Green City, Clean Waters

Evaluation and Adaptation Plan

Consent Order & Agreement

City of Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Submitted to
The Commonwealth of Pennsylvania
Department of Environmental Protection

By The City of Philadelphia
Water Department
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Glossary of Acronyms

AOCC	Administrative Order for Compliance on Consent
BIRT	Business Income and Receipts Tax
BOD	Biological Oxygen Demand
CAD	Computer-Aided Design
CDF	Cumulative Distribution Function
COA	Consent Order and Agreement
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
DCIA	Directly Connected Impervious Area
DSC	Development Services Committee
EAP	Evaluation and Adaptation Plan
ET	Evapotranspiration
FHL	Frankford High Level
GA	Greened Acre
GARP	Greened Acre Retrofits Program
GCCWRC	Green City Clean Waters Research Center
GILL	Green Infrastructure Living Laboratory
GSDM	Green Streets Design Manual
GSI	Green Stormwater Infrastructure
IAMP	Implementation and Adaptive Management Plan
LTCPU	Long Term Control Plan Update
MG	Million Gallons
NEDD	Northeast Drainage District
NMC	Nine Minimum Controls
NPDES	National Pollutant Discharge Elimination System
PADEP	Pennsylvania Department of Environmental Protection
PennDOT	Pennsylvania Department of Transportation
PWD	Philadelphia Water Department
RTC	Real Time Control
SBN	Sustainable Business Network
SEDD	Southeast Drainage District
SMED	Stormwater Management Enhancement District
SMIP	Stormwater Management Incentives Program
SMP	Stormwater Management Practices
STAR	Science to Achieve Results
SWMM	Storm Water Management Model
TSS	Total Suspended Solids
TTF	Tookany-Tacony/Frankford
USD	United States Dollar
US EPA	United States Environmental Protection Agency
WPCP	Water Pollution Control Plant
WQBEL	Water Quality Based Effluent Limit

1.0 Introduction

On June 1, 2011, the Commonwealth of Pennsylvania approved the City of Philadelphia's Combined Sewer Overflow Long Term Control Plan Update (LTCPU) and its supplements, also referred to as the *Green City, Clean Waters* program, and formalized its approval in a Consent Order & Agreement (COA). The COA requires that the City construct and place into operation the controls necessary to achieve the elimination of the mass of pollutants that would otherwise be removed by the capture of 85% by volume of the combined sewage collected in the Combined Sewer System during precipitation events on a system-wide annual average basis. In December 2011, the Philadelphia Water Department (PWD) submitted the *Green City, Clean Waters Implementation and Adaptive Management Plan* (IAMP), which described the implementation approach, program structure, and tools that PWD would evaluate for implementation over the first five years.

Since submission of the IAMP, PWD has submitted eleven additional formal deliverables prescribed in the COA on time or ahead of schedule, and provided summary updates on implementation progress within the COA annual reports, which are appendices to the National Pollutant Discharge Elimination System (NPDES) Permit Annual Reports. This *Evaluation and Adaptation Plan* (EAP) represents the culmination of the first five years of program progress including an assessment of compliance with Water Quality Based Effluent Limits (WQBEL) Performance Standards.

1.1 Program Evaluation

According to paragraph 3e of the COA, an EAP will be submitted at a minimum of every five years, beginning October 30, 2016. Each EAP will include a comprehensive assessment of the City's progress towards WQBEL Performance Standards and descriptions of program elements expected to be implemented in the next five-year period.

The following metrics are included in the WQBEL Performance Standards:

Northeast / Southwest / Southeast Water Pollution Control Plant Upgrades: Design and Construction

PWD operates three Water Pollution Control Plants (WPCPs): the Northeast (NE), Southwest (SW) and Southeast (SE) WPCP. The WPCP upgrade milestones are defined in the LTCPU Facility Concept Plans (FCPs) submitted for each WPCP to the United States Environmental Protection Agency and the Pennsylvania Department of Environmental Protection by June 1, 2013. A revised Northeast WPCP FCP was submitted on December 31, 2013 and subsequently approved by the US EPA on January 28th, 2015. The SW and SE WPCP FCPs are still awaiting approval.

Interceptor Rehabilitation

A mileage target for rehabilitation of the Cobbs Creek and Tacony Creek interceptors has been established. The length of interceptor rehabilitated is tracked and summarized in the COA Annual Report.

Overflow Reduction Volume

Overflow reduction volume is the difference between the volume of overflow in million gallons per year for the condition prevailing at the time of the report and the volume of overflow in million gallons per year for the baseline year. The baseline year represents the condition of Philadelphia's sewerage system as configured on January 1, 2006. These volumes will be estimated for the typical year using the validated hydrologic and hydraulic models described in the LTCPU and its supplements.

Equivalent Mass Capture (TSS, BOD, *Fecal Coliform*)

Equivalent Mass Capture of Total Suspended Solids (TSS), Biological Oxygen Demand (BOD), and *fecal coliform* bacteria are measures of the reduction of these constituents equivalent to what would be removed otherwise by the capture of 85% by volume of the combined sewage collected in the Combined Sewer System. Conformance with these metrics will be documented through simulations performed using the hydrologic and hydraulic models described in the LTCPU and its supplements.

Total Greened Acres

A Greened Acre (GA) is an expression of the volume of stormwater managed by green stormwater infrastructure (GSI), based on the design for the project, and is conditional on the proper maintenance of the project. One Greened Acre is equivalent to 1 inch of managed stormwater from 1 acre of drainage area, or 27,158 gallons of managed stormwater. These volumes will be tracked as GAs using the following equation:

$$GA = IC * Wd$$

IC is the impervious cover using GSI (acres). This quantity can include the area of the stormwater management feature itself, as well as the area that drains to it.

Wd is the depth of water over the impervious surface that can be physically stored in the facility (inches). GSI designs aim to control at least 1.0 inch of runoff, and up to 1.5 inches of runoff, unless otherwise deemed feasible by engineering design.

The COA states that each Evaluation and Adaptation Plan include the following components:

1. Performance tracking of the *Green City, Clean Waters* program using hydrologic and hydraulic models that have been validated with monitoring data, as described in Section 10 of the LTCPU and its supplements.
2. Up-to-date values for each of the metrics that appear in COA Table 1 of the Water Quality Requirements section of the NPDES permits, with detailed descriptions of how the reported values are estimated.

3. An assessment of how each metric's reported value compares to the WQBEL Performance Standards.

4. If any reported metric value does not equal or exceed the corresponding Performance Standard in Table 1 in the Water Quality section of the NPDES Permits, the City shall include in that Evaluation and Adaptation Plan an adaptive strategy for altering appropriate elements of program implementation. This strategy shall describe how the City proposes to ensure that the metric will meet the appropriate Performance Standard by the date of the next Evaluation and Adaptation Plan.

5. Up-to-date values for the following additional metrics:

    - Number of GSI projects used to calculate the total number of GA created;
    - Volume of stormwater (in million gallons per year) managed by new infrastructure, not including GSI; and
    - Volume of Percent Capture for the combined sewer system as a whole.

1.2 Adaptive Management Process

The *Green City, Clean Waters* program was predicated on an adaptive management backbone, described in the LTCPU and affirmed in the COA. An adaptive management approach requires flexibility and periodic program assessments throughout the program lifecycle. The *Green City, Clean Waters* program adaptive management structure has been formalized through the incorporation of Performance Standards via the WQBEL in the COA and assessments via EAPs at each five-year program benchmark. This structure allows for programmatic re-evaluation and/or revision on a regular basis to ensure achievement of WQBEL Performance Standards. PWD anticipates many 'within-program' adaptations and enhancements throughout each five-year implementation period to ensure that WQBEL goals are met, while optimizing and enhancing the program along the way. Large-scale programmatic shifts and course corrections would be proposed via the EAP development process at the end of a given five-year implementation period, or sooner if needed.

Achievement of the Performance Standards serves as the basis of program adaptation decision points. However, additional factors that may influence program adaptations may include implementation costs, emergence of new technologies, or changes in regulatory priorities, among other factors. PWD views the IAMP as the program framework that may be modified or enhanced over time, but will remain structurally intact, unless an adaptive management decision point necessitates a program change. Should this happen, an EAP would suggest a new program framework that would then remain intact through future EAPs, or until another adaptive management decision point necessitates further programmatic shift.

Paragraph 3e of the COA suggests that EAPs include, if needed, a description of the outcome of adaptive management decisions and changes in implementation approach for the ensuing five years. If PWD initiates a program shift, including a change in approach for meeting the milestones, documentation of the alternative approach to implementing GSI and/or targeted traditional infrastructure investments and/or changes in design approaches, must be included in the EAP submission.

1.3 Contents of the Plan

The contents of the EAP are organized into five sections as follows:

Section 1, Introduction, provides an introduction and overview of EAP contents.

Section 2, Program Evaluation, provides an evaluation of the program progress toward each WQBEL Performance Standard along with descriptions of how each value was determined.

Section 3, Assessment of Program Performance, documents the Assessment of Program Performance using monitoring data collected at the stormwater management practice level (in accordance with the Comprehensive Monitoring Plan) during the first five years of the program.

Section 4, Program Adaptations, provides a summary of Program Adaptations made to date to ensure achievement of the WQBEL Performance Standards.

Section 5, Strategy for Achievement of Year 10 WQBEL Performance Standards, documents a Strategy for Achievement of Year 10 WQBEL targets.

2.0 Program Evaluation

Within this section, the Philadelphia Water Department (PWD) documents progress toward each of the Water Quality Based Effluent Limit (WQBEL) Performance Standards (Table 2-1) and where appropriate, provides descriptions for how the values were calculated (Section 2.1-2.7). As of June 1, 2016, the City of Philadelphia has met or exceeded each of the Year 5 Performance Standards as required by the Consent Order and Agreement (COA).

Table 2-1: Up-to-Date WQBEL Values

Metric	Units	Base Line Value	First 5-Year WQBEL Target	Cumulative Amount as of Year 5 (2016)
NE WPCP Improvements	Percent Complete	0	See Section 2.1.1	
SE WPCP Improvements	Percent Complete	0	See Section 2.1.2	
SW WPCP Improvements	Percent Complete	0	See Section 2.1.3	
Miles of Interceptor Lined	Miles	0	2	7.5
Overflow Reduction Volume	Million Gallons Per Year	0	600	1,710
Equivalent Mass Capture (TSS)	Percent	62%	Report value	70.5%
Equivalent Mass Capture (BOD)	Percent	62%	Report value	88.9%
Equivalent Mass Capture (*Fecal Coliform*)	Percent	62%	Report value	72.0%
Total Greened Acres	Greened Acres	0	744	837.7

2.1 WPCP Design and Construction

Upgrades to increase wet weather treatment capacity at each of the City's Water Pollution Control Plants (WPCPs) were described in the Facility Concept Plans, formal deliverables of the COA, submitted to the United States Environmental Protection Agency (US EPA) and the Pennsylvania Department of Environmental Protection prior to June 1, 2013. A revised Northeast Water Pollution Control Plant Facility Concept Plan was submitted on December 31, 2013, and approved subsequently by the US EPA on January 28, 2015. The *Green City, Clean Waters Wet Weather Facility Plan* which supersedes the FCPs was submitted on June 1, 2016. To date, PWD has met or exceeded all June 1, 2016 commitments to WPCP and collection system improvements.

2.1.1 Northeast Water Pollution Control Plant

The following table represents progress during the first five years of the program within the Northeast WPCP (Table 2-2). For more detailed information, please see the *Green City, Clean Waters Wet Weather Facility Plan*.

Table 2-2: Status of Northeast WPCP Improvements

Northeast WPCP Improvements	June 1, 2016 Target Completion	Project Status
Facility Improvements		
Remove Double Deck Effluent Channel in Final Sedimentation Tanks Set-2	100%	Complete
New (4 x 48") conduits from Preliminary Treatment Building to Primary Sedimentation Tanks Set-1	100%	Complete
Secondary Treatment Bypass	50%	On Track
Gravity Sludge Thickeners	25%	On Track
Primary Treatment Building #2	0%	On Track
New Influent Baffles in Primary Sedimentation Tanks Set-2	0%	On Track
Operational Improvements		
Operate with minimal sludge blanket when Gravity Sludge Thickeners in service	0%	On Track

2.1.2 Southeast Water Pollution Control Plant

The following table represents progress during the first five years of the program within the Southeast WPCP (Table 2-3). For more detailed information, please see the *Green City, Clean Waters Wet Weather Facility Plan*.

Table 2-3: Status of Southeast WPCP Improvements

Southeast WPCP Improvements	June 1, 2016 Target Completion	Project Status
Facility Improvements		
Replace Influent Pump Station Coarse Bar Rack	100%	Complete

2.1.3 Southwest Water Pollution Control Plant

The following table represents progress during the first five years of the program within the Southwest WPCP (Table 2-4). For more detailed information, please see the *Green City, Clean Waters Wet Weather Facility Plan*.

Table 2-4: Status of Southwest WPCP Improvements

Southwest WPCP Improvements	June 1, 2016 Target Completion	Project Status
Facility Improvements		
Add Redundant Effluent Pump	0%	On Track

2.1.4 Philadelphia Collection System Improvements

The following table represents progress during the first five years of the program within the Collection System (Table 2-5). For more detailed information, please see the *Green City, Clean Waters Wet Weather Facility Plan*.

Table 2-5: Status of Collection System Improvements

Collection System Improvements	June 1, 2016 Target Completion	Project Status
Improvements		
NE Second 66” Frankford Grit Chamber Bypass In Service	100%	Complete
NE Frankford High Level Second Barrel Rehabilitation	100%	Complete
All Districts: Balancing CSO Regulator Wet Weather Capacities	Study - Ongoing	On Track

2.2 Miles of Interceptor Lined

The WQBEL Performance Standards require two miles of interceptor to be lined by the close of the first five years of the program. As of June 2016, PWD exceeded that target with 7.5 miles completed from five project segments (Table 2-6).

Table 2-6: Interceptor Lining Status by Segment

Project Name	Extents	Length (Miles)
60th and Cobbs Creek Parkway to 75th and Wheeler Sewer Lining	60th and Cobbs Creek Parkway to 75th and Wheeler	2.2
Cobbs Creek Park to 63rd and Market Sewer Lining	Cobbs Creek Park to 63rd and Market	0.5
Cobbs Creek Interceptor Phase 1 Lining	63rd and Market to 62nd and Baltimore	1.6
Tacony Creek Intercepting Sewer Lining Phase 1	Chew & Rising Sun to I & Ramona	1.9
Tacony Creek Intercepting Sewer Lining Phase 2	2nd St & 64th Ave to Chew & Rising Sun; Drainage Right of Way Mascher to Tacony Interceptor; Cheltenham Ave to Crescentville & Godfrey	1.3
Total		**7.5**

2.3 Overflow Volume Reduction

PWD has exceeded the Overflow Volume Reduction Performance Standard of 600 Million Gallons (MG). As of June 1, 2016, the City's Combined Sewer Overflow (CSO) volume has been reduced by 1,710MG from the baseline based on the COA documented typical year precipitation pattern.

2.3.1 Volume Attributed to New Infrastructure other than GSI

The COA requires that PWD assess the benefit of "new infrastructure other than Green Stormwater Infrastructure (GSI)" in the Evaluation and Adaptation Plan (EAP). Two new capital projects have been completed since this baseline date: Indian Creek Daylighting In-line Storage and D44 Regulating Chamber Reconstruction. Simulations were performed with and without the new infrastructure in place, and the system-wide overflow volume was compared. The overflow volume reduction attributable to "new infrastructure other than GSI" is 7 million gallons per year. In addition to the two new capital projects, collection system improvements have been realized as part of routine maintenance and repair.

C05: Indian Creek Daylighting In-System Storage

The project is located in the Cobbs Creek Watershed at the confluence of the East Branch Indian Creek and the West Branch Indian Creek. Before 2013, regulator C05 discharged into the West Branch Indian Creek, and through a culvert before merging with the East Branch Indian Creek to form the mainstem of Indian Creek. The completed Indian Creek Daylighting project diverts the West Branch Indian Creek and restores the surrounding stream channel, and a new regulating structure was constructed near the confluence of the two creeks to control combined sewer overflow.

Approximately 700 feet of 6' x 6' pipe provides storage and conveyance to combined sewer flow from regulator C05 to a new regulating structure. The new regulating structure is set up to maximize the in-line storage during wet weather conditions, and to release stored flow when capacity is available in the collection system. Reduction of CSO is achieved through this in-system storage.

D44 Regulating Chamber Reconstruction

CSO outfall D44 is located along Delaware River by the Sugarhouse Casino in PWD's Southeast Drainage District (SEDD). In 2011, casino expansion required the relocation of the D44 regulating structure and its associated outfall pipe. The regulating chamber relocation was completed in 2015. The new regulating chamber expanded the dry weather outlet pipe connecting to the interceptor, with improved storm relief capacity and controlled CSO.

Additional Collection System Improvements

In addition to the two new capital projects completed since 2011, collection system improvements have been realized as part of routine maintenance and repair, and reflect the City's ongoing commitment to implementation of the Nine Minimum Controls (NMC). In particular, three projects have been completed since 2010-2011 with the goal to maximize flow delivery to the WPCPs (NMC 4): T14 In-System Storage and Northeast High Level – Second Barrel Rehab.

Rock Run Relief Real-Time-Control In-System Storage

The Rock Run Relief Sewer provides flood relief to combined sewersheds in PWD's Northeast Drainage District (NEDD). The Rock Run Relief structure, R15, is a side overflow weir which diverts wet weather flows into the Rock Run Relief Sewer at R15 once flow levels exceed the diversion weir height. This project utilizes approximately 2.3 MG of the Rock Run relief sewer (which is 11 feet in diameter) for storage of combined sewer flows through an inflatable dam in the outfall pipe along with a connector pipe to the Tacony interceptor and control gate to drain the flow for treatment at the NE WPCP as capacity becomes available. The inflatable dam height is controlled to maximize the in-system storage.

T14 Real-Time-Control In-System Storage

CSO outfall T14 is a very large sewer (21' x 24') that discharges into the Tacony Creek during periods of moderate to heavier rainfall, and is located in the NEDD. The T14 combined trunk sewer has a volume of approximately 10 million gallons upstream of the regulator chamber. A crest gate was installed in order to retain flow within the sewer, which reduces CSO discharges to the creek by using the sewer for in-system storage. This control technology provides an additional margin of protection against wet weather discharges while maintaining flood protection for upstream communities. The crest gate retains the stored flow in the sewer and a connector pipe and control gates drain the stored flow for treatment at the NE WPCP as capacity in the interceptor becomes available.

Northeast High Level – Second Barrel Rehab

The Frankford High Level (FHL) interceptor in the City's NEDD begins at the Frankford Grit Overflow Chamber (R_18) located near Hunting Park and Castor Avenues. From here, the FHL interceptor conveys flow to the O Street and Erie Avenue Diversion Chamber (H_22), where flows split into parallel sewers. The FHL second barrel refers to the 78" diameter sewer, which was designed to convey flow in conjunction with the existing sewer to NE WPCP. In May of 2016 the 78" barrel was placed in to service, after rehabbed to allow the conduit to flow under pressurized conditions to increase flow to the plant.

2.3.2 Volume Reduction Calculation Method

The CSO volume reduction calculation methodology is well documented in the Long Term Control Plan Update (LTCPU) "Supplemental Volume 4: Hydraulic and Hydrologic Modeling" and the COA "Supplemental Document #1: PWD System-wide Combined Sewer Overflow Volume Summary." This section describes the updates to hydrologic and hydraulic models since the 2009 LTCPU. The models used for evaluation of the Year 5 EAP have had modifications made, though not significantly, from the ones used to evaluate alternatives for the LTCPU.

One of the notable changes is the use of a new software version for the model simulations [US EPA SWMM (Storm Water Management Model) 5]. SWMM5 is completely re-written in *C,* unlike the previous versions of SWMM which were written in *FORTRAN*. Compared to SWMM4, SWMM5 has no limits on the number of elements that can be simulated; SWMM5 also improves representation of hydraulic controls like orifices and weirs. SWMM5 has the ability to use variable time steps for simulations, and to lengthen short pipes that may cause mathematical solution convergence issues. These improvements, along with an improved solution technique, make the simulations more robust. A significant amount of effort was spent to get the model input formats converted so as to use the SWMM5 simulation engine. Model results generated in SWMM5 were demonstrated to match results of SWMM4 models.

For the model simulations at year 5, in addition to updating the model inputs related to GSI, the models also include operational changes to better use the collector system and new infrastructure added to the system since adoption of the COA. The changes in the model are integrated; separating the benefits that can be purely attributed to individual changes is difficult and in some cases not possible.

Green Stormwater Infrastructure Model Representation

For model simulations, the amount of impervious area that is tributary to GSI is determined based on evaluating and summarizing the 441 completed stormwater management projects (837.7 Greened Acres).

The GSI modeling approach described in the LTCPU "Supplemental Documentation Volume 4: Hydrologic and Hydraulic Modeling" is applied for the Year 5 EAP simulations, with minor refinement to account for the performance of GSI that has been built.

Additionally, for the Year 5 EAP simulations, element sizing is based on construction drawings reviews and summary, which represents an update and improvement to the former approach that determined element sizing of GSI based on the *City of Philadelphia Stormwater Regulations*. Based on evaluation of the completed individual projects, it was decided that the GSI can be divided into the following two broad categories to better represent the GSI performance:

1. GSI that only have an overflow element but do not have a bottom outlet. The runoff volume is controlled by infiltration only.
2. GSI that has both an overflow and a bottom outlet. The runoff volume is controlled by a combination of infiltration and reduced release rate from the bottom outlet.

For both types of control structures, the model methodology that is described in the LTCPU "Supplemental Documentation Volume 4: Hydrologic and Hydraulic Modeling" (Section 4.3.4) is used and the inputs to the model come from the design summaries of the constructed GSI projects.

Model Validation Progress

Since the submission of the 2009 LTCPU, more than 150 temporary flow monitors have been deployed for a period of six months or more in the area contributing to the Combined Sewer System (CSS). Similarly, 98 more temporary flow monitors have been deployed for more than six months in the area served by separate sanitary sewer systems. Data from these additional deployments is being put through a rigorous quality assurance procedure and, once complete, this data will be used to validate the models. An updated model that includes the modifications informed by the increased monitoring data may be available in the coming year. PWD anticipates that the models will be continually validated.

2.4 Equivalent Mass Capture (TSS)

The COA does not include a WQBEL Performance Standard for Equivalent Mass Capture until year 25 of the implementation program. For the interim EAP reporting terms, PWD must report an Equivalent Mass Capture value for each 5-year period. Table 2-7 includes the Effective Mass Capture for each of the three required parameters in the COA as of June 1, 2016.

Table 2-7: Year 5 Equivalent Mass Capture

	2011 Baseline "Equivalent Mass Capture"	Year 5 (2016) "Equivalent Mass Capture"*
TSS	62%	70.5%
BOD_5	62%	88.5%
Fecal coliform	62%	72.0%
Percent (Volume) Capture	62%	66.6%

The Equivalent Mass Capture percentage calculation is based on establishing a relationship between CSO volume reduction, percent (volume) capture, and mass load reduction that would have occurred assuming primary clarification and disinfection as the end-of-pipe treatment technology. Using the method described in "COA Supplemental Document #2: Mass Loading Presumptive Approach," PWD ran the simulation with inputs based on Year 5 progress (including 837.7 Greened Acres and collection system improvements to date) and estimated the pollutant loads.

Pollutant load is the sum of:

- Component of CSO volume derived from sewer baseflow (sanitary sewage and groundwater inflow) x baseflow concentration,
- Component of CSO volume derived from surface runoff not treated by GSI x untreated runoff concentration, and
- Component of CSO volume derived from runoff treated by GSI (if any) x GSI-treated stormwater concentration.

PWD calculates Equivalent Mass Capture by matching the load reduction to the percent (volume) capture that would have produced that same load if primary clarification and disinfection were the end-of-pipe treatment technology.

2.5 Volume Percent Capture for Combined Sewer System

As the result of the collective implementation initiatives, including GSI, collection system improvements and enhancements, system-wide volume percent capture has increased to 66.6% from baseline.

The Year 5 achieved percent capture was assessed by hydrologic and hydraulic modeling, and by applying the volume capture methodology as documented in COA Appendix E, "Document #1 – Technical Memorandum: PWD System-wide Combined Sewer Overflow Volume Summary."

2.6 Greened Acres

PWD has exceeded its Year 5 Greened Acre WQBEL Performance Standard of 744 Greened Acres (GAs). As of June 1, 2016 PWD has attained 837.7 GAs, derived from 441 stormwater management projects. For a complete summary of all projects, please refer to the project list in Appendix A. Greened Acres were accrued from three separate implementation approaches: (Re)Development Regulations, Public Investment, and Incentivized Retrofits. Each implementation approach uses a unique project delivery model, with differences in project initiation, management, funding, and ownership. This diversity in project implementation mechanisms has produced a system-wide geographic distribution of GAs with a large variety of stormwater management practice (SMP) types represented.

2.6.1 Greened Acre Program Summary

The City of Philadelphia has been accruing Greened Acres through three public and private implementation approaches:

- **(Re)Development Regulations:** stormwater management on new and redevelopment projects required for compliance with the City of Philadelphia's Stormwater Management Regulations;
- **Public Investment:** GSI projects implemented on public property, primarily in the public right-of-way (including GSI completed in conjunction with water/sewer projects) and parks, where stormwater infrastructure is the primary purpose of the project and is initiated, funded, designed, constructed, inspected, and maintained by PWD or one of its partners; and
- **Incentivized Retrofits:** Retrofits of non-City-owned property to manage stormwater from impervious surfaces to achieve stormwater billing credits. These may be supported by funding from the Stormwater Management Incentives Program (SMIP) or the Greened Acre Retrofit Program (GARP) grants.

(Re)Development Regulations

Philadelphia's GSI implementation program is led by the City's Stormwater Management Regulations for new and redevelopment, hereafter called (Re)Development. PWD requires stormwater management for land development projects in the City of Philadelphia with more than 15,000 square feet of earth disturbance. Projects must submit plans for conceptual review to pursue a Zoning Permit, while the submission of detailed stormwater management plans must receive a technical review and approval prior to obtaining a Building Permit. PWD inspects stormwater management systems during construction and requires the submission of As-Built documentation and an operation and maintenance agreement. PWD periodically performs post-construction inspections to confirm compliance with the operation and maintenance agreement. By the close of Year 5, (Re)Development provided 423 GAs from 266 projects toward the City's compliance with the WQBEL Performance Standard (Figure 2-1).

The City's Stormwater Management Regulations forms the backbone of the GA commitment in the WQBEL Performance Standard. *The City of Philadelphia Stormwater Regulations* enable the City to allow land development projects to be realized throughout the City while public investments can be distributed to areas not touched by development. The City's vision is that allowing regulated development projects to lead the implementation process will enable the City to achieve equitable distribution of GSI across the CSS.

Public Investment

Public Investment projects are initiated, funded, designed, constructed, inspected, and maintained by PWD or one of its partners. These projects are often constructed in the public right-of-way, but are also installed on publicly owned properties. PWD has worked with City agencies, including Philadelphia Parks & Recreation, the Department of Public Property, and the Streets Department, among others, to thoughtfully integrate stormwater management practices onto public property. Additionally, when possible, water and sewer infrastructure constructed by PWD is coupled with GSI at or near the street surface. Public investments produced 179 GAs from 137 projects during the first five years of the program (Figure 2-2).

Incentivized Retrofits

Incentivized Retrofit projects are the result of proactive self-funded projects and PWD-sponsored incentives, including the SMIP and GARP grants aimed at retrofitting private properties to manage stormwater to achieve a credit on the stormwater portion of their bill. Both the SMIP and GARP grant-funded program tools are new since the submission of the IAMP in 2011 and are valuable Public-Private Partnerships for cost-effectively meeting program goals. For all PWD grant-funded projects, PWD reviews and approves designs, conducts inspections during construction, and requires the submission of As-Built documentation and an operation and maintenance agreement. PWD periodically performs post-construction inspections to confirm compliance with the operation and maintenance agreement. Incentivized retrofits delivered 234 GAs from 38 projects during the first five years of the program (Figure 2-3).

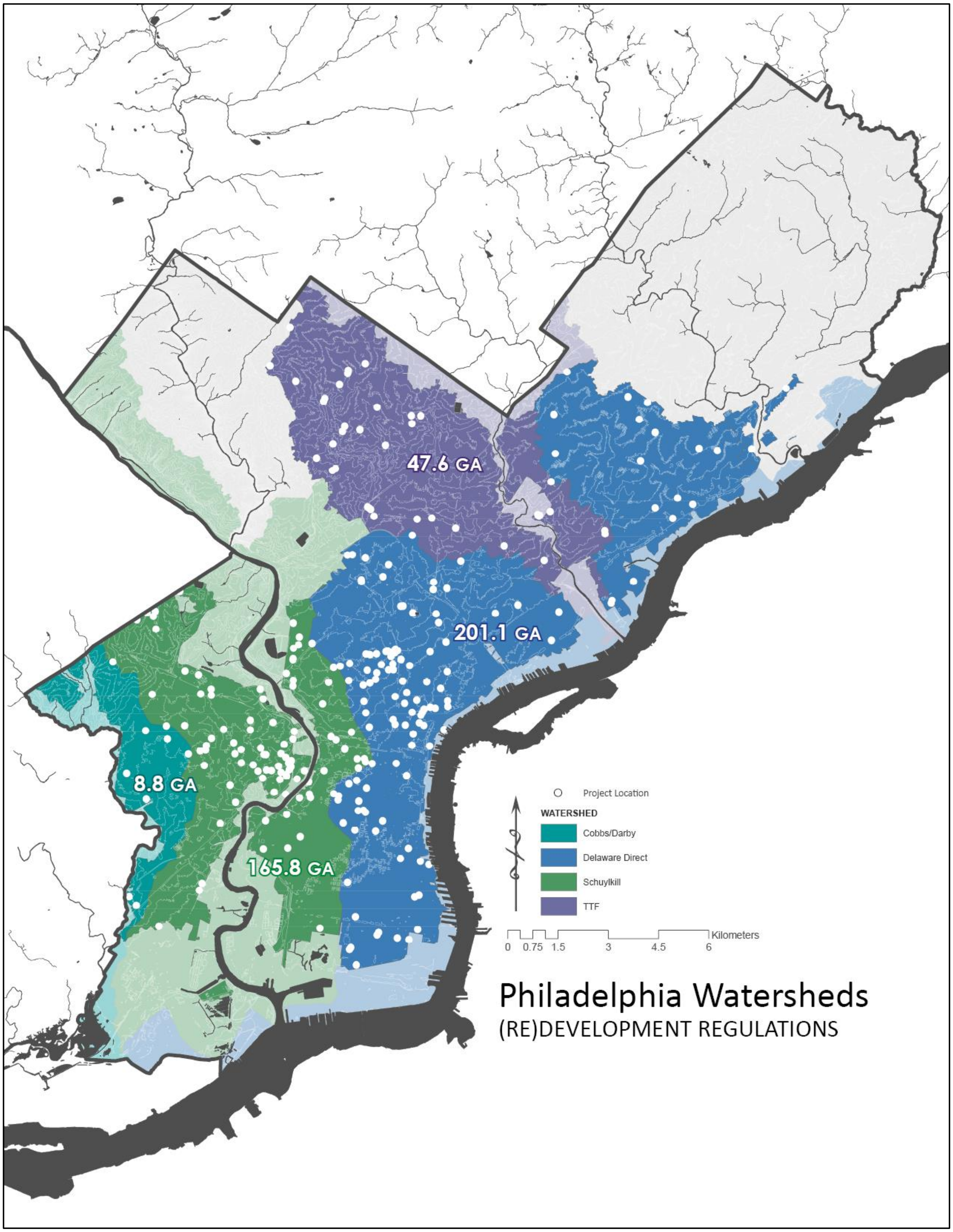

Figure 2-1: (Re)Development Regulation Projects

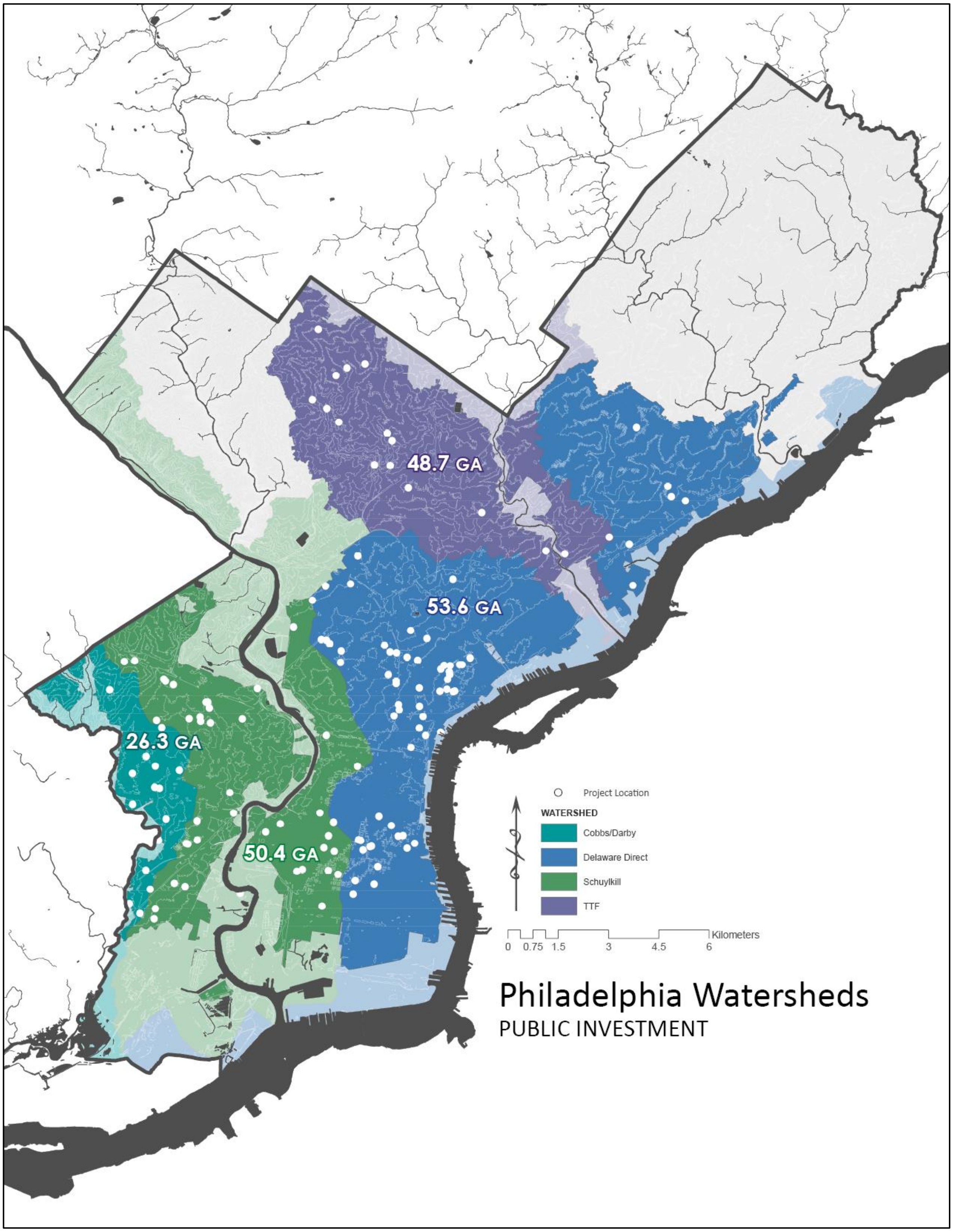

Figure 2-2: Public Investment Projects Completed during the First Five Years of the Program

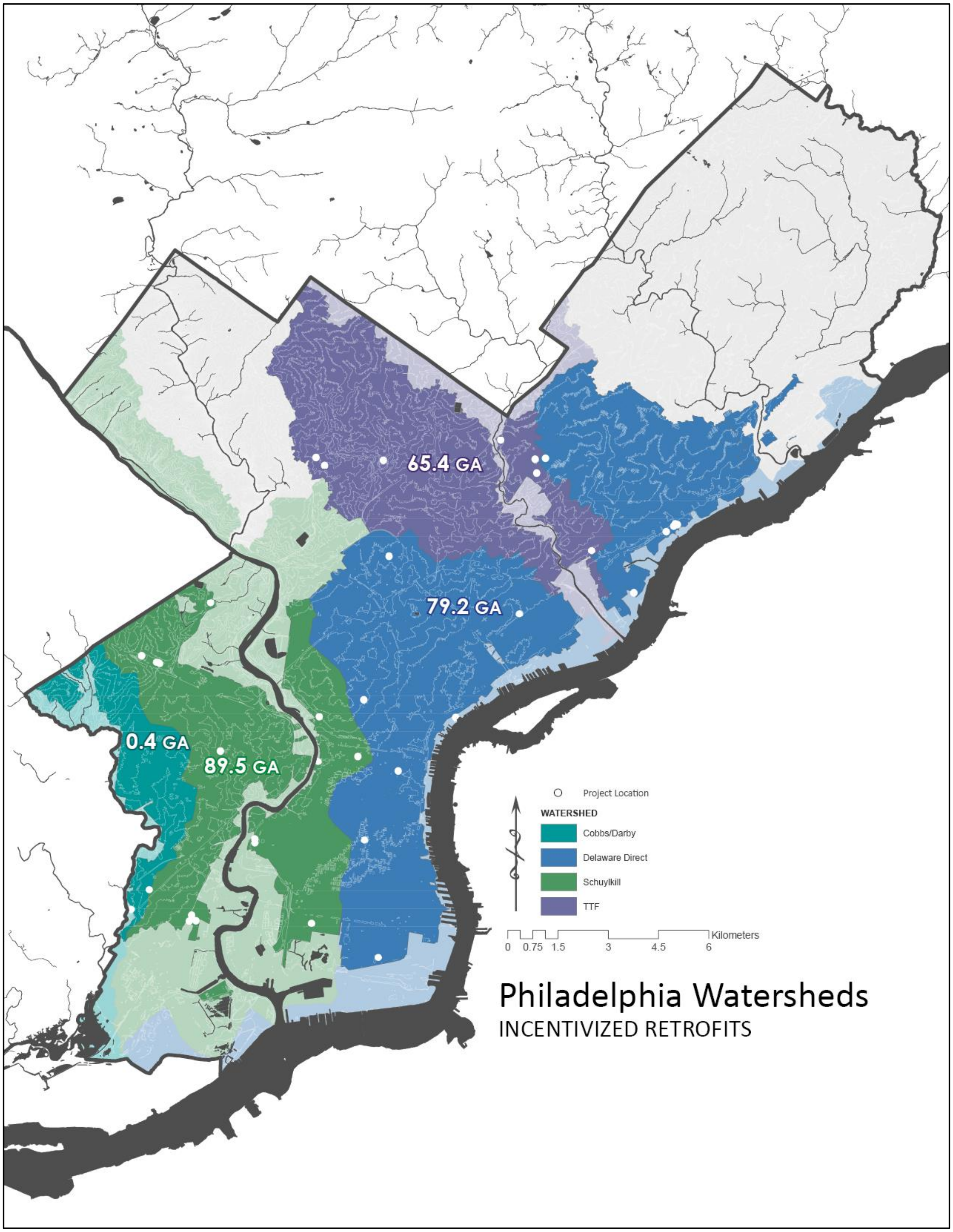

Figure 2-3: Incentivized Retrofit Projects Completed during the First Five Years of the Program

2.6.2 Scale of Implementation

Assessing program progress solely by viewing WQBEL Performance Standards can minimize the impact of implementation across the City during the past five years. Philadelphia is a different city than it was in 2011, as public and private spaces have been transformed physically through the integration of GSI across the landscape. The program success at Year 5 is the product of a multi-pronged implementation approach that allows for new and redevelopment and incentives to access dense residential, commercial, and industrial areas of the City, while allowing PWD to focus public investments on public spaces (Figure 2-4). Leading with private investment allows PWD to target public investments to provide more equitable access to GSI and associated benefits.

PWD regularly updates its "Big Green Map" web interface illustrating the depth and breadth of program implementation to keep residents and partners informed about progress of both completed and upcoming planned projects. The Big Green Map is an interactive, online map that shows GSI at both public and private sites and the individual GSI systems found across the City. It shares information about upcoming projects in design, describes the different GSI tools and includes information about programs not used currently for regulatory reporting, including Rain Check and rain barrel installations. For more information visit http://www.phillywatersheds.org/BigGreenMap.

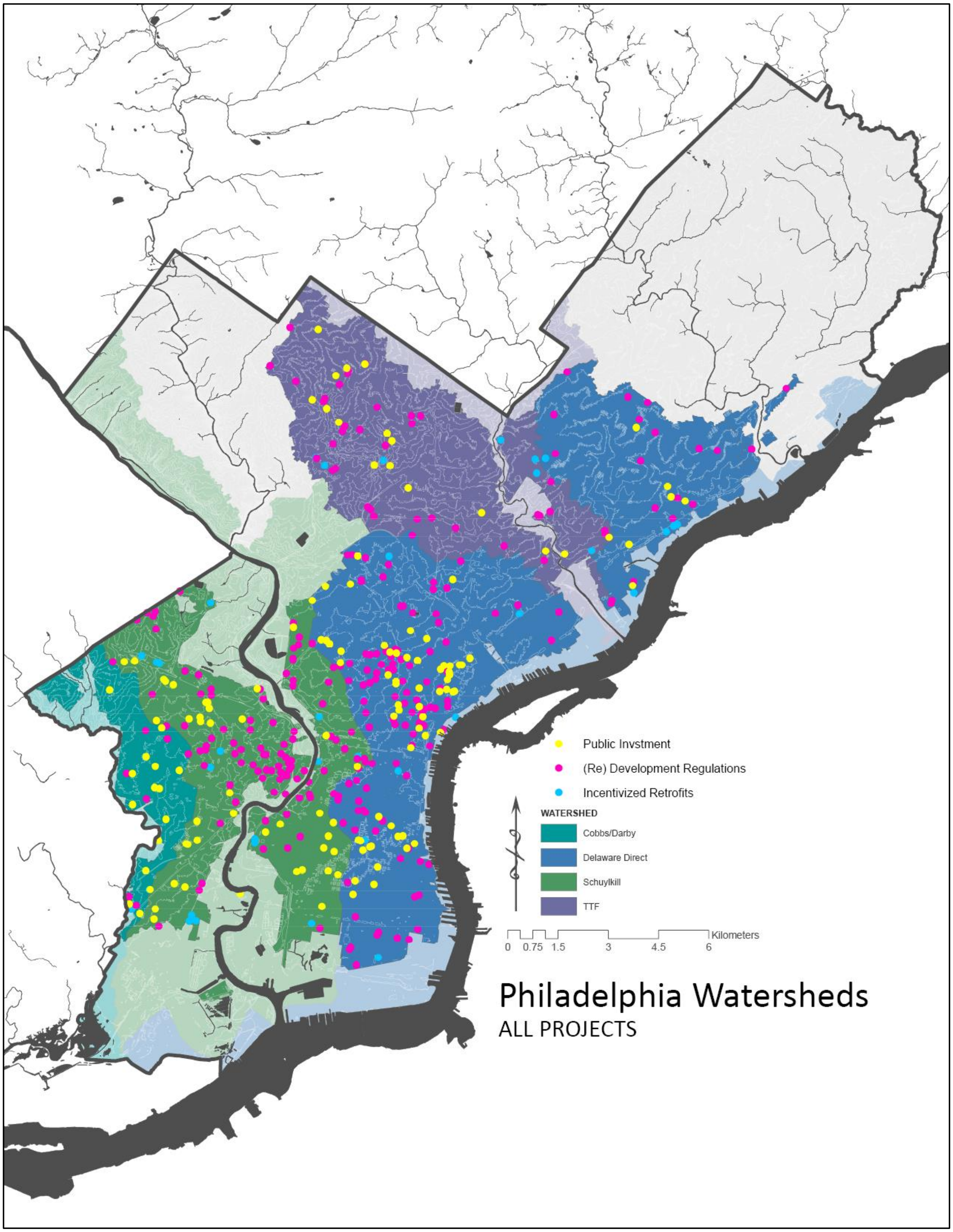

Figure 2-4: Combined Program Distribution of GSI across the CSS during the First Five Years of the Program

2.6.3 Geographic Distribution by Watershed for the Evaluation and Adaptation Plan

At the close of the first five years of the program, PWD examined the distribution of GAs by implementation source (Public Investment, (Re)Development Regulations, and Incentivized Retrofits) and by watershed (Table 2-8). Most of the acreage managed by the City's *Stormwater Regulations* during the first five years has been concentrated in and around Center City; therefore, the Delaware and Schuylkill Watersheds have received the most GAs during this time. However, the public investment in the Darby-Cobbs outweighs the private investment and in the Tookany/Tacony-Frankford (TTF) watershed it is equal.

Table 2-8: Greened Acres by Watershed

Watershed	Total Impervious Area Draining to CSS (Acres)	Public GSI (GAs)	(Re)Development Regulations (GAs)	Incentivized GSI (GAs)	Total GAs
Darby-Cobbs	5,540	26	8.8	0.4	36
Delaware Direct	20,352	54	201	79	334
Schuylkill River	18,160	50	166	89	306
Tookany/Tacony-Frankford Creek	11,715	49	48	65	162
Total Acreage (Year 5)	**55,767**	**179**	**423**	**235**	**837**

To get a sense of programmatic GA distribution during this first 5-year period, PWD evaluated the distribution of public Greened Acre investments by watershed, the distribution of total acres from all implementation sources among the four CSO watersheds, and the area weighted average, which accounts for both the size of the CSO drainage area in each watershed and average depth managed (Table 2-9). The area weighted distribution represents an evaluation of acreage managed within a watershed compared to the total impervious acreage within that watershed. Results indicate that the distribution of public investments is fairly even as compared with investments in the other two programs where investments are driven by a host of other economic factors. In fact, the area-weighted public investment in the Darby-Cobbs is the highest at 0.34%, followed by the TTF at 0.27%.

Table 2-9: Programmatic Distribution and Area Weighted Distribution of Greened Acres by Watershed

	Public Investment			Total Program Greening		
Watershed	GAs	Programmatic Distribution	Area Weighted Programmatic Distribution	GAs	Programmatic Distribution	Area Weighted Programmatic Distribution
Darby-Cobbs	26	15%	0.34%	36	4%	0.49%
Delaware Direct	54	30%	0.17%	334	40%	1.26%
Schuylkill River	50	28%	0.19%	306	37%	1.29%
Tookany/Tacony-Frankford Creek	49	27%	0.29%	162	19%	1.06%

2.7 Greened Acre Calculation Methods

A Greened Acre is a metric to describe the volume of stormwater, in acre-inches, managed by GSI. It is equivalent to the product of the acres of directly connected impervious drainage area and the inches of runoff captured over that area.

$$GA = IC * Wd$$

Where:

IC is the impervious cover utilizing green stormwater infrastructure (acres). This quantity can include the area of the stormwater management feature itself, as well as the area that drains to it.

Wd is the depth of water over the impervious surface that can be physically managed in the facility (inches).

As stated in the COA, GSI designs aim to control at least 1.0 inch of runoff, and up to 1.5 inches of runoff, unless otherwise deemed feasible by engineering design. Based on Philadelphia's hydrology and infiltration performance, a maximum runoff depth of 2.0 inches is deemed appropriate for Greened Acres. Because rainfall events exceeding that depth are infrequent in a typical year, PWD has capped runoff depth at 2.0 inches.

To determine the depth of runoff captured, the available static storage volume is calculated by analyzing post-construction stormwater management plans. Available static storage is the volume of void space between the top of storage elevation and bottom of storage elevation. The volume of void space is dependent on the porosity of the storage media present. Present assumptions for typical storage media are as follows: 40% for gravel, 30% for sand, 20% for soil, 92% for perforated pipes, and 100% for tanks and solid storage pipes. For proprietary structures, the porosity is as defined by the manufacturer.

Static storage volume calculation methods can vary slightly, depending on the design of the system. The volume is converted from cubic feet to inches of runoff, which is then used in the Greened Acre equation.

Storage volume can be managed in one of three ways: infiltration, slow release, or in the case of green roofs, evapotranspiration. Infiltration volume is the static storage below the lowest outlet point to the combined sewer. The top of storage is the elevation of an orifice invert, weir, grate, or riser, below which all water will infiltrate into the surrounding soils. Slow release volume is the static storage volume above an orifice, with the top of storage equal to the head that produces the peak allowable release rate, in cubic feet per second per acre of impervious drainage area, or the elevation of an overflow outlet such as a weir or larger orifice.

Public GSI systems are designed with enough storage for the water quality volume only, between 1.0 and 2.0 inches of runoff. Any runoff that exceeds the static storage volume is designed to bypass the system and drain directly to the combined sewer. Private GSI systems are sometimes subject to requirements related to flooding and public, such as channel protection and flood control. Most systems have additional storage above the water quality volume that releases at higher rates to manage runoff events that exceed the water quality volume. Regardless of the additional storage, the Greened Acre credit is only applied to the water quality volume.

(Re)Development Systems Storage Volume (Stormwater Management Regulations and Incentivized Retrofits)

Storage volume calculations for (Re)Development systems varies by SMP type. This section provides descriptions of the storage volume for the following private SMP types: subsurface slow release, subsurface infiltration, bioretention, bioinfiltration, permeable pavement, green roof, cistern/rain barrel, disconnected impervious cover, and direct discharge.

Subsurface Slow Release

For subsurface slow release systems, the top of storage is defined as the overflow elevation or the head that produces the peak allowable release rate, whichever is lower. The release rate is controlled by an outlet control structure, consisting of a low-flow orifice and one or more overflow outlets, such as larger orifices or weirs. Storage volume of subsurface slow release systems is held in a concrete tank or a combination of gravel, pipes, and other storage structures (Figure 2-5).

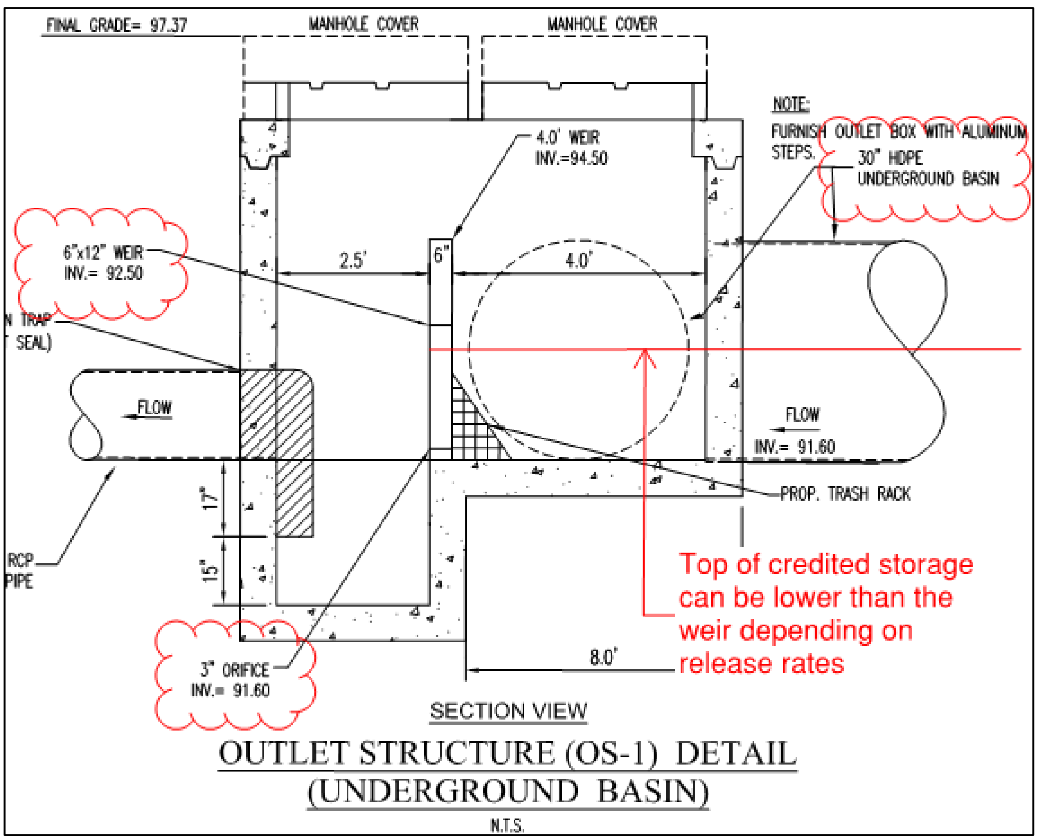

Figure 2-5: Typical Outlet Control Structure Configuration of a Subsurface Slow Release System

Subsurface Infiltration

The top of storage for a subsurface infiltration system is the overflow elevation, controlled by a weir or orifice in an outlet control structure above the bottom of storage. Storage volume is held in a combination of gravel, pipes, and other storage structures (Figure 2-6).

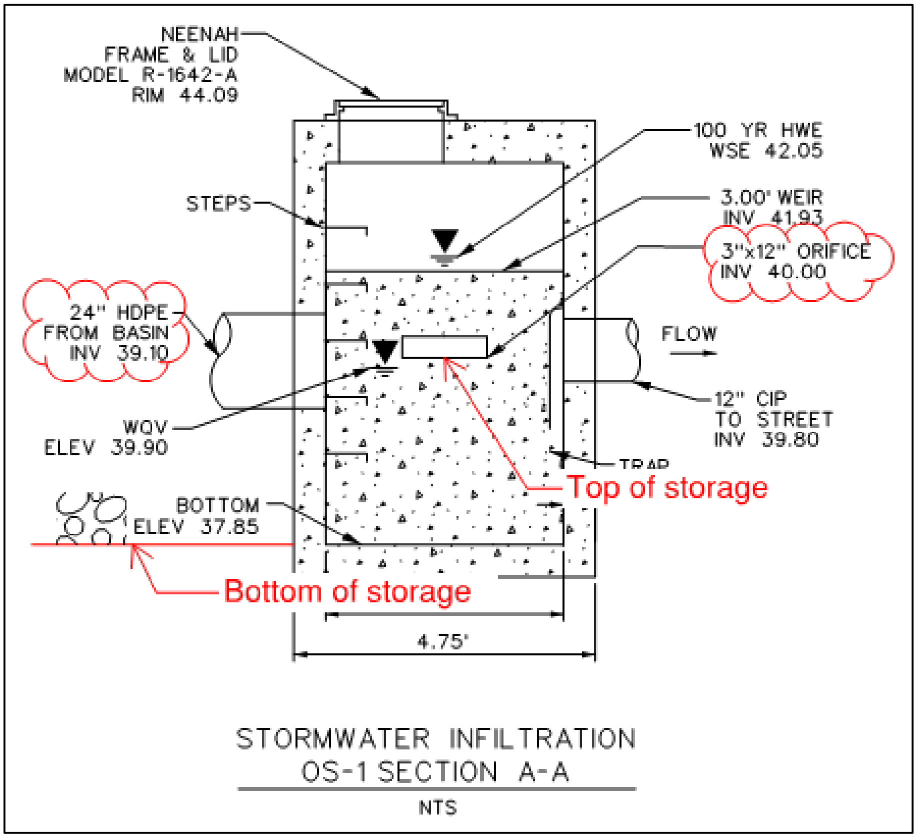

Figure 2-6: Typical Outlet Control Structure Configuration of a Subsurface Infiltration System, with Orifice Raised above the Bottom of Storage

Bioretention

In a bioretention system, the top of storage is the head at the peak allowable release rate or the overflow elevation controlled by a riser above the basin surface. The release rate is controlled by either an orifice or by the soil media itself. The storage volume is typically a combination of surface ponding, bioretention soil, and occasionally gravel (Figure 2-7).

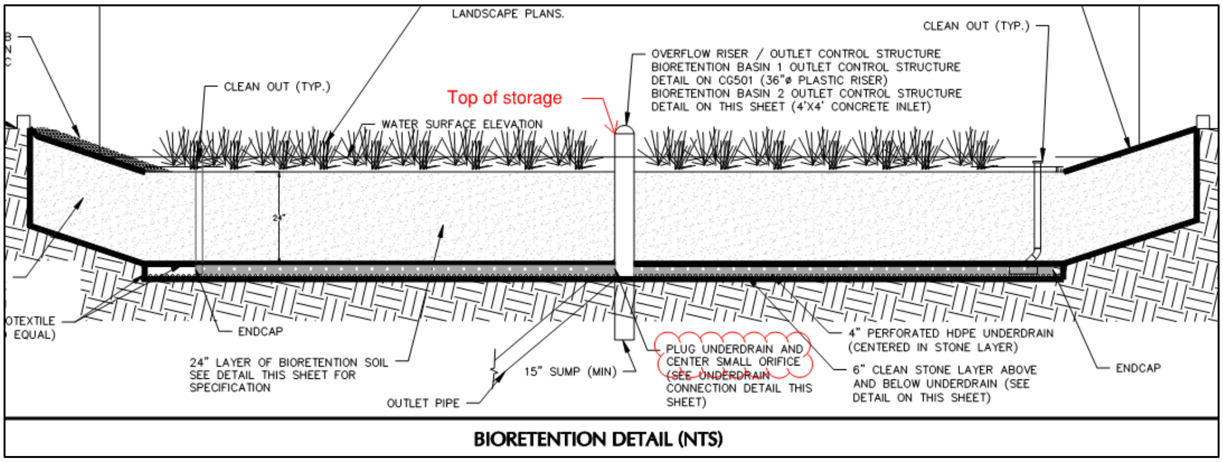

Figure 2-7: Typical Cross Section of a Bioretention Basin, with Underdrain and Orifice to Control Release Rate

Bioinfiltration

For bioinfiltration systems, the top of storage is the overflow elevation. The storage is controlled by a raised inlet, riser, or spillway above the soil surface elevation. The storage volume of a bioinfiltration system is typically a combination of surface ponding, soil, and occasionally gravel (Figure 2-8).

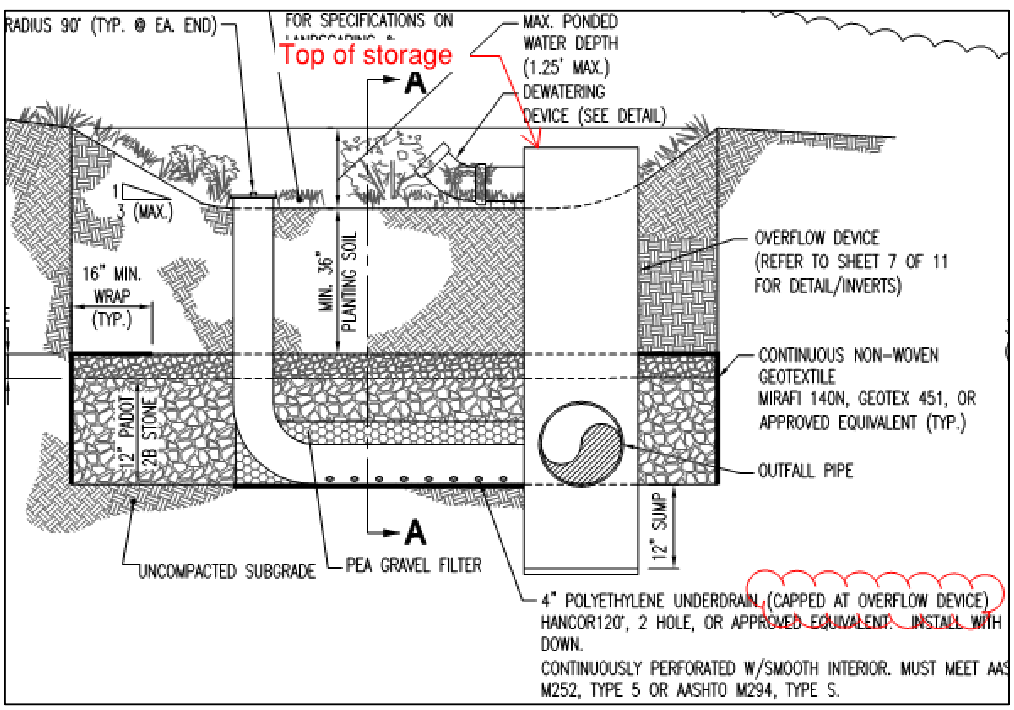

Figure 2-8: Typical Cross Section of a Bioinfiltration Basin, with Capped Underdrain

Permeable Pavement

The storage volume of permeable pavement systems is defined by the depth of gravel media below the pavement surface, which typically exceeds the volume equivalent to 2" of runoff (Figure 2-9).

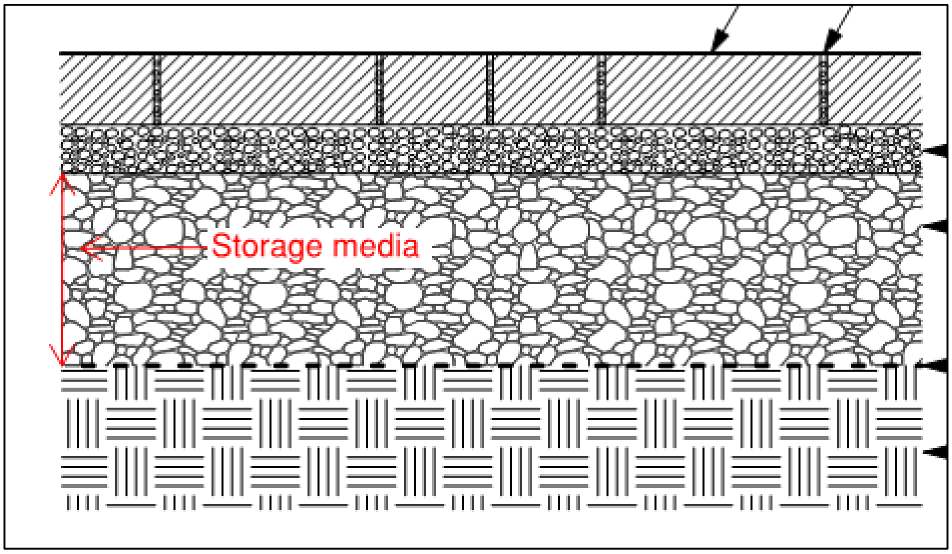

Figure 2-9: Typical Permeable Pavement Cross Section

Green Roof

For a green roof system, the storage volume is defined by the depth of the planting media, with an assumed porosity of 20% (Figure 2-10).

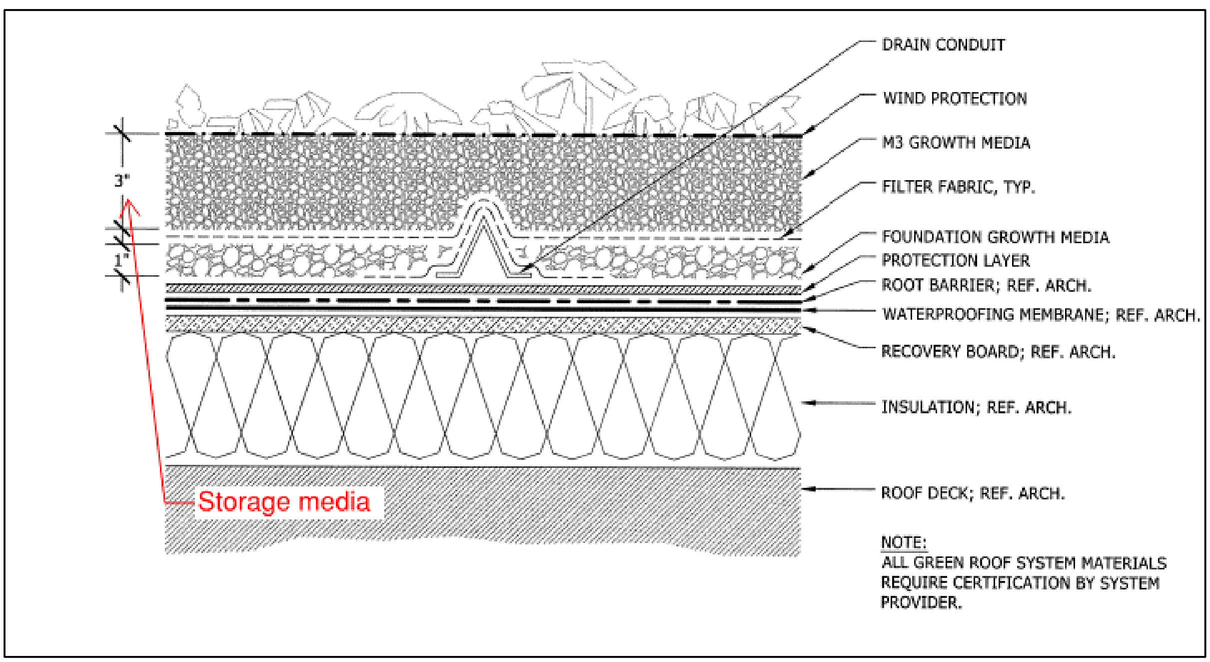

Figure 2-10: Typical Green Roof Cross Section

Cistern/Rain Barrels

In both cistern and rain barrel systems, the storage volume is the maximum volume that the cistern can hold, so long as there is supporting documentation to show that the cistern has year-round demand to drain within 72 hours so that the volume is available for subsequent rainfall events.

Disconnected Impervious Cover

Disconnected impervious cover is impervious area that drains onto a pervious area with a similar flow path, such as paved walkways in a park that drain onto the surrounding grass. A one-to-one credit is applied to this area, such that one acre of disconnected impervious cover equals one Greened Acre.

Direct Discharge

Direct discharge is the impervious area that was previously directly connected to the combined sewer, where post-construction runoff is then drained through pollutant-reducing practices and released directly to the receiving waters. Because all runoff from this area is removed from the combined sewer, the full 2.0" of credit is given for the Greened Acre calculation.

Public Systems Storage Volume

Storage volume for public systems differs from private systems because the total storage volume is designed to be less than the equivalent of 2.0" of runoff over the impervious drainage area. When the storage in the system is full, additional runoff will bypass the system to the combined sewer. If slow release is required, orifices are designed to discharge at the peak allowable release rate when the system is full. Public systems can consist of permeable pavement, subsurface systems, bioretention/bioinfiltration systems, and a combination of both subsurface and bioretention/bioinfiltration SMPs (Table 2-10). The storage volume used in the Greened Acre calculation is the total volume in all hydraulically connected SMPs.

Table 2-10: Public SMP Type Definitions

Public SMP Type Definitions	
Field/Metric	**Definition/Purpose**
Basin	A stormwater basin is a basin or depression that is vegetated with mowed grass. It is designed to detain and release stormwater runoff and/or infiltrate where feasible.
Blue Roof	A blue roof is a storage system designed into a roof surface such that the roof retains stormwater. Blue roofs are designed to reduce the rate of stormwater runoff.
Bump-out	A stormwater bump-out is a vegetated curb extension that intercepts gutter flow. It is designed to detain and release stormwater runoff and/or infiltrate where feasible.

Public SMP Type Definitions	
Field/Metric	**Definition/Purpose**
Cistern/Rain Barrel	A cistern/rain barrel is a tank or storage receptacle that captures and stores runoff and can thereby reduce runoff volume. The stored water may be used to serve a variety of non-potable water needs (e.g., irrigation).
Depaving	Depaving projects remove existing impervious pavement and restore the surface with grass, other types of vegetation, or loose materials (stone, mulch, etc.) such that the area can thereafter be considered pervious area. Depaving projects remove contributing impervious area from the sewer system.
Drainage Well	A stormwater drainage well is a manhole structure designed to manage stormwater runoff by receiving stormwater from upstream collection and pretreatment systems and then discharging the stormwater into the surrounding soils through perforations in the manhole. It is designed to infiltrate stormwater.
Green Gutter	A green gutter is a narrow and shallow landscaped strip along a street's curb line. It is designed to manage stormwater runoff by placing the top of the planting media in the green gutter lower that the street's gutter elevation allowing stormwater runoff from both the street and sidewalk to flow directly into the green gutter. It is designed to slow and infiltrate stormwater.
Green Roof	A green roof is a vegetated surface installed over a roof surface.
Infiltration Column	An infiltration column is a stone column that extends below the bottom of the surrounding GSI system in order to promote infiltration in more permeable sub-grades that exist at greater depths.
Infiltration/Storage Trench	An infiltration/storage trench is a subsurface structure designed to detain and release stormwater runoff and/or infiltrate where feasible.
Non-SMP Tree	A non-SMP tree is a planted tree that does not have stormwater directed to it.
Pervious Paving	Pervious paving is a hard permeable surface commonly composed of concrete, asphalt or pavers. It is designed to detain and release stormwater runoff and/or infiltrate where feasible.
Planter	A stormwater planter is a structure filled with soil media and planted with vegetation or trees. It is designed to detain and release stormwater runoff and/or infiltrate where feasible. Planters often contain curb edging or fencing as barrier protection around the planter.
Rain Garden	A rain garden is a shallow vegetated area designed to detain and release stormwater runoff and/or infiltrate where feasible. Rain gardens may also be referred to as bioinfiltration basins and bioretention basins. They are typically integrated into landscape features (e.g. median strips) and are non-mowed areas.

Public SMP Type Definitions	
Field/Metric	**Definition/Purpose**
Stormwater Tree	A stormwater tree is planted in a specialized tree pit that has stormwater runoff directed to its pit. It is designed to manage stormwater by placing the top of the planting media in a tree pit lower than the street's gutter elevation and connecting the tree pit to an inlet which directs runoff from the street into the tree pit. It is designed to detain and release stormwater runoff and/or infiltrate where feasible.
Swale	A swale is a channel designed to convey stormwater. It can be designed to attenuate and/or infiltrate where feasible.
Tree Trench	A stormwater tree trench is a subsurface infiltration/storage trench that is planted with trees. They are typically linear features that are constructed between the curb and the sidewalk. It is designed to detain and release stormwater runoff and/or infiltrate where feasible.
Wetland	A stormwater wetland is a vegetated basin designed principally for pollutant removal. It typically holds runoff for periods longer than 72 hours and may include a permanent pool. Wetlands can also detain and release stormwater runoff.

Subsurface

Subsurface SMPs consist of tree trenches, subsurface storage trenches, and subsurface basins. The top of storage volume is usually controlled by the elevation of the most downstream inlet. Storage is typically in a combination of gravel, pipes, sand, tree pit soil, and sometimes proprietary storage structures (Figure 2-11).

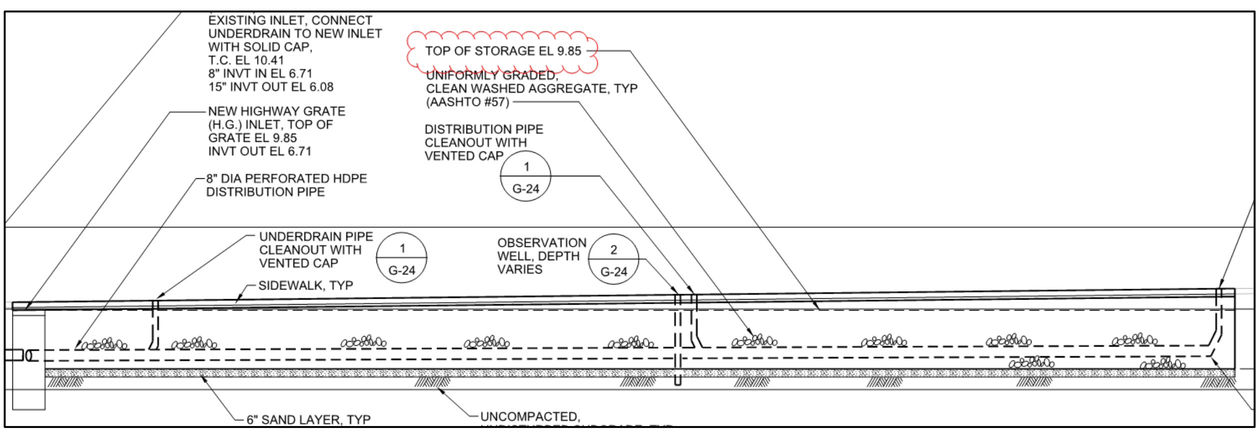

Figure 2-11: Typical Subsurface Storage Cross Section

Bioretention/Bioinfiltration

Bioretention/bioinfiltration SMPs consist of bumpouts, planters, and rain gardens. The top of storage for these systems is typically controlled by the elevation of the most downstream inlet or an overflow riser. The storage is typically a combination of surface ponding and soil (Figure2-12).

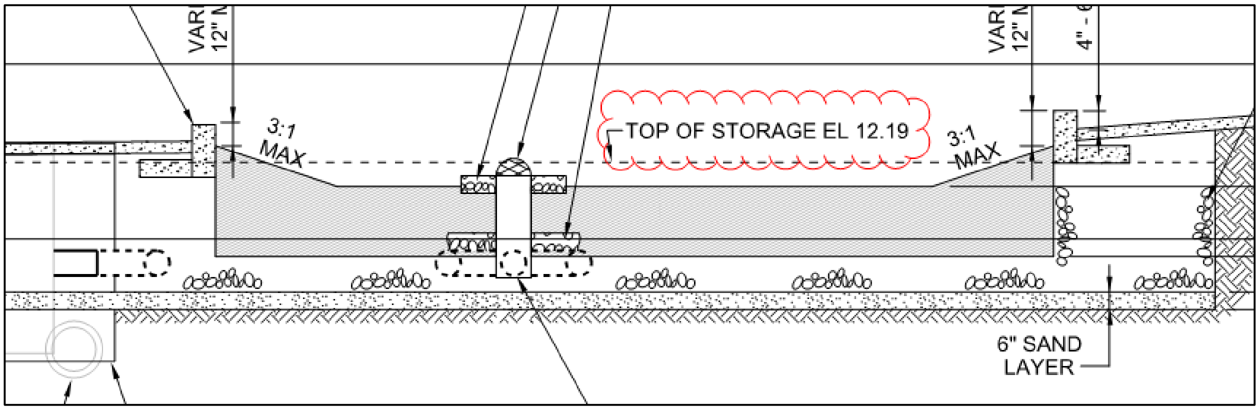

Figure 2-12: Typical Rain Garden Cross Section, in Combination with a Subsurface SMP

Permeable Pavement

Permeable pavement storage is in the gravel beds below the pavement (Figure 2-13).

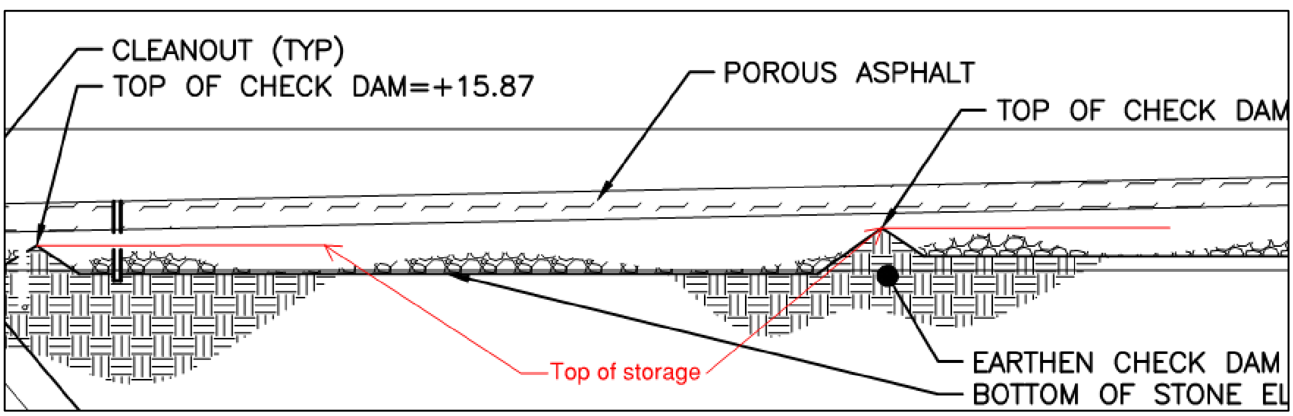

Figure 2-13: Cross Section of Permeable Pavement Storage Beds on a Sloped Street

3.0 Assessment of Program Performance

3.1 Introduction

Both the Consent Order and Agreement (COA) and the United States Environmental Protection Agency (US EPA) Administrative Order for Compliance on Consent (AOCC) require implementation of a monitoring program at a sufficient scale to assess the effectiveness of Green Stormwater Infrastructure (GSI) in removing wet weather flows from the combined sewer system. A key component of this larger monitoring program was creation of a Pilot Program. Pilot Program staff worked with units from throughout the larger wet weather planning and GSI implementation program to design experiments and GSI projects, collect and analyze data, investigate new technologies both in the literature and in the field, and gather information on peer city/utility best practices and innovations. Pilot Program staff also worked with academic researchers, and provided information on lessons learned and recommendations to the implementation groups to be considered for possible program and policy changes.

The Pilot Program was conceptualized in the Implementation and Adaptive Management Plan (IAMP) as a program to evaluate the first five years of the GSI program, a period of growth, evolution, and experimentation. The Pilot Program approach was further developed in the *Comprehensive Monitoring Plan* and subsequent comment responses with the Pennsylvania Department of Environmental Protection and US EPA as PWD's program for assessing GSI effectiveness while also providing critical feedback for enhancing design, construction, and maintenance procedures and refining program cost estimates.

This section summarizes the extensive data collection and analyses that have been performed over the first five years of program implementation, and presents evidence making a strong case that the program is performing as expected or better than expected, and draws conclusions about aspects of design and policy that are driving performance, cost, ease of implementation, ease of maintenance, and community perception. A full *Pilot Program Final Report* has been completed and is included as Appendix B to this EAP.

3.2 Pilot Program Summary and Conclusions

Because a GSI-centered approach to Combined Sewer Overflow (CSO) control is relatively new at the scale planned and executed by PWD, the Pilot Program was designed to test the feasibility and measure the effectiveness of GSI under a range of potential conditions. To accomplish these goals, the Pilot Program established the following steps:

Step 1: Develop a Set of "Pilot Projects"

Pilot projects are defined as GSI projects designed, constructed, and monitored to provide information for improved design and program implementation. One or more of the following were tracked on a total of 244 GSI systems: long-term continuous water level (46), water level response to a synthetic runoff test event (46), porous pavement surface infiltration rate (5), maintenance records (215), and construction cost (226). Of the 46 systems selected for long-term continuous water level monitoring, 36 have produced data of sufficient quality for detailed, quantitative hydrologic and hydraulic analyses.

Step 2: Identify Relevant Project Variables

GSI projects take many forms, are located in a variety of settings, and consist of different technologies and materials. This complex mix of characteristics contributes to differences in performance, cost, ease of implementation, maintenance needs, and community perception among projects. It was hypothesized at the beginning of the program that there might be a subset of these characteristics that is most important in explaining the outcome of a given project. A key mission of the Pilot Program has been to attempt to identify this subset of variables and to use it to inform future choices on how projects are sited, designed, implemented, and maintained. To make this objective assessment, it was necessary to develop a standardized description of the complex variables present in each project, thereby enabling comparisons of these variables across projects. To assess these characteristics contributing to the outcome of GSI projects, 24 descriptive variables (e.g., Land Use Type) were identified, each with a set of levels to be evaluated for the relative importance of their contributions (e.g., schools, parks, streets). Variables are conditions that could affect the ability of GSI to be implemented, its ability to function as designed, or its ability to maintain its functionality over time. These variables have been organized into the following categories:

- Land Use Type
- Drainage Area Characteristics
- GSI System Type
- GSI Design Elements:
  - Inlet Type
  - System Surface/Subsurface Status
  - Loading Ratio
  - Static Storage Volume
  - Vegetation Status
  - Pretreatment Type
  - Inflow Type
  - Street Crossing Type
  - Rooftop Disconnection
  - Domed Riser Depth
  - Energy Dissipater Type
- Materials:
  - Primary Storage Materials
  - Permeable Pavement Type
  - Soil Type
- Physical Conditions:
  - Physiographic Province
  - Tested Soil Infiltration Rate
  - Street Slope

- Policy/Partnerships
- GSI Visibility
- GSI Location Ownership

Each item in this list was labeled as a “Variable” consisting of several “Levels.” For example, the Land Use Type Variable consists of Levels including schools, streets, parks, etc. The full list of Pilot Variables, Levels, and descriptions of each are located in Appendix B, *Pilot Program Final Report*. Applicable Levels of the Variables were assigned to each pilot project. It was the intent to select projects to evaluate as many of the Variables and Levels as possible, and each pilot project is useful in testing multiple Variables.

Step 3: Evaluate the Impact of the Project Variables

Project Variables were evaluated for their effect on the following five categories:

- Hydrologic performance
- Construction cost
- Ease of implementation
- Ease of maintenance
- Community perception

The program is continuously producing a large, and growing, volume of data on GSI. The Pilot Program has developed a two-step process for managing these data. The first step uses statistical algorithms to identify significant relationships and trends in the data. This step eliminates a large amount of data that do not contain significant trends. Some of the relationships and trends identified as potentially significant by the automated algorithms turn out to be significant in an engineering sense, while others are not. Statistical screening does not replace engineering analysis, but it reduces the effort required to perform engineering analysis. Once the statistical analysis identifies Pilot Variables of interest, the second step involves the engineering team analyzing the results to try to identify physical explanations for the behavior that can be translated into conclusions and actionable recommendations.

A total of ten data sets of performance metrics were run through the statistical analysis for each of the 24 Variables, resulting in a total of 240 potential correlations. These performance metrics were used to evaluate three of the five categories, including hydrologic performance, construction cost, and ease of maintenance. Ease of implementation and community perception did not have quantitative data appropriate for this statistical analysis, and were evaluated through staff and community surveys. Of the 240 Variable/performance metric tests, 215 were eliminated for lack of trend or significance. The remaining 25 Variables were further analyzed to assess their impact on the five categories mentioned above.

Conclusions about Hydrologic Performance of GSI

The performance monitoring of GSI has shown that overall, systems are performing better than predicted by PWD’s current engineering design assumptions. The systems overflow less often than predicted, experience higher infiltration rates and faster draindown times than predicted, and have more excess storage capacity available than predicted over a range of events. The performance monitoring period providing data for Pilot Program analyses covers parts of four calendar years (2012-2015). The years 2013 and 2015 had more rainfall than the long-term average, while 2012 and 2014 had less rainfall than the long-term average. Therefore, stormwater management performance of GSI systems during this monitoring period can be considered reasonably representative of performance over a range of conditions.

Results provide strong evidence that these systems are capturing stormwater effectively and keeping it out of the combined sewers, with many fewer system overflows than predicted using conservative design assumptions. After analyzing data from all events at all systems during this monitoring period, it was observed that there were 22 system-events where a system filled to design capacity and only 18 system-events where capacity was exceeded and a system overflowed into the downstream combined sewer. This subset of events represented only 3.6% of the 497 exceedances predicted using current engineering design assumptions, thus showing that the designs are relatively conservative. Only 0.36% of all 5,027 system-events over the monitoring period overflowed into the downstream combined sewer

Comparison of pre-construction and post-construction infiltration rates provides further evidence that field performance is consistently exceeding expectations. Infiltration rates under post-construction field conditions are estimated by observing the rate of water level recession following runoff, in systems where infiltration is the only significant outflow process (i.e., without controlled releases to the combined sewer system). The small number of observed storage capacity exceedances (compared to exceedances predicted by engineering design assumptions) is most likely due to higher than expected infiltration rates under post-construction field conditions, influenced by both vertical infiltration into native soil and fill, horizontal movement through the sides of systems, and movement through preferential pathways. Observed infiltration rates under post-construction conditions for the 22 monitored infiltration-only systems range from 0.49 to 13.2 inches per hour, with an average of 5 inches per hour. Compared to results of the pre-construction infiltration tests which form the basis for system design, these observed post-construction rates are consistently higher for most sites and events, as shown in Figure 3-1. Analysis of these rates indicates that a single pre-construction infiltration test is a conservative indicator of expected post-construction infiltration over the footprint of the system. Although results of unlined borehole percolation tests (accounting for vertical and horizontal infiltration) lie closer to the line of agreement, they also conservatively predict performance.

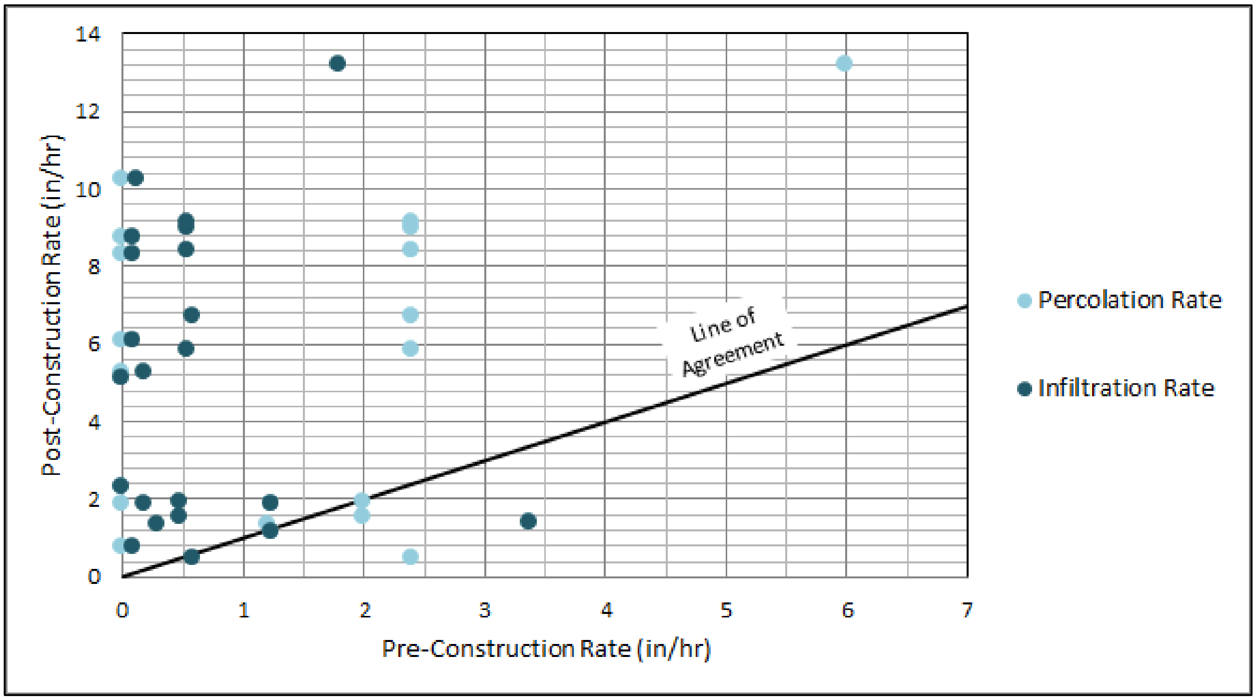

Figure 3-1: Pre- and Post-Construction Infiltration and Percolation Rate Comparisons (Percolation rates are the observed drop in water in a pre-construction infiltration test, while infiltration rates are adjusted with a reduction factor to account for estimated radial flow.)

The evidence of higher than expected infiltration rates is consistent with data showing the portion of storage volume occupied during each storm. Over a range of wet weather event sizes, the fraction of storage capacity utilized is consistently less than predicted by design assumptions, providing further evidence of over-performance. Figure 3-2 shows that for the 15 systems where this data was analyzed, the average maximum portion of available storage used is less than 53% during storms less than 3.0 inches of rainfall depth, and approximately 60% for storms greater than 3.0 inches of rainfall depth. Approximately 95% of storms from 2012 to 2015 (and PWD's "typical year" used in wet weather planning) were 2.0 inches depth or less (Figure 3-3), with 12 storms in the monitoring period above 2.0 inches depth. These results indicate that systems are regularly managing storms in excess of 3.0 inches with significant storage capacity remaining unused.

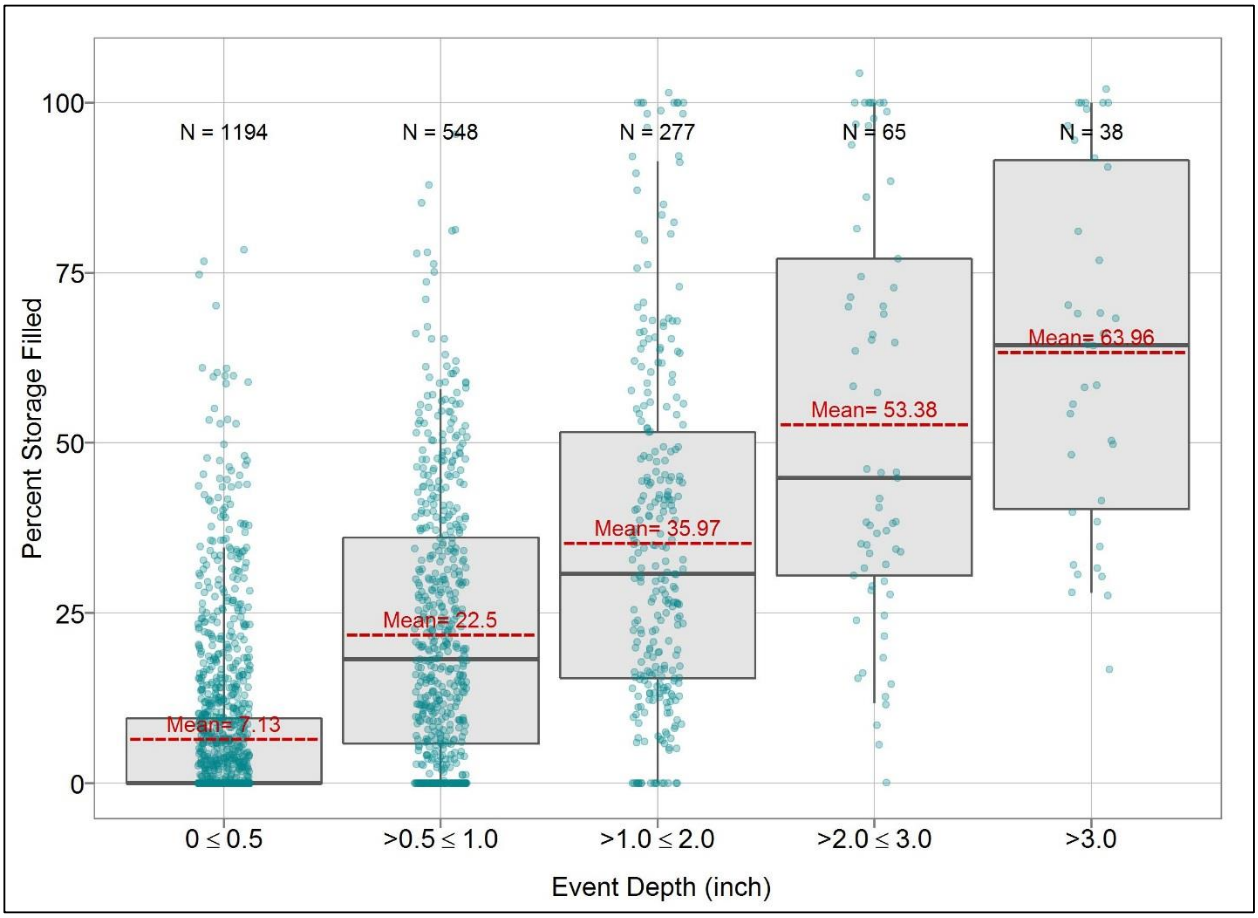

Figure 3-2: Percentage of Storage Filled for 15 Systems (2,120 system-events)

These results suggest it may be possible to design systems less conservatively and still meet design performance objectives. On the other hand, short-term over-performance, if it comes at a relatively low cost, may be desirable if it indicates a resilient system, that is a system able to meet design objectives reliably over a range of local conditions (for example, partial clogging) and external drivers (for example, short-term hydrologic variability and long-term climate change). Oversizing a system initially also leaves open the possibility of diverting additional drainage area to that storage element in a future phase. For example, oversizing a system on a residential street, initially designed to receive runoff only from the street and sidewalk, leaves open a possibility of diverting rooftop runoff to the storage element in a future phase.

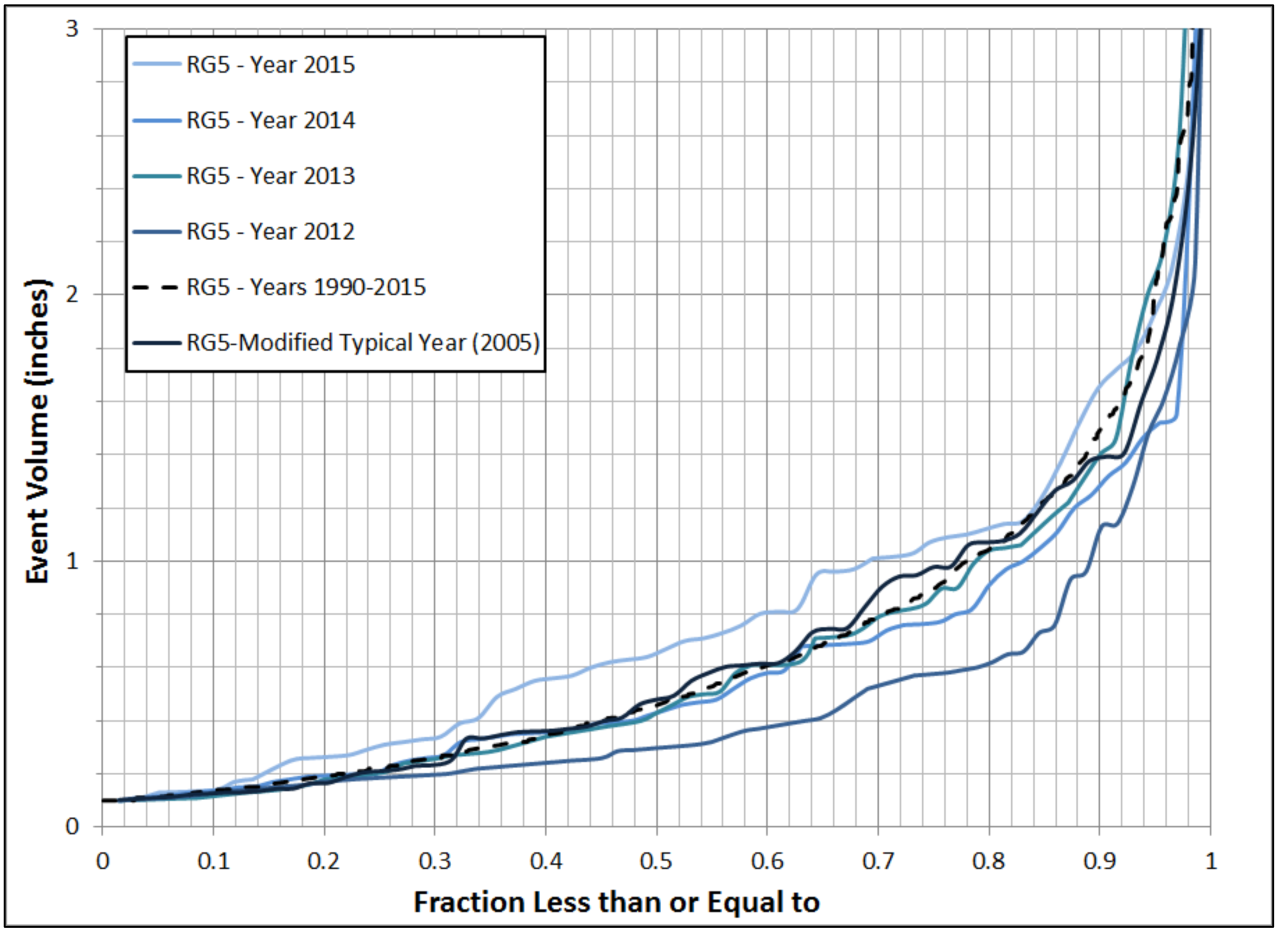

Figure 3-3: Cumulative Distribution Function for Years 2012-2015 with Long-Term (1990-2015) and Typical Year (modified 2005) Rain Gage 5

Additional evidence that Philadelphia's GSI systems are over-performing compared to design assumptions is provided by analysis of the time required for systems to drain following runoff events. The systems are designed to drain within 72 hours. Analysis of the continuous water level data indicated that only six of the 40 monitored systems with high-quality data ever had recession durations longer than 72 hours, and only two of these systems ever took longer than 72 hours to drain following simulated runoff tests. These relatively few instances of longer than expected draindown times may be influenced by soil conditions and storm shape; a long duration, large volume storm can fully saturate the soil and cause a longer draindown period, while an intense, 1.0 inch storm (typical of summer convective events and the synthetic runoff tests), will less fully saturate soils and drain down more quickly. Figure 3-4 is an example of differing draindown responses of three nearby systems to the same rainfall event.

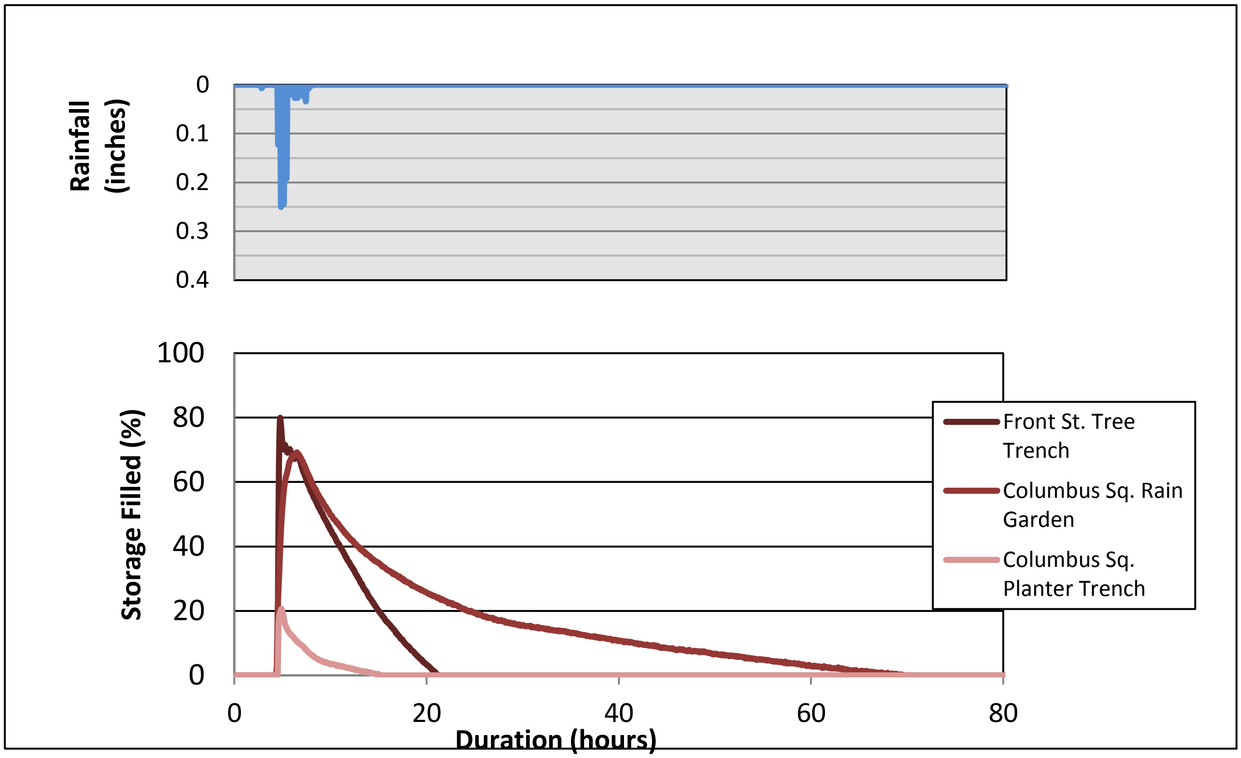

Figure 3-4: System Response at Columbus Square and Front Street SMPs to a 1 Inch Event on June 27, 2014

Long draindown times cause undesirable combined sewer system performance only if they cause storage capacity to be exceeded when it otherwise would not be during a subsequent event. During the monitoring period, only one instance was observed where a slow draining system caused a subsequent event to exceed storage capacity. In this case, the excess volume was diverted into another GSI system rather than directly to a combined sewer, and therefore was unlikely to contribute to combined sewer overflow.

The results of infiltration rate, storage use, and drain down duration analyses together make a strong case that PWD's GSI systems are performing better than predicted using current engineering design assumptions. A further initiative of the program was to try to create accurate water budgets for each system, showing the breakdown between the amount of water leaving the system through infiltration and slow release. Several factors make it difficult to create these water budgets without significant uncertainty. This is an area where further research may be useful.

Key Design and Siting Variables that Affect Hydrologic Performance

Analysis of monitoring data within the Pilot Variable Framework yielded limited information on siting and design decisions with significant effects on variation on performance between sites. A possible reason for this finding is that PWD's systems are all designed with the same performance criteria, limiting performance variation between sites. Another possibility is that differences in performance between sites are explained by factors, or combinations of factors, not captured in the Pilot Variable Framework.

There was one location-related finding of interest identified in the analysis. An early analysis of pre-construction infiltration rates indicated better performance within the Piedmont physiographic province than in the Coastal Plain, which is supported by the post-construction infiltration data.

Conclusions about GSI Construction Cost

Construction bid costs were analyzed to identify factors affecting construction cost. The purpose of analyzing system construction cost was to relate the cost of constructing individual systems to key Pilot Variables. A few interesting conclusions can be drawn from the results:

- Several economy of scale effects are evident in the data. Construction cost per unit of drainage area exhibits economies of scale with respect to both contract size (measured by total impervious drainage area; Figure 3-5), and with respect to drainage area per individual system. The economy of scale effect is weaker but still visible with respect to cost per unit storage volume.

Figure 3-5: Bid Price (2015 USD) per Managed Impervious Area by Managed Impervious Area by System

- Some clear trends are seen with respect to GSI system type, with higher unit costs for infiltration/storage trenches and systems with planters (Figure 3-6). In both cases, the more expensive systems were smaller surface systems within the right-of-way.

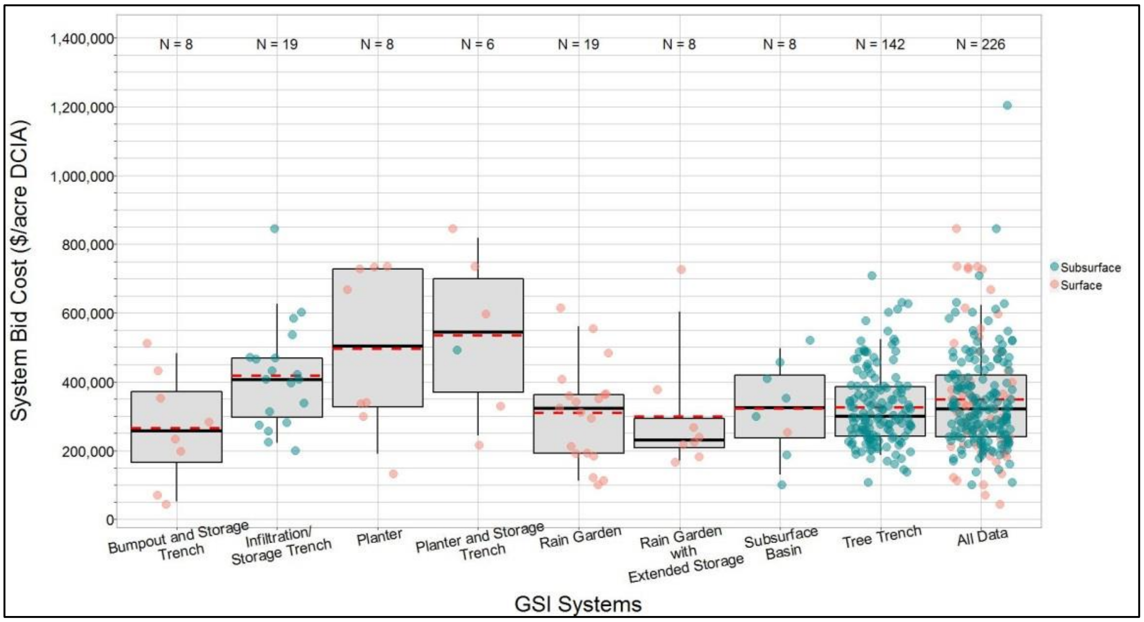

Figure 3-6: Bid Price per Managed Area (2015 USD) by GSI System Type

- Land use, as defined by this study, type did not appear to have a significant impact on variation in unit area construction cost among sites.
- Systems with lower loading ratios had higher construction costs per unit drainage area than systems with loading ratios above 10:1 (Figure 3-7).

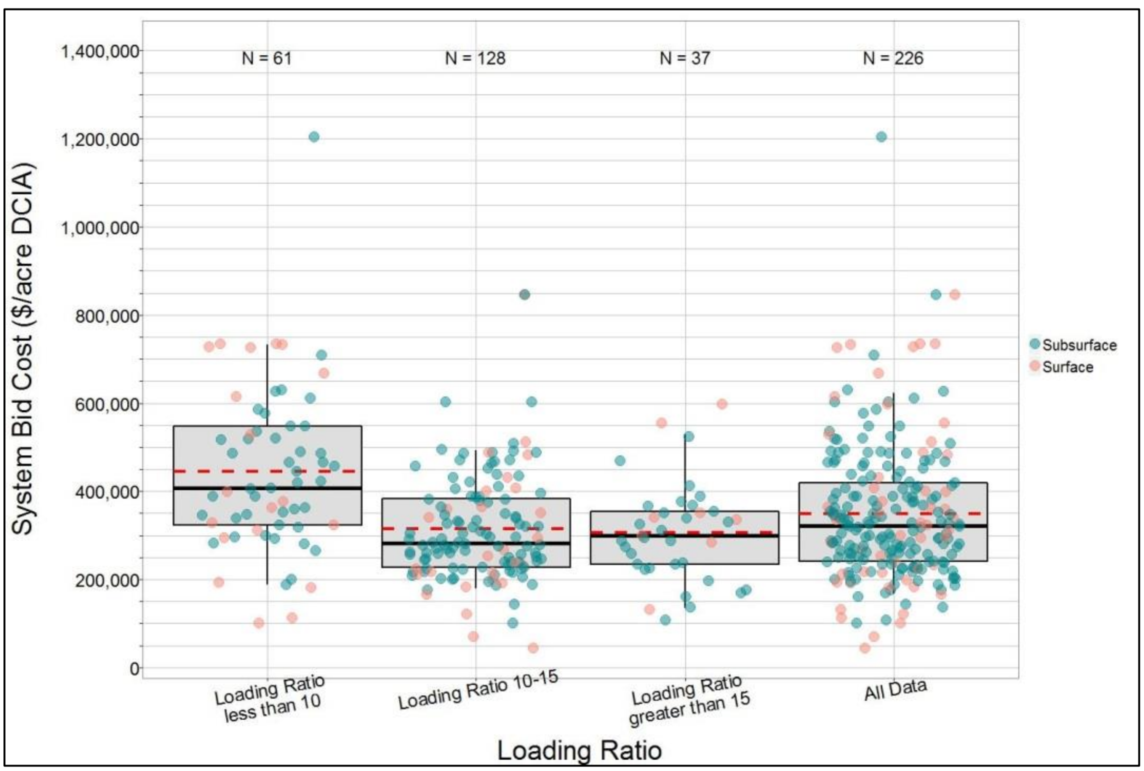

Figure 3-7: Bid Price per Managed Impervious Area (2015 USD) by Loading Ratio

- Systems where runoff is conveyed across the street have lower costs per unit drainage area than systems without the additional conveyance, because adding the additional drainage area outweighs the cost of additional piping.
- At the beginning of the program, it was hypothesized that unit cost might decrease over time and with construction of more sites over time, as designers and contractors "learn by doing," becoming more efficient and less risk-adverse. This hypothesis was not fully supported based on data from the first five years of the program. PWD plans to continue monitoring cost to determine if a trend can be observed over longer periods of time.
- Prior to data collection, it was hypothesized that increasing design storage volume on any given site would increase construction cost. This hypothesis was not fully supported following analysis of data from a large number of sites. In other words, sites with more storage volume per unit of drainage area do not have higher construction costs, on average, than sites with less storage volume. This result suggests that factors other than storage volume are important drivers of variation in cost between sites. One implication of this result is that using less conservative design assumptions (e.g., reduced storage volume) may not be an efficient approach to bringing down unit costs.

Conclusions about Ease of GSI Implementation

"Ease of implementation" was characterized with a wide variety of factors that may affect the implementation process of GSI, by either making it easier or more difficult in planning, design, and/or construction completion. PWD staff professionals were consulted and have provided some key points for consideration. Staff consulted included those responsible for the implementation of GSI, such as urban planners, who are tasked with finding locations for GSI projects, and design engineers, who manage projects from concept design through preparation of construction bid documents.

A number of factors were identified by planning professionals as affecting ease of implementation.

- Involvement of civic groups and non-government organizations was viewed as easing implementation. These can increase early buy-in and acceptance of projects, although they do require time and effort to coordinate. However, the involvement of multiple stakeholders and multiple uses of the site can add difficulty to project implementation. This applies especially to schools, athletic fields, recreation centers, and vacant lands.
- Permitting and review processes required by various public agencies such as education and transportation agencies can add time and difficulty to project planning and design. On the other hand, projects located in the public right-of-way tend to have clearly established standard procedures, processes, and guidance, which can help streamline the planning process. Some standard procedures for working with stakeholders on other types of public sites are still in development.
- Implementation on private land was most successful through incentive programs involving public funding for implementation on the private parcel by the private landowner.

- Capturing runoff from private parking lots and roofs for management in GSI systems on the street or other public land was identified by planning professionals as challenging.

Engineering design staff identified a number of conditions that affect ease of implementation.

- High-density residential streets, commercial corridors, traffic triangles, and medians complicate the design process due to concentrated presence of utilities and laterals.
- Rooftops with internal drainage systems that mix sanitary sewage and stormwater make management of roof runoff more difficult.
- Rights-of-way around school perimeters and other streets without a significant presence of utilities and laterals have greater ease of implementation due to fewer space constraints. Open space park sites have higher potential for capture of large drainage areas in a single GSI footprint.
- Bumpout (curb extension) designs were perceived as causing vehicular traffic, turning and parking concerns, and therefore being difficult to coordinate with transportation agencies.
- Conveying runoff across a crowned street is sometimes difficult when there is presence of underground utilities.
- Steeper streets result in higher flow velocities, affecting inlet design. Because storage elements require flat bottoms to maximize storage, steeper streets require either deeper excavation on the upstream end of the system, or stepped systems, increasing design and construction complexity.
- Standard available storage materials, such as stone and bioretention soil, are easy to acquire and incorporate in designs. Less common materials such as arched chambers, structural vaults, and structural soil are perceived as relatively expensive. Engineering staff and partners express structural concerns about storage technologies containing plastic elements, and about suspended pavement cells.

Conclusions about Ease of GSI Maintenance

The key GSI maintenance metrics analyzed were base maintenance cost, defined as the cost of maintenance activities expected to regularly occur in a given year minus occasional as-needed costs such as structural repairs, and total volume of material removed during maintenance activities. Performance metrics were developed from this data that were run through the Pilot Variable Framework statistical analysis to determine if any of the Pilot Variables showed trends that could be a potential driver of maintenance cost or material deposition.

- Data from the first five years reflect the choice PWD has made to maintain its surface GSI systems to a high aesthetic standard rather than only to meet more limited stormwater performance objectives. Maintenance cost data show that these high-value systems also have somewhat higher maintenance costs than subsurface systems (Figure 3-8). The most likely explanation is simply that these sites have been visited more often during the growing season to perform aesthetic landscape maintenance. In some cases, they have experienced littering and dumping which does not affect stormwater performance directly, but results in an unacceptable condition for members of the community. This data set provides valuable information for future decisions about how to balance maintenance cost with aesthetics and engage partners to help ensure community benefits while allowing PWD to focus on its core stormwater management mission.

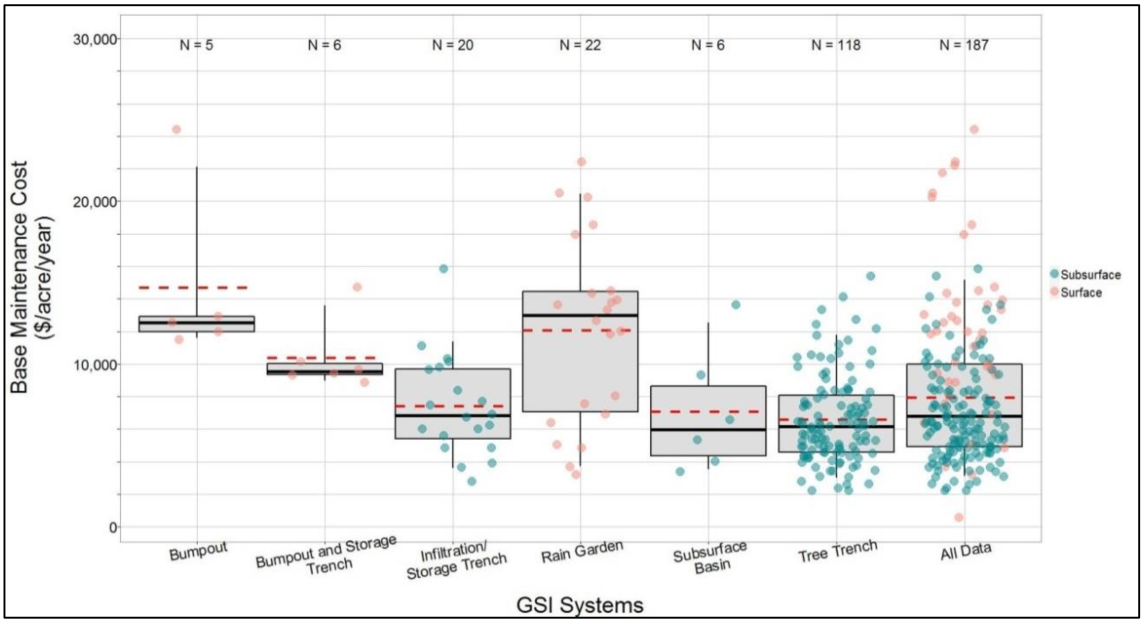

Figure 3-8: Base Maintenance Cost per Directly Connected Impervious Area per Year by GSI System Type

- Maintenance cost per unit of GSI footprint is higher for systems where risers have been installed with rims less than 3 inches above the surface of the soil. In smaller storms where subsurface storage is not filled to capacity, this design limits surface ponding to the height of the riser rim. In systems with lower riser rims and relatively impermeable planting soils, filter bags installed in the risers may be more likely to clog with sediment and inundate the surface of the system with water for periods of time that exceed design guidelines, requiring maintenance.
- An early hypothesis of the Pilot Program was that systems with higher ratios of drainage area to GSI footprint area would have more concentrated loads of solids and trash to GSI systems, and therefore might have higher maintenance costs per unit of drainage area. This hypothesis was not proven. Data show that systems with loading ratios less than 10 have slightly higher maintenance costs per unit drainage area (Figure 3-9). This result suggests that loading ratio alone may not be a good predictor of maintenance cost.

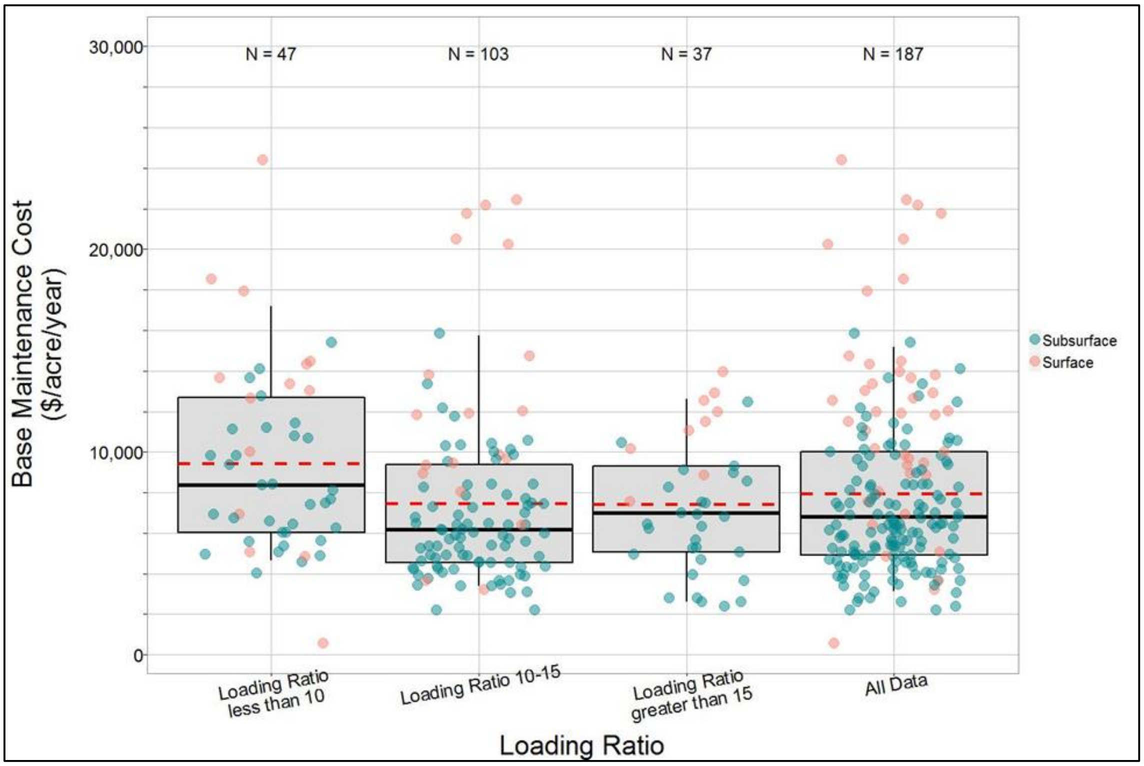

Figure 3-9: Base Maintenance Cost per Directly Connected Impervious Area per Year by Loading Ratio

Conclusions about Community Perception of GSI

Members of the public provided information about familiarity with GSI and the *Green City, Clean Waters* program, as well as preference for the tools used to capture stormwater, preferable locations of infrastructure, and perceived effects of GSI in the community. While this information may not meet the standards of a scientific survey, it provides some initial insights into how the program is being received by people who live and work in Philadelphia.

- Members of the public who chose to comment generally confirmed the perception of the professional planning staff that they see value in visible, surface vegetated systems. The most popular tools included rain gardens and swales, stormwater planters, stormwater tree trenches, green roofs and permeable pavements.
- There is wide support for GSI across various land use types.
- Residents would be willing to work with PWD to disconnect the downspout on their house or business if stormwater runoff could flow into public GSI.

4.0 Program Adaptations

The Philadelphia Water Department (PWD) has achieved or exceeded each of the Year 5 Water Quality Based Effluent Limit (WQBEL) Performance Standards; therefore, significant program adaptations are not planned at this time. As described in the Implementation and Adaptive Management Plan (IAMP), adaptations in the management approaches are expected throughout each five-year implementation period to ensure that program goals are met, to optimize and enhance the program, to maximize benefits, and to minimize the costs of implementation.

Within this section, PWD has highlighted a number of within-program adaptations and enhancements, predominantly to the implementation of Green Stormwater Infrastructure (GSI) that have been undertaken during the first five years of the program to support achievement of the WQBEL Performance Standards.

4.1 Traditional Infrastructure Adaptations

Please refer to the *Green City, Clean Waters Wet Weather Facility Plan* for details on adaptations to the projects and schedules outlined in the Water Pollution Control Plant Facility Concept Plans.

4.2 Green Program Adaptations

During the first five years of the program, implementation of GSI across the City of Philadelphia evolved and matured from the ideas and concepts put forth in the IAMP to a robust, multi-pronged implementation program. The three program implementation approaches have evolved from those put forth in the IAMP "Strategic Initiatives" including: 1) PWD-initiated GSI projects, 2) GSI following "public works" projects; and 3) private investment (via the *City of Philadelphia Stormwater Regulations* and proactive retrofits for stormwater bill credits). At the close of the first five years of program implementation, PWD has a refined set of GSI implementation approaches including: 1) (Re)Development Regulations (via the *City of Philadelphia Stormwater Regulations)*, 2) Public Investments, which include both PWD-initiated GSI projects and GSI following public works, and 3) Incentivized Retrofits, which did not exist in 2011 when the IAMP was developed.

4.2.1 (Re)Development Regulations Adaptations

(Re)Development Regulations in the City of Philadelphia continue to provide a significant portion of the Greened Acres (GAs) for the program. Since 2011, program adaptations have been made to maximize benefit of the City's *Stormwater Regulations*. This section includes a description of the milestones and major accomplishments during the last five years, most notably recent updates to the *Stormwater Regulations*, the release of Version Three of the *Stormwater Management Guidance Manual*, and implementation of complementary City Code incentives.

Regulation Updates

The *City of Philadelphia Stormwater Regulations* were revised significantly in January of 2006, providing the foundation of land development's role in achieving WQBEL Performance Standards. Since then, all new and/or redevelopment sites disturbing greater than 15,000 square feet of earth require on-site stormwater management that meet the City's design, construction, and maintenance standards. Since 2006, PWD collected ad hoc feedback from the development community regarding improvements to the implementation of its Regulations. In 2012, PWD launched the Development Services Committee (DSC) to formalize feedback loops and to strengthen its relationship with the Philadelphia development community. The DSC established a working group composed of developers, public land managers, engineers, and other stakeholders who interact with the *Stormwater Regulations* for the purpose of identifying and vetting potential improvements to the process.

Since 2012, PWD has hosted 13 DSC meetings to discuss the program and opportunities for improvement. The dialogue with the DSC helped to inform decisions as PWD planned for a major update to the *Stormwater Regulations*. The goals of this update were to maximize stormwater management from land development opportunities and to implement business friendly plan review process improvements. The process changes were intended to benefit both the development community and PWD, addressing feedback from applicants and design engineers while maximizing benefit for the City's Greened Acre (GA) goals. Improvements were aimed at streamlining the timeline for project approvals, providing clear application resources, and improving the quality of plan submissions. The regulatory changes were designed to manage stormwater on each new development in a way that maximizes compliance benefits on private property (Table 4-1).

Specifically, the three water quality improvements included:

1. **Increasing runoff depth managed from 1 to 1.5 inches:** retains more stormwater volume on each (Re)Development site;
2. **Decreasing the release rate from 0.24 cfs/acre to 0.05 cfs/acre for slow release systems:** reduces the peak release rate of runoff and increases the capacity of the combined sewer system during wet weather; and
3. **Increasing volume reducing requirement from 20% to 100%:** ensures that 100% of the stormwater managed with GSI goes through a pollutant-reducing practice to decrease the mass of pollutants to the receiving waterways.

The business friendly improvements included:

1. **Faster project approvals:** A new expedited, five-day review for surface green stormwater infrastructure;
2. **Clear application resources:** Simplified application and worksheets to improve submissions; and

3. **Accessible information:** Online, user friendly Guidance Manual and new Stormwater Plan Review website.

The updated *Stormwater Regulations* went into effect July 1, 2015. As part of the implementation process, PWD engaged in robust outreach efforts with both the DSC and development community as a whole to ensure that all developers and design engineers were prepared for the regulatory changes.

Coupled with extensive outreach and dialogue regarding the updated regulatory framework, PWD sought to provide the development community with enough time to assess impacts to current or potential projects. Leveraging the DSC, existing partnerships and contacts with professional organizations, PWD led a series of meetings, presentations, focus groups, and information sessions dedicated to the discussion of upcoming regulatory changes over the course of two years. The implementation process greatly benefited from this effort, as the audience was well-informed at the time changes went into effect. Similarly, the successes gleaned from robust outreach have reinforced PWD's commitment to sustaining ongoing dialogue with the development community.

Table 4-1: Summary of July 2015 Regulatory Changes

	Pre-July 2015	Current
Water Quality Volume	1.0"	1.5"
Water Quality Rate	0.24 cfs/acre	0.05 cfs/acre
Water Quality Treatment: Combined	20% Volume Reducing	100% Pollutant Reducing
Minimum Orifice Diameter	3 inches	1 inch (Traditional)
		½ inch (Underdrain)
Surface Loading Ratio	10:1	16:1
Subsurface Loading Ratio	5:1	8:1
Bioretention Soil Volume Credit	None	20% Void Space
Minimum Infiltration Rate (for Infiltration-only Systems)	0.5 in/hr	0.4 in/hr

PWD will continue to engage the stakeholders involved in the stormwater plan review process to make additional improvements and continue evaluating opportunities for future enhancements.

Website Updates

PWD updated the web interface: http://www.PWDPlanReview.org to address both ad hoc feedback collected since 2006 and feedback from targeted outreach efforts (Figure 4-1). The website was redesigned to focus on two primary uses: submitting project initiation applications and accessing the *Stormwater Management Guidance Manual*. The new web-based platform fully integrates the Manual Version 3.0 into the Stormwater Plan Review website, promoting ease of use through searchable content and links to related sections and external resources. To accommodate all types of users, the Manual is available for download either in its entirety or as individual sections.

A significant focus of the redesign was the implementation of a "smart" application based on regulatory logic to streamline data inputs for applicants. As a result of this logic, users can clearly identify required fields and plan submissions. To facilitate the tracking of application submissions and review statuses for applicants, log-in functionality was incorporated into the revised website design. This new feature allows users to work on several applications and check the status of a particular project in the plan review process.

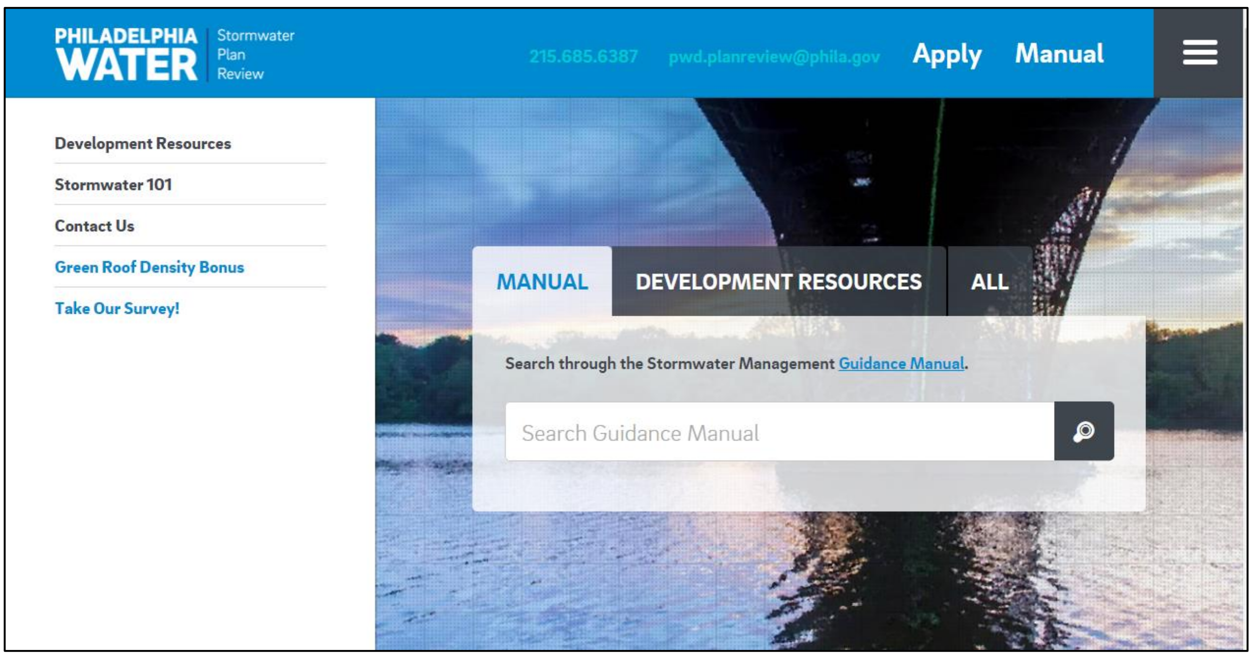

Figure 4-1: Screen Capture of the New Homepage for PWDPlanReview.org

Stormwater Management Guidance Manual

In addition to redeveloping the website and tools, PWD engaged in a comprehensive update of *Stormwater Management Guidance Manual*. Building upon nearly a decade of program growth and technological advances, the update sought to streamline the technical design requirements and improve the organizational structure to assist the development community in meeting the *Stormwater Regulations*. With a goal of creating business friendly resources, PWD leveraged input from design engineers and developers to restructure the Manual to better reflect project lifecycles.

Since the *Stormwater Regulations* were first revised in 2006, PWD has received frequent requests from applicants to identify PWD's most preferred types of stormwater management practices. To accommodate these requests, PWD examined the performance, triple bottom line benefits, and other ancillary benefits of eight practices, resulting in a formalized hierarchy available through the updated manual. PWD's most preferred practices include bioinfiltration/bioretention basins, porous pavement and green roofs. Incentives are aligned with these practices to encourage their integration into site designs through expedited reviews and standardized design tools.

Within the Manual, PWD focused on clearly identifying review paths based on the regulatory requirements, including flow charts to help clarify the submission process. The revised Manual encourages developers to consider stormwater management integration earlier in the (Re)Development process, taking advantage of opportunities to incorporate surface practices in the site layout. This is further promoted through the formalized hierarchy of management practices. Furthermore, the most preferred management strategies in the hierarchy are incentivized through a new expedited review. Known as the "Surface Green Review," this new expedited review option expands the traditional "Disconnection Green Review" by expanding the types of eligible Stormwater Management Practices (SMPs). Previously, projects using green roofs, porous pavement, or other disconnection practices qualified for a five-day review time. Building on the existing expedited review process and the newly developed Stormwater Management Practice (SMP) Hierarchy, PWD established the Surface Green Review to include bioinfiltration and bioretention basins in addition to the practices eligible for the Disconnection Green Review. As a result, more projects are now eligible to pursue expedited reviews.

The new Manual also clarifies the process for maintaining compliance with the *Stormwater Regulations* before, during, and after construction. As part of the reorganized and updated technical design guidance, PWD created a subchapter entitled "How to Show Compliance," which provides applicants with a single resource for demonstrating compliance with each regulatory requirement. Step-by-step instructions allow applicants to confirm that the submission package complies with the *Stormwater Regulations*, and to ensure that the Stormwater Plan Review staff has access to the appropriate documentation. In addition to the design process, the Manual includes comprehensive construction guidance regarding the active construction inspection process, identifies required documentation, and addresses common construction issues and solutions for installing SMPs and erosion and sedimentation control. Similarly, the Manual contains a new section on the post-construction inspection and enforcement process, where PWD inspectors continue to verify performance after construction. While describing typical maintenance activities for property owners, the Manual also includes a discussion of the stormwater billing credit opportunities available to projects that meet the requirements of the *Stormwater Regulations*.

Additional Process Enhancements

Other implementation tools that improve the Stormwater Plan Review process and submission quality include:

- Submission checklists and guidance information for PWD unit reviews, and city and state agency coordination;
- Revision and enhancement to infiltration testing policy and guidance, including an example soil characterization and infiltration testing plan which can be used by applicants as a template when preparing for geotechnical investigation;
- Banking and trading guidance for same parcel trading or same owner banking;
- Updated SMP-specific design requirements, recommended design considerations, construction and maintenance guidance, and standard details;
- SMP one-sheets, renderings, and standard details that can be shared with developers early in the design process;
- Water quality bio-basin sizing table representing the minimum design requirements to facilitate and incentivize the use of bioinfiltration/bioretention basins;
- Sample Record Drawing for applicants to reference while preparing the submission of As-Built documentation; and
- Post-construction guidance for property owners to ensure long-term maintenance.

City Code Incentives

Beyond the formal update to the *Stormwater Regulations* and its supporting guidance materials, PWD worked with the City Planning Commission and City Council to further incentivize developers to maximize stormwater management. This includes the development of two new zoning code incentives and an expansion of the Green Roof Tax Credit. For additional information about these incentives visit: http://www.phillywatersheds.org/whats_in_it_for_you/residents/green-roofs.

Green Roof Residential Density Bonus

PWD worked with the City Planning Commission to create exceptions to certain residential density rules when a new development or redevelopment project includes a green roof. These exceptions can increase the number of dwelling units permitted in a residential building, depending on the zoning district and size of the building. For development projects exempt from the Regulations, the density bonus results in voluntary stormwater management using one of PWD's preferred practices. For developers required to comply with the *Stormwater Regulations*, the bonus provides an additional incentive to use a green roof as an SMP.

Callowhill Stormwater Floor Area Ratio Bonus

PWD worked with the City Planning Commission to add stormwater systems to the list of practices that are eligible to receive height bonuses for properties of at least 15,000 square feet to the new East Callowhill Overlay District. Stormwater open space and/or on-site systems to manage street drainage from the public right-of-way can be installed to gain a maximum of 72 feet of height bonus. It is important to note that PWD's *Stormwater Regulations* do not require the management of public street drainage, thus this legislation encourages developers to go above and beyond current requirements.

Green Roof Tax Credit

The Green Roof Tax Credit was first introduced in 2007 and incentivized the construction of green roofs, by offering a Business Income and Receipts Tax (BIRT) rebate for 25% of green roof costs up to $100,000. PWD worked with Councilmember Reynolds Brown to increase the BIRT rebate from 25% to 50% of the cost of constructing a green roof. Every individual, partnership, association, and corporation engaged in a business, profession, or other activity for profit within the City of Philadelphia must file BIRT. This includes property managers, developers (residential, commercial, industrial), estates and trusts, retail and wholesale businesses, and manufacturers. This tax credit can further motivate developers to use green roofs to comply with the *Stormwater Regulations*.

Interstate 95 Coordination

Throughout much of the duration of the Consent Order & Agreement (COA) implementation period, the Pennsylvania Department of Transportation (PennDOT) will be performing reconstruction and expansion work on Interstate 95 (I-95) in phases between Bleigh Avenue and Race Street. PWD has initiated a collaborative partnership with PennDOT to facilitate large-scale, incremental stormwater disconnection and installation of GSI. PWD's goals for this collaborative effort include: 1) ensuring that (Re)Development occurs in a manner consistent with the Philadelphia Stormwater Management Regulation; 2) when possible, disconnection of stormwater from the combined sewer system; and 3) installation of green stormwater infrastructure (GSI) in the public right-of-way.

To support this process, PWD created a PennDOT liaison position to coordinate with PennDOT on each of the design/construction sections. In the first sections where PWD and PennDOT sought to collaborate, the agencies often confronted physical and environmental obstacles that greatly complicated disconnection to the river. Over the course of a year, PWD and PennDOT collaborated on establishing the "Hierarchy of Stormwater Management Regulation Compliance on the I-95 Improvements Project," a decision tree for use by PennDOT as it plans for stormwater management in each section. This Hierarchy enables PWD to leverage GSI installation or the construction of a centralized stormwater facility, in addition to or instead of straight disconnection, when opportunities present themselves. This liaison position and decision tree have streamlined the coordination process and helped PWD to maximize this opportunity for stormwater management on a large-scale, long-term basis.

4.2.2 Public Investment Adaptations

PWD has spent the first five years of the program developing, enhancing, and standardizing its GSI implementation process to build the framework necessary for continued compliance. Most notably, PWD has significantly evolved its project identification and planning approach since the release of the IAMP. PWD has shifted from the original project identification approach based on land use and/or partner types (for example, campuses, schools and schoolyards, publicly owned parking facilities, publicly owned vacant lands) to a geographic approach with planning districts and multi-disciplinary staff performing more holistic opportunity evaluations of swaths of land. This planning process evolved from the original concept conceived of as Stormwater Management Enhancement Districts (SMEDs), where individual geographic areas were identified for holistic and maximum impact project opportunities. PWD has been providing updates through the COA Annual Reporting process on the progress of the original SMED locations. PWD does not anticipate following the SMED process for new areas moving forward. However, based on lessons learned from the SMED planning processes, PWD evolved from the land use-based planning process to a geographically oriented approach by delineating planning districts based largely on the Philadelphia City Planning Commission Districts within the Combined Sewer System.

To facilitate a geographically focused project identification approach, the Combined Sewer System drainage area has been delineated into four planning districts (Figure 4-2), each with multi-disciplinary staff including planners, engineers, public engagement specialists, and landscape architects as well as access to contractual resources. Staff coordinates with City Council, City agencies, and key neighborhood leaders to better understand where GSI project opportunities can be maximized in coordination with technical feasibility. With that understanding, the staff develops prioritization strategies for analyzing GSI opportunity within each planning district. Taking a geographic approach to analysis and implementation has allowed PWD to make concentrated and interconnected investments in GSI while leveraging coordination and cost sharing. Additionally, PWD has developed standardized planning and engineering approaches that allow staff to evaluate areas of varying size and opportunity.

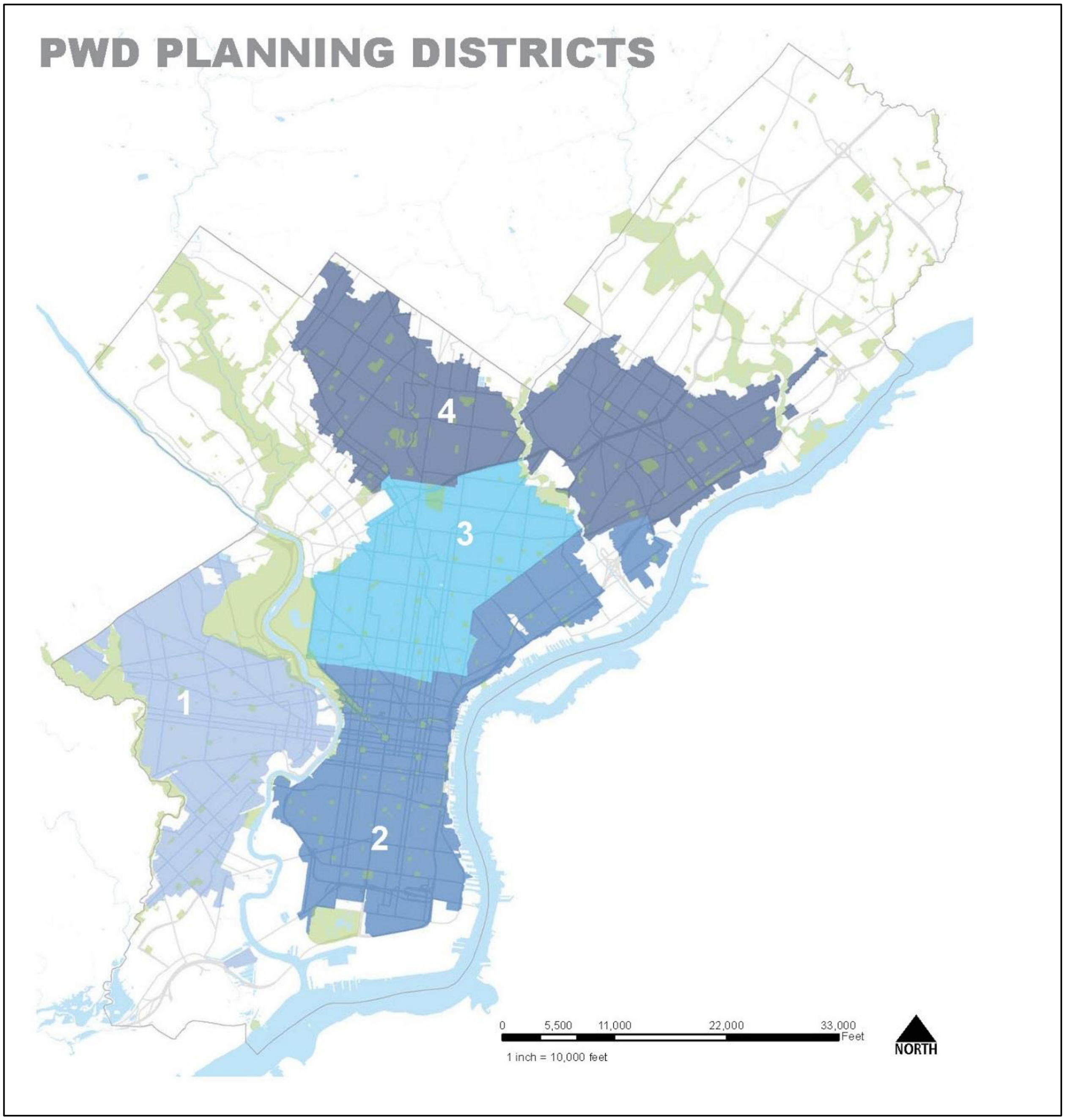

Figure 4-2: Planning District Map

Planning Study Area Analyses

The four planning districts are further delineated into manageable sections to conduct analyses called Planning Study Areas. Planning staff can build relationships with implementation partners within each District and curate a strategic queue of projects to move to design. The purpose of the Planning Study Area process is to evaluate areas of varying size using a standardized planning and engineering approach. This approach has allowed PWD to identify cost-effective GSI projects that maximize stormwater management potential and leverage opportunities for coordination and cost sharing. Additionally, large publicly owned parcels are sometimes situated at an ideal elevation in comparison to surrounding neighborhoods where a centralized storage/infiltration facility may be the best GSI solution. When these opportunities present themselves, PWD delineates study areas around them to assess the potential that may exist for maximizing stormwater management. This approach also allows staff to compare alternatives when multiple management opportunities are identified.

Planning Study Area Analyses include the following processes:

1. **Existing Conditions Analysis:** During this first phase, Geographic Information System base maps and other available existing conditions data are used to produce existing conditions mapping. This mapping includes any ongoing planning initiatives that affect the stormwater management potential of the site or study area.
2. **Drainage Area Delineation**: All drainage areas within the study area boundary are delineated using Geographic Information System to allow for comprehensive analysis of potential GSI locations. Unique drainage area identification numbers are assigned and each segment is labeled as a street, rooftop, or parcel.
3. **Feasibility Analysis**: Potential GSI locations are evaluated concurrently with the categorization of potential drainage areas. All available utility information is reviewed to understand and record constraints. Potential SMP footprints are drawn and associated drainage areas categorized as having high, medium, or low stormwater management potential.
4. **Alternative Selection**: After the feasibility analysis is complete, site visits are conducted for recommended sites to ground check assumptions made during desktop analysis. After site visits are completed, project summary sheets are created and updates to data and mapping are made.
5. **Final Recommendations**: Relevant maps, statistics, and supporting text summarize methodology, opportunities, challenges, and recommended outcomes.
6. **Packaging**: Recommended SMP locations, typically proximate to one another, are assembled into a project package(s). Once a package is finalized and approved, GSI design is initiated.

Each study area results in a list of potential projects to be implemented in the short and long term. Taking a geographic approach to analysis and implementation has allowed PWD to make more contextualized and interconnected investments in GSI while making us more responsive to opportunities for leveraging coordination and cost sharing.

As an example of the revised planning process, in 2015, a Planning Study was initiated for the Strawberry Mansion neighborhood in Lower North Philadelphia. The study area was a 258-acre tract adjacent to East Fairmount Park, bounded by 33rd Street, Lehigh Avenue, 29th Street, and a railway corridor. Figures 4-3 and 4-4 show results of existing conditions analyses and drainage area delineations. With a high density of vacant land, an expansive park, and several schools, the area was a prime location for identifying and implementing GSI.

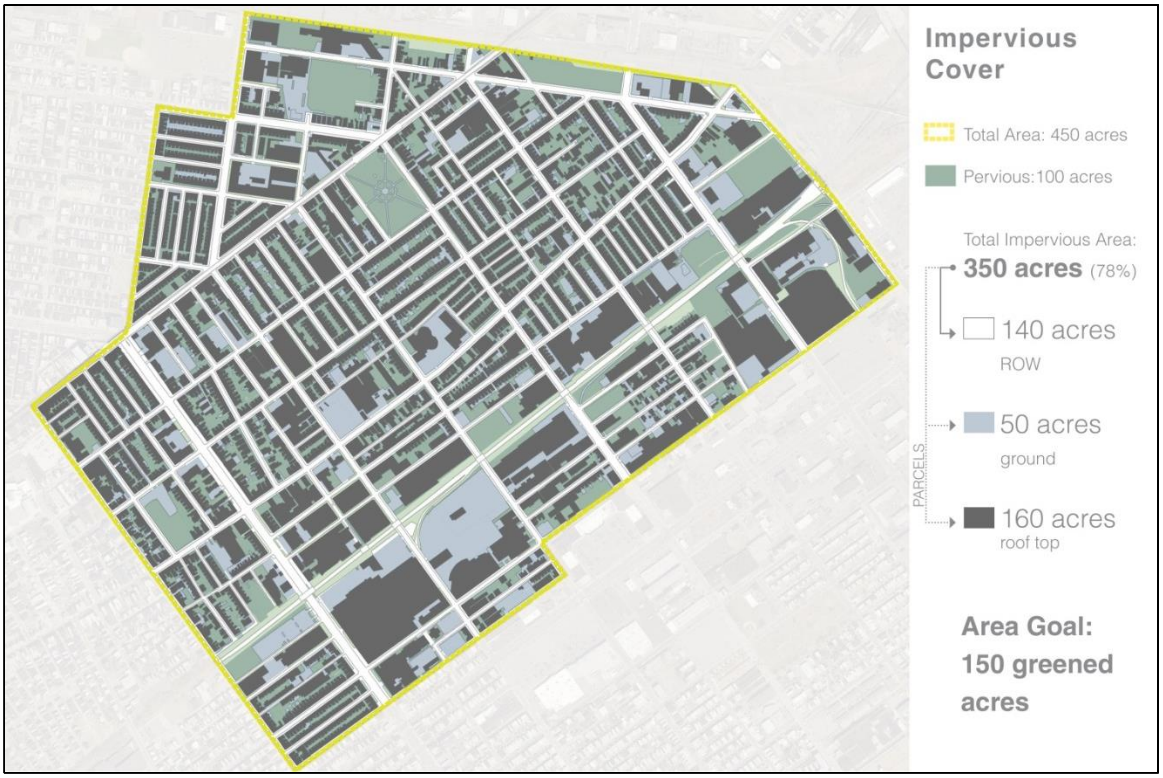

Figure 4-3: Impervious Cover Mapping for Kensington Study Area

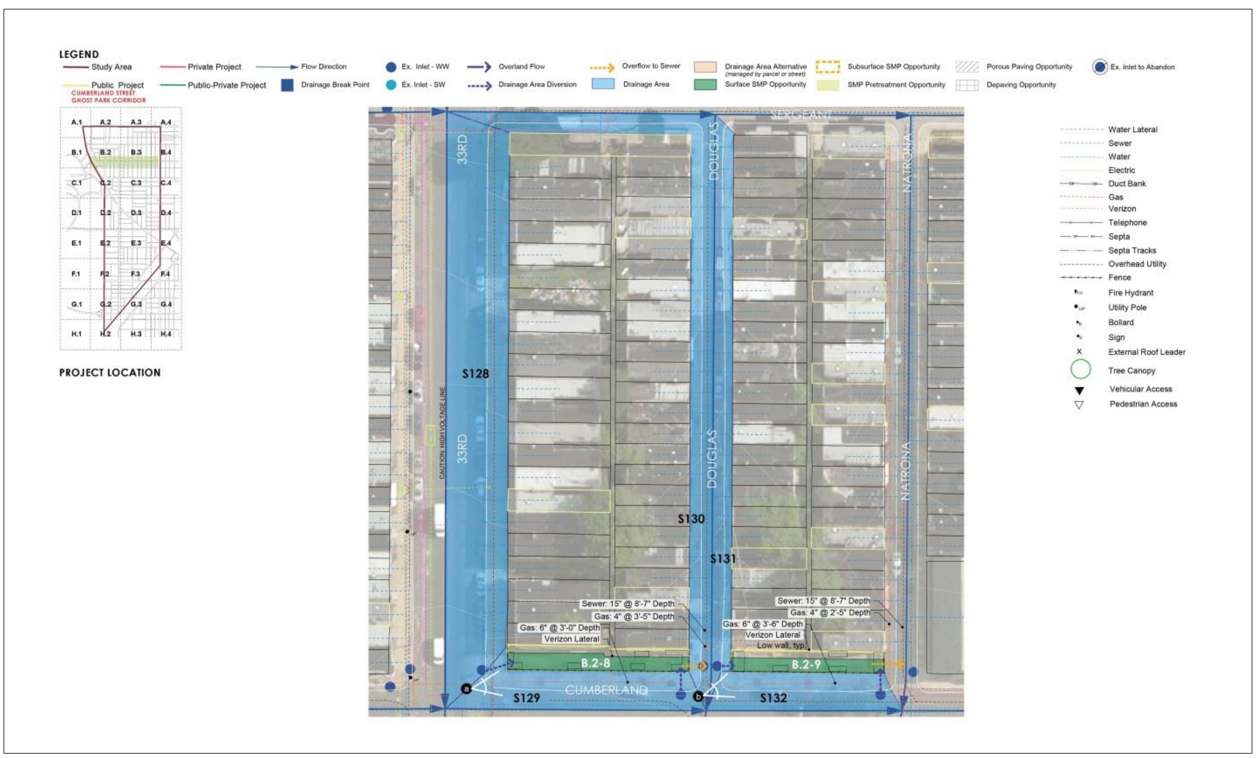

Figure 4-4: Site Level Drainage Area Delineation

As a result of this analysis, staff was able to:

- Identify over 140 potential projects that could result in 48 acres of managed drainage area;
- Determine metrics for potential stormwater capture by land use type and ownership;
- Develop a prioritization strategy for an area with an abundance of vacant parcels;
- Document land use issues that pertain to the implementation of GSI on vacant land; and
- Identify opportunities for coordination with ongoing Philadelphia City Planning Commission and Philadelphia Parks and Recreation initiatives.

Development of Manuals and Standards

Prior to the submission of the Long Term Control Plan Update and its supplements in 2009, PWD implemented a number of pilot projects aimed at demonstrating the utility of various GSI techniques in highly urbanized areas. The lessons learned from these early pilot projects in addition to those implemented during the first five years of the COA implementation period have led to the development of project identification, design, and landscaping standards for the program. Numerous resources have been developed to guide planners, designers, and contractors through the implementation process and can be found online at http://www.phillywatersheds.org/gsi_design_resources (Figure 4-5). PWD is presently consolidating these resources into a *GSI Planning and Design Manual* and resource website, to be released by the close of 2016. Standards are an essential requirement for increasing the scale of implementation demanded by the program. These standards also provide a clear baseline for PWD to measure continuous improvement over the coming years. PWD performs periodic updates to these documents to reflect lessons learned, and anticipates continuing this practice over the coming years. Additionally, PWD has hosted a number of contractor trainings to connect these resources with contractors and developers.

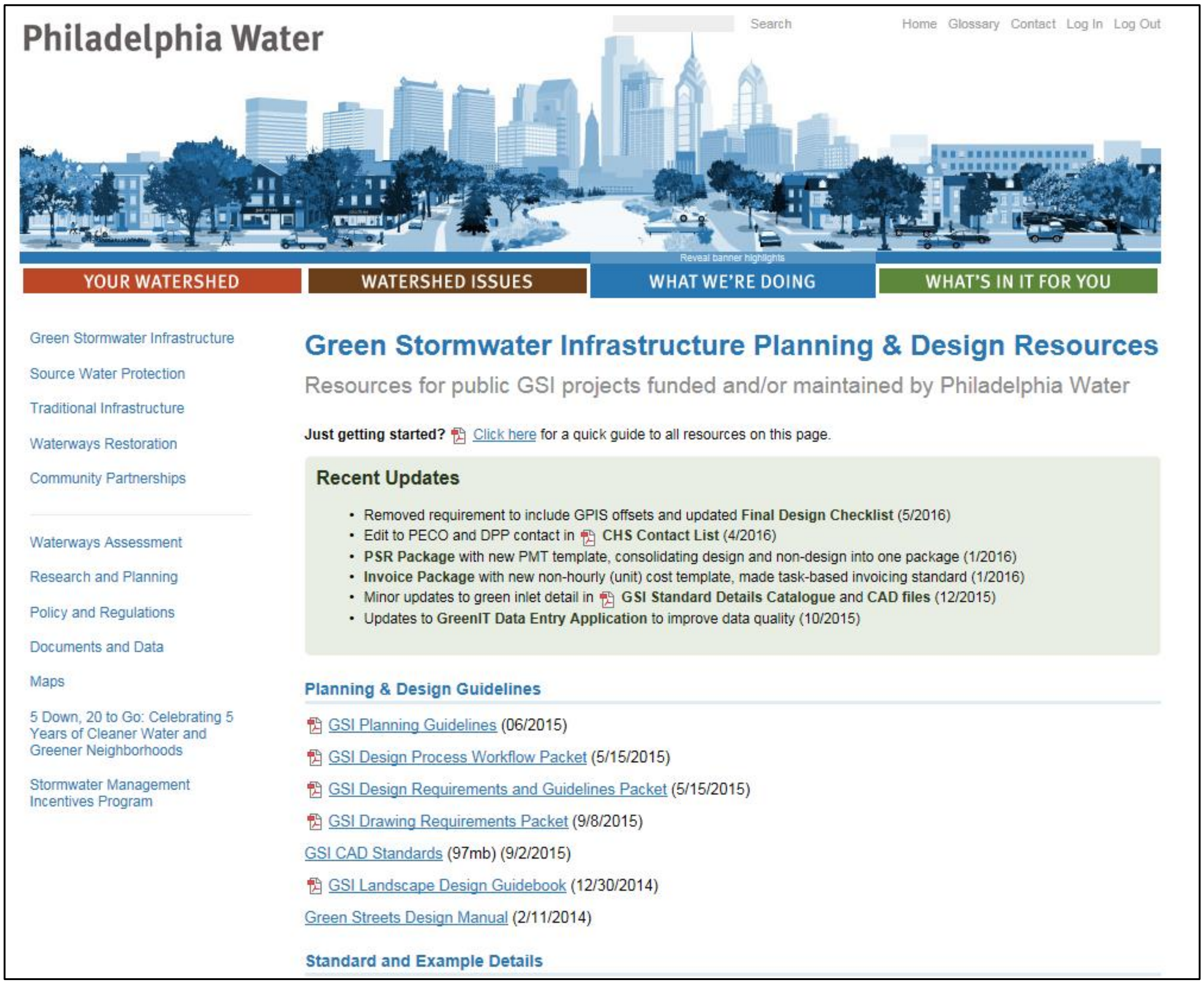

Figure 4-5: Screen Capture of GSI Planning and Design Resources

GSI Design Guidance

PWD regularly expands and improves upon its GSI design guidance. Lessons learned from early projects along with feedback from PWD's construction, monitoring, and maintenance teams have provided critical insights about constructability, site sustainability, and function of GSI. These insights have allowed PWD to improve design guidance and resources to streamline the design process. At present, PWD's resources for public GSI projects are summarized in nine separate documents, including the *GSI Planning Guidelines*, *GSI Design Process Workflow* Packet, the *GSI Design Requirements and Guidelines* Packet, the *GSI Drawing Requirements* Packet, the *GSI CAD Standards*, the *GSI Landscape Design Guidebook*, *the Green Streets Design Manual*, the *GSI Standard Details Catalogue*, *the GSI Standard Details for Public Parks & Recreation Facilities*, and the *Green Master Specifications*.

GSI Planning Guidelines

PWD developed *GSI Planning Guidelines* to standardize and streamline the project identification and process evaluation. The guidelines provide detailed guidance for delineating drainage areas, analyzing potential GSI locations, and tracking planning level decisions. A consistent approach to analysis and data collection is a key component of the overall planning strategy for successful implementation of short- and long-term projects. To ensure the outputs of planning level work can transfer seamlessly into the design phase, the information provided in the *GSI Planning Guidelines* aligns with the current *GSI Design Requirements and Guidelines*. The Guidelines have been updated periodically to reflect changes in planning approach and project identification.

GSI Design Process Workflow Packet

This packet provides detailed workflows and comprehensive process descriptions that define the design process for GSI projects funded and/or maintained by PWD. This guidance is primarily for PWD design consultants and other agencies or partner organizations working with PWD. The workflows describe the multiple implementation tracks in the typical design process, from design initiation to final design, and document the submission and review milestones.

GSI Design Requirements and Guidelines

The *GSI Design Requirement Guidelines* are used for all GSI projects funded and/or maintained by PWD. The Guidelines include detailed sizing, maintenance, and placement guidance as well as submission requirements, survey, geotechnical testing, and reporting guidelines. This information is derived from existing PWD policies and past experience. The Guidelines are regularly updated to reflect improvements in best practices and lessons learned throughout implementation.

GSI Drawing Requirements Packet

The *GSI Drawing Requirements Packet* summarizes requirements to be used in the drawing of all GSI projects funded and/or maintained by PWD. The packet includes standards for line types, symbols, and sheet layouts. Consistency in design drawings improves project outcomes by limiting misinterpretation during construction as well as post-construction management, record keeping, and maintenance.

GSI CAD Standards

PWD developed *GSI CAD Standards* that include all necessary files for drawing to PWD standards. The standards include templates (.DWT), pen tables (.CTB), support files (.SHX and block libraries), and a supporting user manual. Templates are supplied with pre-loaded styles and layers corresponding to the stages of plan preparation: base plan and design plan. The objective of establishing CAD graphical standards is to ensure contract documents conform to a widely recognized format. This conformance creates consistency among PWD projects and phases executed by varied consultants and streamlines the project review process.

GSI Landscape Design Guidebook

In 2014, PWD released the *Landscape Design Guidebook*. The Guidebook is the synthesis of knowledge from PWD's experience implementing GSI, partner preferences, current research, and municipal guides from other communities. The Guidebook was, in part, informed by PWD's annual SMP planting surveys. PWD has been systematically documenting species performance to improve plant selection. The Guidebook includes guidance on site assessment, landscape guidance, plant palettes by SMP, example scenarios, and landscape plans and an approved plant list. A revised version of the Guidebook is slated to be released in 2016. The new version will also include design requirements, which were summarized previously in the *GSI Design Requirements and Guidelines*. PWD anticipates making periodic updates as best practices evolve.

Green Street Design Manual

The City of Philadelphia's *Green Street Design Manual* (GSDM), finalized in 2014, summarizes design standards and guidance for public and private developers building GSI within the City right-of-way. The GSDM revolutionized PWD's ability to design and build green streets, by establishing a set of mutually agreed upon standards for GSI with the Streets Department. It is now the common framework that brings PWD and the Streets Department together and serves to align organizational goals. The GSDM provides detailed design templates that are flexible enough to be applied in a variety of urban street conditions. The GSDM has also become a national model for green street implementation, increasing public awareness and advancing knowledge for the burgeoning field of GSI.

GSI Standard Details Catalogue & Auto Computer-Aided Design (CAD) Files

The *Standard Details Catalogue* includes standard and example details required for use on PWD GSI projects. It serves as a toolbox for design engineers, and standardizes GSI components for ease of design and maintenance. The standard details were first developed from projects designed during the demonstration phase of the program. PWD regularly updates its standard details to reflect lessons learned. For example, PWD recently updated its standard details for curb cuts, standard inlets, and trench drains to eliminate the potential for runoff to bypass the SMP. This included the development of standard details for concrete aprons to intercept and guide flows into SMPs. This adaptation was triggered by feedback from the GSI monitoring and maintenance teams. PWD also makes public AutoCAD files for its standard details.

GSI Standard Details for Public Parks & Recreation Facilities

PWD worked with the Department of Parks and Recreation and the Department of Public Property to develop an initial set of standard GSI details. The details were developed as standards to assist in streamlining the design process for both in-house design and consultant-led projects. They are intended to be implemented and applied to a range of park development, redevelopment, and retrofit projects. The detail template includes basic material specifications and practices that can be applied to an overall GSI system design. Basic maintenance practices have been outlined and provisions included for developing sizing criteria for each detail.

Green Master Specifications

PWD has developed Green Master Specifications that define contractor requirements for all GSI projects. Specifications communicate to the contractor the definitive directions, procedures, material, and equipment requirements necessary for completing the contract work. The development of the Green Master Specifications is significant, as specifications can directly affect the quality of materials and construction. PWD frequently updates the Specifications to improve project outcomes. For example, PWD recently updated its soil specifications to include a high flow rate option. PWD modified its soil specifications to enable better drainage, to allow for additional filtration of stormwater going from the surface to subsurface storage within a system. Using higher flow rate soil mixes to filter runoff has allowed PWD to reduce the need for domed risers and distribution pipes.

As-Built Manual

The Green Stormwater Infrastructure (GSI) As-Built Survey and Drafting Manual was developed in 2015 and is being referenced in the specifications for GSI projects being bid by PWD moving forward. The manual describes the details and process for collecting and drafting As-Built survey data for GSI systems. It is to be used as a guide for construction contractors to perform the field survey and to draft As-Built drawings that are clear, consistent, and accurate. Supplemental CAD template and sample files are provided to contractors to assist with drafting of As-Builts. The manual and CAD files can be found on PWD's contractor resources page:
http://www.phila.gov/water/aboutus/buswithpwd/Pages/contractor.aspx

Contractor Trainings

PWD has also engaged in significant workforce development efforts. PWD has recognized the need to grow not only its own staff but also the expertise of the regional labor force, including planning, engineering, and construction firms. PWD offers semi-annual seminars to provide information to area contractors about PWD contracting opportunities, details on industry best practices, specifications on projects, and minority, women, and disabled business enterprise inclusion goals and requirements. PWD has also hosted GSI-specific training sessions for selected design contractors to review the typical GSI planning and design process, highlight key resources, and contract administration. Since 2011, PWD has held multiple contractor trainings for both design and construction firms. Additionally, PWD has cultivated a relationship with the Sustainable Business Network (SBN) to assist in green job development. In the summer of 2015, SBN hosted three GSI maintenance trainings and plans to offer the training again in 2016. More information about this training course is available here:
http://gsipartners.sbnphiladelphia.org/gsi-o-m-course/

4.3 Incentive Retrofits Program Adaptations

PWD has developed a variety of complementary incentive programs to encourage commercial and industrial property owners to retrofit their properties to manage stormwater on site to qualify for a credit to reduce the stormwater portion of their bill. Stormwater credits can be earned as a result of the construction and maintenance of privately owned SMPs that reduce a parcel's contribution of stormwater to the City's sewer systems and surrounding waterways.

Both retrofit and private development projects developed in accordance with the *Stormwater Regulations* are eligible for a reduction in their stormwater charge upon completion of construction. Owners must renew their credits every four years.

4.3.1 Evolution of Incentive Programs

Initially, to encourage a property owner to retrofit a property, PWD offered free site evaluation and concept planning services for customers for stormwater management. This assistance provided preliminary concept plans, cost benefit analyses, and helped the property owner understand the types of SMPs suitable for their property. As described in the IAMP, PWD coupled this support with a low interest loan program in launching the Stormwater Management Incentive Program (SMIP) in 2011. Unfortunately, demand for the loan program was minimal. As discussed in the 2012 Natural Resources Defense Council report, *Financing Stormwater Retrofits in Philadelphia and Beyond*, "although Philadelphia's new stormwater billing system provides one of the most compelling stormwater fee credits available nationally, the upfront costs of installing retrofits on a parcel will often remain prohibitively high for many of Philadelphia's non-residential property owners." Recognizing the limitations of the loan program, PWD in partnership with the Philadelphia Industrial Development Corporation, evolved the SMIP loan program to a grant program that provides funding to non-residential property owners to design and construct SMPs.

The SMIP program provides grants directly to non-residential property owners who want to construct stormwater retrofit projects. SMIP applications are evaluated based on a variety of criteria, including total volume of stormwater managed, cost competitiveness, and other environmental and educational benefits. Applications for grant requests are limited to $100,000 or less per impervious acre and manage at least the first 1" of runoff. As the result of the first five years of the SMIP program, Philadelphia has seen 163.7 GAs managed through this program.

Though the SMIP program has been successful in reaching customers throughout the City, many property owners have limited organizational capacity to manage the design and construction of GSI, and PWD saw limited participation from the large industrial and commercial properties where the return on investment would be most beneficial. Through the lessons learned implementing SMIP and from the financing strategies explored via research, PWD developed Greened Acre Retrofit Program (GARP).

The GARP Grant Program, launched in 2014, provides grant assistance to companies and project aggregators that can assemble large areas, often over multiple properties, for stormwater management projects. The GARP grant provides a scalable model for private stormwater management. Private property owners enter into a contract with a project aggregator; the aggregator manages the application, design, construction, and maintenance of the SMPs. This model reduces the administrative burden on the property owners, encourages growth in the private sector, and produces cost effective stormwater management. In less than two years of this program, 62.8 GAs were constructed. PWD has seen a great deal of interest in this program and a significant opportunity for additional cost effective GAs as the program continues.

4.3.2 Development of Manuals and Tools

PWD has developed numerous manuals and tools to encourage participation from property owners and to standardize incentive administration. Private property owners now have a suite of resources to inform their decision to retrofit, with guidance about planning to long-term maintenance. These resources can be accessed at the links below:

Grant Manual

PWD regularly updates the Grant Manual which outlines the requirements and application procedures for both the SMIP and GARP grant programs.
http://www.phila.gov/water/wu/Stormwater%20Grant%20Resources/SMIP_Manual_v1_LowRes.pdf

Stormwater Management Practice Operation & Maintenance Manual

Launched in 2015, this manual suggests maintenance actions and frequencies by SMP type, providing printable inspection and maintenance log forms.
http://www.phila.gov/water/PDF/Retrofit-O.M.Manual.pdf

Stormwater Retrofit Manual

In 2015, PWD developed the Stormwater Retrofit Guidance Manual. This manual includes information on credits, incentives, and planning and designing SMPs.
http://www.phila.gov/water/PDF/SWRetroManual.pdf

Stormwater Credits Explorer

As a digital complement to the Stormwater Retrofit Guidance Manual, PWD launched the Stormwater Credits Explorer. This groundbreaking application allows anyone with access to a computer or smartphone to virtually add GSI tools to non-residential properties and instantly see potential savings.
http://water.phila.gov/swexp/

5.0 Strategy for Achievement of Year 10 WQBEL Performance Standards

Program enhancements described in Section 4 have armed the Philadelphia Water Department (PWD) with the tools and approaches necessary to achieve the Year 10 Water Quality Based Effluent Limits (WQBEL) Performance Standards (Table 5-1). There are no additional major programmatic shifts planned at this time. As PWD looks ahead toward the next 5-year implementation horizon, we stand confident in our ability to meet the challenges ahead.

Table 5-1: Year 10 WQBEL Performance Standards

Metric	Units	WQBEL Target
NE WPCP Improvements	Percent Complete	See Section 5.1
SE WPCP Improvements	Percent Complete	
SW WPCP Improvements	Percent Complete	
Miles of interceptor lined	miles	6
Overflow Reduction Volume	million gallons per year	2,044
Equivalent Mass Capture (TSS)	percent	Report value
Equivalent Mass Capture (BOD)	percent	Report value
Equivalent Mass Capture (*Fecal Coliform*)	percent	Report value
Total Greened Acres	Greened Acres	2,148

5.1 Water Pollution Control Plant Upgrades

Commitments and schedules for wet weather treatment capacity and collection system enhancements for each of the City's Water Pollution Control Plants (WPCPs) are now outlined in the *Green City, Clean Waters Wet Weather Facility Plan* submitted in June 2016.

Over the coming five years, the wet weather treatment capacity at the Northeast WPCP will be increased through the construction and use of a secondary treatment bypass conduit. A gravity sludge thickening facility will be constructed to allow for the operation of the primary sedimentation tanks without a sludge blanket. Gravity sludge thickeners are anticipated to be complete by 2018 and the Secondary Treatment Bypass is anticipated to be complete by 2021.

5.2 Miles of Interceptor Lined

As of April 2016, PWD completed 7.5 miles of interceptor lining, surpassing the year 10 Performance Standard of 6 miles. Additionally, there are 4.3 miles in contract management and 3.3 miles in design (Table 5-2).

Table 5-2: Interceptor Lining in Progress

Project Name	Extents	Length (Miles)
In Contract Management		
Cobbs Creek Intercepting Sewer Lining Phase 2	61st and Baltimore to 60th and Warrington	*1*
Cobbs Creek Interceptor Lining Phase 3	City Avenue to Drainage Right of Way in former 67th Street	*1.7*
Cobbs Creek Intercepting Sewer Lining Phase 4 (Indian Creek Branch)	City Avenue to Drainage Right of Way in former 67th Street	*1.6*
Total		**4.3**
In Design		
Tacony Creek Intercepting Sewer Lining Phase 3	I & Ramona to O & Erie	*1*
Upper Frankford Lower Level Collector/Tacony Intercepting Sewer Lining Phase 4	Castor & Wyoming to Frankford/Hunting Park	*1.1*
Upper Frankford Creek Lower Level Collector/Tacony Intercepting Sewer Lining Phase 5	Frankford/Hunting Park to Luzerne & Richmond	1.2
Total		**3.3**

5.3 Volume and Equivalent Mass Capture

The combination of 2,148 Greened Acres (GAs) with WPCP modifications planned for the coming five years are anticipated to meet or exceed the Year 10 WQBEL Performance Standards for both Volume and Equivalent Mass Capture.

5.4 Greened Acres

During the coming five years, the program must realize at least 1,310 additional GAs to achieve the year-10 WQBEL Performance Standard of 2,148 GAs. Enhancements and adaptations made to the Green Stormwater Infrastructure (GSI) implementation program during the past five years have established a basis for continued success in future WQBEL Performance Standards. During the first five years of the program, PWD analyzed each of the Greened Acre (GA) implementation approaches, including (Re)Development Regulations, Public Investments and Incentivized Retrofits, to understand the implementation process, expected duration and general trends for each. This tracking and analysis informed PWD's projections for each approach for the coming five years.

5.4.1 (Re)Development Approach

When PWD developed the program strategy in the Implementation and Adaptive Management Plan in 2011, it was based on the best data available at the time, which included the (Re)Development trends in the City between 2006 and 2011. At that time, the rate of development that would be required to comply with the *City of Philadelphia Stormwater Regulations* was projected to be between 0.5% and 1.0% per year. PWD tracked

(Re)Development projects, schedules and trends very closely during the ensuing years. Since the *Stormwater Regulations* have been in place, 423 GAs from 266 projects were realized from this implementation approach. Data collected over the past five years indicates that it takes an average project 2.25 years from the time of technical submittal to complete construction. Not all projects that submit for technical approval complete construction, but those that did have an average project size of just over 1.5 GAs.

Understanding the trends and potentials of this implementation source allows PWD to form an implementation strategy for public investments and inform the expectations for other implementation approaches. PWD is using a data-driven approach to long-term planning, while maintaining flexibility to respond to deviations from existing trends. Specifically, when evaluating (Re)Development data, it has been seen that a large portion of the Greened Acres come from a few relatively large (Re)Development projects. Additionally, there are many challenges to establishing trends and projecting forward the potential benefit of (Re)Development, as the number and size of projects constructed in a given year is influenced by numerous outside factors (i.e. the market within the City, project financing, and other economic forces).

PWD has attempted gain a better understanding of economic trends and the GA potential from the *Stormwater Regulations* implementation approach. PWD commissioned a study of private trends and potential in 2013. Within the subsequent report *Future Greened Acres: Development Projections and Acres of Earth Disturbance Through 2036*, it was estimated that over the 2014-2036 period, there would be 6,425 acres of earth disturbance, an average of 279 acres per year generated citywide and of which 2,265 acres of earth disturbance at an average of 99 acres per year would occur within the combined sewer service area.

Projections for this pipeline are conservative as PWD looks toward Year-10. At present, there are 172 projects in the (Re)Development queue, ranging from technically approved (pending construction) to constructed but pending verification. PWD will attempt to identify opportunities to work with the property owners and engineers to maximize stormwater management potential. This will be done best if coordination can happen at the earliest stages of development planning as possible. Through ongoing and continuous outreach to the development community, PWD will help expand the opportunities for maximizing stormwater management on regulated sites.

Interstate 95 Coordination

The target area for stormwater planning along the Delaware River is bounded roughly by the Pennypack Creek to the north, the Philadelphia Naval Yard to the south, I-95 to the west, and the Delaware River to the east. The I-95 Improvements Project offers a partnership opportunity to address large-scale, incremental stormwater disconnection and installation of GSI. During 2015, PWD initiated a study that will enable PWD to better coordinate with PennDOT during its highway reconstruction project to ensure that opportunities for the installation of green streets and stormwater disconnection are maximized. More specifically, the study offers a framework to: 1) provide guidance on where PWD prefers that PennDOT focus its efforts for dedicated stormwater pipes and green streets so that the maximum amount of drainage area can be captured and removed from PWD's infrastructure along the I-95 corridor; and 2) allow PennDOT the opportunity to evaluate how dedicated stormwater pipes or green streets fit into PennDOT project programming along the I-95 corridor.

PennDOT has divided I-95 into programming sectors, sections, and phases (Figure 5-1). Sectors A and B compose the majority of the highway that passes through Philadelphia. Sector A, which extends from Bleigh Avenue to Race Street, is subdivided into five design/construction sections: CPR, BSR, BRI, AFC, and GIR. These sections are further subdivided into approximately 25 phases. Within the next five years, it is anticipated that phases CP2, BR0, AF1, GR1, GR2, and GR3 will have completed construction. Each phase has been subject to review by PWD's Stormwater Plan Review Group, and has incorporated stormwater management practices, such as rain gardens, infiltration and detention basins, vegetated swales, and stormwater tree trenches, to manage runoff from the highway. Of note, six dedicated stormwater pipes will be constructed as part of CP2 with the capacity to accommodate 100 acres of impervious cover disconnection between I-95 and the Delaware River. As parcels in this area are redeveloped, their connections can be redirected to these pipes thereby removing them from the Combined Sewer System drainage. Sector B, which extends from Race Street to the airport side of the Girard Point Bridge, received notice-to-proceed in 2015 for a three-year planning study.

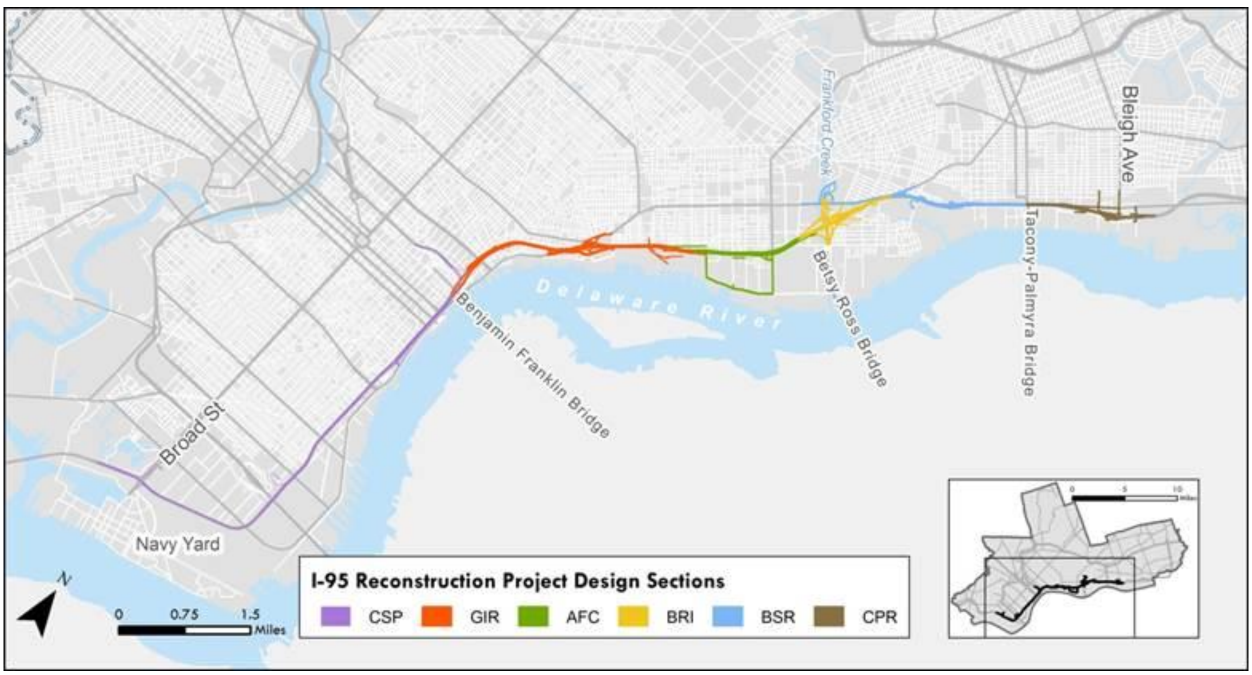

Figure 5-1: Interstate 95 Reconstruction Project Design Sections

5.4.2 Public Retrofits

PWD will continue to generate GAs with our public implementation approach. Often led by PWD, these projects are focused on City-owned properties and rights-of-way, where the City will own and maintain the resulting stormwater management practice. Through detailed evaluation of the first five years of implementation, PWD has a thorough understanding of the process and expected duration for implementation via the Public Retrofit implementation approach. During the first five years of the program, PWD achieved 180 GAs from 137 public retrofit projects. PWD has observed that public retrofit projects take on average 2.6 years from the point that they initiate design through construction completion. The average project size based on work number to date has been 2.9GAs.

Looking ahead toward the Year 10 WQBEL Performance Standard, PWD already has 276 projects in progress ranging from "in design" to "in construction". With the enhanced project identification approach that has evolved over the past few years of the program, PWD has optimized public retrofit potential. As described in Section 4, PWD has standardized its public GSI project delivery through continual system evaluation, identification of suboptimal outcomes and regular small and large scale process improvements. A new planning method presently under evaluation is the "Large Area Disconnection" performed on large publicly owned parcels that are situated at an ideal drainage elevation. These evaluations seek opportunities for large centralized storage/infiltration facilities to disconnect large swaths of impervious cover and centralize the management of that stormwater on a single site. The key to making one of these large-scale projects work is finding the correct combination of grading within the drainage area, space to manage stormwater, and limited utility conflicts for connecting a drainage network. PWD has completed several planning level studies and has a few projects in design. An example of such a project is at Lanier Playground, a multi-phased project currently in design with the potential to manage up to 45 GAs on a park site.

Rebuilding Community Infrastructure

There is a significant potential programmatic leverage opportunity on the horizon for the coming years of the program. On the November 2016 election ballot, Philadelphia residents will have the opportunity to vote on a bond referendum to approve the Rebuilding Community Infrastructure ("Rebuild") initiative. If supported through the fall referendum, the initiative will be funded by $300 million in general obligation bonds at $100 million per year over a three year period. Rebuild proposes to partially or fully redevelop hundreds of park, recreation and library sites throughout Philadelphia over the next six to eight years.

PWD intends to coordinate with Philadelphia Parks & Recreation and the Department of Public Property to maximize the volume of runoff managed at high-opportunity Rebuild sites, both from on-site stormwater management and from collecting and managing stormwater runoff from the surrounding streets. A preliminary analysis of potential Rebuild sites in the combined sewer area, suggests that as they are redeveloped, in addition to managing on-site stormwater volume for the sites, there is the potential to manage up to 5 times the stormwater volume from the right-of-way relative to on-site runoff. In anticipation of this referendum passing and the program becoming a reality, PWD is currently developing a workflow to manage the design, construction, and cost share arrangements for these projects.

5.4.3 Incentivized Retrofits

Although the Incentivized Retrofits approach is the newest implementation source in the program, PWD recognizes that it has potential for garnering a significant amount of acreage at a cost-effective threshold. In these first years of the program, Stormwater Management Incentives Program (SMIP) achieved 168 GAs and Greened Acre Retrofit Program (GARP) 63 GAs. An additional 8 GAs have been achieved through voluntary site retrofits without PWD grant funds. The average SMIP and GARP project size is 6.2 GAs. To date, PWD has observed that the average SMIP implementation duration is approximately two years while the average GARP project implementation duration is just under one and a half years. Trends are based on limited data at this time as both grant programs are fairly young. SMIP grants were first offered in 2012 and GARP in 2014.

PWD has observed that GARP helps to reduce overall program costs because of the efficiency of design and construction being managed by a single entity and the ability to aggregate multiple projects within a single portfolio. PWD maintains oversight on each phase of SMIP and GARP projects by approving applications, reviewing and approving the stormwater management plans, performing construction inspections, approving all funding and payment requests and performing long-term maintenance inspections to verify that the SMPs are being maintained and are compliant with PWD's Maintenance Agreement.

Because the programs are so new, it is challenging for PWD to put forth a future program projection based on data and trends; however, PWD plans on budgeting a combined $15 million per year to support both SMIP and GARP grants through 2021. As of June 2016 there are 79 GAs worth of awarded projects currently in progress.

PWD is exploring ways to make the SMIP and GARP agreement structures more attractive to project developers by minimizing up-front and carrying costs. Additionally, PWD is looking at ways to better match project developers with property owners who desire stormwater retrofits. PWD may also continue to pursue the management of right-of-way runoff on private property by oversizing SMPs developed via SMIP and GARP. As the number of applications increases, PWD could prioritize funding for projects that maximize management through right-of-way capture. Lastly, PWD staff also look to engage land developers early in the submittal process to Plan Review to explore ways to maximize the stormwater management potential on each regulated site, and PWD's grant programs will be an important tool in those negotiations.

5.4.4 Research and Innovation

The program maturation experienced over the past five years has produced a more refined set of tools. PWD believes that there is more to learn and opportunity for within-program enhancements to be continually evaluated and to better understand the benefits and costs of various treatment types and continues to seek the most cost-effective means for implementing the program. To help ensure the program continues to stay on the leading edge of knowledge and practices going forward, PWD supports a number of research and innovation partnerships.

PWD continues to support the United States Environmental Protection Agency Science to Achieve Results (STAR) Grant research endeavors. Initiated in 2012, the STAR grant proposals were aimed at research on and demonstration of the performance and effectiveness of GSI practices to address combined sewer overflows in the City of Philadelphia. Research agreements were signed with 5 universities: Swarthmore College, Villanova University, Temple University, The University of Pennsylvania, and The University of New Hampshire. PWD has provided data and helped coordinate site selection for instrumentation of GSI systems and SMPs. These monitoring partnerships have begun to provide data complementing monitoring results from PWD's own monitoring programs. Grantees have begun to share research results at conferences and in peer-reviewed journals. The following is a brief summary of each university's research focus:

- **Swarthmore College:** Subsurface monitoring of PWD GSI sites; multi-objective, spatial optimization model for GSI placement
- **Villanova University:** Monitoring and analysis of PWD GSI to develop "next generation" GSI focused on infiltration, evaporation, and transpiration
- **Temple University:** Surface and subsurface monitoring of installations in and around the Temple campus
- **University of Pennsylvania:** Analysis of financial and economic factors affecting decisions in the private sector, and development of tools that may facilitate better stormwater management in the private sector
- **University of New Hampshire:** Assistance to neighborhood groups seeking to implement GSI; experiments on GSI installations derived from PWD specifications

In 2015, PWD initiated the *Green City, Clean Waters* Research Center (GCCWRC), a research partnership between PWD and Villanova University. The mission of this partnership is to increase PWD's knowledge of GSI best practices and state of the art research in peer cities, utilities and institutions, as well as to advance GSI with laboratory and field research. The results of this research will inform urban GSI practices that are effective, cost-effective, constructible and maintainable. During the first year of the GCCWRC, Villanova University initiated a literature review and peer city studies on several topics of interest to PWD including the following:

- **Evapotranspiration (ET):** The main research question driving this evaluation is whether and how to refine consideration of ET in the design and regulatory crediting of GSI practices. Focusing on rain gardens (bioretention and bioinfiltration systems) and green roofs among the GSI practices, a comprehensive literature review and peer city study along with the findings from past and ongoing research at Villanova University have been used to show the significance of ET in the long-term performance of GSI practices, and to refine methods for estimating ET.
- **Infiltration:** There are two main groups of research questions driving this evaluation. The first group of questions are about the best methods for measurement and prediction of the infiltration rate of soils underlying proposed GSI systems. The

second group of questions encompass the temporal and spatial variation of infiltration behavior at an Stormwater Management Practice (SMP) site, with implications for the design, monitoring, and maintenance of infiltration SMPs. In summary, variation over time and space as well as field investigation techniques are three important issues when determining expected infiltration assumptions for use in design.

- **Pretreatment / Inlet Hydraulics:** Existing design manuals and technical reports from multiple peer cities were investigated in order to establish whether there are innovative practices used elsewhere that can be beneficial to Philadelphia. With an understanding of existing practices, recommendations and future research ideas are evaluated based on the needs of PWD.

The product of the first year of the GCCWRC has proven valuable to the GSI design staff. PWD plans to continue this research endeavor over the coming years. PWD has assembled a list of topics for consideration by the GCCWRC. Topics under consideration for research in the coming years (in no particular order) include:

- **Evapotranspiration:** Seek to further evaluate how ET pathways work in GSI systems. The GCCWRC may seek to develop a scientific approach to incorporation of evaporation in regulatory reporting metrics.
- **Infiltration:** Seek to further evaluate how infiltration pathways work in GSI systems. Results may lead to new approaches to successfully and cost effectively enhance GSI infiltration. They may also seek to evaluate whether changes should be expected in infiltration rates over time including both decreases and increases, and how this can be accounted for in design.
- **Controlled Release:** The GCCWRC may evaluate new technologies or enhancements that provide increased control over release of stored stormwater to the combined sewer system.
- **Planting, Filtration and Storage Media:** Evaluate various media for effects on plant growth and infiltration including engineered storage media or mixes of native and engineered storage media. Results may help refine assumptions about soil properties such as porosity, effective porosity, soil moisture characteristics, and degree of compaction. The program may evaluate soil and storage technologies such as structural soils, structural cells, gravel, or manufactured storage materials.
- **Pretreatment, Sedimentation, Energy Dissipation:** Seek to further evaluate the most successful and cost-effective pretreatment approaches (for example forebays, sumps, filters, separators, changes in maintenance frequency). Results of this research topic could help avoid clogging, reduce maintenance, or increase expected system life span.
- **Inlet/Curb Cut Design:** Further evaluate inlet design enhancements aimed at ease of maintenance, improved efficiency, controlling flow rate, or collecting sediment and trash. A literature review and peer city study on inlet trash systems followed by on-site tests may be considered.
- **Real Time Control (RTC):** Evaluate real time control to assess its potential for improving cost-effective function of SMPs. This may include evaluation of pumping

or other RTC devices and evaluation of soil moisture-based monitoring and controls. Other possibilities include automatic notification and download of new data, notification of monitoring equipment failure, notification of data outside an expected range, and notification of suspected GSI maintenance needs (for example if the system has not drained for a certain amount of time in dry weather).

- **Trees/Vegetation:** Evaluate recent refinements to GSI tree/vegetation requirements or guidelines other cities have made that are relevant to Philadelphia's climate. For example, they may look for programs that successfully improve performance or service life using specific tree and vegetation types, such as deep rooted grasses. They may seek to better understand how drought tolerance and soil moisture characteristics affect performance and survival of plants within a system.
- **Geotechnical and Geophysical Testing:** Evaluate expanded use of technologies such as ground-penetrating radar to assess whether this can be used to support design and maintenance.
- **Monitoring:** Evaluate various technological enhancements to sensors and communications equipment.
- **Porous Pavement:** Evaluate advances and best practices in use of porous asphalt, concrete, and paver technologies.
- **Maintenance:** Evaluate leading edge maintenance practices and technologies used by peer cities and utilities, and how system design impacts ease of maintenance.
- **Climate Change:** Evaluate resilience of GSI systems under climate change conditions and seek to develop appropriate assumptions for design of system under changing long-term conditions.

In 2016, PWD anticipates the development of a "Green Infrastructure Living Laboratory" (GILL) in partnership with Drexel University. The study area for GILL will be focused on the area in the University City District of Philadelphia. University City includes Drexel's future Innovation Neighborhood, the Drexel University campus, the University of Pennsylvania campus and surrounding communities in Mantua and Powelton Village. This 1.34 square mile study area is generally bounded by Spruce Street to the South, 40th street to the west, Mantua Avenue to the North, and the Schuylkill River to the East. Drexel is a major property owner in the region, with at least 19 different GSI installations on campus. Within the GILL study area, Drexel researchers will monitor the performance of innovative GSI, derive conclusions and make recommendations for design, construction, and maintenance of GSI in Philadelphia.

5.5 Conclusion

The City of Philadelphia has either met or exceeded all Year 5 WQBEL Performance Standards as required by the COA. This document has provided an assessment of the City's progress towards the WQBEL Performance Standards and descriptions of program elements expected to be implemented in the next five-year period. The performance monitoring of GSI has shown that overall, systems are performing better than predicted by our current engineering design assumptions. Results (including infiltration rate, storage use, and drain down duration analyses) indicate that systems are regularly managing storms in excess of 3.0 inches with significant storage capacity remaining unused and available to manage back-to-back storms that may occur, and also allowing for the opportunity to disconnect additional impervious area to the site should opportunities present themselves in the future.

The adaptive management process has been successful in guiding the City towards programmatic re-evaluations and/or revisions on a regular basis, encouraging 'within-program' adaptations and enhancements throughout the first five-year implementation period. The City will continue this process to ensure that WQBEL Performance Standards are met, while optimizing and enhancing the program along the way. The City is confident that steps taken and knowledge gained during the first five years have equipped PWD with the necessary tools and processes to achieve Year 10 WQBEL Performance Standards. In the coming years, PWD anticipates additional model enhancements, implementation enhancements, innovation and evaluations to ensure that the WQBEL Performance Standards are achieved in the most cost-effective way. PWD plans to continue the monitoring program as described in the Comprehensive Monitoring Plan (CMP) until a CMP update is initiated.