Perspectives on Low Impact Development (LID) Innovations at Multiple Scales: Oklahoma and Beyond

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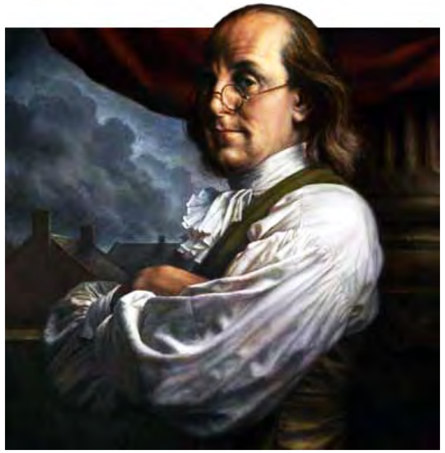
"…covering a ground plot with buildings and pavements, which carry off most of the rain and prevent its soaking into the Earth and renewing and purifying the springs … the water of wells must gradually grow worse, and in time be unfit for use as I find has happened in all old cities."

Benjamin Franklin, 1789



Painting by Michael J Deas

LID – An Engineer's Perspective

- The goal of *low impact development (LID)* is to reduce runoff and to **mimic a site's predevelopment hydrology** by infiltrating, filtering, storing, evaporating, and detaining stormwater runoff (EPA, 2000).
- The term *low impact development (LID)* refers to systems and practices that use or **mimic natural processes** that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat. (EPA website, 4/1/2018)

LID Design Goal:
Pre-development Runoff =
Post-development Runoff

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LID – A Landscape Architect's Perspective

- Water creates place.
- Enables the co-benefits of water in urban ecosystems services.
- Framework of innovation. *Corner, 1997*

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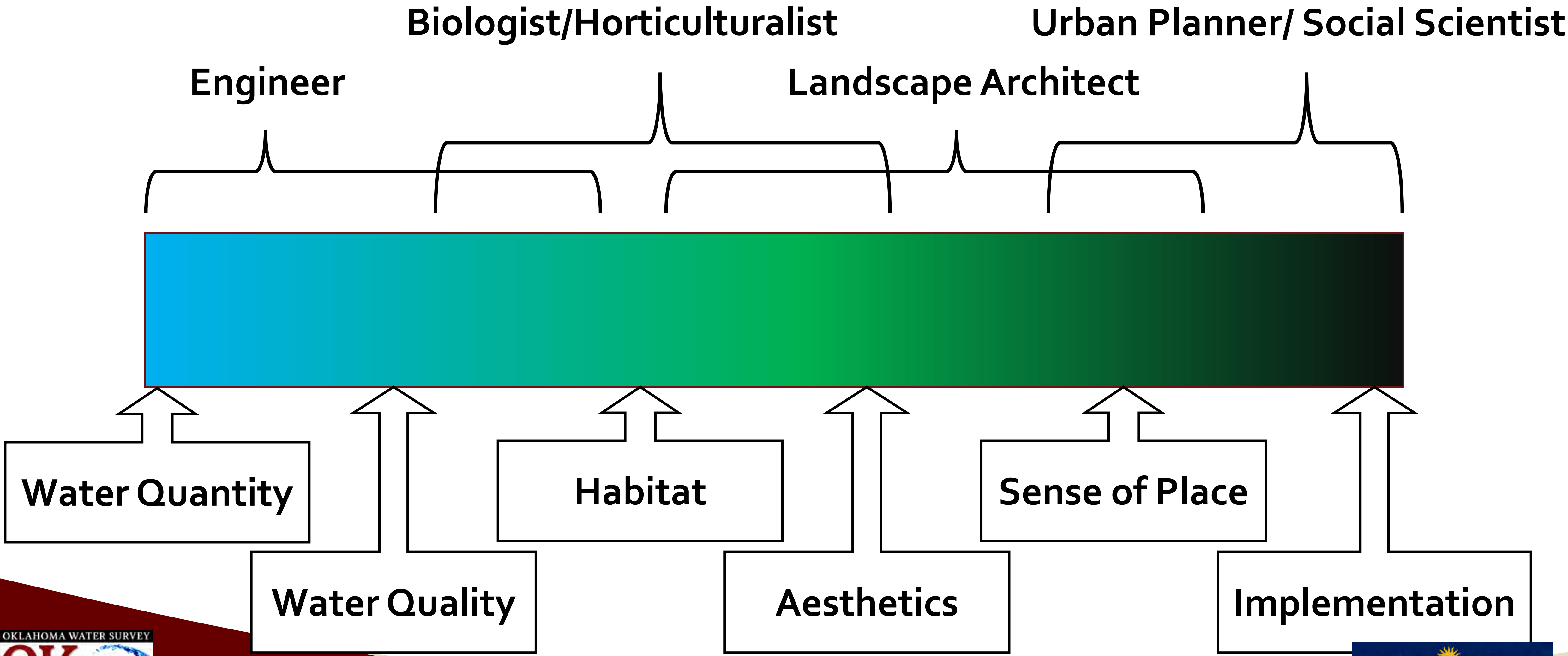
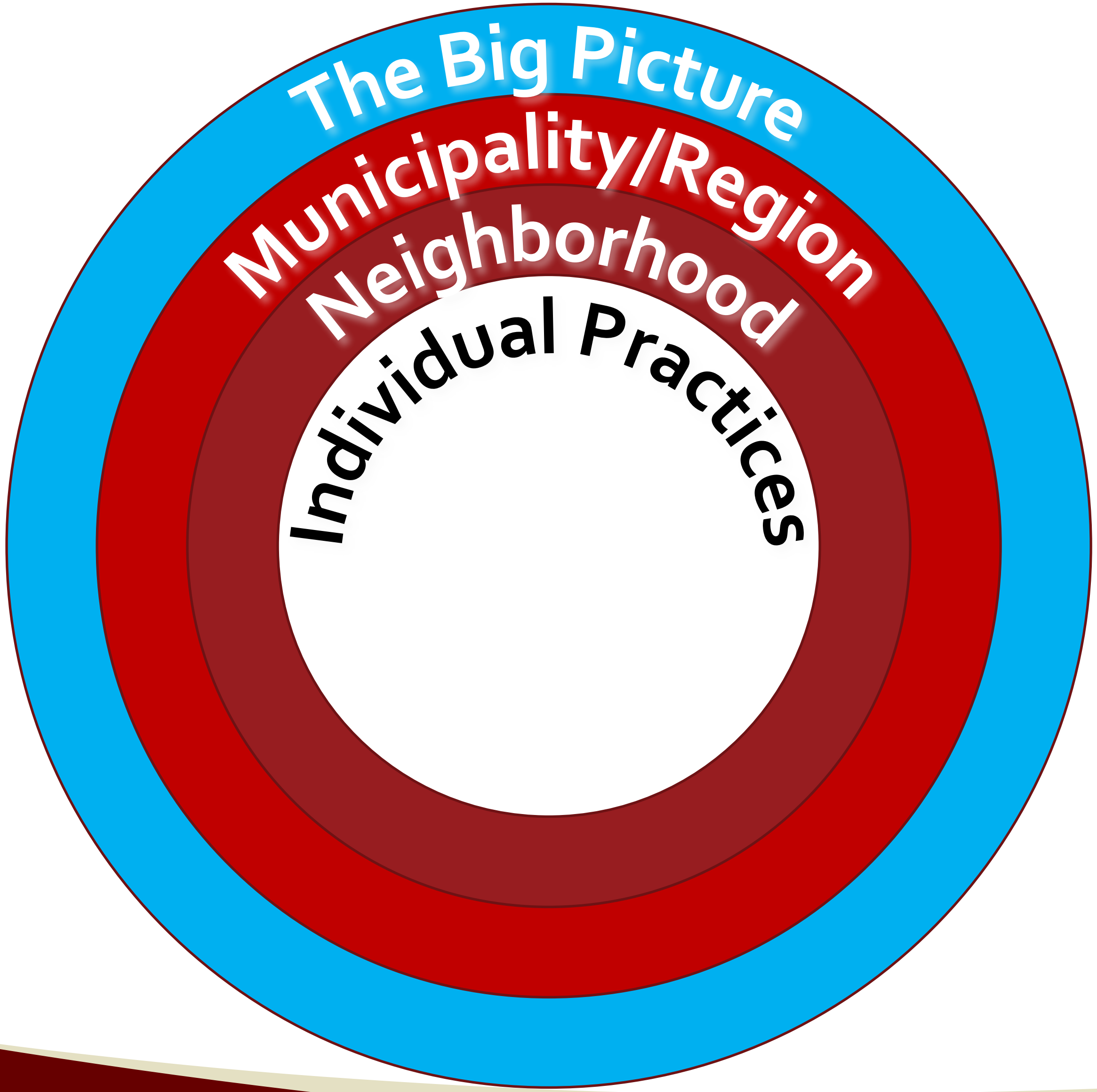
LID Continuum of Contributors



LID Innovations – Oklahoma and Beyond



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LID Innovations: the Individual Practice Scale

Individual Practices

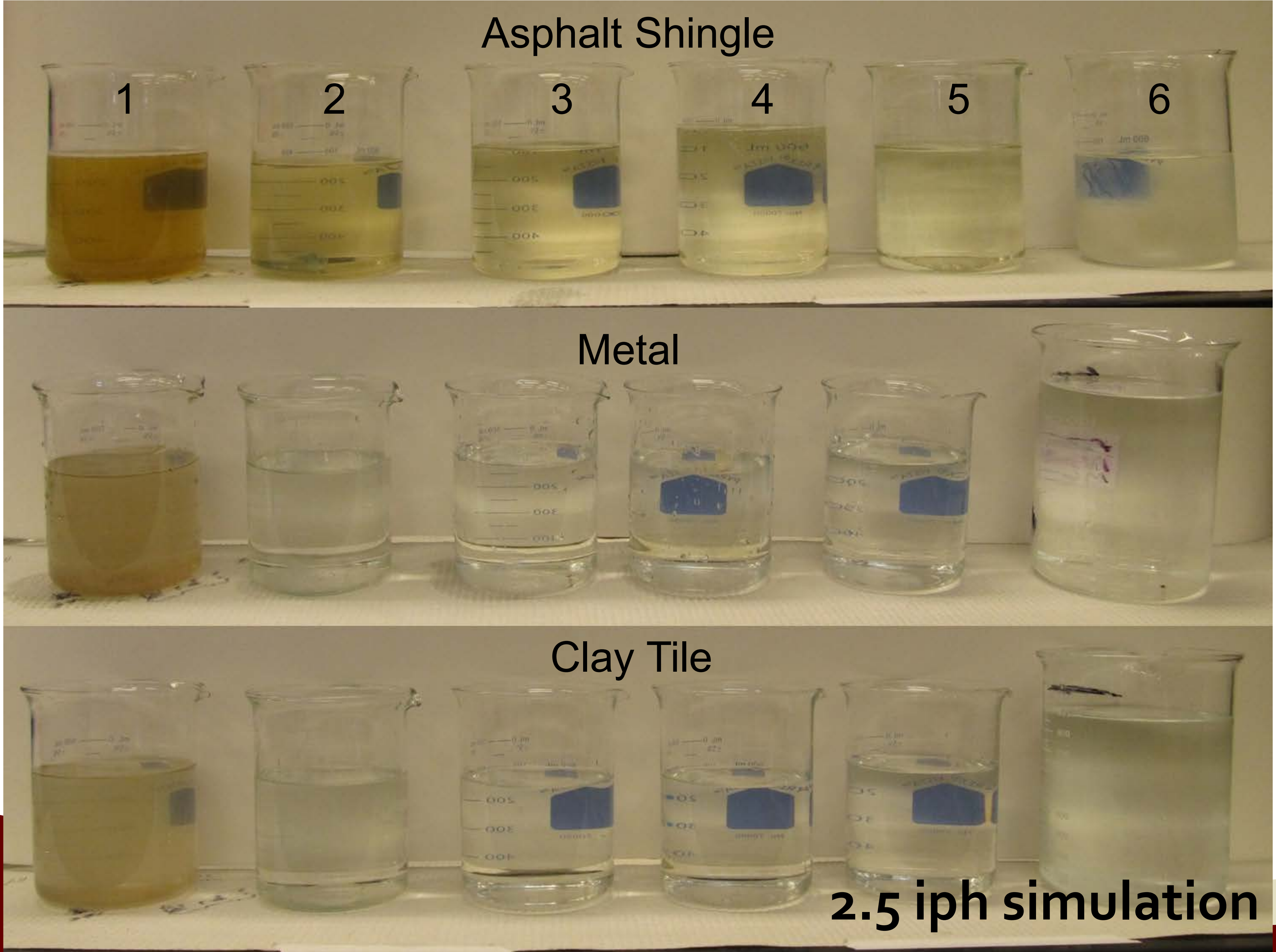
Individual Practices

First Flush Diverter Sizing

Objective: Investigate sizing of first flush diverters for rainwater harvesting.

- Background:
  - Majority of a rooftop's dust and debris is believed to be washed away during the "first flush"
  - Yaziz et al. (1989): 1.3 gallons/194 ft^2 galvanized-iron and concrete tile roofs
  - Martinson and Thomas (2005): Each mm of diverted rainwater halves contamination
  - *Texas Manual on Rainwater Harvesting* (2005): 1 – 2 gallons/100ft^2 of catchment area

Yet to be a universal consensus on what exactly constitutes a first flush



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USGS
science for a changing world

First Flush Diverter Sizing

TWDB Recommends 0.41 – 0.82 mm diversion

Percent Mass Removals	Asphalt Shingle (n = 93) Diversions (mm)	Metal (n = 110) Diversions (mm)	Clay Tile (n = 72) Diversions (mm)	Tar & Gravel (n = 22) Diversions (mm)
TSS	**92% CL**	**95% CL**	**93% CL**	**83% CL**
50%	3.0	4.6	1.0	1.1
75%	7.3	6.6	4.8	1.6
90%	10	12	8.3	2.1
95%	12	13	10	2.4
Commonly Detected PAHs	**90% CL**	**94% CL**	**90% CL**	**83% CL**
50%	2.3	0.95	0.67	0.52
75%	6.1	2.4	1.0	0.89
90%	12	6.6	1.2	1.2
95%	15	8.8	1.9	1.3
Carcinogenic PAHs	**90% CL**	**94% CL**	**90% CL**	**83% CL**
50%	2.4	0.92	0.63	0.52
75%	5.9	1.5	0.95	0.88
90%	8.0	2.3	1.1	1.2
95%	8.7	2.7	1.2	1.3
Fluoranthene	**90% CL**	**93% CL ***	**90% CL**	**67% CL ***
50%	4.7	1.0	0.71	0.20
75%	12	1.6	1.1	0.30
90%	16	6.0	1.7	0.36
95%	18	6.3	2.0	0.38
Benzo(a)pyrene	**90% CL**	**94% CL**	**0.43% CL [a]**	**74% CL ****
50%	2.7	0.78	0.60	0.42
75%	5.6	1.4	0.90	0.60
90%	8.1	2.0	1.1	0.72
95%	8.7	2.2	1.1	0.76

Upper Confidence Limits based on α = 0.2

*n = 5; **n = 6; ***n = 27; [a]All samples had same diversions for respective mass removal rate

Fly Ash for Enhanced Phosphorus Removal in Bioretention Cells

Individual Practices

- Find an inexpensive filter media with high P sorption.
    - Lab screening
    - 1-D modeling
- Construct the Grove BRC
    - Standardize design and document construction
    - Quantify filter media during construction
- Perform detailed 3-D modeling of “As-Built”
- Sample filter media and water to evaluate BRC performance after operating for seven years.

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Estimation of Load Reduction

Individual Practices

Regressions on the measured influent and effluent concentrations and flow, as a function precipitation, were used to estimate the total mass removal for 2015, using the full year rainfall.

Cell	Nitrogen (lb/yr)	P (lb/yr)	Sediment (ton/yr)
Elm Creek Plaza	2.02	0.38	0.15
Grove High School	0.80	0.32	0.38

Elm Creek Plaza BRC

Other work on these cells includes

Individual Practices

- Construction costs
- Construction standards
- Maintenance issues
- Planting
- Plant survival

- Initial water quality
- Initial hydraulics
- Current hydraulics
- Heavy metal removal
- Bacteria removal

Next Steps

- Investigating aggregated fly ash as an underdrain insert for P and heavy metal removal
- Exploring other additives

Constructed Wetlands for Treating Nursery Runoff

Individual Practices

Cedar Valley Nursery

Ada, OK

Constructed Wetlands for Treating Nursery Runoff

Individual Practices

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cedar valley NURSERIES

Precure Nursery & Garden Center

USDA

Non-pesticide Analytes in a Subsurface-flow Constructed Wetland

Individual Practices

Constituent	P-value	Number of Paired Samples	Mass Reduction
Runoff Volume	<0.001*	159	78%
Nitrate-N	< 0.001*	16	86%
Ortho Phosphate-P	< 0.001*	16	79%
Total Nitrogen	0.002*	14	85%
Total Phosphorus	< 0.001*	14	78%
Total Suspended Solids	0.002*	12	89%

* – Statistically significant with 95% confidence

Pesticide Mass Reduction
(compounds present for >50% of events)

Individual Practices

Compounds	P-value	Paired Samples	Mass Reduction
Chlorothalonil	0.009*	9	92%
Bifenthrin	0.004*	11	92%
Chlorpyrifos	0.036*	6	99%
Dimethanamid	0.009*	9	97%
Indaziflam	0.035*	7	86%
Isoxaben	0.021*	8	88%
Myclobutanil	0.004*	11	92%
Oxadiazon	0.004*	11	89%
Oxyfluorfen	0.295	6	74%
Pendimethalin	0.006*	10	79%
Propiconazole	0.004*	11	88%

Modeling Structured Gravel Parking

Individual Practices

Objective: Determine the appropriate initial abstraction (Ia) and curve number (CN) to use for designing structured gravel parking lots.

Hypothesis: The initial abstraction will be a function of the depth and porosity of the gravel, and the curve number will match that of the underlying soil

Curve Number Calculations

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$$I_a = 0.2S$$

$$CN = \frac{1000}{10 + S}$$

Q = Runoff Depth (inches)

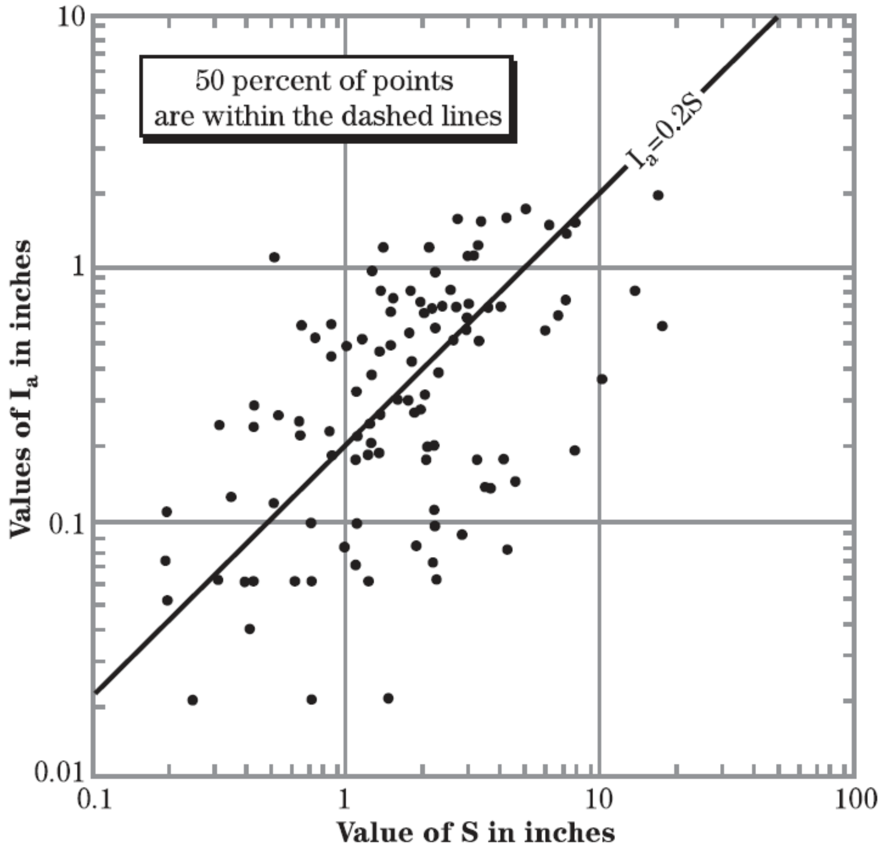
P = Rainfall Depth (inches)

S = Potential Maximum Retention

I_a = Initial Abstraction

CN = Curve Number

Relationship between Initial Abstraction (Ia) and Potential Maximum Retention (S)



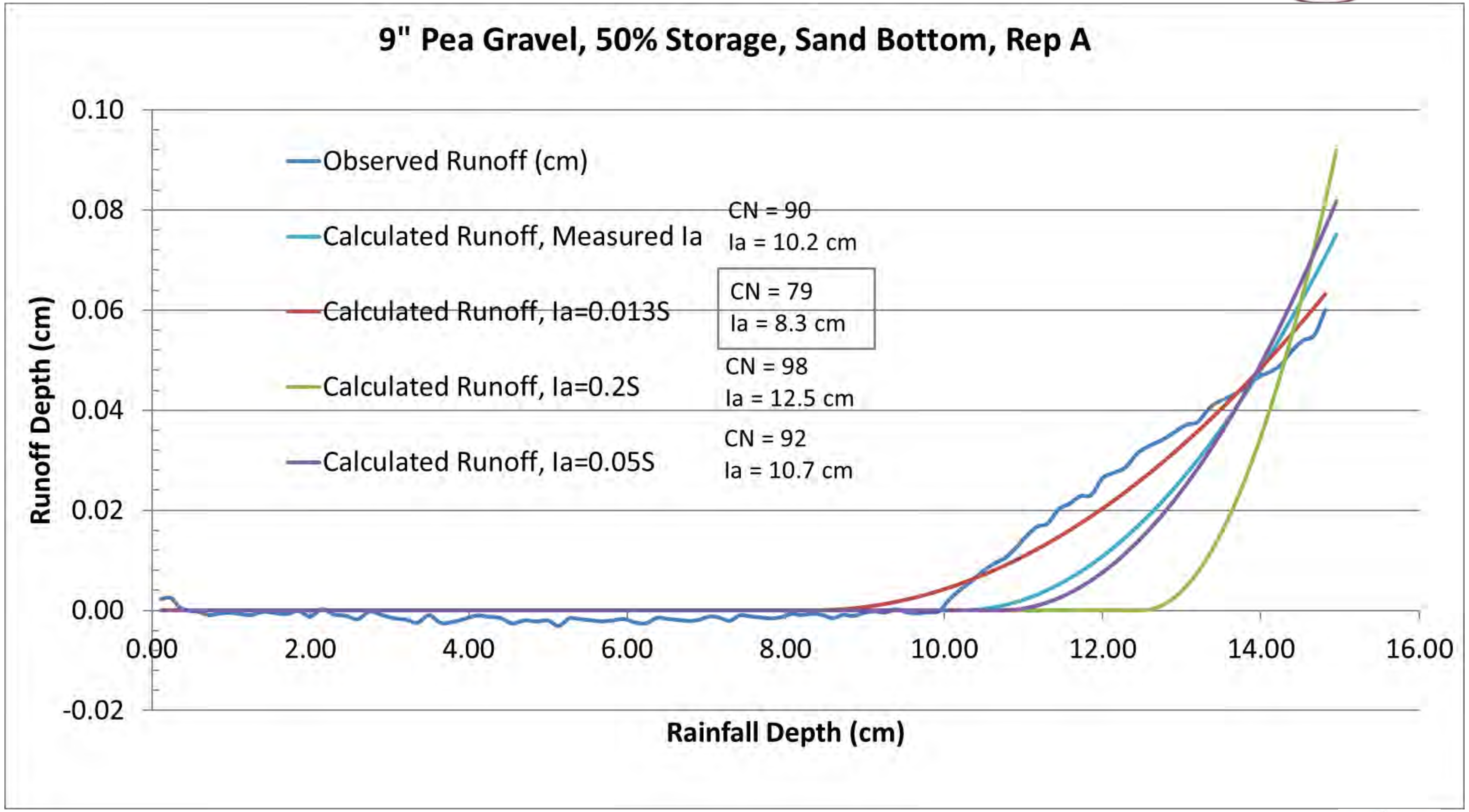
NRCS National Engineering Handbook Part 630

Modeling Structured Gravel Parking

Individual Practices

Issue: Is 0.2S the appropriate estimation for the Ia for gravel parking lots, when it was actually developed for soil?

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$



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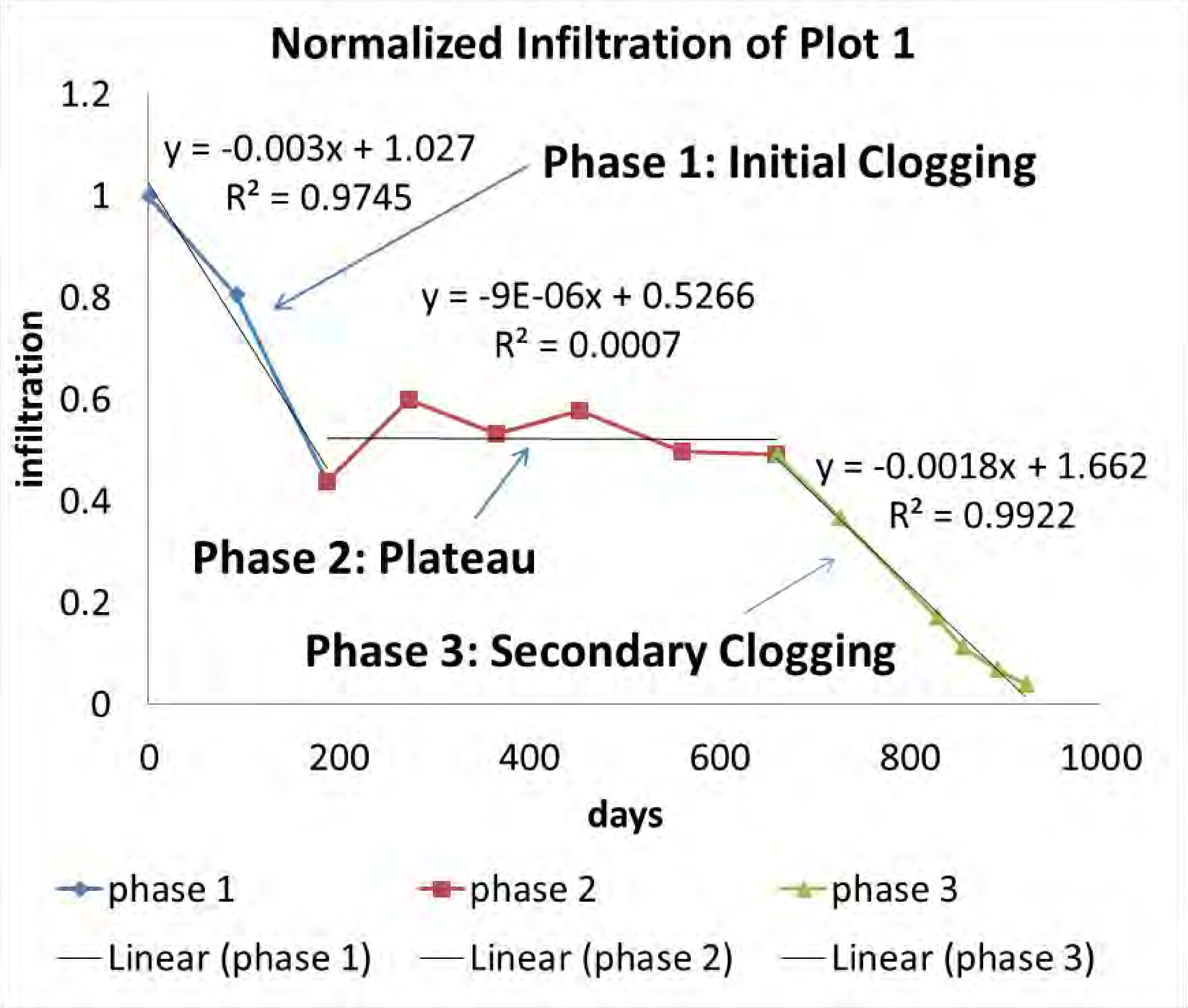
Long-term Clogging and Deep Cleaning of Pervious Concrete

Long-term Clogging

- Strongly Correlated to bulk density when installed



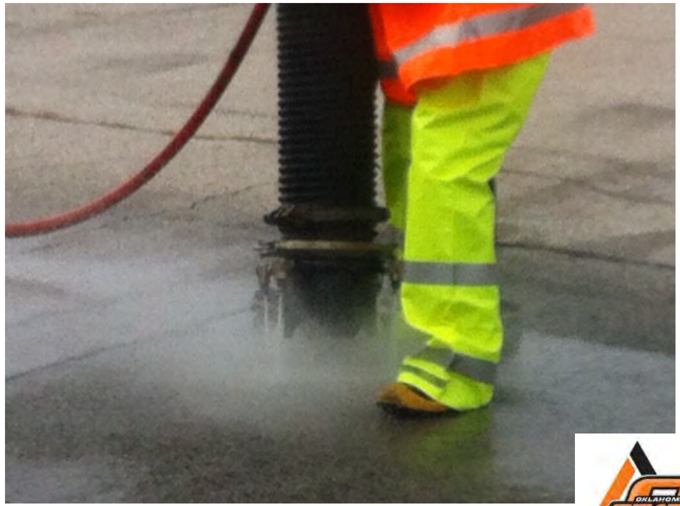
Deep Cleaning

1. Dry vacuum

2. Wet vacuum

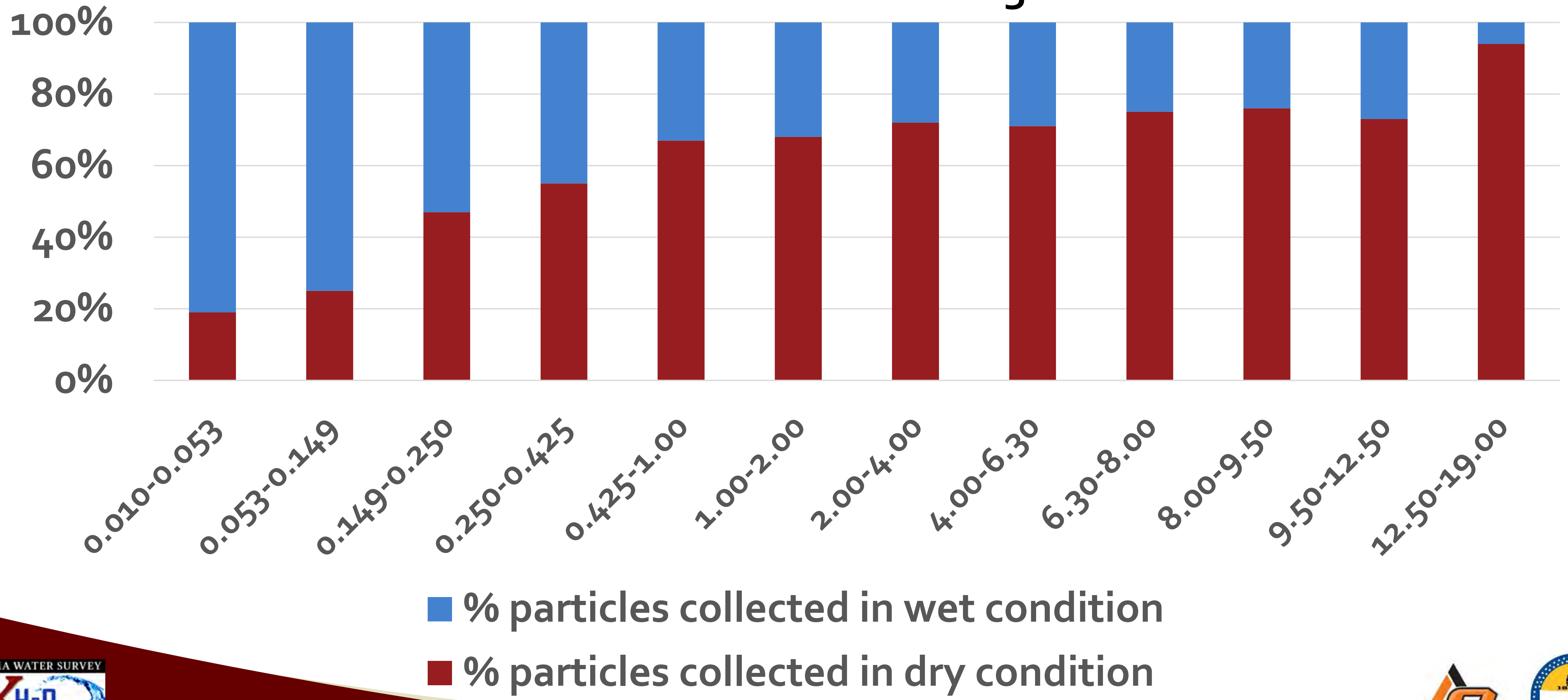
3 & 4. Vacuum sweeper (wet and dry)

5. Pressure wash and vacuum combination



Results

20 kg particle collected in dry cleaning, 14 kg particles collected in wet cleaning



Leaching from Compost Filter Socks

Individual Practices

Objective: Determine the leaching potential of compost filter socks based on the contaminant concentration of incoming runoff.

Hypothesis: Leaching of contaminants (specifically P) will be correlated to influent P and sediment.

↑ P Leaching = ↓ Influent P & ↓ Influent Sediment

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MINICK MATERIALS SINCE 1958 SOIL · STONE · SERVICE

Methods

- Amended ASTM method for testing silt fences
- Testing a factorial design of sediment and nutrients
- Completed testing on socks from Minnick Materials/Fertile Ground
- Plan to test from City of Midwest City.

Individual Practices

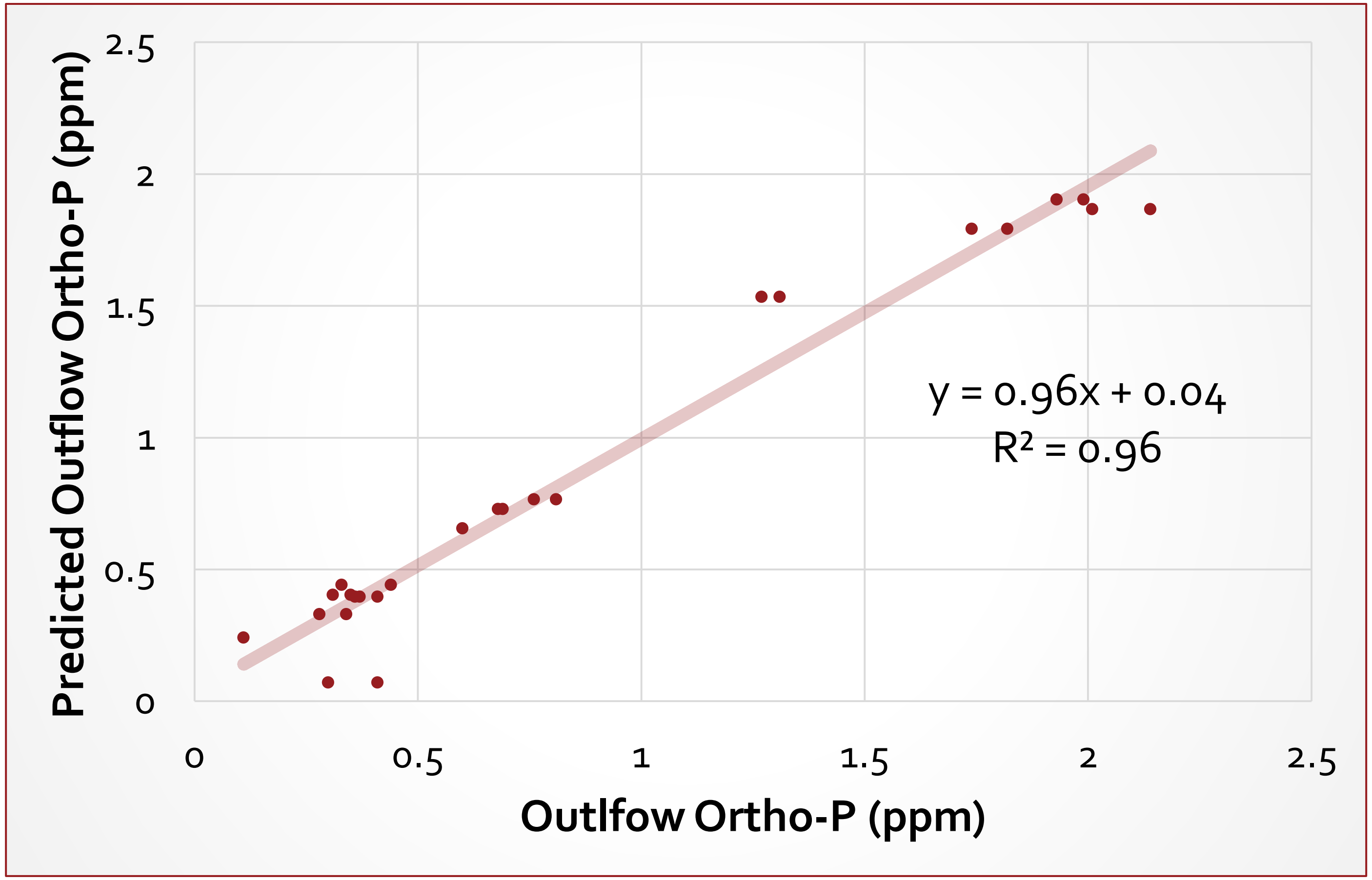
Preliminary Results

Individual Practices

- **Outflow ortho-P =**

  0.279 + 0.812(Inflow P) - 0.018(Inflow sed)

  - All p-values <0.01
  - R-squared = 0.96
  - All values are mg/L



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MINICK MATERIALS

Floating Wetland Breakwaters

Individual Practices

Objective: Design, test, install, and monitor a Floating Wetland Breakwater optimized for wave reduction to reduce shoreline erosion

(Photo: Martin Ecosystems)

NWC Experimental Green roof

Individual Practices

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Petra Klein, PhD
Associate Professor of Meteorology,
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Lee Fithian, LEED AP
Assistant Professor of Architecture,
University of Oklahoma

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Assistant Professor of Biosystems and Agricultural Engineering,
Oklahoma State University

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Fig. 1. Photos of (a) installation, (b) initial setup in May 2010, and (c) plant coverage in Spring 2012.

Individual Practices

Klein, P., and Coffman, R., 2015. Establishment and Performance of an Experimental Green Roof under Extreme Climatic Conditions. *Science of the Total Environment* Volumes 512–513, 15 April, Pages 82-93,

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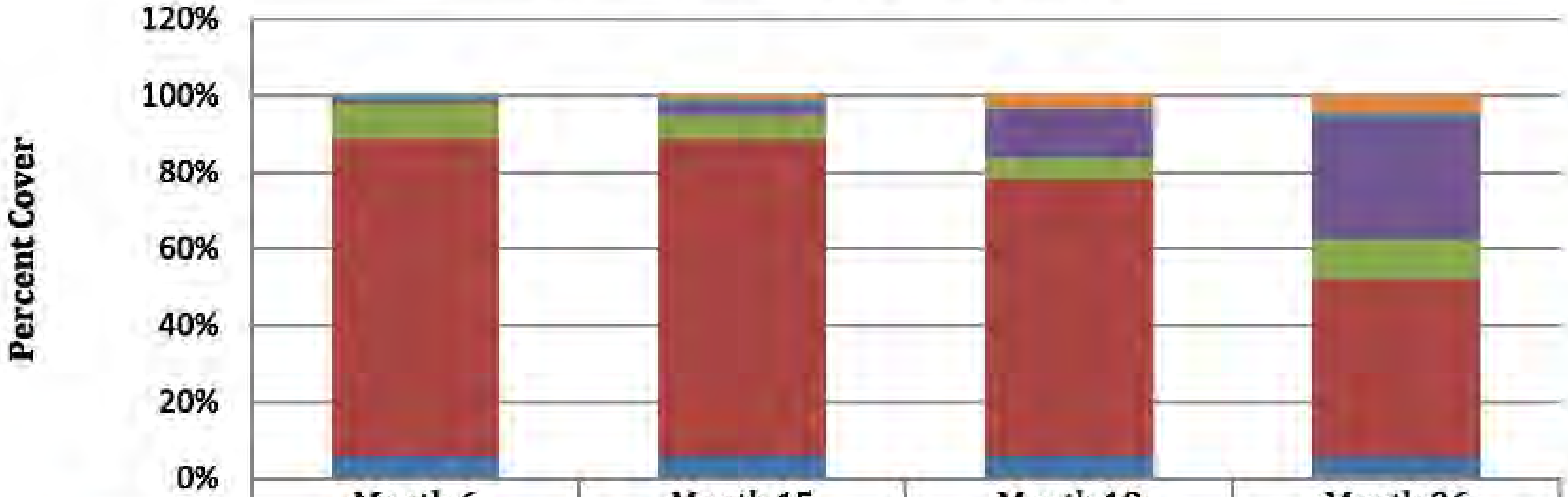
Individual Practices

Material Coverage of the Roof

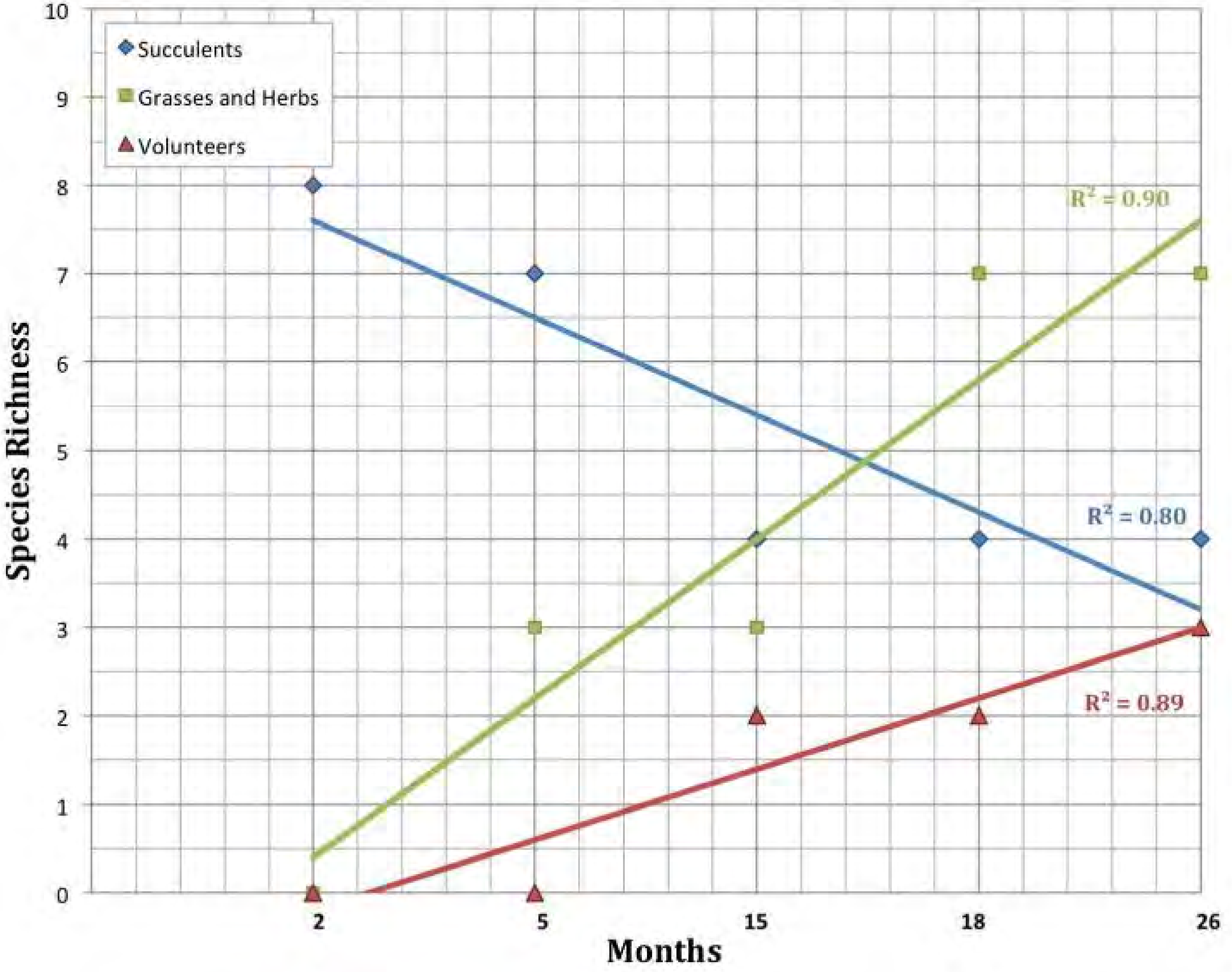


	Month 6	Month 15	Month 18	Month 26
Weeds	0.00%	0.84%	3.21%	4.49%
Wildflowers	0.87%	1.32%	0.30%	1.10%
Grasses	0.79%	3.24%	12.60%	31.63%
Succulents	9.25%	5.93%	5.70%	10.61%
Bare Soil	82.98%	82.66%	72.20%	46.43%
Black Plastic	6.00%	6.00%	6.00%	5.71%

Fig. 5. Surface coverage of materials showing a decreasing area of bare soils and increasing native grass cover during the initial 26 month establishment period.

Klein, P., and Coffman, R., 2015. Establishment and Performance of an Experimental Green Roof under Extreme Climatic Conditions. *Science of the Total Environment* Volumes 512–513, 15 April, Pages 82-93,


swbiodiversity.org


Succulents
Grasses and Herbs
Volunteers
Species Richness
Months
0
1
2
3
4
5
6
7
8
9
10
2
5
15
18
26
R² = 0.90
R² = 0.80
R² = 0.89

NEDlab
NOVEL ECOLOGY DESIGN LAB

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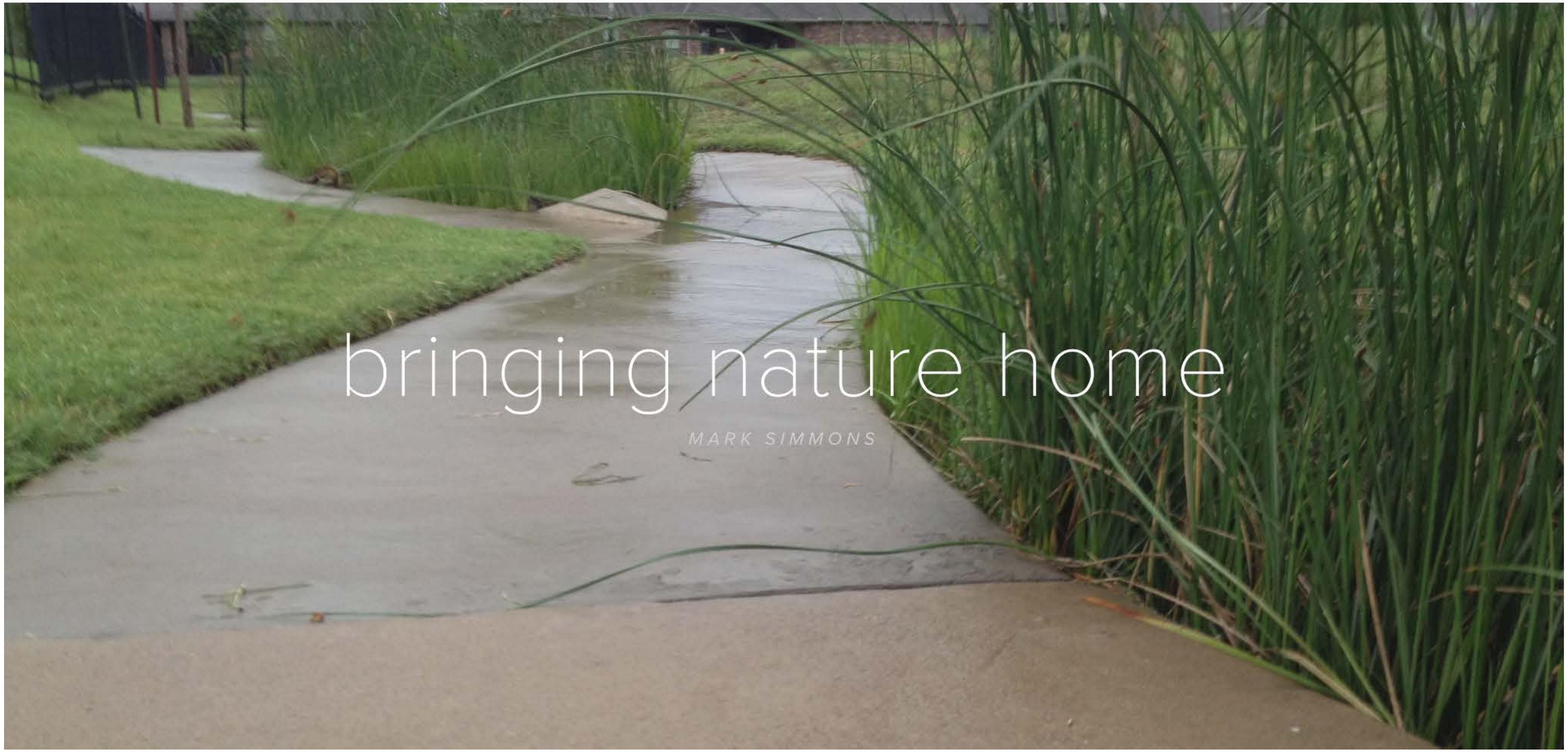
Individual Practices



www.NEDlab.org

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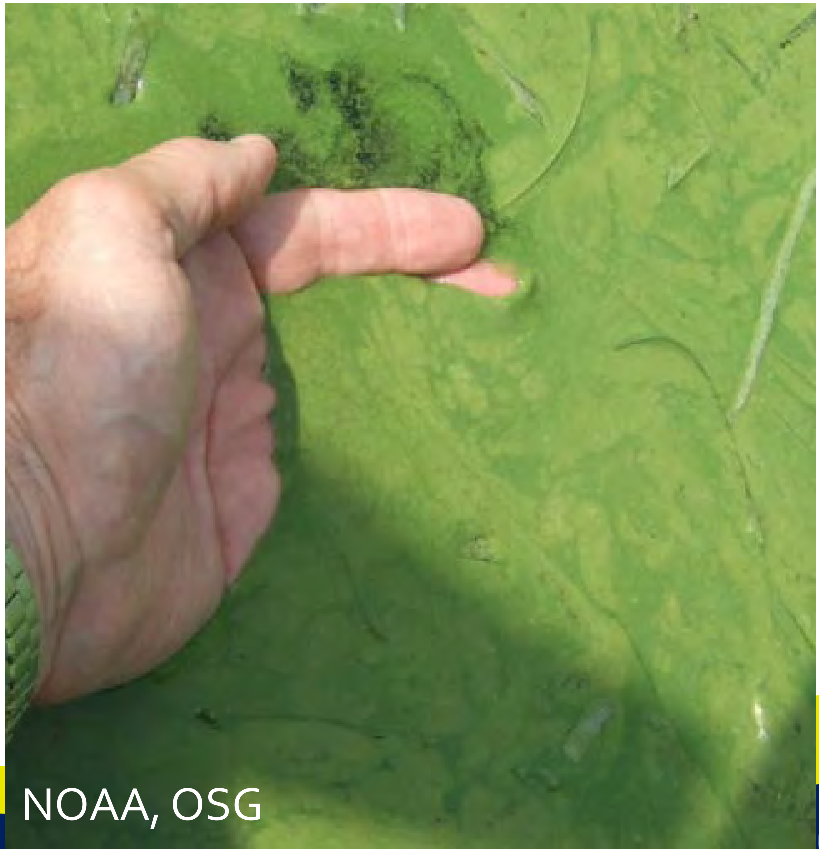
NASA Landsat 8 *September 26, 2017*

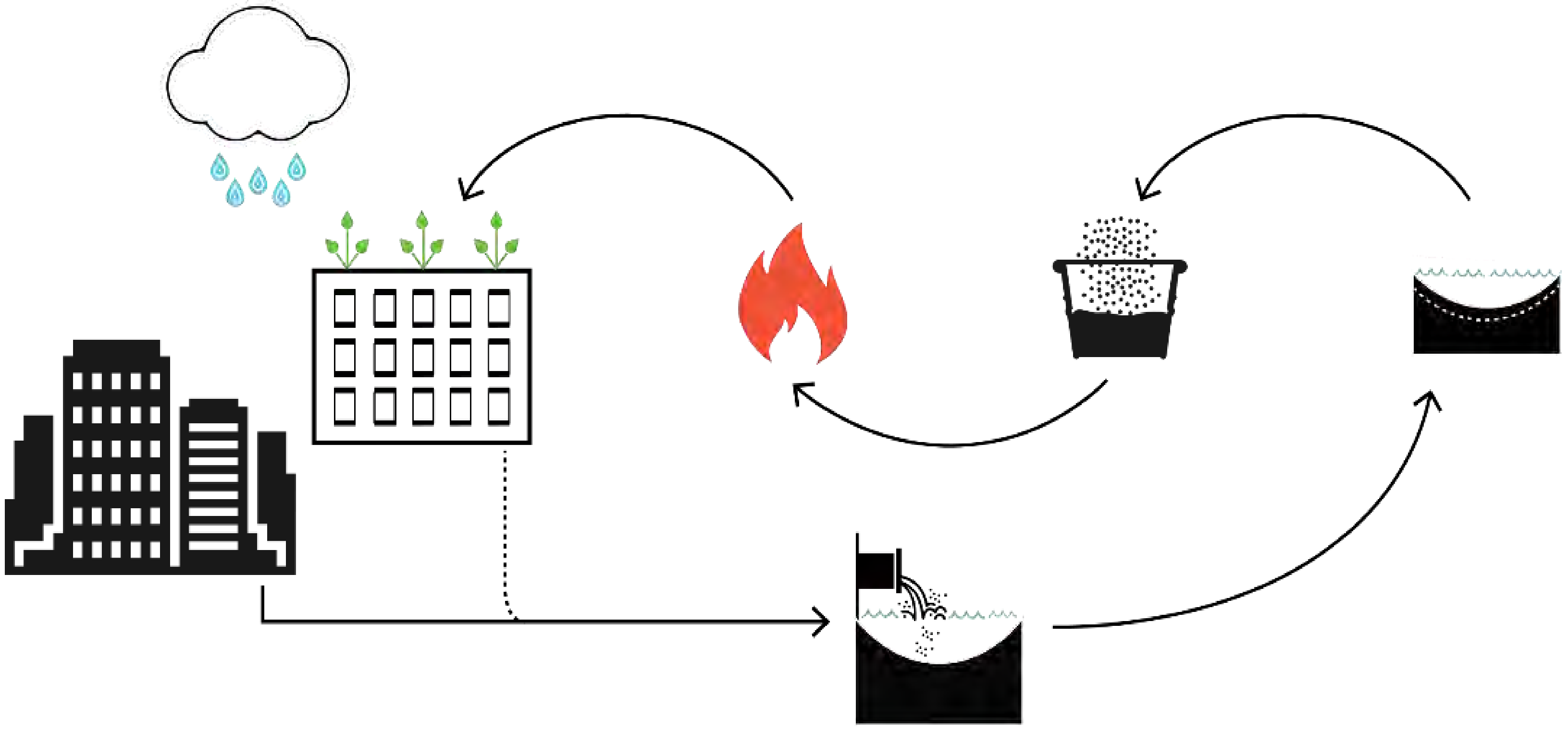
NASA Landsat



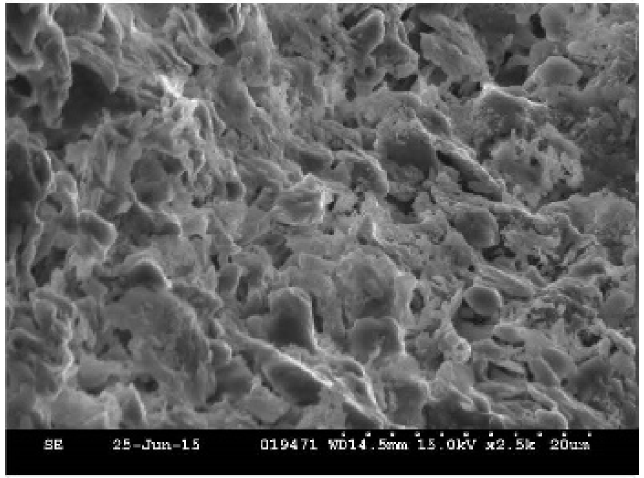
NOAA, OSG

wksu.org

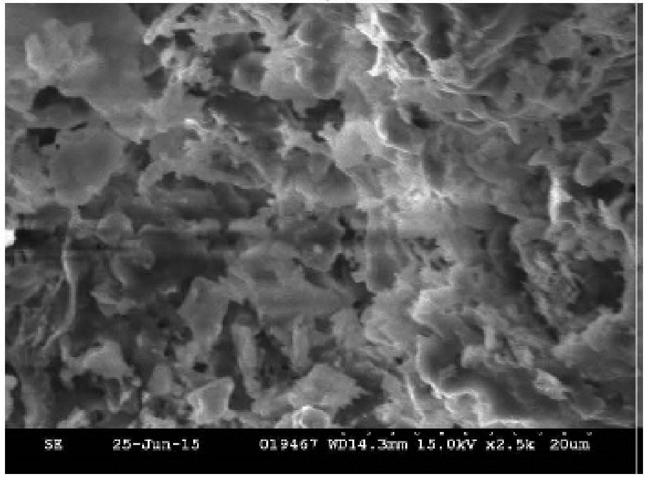
Beneficial Dredge Re-Use



Materials 2016, 9, 611



(a) S2_5%_1000



(c) S2_5%_1100

Greater Hydrologic Retention

Growing Rare Plants

Violia peditifida

Solidago ptarmicoides

Moos Lake Water Plant 1914 *Zurich, Switzerland*

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Co-Benefit Biodiversity Roofs

- 5 year agreement
- Design **speculative habitat** roofs and other forms of living architecture based on bedrock remnant prairies in NE Ohio.

The Future of LID Innovation on Individual Practices

Individual Practices

Engineering

- Amendments
- Investigating the role of plants
- Greenroof plants for Oklahoma
- Designing for maintenance
- Optimizing underdrain design for water quality
- Optimizing co-benefits

Landscape Architecture

- Ecologically productive buildings
- Regionally distinctive site practices
- Plant selection/performance

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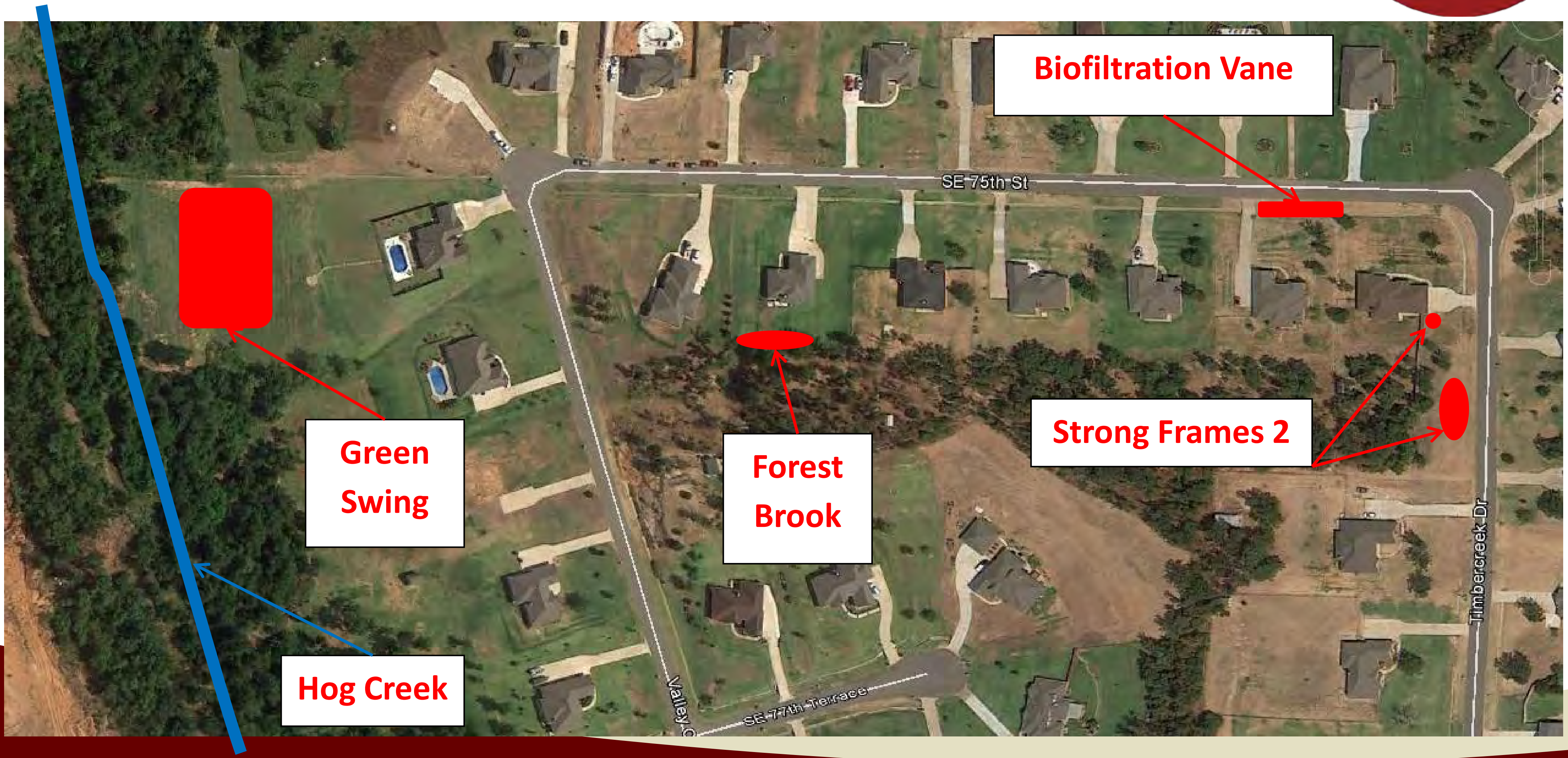
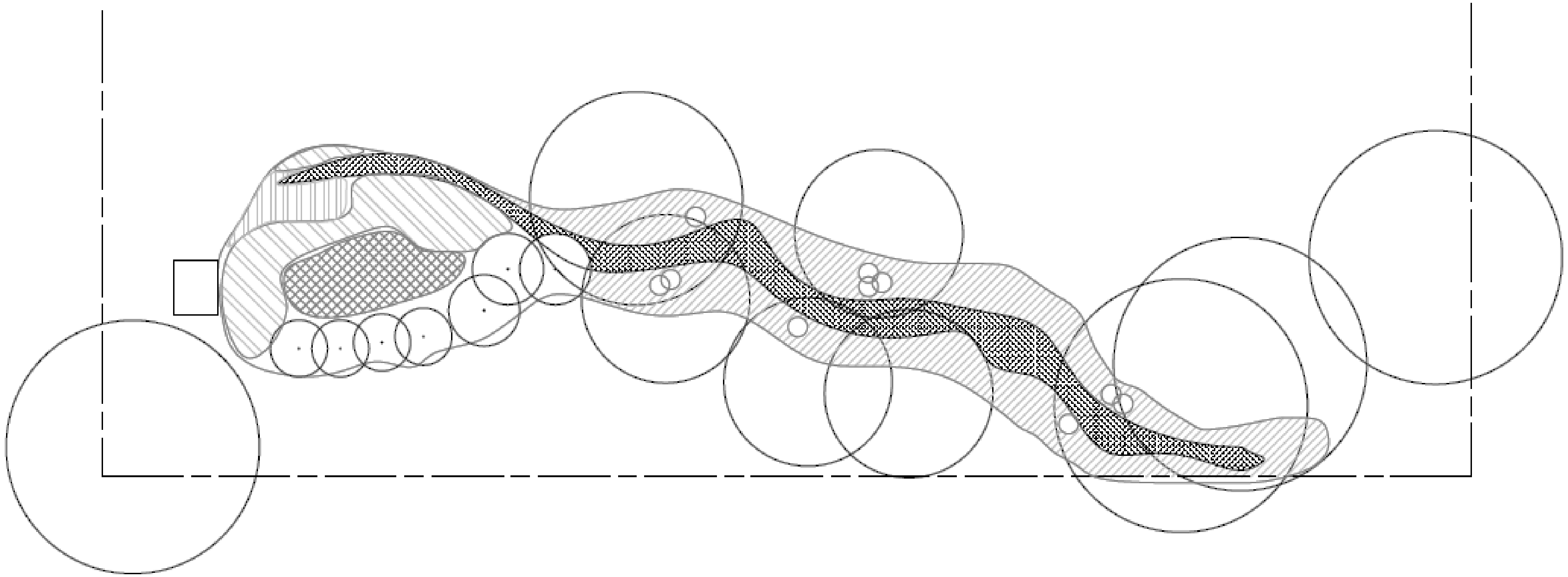
LID Innovations: the Neighborhood Scale

Deerfield Estates Neighborhood Retrofit



‘Forest Brook’ Concept

- *This concept provides the personal feature of a stone stream channel meandering within a forested garden setting.*
- 360 ft^2 rain garden with no underdrain in residential back yard with dry creek bed channel to reduce erosion on higher slope; Cost = $8K



‘Forest Brook’ After Construction

Neighborhood
Individual Practices

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‘Forest Brook’ the next year

Neighborhood
Individual Practices

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Biofiltration Vane

Neighborhood Individual Practices

Bioretention

+

Grass swale

+

Cross vane

Kestonestream.org

Retention, infiltration, and treatment

Handle higher flow velocities

Natural grade control structure

=

Biofiltration vane

- Retention/infiltration
- Treatment
- Stormwater drainage

Biofiltration Vane

Neighborhood
Individual Practices

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Biofiltration Vane

Neighborhood
Individual Practices

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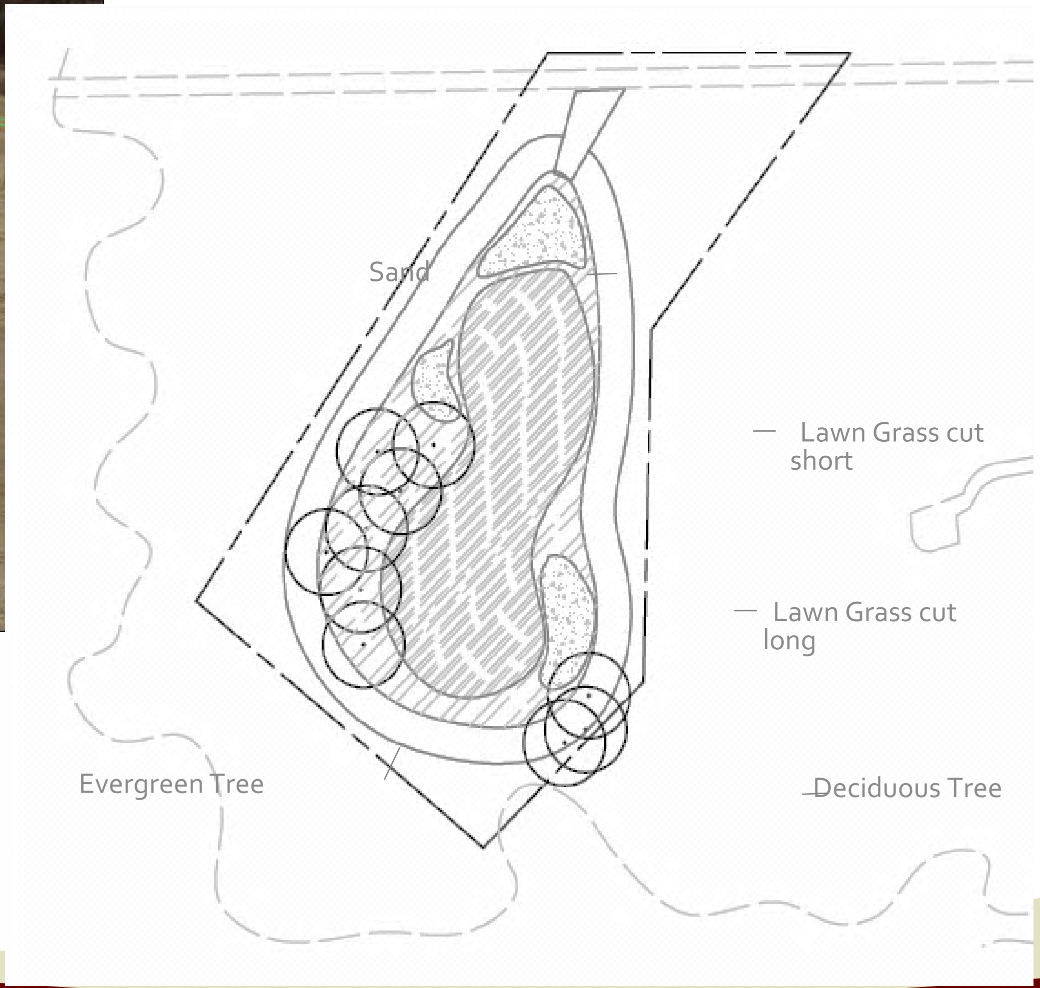
'Green Swing' concept

Neighborhood Individual Practices



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‘Green Swing’ construction

- Golf green look and function

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'Green Swing' a year later

Neighborhood
Individual Practices

- Reduction of:
  - Bacteria
  - Phosphorus
  - Sediment

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TRAILWOODS Greenstreet BMP

Neighborhood Bioretention Project

Neighborhood Individual Practices

Multiple Benefits

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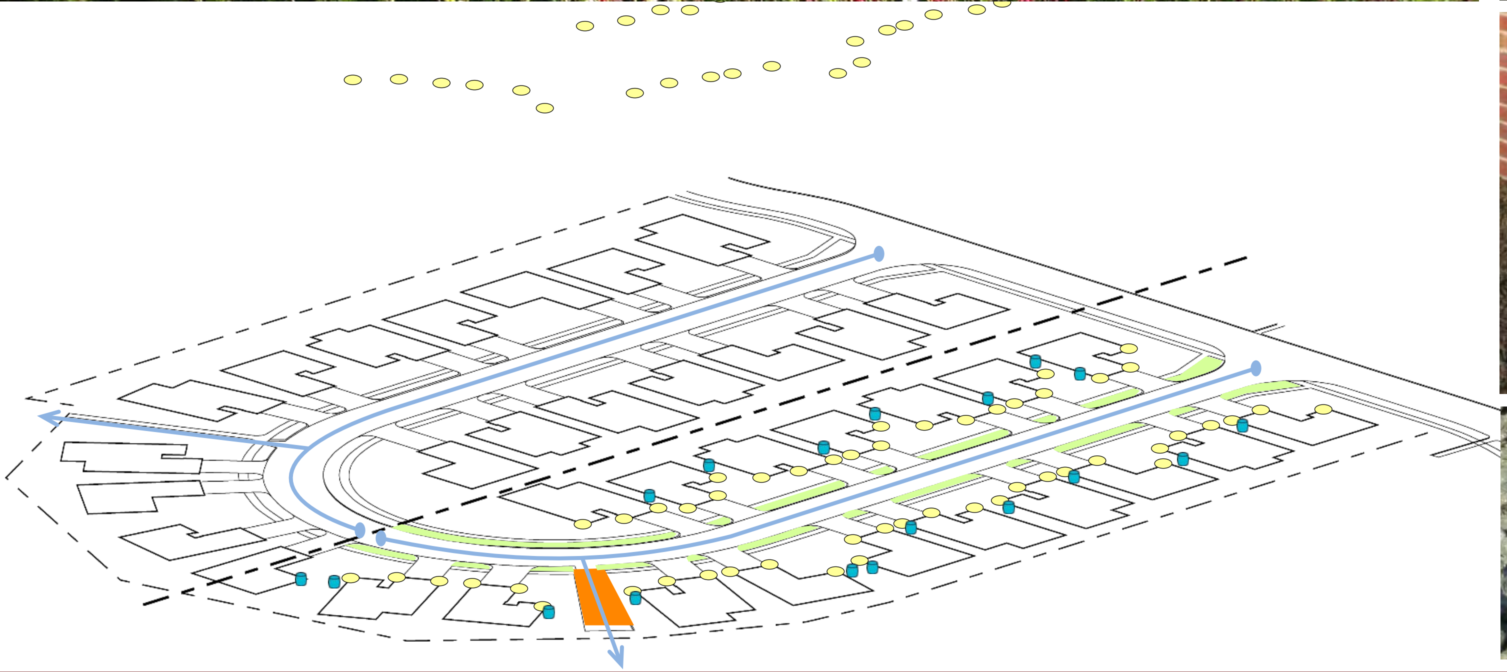
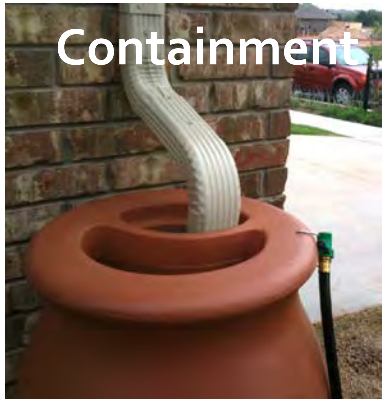
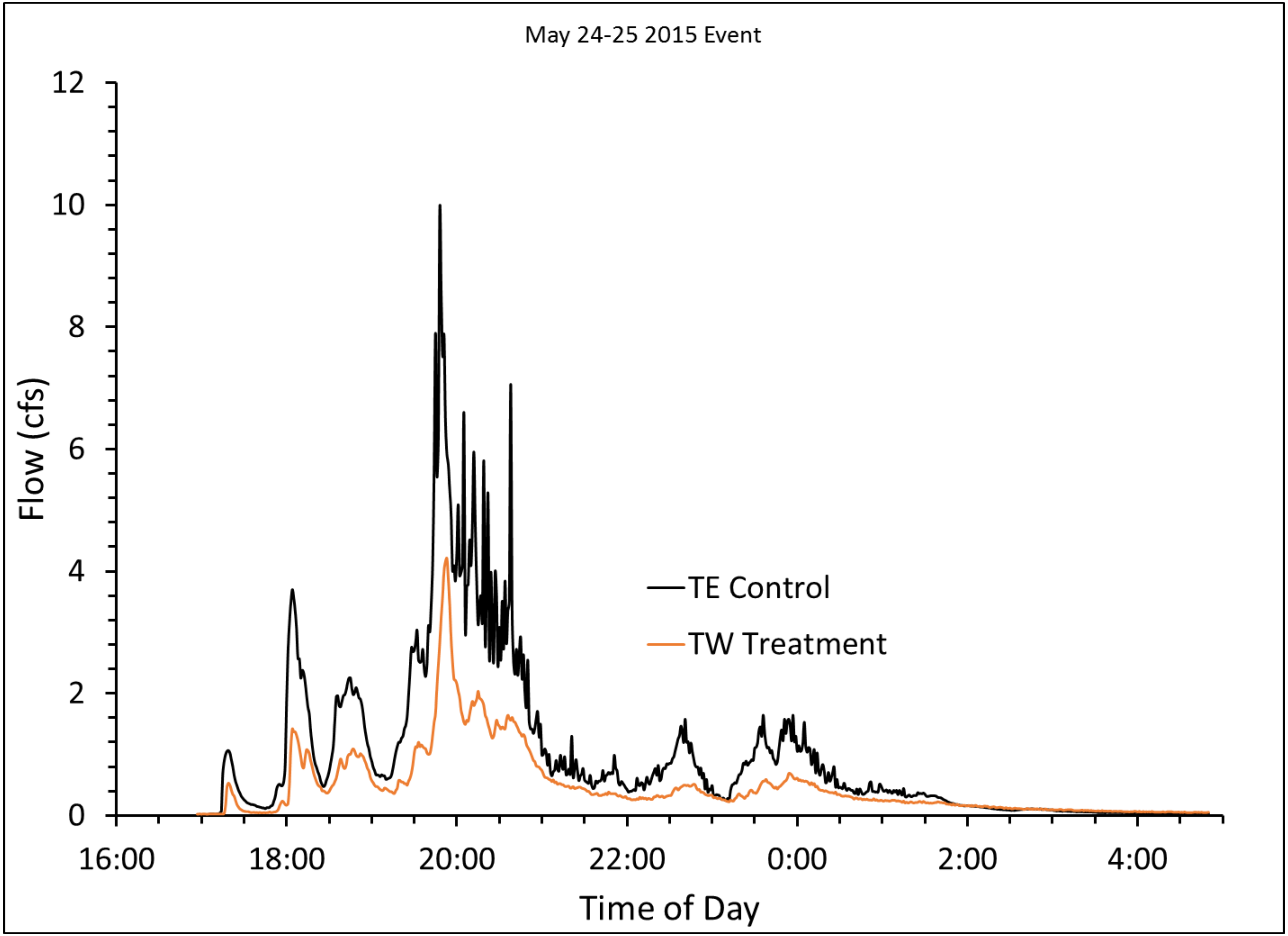
Neighborhood
Individual Practices



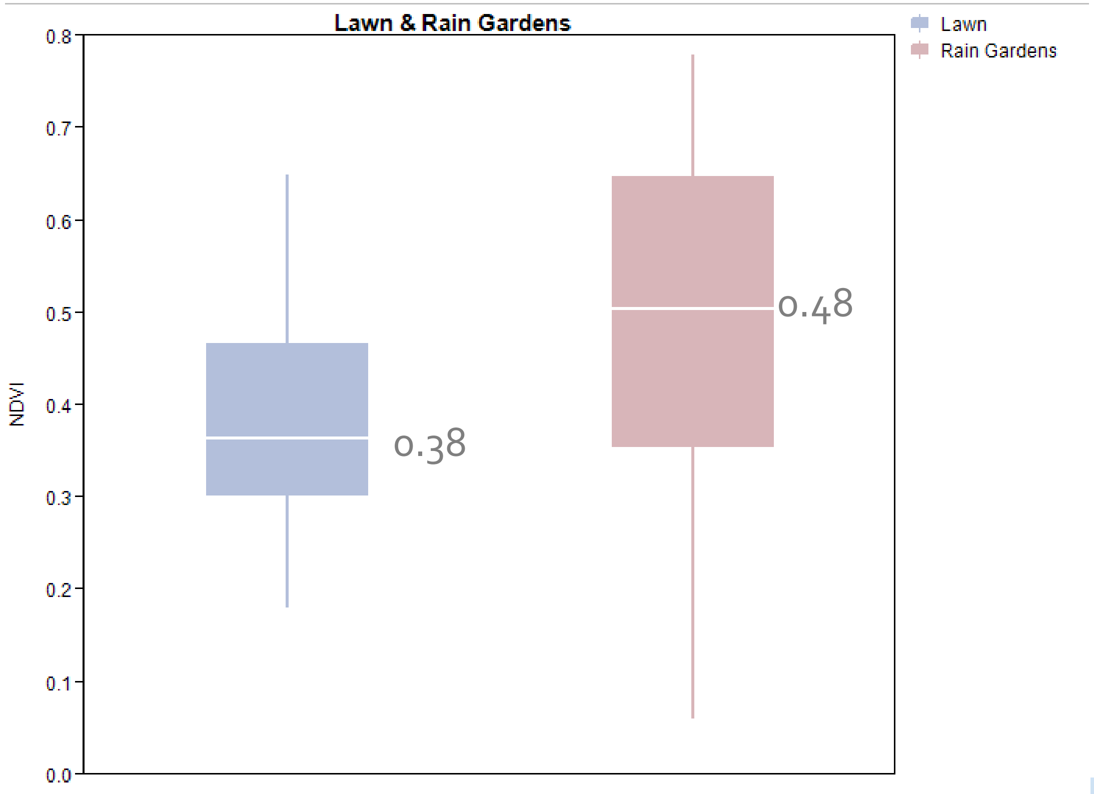


Peak Discharge Reduction



Nairn, OCLWA 2016

Performance



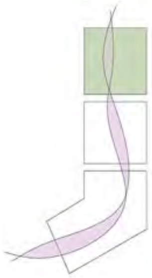
Lawn	0.38	t-Ratio	-3.37293
Rain Gardens	0.485	DF	55
Mean Difference	-0.105	Prob > |t|	0.0014*
Std Error	0.03113	Prob > t	0.9993
Upper 95%	-0.0426	Prob < t	0.0007*
Lower 95%	-0.1674		
N	56		
Correlation	-0.1653		

- Higher ecological and biological processing that conventional tree lawns (NDVI)

The rain gardens possessed a higher mean NDVI (0.48) when compared to the lawn (0.38), $t(55) = 3.38$, $p < .001$) using JMP software

Plant Palette

Prairie



Stonecrop Sedum
Sedum acre 'Arabicus'

Dwarf Fountain Grass
Pennisetum alopecuroides

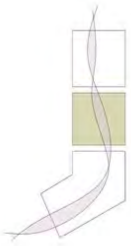
Dwarf Japanese Juniper
Juniperus procumbens 'Nana'

Autumn Sage
Salvia greggii

Wormwood
Artemisia 'Powis Castle'

Desert Willow
Chilopsis linearis

Parkland



Mexican Primrose
Oenothera macrocarpa

Little Blue Stem
Schizachrium scoparium

Bermudagrass
Cynodon spp.

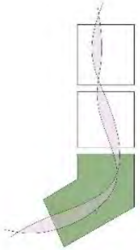
Daylily
Hemerocallis 'Aztec Gold'

Broadmore Juniper
Juniperus sabina 'Broadmore'

Russian Sage
Perovskia atriplicifolia

Common Redbud
Cercis canadensis

Forest



Garden Verbena
Verbena canadensis 'Homestead Purple'

Big Blue Liriope
Liriope muscari 'Big Blue'

Purple Coneflower
Echinacea purpurea

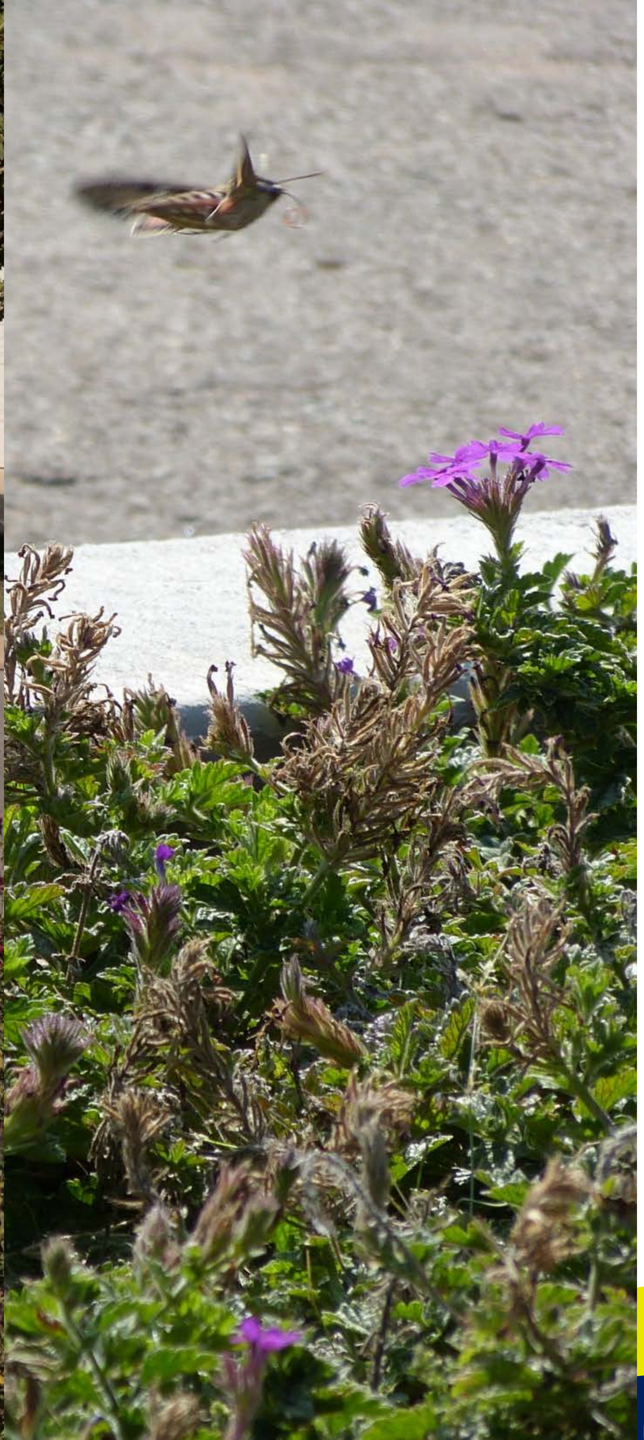
Riverbirch
Betula nigra

Cedar Elm
Ulmus crassifolia

Loblolly Pine
Pinus taeda

London Planetree
Plantanus x hisanica

The LORAX
By
Dr. Seuss

The Future of LID Innovation at the Neighborhood Scale

Neighborhood
Individual Practices

Engineering

- Integrated modeling
- Treatment Trains
- Big Data

Landscape Architecture

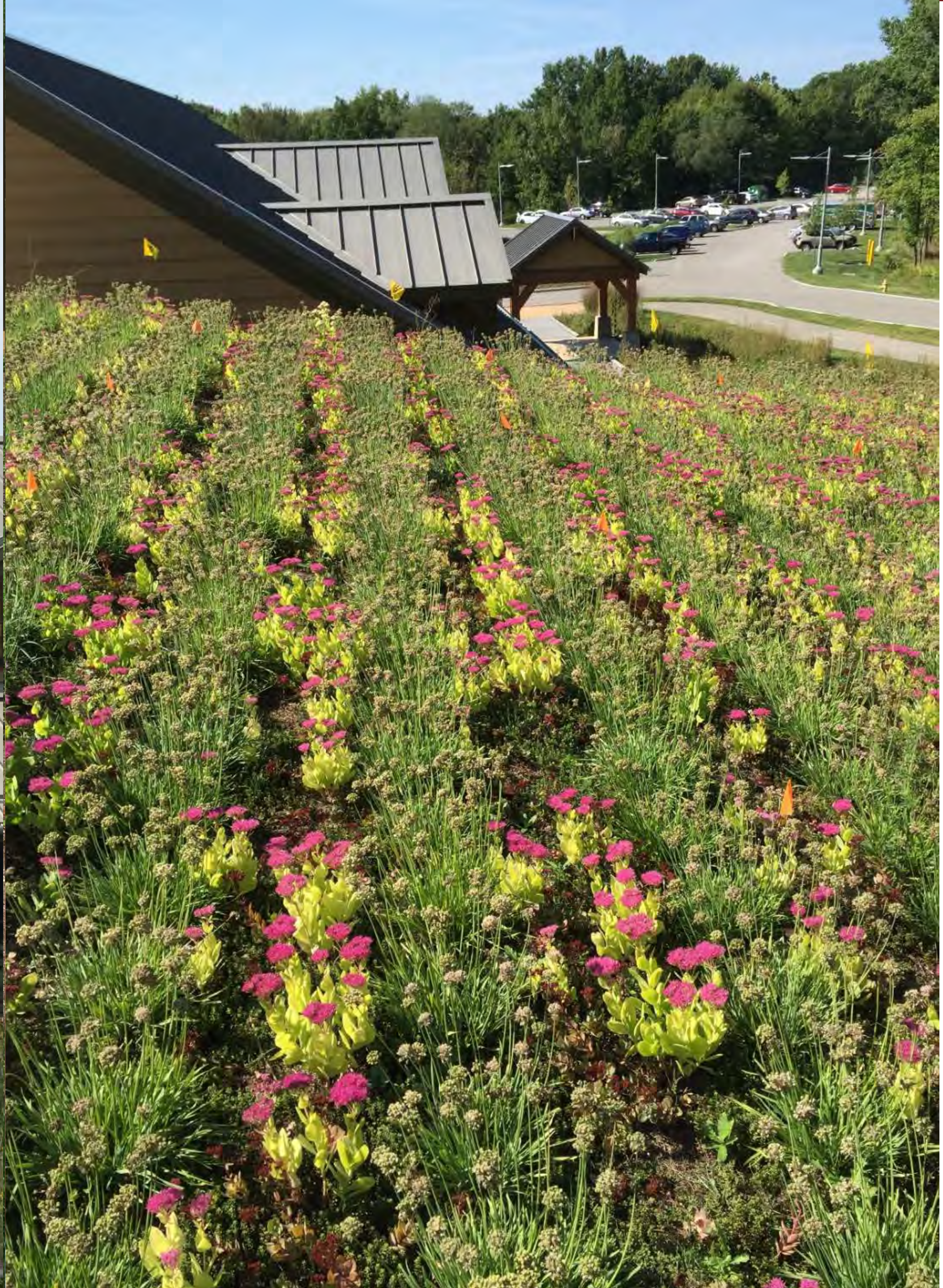
- Public Space
- Identity and Purpose
- Aesthetics of Place

LID Innovations: the Municipality/Regional Scale

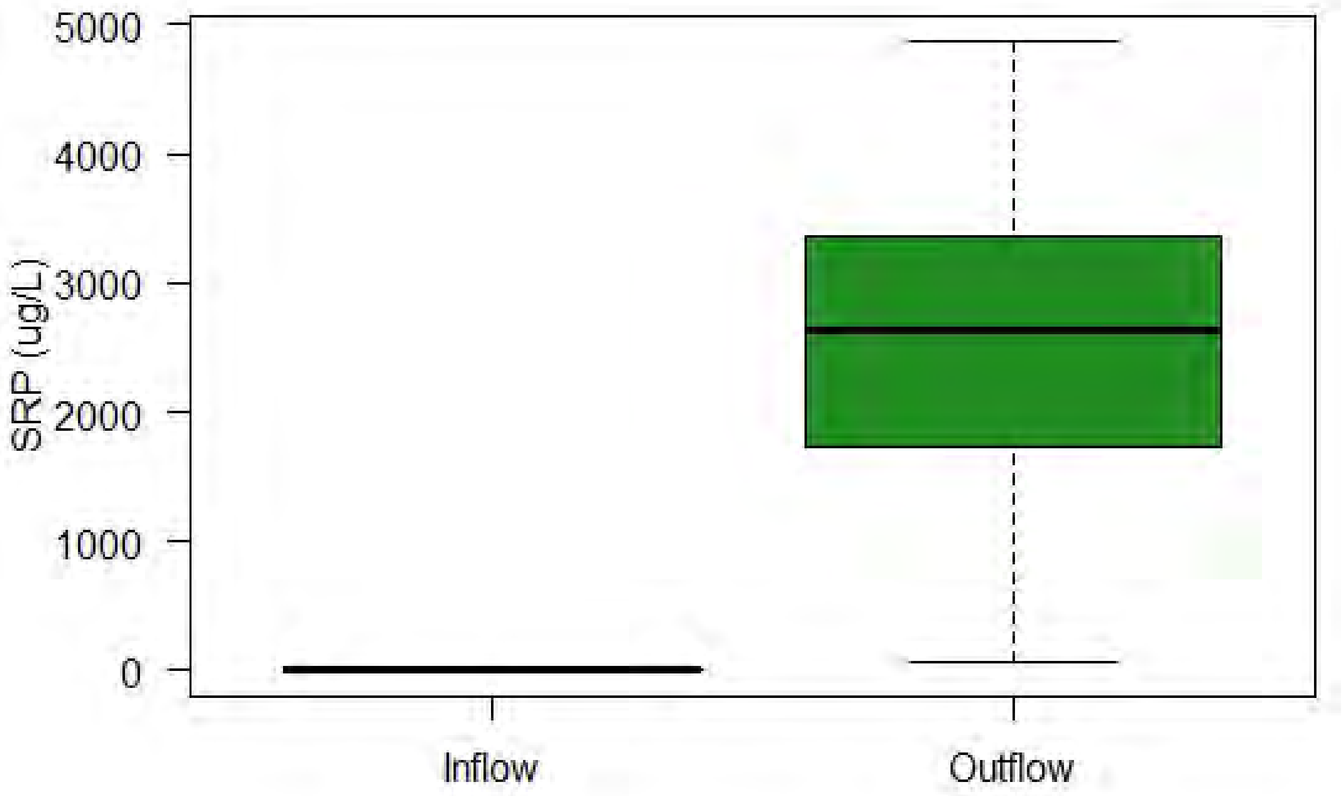
Cleveland Metroparks Watershed Stewardship Center Roof

Germany – co-benefits for stormwater and energy

Cleveland Metroparks Watershed Stewardship Center Roof

Phosphorus Leaving the Roof



Sugano, Jefferson, Kinsman-Costello and Avellaneda, *Evaluation of Bioretention Cell and Green Roof Performance in Parma, Ohio.* Ohio Stormwater Conference. May 2017

osmocote

Team Tool

Advisory Board

2015-2017: Quarterly mtgs.

1. Keely Davidson-Bennett *Chagrin River Watershed*
2. Elizabeth Hieser *Cuyahoga County Soil and Water*
3. Rachel Webb *NEORSD*
4. Jay Dorsey *ODNR*
5. Dan Bogoevski *OEPA*
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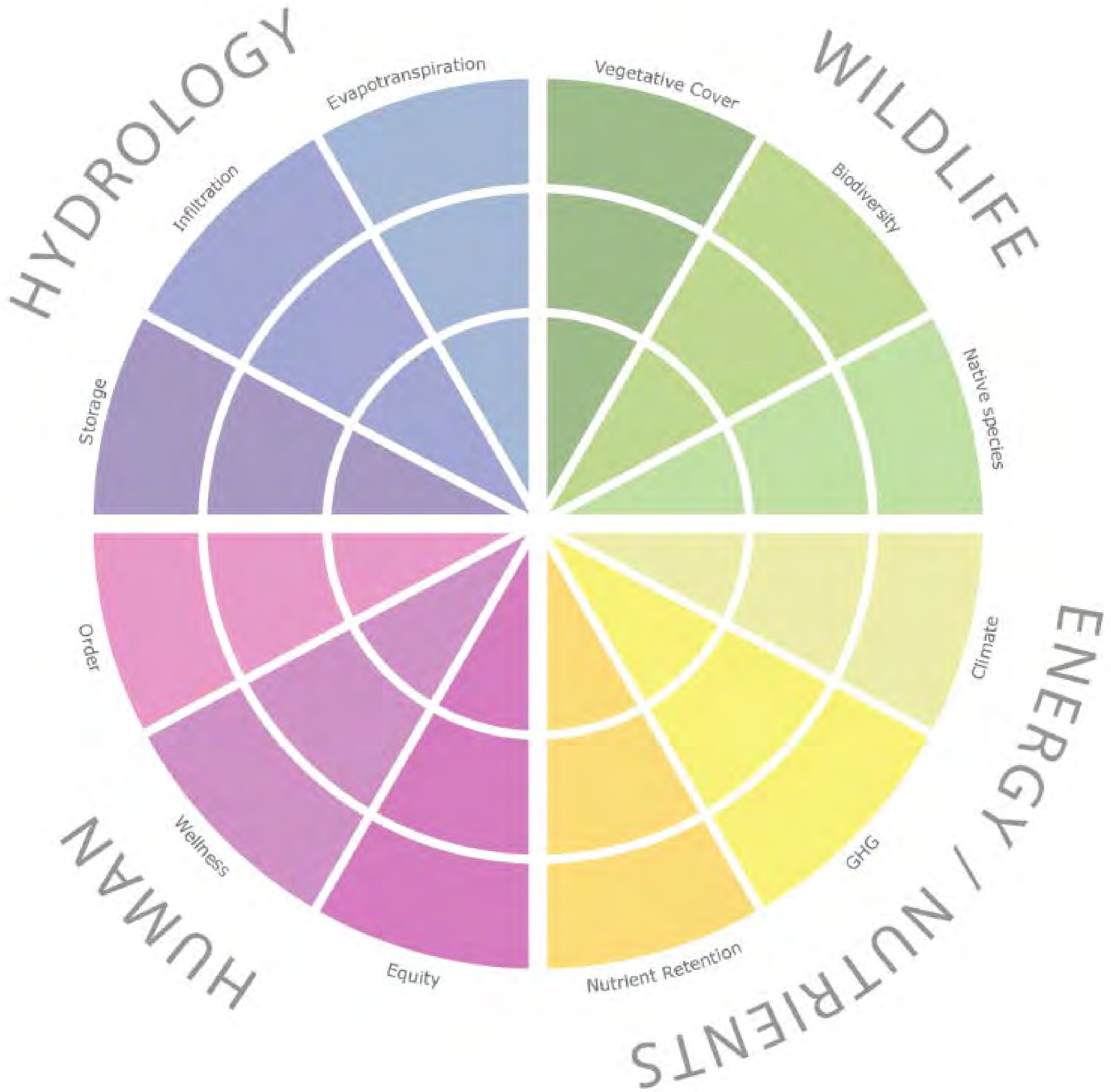
7. Rick Espe *MKSK*
8. Paul Novak *US EPA*
9. Jonathan Moody *US EPA*
10. Mark McCabe *Graham, Smith and Partners*
11. Aaron Jennings *Case Western*
12. Kelly Turner *Kent State University*
13. Laura Johnson *Heidelburg University NCWQR*
14. Chris Cheraso *Cleveland Metroparks*

Project Signature

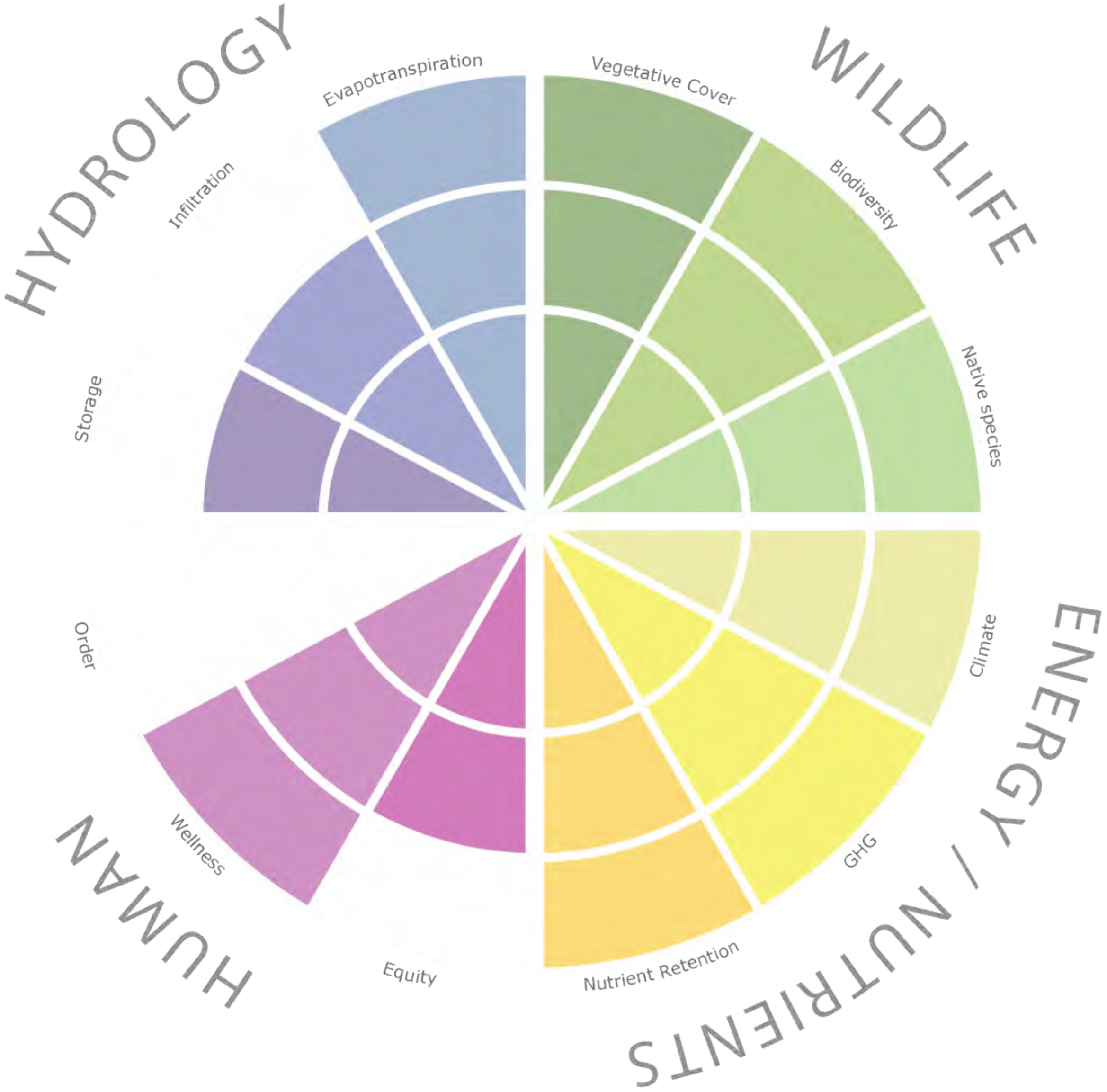


Utopian Ecosystem

Project Signature

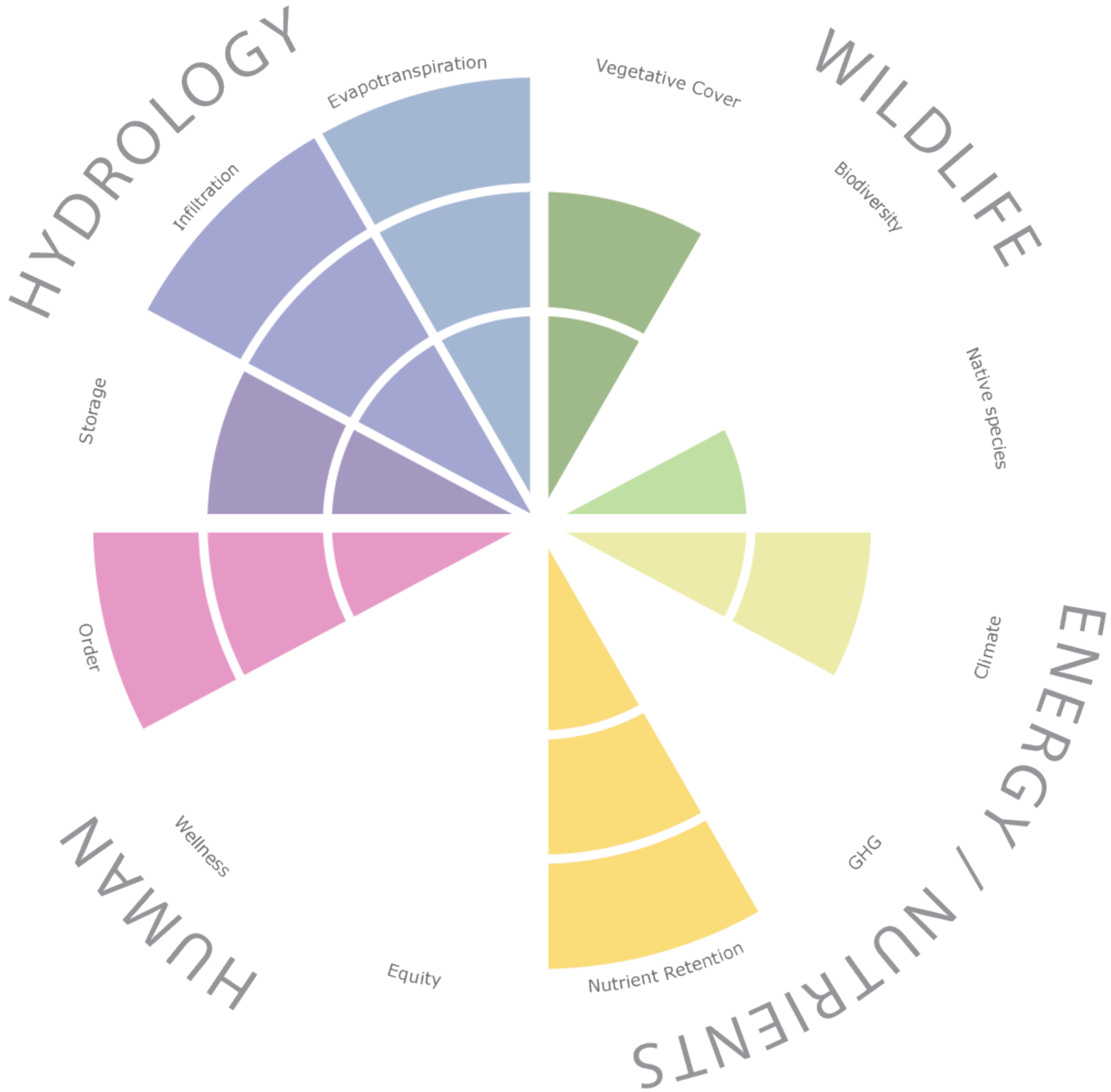
Trade-offs

Project Signature



Forest

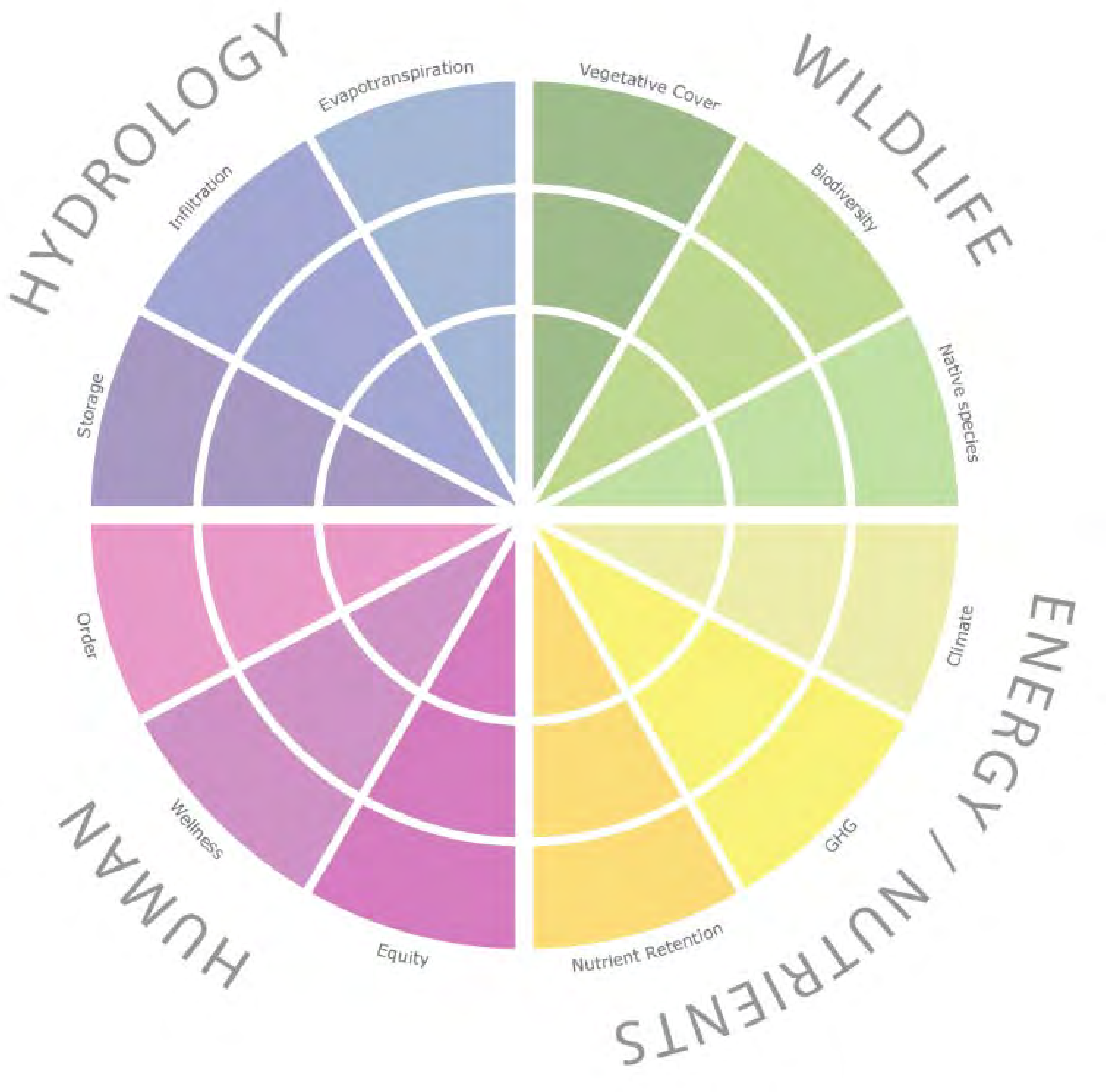
Project Signature



Bioretention Cell

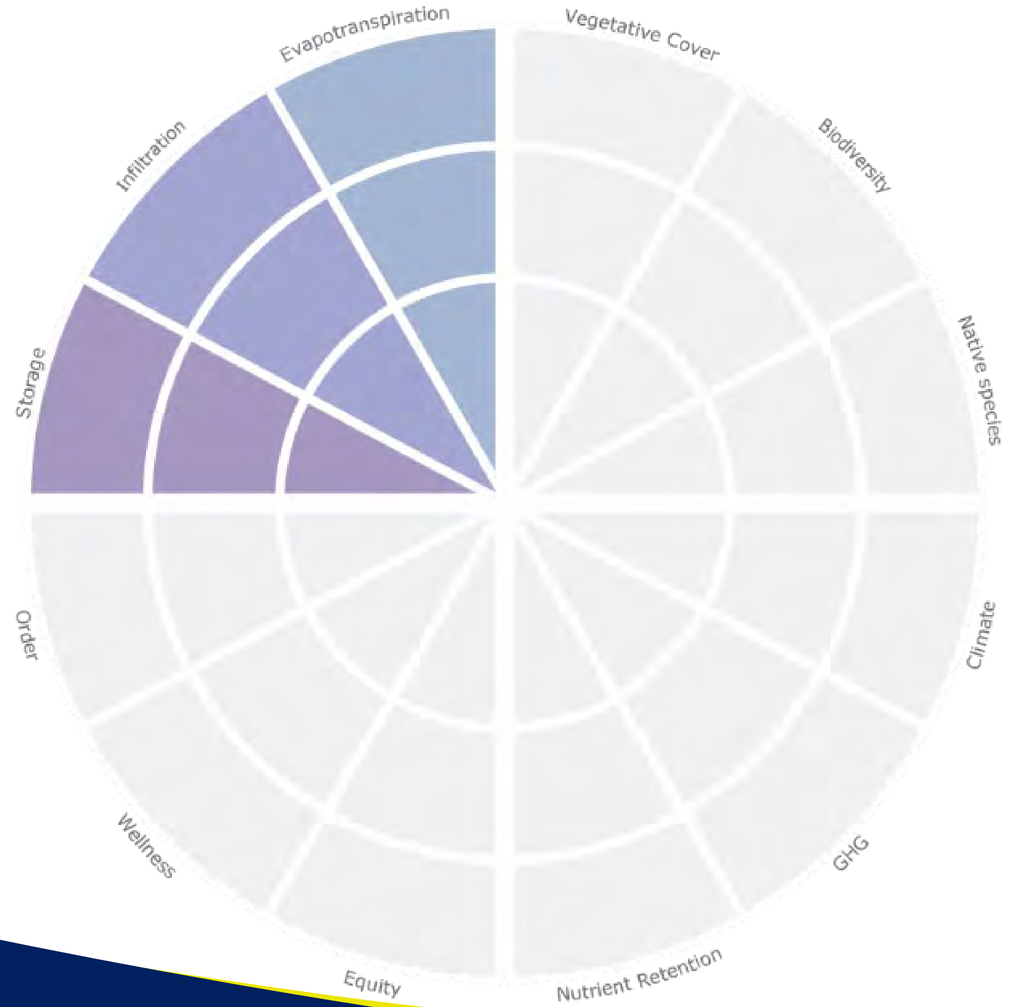
Cleveland Metroparks

Project Signature



Our Domains

Project Signature Hydrology Domain



Storage

Site and rainfall water storage. Water capture for use by plants, people or animals.

Others terms: event based capture and discharge (i.e. 2 yr storm event), water recycle and reuse.

Infiltration

Water moving into the soil saturating the surface soil for plants and other organisms and groundwater recharge.

Others terms: soil saturation, baseflow, interflow, aquifer recharge

Evapotranspiration

"Drying-out" of land, moving liquid water to atmospheric gas state

Other terms: atmospheric moisture, humidifying

KENT STATE UNIVERSITY

Cleveland Metroparks

Project Signature

Human Domain

Equity

Accessibility, assembly, social inclusion, and participation with the infrastructure/site

Others terms: democracy, fellowship, inclusion, participation, knowledge, education

Wellness

The positive effects on physiological and psychological improvement to humans.

Others terms: Recreation, activity, stress reduction, restoration therapy, concentration,

Order

A legible landscape for practical purposes and human meaning.

Other terms: legibility, functionalism, visual quality, formal aesthetics

Nutrient and Energy Domain

Climate

Working against the urban heat island to create comfortable environments and conditions habitable by all species.

Others terms: air temperature, urban cooling, solar interception, surface temperature, flux

Green House Gases

Regulation of carbon dioxide, methane and harmful atmospheric gases

Common examples include: carbon, methane,

Nutrient Retention

To regulate the nutrients in the terrestrial water supply.

Others terms: phosphorus reduction, nitrate reduction, trace element management: Fe, PB, TSS, OM, Etc.

Project Signature *Biodiversity Domain*

Vegetative Cover

The area of trees, shrubs, grasses, legumes, forbs, and mosses.

Others terms: biomass, canopy cover, harvest

Biodiversity

The variety of life forms including the full range of plant, animal and other species present in an area.

Others terms: species diversity, ecosystem diversity, functional diversity, refuge/nursery

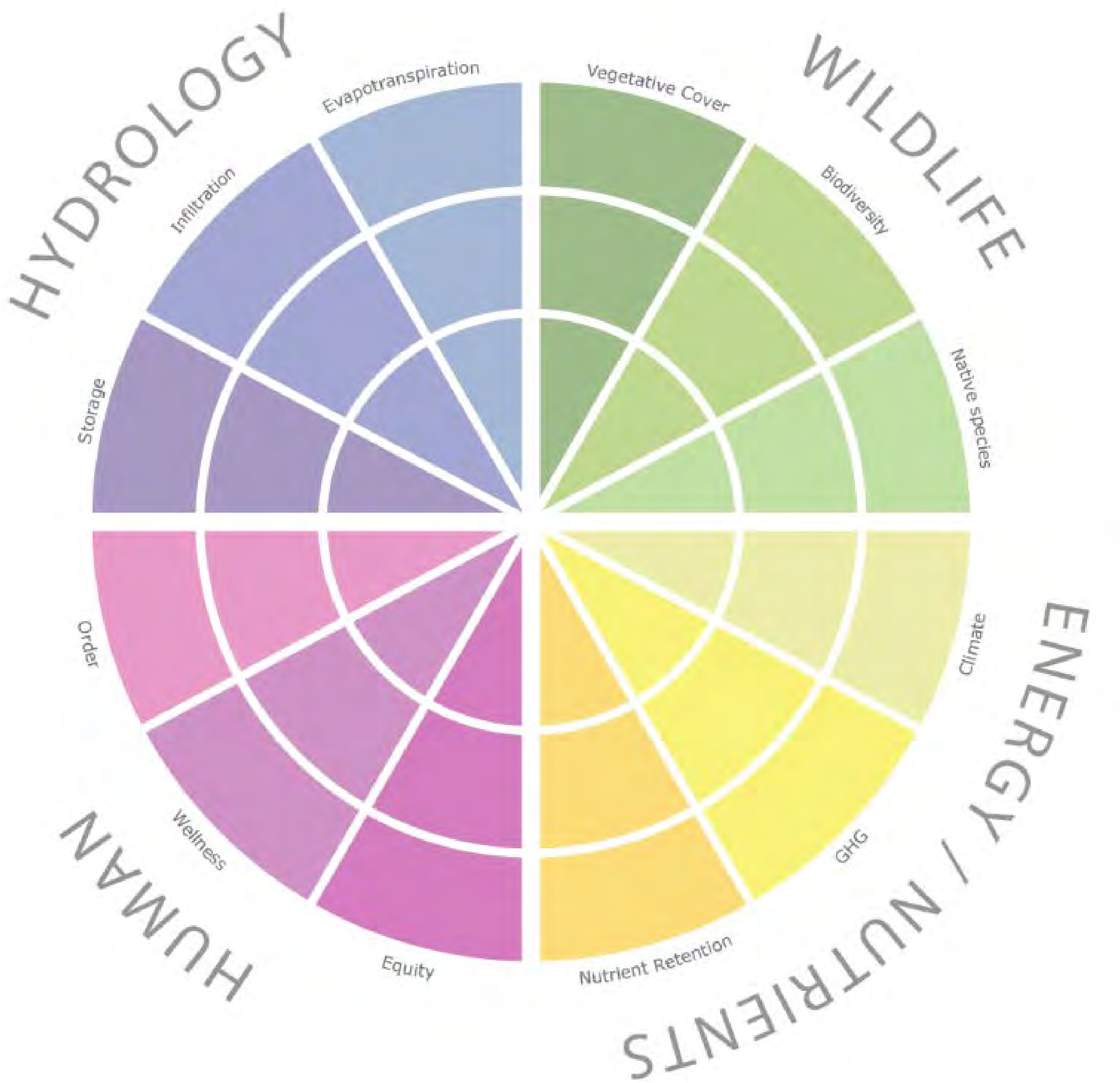
Native Species

Use and protection of native plant species to an area.

Others terms: nativity, local species, regional

Cleveland Metroparks

Project Signature



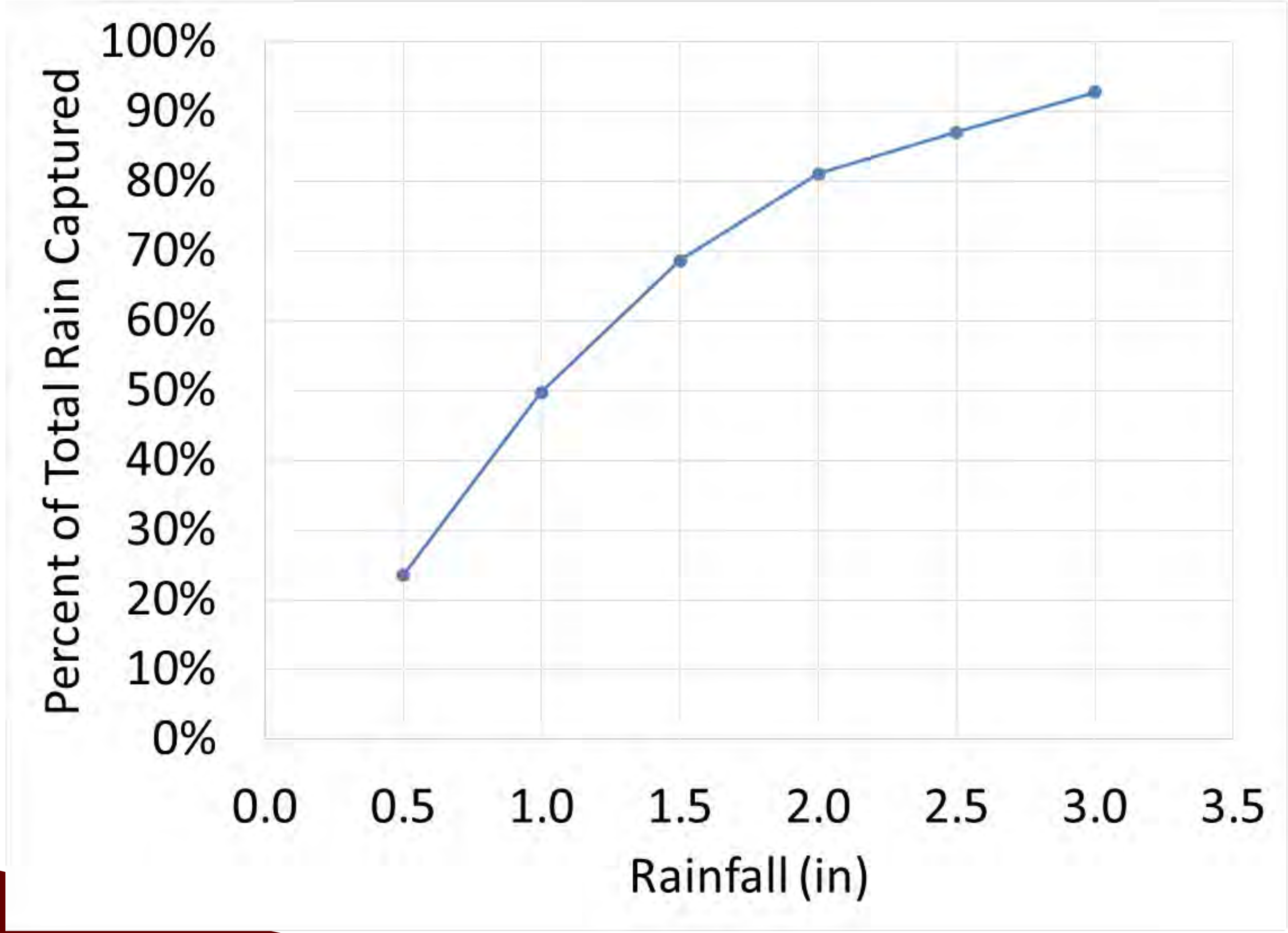
Our Domains

Cleveland Metroparks

City of Tulsa Design Criteria Manual

- For implementation of LID at a widespread scale, practitioners need defined goals to design to.
- Select a design goal, known as the stormwater volume (SWV).
- Specific design goals for each practice.
- Will be use for an incentive program to be designed in the future.
- Maintenance and inspection procedures and specifications are next on the list.

Stormwater Volume Determination



- Percentile Storms for Tulsa
  - 90th Percentile: 1.48 in
  - 85th Percentile: 1.15 in
  - 80th Percentile: 0.98 in

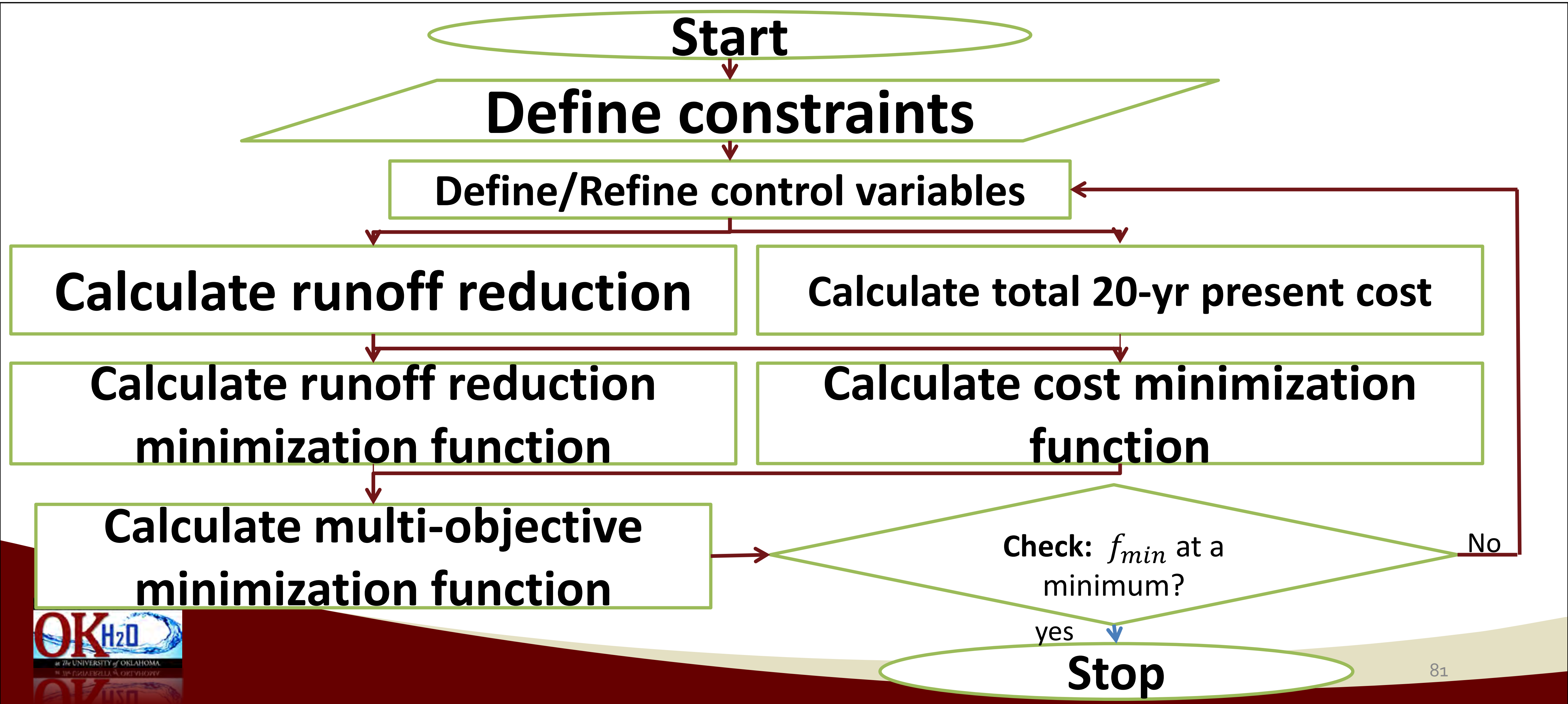
Source: Bixby Mesonet Station

- **We chose 1.0 inches of runoff from impervious surfaces as a design goal for the SWV.**
  - Approximately 85% storm
  - 50% of total rain captured

Design Criteria Manual Innovations

- Bioretention and Pervious Pavement:
  - Allow for credit for infiltrated volume over the first four (4) hours of the storm
  - Very specific underdrain requirements
- Pervious Pavement: Overdrain required if no underdrain
- Rainwater Harvesting:
  - Orifice outlet to drain stormwater volume over 48 hours
- Downspout Disconnection:
  - Use field data to validate partial credit for downspout disconnection under specific circumstances
- Greenroofs:
  - Blanket 60% credit because volume reduction is not correlated to thickness or other parameters

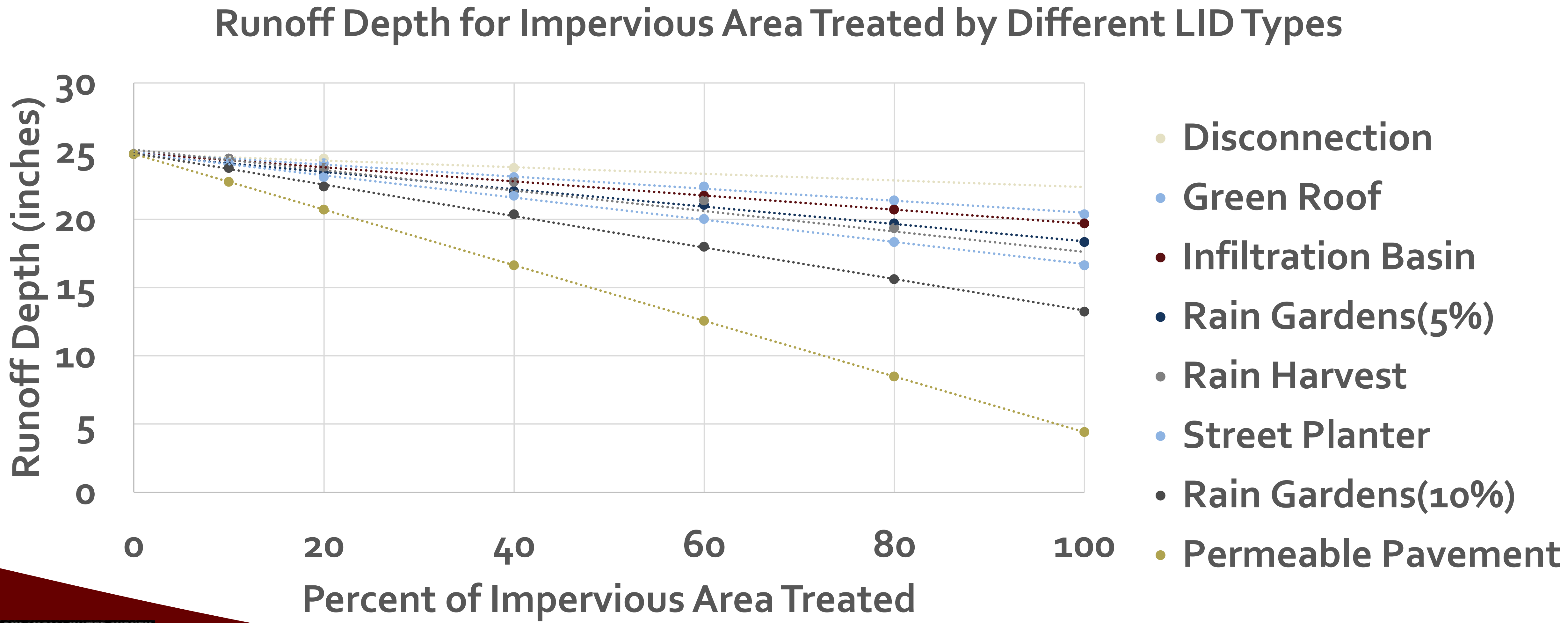
Optimization LID Using the EPA Stormwater Calculator and Excel Solver



Regression

- EPA Stormwater Calculator output for different percentages of impervious area treated by each singular LID type

Regression (cont.)



Minimization Function

How should I approach this?

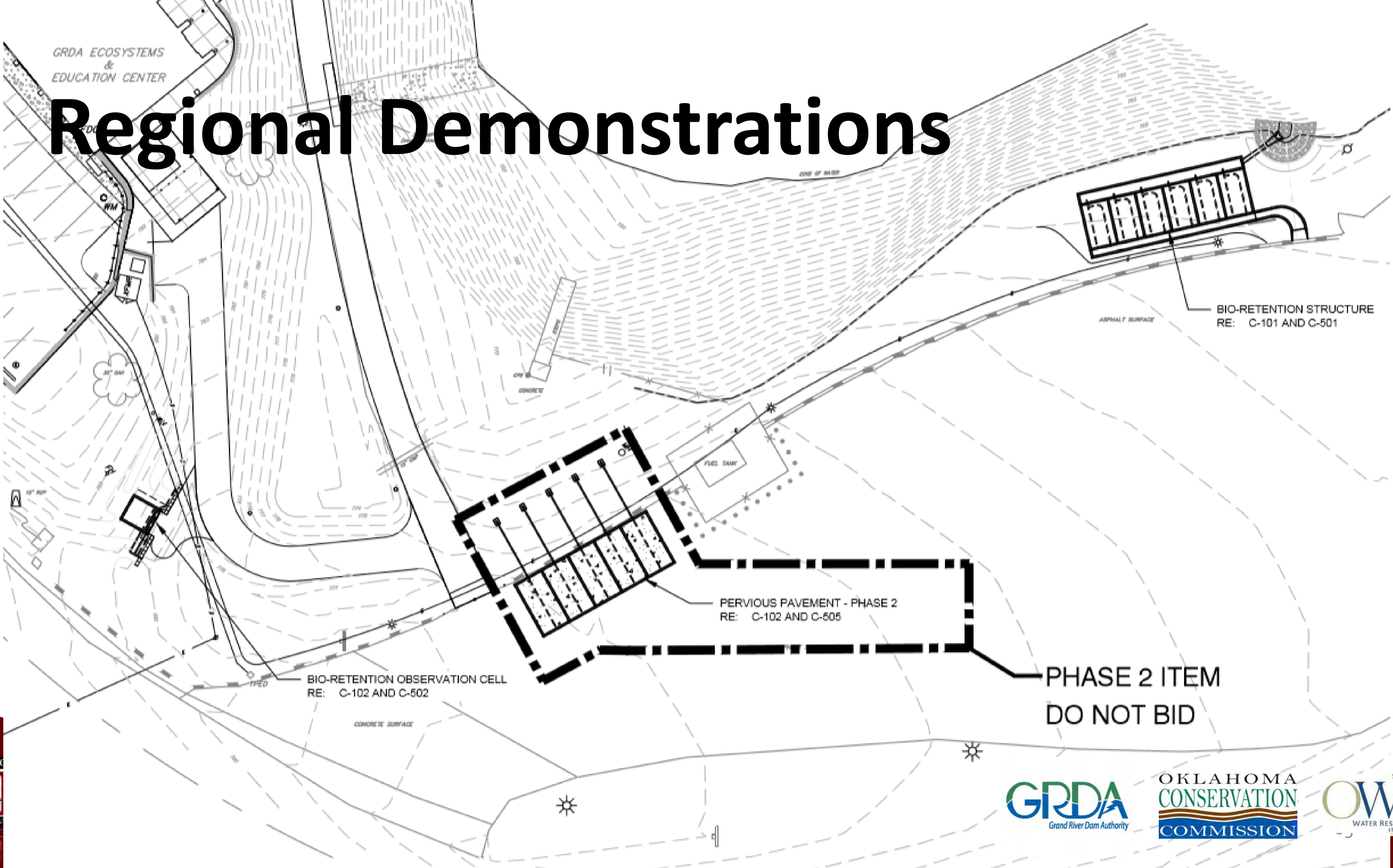
I am reasonably skilled with a computer.

Use the Solver Function in Microsoft Excel.

I enjoy spending hundreds of hours doing calculations by hand.

We'll see you next month.

Regional Demonstrations

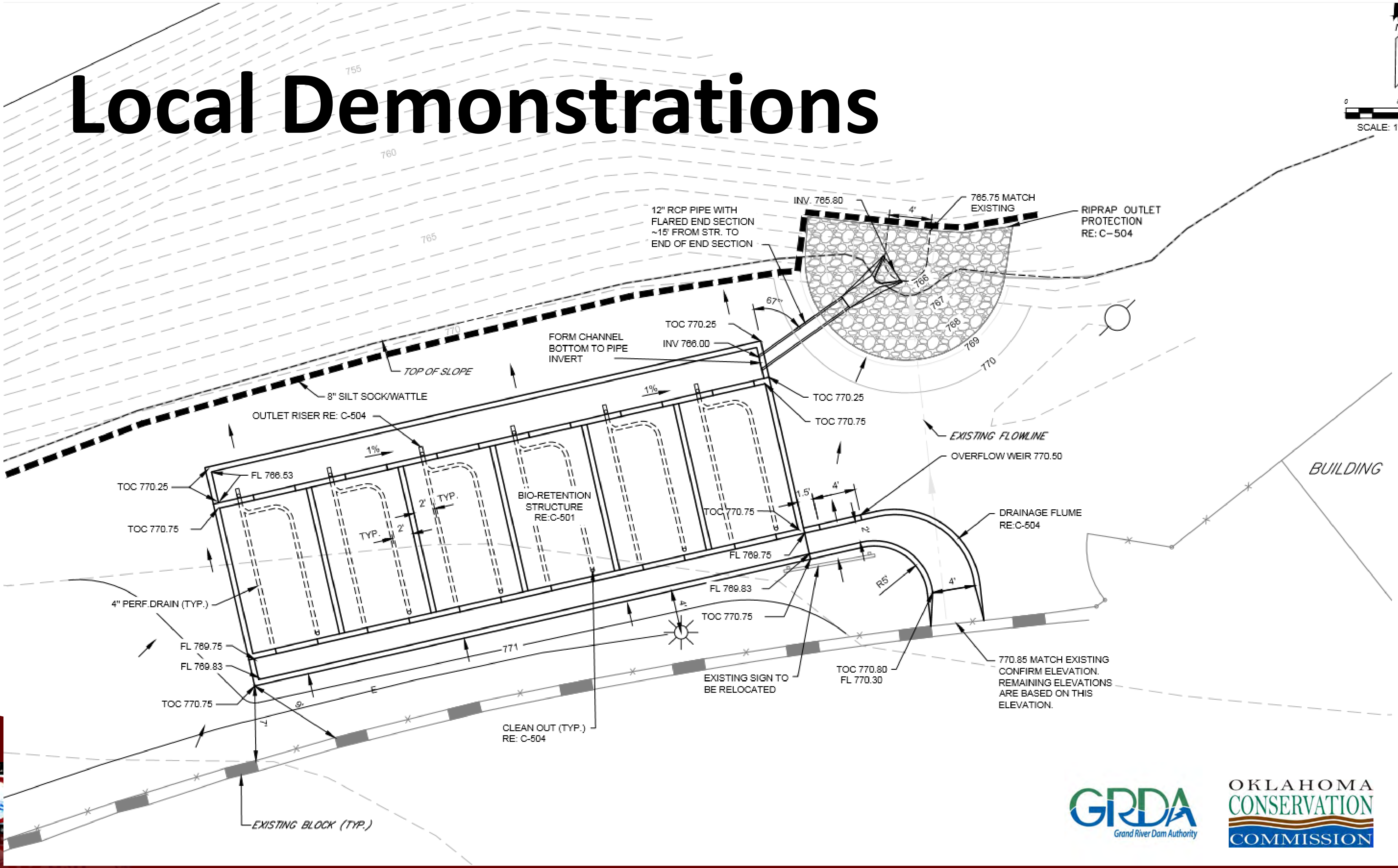


GRDA Grand River Dam Authority

OKLAHOMA CONSERVATION COMMISSION

State of Oklahoma OWRB WATER RESOURCES BOARD the water agency

Local Demonstrations



GRDA Grand River Dam Authority
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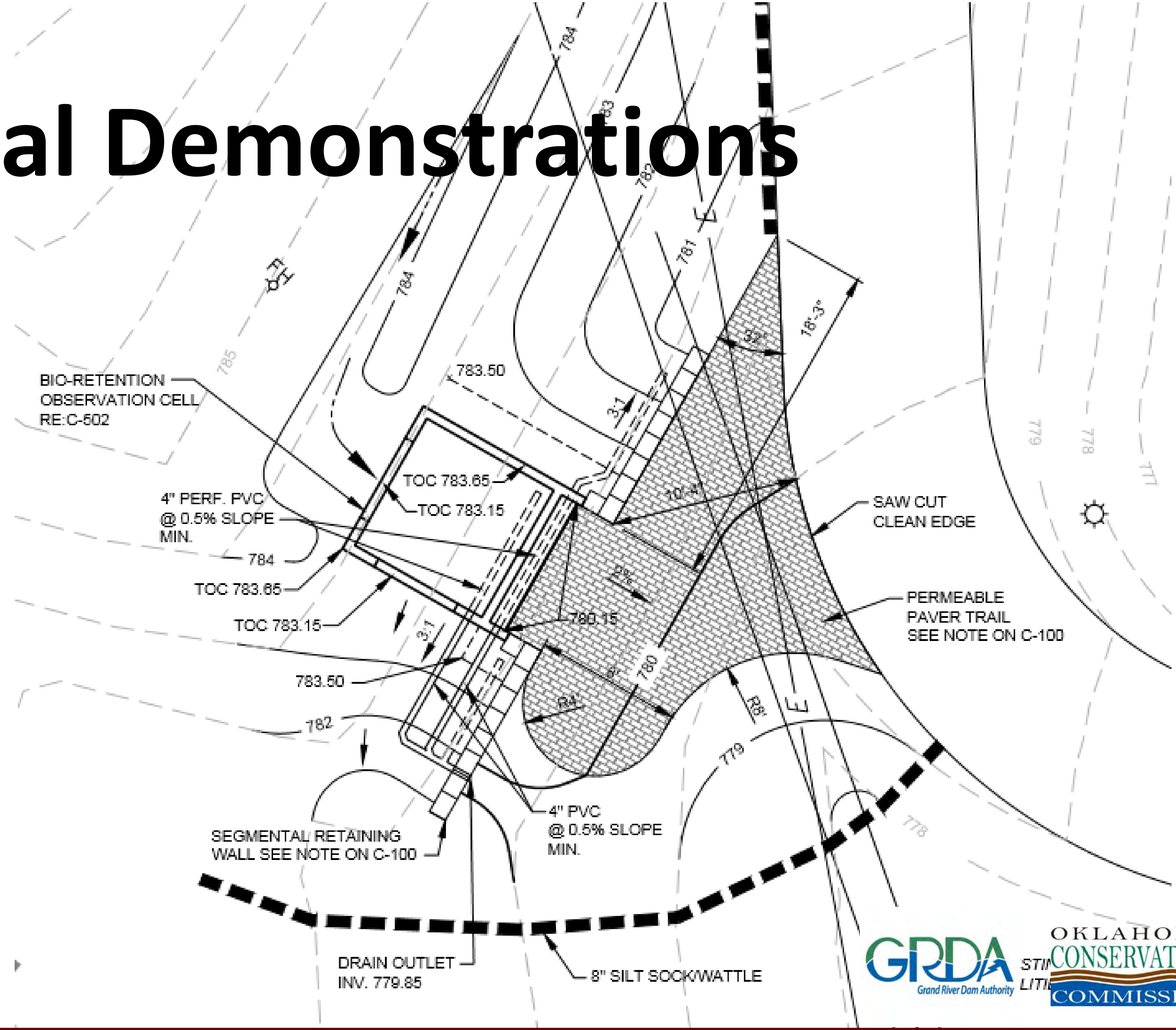
Regional Demonstrations



Regional Demonstrations

The Future of LID Innovation at the Municipality/Regional Scale

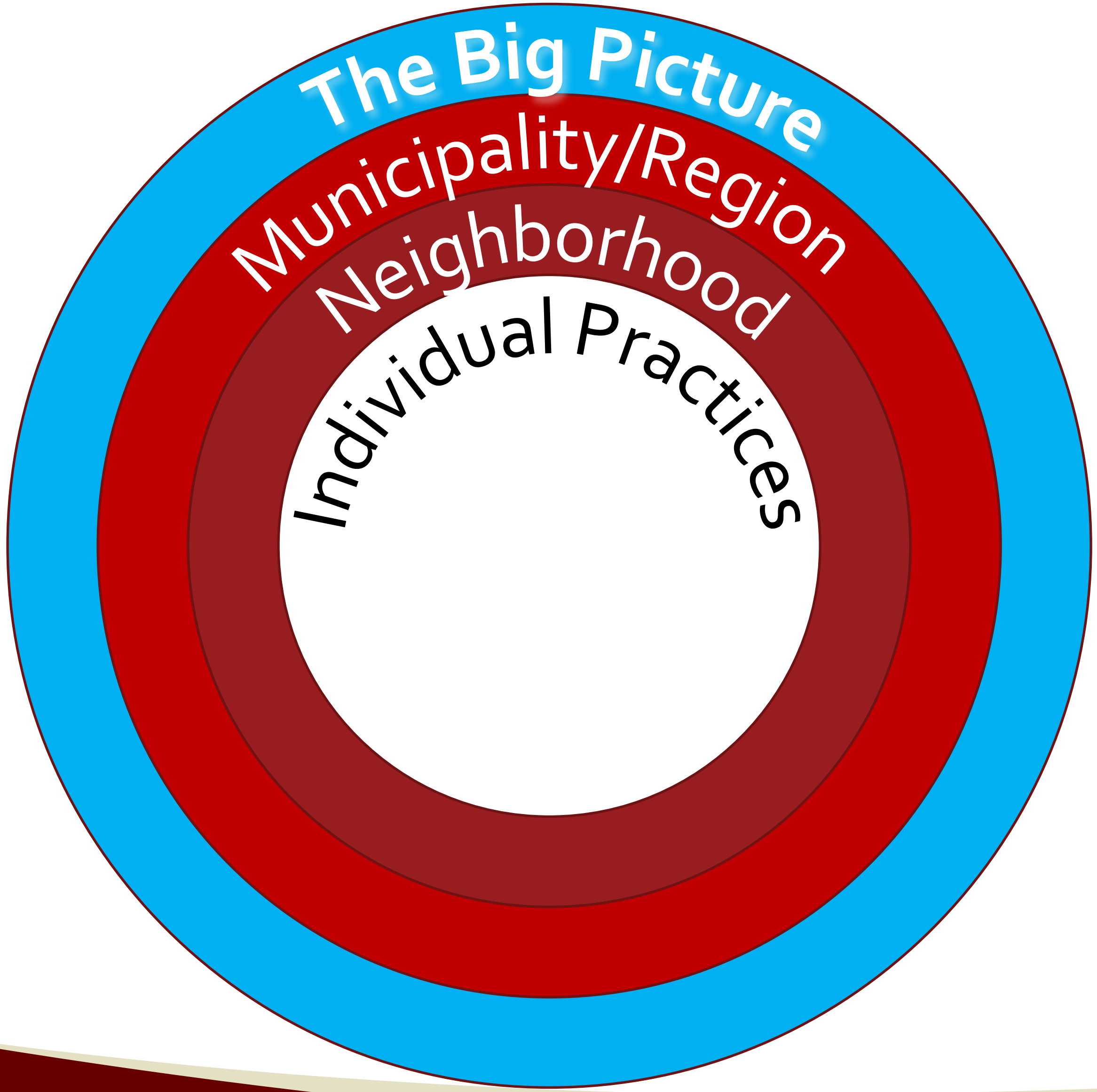
Engineering

- Watershed-based implementation and modeling
- Integration with TMDL’s
- Design optimization for more parameters
- Big data
- Regional demonstrations

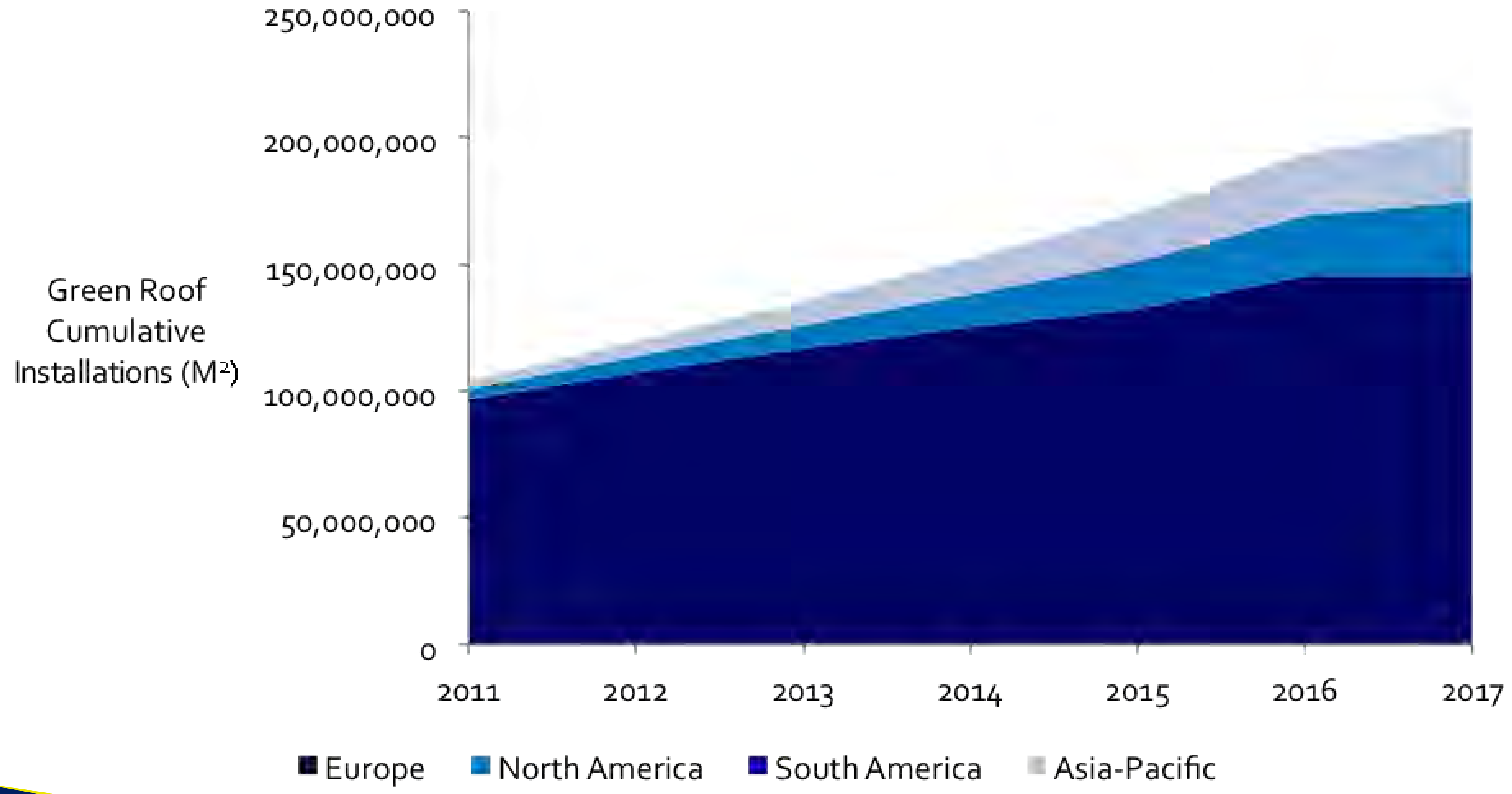
Landscape Architecture

- Park systems
- Resilience Planning
- Co-Benefits/Trade-offs
- Public Investment

LID Innovations: the Big Picture

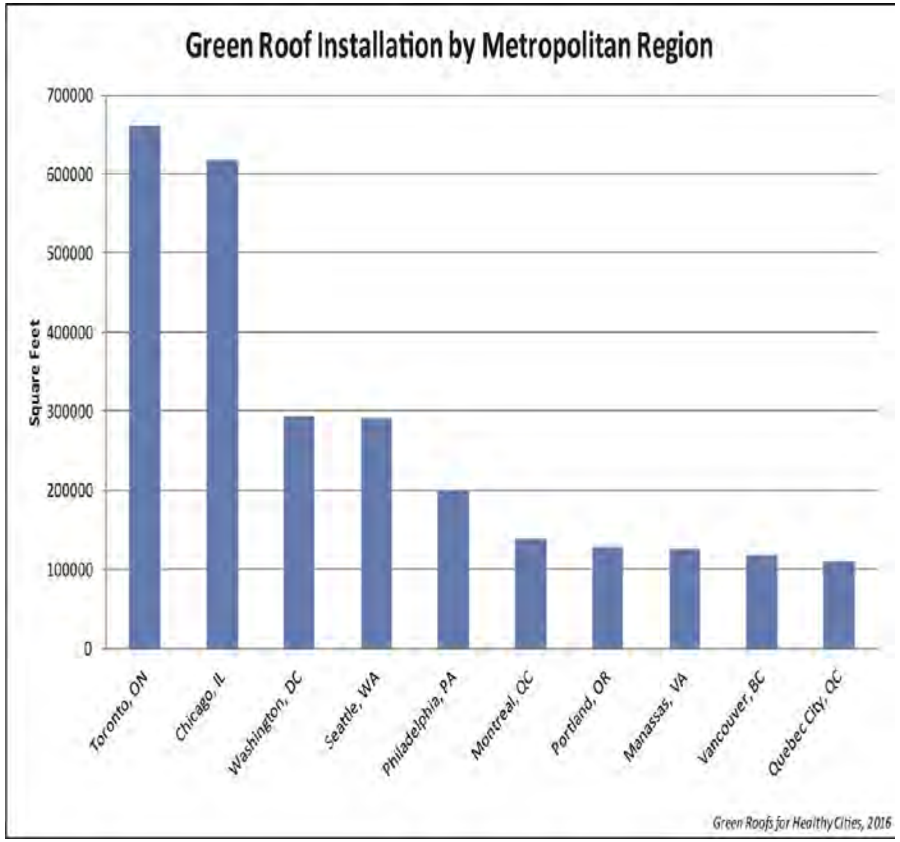


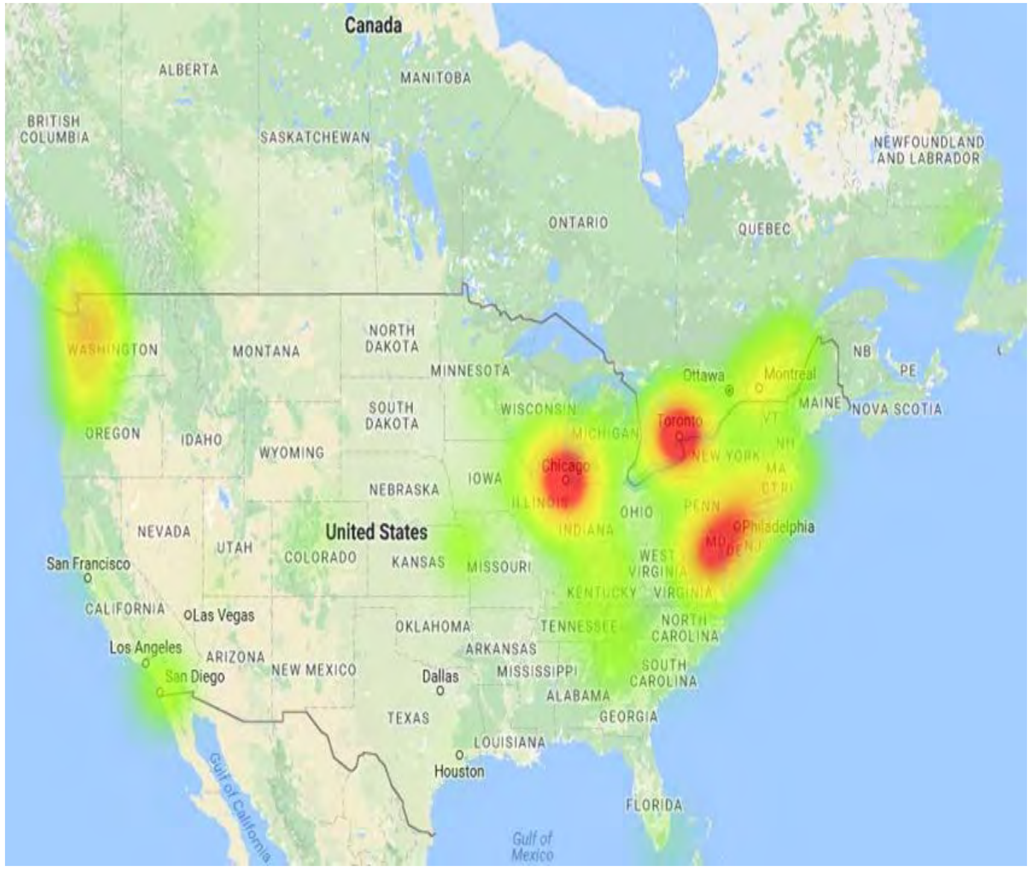
World Green Roof Market



http://meetingoftheminds.org/building-integrated-vegetation-mitigating-urban-environmental-challenges-with-building-material-technologies-8238

Green Roof Market Growth





In 2016,

4,061,024 s.f.

of green roofing installed.

(respondents recorded 889 projects in 40 US states and six Canadian provinces)

10.3% growth rate over 2015

(source GRHC)

Green Roofs for Healthy Cities (GRHC) *is a non-profit industry association working to promote the green roof and wall industry throughout North America.*

Mission

GRHC's mission is to **develop and protect the market** by increasing the awareness of the economic, social, and environmental benefits of green roofs, green walls, and other forms **of living architecture** through education, advocacy, professional development and celebrations of excellence.

Services

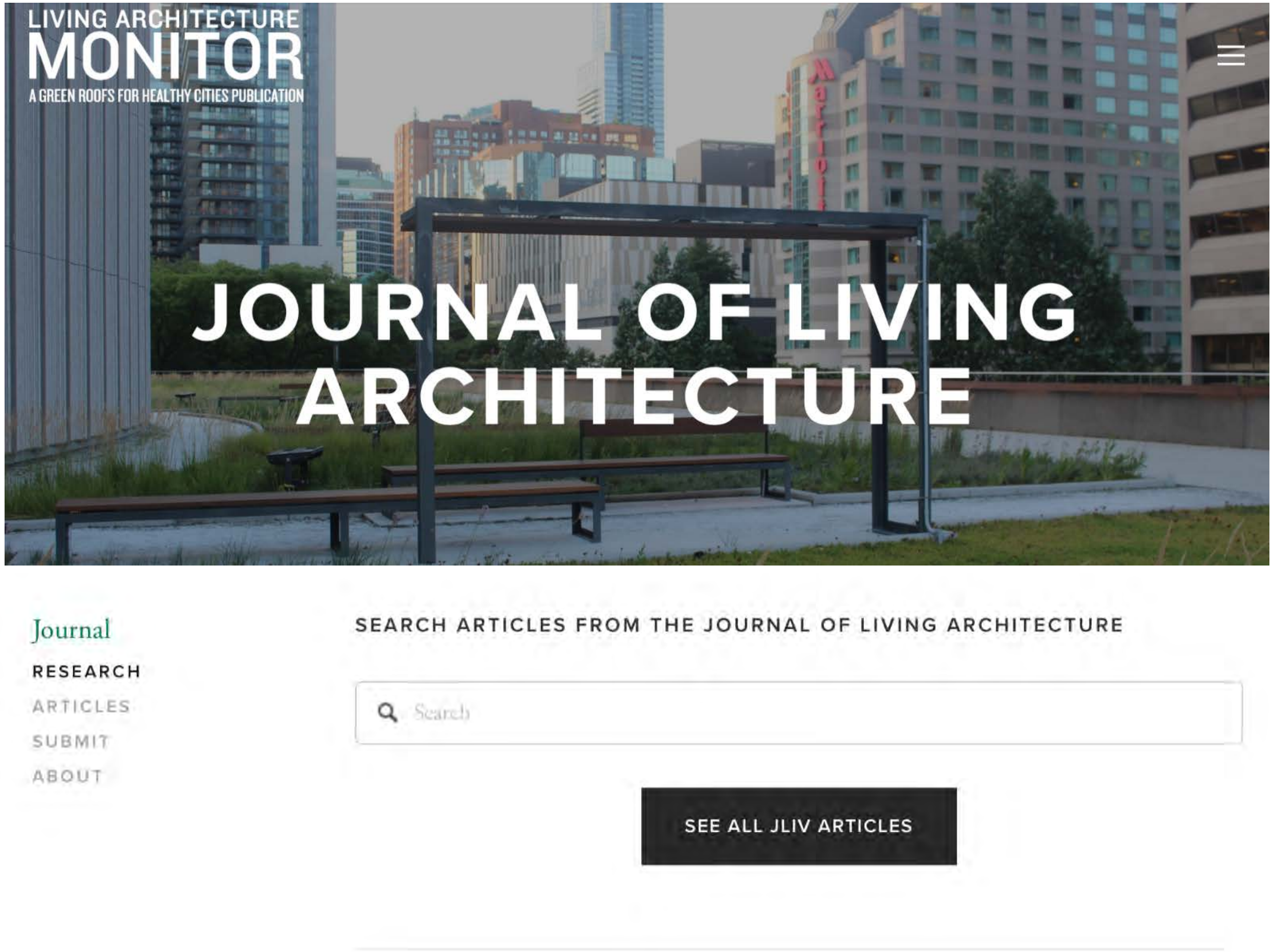
Annual Conferences
- *CitiesAlive* National Conference
- *Grey to Green* Regional Conference

Local Advocacy Efforts
- Symposia

Resource Generation
- Market Survey

Publications
- Journal of Living Architecture (JLIV)
- Living Architecture Monitor

JLIV *Journal of Living Architecture*



LANDSCAPE PERFORMANCE SERIES

by the Landscape Architecture Foundation

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- Fast Fact Library
- Benefits Toolkit
- Collections

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- Blog
- Training
- Guide to Evaluate Performance
- Resources for Educators
- Contact

The Landscape Performance Series is the online set of resources to help designers, agencies, and advocates evaluate performance, show value and make the case for sustainable landscape solutions.

Renaissance Park

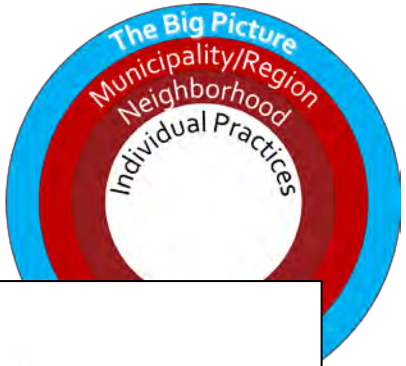
- Active Living >
- Resilience >
- Biodiversity >

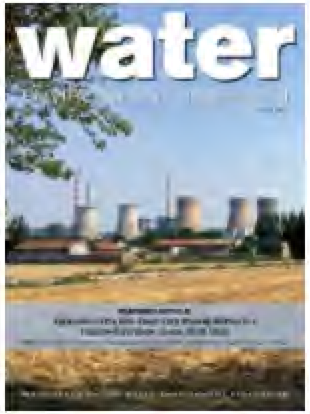
Gary Comer Youth...

- Revitalization >
- Social Equity >
- Water Management >

landscapeperformance.org

Creating Learning Communities





Critical Review of Technical Questions Facing Low Impact Development and Green Infrastructure: A Perspective from the Great Plains

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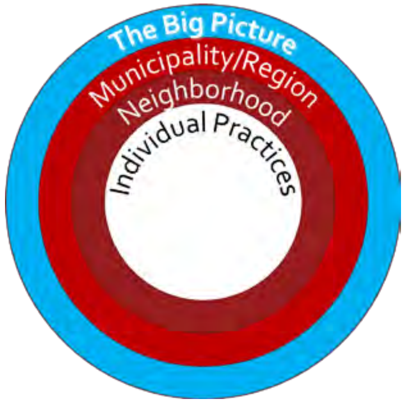

Authors: Vogel, Jason R.; Moore, Trisha L.; Coffman, Reid R.; Rodie, Steven N.; Hutchinson, Stacy L.; McDonough, Kelsey R.; McLemore, Alex J.; McMaine, John T.
Source: Water Environment Research, Volume 87, Number 9, September 2015, pp. 849-862(14)
Publisher: Water Environment Federation
DOI: https://doi.org/10.2175/106143015X14362865226392

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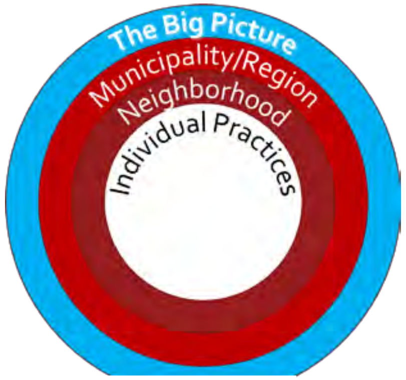
ABSTRACT:

Since its inception, Low Impact Development (LID) has become part of urban stormwater management across the United States, marking progress in the gradual transition from centralized to distributed runoff management

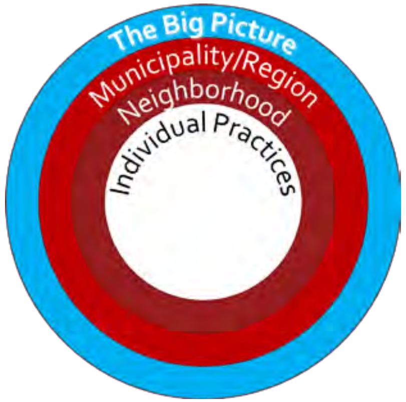
National Green Infrastructure Certification Program



www.ngicp.org

OKLAHOMA WATER SURVEY
OK H2O
at The UNIVERSITY of OKLAHOMA

The Future of LID Innovation: the Big Picture



Engineering

- Create regional/national interdisciplinary communities and platforms
- Design and Maintenance Training/Certification
- Integration of Disciplines

Landscape Architecture

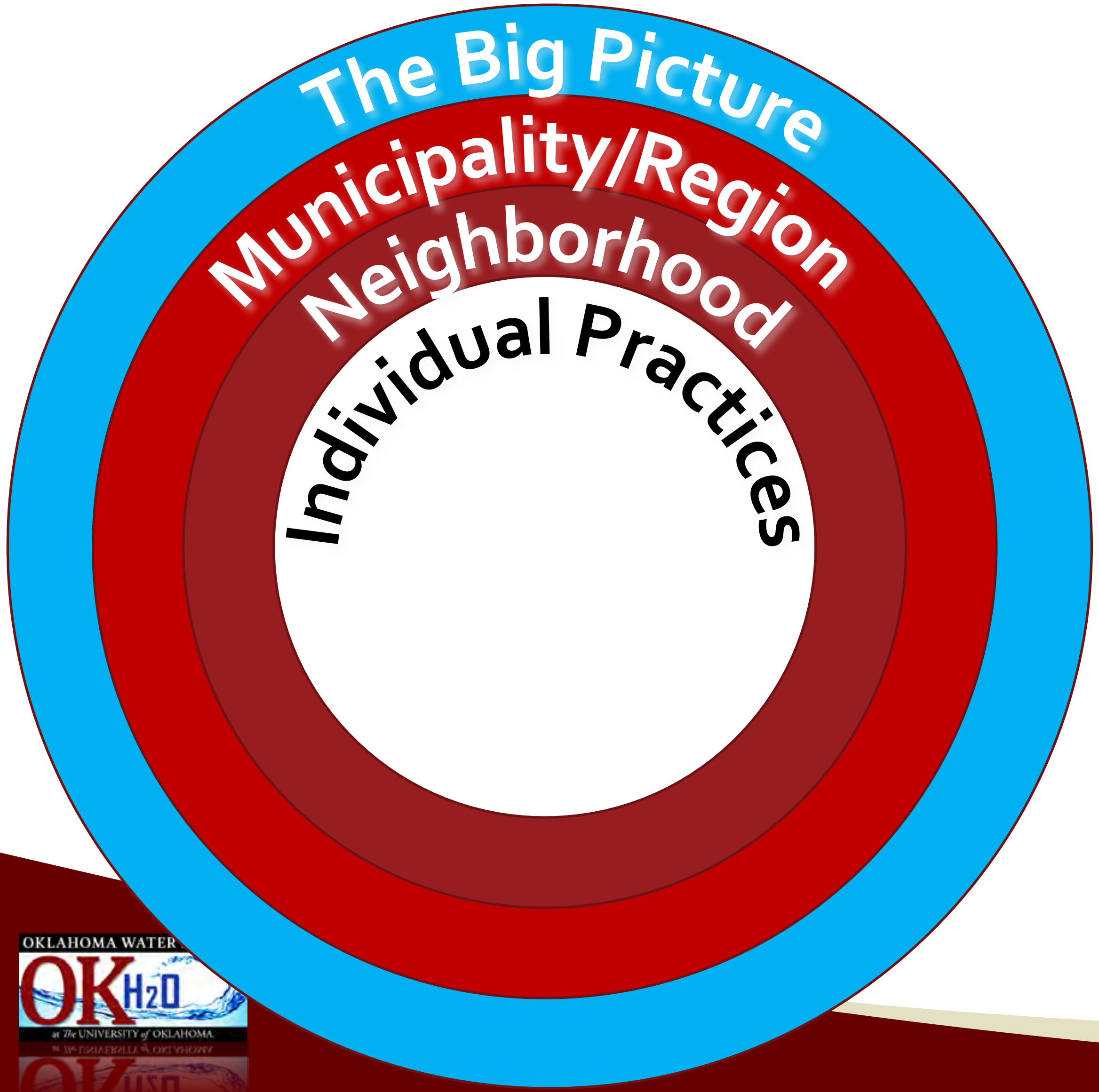
- Policy for Green roofs
- Landscape Performance
- Systems Thinking
- Bundling Ecosystem Services

Concluding Remarks

- Optimizing co-benefits at all scales
- Provides platform for creativity
- Interdisciplinary is the way to go
- We must work together for solutions

Thanks to our students, partners, and funding agencies who make this work possible.

Low Impact Development Innovations – Oklahoma and Beyond



Jason Vogel

Individual Practices	Neighborhood
Rainwater Harvesting First Flush Fly Ash Bioretention Pesticides Constructed Wetlands Pervious Concrete Clogging Compost Filter Socks Floating Wetland Wavebreaks	Deerfield Estates Bioretention EPA Stormwater Calculator Optimization
Municipality/Region	**The Big Picture**
COT Design Criteria COT Maintenance and Inspection	Great Plains LID Symposium & Competition Oklahoma Demonstrations/Education NGICP *Water Environment Research* Lit Reviews

Reid Coffman

Individual Practices	Neighborhood
NWC Green Roof	Trailwoods Development
Municipality/Region	**The Big Picture**
Oklahoma Bioretention Plants OKC Green Roof Symposium	Ecosystem Services Journal of Living Architecture