Perspectives on Green Infrastructure: Where We Have Been and Where We Are Going

Thomas P. Ballestero, James Houle, Timothy A. Puls

12th Annual North Country Stormwater Trade Show and Conference

20 October 2016

Lake George, NY

UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER

University of New Hampshire

Overview

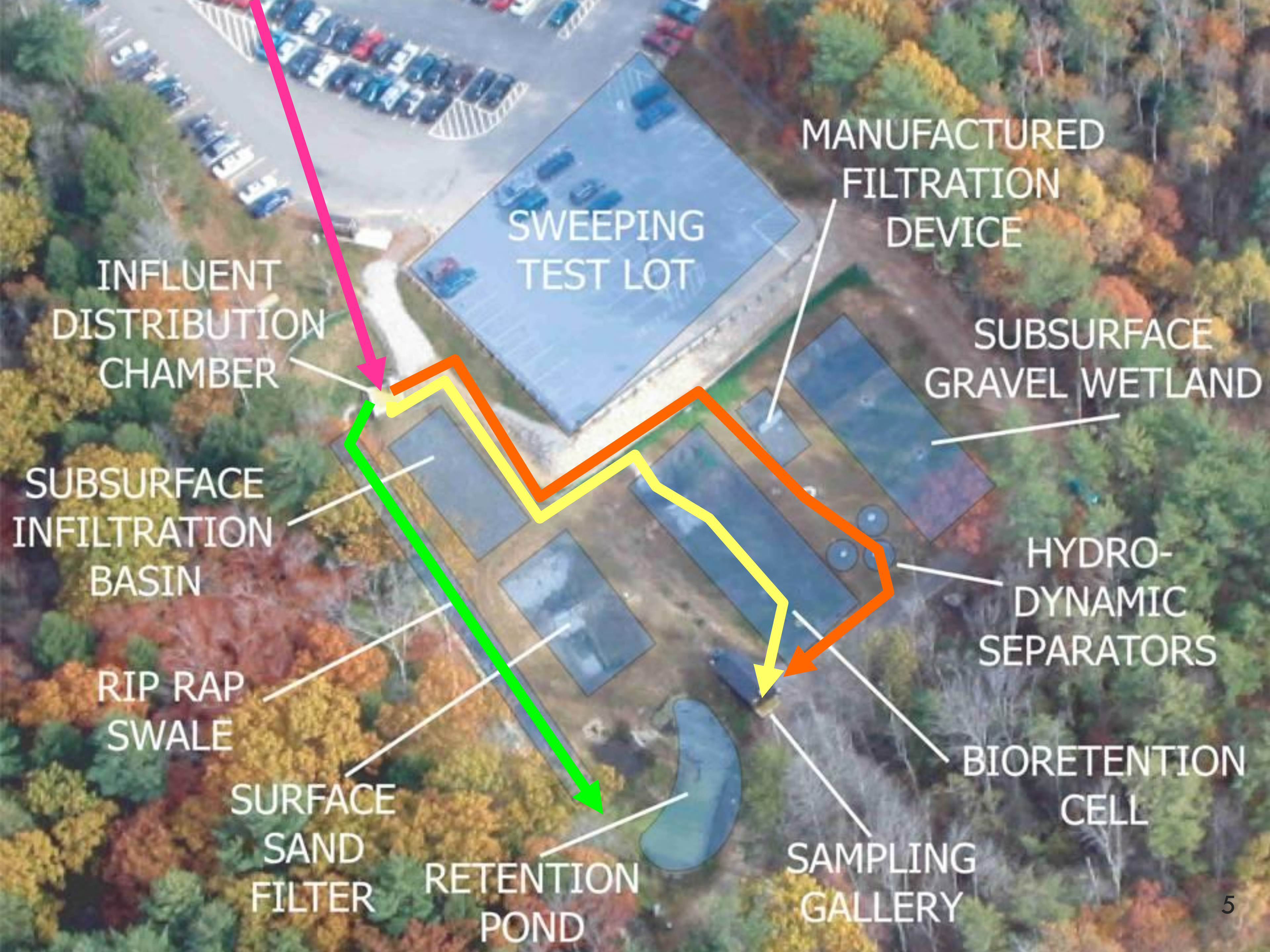
- General overview of the UNHSC
- Overview of stormwater management practice performance
  - Hydraulic
  - Hydrologic
  - Water Quality
- Economics and costs of LID
- GI practice maintenance
- Subsurface gravel wetlands
- Modern trends in bioretention practices
- Performance of undersized systems

General overview of the UNHSC

BMP Performance Monitoring

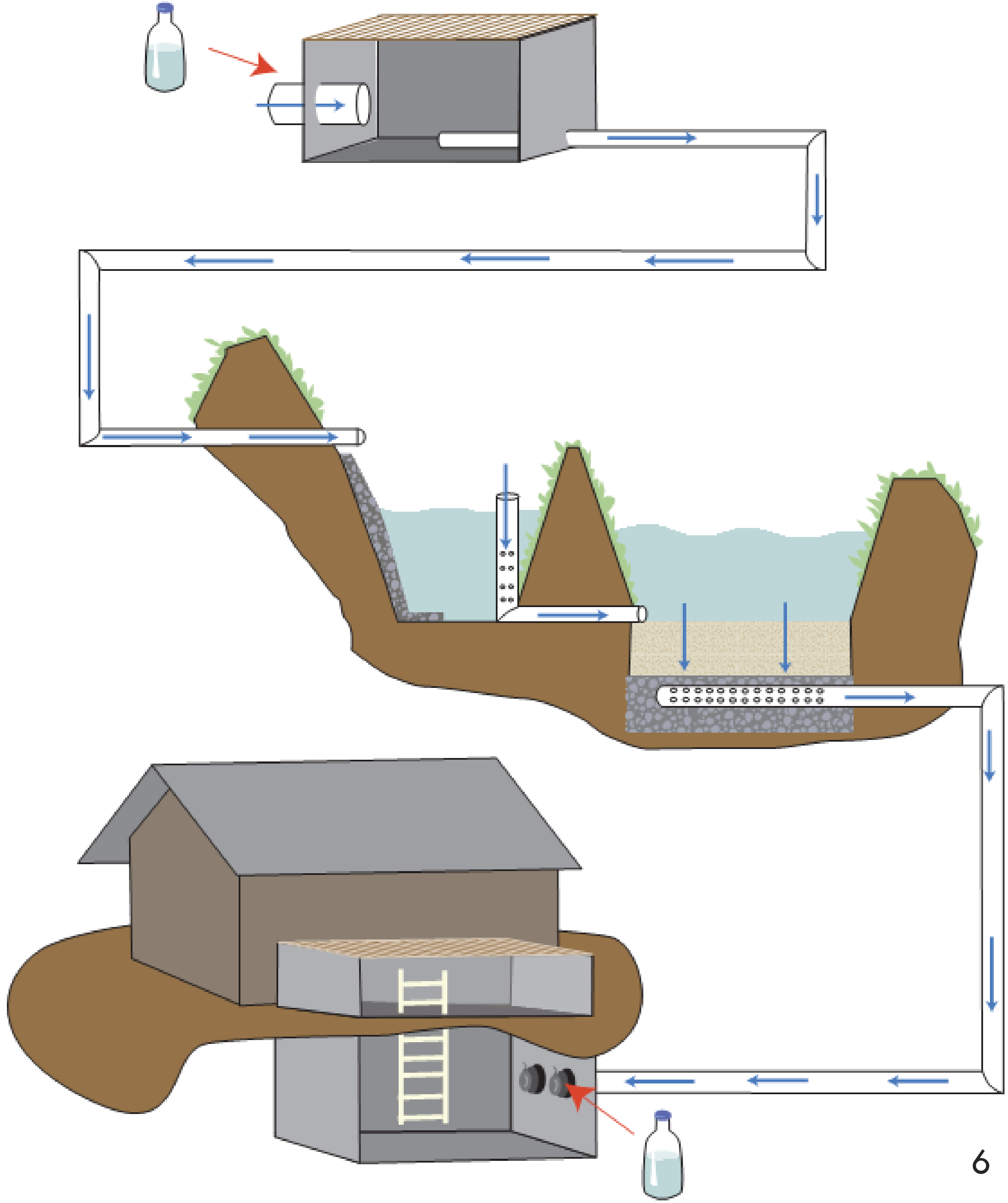
Research Field Facility at UNH

Tc ~ 19 minutes


MANUFACTURED FILTRATION DEVICE
SWEEPING TEST LOT
INFLUENT DISTRIBUTION CHAMBER
SUBSURFACE GRAVEL WETLAND
SUBSURFACE INFILTRATION BASIN
HYDRO-DYNAMIC SEPARATORS
RIP RAP SWALE
BIORETENTION CELL
SURFACE SAND FILTER
RETENTION POND
SAMPLING GALLERY

Parallel Performance Evaluation

- Each system uniformly sized to treat 1" runoff for 1 acre of impervious area
- WQV=3300 cf
- Q_{wqv}=1 cfs
- Uniform contaminant loading
- Uniform storm event characteristics
- Systems lined for mass balance
- Long term record of hydrology and contaminants




Hydrodynamic Separator


Isolator Row


Subsurface Infiltration


Filter Unit


Porous Asphalt


Pervious Concrete


Retention Pond


Stone Swale


Veg Swale

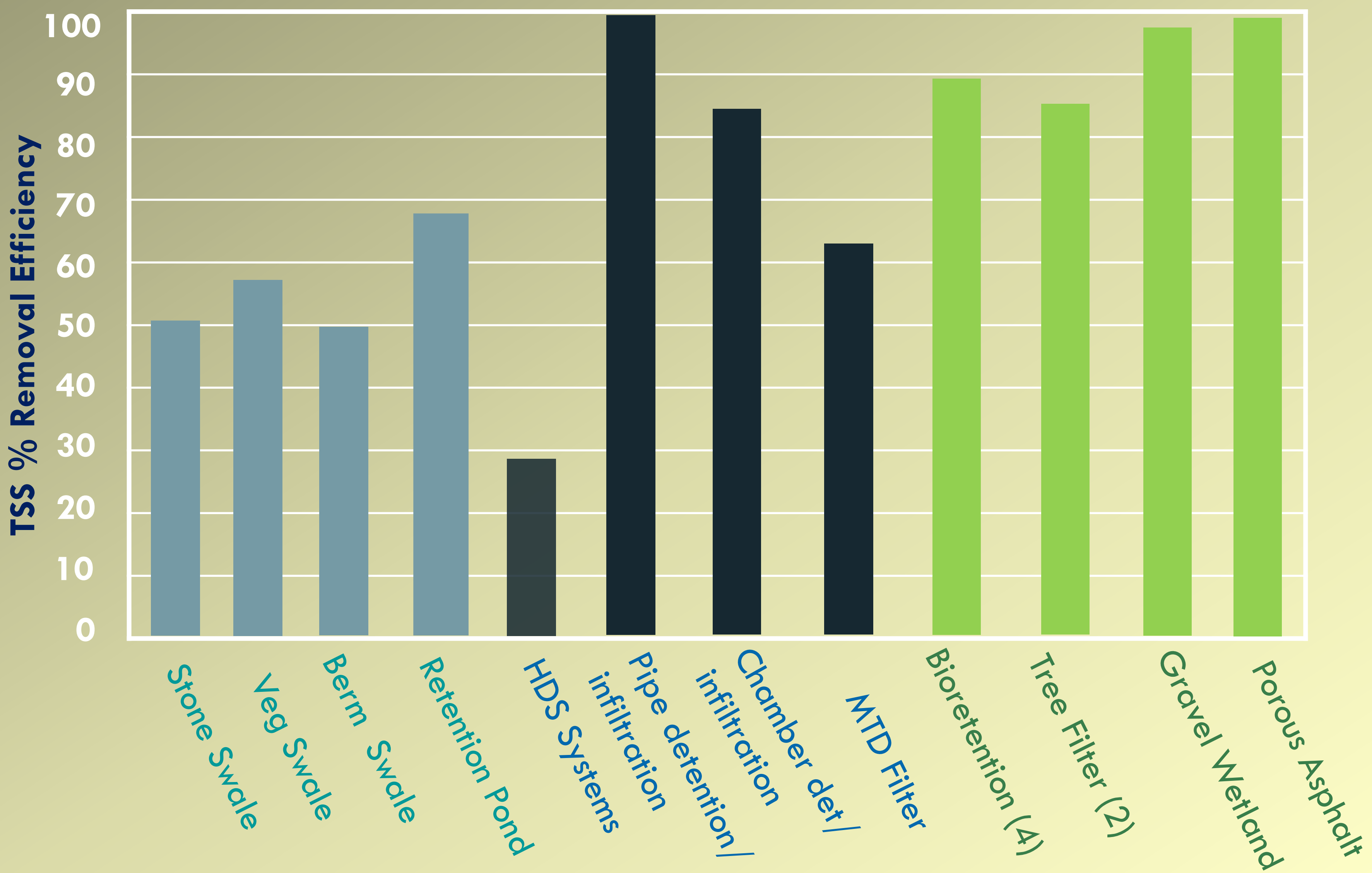

Gravel Wetland


Sand Filter

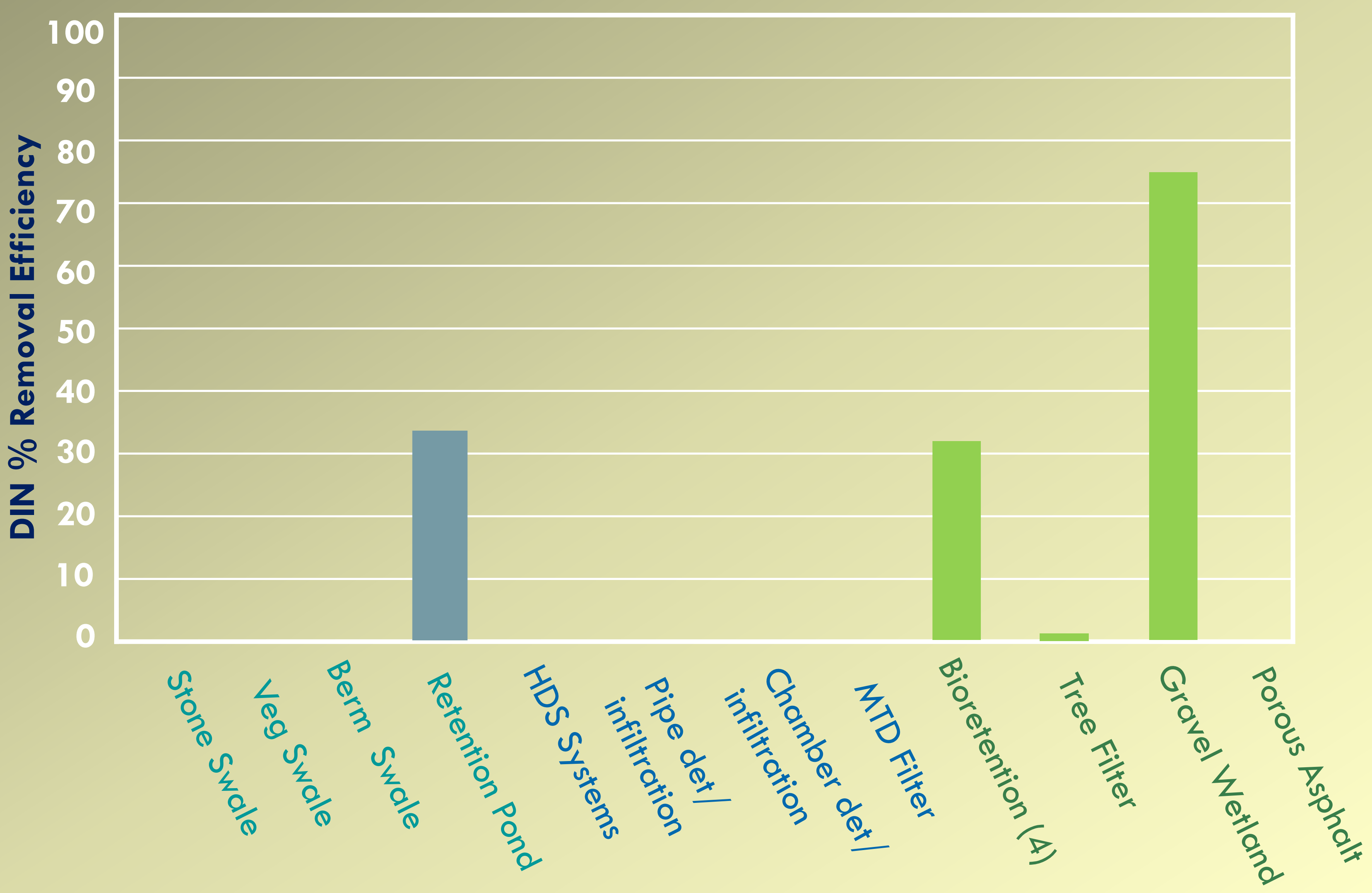

Bioretention Unit


Tree Filter

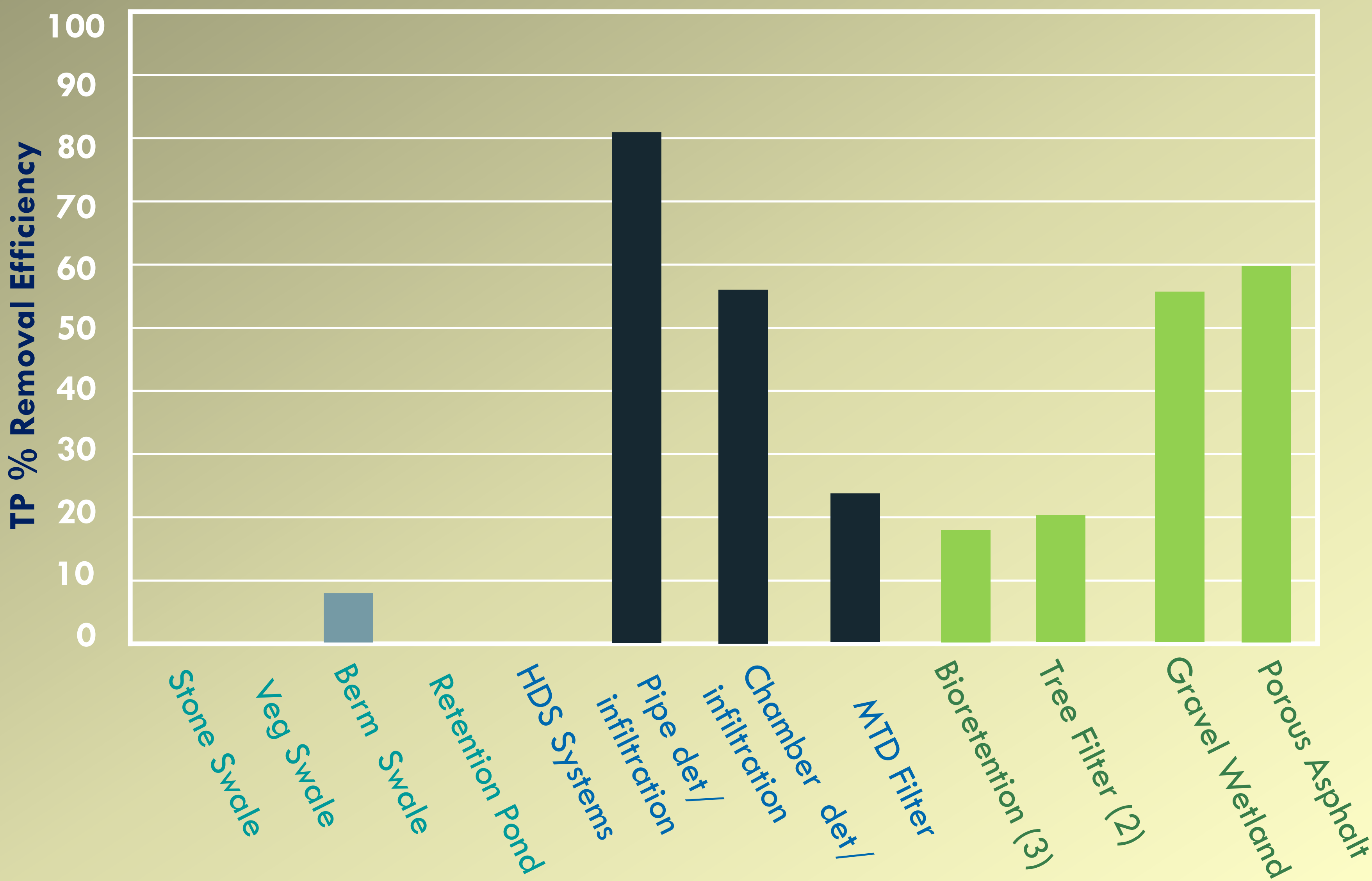
TSS Removal Efficiencies



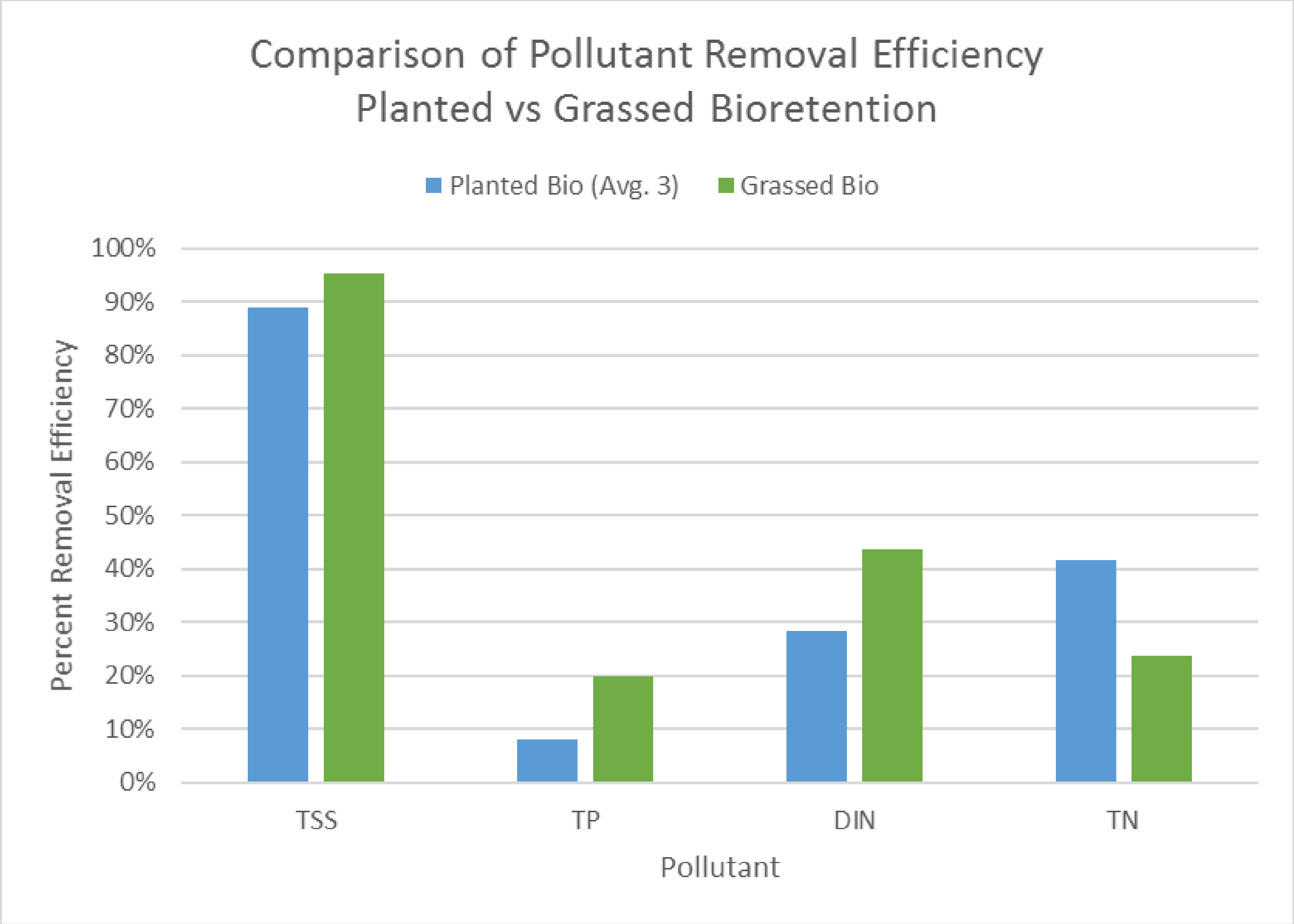
DIN Removal Efficiencies



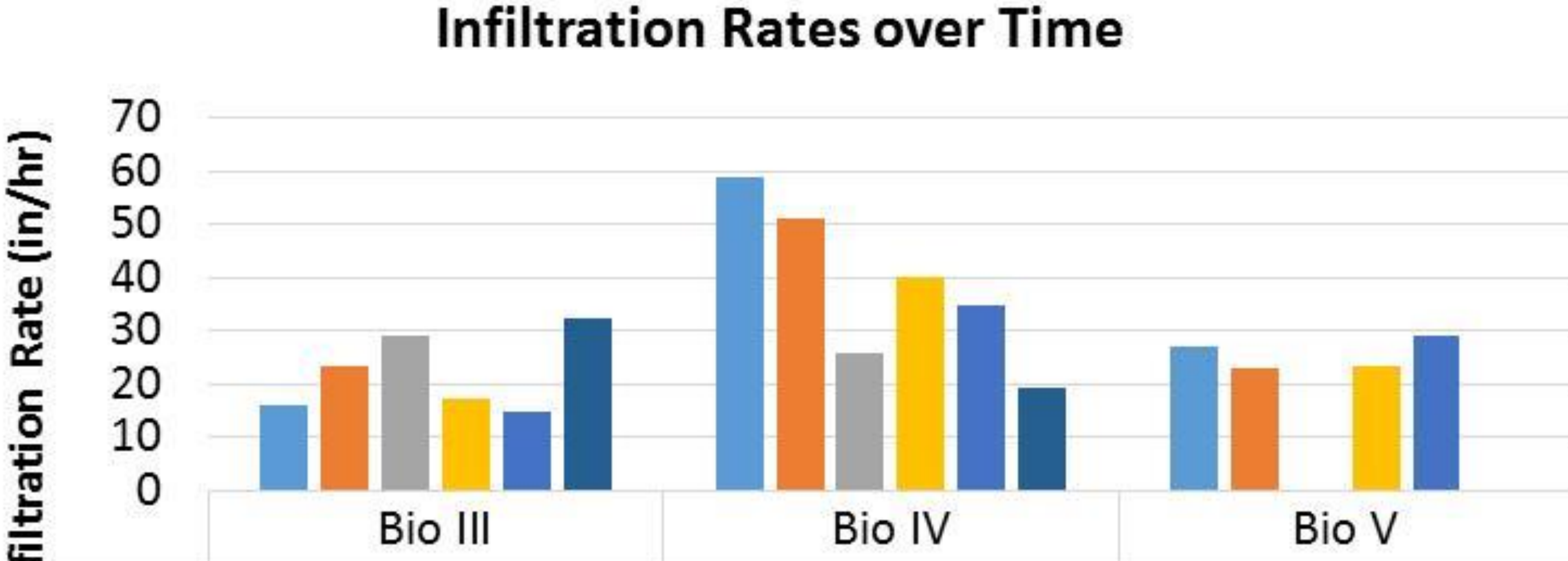
TP Removal Efficiencies



The Role of vegetation



Long-term Infiltration Testing



	Bio III	Bio IV	Bio V
Year 1	16.2	58.7	27.2
Year 2	23.6	51.0	23.1
Year 3	29.2	25.7	0.0
Year 4	17.1	40	23.5
Year 5	14.8	35	29.0
Year 6	32.5	19.3	

Economics and Costs

Boulder Hills, Pelham, NH

- 2009 Installation of 900 ft of first PA private residential road in Northeast
- Site is nearly Zero discharge (HSG A soils)
- LID subdivision 55+ Active Adult Community
- PA Cost 25% greater per ton installed than DMA

Conventional Site Design

LID Design

Boulder Hills Specs

- Built on 9% grade
- Avoided use of 1616 ft of curbing, 785 ft pipe, 8 catch-basins, 2 detention basins, 2 outlet control structures
- 1.3 acres less of land clearing
- Conventional SWM = $789,500

LID SWM = $740,300

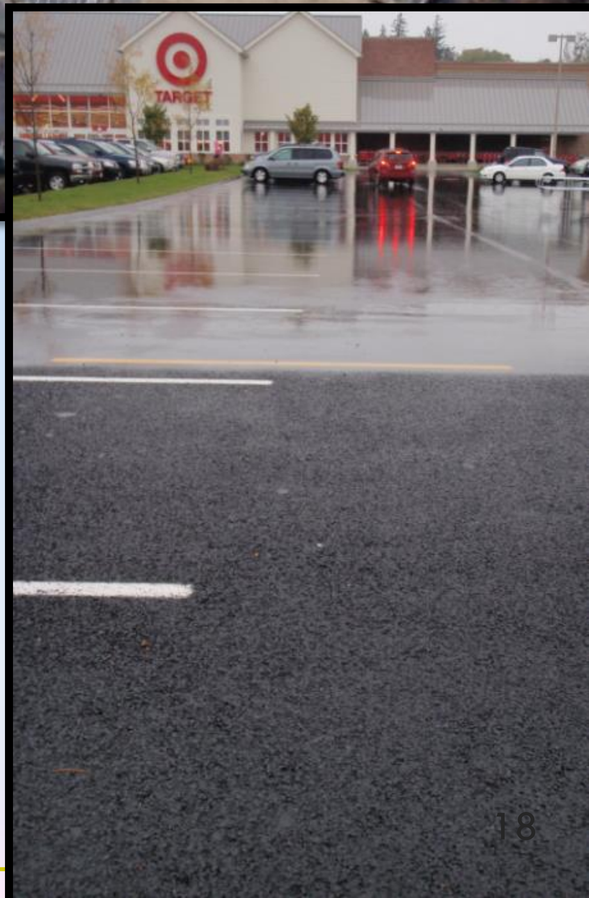
$49,000 savings (6.2%)

Comparison of Unit Costs

Item	Conventional	LID	Difference
SITE PREPARATION	$23,200.00	$18,000.00	–$5,200.00
TEMP. EROSION CONTROL	$5,800.00	$3,800.00	–$2,000.00
DRAINAGE	$92,400.00	$20,100.00	–$72,300.00
ROADWAY	$82,000.00	$128,000.00	$46,000.00
DRIVEWAYS	$19,700.00	$30,100.00	$10,400.00
CURBING	$6,500.00	$0.00	–$6,500.00
PERM. EROSION CONTROL	$70,000.00	$50,600.00	–$19,400.00
ADDITIONAL ITEMS	$489,700.00	$489,700.00	$0.00
BUILDINGS	$3,600,000.00	$3,600,000.00	$0.00
PROJECT TOTAL	$4,389,300.00	$4,340,300.00	–$49,000.00

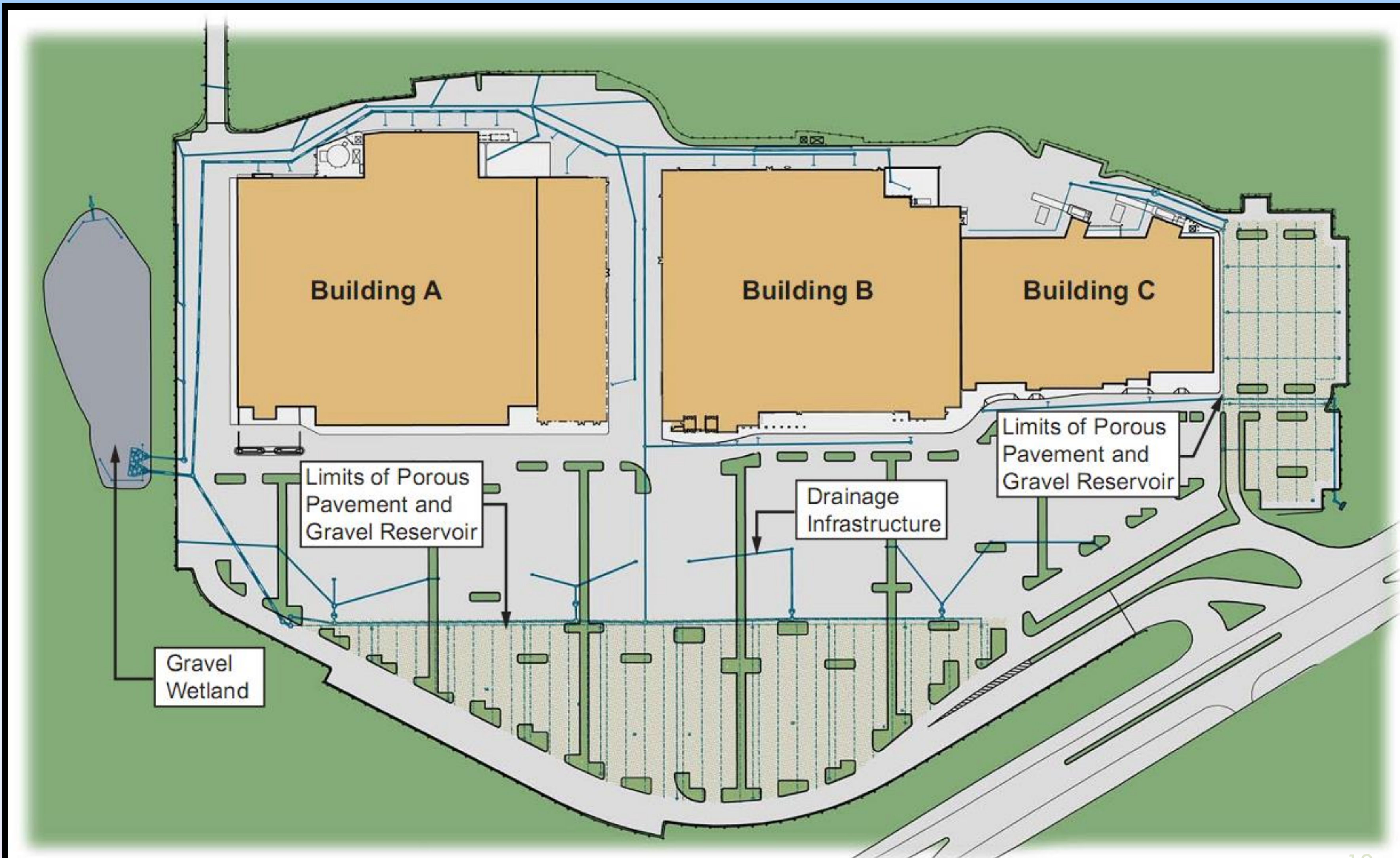
6% savings on total cost of SW infrastructure for a ~zero discharge site

Greenland Meadows Commercial, Greenland, NH



- "Gold-Star" Commercial Development
- Cost of doing business near Impaired Waters/303D
- Brownfields site
- Proposed site >10,000 Average Daily Traffic count on >30 acres

Greenland Meadows



Comparison of Unit Costs

Item	Conventional Option	LID Option	Cost Difference
MOBILIZATION / DEMOLITION	$555,500	$555,500	$0
SITE PREPARATION	$167,000	$167,000	$0
SEDIMENT / EROSION CONTROL	$378,000	$378,000	$0
EARTHWORK	$2,174,500	$2,103,500	–$71,000
PAVING	$1,843,500	$2,727,500	$884,000
STORMWATER MANAGEMENT	$2,751,800	$1,008,800	–$1,743,000
ADDITIONAL WORK-RELATED ACTIVITY (utilities, lighting, water & sanitary sewer service, fencing, landscaping, etc.)	$2,720,000	$2,720,000	$0
PROJECT TOTAL	$10,590,300	$9,660,300	–$930,000

LID Retrofit: UNH Parking Lot Bioretention

- Simple, used existing infrastructure and median
- $14,000/acre retrofit for everything
- Labor and install was $8,500/ac   (2012)
- Materials and plantings $5,500/ac

School Street School LID Retrofit

Background:

- School Street School is 0.6 acres of impervious surface with no stormwater management, and 64% IC
- No drainage structures exist resulting in sheet flow runoff from all impervious areas during storms to playground
  - Localized flooding
  - Reduced use of playground facilities
  - Damage to adjacent road and sidewalk
  - Water quality impacts to Willow Brook

Retrofit Accomplishments

- Improved drainage and usability
- Intercept runoff, divert from principle use areas (playground and parking lot)
- Store, treat, infiltrate, convey
- Increased pedestrian safety (reduced ponding, snow and ice).
- Retrofits treated % 80 of IC
- $IC_{initial}$= 64% → EIC 13%

Existing Conditions

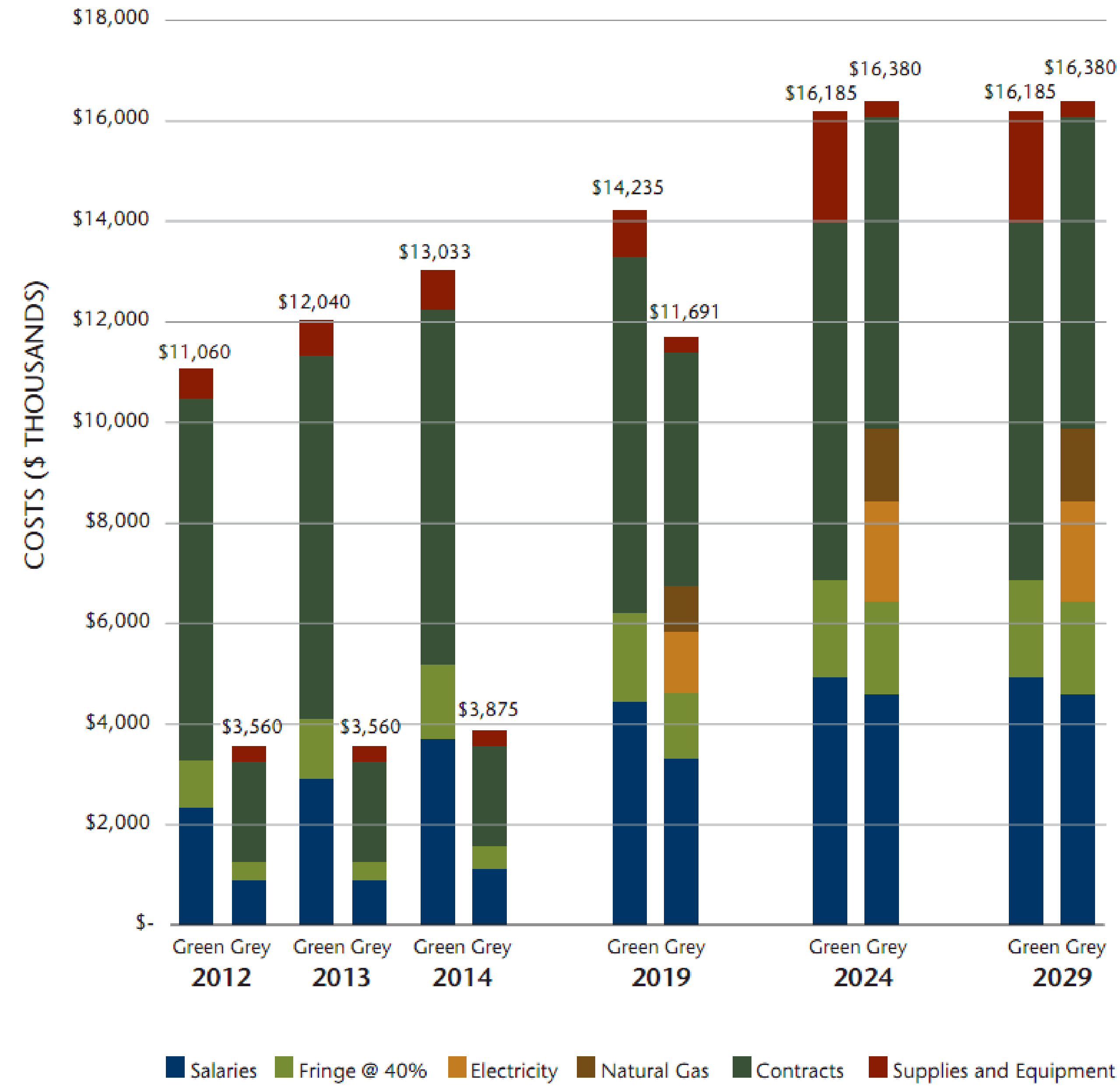
LID Installations





NYC O&M Costs CSO Control Scenarios

- Funds for labor, supplies, and equipment
- Replacing energy demands of grey infrastructure



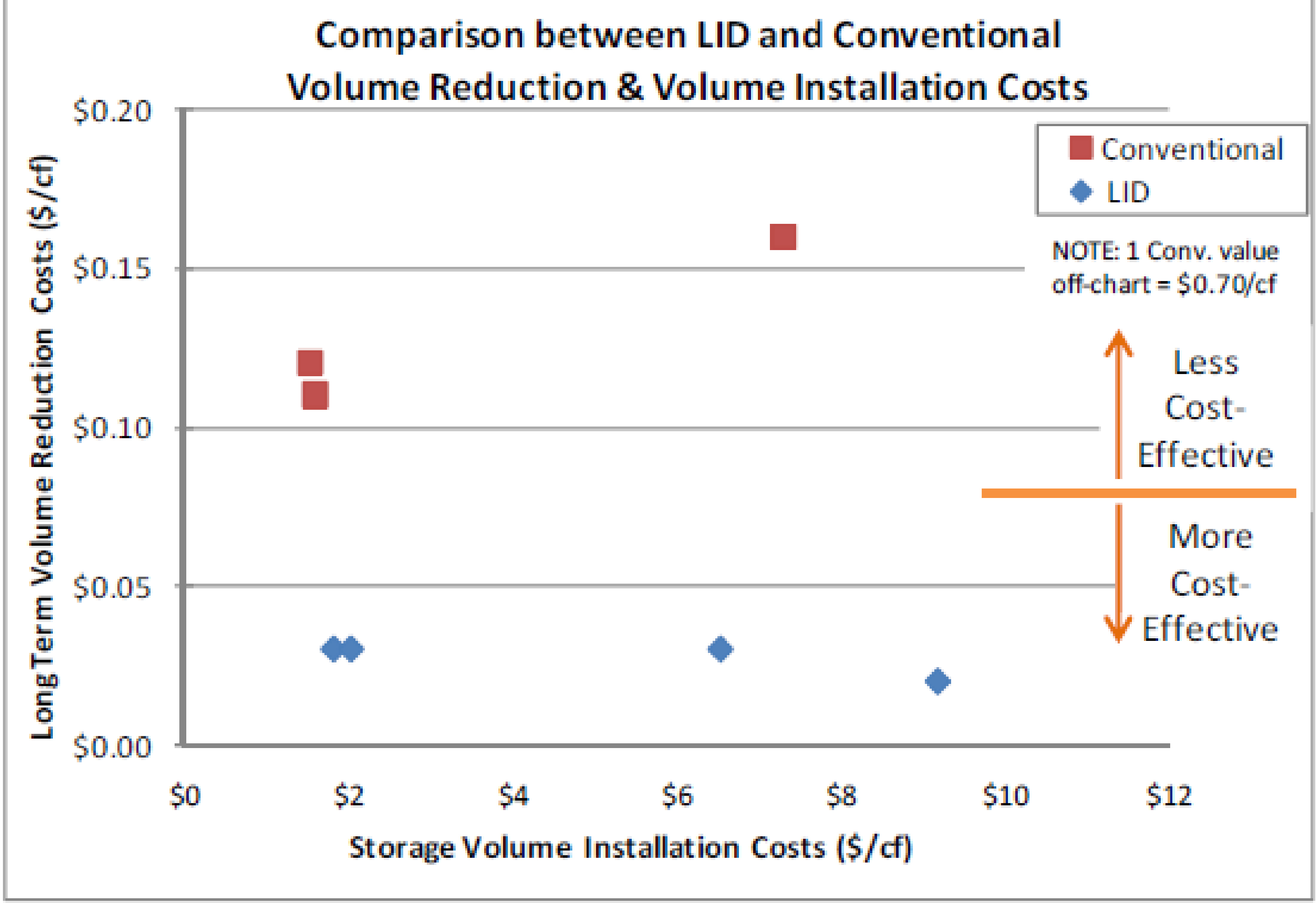


Figure #. BMP Long Term Volume Reduction Cost vs. Storage Volume Installation Cost

GI practice maintenance

Critical components of a best-case scenario:

1. Appropriate Design
2. Installation

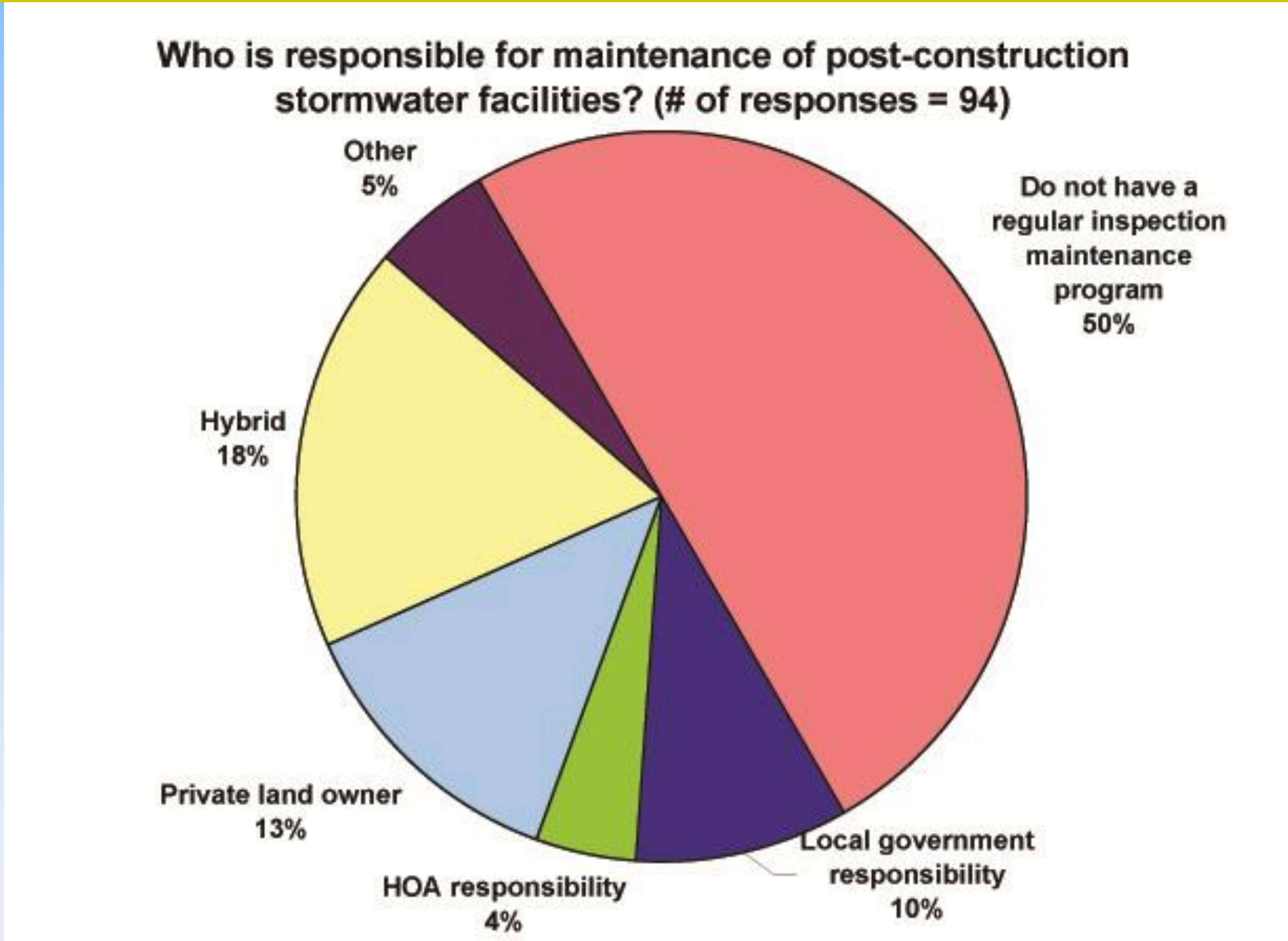
…. Then Maintenance

People who pay for the maintenance or maintain the systems should be involved with the design

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

Uncategorized Maintenance

- Crack sealing
- Filling pot holes
- Resetting curbs
- Culvert reinforcement/replacement/renewal
- Pipe lining/repair
- Median mulching
- Beautification/sodding
- 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

Stormwater Maintenance
Tools of the trade…

Tools of the trade...

Tools of the trade…

Winter Maintenance

What is it About Winter That is Different?

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

Wintering tree filter

Wintering infiltration system

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 when they happen
- De-ice as necessary
- Plow
- Snow removal

Basically the same for GI

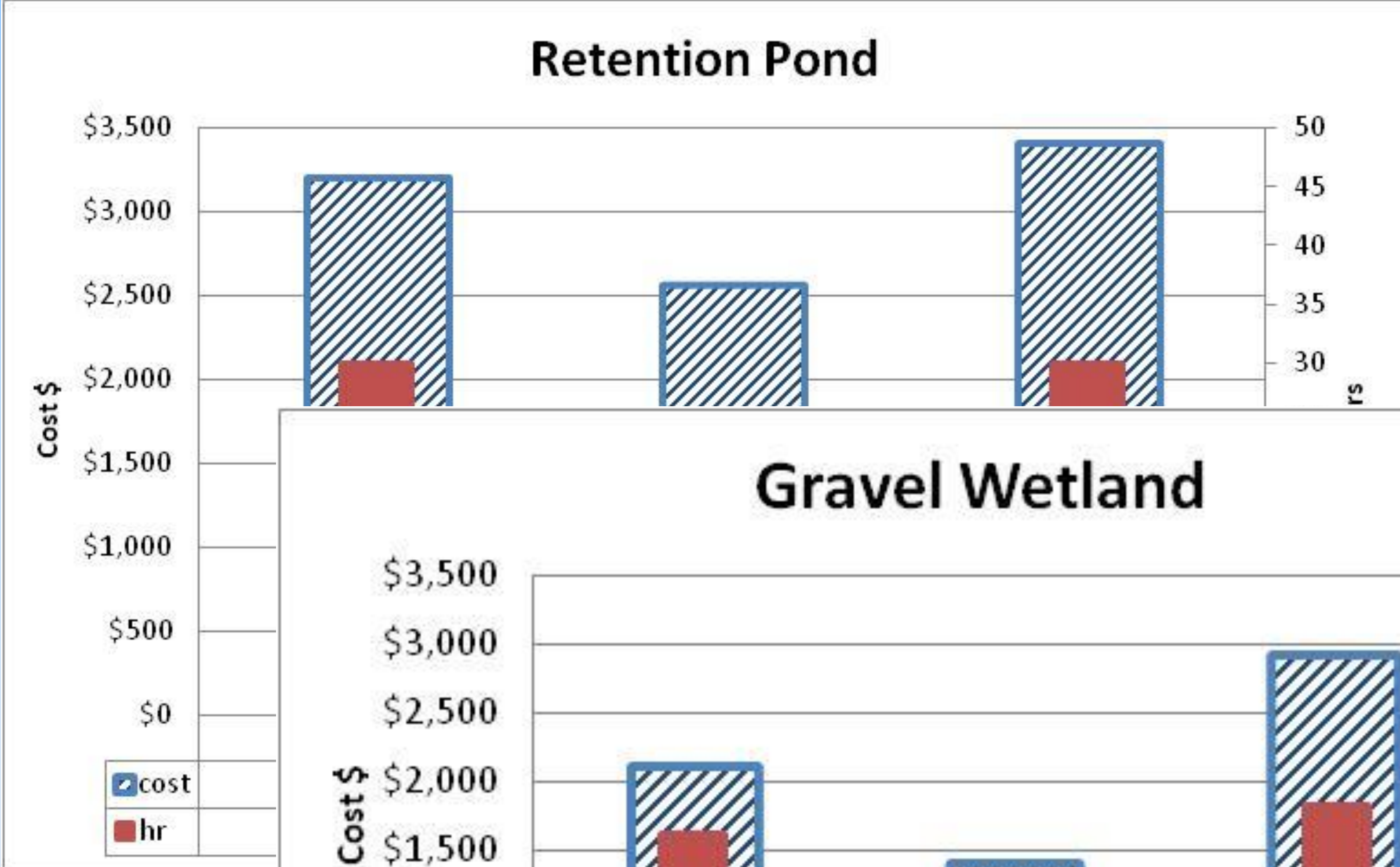
Maintenance is in the eyes of the beholder

A tale of two raingardens

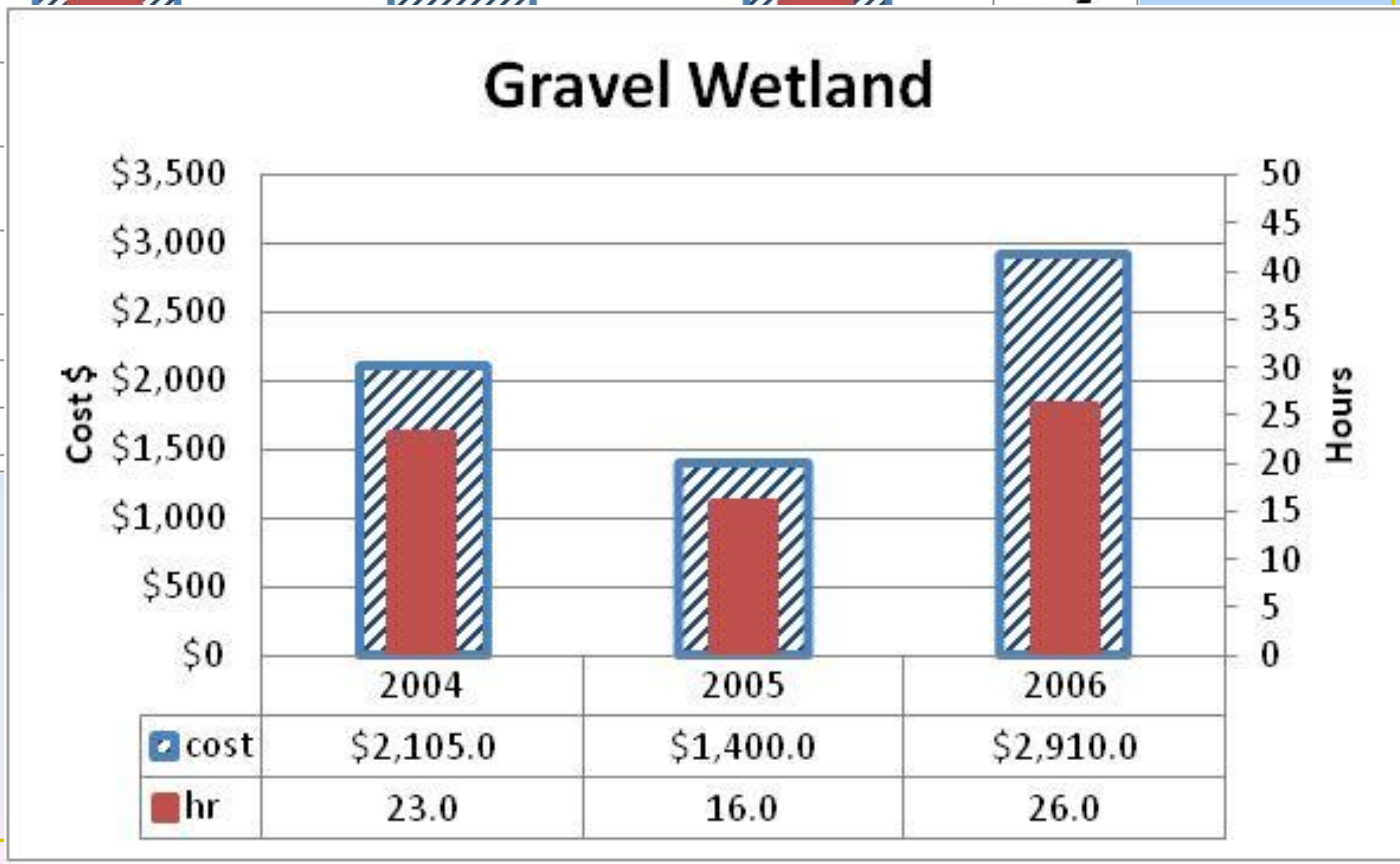
Maintenance solved?

Maintenance Costs - Assumptions

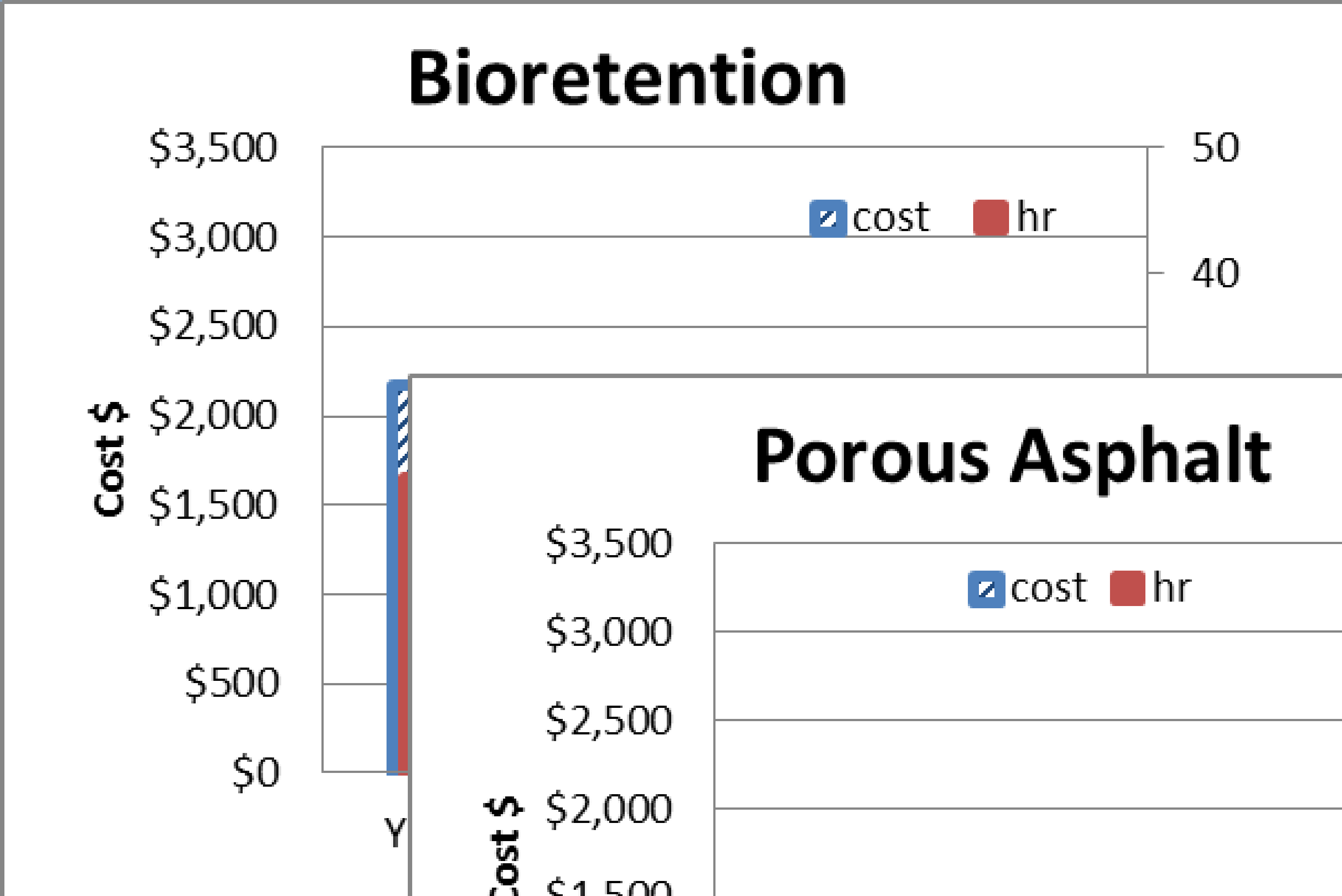
Category of Maintenance	Type of Maintenance	complexity	price ($)
Reactive maintenance	Structural Repairs	complicated	135
	Partial Rehabilitation	complicated	135
	Rehabilitation	complicated	135
Periodic/Predictive maintenance	Solids and Debris Removal	moderate	115
	Inspection	simple	95
	Mowing	minimal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



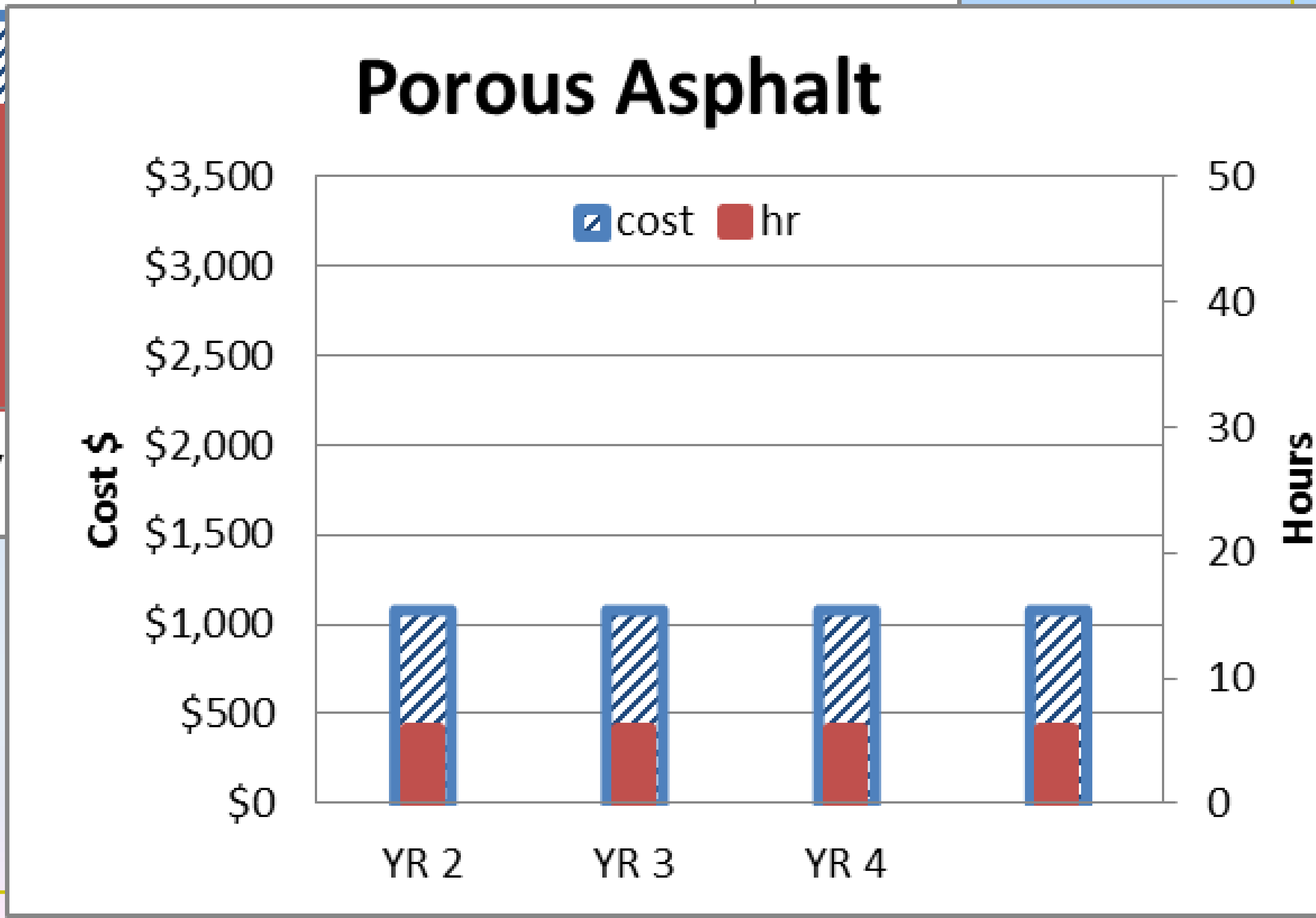
Retention Pond
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
50
45
40
35
30
cost
hr



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



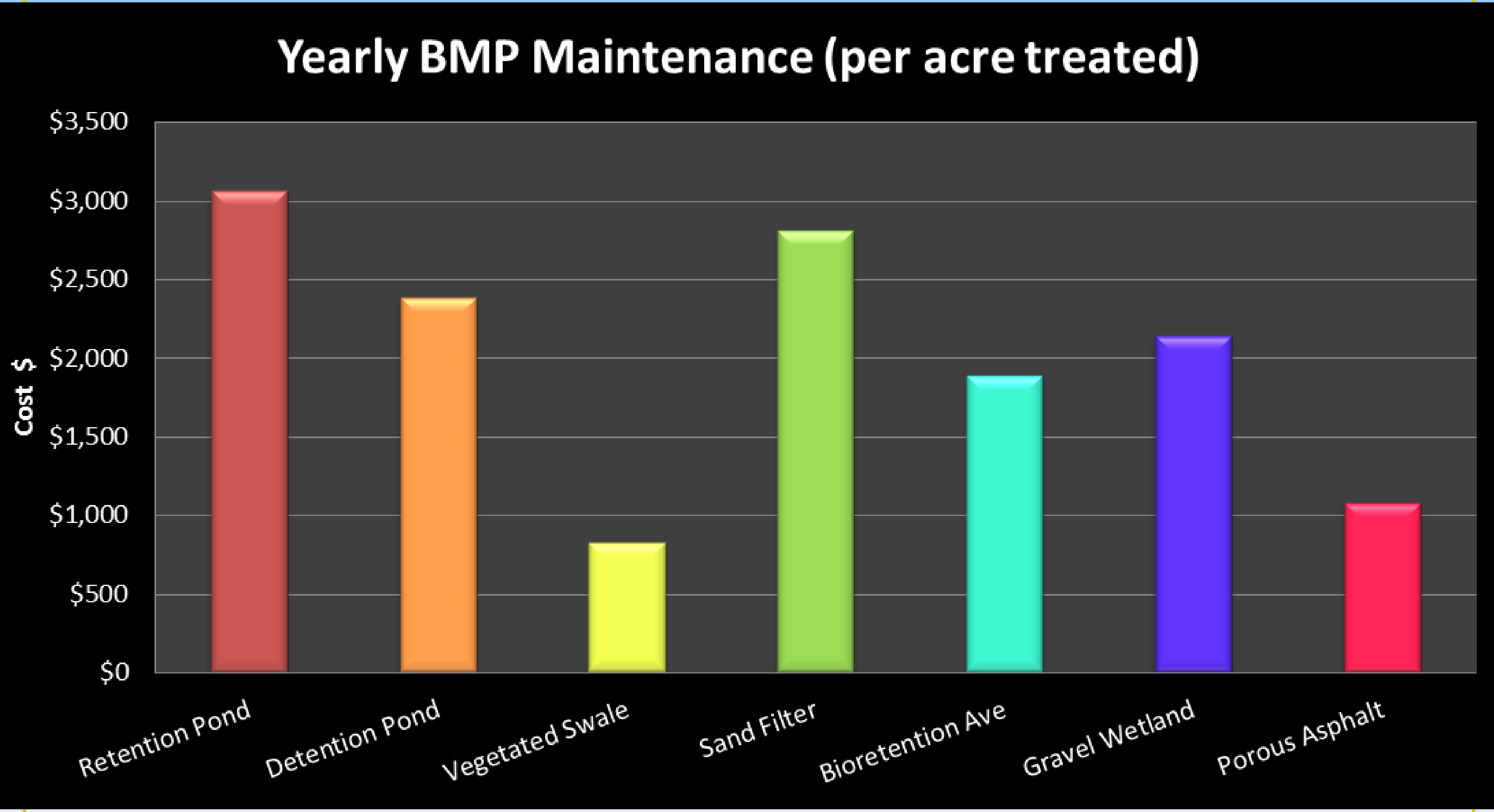
Bioretention
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
cost
hr
50
40

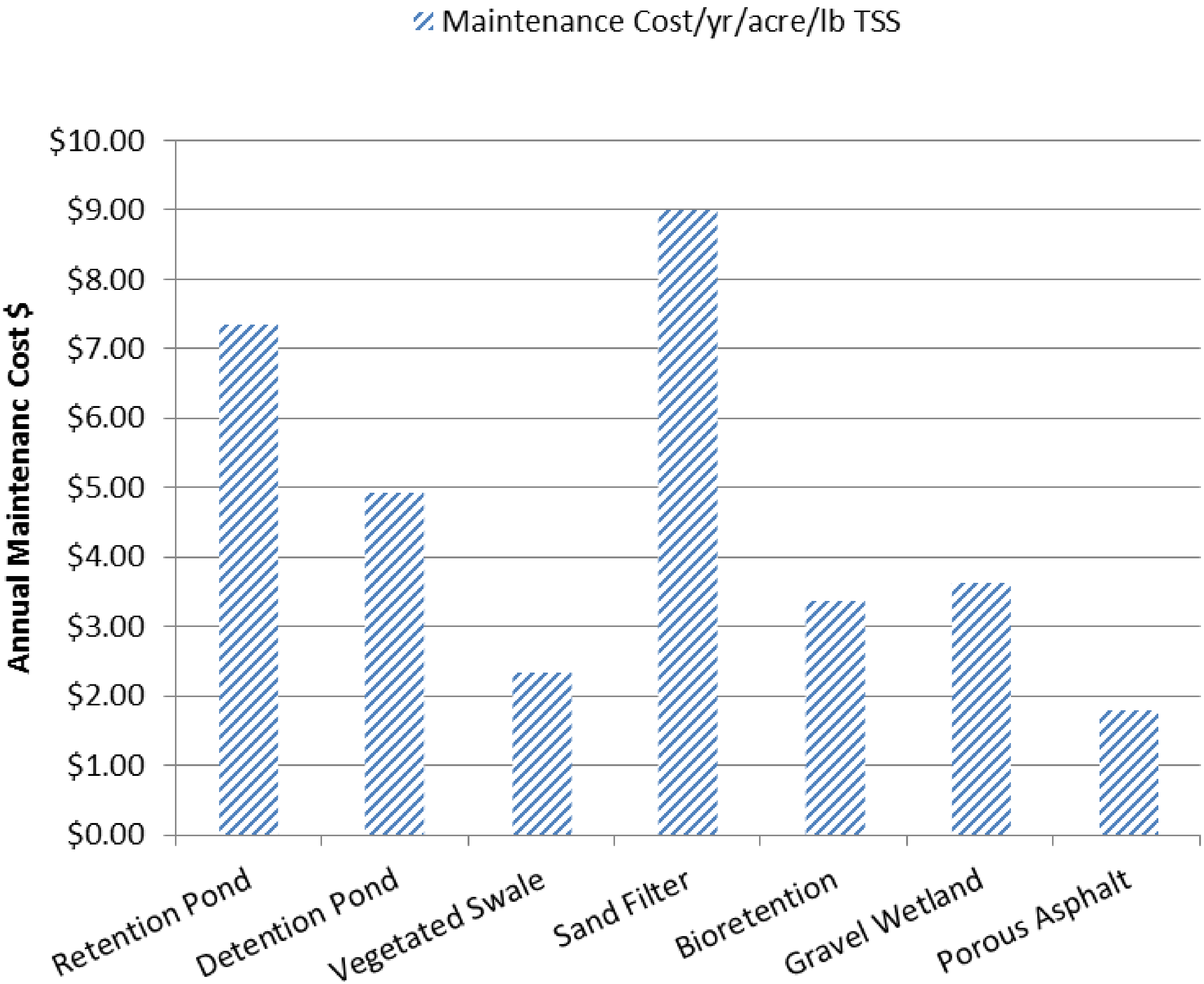


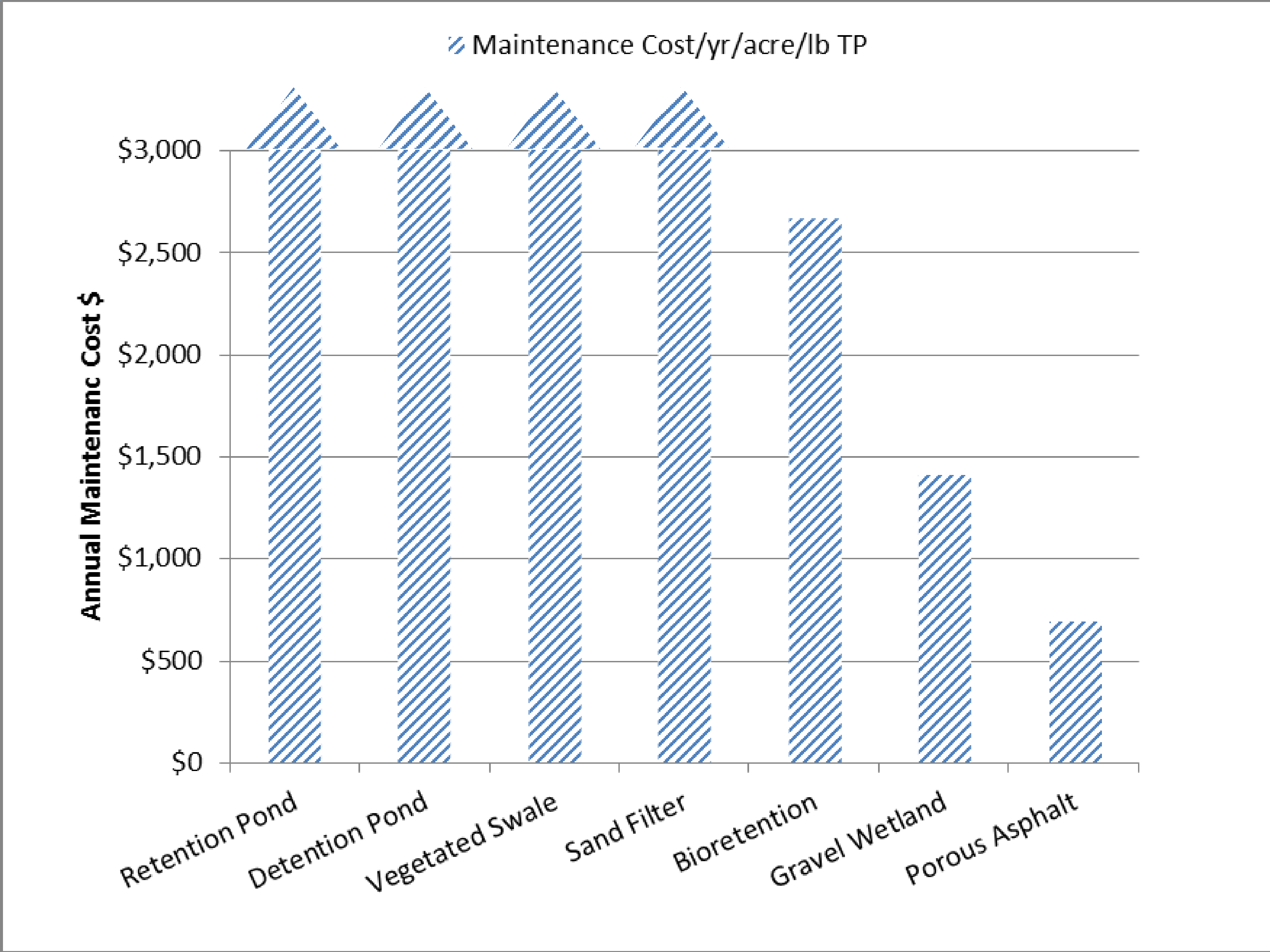
Porous Asphalt
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost $
cost
hr
50
40
30
20
10
0
Hours
YR 2
YR 3
YR 4

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

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

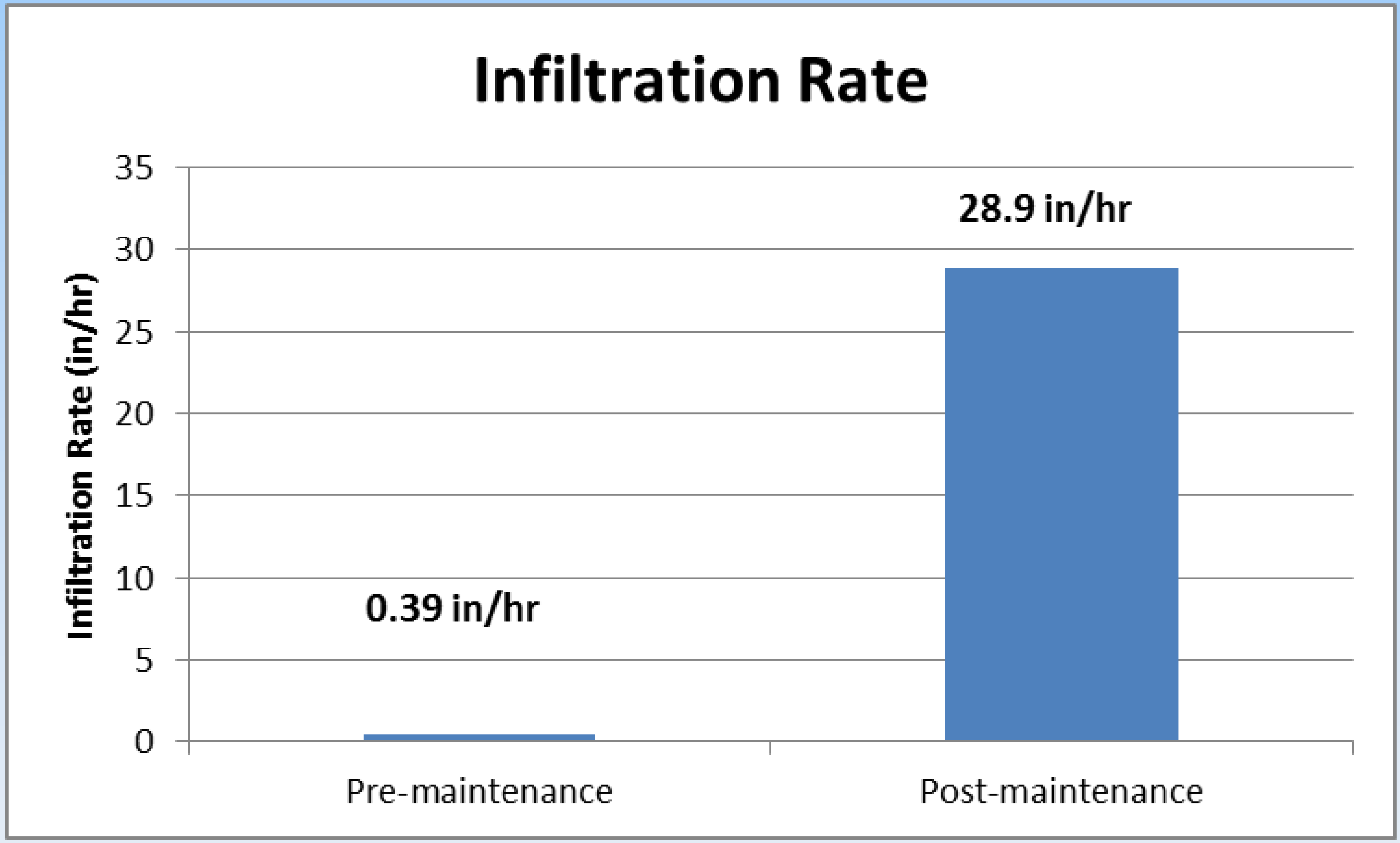
Reactive Maintenance

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

Bioretention/Sand Filter/Tree Filter/Subsurface gravel wetland

- 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	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

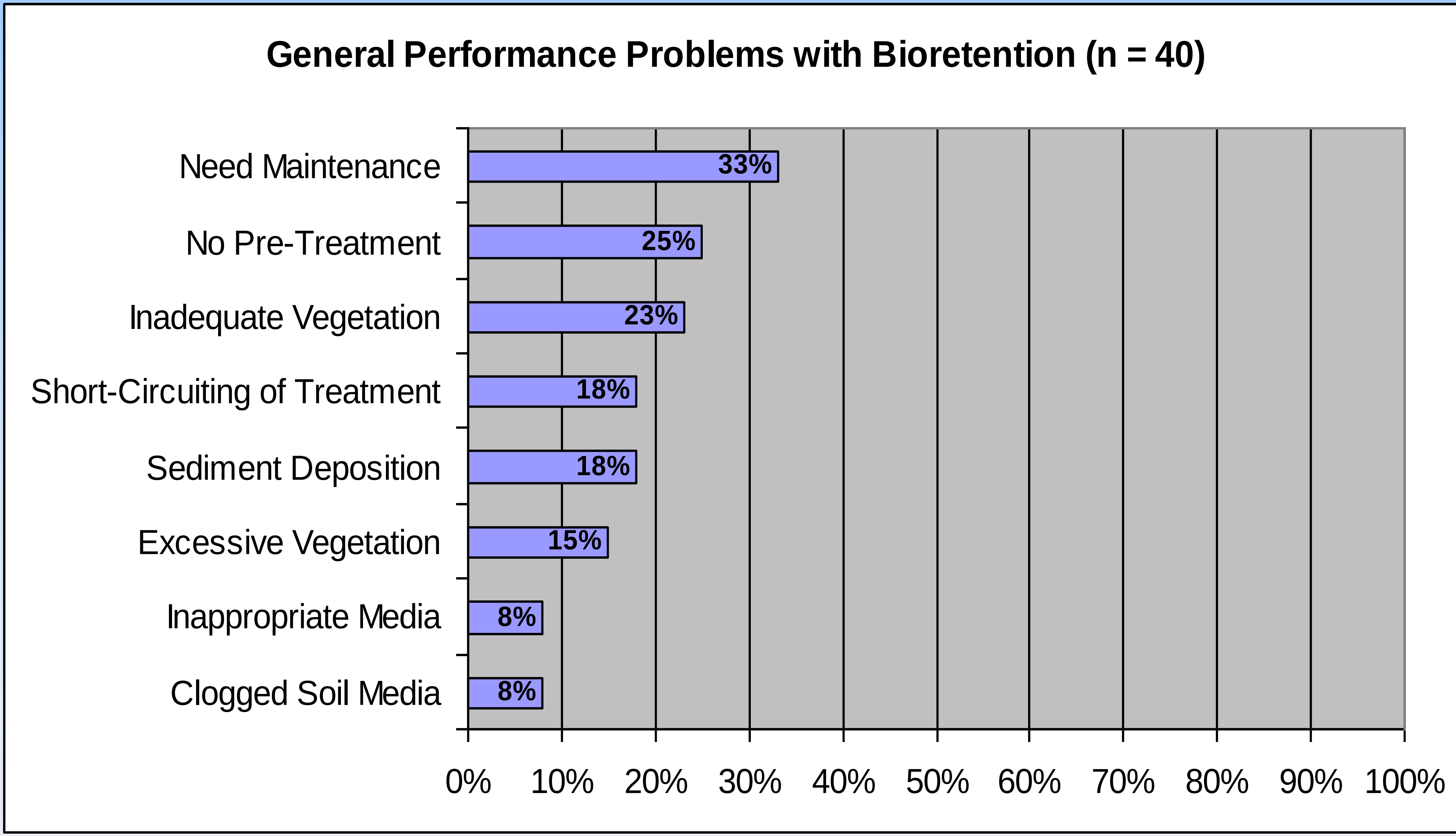
Total personnel hours per year: 16-21 hours

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

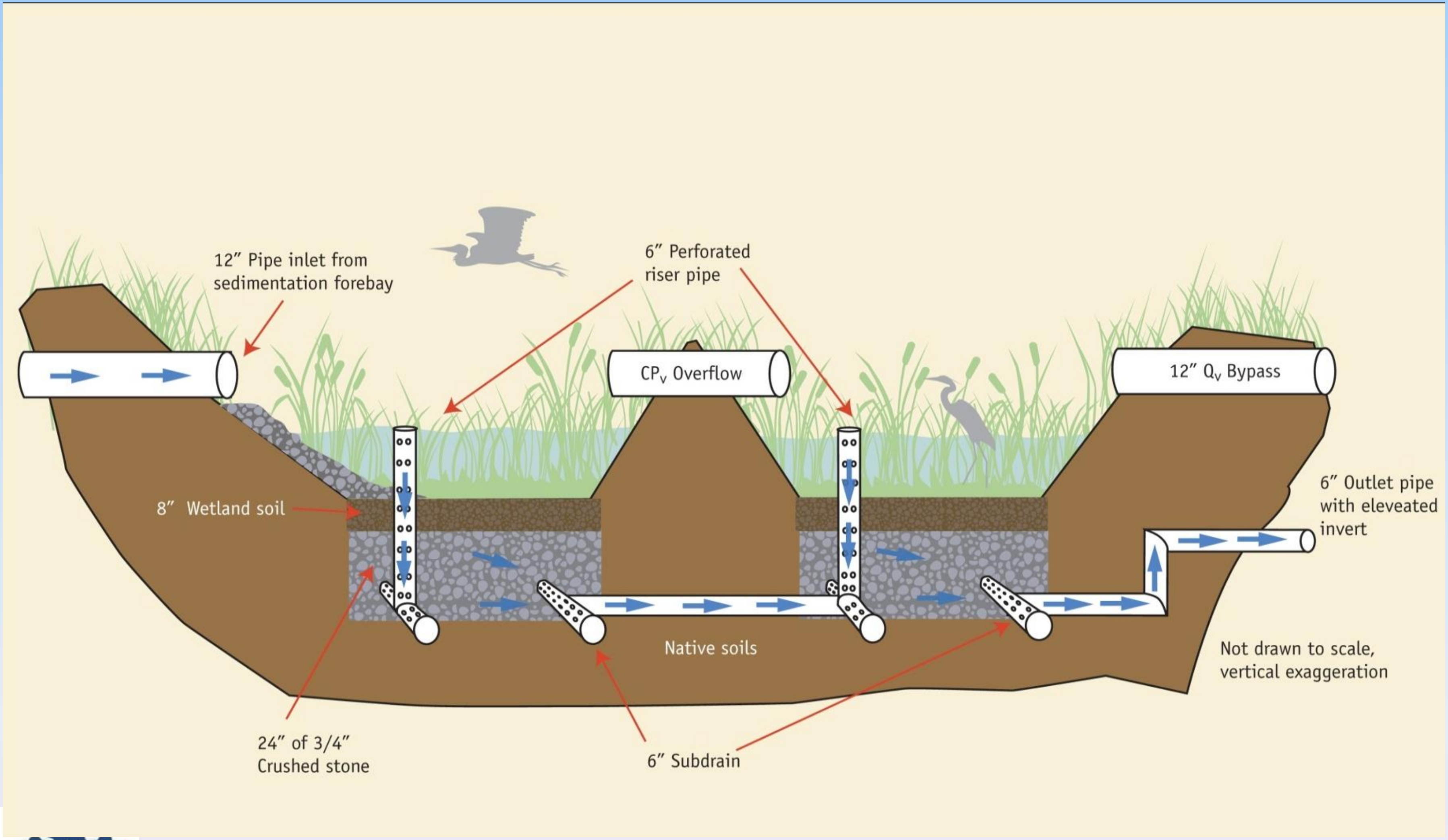


Subsurface Gravel Wetlands

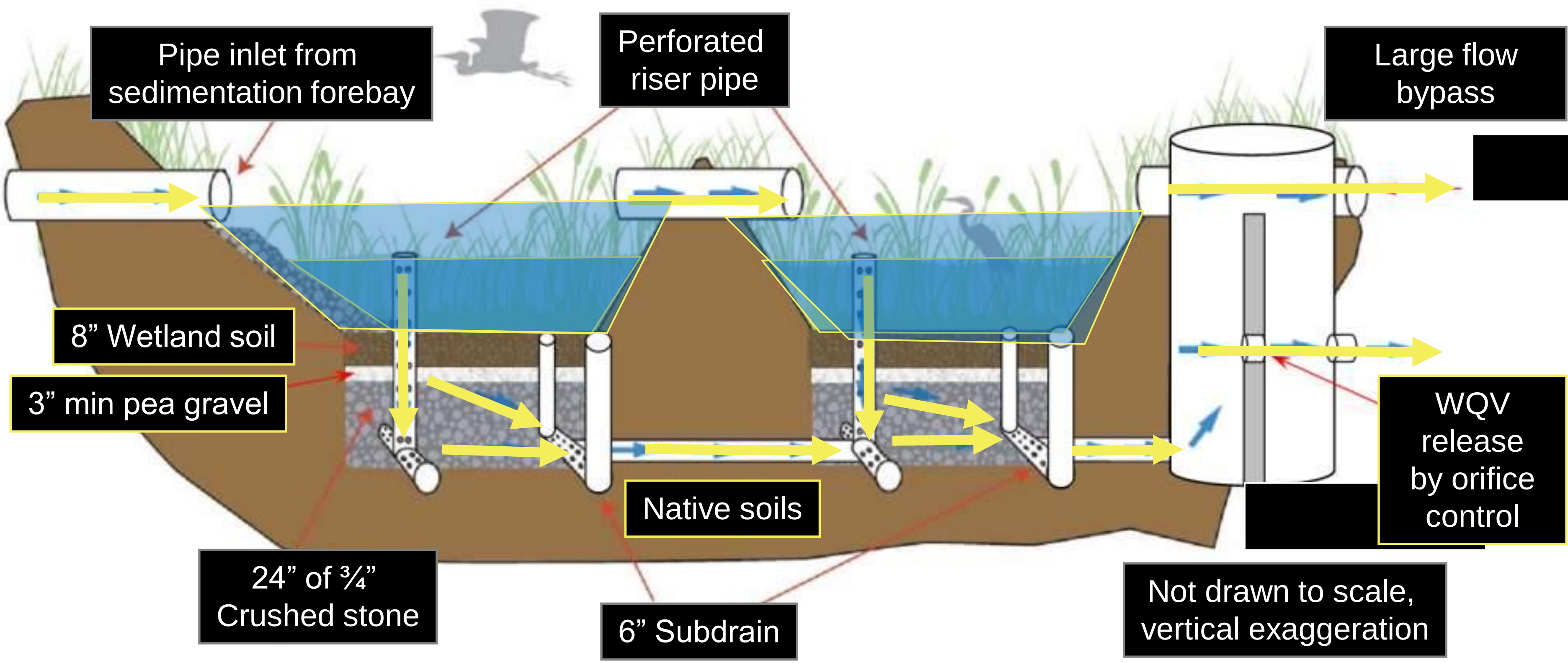
SUBSURFACE GRAVEL WETLAND FUNCTIONALITY AND PERFORMANCE

Subsurface Gravel Wetland

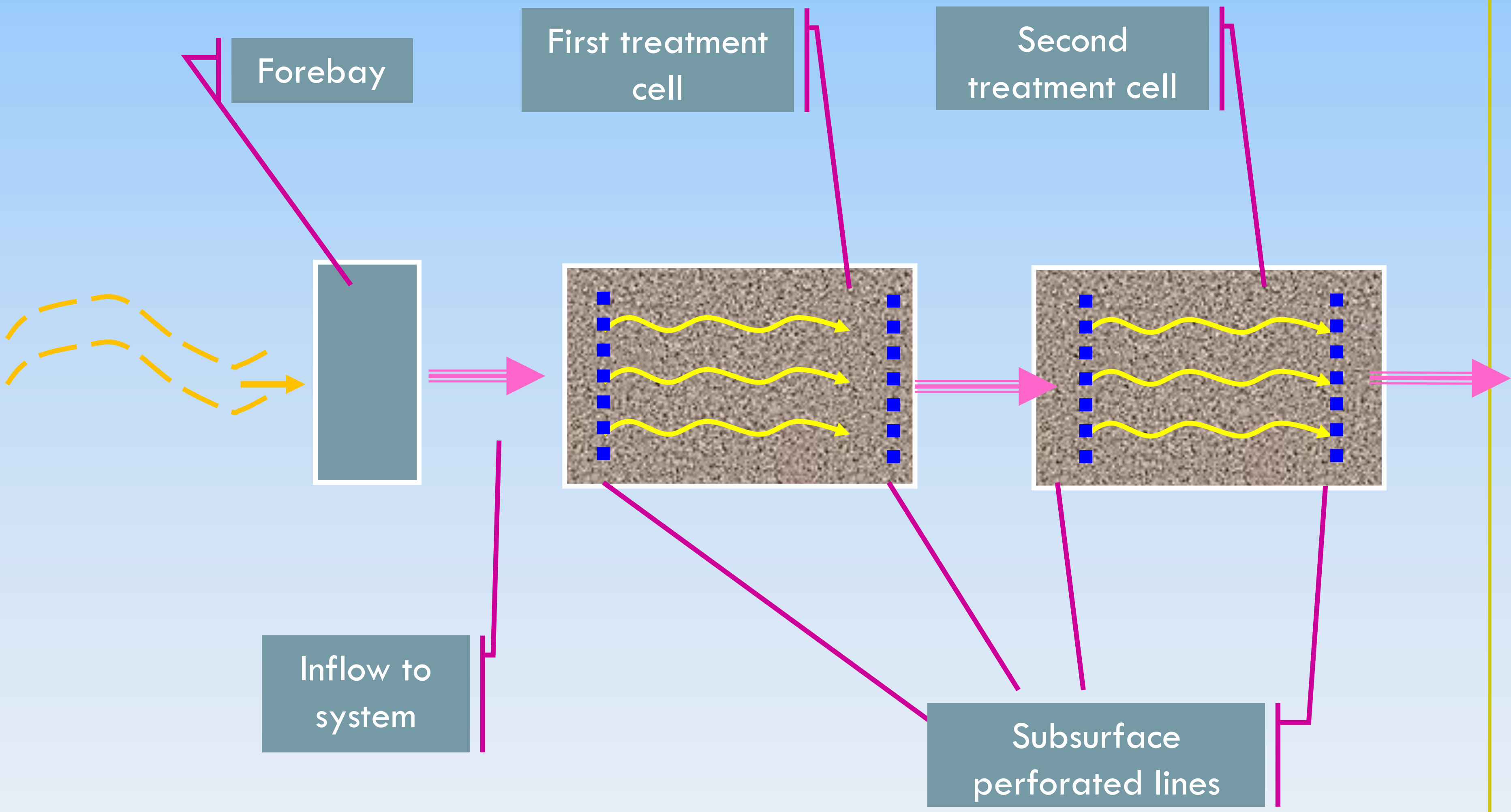
Subsurface Gravel Wetland Components



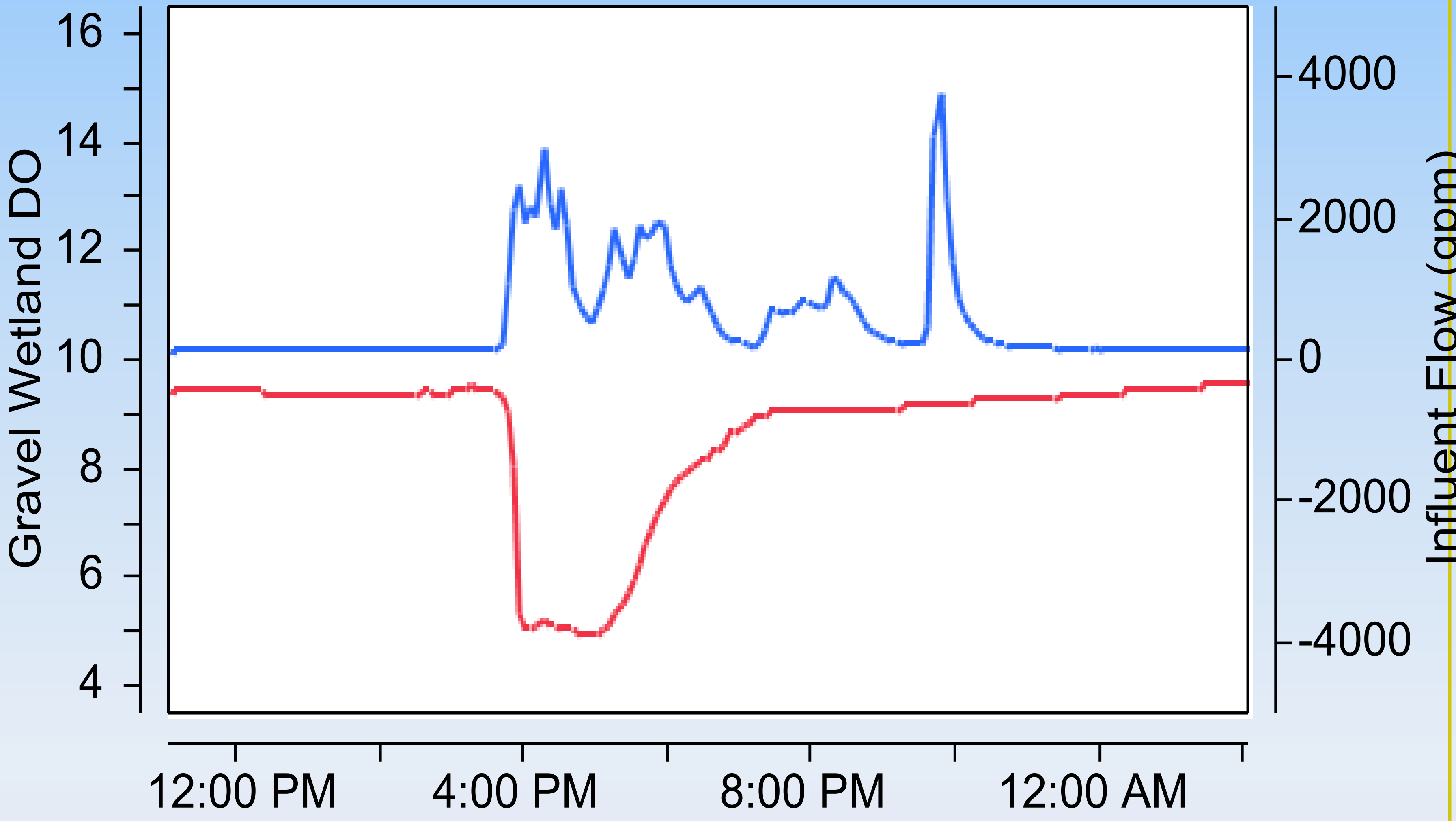
UNHSC Subsurface Gravel Wetland

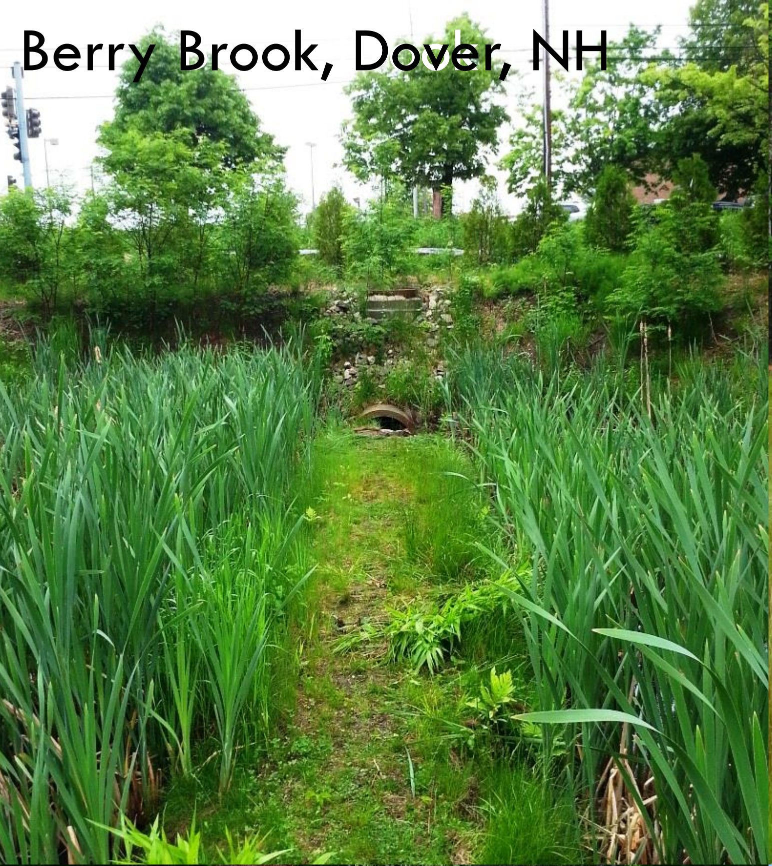


Design Sources:
UNHSC, Roseen, R. M., Ballestero, T. P., and Houle, J. J. (2008). "UNHSC Subsurface Gravel Wetland Design Specifications." University of New Hampshire Stormwater Center, Durham, NH.
Claytor, R. A., and Schueler, T. R. (1996). Design of Stormwater Filtering Systems, Center for Watershed Protection, Silver Spring, MD.
Georgia Stormwater Management Manual, Volume 2: Technical Handbook, August 2001, prepared by AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, Atlanta Regional Commission.


Forebay
First treatment cell
Second treatment cell
Inflow to system
Subsurface perforated lines

Dissolved Oxygen in Gravel Wetland Effluent




Berry Brook, Dover, NH

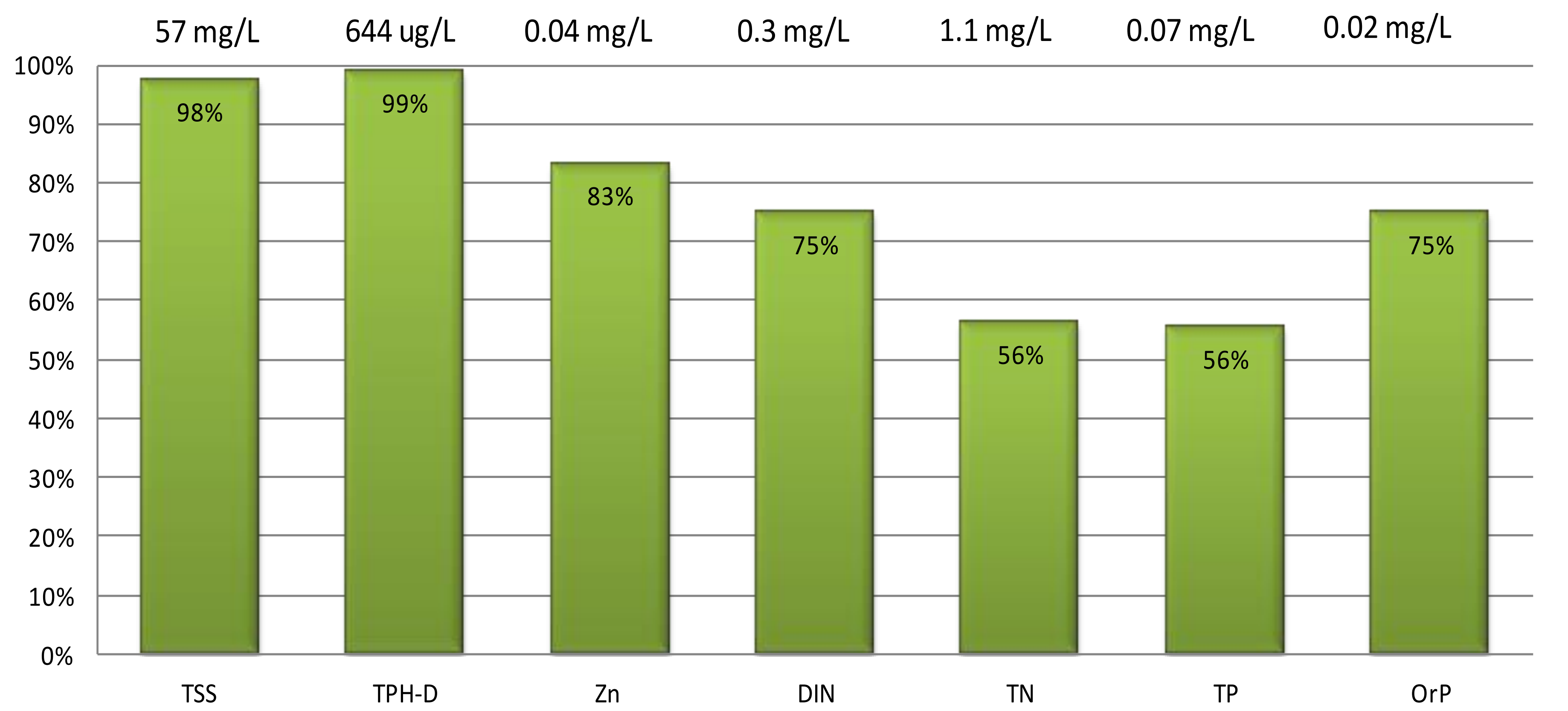

The Cottages, Durham, NH


Oyster River Road

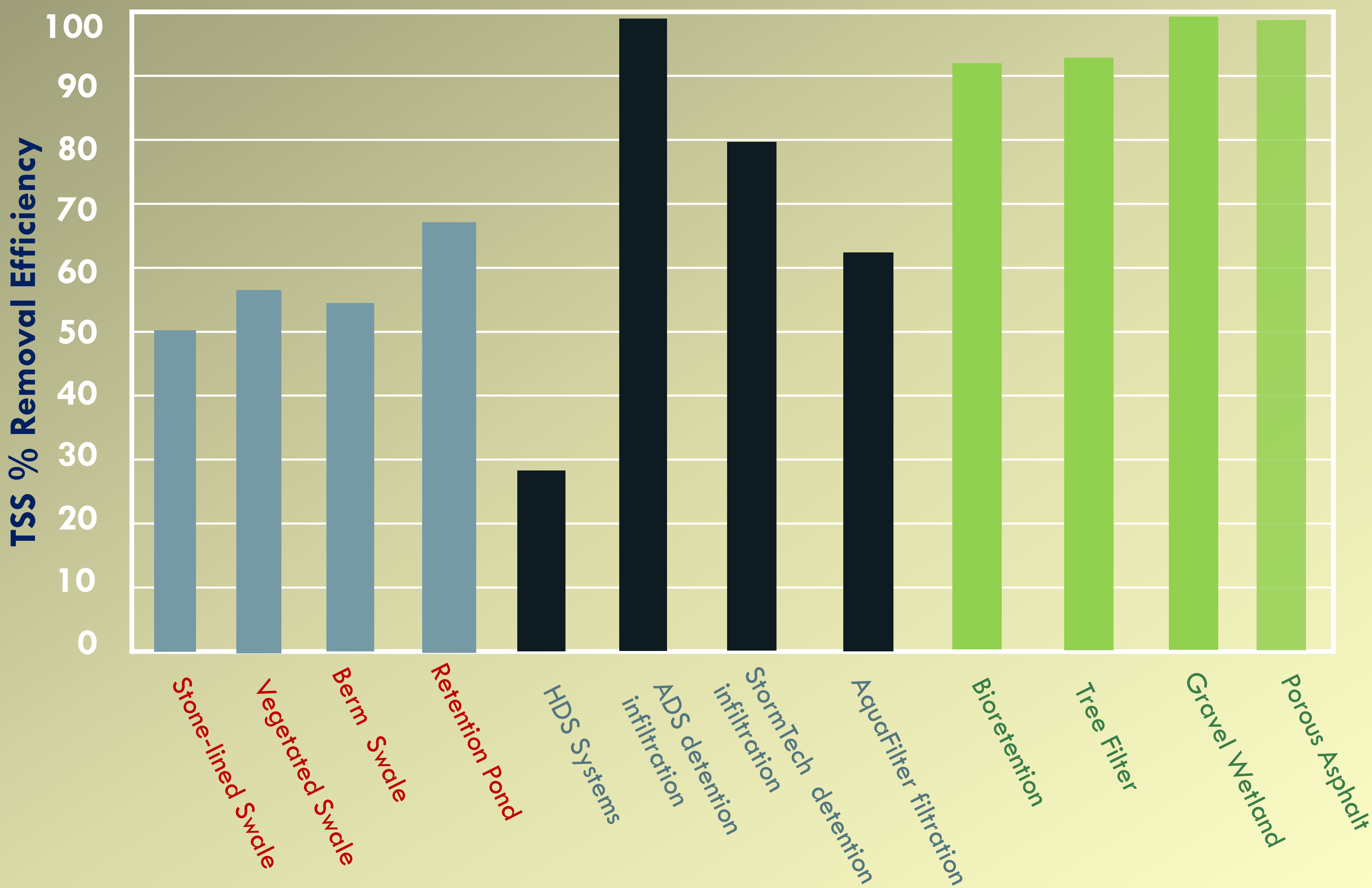

Route 1, Portsmouth, NH

Subsurface Gravel Wetland MedianRemoval Efficiencies

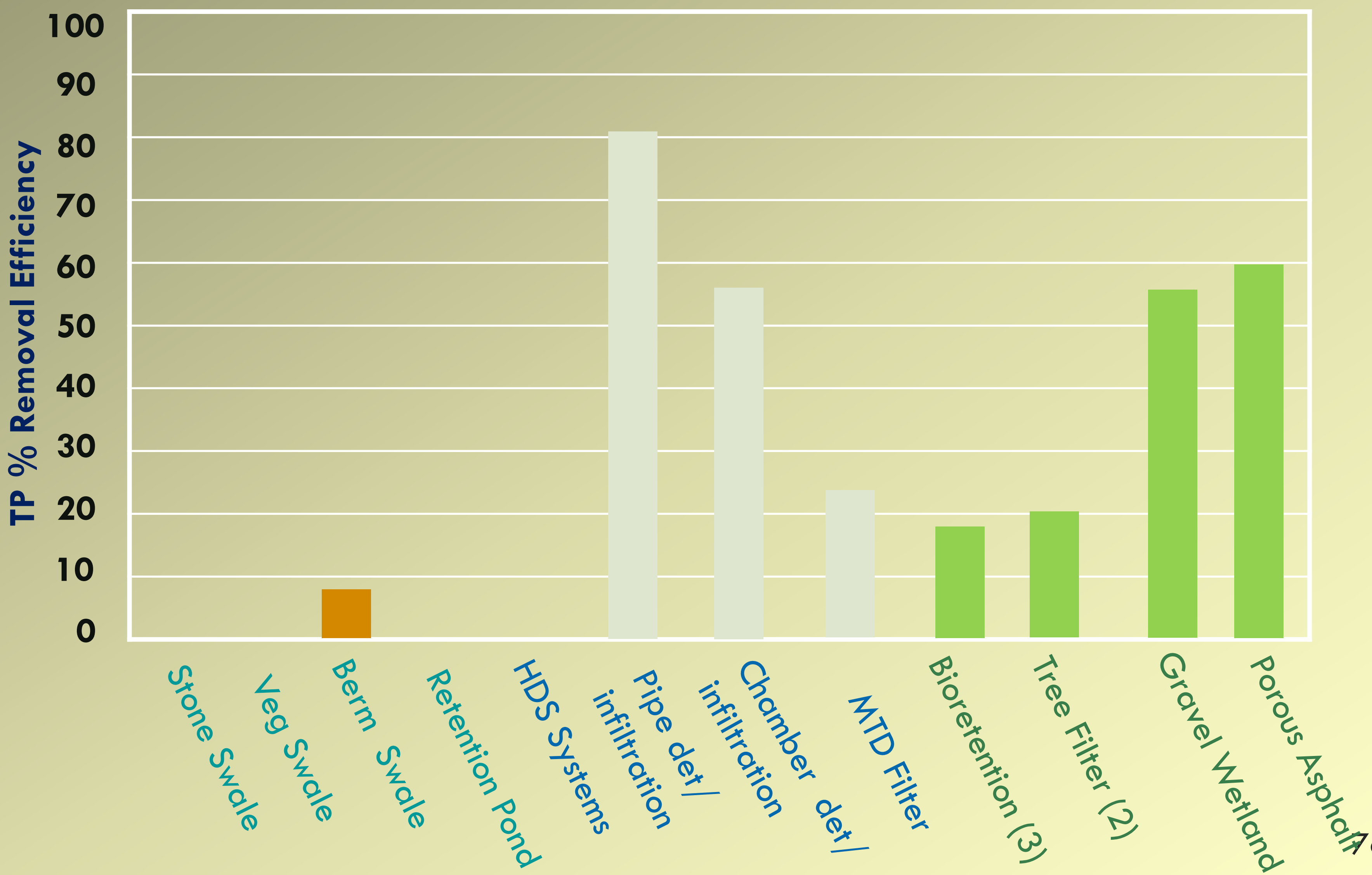
6 years of data with Influent EMC medians



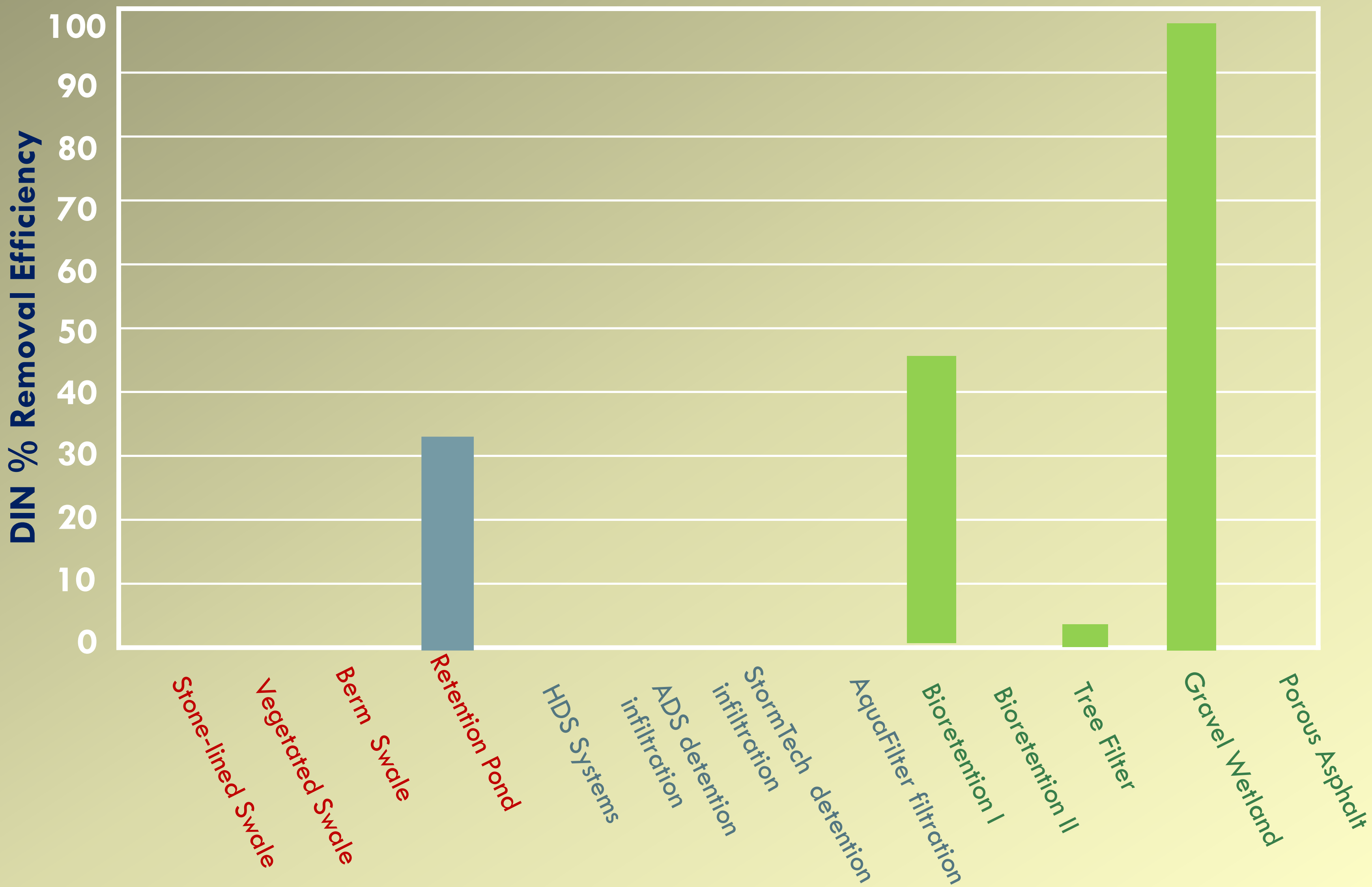
TSS Removal Efficiencies



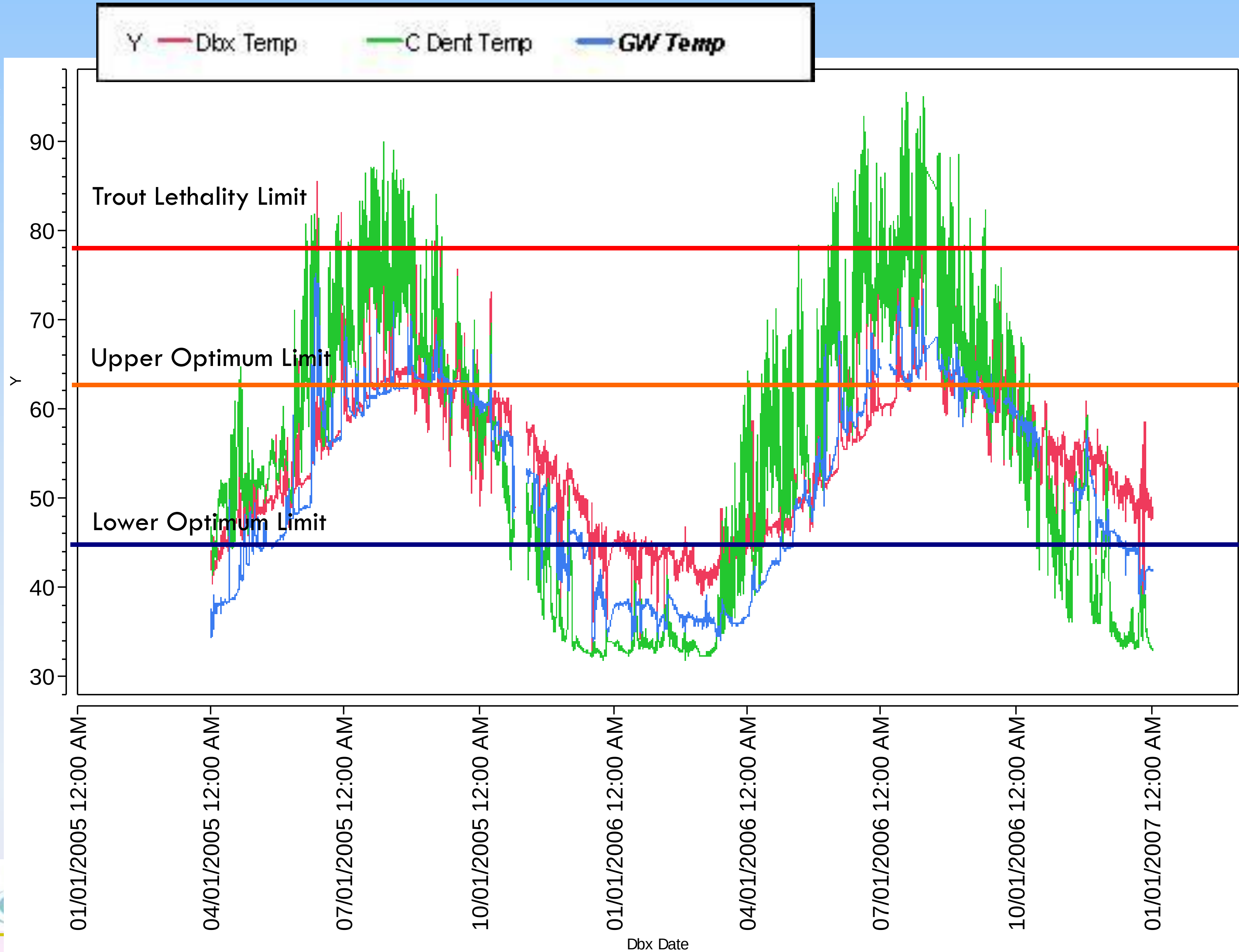
TP Removal Efficiencies



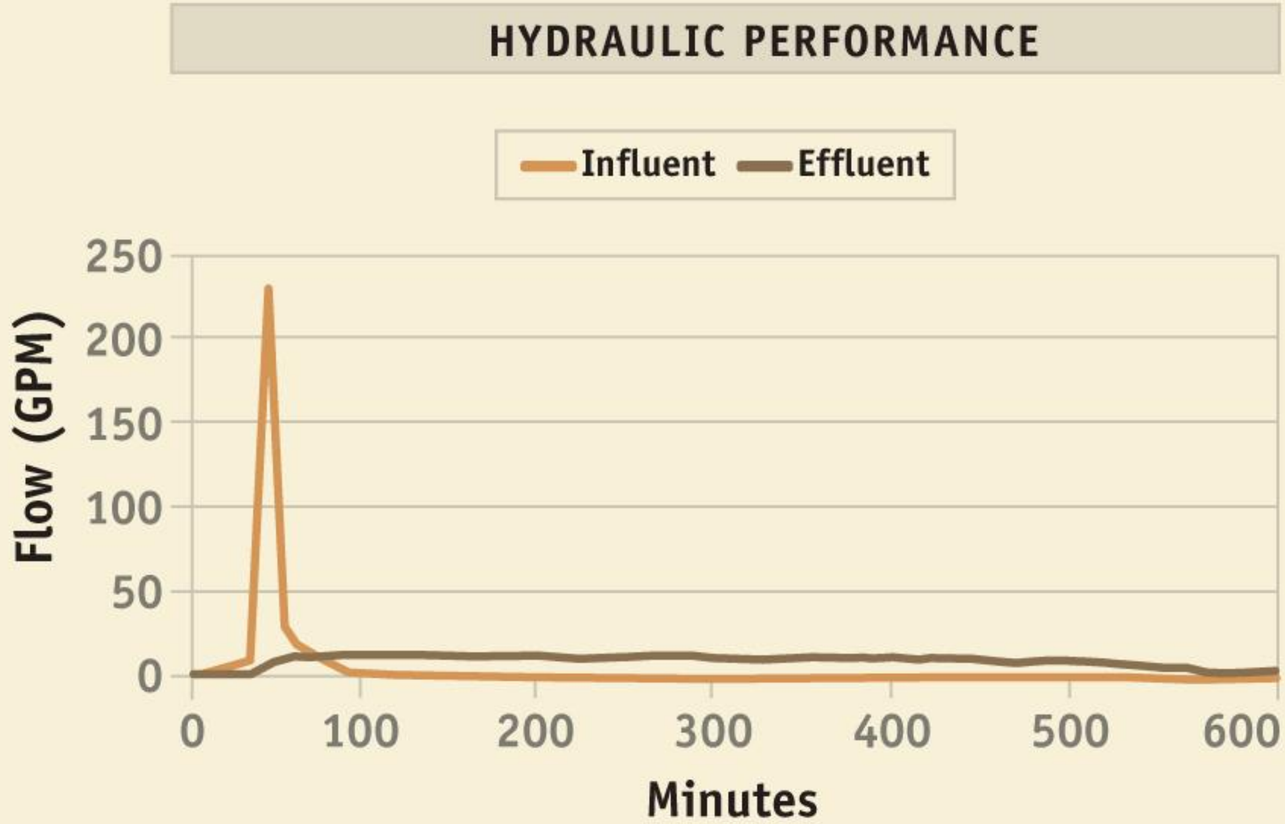
DIN Removal Efficiencies



Thermal Impacts

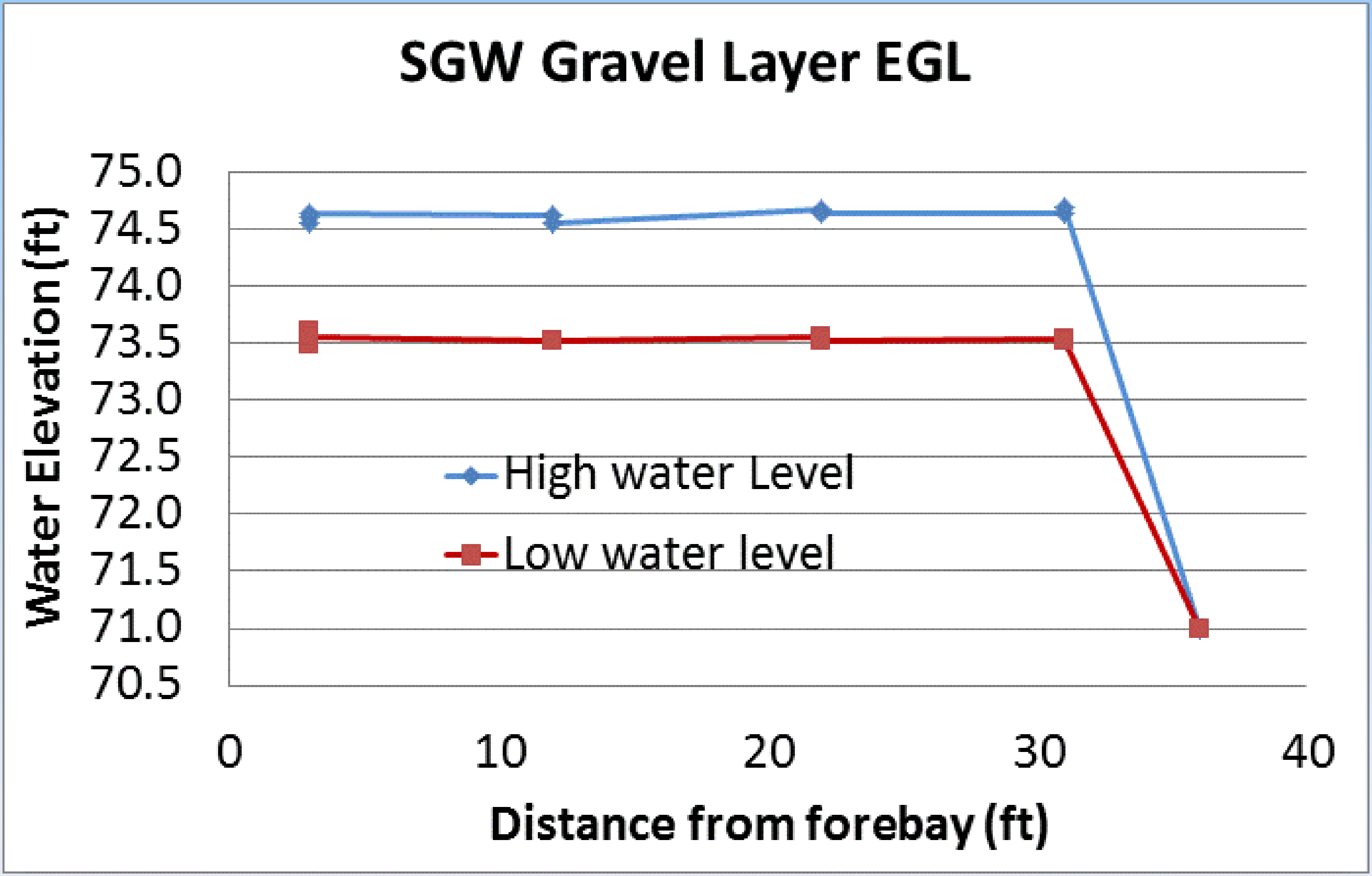


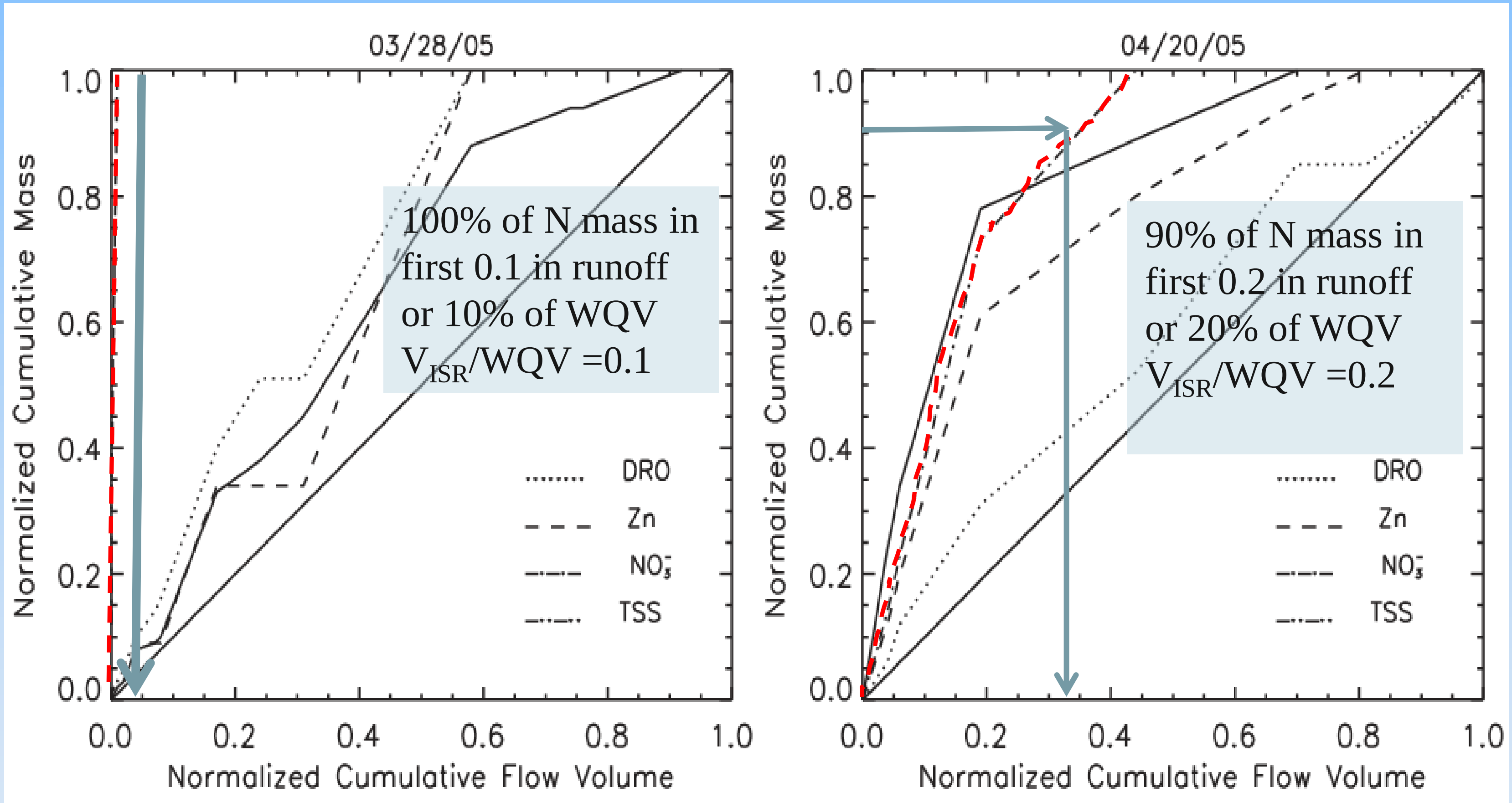
Subsurface Gravel Wetland Hydraulic Performance



	Winter	Summer	Annual Average
Average Peak Flow Reduction	85%	77%	81%
Average Lag Time (minutes)	318	313	315

Hydraulic Profile





Mass loading for DRO, Zn, NO3, TSS as a function of normalized storm volume for two storms: (a) a large 2.3 in rainfall over 1685 minutes; (b) a smaller 0.6 in storm depth over 490 minute. DRO=diesel range organics, Zn= zinc, NO3= nitrate, TSS= total suspended solids

Column Study of Nutrient Removal

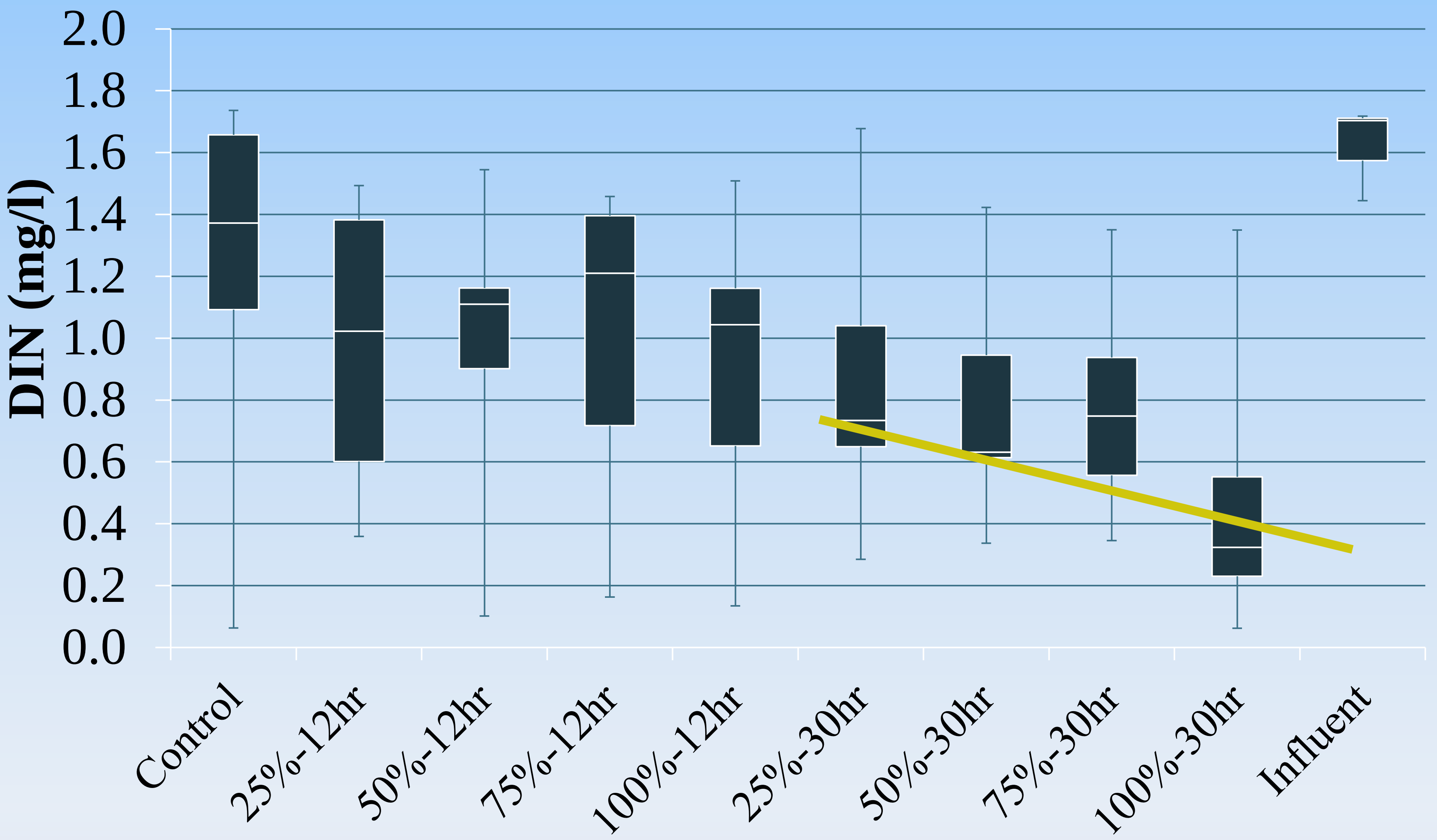
- Amendments for Phosphorus
  - Alum sludge
  - Zero valent iron
  - Limestone sand
  - Electric blast furnace slag
- Internal storage volume for nitrogen
- Effect of compost

Phase 1: Nitrogen

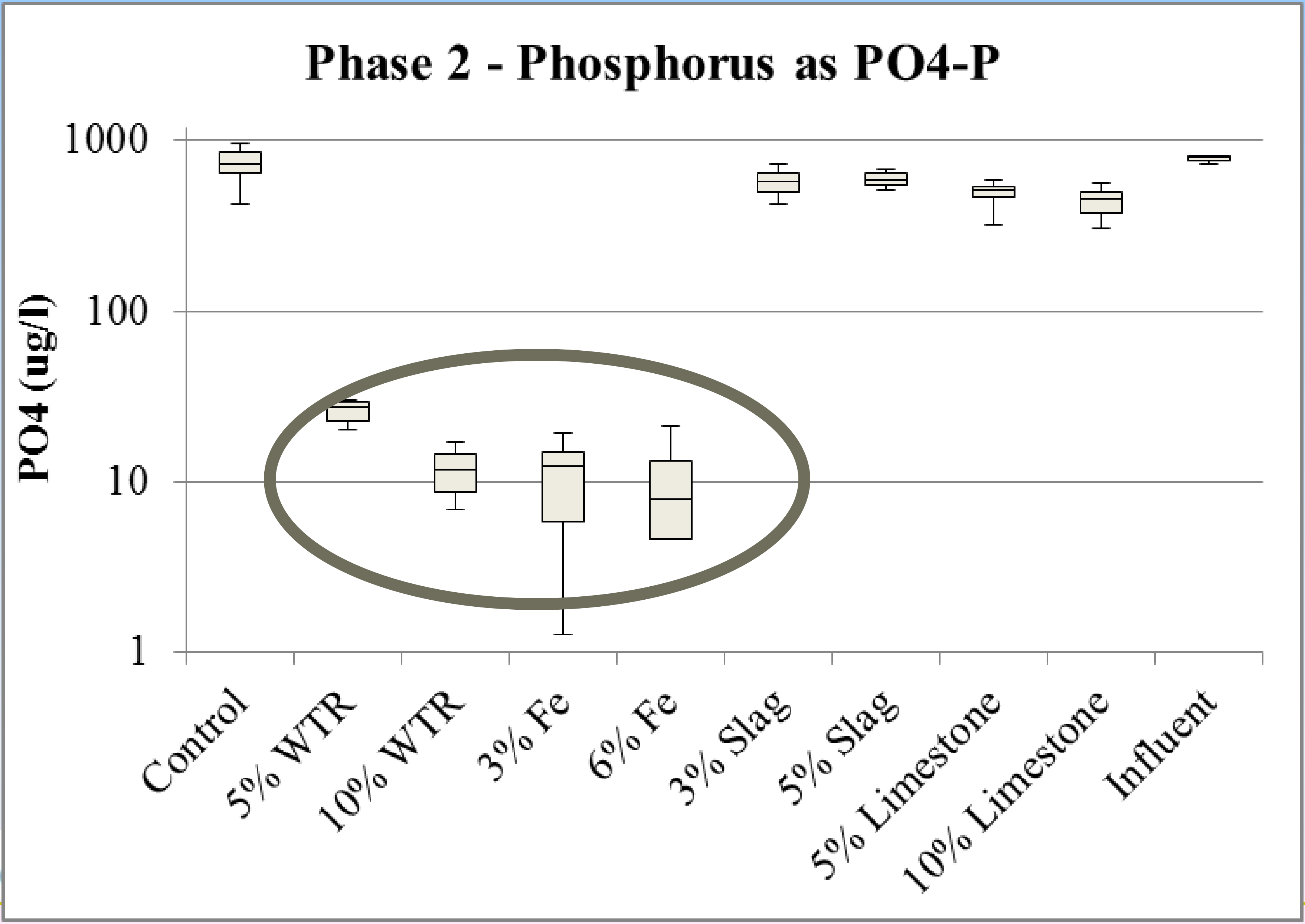
Column #	Soil Mix and saturation zone size	Notes
T1-N0	UNHSC BSM with no saturation zone (control)	• Drainage to filter ratio 80:1 • Soil depth in columns: 24” • 12 hour drain time • Soil tested: UNHSC mix
T1-N1	UNHSC BSM with 25% WQV	
T1-N2	UNHSC BSM with 50% WQV	
T1-N3	UNHSC BSM with 75% WQV	
T1-N4	UNHSC BSM with 100% WQV	
T1-N5	UNHSC BSM with 25% WQV	• Drainage to filter ratio 80:1 • Soil depth in columns: 24” • 30 hour drain time • Soil tested: UNHSC mix
T1-N6	UNHSC BSM with 50% WQV	
T1-N7	UNHSC BSM with 75% WQV	
T1-N8	UNHSC BSM with 100% WQV	

- Size ISR
- Retention Time

Nitrogen Results



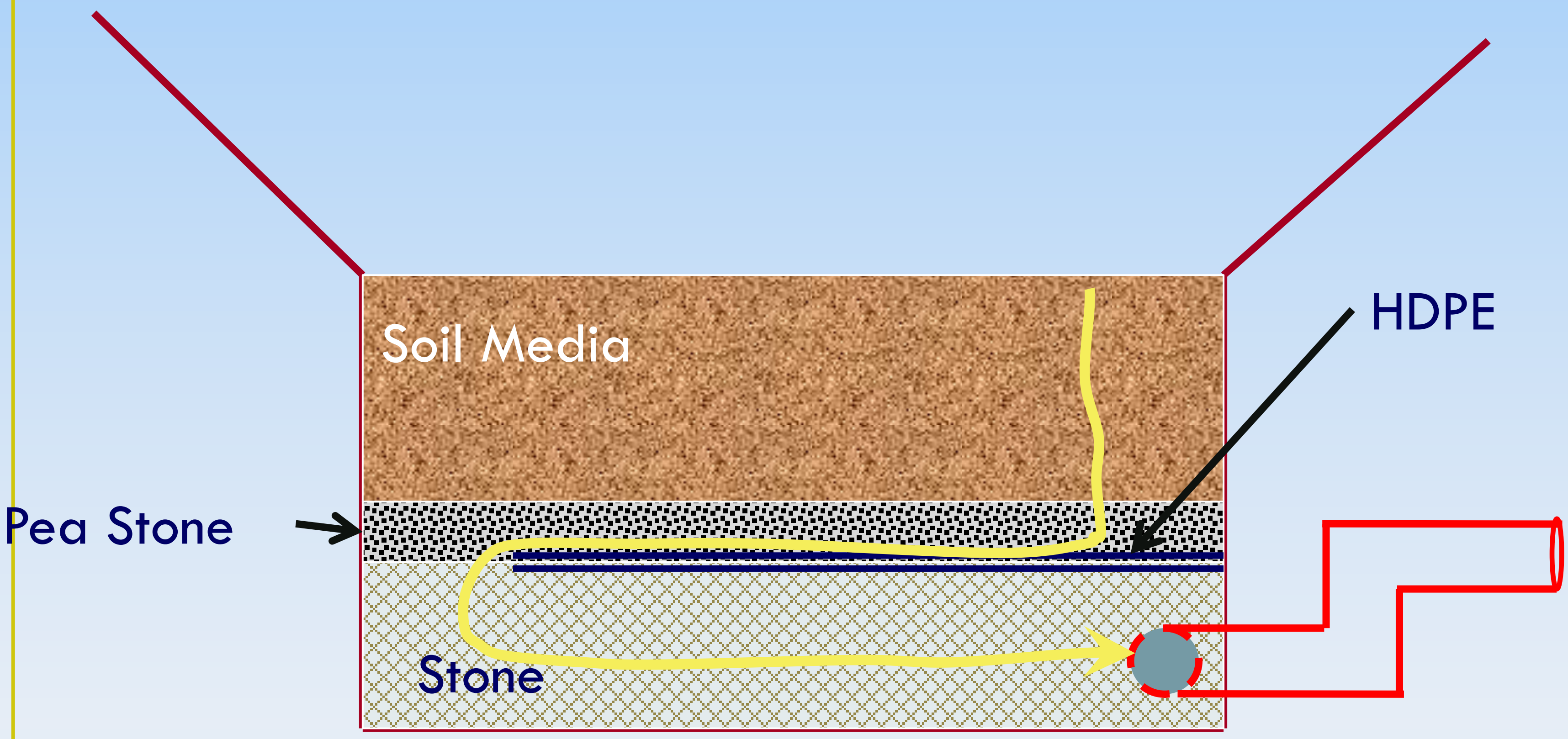
Phosphorus Results



Bioretention Hybrid Systems

- Bioretention with Internal Storage Volume

ISV Plumbing



Inspection and Maintenance

4 - yr Forebay Maintenance - June 2008

Maintenance

- The forebay to the gravel wetland, and probably all stormwater systems may become a source of contamination as the system ages—maintenance is essential

- Improved forebay designs would include a deeper pool of water in excess of one meter, or a deep sump catch basin or proprietary treatment device for removal of solids.

Maintenance

- Sediments and plant debris stored in the forebay may be re-suspended and released in subsequent storms. Routine maintenance is an important component in maintaining performance—2-3 year interval.
- Nutrients that collect in plants are released when the plant dies and decomposes in the system, therefore above ground plant litter should be removed every 2-3 years or more frequently.

Infiltration and Volume Reduction

When to Design for Infiltration

- Volume reduction (hydrologic transparency)
- Load reduction (CSO)

Constraints

- Nearby infrastructure receptors
- Existing soil/groundwater contamination
- Contamination hot spots
- Vertical setbacks
  - Groundwater
  - Bedrock

Need for Underdains

- Low infiltration rate
  - < 0.25 in/hr (Philadelphia)
  - < 0.5 in/hr (EPA, NJ, NY, NH, ME, VT)
  - < 0.52 in/hr (MD, Center for Watershed Protection)
  - < 0.17 in/hr (MA)

Texture Class	Effective Water Capacity (C_w) (inch per inch)	Minimum Infiltration Rate (*f*) (inches per hour)	Hydrologic Soil Grouping
Sand	0.35	8.27	A
Loamy Sand	0.31	2.41	A
Sandy Loam	0.25	1.02	A
Loam	0.19	0.52	B
Silt Loam	0.17	0.27	B
Sandy Clay Loam	0.14	0.17	C
Clay Loam	0.14	0.09	D
Silty Clay Loam	0.11	0.06	D
Sandy Clay	0.09	0.05	D
Silty Clay	0.09	0.04	D
Clay	0.08	0.02	D

* Source: Rawls, Brakensiek and Saxton, 1982

Systems Presented Today

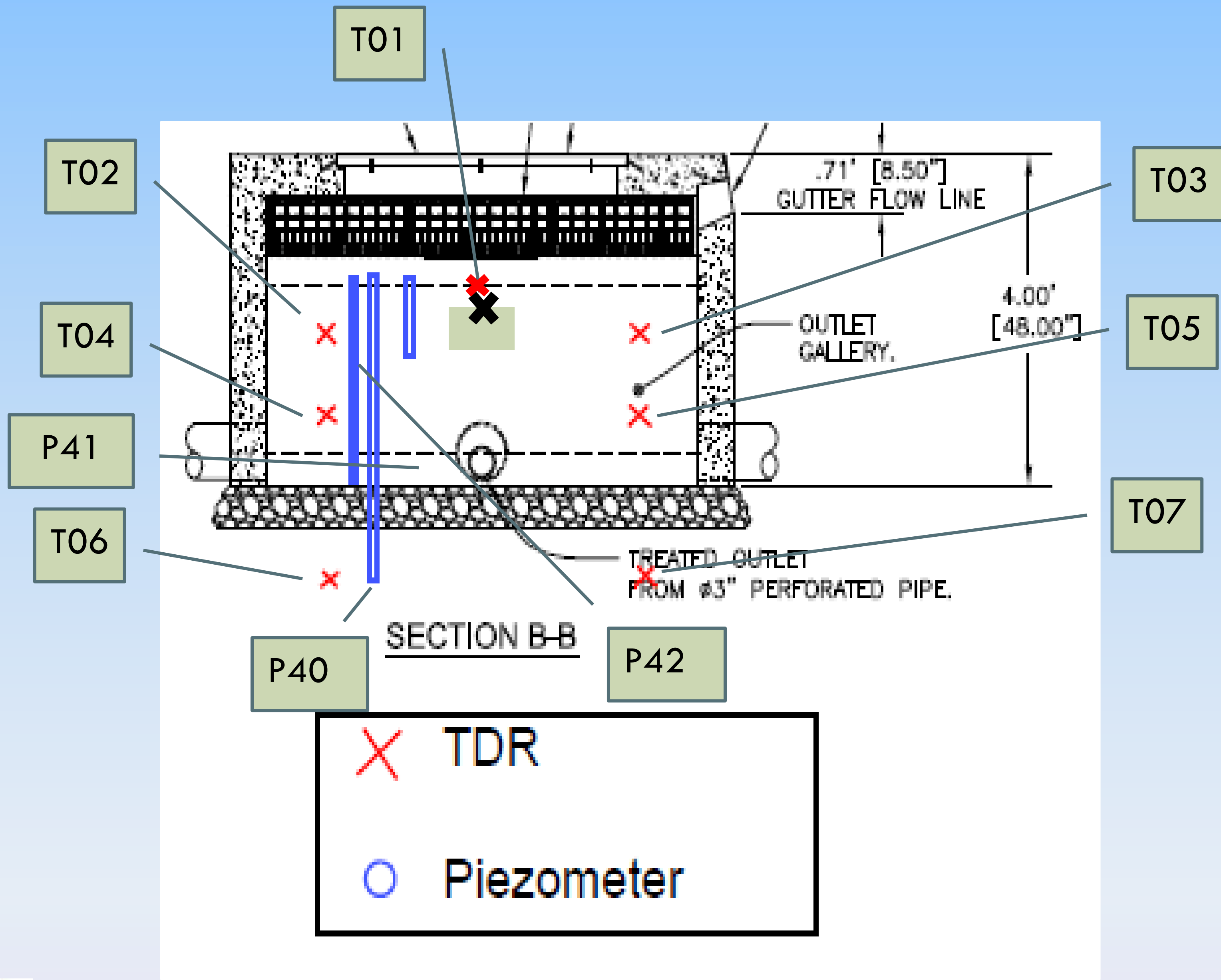
- Tree Filter
  - Design by water quality flow
- Tree Trench
  - Water quality volume design
  - Static sizing

Tree Box Filter

Tree Box Watershed

Tree box filter design

- Manufacturer sizing: 36 gpm (1 gpm/ft^2)
- NH water quality flow sizing – 198 gpm
- For media IC of 100 in/hr, capacity is 36 gpm
- Media: 80% Sand : 20% UNH Compost
- Native soil infiltration capacity ~ 0.3 in/hr


T01
T02
T03
T04
T05
P41
T06
T07
P40
P42
.71' [8.50"]
GUTTER FLOW LINE
4.00'
[48.00"]
OUTLET
GALLERY.
TREATED OUTLET
FROM ø3" PERFORATED PIPE.
SECTION B-B
TDR
Piezometer

Site Characteristics

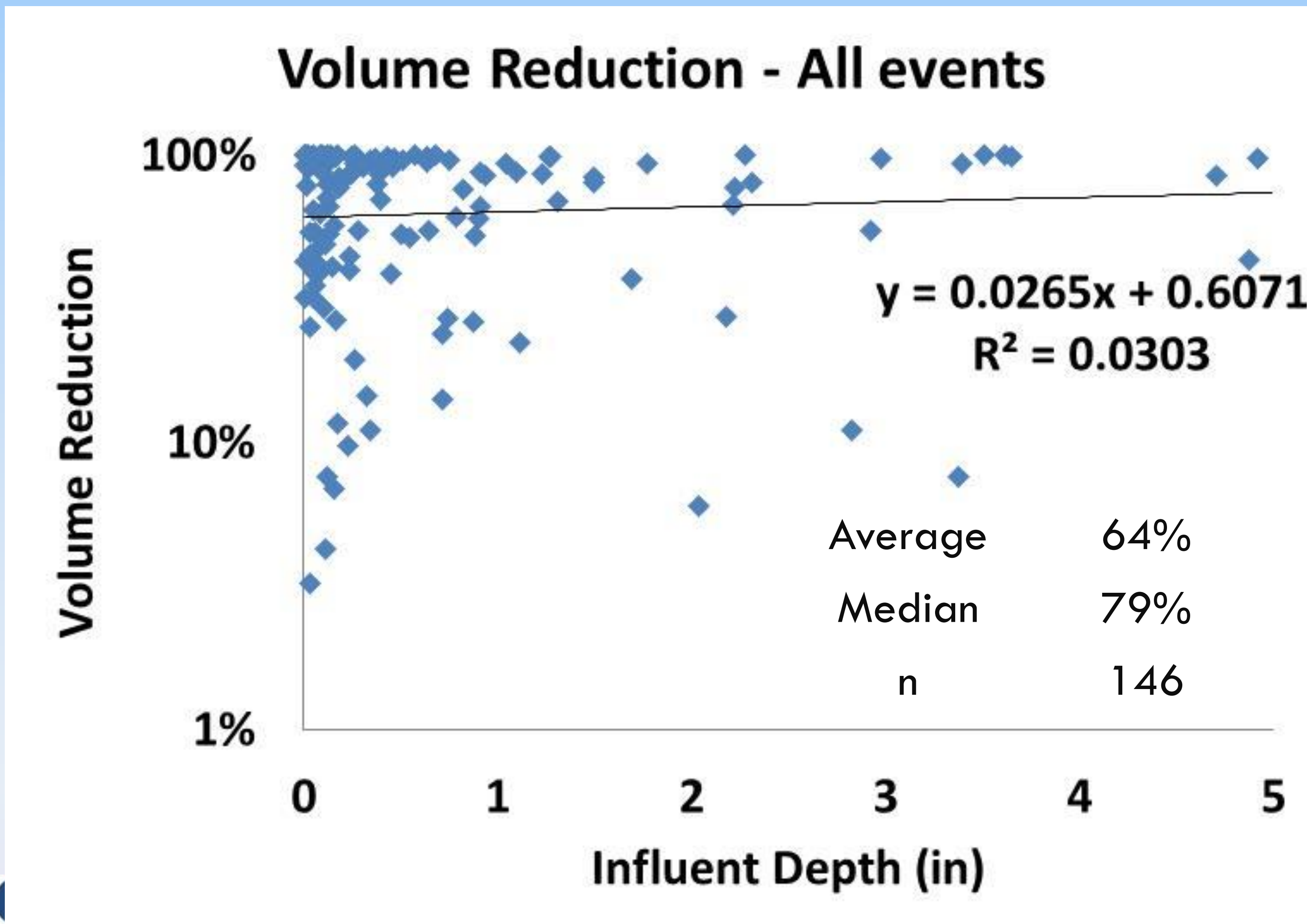
System	Watershed area (acres)	System filter area (sq. feet)	Watershed area to filter area ratio
Tree box filter	0.48	36	577
Tree trench	0.58	2,550	9.9

Overall Hydraulic Performance – tree box filter monitoring

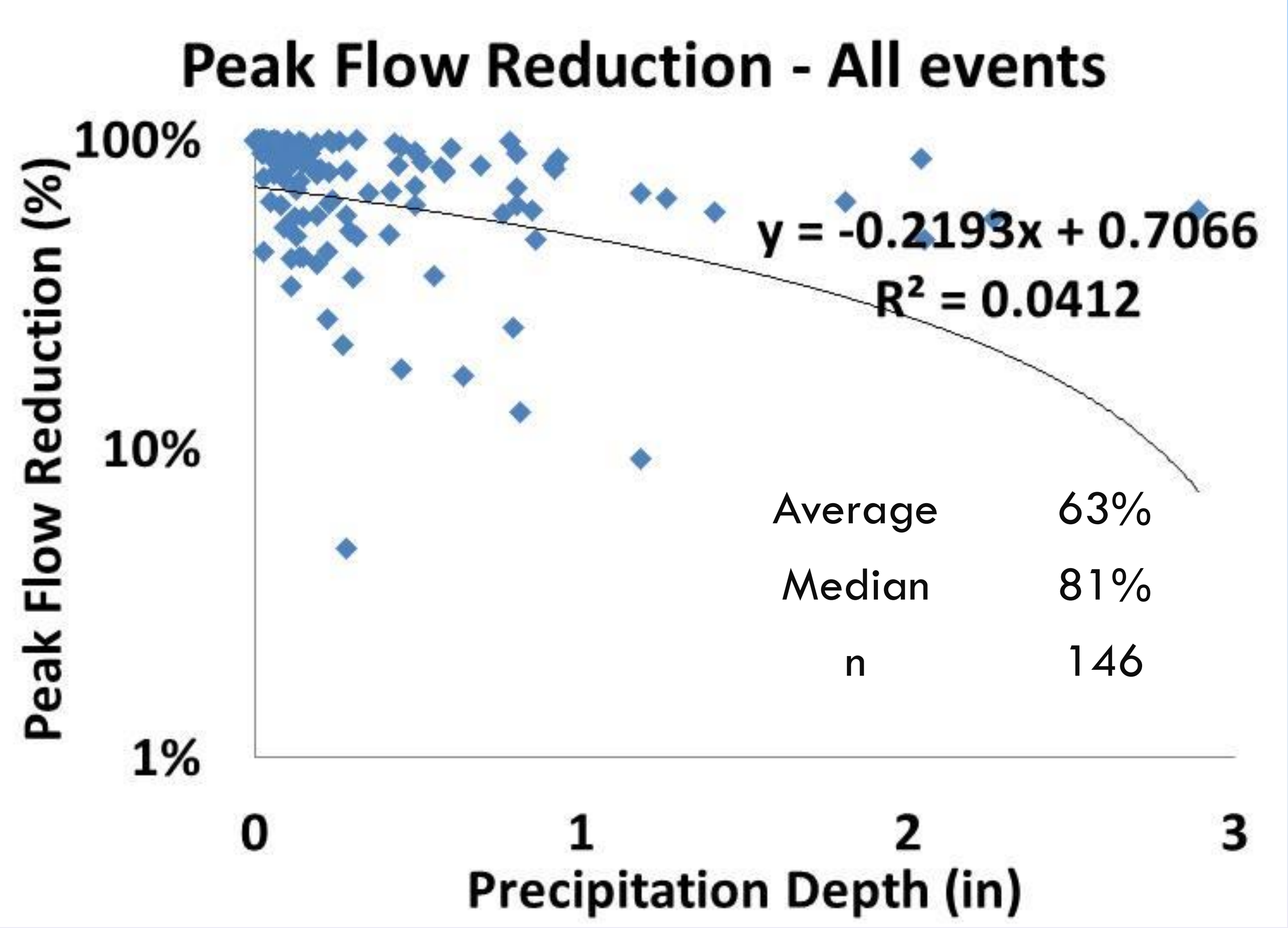
- Inflow (calibrated weir/orifice)
- Outflow (calibrated weir/orifice)
- Inflow Estimate: precipitation times watershed area times runoff coefficient
- In system well

Monitoring period – 12 Jun 2012 – 5 June 2014

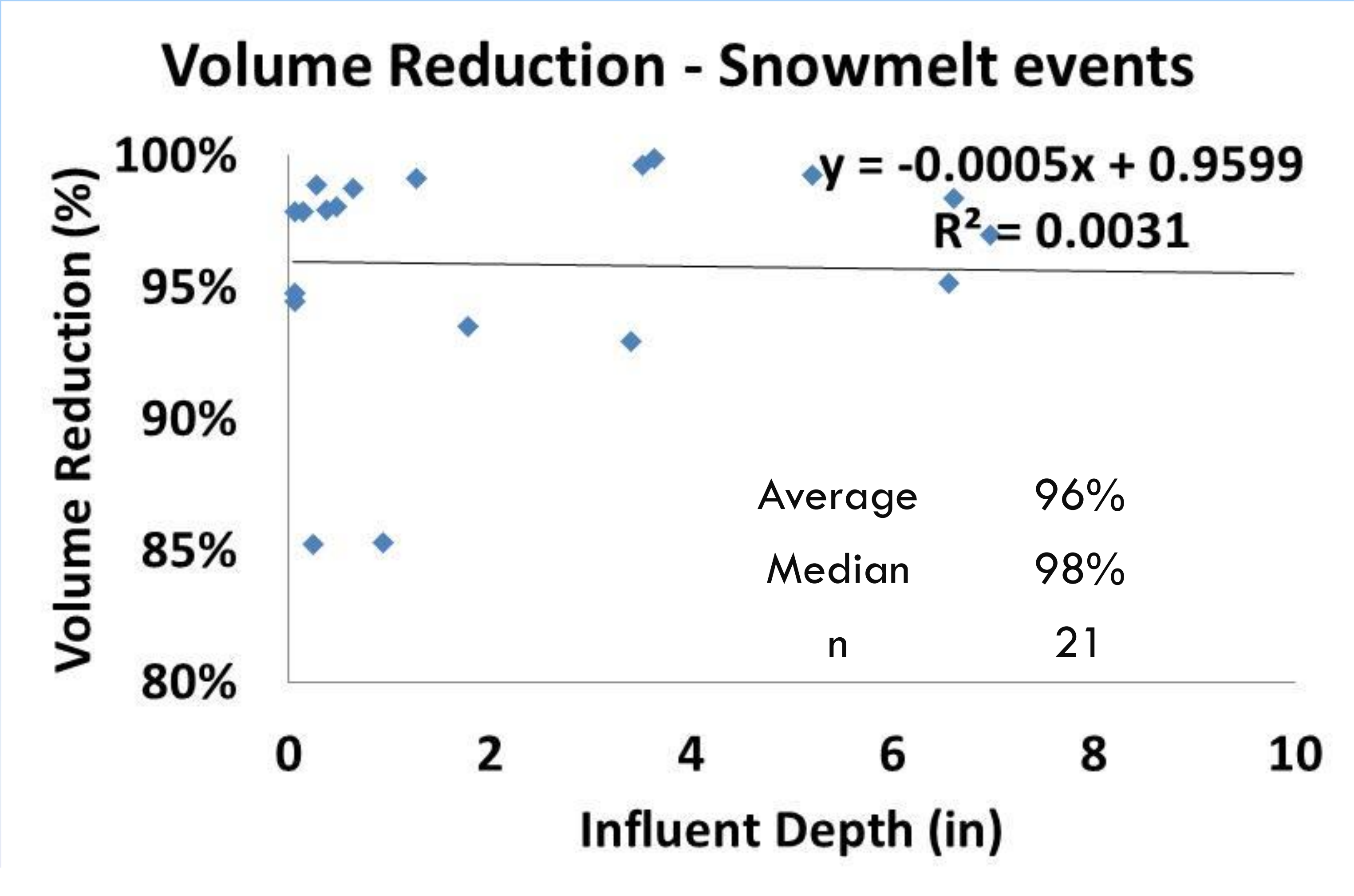
Overall Hydraulic Performance – tree box filter all data



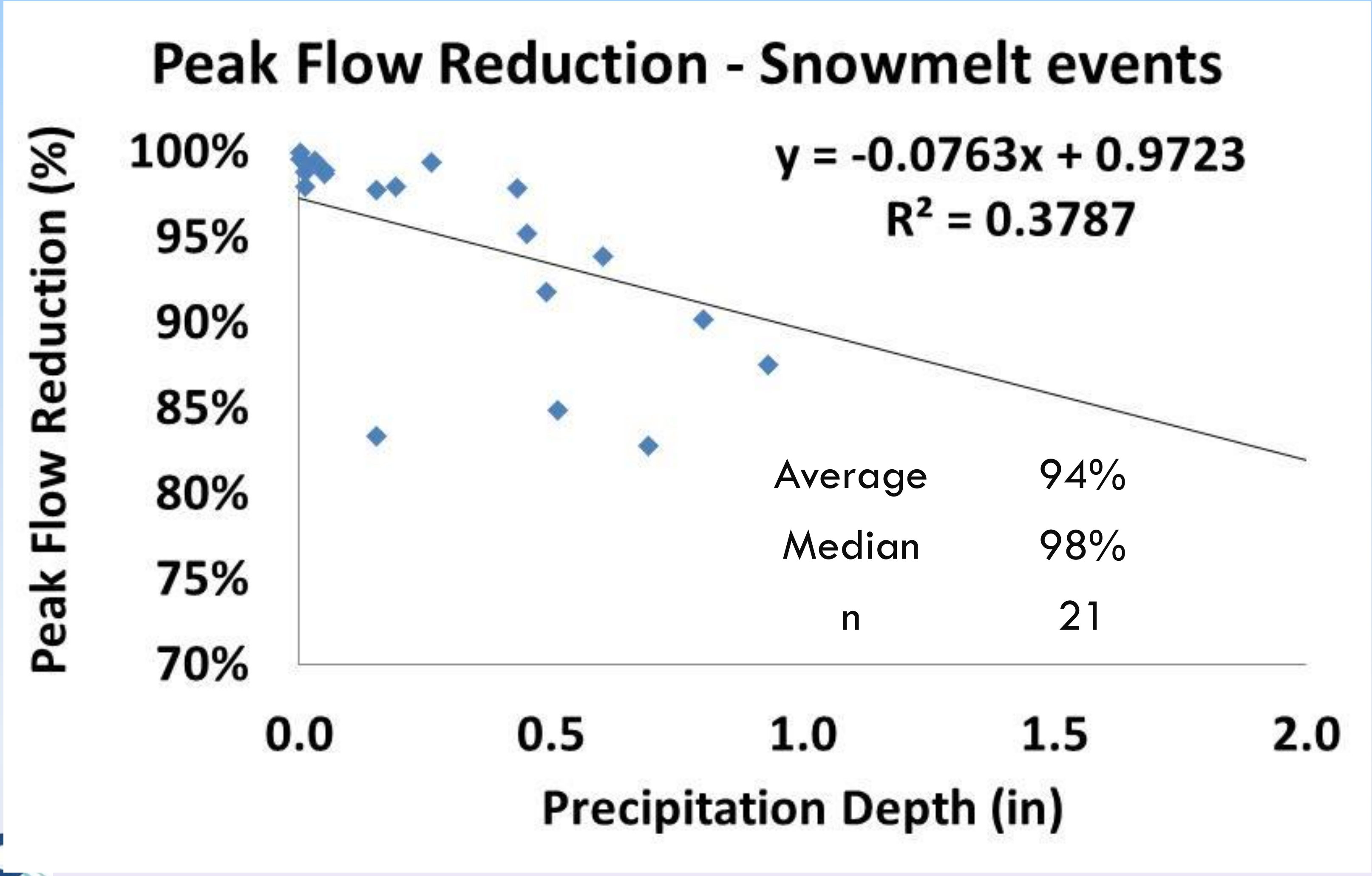
Overall Hydraulic Performance – tree box all data



Overall Hydraulic Performance – tree box filter snowmelt



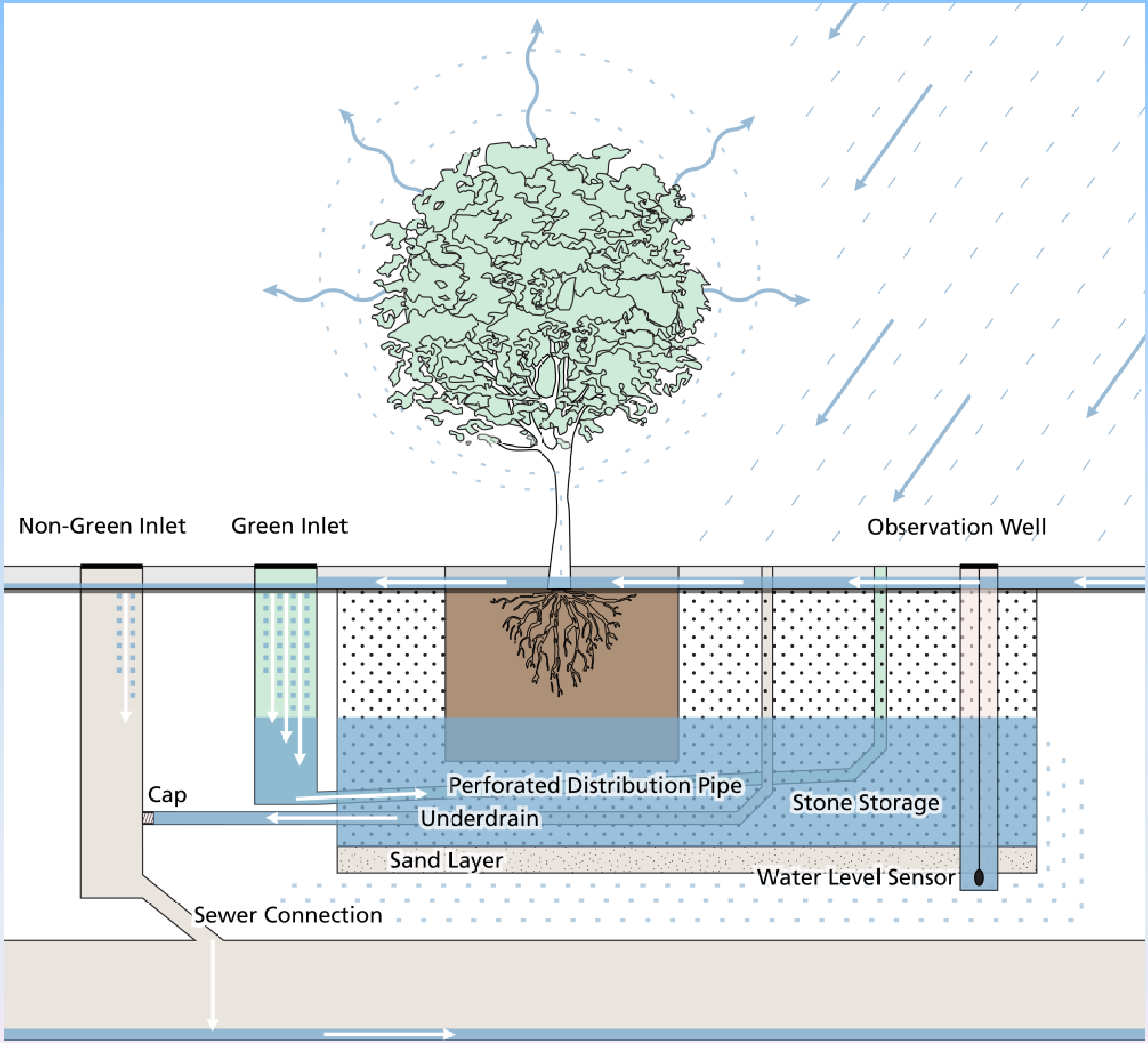
Overall Hydraulic Performance – tree box filter snowmelt



Average	94%
Median	98%
n	21

Philadelphia Tree Trench

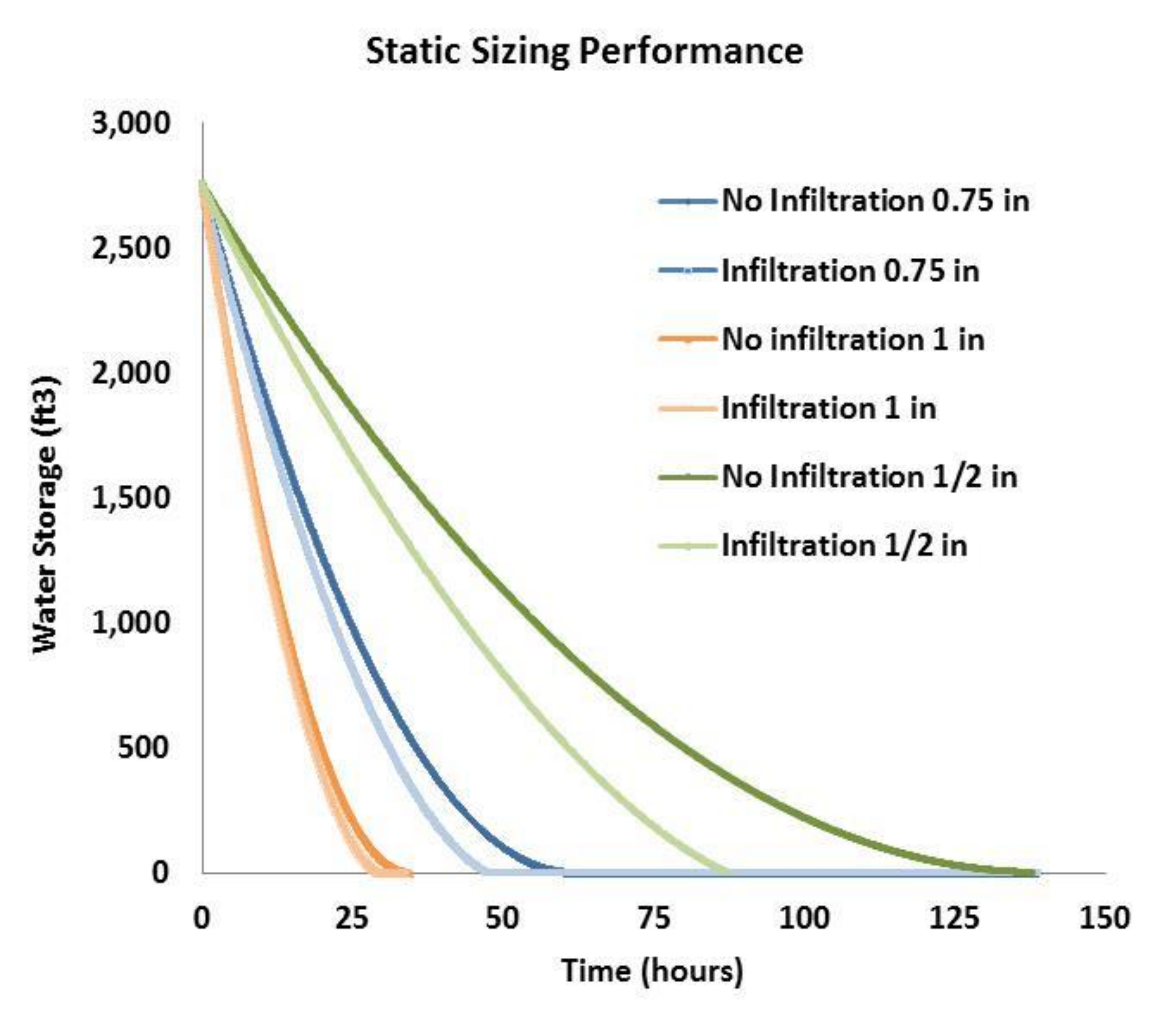
Green Streets Design Manual 31


Non-Green Inlet
Green Inlet
Observation Well
Perforated Distribution Pipe
Cap
Underdrain
Stone Storage
Sand Layer
Water Level Sensor
Sewer Connection

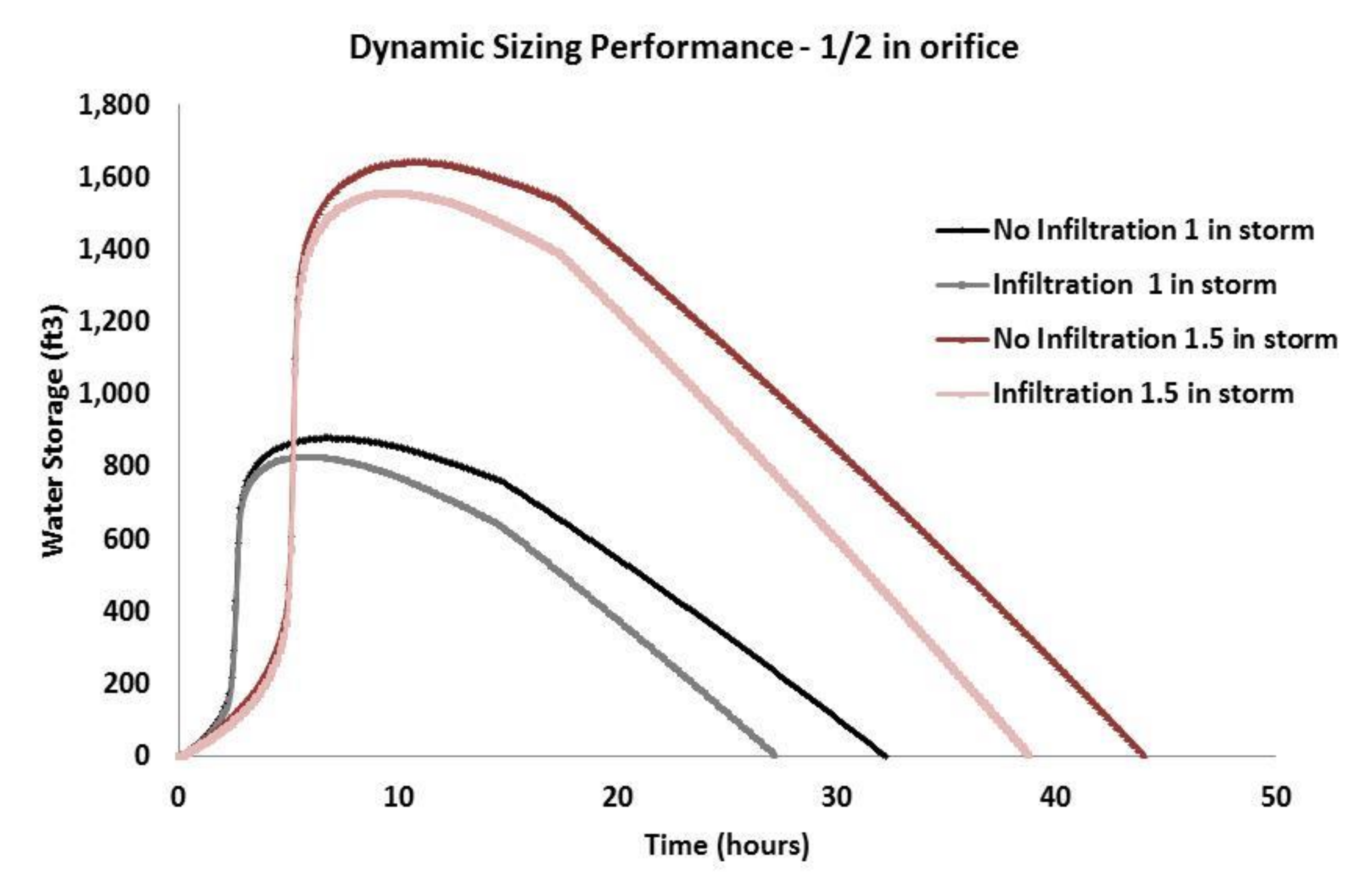
Tree Trench Design Components

- One inch water quality volume
- If design infiltration rates are found to be less than **0.25 inches** per hour, or if system is not able to completely drain in 72 hours, the system should be designed for detention/slow-release.
- Detention/slow-release systems should be designed to release at a maximum rate of 0.05 cfs per acre of contributing impervious drainage area.
- Orifice diameters must not be less than 0.5".

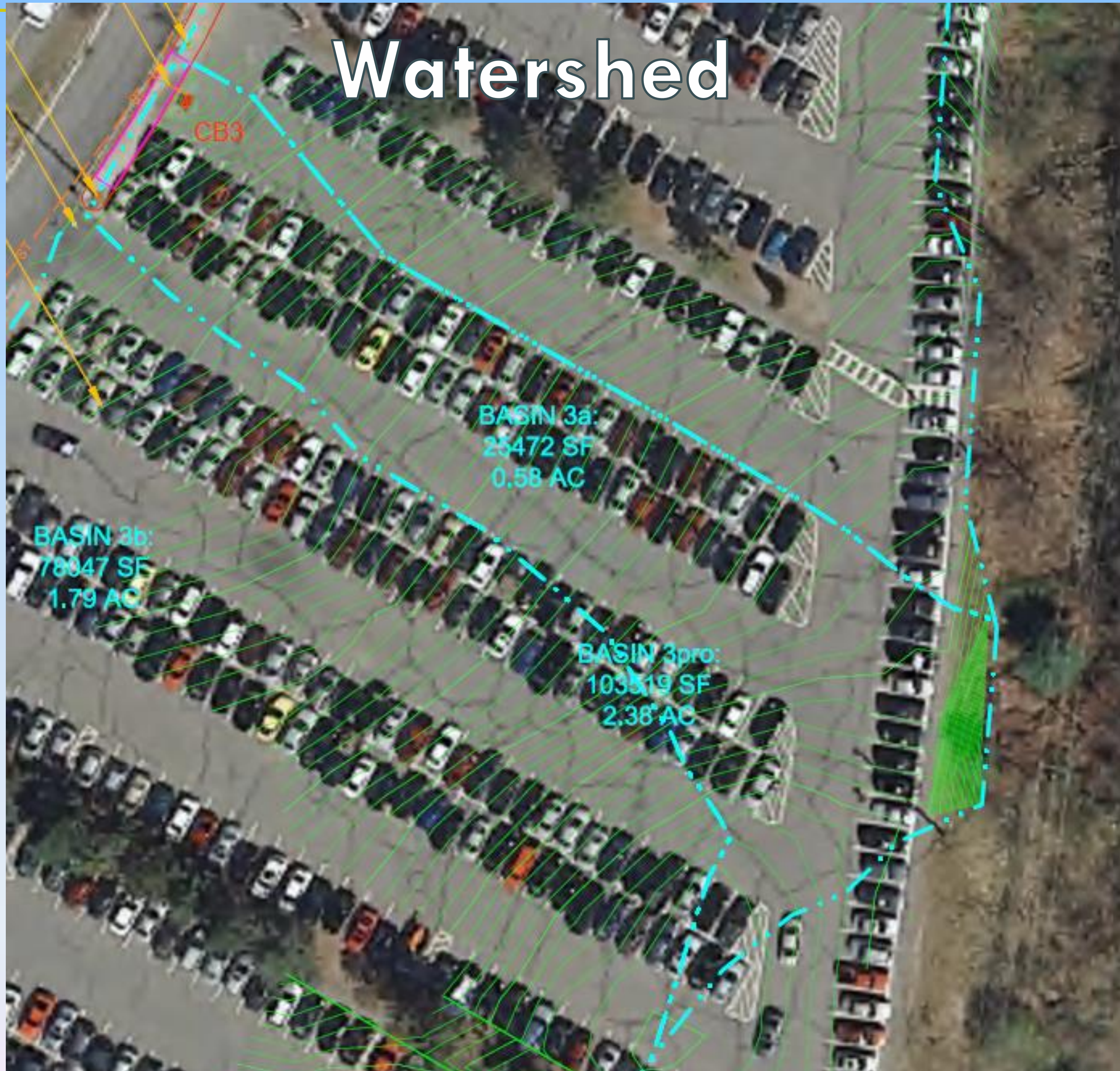
Static Sizing



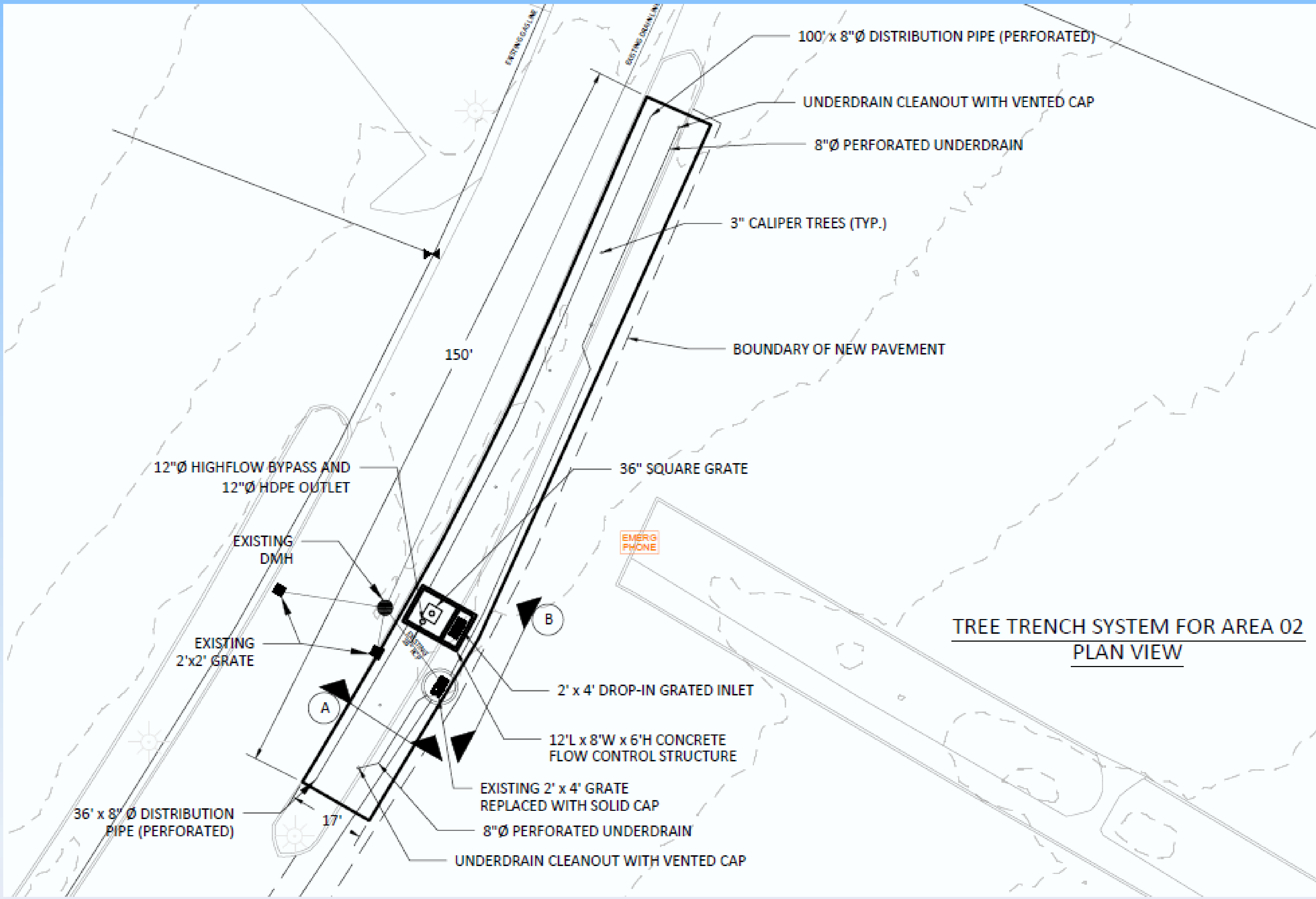
Dynamic Sizing



Watershed



CB3
BASIN 3a:
25472 SF
0.58 AC
BASIN 3b:
78047 SF
1.79 AC
BASIN 3pro:
103519 SF
2.38 AC


100' x 8"Ø DISTRIBUTION PIPE (PERFORATED)
UNDERDRAIN CLEANOUT WITH VENTED CAP
8"Ø PERFORATED UNDERDRAIN
3" CALIPER TREES (TYP.)
BOUNDARY OF NEW PAVEMENT
150'
12"Ø HIGHFLOW BYPASS AND
12"Ø HDPE OUTLET
36" SQUARE GRATE
EXISTING
DMH
EMERG
PHONE
EXISTING
2'x2' GRATE
B
A
2' x 4' DROP-IN GRATED INLET
12'L x 8'W x 6'H CONCRETE
FLOW CONTROL STRUCTURE
EXISTING 2' x 4' GRATE
REPLACED WITH SOLID CAP
36' x 8' Ø DISTRIBUTION
PIPE (PERFORATED)
17'
8"Ø PERFORATED UNDERDRAIN
UNDERDRAIN CLEANOUT WITH VENTED CAP
TREE TRENCH SYSTEM FOR AREA 02
PLAN VIEW

Pre-Existing Site

Soil at the Site

- **ScA—Scantic silt loam, 0 to 3 percent slopes**
- Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)

Location	Turf Tec (in/hr)	Double Ring (in/hr)
1	0.13	0.03
2	1.27	-
3	0.36	-
4	1.98	-

Turf Tec Median = 0.8 in/hr (~0.2 in/hr calibrated to DRI)


2014/07/31

Site Today


STOP
University of New Hampshire
Lot A
Section 2
Permit Required
P
Mon-Fri 7am 6pm
Commuter
Faculty/Staff
Ticketing and Towing Enforced
Questions? Call 862-1010
04/26/2015

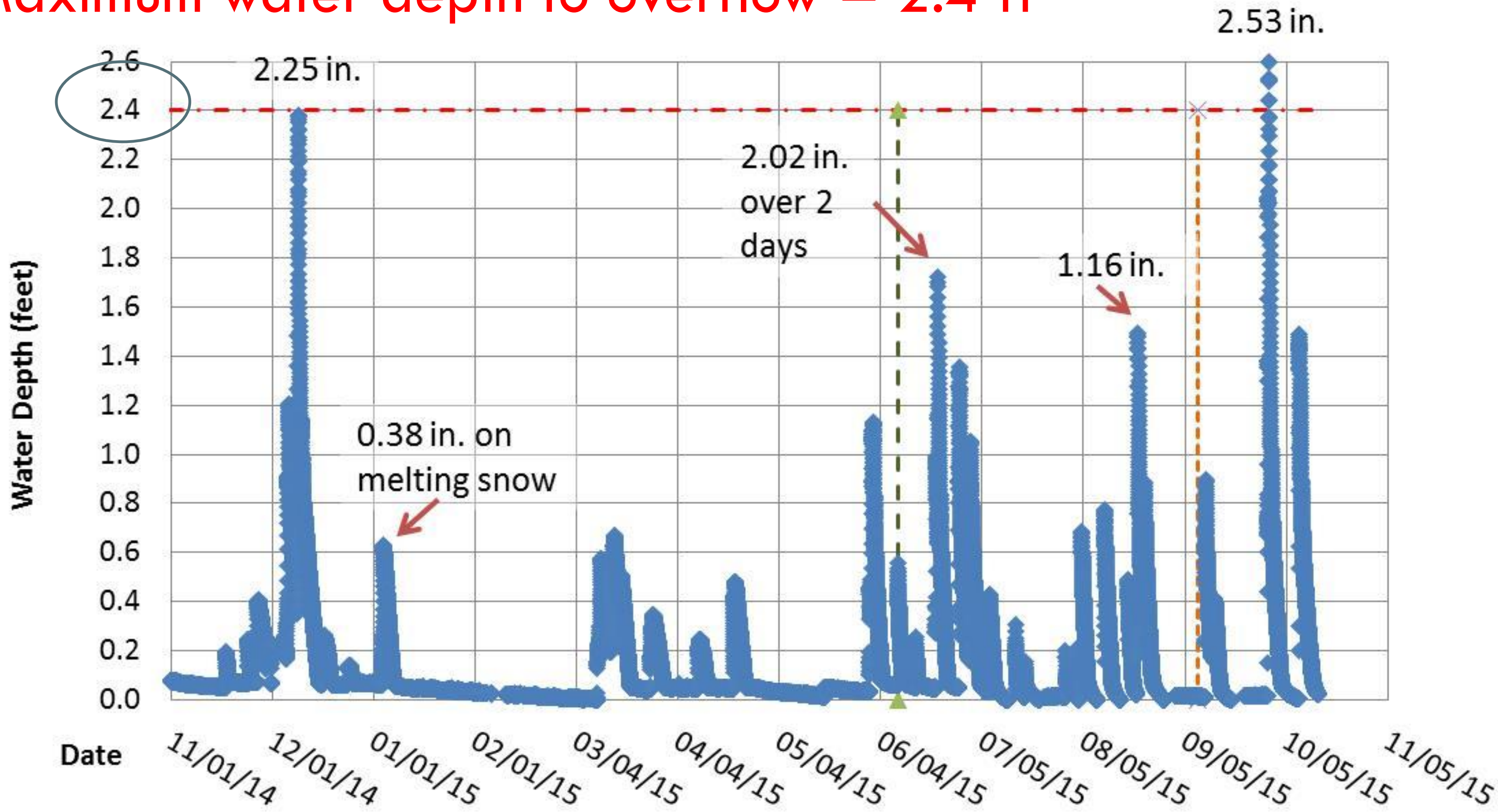
SC

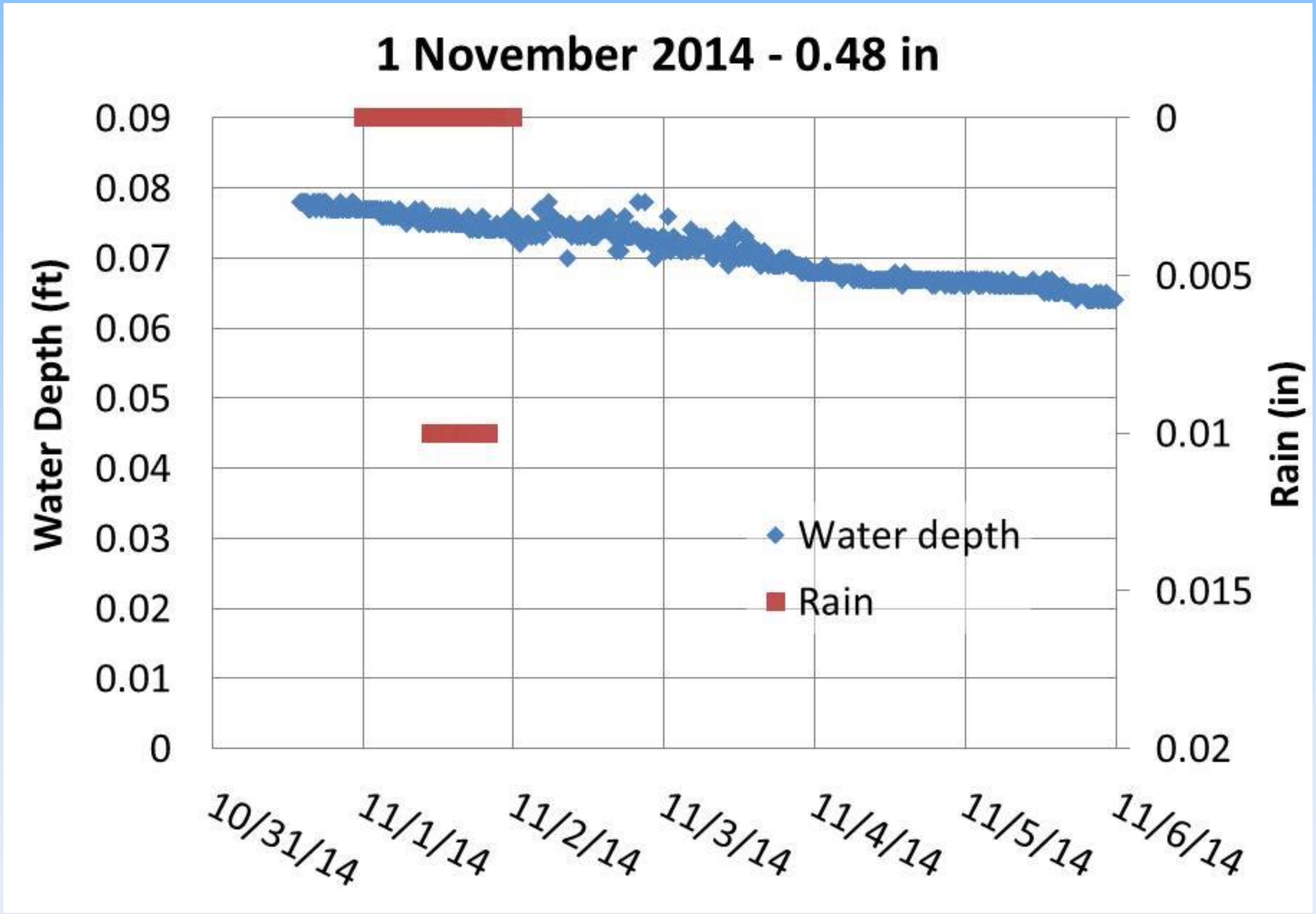
Tree Trench Monitoring

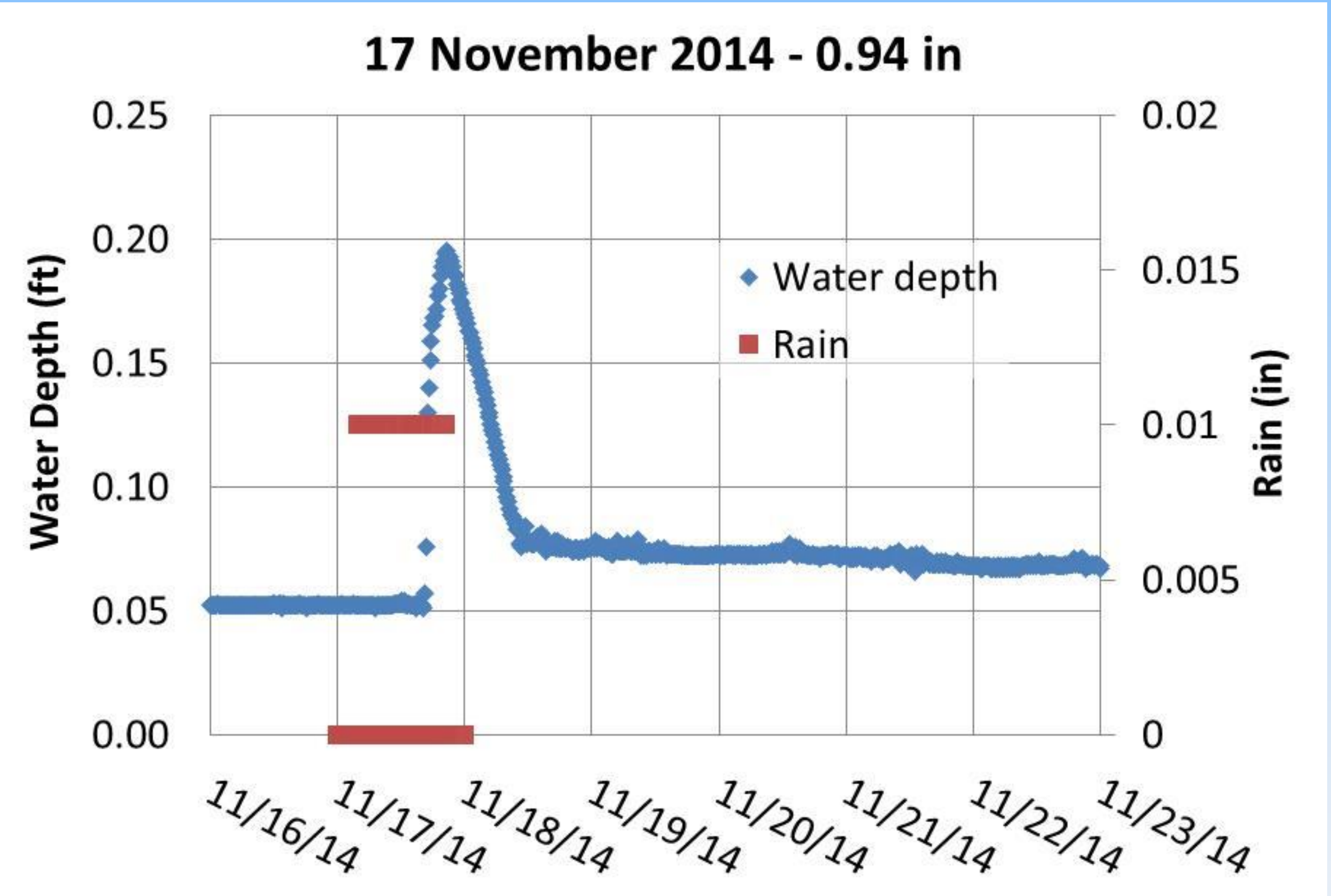
- Inflow volume – precipitation times watershed area times runoff coefficient
- Outflow – estimated from system well water level

Monitoring period – 31 October 2014 – 2 November 2015

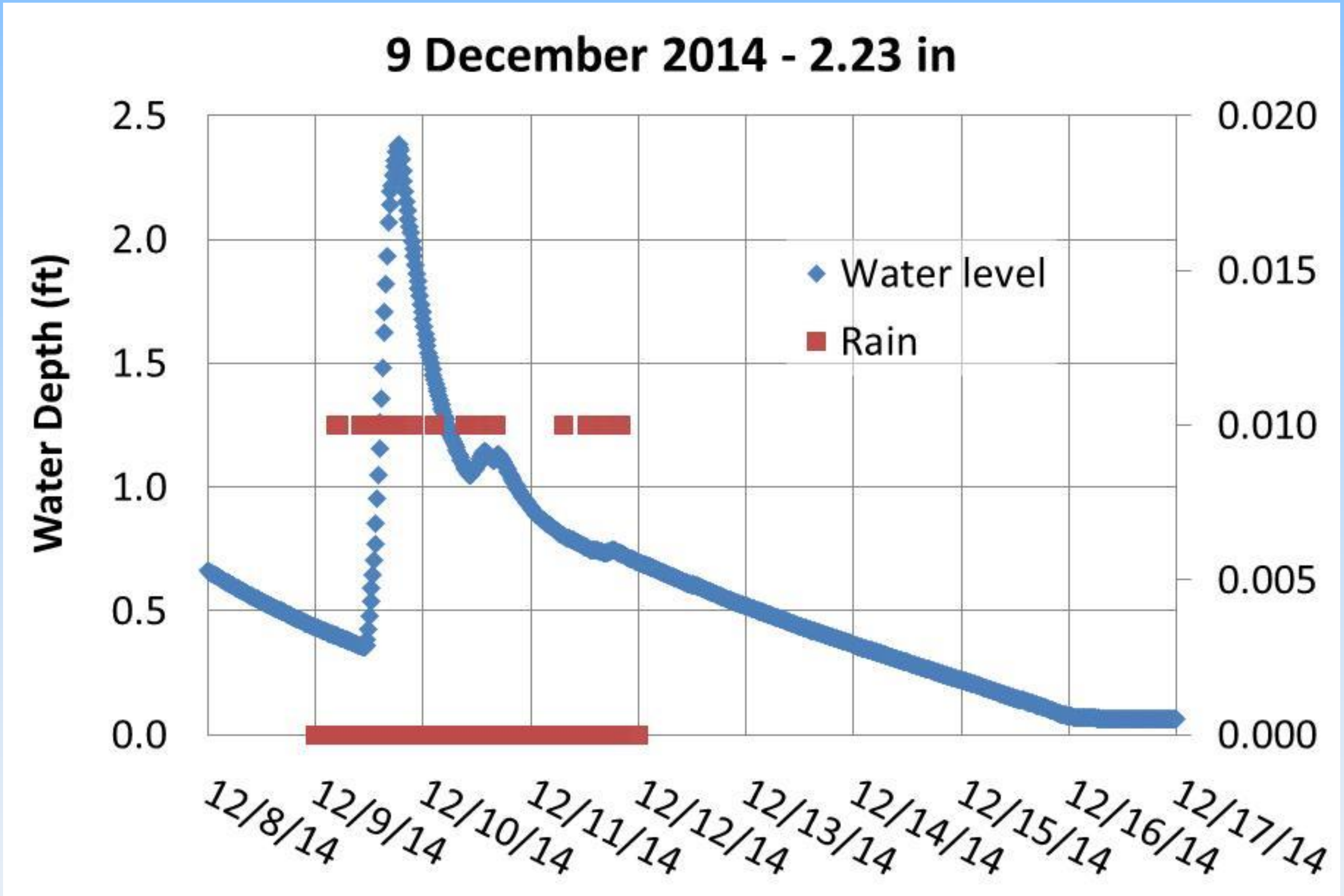
Maximum water depth to overflow = 2.4 ft




1 November 2014 - 0.48 in
Water Depth (ft)
Rain (in)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.005
0.01
0.015
0.02
10/31/14
11/1/14
11/2/14
11/3/14
11/4/14
11/5/14
11/6/14
Water depth
Rain

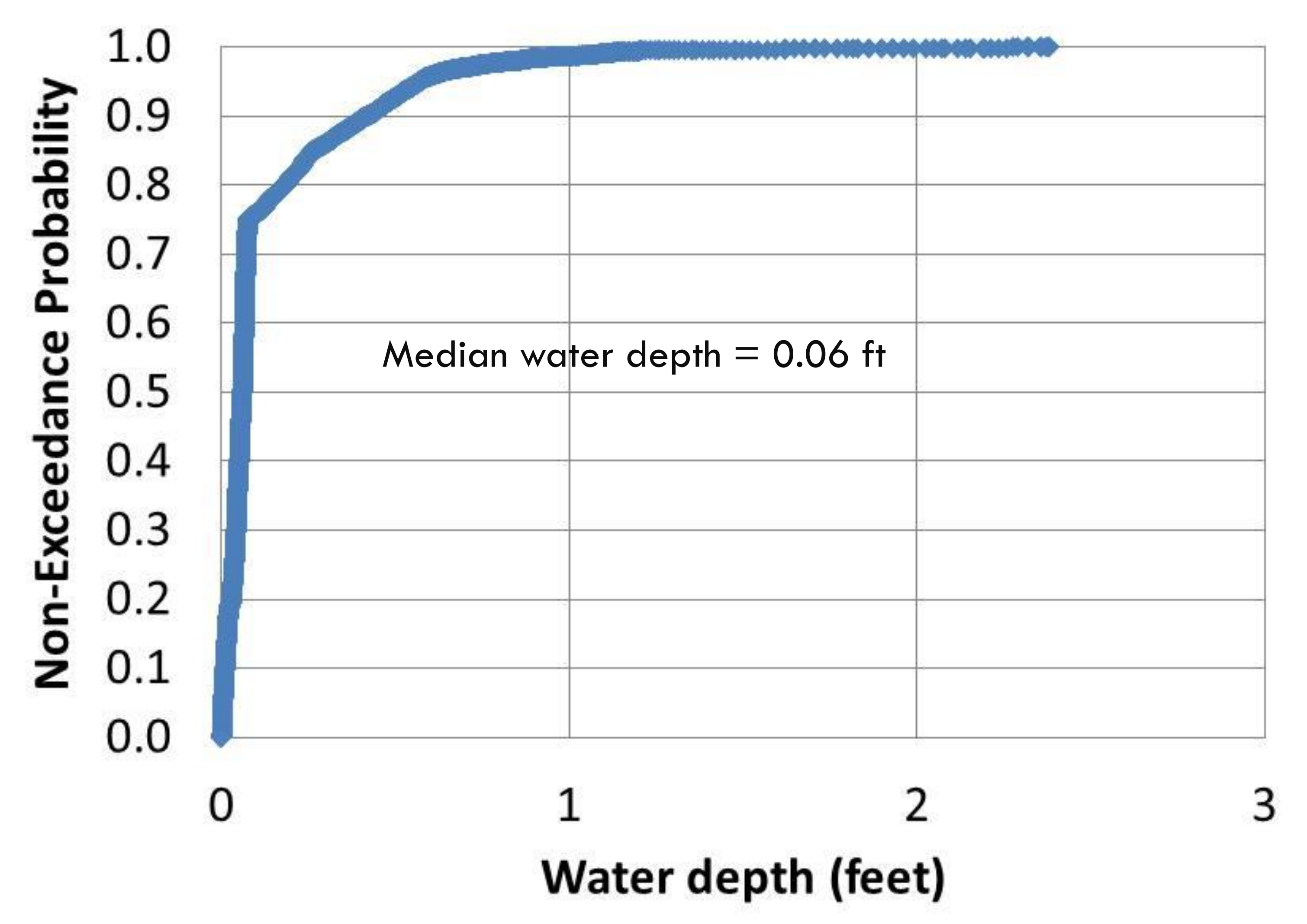


17 November 2014 - 0.94 in
Water Depth (ft)
0.25
0.20
0.15
0.10
0.05
0.00
Rain (in)
0.02
0.015
0.01
0.005
0
Water depth
Rain
11/16/14
11/17/14
11/18/14
11/19/14
11/20/14
11/21/14
11/22/14
11/23/14

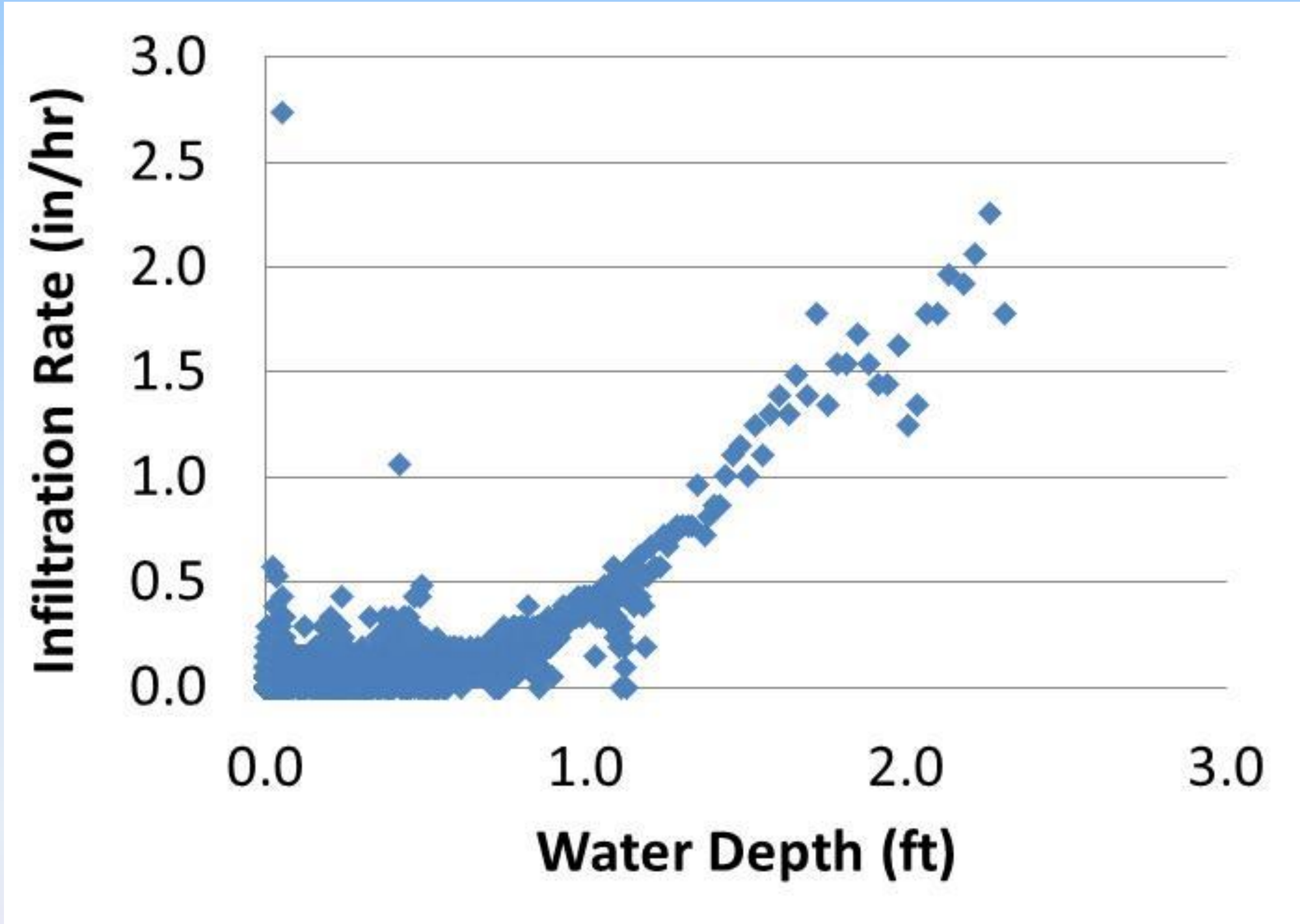


9 December 2014 - 2.23 in
Water Depth (ft)
2.5
2.0
1.5
1.0
0.5
0.0
0.020
0.015
0.010
0.005
0.000
Water level
Rain
12/8/14
12/9/14
12/10/14
12/11/14
12/12/14
12/13/14
12/14/14
12/15/14
12/16/14
12/17/14

Water Depth Probability



Changing Infiltration Rate

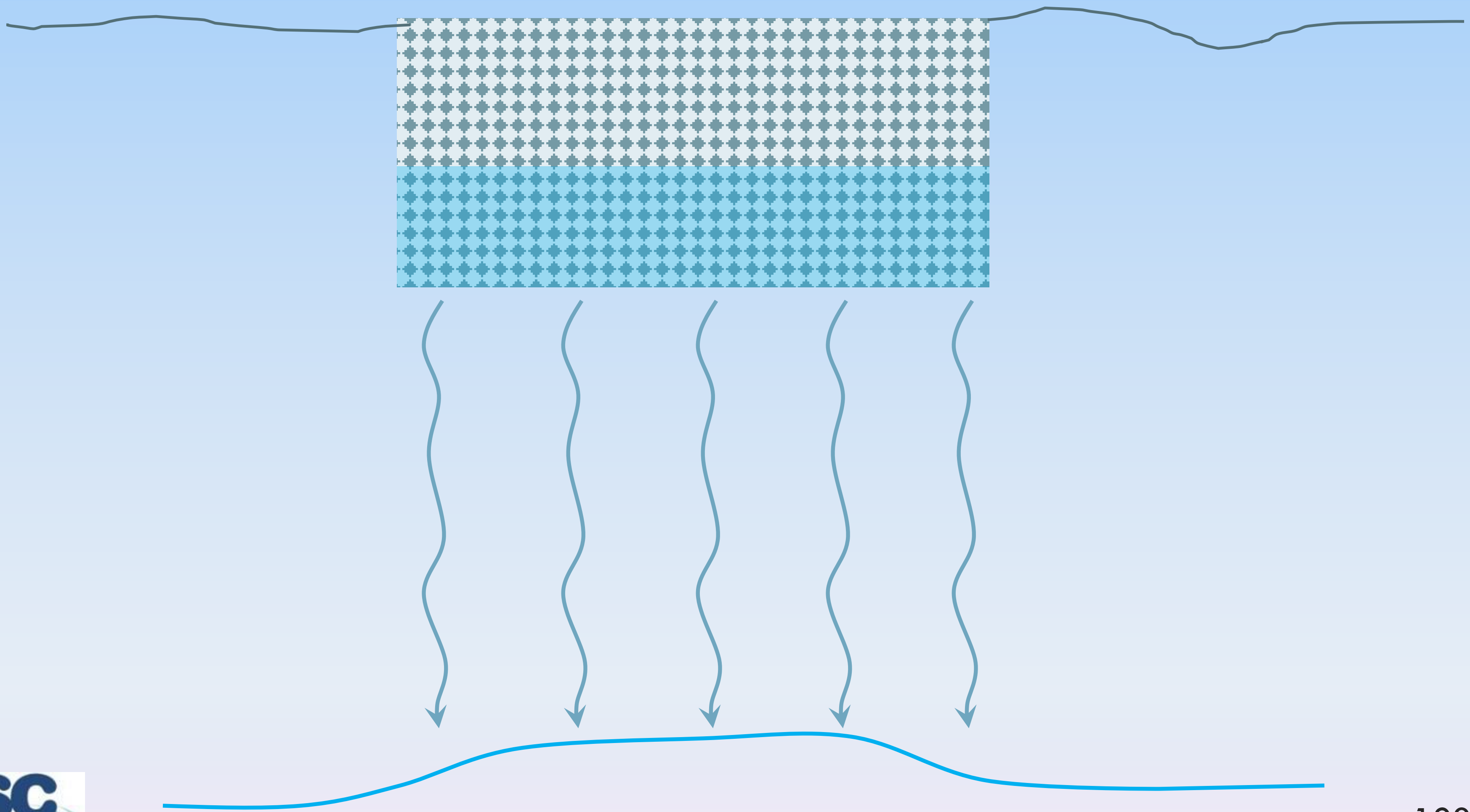


Infiltrated Volume

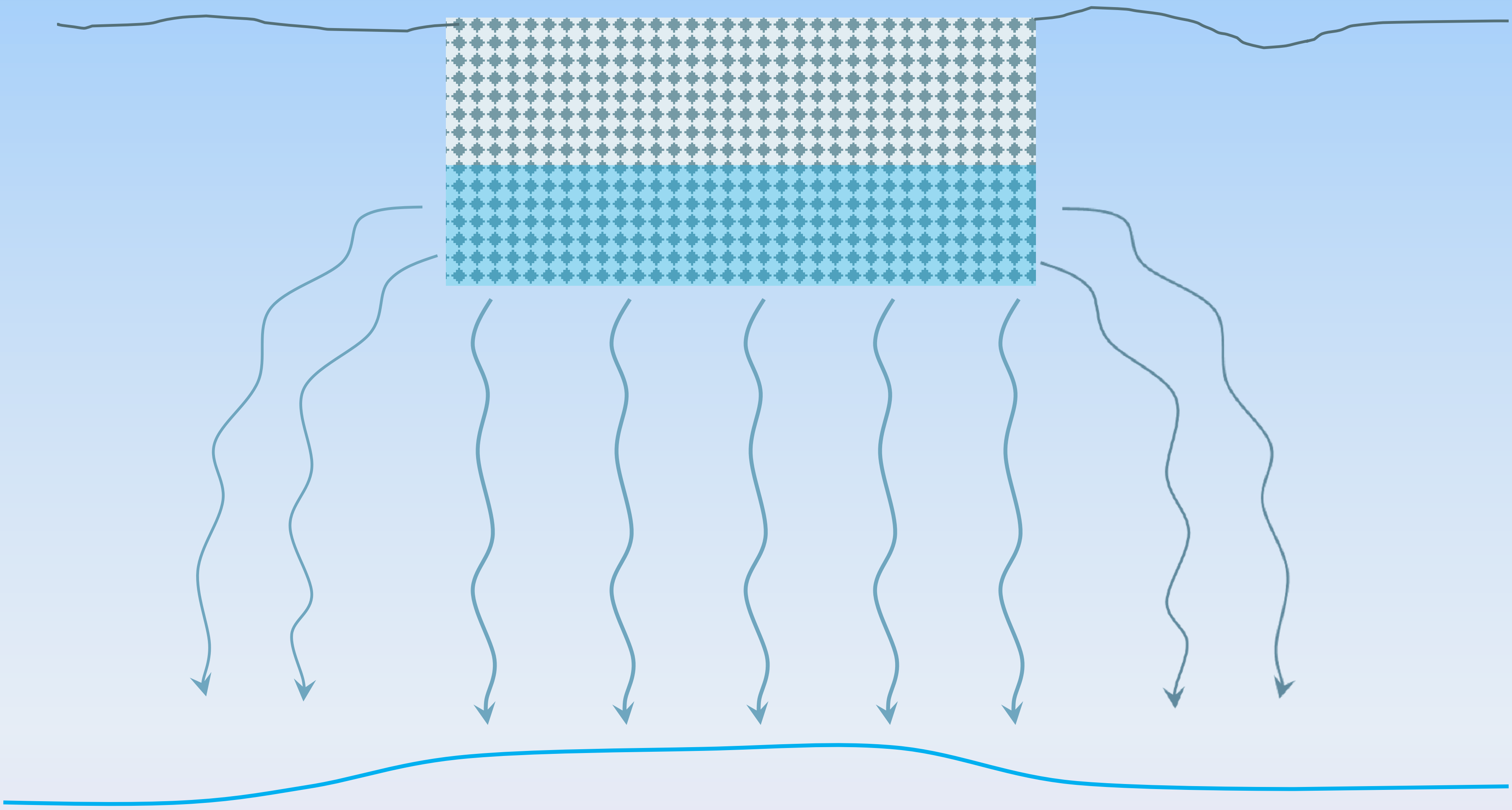
- For the 366 day period
  - 41.47 in. precip.
  - Precip. Volume = 87,300 ft^3
  - Runoff volume (C = 0.92) = 80,330 ft^3
  - Infiltrated volume = 64,583 ft^3

    (estimated from water depth)
  - Total Volume reduction = 80%

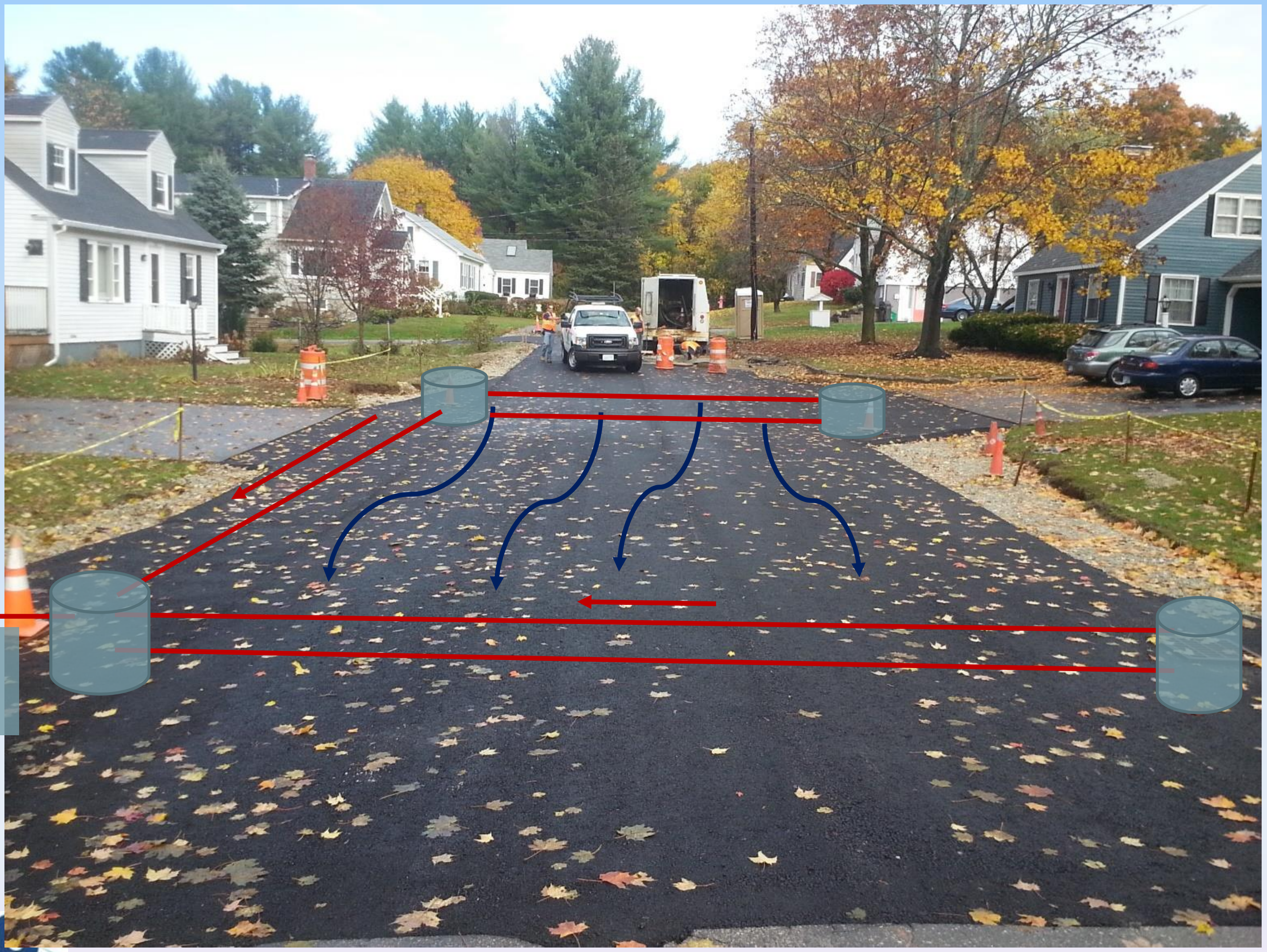
Design/Regulatory Model



More Realistic Model



GI: Subsurface Gravel Filter



To Existing Swale

Excavation

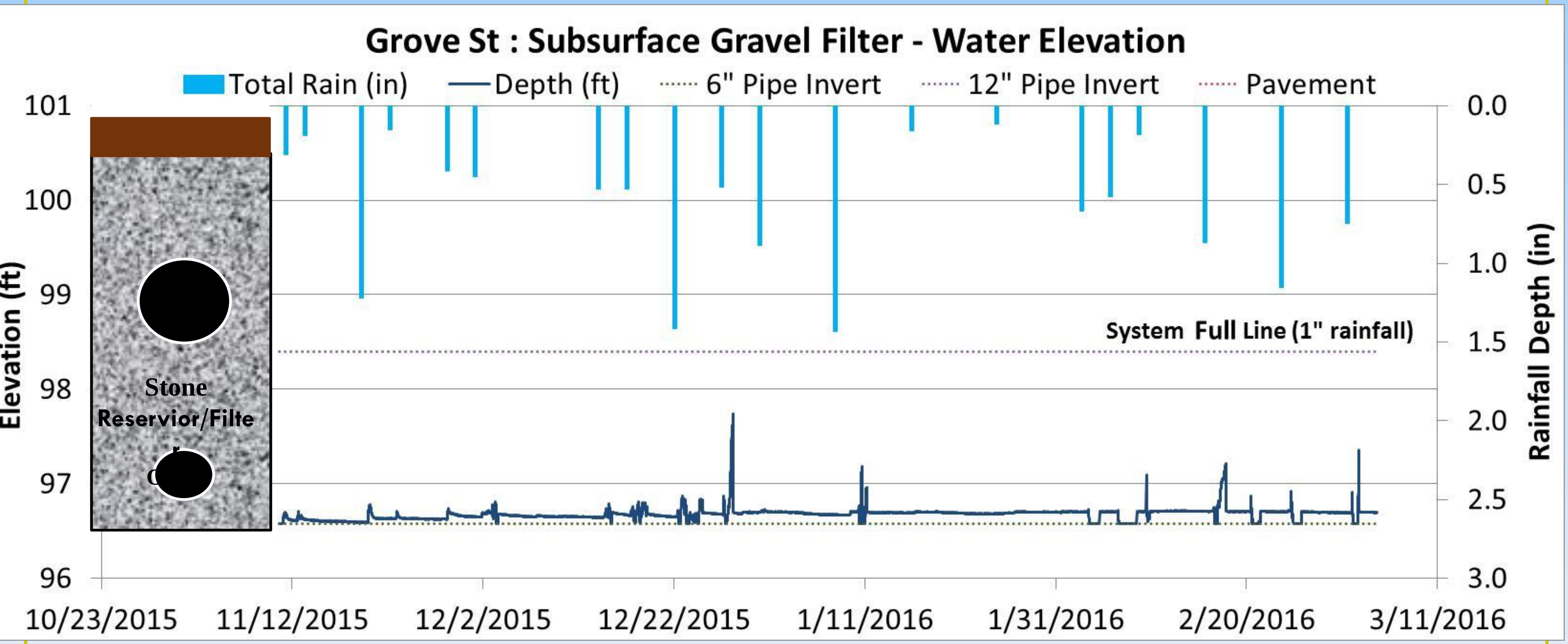
Excavation 90% complete

October 7, 2015

Pipe installation

Pipe installation between CB#1 & CB#2

October 8, 2015


Grove St : Subsurface Gravel Filter - Water Elevation
Total Rain (in)
Depth (ft)
6" Pipe Invert
12" Pipe Invert
Pavement
Elevation (ft)
Rainfall Depth (in)
101
100
99
98
97
96
0.0
0.5
1.0
1.5
2.0
2.5
3.0
System Full Line (1" rainfall)
Stone
Reservior/Filte
r
10/23/2015
11/12/2015
12/2/2015
12/22/2015
1/11/2016
1/31/2016
2/20/2016
3/11/2016

Conclusions

- Infiltration systems yield higher infiltration rates than design rate presumably because most design methods
  - Use only bottom area
  - Use a fraction (1/2 to 1/3) of field measured rates.

- This is leading to unnecessarily oversized systems and larger capital and maintenance costs

Performance analysis of two relatively small capacity urban retrofit stormwater controls

Sizing Details

System	WQV ft^3 (m^3)	Actual WQV ft^3 (m^3)	% of normal design	Rain Event in (mm)	Sizing Method
SGWSC	7,577 (214.6)	720 (20.4)	10%	0.10 (2.5)	Static
IBSCS	1,336 (37.8)	310 (8.8)	23%	0. 23 (5.8)	Dynamic

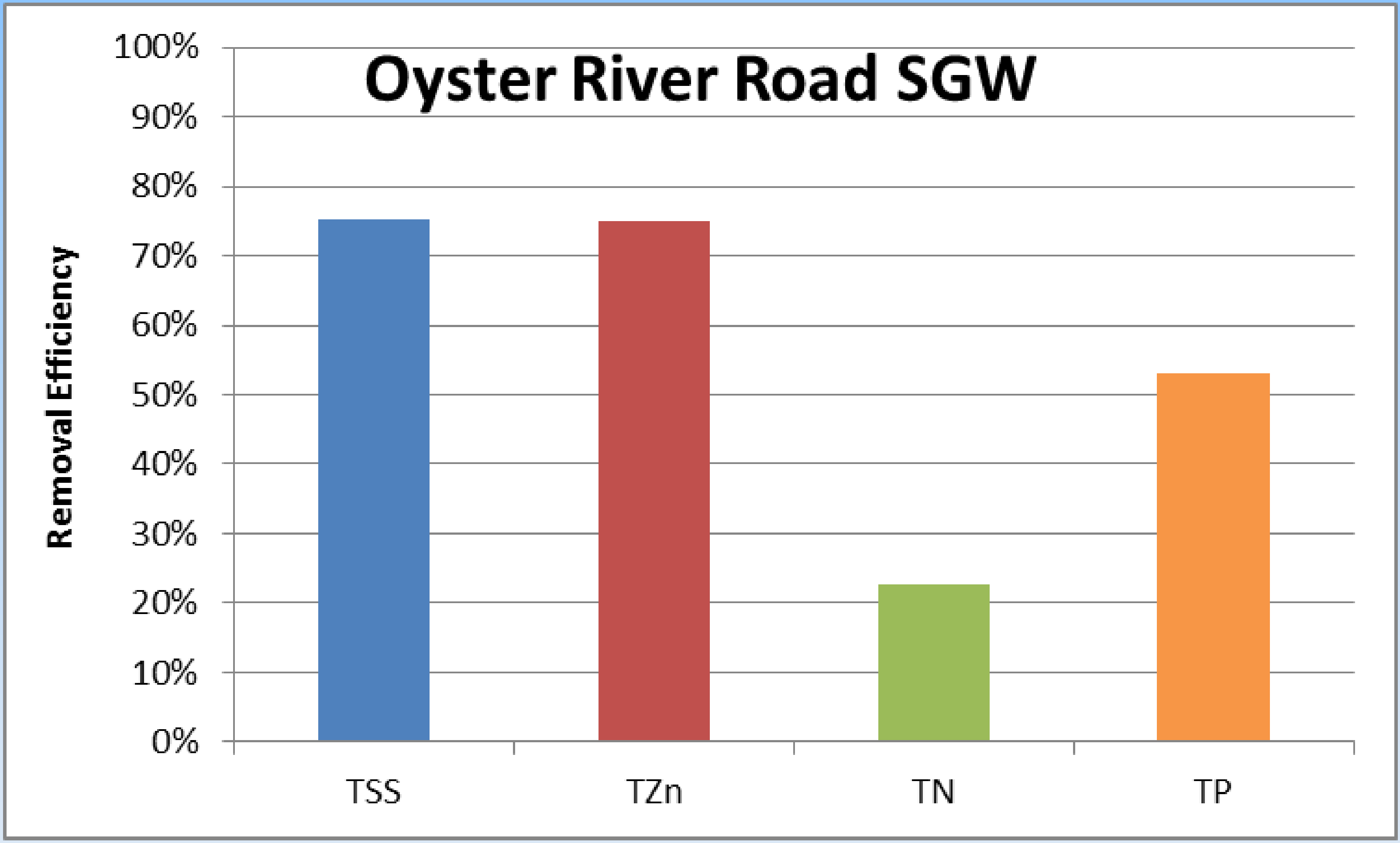
$$WQV = \left(\frac{P}{12}\right) x\ IA$$

Static SGW System Sizing

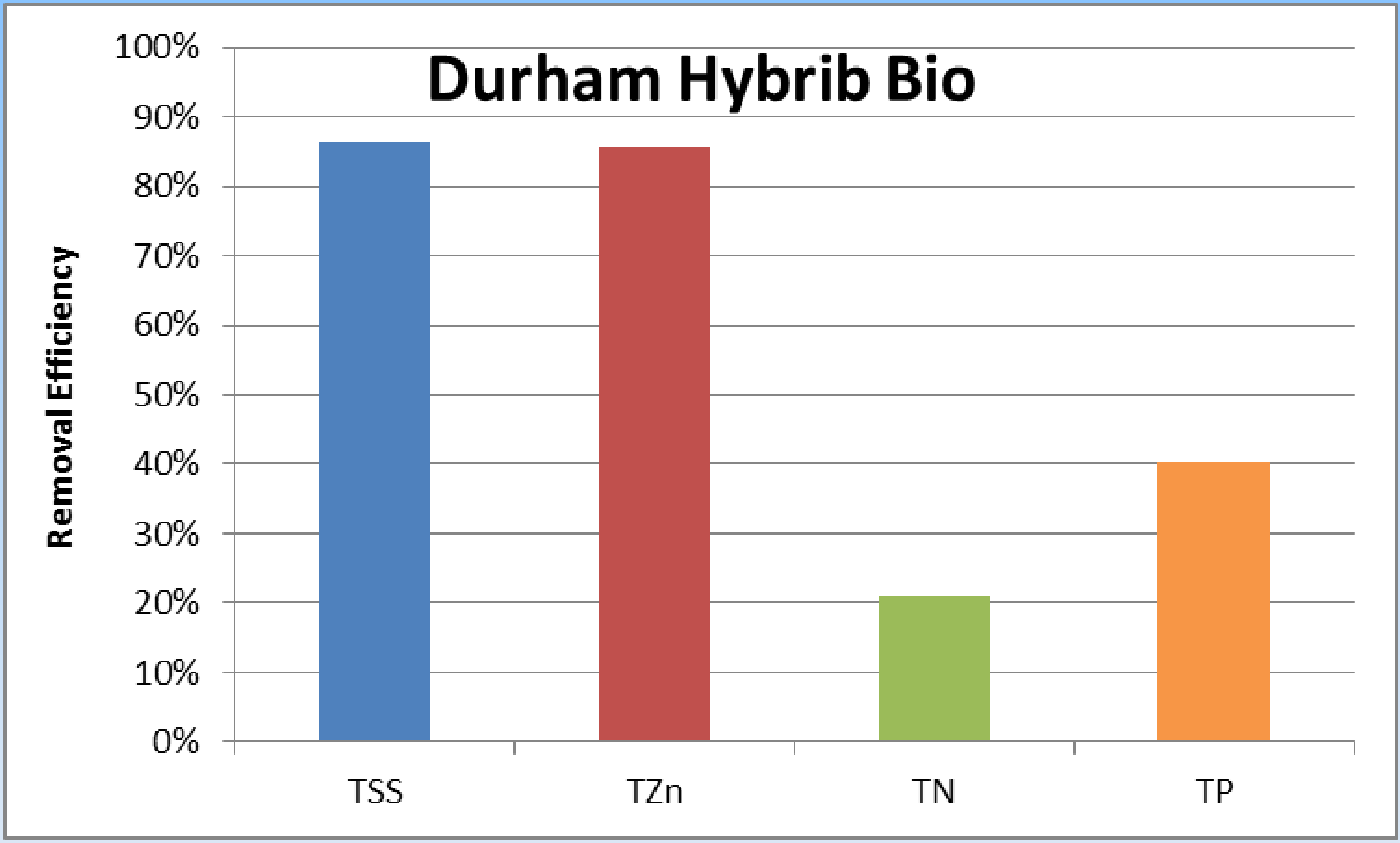
Dynamic Bioretention Sizing

$$Q = CdA\sqrt{2gh}$$

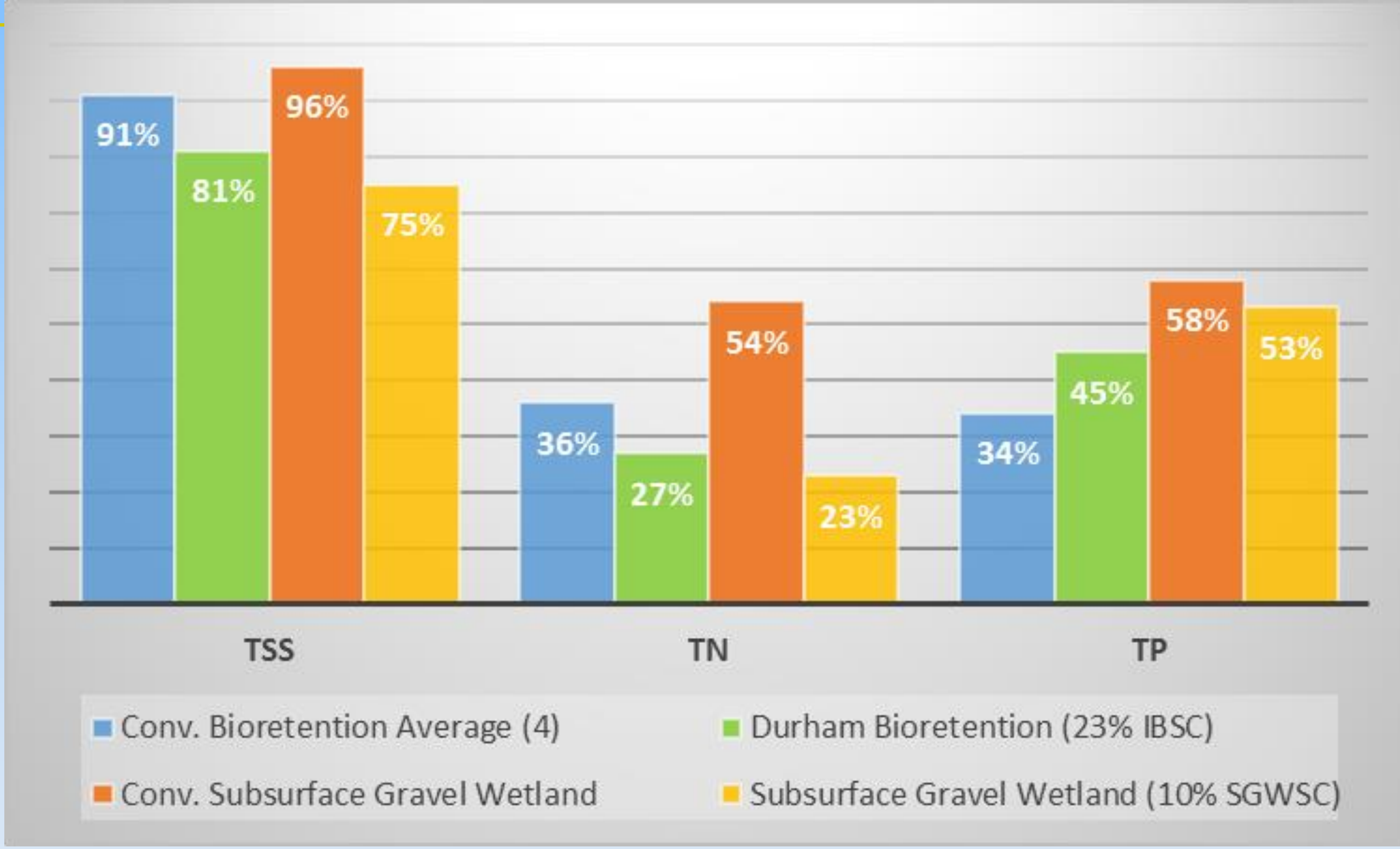
$$Af = Vwq * \frac{df}{(i(hf + df)tf)}$$



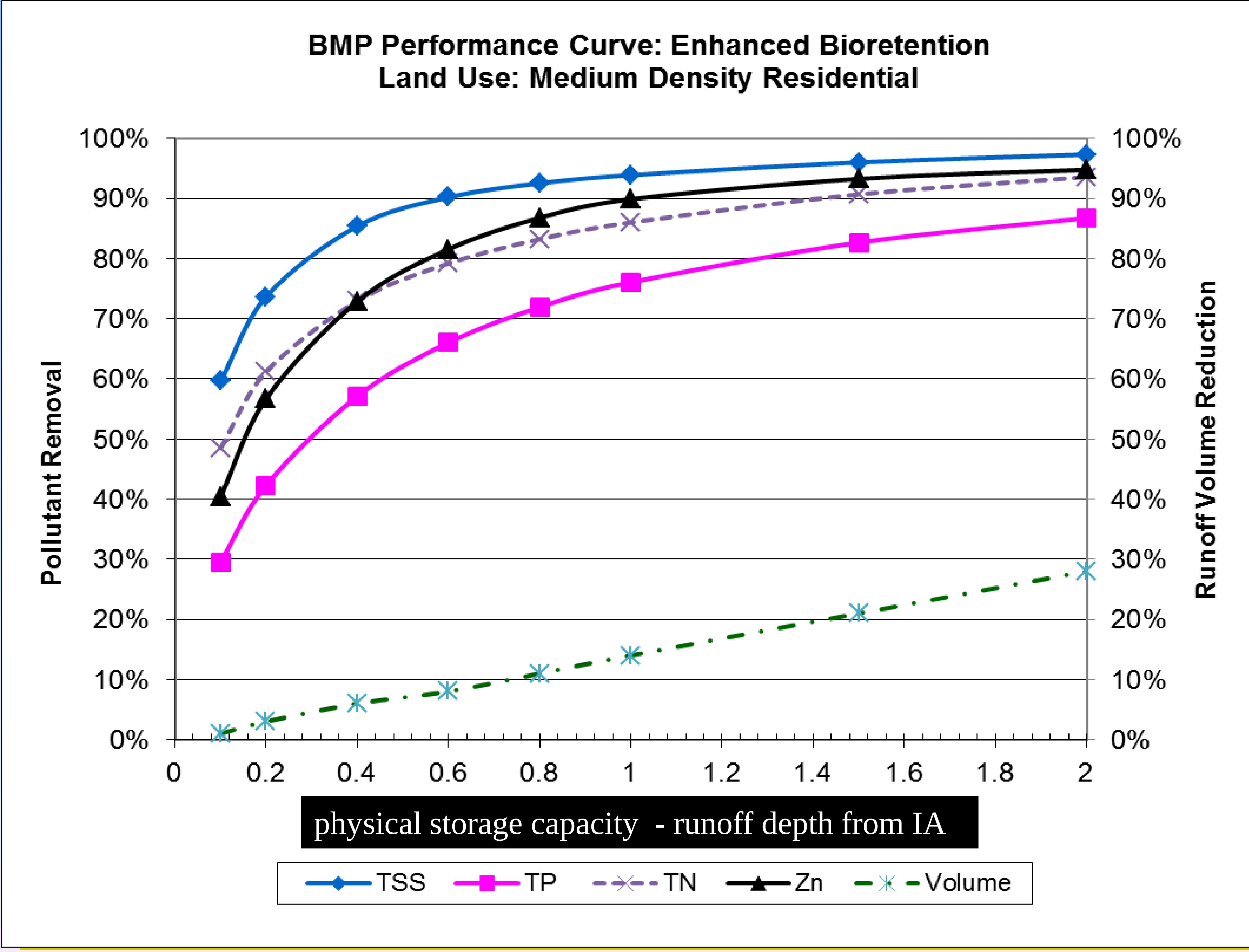
TSS EMC (mg/l)		TZn EMC (mg/l)		TN EMC (mg/l)		TP EMC (mg/l)	
n= 15		n= 9		n= 15		n= 15	
Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
107	17	0.3	0.1	2.1	1.5	0.3	0.1



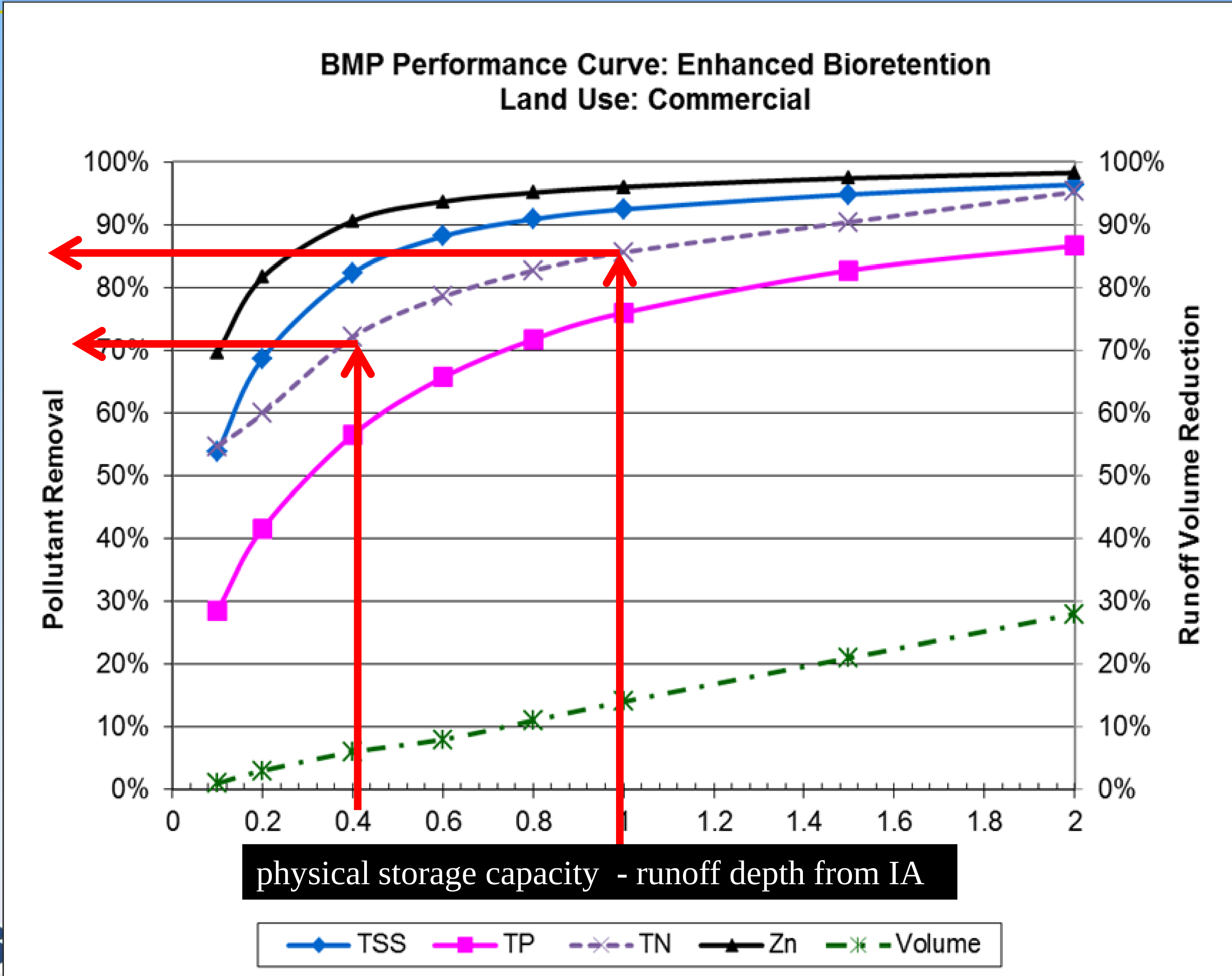
TSS EMC (mg/l)		TZn EMC (mg/l)		TN EMC (mg/l)		TP EMC (mg/l)	
n= 19		n= 19		n= 19		n= 18	
Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
106	21	0.11	0.02	1.9	1.4	0.14	0.07



System	TSS	TN	TP
Conv. Bioretention Average (4)	91%	36%	34%
Durham Bioretention (23% IBSC)	81%	27%	45%
Conv. Subsurface Gravel Wetland	96%	54%	58%
Subsurface Gravel Wetland (10% SGWSC)	75%	23%	53%



BMP Performance Curve: Enhanced Bioretention
Land Use: Medium Density Residential
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
physical storage capacity - runoff depth from IA
TSS
TP
TN
Zn
Volume



BMP Performance Curve: Enhanced Bioretention
Land Use: Commercial
Pollutant Removal
Runoff Volume Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
physical storage capacity - runoff depth from IA
TSS
TP
TN
Zn
Volume

The Big Picture

- WQV design is a great concept
- For retrofits, cannot always fully size to the WQV
- Undersized system performance is still remarkable
- Adding in dynamic sizing means that we could be saving 30% to 60% of the cost estimates floating around to meet TMDL targets….literally billions of dollars

Stormwater Management Design - 70.5 acre Ultra-Urban Drainage Area			
Sizing Comparison of Capital Costs and Relative Phosphorus Load Removal Efficiency			
Best Management Practice Size	Depth of Runoff Treated from Impervious Area (in)	*Storage Volume Cost ($/ft³)	**Total Phosphorus Removal Efficiency (%)
Subsurface Gravel Filter - Minimum Size	0.35	$1,016,912	62%
Subsurface Gravel Filter - Moderate Size	0.5	$1,452,732	80%
Subsurface Gravel Filter - Full Size	1.0	$2,905,463	96%
*Storage Volume Cost estimates provided by EPA-Region 1 for Opti-Tool methodology, 2015-Draft			
**Total Phosphorus %RE based on Appendix F Massachusetts MS4 Permit			

http://www.unh.edu/erg/cstev

SC
UNIVERSITY OF NEW HAMPSHIRE
STORMWATER CENTER