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alcosan allegheny county sanitary authority

Metrics that Matter –

Evaluating Green Stormwater Infrastructure Performance

May 26, 2022

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Water Resource Center

Southwestern Pennsylvania Commission

Planning future workshop/webinar topics is currently underway! Please contact Erin Kepple-Adams, Water Resource Manager at ***ekepple@spcregion.org*** *and let her know what your needs are. She is happy to try to accommodate your requests.*

Agenda

- Objective
- Planning Approach
- Design Considerations
- Construction Phase
- Post-Construction Evaluation
- Operations & Maintenance
- Conclusions

Poll Question #1

Are you planning to implement green stormwater infrastructure (GSI) in the near future?

A. Yes, we have already implemented some type of GSI and are eager to do more.

B. Yes, we are planning to, but haven't done so before.

C. We are considering it as a possibility.

D. No, not unless we have to!

Objective

With Municipal Separate Storm Sewer System (MS4) and Consent Order and Agreement (COA) reporting requirements, this presentation will share some methods of assessing different types of GSI projects.

From site analysis through post-construction and operations & maintenance monitoring, these methodologies can provide reasonable estimates (and assurance) of project performance.

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- **Planning Approach**
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- Construction Phase
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- Conclusions

Planning Approach

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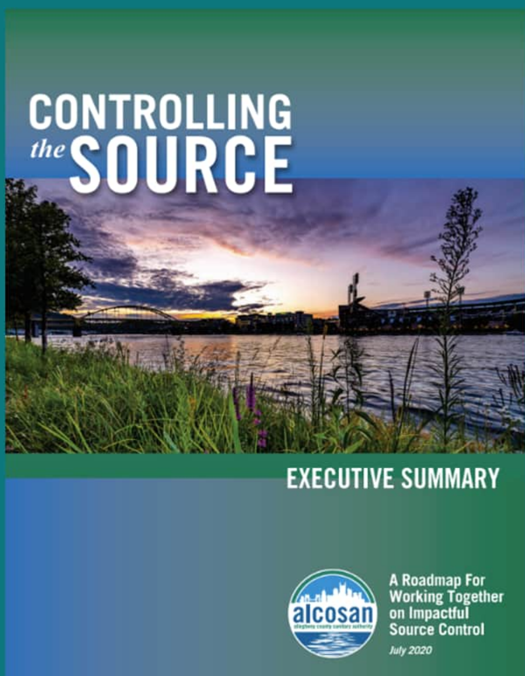


Context	Performance & Benefits	Constraints	Opportunities	Concept Plans and Costs	Prioritization

Context	Performance & Benefits	Constraints	Opportunities	Concept Plans and Costs	Prioritization
Understand context for natural and built systems, such as watershed/ sewershed boundaries, land use, population, soils, and sewer infrastructure systems.	Highlight areas where significant overflow reduction can be achieved based on the characteristics of the sewer system.	Analyze constraints including natural characteristics such as shallow bedrock, steep slopes and poor soils for infiltration.	Consider previously identified projects and identify new opportunity areas by analyzing parcel ownership and land use with relatively low constraints; situated in areas where significant overflow reduction can be achieved.	Develop site-specific concept plans and cost estimates, considering integrated costs versus standalone project costs.	Evaluate and prioritize opportunities based on cost and anticipated reduction.

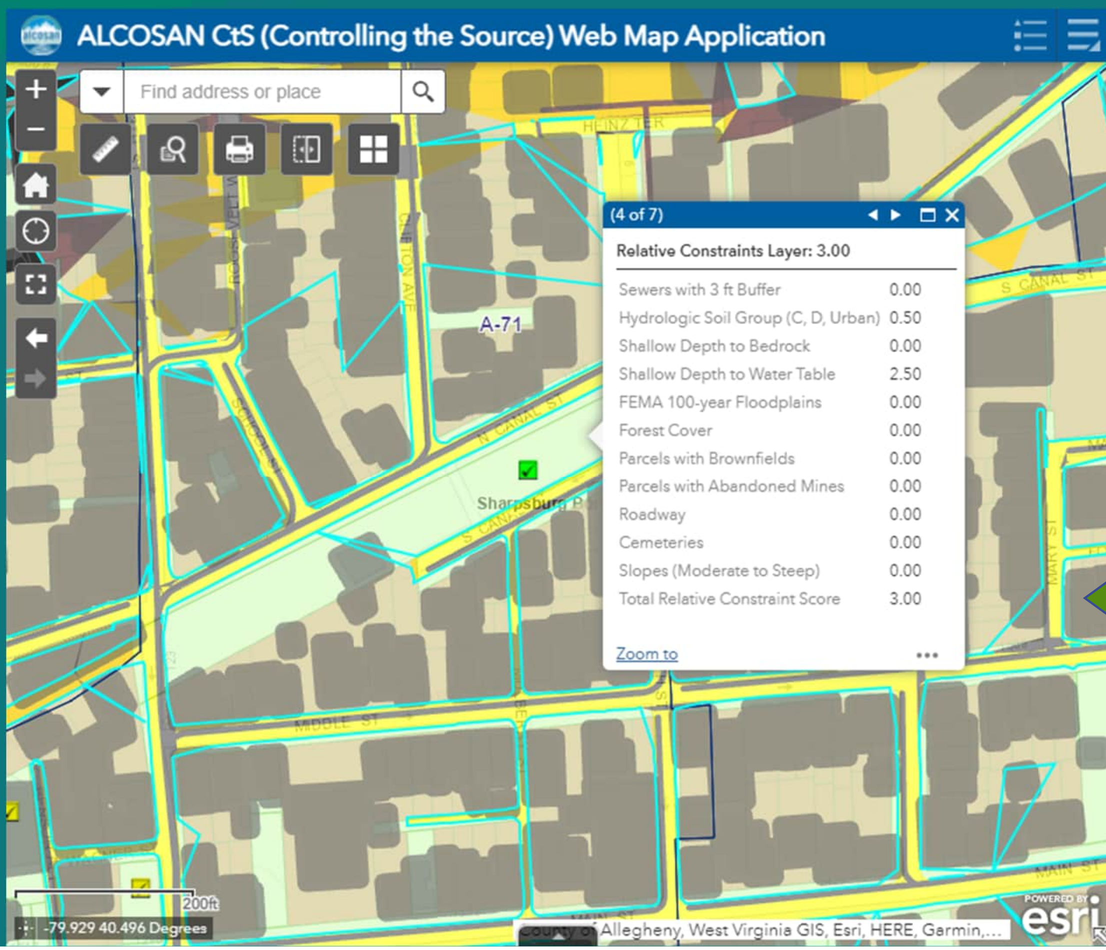
What information is important to have to inform the type, the scale, and potential benefits of GSI?

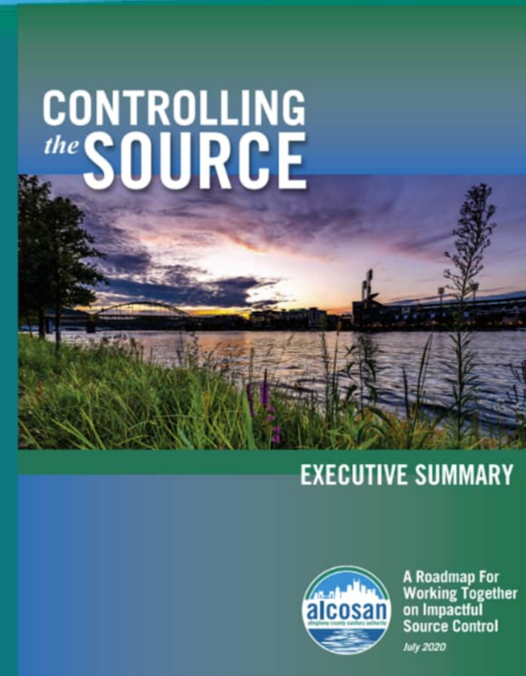
- **Site Information** → subsurface conditions, soils, utilities, slope, available space for GSI
- **Existing drainage conditions** → storm infrastructure, connectivity, flooding issues, overflow volumes
- **Potential drainage area to GSI and characteristics** → what is to be controlled and how “dirty” is the runoff expected to be

Assessing the expected runoff, sediment, trash, and debris characteristics can inform GSI type, pretreatment needs, and O&M expectations

Data sources include GIS, survey, geotechnical and other field investigations, stormwater sampling, and pre-construction monitoring

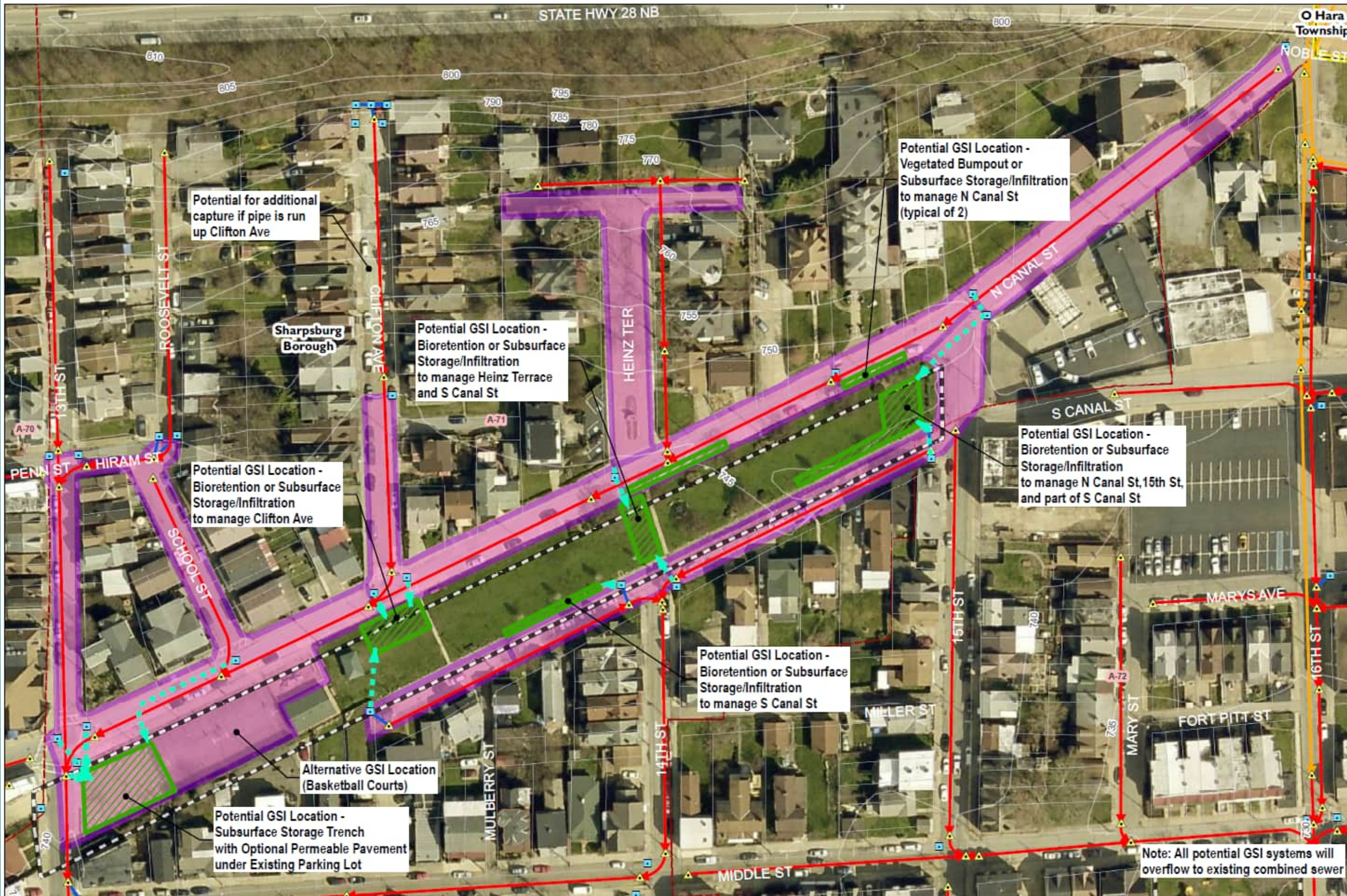
Gathering Information





Constraints analysis from Controlling the Source

www.alcosan.org/our-plan/plan-documents/controlling-the-source



3 RIVERS PROUD

Allegheny County Sanitary Authority

Upper Allegheny
GSI CONCEPT PLAN

UA-29: Kennedy Park
Sharpsburg Borough/ POC A-71

- Existing Inlets
- Sewer Structures
- Proposed Separate Storm Sewer

Sewer Pipes
- Combined
- Sanitary
- Stormwater
- Other Sewer Type
- Project Parcel Boundary
- Parcels
- Municipal Boundary
- GSI Footprint
- Impervious Drainage Area
- Surface Water
- Combined Sewer Area
- Runoff To Combined Area
- Separate Sewer Area
- Non-contributing Area (NCA)

Data Sources:
ALCOSAN: Sewer Structures, Sewer Pipes, Subcatchments
Allegheny County: Parcel Data, Contours
JACOBS: Existing Inlets

Note that limited sewer data information is available in GIS, so all existing sewer system information may not be shown on this map.

N 0 50 100 Feet

Map prepared by JACOBS- April 2019

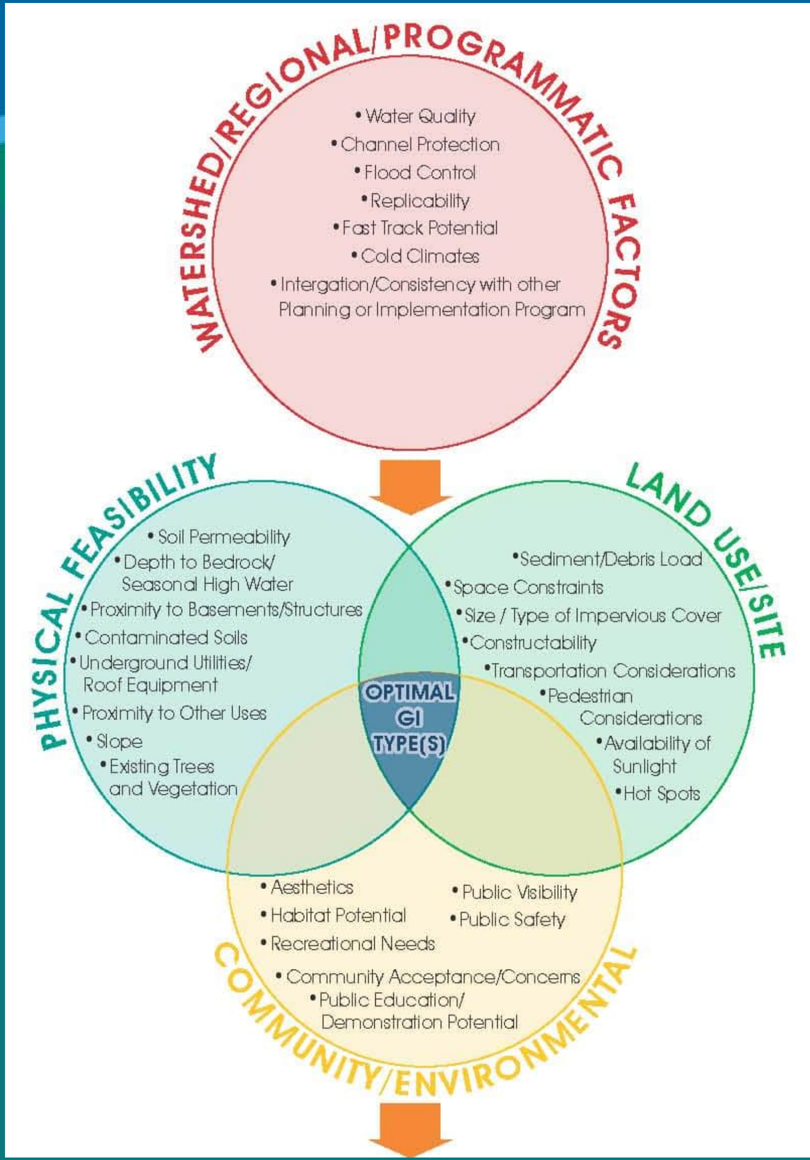
Kennedy Park has significant potential for GSI implementation due to its location and large expanse of open space. In the park, there are multiple opportunities to place small bioretention areas (rain gardens) with subsurface storage trenches to manage adjacent Canal St runoff in addition to several other streets that drain down towards the park. By installing short segments of new storm pipe at strategic locations, a larger potential contributing drainage area can be conveyed across N Canal Street and directed into the park. Vegetated bumpouts on N. Canal can manage roadway runoff while also slowing down traffic. The new GSI features should be sited in a way that does not impede existing park programming and available gathering space for festivals and events. In the parking lot to the west of the park, a subsurface storage trench can be located underneath the existing parking spaces with either a permeable or conventional pavement surface.

Project ID	Parcel Owner	Impervious Area Captured (ac)	*Construction Cost for Stand-alone GSI	*+Construction Cost for Integrated GSI	Relative Constraint Score	Runoff Capture (gal/yr)	Overflow Reduction Efficiency (ORE)	CSO Reduction (gal/yr)	**Cost Efficiency ($/gal/yr overflow reduction)
UA-29	Sharpsburg Borough	2.7	$670,000	$470,000	3.0	2,190,000	109%	2,390,000	$0.28

*Costs are planning-level estimates with an expected accuracy range of -25% to +50%, +Integrating GSI with other planned site improvements is assumed to result in a 30% cost reduction, **Efficiency based on construction cost for stand-alone GSI

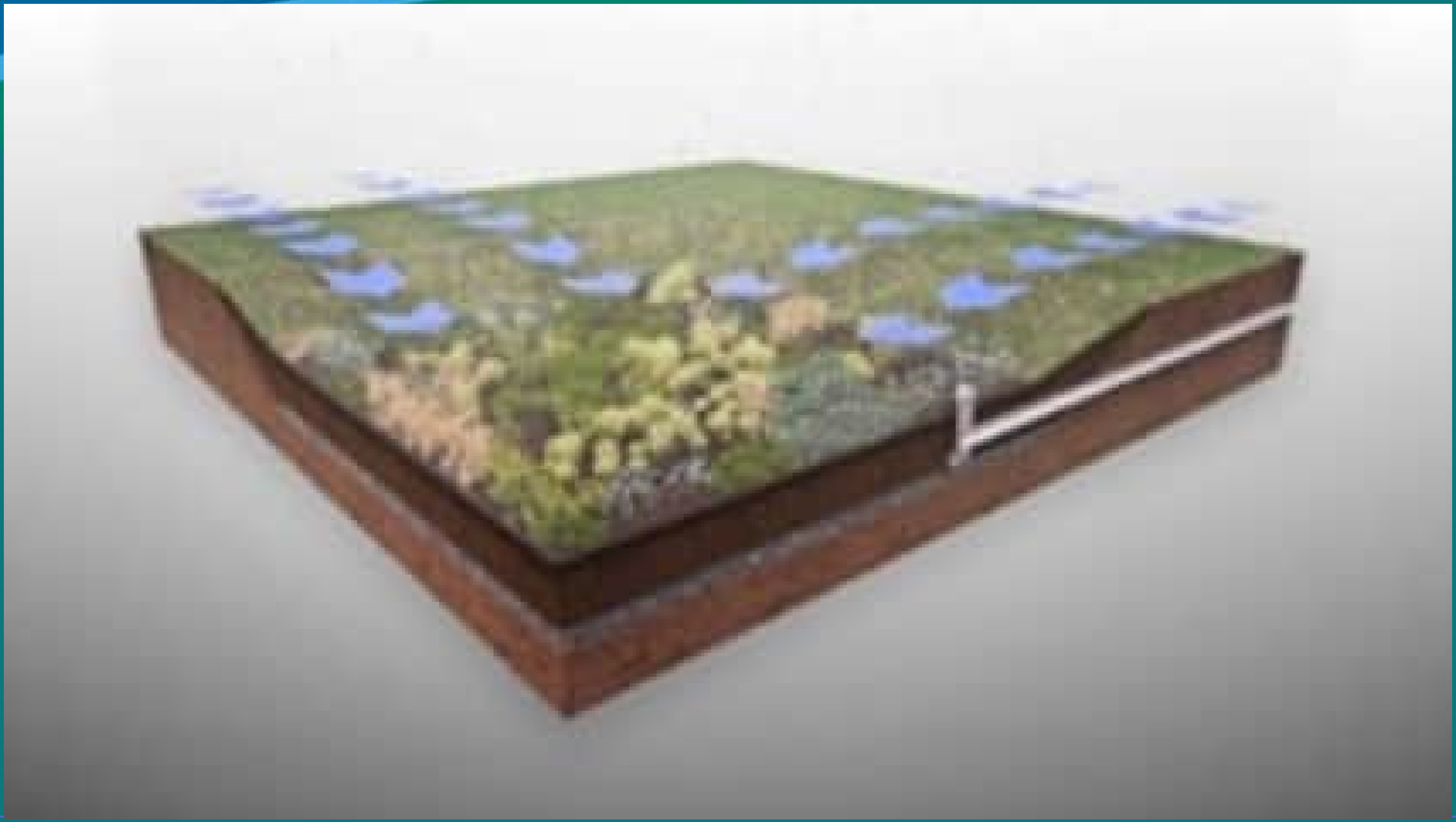
GSI Practice Selection

What are the most practical and effective GSI practices for a given site?



Source: Green Infrastructure Implementation (WEF, 2014)

Example GSI practice



[Bioretention / Rain Garden](https://www.gwinnettcounty.com/web/gwinnett/departments/water/whatwedo/stormwater/bmpsanddetentionponds)

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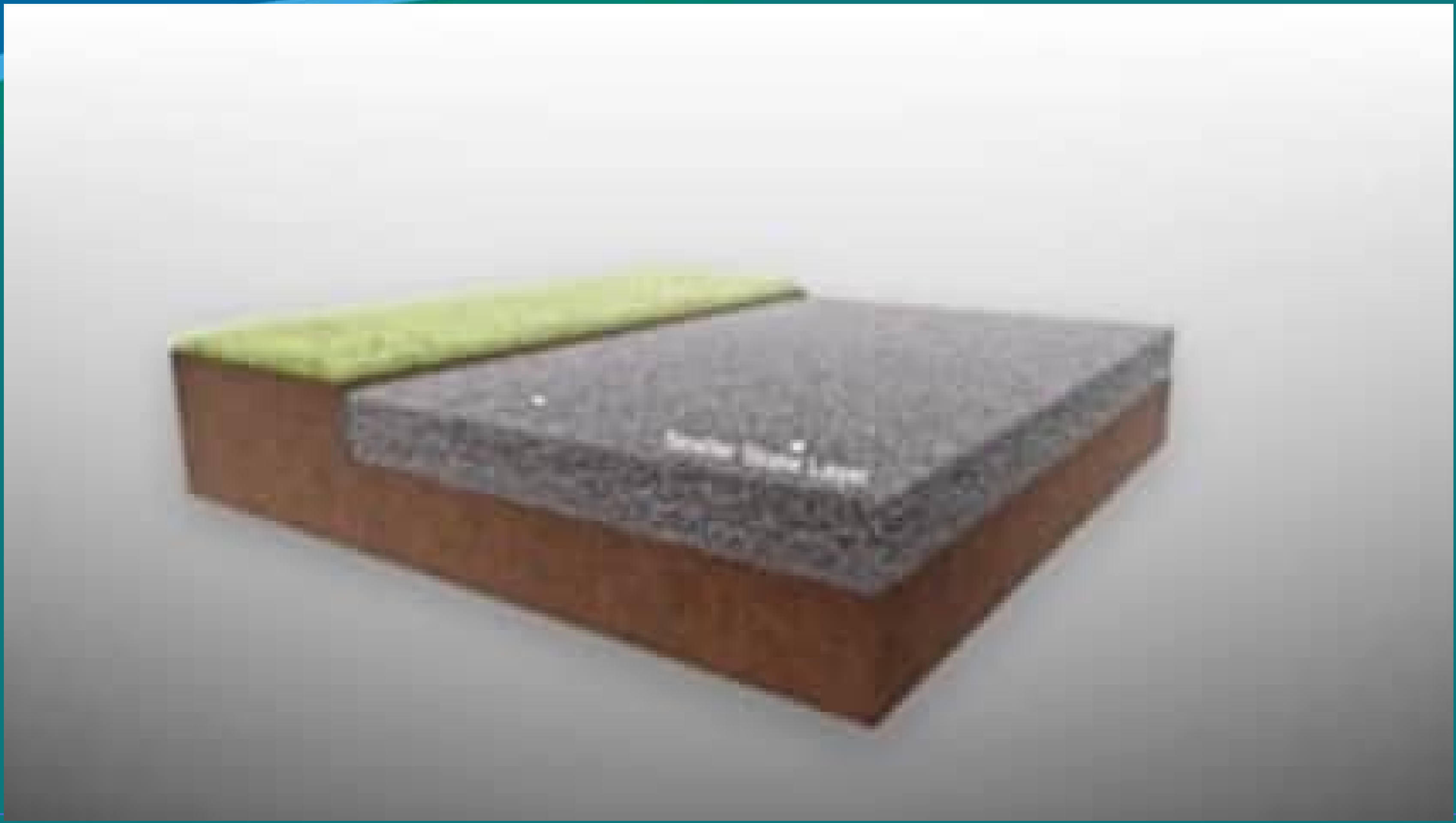
Example GSI practice



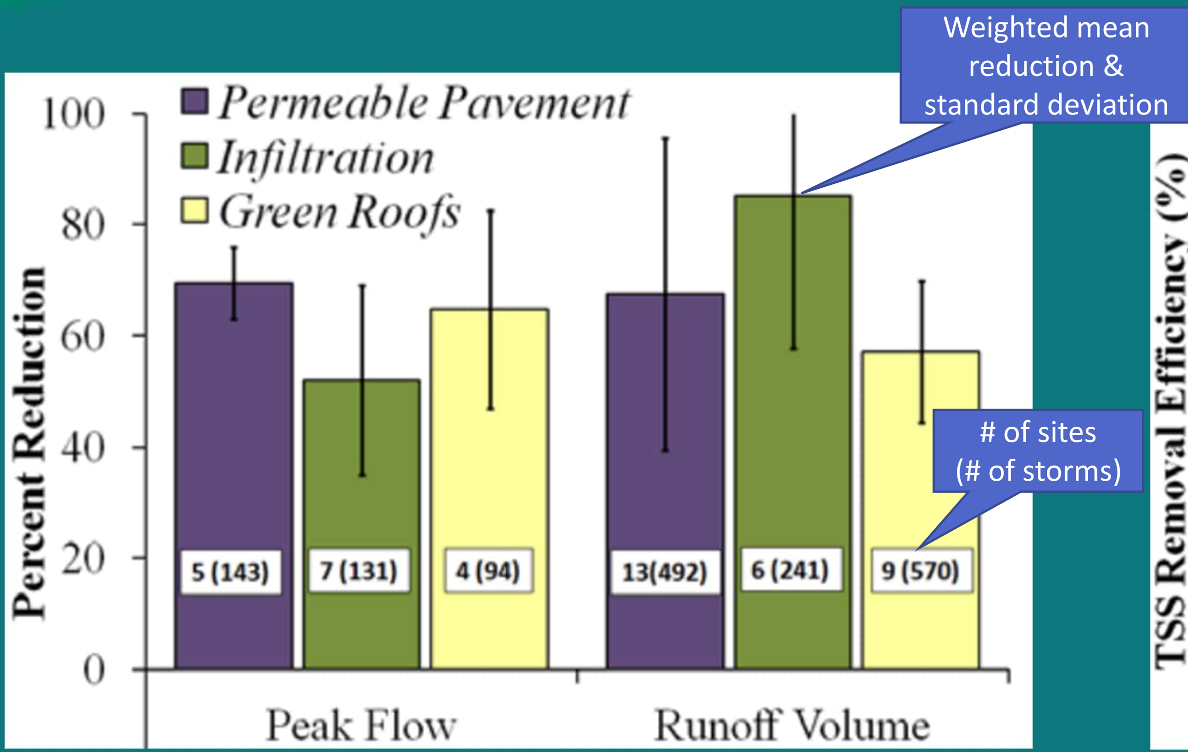
[Permeable / Pervious / Porous Pavement]

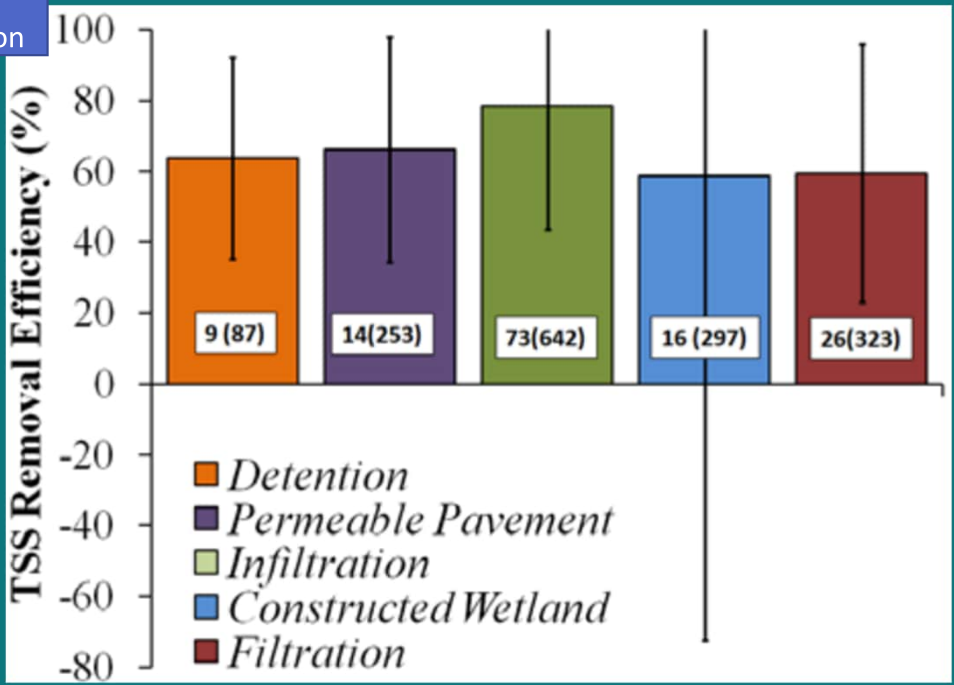
Estimating the Benefit

Wide range of options, depending on the metrics of interest and the project size, type, and complexity:

- Least complex: engineering formulas / spreadsheets
- Moderately complex: packaged tools (National Stormwater Calculator, HydroCAD, etc.)
- Most complex: detailed hydrologic and hydraulic (H&H) Modeling

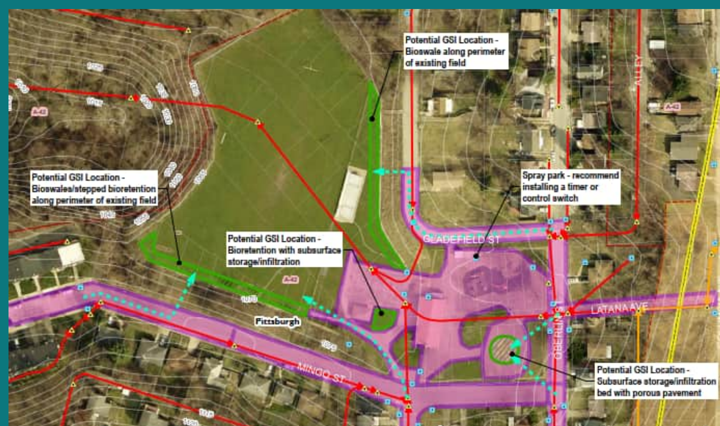
Estimating the Benefit – Peak Flow, Runoff Volume, and Pollutant Removal

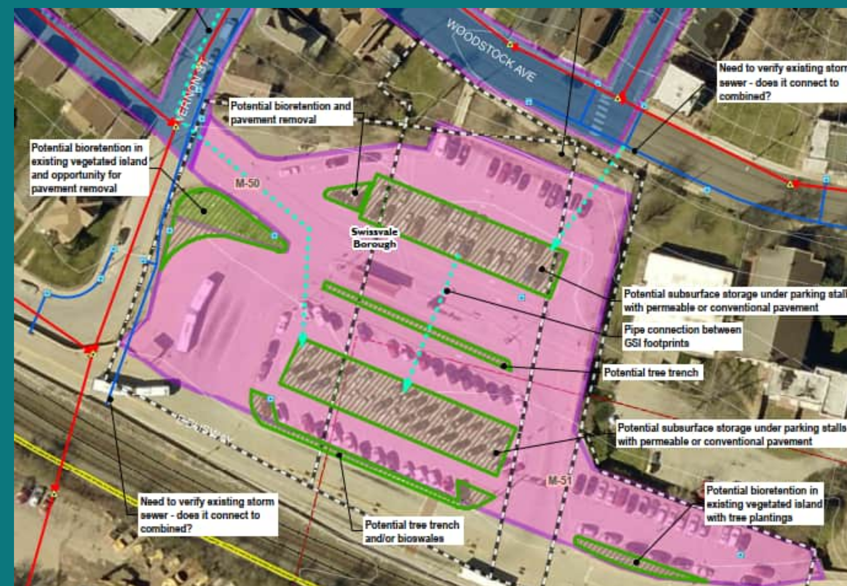




The Illinois Green Infrastructure Study (University of Illinois et al., 2010)

Range of Project Types/Complexities





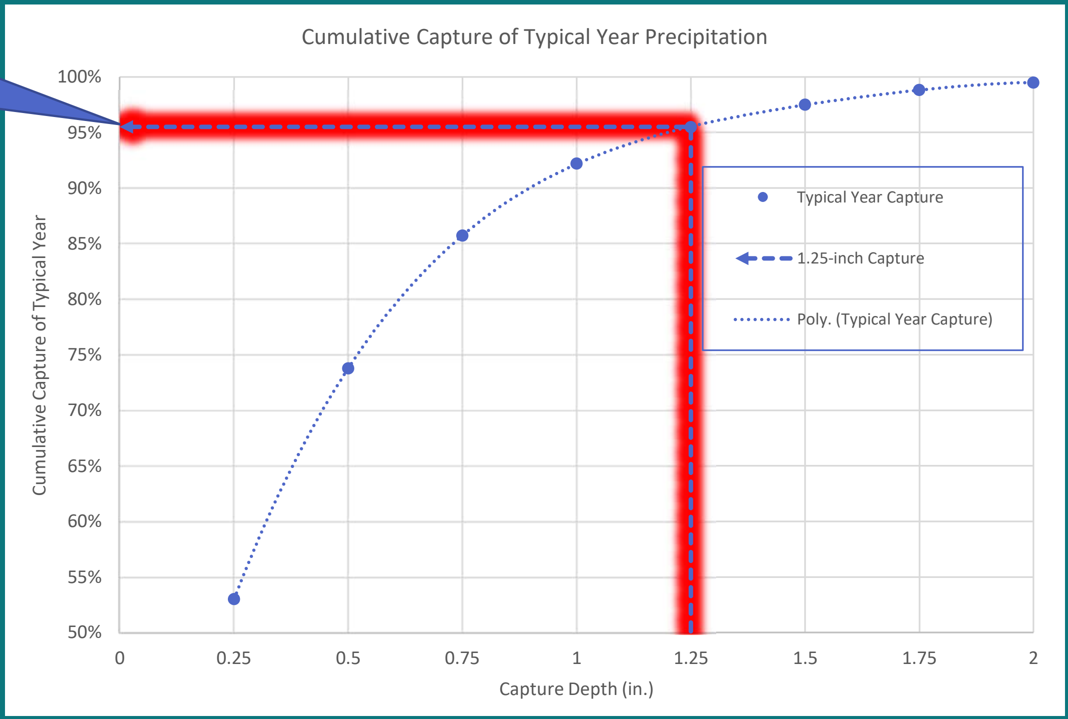
Least complex:
1-2 separate GSI practices w/ similar designs, simple hydraulics, small drainage area, uniform soil / subsurface conditions, etc.

Moderately complex:
several GSI practices w/ some connectivity and design variability, medium sized drainage area, several inflows / overflows, varying soil / subsurface conditions, etc.

Most complex:
multiple interconnected GSI practices, complicated hydraulics, multiple inflows / overflows at varying depths, large drainage area, localized flooding, other mitigating issues, etc.

Estimating the Benefit (Least Complex): Formula Example

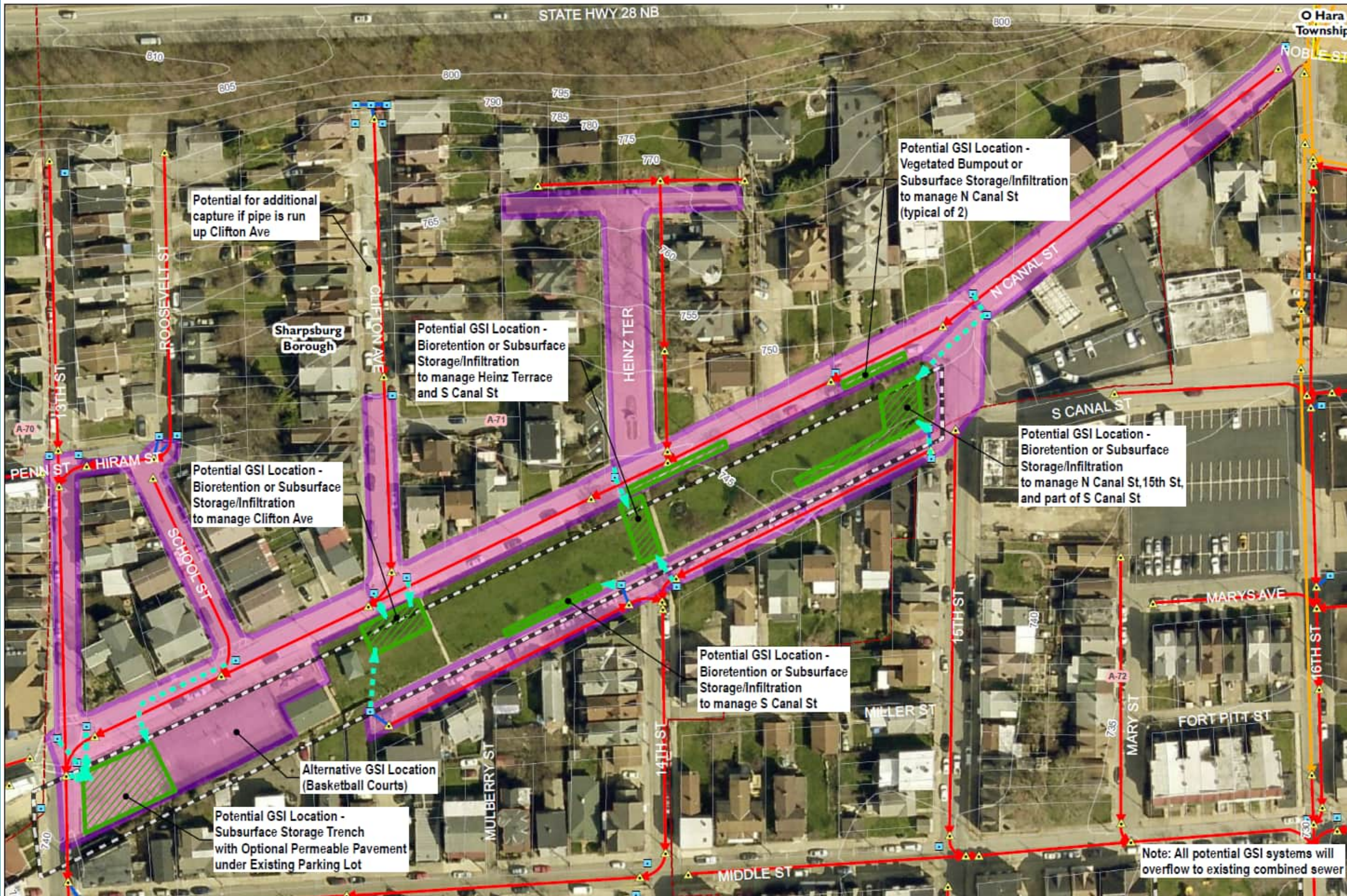
1.25" from all storms totals to 95.5% of the annual rainfall



Estimate capture depth in terms of inches from the tributary impervious area

Example: 1.25-inch capture from 1 impervious acre with 37.7 inches average annual rainfall:

- Rainfall volume: 43,560 SF x 37.7"/year x 1'/12" = 136,900 CF (1.02 MG) per year
- Runoff volume: 1.01 MG rainfall/yr x 0.85 annual runoff coeff. = 0.87 MG per year
- Capture volume: 870,000 gal runoff/year x 95.5% capture (from curve) = 0.83 MG per year



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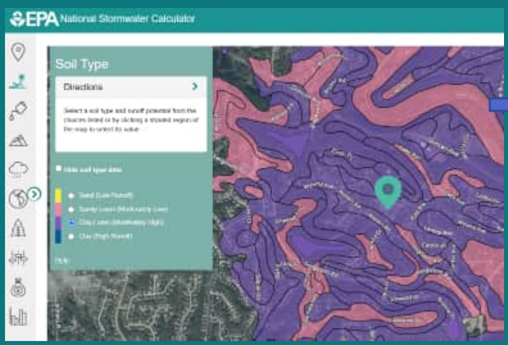
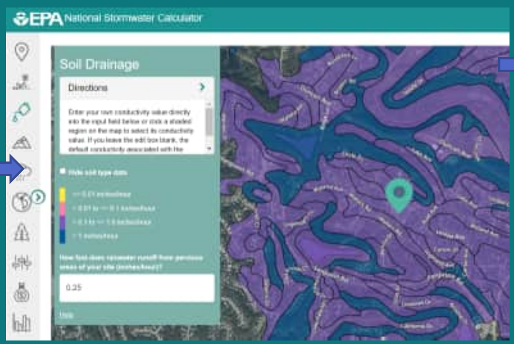
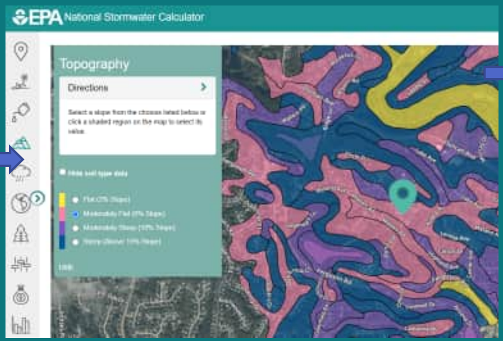
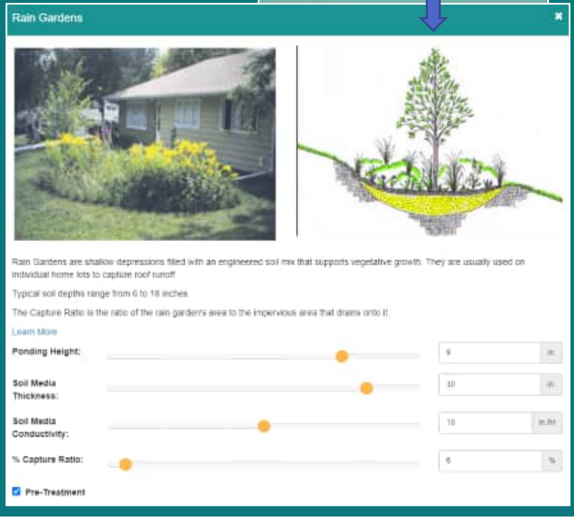
2.66 acres x 822,000 gal/acre/yr = 2.19 MG/yr

Estimating the Benefit (Moderately Complex): National Stormwater Calculator Example







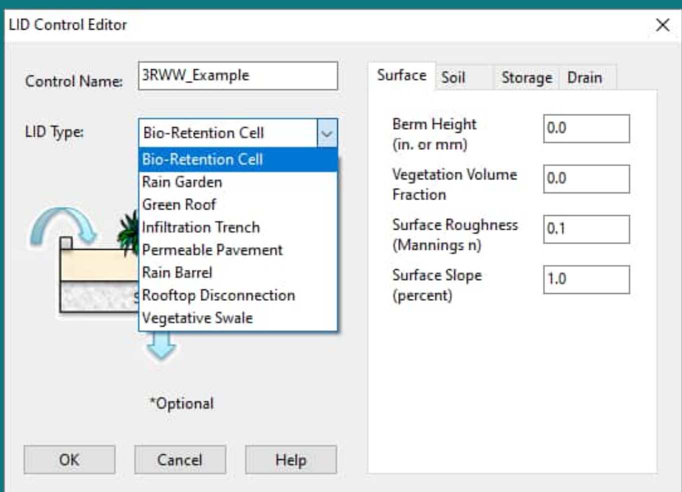


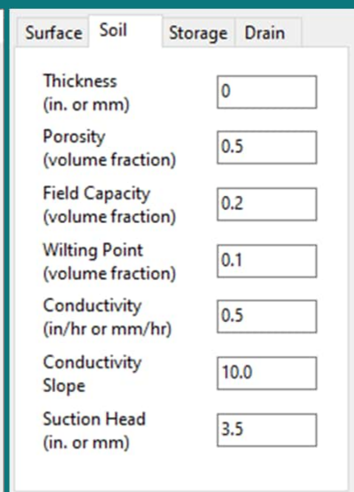
Example: 1.25-inch capture from 1 impervious acre (split b/w rain garden and permeable pavement) with 37.7 inches average annual rainfall:

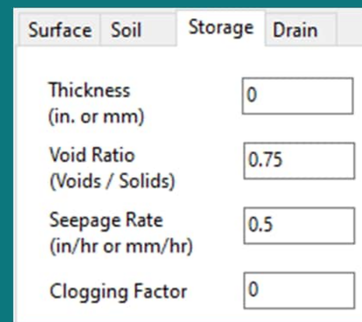
- Rainfall volume: 43,560 SF x 37.7"/yr x 1'/12" = 137,000 CF (1.02 MG) per yr
- Runoff w/o GSI: 0.84 MG per yr
- Runoff with GSI: 0.07 MG per yr
- Capture volume: Runoff w/o GSI – Runoff w/ GSI = 0.77 MG per yr

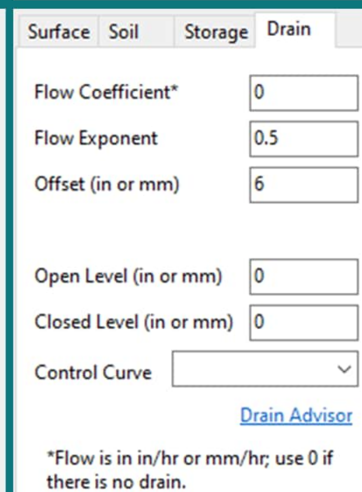
Estimating the Benefit (Most Complex): H&H Model (SWMM) Example

Options range from simple
(reduce percent impervious in model)
to more complex
(storage nodes or SWMM LID Module)

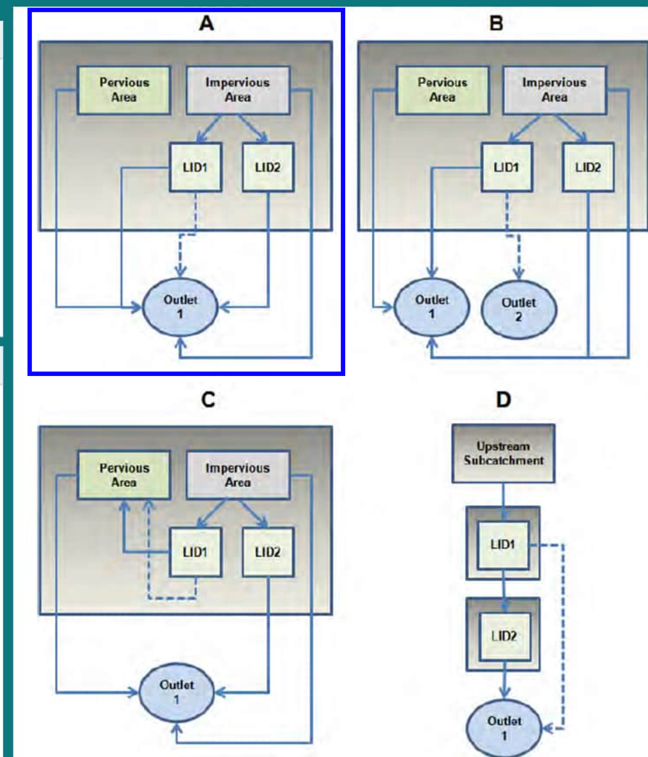








Different Options for placing LID Controls in SWMM



Storm Water Management Model Reference Manual Volume III (EPA, 2016)

Other Tools: WRF GSI Triple Bottom Line Tool

- Released in 2021
- Developed in coordination w/ WRF's Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) tool
- ***Purpose*** *is to quantify and monetize the TBL benefits of GSI (financial, social, and environmental)*
- Intended for utility and municipal staff or other interested GSI practitioners
  - *requires some level of expertise/familiarity with GSI, but not with economics!*

https://www.waterrf.org/research/projects/economic-framework-and-tools-quantifying-and-monetizing-triple-bottom-line

THE Water Research FOUNDATION

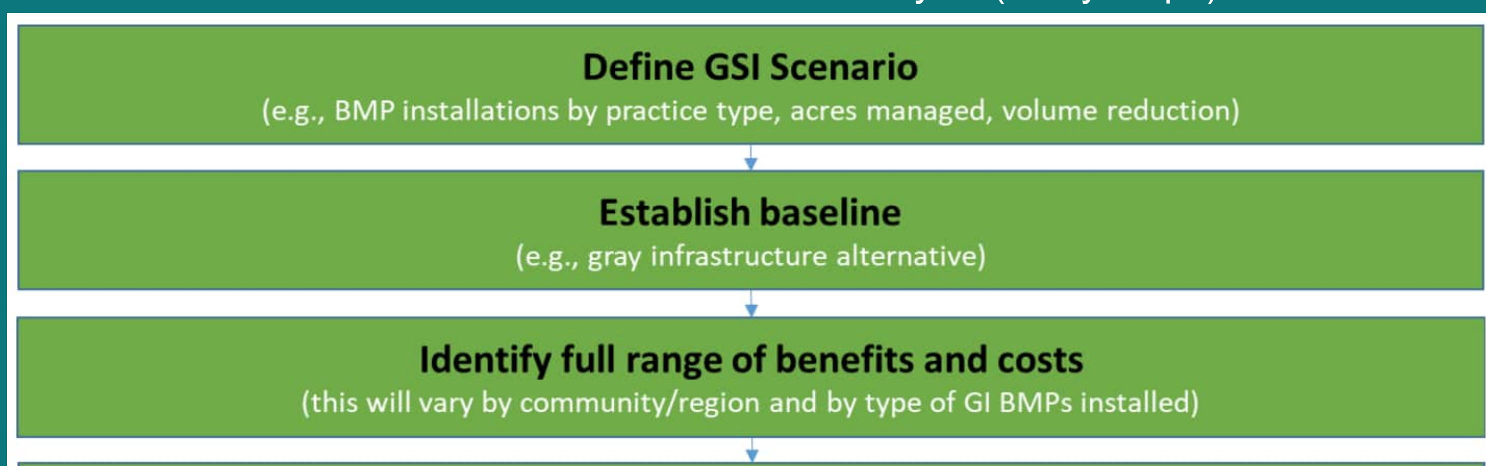
CORONA ENVIRONMENTAL CONSULTING

Kennedy/Jenks Consultants

Other Tools: WRF GSI Triple Bottom Line Tool

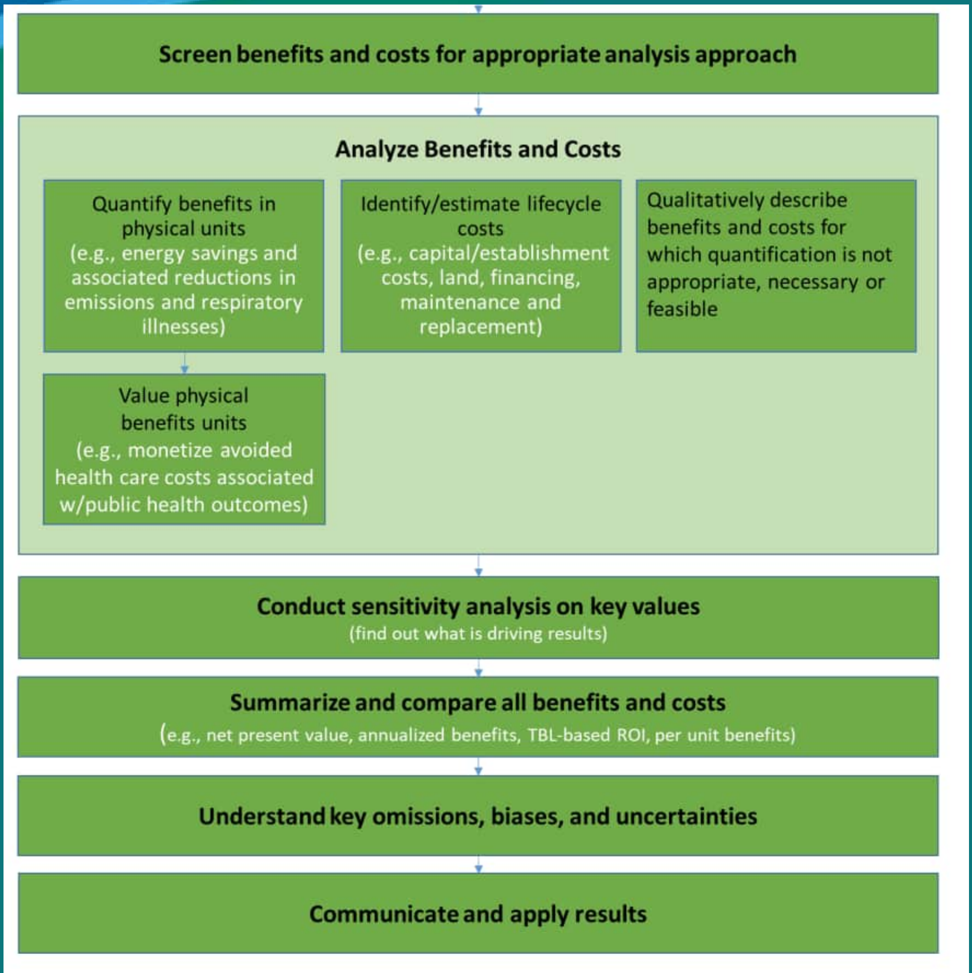
- Excel-based tool
- Results dashboard, key inputs, GSI scenario, costs and timeline
- 12 benefit categories:
  - Avoided infrastructure costs, avoided replacement costs, energy savings, water supply, air quality, property values, heat stress, recreation, green jobs, water quality, carbon, ecosystem

Economic Framework for TBL Analysis (8 key steps)



Other Tools: WRF GSI Triple Bottom Line Tool

Economic Framework for TBL Analysis (8 key steps; continued)



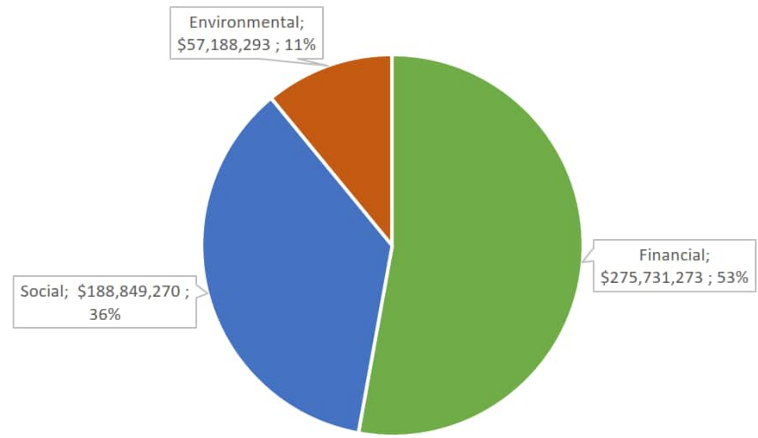
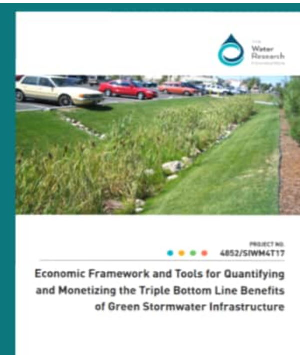


Figure 5-10. Present Value Benefits of Lancaster 25-Year GSI Implementation Scenario, Over 50-Year Analysis Period, by TBL Category.



See report for more background and case studies (Saint Paul, MN; Lancaster, PA; Seattle, WA; and Cleveland, OH)

Other Tools: Continuous Simulation Modeling w/ Infiltration

- A Green Infrastructure Leadership Exchange (GILE) initiative led by the City of Kitchener, Ontario with support from Lotus Water and Jacobs Engineering
- Participating cities: DC, Denver, Kitchener, Portland, San Francisco, Toronto, Tucson, Vancouver
- ***Purpose:*** *a tool for non-modelers to predict the volume capture and water quality benefits of various design GSI scenarios*
- [Resources | Green Infrastructure Leadership Exchange (giexchange.org)]

Washington, D.C. GI BMP Sizing Tool (Created July 2021)

			UNITS	DESIGN VARIABLES
Project Information		Project Name:		Example Site
		Location:		City, State
		Prepared By:		Name
		Date Prepared:		Friday, September 10, 2021
Site Information		Total Controlled Site Area	acres	1.888
		Number of BMPs onsite	-	2
Results		Annual Runoff Reduction %	-	91%
		Annual Water Quality Treatment %	-	91%
BMP 1		Type of BMP	-	
	Infiltration /Seepage Rate	Site Soil Seepage Rate	in/h	
		Safety Factor for Seepage Rate	-	
		Design Seepage Rate	in/hr	
	Area Draining to BMP	Directly Connected Impervious Area	acres	
		Pervious Area	acres	
		Runoff Coefficient of Pervious Area (C Value)	-	
	BMP Footprint	BMP Footprint Size	sf	
		GI Sizing Factor	-	
	Green Roof	Green Roof Soil Thickness		
BMP 2		Type of BMP		
	Infiltration /Seepage Rate	Site Soil Seepage Rate	in/hr	1
		Safety Factor for Seepage Rate	-	2
		Design Seepage Rate	in/hr	0.5
	Area Draining to BMP	Directly Connected Impervious Area	acres	0.500
		Pervious Area	acres	0.000
		Runoff Coefficient of Pervious Area (C Value)	-	0
	BMP Footprint	BMP Footprint Size	sf	1000
		GI Sizing Factor	-	0.044
	Green Roof	Green Roof Soil Thickness	in	

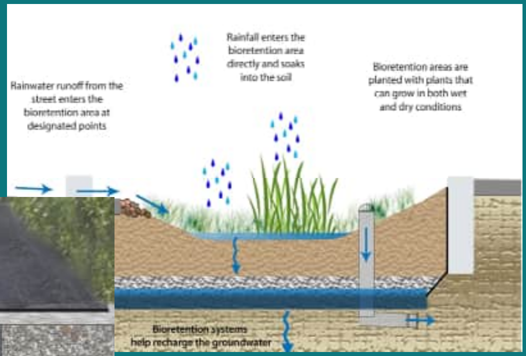
Get Results!

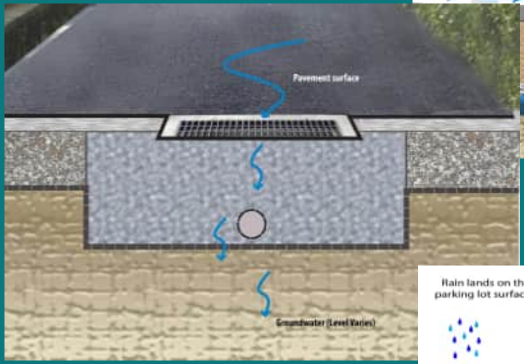
Enter project info

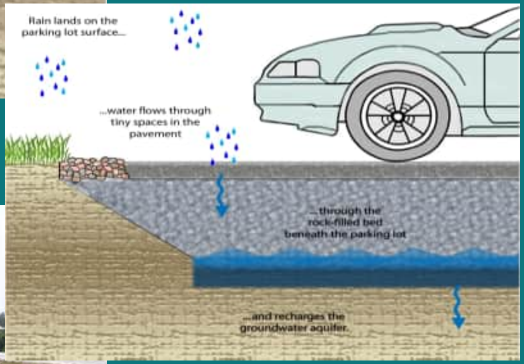
the green infrastructure leadership exchange
A practitioner network supporting green infrastructure communities

Other Tools: Continuous Simulation Modeling w/ Infiltration

- 100's of continuous simulation runs in SWMM; variables included:
  - GSI type, underdrain, sizing factor (loading ratio), soil infiltration rate
- Applicable GSI (w/ typical dimensions): Bioretention, Green Roofs, Infiltration Trenches, Permeable Pavement
- Primarily for use in conceptual design to help size GSI (allows up to 2 GSI practices)
- Tool will lookup and output the resulting:
  - Annual Runoff Reduction as a %
  - Annual Water Quality Treatment as a %
- ***Benefit:*** *easy-to-use tool that yields "right-sized" GSI for your site based on extensive, previously completed H&H modeling (for specific cities)*







Poll Question #2

How do you typically estimate the potential benefits/performance of your GSI projects?

A. Formula/Spreadsheet

B. Moderately Complex

C. Most Complex

D. Other

E. We don’t typically estimate the benefits

Agenda

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- Planning Approach
- **<u>Design Considerations</u>**
- Construction Phase
- Post-Construction Evaluation
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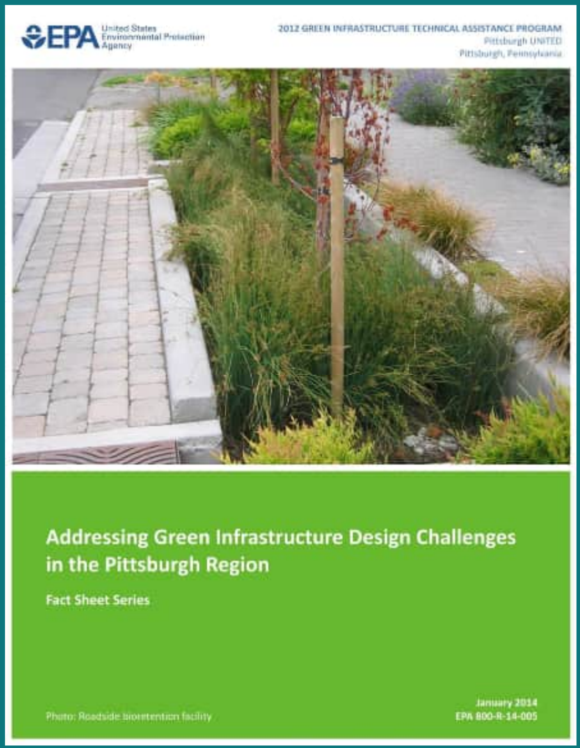
Design Considerations – GSI will work here!



EPA United States Environmental Protection Agency

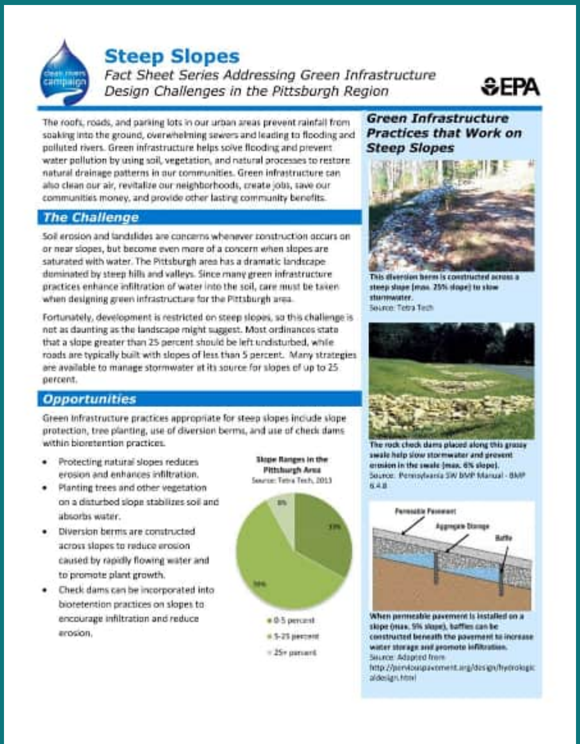
2012 GREEN INFRASTRUCTURE TECHNICAL ASSISTANCE PROGRAM
Pittsburgh UNITED
Pittsburgh, Pennsylvania

Addressing Green Infrastructure Design Challenges in the Pittsburgh Region

Fact Sheet Series

Photo: Roadside bioretention facility

January 2014
EPA 800-R-14-005



Steep Slopes

Fact Sheet Series Addressing Green Infrastructure Design Challenges in the Pittsburgh Region

EPA

The roofs, roads, and parking lots in our urban areas prevent rainfall from soaking into the ground, overwhelming sewers and leading to flooding and polluted rivers. Green infrastructure helps solve flooding and prevent water pollution by using soil, vegetation, and natural processes to restore natural drainage patterns in our communities. Green infrastructure can also clean our air, revitalize our neighborhoods, create jobs, save our communities money, and provide other lasting community benefits.

The Challenge

Soil erosion and landslides are concerns whenever construction occurs on or near slopes, but become even more of a concern when slopes are saturated with water. The Pittsburgh area has a dramatic landscape dominated by steep hills and valleys. Since many green infrastructure practices enhance infiltration of water into the soil, care must be taken when designing green infrastructure for the Pittsburgh area.

Fortunately, development is restricted on steep slopes, so this challenge is not as daunting as the landscape might suggest. Most ordinances state that a slope greater than 25 percent should be left undisturbed, while roads are typically built with slopes of less than 5 percent. Many strategies are available to manage stormwater at its source for slopes of up to 25 percent.

Opportunities

Green Infrastructure practices appropriate for steep slopes include slope protection, tree planting, use of diversion berms, and use of check dams within bioretention practices.

- Protecting natural slopes reduces erosion and enhances infiltration.
- Planting trees and other vegetation on a disturbed slope stabilizes soil and absorbs water.
- Diversion berms are constructed across slopes to reduce erosion caused by rapidly flowing water and to promote plant growth.
- Check dams can be incorporated into bioretention practices on slopes to encourage infiltration and reduce erosion.

Slope Ranges in the Pittsburgh Area
Source: Tetra Tech, 2013

0-5 percent
5-25 percent
25+ percent

Green Infrastructure Practices that Work on Steep Slopes

This diversion berm is constructed across a steep slope (max. 25% slope) to slow stormwater.
Source: Tetra Tech

The rock check dams placed along this grassy swale help slow stormwater and prevent erosion in the swale (max. 6% slope).
Source: Pennsylvania SW BMP Manual - BMP 6.4.8

Permeable Pavement
Aggregate Storage
Baffle

When permeable pavement is installed on a slope (max. 5% slope), baffles can be constructed beneath the pavement to increase water storage and promote infiltration.
Source: Adapted from http://perviouspavement.org/design/hydrologicaldesign.html

Clay Soil

Fact Sheet Series Addressing Green Infrastructure Design Challenges in the Pittsburgh Region

EPA

The roofs, roads, and parking lots in our urban areas prevent rainfall from soaking into the ground, overwhelming sewers and leading to flooding and polluted rivers. Green infrastructure helps solve flooding and prevent water pollution by using soil, vegetation, and natural processes to restore natural drainage patterns in our communities. Green infrastructure can also clean our air, revitalize our neighborhoods, create jobs, save our communities money, and provide many other lasting community benefits.

The Challenge

The Pittsburgh region's clay soil is sometimes perceived as a challenge to green infrastructure practices. Clay soil is often thought to allow little to no infiltration of water to the groundwater table.

In actuality, undisturbed clay soil can infiltrate water quite well. The real challenge is when soil has been disturbed and compacted by construction. Compacted soil often results in very little infiltration and ponding is often observed.

While the design of green infrastructure practices for sites with clay soils may require greater care, the right green infrastructure practices can work well in Pittsburgh's clay soil.

Opportunities

Green Infrastructure practices such as rain gardens, permeable pavement, and bioretention are all practices that are successful in clay soils.

- Rain Gardens capture stormwater draining from roofs. Even in clay soils, infiltration can be expected if the soil is protected from compaction or restored through deep plowing.
- Permeable pavement is used for sidewalks, parking lots, and roads. It allows water to drain through it to a stone storage layer. Underdrains can be laid in the storage layer to help the practice drain in clay soils.
- Bioretention is similar to a rain garden but is typically more engineered. In clay soil, an underdrain is generally installed to ensure drainage.

This diagram shows a bioretention system. Underdrains drain the system in clay soils.
Source: Brown, R., Hunt, W. and Kennedy, S. 2009. Urban Waterways: Designing Bioretention with an Internal Water Storage Layer. NC Coop. Ext.

Green Infrastructure Practices that Work with Clay Soils

This rain garden collects roof water through a downspout.
Source: Tetra Tech

Stormwater drains through this permeable paver drive to a stone storage layer.
Source: Tetra Tech

This roadside bioretention collects and treats roadway stormwater.
Source: Tetra Tech

Recommended Setbacks

Table 2-1. Recommended Setbacks

Constraining Feature[1]	Minimum Distance between GSI and Constraining Feature (ft)	Distance Type (Horizontal or Vertical)	Notes
Wetlands	10	Horizontal	N/A
Streams	20	Horizontal	N/A
Railroad	15	Horizontal	N/A
Building Foundation / Underground Structures (basements, tunnels, storage tanks, etc.)	10	Horizontal	Note if building has basement.
Utility Lines	3	Horizontal	N/A
Utility Lines	1 - 1.5	Vertical	Depends on utility size, type, age and condition.
Sewer Lines or Sewer Laterals	3	Horizontal	Infiltrating GSI should be prevented from infiltrating within a 1:1 slope from the invert of the sewer (i.e. zone of influence)
Utility Infrastructure (underground vaults, manholes, traffic lights, telephone poles, 'No Parking' signs, parking meters, guy wires etc.)	5	Horizontal	N/A
Fire Hydrant	3.5	Horizontal	N/A
Trees / Vegetation	10 ft radius from tree center	Horizontal	Depends on condition of tree, relative benefits of new GSI vs. existing tree preservation. If necessary, use shovel or soft-excavation and avoid tree roots.
ROW Property Lines	3	Horizontal	To protect systems from future construction on adjacent parcels.
Non-ROW Property Lines	5	Horizontal	5 ft minimum. 10 ft preferred.
Infiltration-Limiting Layer (bedrock, high groundwater, etc.)	2	Vertical	Up to 3 ft.
Other Infiltration Facilities (other GSI practices, drain/disposal fields, seepage pits, etc.)	50	Horizontal	N/A
Steep Slopes / Landslide Prone Areas	50 - 200	Horizontal	200 ft from down-gradient slopes greater than 20%. Geotech analysis required if facility affects slope greater than 15%. Moderate to steep slopes (5% - 25%) should be considered a constraint to GSI placement.
Curbs, Curb Ramps, Sidewalks to Remain	2	Horizontal	N/A
Inlets to Remain	2	Horizontal	N/A
Crosswalk	5	Horizontal	Planters/curb extensions may be within or closer than 5 ft. from crosswalks

[1]Practitioners should use engineering judgment for setbacks to constraints not included such as subway entrances, driveways, fences, bus stops etc.

Source: ALCOSAN's Green Stormwater Infrastructure Guidance Manual – March 2019

Recommended Loading Ratios

Table 4-3. Recommended Loading Ratios

GSI Mechanism[1]	Surface Receiving Runoff	Recommended Loading Ratios of Impervious Drainage Area to GSI Area[2]
Infiltration / Runoff Reduction	Subsurface	5:1 - 12:1
	Surface (Vegetated)	10:1 - 20:1[3]
Slow Release	Subsurface	10:1 - 20:1
	Surface (Vegetated)	15:1 - 25:1[3]

[1]To protect against surface clogging, the loading ratio for permeable pavement should be kept at 3:1 or as recommended by manufacturers. However, the storage / infiltration system underneath permeable pavements can have higher loading ratios, provided the contributing drainage area is drained by inlets with pretreatment.

[2]Ratios are for stabilized drainage areas. Practitioners should consider the amount of sediment loading expected, factoring in ground cover and land use. Practitioners should consult a geotechnical engineer for special cases (e.g. carbonate soils, karst geography, landslide-prone areas, fractures, faults, other geologic features). Higher loading ratios necessitate more robust pretreatment.

[3]Loading ratios for surface systems could be increased by using high flow media.

Source: ALCOSAN's Green Stormwater Infrastructure Guidance Manual – March 2019

Design Considerations – GSI Sizing

Table 4-1. Recommended Void Percentages for Storage Calculations

Storage Material	Void Space
Gravel / Open graded aggregate / Stone	35-45%
Soil	15-25%
Sand	25-35%
Pipes embedded in GSI	90-94%
Modular storage	product specific

Table 4-2. GSI Component Storage Depths

GSI Type	GSI Component	Depth (inches)
GSI Practices with Surface Storage	Ponding	3 - 12[1,2]
GSI Practices with Vegetation	Engineered/Bioretention Soil	18 – 36
GSI Practices with Subsurface Storage Under Pavement	Aggregate	12 - 24[2]
GSI Practices with Subsurface Storage Under Vegetation	Aggregate	6 - 24[2]
GSI Practices with Subsurface Storage	Sand Filter (if applicable)	6 - 8

[1]Stormwater wetlands can have surface depths up to 6 feet.

[2]Depths include freeboard, which is typically 6 inches minimum.

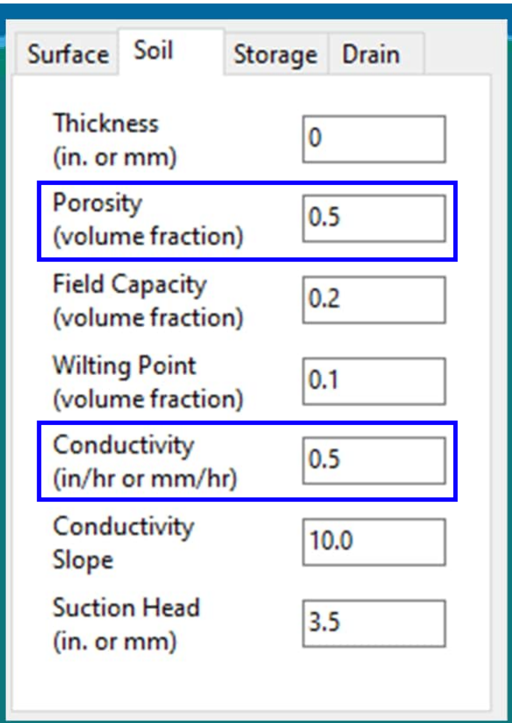
Source: ALCOSAN's Green Stormwater Infrastructure Guidance Manual – March 2019

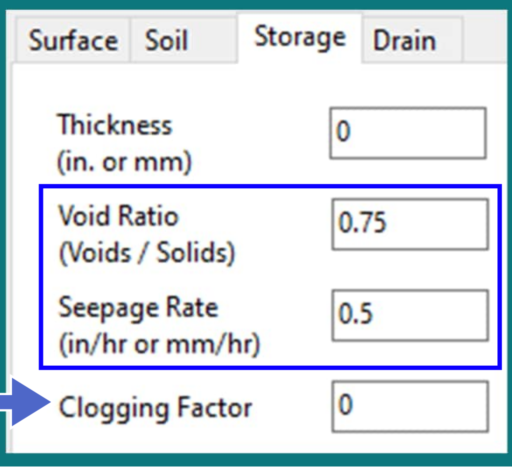
Design Considerations (cont.)

Consider reduction factors to reflect post-construction and beyond. For example:

- void space/ratio, porosity
  (e.g., void space being lost over time by sediment accumulation)
- soil permeability/conductivity/seepage
  (e.g., potential compaction during construction and partial clogging over time after construction)
- other potential considerations: type of permeability test performed, variability of site soils, level of pretreatment / expected sediment load, redundancy / resiliency, compaction during construction, etc.

For example, SWMM offers a “clogging factor” for certain parameters associated with LID controls.





Design Considerations

- Design with monitoring & performance evaluation in mind (whether passive or active)
    - Consider in-GSI, in-sewer, and/or other monitoring
    - Wet weather inspections

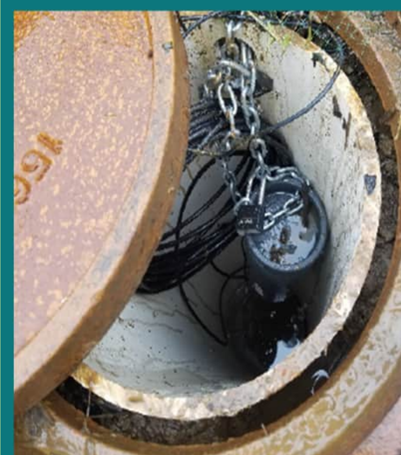
- For projects that will be modeled consider how the project will be modeled to ensure that monitoring information will help validate model after construction.

SCAN ME


Green Stormwater Infrastructure and
Source Control Monitoring Guide

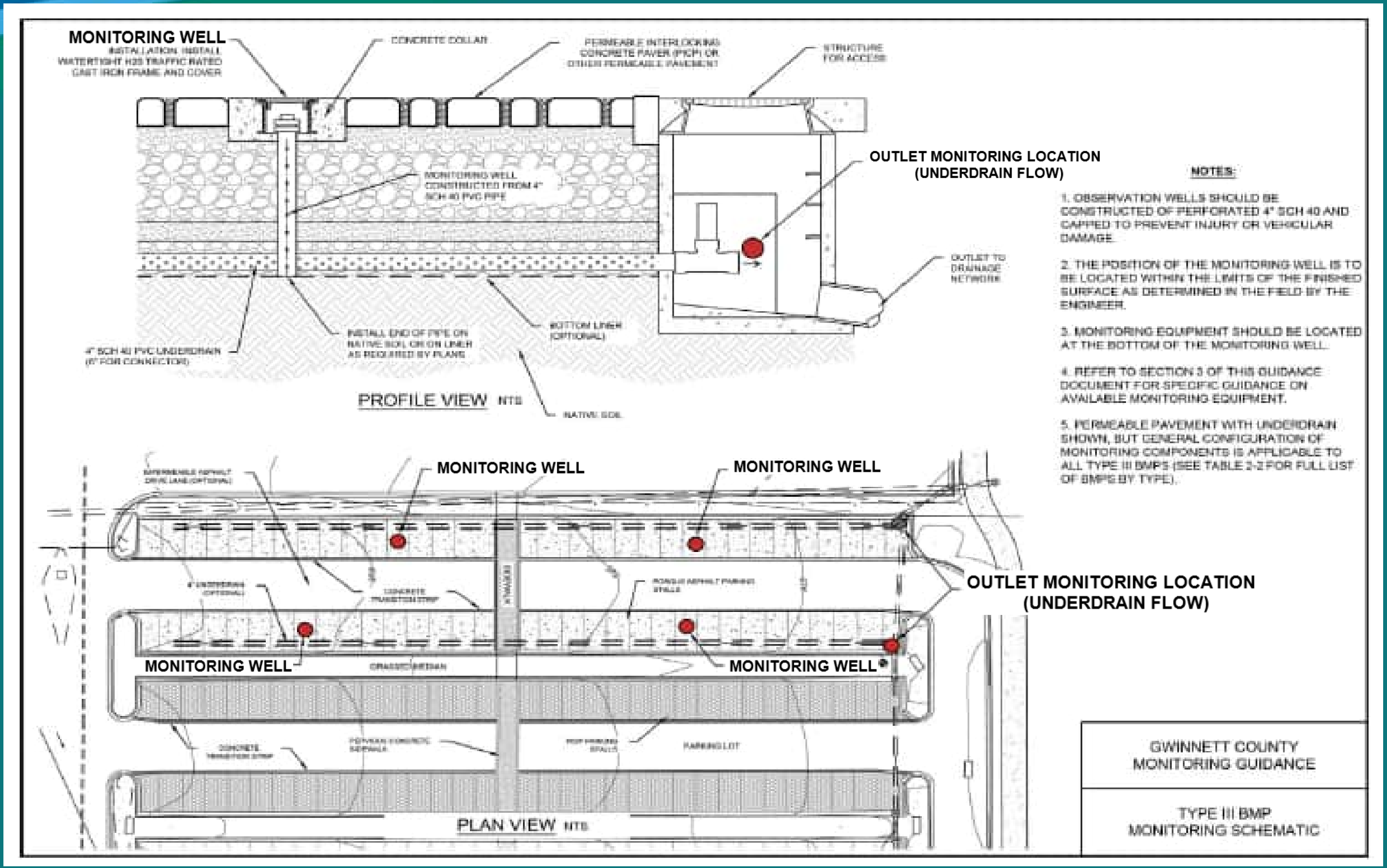
3 RIVERS PROUD

May 2019


Pressure transducer inside monitoring well allows for water depth readings (image: PWSA)


V-notch weir facilitates flow measurements in an irregular channel (image: PWSA)

Example Monitoring Schematic



Agenda

- Objective
- Planning Approach
- Design Considerations
- **Construction Phase**
- Post-Construction Evaluation
- Operations & Maintenance
- Conclusions

Construction Phase

- Education
- Communication
- Material test results
- Construction observations/oversight
- Verification of ponding depths, side slopes, infiltration rate, etc. (wet weather inspections, simulated runoff tests)
- Gathering accurate as-built information

Sequence! Protect what has been built!
Keep equipment off infiltration soils!

Key Construction Inspection Activities

- Pre-construction meeting AND pre-planting meeting
- Review construction material cleanliness and conformance to specifications
- Multiple inspections at critical stages
- Final inspection and site walk-through
- Wet weather inspection(s)
- On-going inspections during plant establishment and warranty period

Dirty, unprotected excavation and dirty stone!

Construction Resources

Construction inspection guidelines (next slide) and forms for bioretention, infiltration trenches (below), and permeable pavement

GREEN REVITALIZATION of OUR WATERWAYS

ALLEGHENY COUNTY SANITARY AUTHORITY
Green Revitalization of Our Waterways (GROW)
Green Stormwater Infrastructure (GSI) Practices
CONSTRUCTION INSPECTION FORM

INSPECTION INFORMATION				
Inspector:			Date of Inspection:	
Contractor Present?	☐ Yes	☐ No	Start Time:	End Time:
Inspection Type:	☐ Follow Up	☐ Regular	Current Weather:	
Photographs Taken?	☐ Yes	☐ No		
Reason for Inspection:	☐ Material Review ☐ Other:	☐ Regularly Scheduled/ Milestone ☐ Field Change/Question	☐ Pre-Construction ☐ Final Closeout	

SITE INFORMATION		
Site Description/Name:		
Site Address:		
Collection System Type:	☐ Combined Sewer	☐ Separated Sewer
Facility Types to Be Inspected on Site:	☐ Bioretention ☐ Infiltration Trench	☐ Permeable Pavement ☐ Other:

MUNICIPAL INFORMATION	
Municipality or Municipal Authority:	
Contact Name:	Phone:
Contact Address:	Email:

CONTRACTOR INFORMATION	
Primary Contractor:	
Contact Name / Person Present:	Phone:
Contact Address:	Email:

PRE-CONSTRUCTION CHECKLIST			
Site Plans & Details Reviewed?	☐ Yes	☐ No	☐ N/A
GSI Construction Specifications Reviewed?	☐ Yes	☐ No	☐ N/A
Soils Tested and Results Reviewed?	☐ Yes	☐ No	☐ N/A
Construction Schedule and Sequence Reviewed?	☐ Yes	☐ No	☐ N/A
Pre-Construction Meeting Complete?	☐ Yes	☐ No	☐ N/A
If yes, date of meeting:	If no, scheduled meeting date:		

CONSTRUCTION SITE INSPECTION – INFILTRATION TRENCH

Site Name:

Infiltration Trench Type: ☐ Tree Trench/Trench below Vegetation ☐ Trench below Pavement ☐ Surface Flow Infiltration ☐ Other:

CONSTRUCTION SITE CONDITIONS – INFILTRATION TRENCH

See Table 2-2 in the GSI Construction Inspection Guide for more detailed information on each construction task.

TASK NUMBER	CONSTRUCTION TASK	STATUS	PHOTO NO.	NOTES/ACTIONS
I1	**E & S:** E&S controls installed and properly maintained to prevent fouling of GSI facilities?			
I2	**Site Access/Safety:** Pedestrian and vehicle access restricted with adequate public safety controls in place?			
I3	**Material Storage:** Storage areas located according to plans and adequately protected?			
I4	**Tree Protection:** Tree protection installed according to plans and no equipment/material storage within root zones?			
I5	**Utilities:** Existing utilities within the limit of disturbance located and properly marked out?			
I6	**Demolition/Clearing & Grubbing:** Demo/Clearing zones are limited to area of work only?			
I7	**Excavation:** Excavation within GSI footprint to line and grades indicated on plans? Equipment kept off of all infiltrating surfaces? Tree roots are cleanly cut, flush with side walls?			
I8	**Subgrade:** Exposed sub-grade is uniform, uncompacted and free of sediment and deleterious materials? Subgrade elevation in accordance with plans? Protected from sediment once final elevation reached?			
I9	**Geotextile/Liners:** Geotextile/liner is clean, undamaged, and installed according to plans and details? Seams are properly overlapped?			
I10	**Underdrain/Distribution Pipes:** Size, material, location, perforations, and elevation of pipe per plans?			
I11	**Inlets, Catch basins, Outlet Structure:** Size, material, location, and elevations per plans?			
I12	**Weir and Baffles (if Applicable):** Structures submitted meet requirements of specification? Submittal has been reviewed and approved?			
I13	**Storage Aggregates:** Aggregate material is clean and sized according to plans and specifications? Material submittal reviewed and approved?			
I14	**Storage Aggregate Placement:** Aggregate has been placed in proper lifts to depths indicated on plans and has been compacted according to specifications? Geotextile/liner is undamaged and infiltrating subgrades have not been compacted during placement?			

TASK NUMBER	CONSTRUCTION TASK	STATUS	PHOTO NO.	NOTES
I15	**Graded Aggregate Filter Layer:** Aggregate material is clean and sized according to plans and specifications?			
I16	**Graded Aggregate Filter Layer Placement:** Aggregate Filter Layer place between storage aggregate and backfill material? Filter Layer placed to depth indicated on plans? Compaction equipment has not crushed aggregate?			
I17	**Backfill:** Material meets specifications? Material submittal reviewed and approved?			
I18	**Backfill Installation:** Geotextile his been properly wrapped over the top of storage aggregates with 18" minimum overlap? Depth of placement matched design plans and detail? Geotextile hasn't been damaged?			
I19	**Finish Grading and Surfacing:** Grading and surface elevations match plans and details? Vegetated surfaces are protected from erosion? Pavement installed to line and grade shown on plans?			
I20	**E & S Controls:** Adjacent areas are stabilized and/or proper E & S controls are in place to protect surface infiltration zones from sedimentation? Infiltration areas free from sediment following rain events?			
I21	**As-Builts:** As-builts drawings are complete and properly document any field changes to the design?			
I22	**Flow Monitoring Equipment:** Flow monitoring equipment meets the requirements of the plan, details, and specification? Equipment in correct locations per design? Equipment properly protected from vandalism and theft?			

OTHER RELEVANT OBSERVATIONS/FIELD REQUIRED CHANGES TO DESIGN

SCAN ME

CHAPTER 4

GSI Construction Inspection Guidance Document

Construction Task	Task Summary	Inspection Items	Inspection Timing	Inspection Responsibility	Potential Corrective Actions
Erosion and Sedimentation (E&S) Contro…	• Protect infiltration zones and subgrades from sediment contamination and clogging • Protect catch basins from collecting and conveying sediment laden runoff to GSI facilities or offsite	• E&S controls installed according to plans • Infiltration trench surfaces are adequately protected from sediment and debris	• Prior to initial site disturbance • Regularly throughout construction • Following installation infiltration	• Contractor • Owner's representative (engineering inspector)	• Sedimentation of exposed infiltration zone subgrades: Remove sediment and scarify subgrade • Sedimentation of infiltration trench
Site Access & Mat…					
Tree Prote…					
Utiliti…					
Demolition/Cleari…					
Excavat…					

Construction Task	Task Summary	Inspection Items	Inspection Timing	Inspection Responsibility	Potential Corrective Actions
Subgrade	• Ensure subgrade elevation and extent matches design plans • Bed bottoms are typically level unless otherwise indicated on plans to promote even infiltration and prevent clogging	• Exposed subgrade to be uniform, uncompacted and free of sediment and deleterious material • Subgrade to be excavated to elevations	• Inspect when final subgrade is reached and excavation is completed	• Contractor (demonstrating elevations are per plan) • Owner's representative	• If facility bottom is not level, confirm that it conforms to the design plans/intent or contractor to level • If sediment or debris accumulation has
Geotextile/Lin…					
Underdrain/Distributi…					
Inlets, Catch Basins, … Structure					
Weir and Baffles (if Ap…					
Storage Aggregates or A… Storage Media					

Construction Task	Task Summary	Inspection Items	Inspection Timing	Inspection Responsibility	Potential Corrective Actions
Graded Aggregate Filter Layer	• Graded aggregate filter layer is placed between storage aggregate and backfill material when infiltration trench is designed for surface infiltration – e.g. finish grade is planting soil and landscape or decorative cobbles/riverstone • Place filter layer to depth indicated on plans and lightly compact • Do not crush aggregate with compaction equipment	• Confirm material is clean and gradation meets specification when it arrives on site • Depth of placement matches design plans and details • Rock hasn't been crushed during compaction	• Confirm material meets specifications once it arrives on site • Inspect once installation commences and following completion of work	• Owner's representative (engineering inspector)	• Reject aggregate material if it is not clean and/or does not meet specification • Do not over-compact
Backfill (Aggregate sub-base, planting soil or top soil for turf)	• Fully wrap geotextile over storage aggregates with minimum overlap of 18" to prevent migration of fines into infiltration trench • Place graded aggregate filter layer over storage aggregate rather than geotextile when infiltration trench is designed for surface infiltration • Place backfill material to depth indicated on plans and compacted to provide a level surface for finish grade • Compact per plans and specifications	• Confirm that geotextile has been properly wrapped over the top of storage aggregates with 18" min overlap prior to backfill • Confirm material meets specification when it arrives on site • Depth of placement matches design plans and details • Geotextile hasn't been damaged or perforated prior to backfill placement	• Confirm material meets specifications once it arrives on site • Inspect once installation commences and following completion of work	• Owner's representative (engineering inspector)	• Reject backfill material if it is not clean and/or does not meet specification • Completely cover top of trench aggregate with geotextile or with graded aggregate prior to installing backfill material • Replace damaged or punctured geotextile material
Finish Grading and Surfacing	• Complete finish surface grading according to plans and details, ensuring that infiltration trench surface is graded to collect and infiltrate water when included in design • Install surface treatment – pavement, turf or landscape plantings, trees, etc. according to plans and details	• Confirm grading and surface elevations are completed according to plans and details • Confirm that vegetated surfaces are protected from erosion with use of erosion control blanket or other means until vegetation is established • Confirm pavements are installed to line and grade shown on plans and details	• Inspect once installation commences and following completion of work	• Owner's representative (engineering inspector)	• Contractor to correct surface grading that does not match plans • Contractor to correct or replace pavements that are not installed according to plans and details.
Erosion & Sedimentation Control following Installation	• Stabilize adjacent areas and ensure proper E&S controls are in place to protect surface infiltration zones from sedimentation • Keep vegetated areas that are part of the infiltration trench system offline if possible until vegetation is established	• E&S controls installed that adequately protect surface infiltration features from sedimentation • Sand bags, etc. are properly installed to divert runoff during establishment (if required)	• Immediately following installation of final surface treatment • Before and immediately following rain events	• Contractor • Owner's representative (engineering inspector)	• Sedimentation of infiltration surfaces: Remove sediment with hand tools, scarify soils surfaces, replace surface treatment (cobble, mulch) with clean material
Post-Construction	• Document built conditions through development of construction as-builts • Install flow monitoring equipment on-site to monitor GSI performance per plans and specifications • Complete performance testing in accordance with project specifications	• Confirm as-builts drawings are complete and have fully documented all field changes to the original design • Confirm that flow monitoring equipment meets requirements of plans, details and specifications • Confirm that flow monitoring equipment has been installed in the correct location and per design plans and details • Confirm that flow monitoring equipment is protected from vandalism and theft	• Confirm monitoring equipment meets specifications once it arrives on site • Inspect once following installation	• Owner's representative (engineering inspector) • Monitoring staff	• Reject monitoring equipment if it is does not meet specification • Revise as-builts until they are complete and document all constructed site conditions • Reinstall monitoring equipment if it has not been installed according to plan or consult design/monitoring team to relocate the monitoring equipment as required to properly collect flow data

Agenda

- Objective
- Planning Approach
- Design Considerations
- Construction Phase
- **Post-Construction Evaluation**
- Operations & Maintenance
- Conclusions

Post-Construction Evaluation

Prior to monitoring data being available, use as-built information, wet weather inspections, simulated runoff tests to update calcs or model.

Simulated Runoff Test
(source: Seattle Public Utilities)

Apron not depressed enough – bypass!

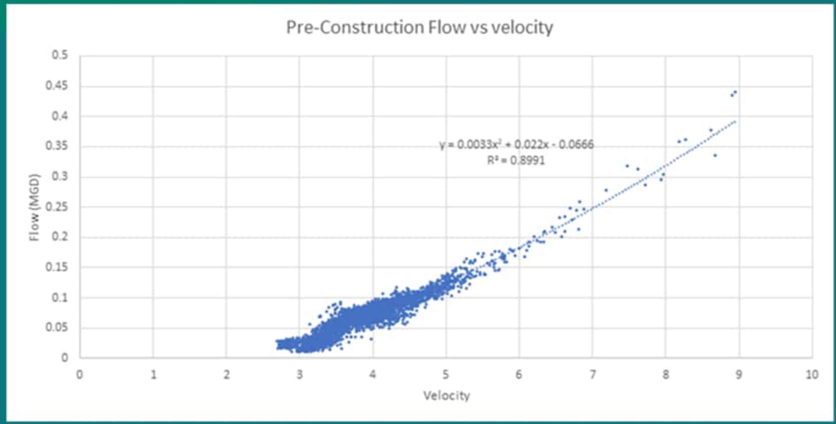
Wet weather inspections

Ask the question, "Are there significant changes?"

- Drainage areas or GSI footprint
- Storage volumes
- Critical materials *(e.g.: storage materials, bioretention soils)*

Were subgrade soils as expected?
(Any changes to anticipated infiltration rates?)

Monitoring

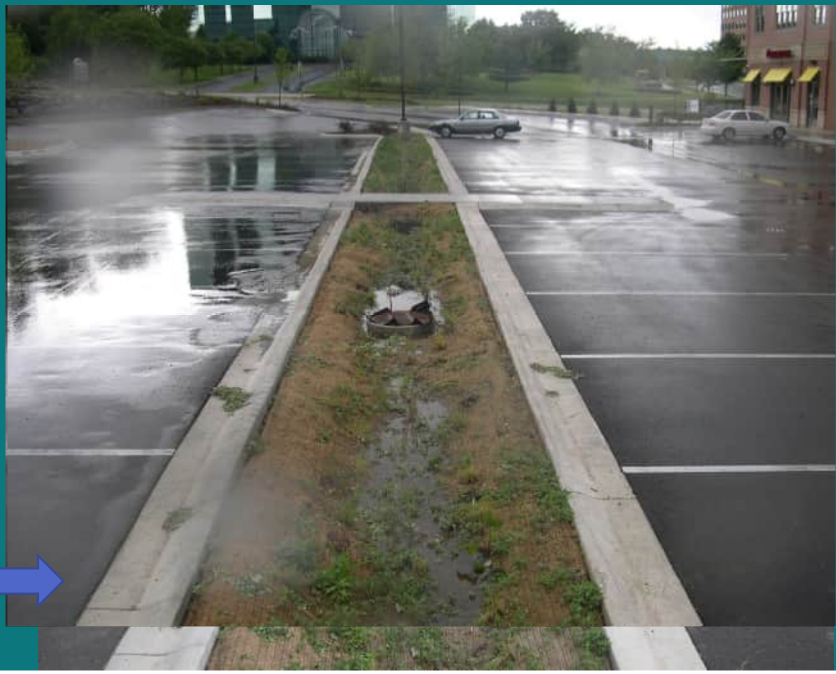


- Consider redundancy to have better confidence in data and to have backup
  (e.g., more than one depth sensor, couple depth and velocity measurements for flow monitoring)

- Consider whether in-GSI or in-sewer monitoring (or both) is optimal

- Couple data with field observations
  (e.g., bypass, GSI condition) and/or rain-activated time-lapse cameras

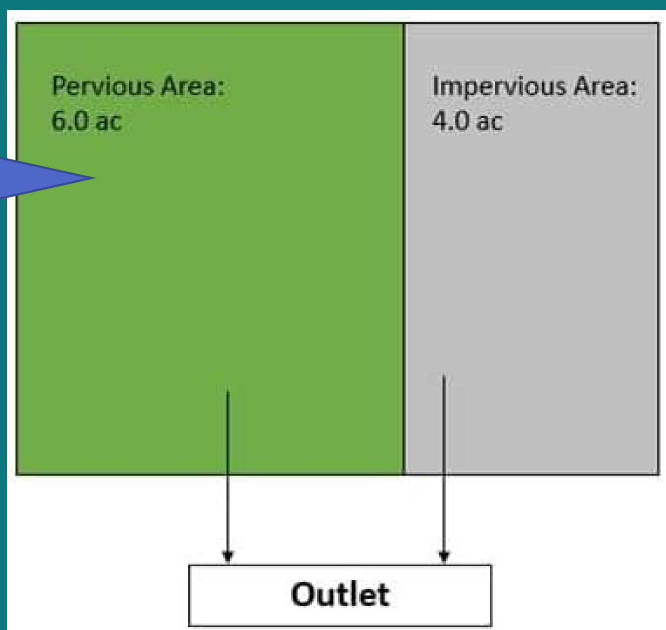
- Consider remote, real-time monitoring via web-based platforms



Monitoring and Modeling

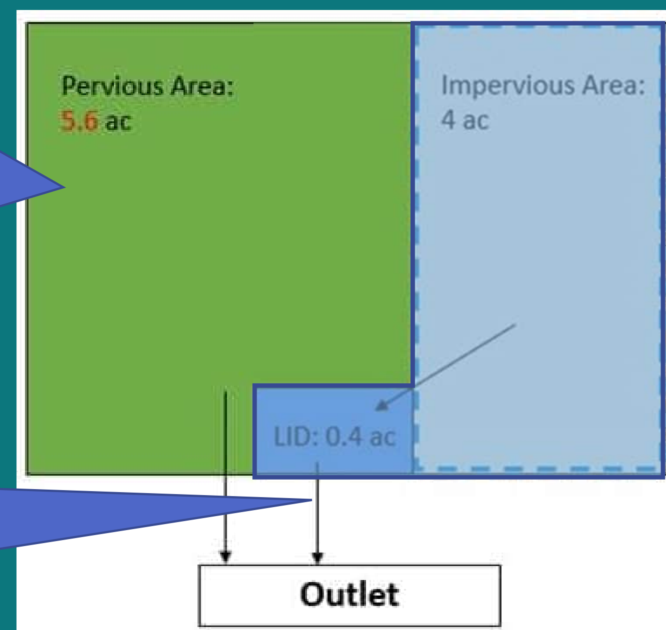
- Use post-construction monitoring to validate/calibrate calculations/model

SWMM subcatchment before GSI (“LID”): 10 acres, 40% impervious



Following SWMM option A of embedding GSI (“LID”) in the subcatchment and routing the impervious to it

Monitoring of the GSI discharge would represent this, so would be calibrating/ validating that portion of the subcatchment



Poll Question #3

Which phase of the GSI implementation process have you typically found to be most challenging?

A. *Planning*

B. *Design*

C. *Construction*

D. *Operations and Maintenance*

Agenda

- Objective
- Planning Approach
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- Construction Phase
- Post-Construction Evaluation
- **Operations & Maintenance**
- Conclusions

Monitoring and Maintenance

- Ensure adequate ongoing maintenance to maintain performance
  - Use monitoring to help know when maintenance is needed

ALCOSAN O&M Guidance Manual

- Guidance for GSI projects to develop a Maintenance Plan
- Routine, Non-routine, and General Maintenance Activities by GI type
- Maintenance Frequencies
- Includes Maintenance Inspection Checklists
- Manuals/guidelines protect the investment in GSI

Table 2-8. Routine Maintenance Task Frequencies by Service Level and GSI Type

	Maintenance Activity	Recommended Typical Frequency[1]		
		High Service Level	Moderate Service Level	Low Service Level
All GSI Technologies	GSI Inspection[3]	Monthly	Quarterly	Biannually
	Trash & Sediment Removal	Monthly	Quarterly	Biannually
	Organic Debris Removal	Quarterly	Biannually	Annually
	Sediment removal from vegetated areas and/or forebay	Monthly	Quarterly	Annually
	Collection System Cleaning	After each 1-inch storm event	Monthly	Quarterly
	Collection System Pretreatment Device Replacement	Device missing, damaged or nonfunctioning		
Vegetated GSI Systems	Weeding	Monthly	Quarterly	Biannually
	Mowing (if turf grass is present)	Weekly or biweekly during growing season	Quarterly	Annually
	Mulching	Biannually	Annually	
	Remove & Prune Plants	Biannually	Annually	
	Watering/Irrigation	Establishment/As needed		
	Cutting Back Vegetation	Annually		
	Clear overflow and drainage structures	After each 1-inch storm event	Monthly	Quarterly
	Winterization	Annually		
Infiltration Systems	Structure & System Vacuum Cleaning	Biannually		Annually
	Pipe Inspection/Pipe Jetting	Annual Inspection/Jetting as needed when 10% or more of cross section area is clogged with debris/sediment		
	Inlet Pretreatment Maintenance	Quarterly	Biannually	Annually
	Maintenance of Surface Aggregates (when present)	Quarterly	Biannually	Annually
	Bolt & Lock Care	As needed		
	Tree Care	Biannually or as needed	Annually or as needed	
	Winterization	Annually		

Operations & Maintenance Critical to Long-Term Performance

ALCOSAN's GSI Guidance Document includes maintenance condition tables and maintenance inspection checklists.

Bioretention maintenance condition table (1st page shown to right) covers 27 different site conditions.

Table 3-1. Bioretention Facility Maintenance Conditions

Site Condition	Expected Condition (Satisfactory)	Condition when Maintenance is Needed (Marginal)	Defect or Problem that requires Corrective Action (Unsatisfactory)	Reason for Maintenance/ Objective	Possible Corrective Actions
			General Site Conditions		
Obstructed Access to Site or Structures for O&M	Access is not obstructed	Access feasible but inhibited	Access to site and critical structures in the site is not feasible	System and structures must be accessible to conduct inspections and monitor system functionality.	• Prune or remove obstructing vegetation • Remove objects/barriers as needed
Stormwater Runoff Bypassing System Inlets (curb cuts, inlet pipe, etc.)	Water easily enters facility, or no indication of bypass as indicated by watermarks, debris buildup, signs of erosion	Indication of moderate bypass observed during rainfall or by watermarks, debris buildup, signs of erosion	Indication of significant bypass observed during rainfall or by watermarks, debris buildup or erosion	Water unintentionally bypassing the system indicates that the system is not able to manage stormwater at full capacity. Prevent runoff bypass to ensure system provides stormwater management benefits.	• Clean or regrade areas around GSI system to direct surface runoff to inlets and correct flow path to facility • Install new inlets at low points surrounding system to promote surface conveyance to system
Unpleasant Odors	Unpleasant odor not detected (minor smell from compost or other soil amendments is acceptable)	N/A	Unpleasant odor detected (minor smell from compost or other soil amendments is acceptable)	Odors may be an indication of surface clogging preventing runoff from reaching the soil layer or underdrain clogging preventing adequate drain down of the facility. (Minor smell from compost or other soil amendments is acceptable.)	• Conduct infiltration testing and remediate bioretention soil as necessary • Inspect underdrain and outlet control structure for clogging. CCTV and jet clean underdrain, if clogged • Ensure weed barrier or geotextile fabric has been used properly and is not clogged • Remove any decaying organic material or other source of odo
Vandalism / Damage to Components or Entire System	No evidence of vandalism or damage such as trampling or impacts from nearby construction	Some vandalism or damage present but not impacting the function of the GSI system	Significant vandalism or damage present that affects the function of the GSI system	Vandalism, including graffiti and removal of structures, can compromise the overall performance and/or aesthetics of the system.	• Remove graffiti • Plant individual replacement plants • Repair the GSI structures and inlets • Install protective barriers or implement other strategies to prevent continued vandalism

GROW
GREEN REVITALIZATION of OUR WATERWAYS

ALLEGHENY COUNTY SANITARY AUTHORITY
Green Revitalization of Our Waterways (GROW)
Green Stormwater Infrastructure (GSI) Practices
MAINTENANCE INSPECTION FORM

PP - PERMEABLE PAVEMENT

Inspected By: ______________________ **Phone:** ______________________

Inspection Date: ______________________

Address: ______________________

Installation Date: ______________________

Site Type:
☐ **Porous Asphalt** ☐ **Porous Concrete**
☐ **Open Grid Pavers** ☐ **Other** ______

Instructions to Inspector: Fill in the status, co[…]
must be taken to address each site condition […]
Refer to Table 3-3 in Chapter 5 for suppleme[…]
(S) Satisfactory – In compliance, expected co[…]
(M) Marginal – In compliance, needs mainten[…]
(U) Unsatisfactory – Needs immediate attenti[…]
(NA) Not Applicable – Not present at this site

SITE CONDITION	STATU[…]
1. General Site Conditions	
Access to Site or Structures Obstructed	
Stormwater Runoff Bypassing System	

SITE CONDITION	STATUS	PICTURE NUMBER	NOTES	POSSIBLE MAINTENANCE SOLUTION(S)
2. Standing Water				
Surface Ponding or Indication of Ponding (watermarks, etc.) on Permeable Pavement Surface				
Standing Water Present in the Monitoring Well or Structures at a Level Indicating that the System is Not Draining Completely				
Mosquitos or Larvae Observed in Inlet Structures or Elsewhere				
3. Surface Conditions				
Sediment or Silt Buildup on Permeable Pavement Surface				
Paver Joints Clogged				
Accumulated Trash and Debris on Permeable Pavement Surface				
Excess Oil, Staining, or Other Visible Contaminants on Pavement Surface				

4. Vegetation				
Vegetation Damage, Bare Spots, or Weed Growth in Grass Paver Systems				
Destabilized Contributing Landscape Areas				

SITE CONDITION	STATUS	PICTURE NUMBER	NOTES	POSSIBLE MAINTENANCE SOLUTION(S)
Weed Growth in Paver or Expansion Joints				
5. Structures				
Lids, Grates, or Caps Missing or Damaged				
Inlet Blockage or Excessive Sediment/Debris in Control Structure or Inlet Filter Insert				
Underdrain Blockage or Excessive Sediment/Debris in Control Structure				
Inlet Filter Inserts Damaged or Missing				
Monitoring Equipment Damaged or Missing				

Highlights of Recent O&M Inspections of 15 GSI Projects in the Region

INSPECTION REPORT

GROW ID #:

DATE OF INSPECTION: 04/20/22

PROJECT NAME: Anonymous
LOCATION:

INSPECTED BY: Andrew Potts, Jacobs
Aini Sun, Jacobs
Kevin Moore, MDA

WEATHER: 35 °F, sunny, dry

INSPECTION NOTES:

The rain garden facility inspected is a small, high performance rain garden at the located along The rain garden accepts water collected from roof leaders and sidewalk decorative trench drains along

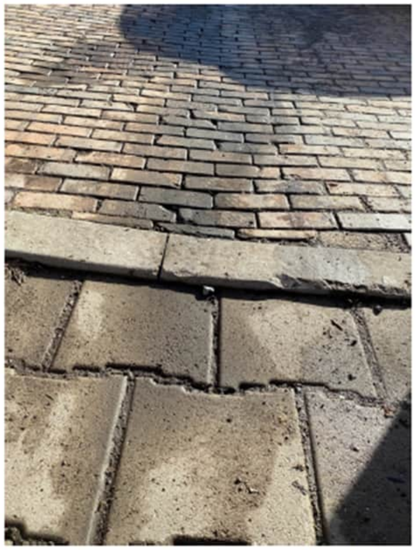
In general, the facility appears to be functioning as designed and has been maintained to a satisfactory level.

At the time of inspection, debris collected over the winter was evident but was not interfering with the function of the facility. Little or no mulch was evident in the rain garden and it was bare ground between the perennial plants. The no-mow fescue swale has been maintained to a satisfactory level and appeared to be functioning to slow and filter the water flowing through.

There was some litter and winter debris in the rain garden. Weeds were also germinating in nearly 100% of the bare ground between the perennial plants. Given the early spring timing of the inspection, it is reasonable to assume the weeds and mulch will be addressed with the spring maintenance when performed.

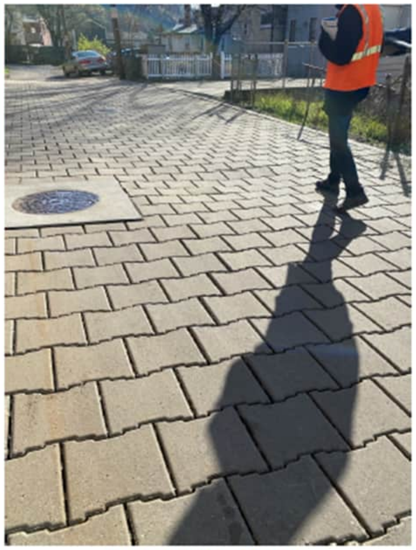
The street trees and rain garden shrubs planted in the basin appear to be healthy although none were leafed-out at the time of inspection. Perennial plants were also still dormant at the time of inspection. A second inspection in six to eight weeks will allow for better assessment of the health and vigor of the trees and plants.

The trench drains running through the sidewalks on both sides of and along one side of are all appear to be functioning as designed. There was some trash, debris and sediments noted at various point in the trench and in the tree grates.



Paver edge, snow plow damage, clogged pavers

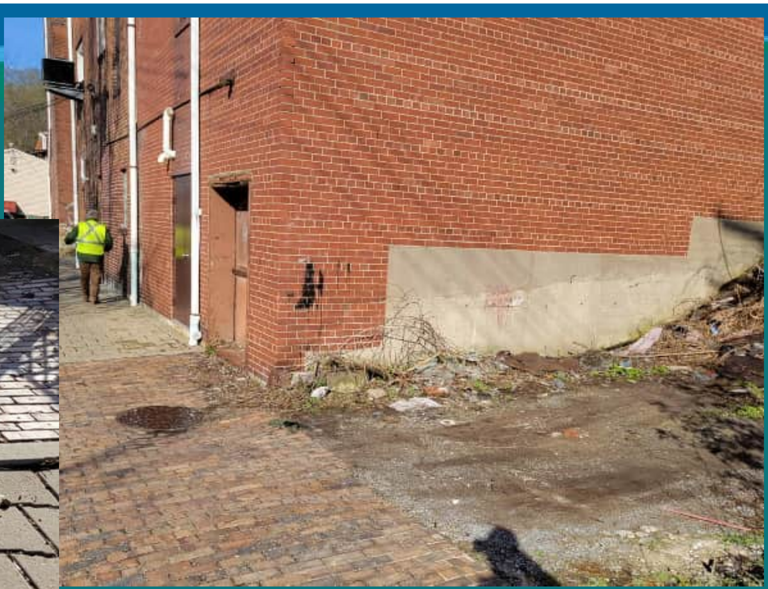
Pavers clogged with silt, weeds growing



pavers, depressed areas

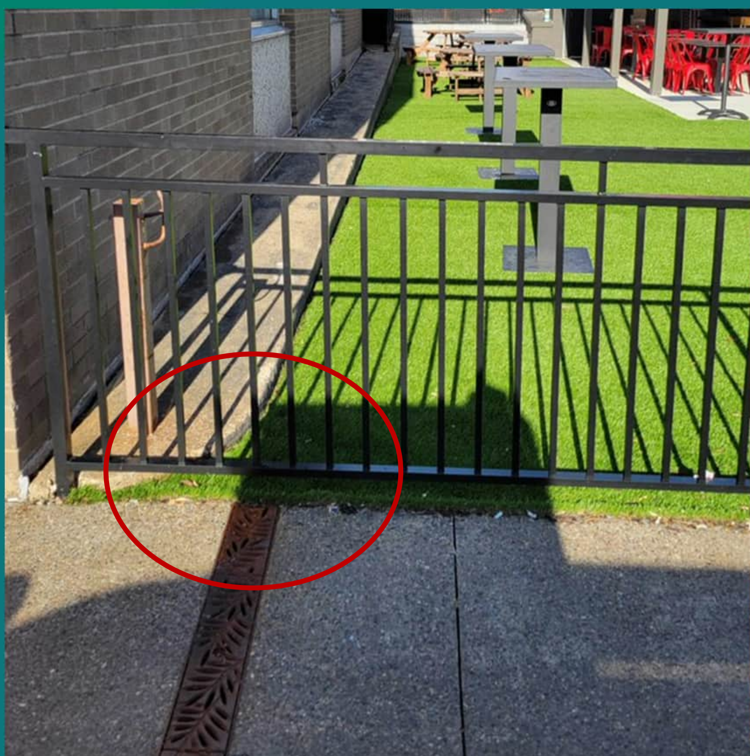
Disconnected roof leader

Permeable Pavement



- Permeable pavers being impacted by adjacent/upgradient unstabilized areas

Drainage Area Changes



Pavers in good shape

Weed growth

Bioretention

Bioretention




Agenda

- Objective
- Planning Approach
- Design Considerations
- Construction Phase
- Post-Construction Evaluation
- Operations & Maintenance
- **<u>Conclusions</u>**

Conclusions

- Estimating and verifying performance of GSI is critical and can be challenging, but there are a range of methods available that can be scaled based on the project parameters
- Consider performance at all stages of the project: from planning and design to construction to monitoring and maintenance
- There are good resources and tools available to assist, and we can share lessons learned throughout the region as more GSI is implemented

Questions?

Metrics that Matter – Evaluating Green Stormwater Infrastructure Performance

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