Chesapeake Water Environment Association

Stormwater: Too Simple?

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Villanova Center for the Advancement of Sustainability in Engineering,
Villanova Urban Stormwater Partnership

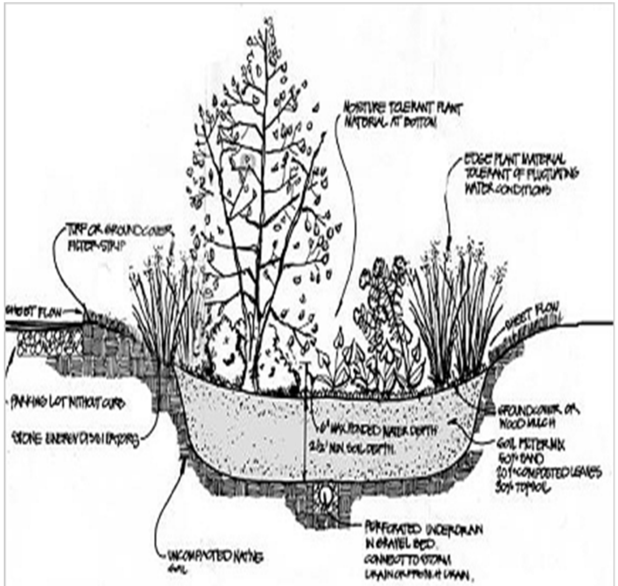
And Dr's Welker, Wadzuk, Komlos, Smith, Sample-Lord and many grad and UG students!

VUSP Mission Statement

To advance the evolving field of sustainable stormwater management and to foster the development of public and private partnerships through research.

http://www.villanova.edu/vusp

Bioretention – 1990's?



(From The Bioretention Manual, Prince George's County, Maryland)

Tools - NRCS Type II Distribution – CN?

Vol - Static Design?

Peak -

% Removal by rate?

2020?

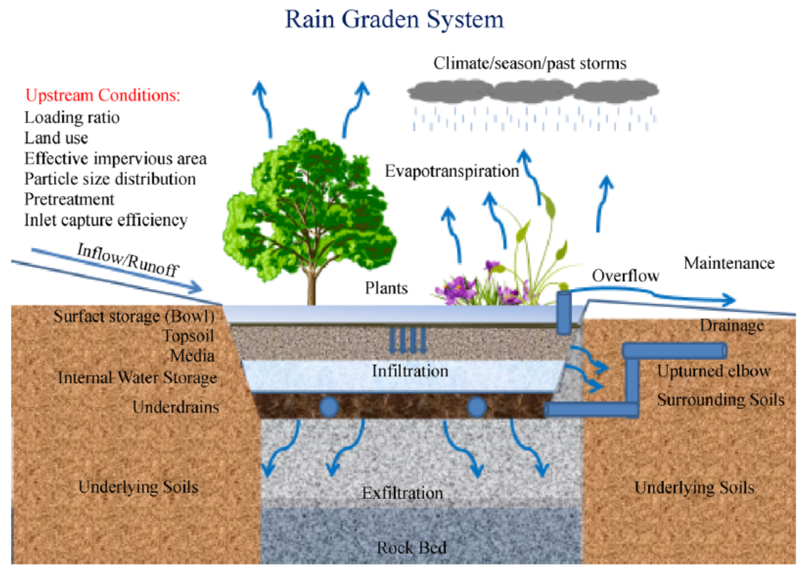
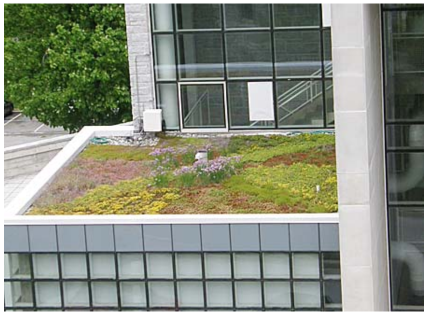


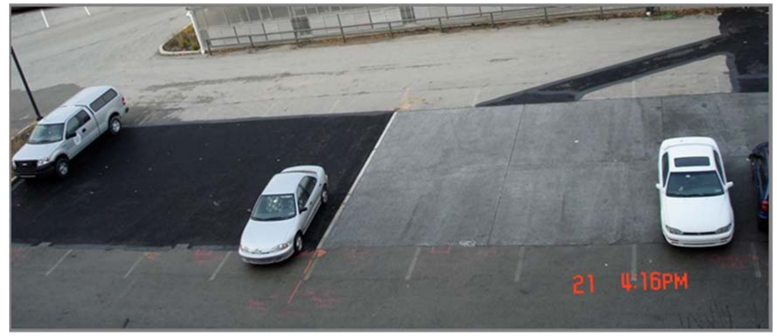
Fig. 2 Rain garden system (Drawing: Carla Windt)

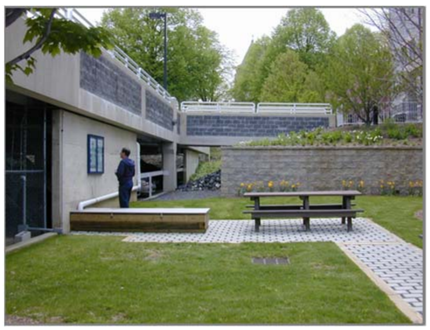
Traver, R.G. & Ebrahimian, A. Front. Environ. Sci. Eng. (2017) 11: 15. https://doi.org/10.1007/s11783-017-0973-z

Tools - ?

Villanova’s SCM Research and Demonstration Park









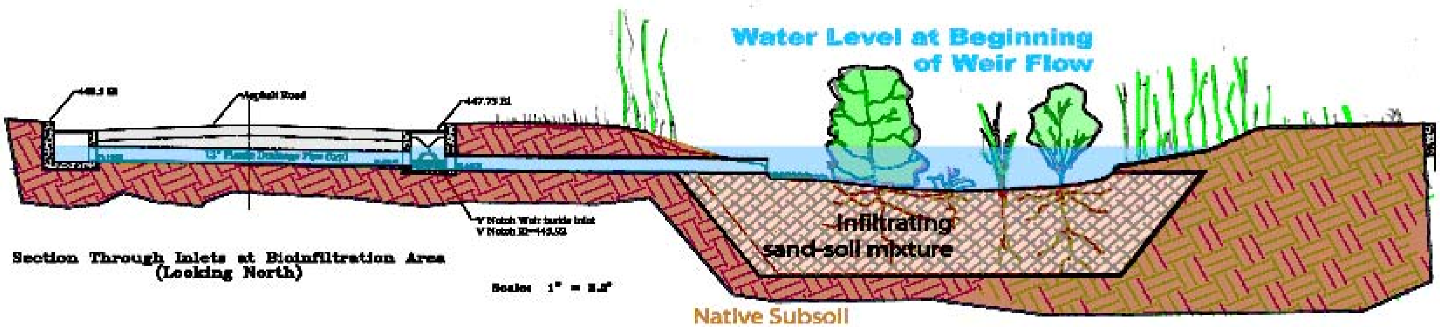

Rain Garden

Advantages

- Relatively Simple
- Takes advantage of available sites
- Attractive
- Easy to build multiple small sites
- Place to put snow!
- Can be replaced

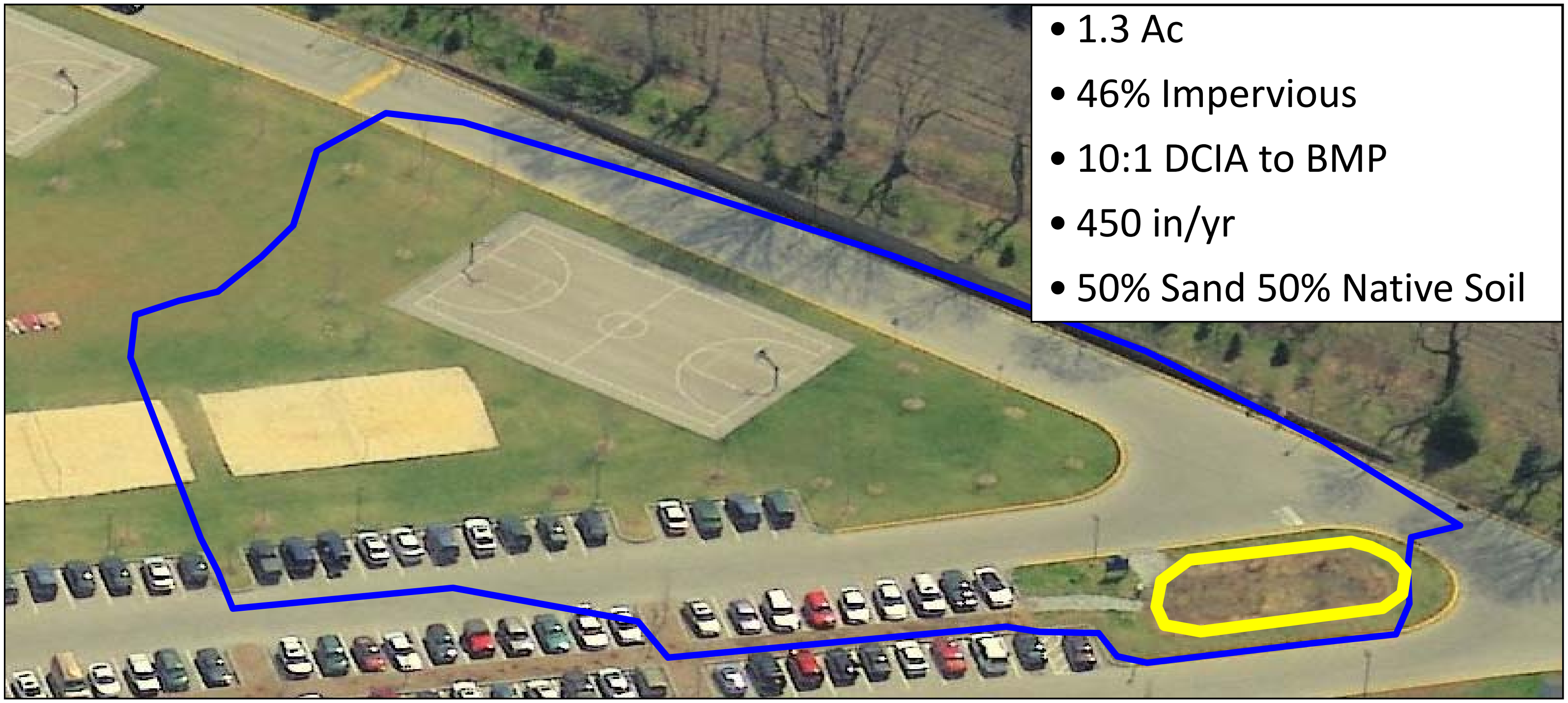
Needs ..

- Gravity
- Infiltration or ET
- Trash Maintenance



Sizing Drainage Area

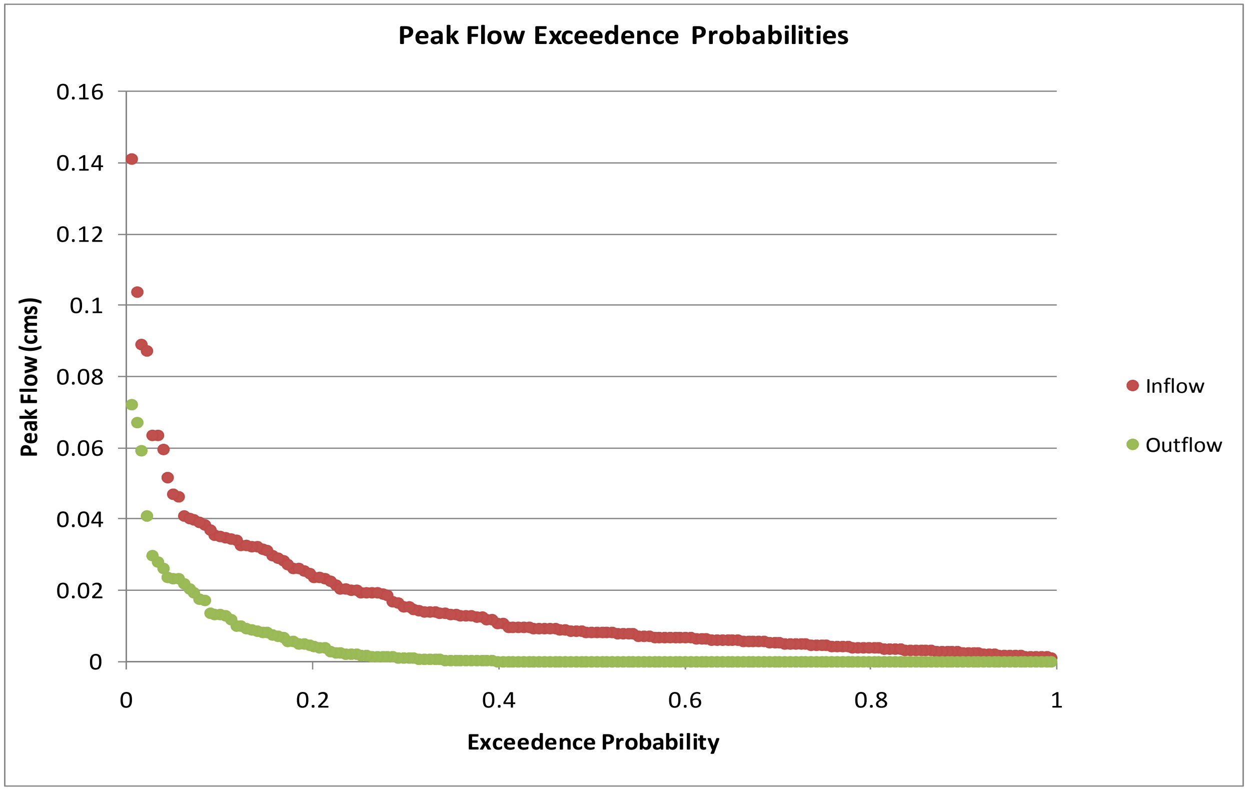
Good rule of thumb - 5:1 to 10:1 impervious footprint to infiltrating area

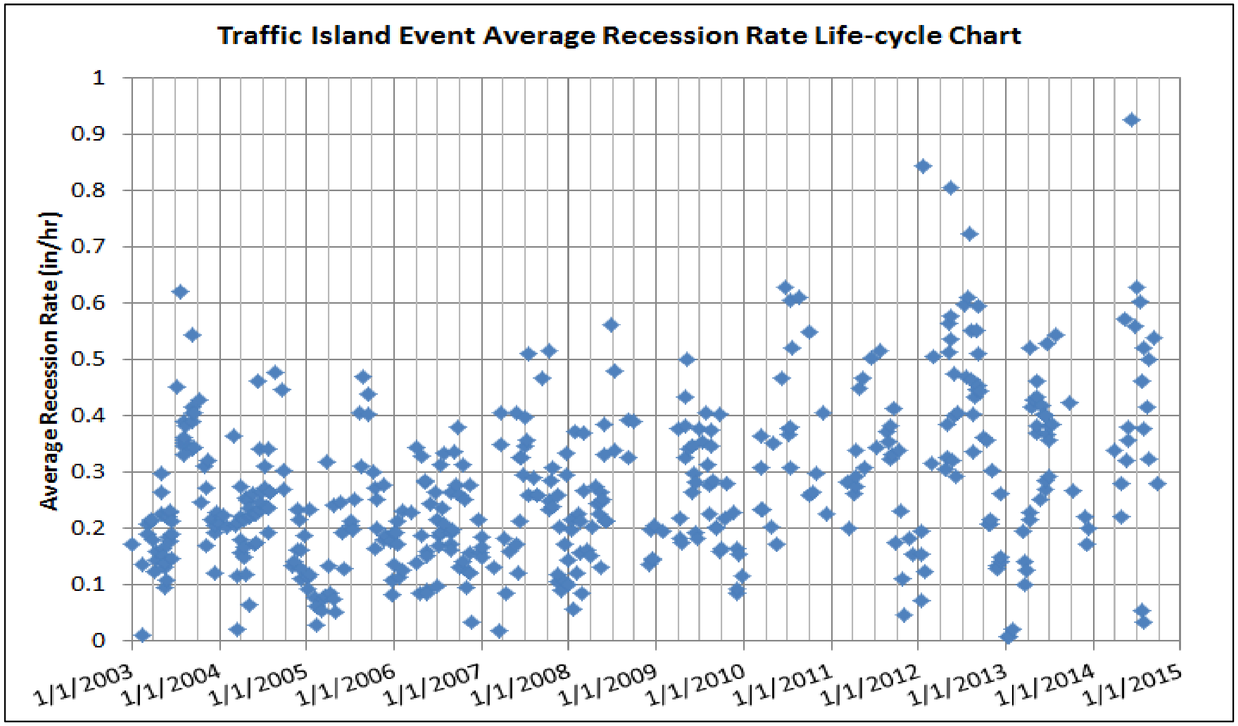


- 1.3 Ac
- 46% Impervious
- 10:1 DCIA to BMP
- 450 in/yr
- 50% Sand 50% Native Soil

Bioinfiltration Traffic Island Construction

VU Bioinfiltration - Peak Flow Reduction




Traffic Island Event Average Recession Rate Life-cycle Chart
Average Recession Rate (in/hr)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/1/2015

VUSP

Water Quantity Results - Static

- Model of inflow & overflow (Heasom et al. 2006)
- 364 storms analyzed
- Overall average reduction – 82%
- Statistically significant reductions ($p<0.0001$)

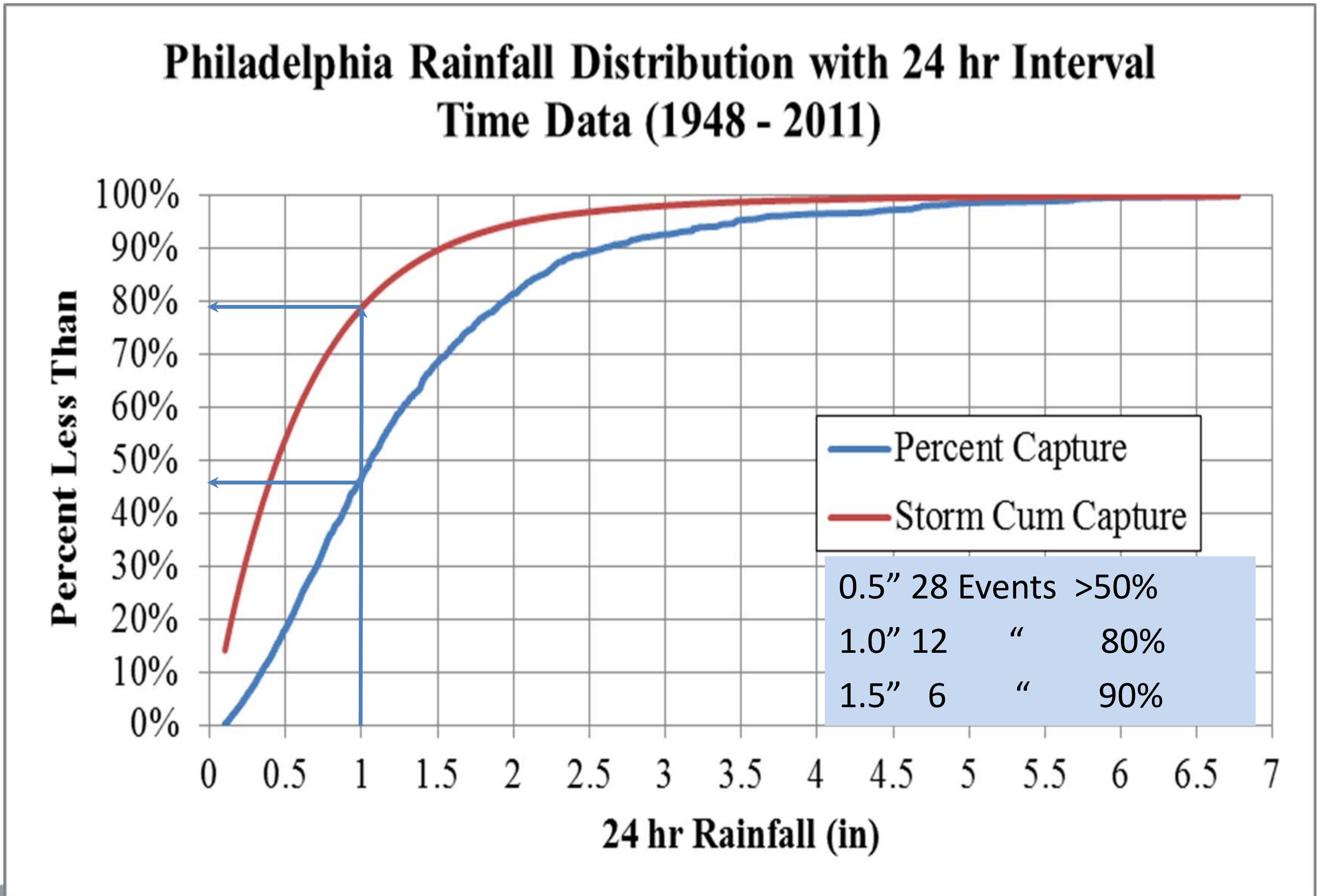
Storm Size	Sample Size	Average Volume Reduction
Small (<1.27 cm) (<0.5 in)	115	100%
Medium (1.27-2.54 cm) (0.5 – 1.0 in)	127	97%
Large (>2.54 cm) (> 1.0 in)	122	50%

From a surface water quality perspective,

if 1" Rain is around 85% of the annual flow…………

And the rain garden works as a filter….

Source, L. Lord Thesis 2013


Philadelphia Rainfall Distribution with 24 hr Interval Time Data (1948 - 2011)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Less Than
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
24 hr Rainfall (in)
Percent Capture
Storm Cum Capture
0.5” 28 Events >50%
1.0” 12 “ 80%
1.5” 6 “ 90%

Surface Water Quality Data

Table 1. Bioinfiltration Rain Garden - Surface Flow Performance 2003 – 2016

Traffic Island Surface Water Analysis				
Lifetime Totals (2003-2016)				
	# of Storms	Inflow	Overflow	Removal Efficiency
Water Quantity (Events with R > 0.25")*	614	33088541	15162513	54.2%
Water Quantity (Events 0.05" <= R <=1.6")*	948	15161550	1698380	88.8%
Water Quantity (Events with Water Quality Measured)*	216	13323477	7427551	44.3%
Total Suspended Solids (TSS)	180	2608	164	93.7%
Total Dissolved Solids (TDS) **	183	1738	307	82.3%
Total Nitrogen (TN) Multiple Tests***	50	4498.98	662.8	85.3%
Total Kjeldahl Nitroen (TKN) as N	79	6759	2180.0	67.7%
NO_2 as N	146	549.661	211.2787	61.6%
NO_3 as N	144	16507	7987	51.6%
Total Phosphorus Multiple Tests***	161	8654	4389	49.3%
Total Phosphorus (TKP) as P (EasyChem)	60	635	337	46.9%
Phosphate (PO4) as P	134	2858	671	76.5%
Chloride (CHL)	158	522	133.2	74.5%
Total Cadmium	106	3784	3307	12.6%
Total Chromium	120	209335	48157	77.0%
Total Copper	138	193528	82918	57.2%
Total Zinc	99	1096671	440975	59.8%
Total Lead	123	72359	15994	77.9%

*Assumes Curve Number flow of 98 from impervious surface

**The TDS values obtained for the period of 2003 to 2015 is from testing, and TDS data for 2016 were obtained from conductivity. (See page 12)

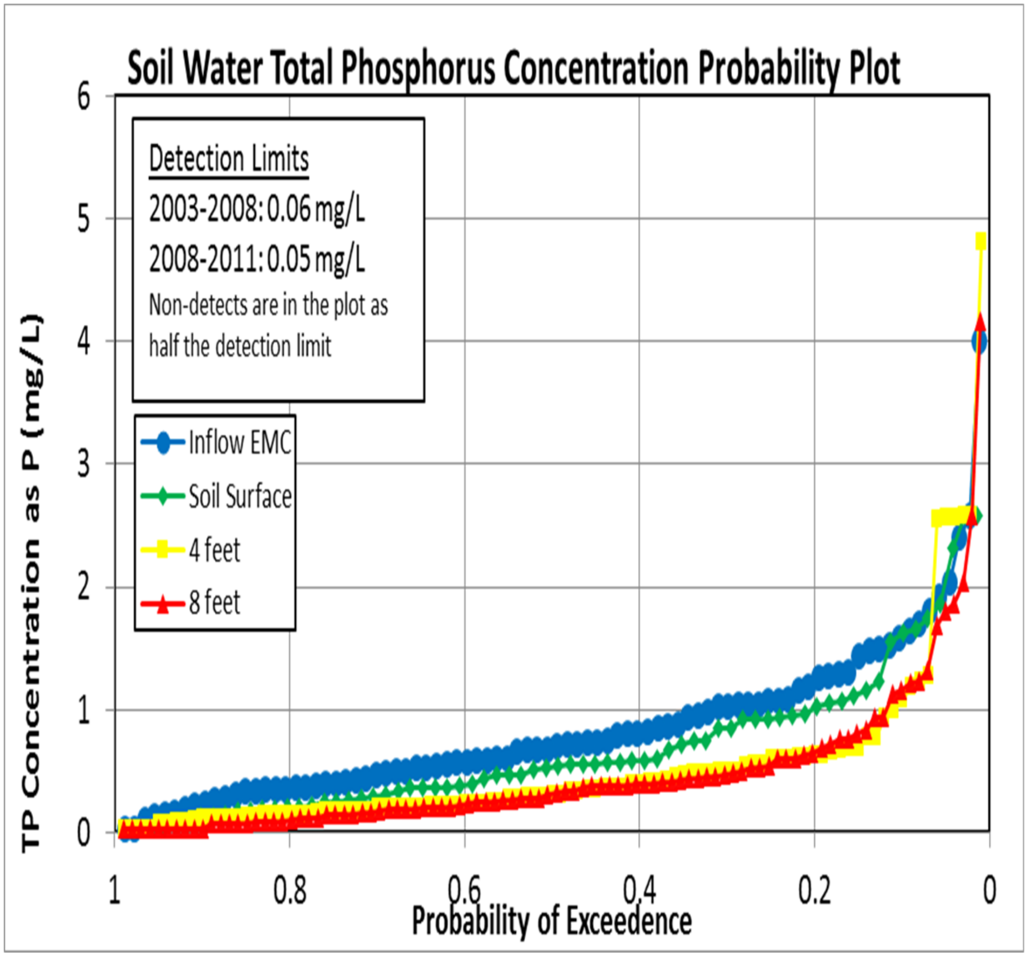
*** Total N or P from both the HACH and current EAZYCHEM analysis

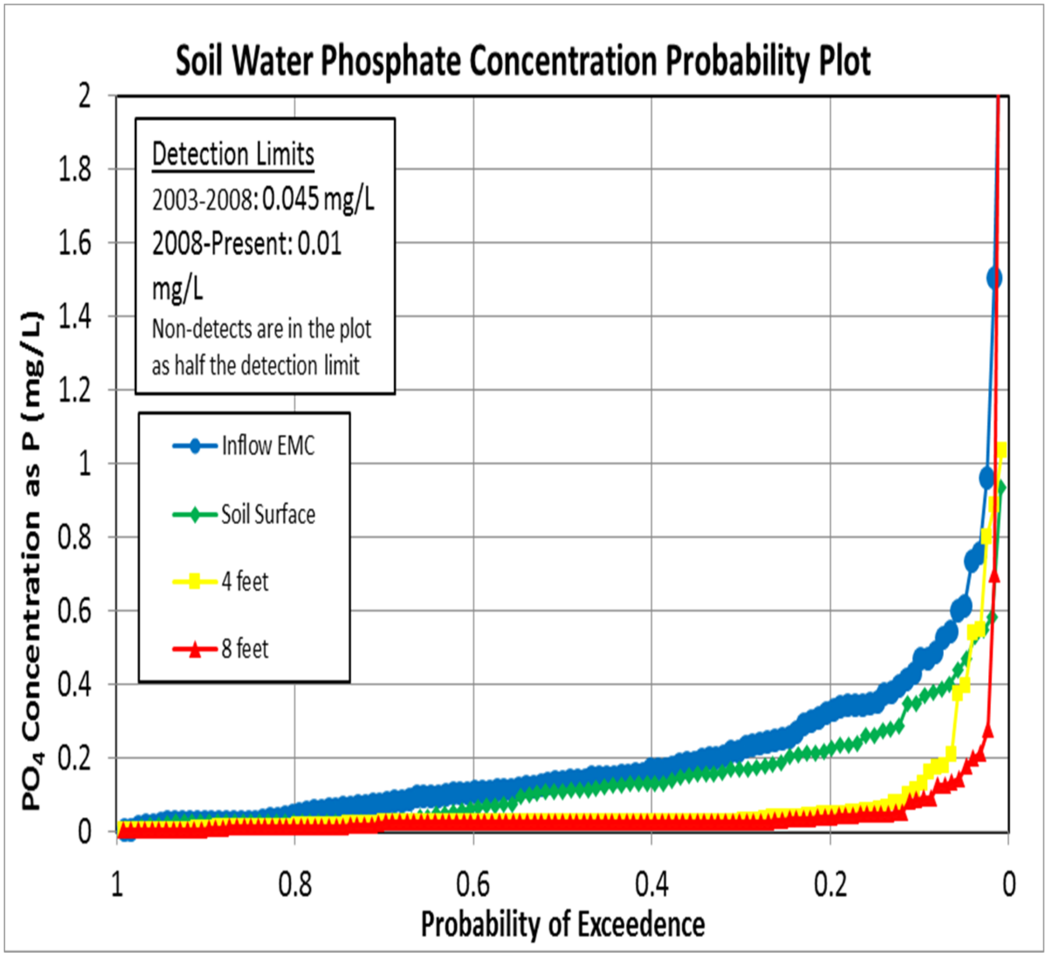
Problem,

Most rain storms sampled
Are larger,

So GREATLY underestimating
Performance.

Vadose Zone Quality Data





Mounding Volume? Ms. Megan Farnsworth

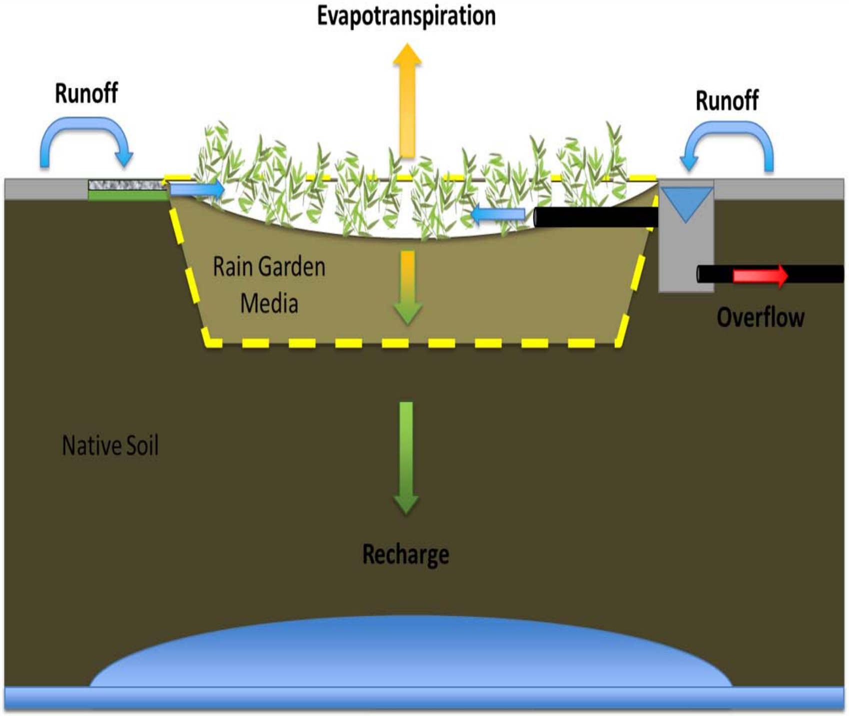


Figure 4.1: Flow Paths through BTI Rain Garden and Control Volume (Not to Scale)

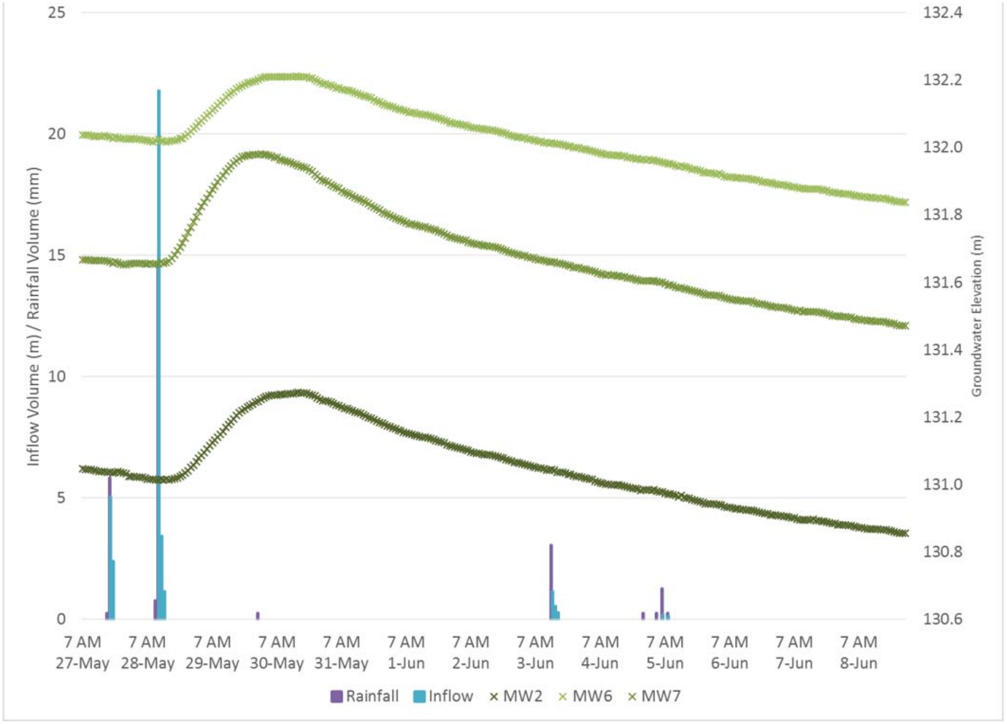
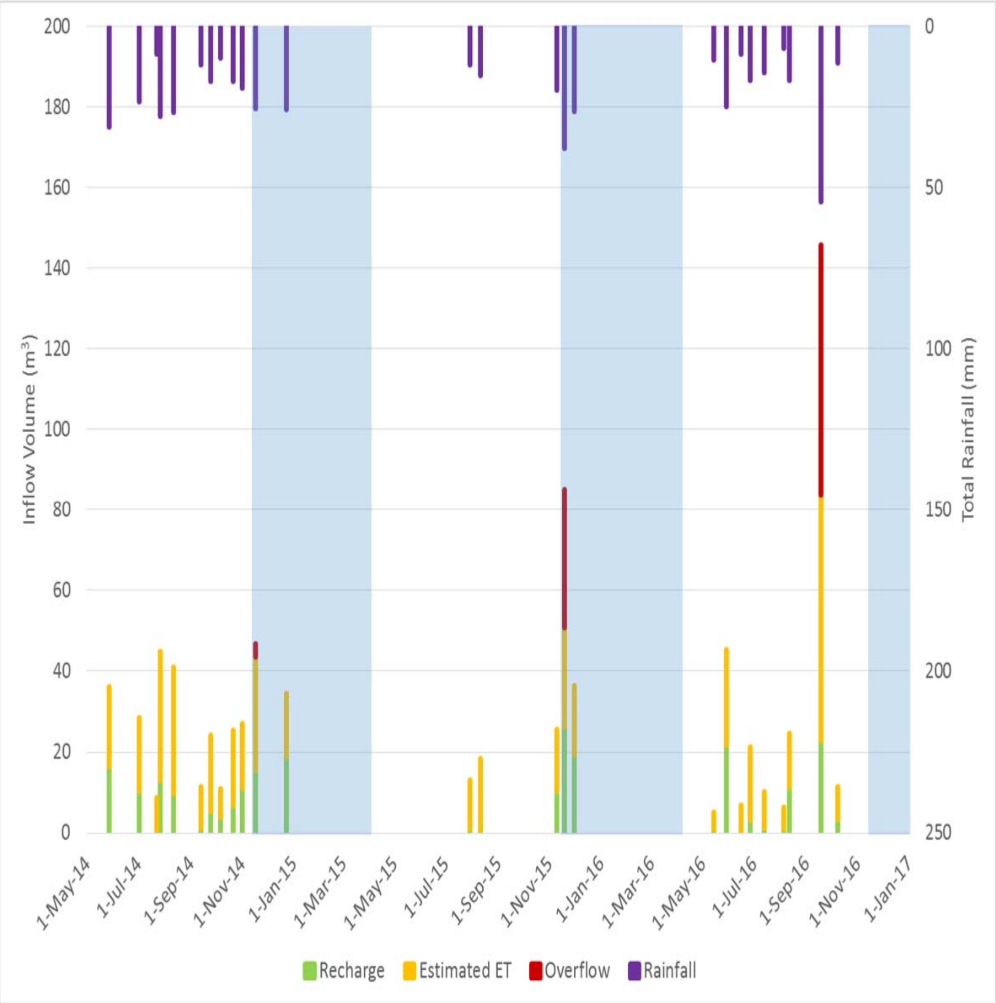


Figure 4.5: Rainfall, Inflow, and Groundwater Elevation at Rain Garden for a Medium Event (May 27, 2014)

Ms. Megan Farnsworth



Question… For storms < 1”

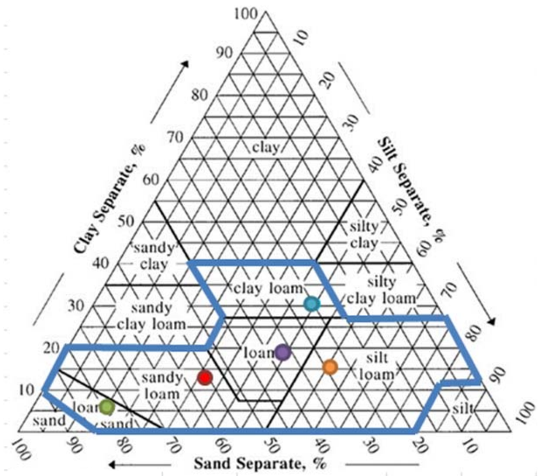
Majority of Annual Loading….

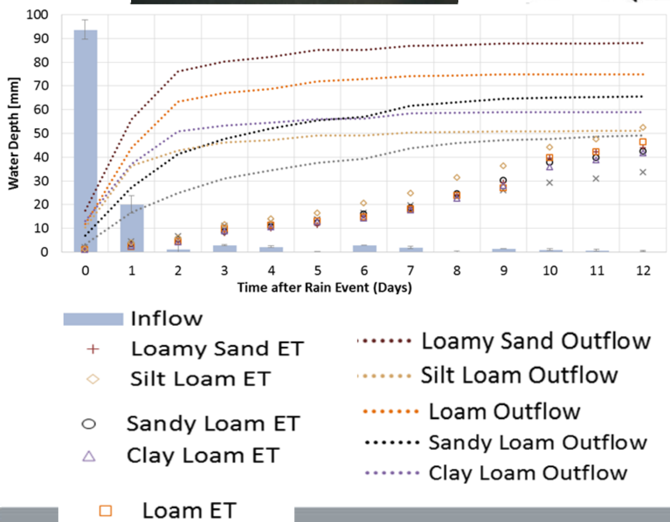
No Overflow (0 Outflow)

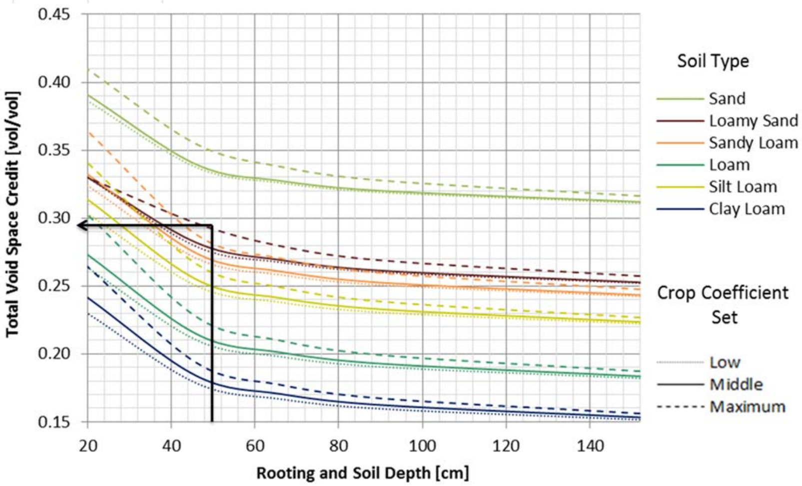
Significant ET, so less contribution to recharge.

How does percent removal represent this without including volume / flow?

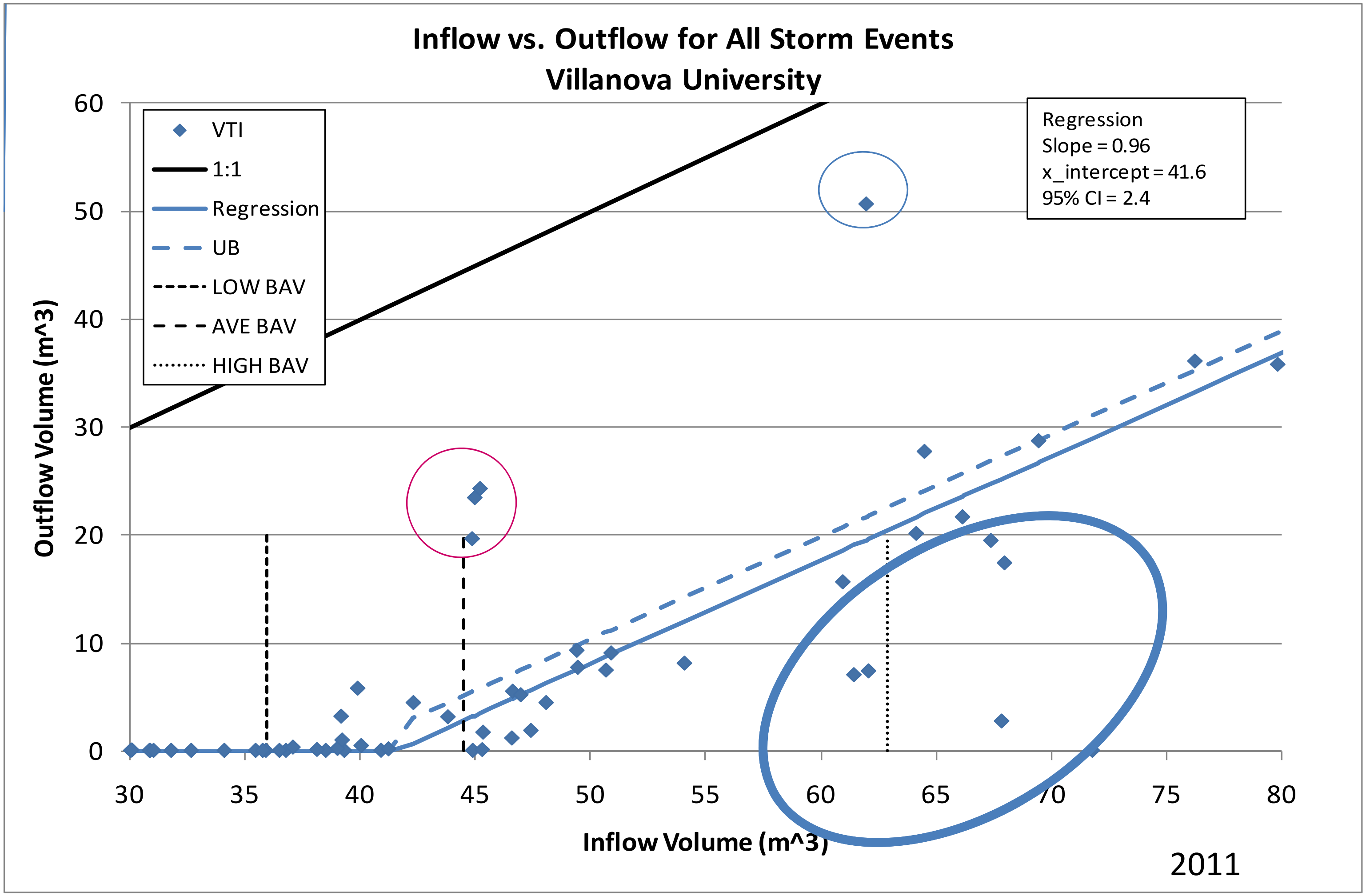
Rain Garden Lysimeters







PADEP Growing Greener: Dr. Amanda Hess (5/2017), Taylor DelVecchio (5/2017), Michael Bossman (5/2019)

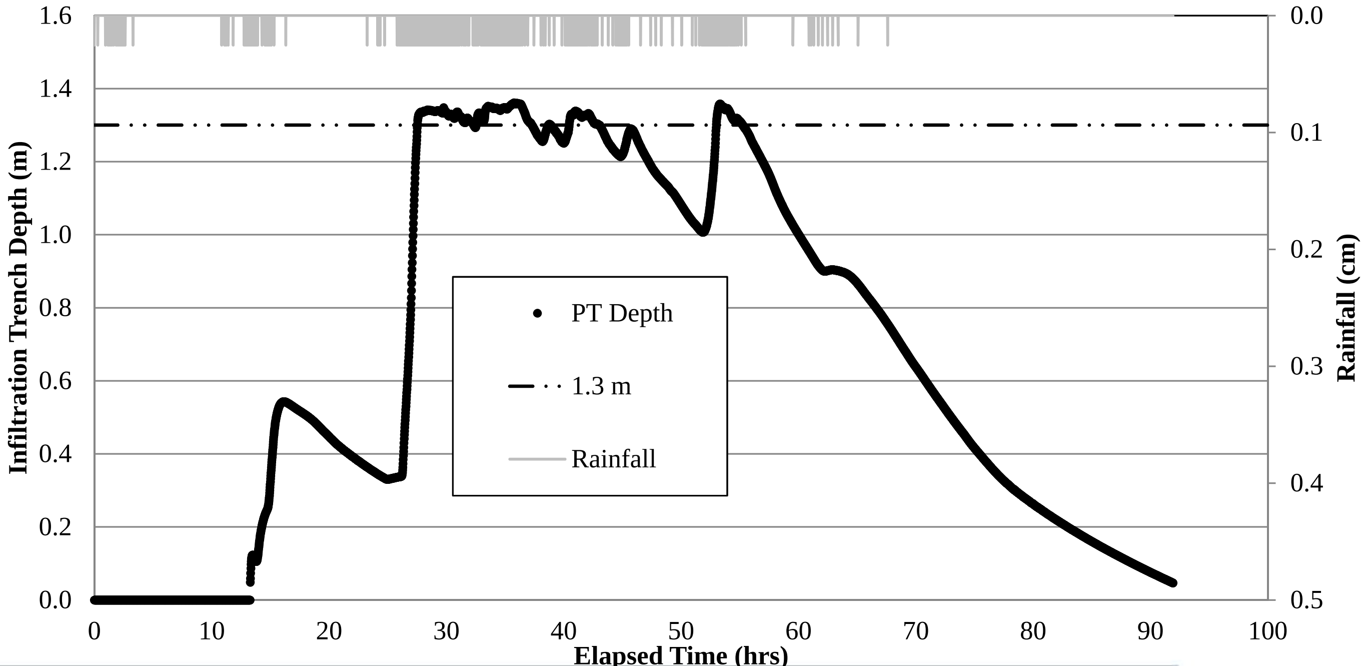

Inflow vs. Outflow for All Storm Events
Villanova University
Outflow Volume (m^3)
Inflow Volume (m^3)
60
50
40
30
20
10
0
30
35
40
45
50
55
60
65
70
75
80
VTI
1:1
Regression
UB
LOW BAV
AVE BAV
HIGH BAV
Regression
Slope = 0.96
x_intercept = 41.6
95% CI = 2.4
2011

Vegetated pathways

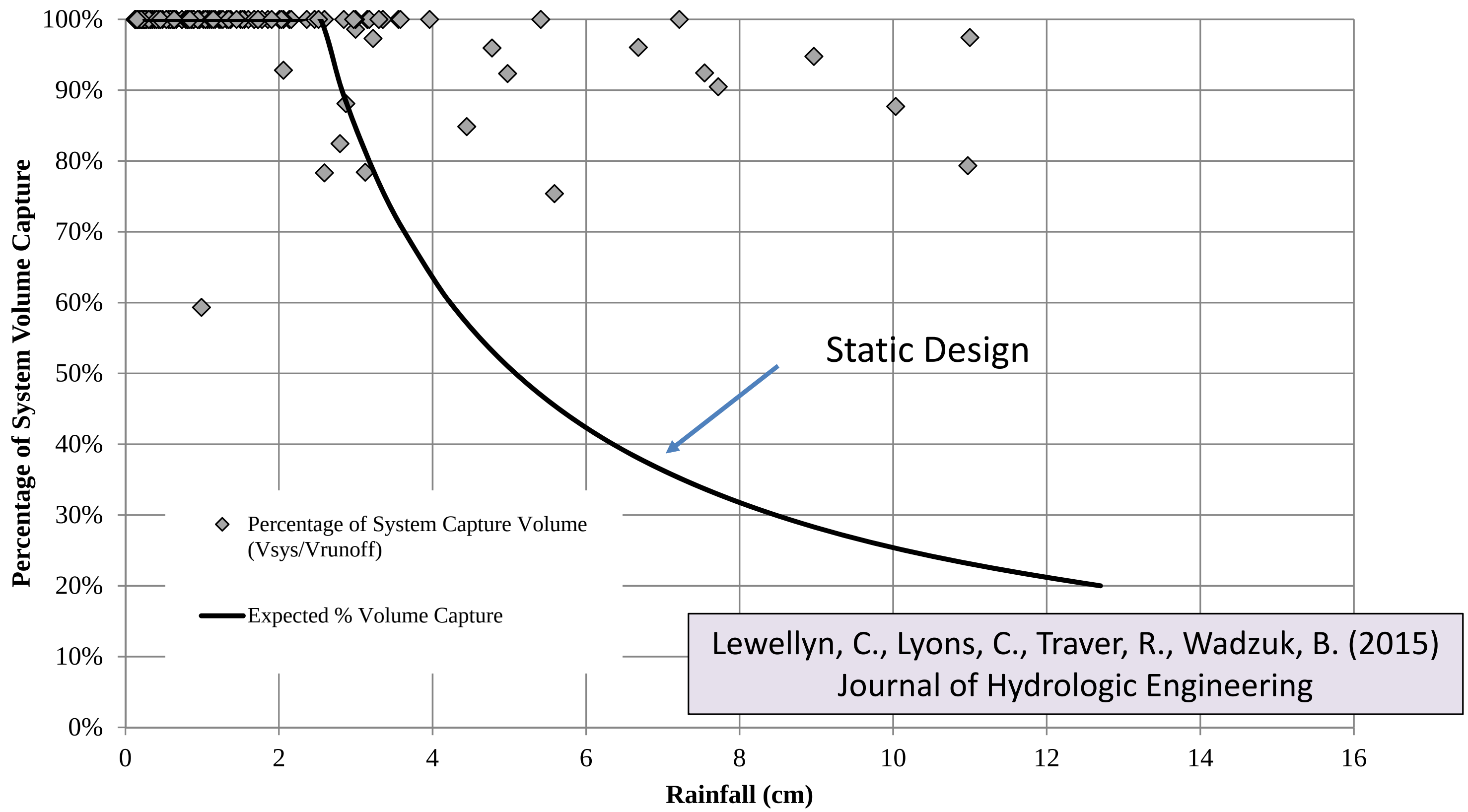
Villanova Treatment Train
Superstorm Sandy

- Rainfall: 11 cm 4.3 in
- Volume of runoff: 101 m^3
- Total system capture: 98 to 100 m^3
- Overflow: 1 to 3 m^3
- Average rainfall intensity: 0.065 cm/hr 0.165 in/hr

Lewellyn, C., Lyons, C., Traver, R., Wadzuk, B. (2015)
Journal of Hydrologic Engineering



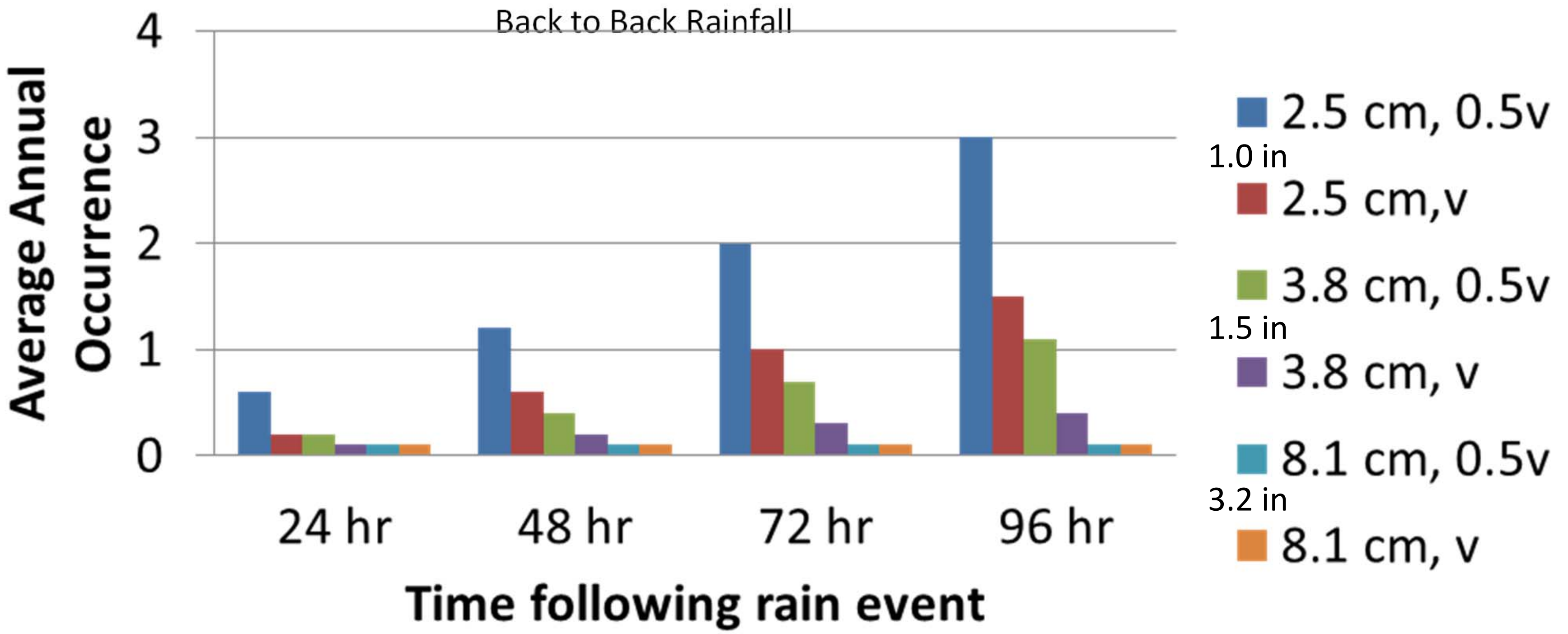
Villanova Treatment Train
Large Event Performance



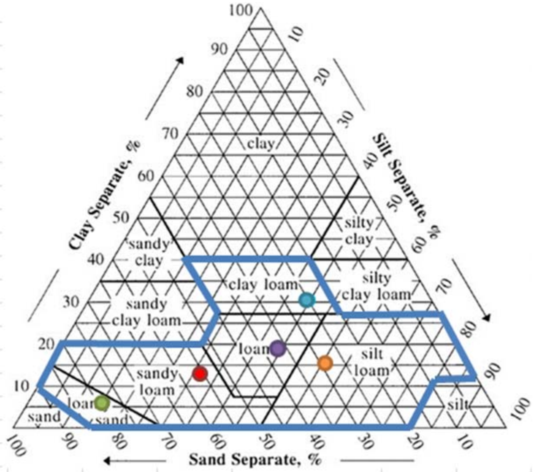
Risk + Myth Busting

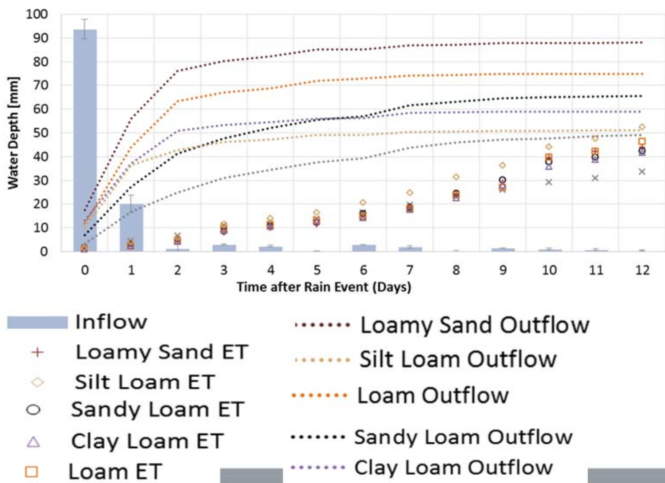
Model analysis of overflows at Treatment Train

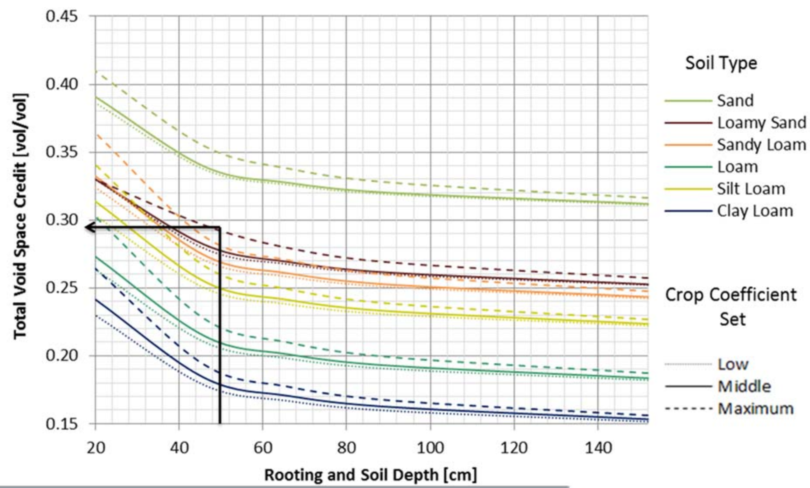
What is the acceptable risk? Overflow under climate projections



Rain Garden Lysimeters







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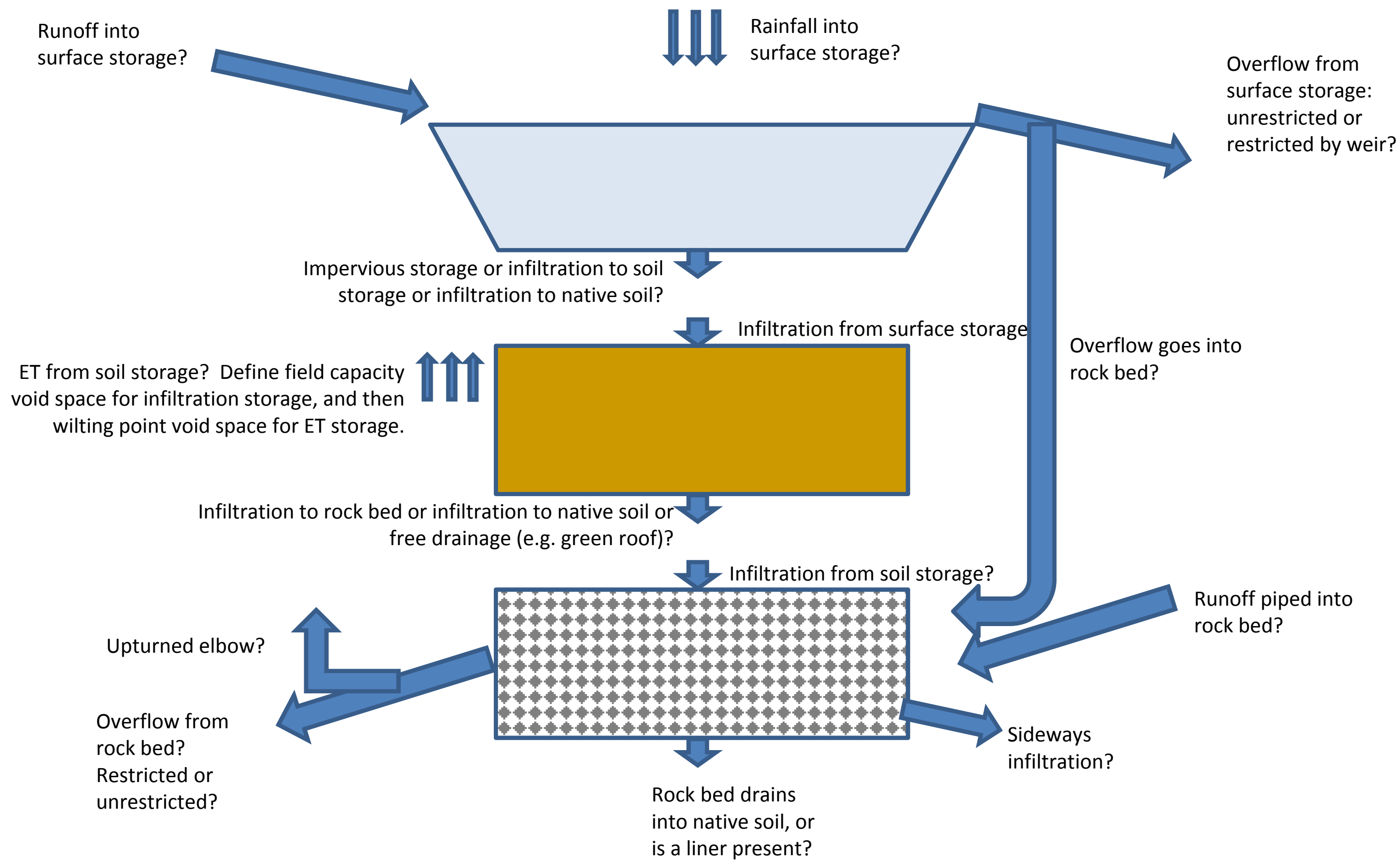
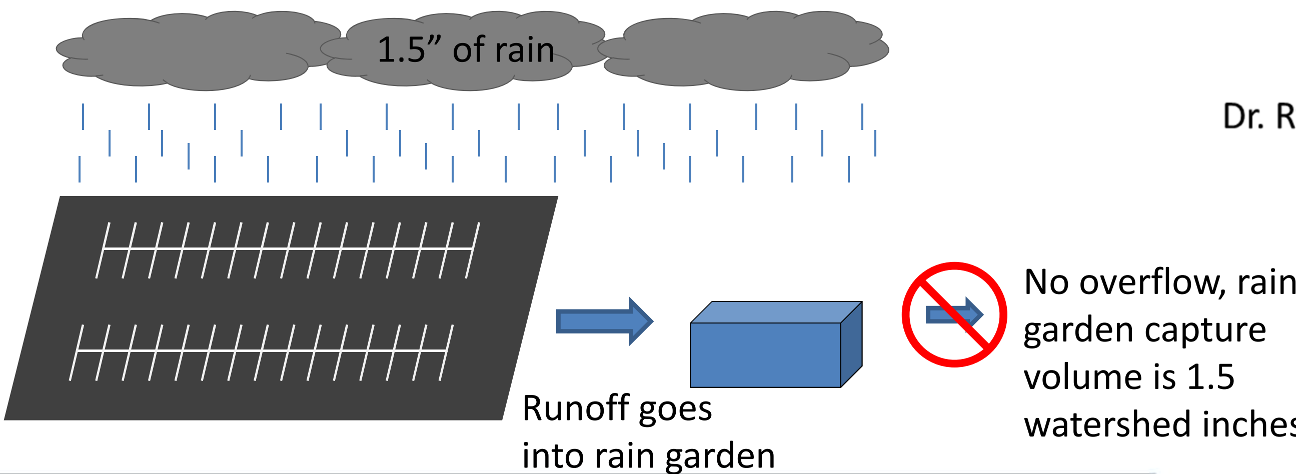
Rain Garden Schematic



Volume Reduction Model

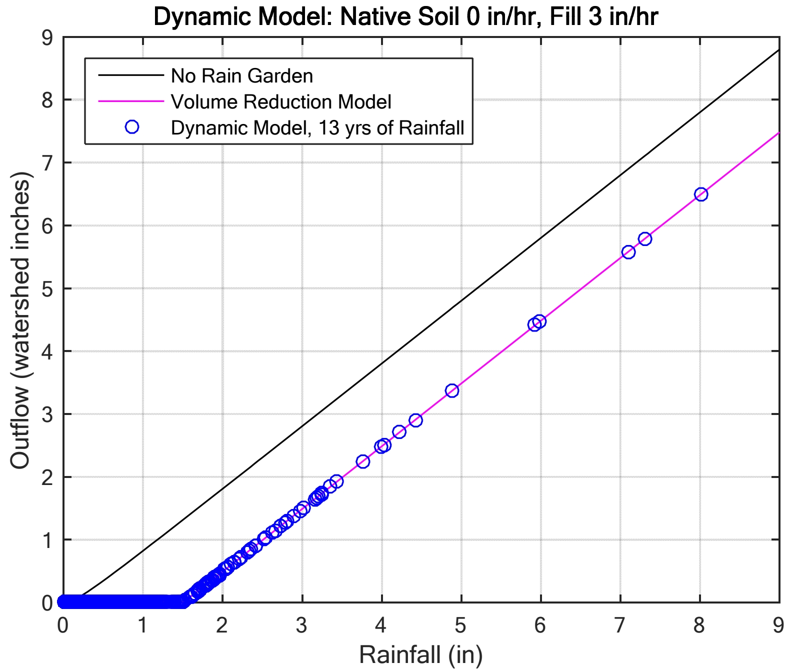
- How does the volume reduction model behave?
- E.g. An impervious watershed with rain garden designed to capture 1.5 "watershed inches"



Dr. Ryan Lee

Dynamic Model

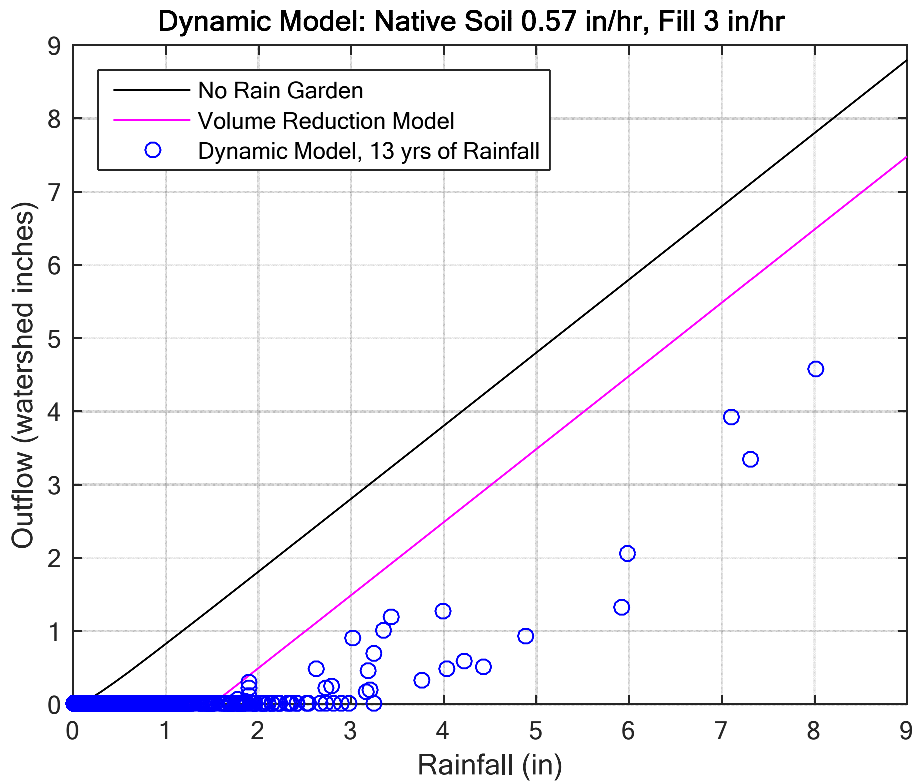
- First example, fill media infiltration only and NO native soil infiltration (should match Volume Reduction Model)



Disclaimer: We don't expect a real system to have no native soil infiltration… this is just for illustrative purposes.

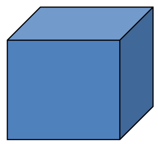
Dynamic Model

- Medium Native infiltration rate (HSG C → B)

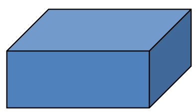


Dynamic Model

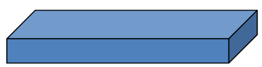
- A look at changing geometry – need dynamic model to evaluate! (all three have 1" volume in the basin, 0.5" volume in the fill media)



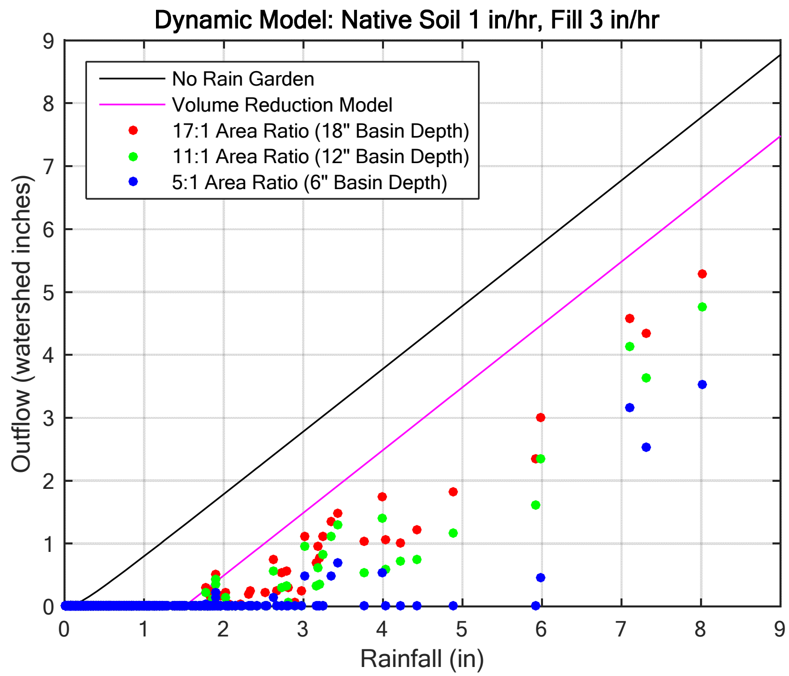
Less area, deep



Medium



More area, shallow



Research Focus is to develop a more holistic approach to design and implementation…

- considering climate, hydrologic, geotechnical, environmental and economic constraints.
- utilizing both the infiltration and evapotranspiration (ET) capabilities.

Research Vehicle is to intensively monitor three common Philadelphia green infrastructure practices

BioInfiltration Rain Garden – Sidewalk Tree Trench – Sidewalk Planters

Storm simulations used to create controlled events.

We are learning that our current practices underestimate GI performance on a volume capture basis, and fail to optimize the full capabilities of GI with respect to urban hydrology.

From Research by Cara Albright – PhD Candidate

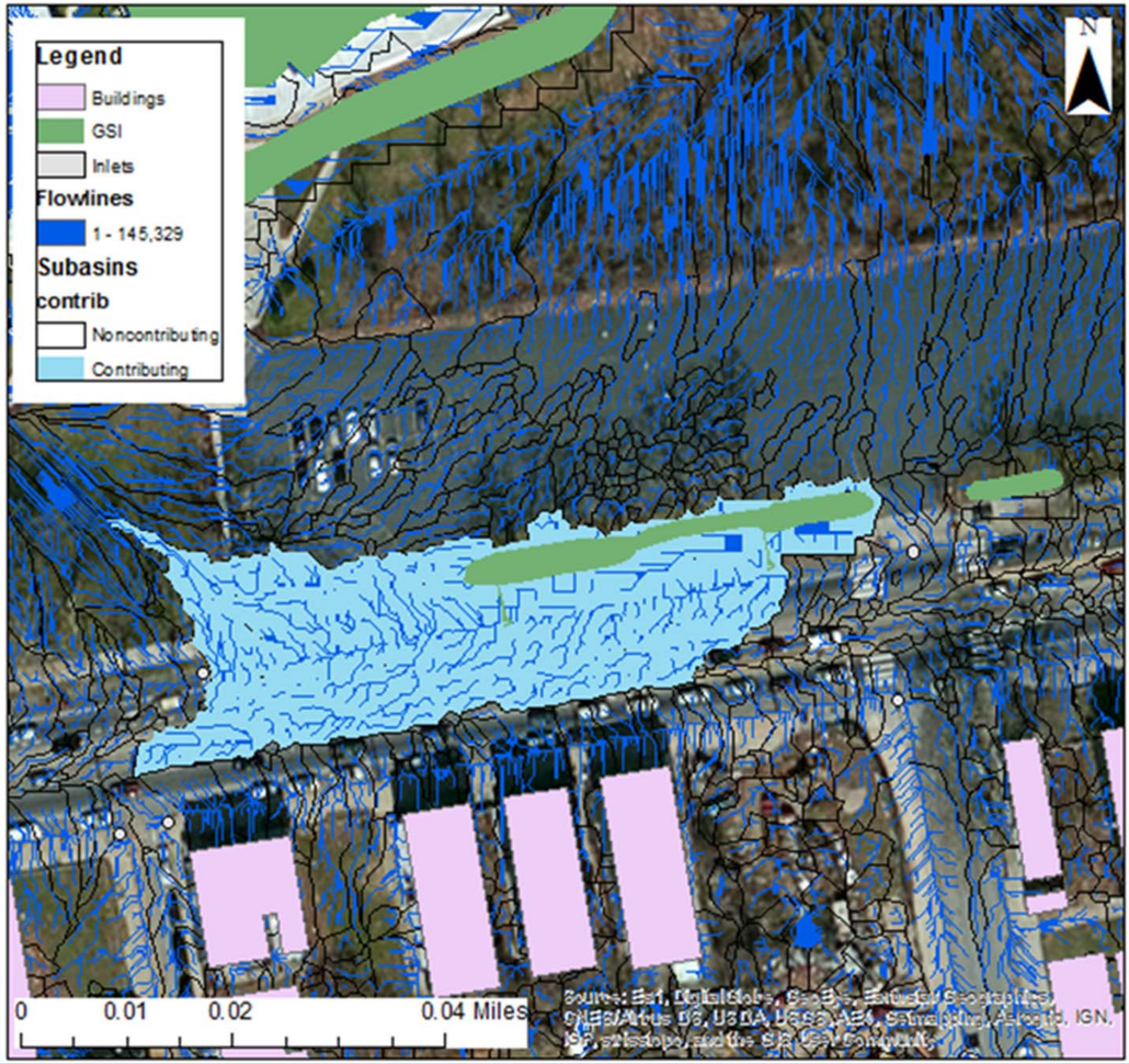
USEPA – Philadelphia Zoo

- Hydraulically connected system
- Surface inflow
- 23,600 ft^2 total drainage area (11:1)
- 16,116 ft^2 total DCIA
- Site area:
  - Upper - 1,280 ft^2
  - Lower - 810 ft^2
- Built in 2013

Ms. Cara Albright

LiDAR / GIS!

Dr Smith

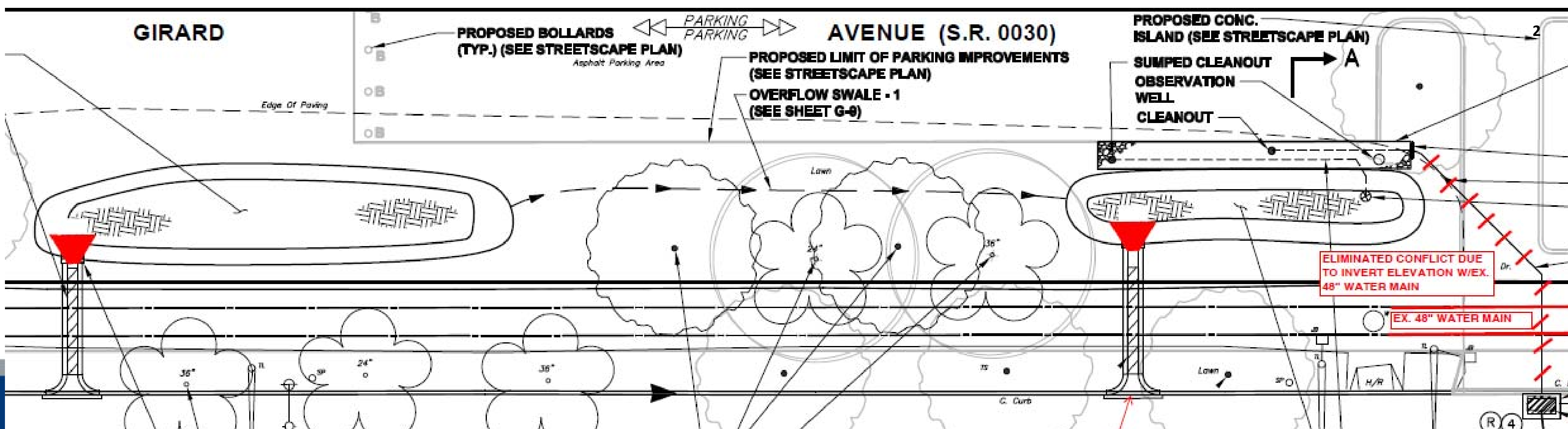


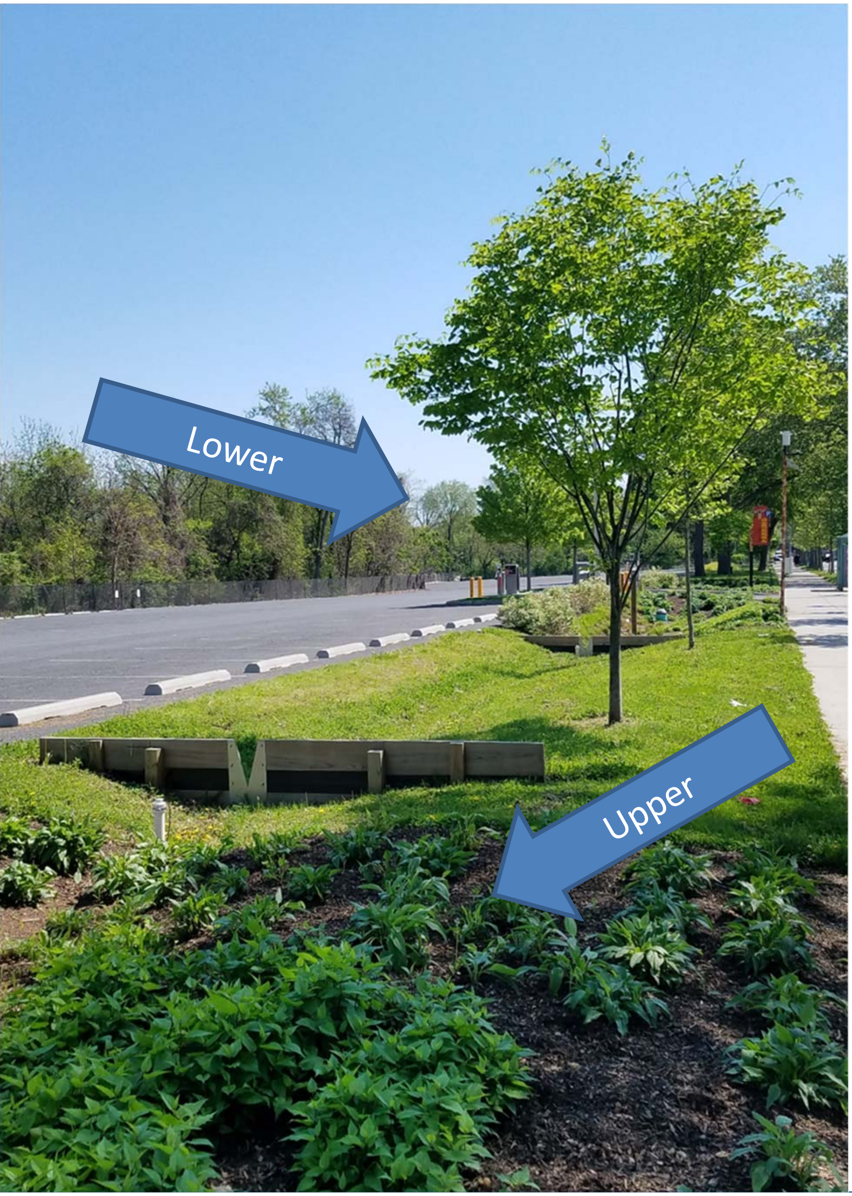
Zoo Rain Gardens

Design:

4.9 cm 1.9 in impervious

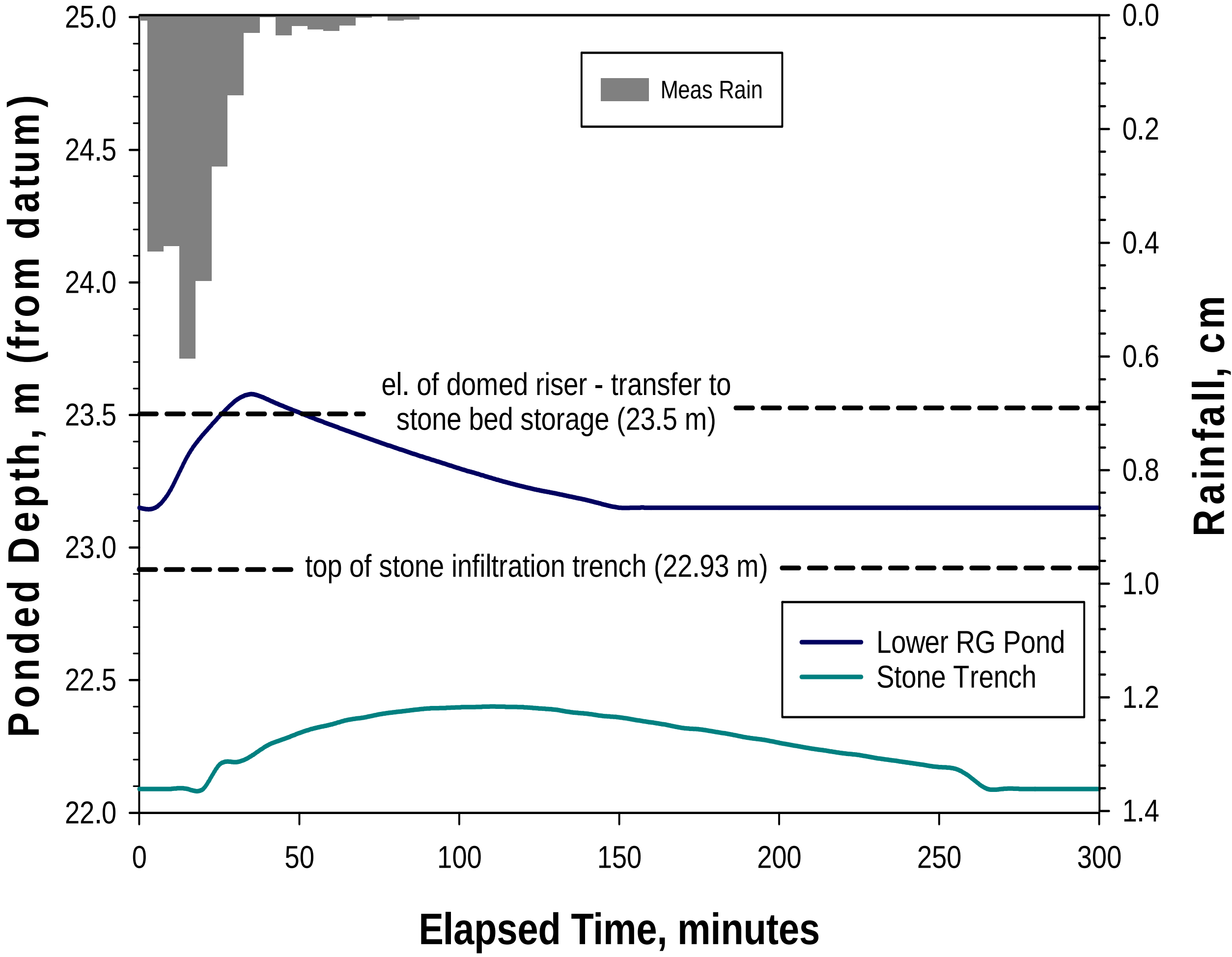
Static Volume





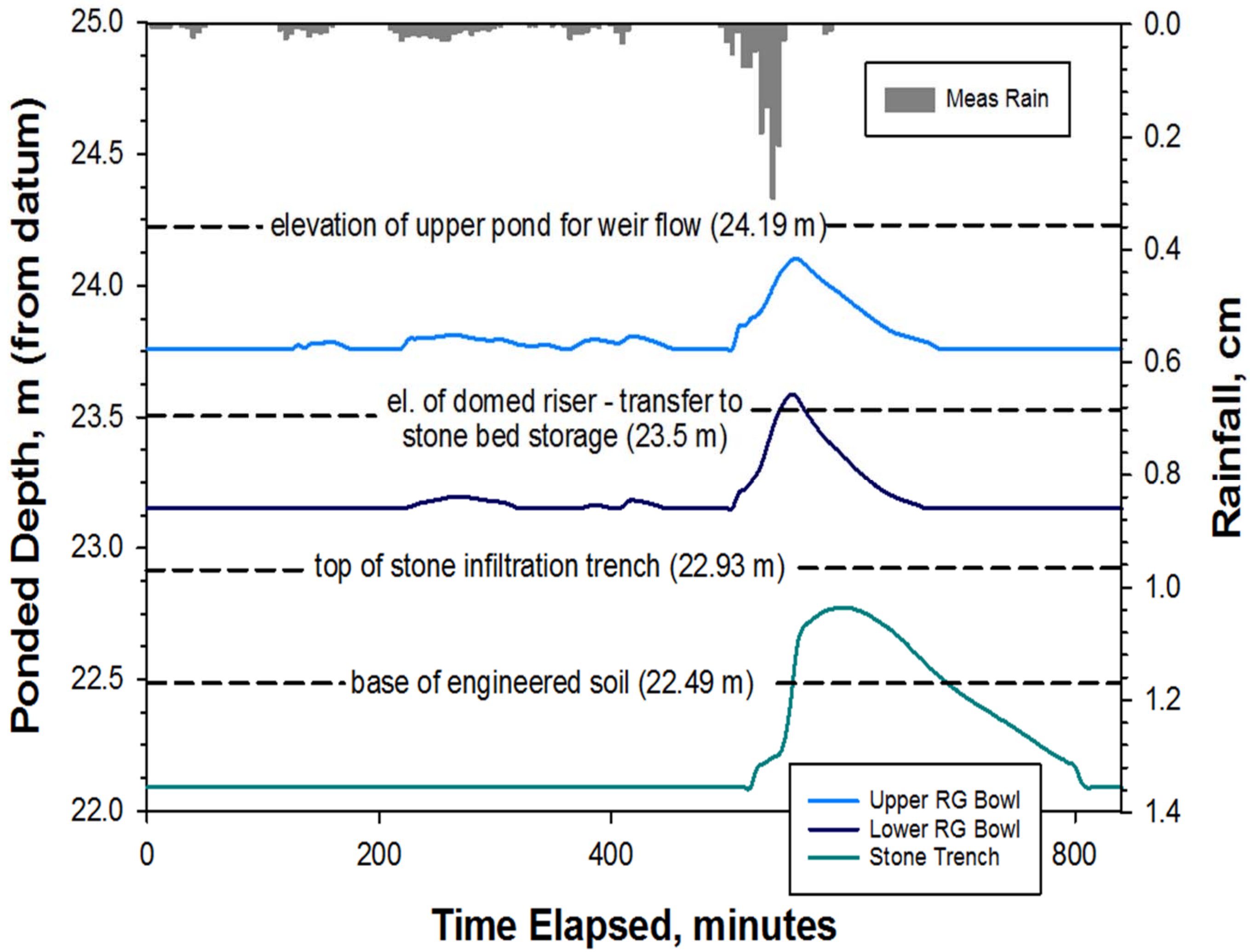
Lower Rain Garden

2.5 cm – 1.0 in ~ 90 Minute

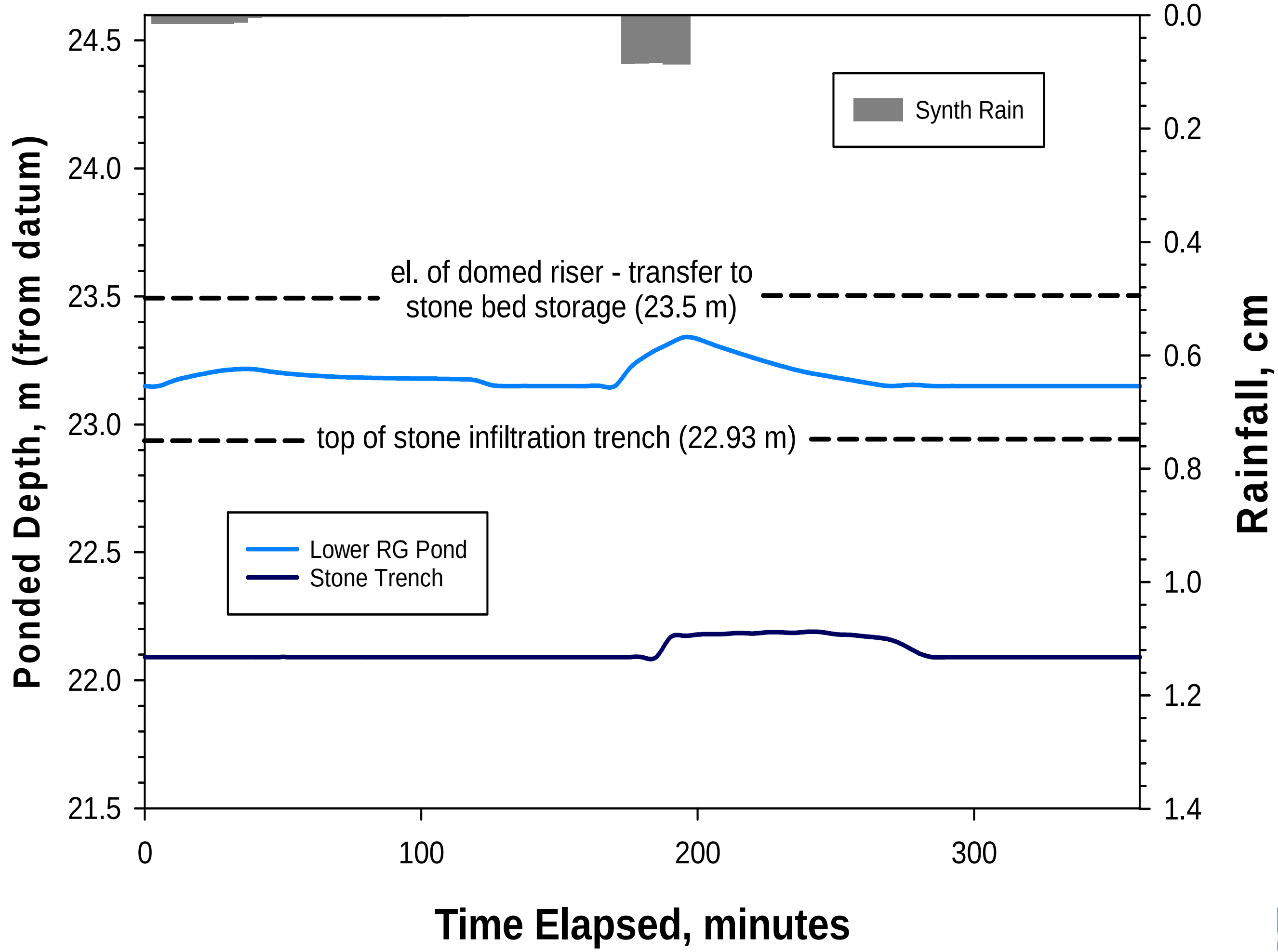


4.9 cm 1.9 in ~ 10 Hours

- Late peaking storm
- Exceed Design Vol
- Upper RG
  - Did not overflow
  - Excess capacity
- Lower RG
  - Did not overflow
  - Transfer pipe to rock bed barely used.
  - Excess Capacity

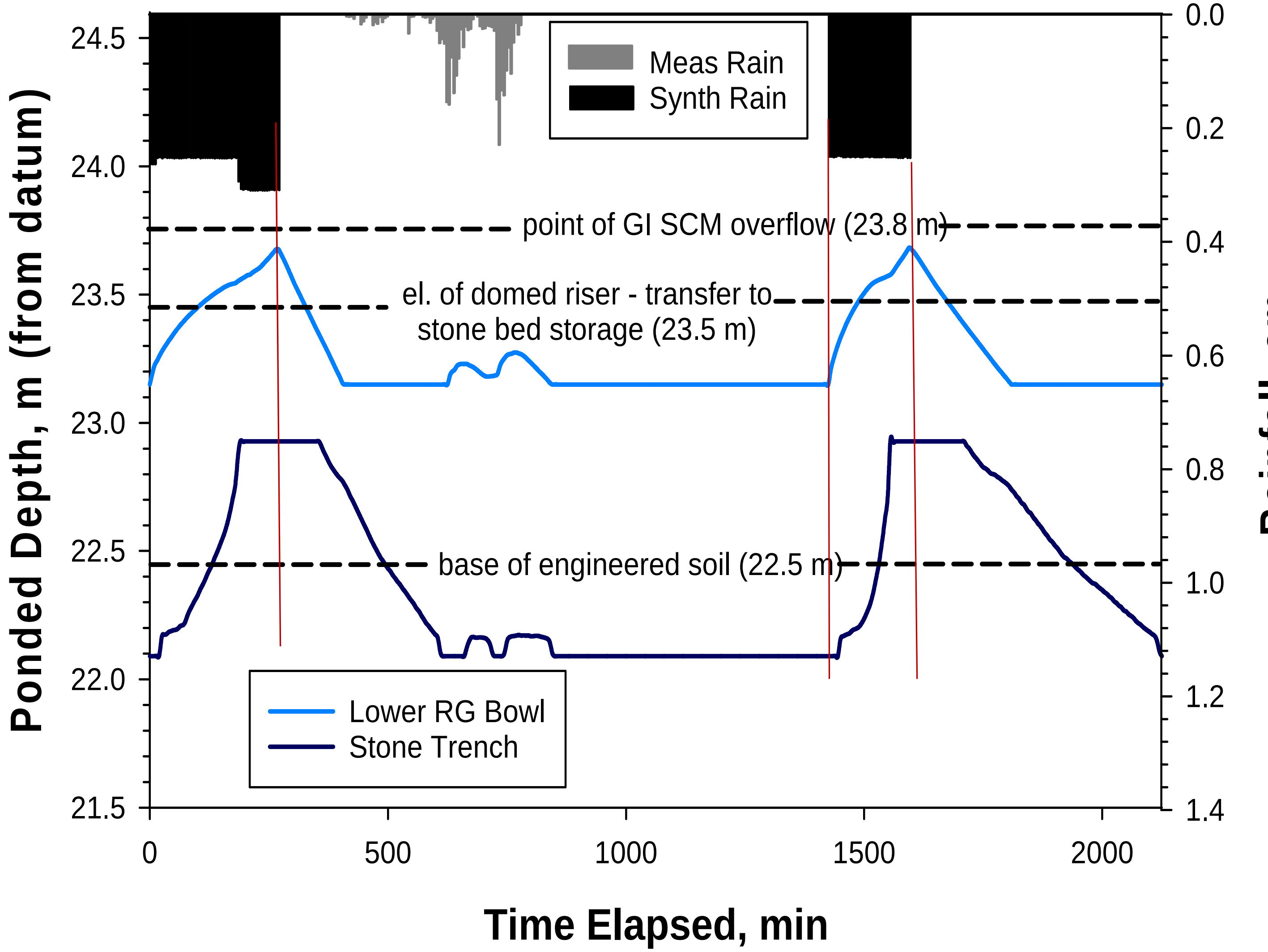


Back to Back 1.3 cm test



Back to Back Extreme Event

- SRT
- Day 1 - 7.6 cm – 3.0 in
- Night 1 - 2.6 cm - 1.0 in
- Day 2 - 5.1 cm –2.0 in
- Upper RG
  - Overflowed to Lower
- Lower RG
  - Transfer pipe to rock bed extensively used.
  - Did NOT overflow



Research Continues…

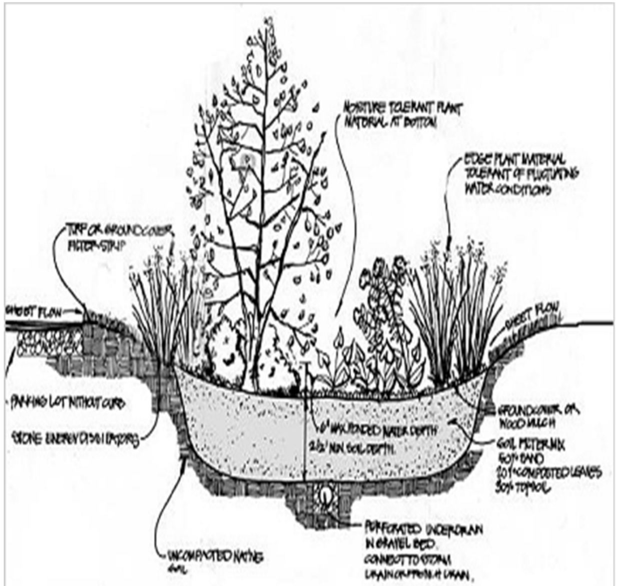
- Green stormwater infrastructure is a dynamic system.
  - Climate ⟳ Soil ⟳ Water ⟳ Plants
  - We need to design it that way.
- Static design underestimates performance,

and fails to take advantage of a sites potential.

Our research clearly shows that in order to take advantage of the full potential of GI, we must treat it as a system that integrates climate and surroundings in our designs. Doing so will allow us to set and achieve benchmarks that will maximize the potential of GI and integrate it with *broader concepts such as risk, resilience and sustainable communities.*

So, Yes!

Bioretention – 1990's?



(From The Bioretention Manual, Prince George's County, Maryland)

Tools - NRCS Type II Distribution – CN?
Vol - Static Design?
Peak -
% Removal by rate?

2020?

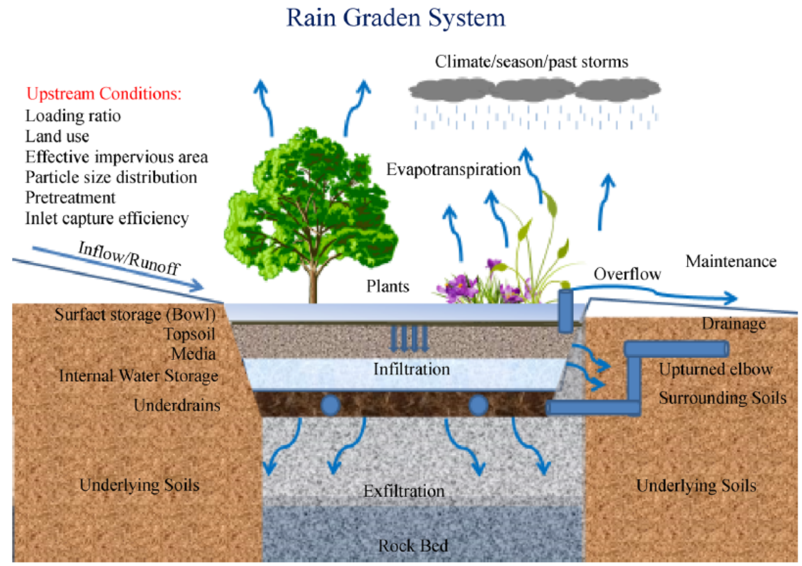


Fig. 2 Rain garden system (Drawing: Carla Windt)

Traver, R.G. & Ebrahimian, A. Front. Environ. Sci. Eng. (2017) 11: 15.
https://doi.org/10.1007/s11783-017-0973-z

Tools – Continuous Simulation (20 years?)
- Dynamic (Inf / ET / Maintenance?)
- Annual Loading

Acknowledgements

- Research funded by the US Environmental Protection Agency's Science To Achieve Results (STAR) program
- Philadelphia Water Department, Office of Watersheds: especially Jason Cruz, Stephen White, Chris Bergerson, and many, many graduate students and co-ops
- 319 NPS Program / NSF
- Villanova Faculty and Graduate Students.

Disclaimer: This presentation was developed under Assistance Agreement No. 83555601 awarded to Villanova University and has not been formally reviewed by EPA. The views expressed are solely those of Villanova University and do not necessarily reflect those of the Agency.

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