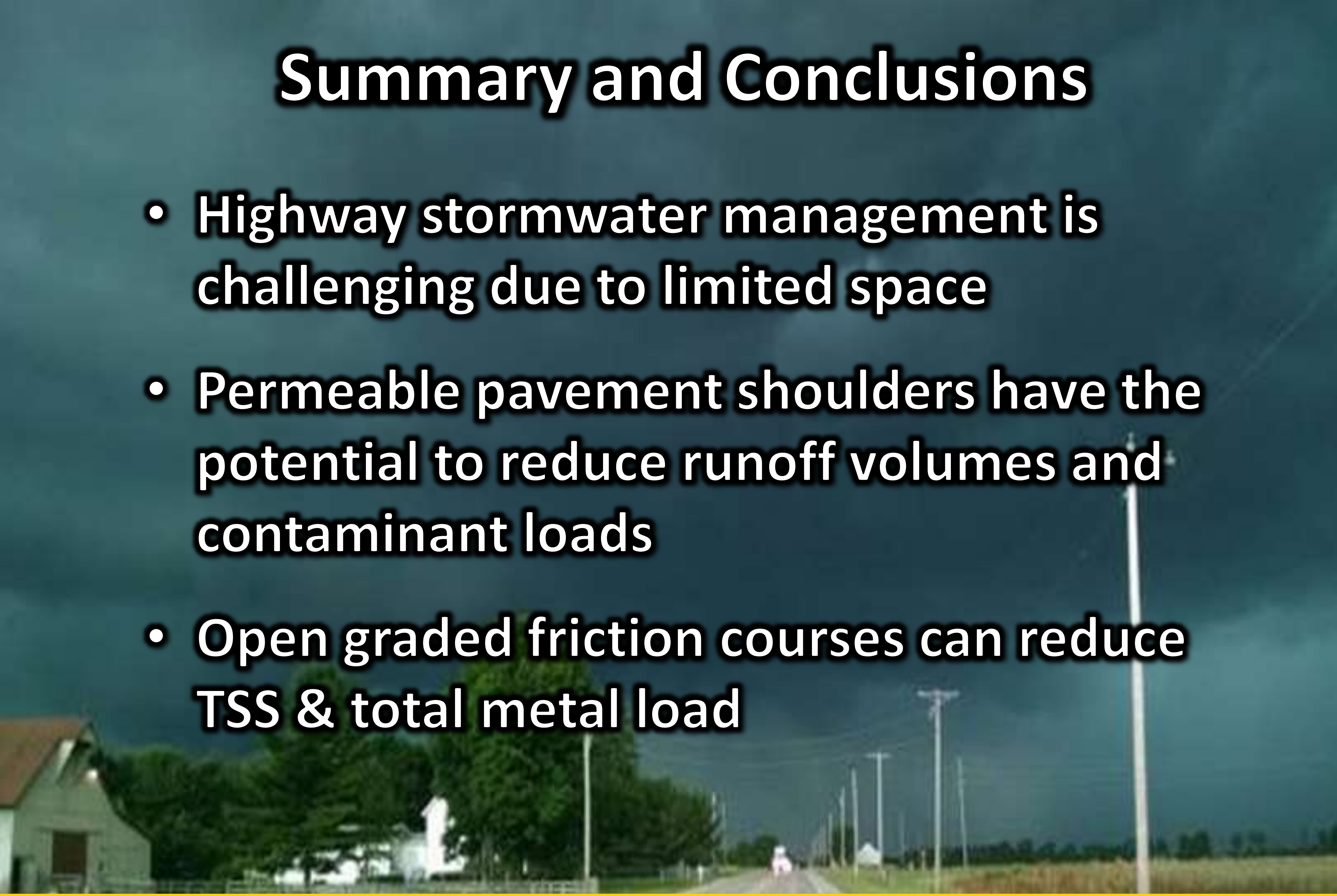
Summary and Conclusions

- Highway stormwater management is challenging due to limited space
- Permeable pavement shoulders have the potential to reduce runoff volumes and contaminant loads
- Open graded friction courses can reduce TSS & total metal load



Heavy Rain in Central Indiana on June 15, 2016.
Photo: Kim Mosier

Summary and Conclusions (Cont')

- Typical swales can reduce runoff volume, TSS & metal loads
- A method has been developed to estimate annual infiltration performance of swales, most of which occurs on side slope
- IESF check dams have the potential to reduce dissolved phosphorus and dissolved metal loads

Heavy Rain in Central Indiana on June 15, 2016.
Photo: Kim Mosier

Thank you for your attention!

Questions?

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Photo Source: roads.Maryland.gov

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