Low Impact Development Performance and Policy Implications in Ohio

June 9/10, 2015

Objectives

- Increase participant understanding of bioretention and permeable pavement performance on clay soils in Northern Ohio.
- Increase participant understanding of design, construction, and maintenance considerations for optimum bioretention and permeable pavement performance.
- Provide recommendations on ways to credit the contribution of LID stormwater control measure toward state and local stormwater requirements.
- Gather feedback on how project results may be used by stormwater professionals for plan review, design and construction.

National Estuarine Research Reserve System

- State-federal partnership

Research

Stewardship

Education

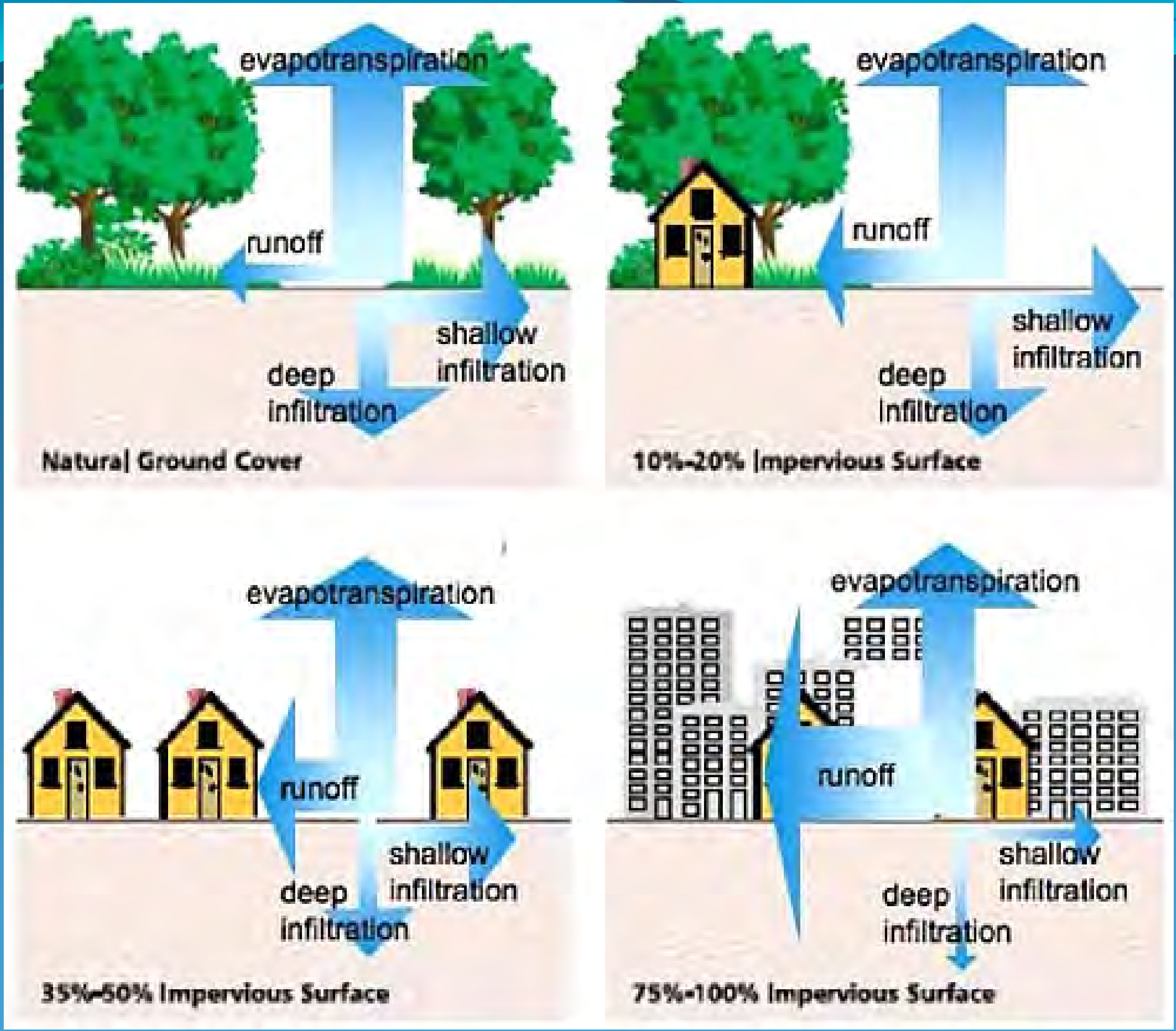
National Estuarine Research Reserve System

NERRS Science Collaborative

- NOAA funds through University of New Hampshire
- Applied research informed by intended users
- Research addresses problems affecting estuary & NERR

How did collaborative learning inform this project?

- Ohio EPA, ODNR, Designers, Plan Reviewers
- Helped decide:
  - which SCMs to monitor
  - aspects of research design
  - how to translate results


evapotranspiration
runoff
shallow infiltration
deep infiltration
Natural Ground Cover
evapotranspiration
runoff
shallow infiltration
deep infiltration
10%-20% Impervious Surface
evapotranspiration
runoff
shallow infiltration
deep infiltration
35%-50% Impervious Surface
evapotranspiration
runoff
shallow infiltration
deep infiltration
75%-100% Impervious Surface

Low Impact Development (LID) Stormwater Control Measures (SCMs)

Project Motivation

- Lack of widespread use of LID SCMs
  - LID not credited towards peak discharge
  - Need for better design guidance & tools
  - Zoning requirements impede LID
  - Pipe & pond culture
- Some people not convinced LID works in Ohio's conditions
  - Poorly draining soil
  - Cold winter

Objectives

- Appropriately credit LID SCMs for volume reduction and peak discharge attenuation

  -Statewide runoff reduction option for WQv

  -Local community code credit for flood control

- Evaluate bioretention & permeable pavement performance on HSG C & D soils



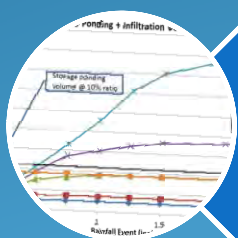
Project Components

Design & Construction

LID demonstration projects

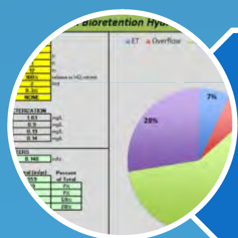
Monitoring

Acquire BMP hydrology data



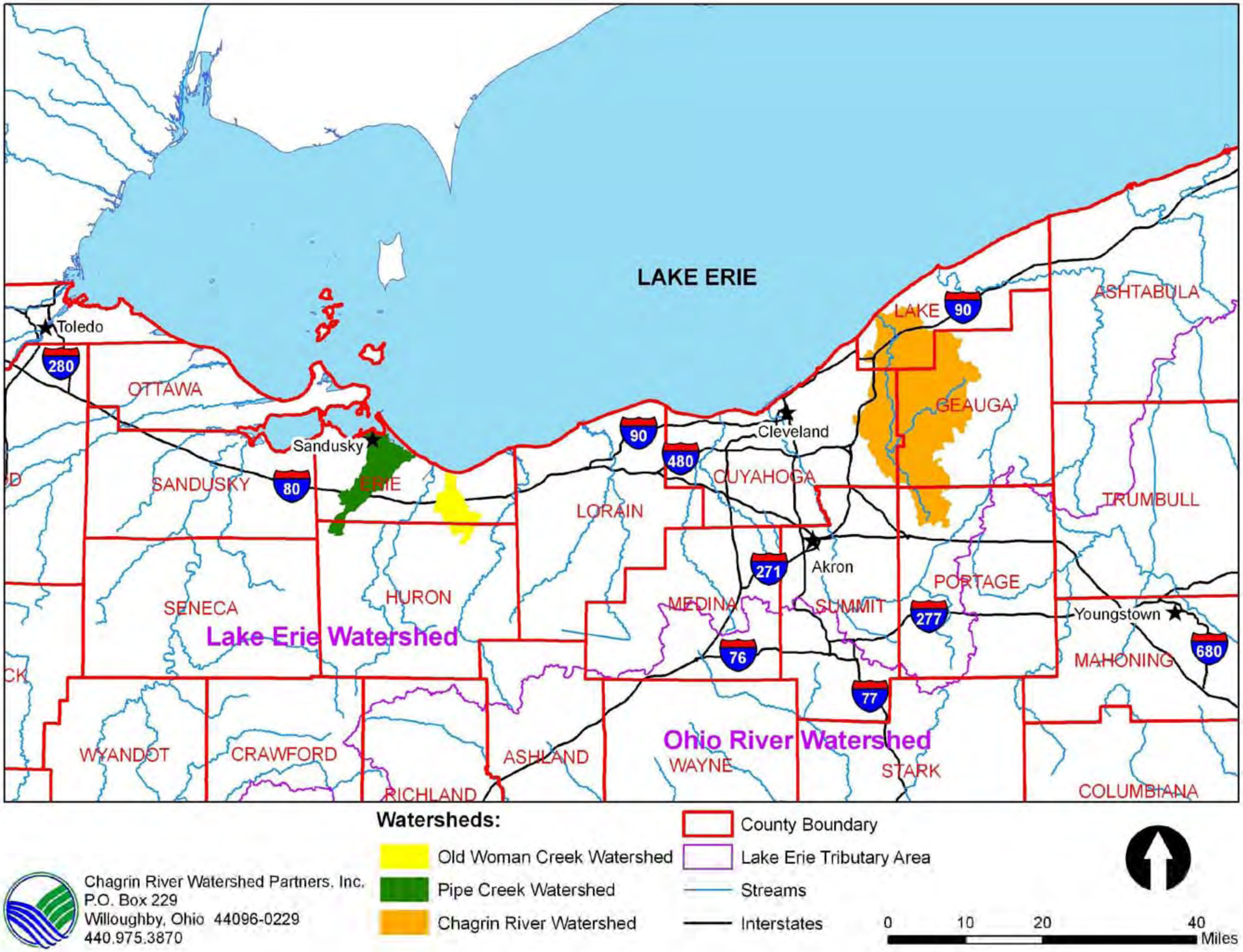
Modeling

Characterize hydrologic performance under current and projected precipitation patterns



Tools and Guidance

Case studies, model codes, revised design standards, credit recommendations


LAKE ERIE
Toledo
Sandusky
Cleveland
Akron
Youngstown
280
80
90
480
271
277
76
77
680
OTTAWA
SANDUSKY
ERIE
LORAIN
CUYAHOGA
LAKE
GEAUGA
ASHTABULA
TRUMBULL
PORTAGE
SUMMIT
MEDINA
HURON
SENECA
MAHONING
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
COLUMBIANA
Lake Erie Watershed
Ohio River Watershed
Watersheds:
Old Woman Creek Watershed
Pipe Creek Watershed
Chagrin River Watershed
County Boundary
Lake Erie Tributary Area
Streams
Interstates
0 10 20 40
Miles
Chagrin River Watershed Partners, Inc.
P.O. Box 229
Willoughby, Ohio 44096-0229
440.975.3870


Lake Erie
Perkins Township Administration Building
Pervious Concrete Parking Lot
Old Woman Creek
National Estuarine Research Reserve
Pervious Pavers and Rainwater Harvesting
Vermilion River
Pipe Creek
Erie
Huron River
Old Woman Creek
Huron
0 1 2 3 4 Miles

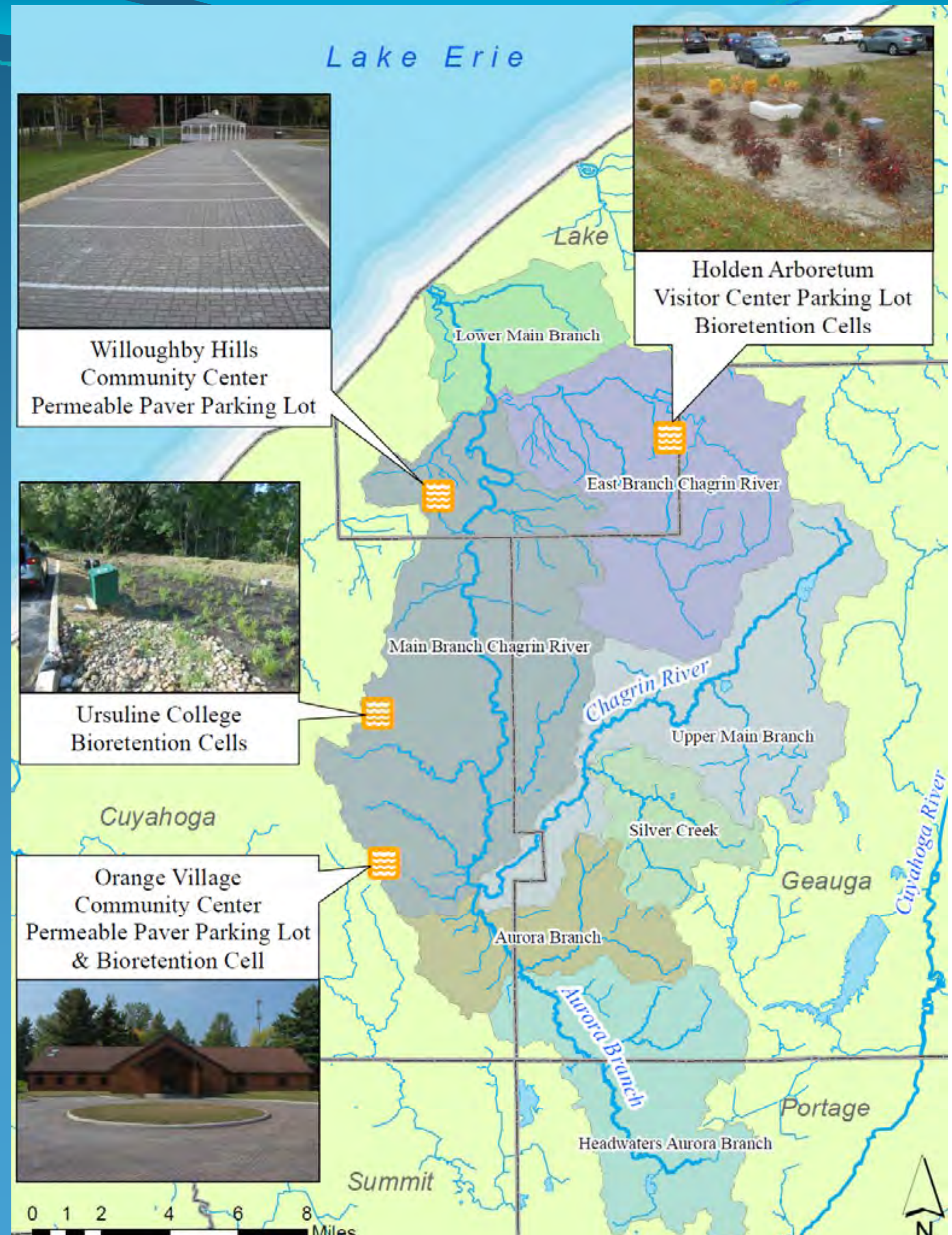

Lake Erie
Willoughby Hills
Community Center
Permeable Paver Parking Lot
Holden Arboretum
Visitor Center Parking Lot
Bioretention Cells
Lake
Lower Main Branch
East Branch Chagrin River
Ursuline College
Bioretention Cells
Main Branch Chagrin River
Chagrin River
Upper Main Branch
Cuyahoga
Silver Creek
Orange Village
Community Center
Permeable Paver Parking Lot
& Bioretention Cell
Geauga
Cuyahoga River
Aurora Branch
Aurora Branch
Portage
Headwaters Aurora Branch
Summit
0 1 2 4 6 8 Miles
N

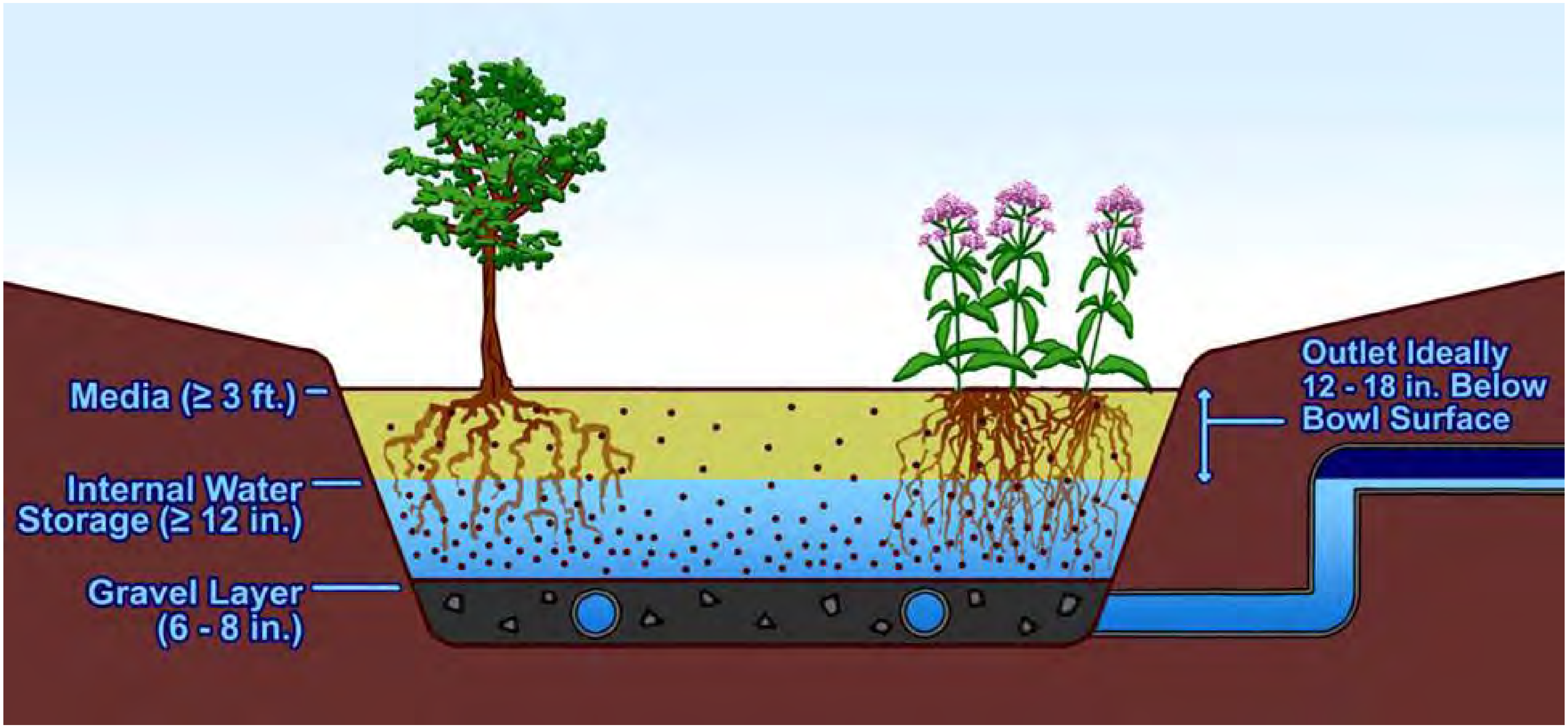
Table Discussion

- Your name & affiliation
- Please share your background or experience with LID including an y challenges or questions about LID.

Bioretention Performance

Ryan Winston (NCSU) & Jay Dorsey (ODNR)

Bioretention Schematic



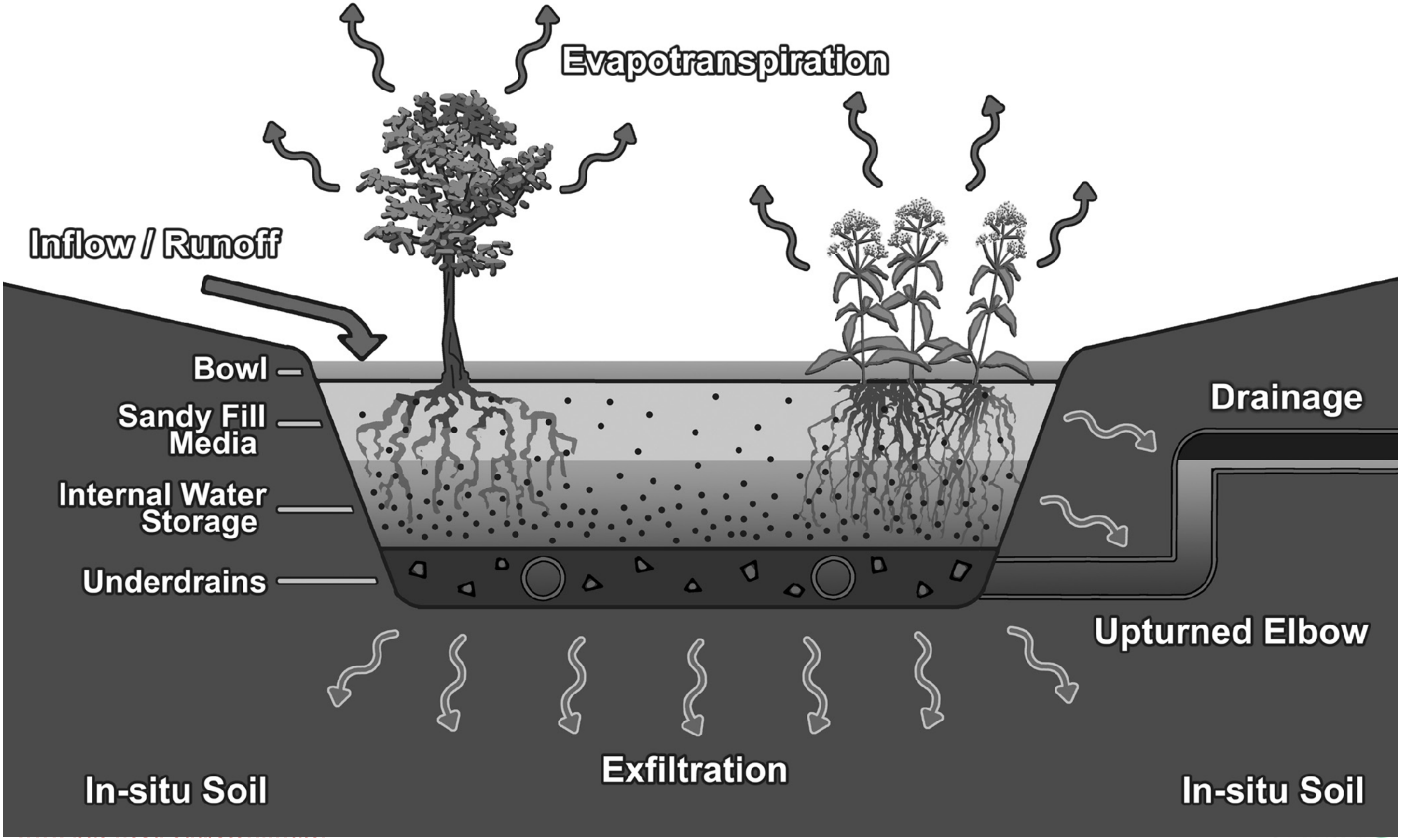
Q: How does Bioretention work: Hydrologic (Flow) Control

- Temporary surface storage
- Slow flow through porous media (peak flow control).
- Media with good field capacity means volume control, whether or not exfiltration is possible.
- Especially effective for small(ish), frequently occurring storm events → typically little to no system discharge!
- Bypass of large events

+ 4 Hours

+14 Hours

Design Features



Monitoring Sites

Orange Village Community Center

Permeable Pavers & Bioretention Cell

Ursuline College

Bioretention Cell

Willoughby Hills Community Center

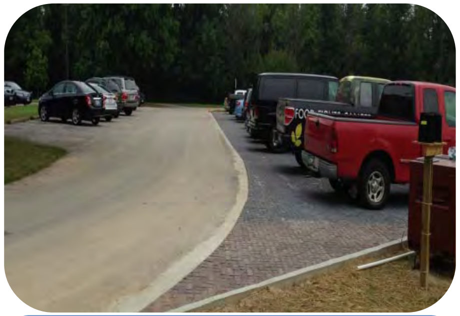
Permeable Interlocking Concrete Pavers

Holden Arboretum

Bioretention Cells

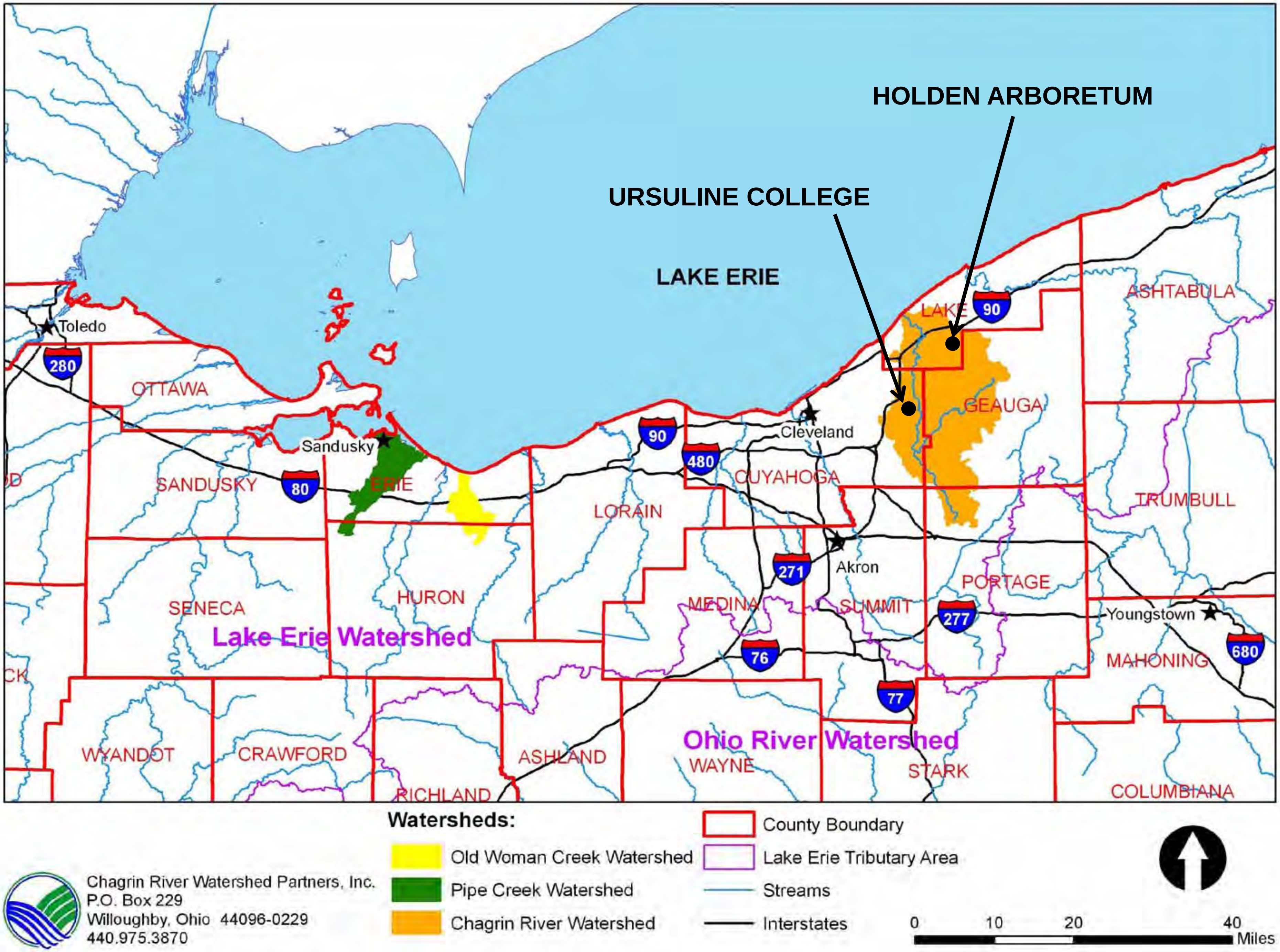
Perkins Township Administration Building

Pervious Concrete



Old Woman Creek NERR

Permeable Interlocking Concrete Pavers


HOLDEN ARBORETUM
URSULINE COLLEGE
LAKE ERIE
Toledo
Sandusky
Cleveland
Akron
Youngstown
280
80
90
480
271
277
76
77
680
OTTAWA
SANDUSKY
ERIE
LORAIN
CUYAHOGA
LAKE
GEAUGA
ASHTABULA
TRUMBULL
PORTAGE
SUMMIT
MEDINA
HURON
SENECA
MAHONING
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
COLUMBIANA
Lake Erie Watershed
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Watersheds:
Old Woman Creek Watershed
Pipe Creek Watershed
Chagrin River Watershed
County Boundary
Lake Erie Tributary Area
Streams
Interstates
0
10
20
40
Miles
Chagrin River Watershed Partners, Inc.
P.O. Box 229
Willoughby, Ohio 44096-0229
440.975.3870

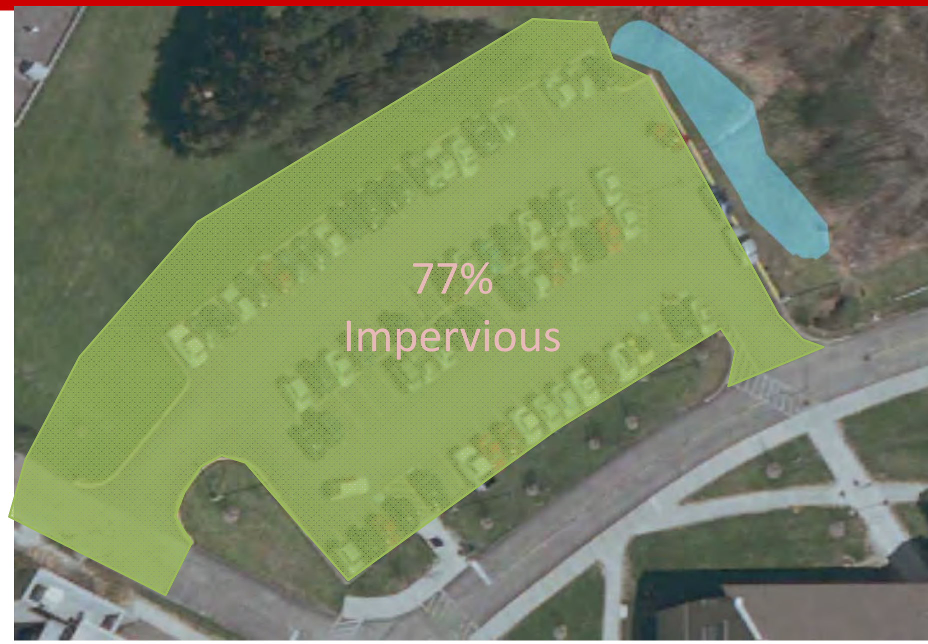
Ursuline College Bioretention

Constructed Apr-May 2014

Monitored May-Dec 2014

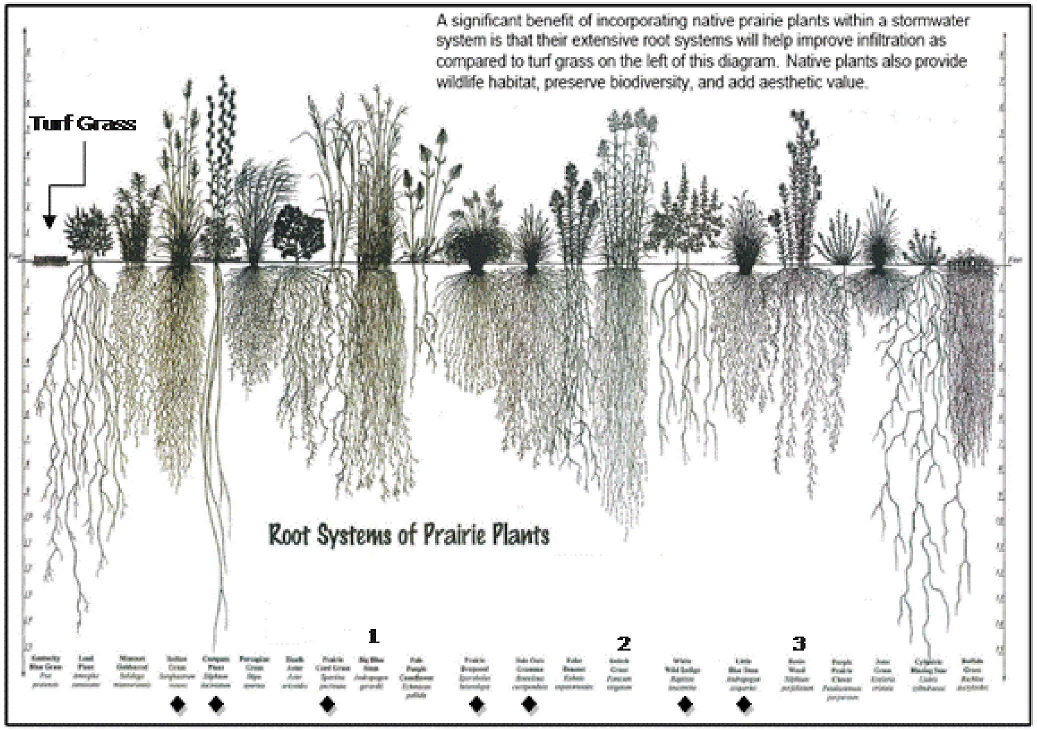
Surface area: 1960 ft^2
(6.2% of imp. drainage area)

Hydrologic loading ratio: 21.2



Storm Events (#)	Total Rainfall Depth (in)	Rainfall Depth Range (in)
50	29.21	0.1-3.51

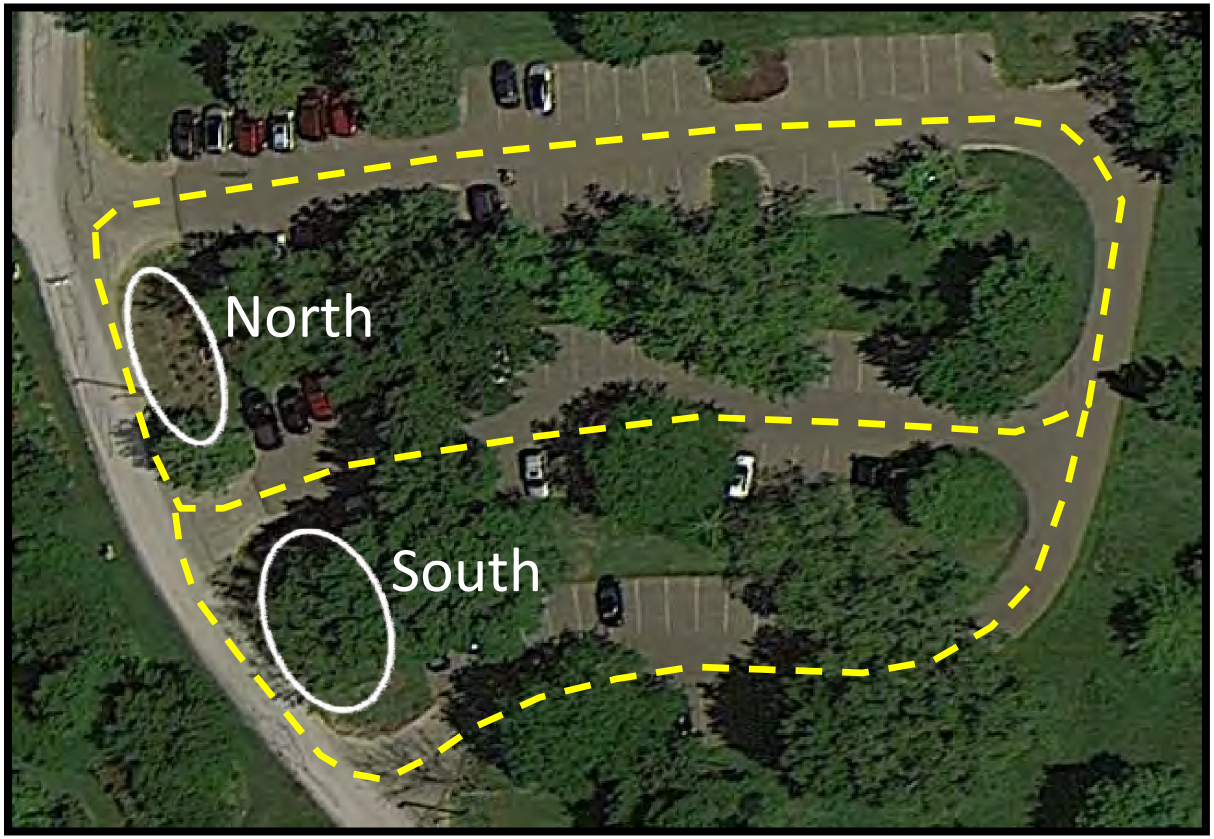
Holden Arboretum



Courtesy: Nature 2012

Bio&Ag ENGINEERING

Holden Site Characteristics



Constructed: Sept 13

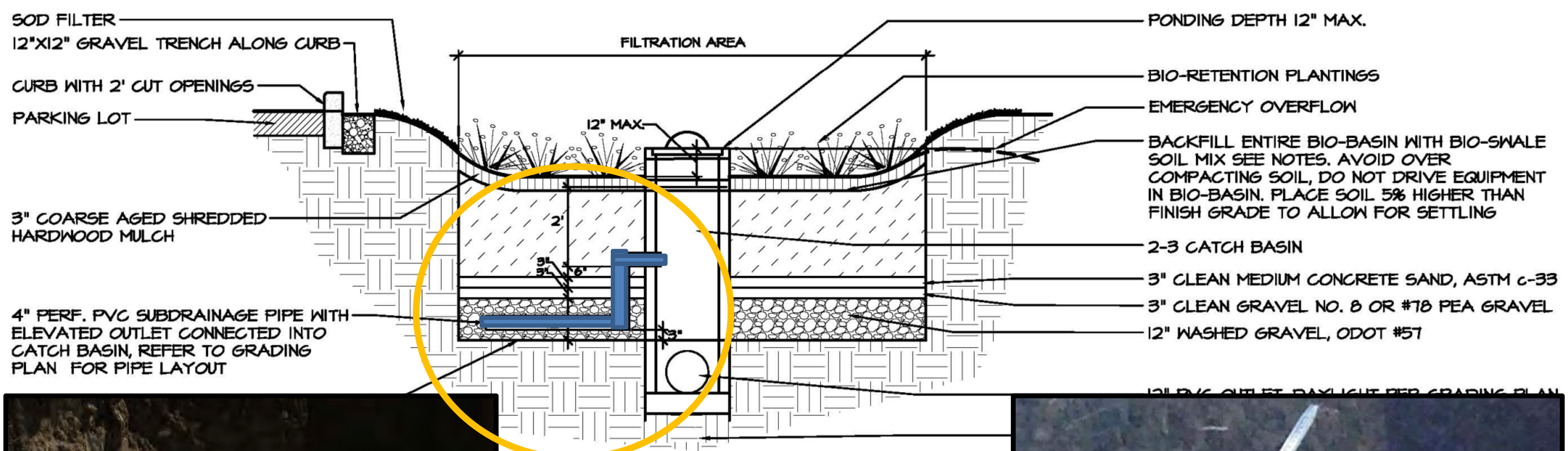
Monitored:
Oct 13 - Dec 14

Storm Events (#)	Total Rainfall Depth (in)	Rainfall Depth Range (in)
90	46.24	0.1-2.79

Design Characteristics

Site Name	Cell Name	Catchment % Imp.	Avg. Bowl Depth (in)	Media Depth (ft)	Gravel Layer (in)	Total Depth (ft)
Ursuline College	-	77.3	11	2	12	5
Holden Arboretum	South	58.3	15	3	12	6
	North	58.2	16	3	12	6

Internal Water Storage (IWS) Zone



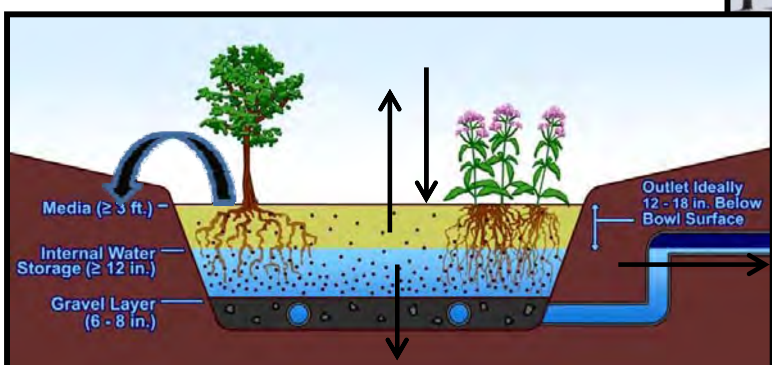
Ursuline: 24 in

Holden N: 18 in

Holden S: 15 in

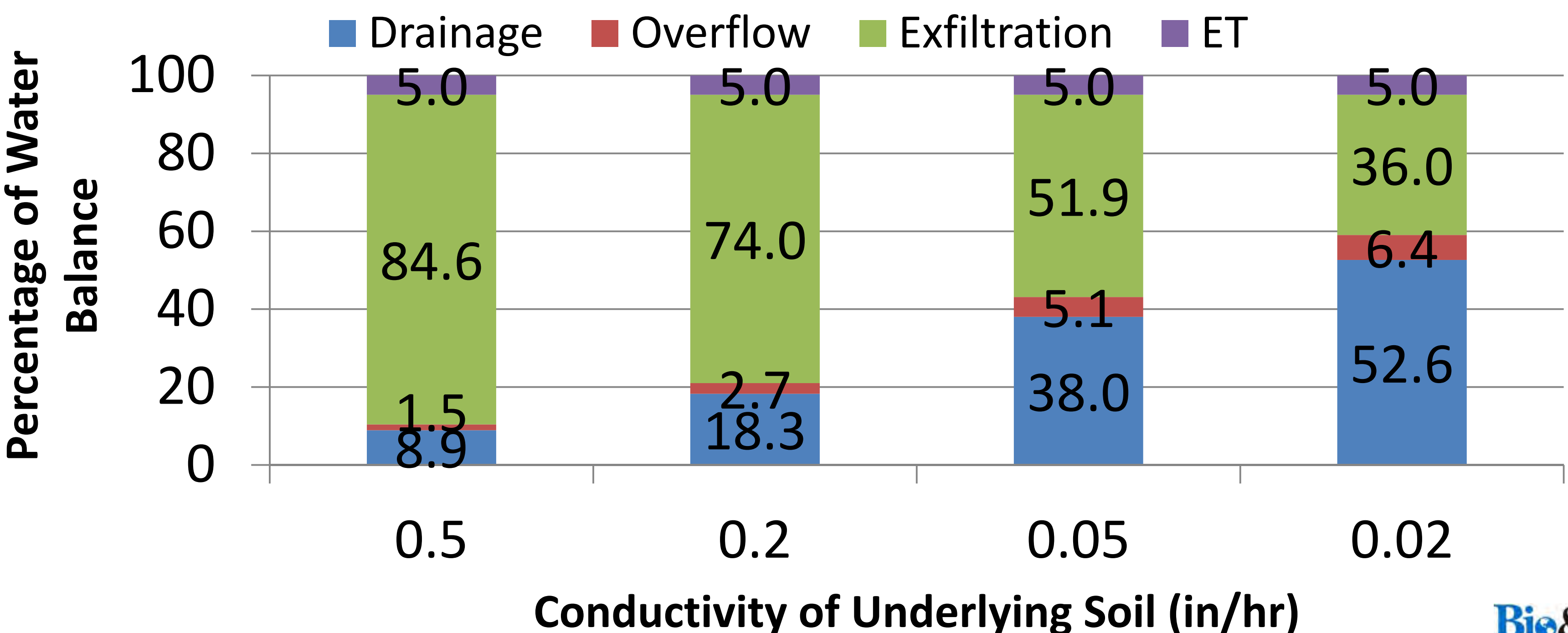
Hydrologic Monitoring

- **Quantify the water balance:**
  - Rainfall
  - Evapotranspiration
  - Exfiltration
  - Drainage
  - Abstraction
  - Overflow



Keys to Long-Term Performance

- Maintenance: Preventing clogging of the media
- Maintenance: Plant Health
- Design: Underlying soil infiltration rate
  - Ability of soil to accept water

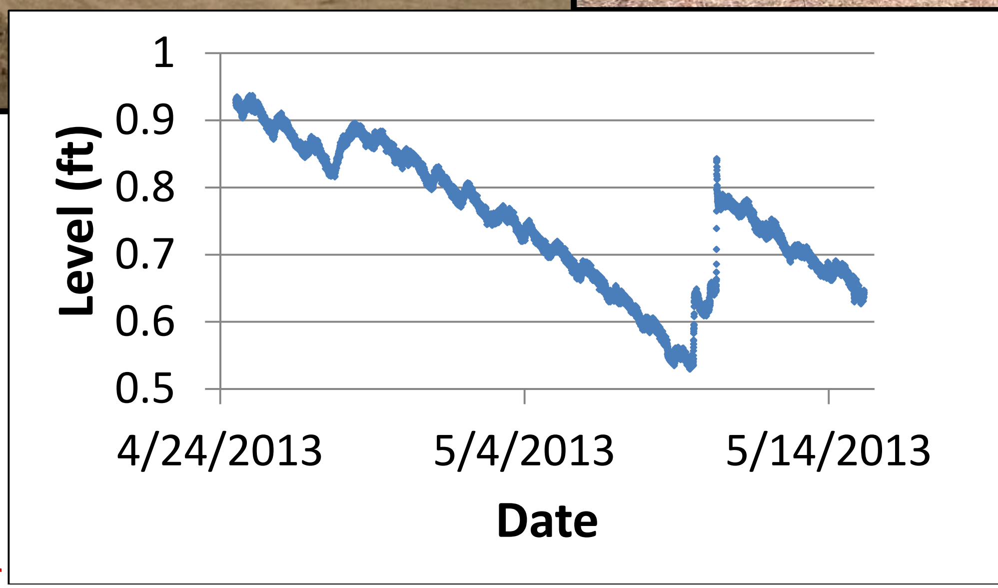


Pre-Construction Infiltration Testing

Site	Mapped Soil	Subgrade Soil Texture	Measured Kfs (in/hr)
Holden Arboretum	Platea (North) Pierpont (South)	Silty Clay Loam	North – 0.02, 0.02 South - 0.02, 0.08
Ursuline College	Mahoning	Fill	0.02, 0.02, 0.03

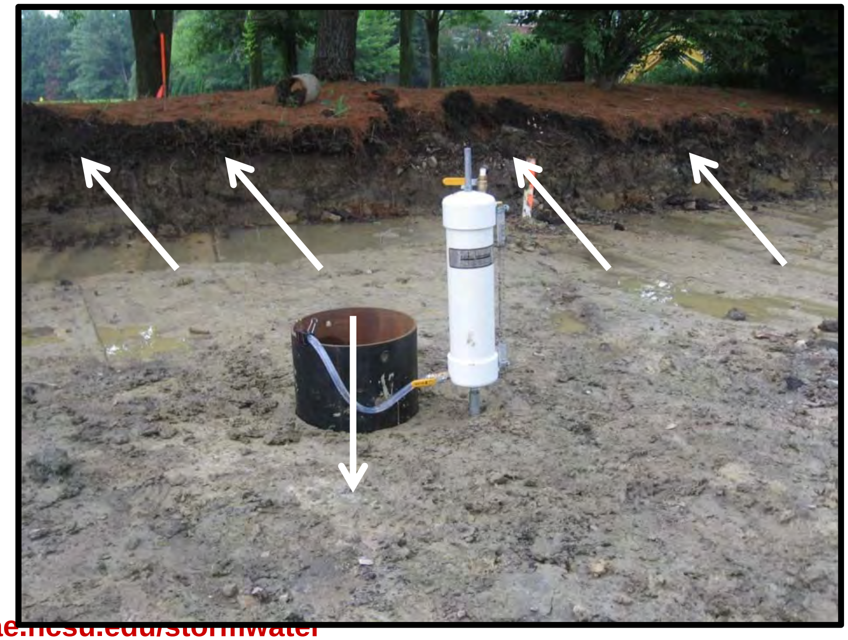
Monitoring Results

Monitoring Drawdown



Post-Construction Drawdown Rates

Site	Pre-Construction Kfs (in/hr)	**Average** Measured Drawdown Rate (in/hr)
Holden North	0.02, 0.02	0.065
Holden South	0.02, 0.08	0.083
Ursuline	0.02, 0.02, 0.03	0.172



Single ring infiltrometer tests:

Provide estimates of vertical soil hydraulic conductivity

Drawdown Rates:

Includes lateral movement of water into the soil + ET

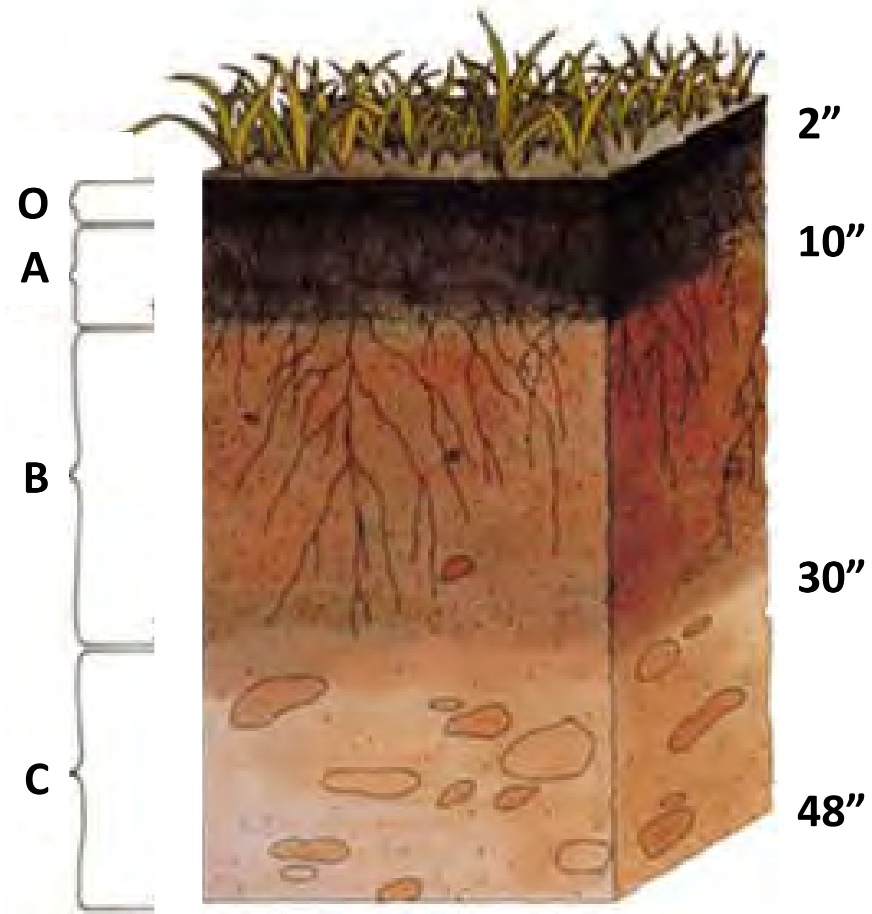
Intro to Soils: Hydrologic Soil Group (HSG)

- HSGs based on minimum infiltration rate of bare soil after prolonged wetting (NRCS TR-55)
- Controlled by surface conditions *and* subsurface water transmission

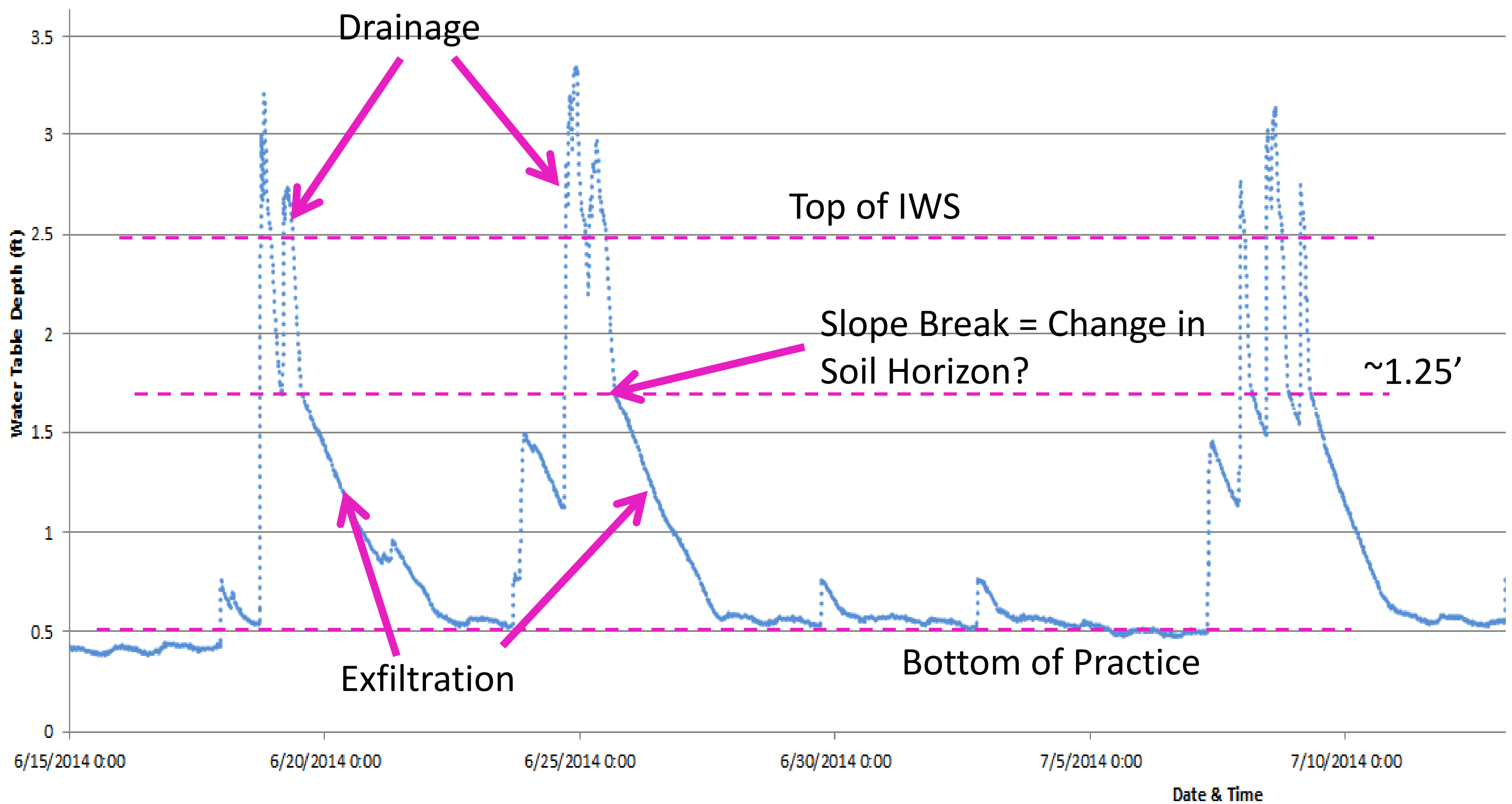
HSG	Rate of Transmission	Soil Texture
A	> 0.3 in/hr	Sand, loamy sand, sandy loam
B	0.15-0.3 in/hr	Silt loam, loam
C	0.05-0.15 in/hr	Sandy clay loam
D	< 0.05 in/hr	Clay loam, silty clay loam, sandy clay, silty clay, clay

Intro to Soils: Vertical Heterogeneity

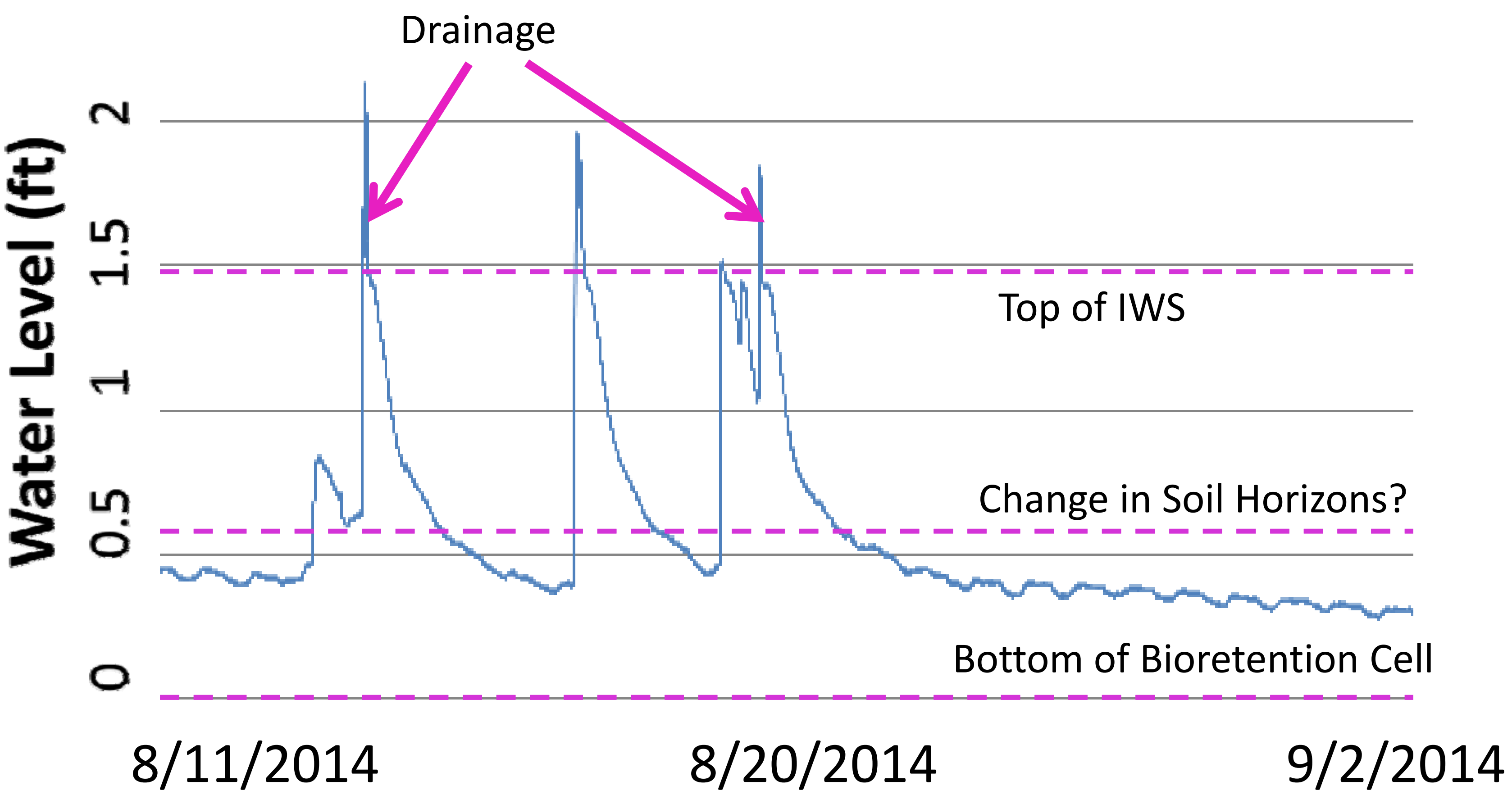
- Soils have layers (horizons) w/ varying properties
- Parent material, underlying geology, vegetation, climate, and landscape position affect profile



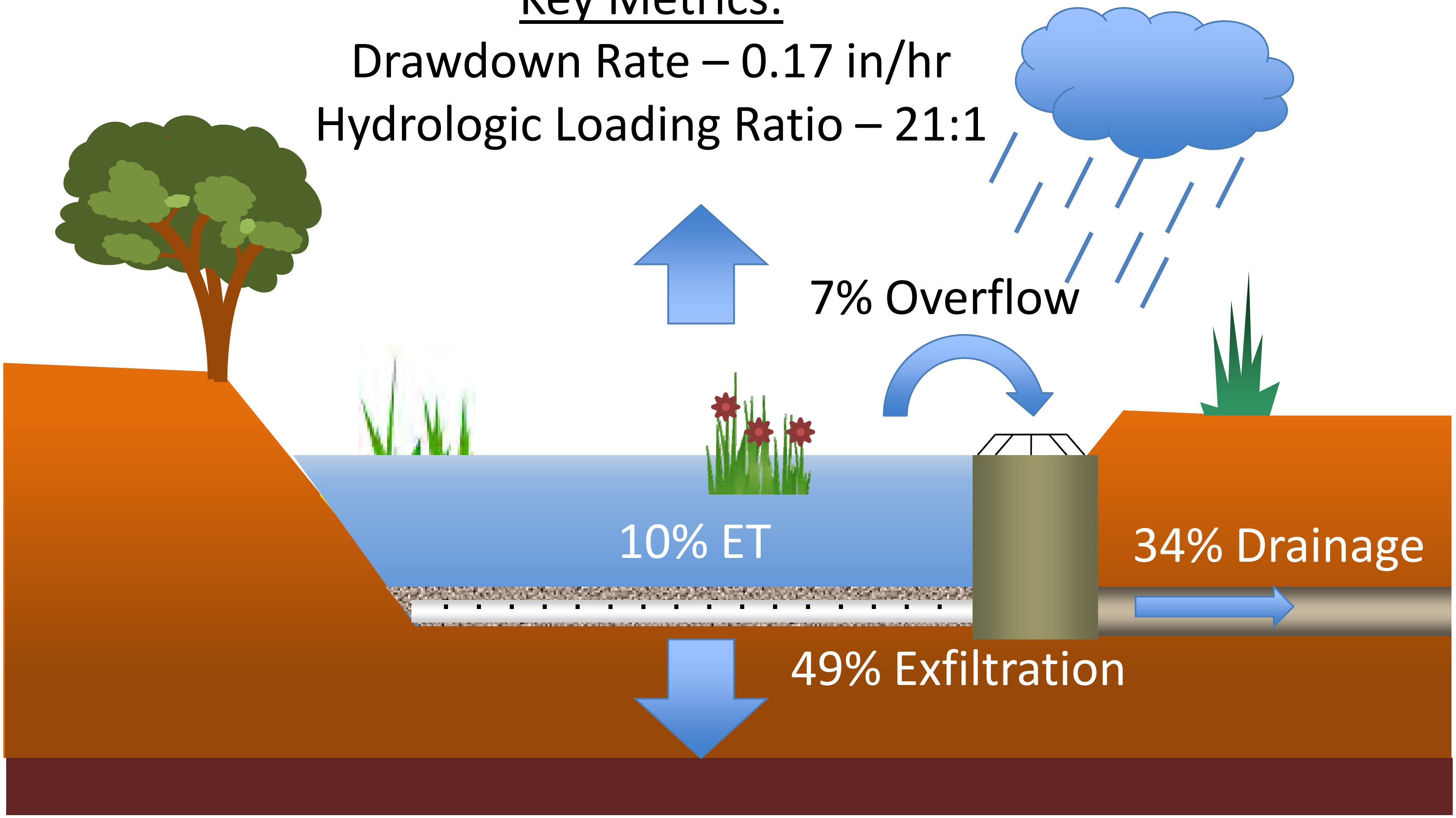
Ursuline Water Table



Holden Water Table



Hydrologic Fate: Ursuline College



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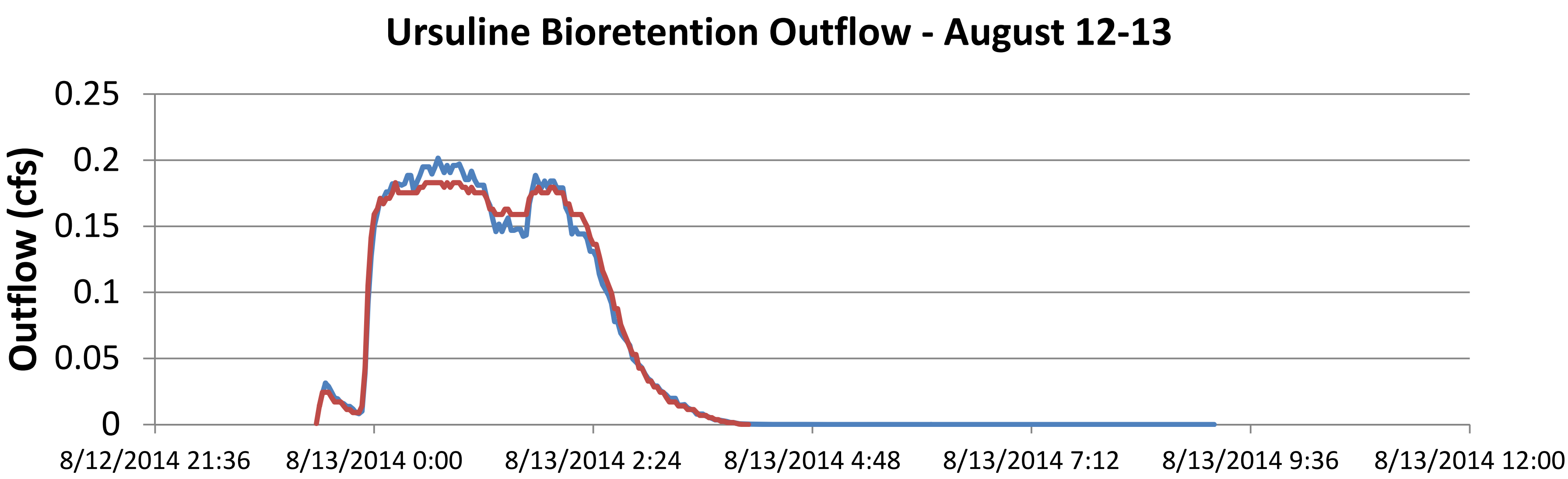
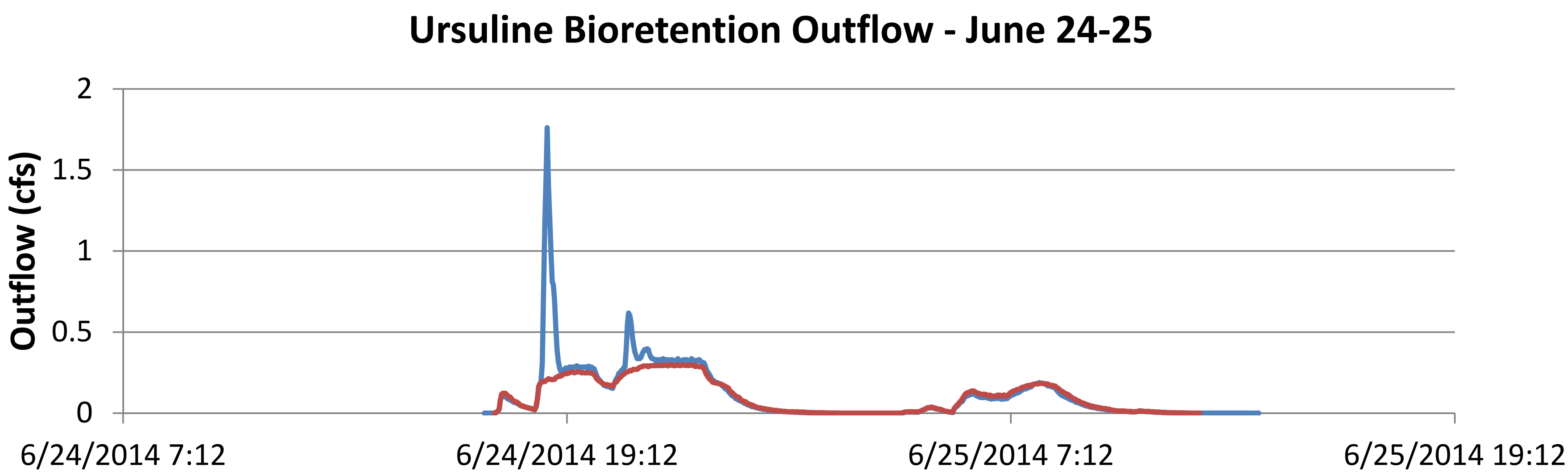
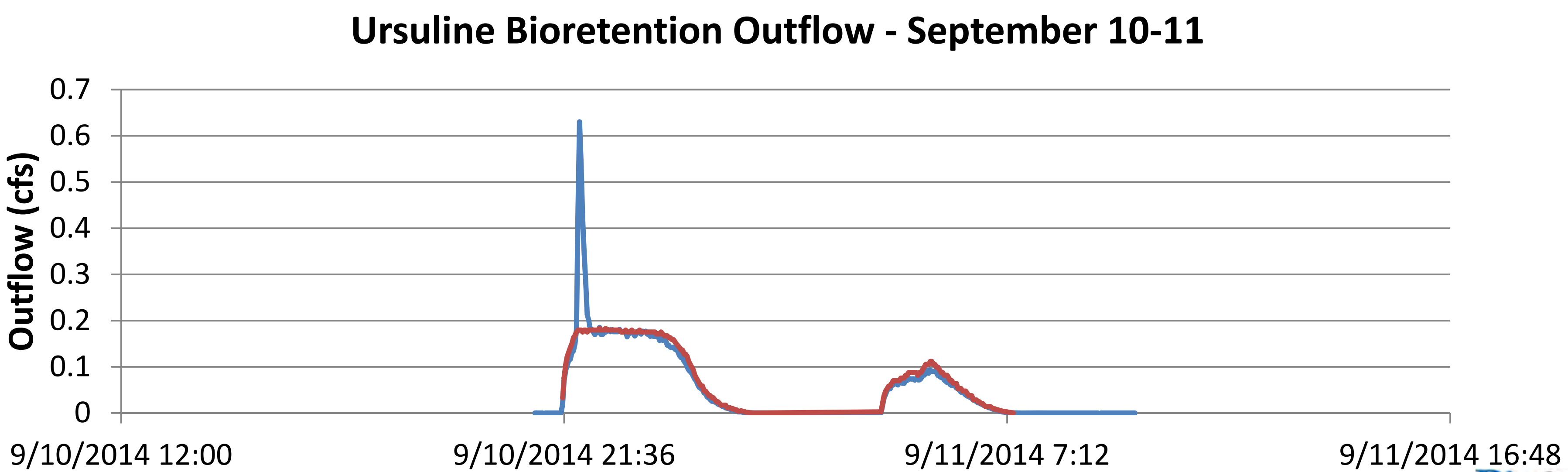
Ursuline Flow Modeling in SWMM

- U.S. EPA Storm Water Management Model
- Combined hydrologic (rainfall-runoff) and hydraulic (conveyance, routing) model
- Under development/improvement since 1971



Benefit of Modeling: Hydrograph Separation





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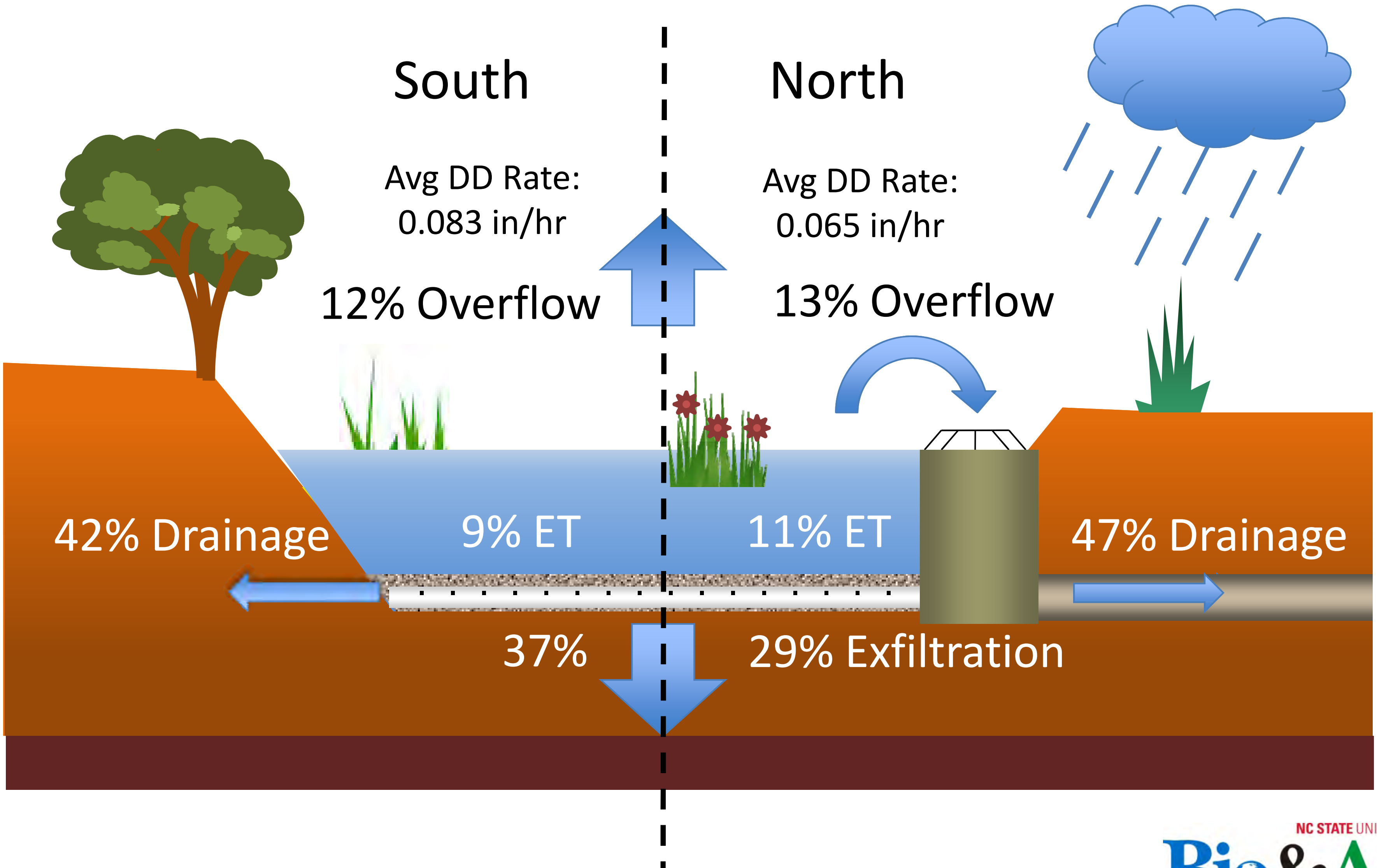
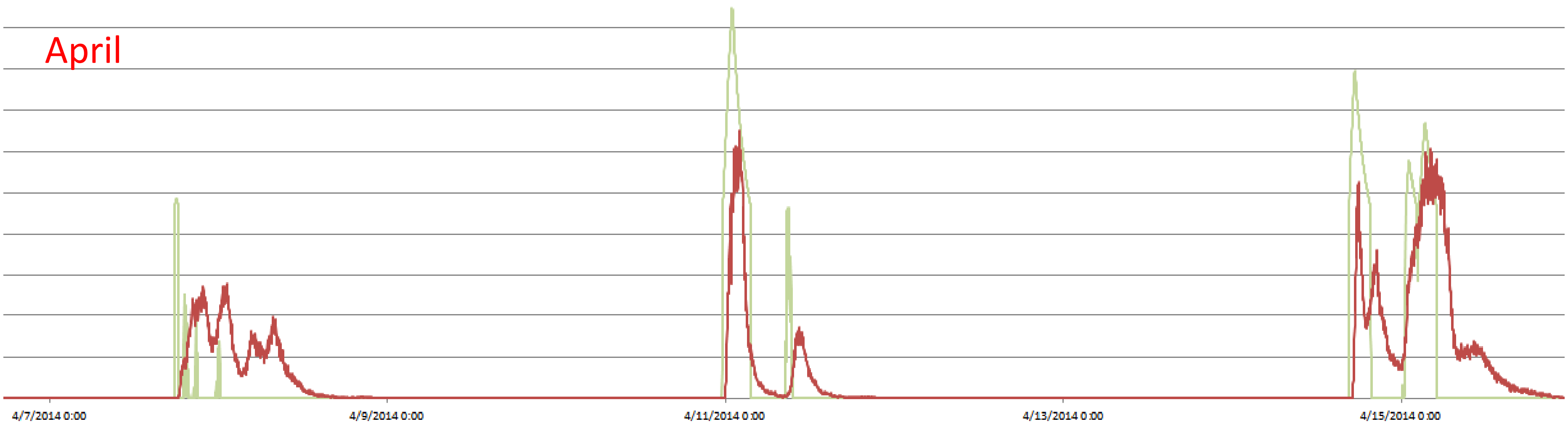
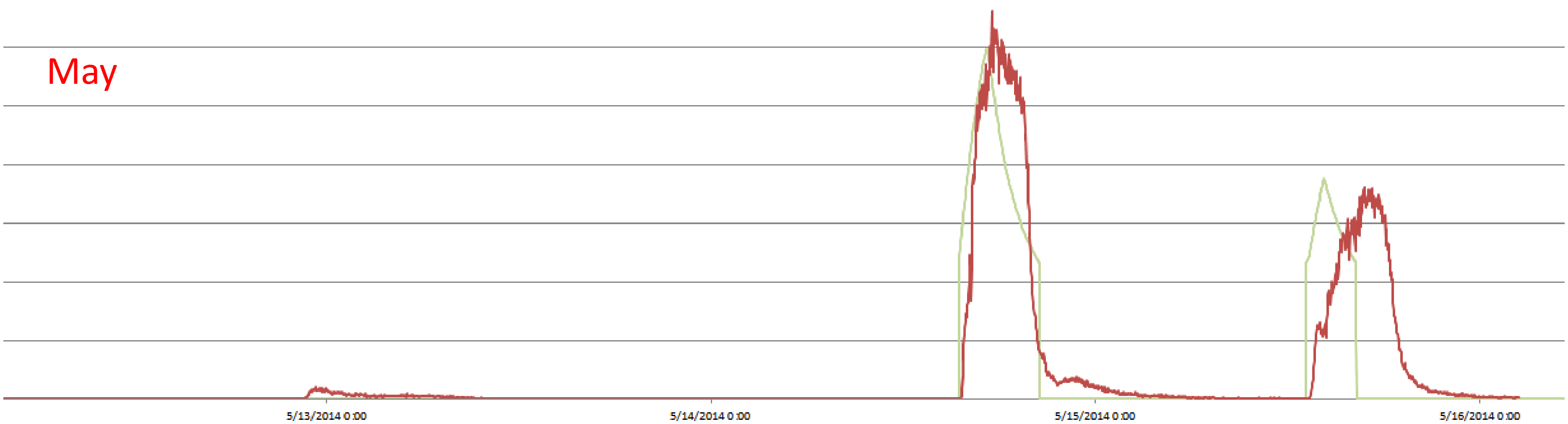
Hydrologic Fate: Holden Arboretum

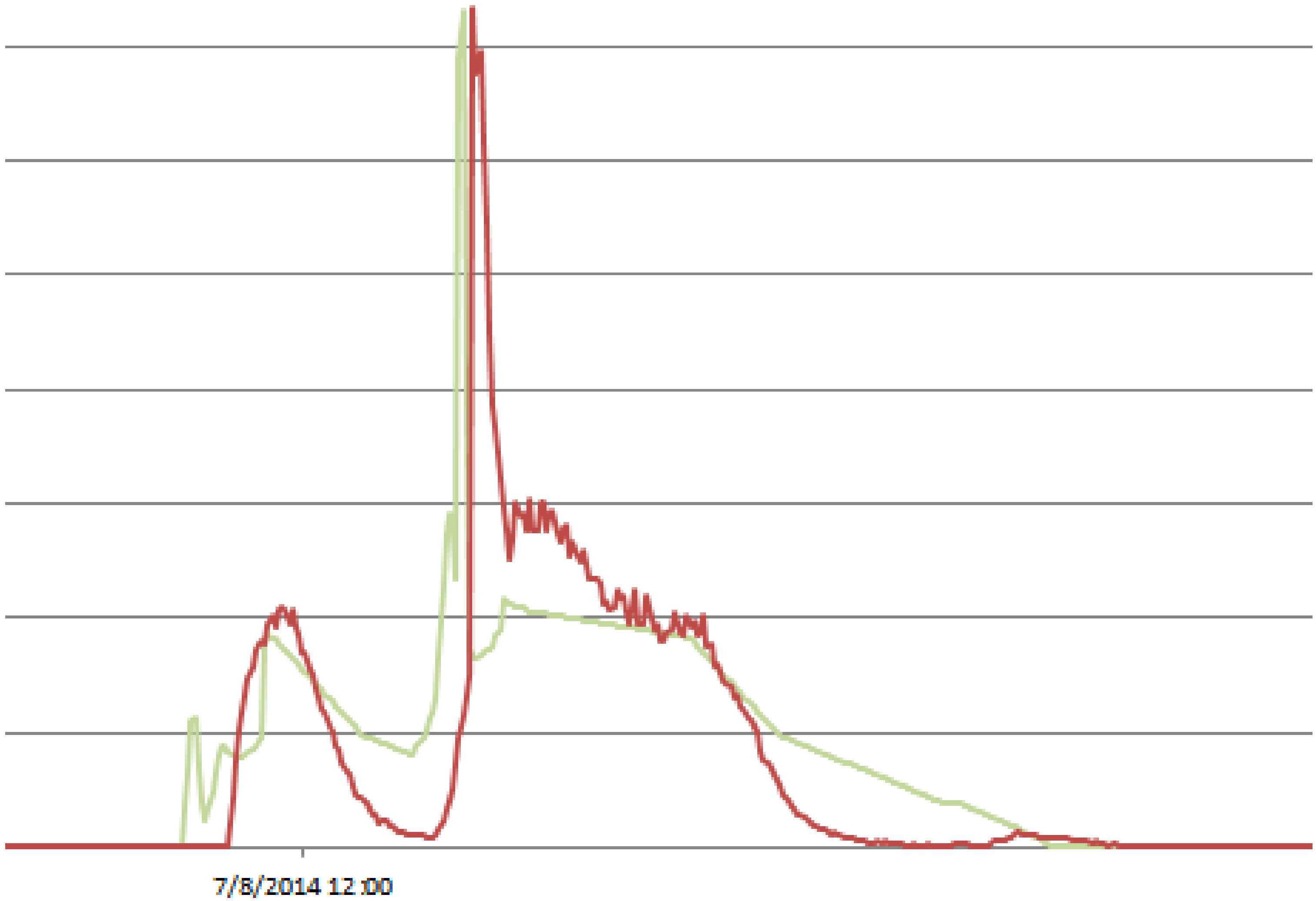


Holden Arboretum SWMM Modeling

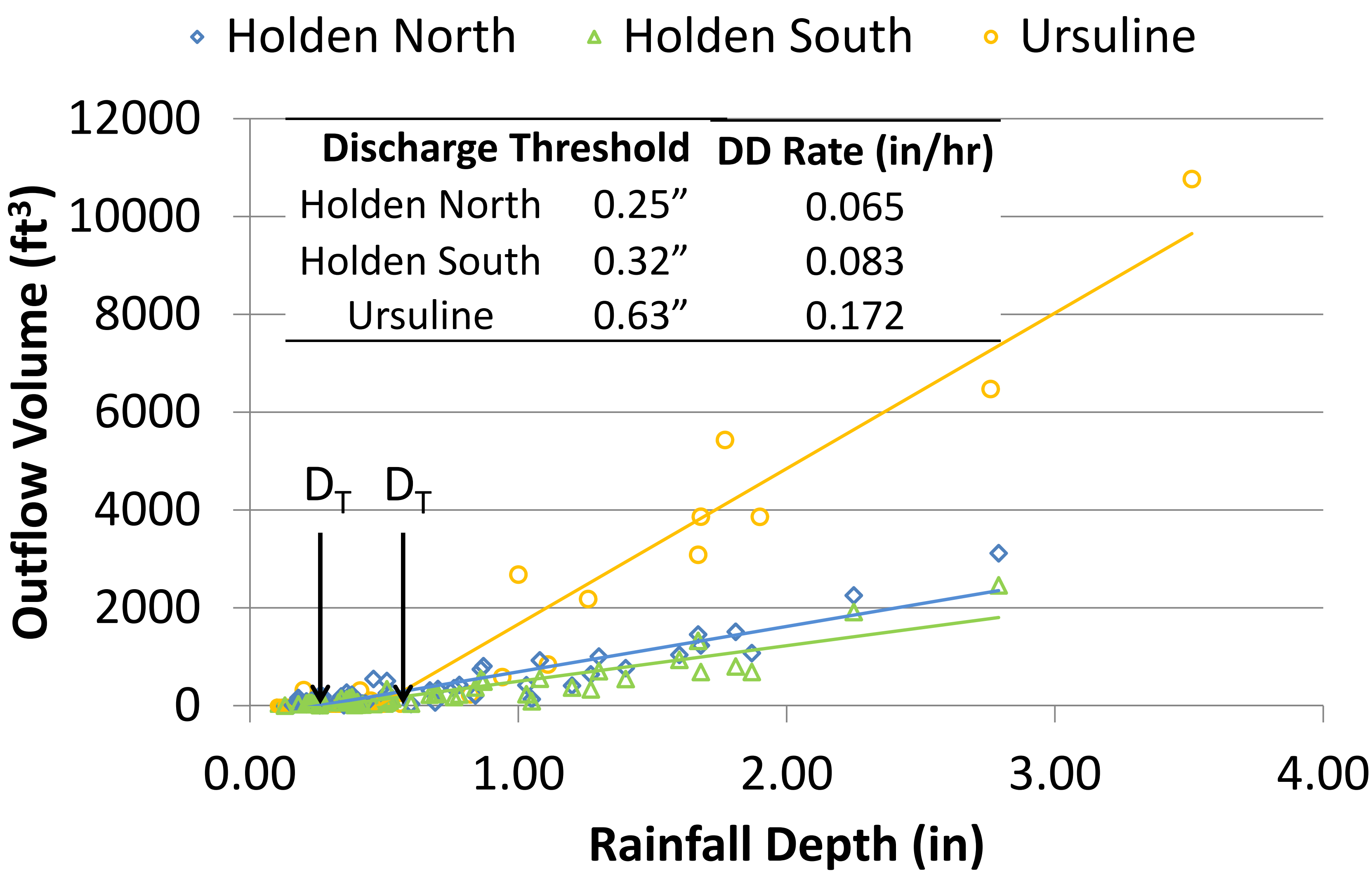




Hydrograph Example: SWMM



Discharge Threshold



Discharge Threshold		DD Rate (in/hr)
Holden North	0.25”	0.065
Holden South	0.32”	0.083
Ursuline	0.63”	0.172

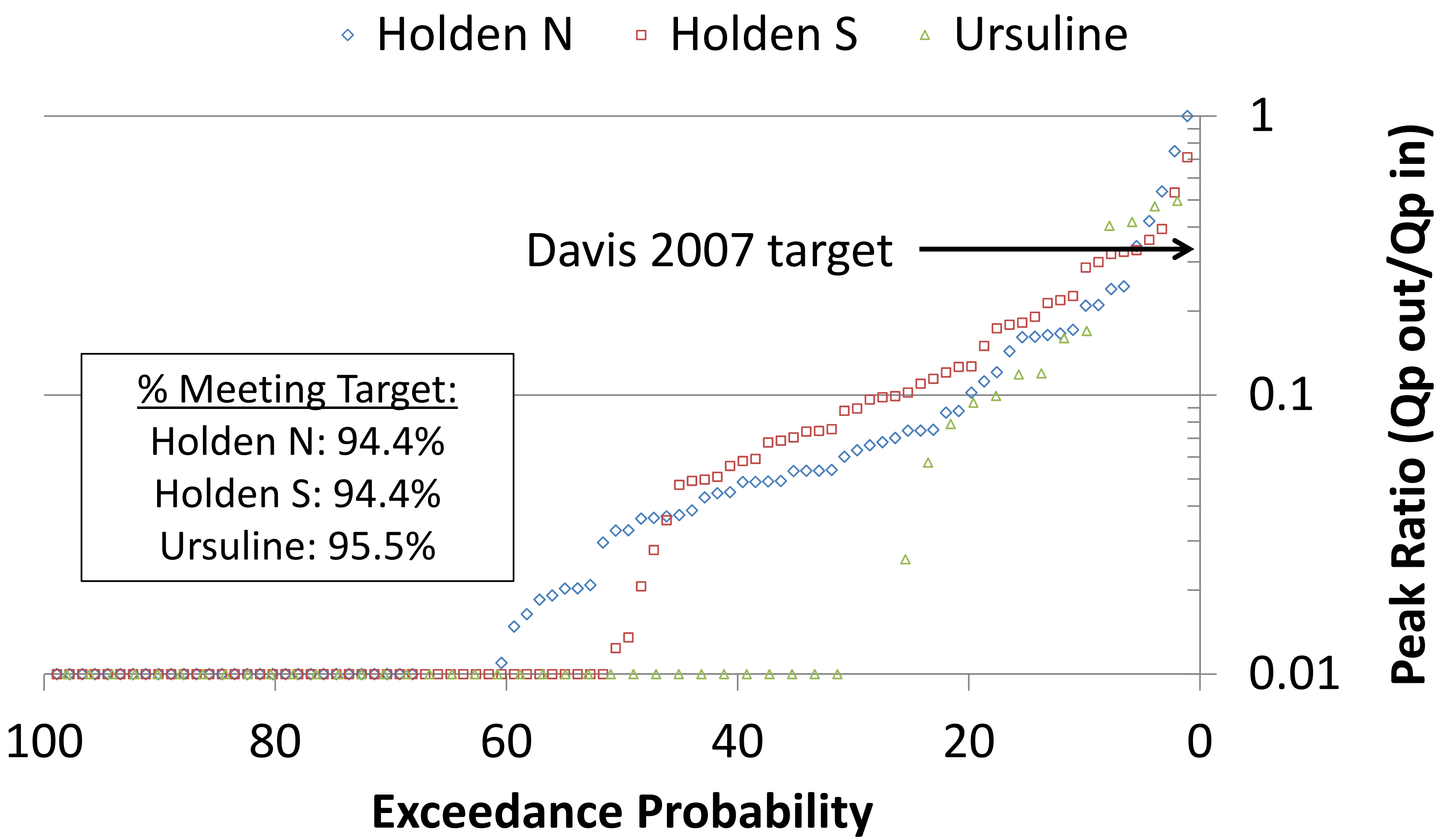
Completely Captured Events

Site Name	Cell Name	Events Completely Captured (#)	Events Completely Captured (%)	Depth of Completely Captured Events (in)
Ursuline College	-	33/50	66	0.1-0.56
Holden Arboretum	South	41/90	46	0.1-0.51
	North	28/90	31	0.1-0.51

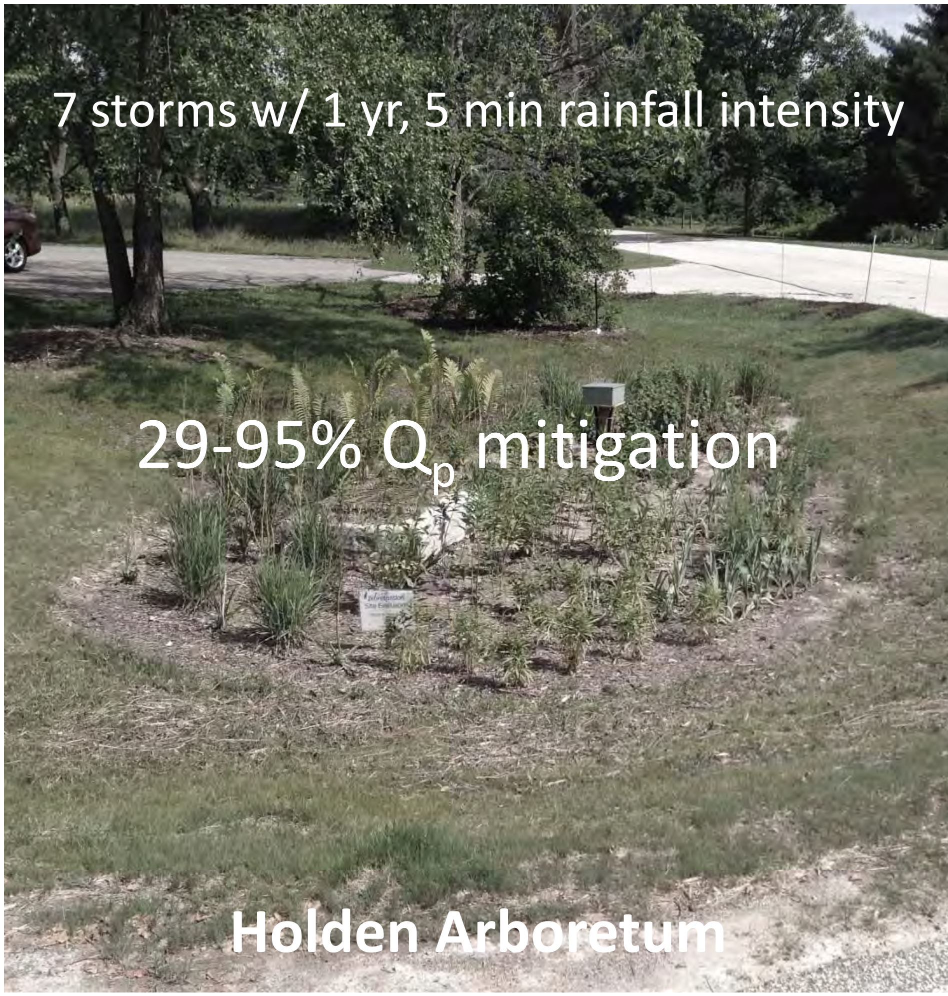
Peak Flow Mitigation

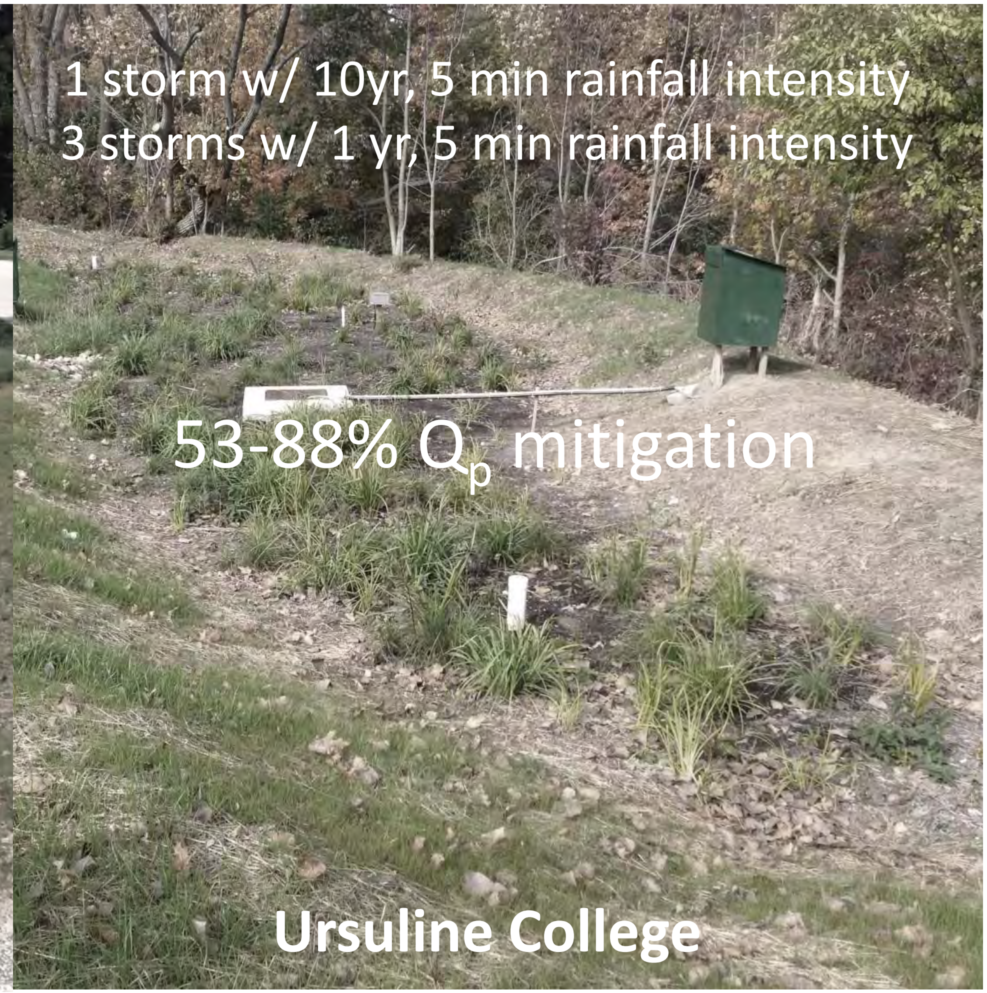
- Peak flows provide most erosive forces and cause stream incision/bank erosion

Peak Flow Mitigation



Q_p Mitigation during Most Intense Rainfall Events





Monitoring Summary

- Measured post-construction drawdown rates were better than pre-construction infiltration tests
  - Perhaps due to lateral exfiltration?
- A mapped HSG D soil is not always what it seems…
  - Exfiltration rates were in range expected for HSG C
- Runoff threshold between 0.25-0.63 in } Function of infiltration rate

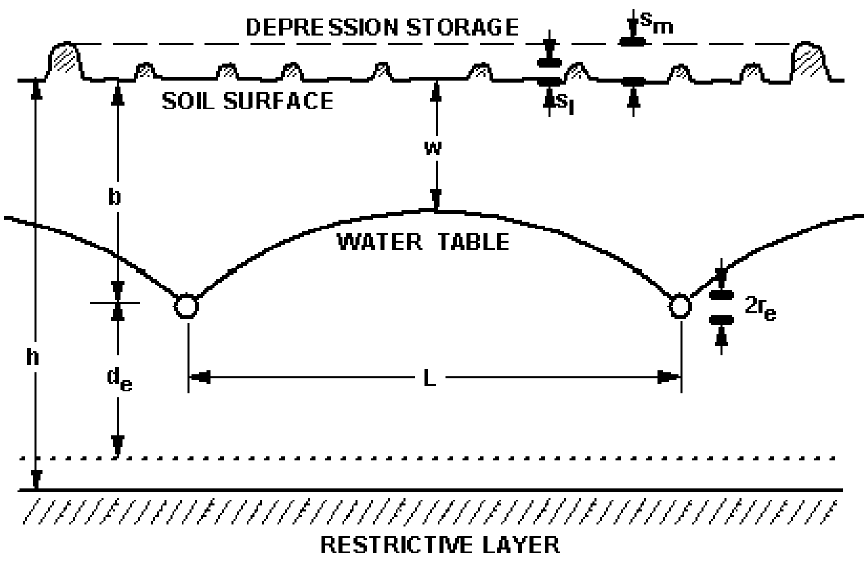
Summary

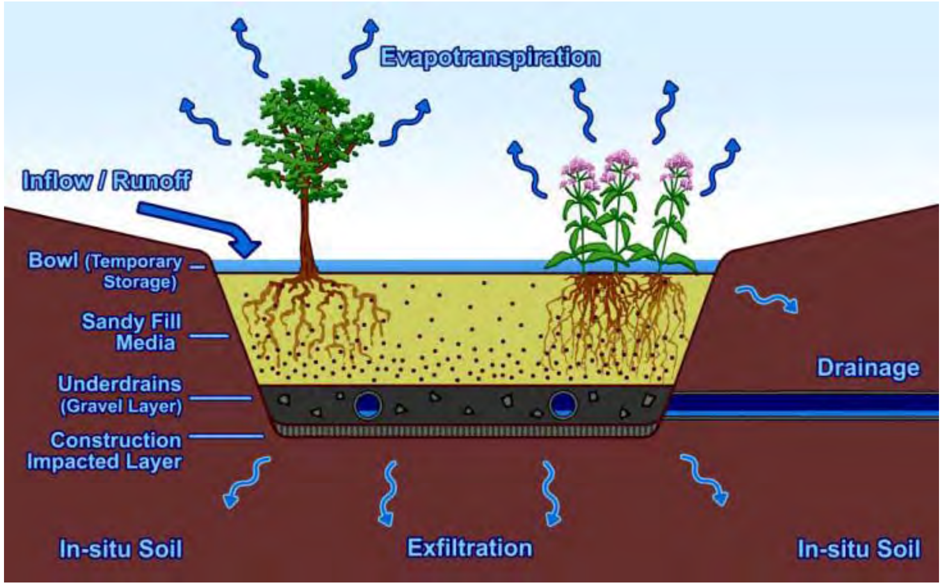
- Bioretention works in poor soils!
  - 40-59% runoff reduction
  - Modifies the fractions of exfiltration vs. post-filtration discharge
  - Some peak flow mitigation during largest storms

Median Curve Number		
Site	Watershed CN	Watershed + BRC
Holden North	90.5	83.5
Holden South	90.5	85
Ursuline	93.9	88.6

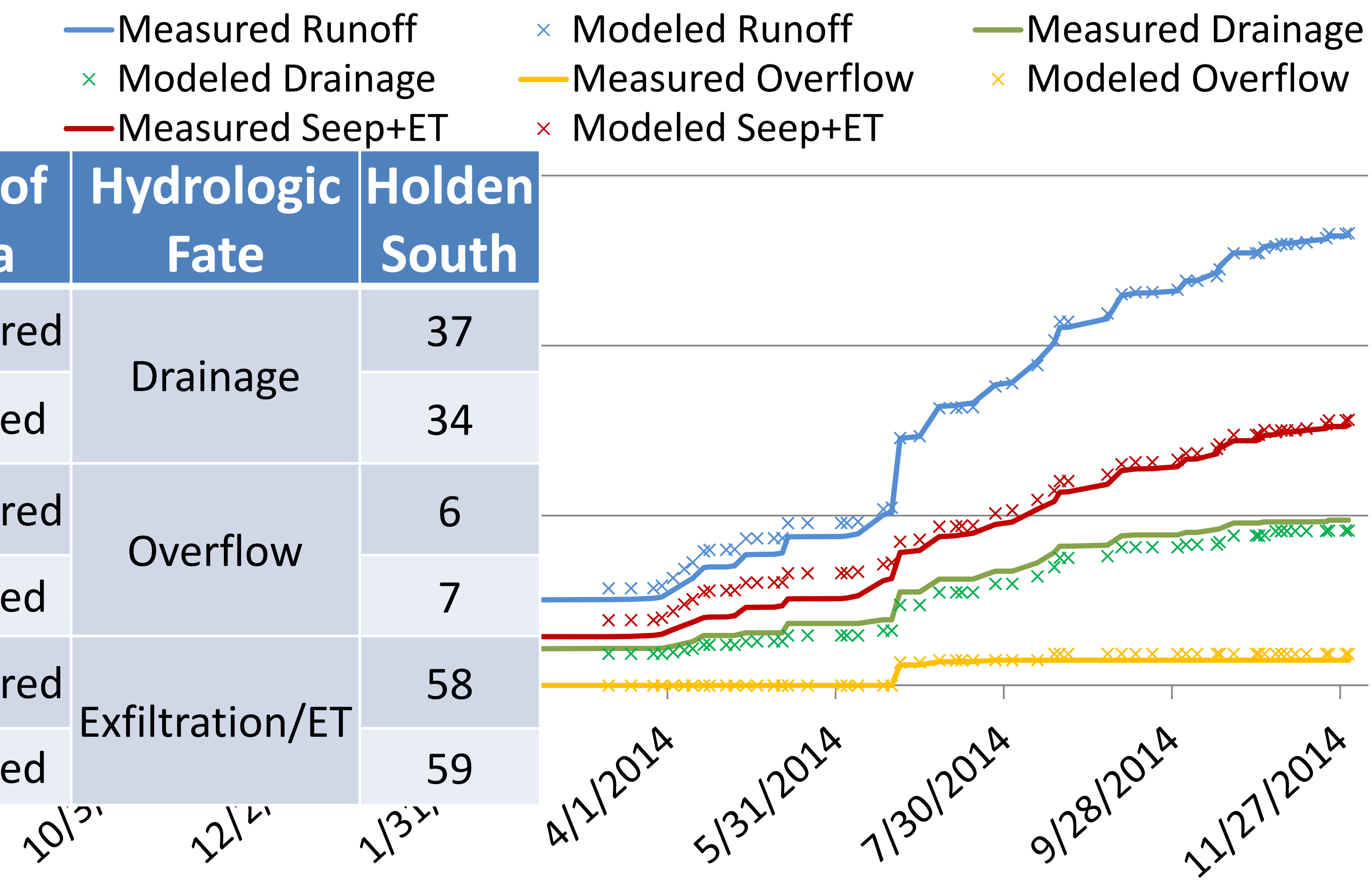
Bioretention Modeling in DRAINMOD

- Concepts of water movement in BRCs are very similar to Ag. fields with drain pipes
- Many bioretention design specifications correspond directly to DRAINMOD inputs





Model Output for Monitored Data: Holden South



Type of Data	Hydrologic Fate	Holden South
Monitored	Drainage	37
Modeled		34
Monitored	Overflow	6
Modeled		7
Monitored	Exfiltration/ET	58
Modeled		59

Adjusting Design Parameters:
Sensitivity Analysis

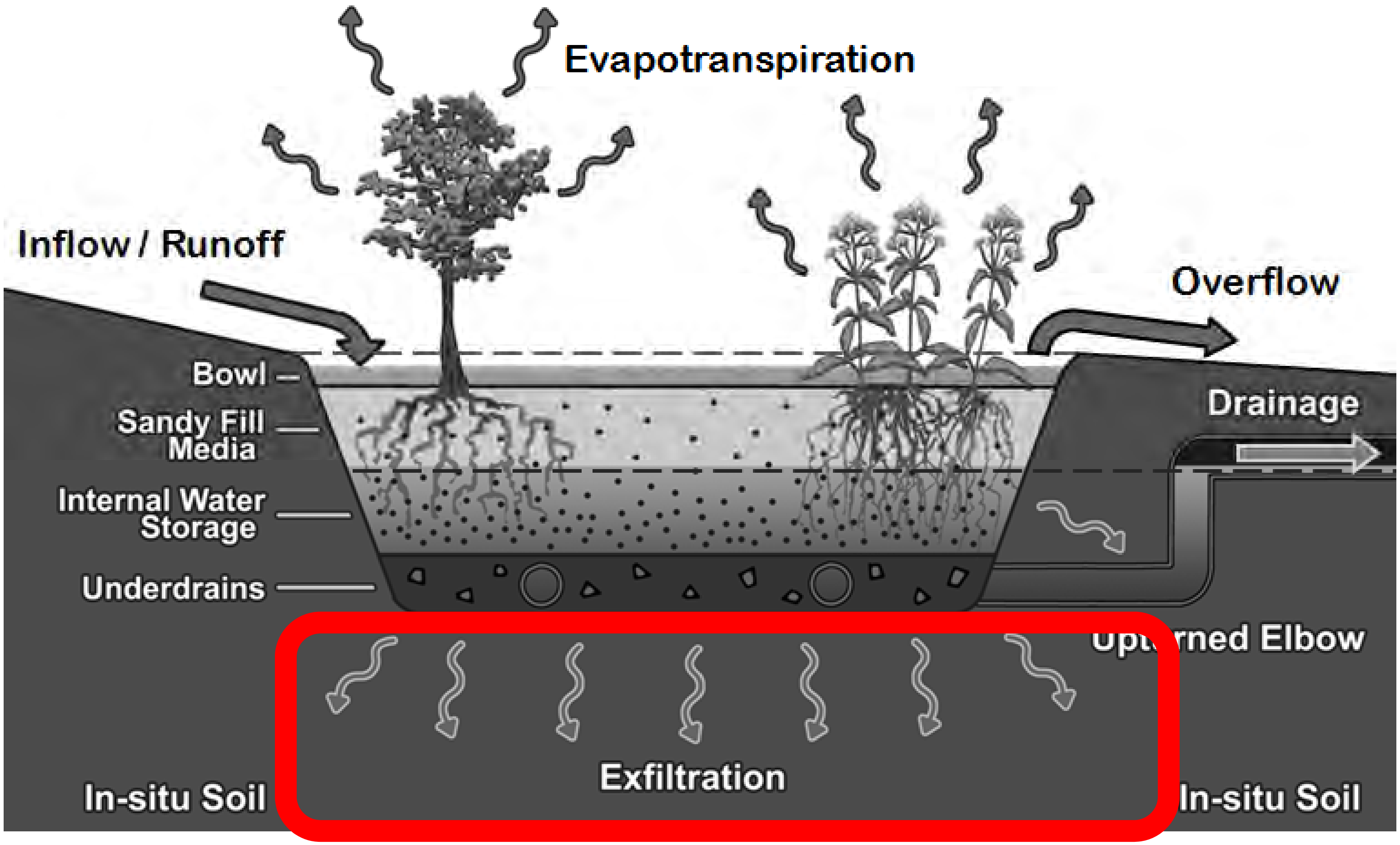
How is the long-term hydrologic fate affected by:

- Media depth
- Internal Water Storage Zone
- Rooting Depth
- Bowl Storage Depth
- Hydraulic Loading

Weather Sources: Modeling

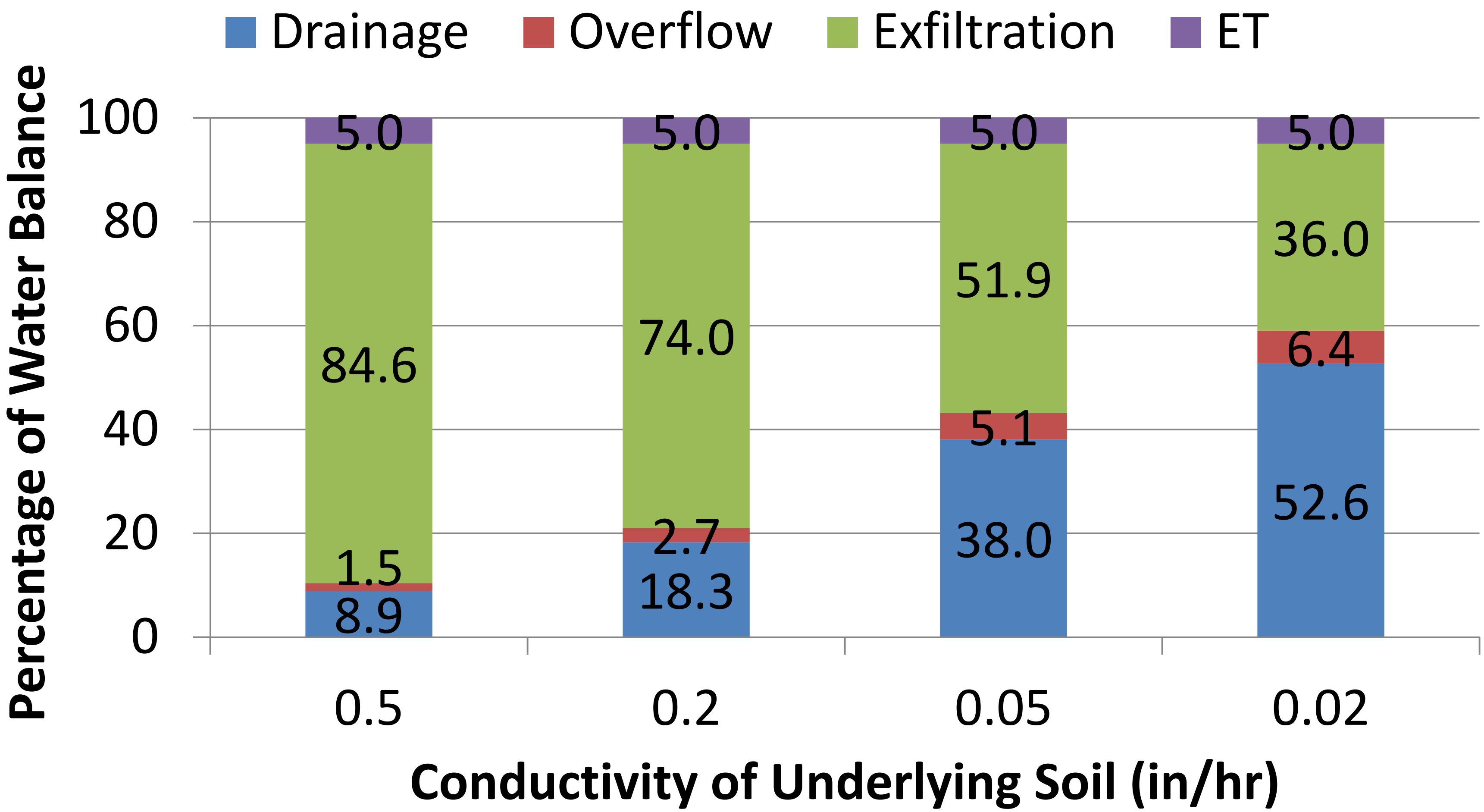
- **Long-term Weather Station**
  - Cleveland Hopkins International Airport (40 miles from Holden Arboretum)
    - *Primary weather source for simulations*
- **Long-term data range: 1983-2012 (30 yr simulations)**
  - Daily Max. & Min. Temperature
    - *Source: NOAA - National Climatic Data Center*
  - Hourly Rainfall
    - *Source: NOAA - National Climatic Data Center*

Underlying Soil K_{sat}



Underlying Soil K_{sat}

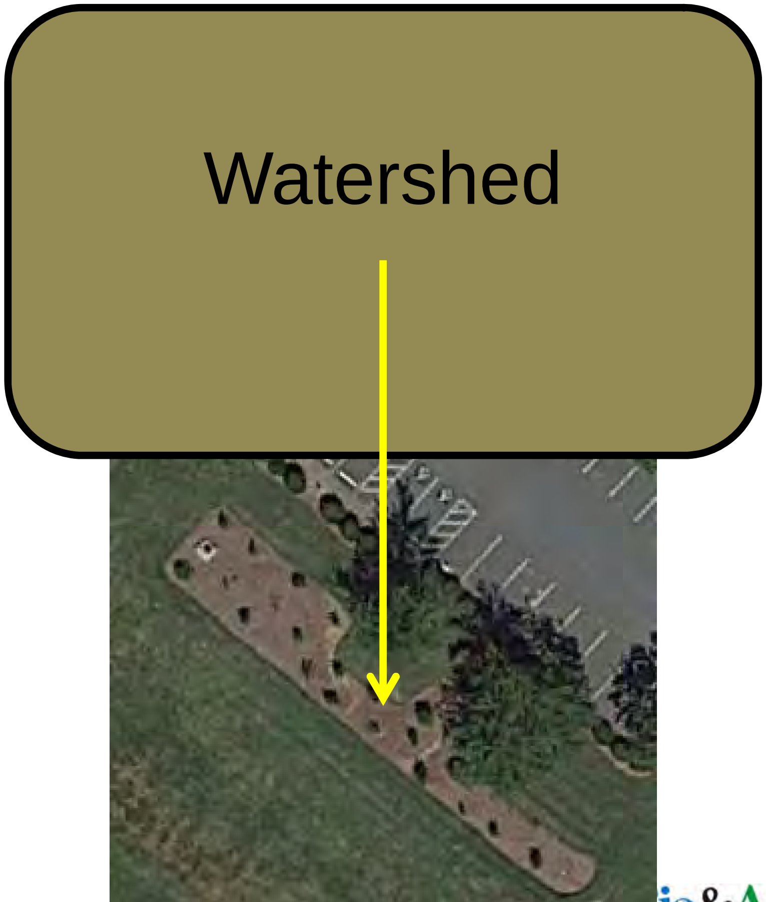
Baseline Models



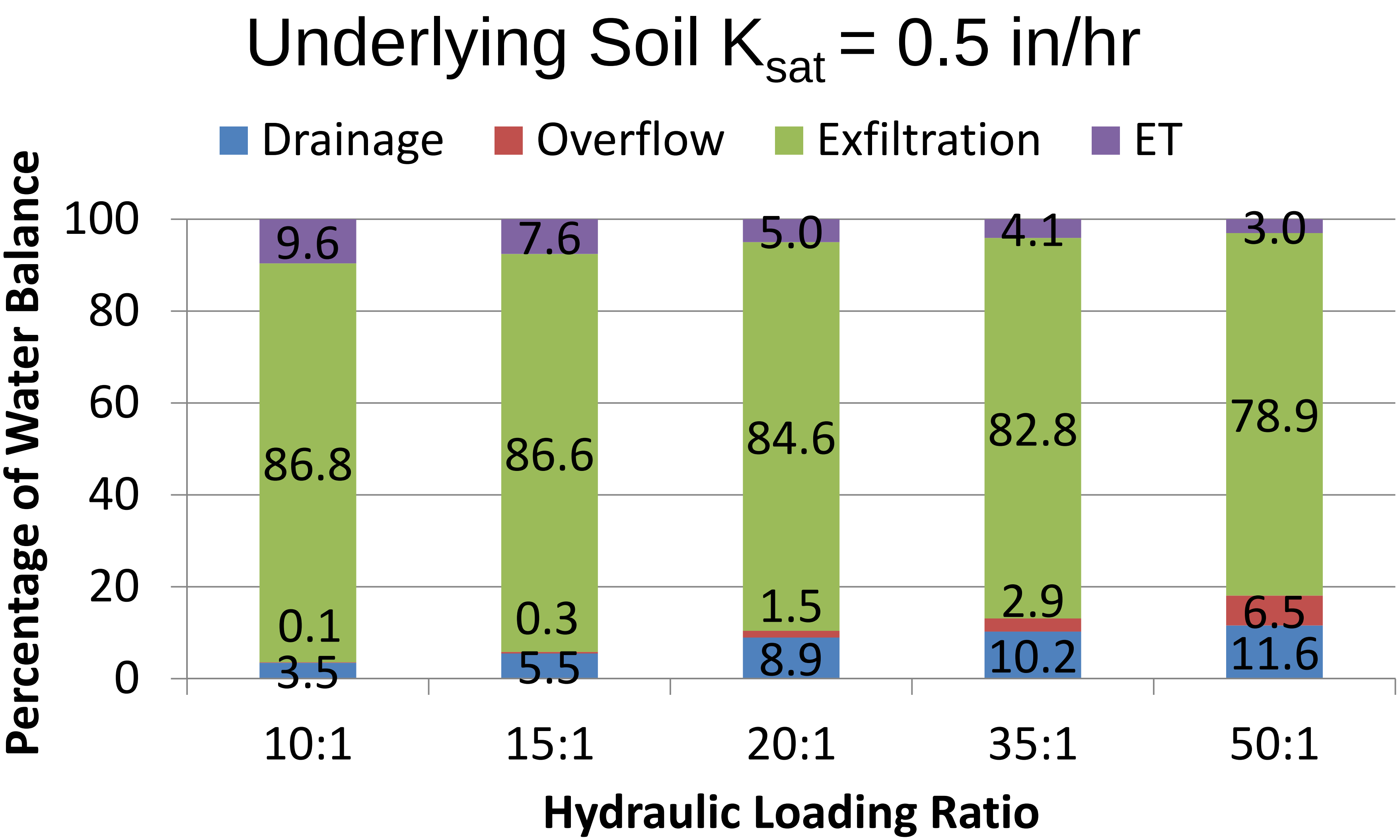
Over/Under-Sized Bioretention

- Ohio Design Event =0.75 inch
- Impervious drainage Area : Bioretention Area
  - **10:1**
  - **15:1**
  - **20:1 (baseline model)**
  - **35:1**
  - **50:1**

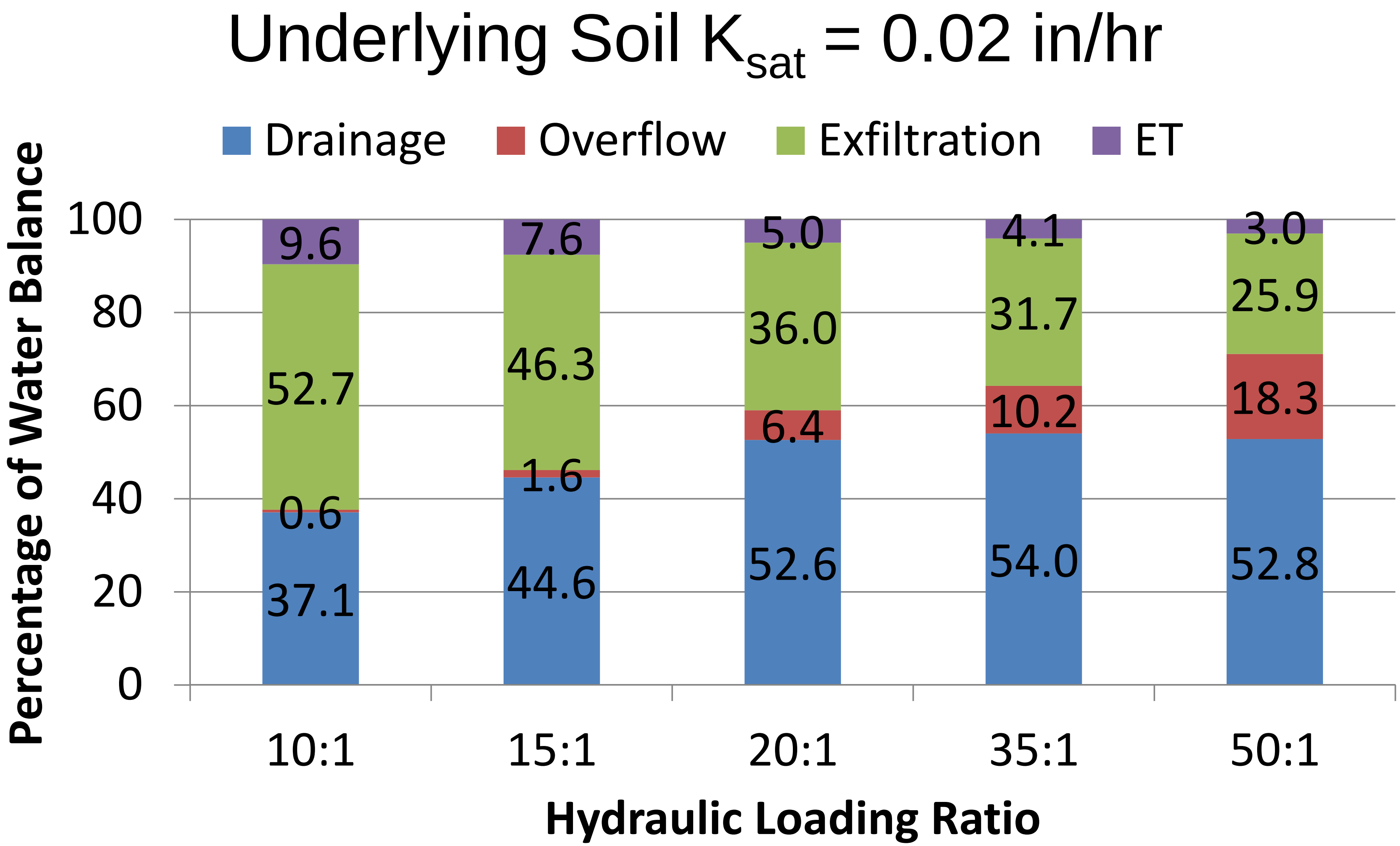
Changed field ratio in model



Over/Under-Sized Bioretention



Over/Under-Sized Bioretention

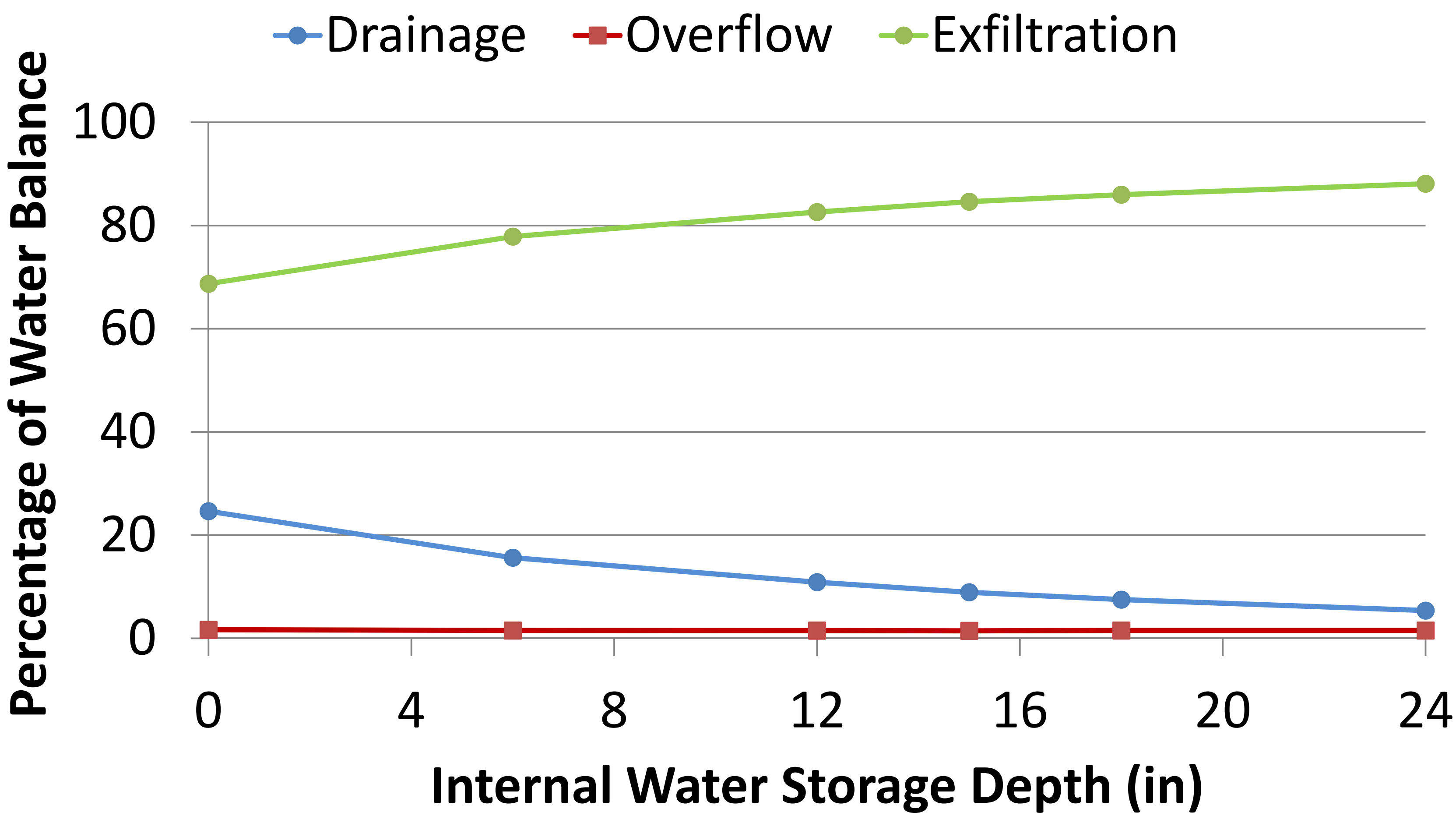


Internal Water Storage

- Modeled IWS zone depths of:
  - 0 inches (standard underdrain)
  - 6 inches
  - 12 inches
  - 15 inches (baseline model)
  - 18 inches
  - 24 inches

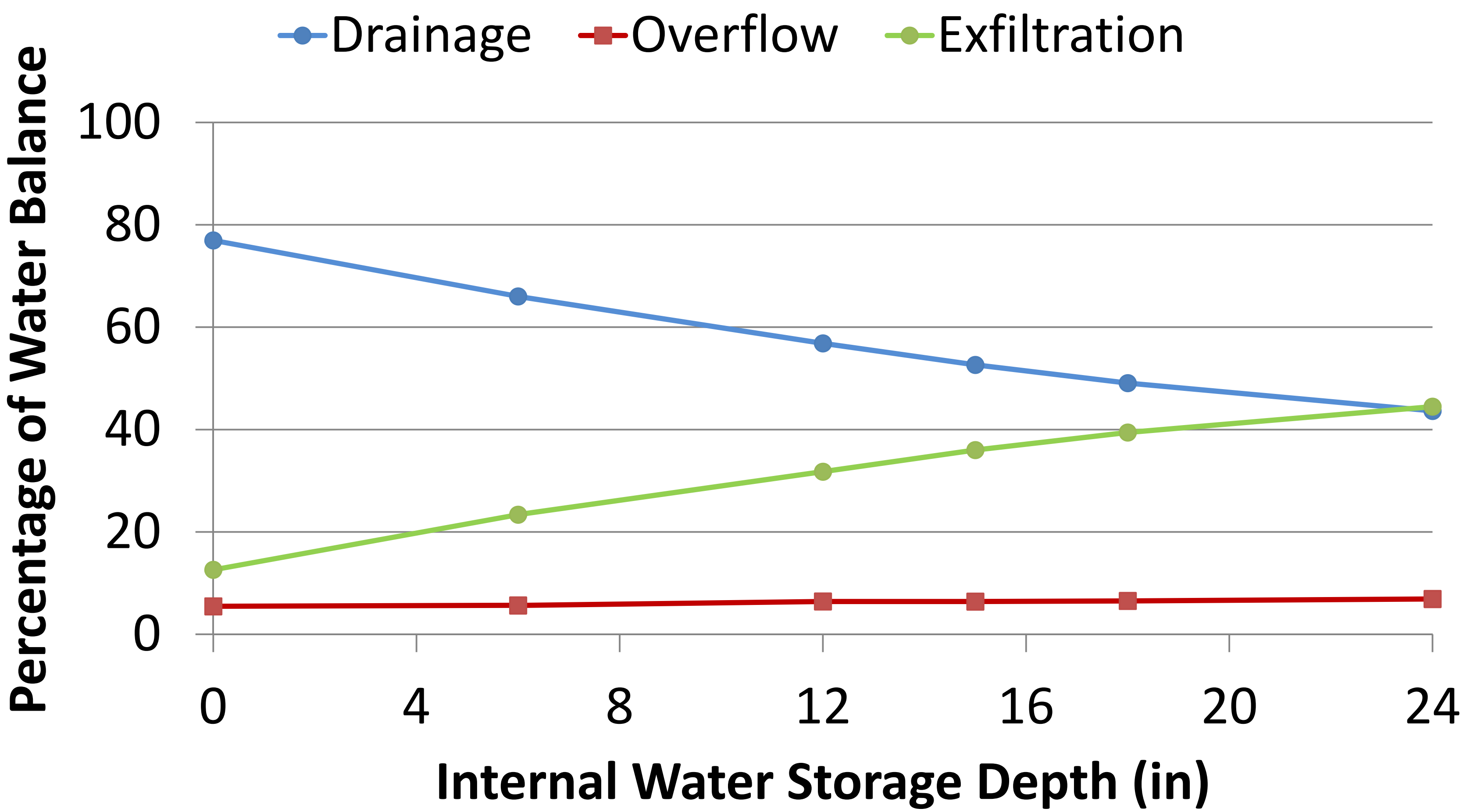
Internal Water Storage

Underlying Soil K_{sat} = 0.5 in/hr



Internal Water Storage

Underlying Soil K_{sat} = 0.02 in/hr



DRAINMOD Bioretention Modeling: Lessons Learned

- Underlying soil conductivity and presence of IWS two biggest factors on long-term water balance
- Sensitivity of Model:
  - Most: Underlying soil $K_{sat,}$ Internal Water Storage
  - Moderate: Over/Under Sizing (Hydraulic Loading Ratio)
  - Little: Bowl storage, media depth – mainly affect overflow
  - Least: Rooting Depth

Table Discussion

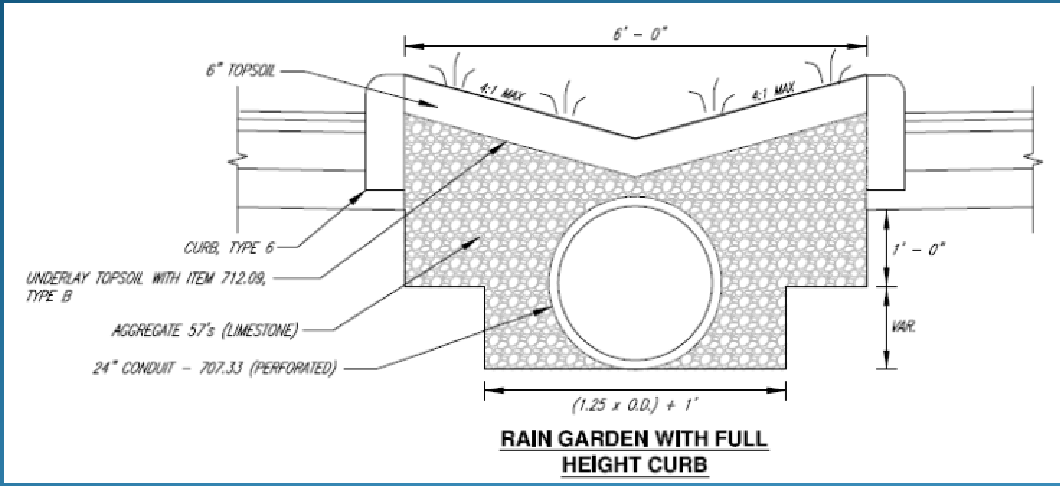
- What are your thoughts on the implications for your work and what this means to you?
- What else do you wish you knew?

Bioretention Design, Construction, & Maintenance Tips

Jay Dorsey (ODNR) & Roger Gettig (Holden Arboretum)

Concept Stage

Clarity of Goals



LID Reality Check

- Appearance/aesthetics (plants, open drainage, standing water in landscape, etc.) – visits to other project sites invaluable
- Maintenance commitment
- Costs and benefits
  - Have buy-in on the "why" for LID approach
  - Outside funding (e.g., SWIF, 319) is nice incentive
- Involve folks with LID experience - practices, procedures, issues

LID Reality Check

Familiarity with Site is Critical

- Site history
- Utilities
- Soils and soil infiltration capacity
- Available outlets
- Topography
- Future development

Mapped Soil is Tioga Loamy Sand or Sandy Loam

Design Stage

Familiarity with Bioretention Components and Function

- many functional components at odds with traditional stormwater training/experience
- openness to unfamiliar ideas/concepts

Design for Constructability

- Site stabilization and sediment control
  - Be explicit about staging/phasing
- Matching working spaces and equipment needs
  - Specify approach/equipment to be used for excavation and media placement
  - Specify when work should be completed by hand

Design for Maintainability

- Plan for/minimize sediment sources
- Pretreatment, pretreatment, pretreatment
- Access for maintenance equipment/activities
- 4:1 or gentler side slopes
- Specify turf for sideslopes

Design – Construction Notes

- Clear guidance in plan notes for:
  - Construction site and post-construction sediment control
  - Sequencing/staging
  - Scarifying bottom of excavation
  - Sourcing and verifying materials – aggregate, filter media, plants
    - require testing/inspection for acceptance
  - Critical equipment to be used for specific tasks (including which tasks to perform with hand equipment)

  - Be as specific as possible

Construction Stage

Construction oversight with knowledgeable staff is critical!

Proactive communication needed through plan set and bid package development, pre-bid meeting, contractor selection, pre-construction meeting, construction

Pre-Construction

- Educate site owners, designers, inspectors, all contractors, and others about purpose and function of LID SCMs
- Use specific language to describe LID SCMs when advertising projects - provide supporting information for potential bidders
- When possible, hire certified and/or experienced installers and contractors
- Ensure site inspectors are experienced and knowledgeable about LID SCMs
- Communication between designer, owner and contractor is crucial to insure construction is sequenced correctly

Pre-Construction Meeting

- Review plans with designers, owners, contractors and inspectors
  - Construction sequencing and practices
    - Erosion/sediment control and site stabilization to prevent clogging
    - Avoid subgrade compaction/scarify underlying soils
    - Clarify which work will be performed by specific equipment, and which work must be performed by hand
  - Material specifications and expectations
  - Monitoring equipment installation (if applies)
  - Design engineer verification at critical installation points

Construction Issues

- Construction season/timing
- Excavation in fill material
- Contractor experience with LID
  - Final preparation of excavated surface
  - Elevations of filter surface and overflow outlets

Construction Issues

- Keeping sediment out of bioretention media during construction – staging, site drainage and erosion control during construction, site stabilization
  - Relatively easy fix if filter surface is clogged during construction
- May be worth expense/effort to quickly stabilize turf sideslopes with sod
- Most sites benefit from touch-up work 30-60 days after initial completion of construction

Source: Amy Dutt, Urban Wild

Materials

- Ask materials source(s) before delivery for lab test results for planting soil to show compliance with Rainwater manual specification
  - Check, in particular, texture (sand & clay), phosphorus, organic matter

LAB. NO.: 609770
TEST PARAMETER: MEHLICH 3 PHOSPHORUS

SAMPLE ID	RESULTS	UNITS
BRC NORTH	34	ppm

LAB. NO.: 609771
TEST PARAMETER: MEHLICH 3 PHOSPHORUS

SAMPLE ID	RESULTS	UNITS
BRC SOUTH	30	ppm

SOIL TEXTURE ANALYSIS REPORT

LAB. NO.	SAMPLE IDENTIFICATION	MECHANICAL ANALYSIS % SAND	% SILT	% CLAY	U.S.D.A. TEXTURE CLASS
626262	BIO-RET-BV	87	4	9	LOAMY SAND

ORGANIC MATTER	4.3	%

Materials

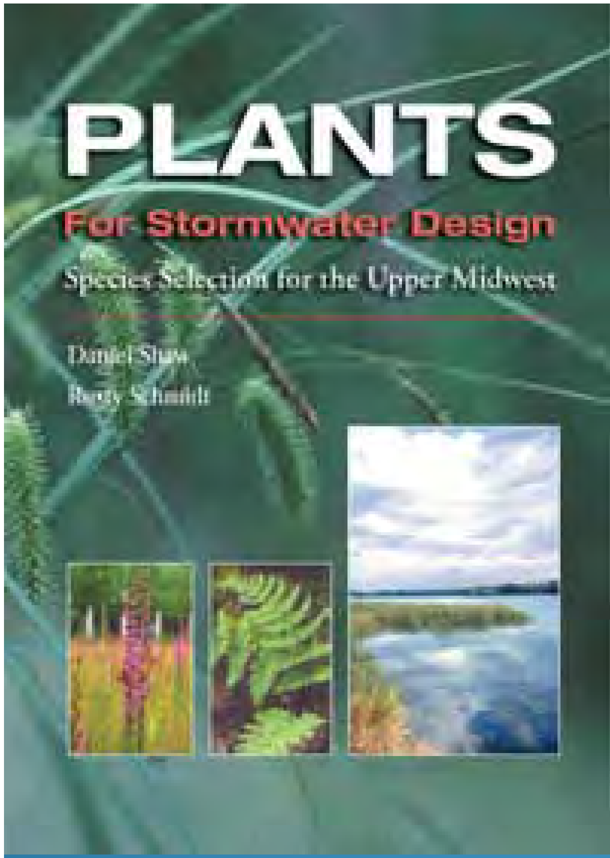
- Ask materials source(s) to provide samples of planting soil, clean sand and pea gravel filter material, and washed aggregate to eliminate need to send materials back




Plants for rain gardens and bioretention

The HOLDEN® Arboretum

- **Roger Gettig, Director of Horticulture and Conservation**



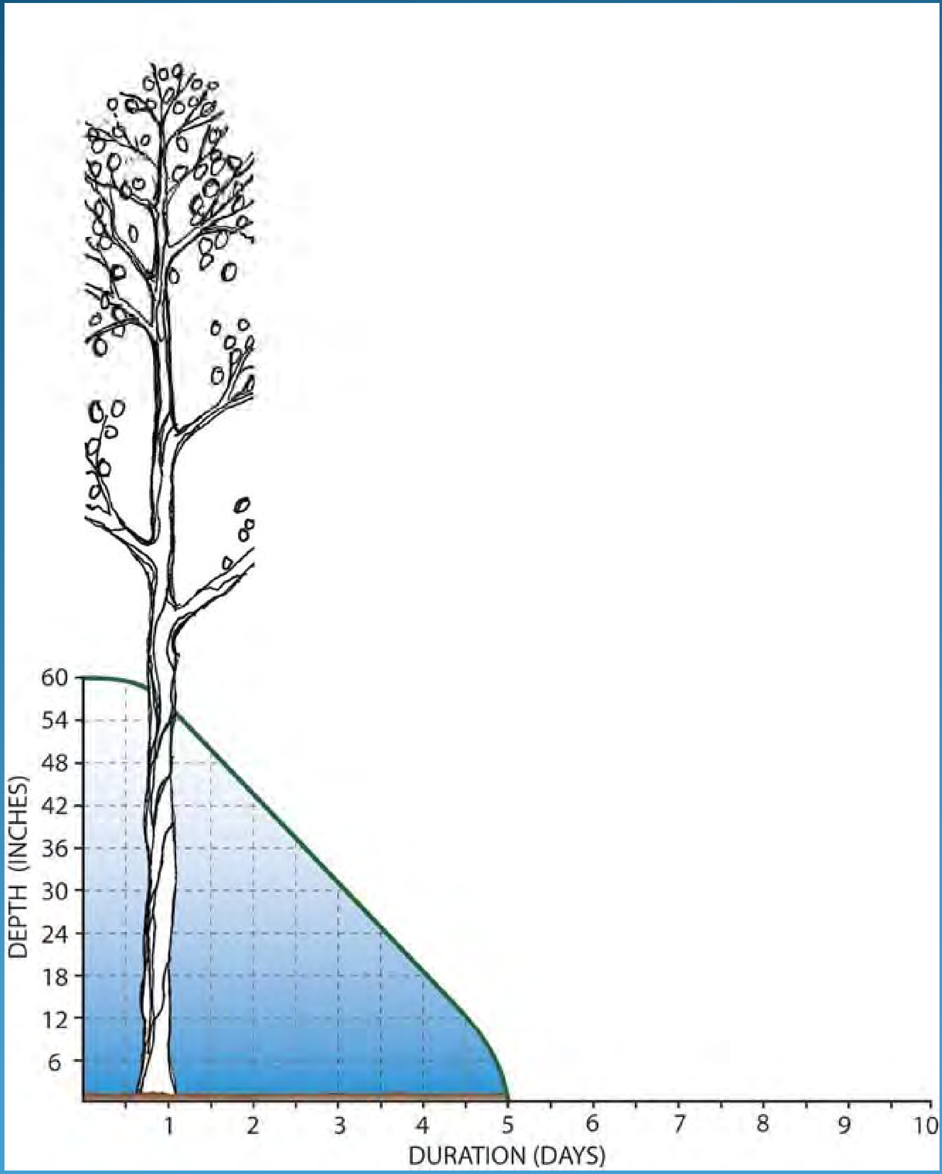
Plants for Stormwater Design

Daniel Shaw & Rusty Schmidt

- http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-management/plants-for-stormwater-design.html

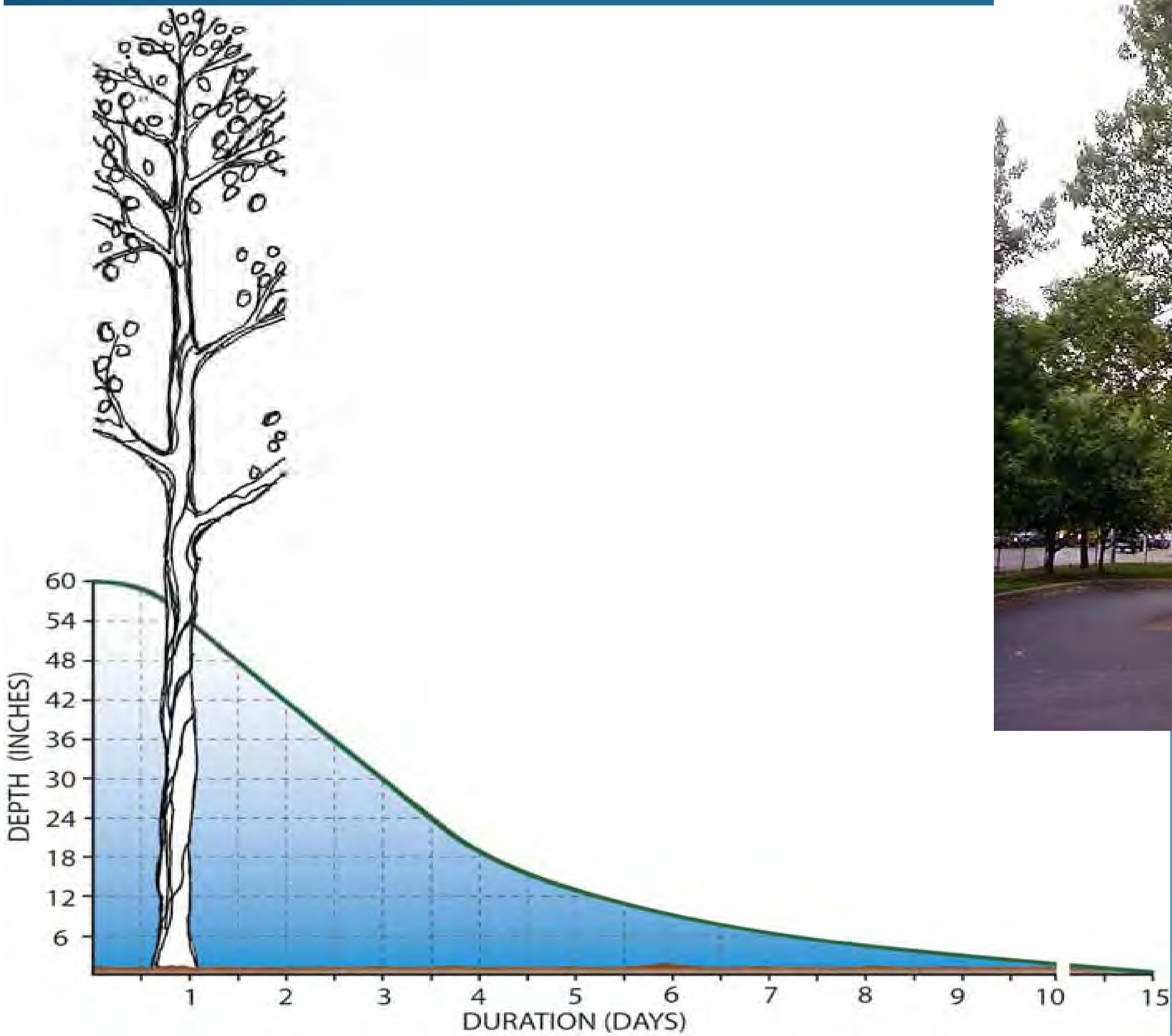
Betula nigra 'Heritage'

River birch



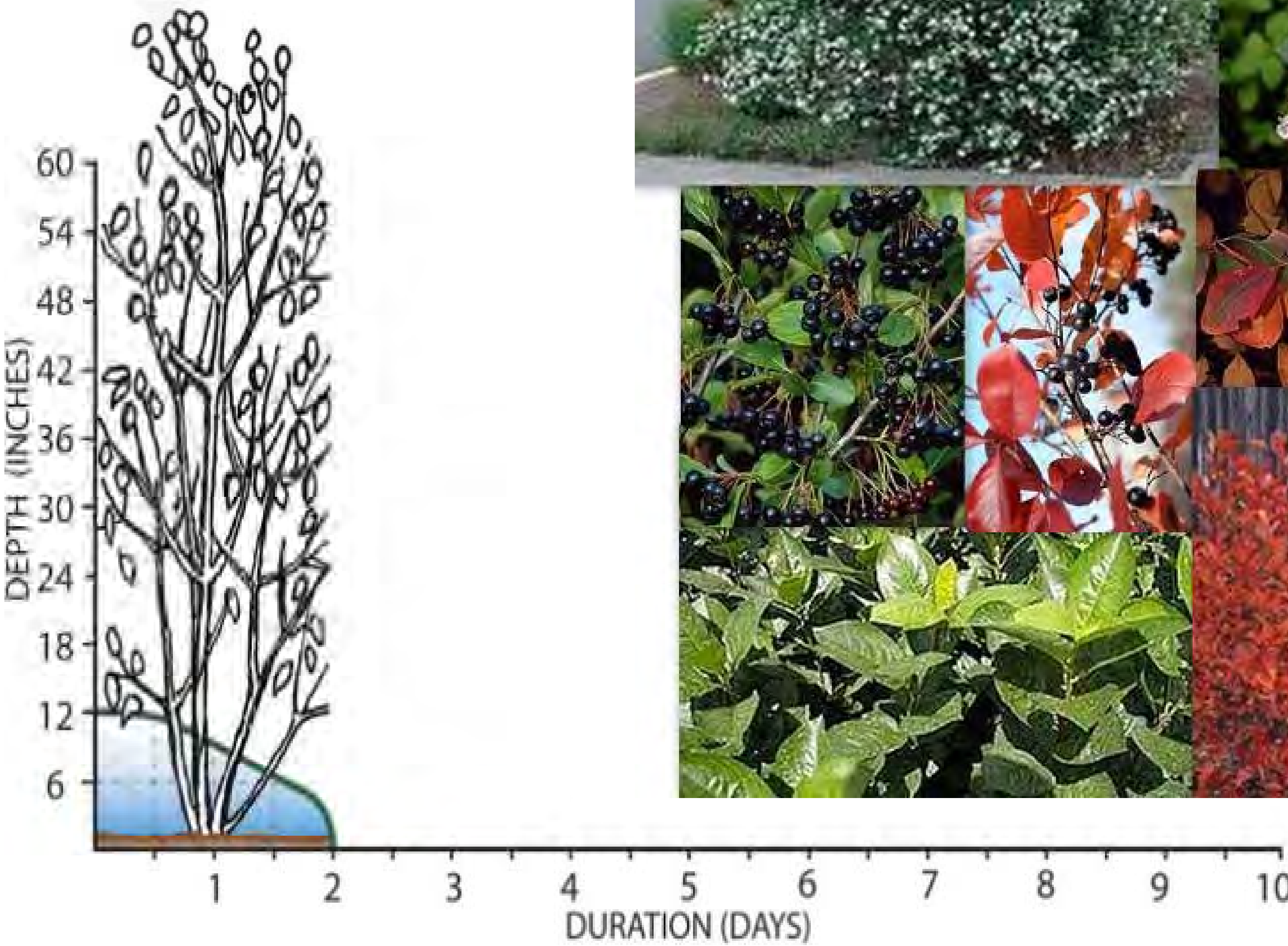
Quercus bicolor

Swamp white oak



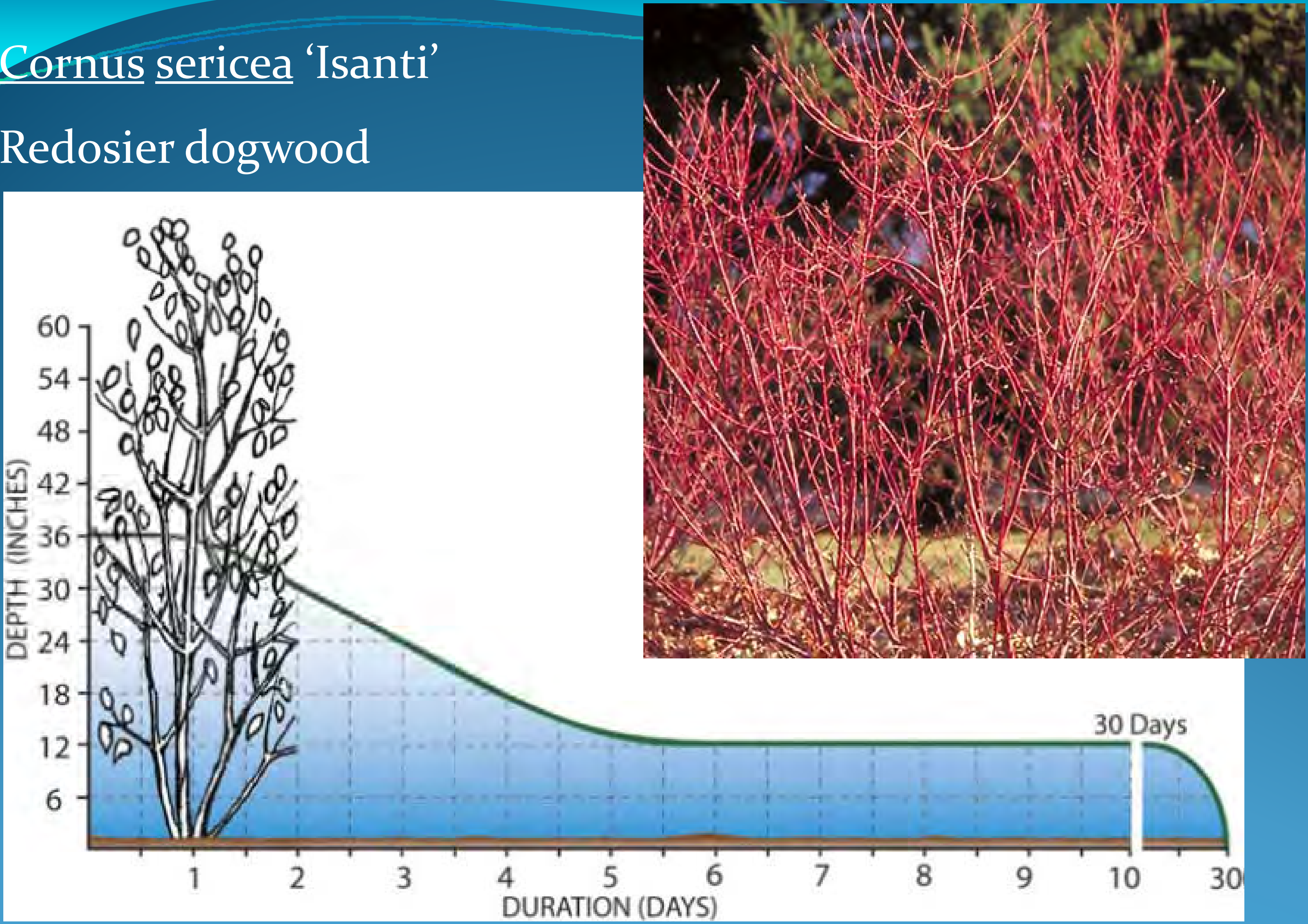
Aronia melanocarpa
'Autumn magic'

Black chokeberry



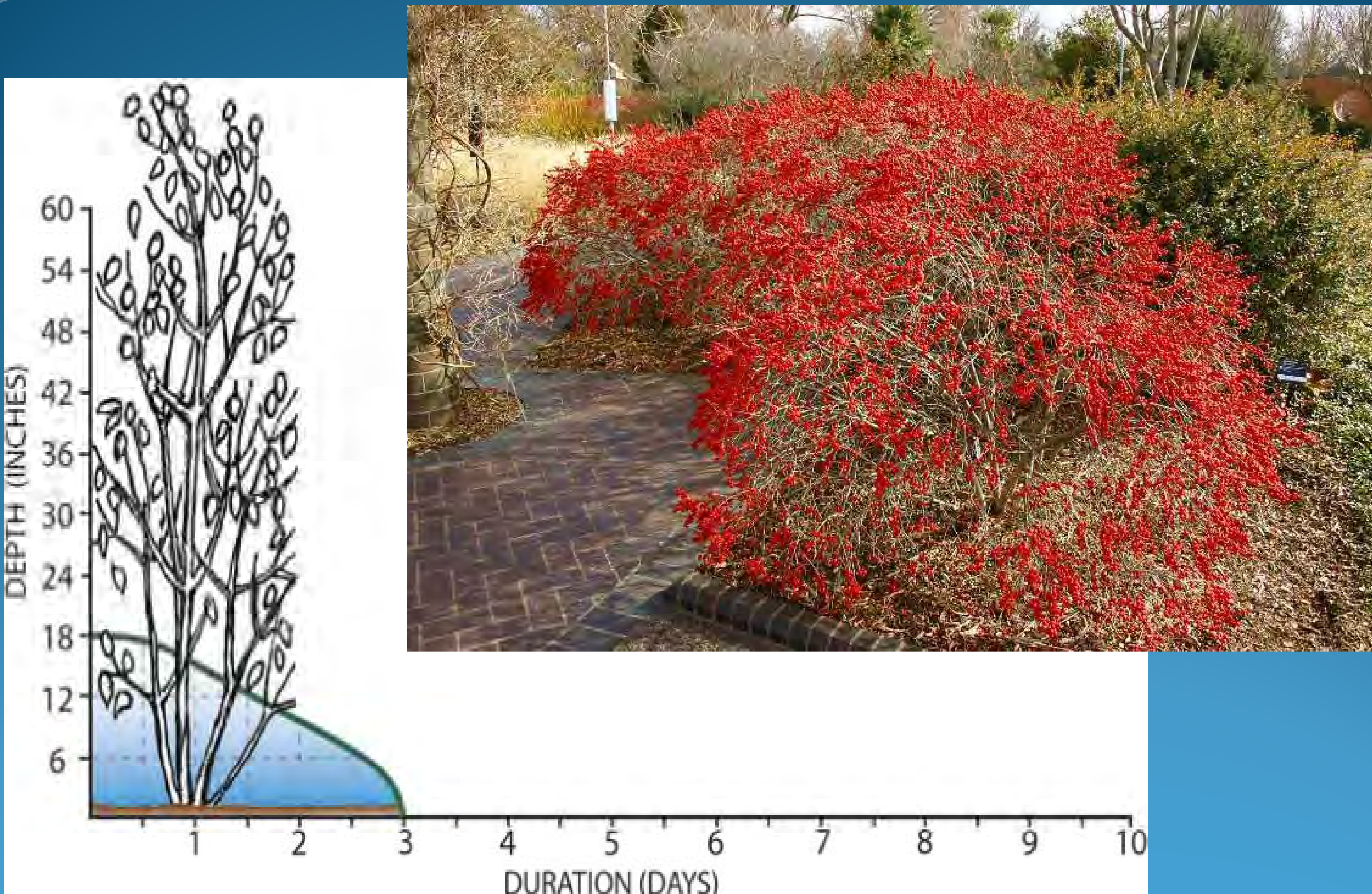
Cornus sericea 'Isanti'

Redosier dogwood



Ilex verticillata 'Red Sprite'

Winterberry

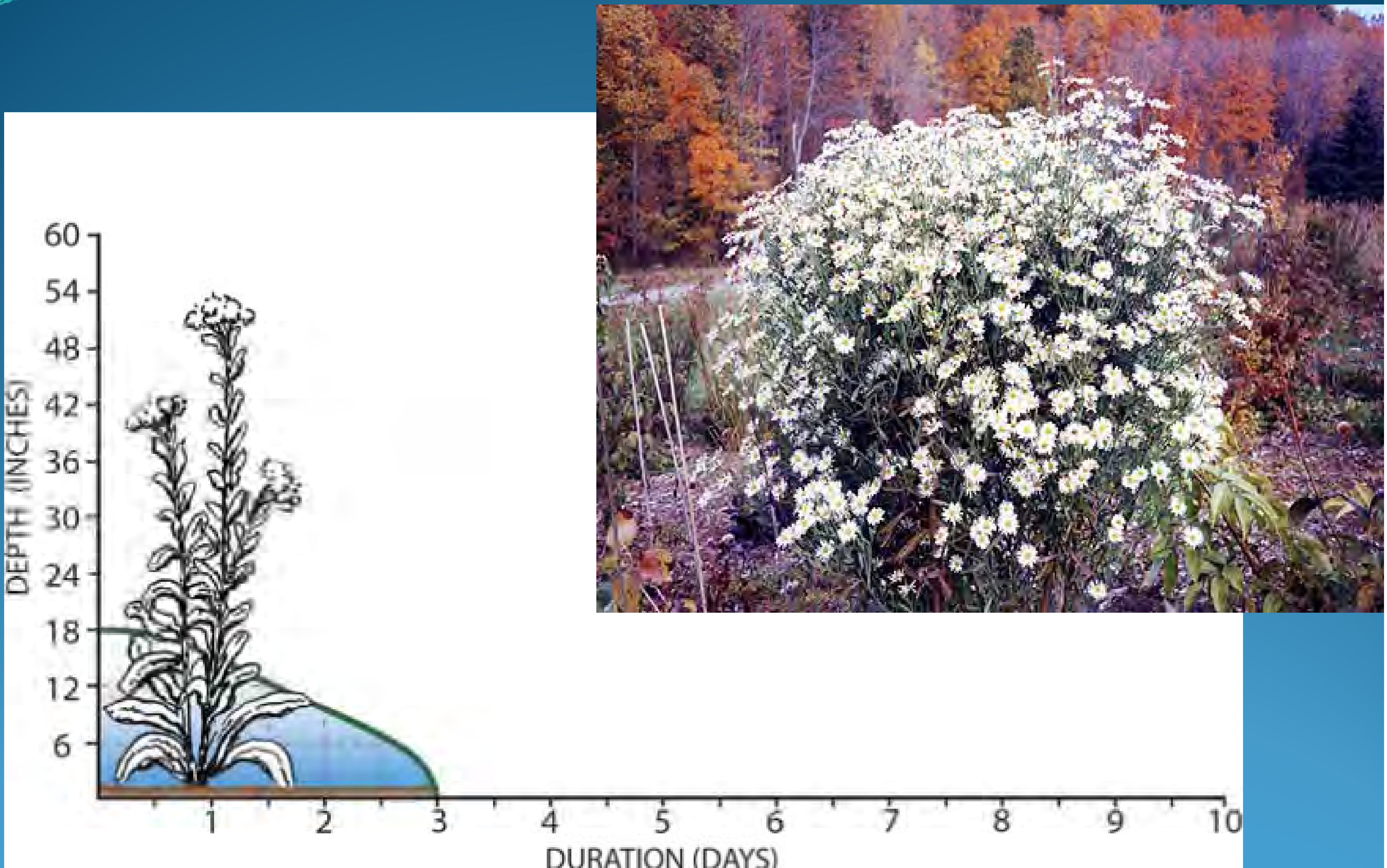


Asclepias incarnata

Swamp milkweed

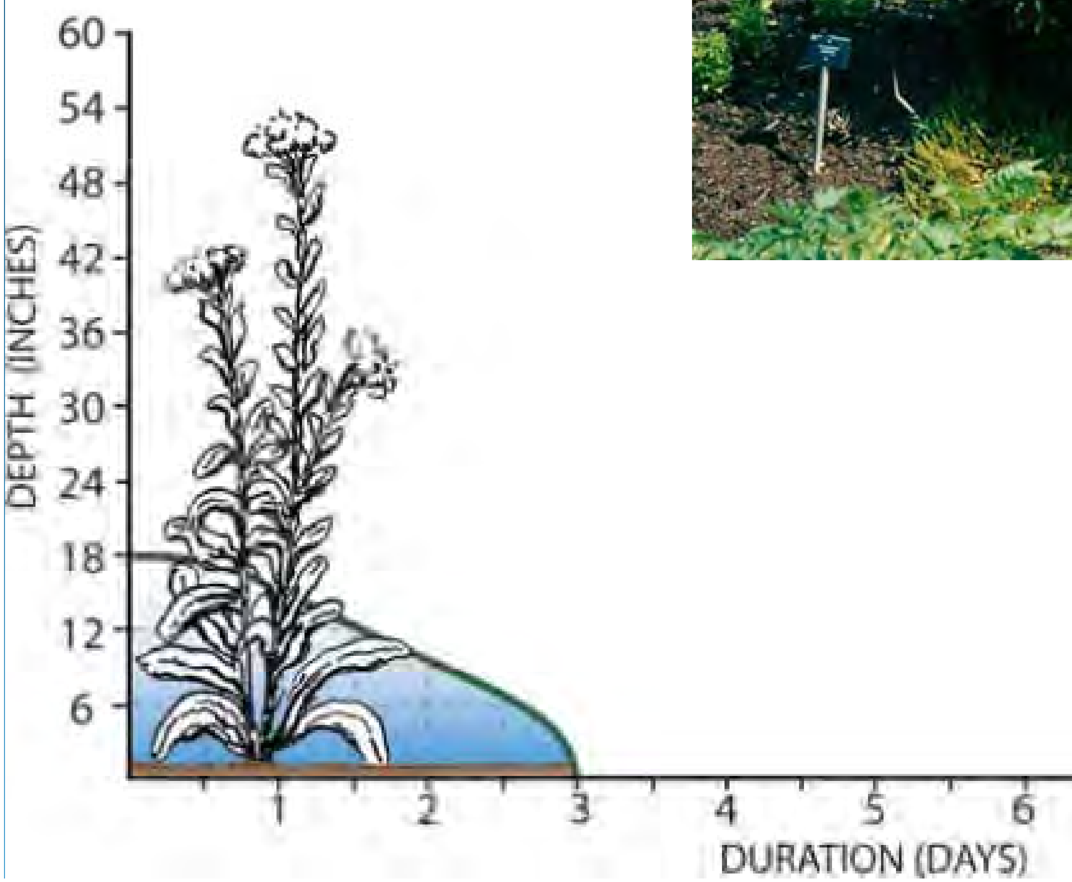
Boltonia asteroides 'Snowbank

Boltonia



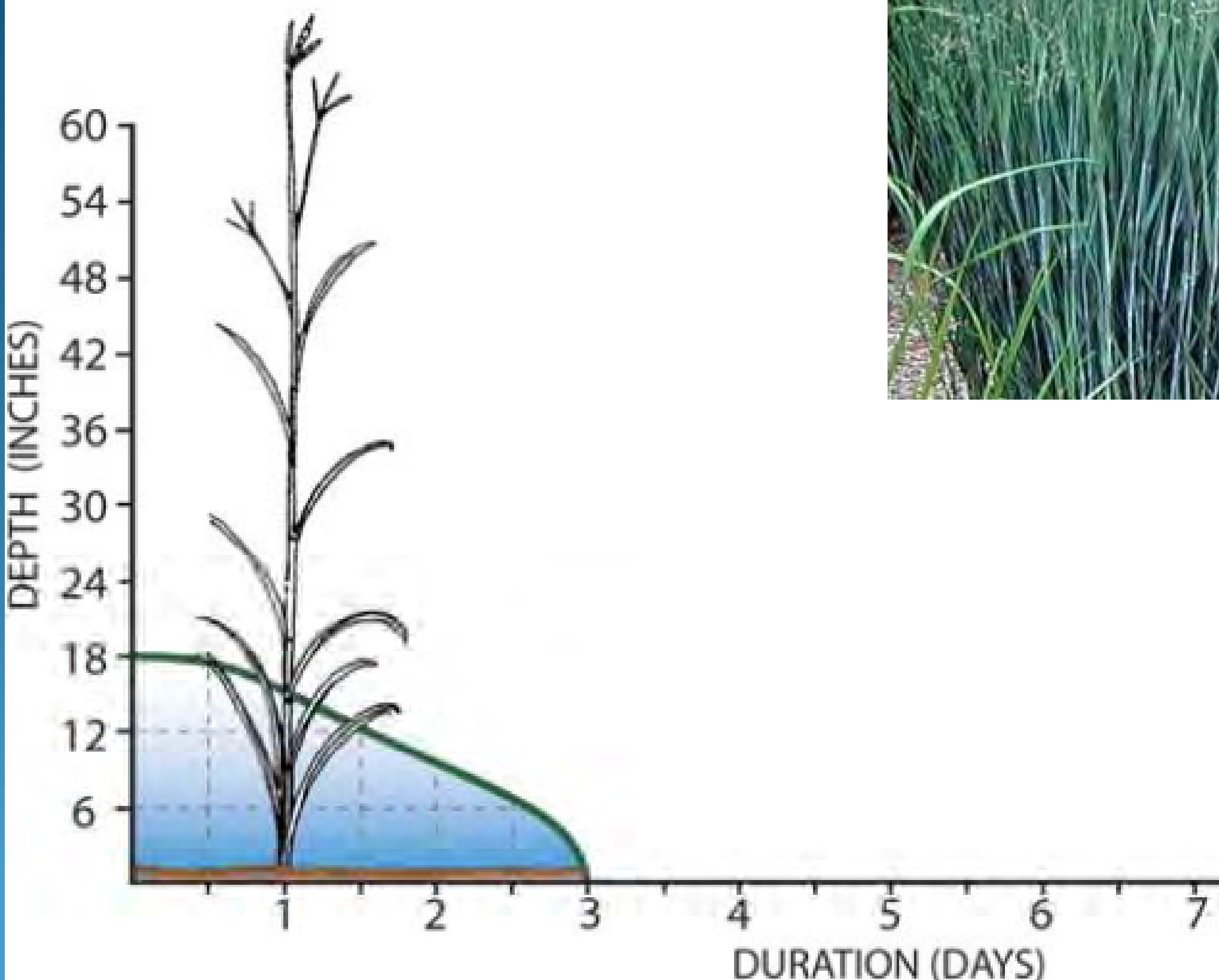
Veronicastrum virginicum
'Lavender towers'

Culver's root

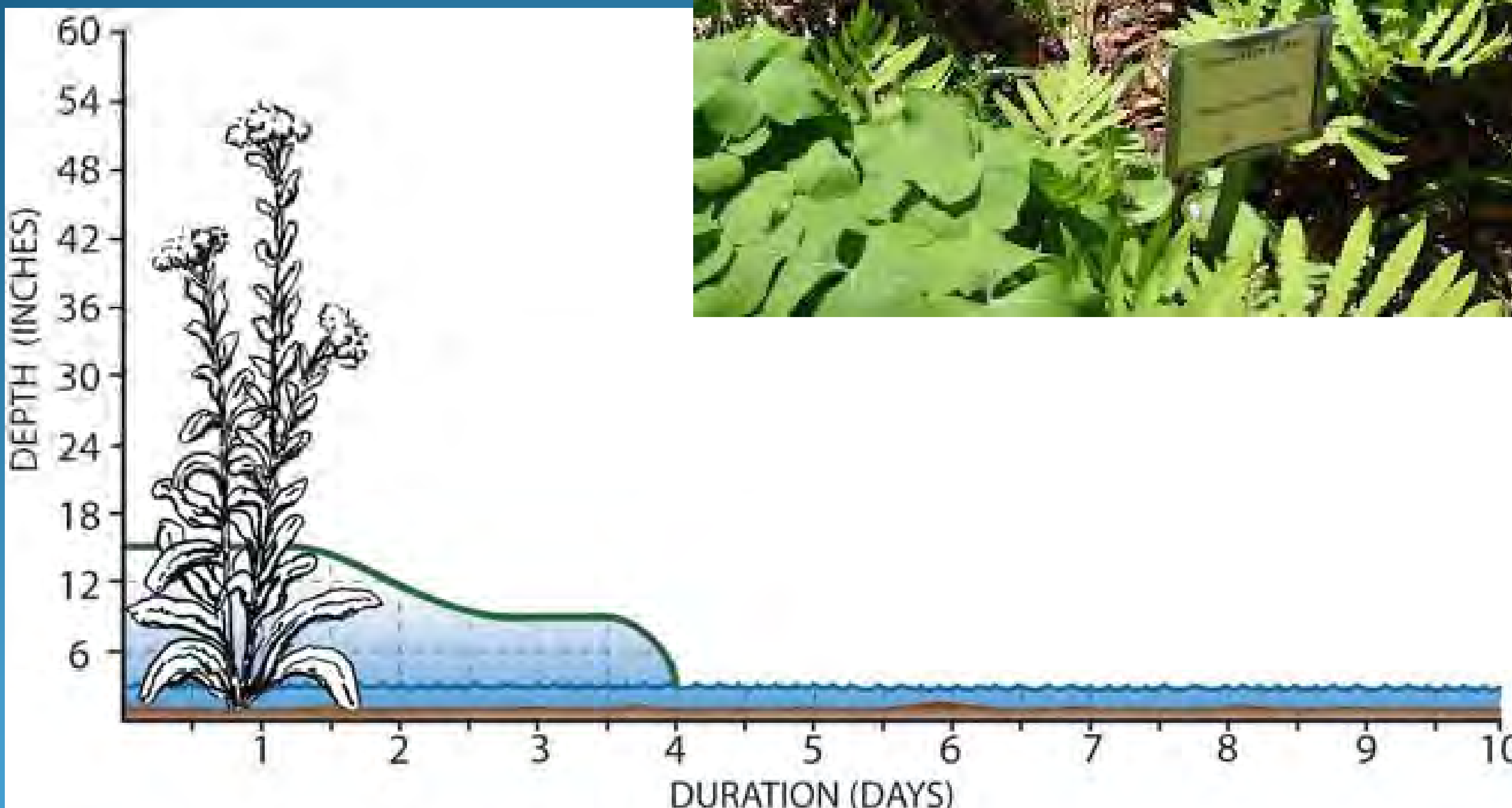


Panicum virgatum
'Shenandoah' and 'Northwind'

Switch grass



Onoclea sensibilis
Sensitive fern



Maintenance

- Water until established 1st season
- Aesthetics
- seasonality
- garbage
- Replace poor performing plants ASAP

Maintenance

- erosion at inlet
- erosion mats (e.g., curlex); or
- sod
- Fine sediment

  mini-forebay

Maintenance

- mulch
- not too much: double-shredded
  - takes up volume meant for water;
  - interferes with infiltration
- eliminate mulch over time: dense vegetation weed control
- Fall clean-up (just like a normal landscape!)

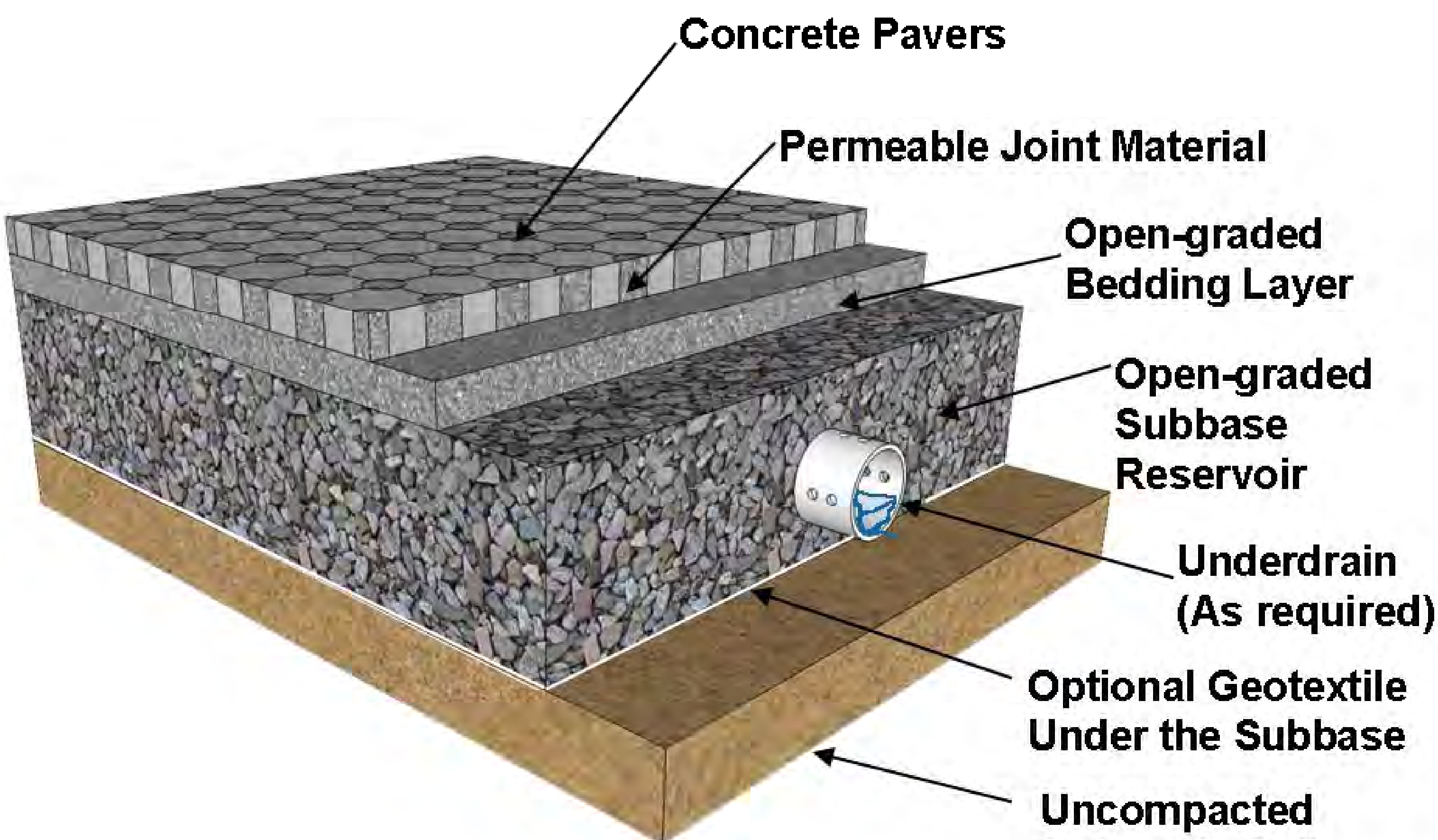
Table Discussion

- How does what you just heard fit with your experience in the past?
- How might it influence what you do in the future?
- What do you see as the biggest challenge that prevents people from using bioretention?

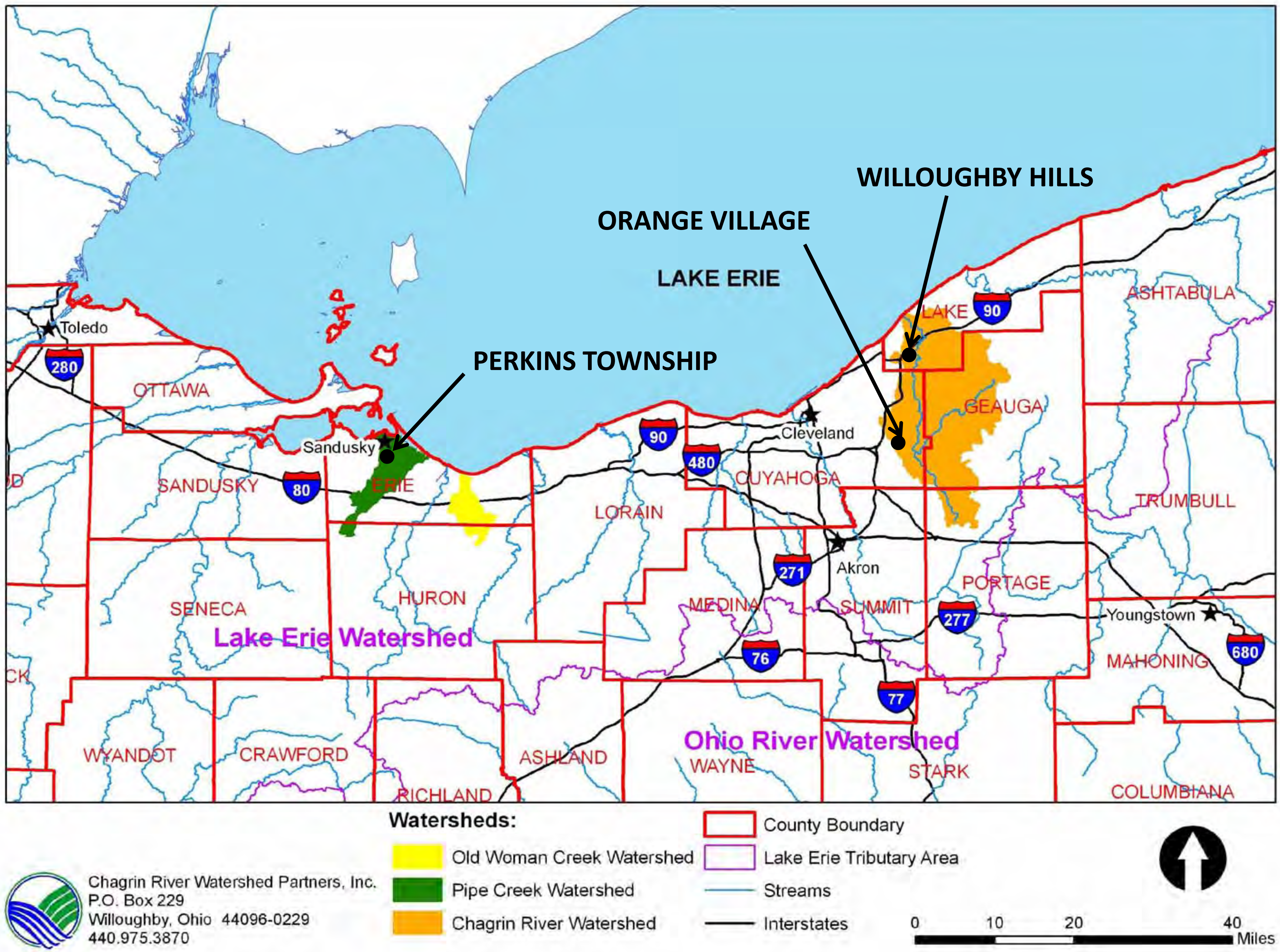
Permeable Pavement Performance

Ryan Winston & Alessa Smolek (NCSU)

Permeable Pavement Typical Section



Courtesy: Matthew Jones


WILLOUGHBY HILLS
ORANGE VILLAGE
LAKE ERIE
PERKINS TOWNSHIP
Toledo
Sandusky
Cleveland
Akron
Youngstown
OTTAWA
SANDUSKY
ERIE
LORAIN
CUYAHOGA
LAKE
GEAUGA
ASHTABULA
TRUMBULL
SENECA
HURON
MEDINA
SUMMIT
PORTAGE
MAHONING
WYANDOT
CRAWFORD
RICHLAND
ASHLAND
WAYNE
STARK
COLUMBIANA
280
80
90
480
271
76
77
277
680
Lake Erie Watershed
Ohio River Watershed
Watersheds:
Old Woman Creek Watershed
Pipe Creek Watershed
Chagrin River Watershed
County Boundary
Lake Erie Tributary Area
Streams
Interstates
0
10
20
40
Miles
Chagrin River Watershed Partners, Inc.
P.O. Box 229
Willoughby, Ohio 44096-0229
440.975.3870


Willoughby Hills Site
Small
Large

Willoughby Hills

Small Application:

PP SA: 480 ft^2

Catchment Area: 0.08 ac

Hydrologic Loading Ratio: 8.2

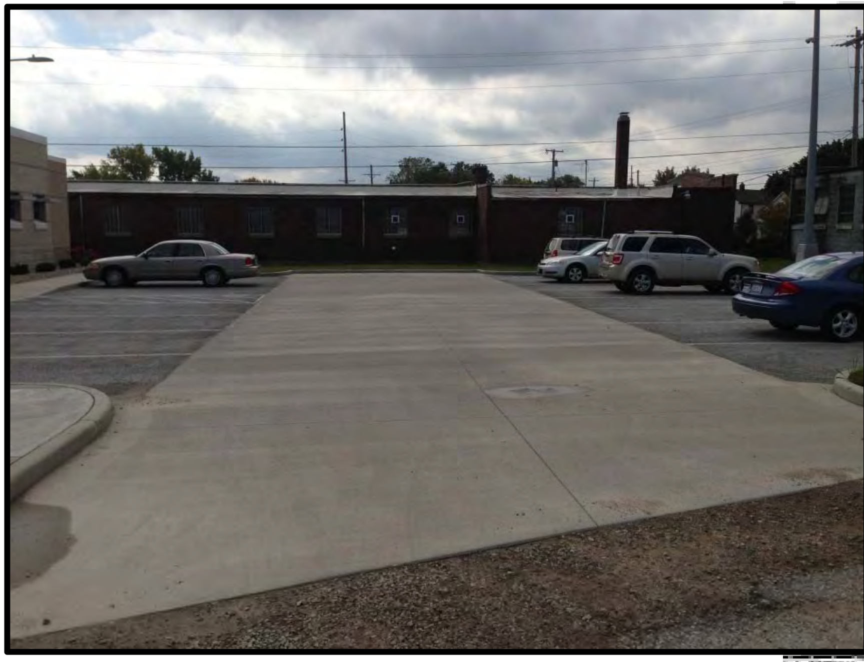
Large Application:

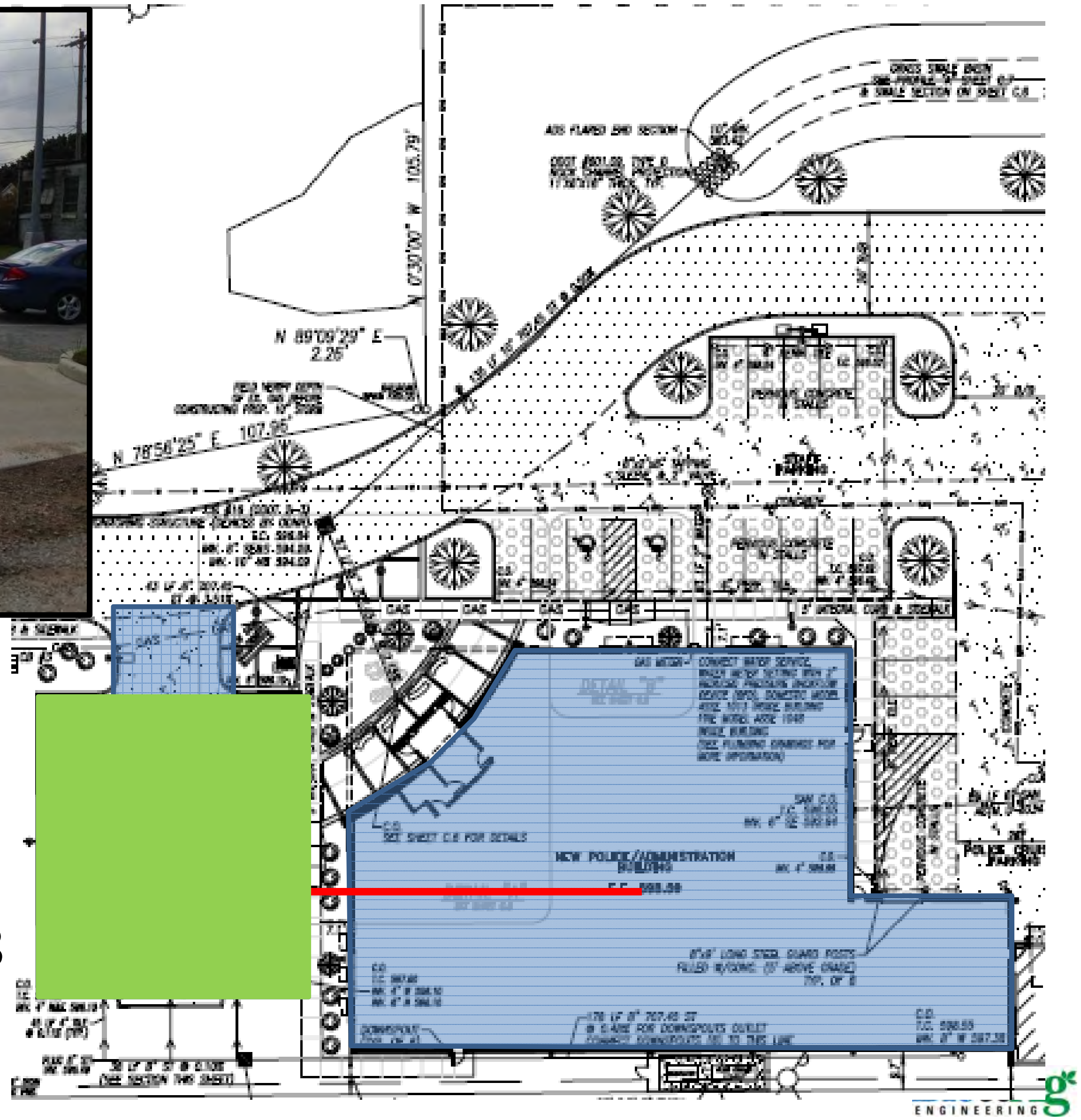
PP SA: 4420 ft^2

Catchment Area: 0.22 ac

Hydrologic Loading Ratio: 3.1

Perkins Township





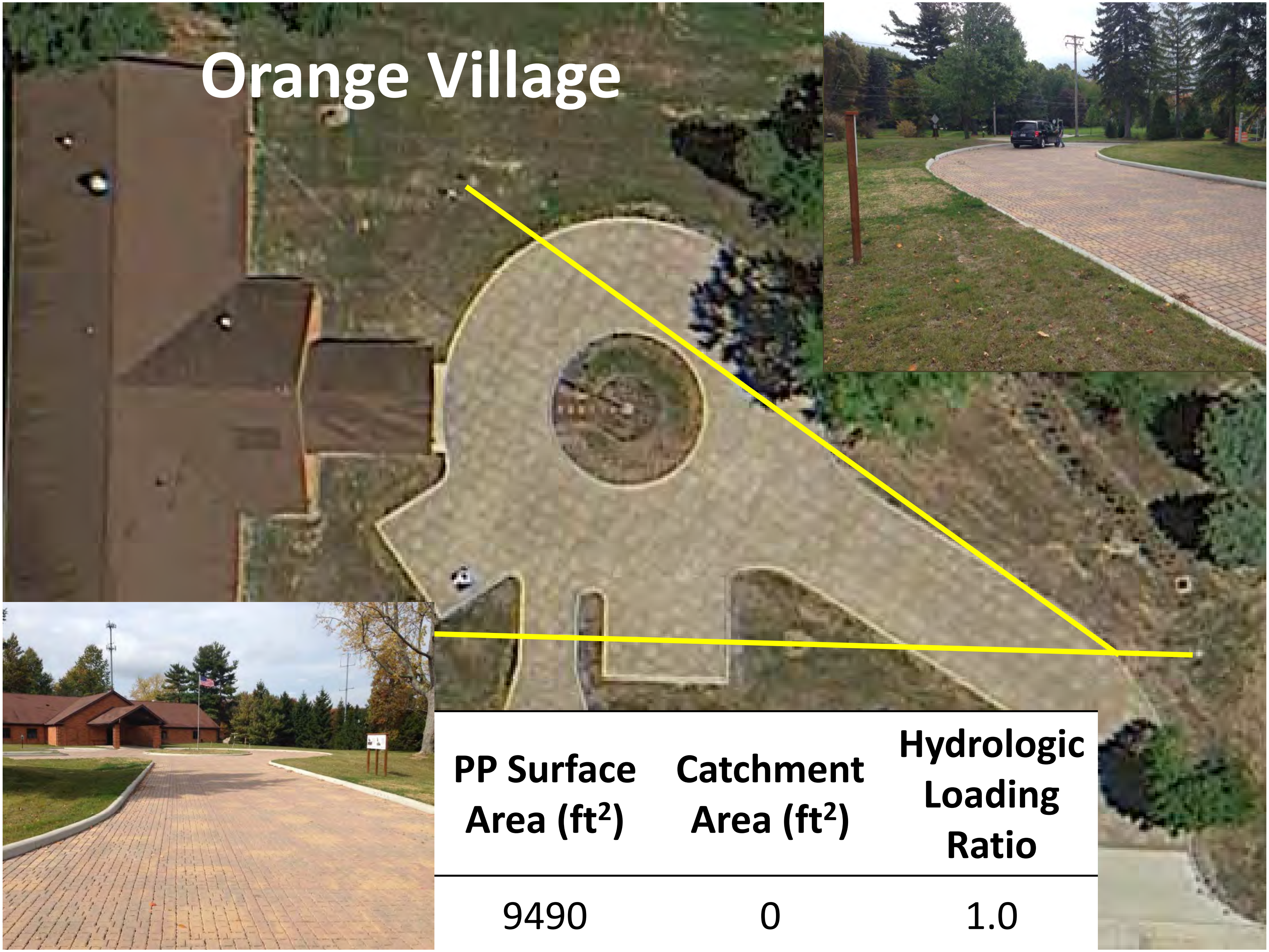
Site Characteristics:

PP SA: 2590 ft^2

Catchment Area: 0.53 ac

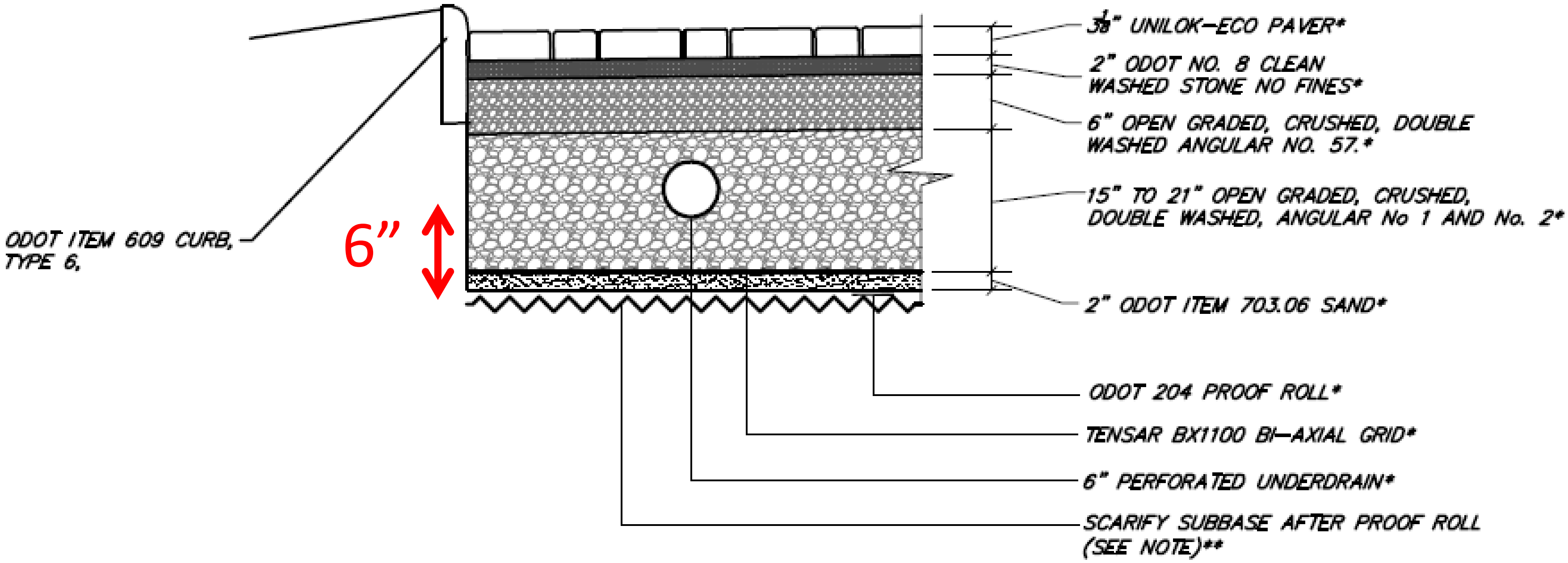
Hydrologic Loading Ratio: 4.8

Orange Village



PP Surface Area (ft^2)	Catchment Area (ft^2)	Hydrologic Loading Ratio
9490	0	1.0

Design Cross-Sections



POROUS PAVEMENT TYPICAL SECTION

SCALE: 1"=1'–0"

Site	WH Small	WH Large	Perkins	Orange
Total Aggregate Depth (in)	20	20	15-18	23-29
Pavement Type	PICP	PICP	PC	PICP

Monitoring Scheme

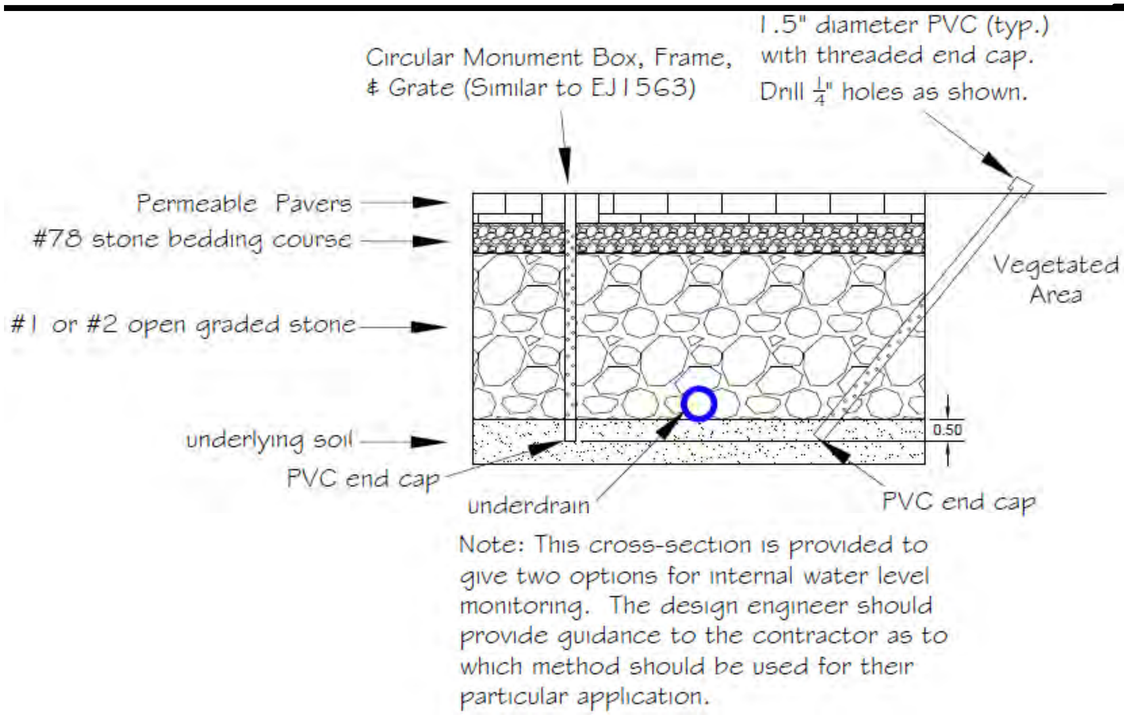
Quantify the water balance for each stormwater control

Permeable Pavement Soil Testing

Site	Mapped Soil	Subgrade Soil Texture	Measured Kfs (in/hr)
Perkins Township	Bennington	Silty Clay Loam	0.01, 0.01, 0.04,0.05
Orange Village	Wadsworth	Fill	0.01, 0.03, 0.05, 0.06, 0.72, 1.54
Willoughby Hills	Mahoning	Fill	Small – 0.01, 0.05 Large – 0, 0.01, 0.04, 0.06

Results

Post-Construction Permeable Pavement Drawdown Rates



Courtesy: Onset Computer Corporation, 2014

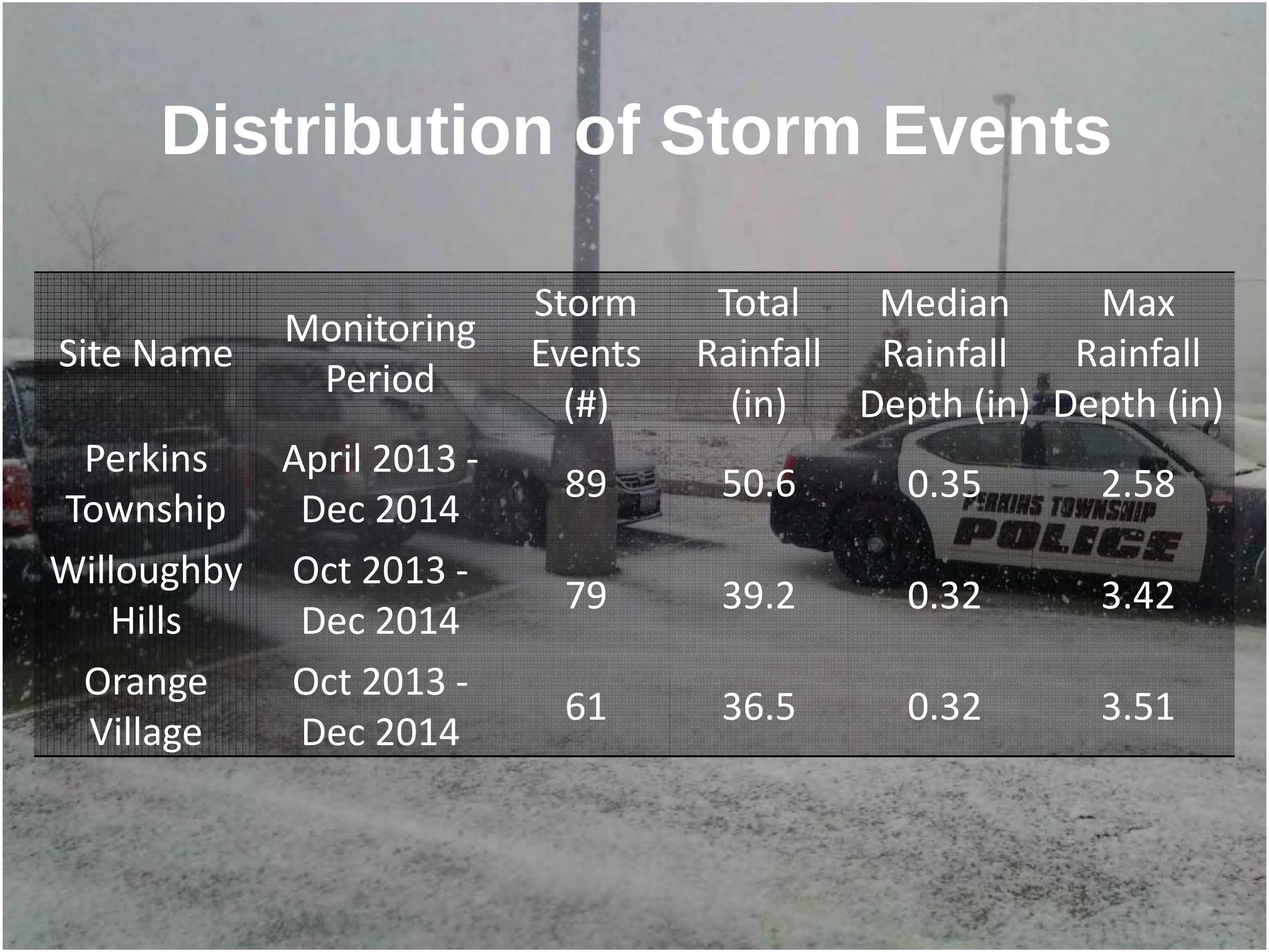
Comparison of Drawdown Rates

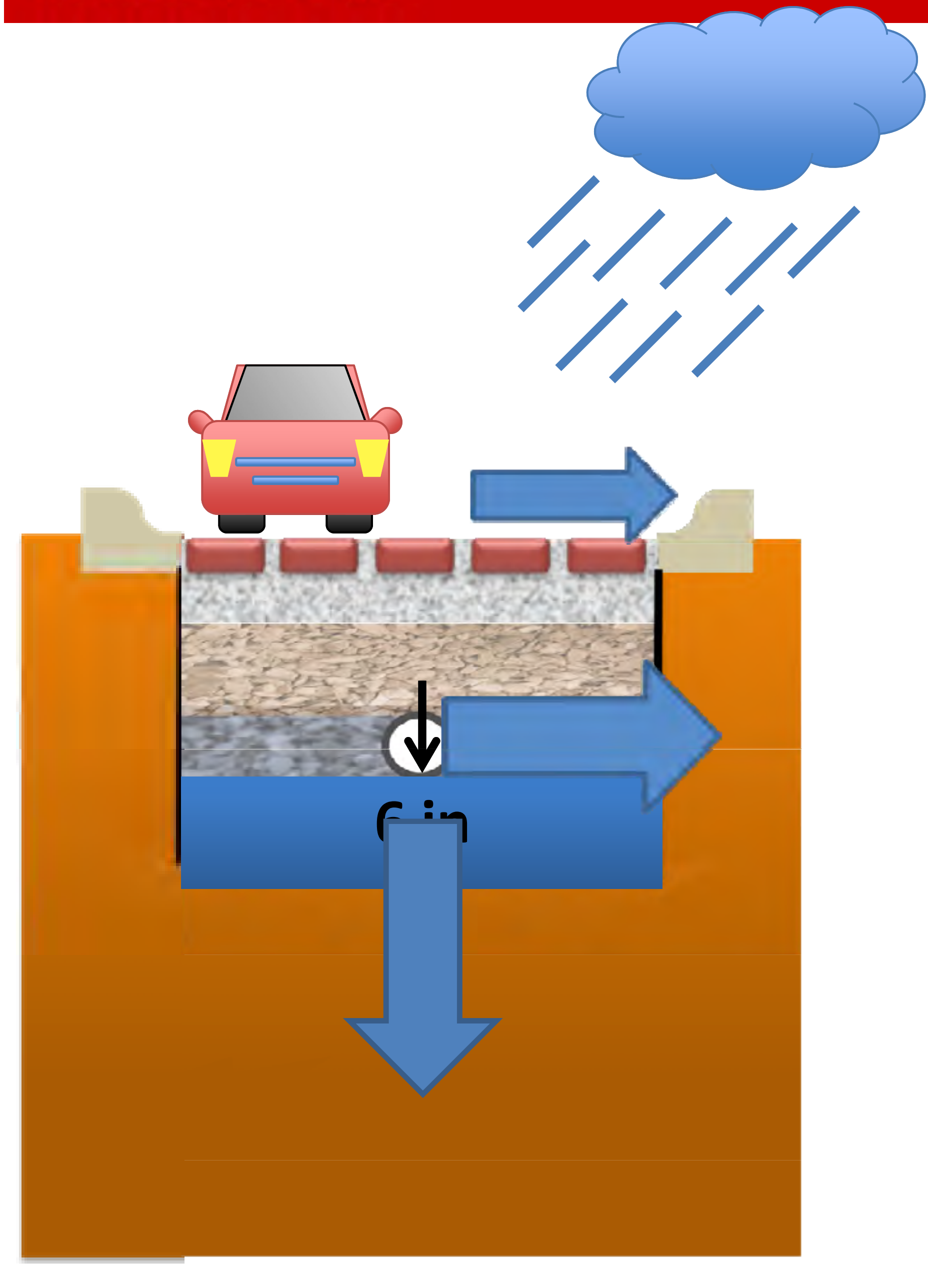
Site Name	Pre-Construction Kfs (in/hr)	Avg Post-Construction Drawdown Rate (in/hr)
Perkins Township	0.01-0.05	0.013
Willoughby Hills Small	0.01-0.05	0.01
Willoughby Hills Large	0-0.06	0.01-0.03

Pre and post-construction rates comparable

Distribution of Storm Events

Site Name	Monitoring Period	Storm Events (#)	Total Rainfall (in)	Median Rainfall Depth (in)	Max Rainfall Depth (in)
Perkins Township	April 2013 - Dec 2014	89	50.6	0.35	2.58
Willoughby Hills	Oct 2013 - Dec 2014	79	39.2	0.32	3.42
Orange Village	Oct 2013 - Dec 2014	61	36.5	0.32	3.51





Perkins Township Water Balance

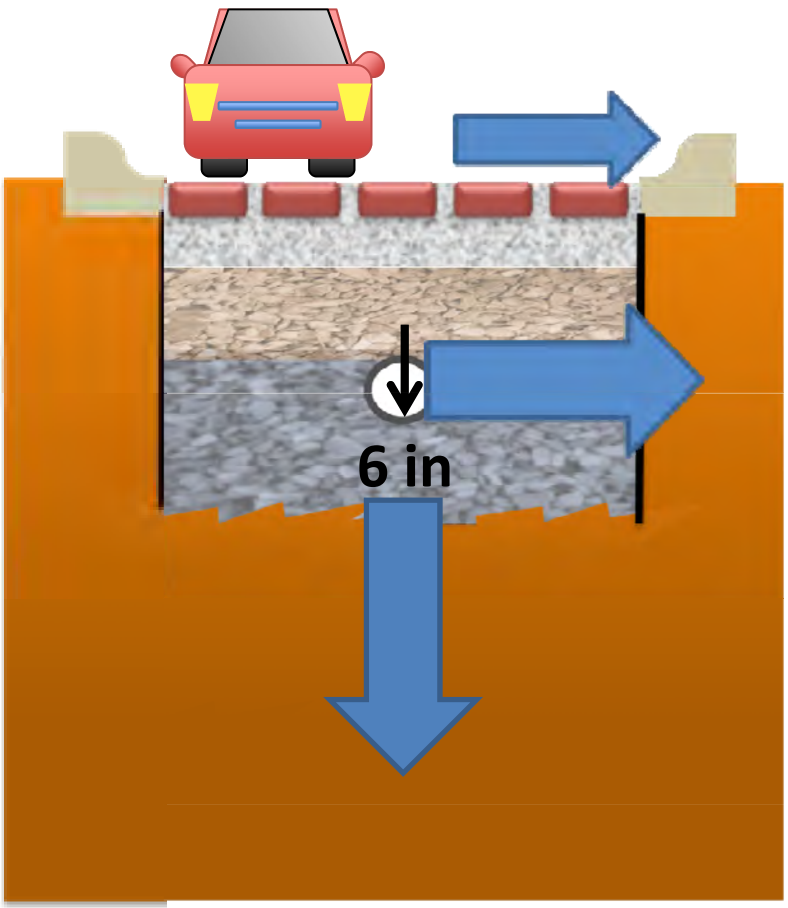
- 5% Evaporation + Abstraction
  - Wetting of rock, pavement, and evaporation
- 42% Exfiltration
  - Infiltration to native soil from IWS zone
- 53% Drainage
  - Flow through underdrain
- 0% Overflow
  - Bypass on surface of pavement

Willoughby Hills Water Balance

<u>Hydrologic Loading Ratios:</u>

Small Bay: 8.2:1

Large Bay: 3.1:1



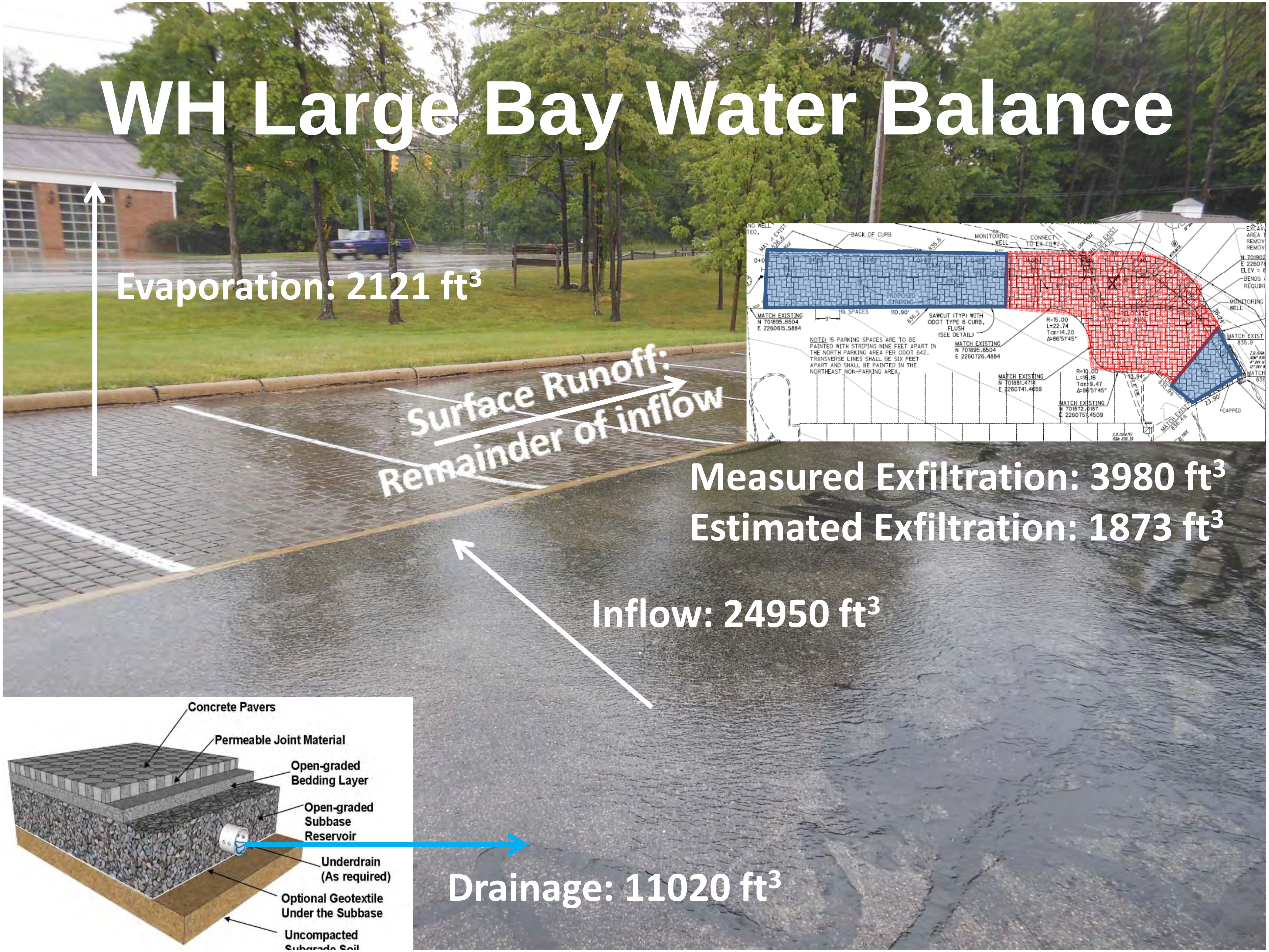
Fate of Water	Small Bay	Large Bay
Evaporation & Abstraction	13.2%	10.5%
Exfiltration	3.5%	21.5%
Drainage	75.3%	44%
Surface Runoff	8%	24%

<u>Measured Drawdown Rates:</u>

Small Bay: 0.01 in/hr

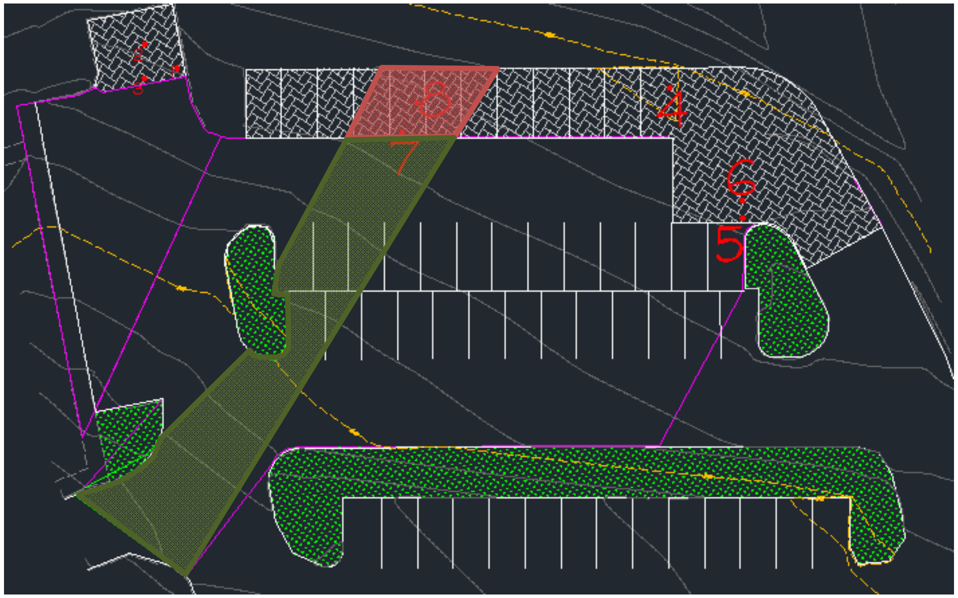
Large Bay: 0.01-0.03 in/hr

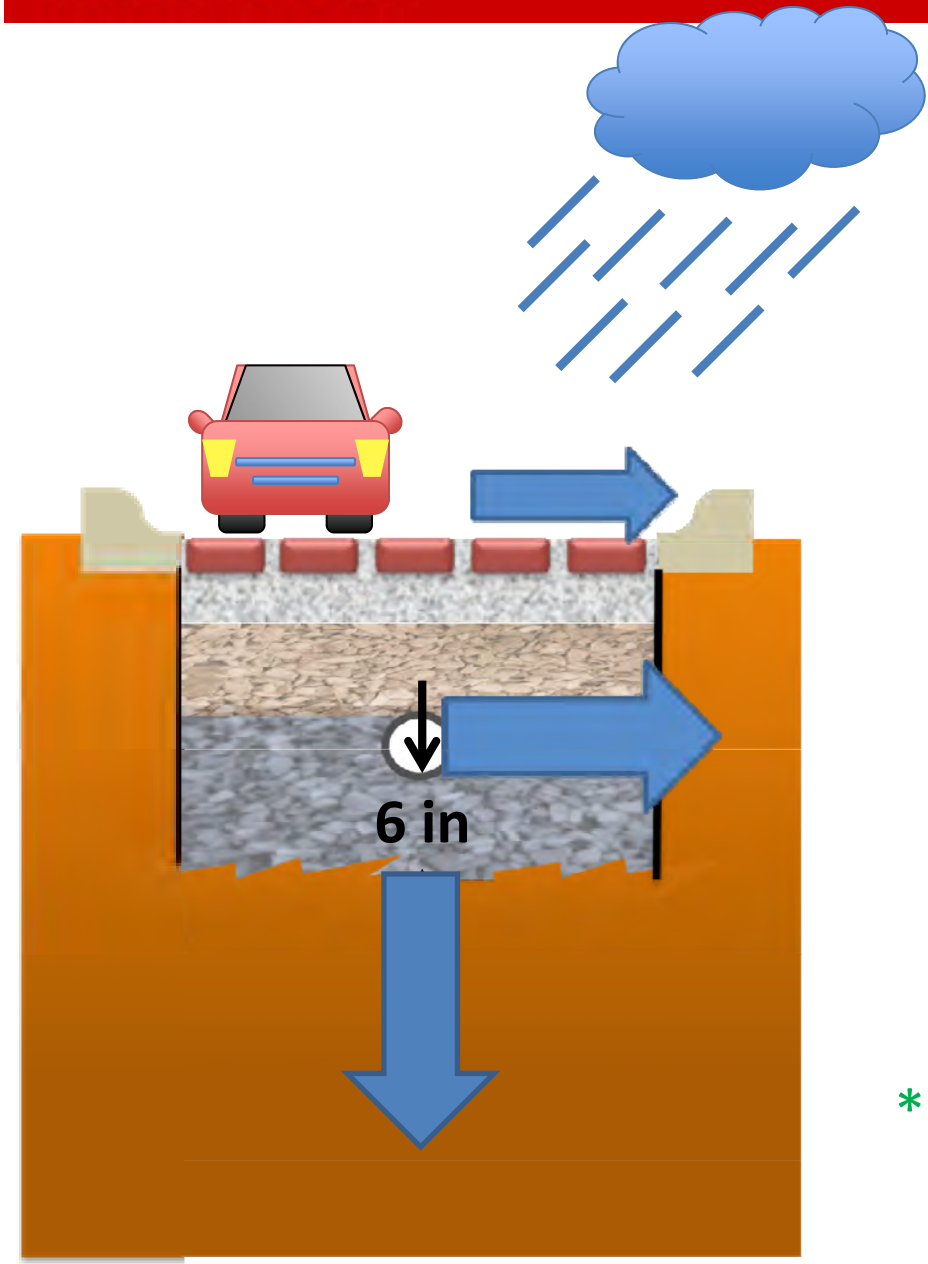
WH Large Bay Water Balance



WH Large Bay Modeling (DRAINMOD)

- Clogging caused surface runoff
  - Estimated appx. 4000 sf of contributing area bypassing the system
- Determined effective runoff area by adjusting the contributing area until monitoring and modeled drainage matched
  - Appx. 550 sf clogged (equiv. to 13% of PICP surface area)
- Equivalent to 24% surface runoff





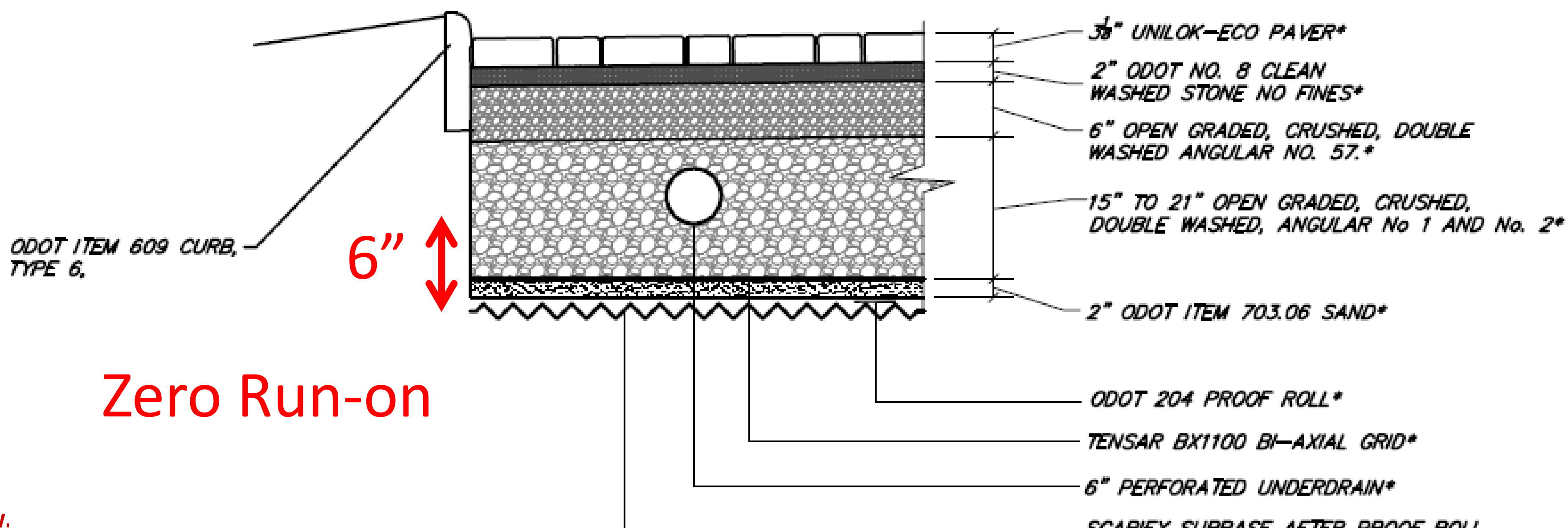
Orange Village Water Balance

- 98.8% Abstraction, Exfiltration, & Evaporation
- 1.2% Drainage
  - Flow through underdrain
- 0% Overflow
  - Bypass on surface of pavement

*Curtain drain present beneath SCM

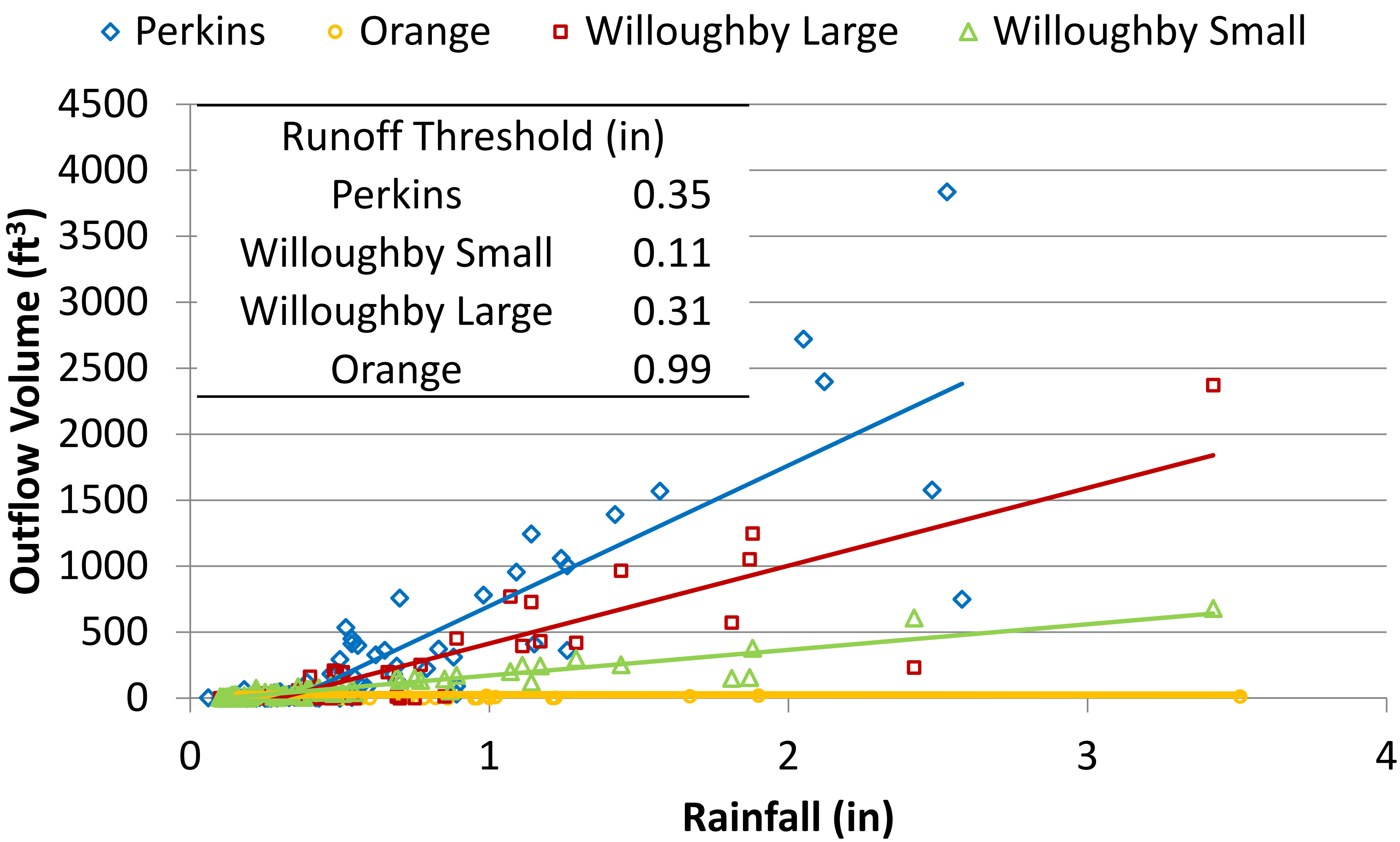
Design Characteristics Critical to Performance

Site	Mapped Soil	Subgrade Soil Texture	Measured Kfs (in/hr)
Perkins Township	Bennington	Silty Clay Loam	0.01, 0.01, 0.04,0.05
Orange Village	Wadsworth	Fill	0.01, 0.03, 0.05, 0.06, 0.72, 1.54
Willoughby Hills	Mahoning	Fill	Small – 0.01, 0.05 Large – 0, 0.01, 0.04, 0.06



Zero Run-on

When does outflow occur?



Bio&Ag ENGINEERING

Q_p Mitigation during Highest Rainfall Intensities

2-5 storms with peak intensities

>1 yr, 5 min storm for Cleveland, OH

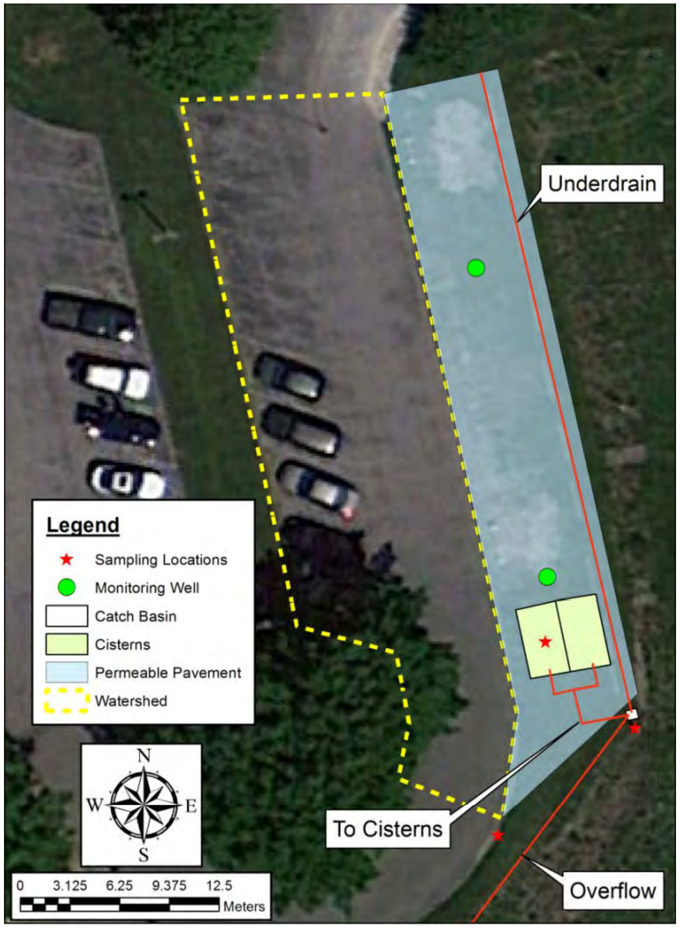
Site	Perkins	Willoughby Large	Willoughby Small	Orange
Peak Flow Reduction (%)	84-98	17-36	27-61	92-99

Hydrologic Monitoring Summary

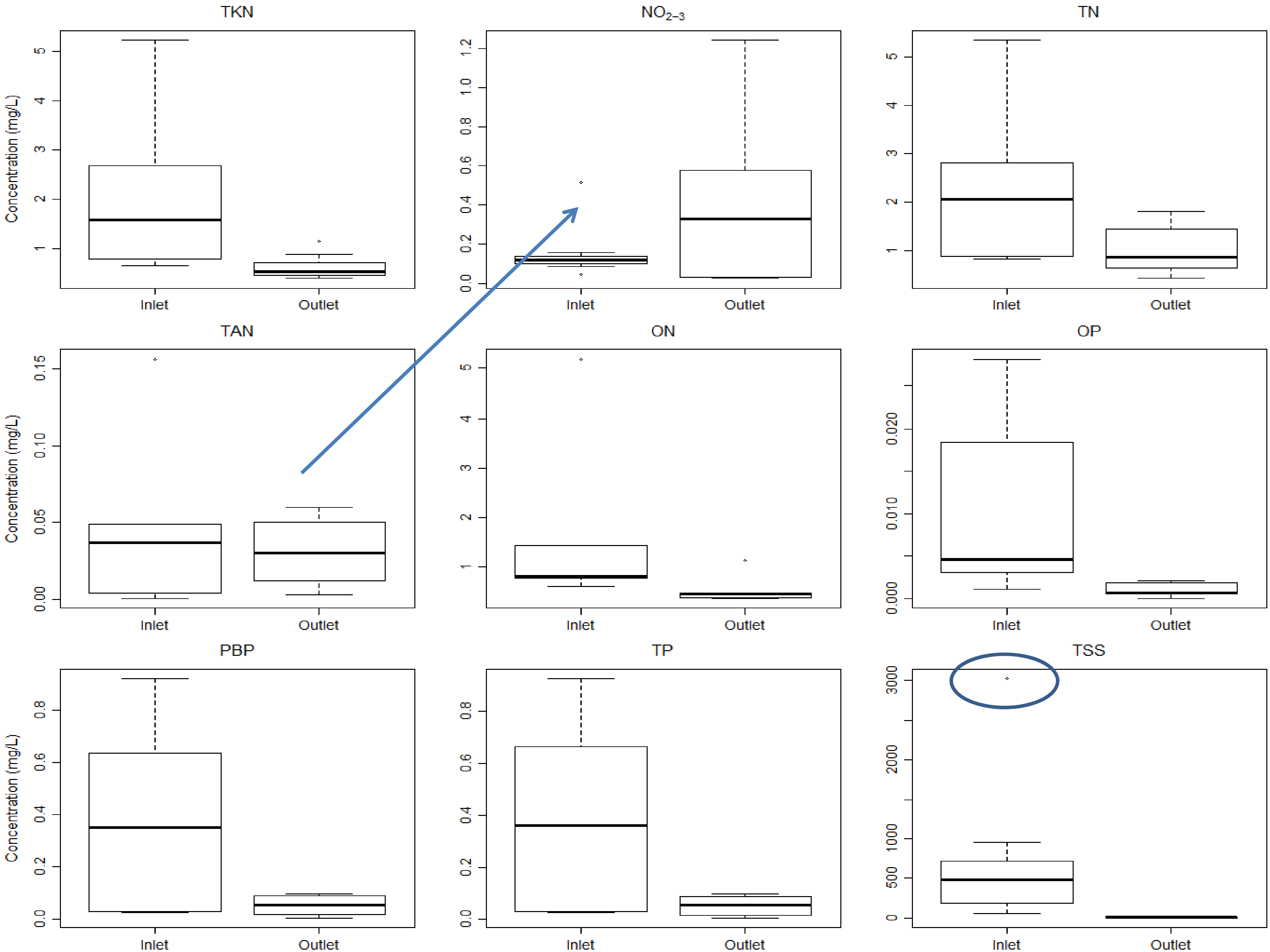
- Permeable pavement reduced runoff volume by 17-99%
  - Discharge threshold between 0.11-0.99 inches
  - Exfiltration 3-98% of water balance
  - ET ~5-10% of water balance
  - Completely captured 5-78% of storm events
  - Varied based on underlying soil infiltration rate and ability to de-water IWS zone
- Curve numbers reduced from 98 (parking lot) to 93.3-94.3 for hydrologic loading ratios from 3.4-8.2

Permeable Pavement Water Quality: Old Woman Creek

Old Woman Creek NERR



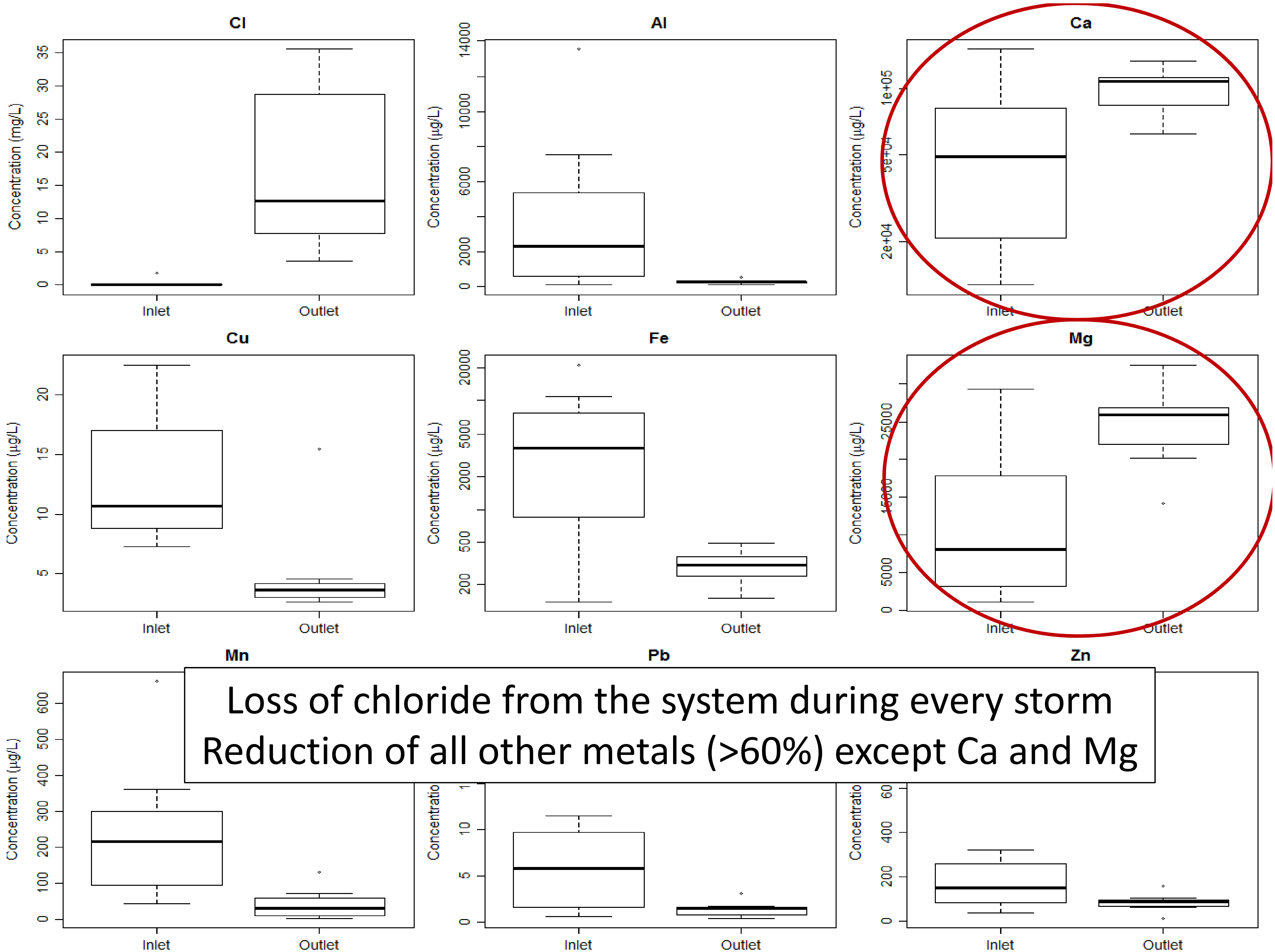
- 7 storm events sampled during 2014 for same set of pollutants
- Untreated runoff vs. spigot



TKN
NO2-3
TN
TAN
ON
OP
PBP
TP
TSS
Concentration (mg/L)
Concentration (mg/L)
Concentration (mg/L)
Inlet
Outlet

Thoughts…

- Aerobic transformation of ammonia to NO_{2-3} within the treatment train
- Excellent capture of particulate nitrogen (ON, TKN >60%), particulate P (87%), and TSS (99%)
- Excellent capture of dissolved P (90%) – binding to cations in aggregate?



Loss of chloride from the system during every storm

Reduction of all other metals (>60%) except Ca and Mg

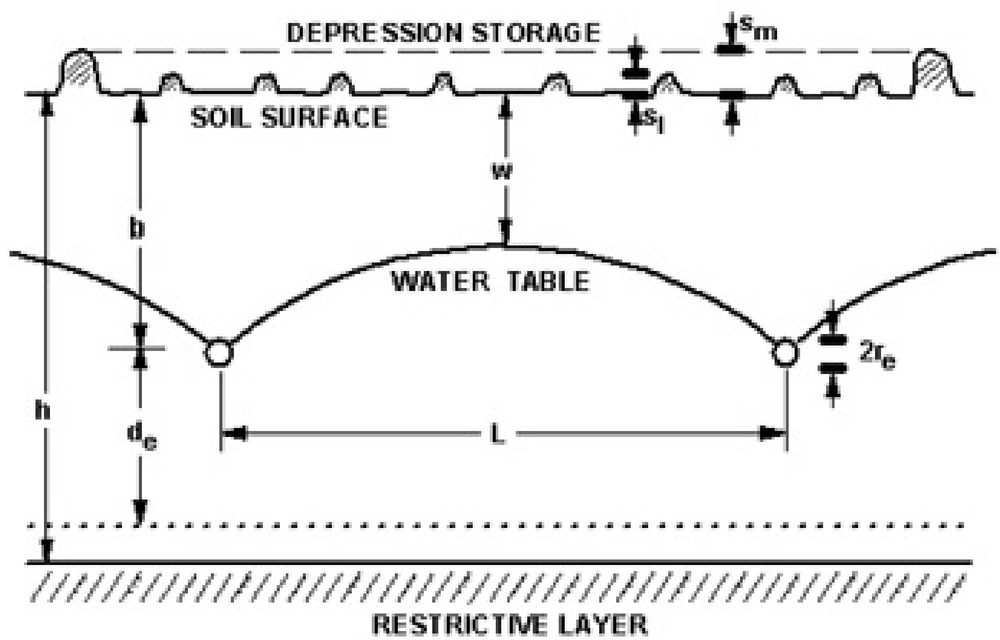
Aggregate Leaching Ca & Mg

- Limestone ($CaCO_3$)
- Dolomite ($CaMg(CO_3)_2$
- Lamar and Shorde (1953)

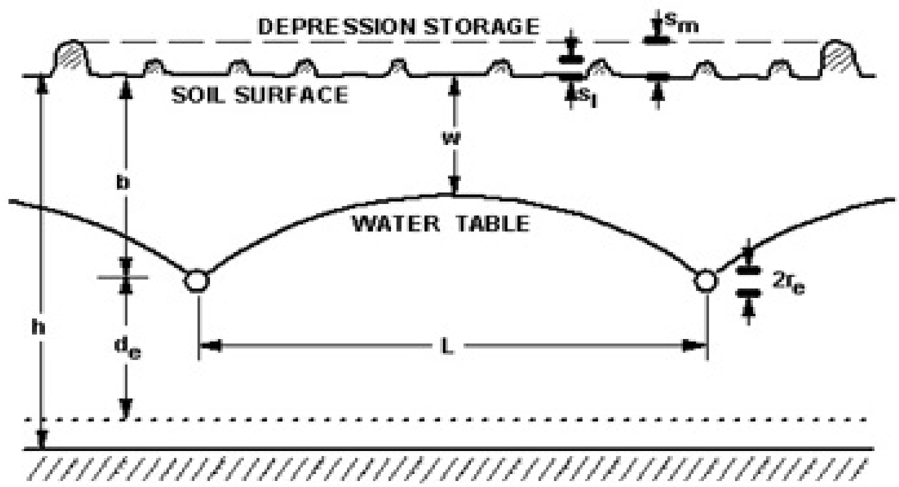
Modeling Permeable Pavement with DRAINMOD

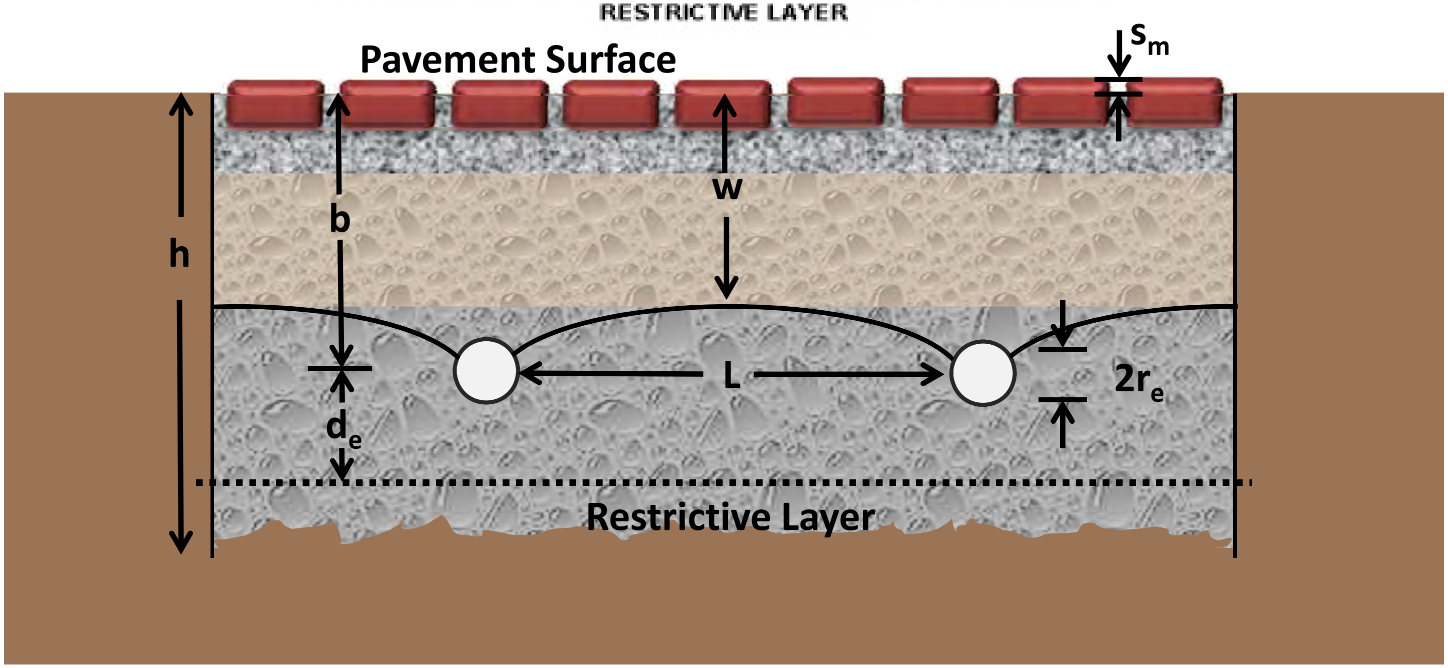
DRAINMOD: Can it apply to PP?

- DRAINMOD
  - Bioretention (Brown et al., 2013)
- Potential use for modeling permeable pavement
  - Primary hydrologic mechanisms
    - Infiltration
    - Drainage



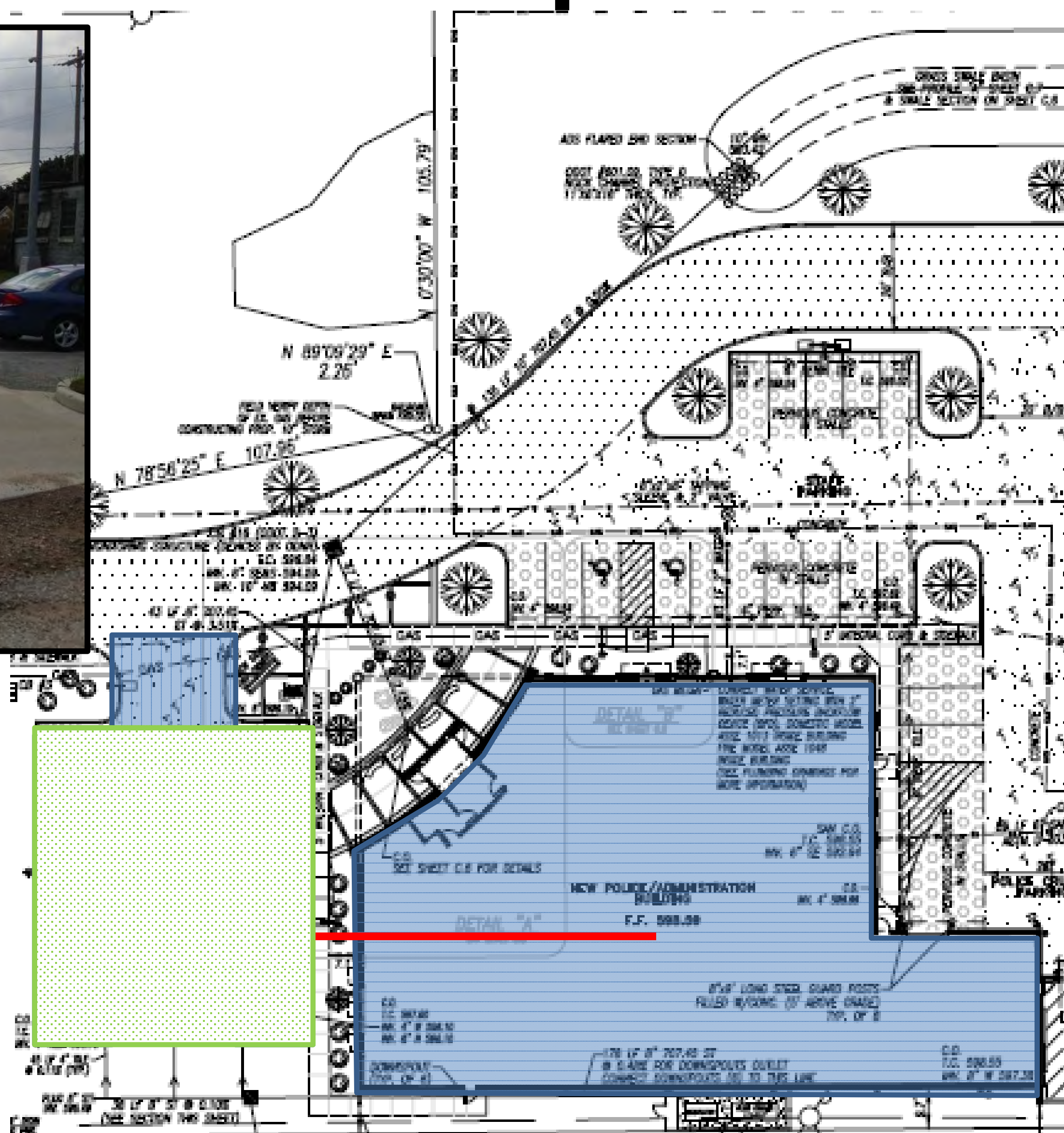
DRAINMOD: Drainage Inputs





Bio&Ag ENGINEERING

Perkins Township



Site Characteristics:

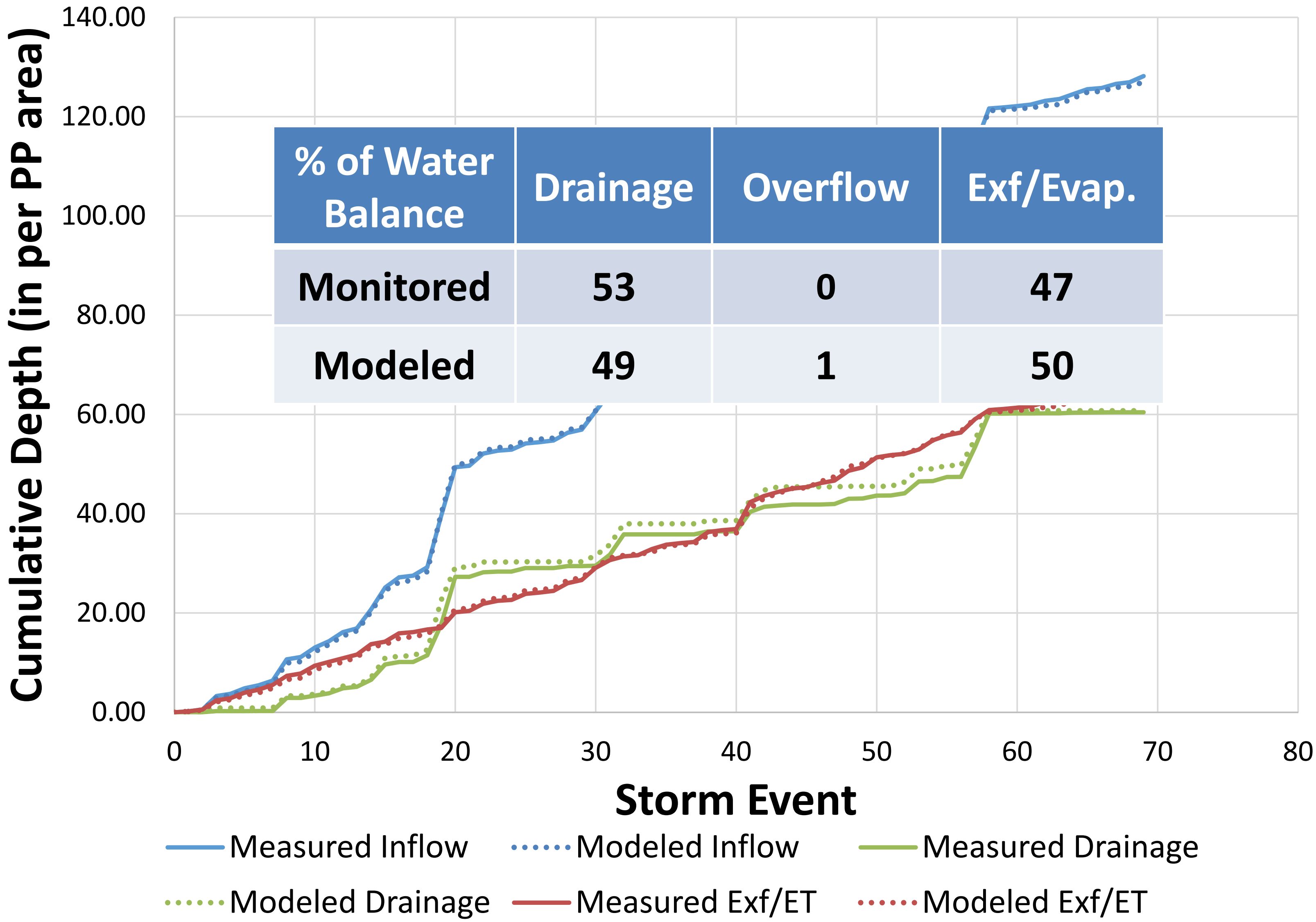
PP SA: 2590 ft^2

Inf. SA: 4820 ft^2

Catchment Area: 0.53 ac

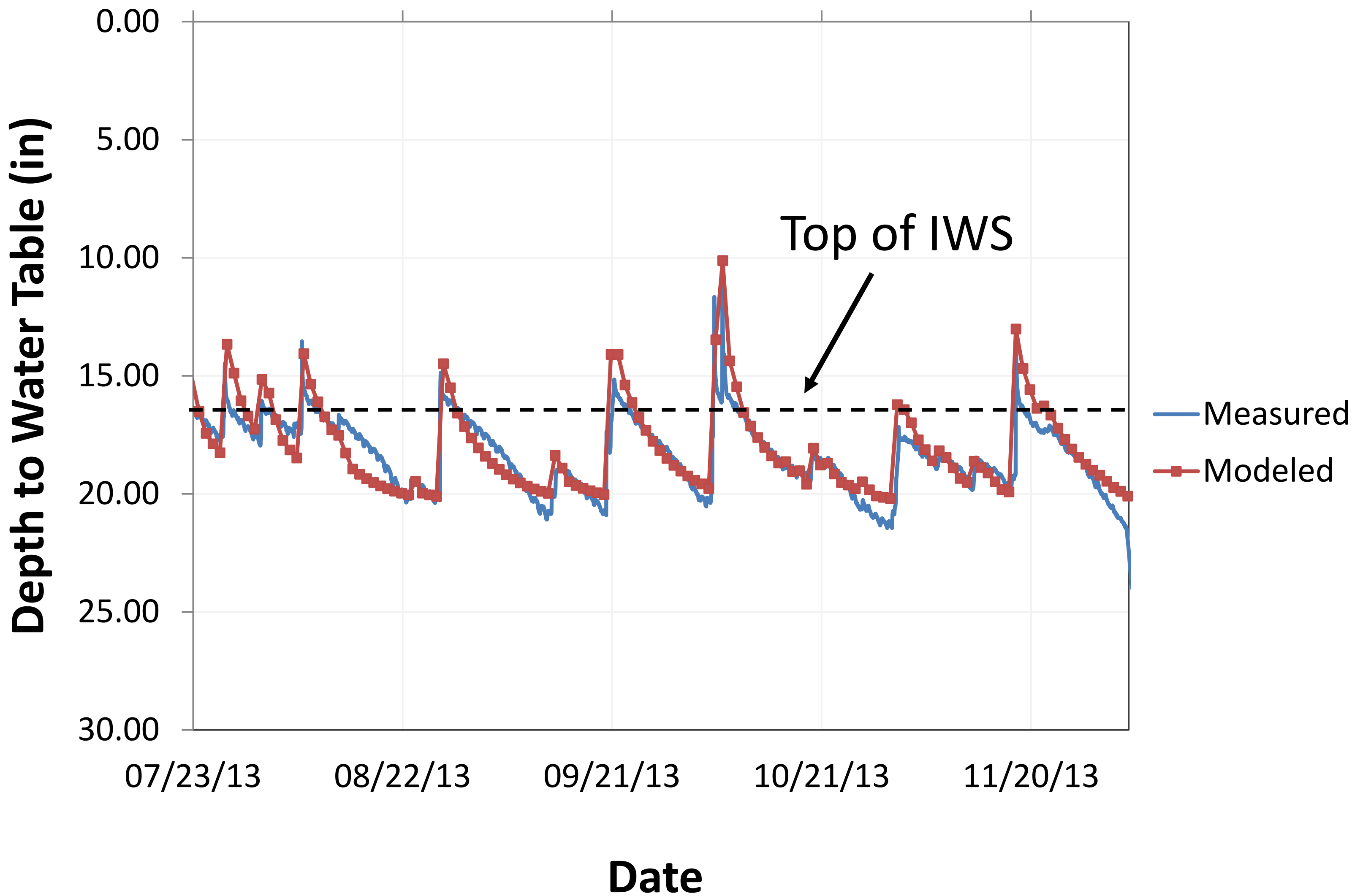
Hyd. Loading: 4.8

Perkins: Cumulative Volume

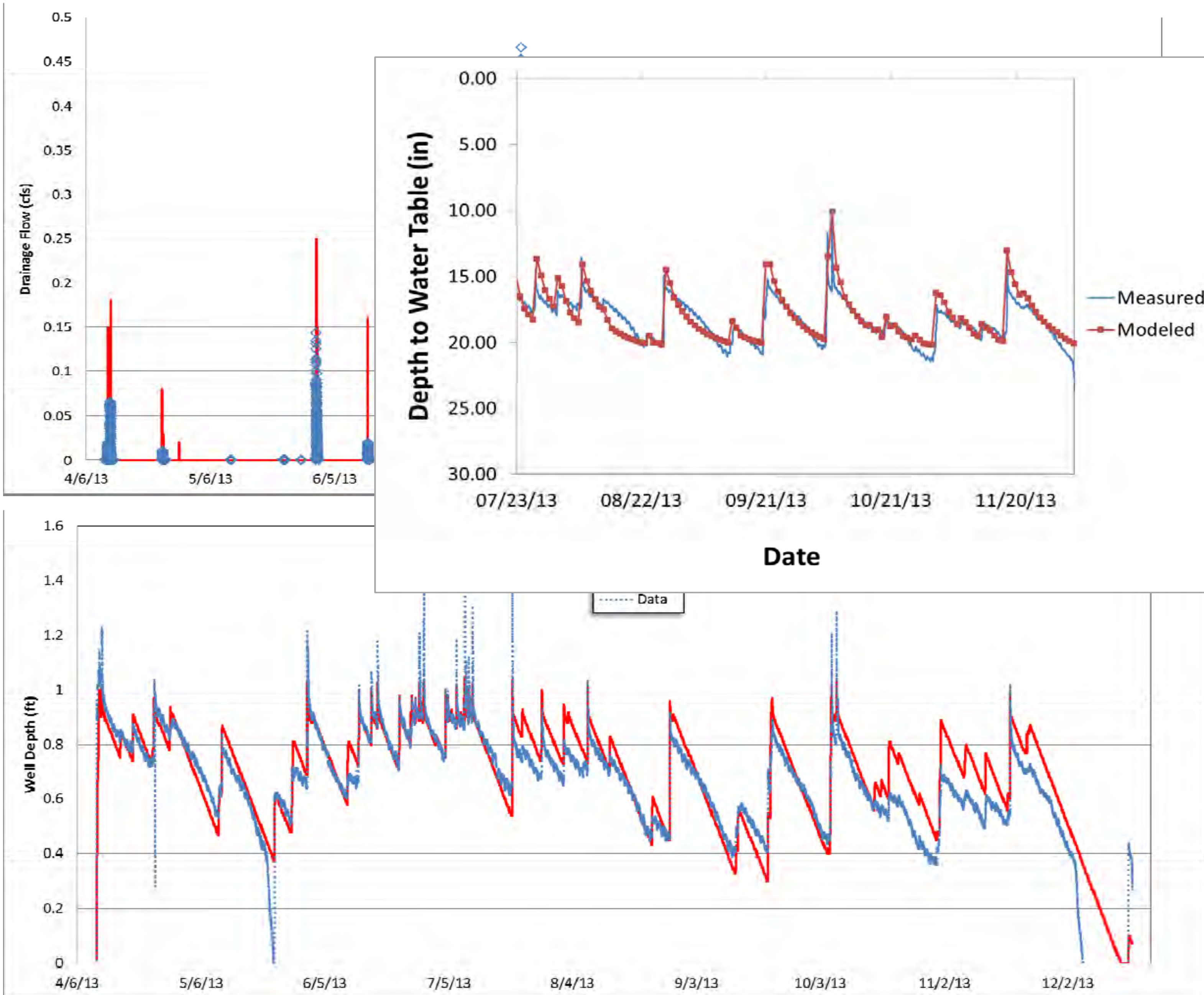


% of Water Balance	Drainage	Overflow	Exf/Evap.
Monitored	53	0	47
Modeled	49	1	50

Perkins: Water Table Depth



SWMM: Storage Unit Model



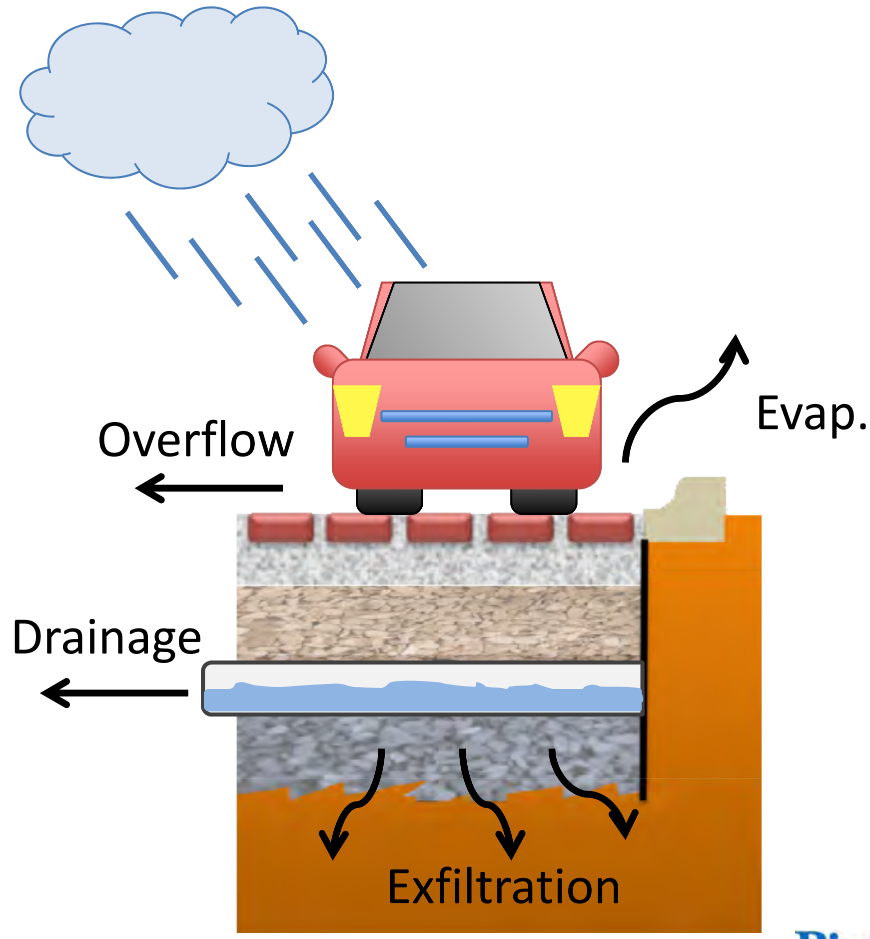
Sensitivity Analysis

How is the long-term hydrologic fate affected by:

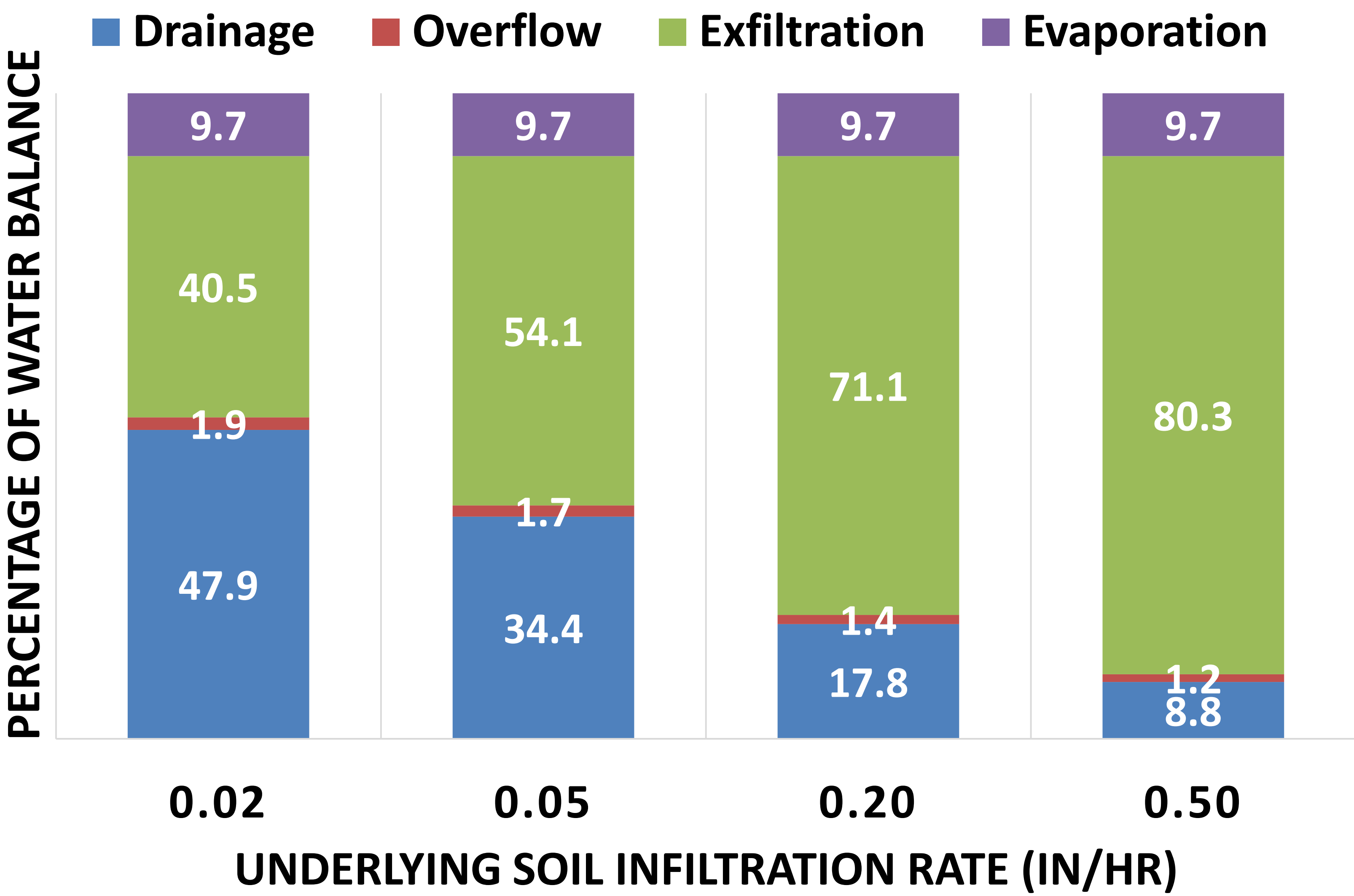
- Underlying Soil K_{sat}
- Aggregate depth
- Internal Water Storage Zone
- Hydraulic Loading

Baseline Models

- Four baseline models created based on conductivity of the underlying soil
  - K_{sat} = 0.5 in/hr
  - K_{sat} = 0.2 in/hr
  - K_{sat} = 0.05 in/hr
  - K_{sat} = 0.02 in/hr
- All other parameters remained the same
- 30-years of rainfall and temperature



Underlying Soil K_{sat}

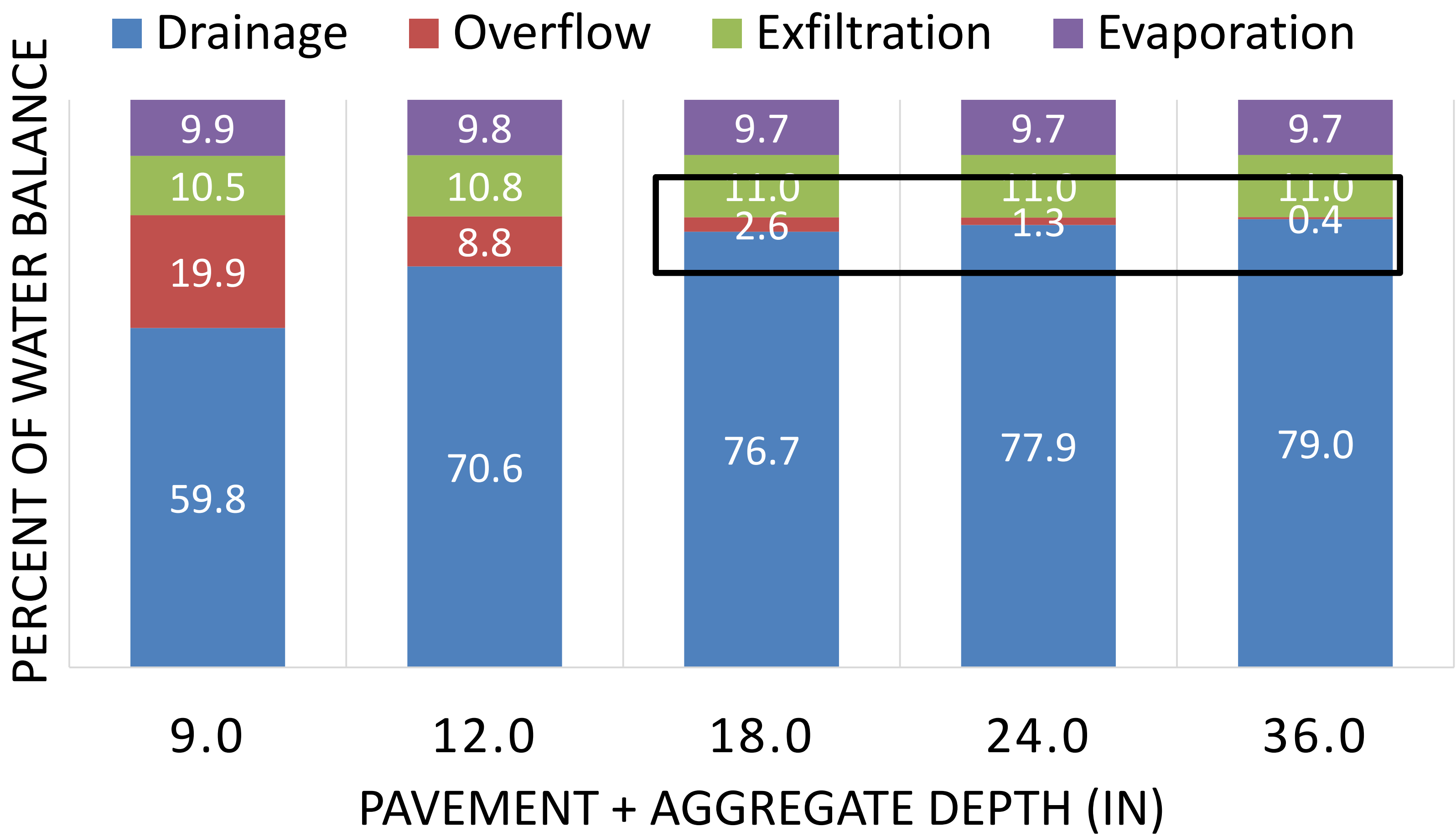


Sensitivity Analysis

- Pavement + aggregate depth
  - 9 in, 12 in, 18 in, 24 in, 36 in
- Internal Water Storage Zone
  - 0 in, 6 in, 12 in
- Contributing Drainage Area : PP Area
  - Existing, None, 1:1, 2:1, 3:1

Effect of Pavement + Aggregate Depth

- **No IWS, 0.02 in/hr infiltration rate**



For typical application, 18 to 24 inches sufficient

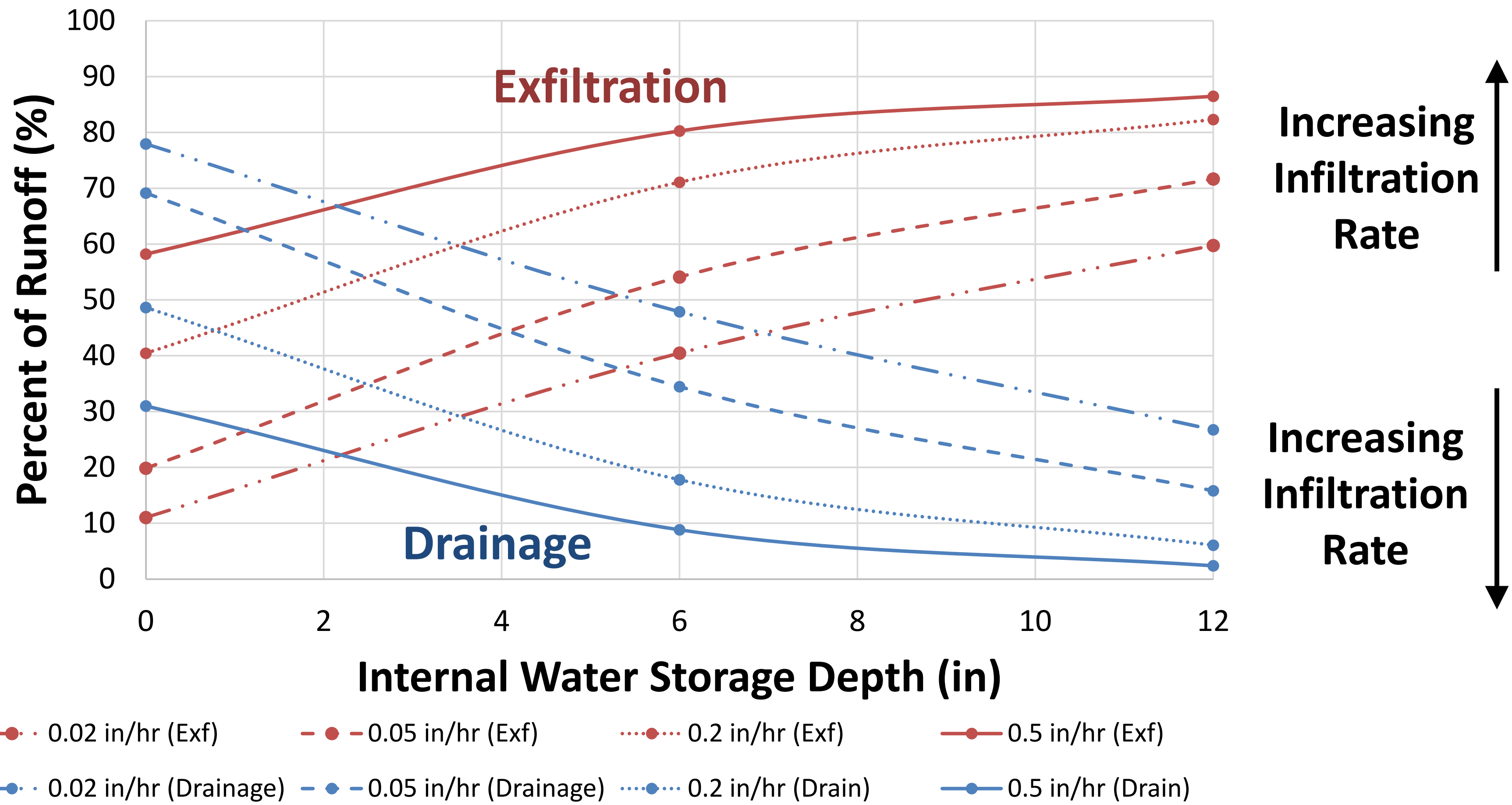
Bio&Ag ENGINEERING

Effect of Pavement + Aggregate Depth

- Most sensitive output: **Surface Runoff**
- Less pronounced as infiltration rate, IWS increases
- Pavement depth often dictated by structural needs
- **18 to 24 inches** adequate for meeting structural and hydrologic needs

Effect of Internal Water Storage

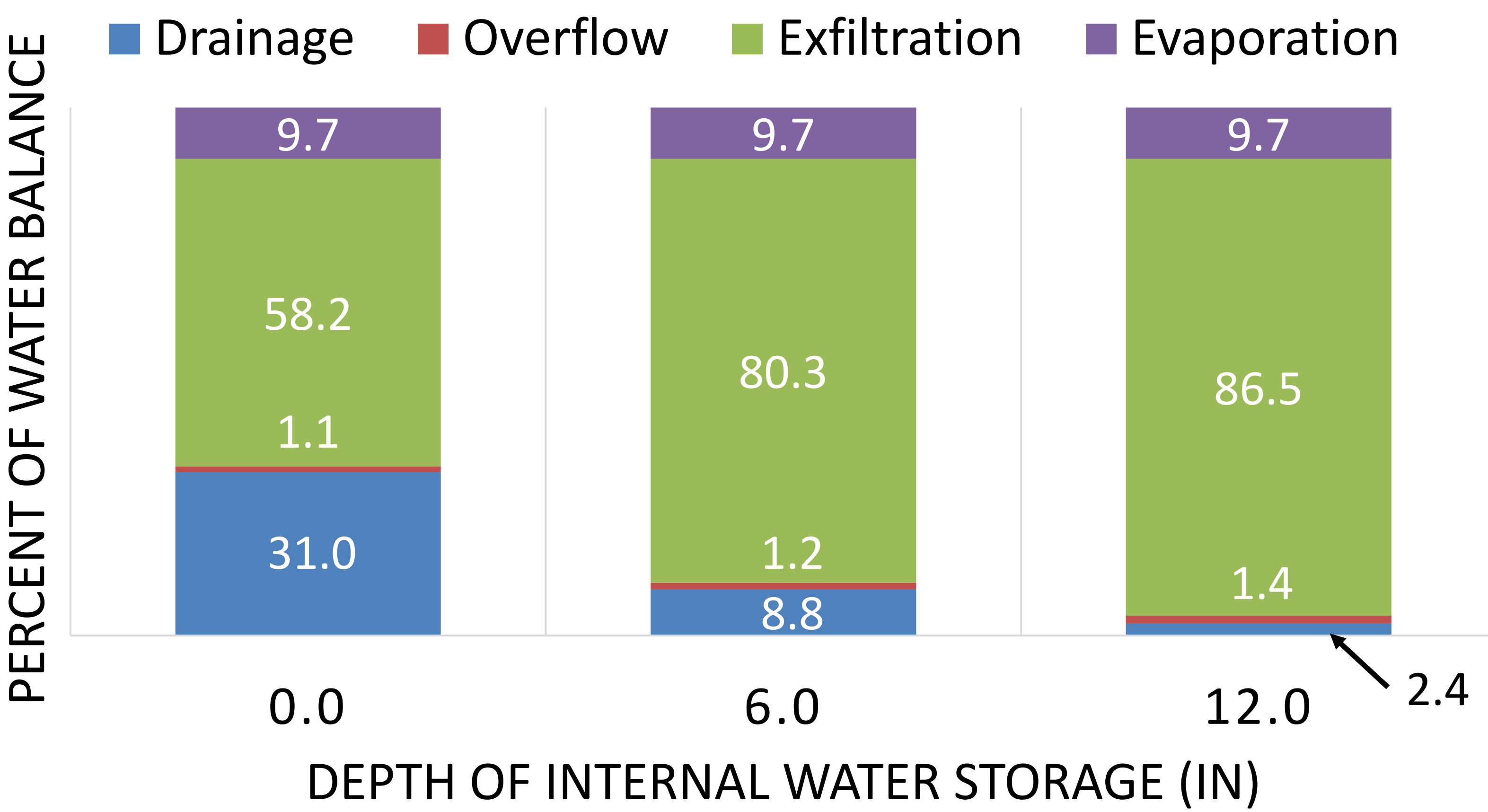
- **Perkins Township, 24" agg depth**



Inf. Rate ↑ Exfiltration ↑ Drainage ↓
Diminishing returns with increasing inf. rate

Effect of Internal Water Storage

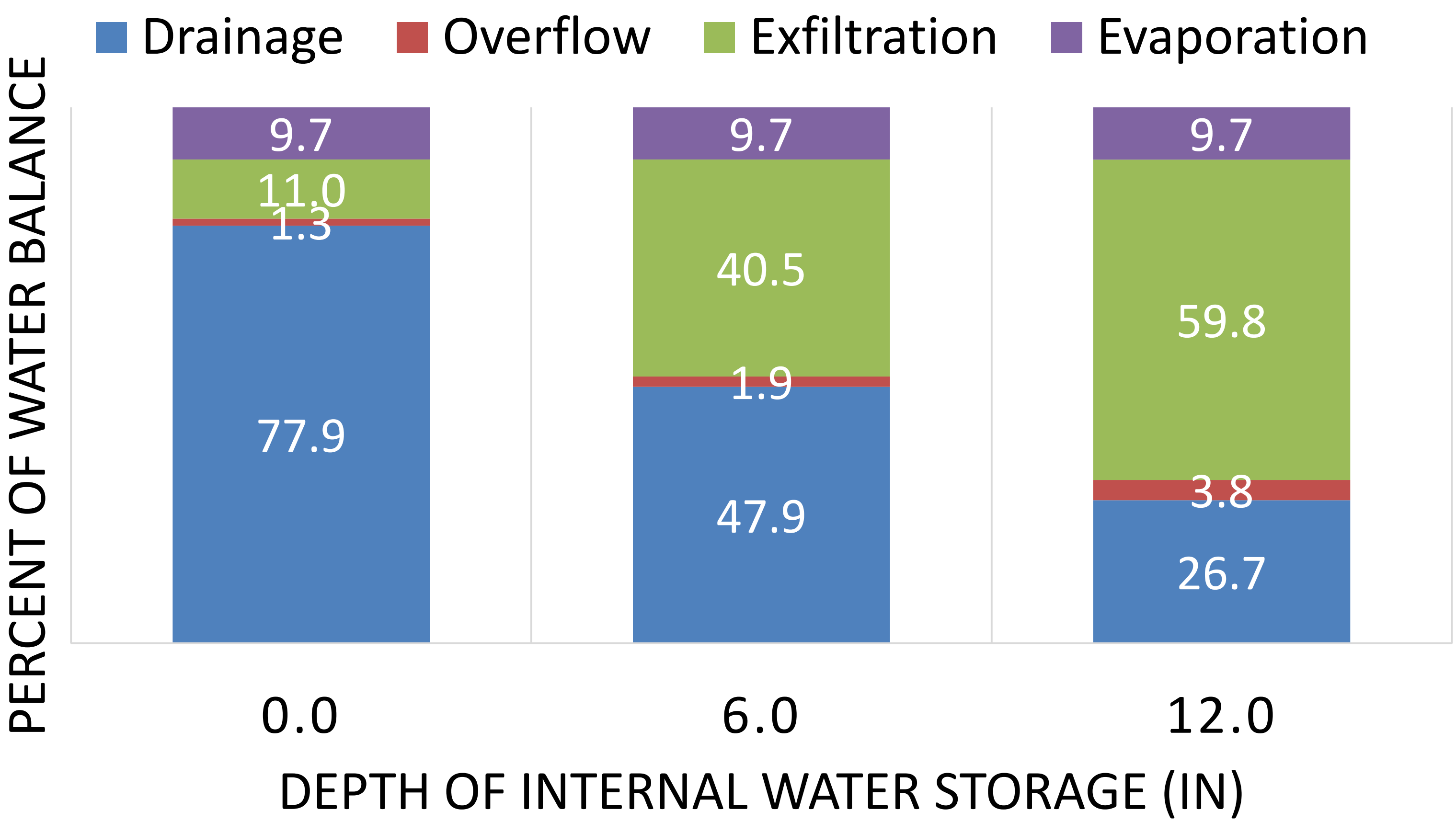
- **0.50 in/hr infiltration rate**



Adding 6 inches of IWS increases volume reduction by 20%

Effect of Internal Water Storage

- **0.02 in/hr infiltration rate**



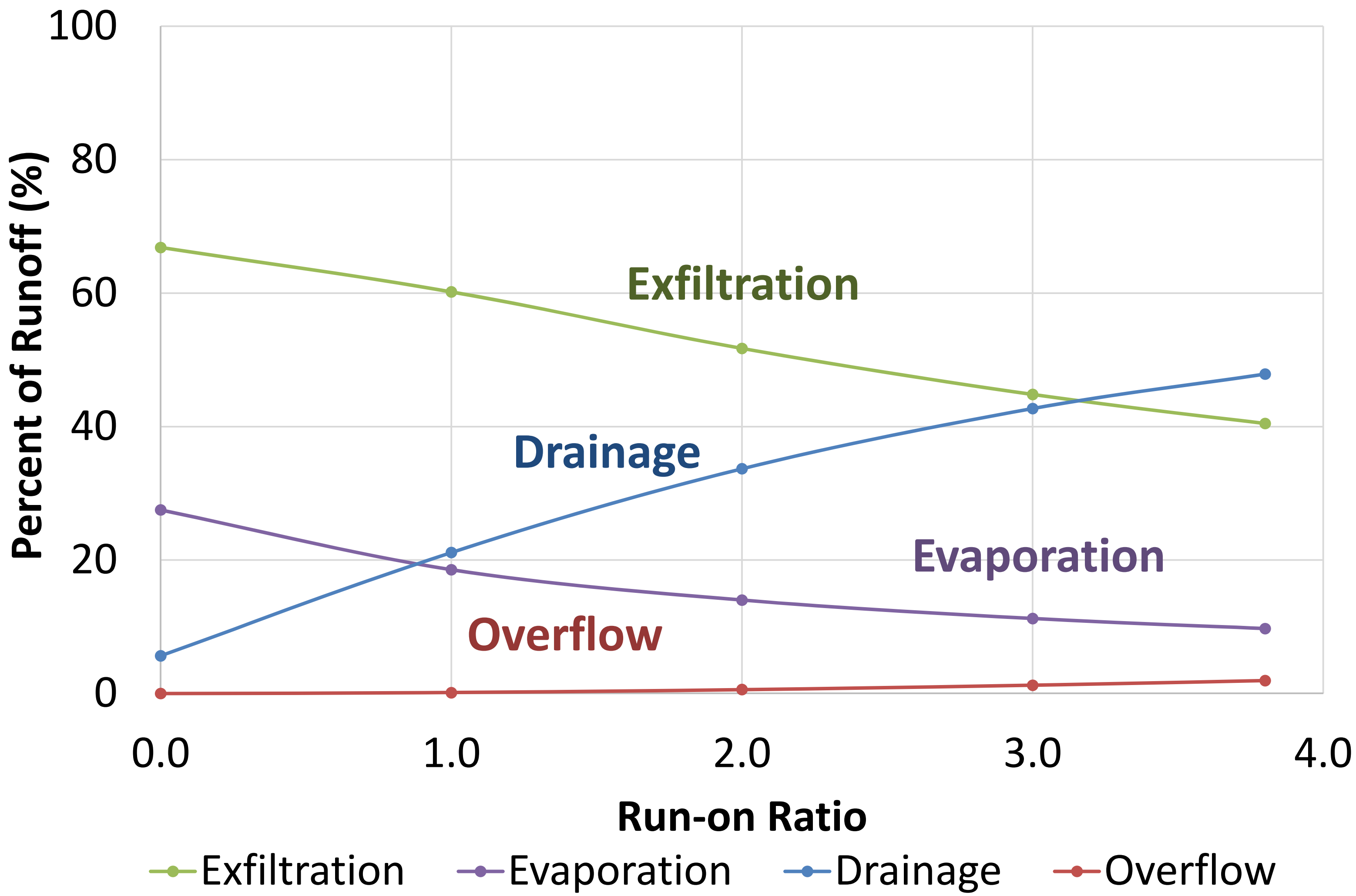
12 inches of IWS required to mimic volume reduction from 0.50 in/hr without IWS

Effect of Internal Water Storage

- Most sensitive output: **Drainage and Exfiltration**
- Little effect on overflow and evaporation
- Marginal returns as infiltration rate increases
- **12 inches** of IWS maximizes exfiltration/evaporation, minimizes outflow (drainage + overflow)
- Greatest impact from increasing IWS observed for lowest infiltration rates (0.02 in/hr, 0.05 in/hr)

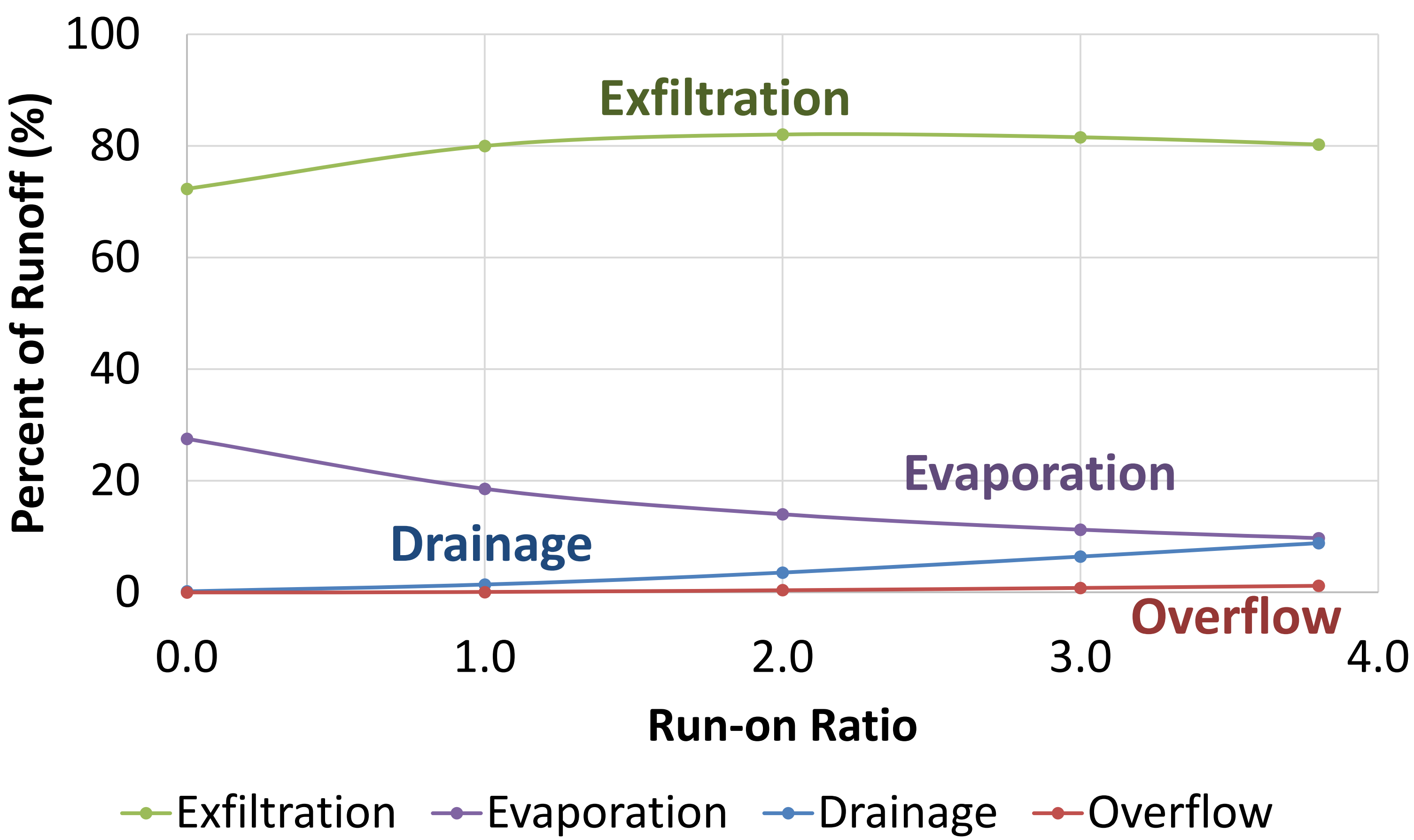
Effect of Contributing Area

- **6” IWS zone, 24” agg. depth, and 0.02 in/hr**



Effect of Contributing Area

- 6" IWS zone, 24" agg depth, and 0.50 in/hr



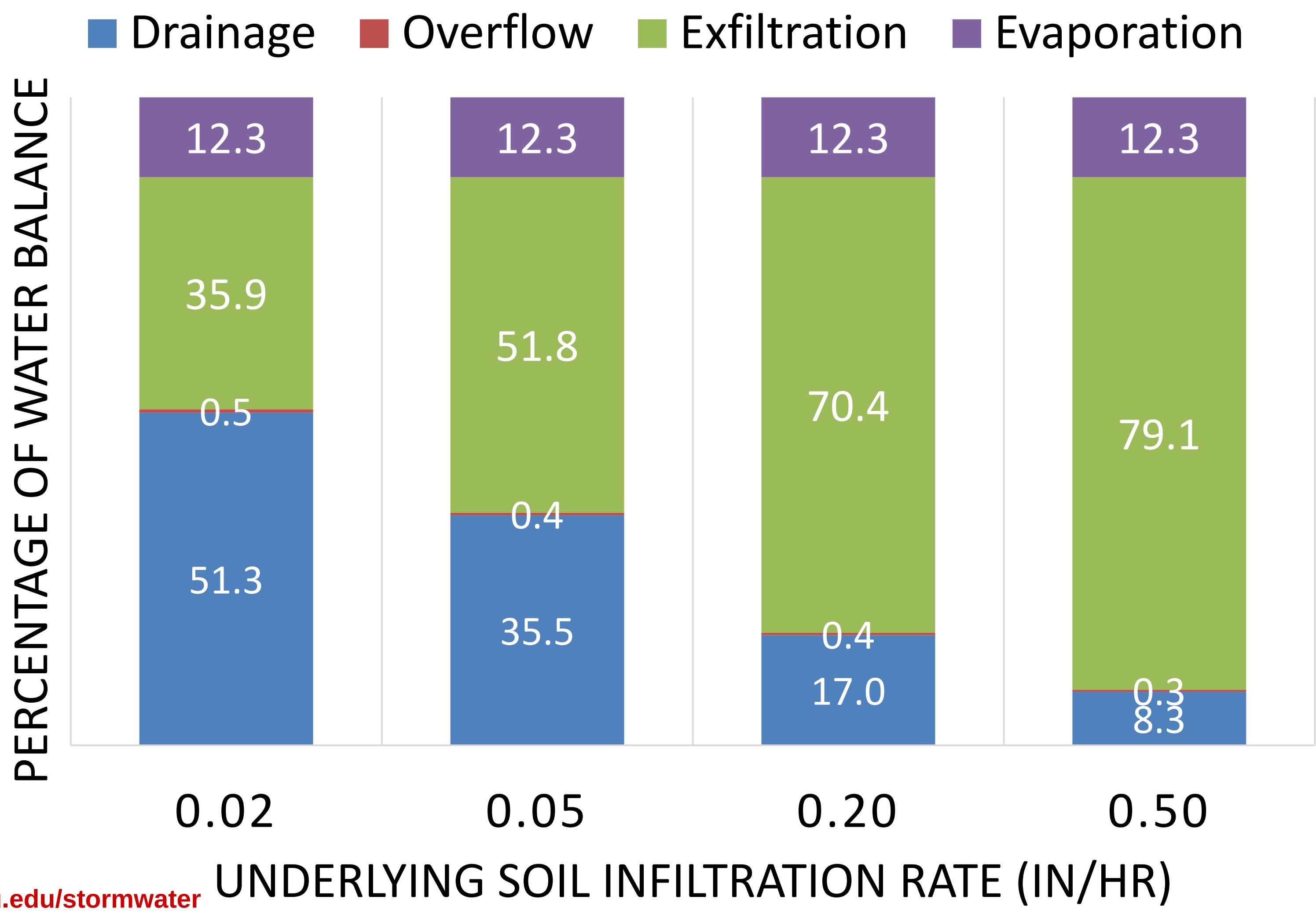
Increasing CA has less effect on high inf. rate soils …but increases susceptibility to clogging

Effect of Contributing Area

- Most sensitive outputs: **Drainage, Exfiltration, Evaporation**
  - Surface runoff not very sensitive (and in general, very low)
- While the percentage of water balance changes…
  - For same permeable pavement footprint, evaporation *volumes* are appx. same regardless of CA
- Balance between maximizing performance and cost-effectively treating watershed area
  - As CA increases, clogging susceptibility increases, increased need for maintenance

Typical Application in Ohio with IWS

- **2:1 run-on ratio, 24" agg depth, 6" IWS zone, 100% impervious watershed**



DRAINMOD Permeable Pavement Modeling: Lessons Learned

- Underlying soil conductivity and presence of IWS two biggest factors on long-term water balance
- Sensitivity of Model:
  - Drainage: Underlying soil $K_{sat,}$ IWS
  - Exfiltration: Underlying soil $K_{sat,}$ IWS
  - Evaporation: Contributing Area
  - Surface Runoff: Pavement + Aggregate Depth
- Future Work: expand sensitivity analysis, future climate modeling

Table Discussion

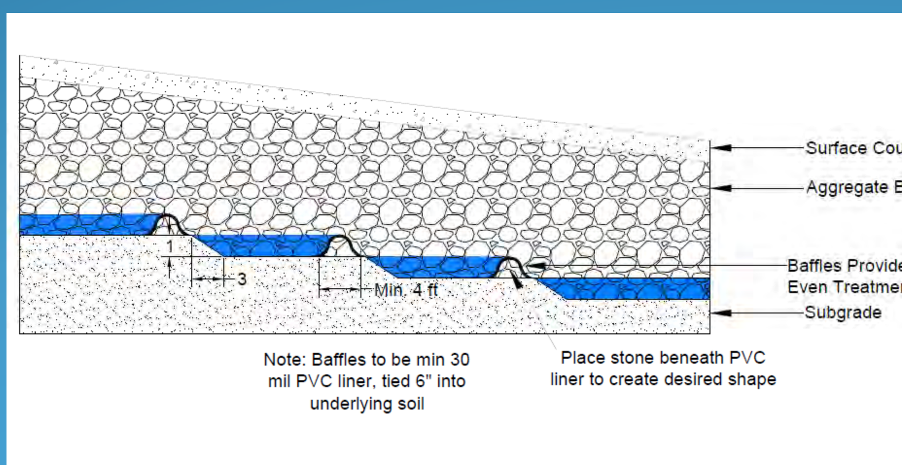
- What are your thoughts on the implications for your work and what this means to you?
- What else you wish you knew?

Permeable Pavement Design, Construction, & Maintenance Tips

Ryan Winston

Design

- Level subgrade maximizes exfiltration through even ponding
  - Terraced designs w/ check dams to address slope
- Include ample underdrain cleanouts
- Specify appropriate materials
  - Permeable pavement - washed angular limestone for base



Design is just the first step

Construction oversight with knowledgeable staff is critical

- Proactive communication needed through plan set and bid package development, pre-bid meeting, contractor selection, pre-construction meeting, construction

Infiltration Tests

- Infiltration tests provide estimate of most important design factor – water movement into underlying soil

Measured Kfs (in/hr)
PP1 (small): 0.01, 0.05
PP2 (large): 0, 0.01, 0.03, 0.06

Pre-Construction

- Educate site owners, designers, inspectors, contractors, and others about purpose and function of LID SCMs
- Use specific language to describe LID SCMs when advertising projects
- Provide supporting information for potential bidders
- Hire certified and/or experienced installers and contractors
- Ensure site inspectors are experienced and knowledgeable about LID SCMs

Pre-Construction Meeting

- Review plans with designers, owners, contractors and inspectors
  - Construction sequencing and practices
    - Protect underdrains before and during construction
    - Erosion control and site stabilization to prevent clogging.
    - Avoid subgrade compaction and scarify underlying soils
  - Material specifications
  - Site stabilization to prevent clogging
  - Monitoring well installation (if applies)
  - Design engineer verification of critical installation points

Construction

- **PICP**
  - Curved paver designs more expensive to install
  - Can be constructed late in season if ground not frozen
  - Mechanical installation significantly reduces costs
- **Pervious concrete**
  - Protect with plastic sheeting during curing
  - Wetting subgrade may improve appearance and reduce raveling

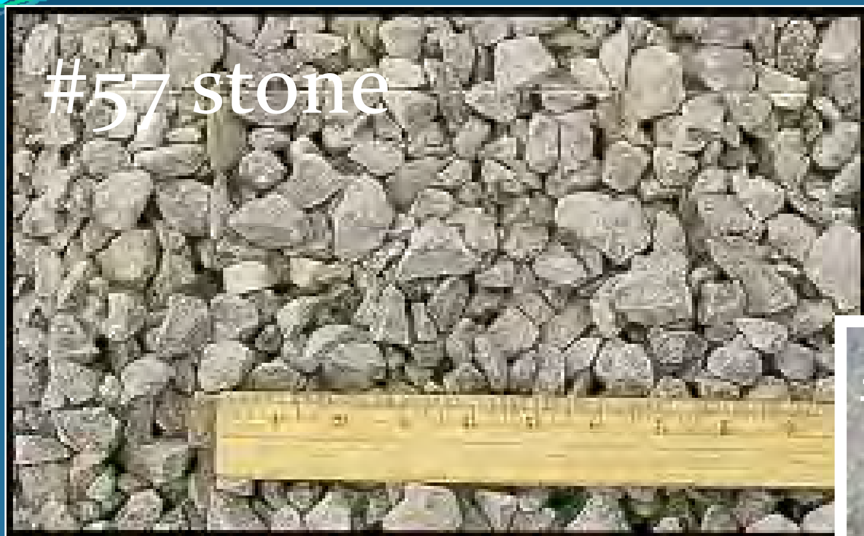
Permeable Pavement Installation

- These systems should be installed by a qualified professional
  - The only exception is very small backyard patios where BMP failure will not be hazardous to human health
  - A list of professionals qualified in permeable paver installation is available through the Interlocking Concrete Pavement Institute (ICPI) – www.icpi.org
  - List of certified pervious concrete installers provided by the National Ready Mix Concrete Association (NRMCA) – www.nrmca.org

Permeable Pavement Installation: Gravel Base

- After soil has been excavated to the correct slope and is smooth, gravel can be added

ase



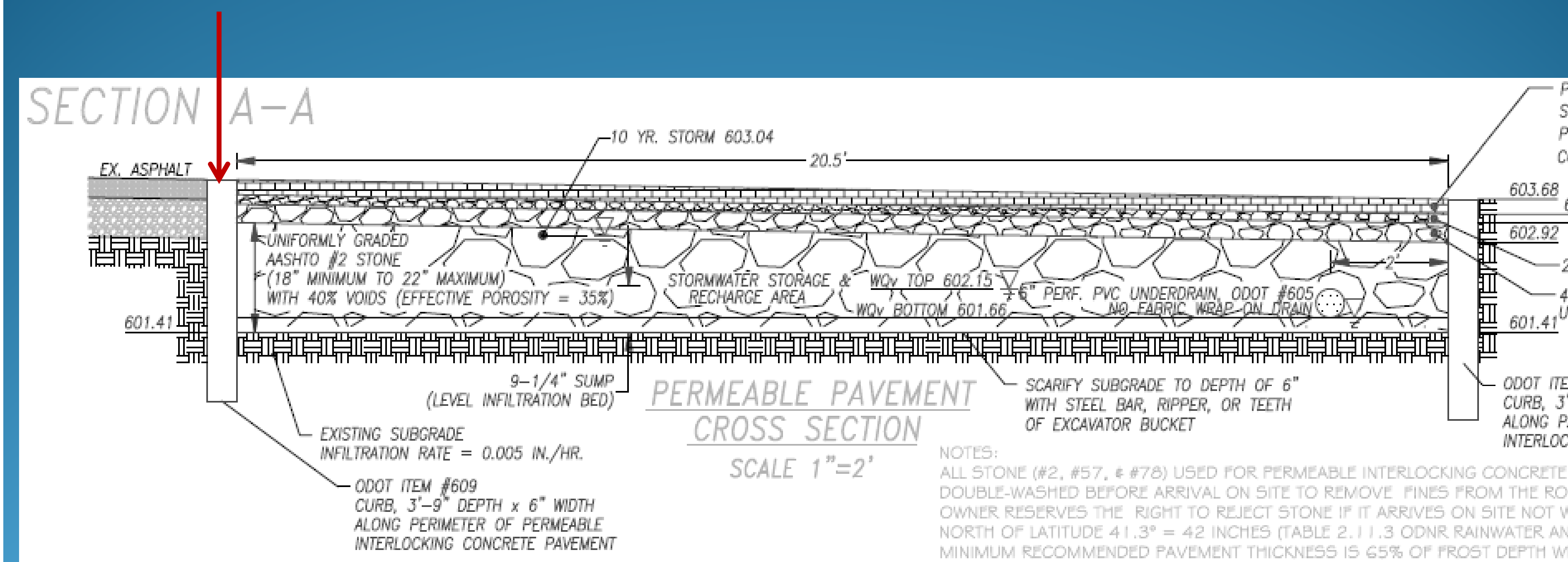
Permeable Pavement Installation: Gravel Base

- The gravel should be compacted with at least a 10 ton roller until there is no visible movement in the gravel base (or equivalent as determined by contractor)

(Adapted from Smith, 2000 – ICPI, reference in manual)

Curbing

- Curb to separate existing asphalt from PICP
- Be careful with slope of flush curb!



What if I Skip the Curbing?

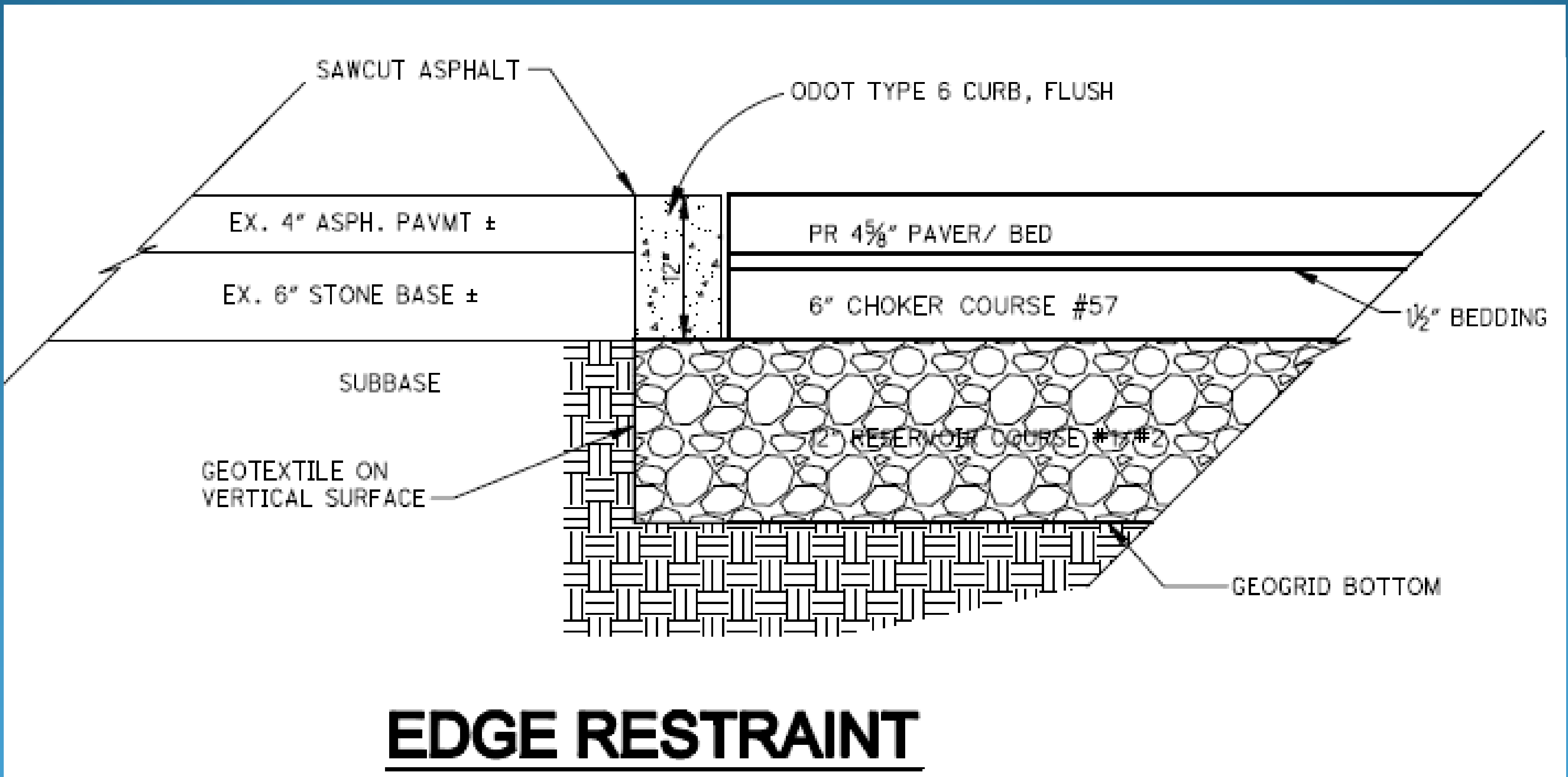
A Potential Monitoring Site

- 4300 ft^2 surface area of permeable pavement
- 7400 ft^2 asphalt drainage
- 1.75:1 run-on ratio

Flush Curbing Critical

Reduce Curb Depth?

- Willoughby Hills plan sheets:



Curbing: Curves vs. Right Angles

Subgrade Soil Infiltration Rate: Why Do We Care?

- Compaction significantly reduces infiltration (clay & sand) (Pitt et al., 2008)
- Earth moving equipment compacts soil, decreases subsoil permeability (Gregory et al., 2006)
- Natural infiltration affected by removal of surface soils and exposure of subsurface soils
- Rain on exposed subsoil shown to cause surface sealing (Gimenez et al., 1992).

How Does Compaction Affect Infiltration?

- Pitt et al., 2009:
  - **In sandy soils**, compaction can decrease infiltration rate by one order of magnitude
  - **In clay soils**, compaction can decrease infiltration rate by factor of 50
- Must minimize subgrade compaction to promote exfiltration

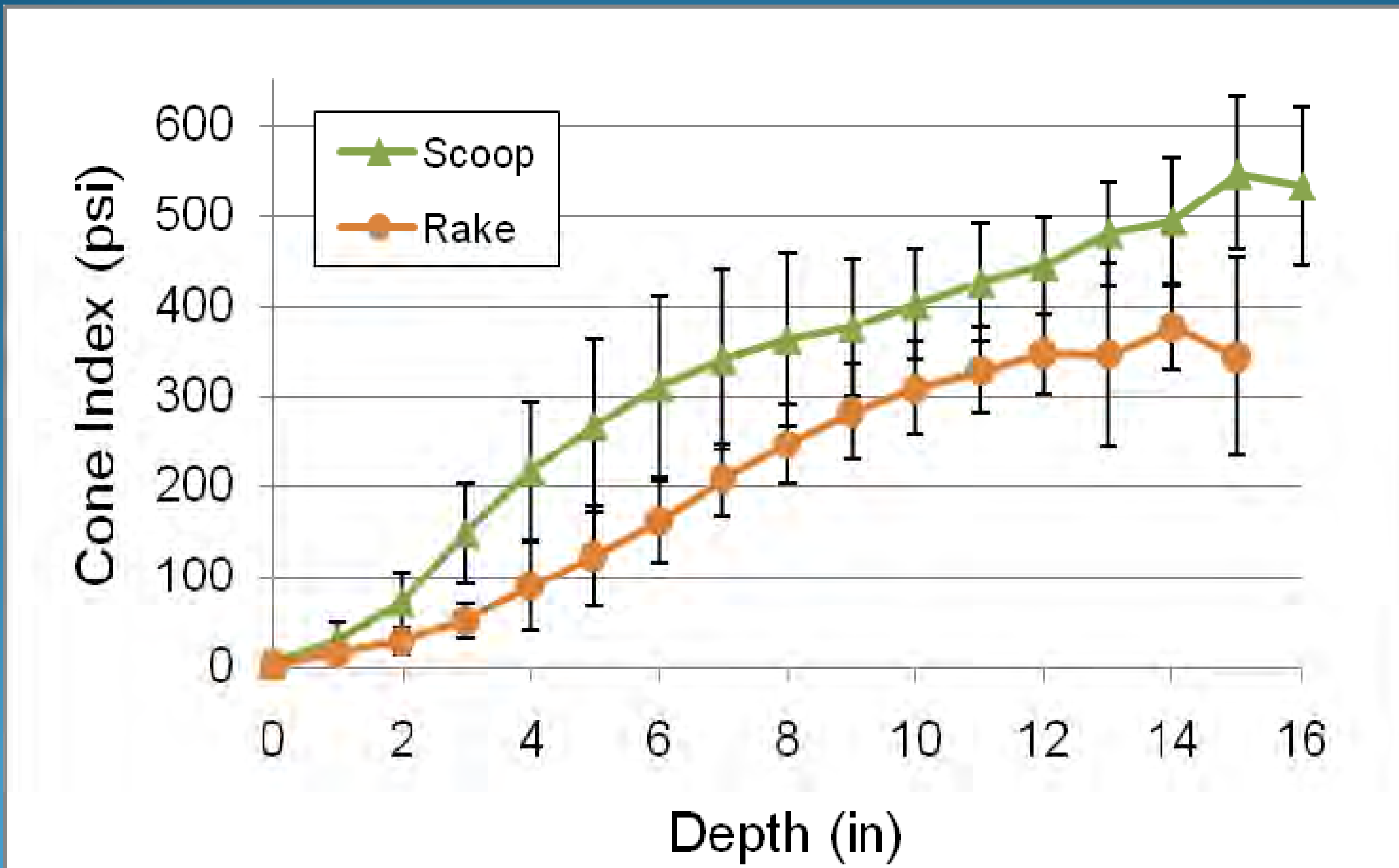
“Ripping” the Subsoil
Tyner et al. (2009)

Side Note: Trenching the Subsoil

Does Excavation Technique Really Matter?

- Brown & Hunt, 2010:
  - Tested infiltration and hydraulic conductivity of "scooped" vs. "raked" subgrades
  - Raking decreased bulk density, significantly improved exfiltration
- Rake when dry for best performance, especially in silt/clay soils

Nashville (Sand) “Wet” Cell

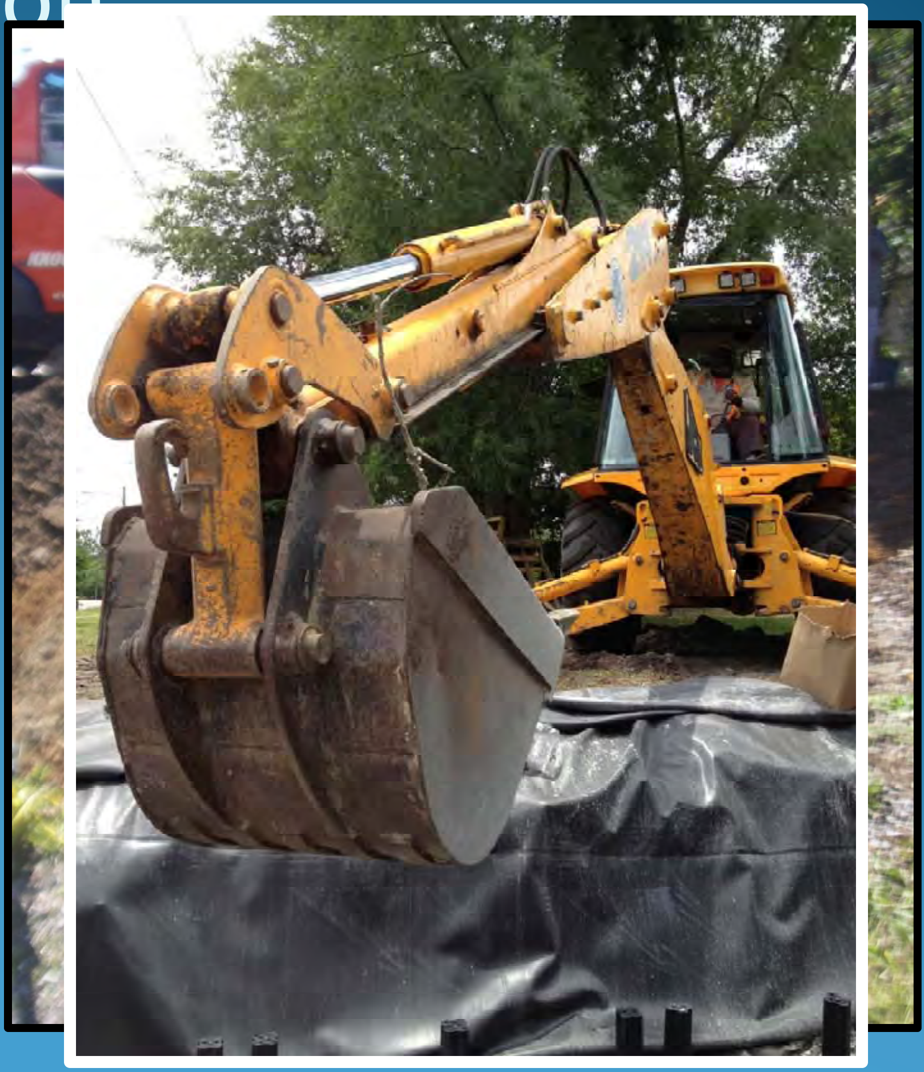


Average Infiltration Clay Site

Soil Type	Moist. Cond.	Excav. Tech.	Ave. Infil. (in/hr)	Std Dev (in/hr)
Clay	Wet	Rake	0.47	0.11
Clay	Wet	Scoop	0.09	0.02
Clay	Dry	Scoop	0.17	0.20
Typical Clay			*0.20*	--

Minimizing Compaction

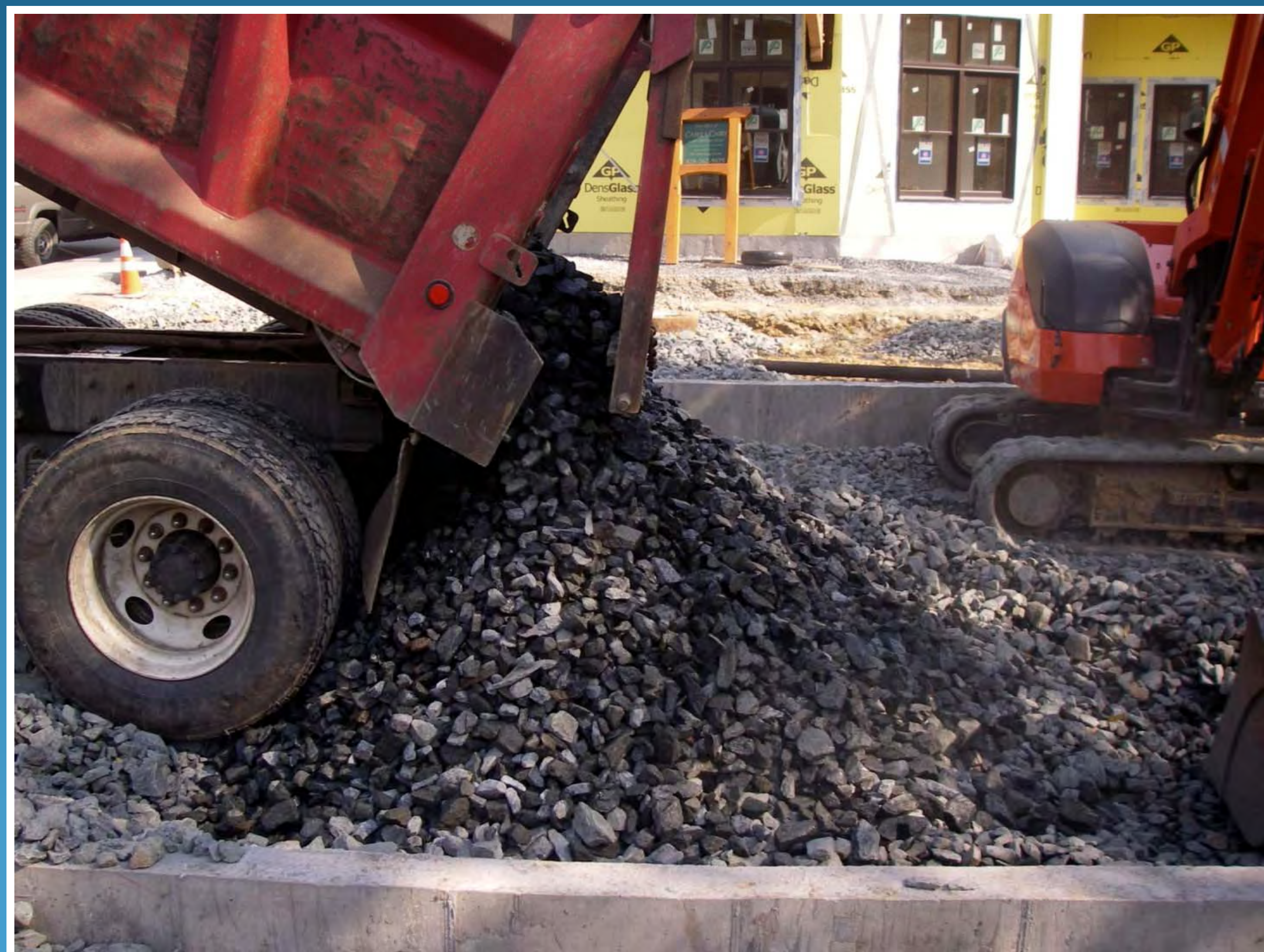
- Excavate in dry conditions as often as practicable
- “Back out” equipment
- Use tracked vehicles
- Excavate final 9-12” with teeth of bucket (**DO NOT SMEAR**)




Upturned underdrain

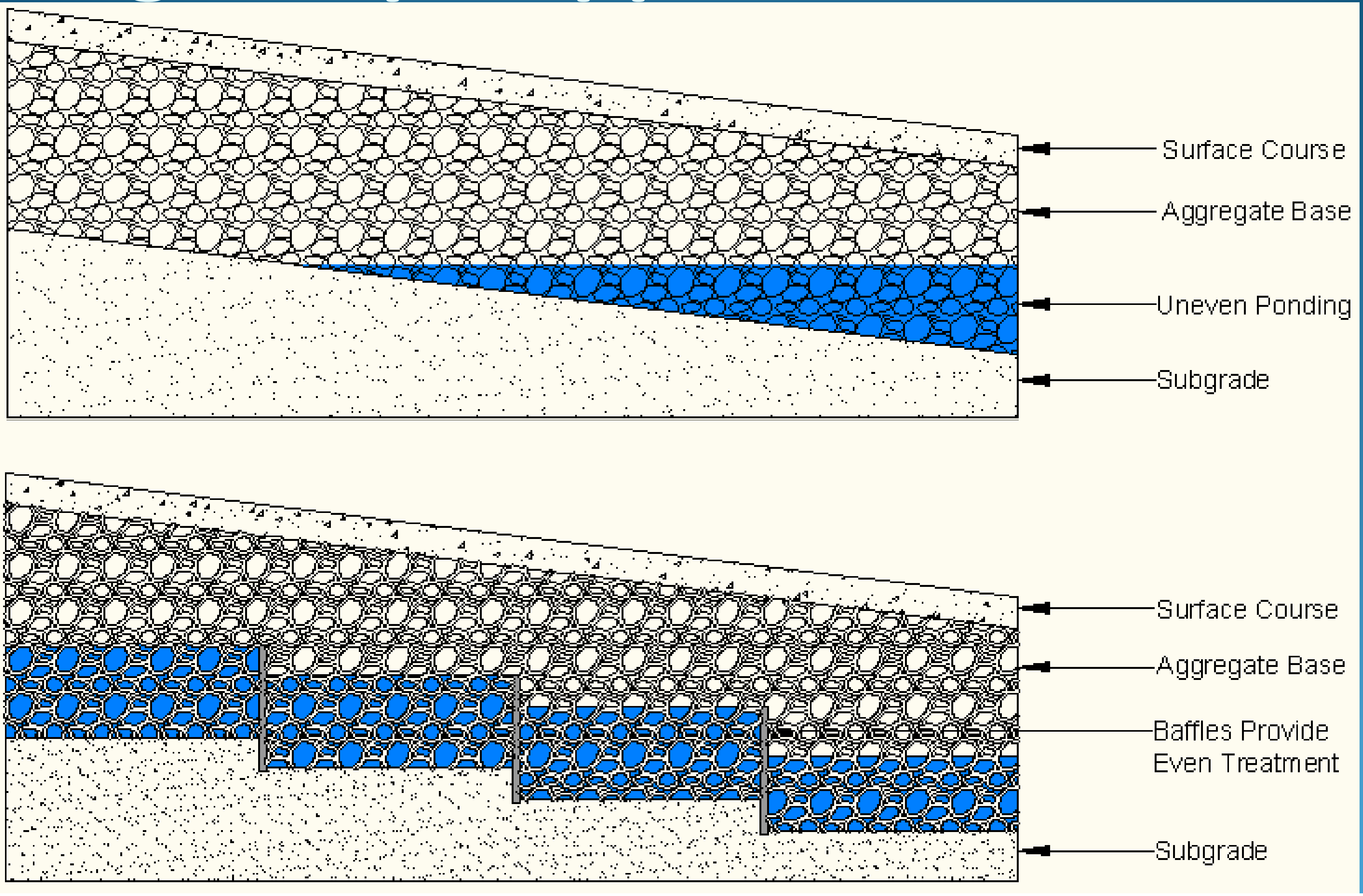
Backfill with (Washed) Gravel

Bringing in Washed #2 Stone



Header Course Saves Time

High Slope Applications



Baffle Material

- Can be constructed of:
  - Concrete curbs (similar to footer walls)
  - Soil (preferably in situ soil) covered in impermeable geomembrane
  - Rock/soil mixture covered in impermeable geomembrane
  - Bags of concrete covered in impermeable geomembrane

Maintaining Permeable Pavement

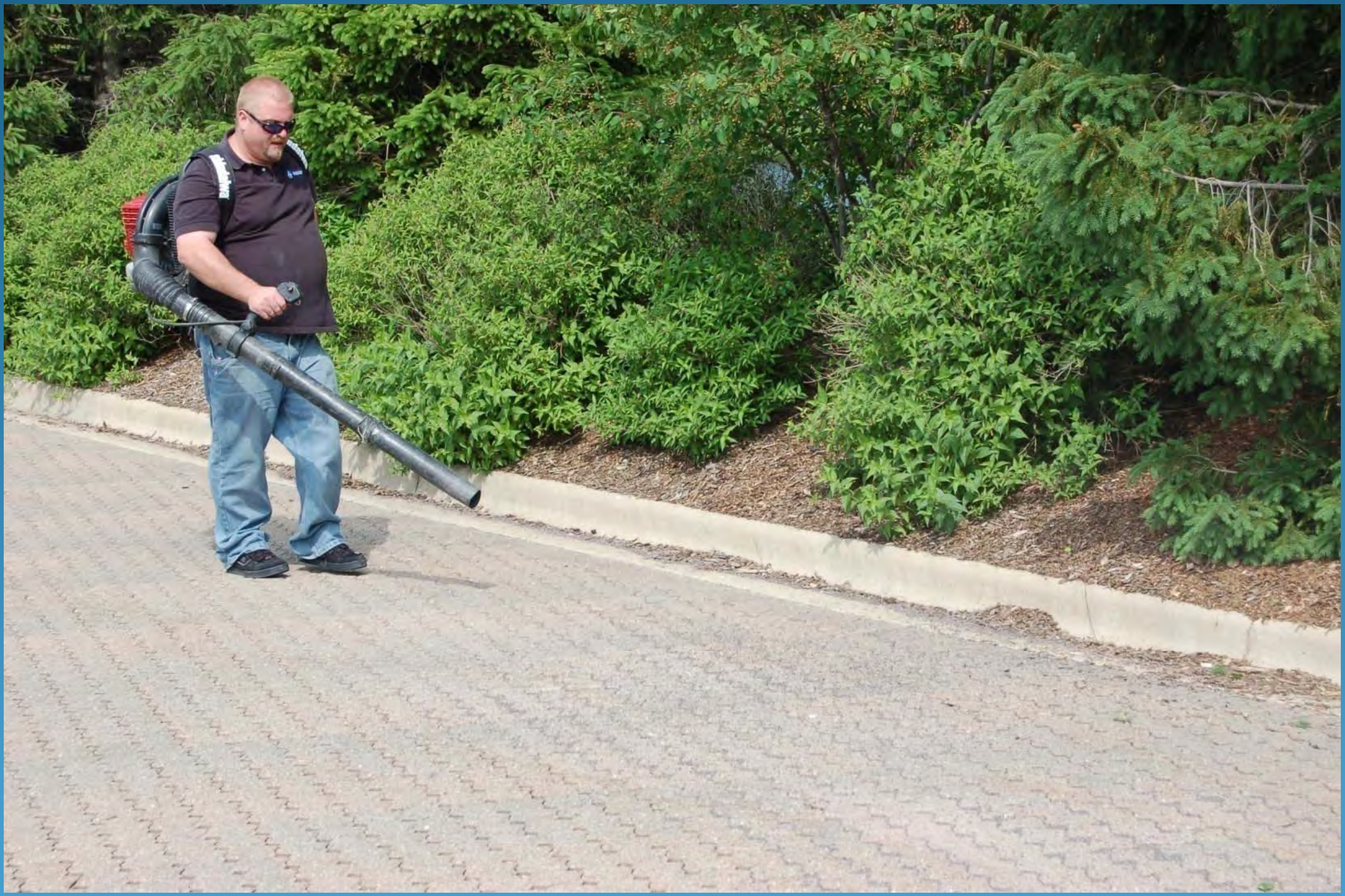
Clogging of Pore Spaces Occurs over Time

Permeable Pavement Problems: Sediment

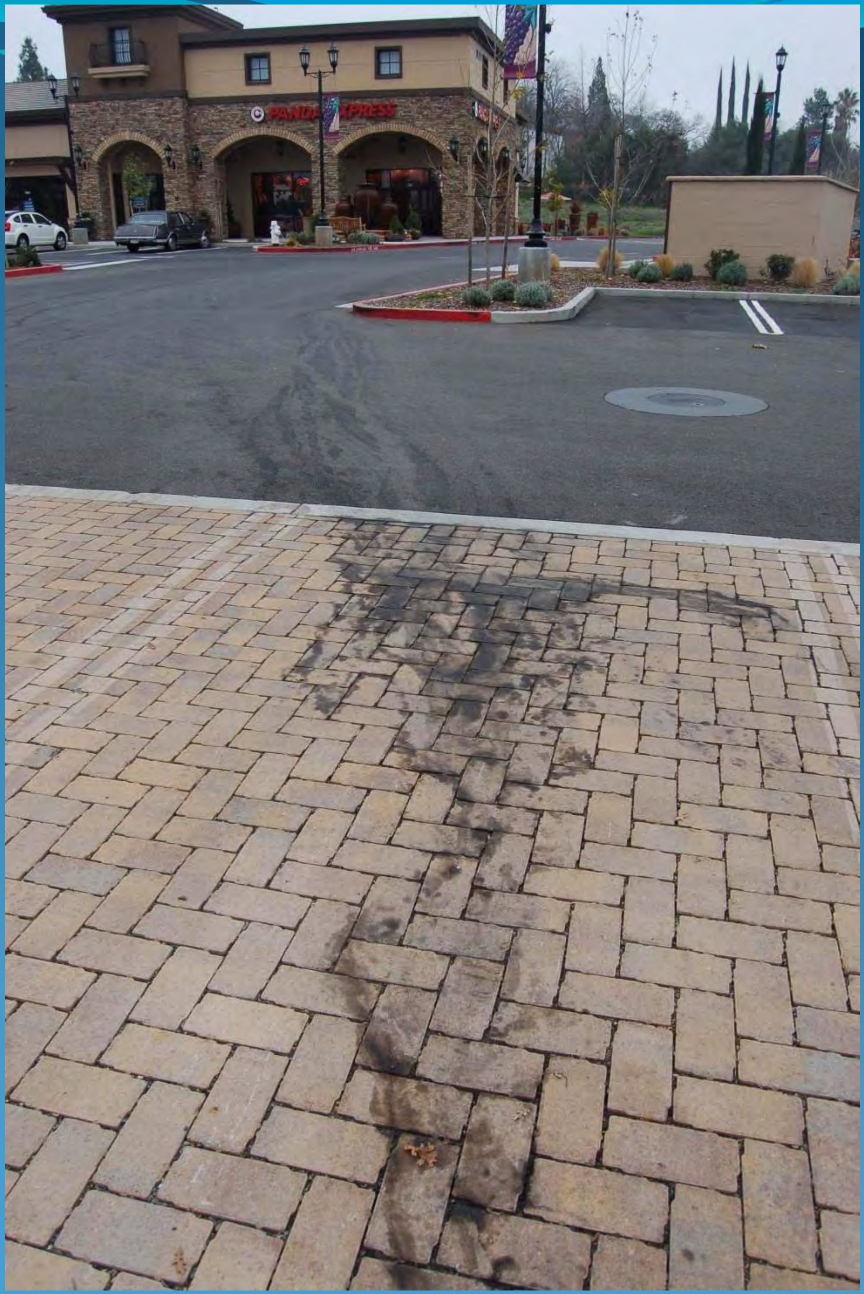
Unstable Catchment

Permeable Pavement Problems: Ground-in leaves and acorns

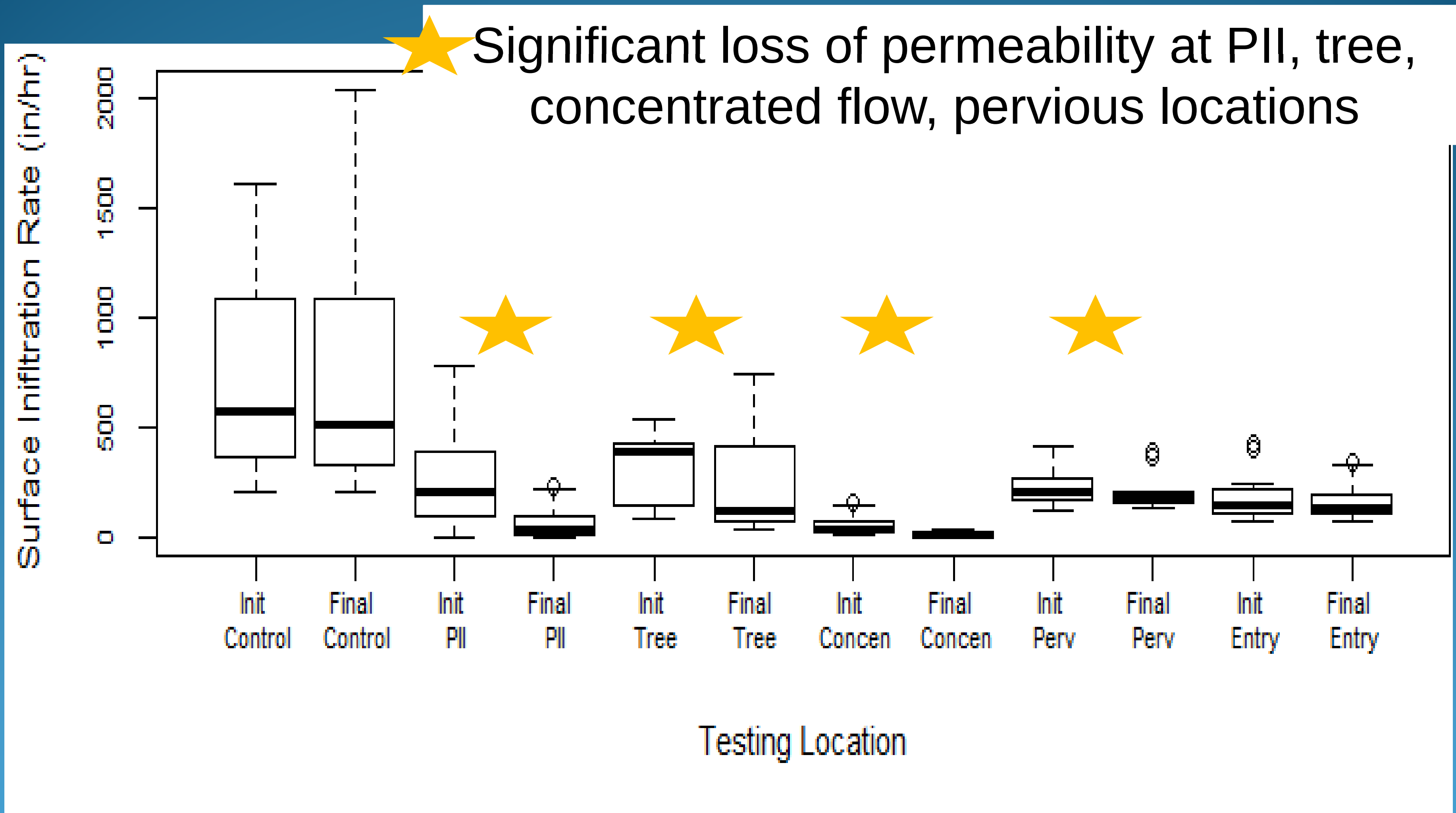
Clean the Catchment: Blowing



Some of your Permeable Pavement will (nearly invariably) Clog



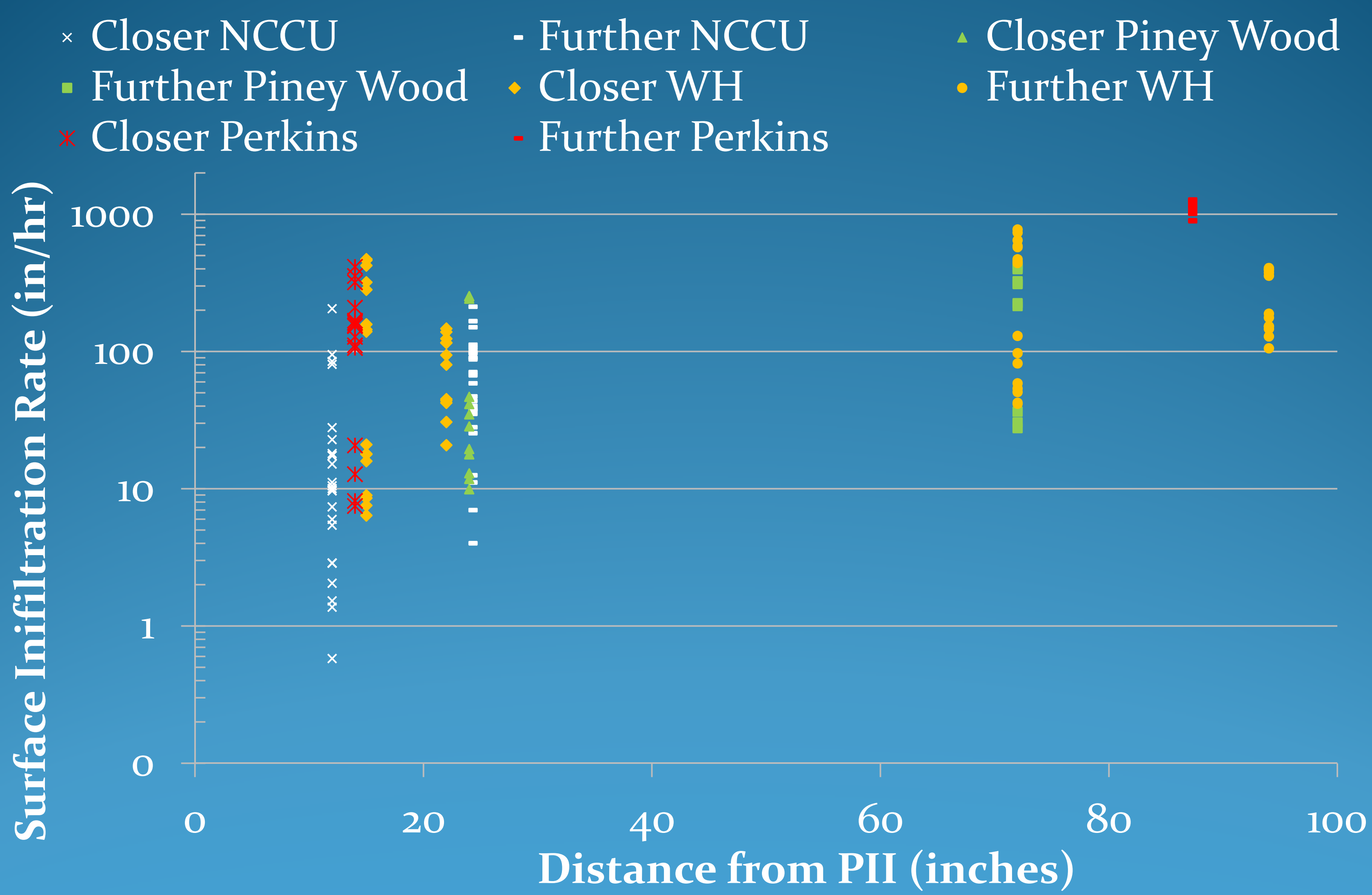
Where does Clogging Occur and Must I Focus Maintenance?



Defining the Permeable/Impermeable Interface (PII)

Clogging at PII

Distance from PII a Factor in Clogging?



Maintenance Methods

- Typically use street sweeper to break up surface clogging layer (*schmutzdecke*)

- Mechanical sweeper only good for minor surface clogging (upper 0.25-0.5”)

Maintenance Methods

- Regenerative air sweeper good for preventative maintenance of areas that don't clog heavily
- Areas prone to heavy clogging (PII) need vacuum truck
  - Additional suction

Gravel Loss: A problem?

Filling gaps with gravel

Introducing the “Simple Infiltration Test”

- Performed in under 5 minutes by individual
- Easily-furnished and cheap materials
- Shallow head conditions…
  - Better predict actual infiltration during rainfall
  - Reduce lateral seepage
- Simple!

Step 1: Construct the Device

- Materials:
  - One 8-foot piece of unwarped 2”x4” lumber
  - Screws and drill
  - 80 oz. plumber’s putty (approx.)
  - 5 gallon bucket of water
  - Stopwatch or timepiece
- Cut 2x4 into four sections and screw together into rectangular frame

Step 2: Apply Plumber's Putty and Place

- Apply 1" bead of putty to the frame (or inside)
- Place frame in area to be tested and apply gentle pressure to seal

Step 3: Rapidly Add 5 Gal. Water & Time

- Apply weight to frame to maintain seal
- Quickly pour contents of one 5-gal bucket and begin timing
- Record time for all standing water to infiltrate joints/voids

Step 4: Assess Performance & Prescribe Maintenance

Drawdown Time	Hydraulic Condition
< 30 seconds	Newly Installed / Recently Maintained
30-90 seconds	Acceptable – Continue Preventative Maintenance. Consider Regen Air S.S.?
90-300 seconds	Partially Clogged – Regen Air Street Sweeper NEEDED
> 300 seconds	Clogged – Vac Truck Time?

Table Discussion

- How does what you just heard fit with your experience in the past?
- How might it influence what you do in the future?
- What do you see as the biggest challenge that prevents people from using permeable pavement?

Crediting Runoff Reduction

Jay Dorsey & Heather Elmer

Why a Runoff Reduction Credit?

- Stormwater management systems based around green infrastructure (GI, also called LID) practices provide significant benefits over traditional stormwater systems (pipe/gutter-based drainage networks and end-of-pipe surface detention)
- There are several barriers to utilization of GI – unfamiliarity, real or perceived higher cost, regulatory hurdles, maintenance concerns, etc.
  - **One consistently communicated barrier is not receiving full credit for the hydrologic functions and services provided by GI**

Peak Discharge Crediting System

- Science-based
- Credits relatively simple to determine for designer and reviewer
- Implementation structure for minimizing failures and unintended consequences
- Costs in line with those for managing other infrastructure
- Program for shortening learning curve

Sources of Information

- CWP/CSN Tech Memo (through 2008)
- Research review (2008-present)
- NERRS Science Collaborative Project
  - Monitored practices (5 permeable pavement, 4 bioretention)
  - Calibrated models w/sensitivity analyses
  - Uncalibrated models
- Spreadsheets, WinSLAMM and other modeling tools

BMPs w/Volume Reduction Function

1. Green roof
2. Soil quality preservation/renovation
3. Impervious area disconnection
4. Grass filter strip
5. Grass swale
6. Wetland basin
7. Dry detention (w/infiltration) basin
8. Infiltration basin
9. Bioretention (including tree boxes)
10. Infiltration trench
11. Permeable pavement
12. Underground detention (w/infiltration)
13. Cistern/rainwater harvesting

Accounting Mechanism – Runoff Reduction Spreadsheet

Runoff Reduction Practice	Description of Area	Impervious Cover in Contributing Drainage Area (acres)	Graded Managed Turf in Contributing Drainage Area (acres)	Natural Profile Managed Turf in Contributing Drainage Area (acres)	Volume Received by Practice (cubic feet)	Description of Credit	% Credit	Storage Volume Provided by Practice (cubic feet)	Runoff Reduction (cubic feet)	Remaining Volume (cubic feet)
1. Vegetated Roof										
Vegetated Roof			N/A	N/A	0	Subtract 100% of the provided storage volume.	100%		0	0
2. Impermeable Surface Disconnection										
Simple Disconnection to A/B Soils or Amended Filter Path			N/A	N/A	0	Reduce volume conveyed to conservation area by 0.04 cu. ft per sq. ft. of conservation area.	N/A	N/A	0	0
Simple Disconnection to C/D Soils			N/A	N/A	0	Reduce volume conveyed to conservation area by 0.02 cu. ft per sq. ft. of conservation area.	N/A	N/A	0	0
To Residential Rain Garden					0	Subtract 100% of the provided storage volume.	100%		0	0
To Rainwater Harvesting			N/A	N/A	0	Subtract a variable % of the provided storage volume based on annual re-use.			0	0
To Stormwater Planter			N/A	N/A	0	Subtract 100% of the provided storage volume.	100%		0	0
3. Permeable Pavement										
Permeable Pavement			N/A	N/A	0	Subtract 100% of the provided storage volume.	100%		0	0
4. Grass Swale										
Grass Swale A/B Soils					0	Reduce volume conveyed through grass swale by 20%.	20%	N/A	0	0
Grass Swale C/D Soils					0	Reduce volume conveyed through grass swale by 10%.	10%	N/A	0	0
Grass Swale with Compost Amended Soils					0	Reduce volume conveyed through grass swale by 30%.	30%	N/A	0	0
5. Bioretention										
Bioretention					0	Subtract 100% of the provided storage volume.	100%		0	0
6. Infiltration										
Infiltration					0	Subtract 100% of the provided storage volume.	100%		0	0
7. Dry Extended Detention Basin										
Dry Extended Detention Basin					0	Reduce volume directed to dry extended detention basin by 10%.	10%	N/A	0	0
8. Sheetflow to Filter/Open Space										
Sheetflow to Conservation Area with A/B Soils					0	Reduce volume conveyed to conservation area by 0.09 cu. ft per sq. ft. of conservation area.	N/A	N/A	0	0
Sheetflow to Conservation Area with C/D Soils					0	Reduce volume conveyed to conservation area by 0.06 cu. ft per sq. ft. of conservation area.	N/A	N/A	0	0
Sheetflow to Vegetated Filter Strip in A/B Soils or Compost Amended C/D Soils					0	Reduce volume conveyed to conservation area by 0.06 cu. ft per sq. ft. of conservation area.	N/A	N/A	0	0

Critical Storm Method

- "Critical Storm" discharge cannot exceed the peak rate of runoff from the pre-development 1-yr, 24-hr event
- For less frequent (higher recurrence interval) events, $Q_{post} < Q_{pre}$
- Even if there is no increase in the 1-yr, 24-hr runoff volume, peak discharge rate must be released at pre-development rates ($Q_{post} < Q_{pre}$)

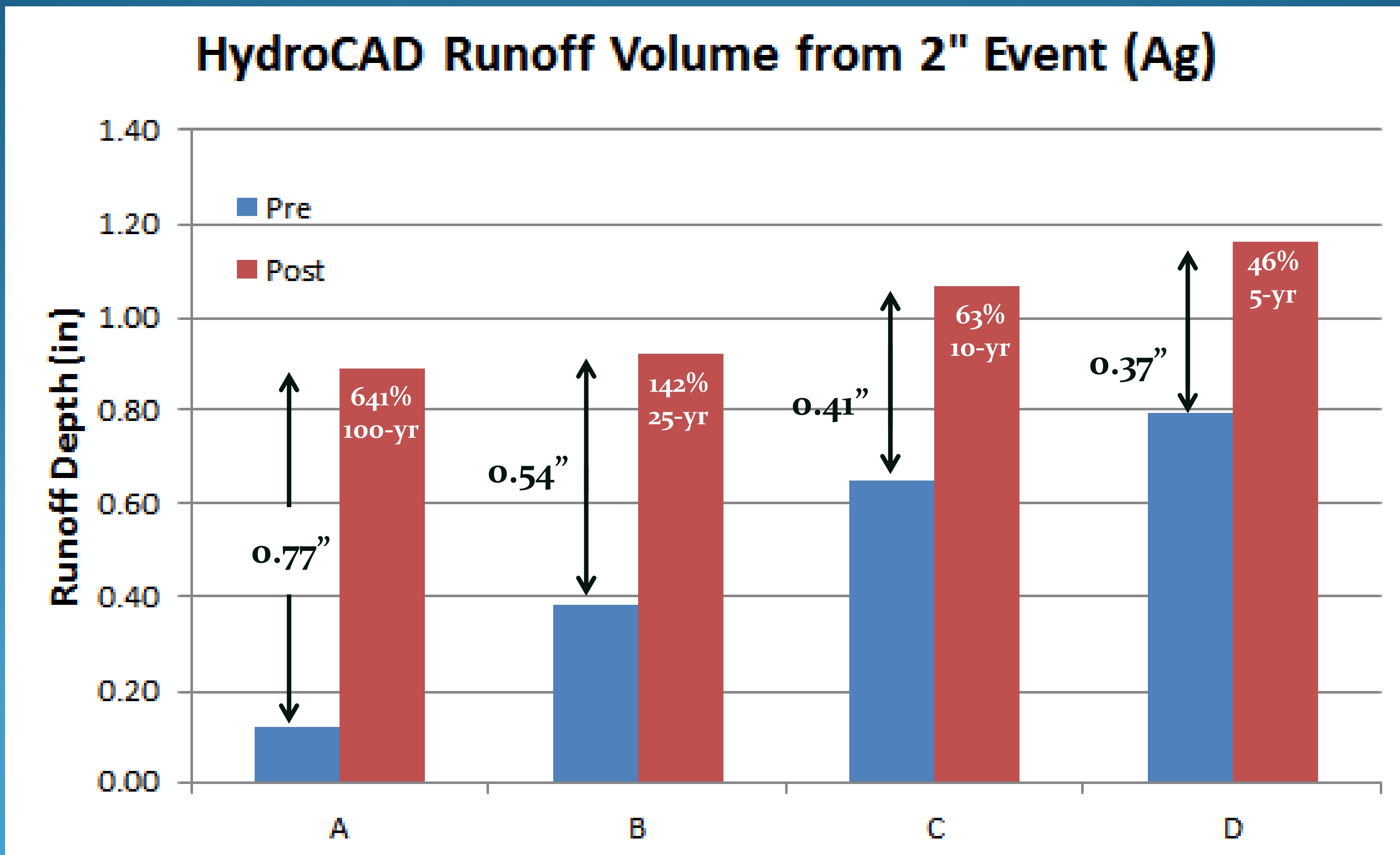
Critical Storm Method

If the % increase in runoff volume for the 1-year, 24-hour storm is:		The <u>Critical Storm</u> for peak rate control is:	P Depth (in)
Equal or greater than	… and less than		
-	10	1-year	1.9
10	20	2-year	2.3
20	50	5-year	2.9
50	100	10-year	3.4
100	250	25-year	4.6
250	500	50-year	5.2
500	-	100-year	5.8

Comparative Runoff Volumes

for 1-year, 24-hour rainfall event (2.0”)

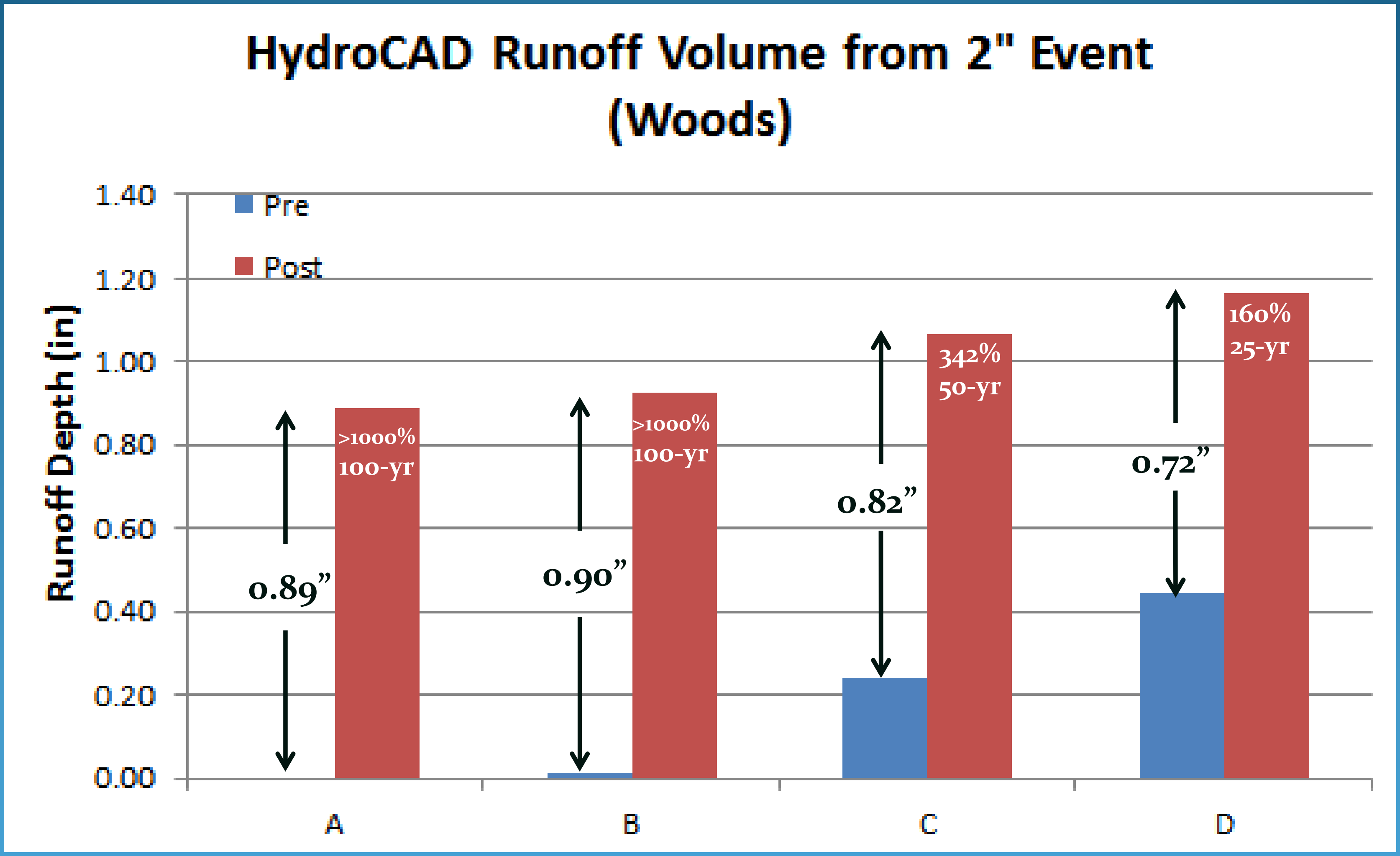
- site with 50% impervious, 50% open space -



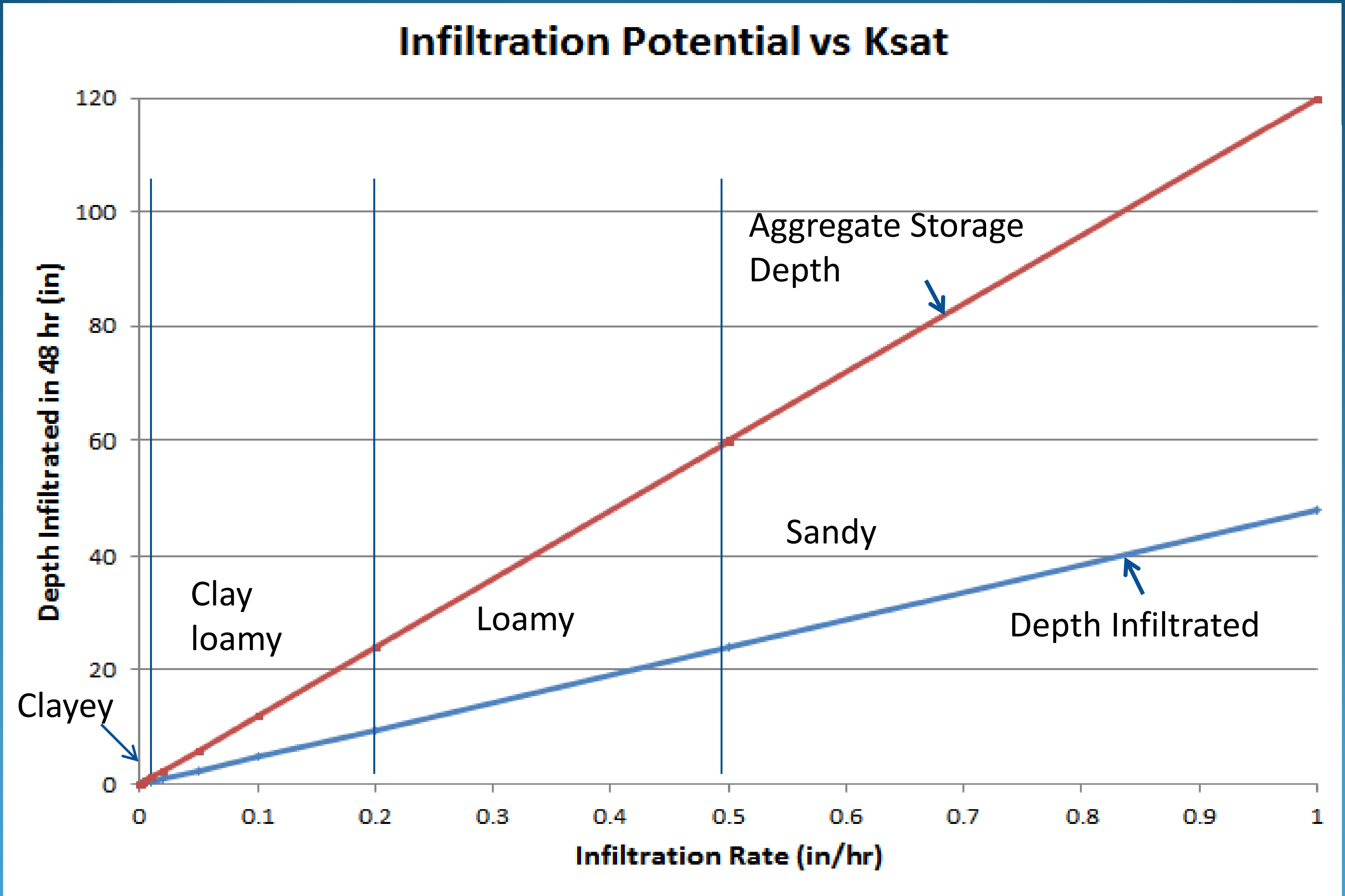
Comparative Runoff Volumes

for 1-year, 24-hour rainfall event (2.0”)

- site with 50% impervious, 50% open space -



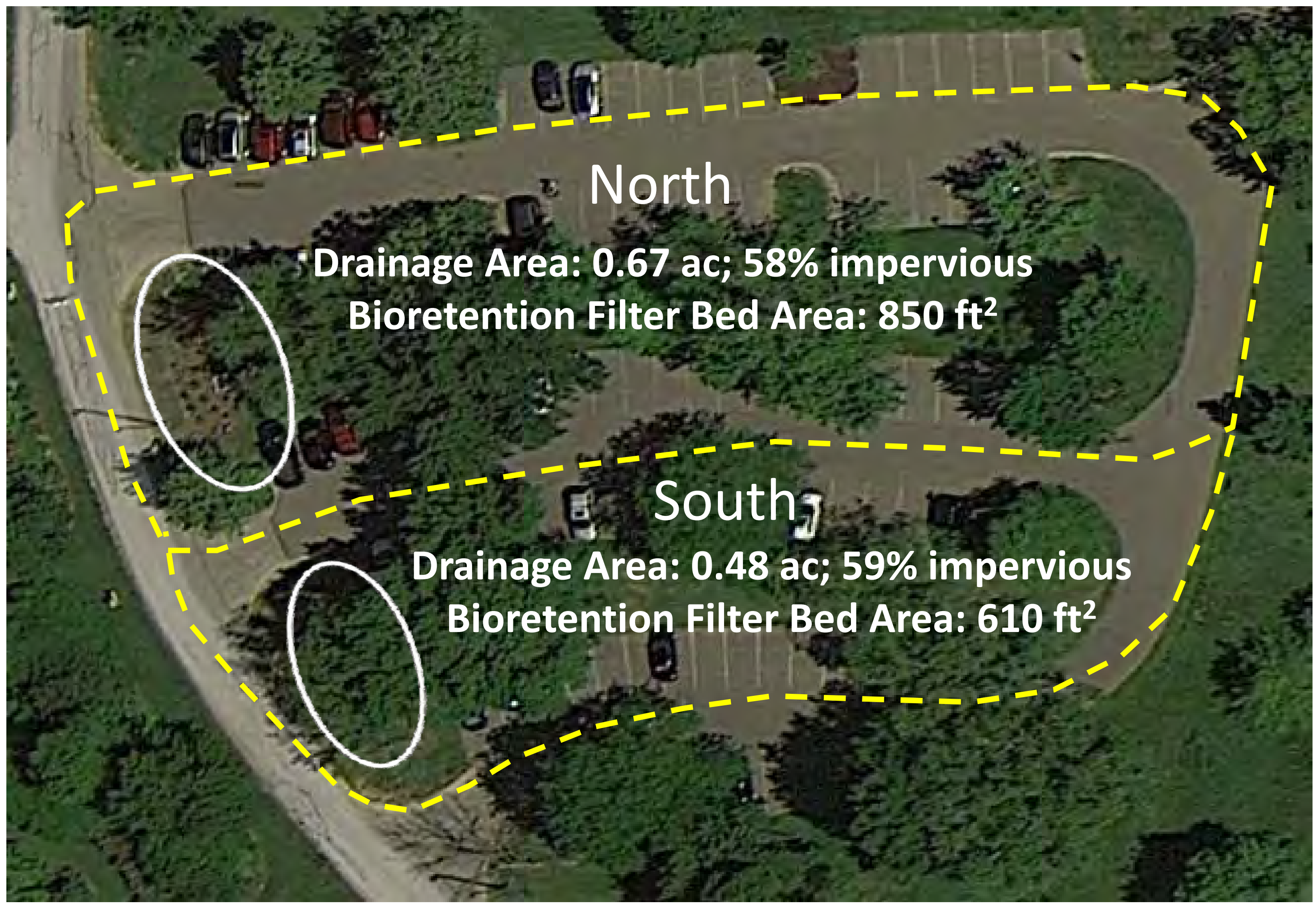
Volume Reduction Potential



Bioretention Runoff Reduction

- Bioretention provides water quality and quantity benefits well beyond those provided by detention basins
- Because of the relatively small footprint of bioretention, performance can be enhanced with:
  - Internal water storage (IWS) zones
    - 18”- 24” recommended for HSG-A, B, C soils
    - 3”- 18” recommended for HSG-D soils
  - Increasing surface ponding below overflow

Holden Arboretum CSM Example



Holden Arboretum CSM Example

- North Watershed
  - Watershed area = 0.67 ac
  - Impervious Area = 0.39 ac (58%)
  - P(1-yr, 24-hr) = 2.07”
  - HSG C soil
  - Q_{post} = 1.15”; Q_{pre} = 0.23”
  - % increase = [(1.15” – 0.23”)/(0.23”)]*100 = 400%
  - Critical Storm = 25-year

+ 0.92”

BRC Volume Retention Capacity

	A	B	C	D	E	F	G	H	I	J
5										
6	Step									
7	1	Drainage Area =	0.67	acres	29185.2	ft^2				
8										
9										
10	2	Imperviousness =	58	%						
11		Contributing Impervious Area =	0.3886	acres	16927.42	ft^2				
12		Volumetric Runoff Coefficient, Rv =	0.572							
13		Water Quality Volume =	1043	ft^3			Based on Rv = 0.05 + 0.9*Aimp			
14										
15		Minimum Filter Bed Area =	846.3708	ft^2						
16	3	Filter Bed Area =	850	ft^2						
17		FB Area/Impervious Area =	5.02	%			Must be at least 5%			
18	4	Length to Width Ratio (L:W)	5	ft/ft			Recommend 2:1 minimum			
19		Length	65.2	ft						
20		Width	13.0	ft						
21	5	Overflow Height =	15	in			Recommend 12" minimum, 18" maximum			
22	6	Sideslopes (Z:1) =	10	ft/ft			Recommend 4:1 minimum			
23		Top Width	38.0	ft						
24		Top Length	90.2	ft						
25										
26		Retention Volume Credit =	2545	ft^3						
27		Retention Depth Credit =	1.05	in						
28										
29										
30	Recovery of volume retention capacity (assumes filter media infiltration rate averages 1 in/hr)									
31		Approx time for BMP to recover capacity	35.9	hr						
32										

Holden Arboretum CSM Example

Runoff Reduction Credits
- Considerations and Questions -

- How do we assure hydrologic performance at installation and over the long-term?

Performance Checks

- Consistent application of CN method protocols
- Constructable and maintainable designs
- Construction oversight
- As-builts
- Clear, enforceable BMP management plans
- MS4 post-construction BMP inspection program

Runoff Reduction Credits
Issues? Questions?

Why use codes as tool?

- MS4s required to have stormwater codes
- MS4s required to consider TMDLs in SCM selection
- Reduce costs of private development to public infrastructure
- Especially appealing for communities with aging & undersized infrastructure

Stormwater Code Recommendations

- Credit volume reduction towards peak discharge requirements
- < 1 acre threshold for comprehensive stormwater management plan
- Incentivize reduction of impervious area & infiltration for redevelopment
- Soil preservation and post-construction soil restoration
- Sites in cold water habitat watersheds include SCMs to reduce runoff temperature

Why credit LID for peak discharge?

- Permeable pavement & bioretention reduce runoff volumes – this should count towards flood control
- Not crediting LID results in pond + LID -> makes LID less economically feasible
- LID offers water quality improvements & aesthetic benefits

Bioretention Volume Calculator

	A	B	C	D	E	F	G	H	I	J
1	Bioretention Volume Retention Calculator									
2										
3	Site inputs - drainage area, percent impervious									
4	Bioretention cell variables - filter bed area, length to width ratio, overflow height, sideslopes									
5										
6	Step									
7	1	Drainage Area =	1	acres	43560	ft^2				
8										
9										
10	2	Imperviousness =	50	%						
11		Contributing Impervious Area =	0.5	acres	21780	ft^2				
12		Volumetric Runoff Coefficient, Rv =	0.5							
13		Water Quality Volume =	1361	ft^3						
14										
15		Minimum Filter Bed Area =	1089	ft^2						
16	3	Filter Bed Area =	1089	ft^2						
17		FB Area/Impervious Area =	5.00	%			Must be at least 5%			
18	4	Length to Width Ratio (L:W)	3	ft/ft			Recommend 2:1 minimum			
19		Length	57.2	ft						
20		Width	19.1	ft						
21	5	Overflow Height =	12	in			Recommend 12" minimum, 18" maximum			
22	6	Sideslopes (Z:1) =	4	ft/ft			Recommend 4:1 minimum			
23		Top Width	27.1	ft						
24		Top Length	65.2	ft						
25										
26		Retention Volume Credit =	1415	ft^3						
27		Retention Depth Credit =	0.39	in						

< 1 acre Threshold for Stormwater Management

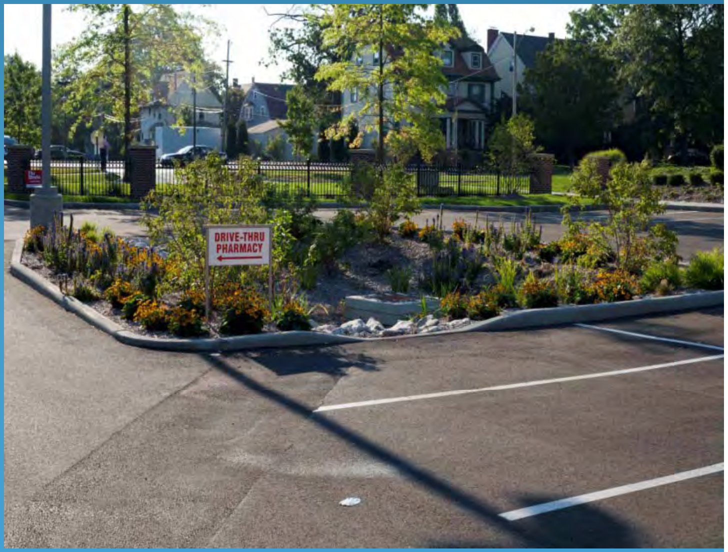
Especially valuable for :

- Areas largely developed before stormwater management required
- Areas with urban flooding problems

Early Adopters

- Federal Government - 5,000 ft² threshold for LID
- Lakewood - 8,000 ft²
- Aurora – 0.5 acre of disturbance for additions to commercial or industrial properties

Recently installed 14,000 ft² CVS in Lakewood uses bioretention



Implementation Considerations

- Review building permits to determine what threshold is appropriate for your community

Incentivize Infiltration for Redevelopment

Photo from NY Times

Require

25% impervious area reduction

OR

Infiltrate 25% WQv

OR

Treat 50% WQv

Soil Preservation & Restoration

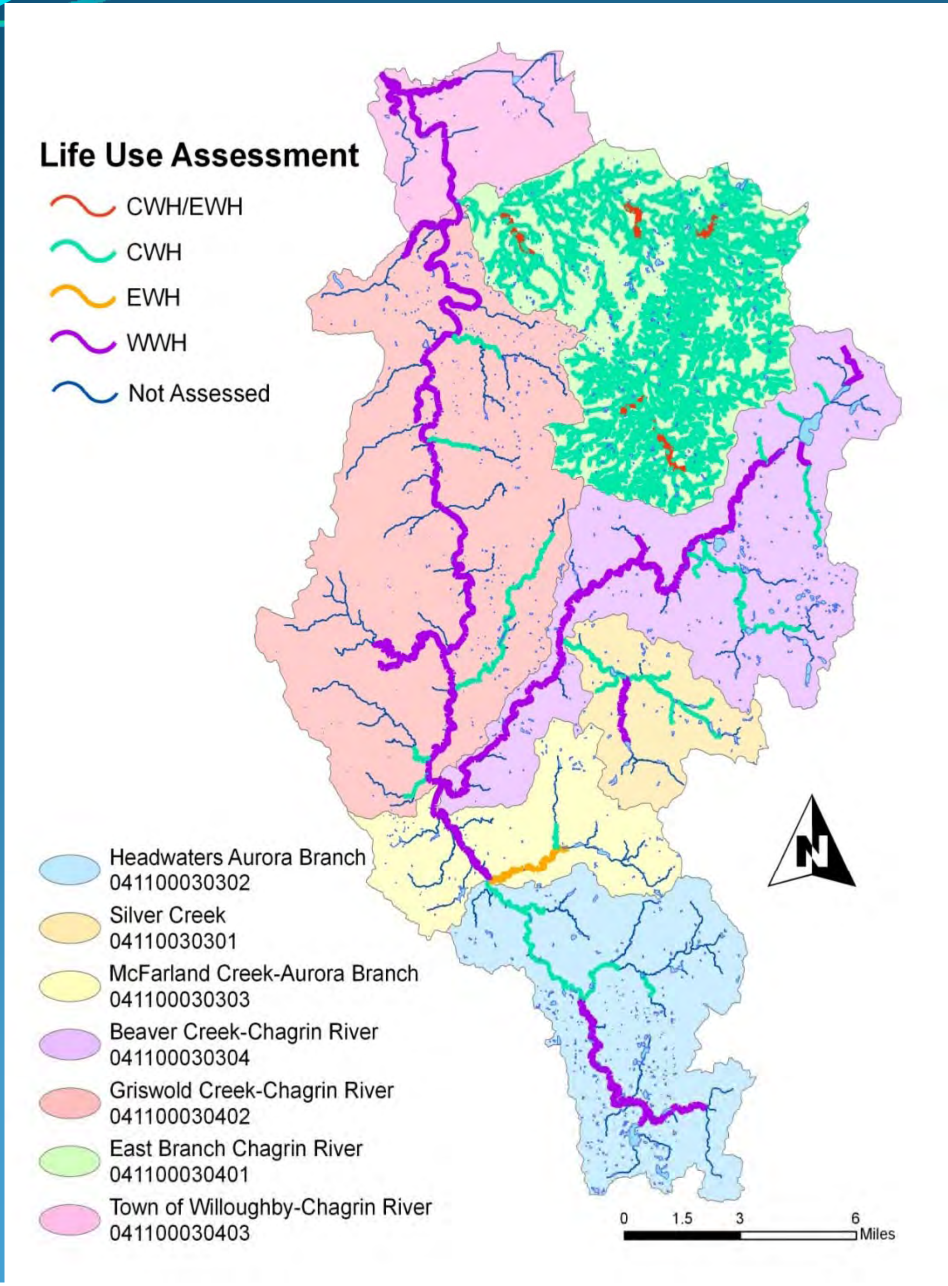
Photo from King County , Washington

- Healthy soils reduce runoff
- Minimize soil disturbance and protect soil from compaction
- Restore disturbed soils
  - Till subsoil to 15-18"
  - Incorporate compost top 12"
  - Replace topsoil to min. 4" depth

Coldwater Habitat (CWH) SCMs

- Require SCMs that reduce temperature in CWH watersheds.
- Meets Chagrin River Habitat TMDL

Coldwater Habitat Streams



Questions? Observations on Codes?

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Final Discussion & Wrap Up