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Green Infrastructure Life Cycle:

Performance, Costs and Maintenance

Thursday, July 25, 2019

1:00 – 3:00 PM ET

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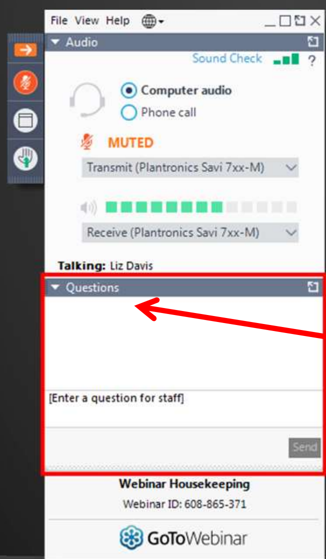
How to Participate Today



- Audio Modes
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this webcast.**

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Today's Moderator

Cindy Baumann

CDM Smith

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Today's Speakers

- Nancy Ellwood
  - *Life Cycle Assessment of Public and Private Green Infrastructure in Cincinnati*
- Ryan Winston
  - *Permeable Pavement: How Design Affects Performance and Maintenance*
- Harry Zhang
  - *Overview of Stormwater Life Cycle Analysis and Green Infrastructure Co-Benefits Projects*
- Sybil Sharvelle
  - *Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)*

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Nancy Ellwood

CDM Smith
Cincinnati, Ohio

CDM Smith

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Life Cycle Assessment of Public and Private Green Infrastructure in Cincinnati

An Evaluation of Long-Term Sustainability of Urban Green Infrastructure

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Overview

- Study description, goals, & approach
- Study area and projects
- Findings – Comparisons over time by green infrastructure (GI) types
- Conclusions

8

Study Description

- Periodic, observational assessment of urban GI condition over time
- Observe multiple GI practice types in multiple settings to provide perspective

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Study Goals: 4 Key Questions

- Are GI practices "surviving" long enough to perform as designed?
- Does GI type or setting impact long-term viability?
- Can typical (and atypical) sources of post-construction failure be identified?
- Are observational assessments a useful tool in performing GI Life Cycle analyses?

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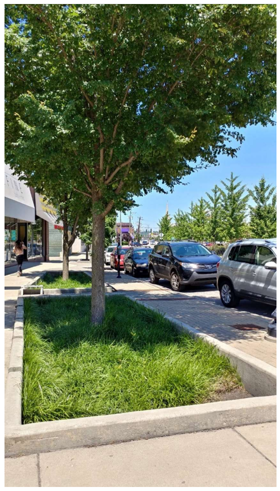
Study Approach



- Identify GI installations to be included
  - Wide array of GI practices
  - Small to large scale
  - Public and private property
- Document conditions of installed urban GI practices over time
  - Periodic site visits
  - Photo documentation

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Study Approach

"Failure" definition

Identified variances from the originally designed and installed system that either result in:

- Circumvention of runoff around/above/under the GI practice; and
- Inability to perform intended functions, such as infiltration, filtering or evapotranspiration

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Study Approach

- Identify signs of potential or actual failure
  - Broken/damaged/worn structures
  - Pooling/stagnant water
  - Erosion/workarounds
  - Displaced materials/blowouts
  - Stressed or missing vegetation
  - Invasive species encroachment
- Conduct interviews with site owner/caretaker when possible

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✗

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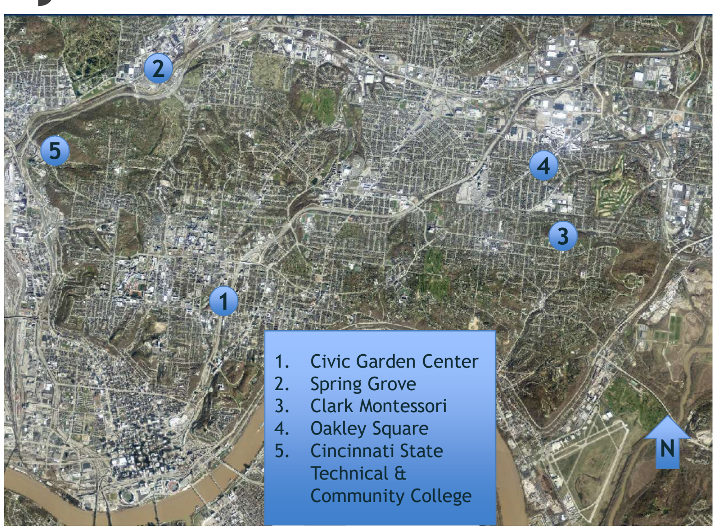
Study Area



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Civic Garden Center

Site Characteristics

- Small scale
- Non-profit owner
- Sloped green roof

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✓

2010

2013

2018

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Civic Garden Center

Site Characteristics

- Small scale
- Non-profit owner
- Bioswale -minimally amended soils

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✓

2011

2018

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Civic Garden Center

Site Characteristics

- Small scale
- Non-profit owner
- Bioswale – amended soils

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✓

2010

2018

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Oakley Square

Site Characteristics

- Small scale
- Public/Streetscape
- Rain Garden

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✓

2012

2018

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Spring Grove Avenue

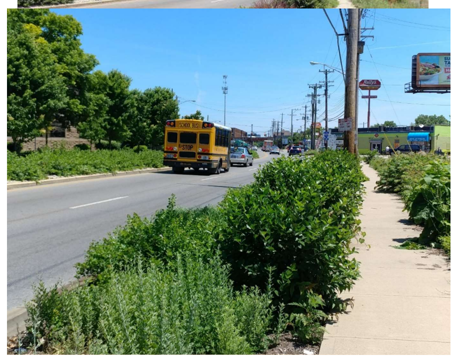
Site Characteristics

- Medium scale
- Public owner
- Streetscaping: bioswales

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✓

20

2014



2018

19

Spring Grove Avenue

Site Characteristics

- Medium scale
- Public owner
- Streetscaping: bioswales

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✗

2018

Missing plants not due to lack of maintenance …

20

Clark Montessori School

Site Characteristics

- Medium scale
- Public owner
- Bioswales

Findings	
Structure	✓
Soil Condition	✓
Materials	✗
Vegetation	✓

2014

2018

Mulch displacement

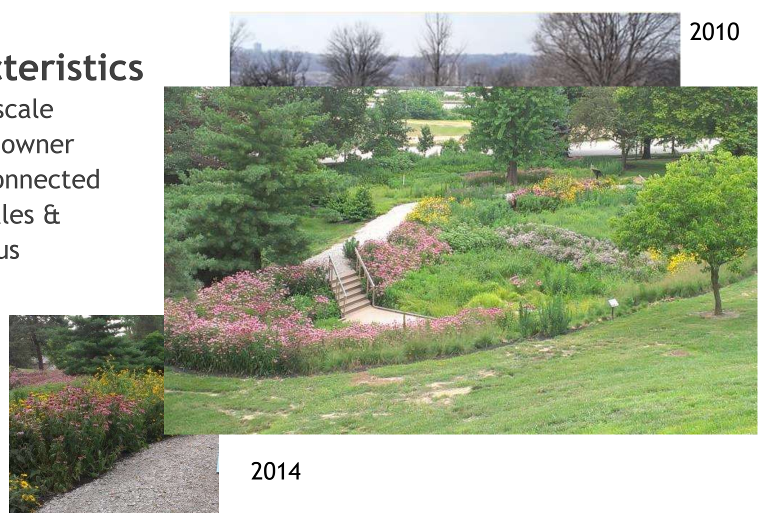
21

Cincinnati State*

Site Characteristics

- Large scale
- Public owner
- Interconnected bioswales & pervious paving

2010



2014

*R. Mirizzi photographs 2010, 2014

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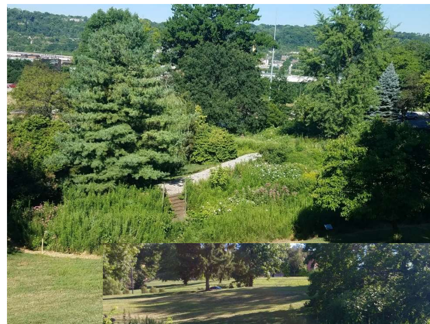
Cincinnati State

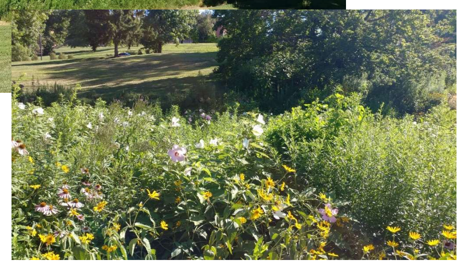
Site Characteristics

- Large scale
- Public owner
- Bioswale

Findings	
Structure	✓
Soil Condition	✓
Materials	✗
Vegetation	✗



2018



2018

Invasive species

*Cincinnati State Technical & Community College

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Cincinnati State

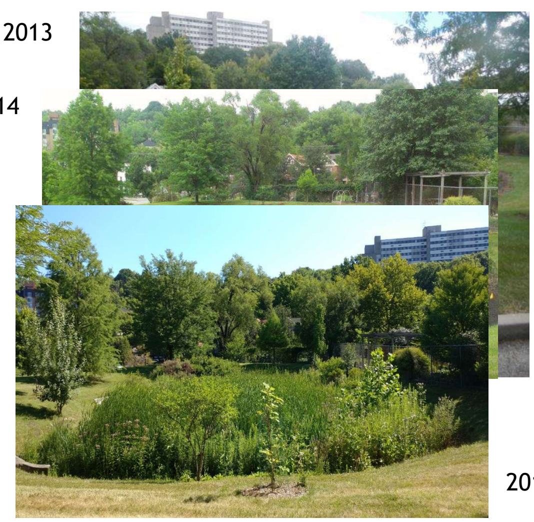
Site Characteristics

- Large scale
- Public owner
- Biodetention retrofit

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	✓

2013

2014



2018

*Cincinnati State Technical & Community College

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Oakley Square

Site Characteristics

- Medium scale
- Public owner
- Urban tree planters, porous concrete sidewalk

2014

2018

Findings	
Structure	✓
Soil Condition	✓
Materials	✗✓
Vegetation	✓

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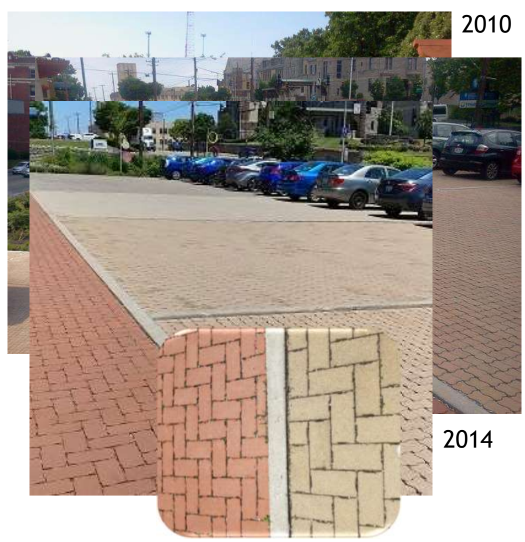
Civic Garden Center

Site Characteristics

- Small scale
- Non-profit owner
- Pervious paving

2010



2014

2018

Findings	
Structure	✓
Soil Condition	
Materials	✓
Vegetation	

Ponding issue!

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Civic Garden Center

Site Characteristics

- Small scale
- Non-profit owner
- Porous concrete & asphalt

Findings	
Structure	✓
Soil Condition	
Materials	✓
Vegetation	

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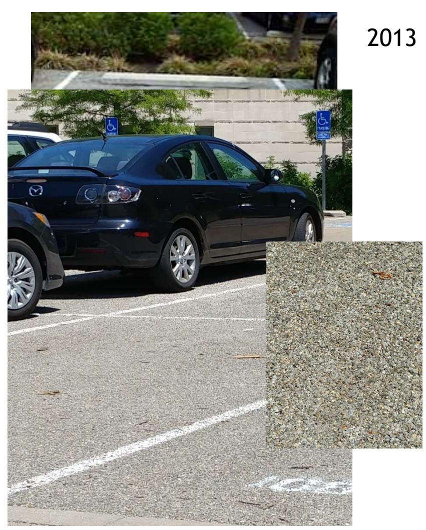
Clark Montessori School

Site Characteristics

- Medium scale
- Public owner
- Porous concrete

Findings	
Structure	✓
Soil Condition	✓
Materials	✓
Vegetation	



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Clark Montessori School

Site Characteristics

- Medium scale
- Public owner
- Pervious paving

Findings	
Structure	✗
Soil Condition	
Materials	✗
Vegetation	✗

2013

2018

Damage to pavers

29

Clark Montessori School

Site Characteristics

- Medium scale
- Public owner
- Pervious paving

Findings	
Structure	✗
Soil Condition	
Materials	✗
Vegetation	✗

Cause of failure - siting

30

Cincinnati State*

Site Characteristics

- Large scale
- Public owner
- Pervious pavers, porous asphalt & concrete, bioswales, rain gardens

2010

2018

13

*Cincinnati State Technical & Community College

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Cincinnati State

Site Characteristics

- Large scale
- Public owner
- Porous concrete

Findings	
Structure	✓
Soil Condition	
Materials	✓
Vegetation	

2014

2018

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Cincinnati State

Site Characteristics

- Large scale
- Public owner
- Pervious pavers

2018

Findings	
Structure	✓
Soil Condition	✗
Materials	✗
Vegetation	

Localized sand accumulation, evidence of flow from upgradient roadway

*Cincinnati State Technical & Community College

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Cincinnati State

Site Characteristics

- Large scale
- Public owner
- Porous asphalt

2014

2018

Findings	
Structure	✓
Soil Condition	
Materials	✓
Vegetation	

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Conclusions

- Vegetated practices
  - Doing well in general
  - Biggest issue is invasive species (likely cause – lack of long-term maintenance plan)
  - Invasives do not affect performance – only appearance
- Pervious/porous paving
  - Porous asphalt is doing great everywhere
  - Porous concrete shows signs of some spalling but this seems to be self-limiting over time
  - Porous pavers do well if sited correctly

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Conclusions

- Urban GI practices seem to be proving viable over time
- Proper siting is critical for long-term success
- Long-term maintenance plans/funding are essential for all types of GI
- GI practices appear to have better longevity with motivated property owners
- While invasive species are an issue in some practices, this does not impact performance

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Conclusions

- Observational assessments are a quick and simple tool in evaluating the long-term viability of GI practices
- Can be used to pinpoint possible issues that may affect longevity & overall performance

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Questions?

Nancy Ellwood, CDM Smith

Email: ellwoodnk@cdmsmith.com

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Ryan Winston, PhD, P.E.

Assistant Professor

Department of Food, Agricultural, and Biological Engineering

Department of Civil, Environmental, and Geodetic Engineering

Core Faculty, Sustainability Institute

Ohio State University

The Ohio State University
Stormwater Management Program

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Permeable Pavement: How Design Affects Performance and Maintenance

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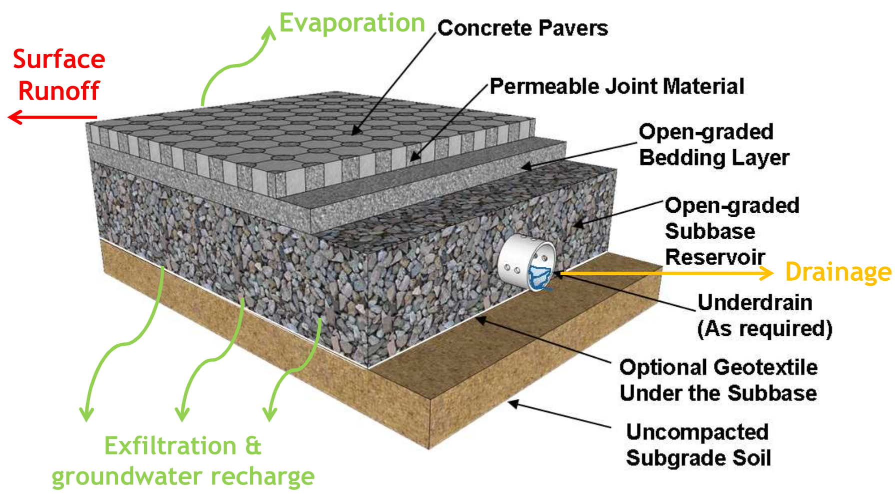
Permeable Pavements



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How Should They Work?

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Thus far….

…most research studies on permeable pavements that treat only direct rainfall

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Permeable Pavements Treating Direct Rainfall

Site	Range	Mean CN	Median CN
Swansboro PICP	37–45	44	45
Kinston CGP	70–89	77	79
Omit Hurricane Floyd	66–93	73	69
Wilmington PC	77–89	80	89

- Bean et al. 2007, *J. Environmental Engineering*
- Impermeable CN = 98

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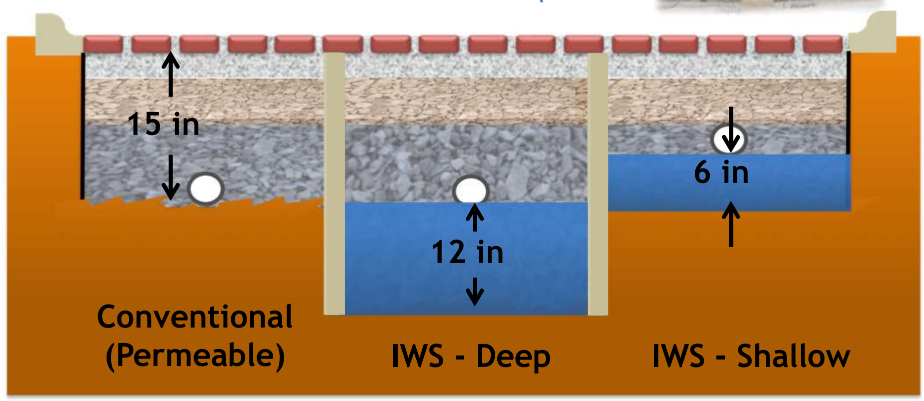
Boone, NC



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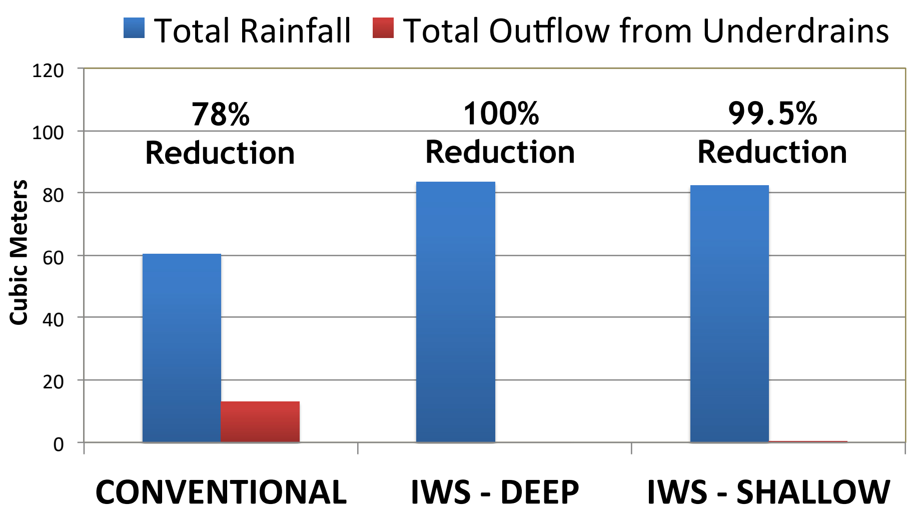
Results



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Run-On

- Increasing run-on reduces construction cost
- Decreasing run-on reduces maintenance cost

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The “New” Standard Design

Two Questions:

1. How do these systems perform for runoff reduction?
2. What are the maintenance needs?

- 1.75:1 run-on ratio
- 2:1 max run-on allowed in Ohio

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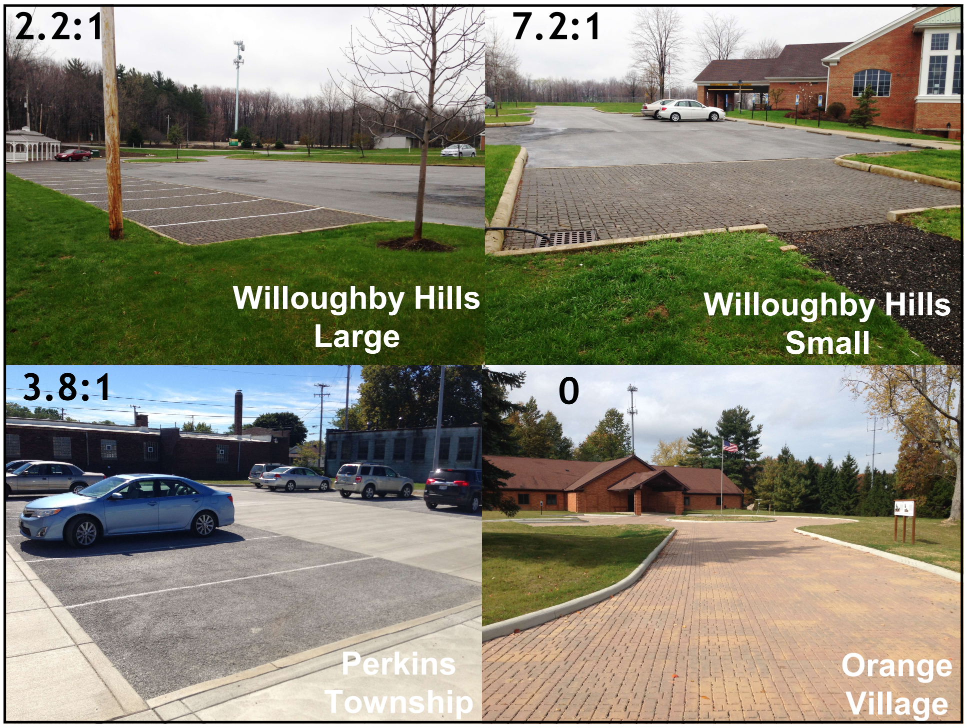

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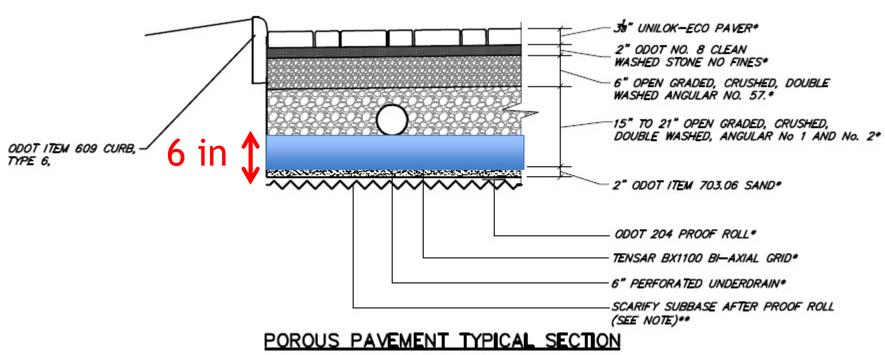
Design Cross-Sections



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

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Observed Storm Events

Site Name	Monitoring Period	Storm Events (#)	Total Rainfall (mm)	Median Rainfall Depth (mm)	Max Rainfall Depth (mm)
Perkins Township	April 2013 - Dec 2014	89	1281	8.9	65
Willoughby Hills	Oct 2013 - Dec 2014	79	1151	8.1	87
Orange Village	Oct 2013 - Dec 2014	61	789	8.1	89

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Water Balance Summary

Site	Run-on Ratio	Drainage (%)	Surface Runoff (%)	Runoff Reduction (%)
PT	3.8	47	0	53
WH small	7.2	76	8	16
WH large	2.2	44	24	32
OV	0	1	0	99

Due to surface clogging

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Q_p Mitigation during Peak Rainfall Intensities

2-5 storms with peak intensities

> 1 yr, 5 min storm for Cleveland, OH

PT	WH Large	WH Small	OV
84-98	0-11	27-61	92-99

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Reynoldsburg, Ohio Meijer

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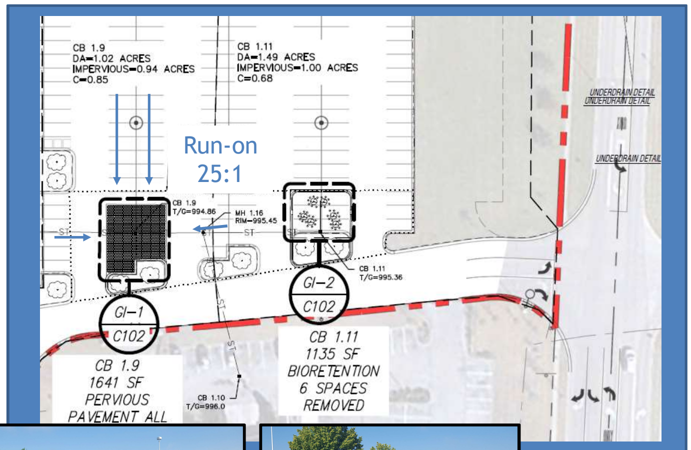
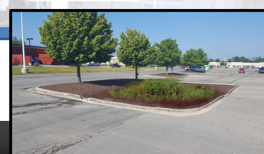
Meijer Parking Lot Retrofit





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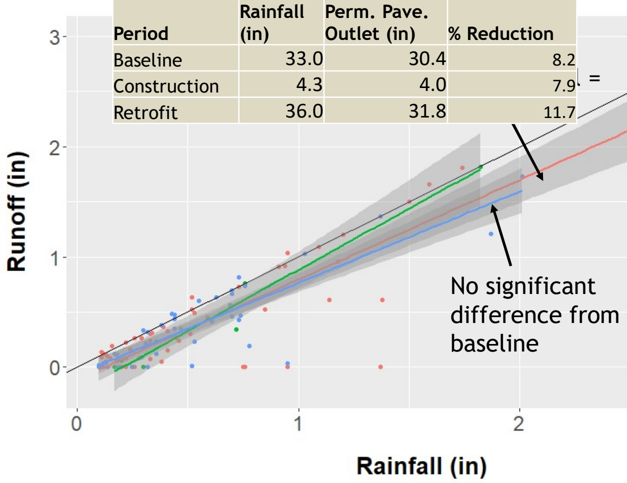
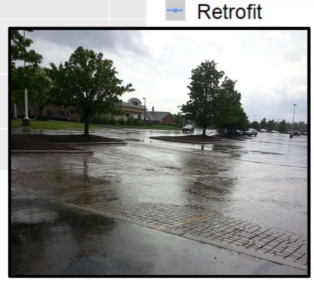
Runoff Volume Reduction

Permeable Pavement

Period	Rainfall (in)	Perm. Pave. Outlet (in)	% Reduction
Baseline	33.0	30.4	8.2
Construction	4.3	4.0	7.9
Retrofit	36.0	31.8	11.7





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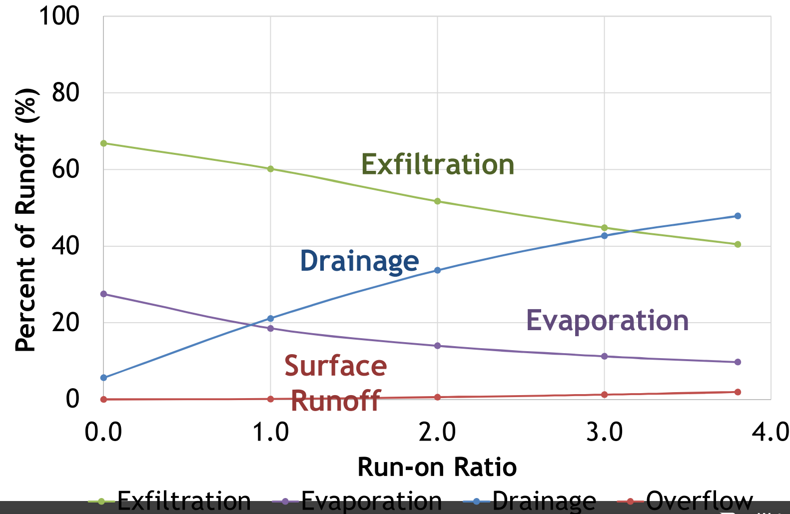
Effect of Run-on Ratio

15 cm IWS zone, 60 cm agg. depth, and clay underlying soil



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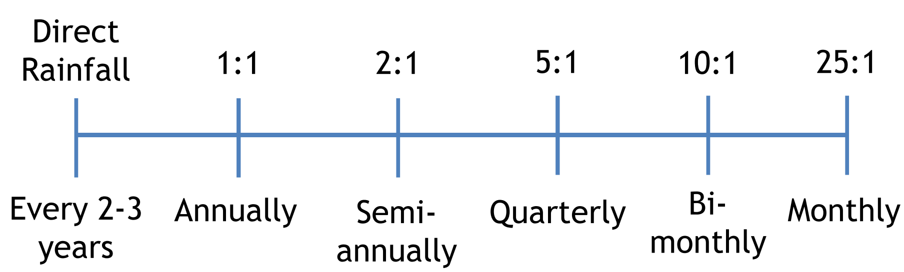
Permeable Pavement Maintenance Schedule

Our experience monitoring various run-on ratios suggests maintenance is needed:



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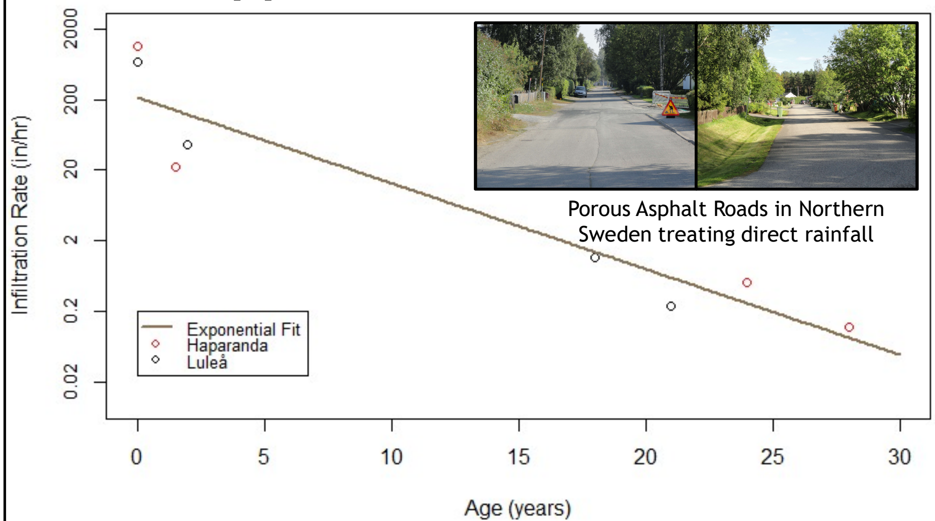
What Happens without Maintenance?



Winston et al. (2016) – *Journal of Environmental Management*

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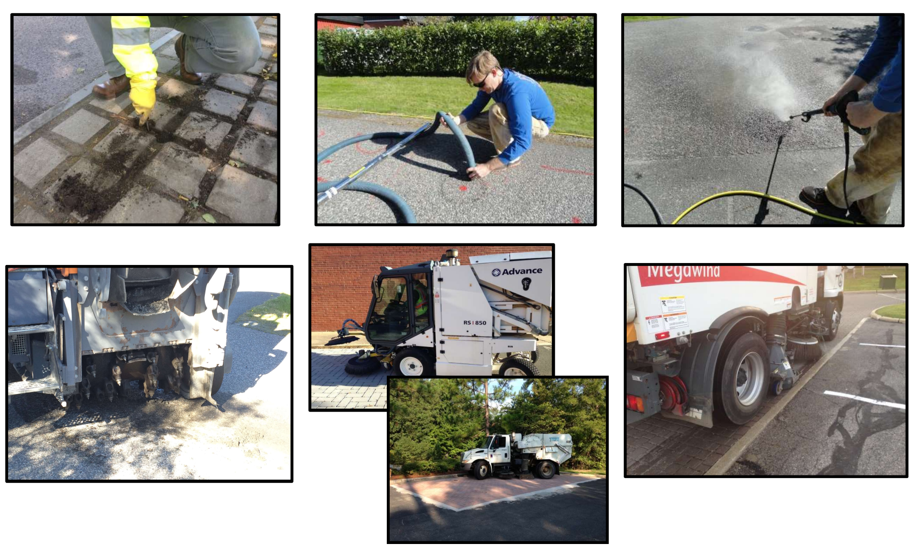
Best Methods for Maintenance?



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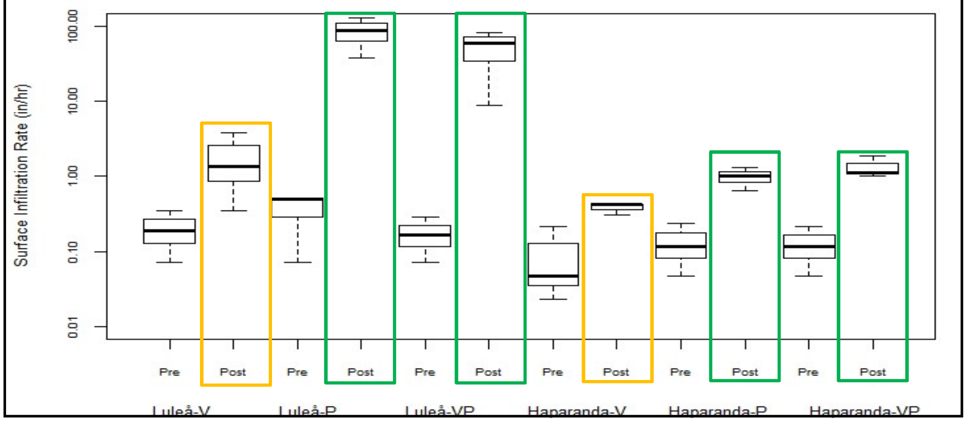
Vacuuming (V), Pressure Washing (P), & Vacuuming + Pressure Washing (VP)

- Porous asphalt roadways (21 and 27 years old at maintenance)
- Pressure washed at 30˚ angle to pavement surface
- P & VP significantly better than V
- P & VP not significantly different



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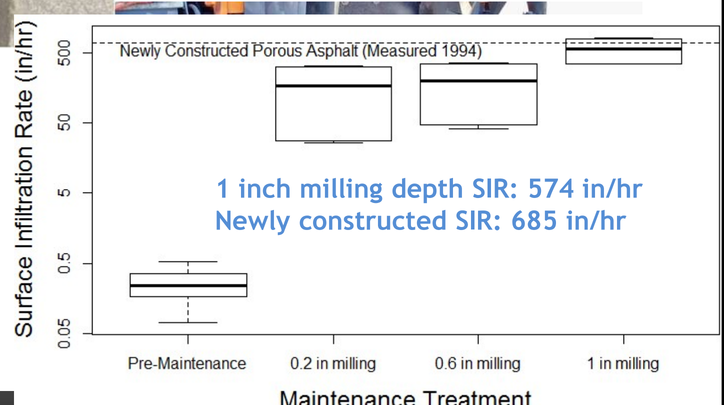
Milling of Porous Asphalt

- Milled 21-yr old porous asphalt street to 0.2, 0.5, and 1.0 in
- All depths significantly improved surface infiltration rate (SIR)

Most successful maintenance practice studied



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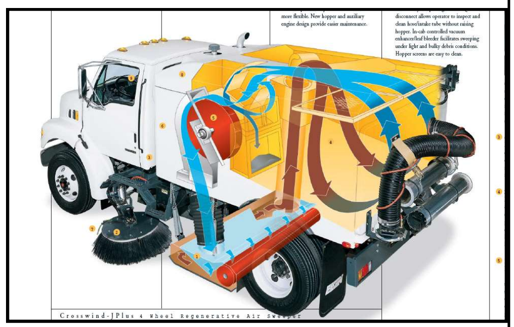
Street Sweepers

Mechanical

Regenerative Air



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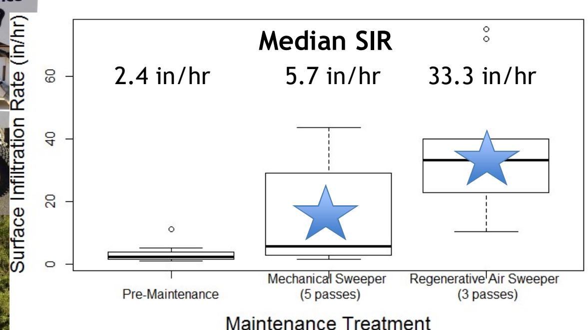
Mechanical vs. Regenerative Air Street Sweeper on PICP



★ Significant improvement

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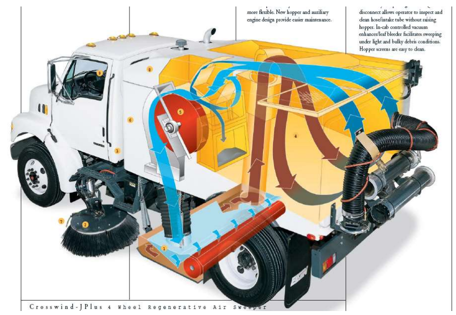
Preventative Maintenance

- Regenerative Air Street Sweeper good for preventative maintenance for:
  - PICP
  - Pervious Concrete
  - Pervious Asphalt
- May not work for restorative maintenance



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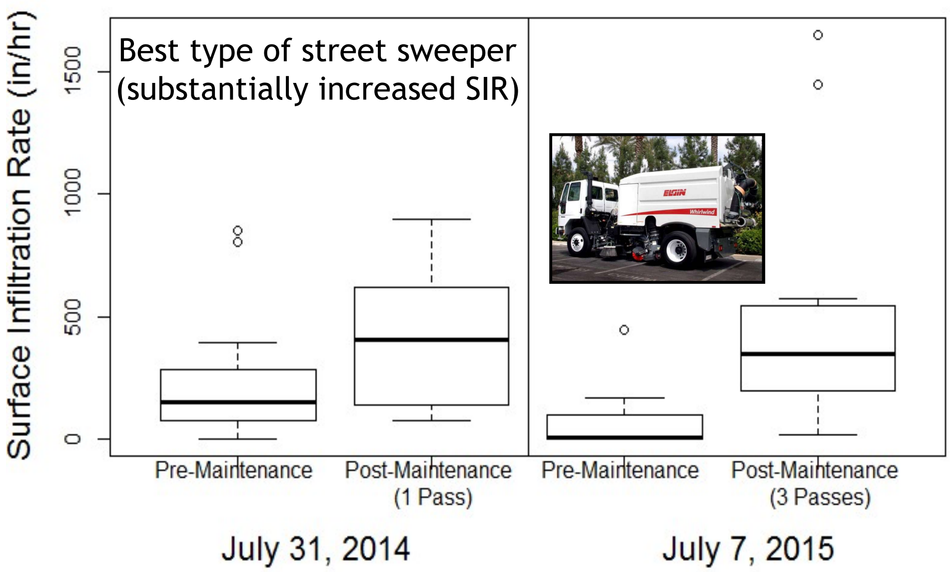
Vacuum Truck (PICP)



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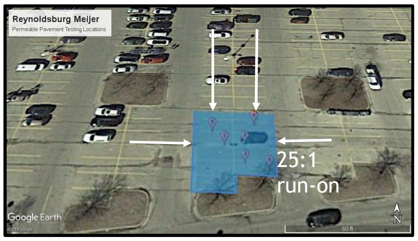
Meijer Maintenance



- Quarterly testing at 6 locations
  - Inform maintenance intervals / type
  - Hot spots for clogging

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Meijer Maintenance

- Permeable pavement was 17 months old at time of maintenance
  - 25:1 run-on ratio
  - Moderately clogged (5-150 in/hr)
  - Performed April 25, 2019
  - 5-15 passes with regenerative air street sweeper

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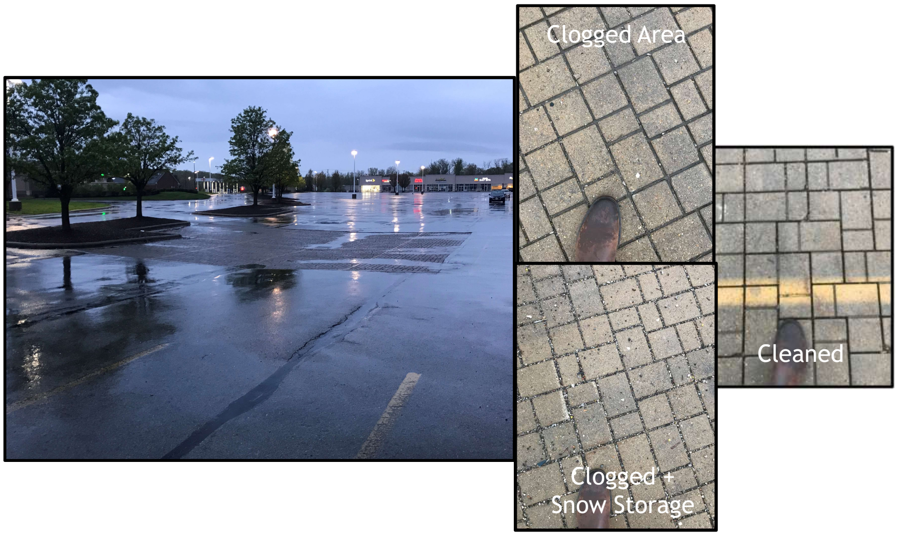
Meijer Store Maintenance



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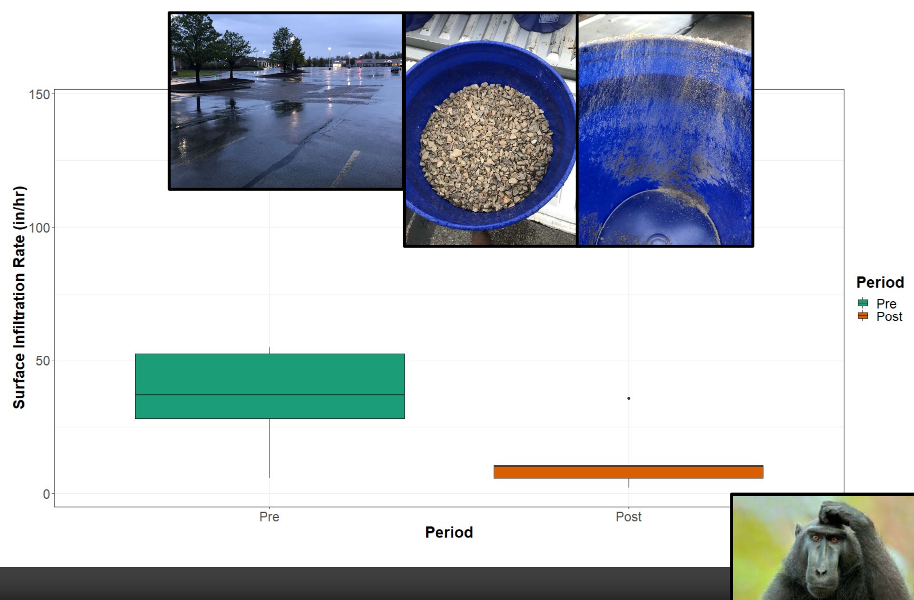
Maintenance Results



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Maintenance Methods

Mechanical Street Sweeper

Regenerative Air Street Sweeper

Vacuum Truck

Industrial Vacuum

Pressure Washing (Porous Asphalt)

Milling (Porous Asphalt)

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Take Home Points

1) Reduce susceptibility to clogging
   - Prevent pervious areas from draining to PP
   - Perform routine catchment cleaning to remove sediment, leaf litter, acorns, etc.
2) Higher run-on = more maintenance & reduced hydrologic and water quality performance
3) Technologies exist to effectively maintain permeable pavement
4) Consider maintenance in design

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Questions?

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Overview of Stormwater Life Cycle Analysis and Green Infrastructure Co-Benefits Projects

Harry Zhang, PhD, PE
Program Director
The Water Research Foundation

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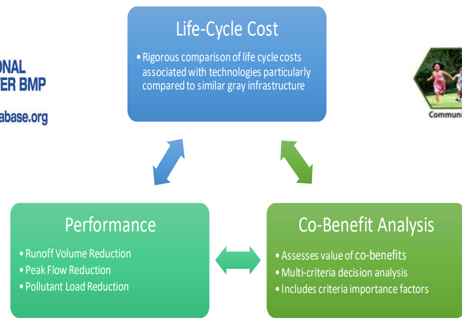
Integrated Stormwater Management: Life Cycle Cost; Co-Benefits and BMP Database

INTERNATIONAL STORMWATER BMP DATABASE
www.bmpdatabase.org



Stormwater Infrastructure (Green & Gray):
- Life Cycle Cost and Co-Benefits of Green Infrastructure

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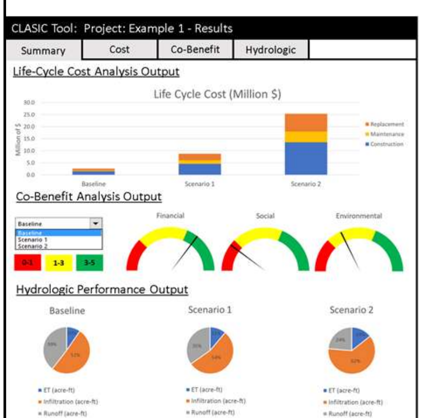
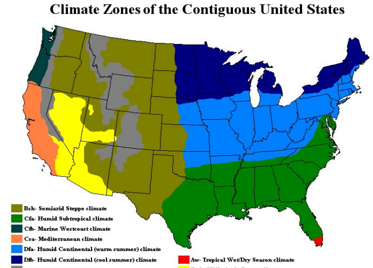
Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)
- EPA National Priorities Grant #836173



Climate Zones of the Contiguous United States



- **Project Duration:** 4 Years (2016-2020);
- **Funding:** $2M from USEPA (plus $0.5M matching funds from WRF);
- **Team:** 7 organizations plus national collaborating partners (e.g. WEF; ASCE; American Rivers);
- **Community Engagement** for Municipalities & Utilities (in all 10 EPA Regions)

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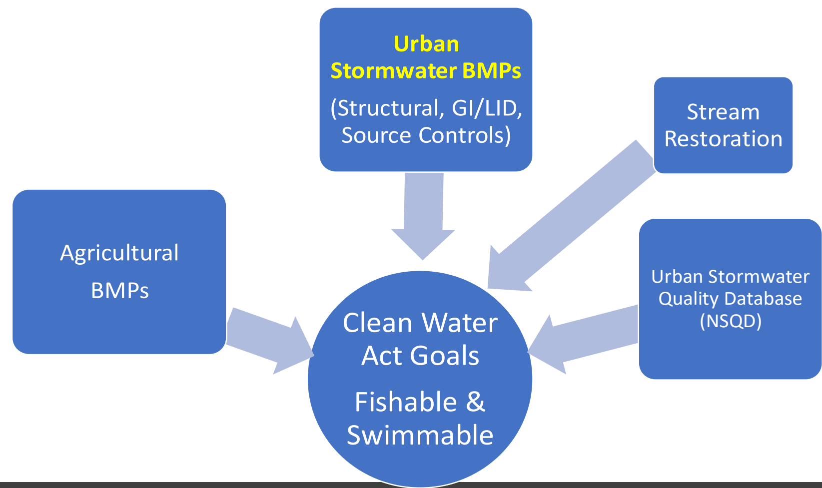
International Stormwater BMP Database

INTERNATIONAL STORMWATER BMP DATABASE
www.bmpdatabase.org



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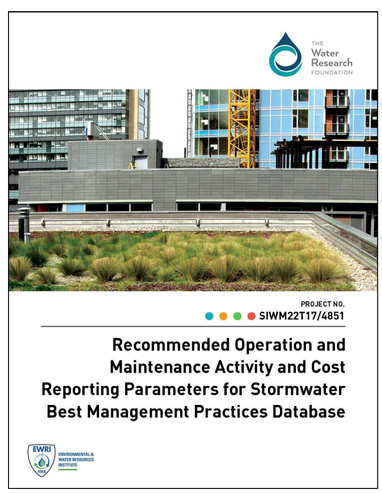
Stormwater O&M Cost Tracking Protocol

- Operation & Maintenance (O&M) cost as part of lifecycle cost
  - Develop a protocol to improve tracking cost data for cross comparison



Funded by ASCE/EWRI (a matching project for EPA National Priorities Grant #836173)

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Framework and Tools for Quantifying Green Infrastructure Co-Benefits and Linking with Triple Bottom Line Analysis

Social
- ✓ Reduced urban heat stress and associated health benefits
- ✓ Greater flood protection
- ✓ Increased property values
- ✓ Improved recreational opportunities
- ✓ Green job creation

Financial
- ✓ Avoided infrastructure costs
- ✓ Asset life extension
- ✓ Energy savings

Environmental
- ✓ Improved air and water quality
- ✓ Groundwater recharge
- ✓ Improved habitat/ecosystem benefits (wetlands)
- ✓ Decreased GHG emissions

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Sybil Sharvelle

- Associate Professor, Colorado State University, Department of Civil and Environmental Engineering

One Water Solutions Institute

Colorado State University

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Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)

EPA National Priorities Grant #836173

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One Water Solutions Institute
Colorado State University

The University of Utah

University of Maryland
Environmental Finance Center

Wichita State University

Geosyntec consultants

WWE
Wright Water Engineers, Inc.

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Primary Team Members

- Harry Zhang, WRF
- Sybil Sharvelle, Tyler Dell, Mostafa Razzaghmanesh - CSU
- Jennifer Cotting, Jennifer Egan – UMD EFC
- Christine Pomeroy – UU
- Tonya Bronleewe - WSU
- Dan Pankani – Geosyntec Consultants Inc.
- Jane Clary – Wright Water Engineers

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Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs

CLASIC Vision

The CLASIC tool is a user-informed screening tool which utilizes a lifecycle cost framework to support stormwater infrastructure decisions on extent and combinations of green, hybrid green-gray and gray infrastructure practices.

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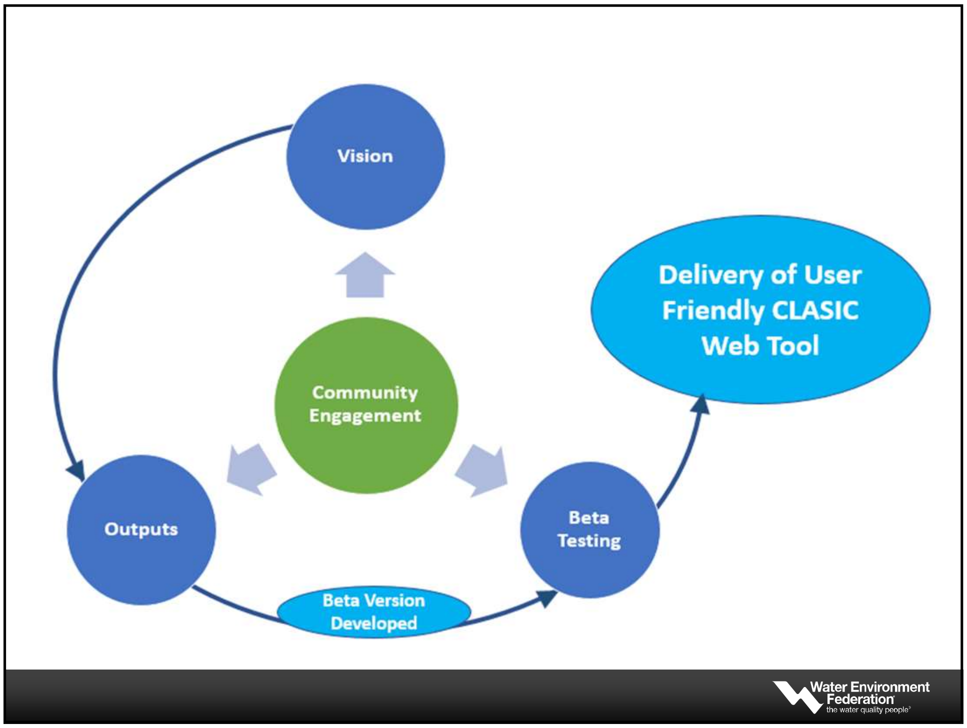

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Questions the CLASIC Tool Seeks to Answer

- How do various scenarios of stormwater infrastructure compare in terms of:
  - Lifecycle cost
  - Runoff volume reduction
  - Pollutant removal
  - Social benefits
  - Environmental benefits
- How does climate change and land use change effect future performance of scenarios of green and gray infrastructure?
- How do maintenance and long-run costs compare for user selected scenarios?

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CLASIC will enable users to

- Assess scenarios of stormwater infrastructure via functional unit analysis for robust decision making based on preferences to evaluate:
  - Regulatory compliance
  - Runoff volume reduction
  - Water quality
  - Social and environmental benefits
  - Lifecycle cost
- Couple financial decision with holistic consideration of benefits (primary and secondary)
- Conduct analysis from neighborhood to watershed scale

Analyses not included in CLASIC

- Site specific design of stormwater infrastructure
- Comparison of spatial distribution of infrastructure within sub-unit or subcatchment
- Algorithms for optimization of design

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National Stormwater Calculator

National Stormwater Calculator

Tool to help control runoff and promote the natural movement of water

EPA's National Stormwater Calculator (SWC) is a software application that estimates the annual amount of rainwater and frequency of runoff from a specific site. Estimates are based on local soil conditions, land cover, and historic rainfall records. Users supply information about the site's land cover and then select the low impact development (LID) controls they would like to use. The LID controls include seven green infrastructure practices. The SWC is designed to be used by anyone interested in reducing runoff from a property, including site developers, landscape architects, urban planners, and homeowners.

Additional Information

Modeling Capabilities

Hydrology Analysis. The SWC allows users to analyze site hydrology for small- to medium-sized (less than 12 acres) locations within the United States, including Puerto Rico, using LID controls. It estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long-term period of historical rainfall.

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	CLASIC	NSWC
SCALE	Designed for flexibility in study area size (neighborhood to watershed) Enables variation of parameters within study area subunits Outputs for multiple subunits within study area at once	Designed for site level design and scale of analysis is limited Desktop version (50 acres max) Web version (12 acres max)
INPUTS	Accesses national database on land use and imperviousness to inform hydrologic model	User enters land use data
SCMs	Includes a more comprehensive set of technologies (12 total) 5 additional: sand filter, grass swales, storage vault, extended detention basins, and wet ponds	More flexibility in LID design specs
WATER QUALITY	Includes water quality projections	No water quality projections
CLIMATE	Considers more advanced climate change scenarios (CMIP5 datasets) including flexibility in assessing multiple climate scenarios	Uses older climate change scenarios (CMIP3 datasets)

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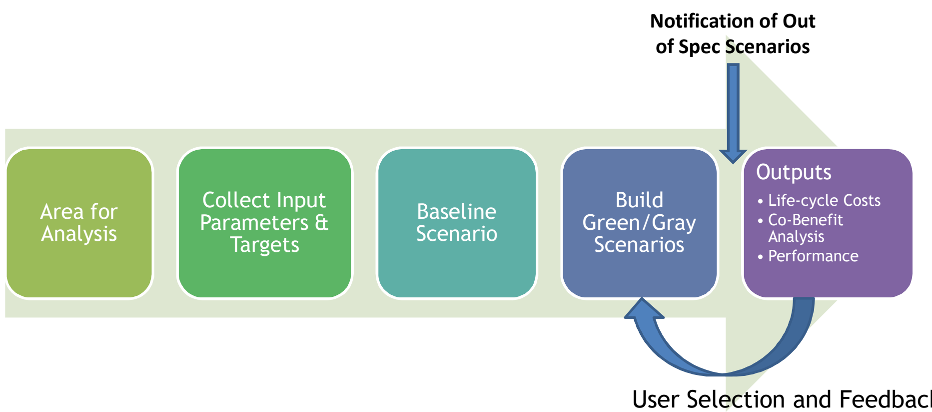
CLASIC Tool Interface Progression



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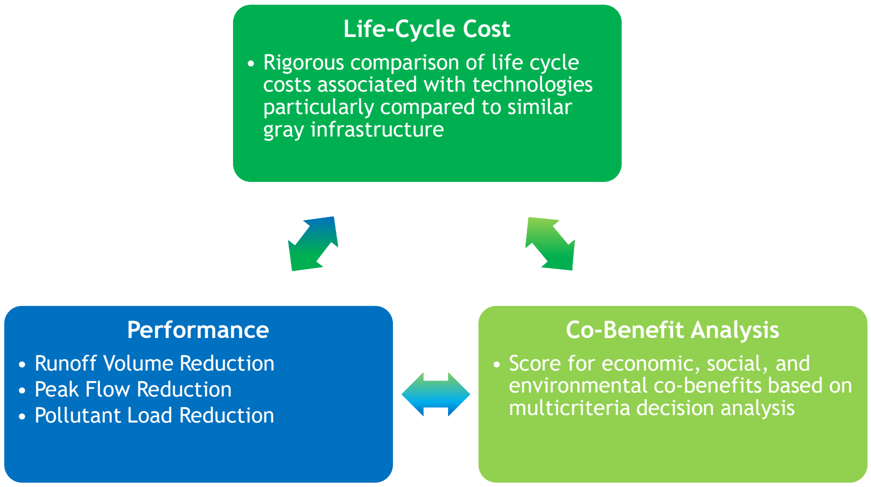
Three Basic Outputs Enable Integrated Assessment



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Output	Included in CLASIC tool
Pollutant Load Reduction	· TSS · TN · TP · FIB
Hydrologic	· Runoff Volume · Volume Infiltrated · Volume Evapo-transpired · Number of runoff events
LCC	· Net Present Value o Construction o Maintenance o Rehabilitation · Average Annual Cost Over Design Life · Per unit cost for scenario comparison
Co-Benefits	· Score of economic, environmental, social performance based on user selected importance factors and performance output

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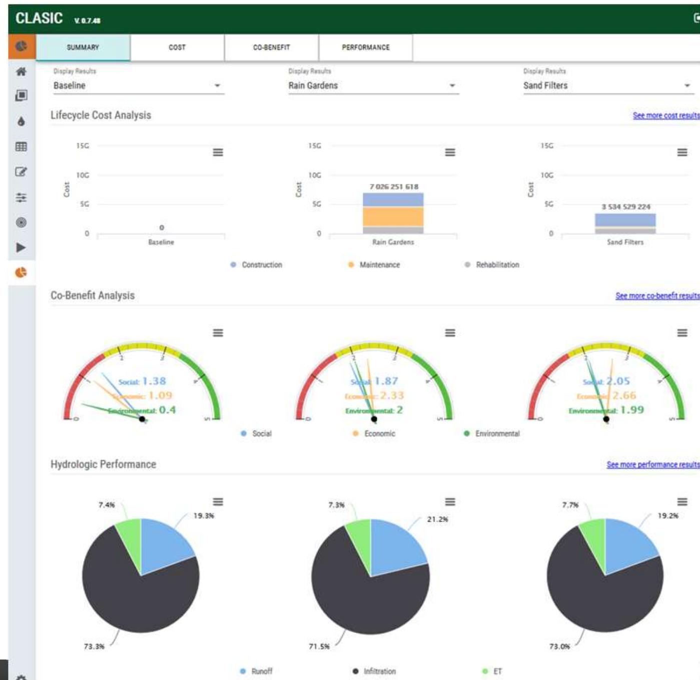

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Technology Categories

- Rain Gardens
- Sand Filter
- Infiltration Trench
- Permeable Pavement
- Green Roofs
- Disconnection
- Grass Swales
- Extended Detention Basins
- Wet Pond
- Stormwater Harvesting
- Storage Tunnel/Vault
- Stream Restoration

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Web-based Geospatial Tool

- Web-based platform developed at Colorado State University
  - Interface
  - Input Parameters
  - Outputs
- Deployed using the Environmental Resource Assessment and Management System (eRAMS)

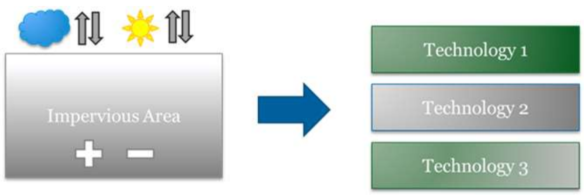
RAMS

Collect Input Parameters

- Soil Datasets (SSURGO/STATSGO)
  - Soil Type
  - Slope
- Land Use/Land Cover (NLCD)
  - % Open, Low, Medium, High, and Other
    - Water Quality (TSS, TP, TN)
    - Overland Flow Length
- Imperviousness (NLCD)
- Climate
  - Precipitation (NOAA – Stormwater Calculator)
  - Evaporation (NOAA – Stormwater Calculator)

Scenario Development

- Create scenarios to evaluate changes of:
  - Stormwater infrastructure adoption
  - Land development pattern
  - Increased impervious area
  - Climate (precipitation/temperature)



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3 Basic Outputs

Performance
Water Quality
Runoff Volume
Volume Infiltrated
Volume Evapotranspired
Number of runoff events

Lifecycle Cost
Cost build up method
Construction
Maintenance
Rehabilitation
- Net present value
- Average Annual Cost Over Design Life
- Per unit cost for scenario comparison

Co-Benefit Analysis
Score of economic, environmental, social elements based on:
- User selected importance factors
- Performance and cost output

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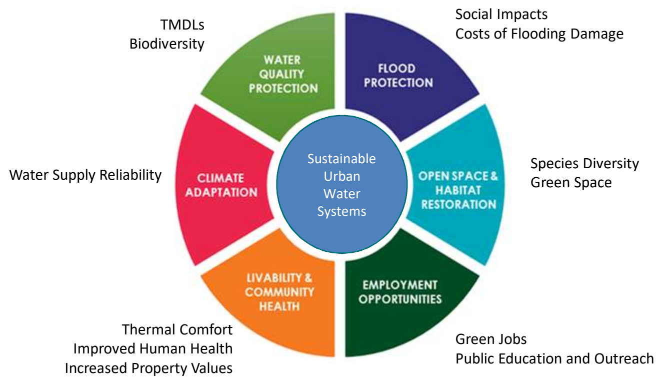
Co-Benefits Analysis



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Schedule for CLASIC Release

- Beta Testing: July 2019 – August 2019
- CLASIC tool refinement: September 2019
- CLASIC tool final testing and case studies: October 2019 – November 2019
- CLASIC Tool Delivered: February 2020

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CLASIC Tool Steps

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CLASIC: Live Demo

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Thank you!

CLASIC

Beta Testing:
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Questions?

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