



Operation and Maintenance of Philadelphia's Green Infrastructure Program: Keys to Success



Presenters: Lia Mastropolo and Akta Patel
CWEA STORMWATER COMMITTEE
Fall Seminar: October 21, 2015

- **Introduction**
- **Maintenance Schedules and Protocols**
- **Training and Workforce Development**
- **Asset Management**
- **Data Analysis**
- **Design and Construction Feedback**

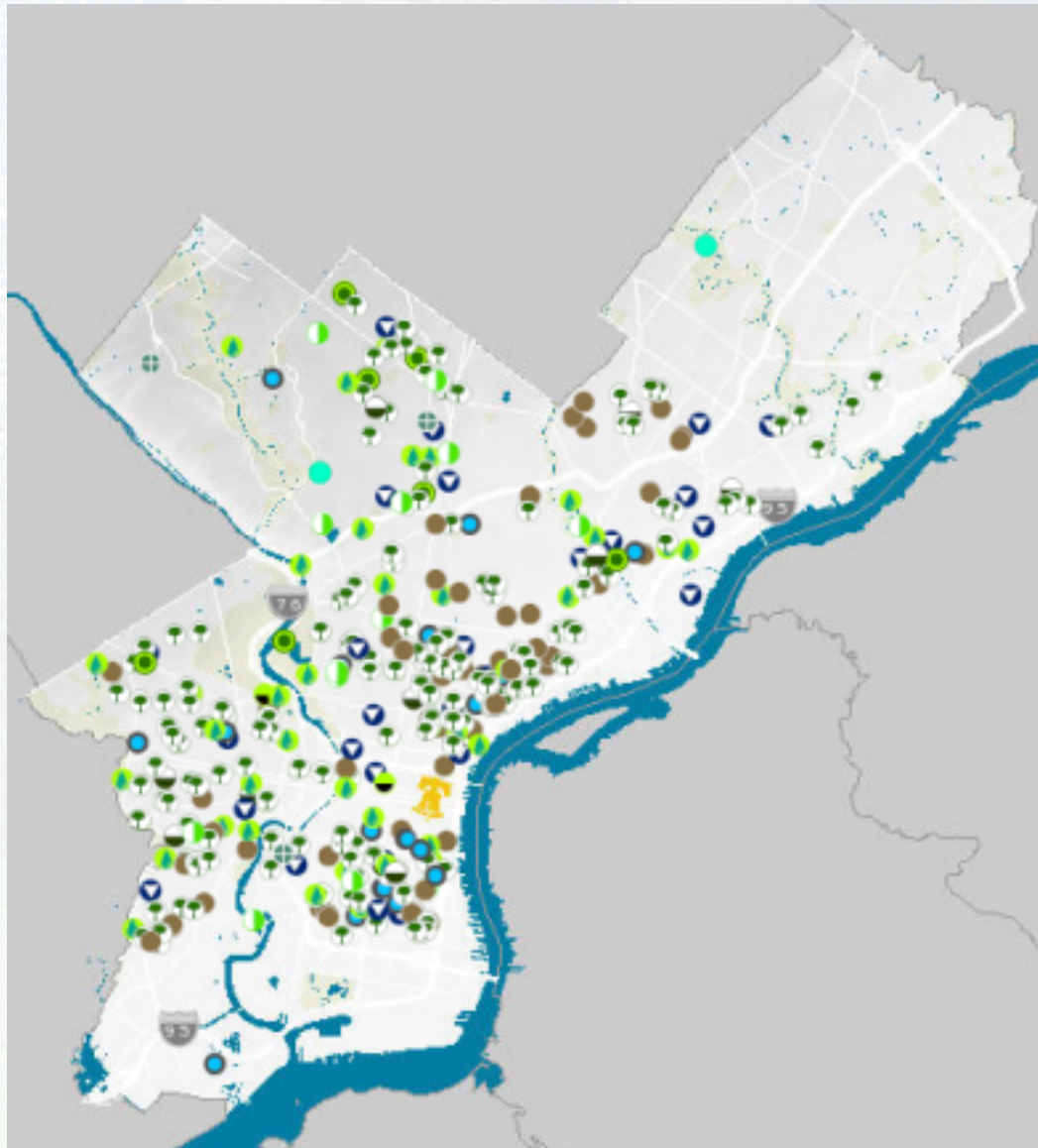


GREEN CITY, CLEAN WATERS

Green City Clean Waters

The City of Philadelphia's Program for Combined Sewer Overflow Control





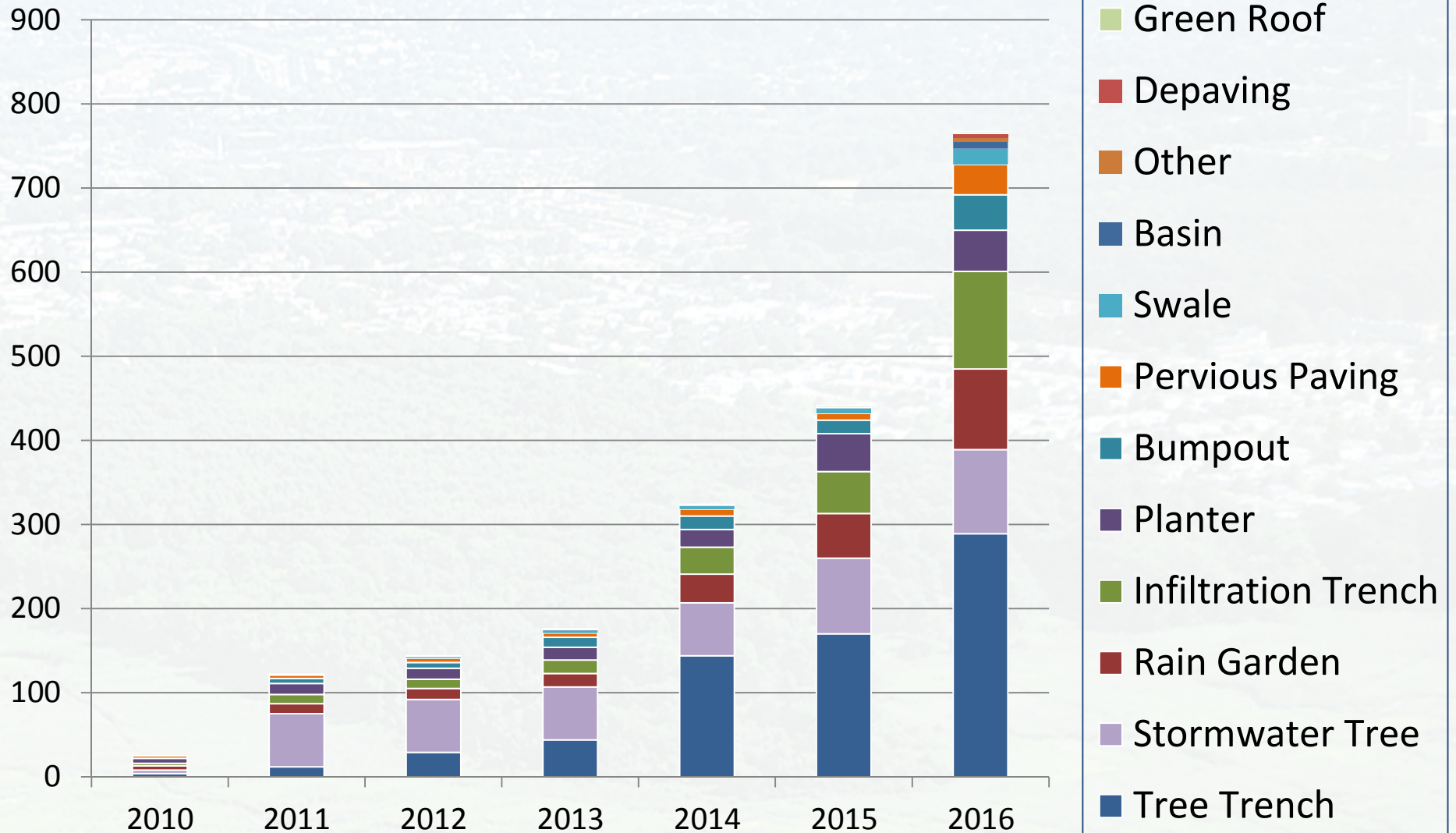
Map Legend

Green Stormwater Infrastructure Projects

- Swale
- Green Roof
- Stormwater Wetland
- Infiltration/Storage Trench
- Other
- Porous Paving
- Stormwater Basin
- Rain Garden
- Stormwater Bumpout
- Stormwater Planter
- Stormwater Tree Trench



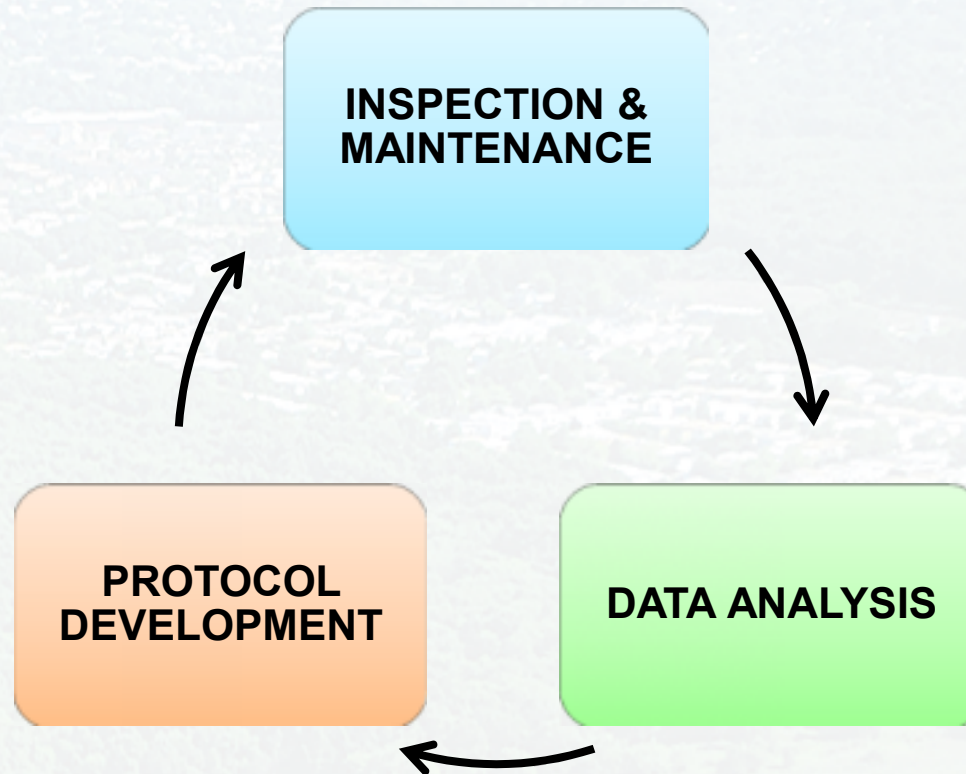
LID / GREEN STORMWATER ASSETS



MAINTENANCE SCHEDULES AND PROTOCOLS



PILOT PHASE: *INSPECTION AND DATA ANALYSIS*





PILOT PHASE: *DEVELOPMENT OF SPECIALIZED CREWS*



LANDSCAPE CARE



PIPE AND INLET
CLEANING



POROUS
PAVEMENT
VACUUMING



ROUTINE LID MAINTENANCE



PILOT PHASE: *EQUIPMENT AND MATERIALS TESTING*





PILOT PHASE: *MAINTENANCE PROTOCOLS AND SCHEDULES*

JUNE 1, 2014

**PROTOCOL
DEVELOPMENT**

**DATA
ANALYSIS**

INSPECTION

MAINTENANCE

2009





MAINTENANCE MANUAL

Green Stormwater Infrastructure Maintenance Manual



The logo for Philly Watersheds, featuring the word 'Philly' in a stylized blue font with a wave-like pattern.

First Edition - June, 2014

http://phillywatersheds.org/doc/GSIMaintenanceManual-1stEdwpreamble_HRes.pdf



ROUTINE MAINTENANCE - SURFACE



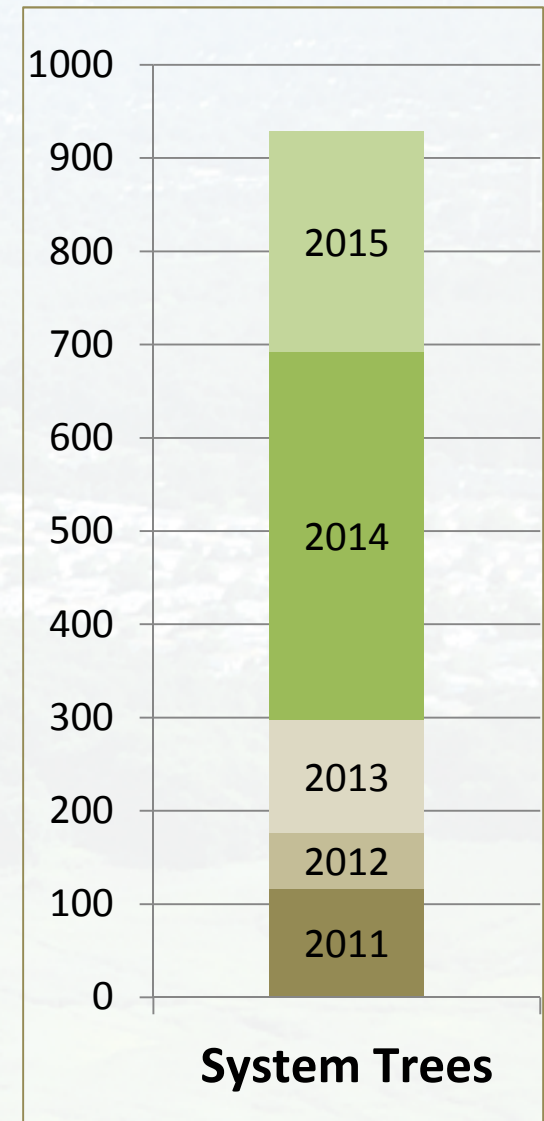
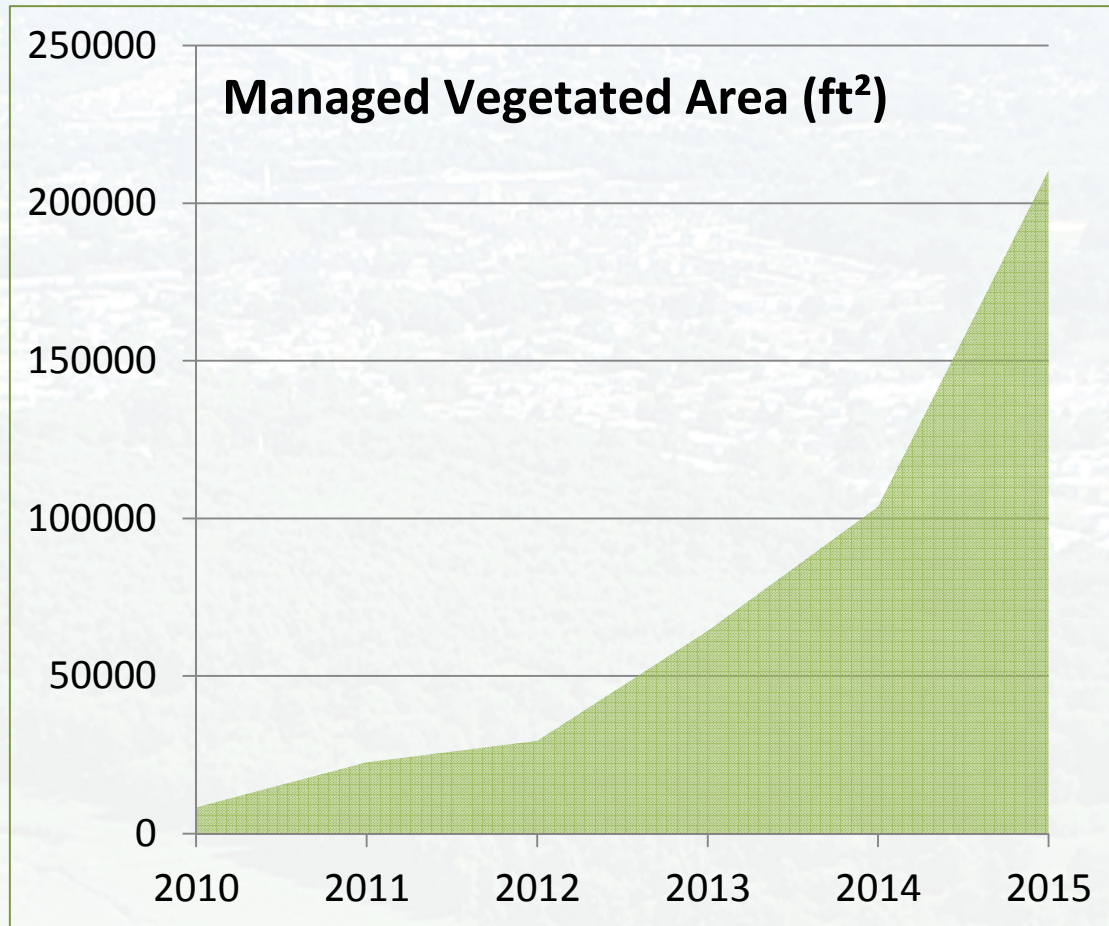


ROUTINE MAINTENANCE – SUBSURFACE



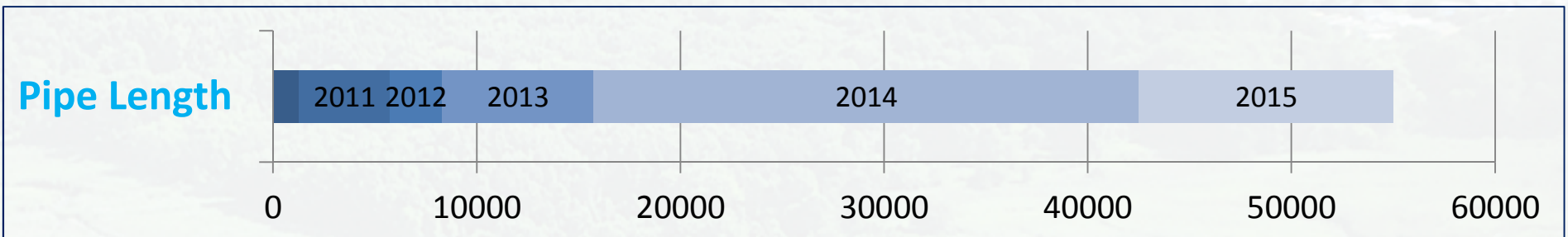
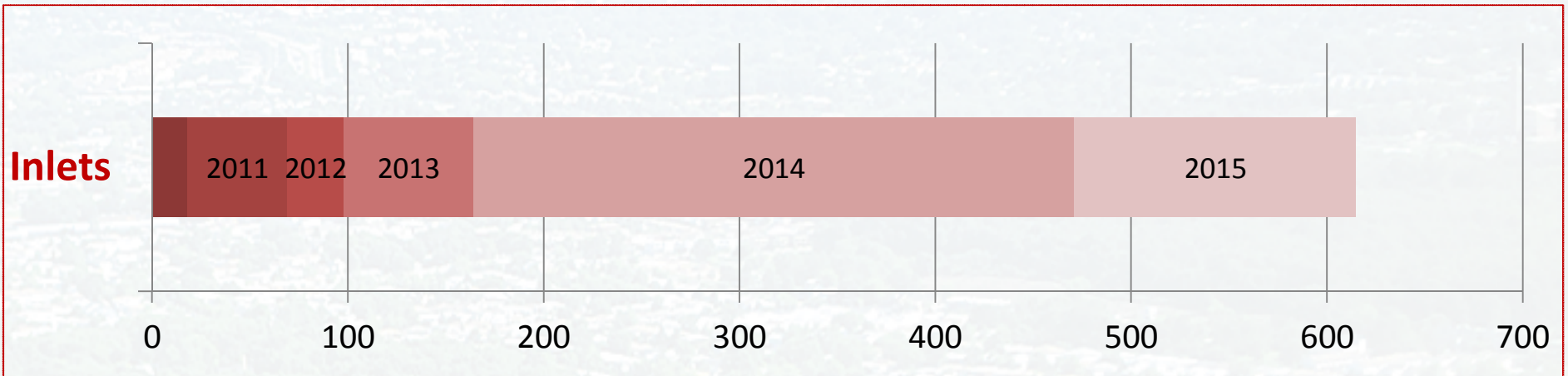


LID/ GREEN STORMWATER ASSETS – SURFACE





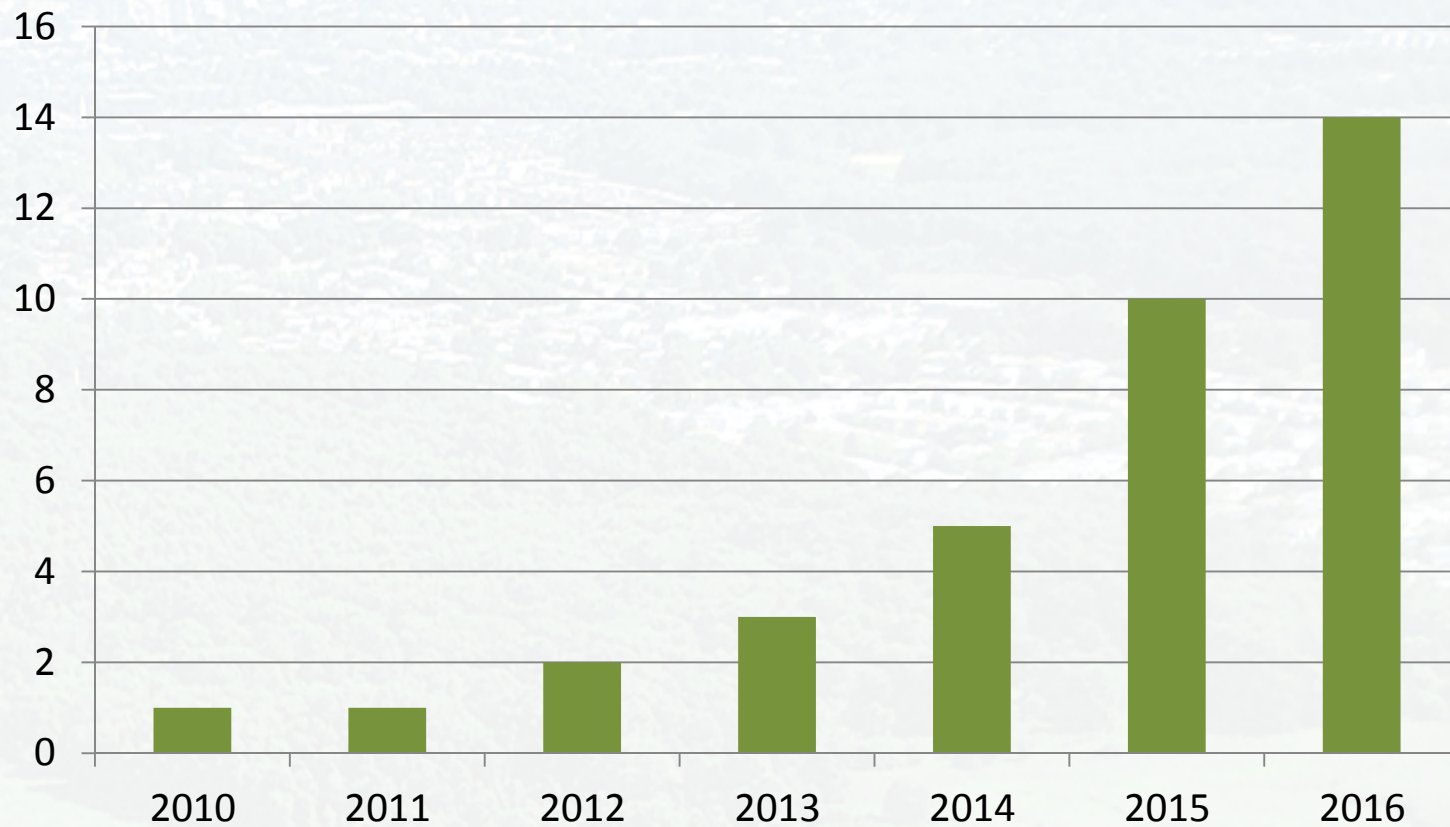
LID / GREEN STORMWATER ASSETS - SUBSURFACE





LABOR DEMAND TO SUPPORT PROGRAM

Number of Maintenance Crews by Fiscal Year



TRAINING AND WORKFORCE DEVELOPMENT



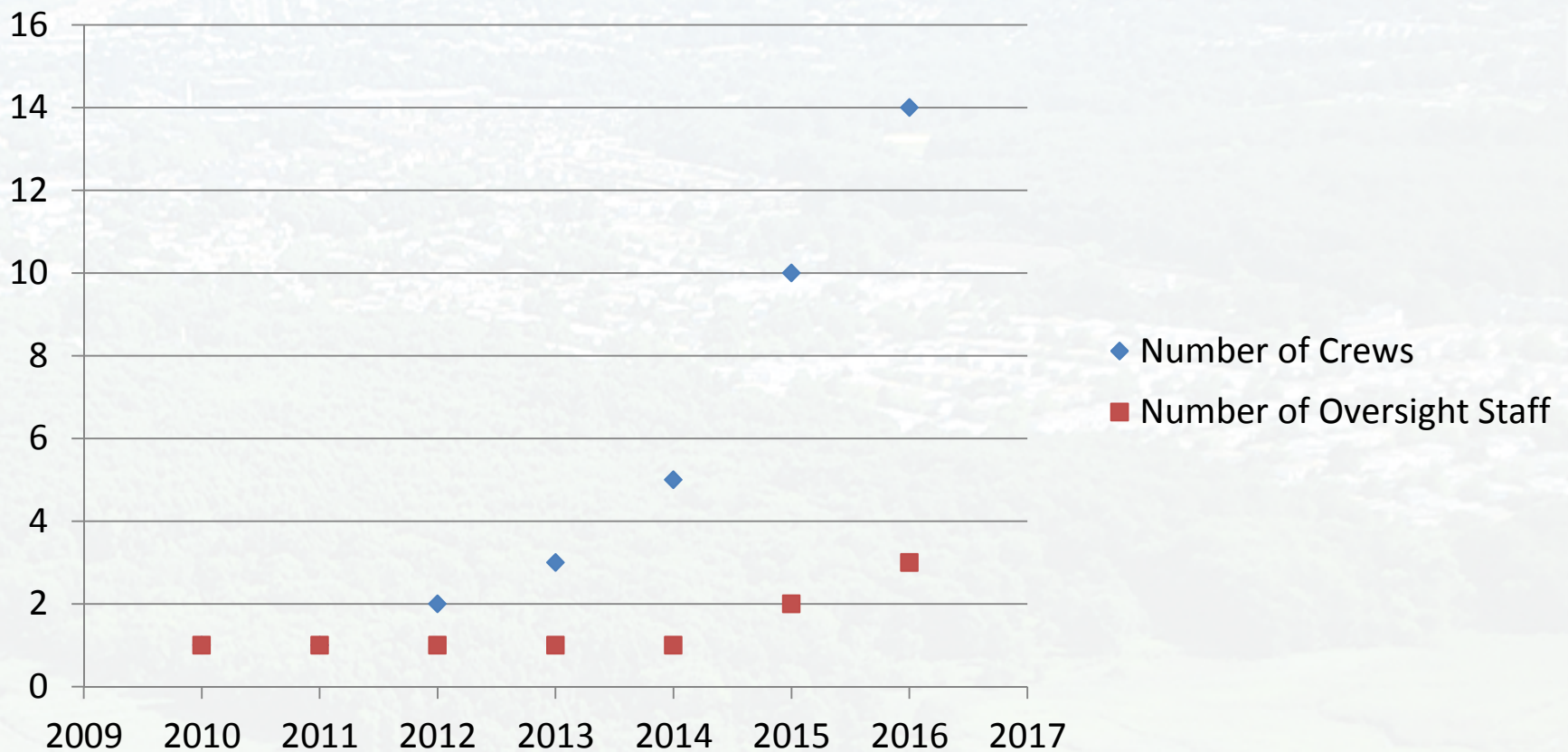
- Specialty Skills Needed to Maintain LID Practices
 - ✓ Native plant care
 - ✓ Arboriculture
 - ✓ CCTV pipe inspection
 - ✓ Pipe and inlet cleaning
 - ✓ Porous pavement vacuuming
 - ✓ Reading design and planting plans
 - ✓ Use of mobile devices and software
 - ✓ Data collection
 - ✓ Identification and reporting of performance issues
 - ✓ Public engagement and outreach

- Workforce Base
 - ✓ Construction
 - ✓ Landscaping/grounds maintenance
 - ✓ Masonry
 - ✓ Pipe inspection/Utility location
 - ✓ Workforce development programs



MANAGEMENT CHALLENGE: MORE WORKERS, LESS OVERSIGHT

Increase in Crews vs. Oversight Staff by Fiscal Year





POWER CORPS PHL



<http://powercorpsphl.org/>



Photo credits: PowercorpPHL, 2013-2014

- First-ever green infrastructure O&M course held in Philly 9/2015



- ✓ 3 full days of training
- ✓ Classroom and field sessions
- ✓ Plant identification
- ✓ Identification of performance problems
- ✓ Emphasis on surface maintenance
- ✓ Introduction to subsurface maintenance



GREEN STORMWATER
INFRASTRUCTURE
PARTNERS
REIMAGINING STORMWATER

Green Stormwater Infrastructure Operation and Maintenance Course

This three-day course is for landscape professionals seeking to strengthen or develop their service portfolio in operations and maintenance of public and private green stormwater infrastructure projects.

The course features two classroom days and one field day, and will provide landscape contractors and landscape managers with an understanding of the importance of operations and maintenance (O+M) of vegetated stormwater management practices, as well as of the tasks involved. The course will cover 16 sections in total, including:

- Identification and understanding of the components of stormwater management practices (SMP's)
- Diagnosis of and response to performance and safety issues
- Adaptive and prescriptive management activities
- Regulatory context for O+M



Photo: David Brothers

Dates:
August 21st 8:00am - 4:30pm
August 28th 8:00am - 4:30pm
September 4th 8:00am - 4:30pm



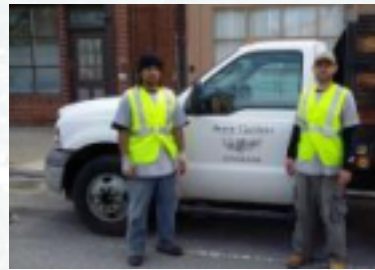
LAUNCH OF O&M TRAINING PROGRAM



Image Credit: Sustainable Business Network of Greater Philadelphia, 2015



14 TRAINED CREWS = 35 MAINTENANCE WORKERS SUPPORTING THE PROGRAM



ASSET MANAGEMENT

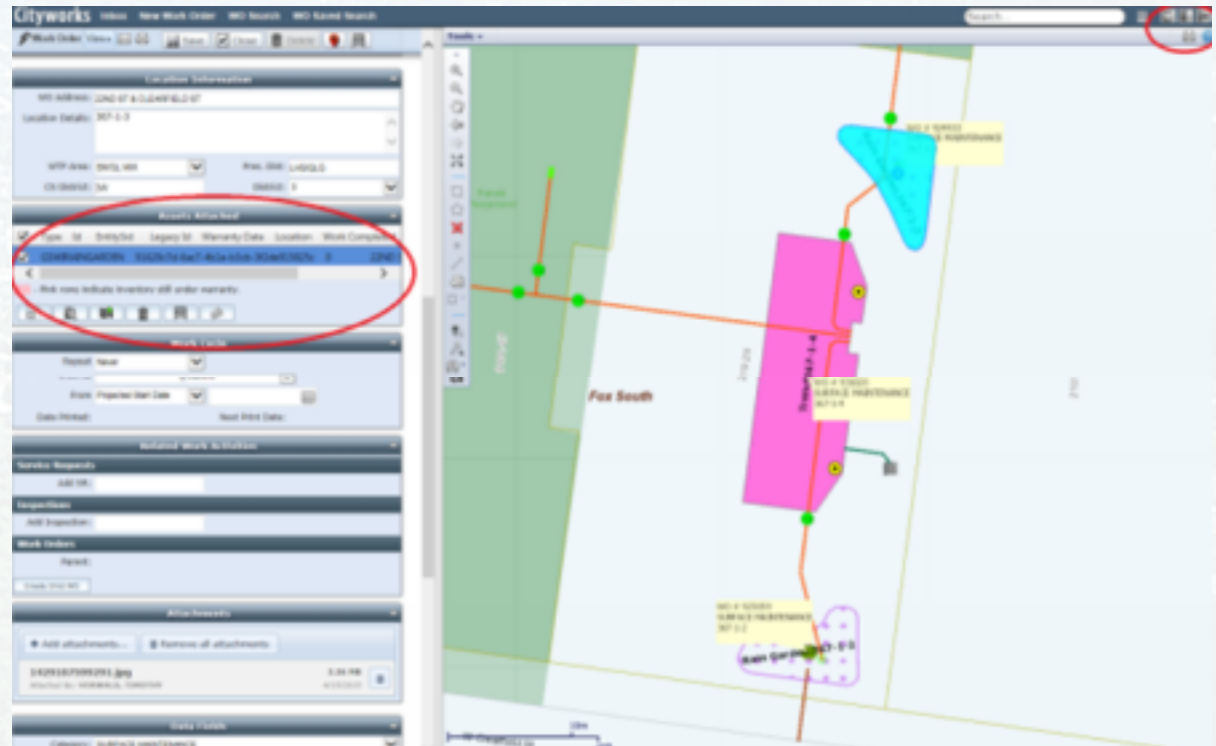


MANAGEMENT CHALLENGE: WHO, WHAT WHERE?

- Scheduling constraints:
 - ✓ Maintain all sites on routine monthly, annual, or semi-annual basis for different tasks (surface, subsurface, porous pavement)
 - ✓ Deal with vehicles parked in the right-of-way
 - ✓ Schedule by proximity to reduce travel time
 - ✓ Assign the same crews to the same sites
 - ✓ Manage non-routine tasks such as repairs, re-plantings, and reconstruction

- Work order management system options
 - ✓ Mobile or paper
 - ✓ Track work by site or by asset / component
 - ✓ Managed by municipality or by contractors
 - ✓ Stand-alone database, or integrated with other public works

- GIS-based system uses integrated citywide asset management framework
- Labor effort, tasks completed, and materials used are tracked for each crew visit to each SMP





DATABASE FIELDS

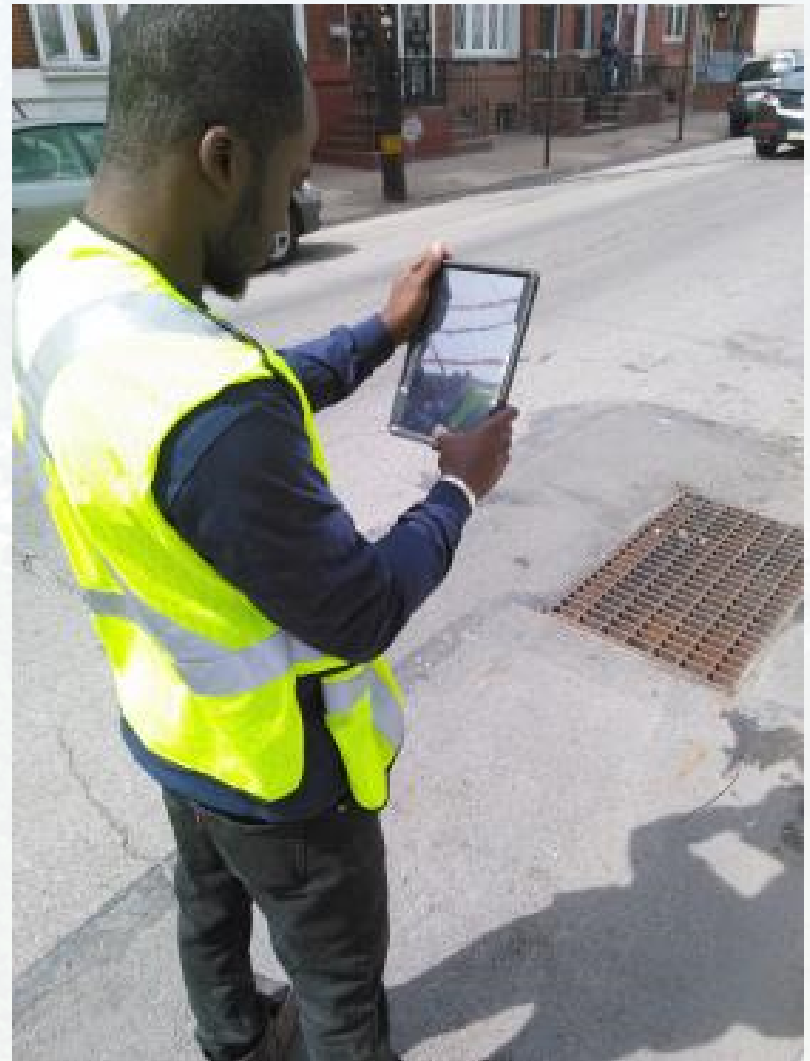
- Green assets:
 - ✓ Location, spatial features, components, type of practice
- Crews
 - ✓ Company, number of crew members
- Labor & Materials
 - ✓ Hours worked and materials used per crew/visit/asset
- Work orders
 - ✓ Dates requested, assigned, completed, closed
 - ✓ Tasks completed

Data Fields	
Category:	SURFACE MAINTENANCE
WO SUBTYPE	<input type="checkbox"/>
ORGANIC DEBRIS REMOVED?	<input type="checkbox"/>
TRASH REMOVED?	<input type="checkbox"/>
SEDIMENT REMOVED?	<input type="checkbox"/>
MULCHING?	<input type="checkbox"/>
WATERING?	<input type="checkbox"/>
TREE/SHRUB PRUNING	<input type="checkbox"/>
PESTICIDE	<input type="checkbox"/>
HERBICIDE	<input type="checkbox"/>
CUTTING BACK VEGETATION	<input type="checkbox"/>
WEEDING	<input type="checkbox"/>
VEGETATION ADDED?	<input type="checkbox"/>
VACUUMED	<input type="checkbox"/>
MOWING?	<input type="checkbox"/>
CLEAR DRAINAGE PIPES	<input type="checkbox"/>
STRUCTURE WINTERIZED?	<input type="checkbox"/>
DEBRIS IN PRETREATMENT BAGS	<input type="checkbox"/>
PRETREATMENT BAGS CLEANED	<input type="checkbox"/>
# PRETREATMENT BAGS REPLACED	<input type="checkbox"/>



MOBILE DATA COLLECTION

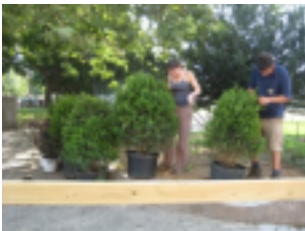
- Data is collected in the field using mobile tablets
- Downloads to a master database that can be queried by location
- Easy reporting allows managers to track crew efficiency
- Other opportunities:
 - ✓ GPS tracking of vehicles
 - ✓ “Check-in” to sites
 - ✓ Integrate crew timesheets
 - ✓ Integrate detailed inspection data



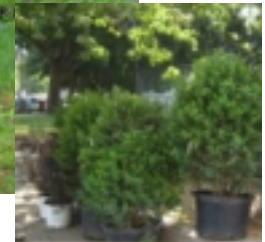
DATA ANALYSIS



Labor 77%



Materials 23%





DATA ANALYSIS – COST DRIVERS

SMP Type	Core Function and Safety Cost	Aesthetic Maintenance Cost
Stormwater Tree Trench	73%	27%
Stormwater Bump Out	78%	22%
Stormwater Planter	71%	29%
Infiltration/Storage Trench	88%	12%
Rain Garden	78%	22%
Stormwater Tree	65%	35%
Pervious Pavement	83%	17%
Stormwater Swale	69%	31%
Mean	78%	22%

- Predict maintenance cost based on design parameters
- Choosing variables for model input
 - ✓ Select characteristic design parameters
 - ✓ Spearman's Rank Correlation
- Linear regression





COST MODEL RESULTS

➤ Surface Maintenance Model

- ✓ Vegetated Footprint Area
- ✓ Number of SMPs
- ✓ Number of Flow Control Structures

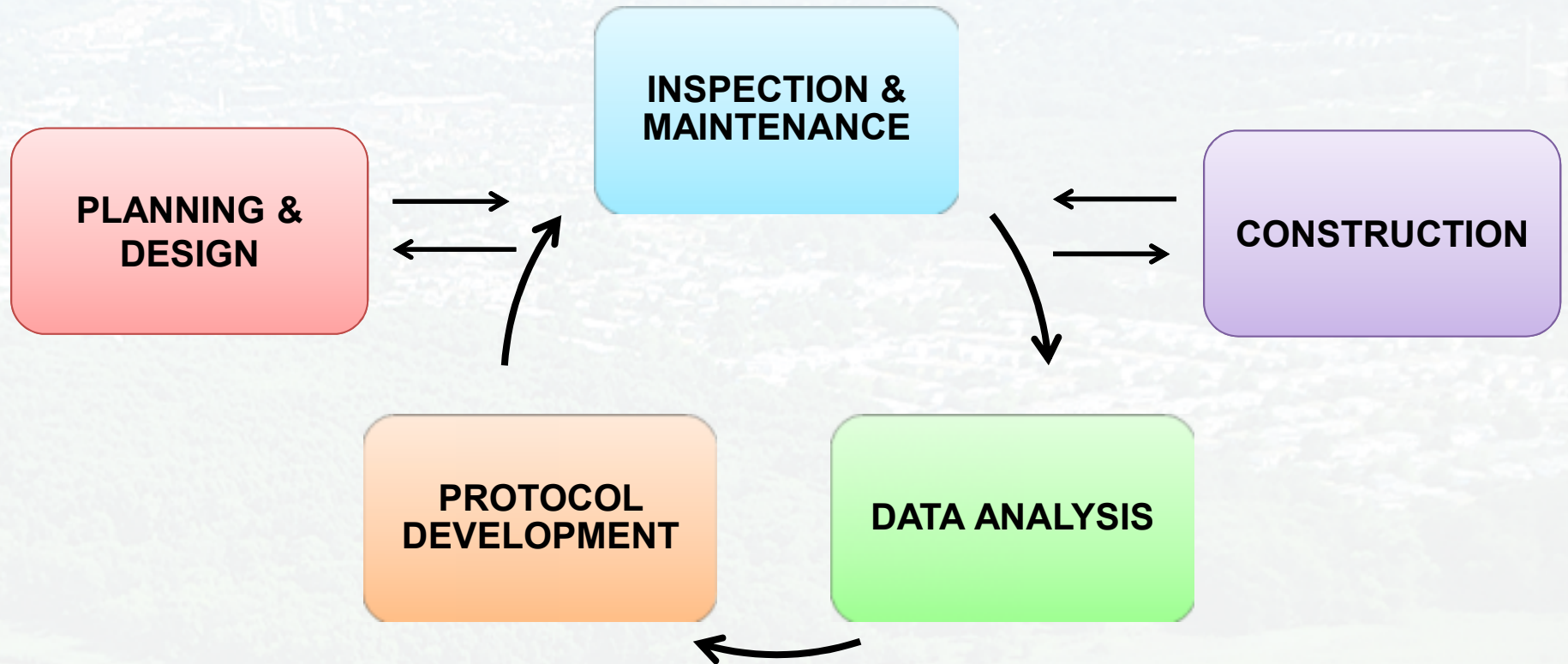
➤ Subsurface Maintenance Model

- ✓ Total Length of Pipe
- ✓ Total Number of Pipes
- ✓ SMP Group (Vegetated or Non-Vegetated)

Response Variable	Model Equation	R ²	Adjusted R ²	Predictive R ²	S
Annual routine subsurface maintenance cost (\$)	GROUP 0 SITES: [Annual Routine Subsurface Maintenance Cost] = XXX + XXX [Number of Pipes] + XXX [Total Pipe Length] GROUP 1 SITES: [Annual Routine Subsurface Maintenance Cost] = XXX + XXX [Number of Pipes] + XXX [Total Pipe Length]	87.29%	86.81%	86.24%	\$ XXX
Annual routine surface maintenance cost (\$)	XXX + XXX [Number of SMPs] + XXX [Vegetated Footprint] + XXX [Number of Flow Control Structures]	95.76%	95.52%	93.56%	\$ XXX

DESIGN AND CONSTRUCTION FEEDBACK





MAINTENANCE CHALLENGES & DESIGN FEEDBACK

- Erosion and sedimentation at inflow points
- Maintenance access
- Debris and sediment loading
- Pipe inspection and maintenance access
- Winter maintenance

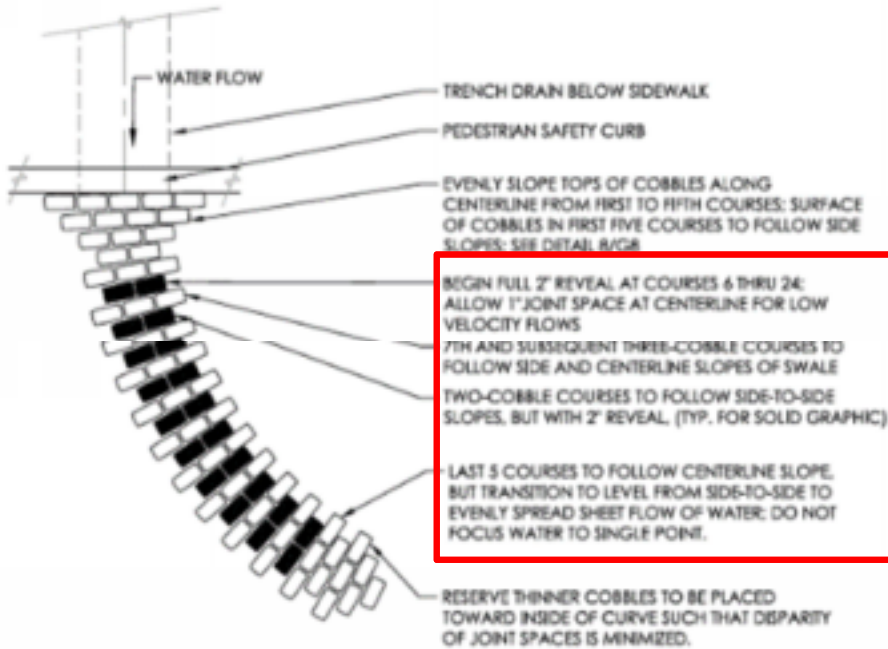




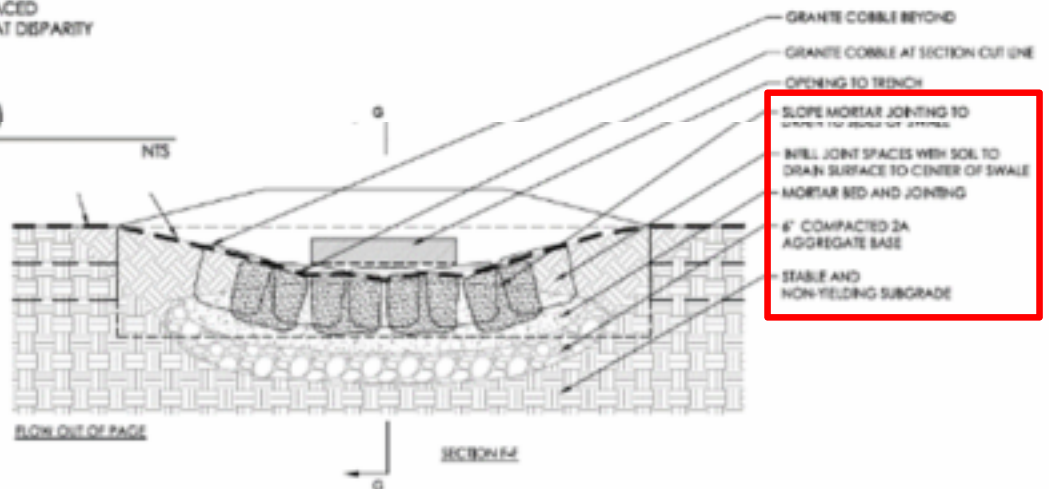
CHALLENGE: EROSION AND SEDIMENTATION AT INFLOW POINTS



DESIGN FEEDBACK: EROSION AND SEDIMENTATION AT INFLOW POINTS



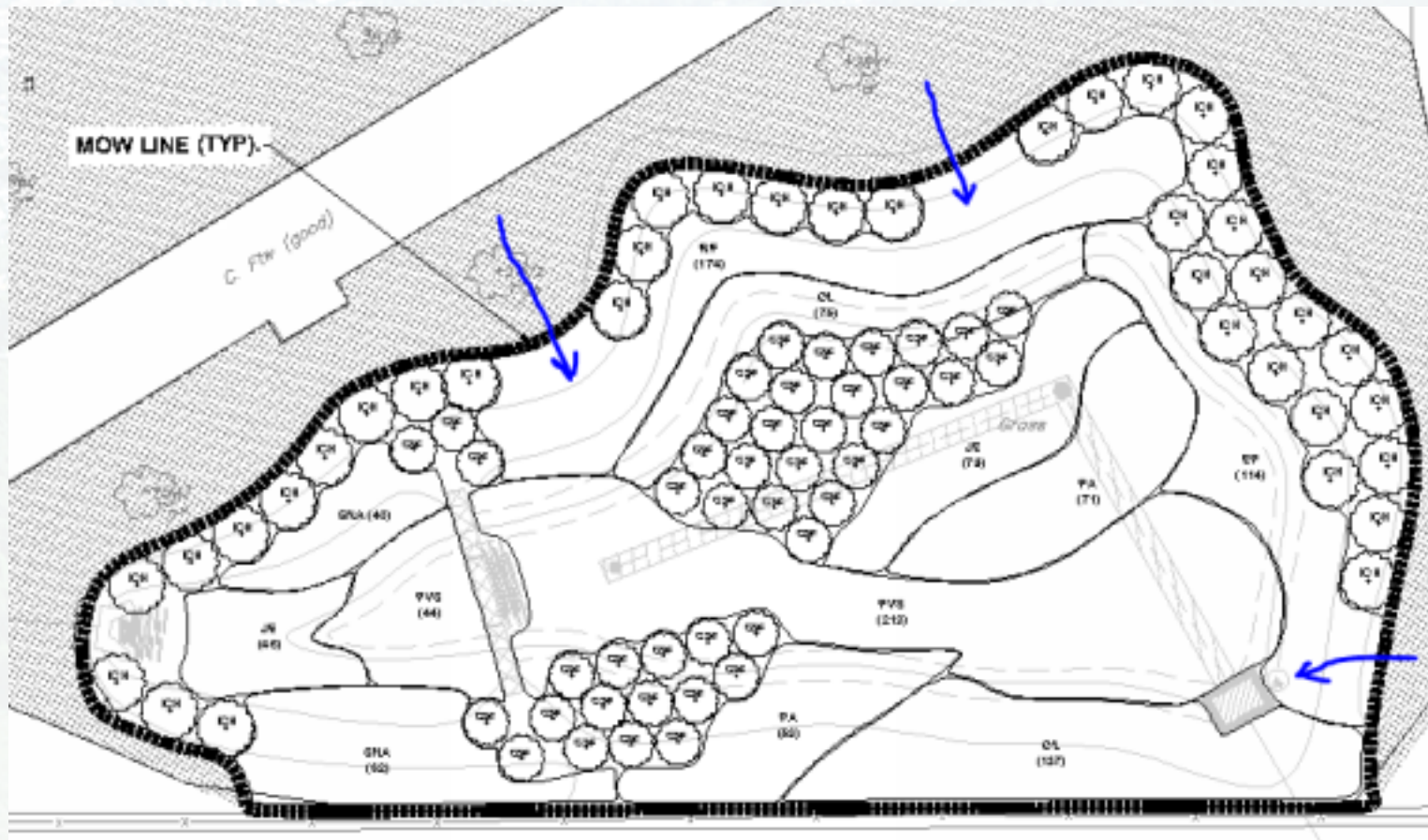
PLAN OF CURB SWALE (TYP)





CHALLENGE: ACCESS





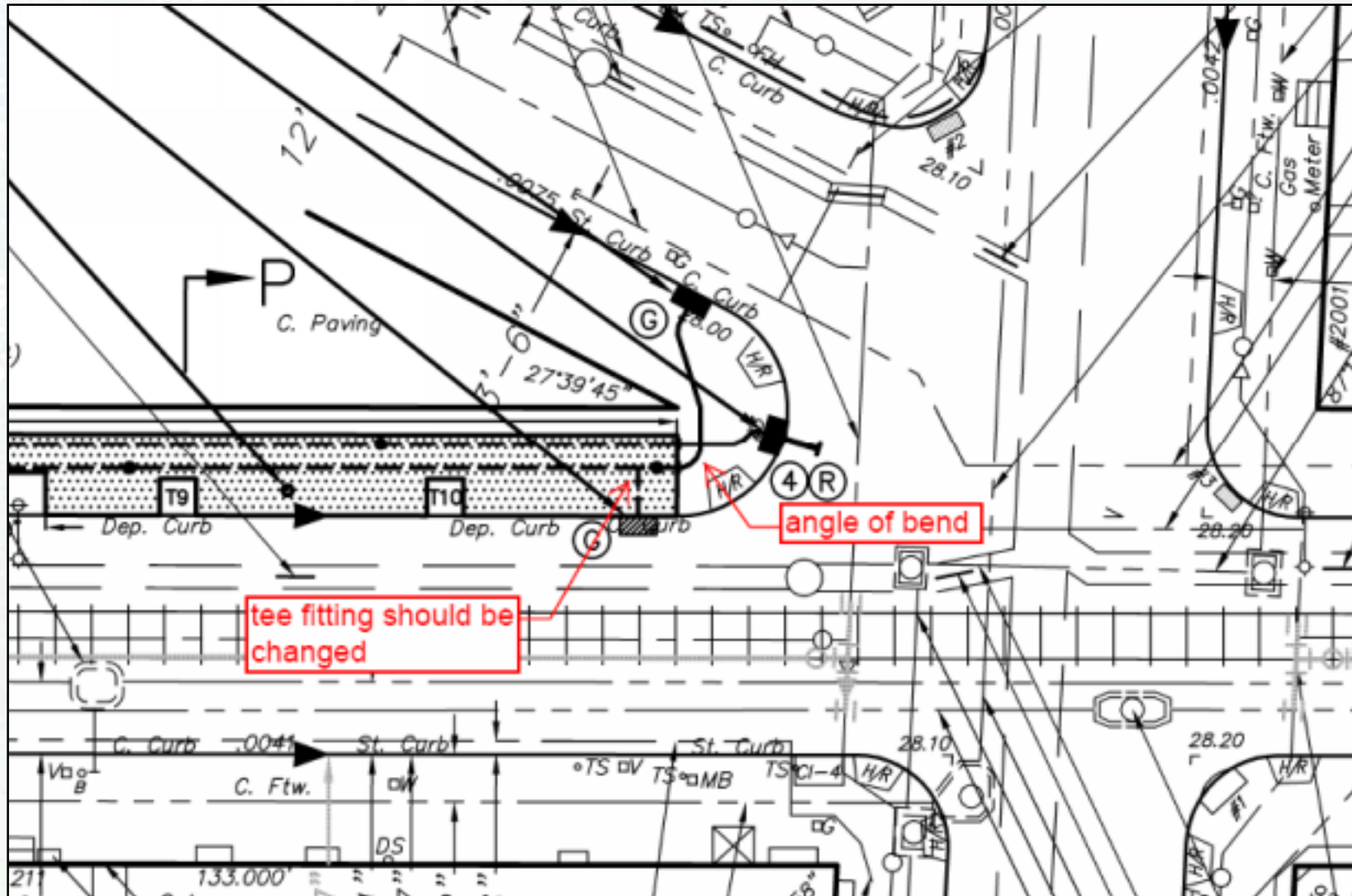


DESIGN FEEDBACK: ACCESS



Geoweb pad for structural support





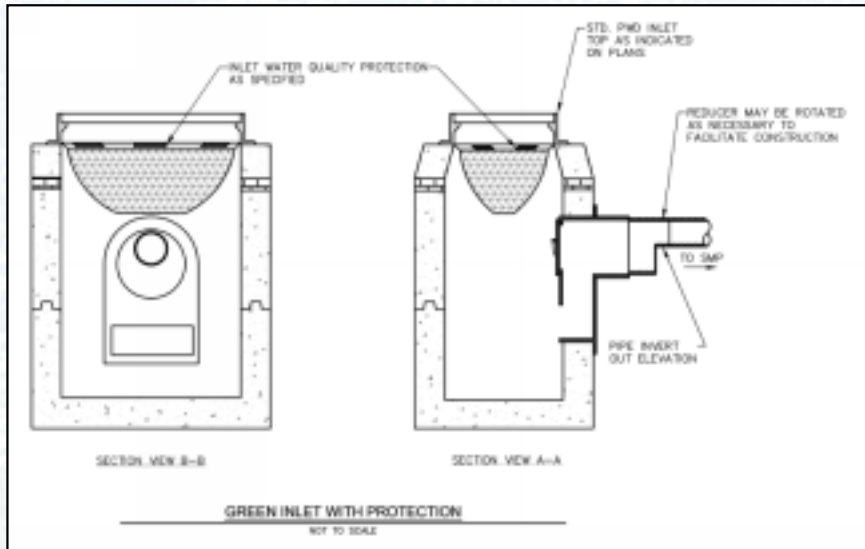


CHALLENGE: HEAVY SEDIMENT AND DEBRIS LOADING





DESIGN FEEDBACK: PRETREATMENT FOR ALL SUBSURFACE SYSTEMS





CHALLENGE: ROOT ENCROACHMENT INTO PIPES



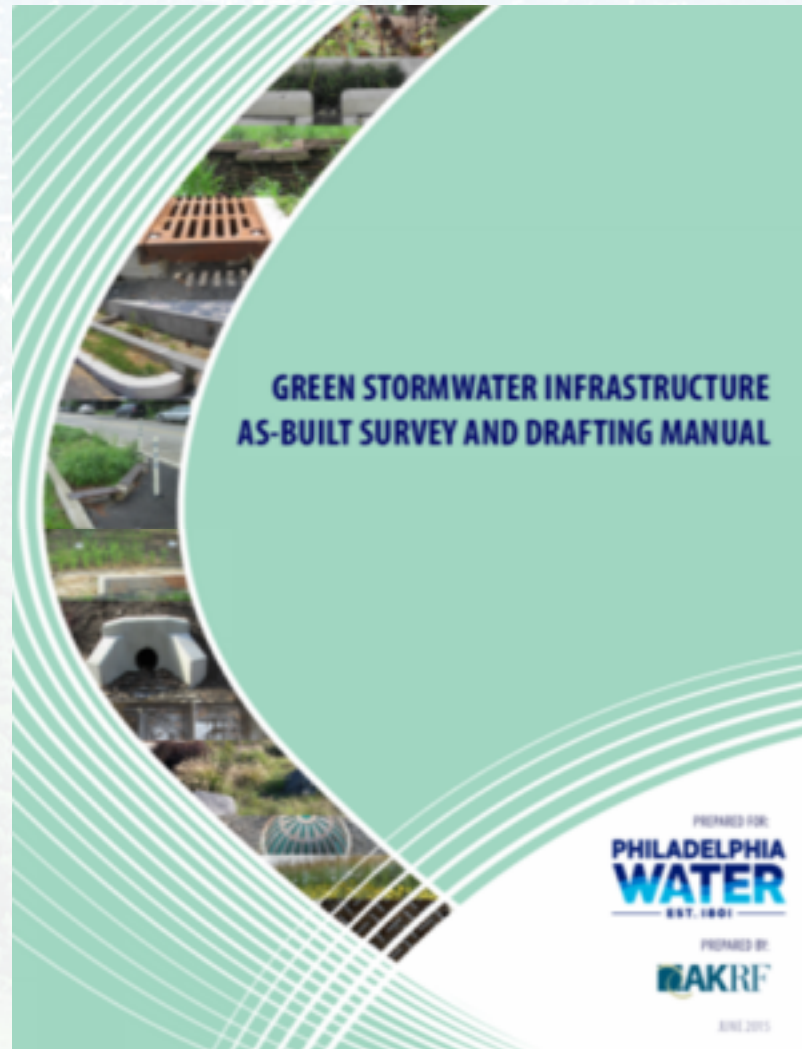


DESIGN FEEDBACK: STANDARD TREE SPECIES SPECIFIED

Plant Name			Form			Bloom Color				Adaptation							SMP Type			
Genus	Species	Common Name	Height	Width	Size	White	Red/Pink	Purple/Blue	Yellow/Orange	Winter interest	Native to US	Inundation Tolerance	Drought Tolerance	Hydrologic Zone Elevation	Light Requirements	Salinity Tolerance	Rain Garden/ Bump Out	Boulevard	Narrow Street	Typical Street
<i>Crataegus</i>	<i>laevigata</i>	English Hawthorn	15-20'	15-20'	S	○	●			❄️	-	Seasonal	High	Middle/Outer	☀️	Low	-	-	-	X
<i>Crataegus</i>	<i>phaenopyrum*</i>	Washington Hawthorn	25-30'	25-30'	S	○				❄️	Yes	Seasonal	High	Middle/Outer	☀️	High	-	-	-	X
<i>Crataegus</i>	<i>punctata*</i>	Dotted Hawthorn	20-30'	20-30'	S	○				❄️	Yes	Seasonal	High	Middle/Outer	☀️	High	-	-	-	X
<i>Crataegus</i>	<i>viridis*</i>	Green Hawthorn	20-35'	20-35'	S	○				❄️	Yes	Seasonal	High	Middle/Outer	☀️	Low	-	-	-	X
<i>Crataegus</i>	<i>x laevifolia</i>	Laville Hawthorn	15-25'	10-18'	S	○				❄️	-	Seasonal	High	Middle/Outer	☀️	Low	-	-	-	X
<i>Cryptomeria</i>	<i>japonica</i>	Japanese Cryptomeria	50-60'	20-30'	L						-	Seasonal	Moderate	Middle/Outer	☀️	N/A	-	X	-	-
<i>Eucommia</i>	<i>ulmoides</i>	Hardy Rubber Tree	40-60'	30-50'	L						-	Seasonal	High	Middle/Outer	☀️☀️	High	-	-	-	X
<i>Fagus</i>	<i>sylvatica 'Fastigiata'</i>	Pyramidal Beech	50-75'	25-35'	L						-	Seasonal	Moderate	Outer	☀️☀️	N/A	-	-	X	-
<i>Ginkgo</i>	<i>biloba (male only)</i>	Maidenhair Tree	40-50'	25-30'	L						-	-	High	Outer	☀️	High	-	-	-	X
<i>Ginkgo</i>	<i>biloba 'Magyar'</i>	Magyar Upright Ginkgo	40-60'	20-30'	L						-	-	N/A	Outer	☀️	High	-	-	X	-
<i>Ginkgo</i>	<i>biloba 'Princeton Sentry' (male only)</i>	Princeton Sentry Ginkgo	40-50'	20-30'	L						-	-	High	Outer	☀️	High	-	-	X	-
<i>Gleditsia</i>	<i>triacanthos var. inermis</i>	Honeylocust	60-80'	60-80'	L						Yes	Seasonal	High	Lowest/Middle/Outer	☀️	High	-	-	-	X
<i>Gymnocladus</i>	<i>dioica (male only)*</i>	Kentucky Coffeetree	60-80'	40-55'	L						Yes	-	High	Middle/Outer	☀️	High	-	X	-	-
<i>Halesia</i>	<i>tetraptera*</i>	Carolina Silverbell	30-40'	20-35'	M	○					Yes	-	Moderate	Middle/Outer	☀️☀️	Low	-	-	-	X
<i>Juniperus</i>	<i>virginiana*</i>	Eastern Redcedar	30-40'	10-20'	M					❄️	Yes	Seasonal	High	Lowest/Middle/Outer	☀️	High	X	-	-	-



CONSTRUCTION OVERSIGHT



TYPICAL SMP SURVEY WORKFLOW

RAIN GARDEN

1. DURING CONSTRUCTION

STORAGE STONE

Once final subgrade has been approved, **survey** subsurface storage perimeter and internal points, and **document** materials, configuration, and dimensions (see page 25).



PIPES

Pipes can be installed once subgrade preparations have been set and approved. **Survey** the pipe inverts and fittings, and **document** materials and configuration (see page 25).



2. POST-CONSTRUCTION

INLETS

Following final installation of the system, **survey** the inlet locations, surface elevations, dimensions of concrete aprons, and inverts of all pipe connections, and **document** inlet type, dimensions, and presence of features within inlet (see page 28).



CONTROL STRUCTURES

Survey the location, grate elevations, and inverts of all pipe connections. **Document** standard type, dimensions, and features (see page 29).



DOMED RISERS

Survey the rim elevation of domed riser structures, and **document** the diameter of both grate and riser pipe, the material of grate and riser pipe, and the presence of other features (see page 30).



SUMPS, TRAPS, & HOODS

Survey structure sumps, and **document** the presence as well as material type of any inlet boards and/or traps (see page 31).



SPILLWAYS & WEIRWALLS

Survey the crest of weir, corners of spillway or weir wall, and the surface elevation slope and downslope of spillway or weirwall, and **document** the material and slope (see page 32).



TRENCH DRAINS

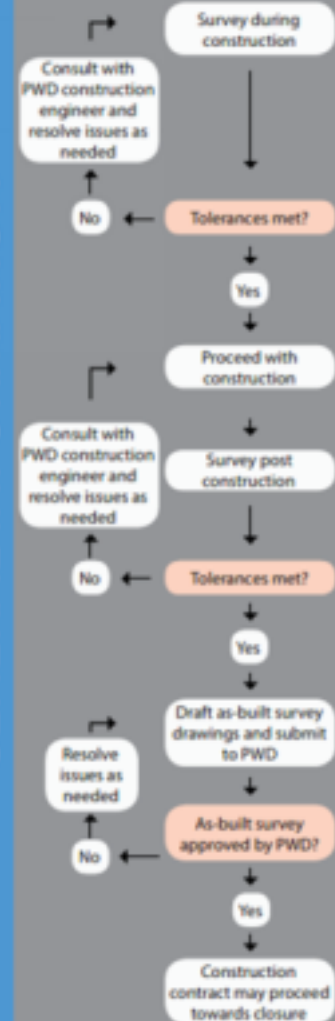
Survey the lowest point and top of grate of trench drain and dimensions of concrete apron, and **document** channel and cover materials and type of trench drain cover (see page 34).



TYPICAL SMP SURVEY WORKFLOWS

AS-BUILT PROCESS OVERVIEW

GENERAL INFORMATION



➤ During Construction Survey Points – e.g., Pipes

REQUIRED SURVEY POINTS

Feature	Required Survey Point	Description of Survey Point
Pipe	X¹ Invert in and out at every pipe end or deflection point.	Bottom interior elevation of pipe at each end of the termination or deflection point.
Fitting	X² Location of fitting	Top/center point of each fitting.



Pipe invert: bottom interior elevation of pipe



Location: of fitting



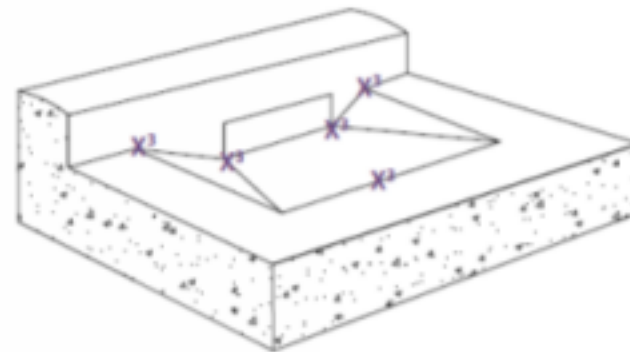
Location: of fitting

➤ Post Construction Survey Points – e.g., Trench Drains

Feature	Required Survey Point	Description of Survey Point
Trench Drain	X¹ Lowest point of trench drain	Lowest points at both upslope and downslope locations along the length of the channel.
	X² Top of grate	Top/center elevation on front and back of grate (width of trench drain to be included).
	X³ Concrete Apron Dimensions	Grade changes of concrete apron along the gutter line, plus apron extent opposite trench drain opening.




Trench drain: lowest point of trench drain, top of grate, and width of the grate.

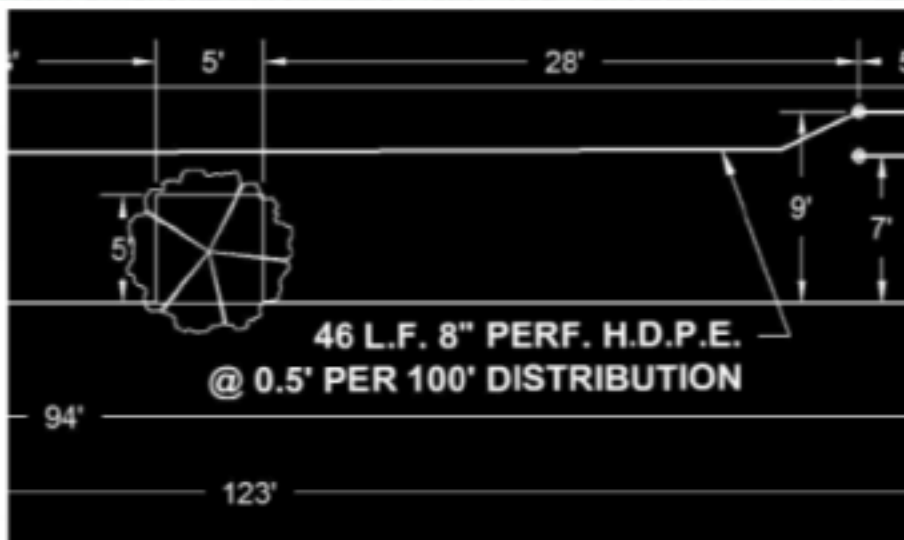


Concrete apron dimensions: Grade changes of concrete apron along the gutter line, plus apron extent opposite trench drain opening.

Conveyance Pipes

CAD Legend Description	New Conveyance Pipe
CAD LineType/ Block Image	
Layer	GSI_Conveyance_New
Color	BLUE
LineWeight	0.70mm
LineType	Continuous
Callout	XX XX L.F. <DIA.>" <MATERIAL> @ X' PER XXX' <PIPE FUNCTION>*

*Underdrain pipes typically have no slope (0' per 100')



CAD user must be of an-built drawing associations and dimensions for pipes and strings.

MATERIAL
D.I.P.
PERF. D.I.P.
H.D.P.E.
PERF. H.D.P.E.
P.V.C.
PERF. P.V.C.
R.C.P.
V.C.P.

PIPE FUNCTION
DISTRIBUTION MAIN
GRAVITY MAIN
TRENCH DRAIN
UNDERDRAIN
LATERAL

- **Classroom sessions for survey contractors – use of manual and Q&A**
- **Separate classroom sessions for municipal survey department (reviewers and construction inspectors)**

- **Defining maintenance schedules and protocols helps limit coordination and improves efficiency**
- **Training and workforce development is critical to ensuring ongoing capacity and quality of work**
- **A simple, well-organized asset management system can allow crews to collect data in the field with minimal oversight**
- **Data collected during routine maintenance can be used to identify cost drivers and inform the design and construction process for new projects.**



ACKNOWLEDGEMENTS

PWD

Lance Butler
Gerald Bright
&
The PWD GSI Maintenance
Team



AKRF

Shandor Szalay
Kevin Flynn
Ryan Fucci
Bilal Khan
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