Maintenance Considerations Comparison of BMP Maintenance Cost, Labor Demands, and System Performance

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UNIVERSITY OF NEW HAMPSHIRE
STORMWATER CENTER

The Maintenance Myth

Imagine the Ultimate System…

But we design things to be low maintenance!

Critical components of a best- case scenario:

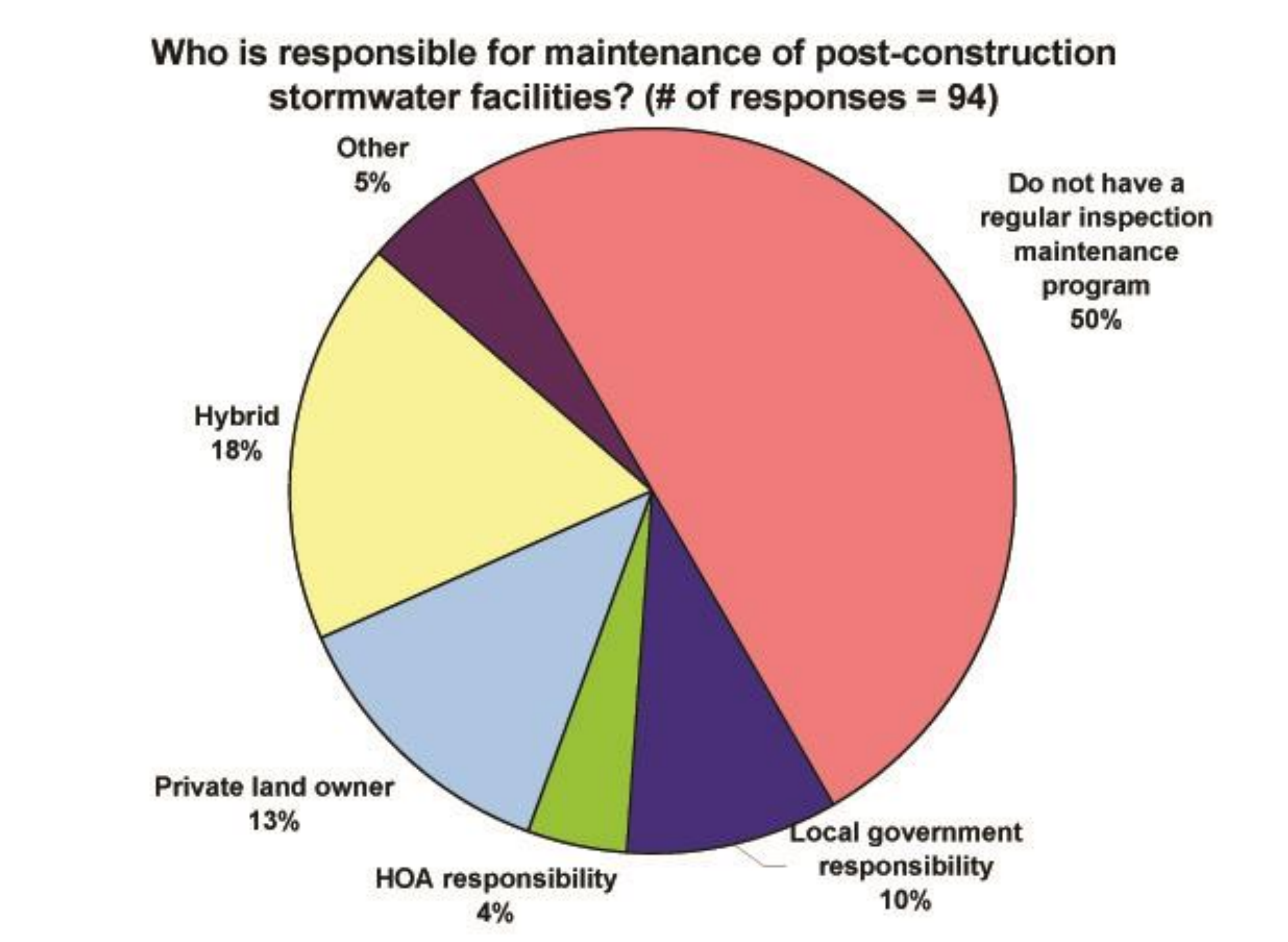
1. Appropriate Design
2. Installation

…. Then Maintenance

1,000 Pound Gorilla

Who has primary responsibility for maintenance?

- local governments or public agencies?
- States and the Federal Governments?
- Private property owners and associations?


Who is responsible for maintenance of post-construction stormwater facilities? (# of responses = 94)
Other 5%
Do not have a regular inspection maintenance program 50%
Hybrid 18%
Private land owner 13%
HOA responsibility 4%
Local government responsibility 10%

HWG, 2011

Maintenance Complexity is defined as:

Minimal	Simple
Stormwater Professional or Consultant is seldom needed	Stormwater Professional or Consultant is occasionally needed
Moderate	**Complicated**
Stormwater Professional or Consultant is needed half the time	Stormwater Professional or Consultant is always needed

Erickson, et al, 2010

Reactive

Episodic maintenance, cheap in short term, expensive in the long term

Periodic/Predictive

Science basis, schedulable activities, more cost effective

Proactive

Cost effective, preventative operations

+ ($) –

Adapted from Reese, A.J., Presler, H.H., 2005

What is Maintenance

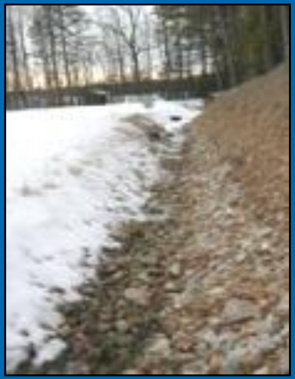
- Often Maintenance only occurs when there is failure
- There is a perception that LID systems require more maintenance
- Some claim LID systems fail and will require expensive repairs
- Our current practices have a high degree of failure and significant cost impacts—however we are familiar with it

Stormwater Systems Studied

Conventional Systems

Detention Basin

Retention Pond



Stone Swale

Veg Swale

Low Impact Development Systems

Porous Asphalt

Gravel Wetland

Sand Filter

Bioretention Unit (3)

Uncategorized Maintenance

- Crack sealing
- Filling pot holes
- Resetting curbs
- Culvert reinforcement/replacement/renewal
- Pipe lining/repair
- Median mulching
- Beautification/soding
- Raking
- Cleaning
- Sweeping

Factors that impact maintenance costs

- Inspection frequency
- Required routine maintenance (frequency and complexity).
- Specialized equipment and speculative unknowns
- Non-routine and rehabilitative maintenance
- Regulatory climate
- Extreme storms
- The fudge factor…


Brian

Stormwater Maintenance
Tools of the trade…

Tools of the trade…

Tools of the trade…

Maintenance Case Studies

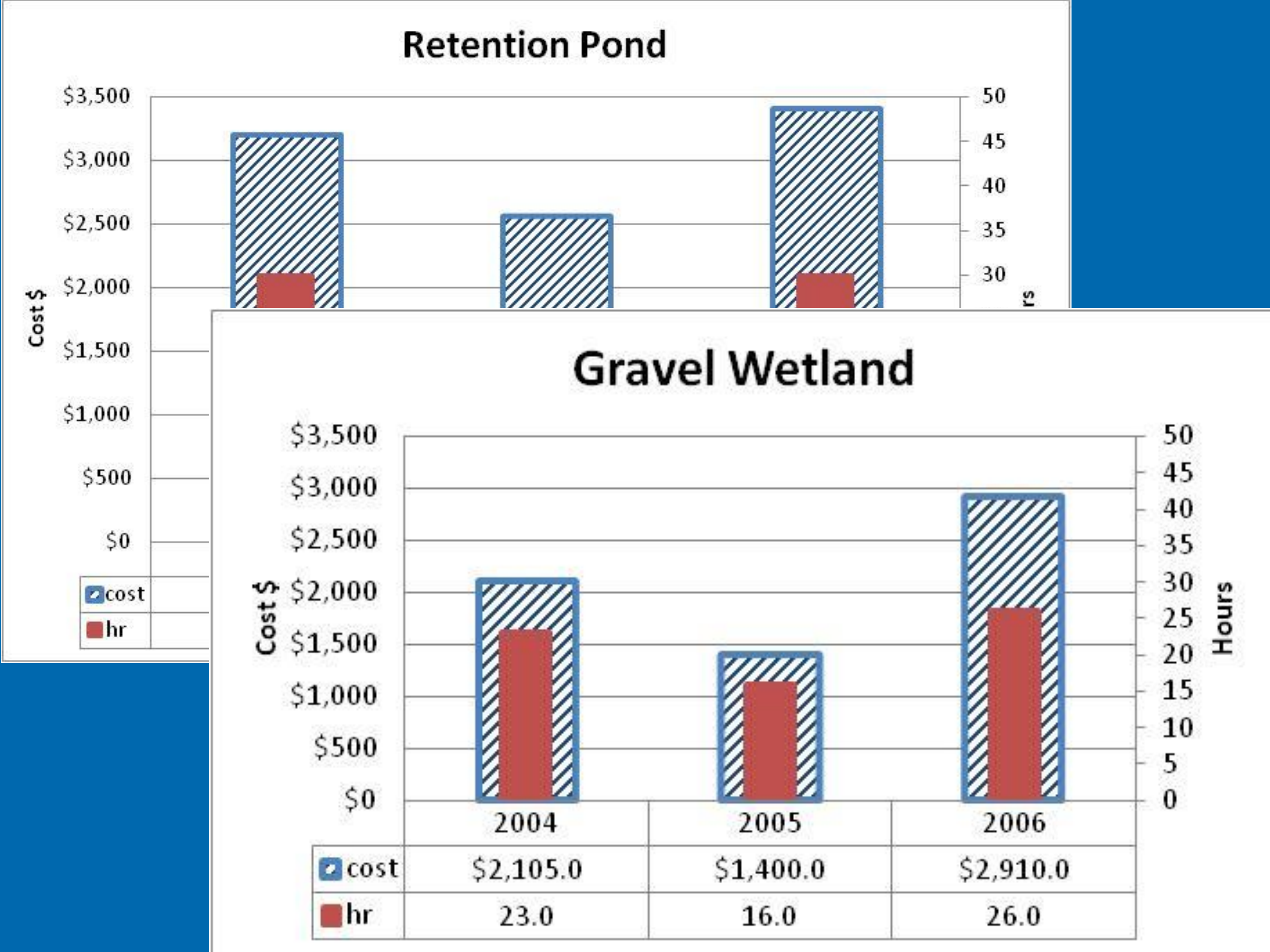
A tale of two raingardens

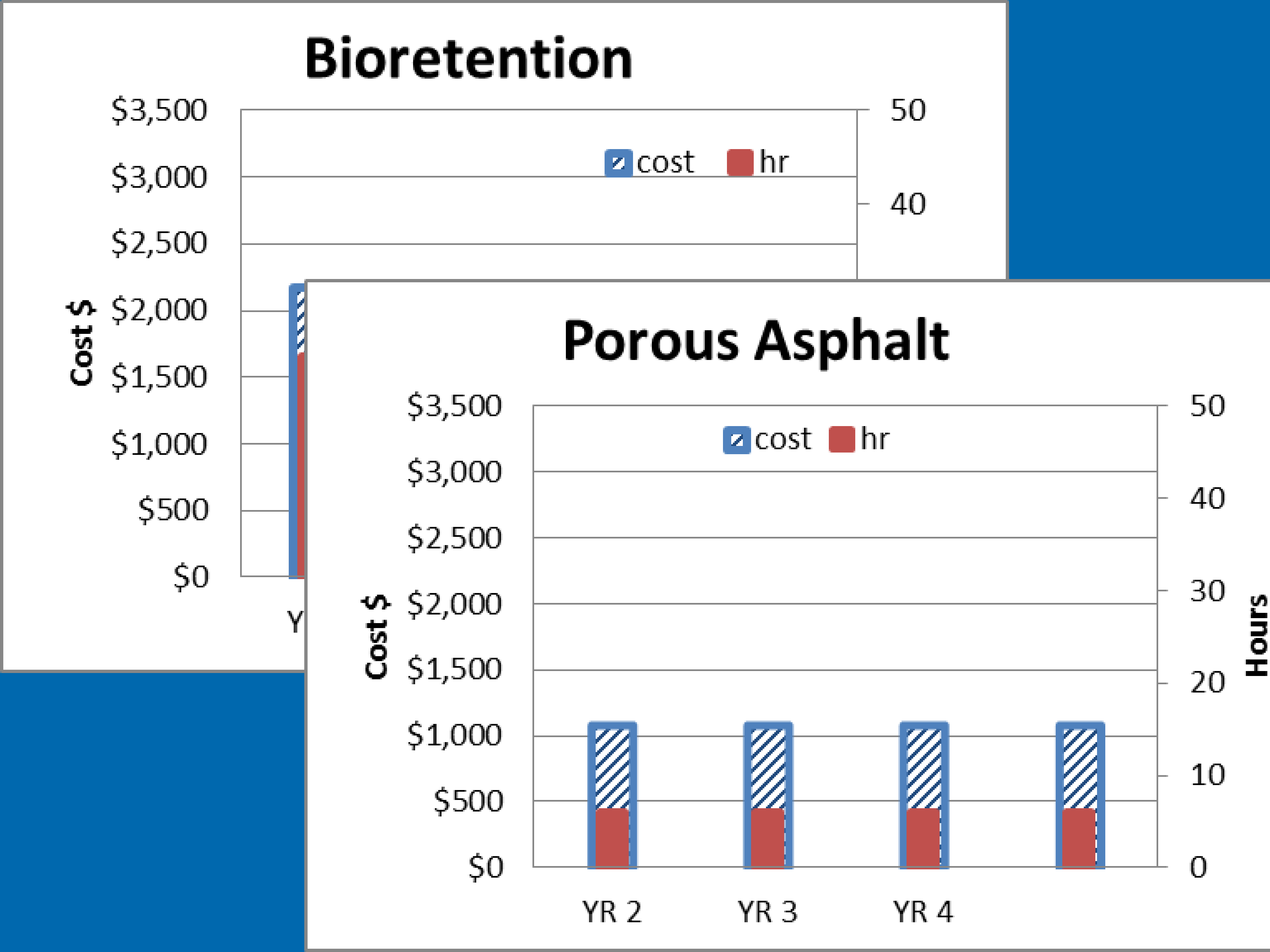
Maintenance solved?

Looking at Costs

Assumptions

Category of Maintenance	Type of Maintenance	complexity	price ($)
Reactive maintenance	Structural Repairs	complicated	135
	Partial Rehabilitation	complicated	135
	Rehabilitation	complicated	135
Periodic/Predictive maintenance	Solids and Debris Removal	moderate	115
	Inspection	simple	95
	Mowing	minimal	75
	Vegetation Management	minimal	75
Proactive maintenance	Pavement Vacuuming	moderate	115
	Erosion control & bank stabilization	simple	95

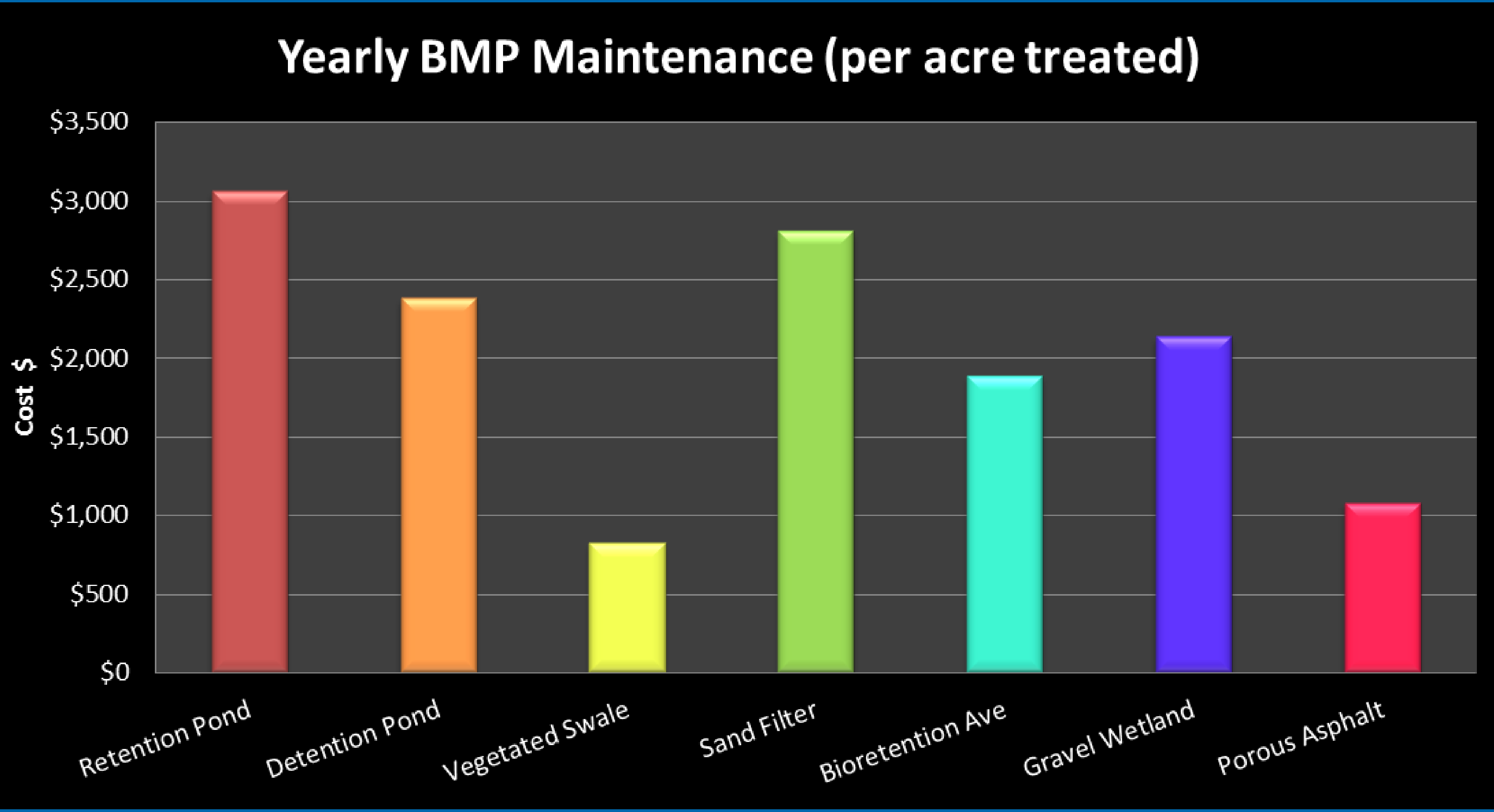

Retention Pond
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
cost
hr
Gravel Wetland
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
25
20
15
10
5
0
Hours
2004
2005
2006
cost $2,105.0 $1,400.0 $2,910.0
hr 23.0 16.0 26.0

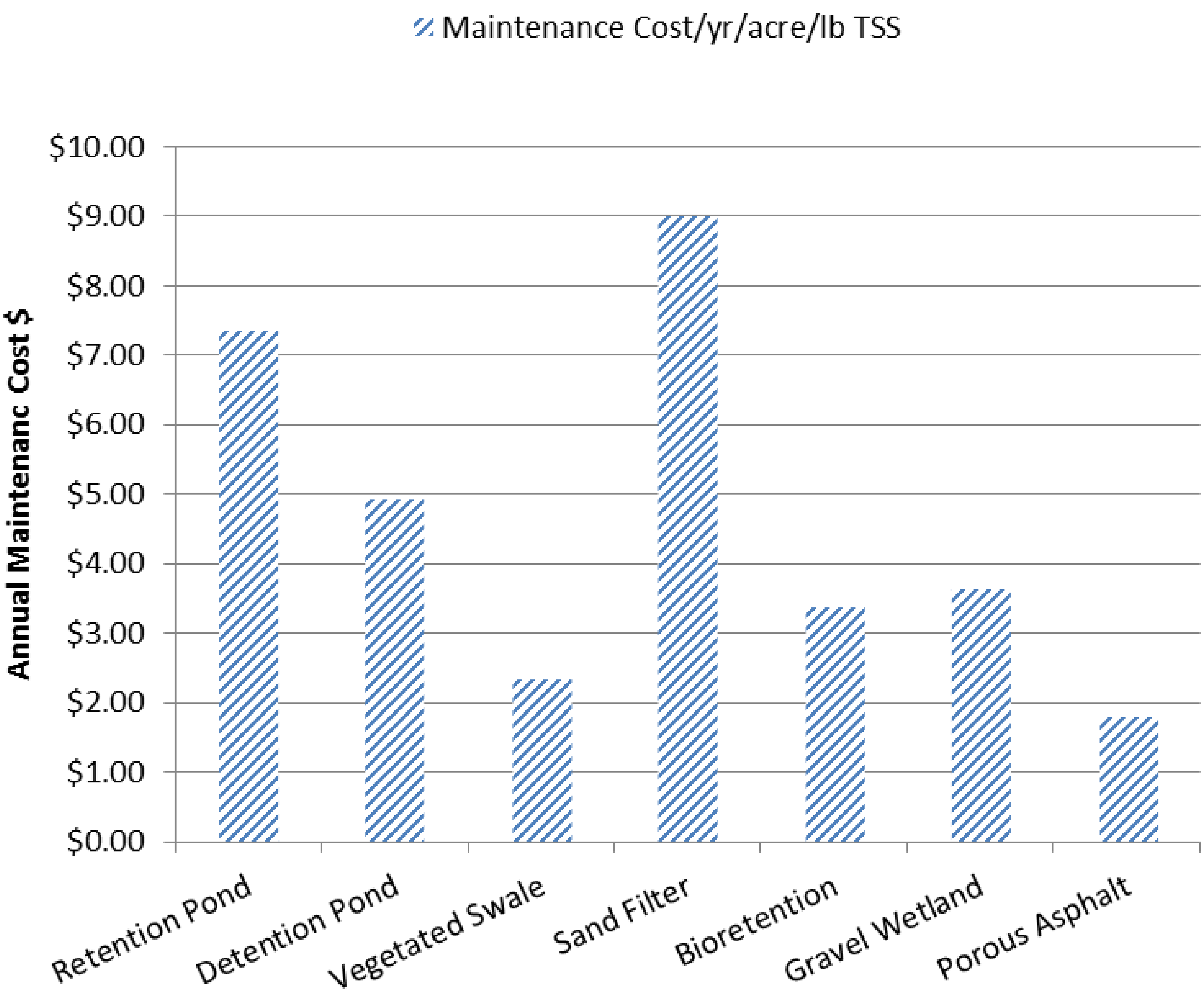


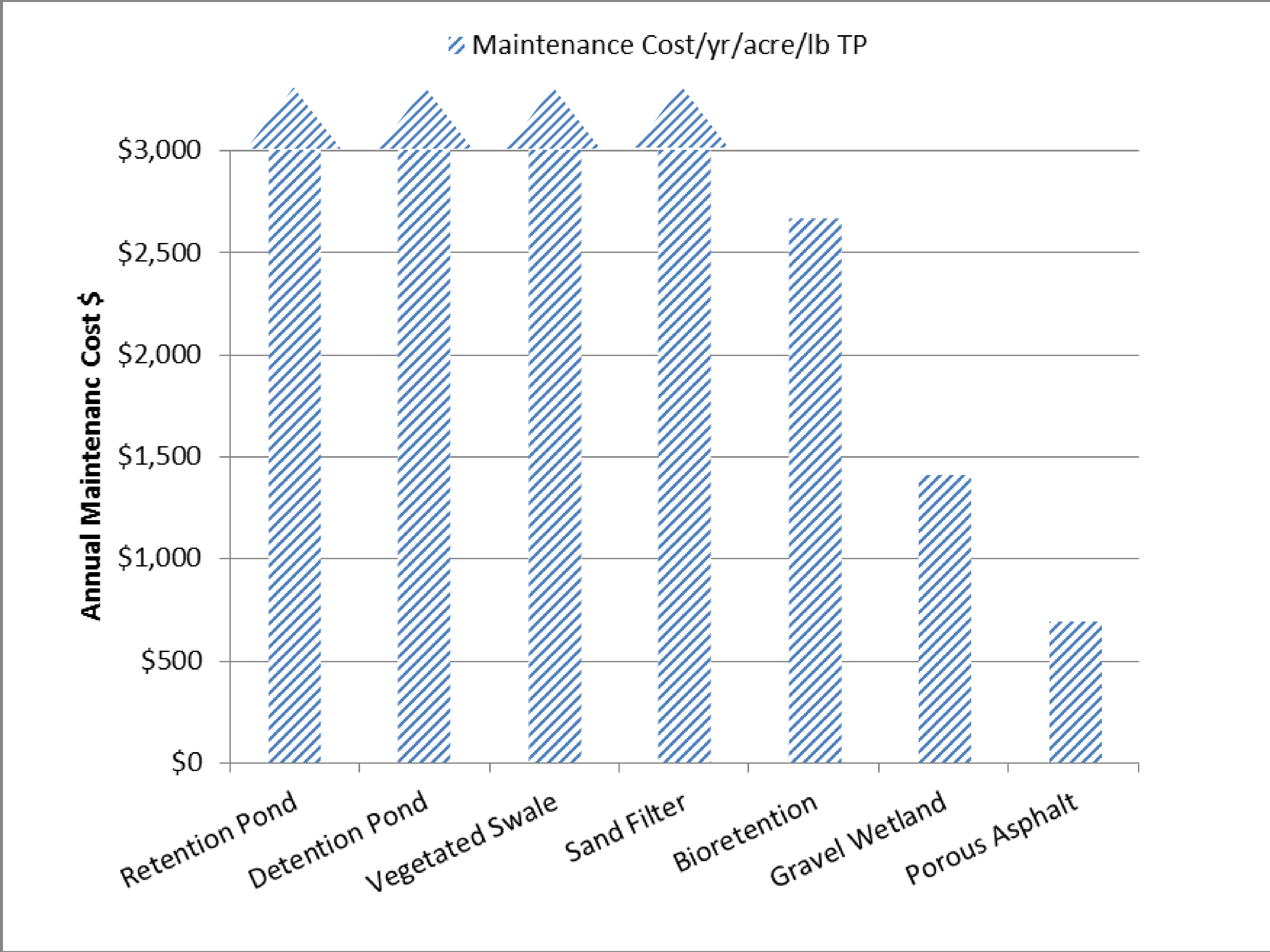
Bioretention
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
40
cost
hr
Porous Asphalt
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
40
30
20
10
0
Hours
cost
hr
YR 2
YR 3
YR 4

Economics of Installation vs Maintenance Costs, normalized by area

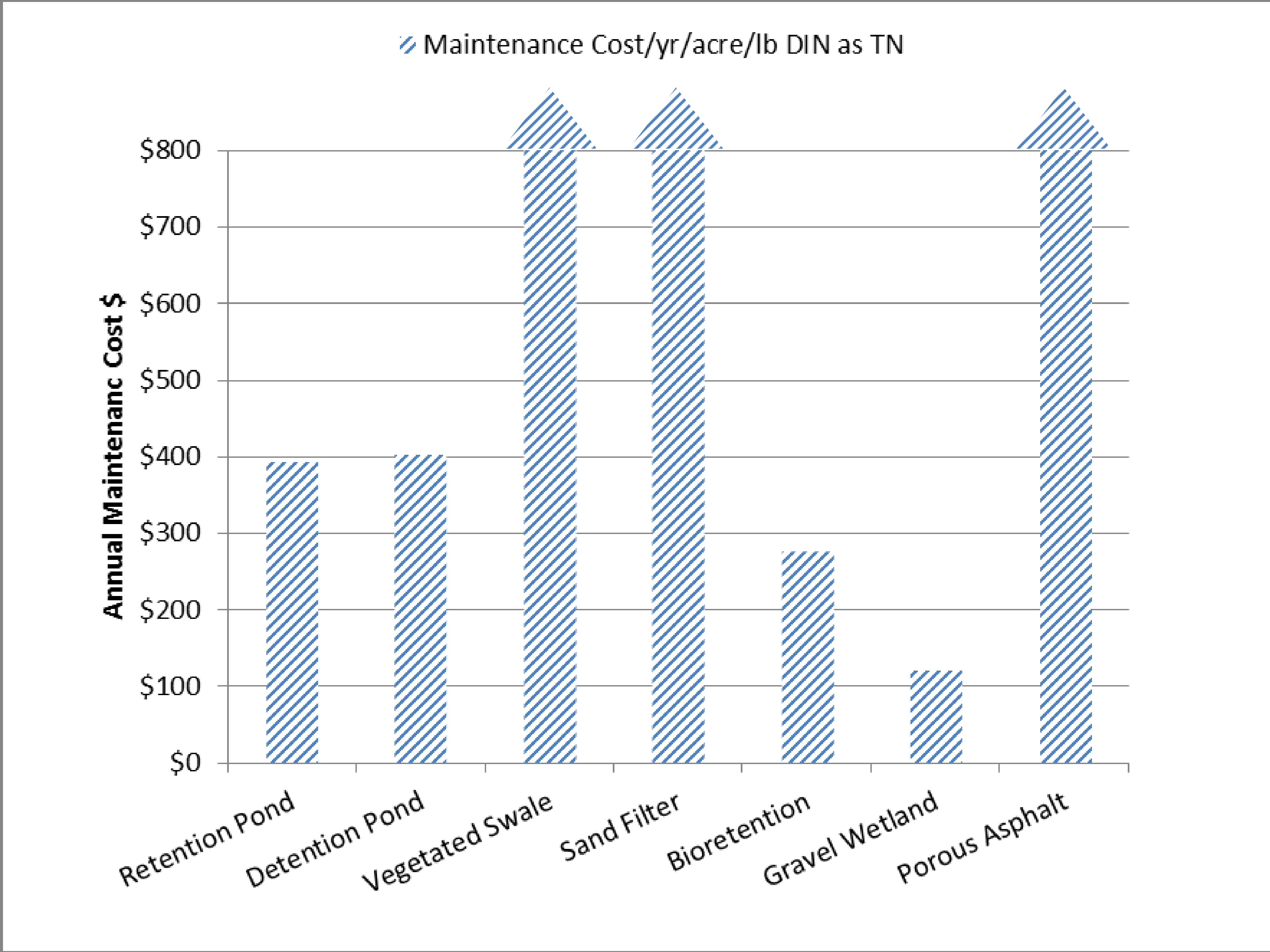
Parameter	Vegetated Swale	Wet Pond	Dry Pond	Sand Filter	Gravel Wetland	Bioretention	Porous Asphalt
Capital Cost ($)	12,000	13,500	13,500	12,500	22,500	21,550	21,800
Inflated 2012 Capital Cost	14,600	16,500	16,500	15,200	27,400	25,600	26,600
Maintenance and Capital Cost Comparison	17.8	5.4	6.9	5.4	12.8	13.5	24.6
Personnel (hr/yr)	9.5	28.0	24.0	28.5	21.7	20.7	6.0
Personnel ($/yr)	823	3,060	2,380	2,808	2,138	1,890	380
Subcontractor Cost ($/yr)	0	0	0	0		0	700
Total Operational Cost ($/yr)	823	3,060	2,380	2,808	2,138	1,890	1,080
Operation/Capital Cost (%)	6%	19%	14%	18%	8%	8%	4%


Yearly BMP Maintenance (per acre treated)
Cost $
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention Ave
Gravel Wetland
Porous Asphalt


Maintenance Cost/yr/acre/lb TSS
Annual Maintenanc Cost $
$10.00
$9.00
$8.00
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention
Gravel Wetland
Porous Asphalt



Maintenance Cost/yr/acre/lb TP
Annual Maintenanc Cost $
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention
Gravel Wetland
Porous Asphalt



Maintenance Cost/yr/acre/lb DIN as TN
Annual Maintenanc Cost $
$800
$700
$600
$500
$400
$300
$200
$100
$0
Retention Pond
Detention Pond
Vegetated Swale
Sand Filter
Bioretention
Gravel Wetland
Porous Asphalt

Periodic/Predictive Maintenance

+ Solids or debris removal
+ Routine inspection
+ Mowing
+ Planned vegetation removal

Proactive Maintenance

+ Street cleaning and vacuuming
+ Snow removal
+ Erosion and sediment control
+ Reseeding

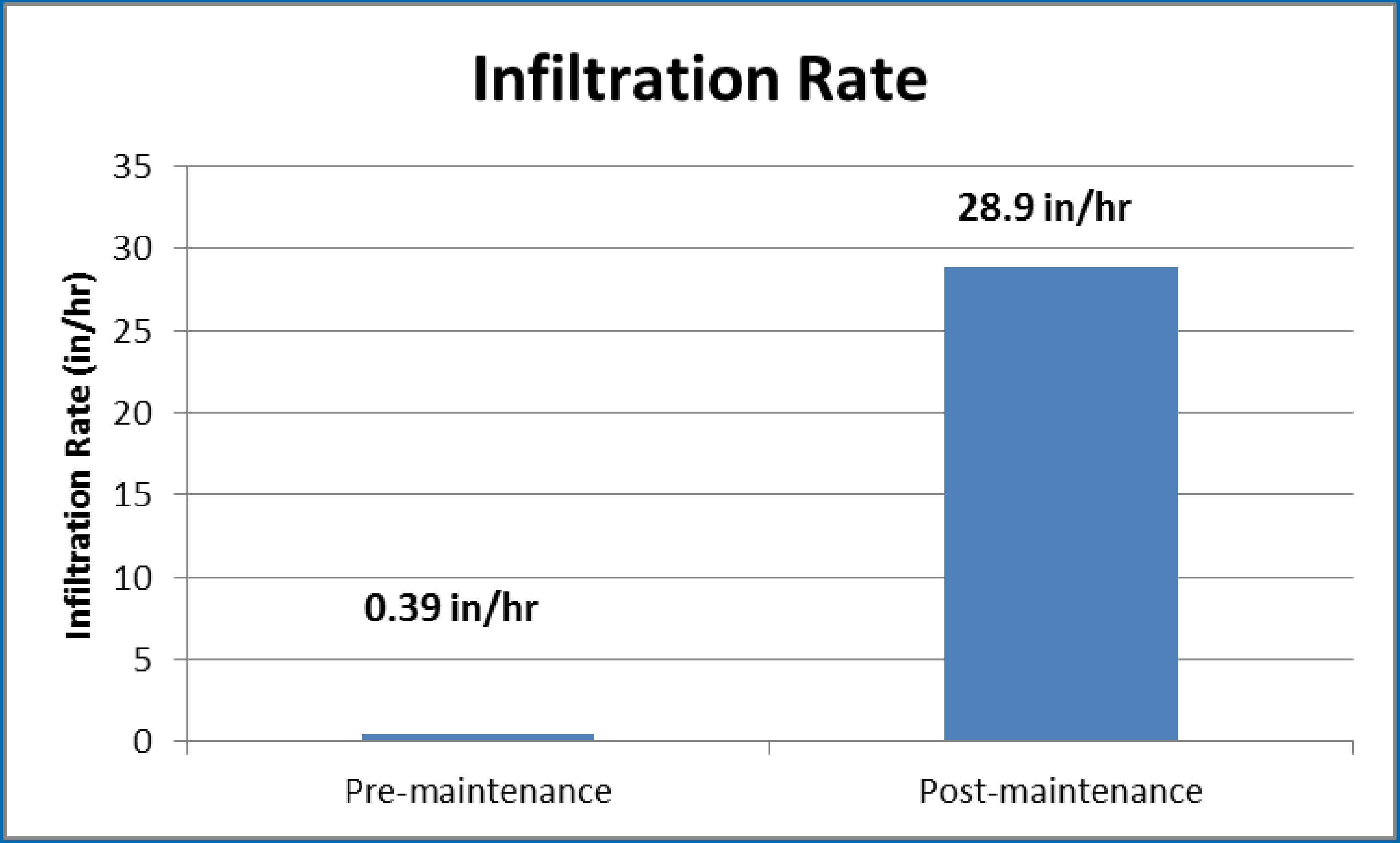
Reactive Maintenance

- Outlet repair
- Redesign for erosive blowouts
- Massive vegetation removal
- Clogged outlet structures
- Structural repairs or rehabilitation

Bioretention/Sand Filter/Tree Filter

- Short term
  - Reseed/replant as necessary
  - Remove excess sediment build-up and trash
  - Invasives control
  - Watering
- Long term
  - Mowing slopes
  - Weeding
  - Sediment and trash removal
  - Clear inlets and outlets
  - Replanting/reseeding

Result of Maintenance



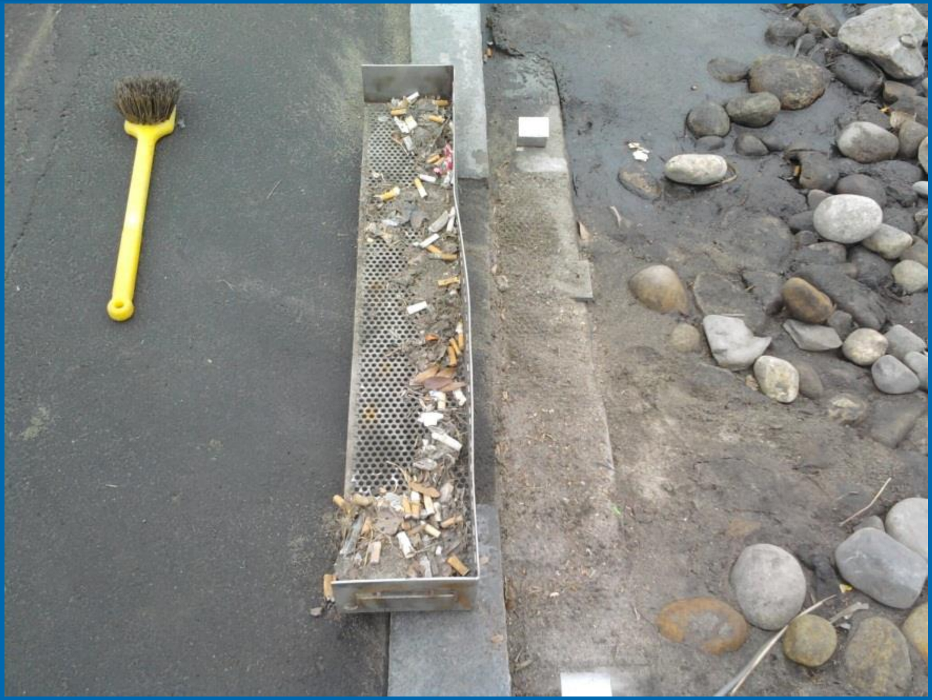
Bioretention Parking Lot Retrofit, Durham, NH

Maintenance Activity	Minimum Frequency	Estimated Time Commitment	Number of Employees
Inspection	2 times per year	30 minutes taking time to fill out checklist in UNHSC document[1]	1
Clean Pretreatment Trash Screens and Pick Up Trash in system	1 time per month on average	30-60 minutes per visit	1
Spring Cleaning	1 time per year	4 hours	2

Total personnel hours per year: 16-21 hours

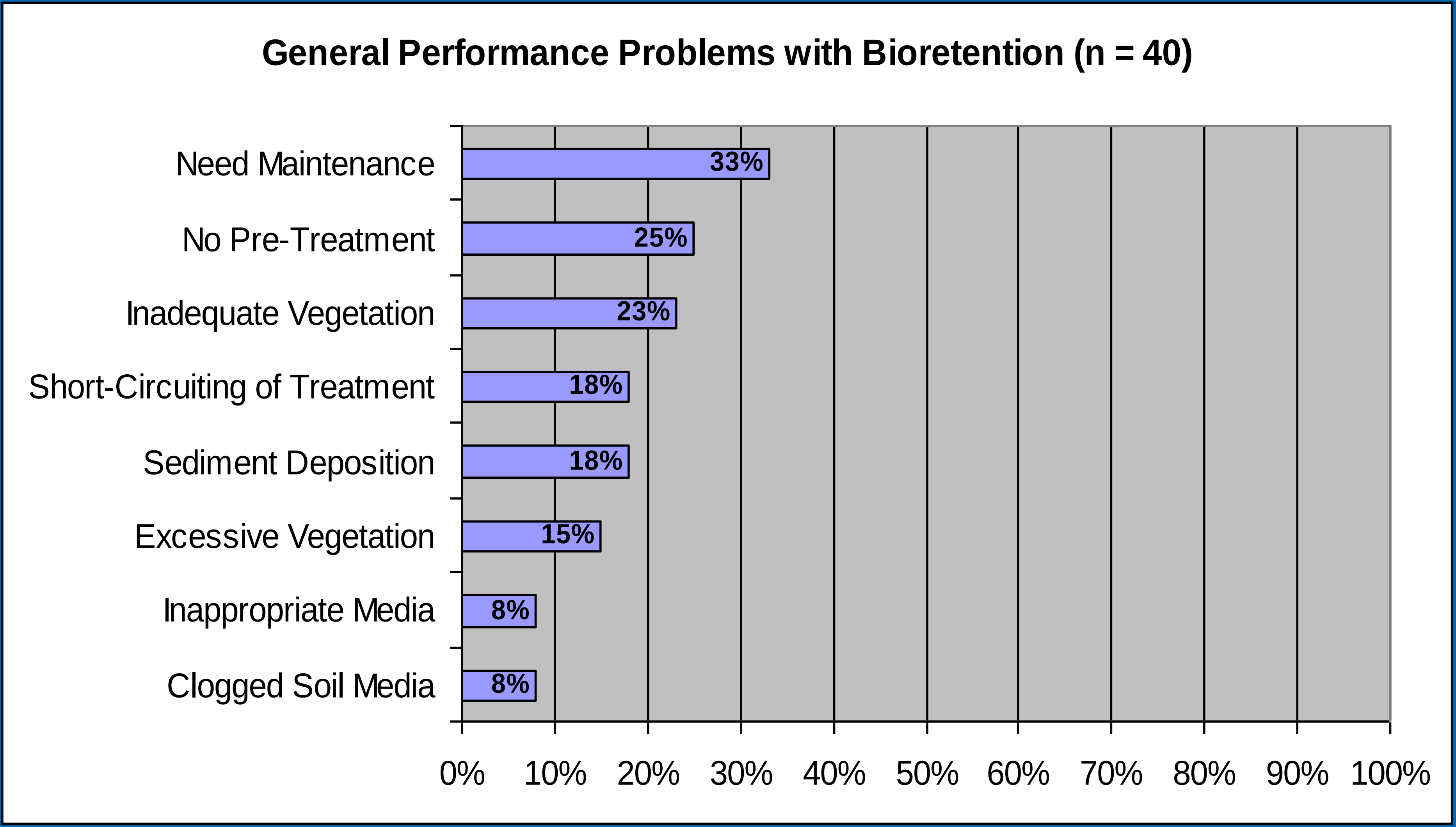
Estimated $1,500 – $2,000 (30,000 sf of IC Treated)

Pollutant (per year)	Amount
TSS	179 lbs.
Cigarette Butts	4,392
Misc. Trash	752



Some Problems are Vexing

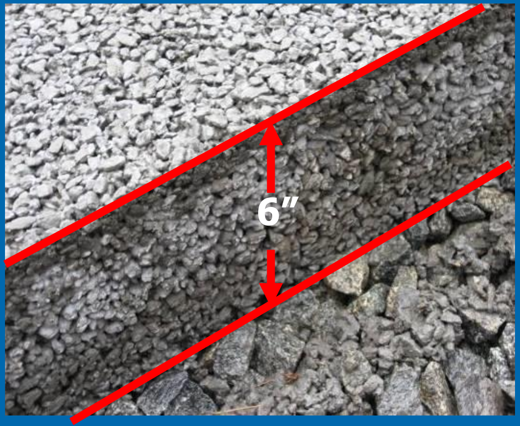
Performance Issues Observed in Field



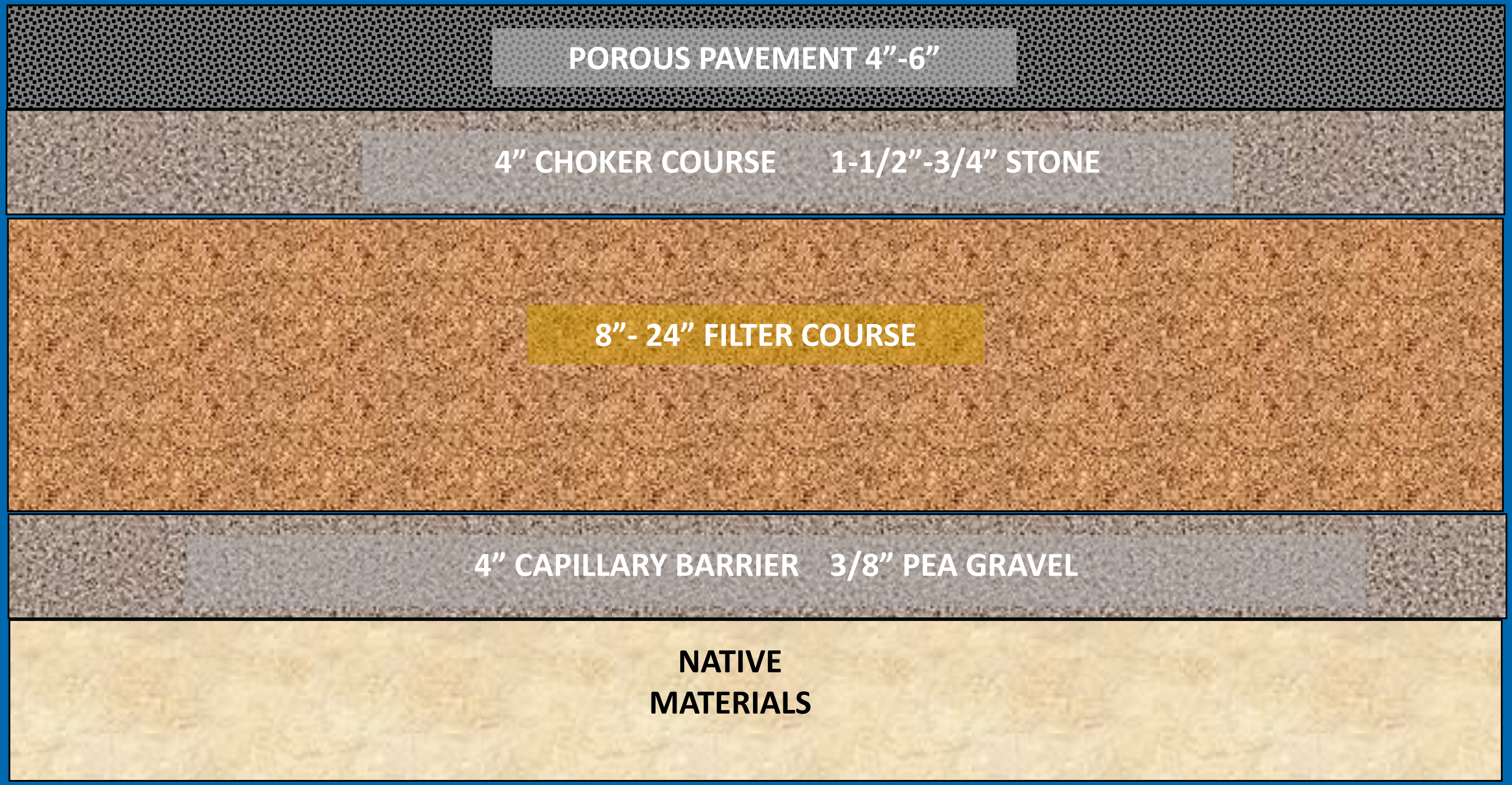
Permeable Pavements

Porous/Permeable Pavements



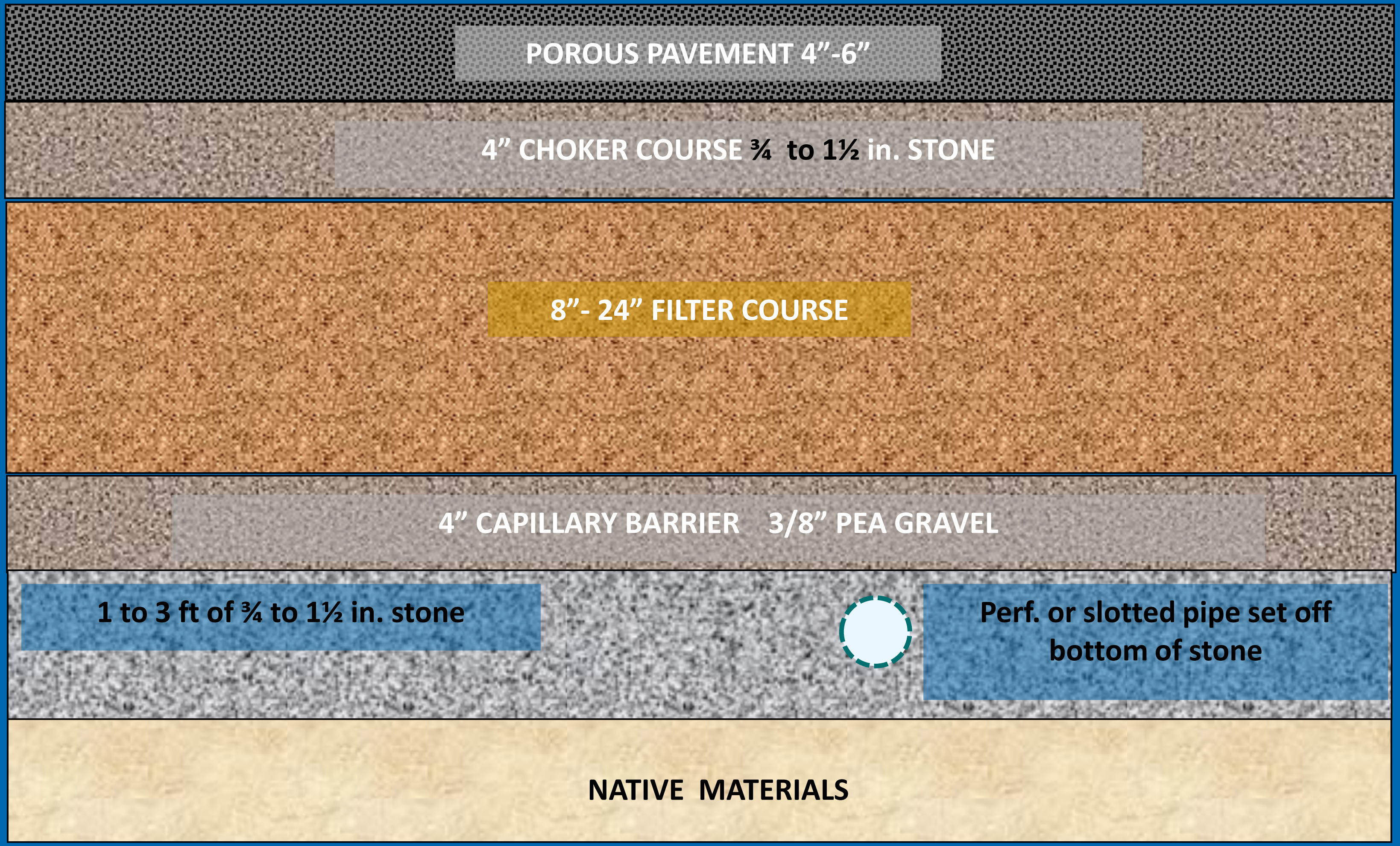



Typical Porous Pavement Parking Lot System Cross-Section – *well draining soil*



- Diverged from design guidance for use of filter coarse for improved water quality function
- Common reservoir base is 1-3” minus bank run sand and gravel

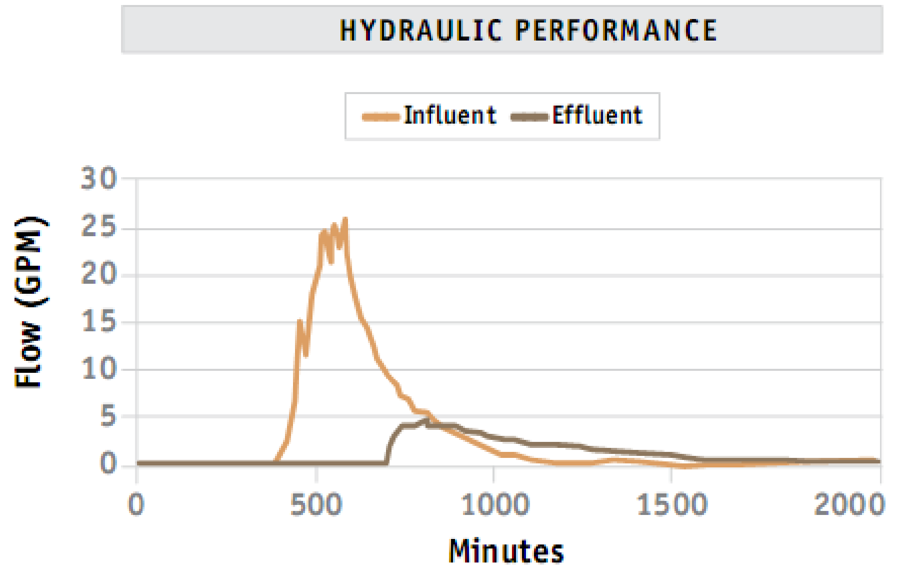
Typical Porous Pavement Parking Lot System Cross-Section – *poor draining soil*



- Use stone at base to store water and infiltrate between storms, drain pipe to remove excess treated water.

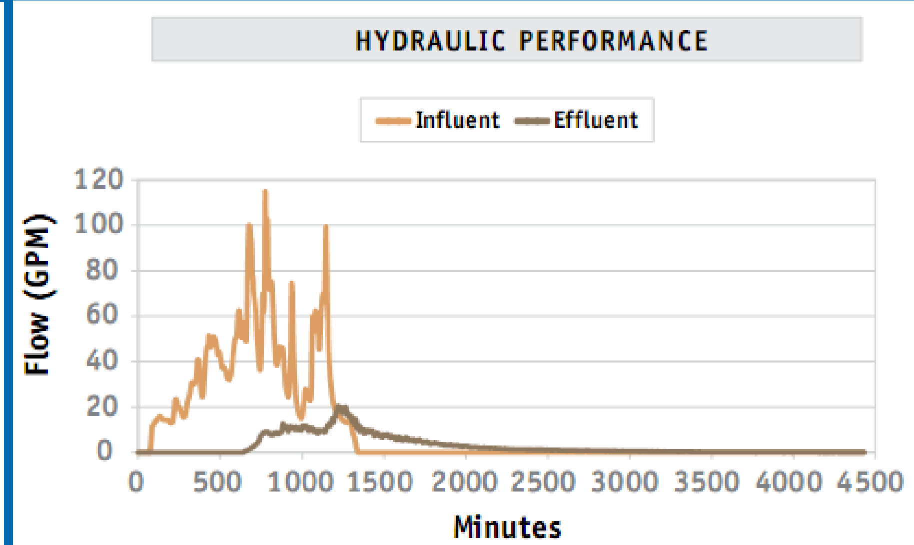
Hydraulic Performance of Porous Pavements

Porous Asphalt (HSG-C)

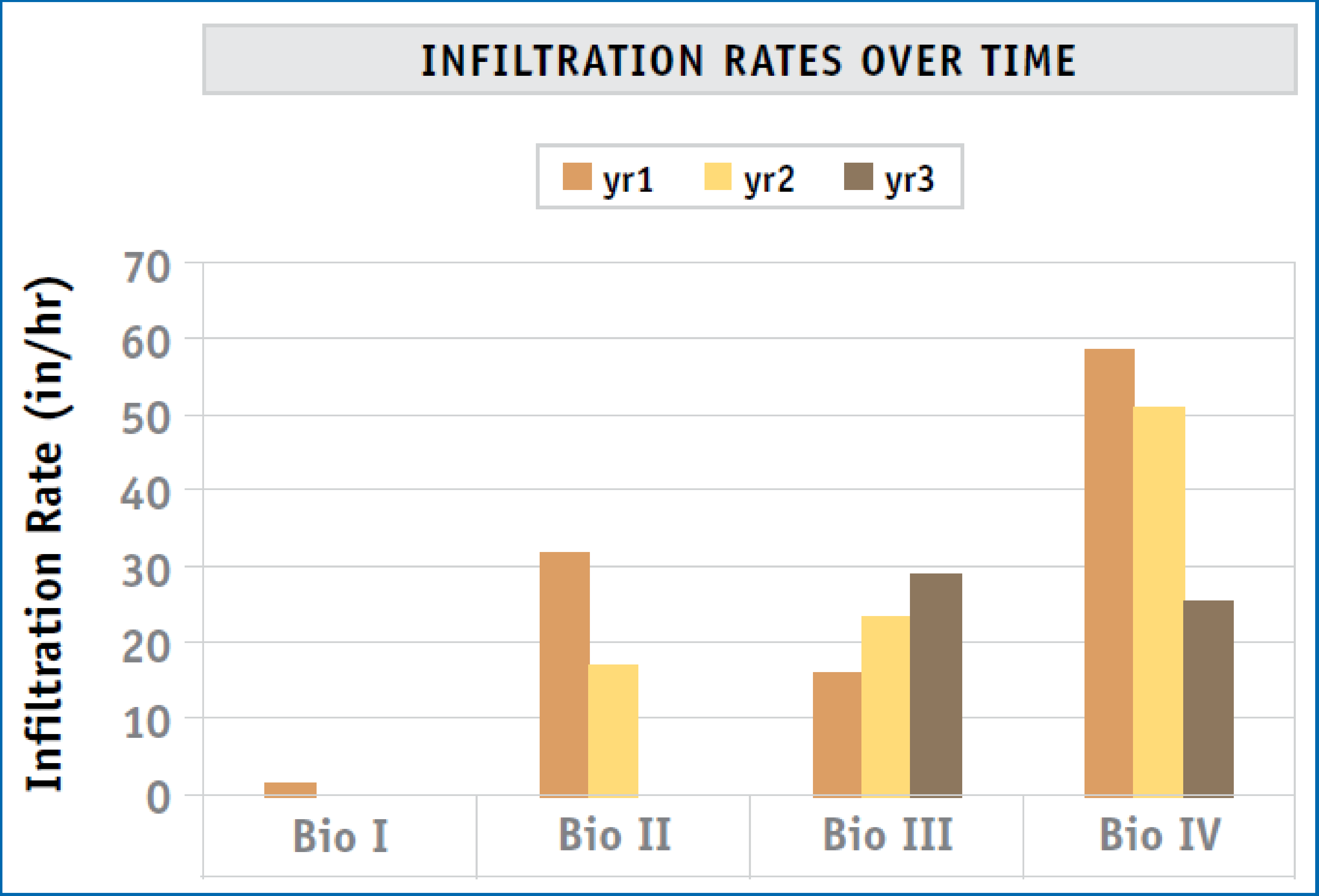


	Winter	Summer	Annual Average
Average Peak Flow Reduction	76%	86%	82%
Average Lag Time (minutes)	1,163	1,375	1,275

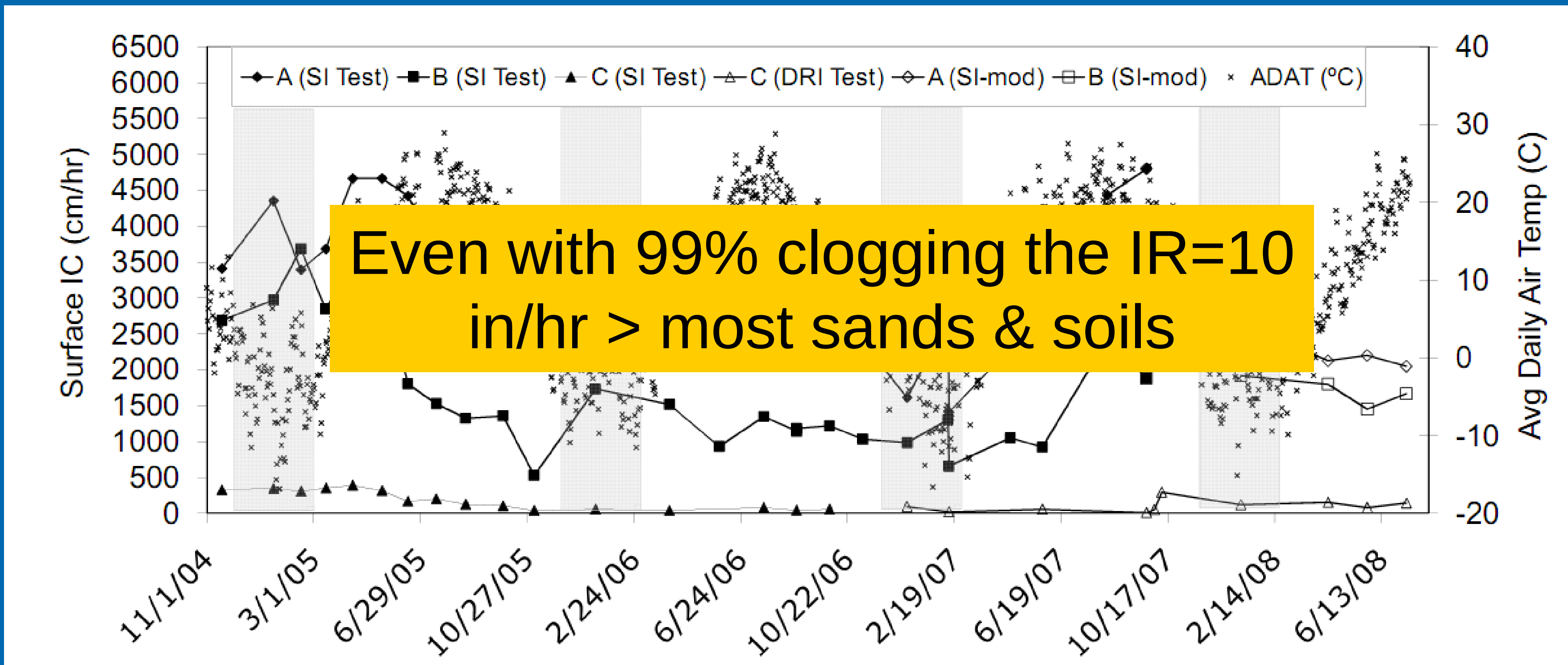
Pervious Concrete (HSG-B)



	Winter	Summer	Annual Average
Average Peak Flow Reduction	88%	97%	93%
Average Lag Time (minutes)	848	1,365	1,144
Average Volume Reduction	91%	98%	95%


INFILTRATION RATES OVER TIME
yr1
yr2
yr3
Infiltration Rate (in/hr)
70
60
50
40
30
20
10
0
Bio I
Bio II
Bio III
Bio IV

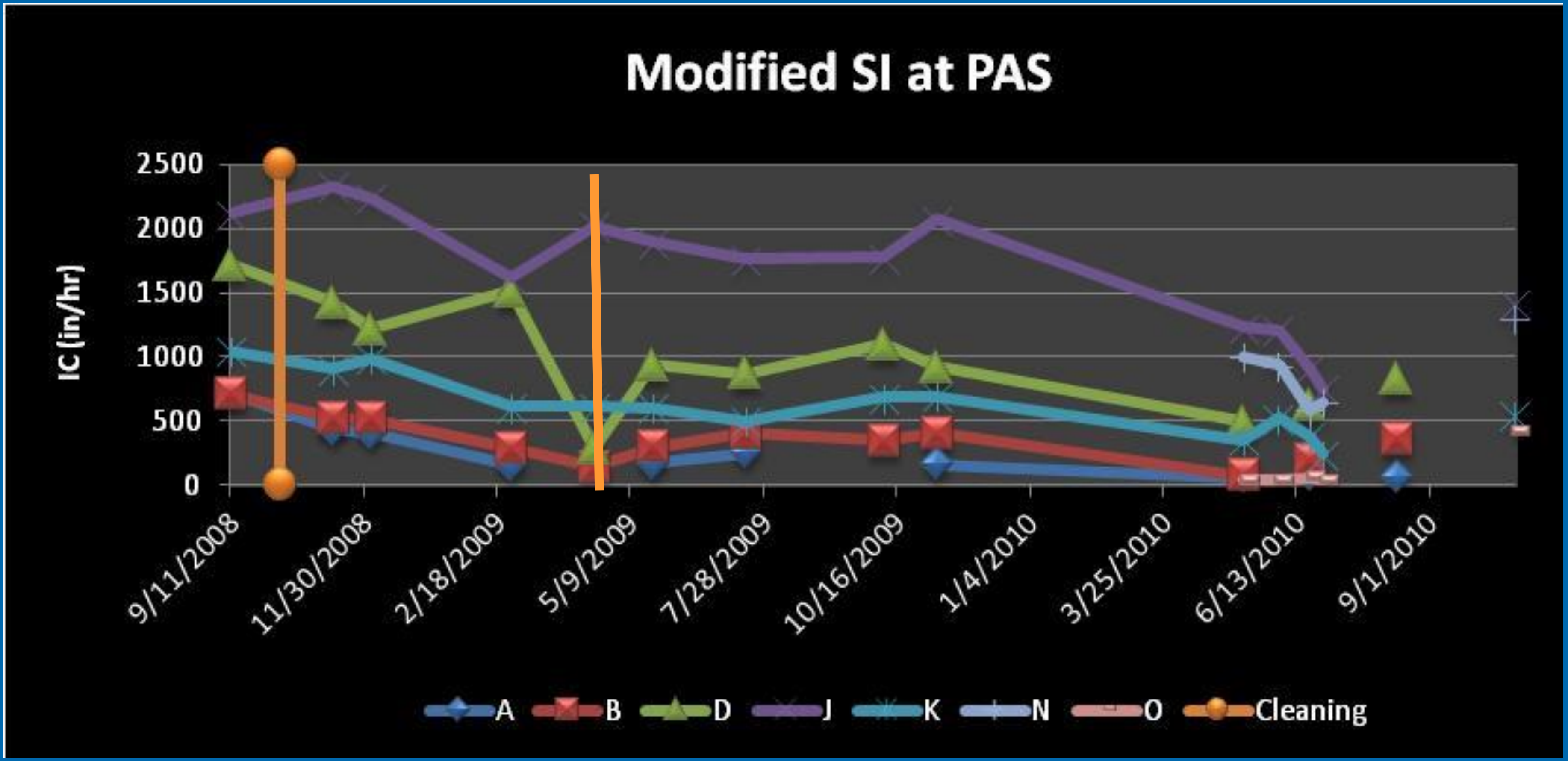
Porous Asphalt Surface Infiltration Rates



Even with 99% clogging the IR=10 in/hr > most sands & soils

- Worst case scenario, no maintenance performed for 3 yrs
- Certain areas have reduced IC (drive lanes) while parking areas remain unchanged
- **Low maintenance sensitivity due to excess infiltration capacity**
- **Clogged areas can drain to adjacent unclogged areas**

Porous Asphalt Surface Infiltration Rates



Permeable Pavements

- Vacuum sweeping
- Broom to dislodge surface debris
- Pressure washer wand (low angle) for clogged areas (surfactant)
- Repair failed areas

Routine Maintenance

Outlet / Catch Basin Inspection

- 1 X per year
- No evidence of blockage
- Good condition, no need for cleaning/repair

Pavement Drainage and Infiltration

- Annual inspections
- Pavement has been cleaned
- Chronic clogging locations have been pressure washed
- Standing water is not evident after rain event

Pavement Condition

- Annual inspection
- Evidence of deterioration
- Cuts or repairs from utilities
- Evidence of improper vehicle load

Repairs and Replacement

- Damage can occur to PA from non-design loads
- Repairs may be needed from cuts for utilities
- Repairs can be made with standard HMA for most damages up to 15% of surface area
- PA can be repaired by heating and rerolling at ~$2000/day for 500’ of trench
- When pavement reaches end of life, it is replaced by milling cleaning and overlay.




Design for Maintenance Avoidance

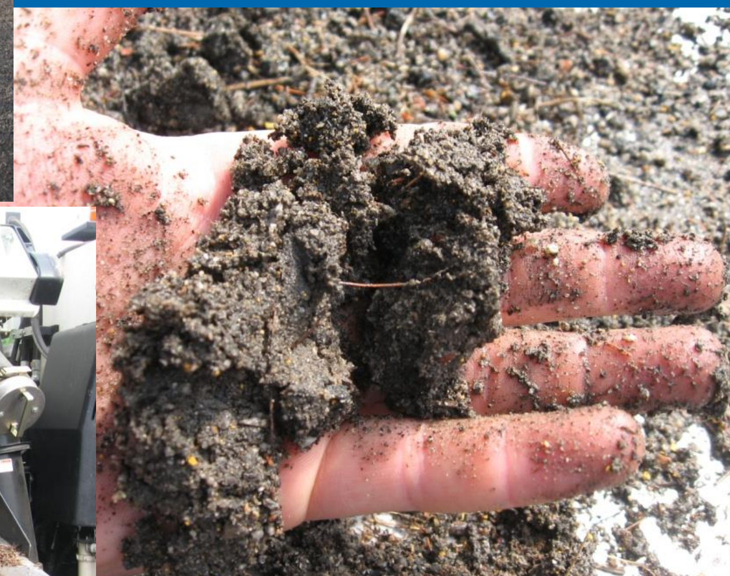
- Avoid run-on from adjacent vegetated areas
- Use of curbs and/or stone edge
- Avoid excessive runoff from adjacent impervious areas
- Avoid areas where tracking on of materials will be expected
- High use areas should consider heavy duty pavement

Pavement Cleaning

- 2-4X/yr minimum, Spring & Fall
- Clean porous pavement to remove sediment and organic debris on the pavement surface via vacuum street sweeper.
- Adjacent non-porous pavement vacuumed
- Clean catch basins (if available)


ELGIN
Whirlwind


BMP
MAINTENANCE
500x

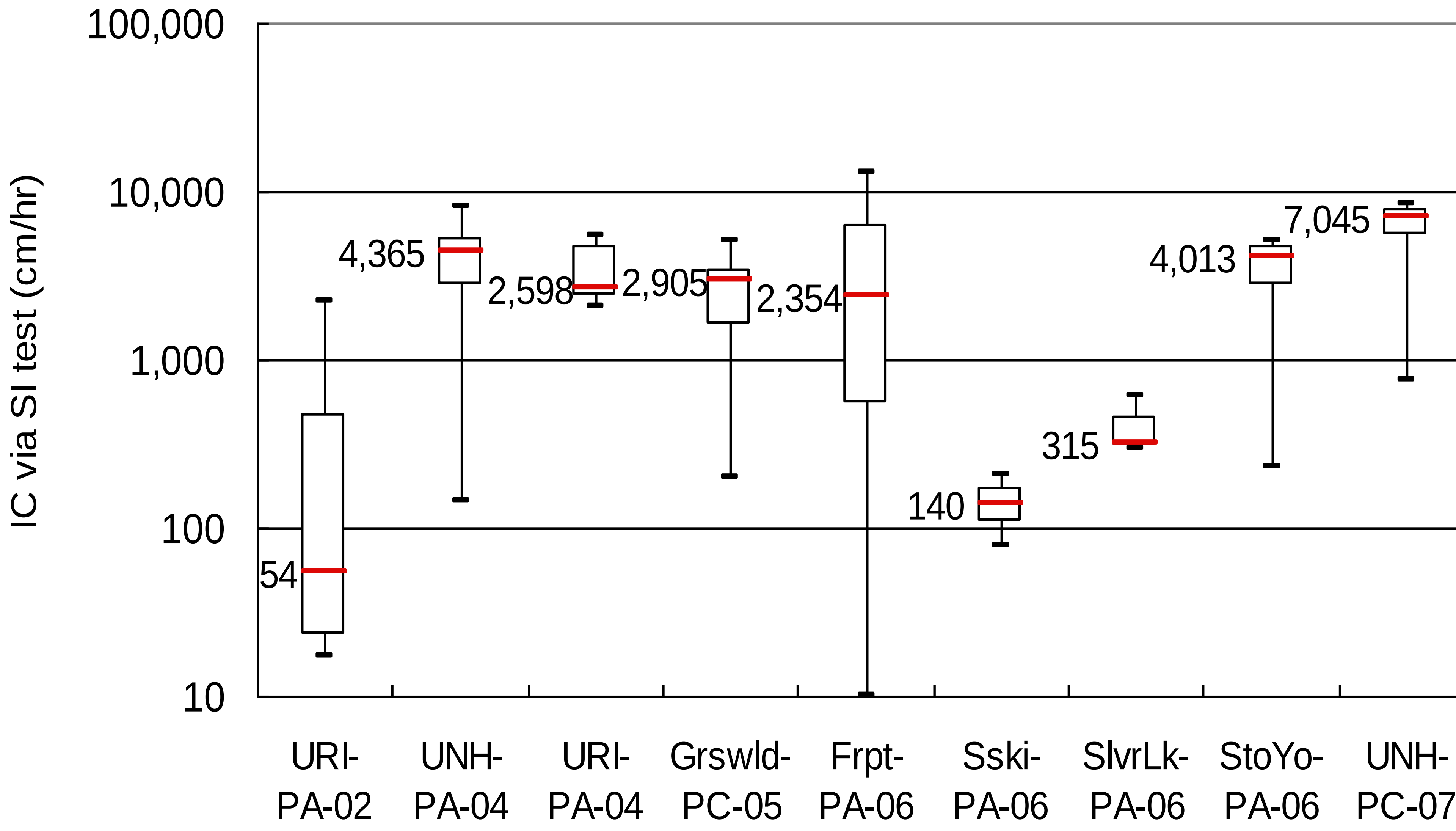


Controlling Run-On

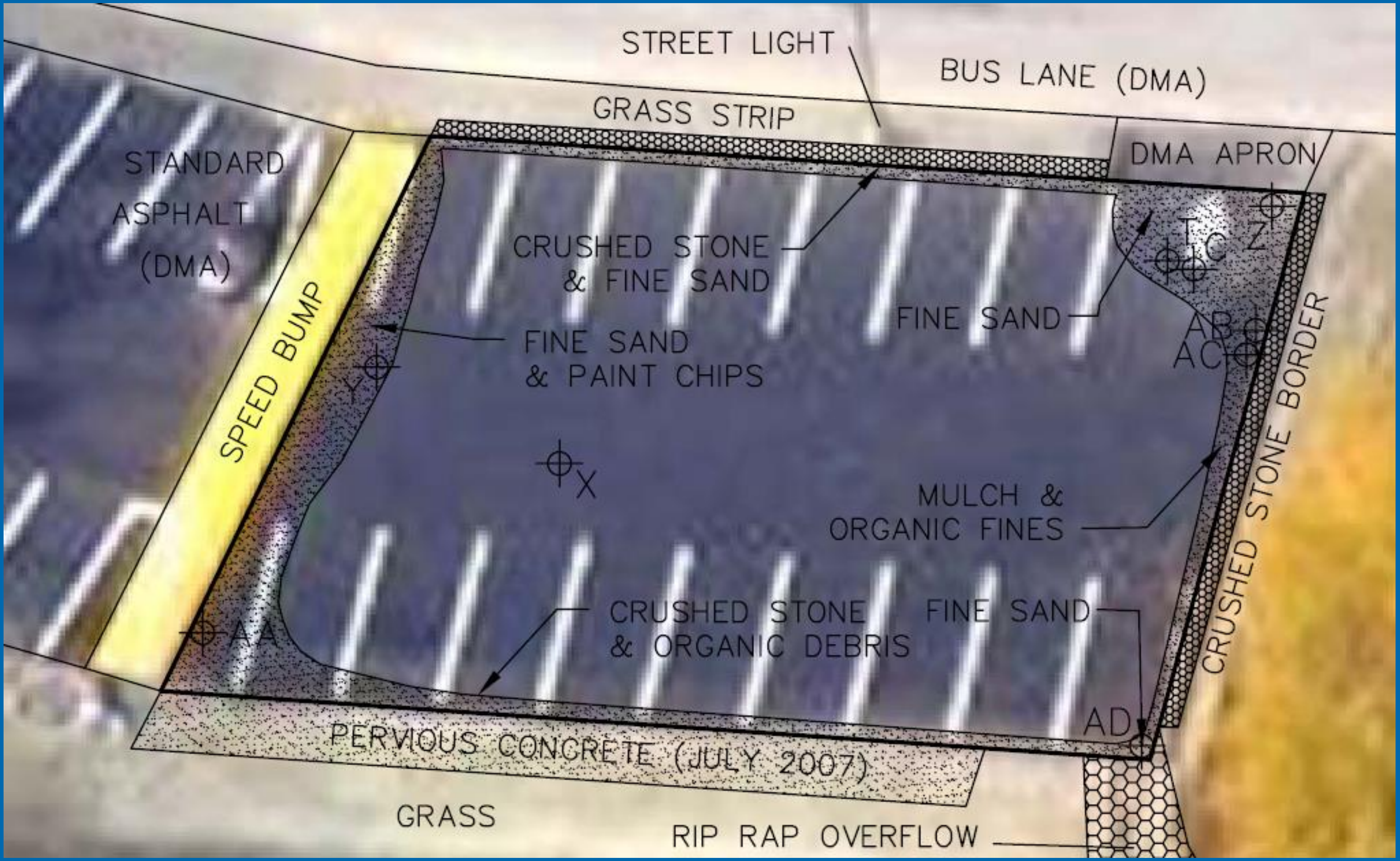
- 2-4 times a year
- Adjacent vegetated areas, inspect for signs of erosion and run-on to porous pavement
- Apply appropriate stabilization measures

Erosion and Sediment Controls Were Removed Too Soon at this Project Site, Causing Sediment-Laden Stormwater Runoff to Temporarily Clog the Porous asphalt Pathway, Campbelltown, PA (Source: CH2M HILL)

Infiltration Capacity by Age

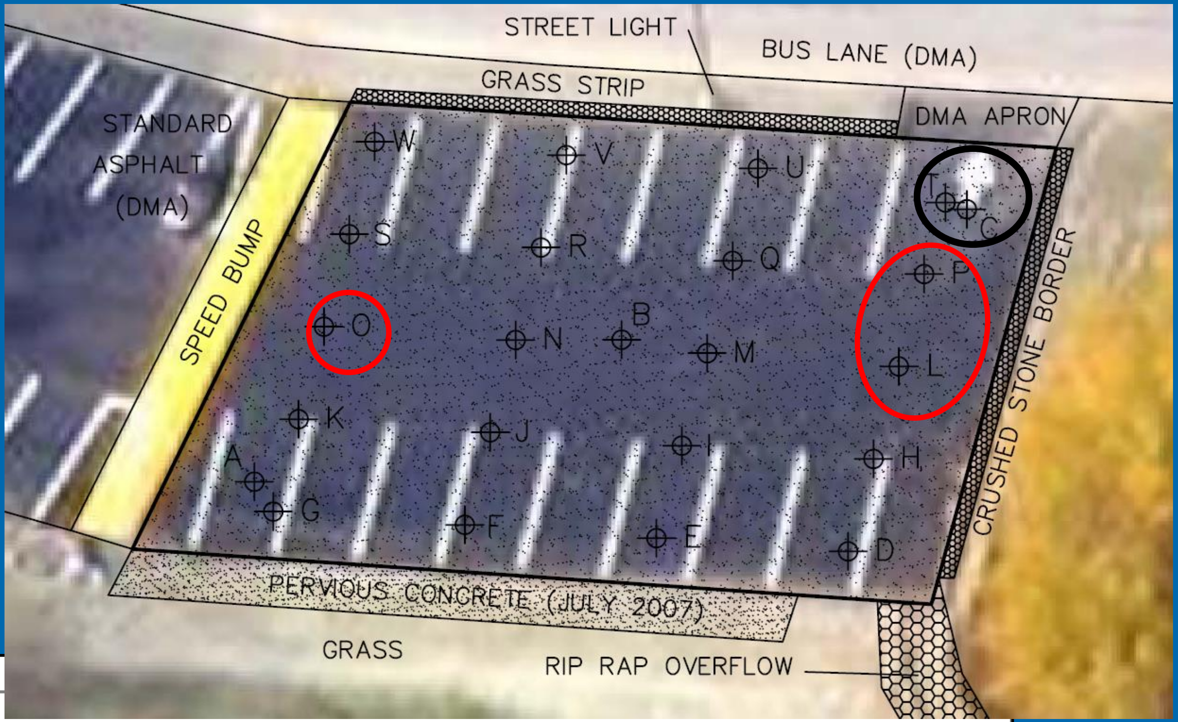


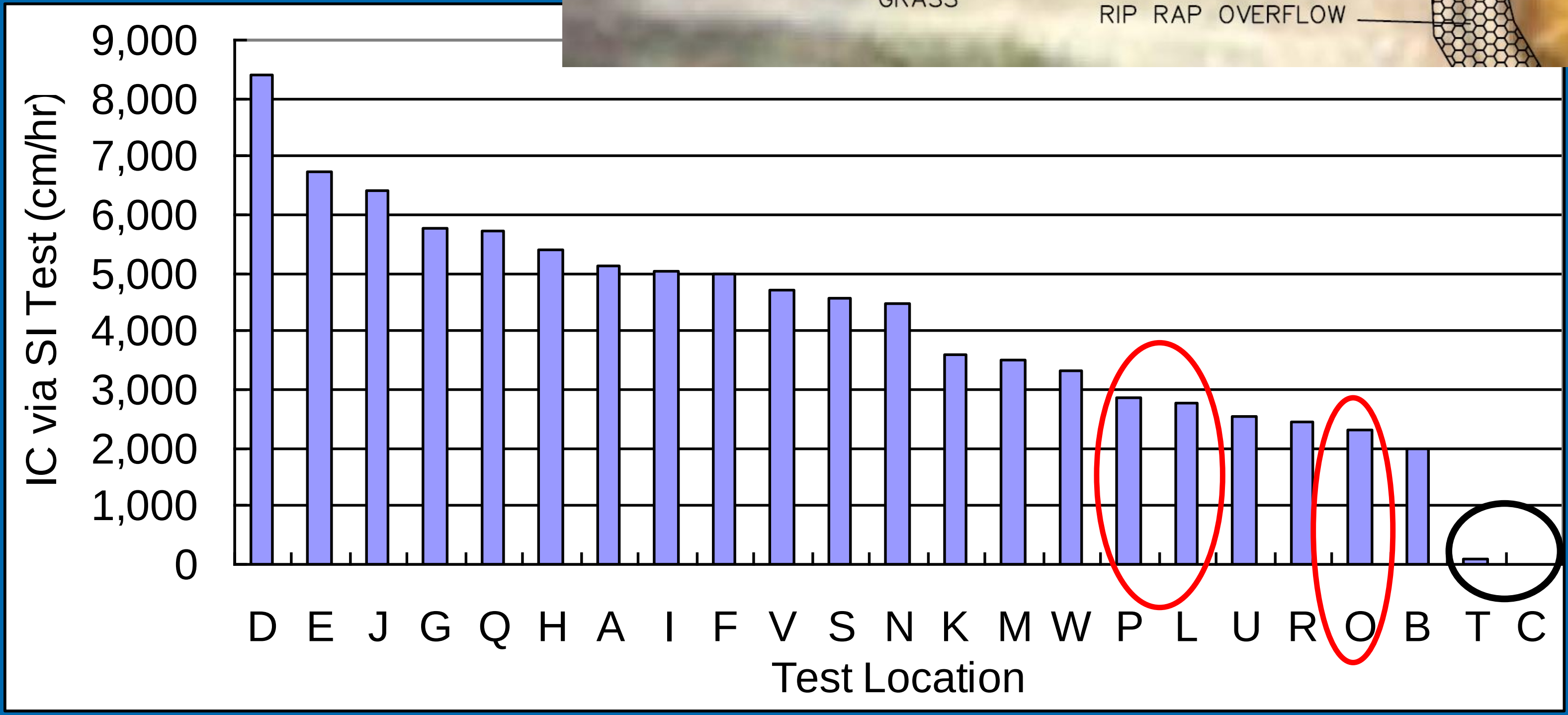
Pre-Tx Extent of Debris/Clogging



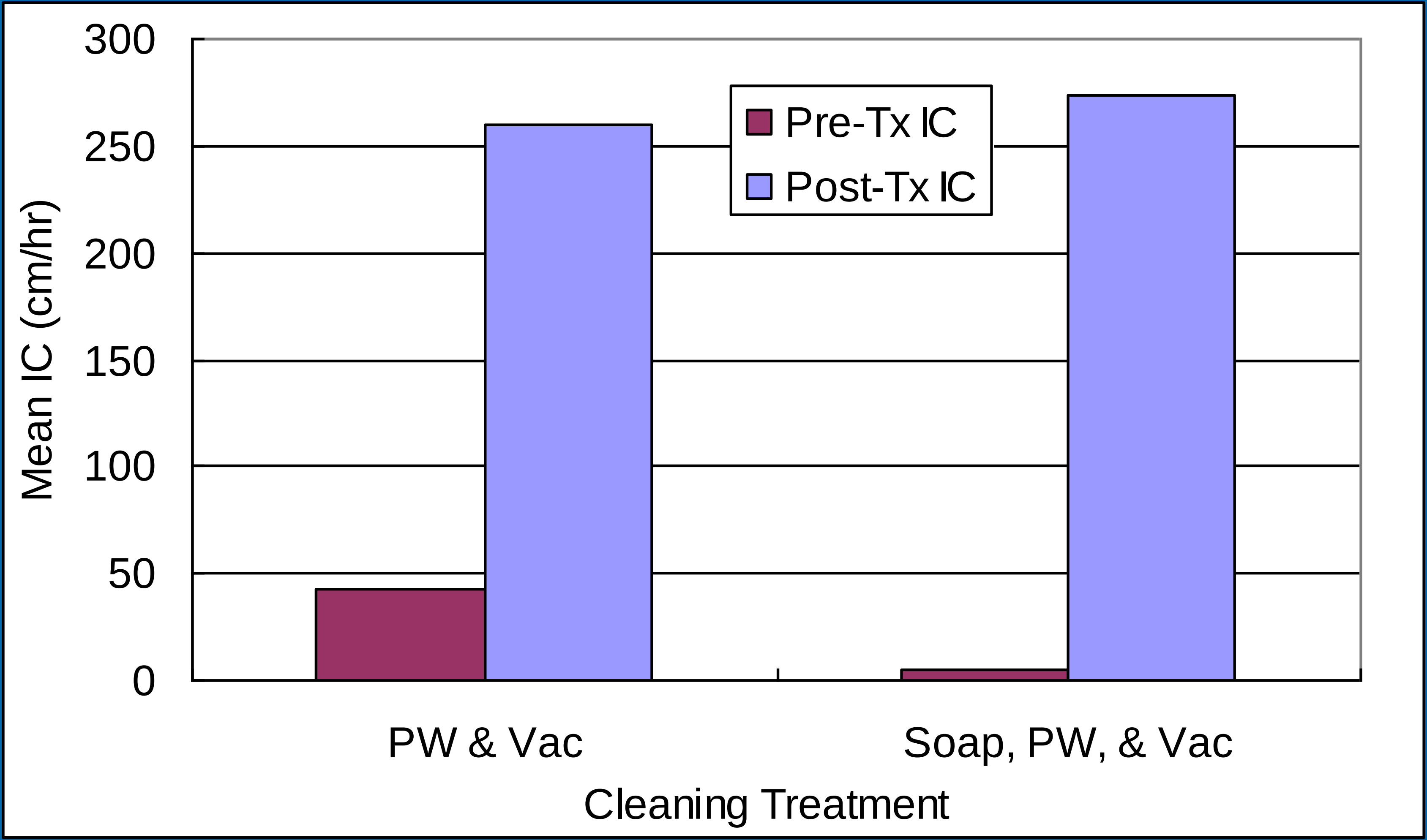
Infiltration capacity via the Pre-Tx DRI test varied from 0 to 53 cm/hr, all effectively clogged when slope is considered.

Pre-Tx Infiltration at Grid Locations





Treatment Effectiveness for Clogged Locations



What is is About Winter That is Different?

- Days are shorter
- Colder
- Vegetation dead or in senescence
- Systems may be frozen
- Snow
- Ice

Tree Filter

Not too Long Ago

Tree Trench


STOP
Lot A
Section 2
Permit
Required
P
Commuter
Faculty/Staff
04/26/2015

Winter Status

What is Winter Maintenance for Conventional Drainage Infrastructure?

- Gutters
- Catch Basins
- Swales
- Ponds
- Storm Sewers

Conventional Systems Winter Maintenance

- Hope it will function until spring
- Hope it does not freeze up
- Clear ice/snow blockages
- De-ice
- Plow
- Snow removal

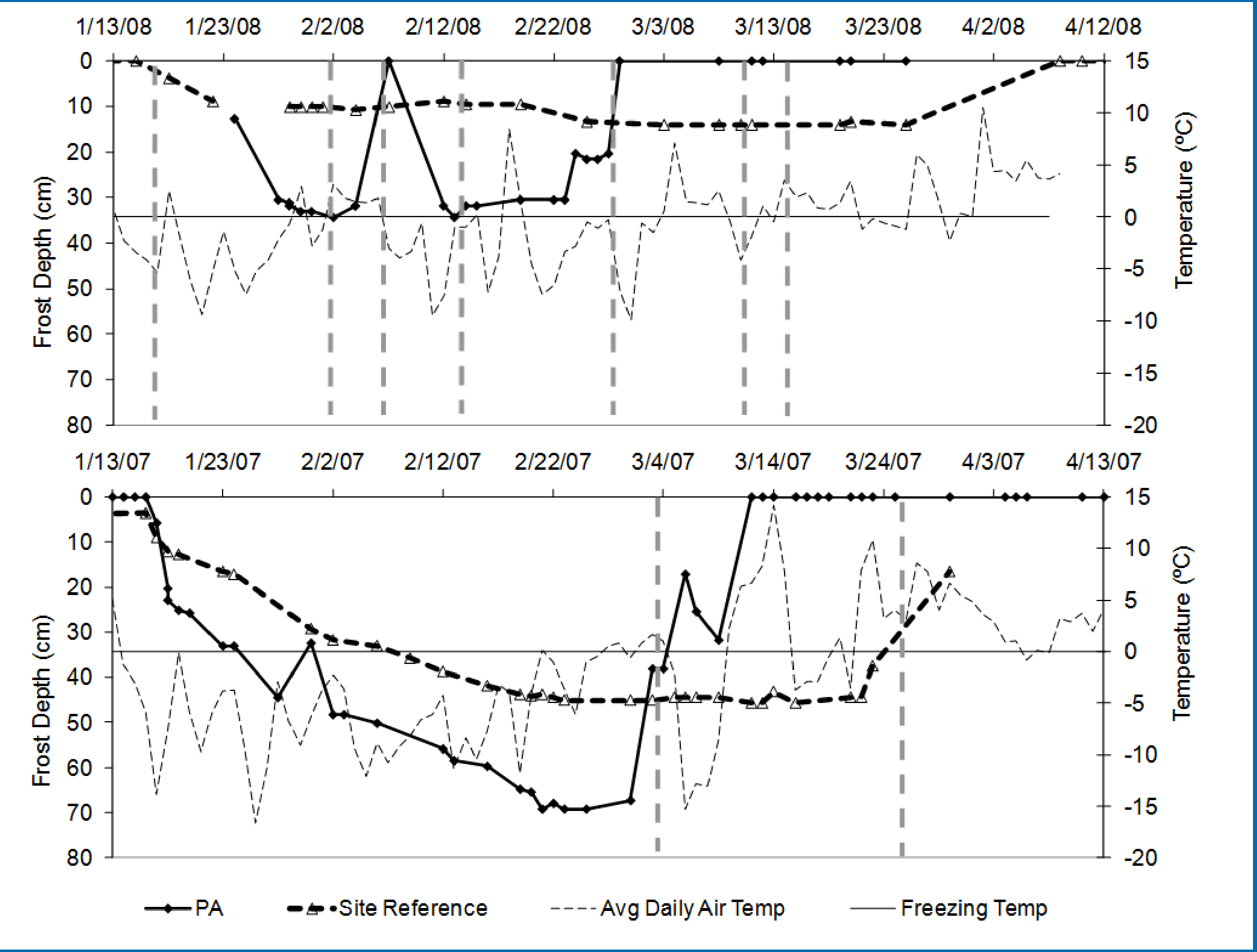
Basically the same for GI

Cold Climate Performance Results

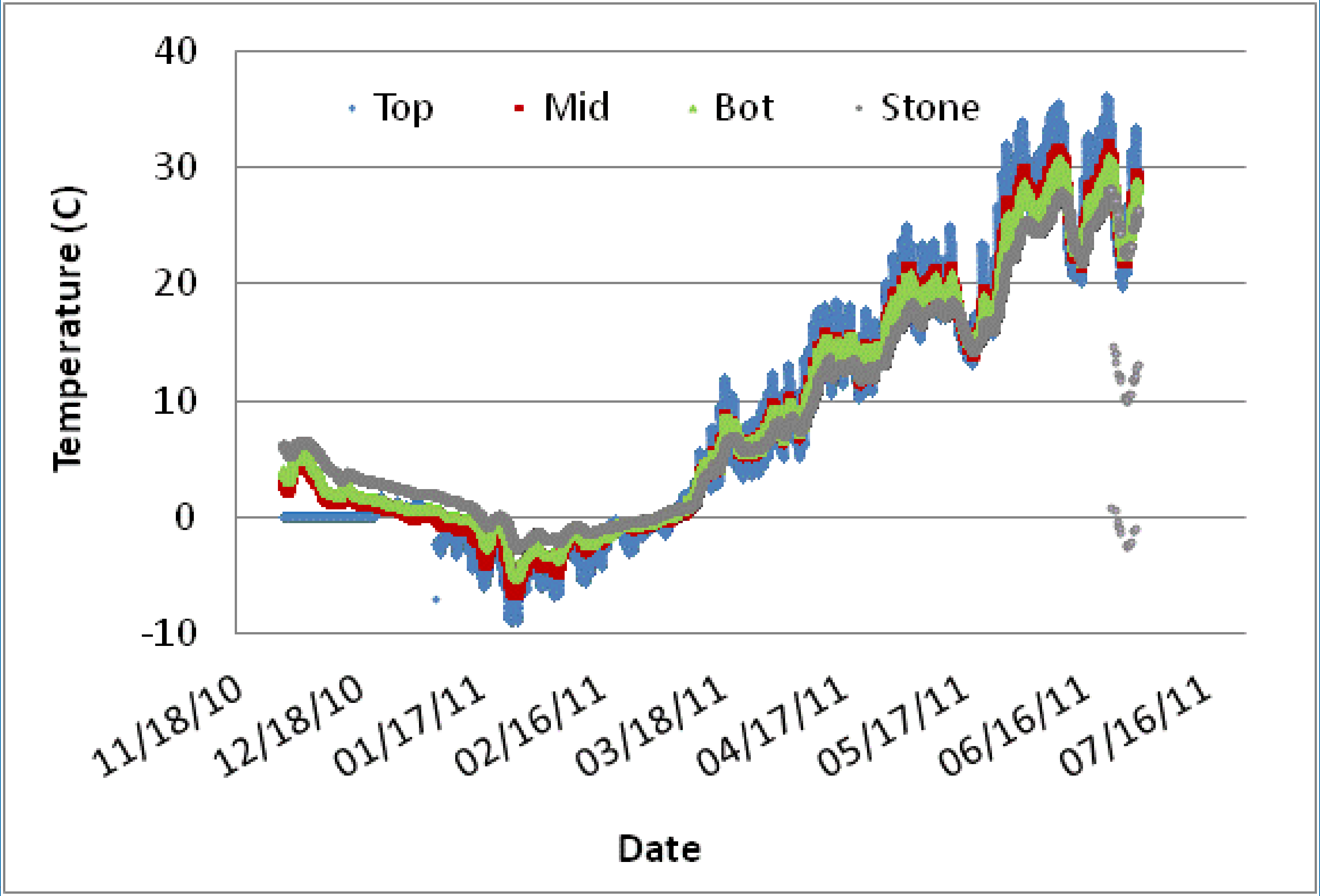
Frost Penetration

- Can be related to pavement failure
- Measured with a ‘field-assembled’ frost gauge (Ricard et al., 1976)
- Show relationships between pavements and soils

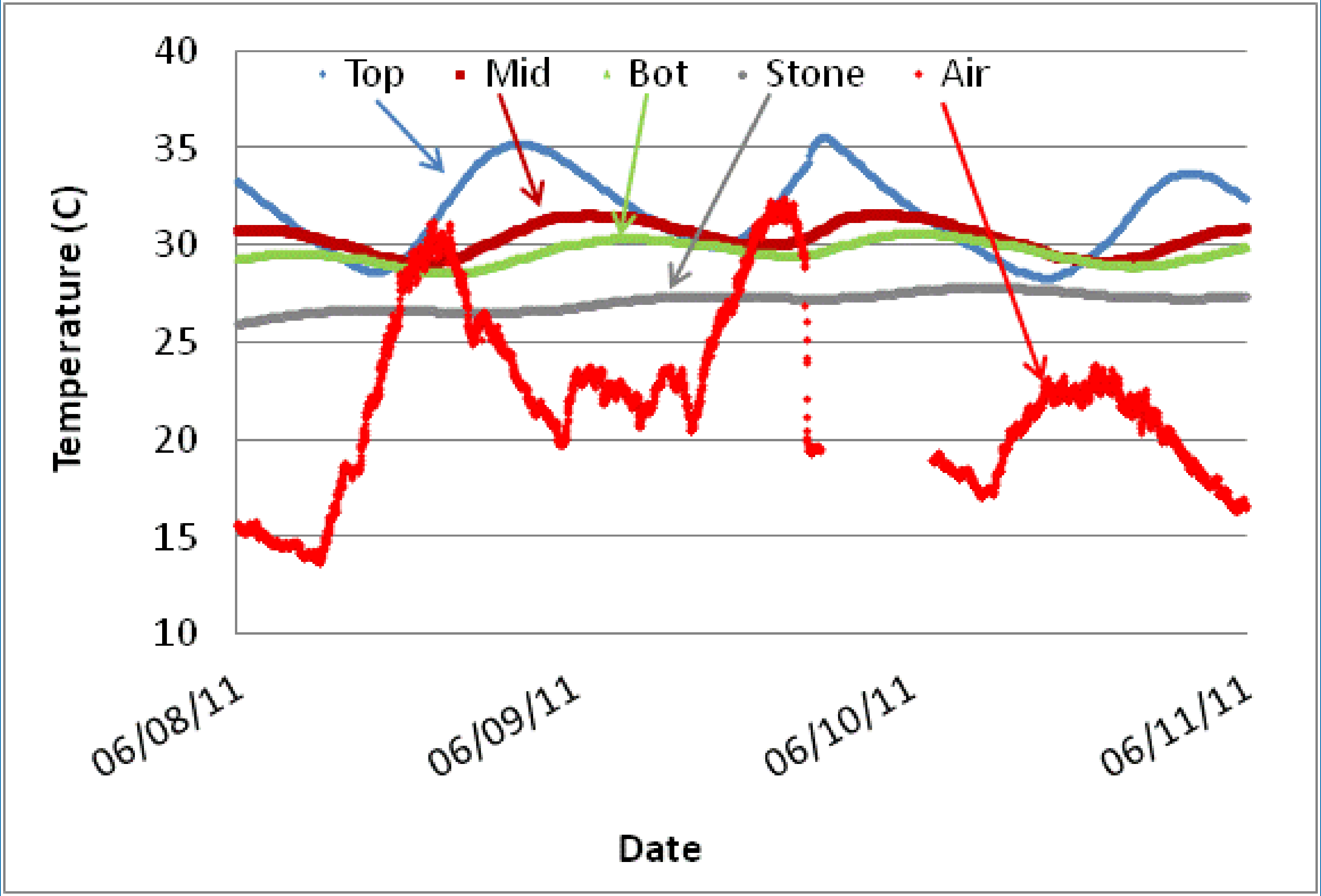
Porous Asphalt Frost Penetration



Temperature



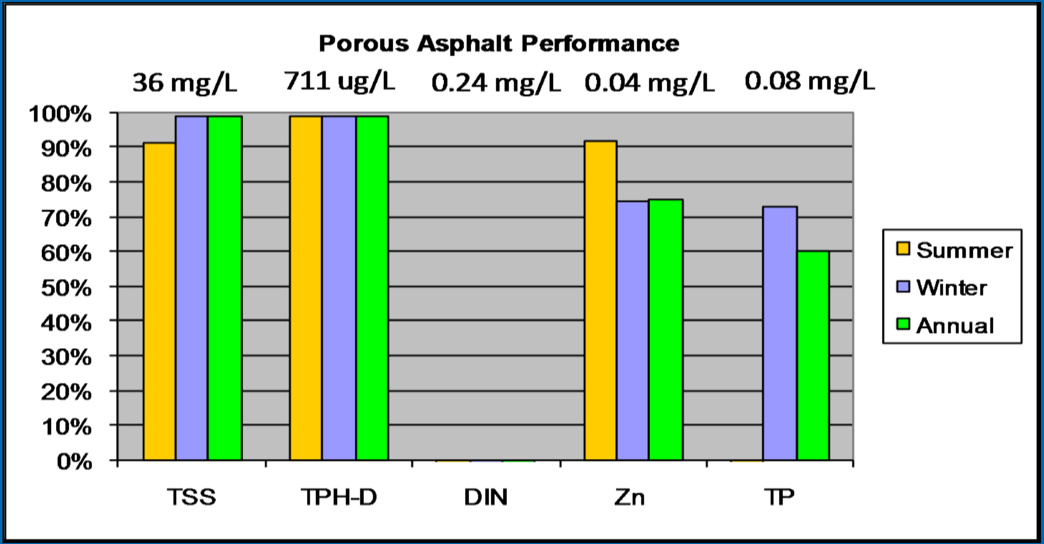
Summer Temperatures

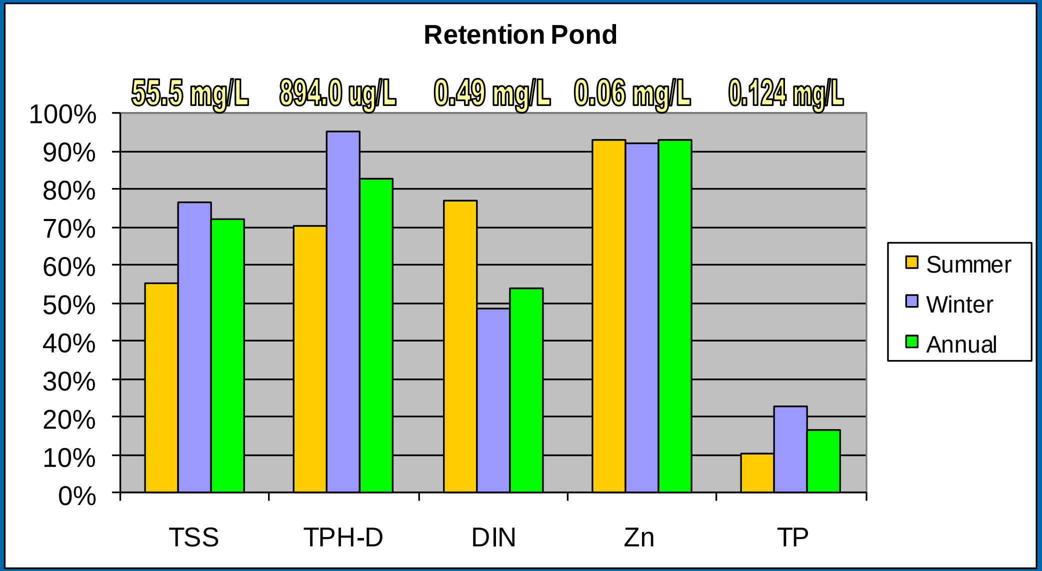


Frost Penetration does not mean or imply Impermeable

Winter Maintenance & Salt Reduction

Seasonal Performance Efficiencies



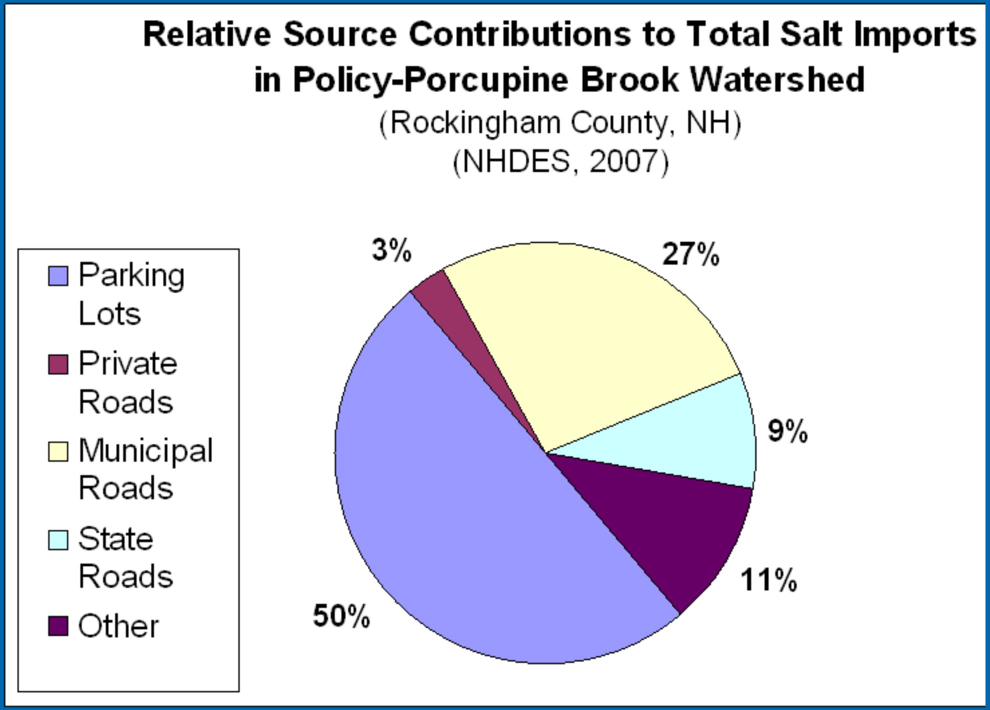


Why is Deicing Practiced?

- For as many as 3-6 months per year, deicing is used routinely :
  - To control ice development caused by the pooling of the meltwater followed by freezing air temperatures, and
  - To control accumulation of compact snow and ice not removed manually.
- On standard pavements, salt is easily dissolved in standing meltwater or washed away with runoff.

Why are we concerned about chloride ?

- No stormwater treatment removes chloride
- 6 chloride TMDLs nationwide
- Usage is on the rise
  - Need for public safety
  - Presumably because 80% TSS reduction is easily achieved by replacing sand with chloride
- Some DOT's use a 100% salt mix



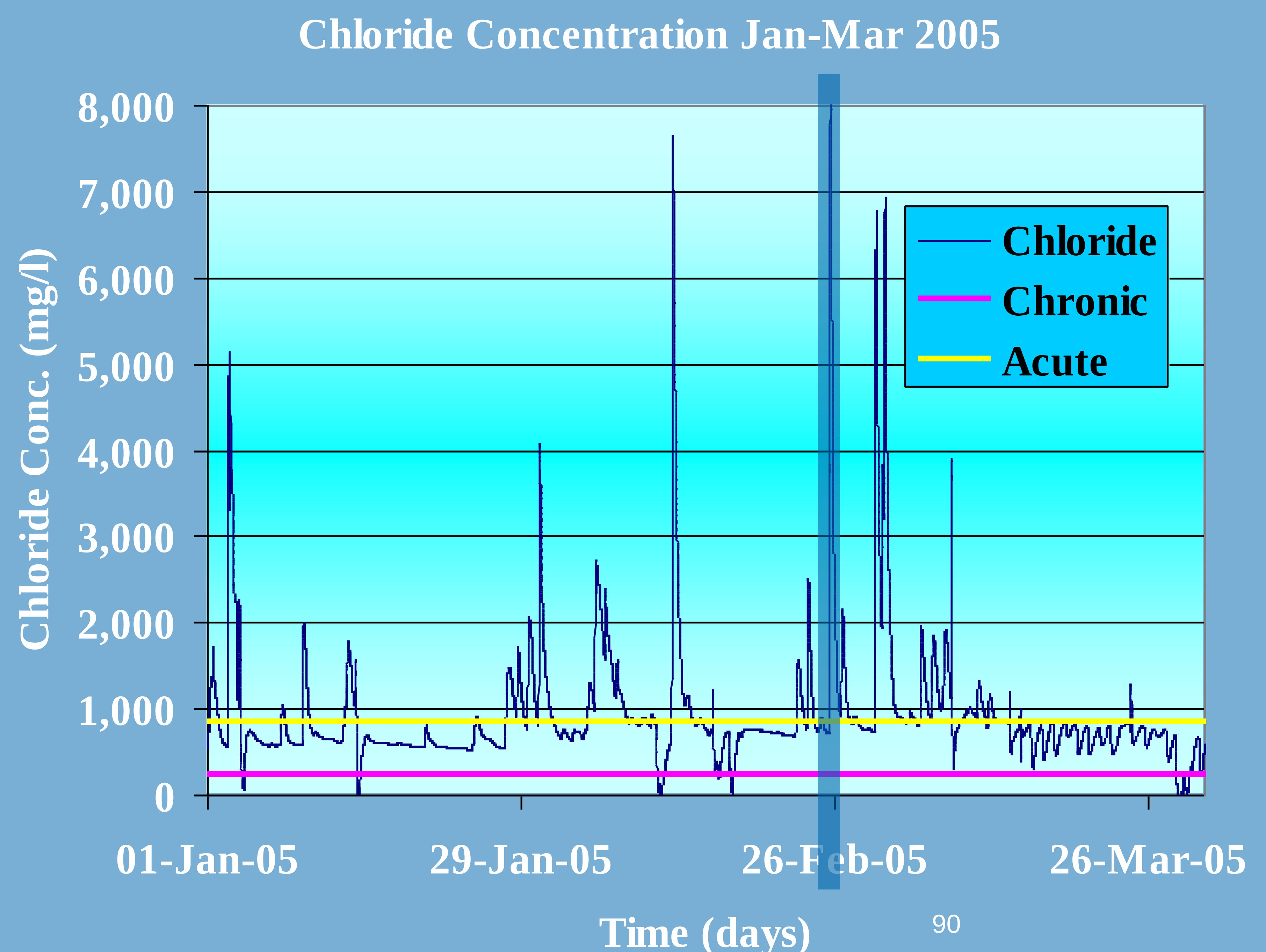
Source: Trowbridge (2007); Sassan and Kahl, (2007): Beaver Brook and Policy Brook I-93 Chloride TMDL; Road salt loading by source, assuming a rate of 6.4 tons/acre/year for parking lots and driveways, and a rate of 17.8 tons/lane mile/year (average annual rate) applied to public and private roads. Most residential driveways are excluded from this calculation.

Organism	Chloride (mg/L)	EC25 (uS/cm)	Test
Aquatic Species	>220	>900	synthesis of many tests; prolonged exposure (>30 days) will eliminate 10% of the species
Rainbow Trout	230	1,000	Minnesota chronic standard for trout (assumed to be for a >100 day adult exposure)
Humans	250	1,000	Federal & State Secondary Drinking Water Standard (mostly for taste)
Daphnids	210- 372	900-1,400	chronic toxicity (>30 day exposure)
Fathead minnows	433	1,600	chronic toxicity (>30 day exposure)
Rainbow Trout	> 900	3,000	significant (25%) adverse effects on trout eggs, embryos & adults in 7 days
Fathead minnows	1,280	4,100	lowest observed effects after 7 days
Daphnids	1,400	4,400	acute toxicity (50% mortality in 4 days)
Mayflies	2100-4300	6500-13,000	lowest observed effects after 7 days
Rainbow Trout	6,743	20,300	acute toxicity (50% mortality in 4 days)

EPA Criteria

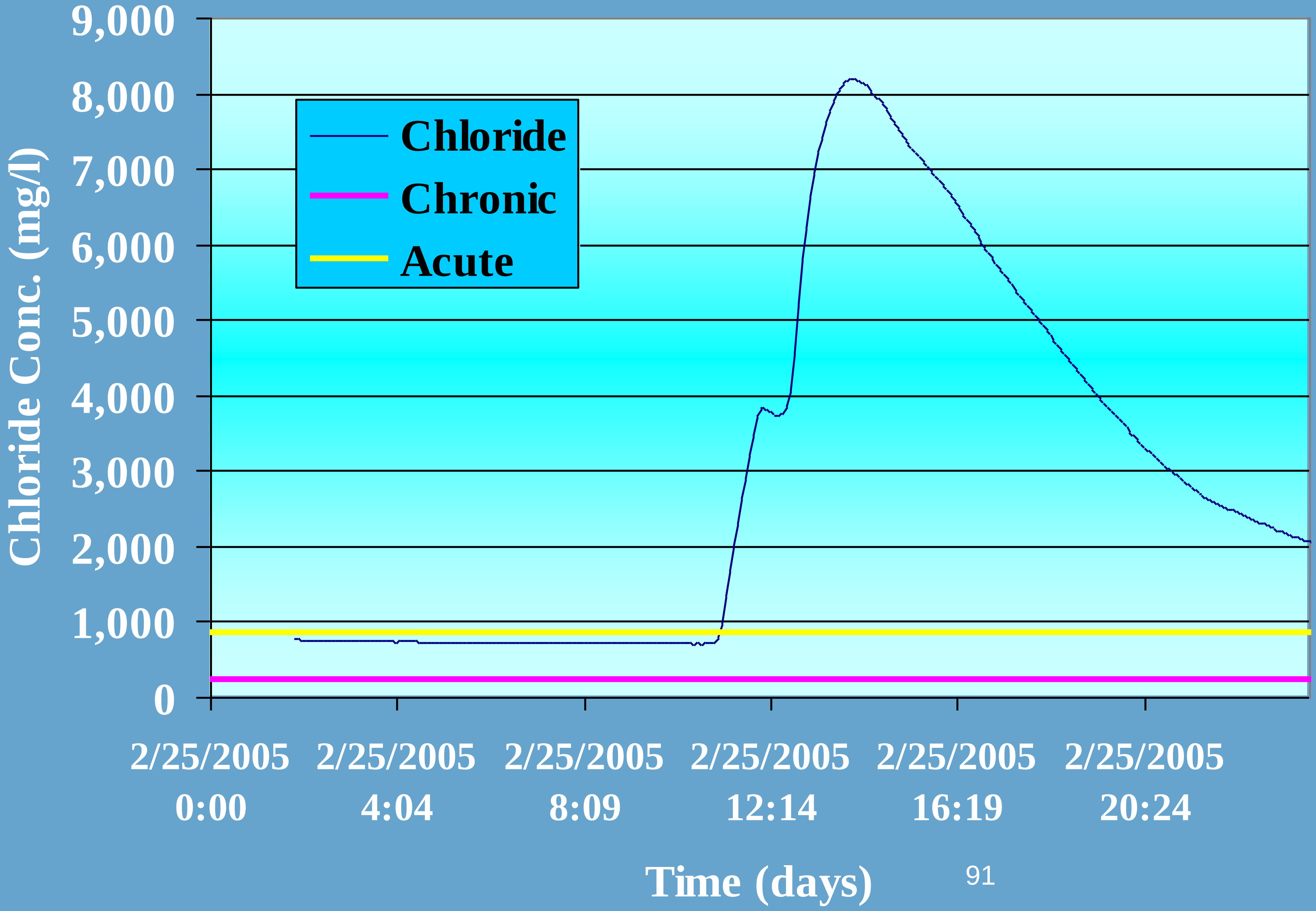
- chronic Cl concentration 230 mg/L (four day average)
- acute Cl concentration 860 mg/L (one-hour average)

- (not to be exceeded more than one day every 3 years)

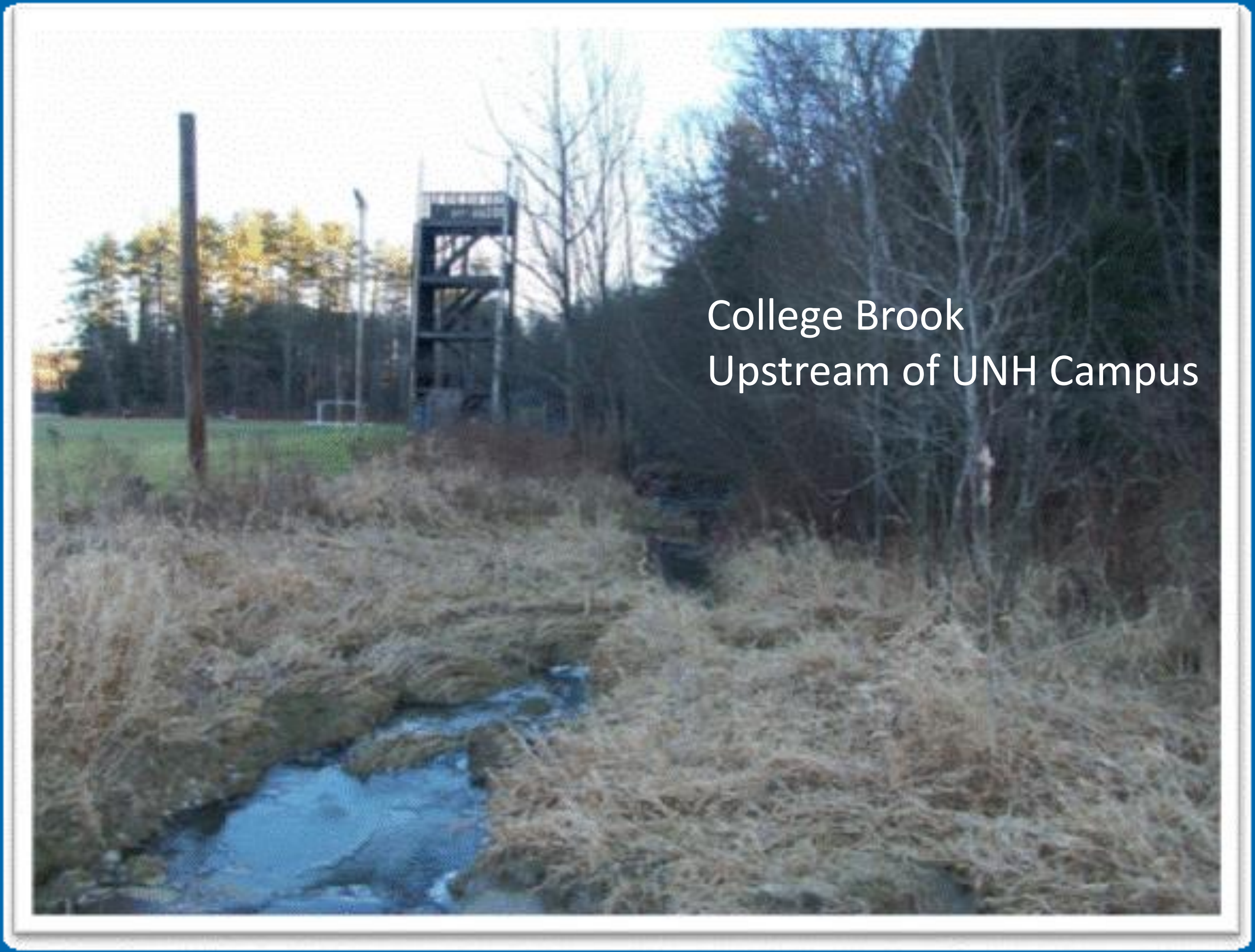


Chloride Concentration Jan-Mar 2005
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Chloride Conc. (mg/l)
Chloride
Chronic
Acute
01-Jan-05
29-Jan-05
26-Feb-05
26-Mar-05
Time (days)

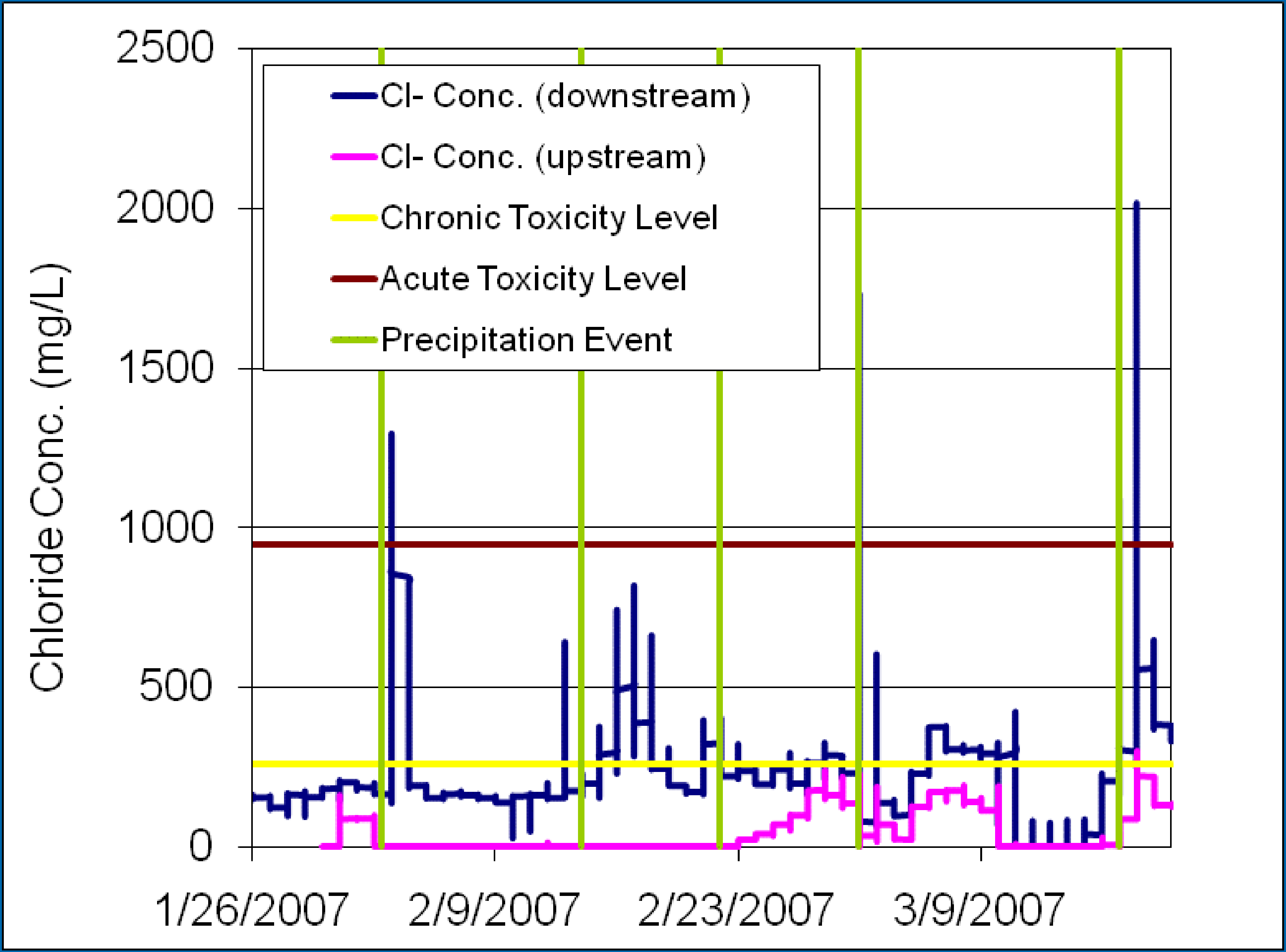
Chloride Concentration Jan-Mar 2005

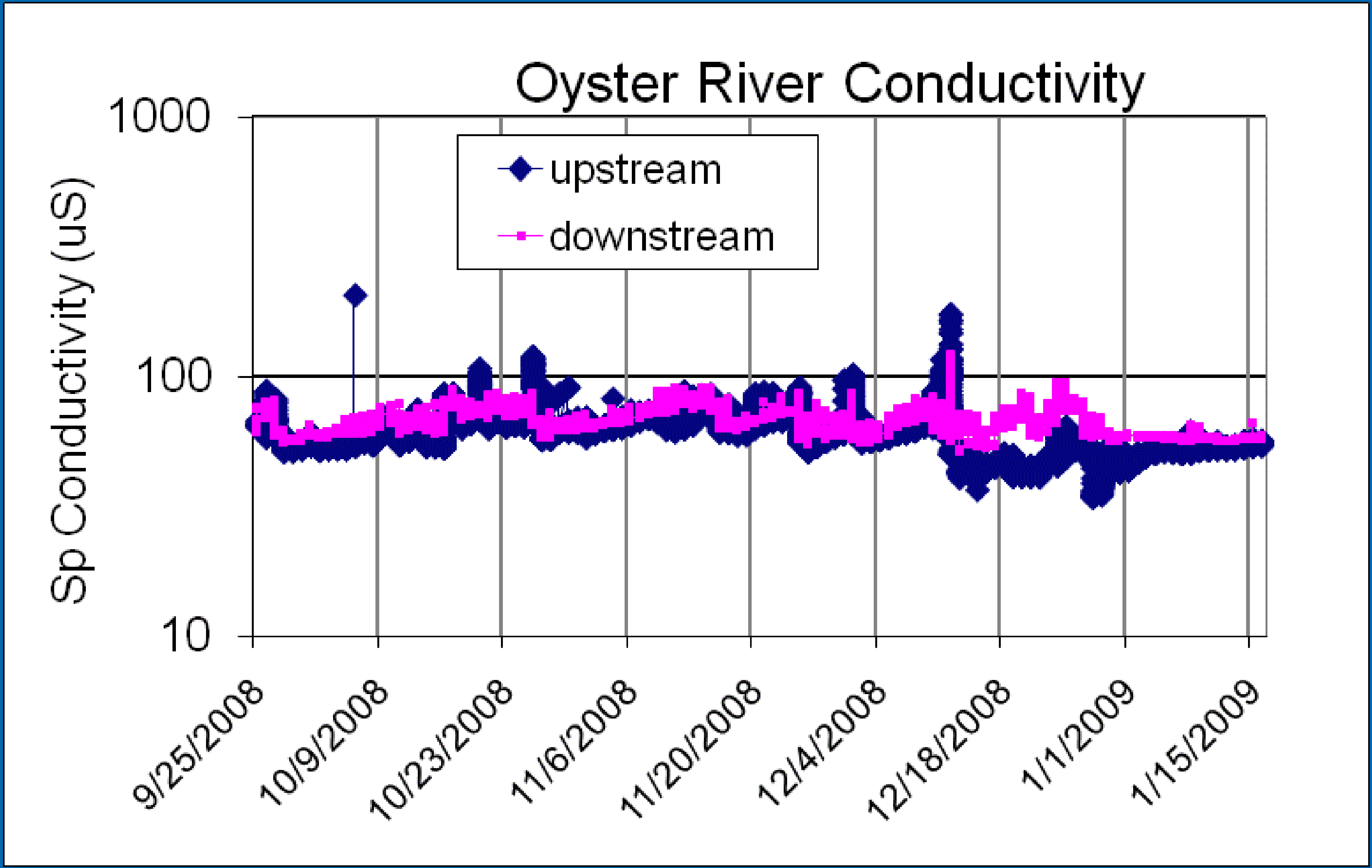


EPA Criteria for Chloride Are For the Receiving Stream



College Brook Conductivity Through the UNH Campus




Oyster River Conductivity
Sp Conductivity (uS)
1000
100
10
upstream
downstream
9/25/2008
10/9/2008
10/23/2008
11/6/2008
11/20/2008
12/4/2008
12/18/2008
1/1/2009
1/15/2009

How Do Porous Pavements Fit In With Salt?

Potential Salt Reduction

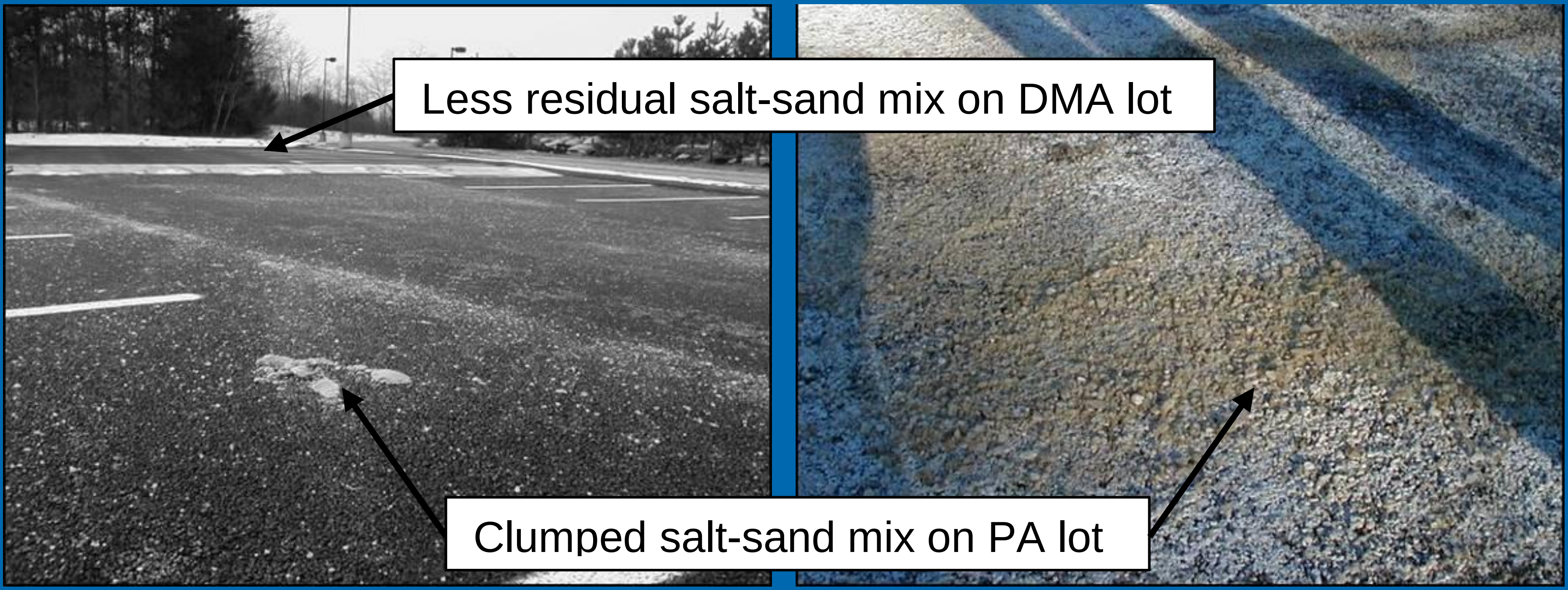


Figure 1. Residual sand and salt mix on PA lot, winter 2005. Clumped mix (top) and close up of mix (bottom).

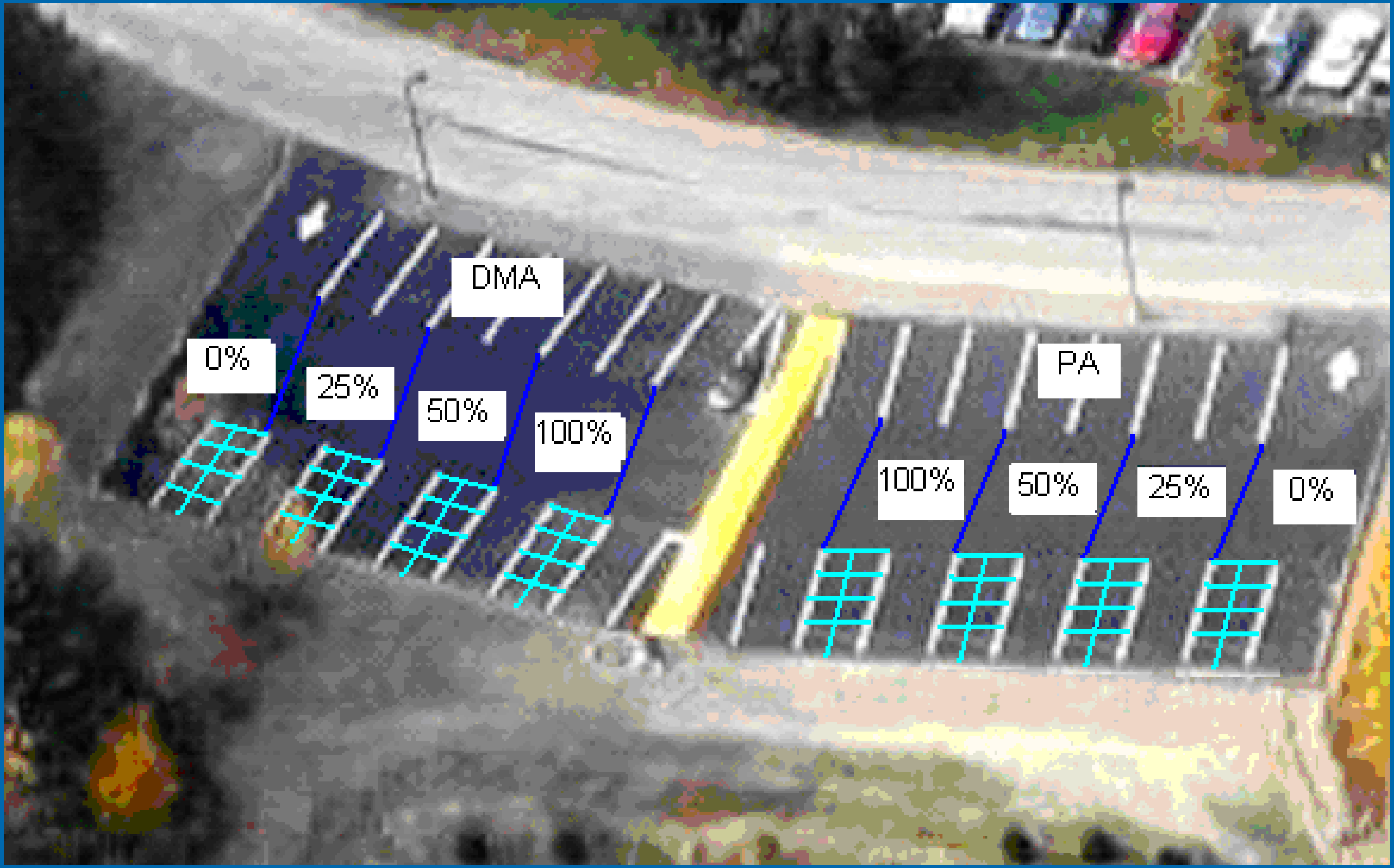
Winter Maintenance & Performance

- No special maintenance arrangements w/ UNH
- Applied mix: 56% Cl, 10% sand
- 21 applications winter 2006
- Snow/Ice melted more quickly on PA than on DMA
- Excessive mix application

Study Details

- March 2005-Jan 2007: A paired design: half dense mix asphalt, half porous asphalt
- Oct 2007 – present: similar studies on PC
- Located at the UNH Stormwater Center in Durham.
- Activity is a combination of passenger vehicles and routine bus traffic.
- Frequent plowing, salting, and sanding during the winter months.

PA Study Area Orientation



Measuring Skid Resistance w/ BPT

ASTM STANDARD E303-93

Chloride (Salt) Recovery

- Vacuumed salt
- Dissolved material in warm water
- Measured specific conductivity
- Applied value to UNHSC regression
- Compared results for both lots

PA/DMA Snow & Ice Cover

Lots one-hour after plowing, -4*C (11AM on 2/3/07)

PA/DMA Snow & Ice Cover

Conditions after thawing and subsequent refreezing (9AM on 3/18/07)

- **No black ice formation on PA**

PC Snow & Ice Cover

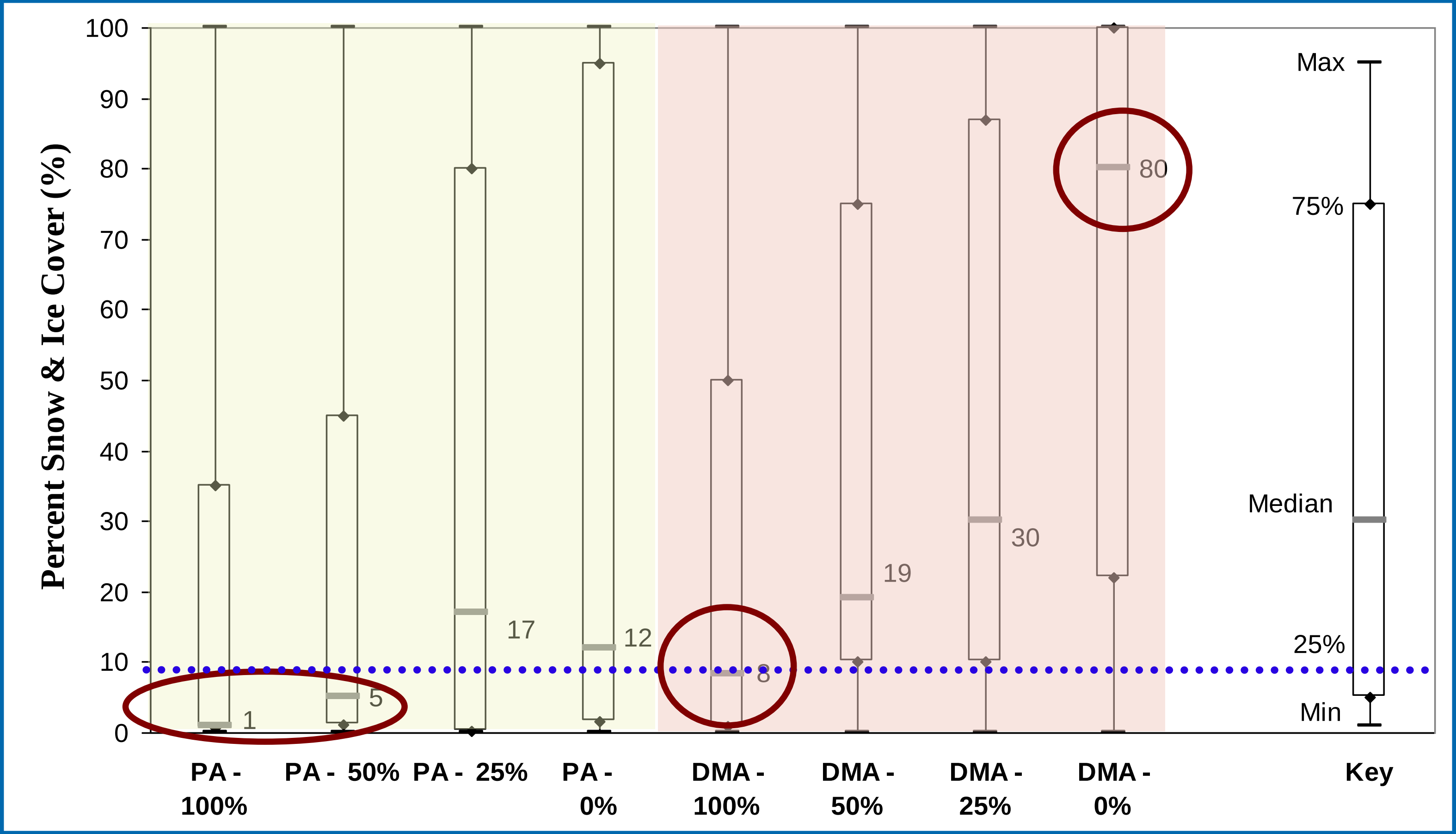
Conditions after thawing and subsequent refreezing (1PM on 2/16/08)

- **No black ice formation on PC**

PC Snow & Ice Cover

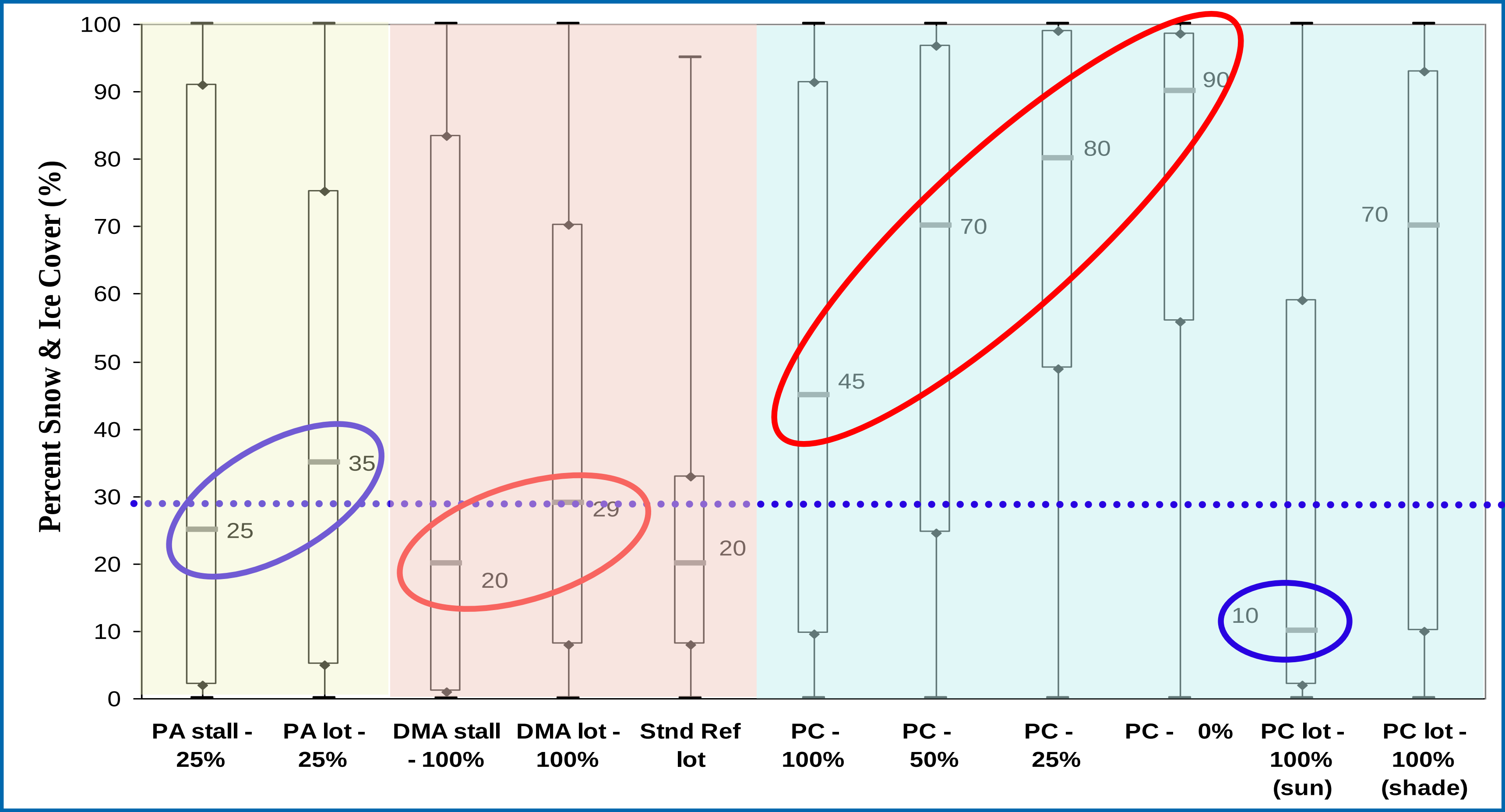
- Shading contributes to amount of cover on PC

Comparison of snow/ice percent cover for study areas on all lots (winter ’06-’07)



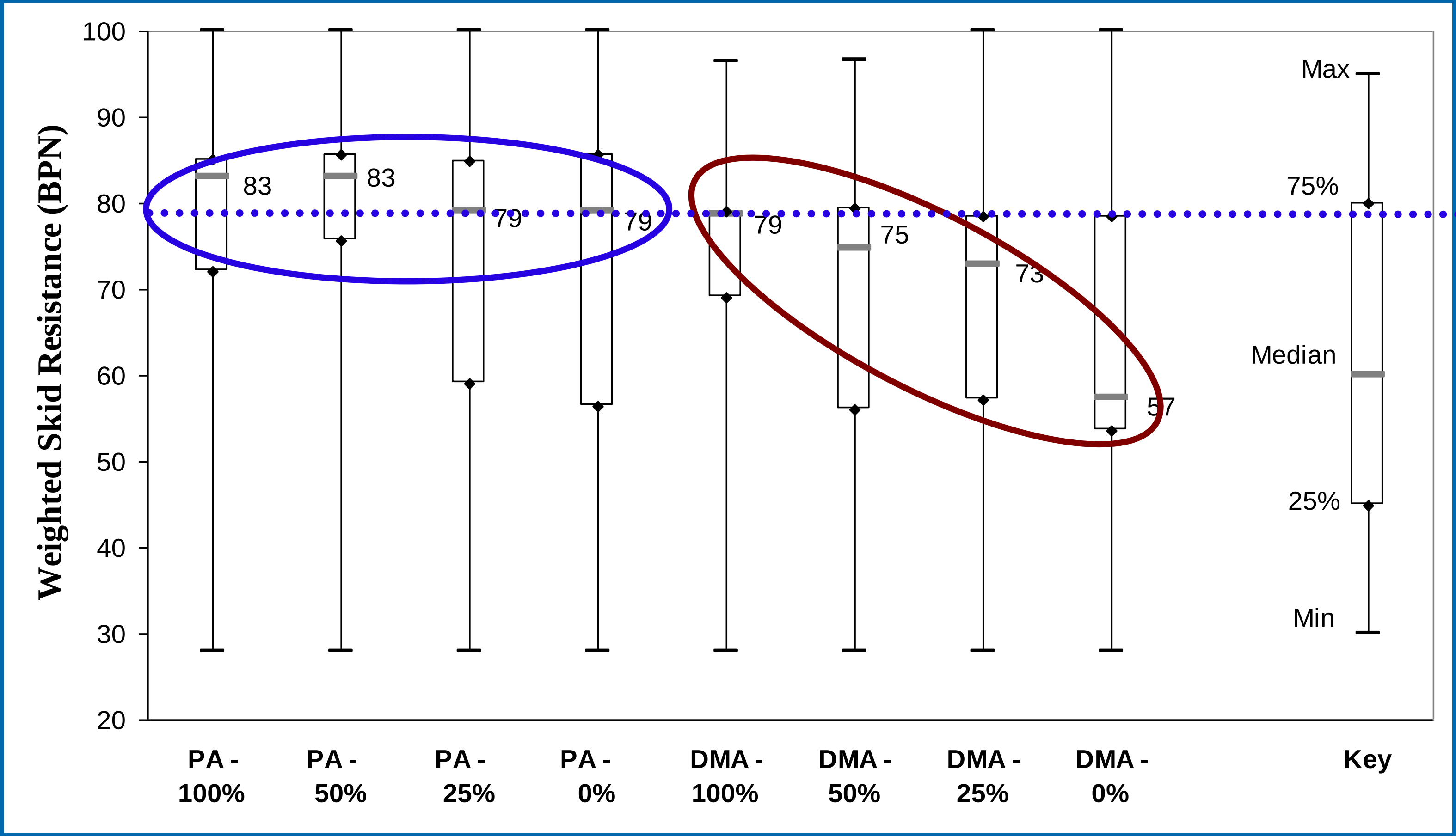
- More snow & ice present on DMA

Comparison of snow/ice percent cover for study areas on all lots (winter ’07-’08)



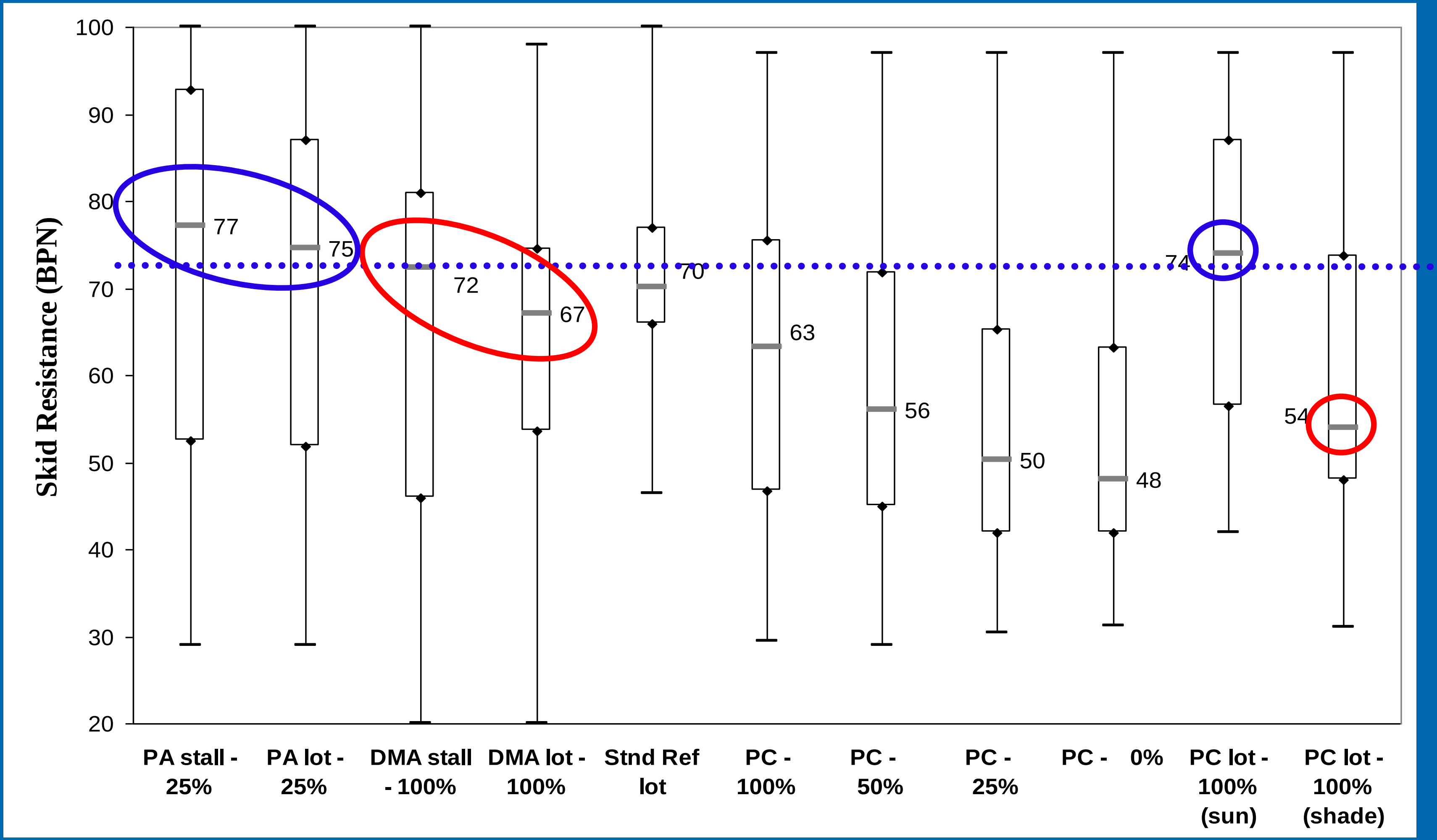
- Snow and Ice Cover is comparable for PA 25%, PC 100% (full sun) and DMA 100% application
- PC does poorly in shaded areas for deicing—no issue for most commercial apps

Weighted skid resistance values as a function of surface cover for all pavement types ('06-'07)

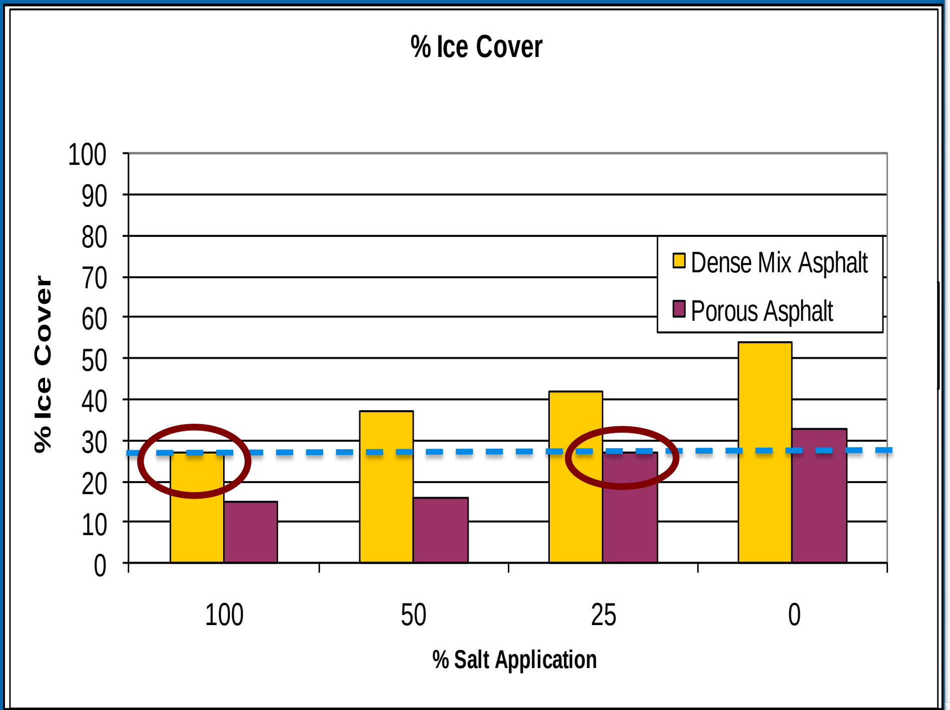


- Weighted SR as a measure of safety
- Higher BPN = safer pavement

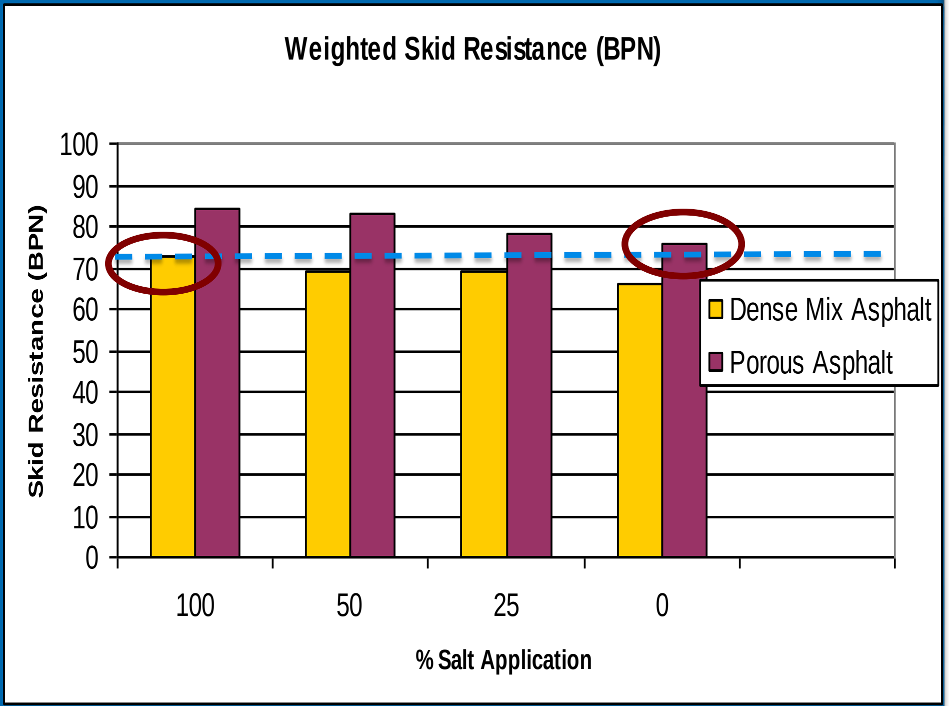
Weighted skid resistance values as a function of surface cover for all pavement types ('07-'08)



- Skid resistance is higher for all conditions for PA
- PC has higher skid resistance (sun only) and is very sensitive to sun exposure


% Ice Cover
100
90
80
70
60
50
40
30
20
10
0
% Ice Cover
Dense Mix Asphalt
Porous Asphalt
100
50
25
0
% Salt Application


DMA after spring rain on snow event


Weighted Skid Resistance (BPN)
100
90
80
70
60
50
40
30
20
10
0
Skid Resistance (BPN)
Dense Mix Asphalt
Porous Asphalt
100
50
25
0
% Salt Application


PA after spring rain on snow event

Effective Salt Reductions

Pavement Type	2006-2007		2007-2008		Reductions Possible when compared to DMA with 100% App. Rate	
	Anti-Icing Apps.	Deicing Apps.	Anti-Icing Apps.	Deicing Apps.	App. Rate	Average Mass Reduction* ('06-'08)
DMA	15	14	23	22	100%	0%
PA	15	6	23	27	25%	75%
PC - shade	-	-	23	31	100%	-20%
PC - sun	-	-	23	23	100%	-2%

* Reduction possible with no loss in skid resistance (safety)

Conclusion About Friction

- **Higher frictional properties on PA and PC**
- **Salt reductions possible during freeze-thaw conditions**
  - **No standing water**
- **Little to no salt needed if plowing occurs**
- **Up to 75% salt reduction from SOP possible**
- **Deicing may still be necessary after freezing-rain**
- **PA and PC are currently the only stormwater strategies that can minimize chloride threat to groundwater w/o lining**
  - **Less chloride applied = Lower risk**

Summary Conclusions

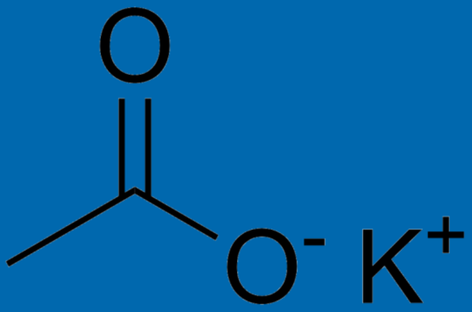
- Results indicate using 0-25% of a typical salt load produces similar conditions to what is observed for DMA.
- Higher frictional properties were recorded on PA with NO salt addition than were observed for DMA at 100% application rate.
- Equivalent snow and ice cover was achieved with only 25% application rate
- Peak flow and volume reduction are substantial-dependent on subdrain design
- Cold climate performance is excellent and differs little from summer
- Frozen filter media and freeze thaw are not an issue
- Can be used as an effective transportation runoff BMP for chloride reduction

Cl-Free De-Icers

Rock salt melting on porous asphalt and infiltrating into pores

Cryotech CF7© Commercial

- Consists of 50% aqueous potassium acetate by volume, and <1% corrosion inhibitors.
- Has been proven effective on impervious surfaces, and freezes around -76 degrees Fahrenheit.



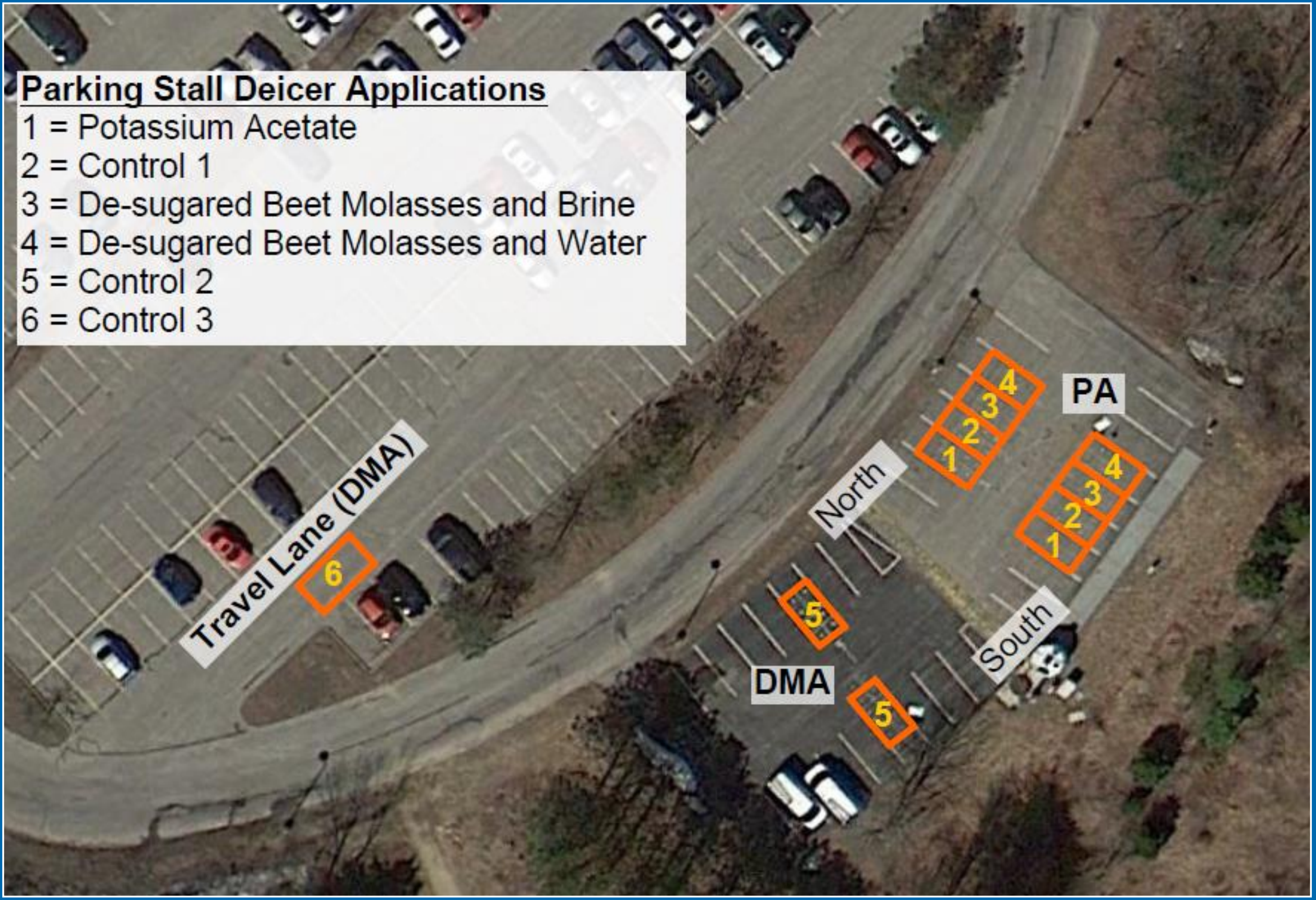
Ice Bite "S"© and Ice Bite©

- ***Ice Bite "S"*** **– Consists of 20% Desugared Beet Molasses and 80% salt brine. Successfully used in impervious pavements in New England and Midwest**

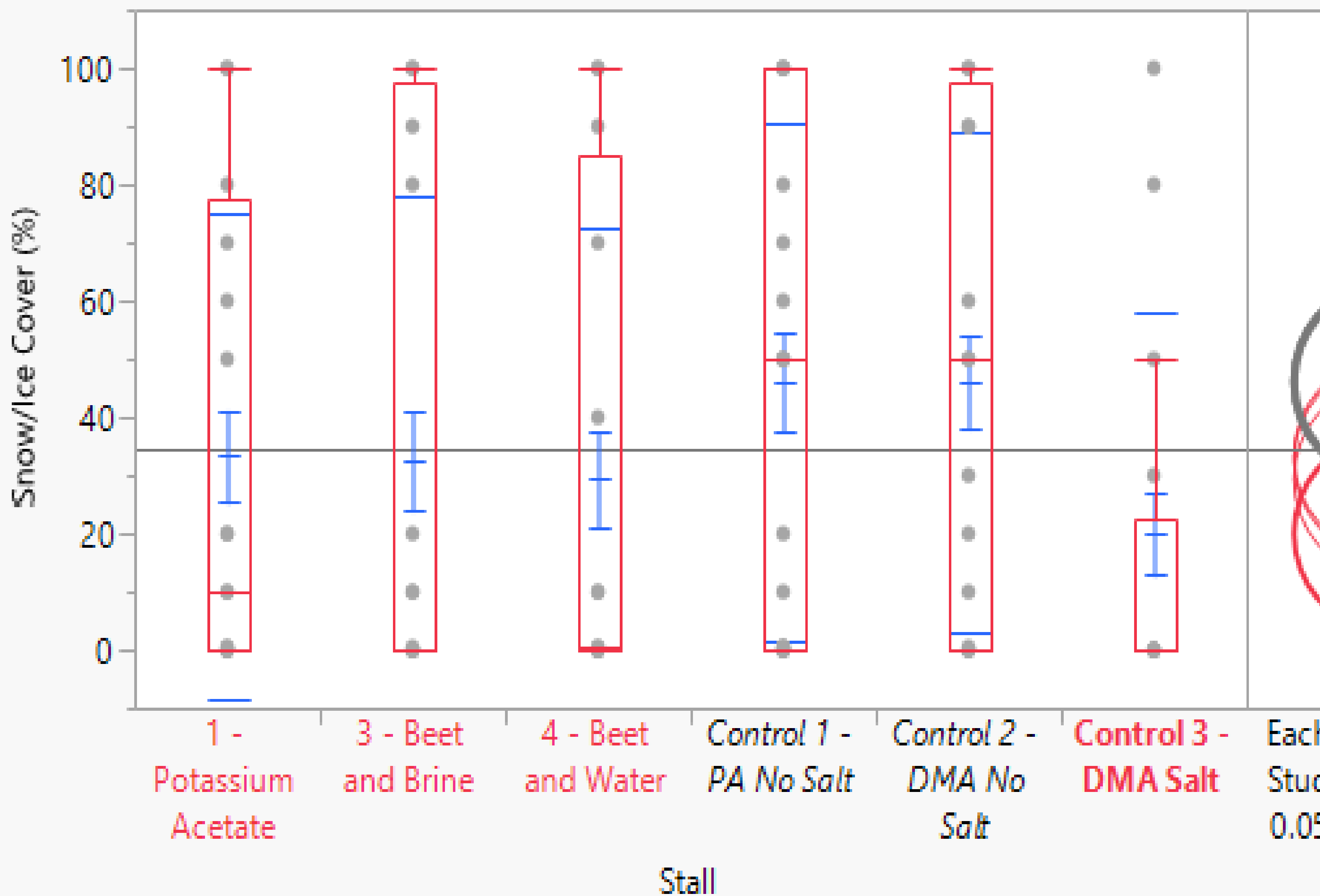
- ***Ice Bite*** **– Consists of 67% desugared beet molasses and 33% water. "Independently" created product and has never been used for this purpose.**

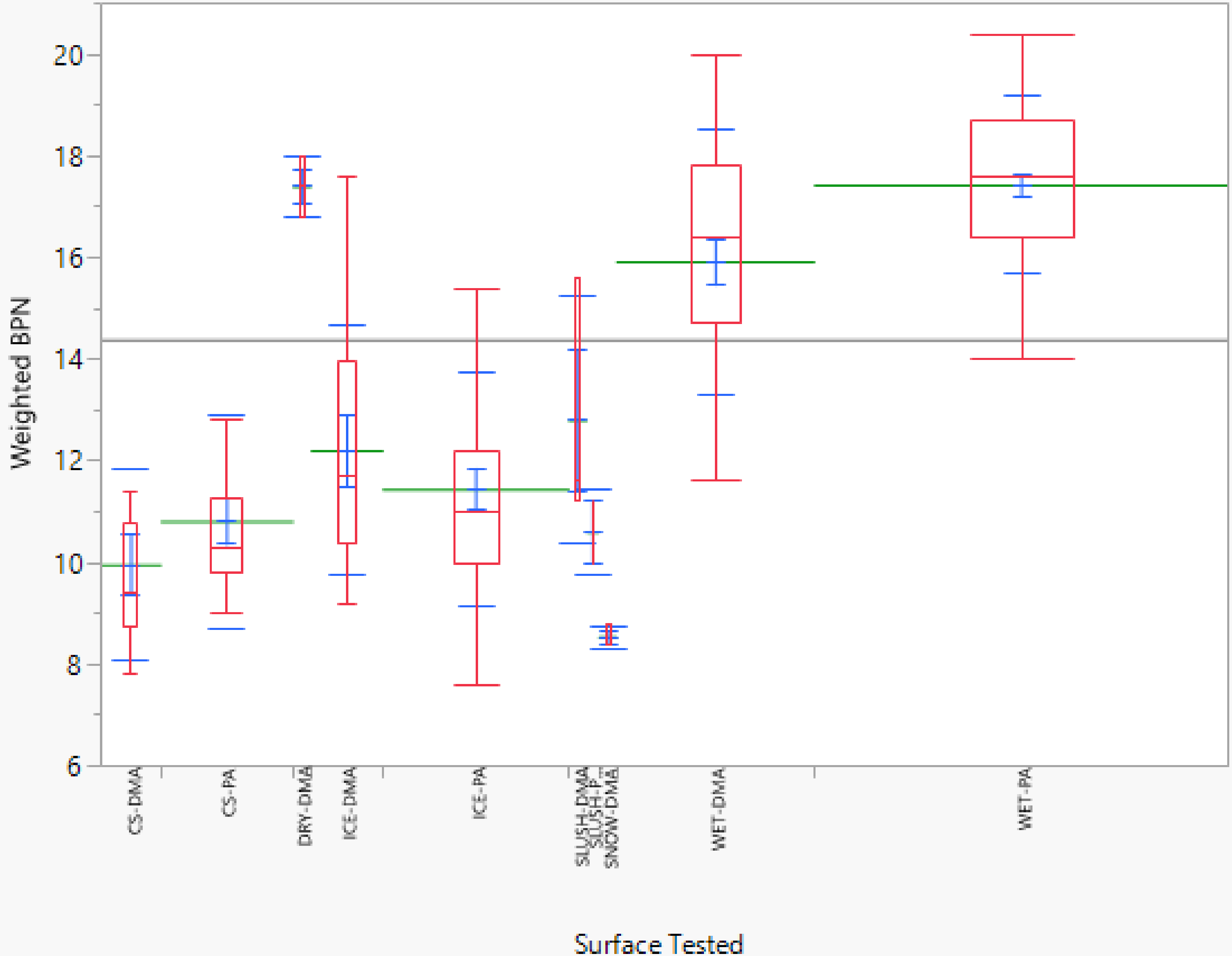
Material	Rock Salt (tons)	CF7 (gals)	Ice Bite "S" (gals)	Ice Bite (gals)*
Cost per gallon or ton	55	6.12	1.43	1.79
Recommended Application Rate (gallons/tons per lane mile)	0.244	95	40	40
Total Cost per lane Mile	$13.42	$581.64	$57.20	$71.60

Liquid De-Icer Studies

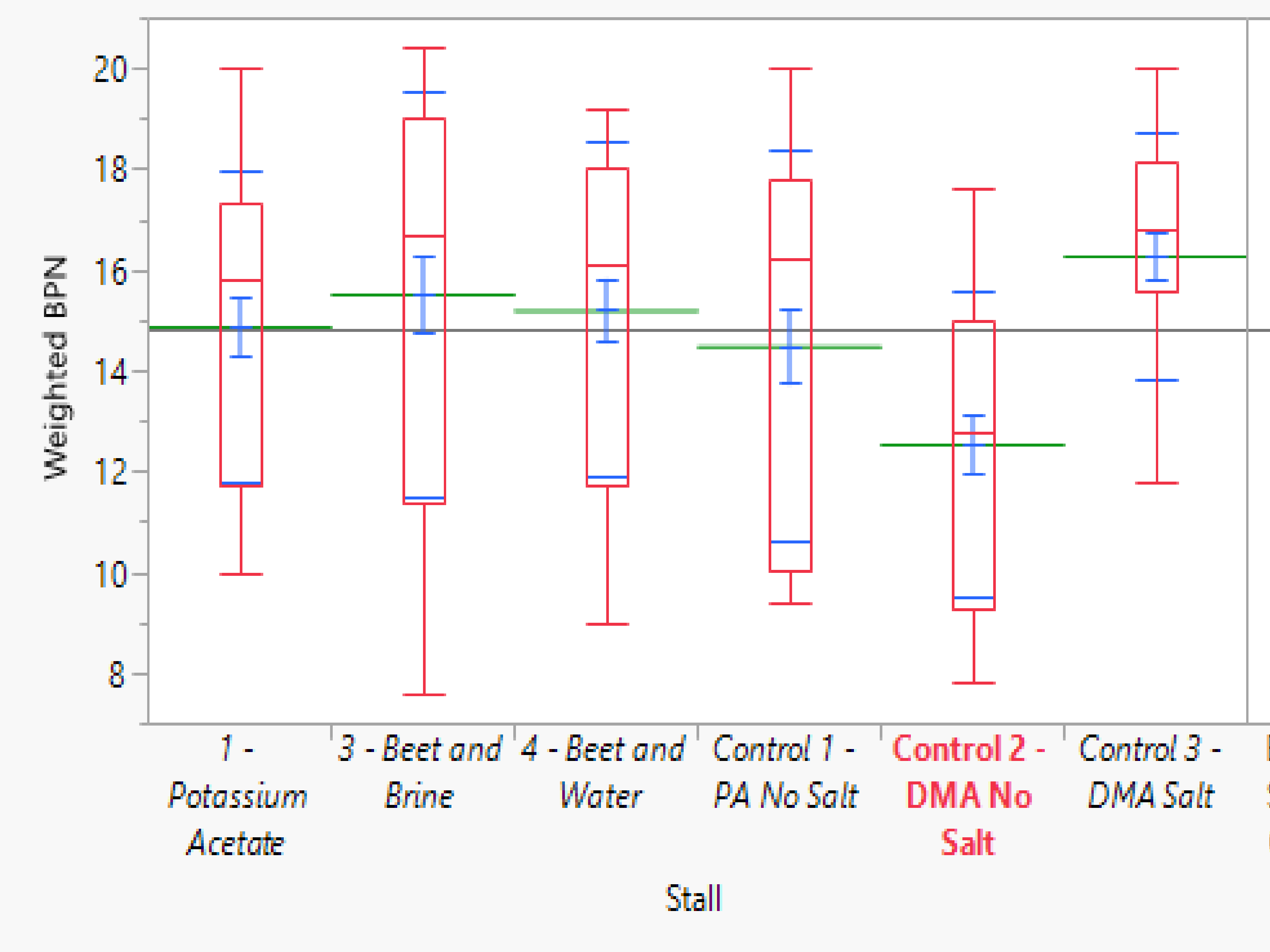


Oneway Analysis of Snow/Ice Cover (%) By Stall



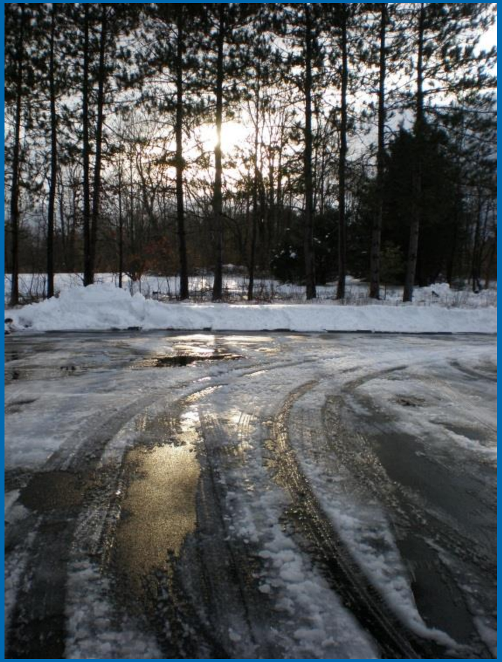


Weighted BPN
20
18
16
14
12
10
8
6
CS-DMA
CS-PA
DRY-DMA
ICE-DMA
ICE-PA
SLUSH-DMA
SLUSH-P
SNOW-DMA
WET-DMA
WET-PA
Surface Tested


Weighted BPN
20
18
16
14
12
10
8
1 - Potassium Acetate
3 - Beet and Brine
4 - Beet and Water
Control 1 - PA No Salt
Control 2 - DMA No Salt
Control 3 - DMA Salt
Stall

Conclusions

- In both the raw and normalized datasets, the CF7 and Ice Bite "S" both appeared to be more effective than the Ice Bite.
- Both Ice Bite "S" and CF7 appeared to be as effective, if not more effective than traditional salting.
- ANOVA – Normalized Data: The Ice Bite, PA No Salt, DMA No Salt, and DMA Salt appear to be "not significantly different" from one another.



Winter Maintenance Guidance

- Salt reduction potential will be site specific and vary depending on shading and climate.
- Plow after every storm.
- Apply anti-icing treatments prior to storms. Anti-icing has the potential to provide the benefit of increased traffic safety at the lowest cost and with less environmental impact.
- Deicing is NOT required for black ice development.
- Apply deicing treatments during, and after storms as necessary to control compact snow and ice not removed by plowing. Excess may be required.

Winter Maintenance Guidance

- Mixed precipitation and compact snow or ice is particularly problematic for porous surfaces. This is prevented by appropriate plowing and corrected by application of excess deicing chemicals.
- In certain instances of compact snow and ice, excess salt may be required, however loading is offset by the overall reduced salt during routine winter maintenance and salt reduction.
- With good sun exposure some porous asphalt installations will require no deicing.
- Porous asphalt provides exceptional treatment for rain on snow events which commonly

Pervious Concrete

Pervious Concrete Spalling


28D N83
U.S.
MARINES

The PC Verdict

There are 3 main curing requirements for PC:

- 30 day cure for structural load
- 90 day cure to protect against freeze-thaw damage,
- >12 month cure prior to aggressive chloride deicing applications.

Winter Maintenance Guidance

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- Deicing is NOT required for black ice development.
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Porous Pavement Limitations

- Porous pavement systems are not a silver bullet
- As with all development, ordinances that protect water resources should still be strictly enforced
- Porous pavements are a filtration/infiltration system as well as a transportation surface. Dual function means:
  - Greater site evaluation and design effort
  - Strict engineering oversight and skilled personnel through all phases of the project
  - Requires a comprehensive maintenance schedule

Pavers


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Questions?