Green City, Clean Waters

Year 10 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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Table of Contents

List of Tables

1.0 Introduction

2.0 Program Evaluation

3.0 Assessment of Program Performance

4.0 Program Adaptation

5.0 Strategy for Achievement of Year 15 WQBEL Performance Standards

List of Figures

1.0 Introduction

2.0 Program Evaluation

3.0 Assessment of Program Performance

4.0 Program Adaptation

5.0 Strategy for Achievement of Year 15 WQBEL Performance Standards

Appendices

Glossary of Acronyms

BOD	Biological Oxygen Demand
CMP	Comprehensive Monitoring Plan
COA	Consent Order and Agreement
COVID-19	2019 novel coronavirus disease
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWL	Continuous Water Level
DCIA	Directly Connected Impervious Area
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DRBC	Delaware River Basin Commission
DSU	Development Services Unit
EAP	Evaluation and Adaptation Plan
EFDC	Environmental Fluid Dynamics Code
EMC	Event Mean Concentration
ERSA	Existing Resources and Site Analysis
GA	Greened Acre
GARP	Greened Acre Retrofit Program
GARR	Gage-Adjusted Rainfall Data
GSI	Green Stormwater Infrastructure
H&H	Hydrologic and Hydraulic
IAMP	Implementation and Adaptive Management Plan
L&I	Licenses and Inspections
LMER	Linear mixed-effect regression
LTCPU	Long Term Control Plan
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
O&M	Operations and Maintenance
PADEP	Pennsylvania Department of Environmental Protection
PCPHL	Power Corps Philadelphia
PCSMP	Post-Construction Stormwater Management Plan
PSU	Percent-of-storage-used
PWD	Philadelphia Water Department
ROW	Right-of-way
RPSU	Relative percent-of-storage-used
SMIP	Stormwater Management Incentive Program
SMP	Stormwater Management Practice
SOD	Sediment Oxygen Demand
SWMM	Storm Water Management Model
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WPCP	Water Pollution Control Plant
WQBEL	Water Quality Based Effluent Limits
WWFP	Wet Weather Facility Plan

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 (CSS) 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. PWD submitted its first Evaluation and Adaptation Plan (EAP) on October 30, 2016, which contained a comprehensive assessment of the first five years of the City's progress with implementing the Approved LTCPU. The Year 10 EAP consists of a comprehensive assessment of program progress at the Year 10 milestone, including an assessment of compliance with Water Quality Based Effluent Limits (WQBEL) Performance Standards and an updated assessment of receiving water conditions.

1.1 Program Evaluation

According to Section 3) e) of the COA, an EAP will be submitted at least 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:

NE / SW / SE Water Pollution Control Plant Upgrades: Design and Construction

PWD operates three Water Pollution Control Plants (WPCPs): the Northeast, Southwest, and Southeast WPCP. The *Wet Weather Facility Plan* (WWFP), which was submitted on June 1, 2016, provides details on scheduling, cost, and anticipated construction completion for each project. The WWFP is available at the following link:
http://water.phila.gov/pool/Wet_Weather_Facility_Plan_website.pdf

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 means 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 is represented by Philadelphia's physical systems as they were configured on January 1, 2006. Both volumes will be determined from modeling, using climatic data representing the same "typical year" for Philadelphia as determined in the LTCPU development process, and a hydrologic/hydraulic model calibrated with flow data collected for verification of actual performance.

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 CSS. Conformance with these metrics will be documented through simulations performed using the hydrologic and hydraulic (H&H) models described in the LTCPU and its supplements.

Total Greened Acres

A Greened Acre is an expression of the volume of stormwater managed by green stormwater infrastructure, based on the design for the project, and is conditional on the proper operation and 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 are tracked as Greened Acres (GAs) using the following equation:

$$\mathbf{GA = IC * Wd}$$

IC is the impervious cover using 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). Green stormwater infrastructure 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.

For more information about the GA calculation method, please refer to Section 2.8 and Appendix B: Calculation Methods.

Evaluation and Adaptation Plan Components

The COA states that each EAP include the following components:

1. Performance tracking of the CSO Program in the form of hydrologic/hydraulic modeling with verification using metered data, as described in Section 10 of the LTCPU;
2. Up-to-date values for each of the metrics that appears in Table 1 of the Water Quality Requirements section of the permits, with details to describe how the reported values were calculated;

3. An assessment of how each reported metric value compares to the Performance Standards provided in Table 1 in the Water Quality section of the NPDES permits;
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 program implementation, describing the means that the City proposes to use to ensure that the metric will meet the appropriate Performance Standard by the date of the next Evaluation and Adaptation Plan; and
5. Up-to-date values for the following additional metrics:
   - Total number of Green Infrastructure projects used to calculate Greened Acres;
   - Volume of stormwater (in million gallons per year) managed by new infrastructure other than Green Infrastructure; and
   - Volume of Percent Capture for the combined sewer system as a whole.

Beginning at Year 10, the EAPs must also include an updated assessment of receiving water conditions, using the results of water quality modeling for the receiving waters.

1.2 Adaptive Management Process

The *Green City, Clean Waters* program is predicated on an adaptive management framework, described in the LTCPU, and affirmed in the COA. An adaptive management approach enables 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 WQBEL Performance Standards in the COA and assessments of progress toward those 5-year benchmarks within EAPs. This structure enables programmatic re-evaluation and/or revision if or when needed. At the close of Year 10 of the program, PWD is not proposing any significant programmatic changes.

1.2.1 Year 10 Deadline Extension

On March 6, 2020, the Governor of Pennsylvania issued a Proclamation of Disaster Emergency in response to the 2019 novel coronavirus disease (COVID-19). At that time, 140 privately led projects and 85 PWD-led projects were under construction and while some private projects received waivers to remobilize, most experienced delays in their construction timelines. Due to the impacts of COVID-19, PWD requested and was granted a seven-month extension to achieve the Year 10 Performance Standards and deliverables under the COA. PWD submitted the request on April 6, 2021, and the extension request was subsequently granted by the Pennsylvania Department of Environmental Protection (PADEP) on April 13, 2021, through the Force Majeure clause in Section 15 of the COA. This approval extended the deadline for achievement of the Year 10 WQBEL Performance Standards of the COA to December 31, 2021, and submission of the EAP to May 30, 2022.

The extension request and approval documentation is available here: https://water.phila.gov/pool/files/coa-year10extension-granted-2021-04-13.pdf

1.3 Contents of the Plan

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

Section 1 provides an introduction and overview of the EAP contents.

Section 2 provides an evaluation of the program progress toward each WQBEL Performance Standard. This section also includes an updated assessment of receiving water conditions as required in the COA for Year 10.

Section 3 documents an assessment of program performance using monitoring data collected at the stormwater management practice level (in accordance with the *Comprehensive Monitoring Plan*) during this implementation period.

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

Section 5 documents a Strategy for Achievement of Year 15 WQBEL targets and a description of program elements anticipated to be implemented in the next five-year period.

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) as required by the Consent Order and Agreement (COA). As of December 31, 2021, the City of Philadelphia has met or exceeded each of the Year 10 Performance Standards.

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

Metric	Units	Base Line Value	Year 10 WQBEL Target	Cumulative Amount as of Year 10 (2021)
NE WPCP Improvements	Percent Complete	0	See Section 2.2.1	
SE WPCP Improvements	Percent Complete	0	See Section 2.2.2	
SW WPCP Improvements	Percent Complete	0	See Section 2.2.3	
Miles of Interceptor Lined	Miles	0	6	9.2
Overflow Reduction Volume	Million Gallons Per Year	0	2,044	3,080
Equivalent Mass Capture (TSS)	Percent	62%	Report value	77.5%
Equivalent Mass Capture (BOD_5)	Percent	62%	Report value	~100.0%*
Equivalent Mass Capture (*Fecal Coliform*)	Percent	62%	Report value	77.1%
Total Greened Acres	Greened Acres	0	2,148	2,196

*BOD_5 capture has met or exceeded the 85% equivalent mass capture. The amount of BOD_5 captured has met or exceeded the load reduction that is associated with 85 percent capture volume treated using primary clarification and disinfection using the end-of-pipe treatment technology.

2.1 Calculation Methods

To simplify referencing, a calculation methods Appendix is included in this Evaluation and Adaptation Plan (EAP). All calculation methods for applicable Performance Standards can be found in Appendix B: Calculation Methods.

2.2 WPCP Design and Construction

Proposed upgrades to increase wet weather treatment capacity at each of the City's Water Pollution Control Plants (WPCPs) are described in the *Green City, Clean Waters Wet Weather Facility Plan*, which was submitted on June 1, 2016. This plan was developed to provide details including schedule, cost, and anticipated construction completion for each project. To date, PWD has met or exceeded all Year 10 commitments to WPCP and collection system improvements.

2.2.1 Northeast Water Pollution Control Plant

The following table represents Northeast WPCP implementation progress to date (Table 2-2).

Table 2- 2: Status of Northeast WPCP Improvements

Northeast WPCP Improvements	Project Status	Reporting Milestone
Facility Improvements		
Remove Double Deck Effluent Channel in Final Sedimentation Tanks Set-2	Complete	2016 (Year 5)
New (4 x 48") conduits from Preliminary Treatment Building to Primary Sedimentation Tanks Set-1	Complete	2016 (Year 5)
High Flow Management System	Complete	2021 (Year 10)
Gravity Sludge Thickeners	Complete	2021 (Year 10)
Primary Treatment Building #2	In Contract Management	2031 (Year 20)
New Influent Baffles in Primary Sedimentation Tanks Set-2	In Planning	2031 (Year 20)
Operational Improvements		
Operate with minimal sludge blanket when Gravity Sludge Thickeners in service	Complete	2021 (Year 10)

2.2.2 Southeast Water Pollution Control Plant

The following table represents Southeast WPCP implementation progress to date (Table 2-3).

Table 2- 3: Status of Southeast WPCP Improvements

Southeast WPCP Improvements	Project Status	Reporting Milestone
Facility Improvements		
Replace Influent Pump Station Coarse Bar Rack	Complete	2016 (Year 5)

2.2.3 Southwest Water Pollution Control Plant

The following table represents Southwest WPCP implementation between 2016 and 2021 (Table 2-4). The project listed has been completed prior to the reporting milestone.

Table 2- 4: Status of Southwest WPCP Improvements

Southwest WPCP Improvements	Project Status	Reporting Milestone
Facility Improvements		
Add Redundant Effluent Pump	Complete	2026 (Year 15)

2.2.4 Philadelphia Collection System Improvements

The following table represents collection system implementation to date (Table 2-5).

Table 2- 5: Status of Collection System Improvements

Collection System Improvements	Project Status	Reporting Milestone
Improvements		
NE Second 66” Frankford Grit Chamber Bypass In Service	Complete	2016 (Year 5)
NE Frankford High Level Second Barrel Rehabilitation	Complete	2016 (Year 5)
All Districts: Balancing CSO Regulator Wet Weather Capacities	On Track	Study - Ongoing

2.3 Miles of Interceptor Lined

The WQBEL Performance Standards require 6 miles of interceptor to be lined by 2021. PWD exceeded this target at Year 5 with 7.5 miles completed prior to 2016. As of 2021, PWD has completed 9.2 miles of interceptor lining with six project segments (Table 2-6).

Table 2- 6: Miles of Interceptor Lined by Segment

Project Name	Extents	Length (Miles)	Reporting Milestone
60th and Cobbs Creek Parkway to 75th and Wheeler Sewer Lining	60th and Cobbs Creek Parkway to 75th and Wheeler	2.2	2016 (Year 5)
Cobbs Creek Park to 63rd and Market Sewer Lining	Cobbs Creek Park to 63rd and Market	0.5	2016 (Year 5)
Cobbs Creek Interceptor Phase 1 Lining	63rd and Market to 62nd and Baltimore	1.6	2016 (Year 5)
Tacony Creek Intercepting Sewer Lining Phase 1	Chew & Rising Sun to I & Ramona	1.9	2016 (Year 5)
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	2016 (Year 5)
Cobbs Creek Interceptor Lining Phase 3	City Avenue to Drainage Right of Way in former 67th Street	1.7	2021 (Year 10)
Total		**9.2**	

2.4 Overflow Volume Reduction

PWD has exceeded the Overflow Volume Reduction Performance Standard of 2,044MG. As of December 31, 2021, the City’s Combined Sewer Overflow (CSO) volume has been reduced by 3,080MG from the baseline based on the COA documented typical year precipitation pattern.

2.4.1 Volume Percent Capture for Combined Sewer System

As the result of the collective implementation initiatives, including Green Stormwater Infrastructure (GSI) and collection system improvements and enhancements, system-wide volume percent capture has increased to 70.7% from baseline (Table 2-7).

Table 2- 7: Year 10 Volume Percent Capture for CSS

	2011 Baseline "Percent (Volume) Capture"	Year 5 (2016) "Percent (Volume) Capture"	Year 10 (2021) "Percent (Volume) Capture"
Percent (Volume) Capture	62%	66.6%	70.7%

2.4.2 Hydrologic and Hydraulic Models

This section summarizes modifications to hydrologic and hydraulic (H&H) models since the last EAP submission in 2016. The CSO volume reduction calculation method has not changed since it was documented in the Year 5 EAP, but the models used for evaluation of the Year 10 EAP have been rebuilt. The CSO volume reduction calculation method can be referenced in Appendix B. A summary overview of the H&H model rebuild is provided below with a full description included in Appendix C.

PWD is committed to building and maintaining mathematical models using the most current and best available information and data to represent physical conditions of the system. This involves a commitment to collect flow and level monitoring data, understanding changes to the waste and storm water collection system, collecting, and reviewing GSI information, and using this data and information to better inform the model. This data and information is used to inform and keep the mathematical models up to date and represent the current physical conditions. Keeping the models up to date is essential to support not only regulatory compliance but also to support planning, design efforts, and operations of the combined and separate sanitary sewer system.

As presented in the Year 5 EAP, by the close of 2016 a series of updates were made to the compliance model, including the transition from the United States Environmental Protection Agency (US EPA) Storm Water Management Model (SWMM) 4 software to the SWMM5 engine and enhancement to GSI representation. Since the submission of the Year 5 EAP, PWD has undertaken a rebuild of the H&H model based on the best available information. The model update was based on a significant amount of flow monitoring data and GSI implementation information, and the model was rebuilt with enhancements that better represent the system. These changes fulfill the commitment made in the Year 5 EAP to use the collected flow monitoring information to calibrate and validate the H&H models and represent the best available information.

A model rebuild occurs infrequently and can be prompted by adoption of new modeling methodology (e.g., transition from planning to implementation), a rebuild of the mathematical simulation engine or a change in software, and/or the accumulation of a critical mass of information. This contrasts with the use of the term model update, which will occur more frequently and can be prompted by updates to the collection system, model inputs or configuration, (e.g., increase in model resolution or elevation corrections in the collection system), updates to hydrologic parameters to represent the best available information, and/or the identification of a flaw.

The 2017/2018 model rebuild includes improvements to the model representation of sewersheds that produce stormwater runoff and the representation of the GSI processes. The rebuild also utilizes the US EPA SWMM5 model engine upgrades. One of the most notable parts of this rebuild is the utilization of additional flow monitoring data collected from combined and sanitary sewer locations across the City of Philadelphia. Other updates include new average dry weather flows based on analysis of the flow monitoring data.

The extensive dataset provided by construction of GSI projects has been used to transition from a planning level representation of GSI to an implementation level representation of GSI in the H&H models. This implementation level model representation is better at representing the physical processes in the GSI.

Green Stormwater Infrastructure Model Representation

When the *Long Term Control Plan Update* (LTCPU) was submitted in 2009, PWD used a planning level model to estimate the benefit of GSI in terms of CSO reductions. Since 2009, PWD has collected and analyzed a large amount of data from constructed GSI projects. The data analysis helped create an implementation level model framework that is robust and flexible. The framework was created so that it can be modified if needed to adapt to changes in GSI implementation programs. Data collection will continue from design drawings, return plans, and pre-construction subsurface infiltration tests. The use of pre-construction subsurface infiltration rates in current GSI models represents a significant improvement over the planning-level model used for the 2009 LTCPU. Additional data being collected from post-construction GSI monitoring, although not used directly in GSI model development to date, may be useful in future updates to the model.

Model Calibration and Validation

Model calibration and validation is essential to accurately represent hydrologic conditions and hydraulic infrastructure. A calibrated and validated model can be used to produce meaningful and reliable simulation results to effectively support regulatory requirements as well as planning, design, and operation of the combined and separate sanitary sewer collection system.

Extensive flow monitoring data is used in hydrologic and hydraulic calibration and validation. Data from 85 flow monitors in the combined sewer area were used to update hydrology with data from 48 of these sites being used for distributing the hydrology information to unmonitored sheds. Data from 124 flow monitors were used to update the wet weather response in the separate sanitary sewer area, this group of monitors is composed of 67 in-City monitors and 57 outlying community monitors. In addition, flow monitoring data collected from the combined and sanitary sewer areas, as well as outlying communities are used to estimate average annual baseflow contributions. A total of 134 in-City flow monitors, 61 outlying community monitors, and 9 WPCP monitors are used for this process. Model calibration is accomplished by adjusting initial estimates of selected model variables (calibration parameters), within a specific range, to obtain a satisfactory correlation between simulated and measured flow. Calibration parameters are typically variables which cannot be easily or directly measured and have a significant impact on model results. After model calibration, an independent monitoring data set is used for the validation process, to verify that the calibrated model within its domain of applicability, possesses a satisfactory range of accuracy consistent with the intended application of the model. In model validation, WPCP data and water level data at regulating structures and/or hydraulic control points are used to verify that hydraulic conditions are accurately represented.

2.5 Equivalent Mass Capture

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 2-8 includes the Equivalent Mass Capture for each of the three required parameters in the COA as of December 31, 2021.

Table 2- 8: Year 10 Equivalent Mass Capture

	2011 Baseline "Equivalent Mass Capture"	Year 5 (2016) "Equivalent Mass Capture"	Year 10 (2021) "Equivalent Mass Capture"
TSS	62%	70.5%	77.5%
BOD_5	62%	88.5%	~100.0%*
Fecal coliform	62%	72.0%	77.1%

*BOD_5 capture has met or exceeded the 85% equivalent mass capture. The amount of BOD_5 captured has met or exceeded the load reduction that is associated with 85 percent capture volume treated using primary clarification and disinfection using the end-of-pipe treatment technology.

2.6 Greened Acres

PWD has exceeded its Year 10 Greened Acre WQBEL Performance Standard of 2,148 GAs. The calculation of GAs at Year 10 was completed using the method outlined in Section 2.7 of the Year 5 EAP. As of December 31, 2021, PWD has attained 2,196 GAs, derived from 835 stormwater management projects. Table 2-9 outlines the number of GAs and projects achieved within each implementation approach. For a complete summary of all projects, please refer to the project list in Appendix A.

Table 2- 9: Year 10 Greened Acres and Projects by Implementation Approach

Implementation Approach	Total Number of Greened Acres	Total Number of Projects
(Re)Development	700	439
Public Investment	690	288
Incentivized Retrofits	806	108

GAs were accrued from the three established implementation approaches: (Re)Development Regulations, Public Investment, and Incentivized Retrofits. Each implementation approach uses a unique project delivery model, with varying strategies for 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. As the city's green infrastructure network continues to grow, a comprehensive map is updated on PWD's website that displays projects by implementation approach. A screenshot of the comprehensive GSI map is provided below in Figure 2-1.

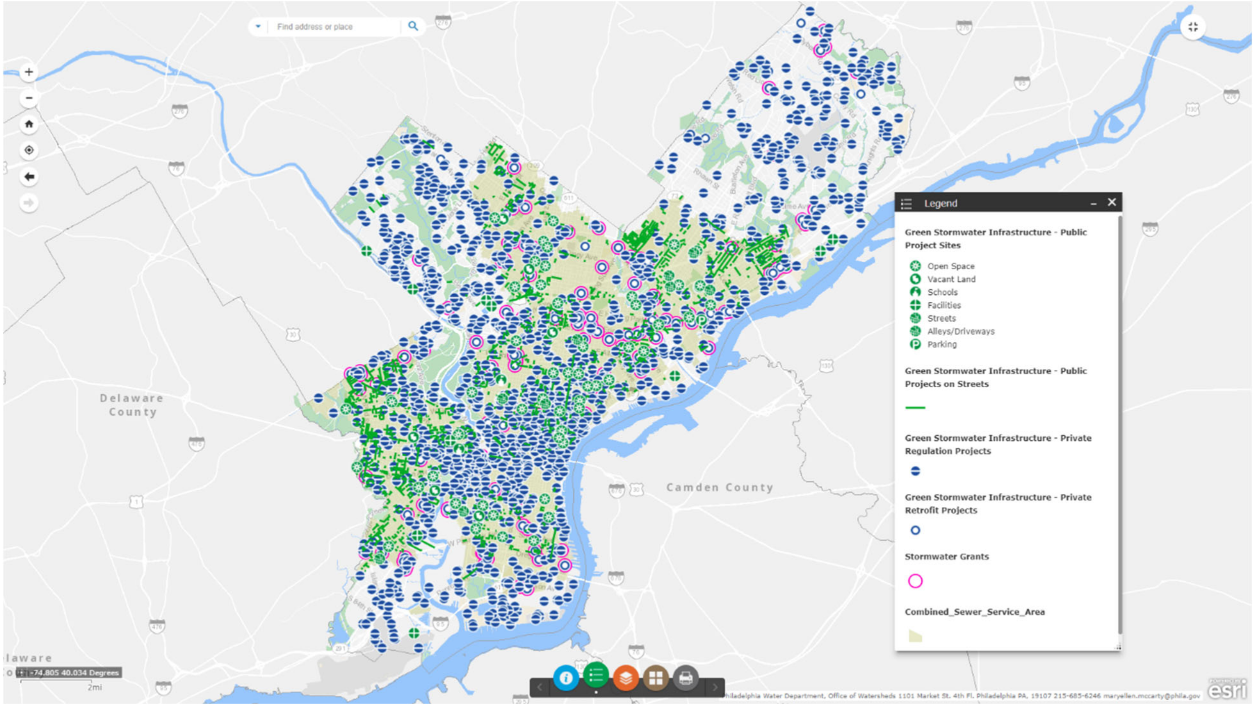

Figure 2- 1: Green City, Clean Waters map of GSI implementation

A live version of the map can be accessed at this link: https://phl-water.maps.arcgis.com/apps/webappviewer/index.html?id=c5d43ba5291441dabbee5573a3f981d2

Proposed revisions to the GA calculation method have been developed. The revisions are based upon the data-driven understanding of performance gained through program implementation, data collection and analyses to date. The revised method is described in detail in Appendix B to this EAP and summarized below. The revised method will be used for future reporting, beginning with the 2022 COA Annual Report submission in September 2022.

In addition to storage, the revised calculation method where applicable, will also account for infiltration and slow-release processes not previously included in the method. This revision is specifically associated with the method for calculating the Wd term in the GA equation. The Greened Acre definition as defined in the COA remains the same. Historically, the method for calculation of the depth of runoff managed is defined as equivalent to the available storage volume in the GSI system, with the following formula:

$$Wd(in) = \frac{V_{storage}(ft^3)}{DCIA(ft^2)} * 12\left(\frac{in}{ft}\right)$$

The revised method for calculation of the depth of runoff managed will account for storage, infiltration, and slow-release processes, with the following formula:

$$Wd(in) = \frac{\left(V_{storage}(ft^3) + V_{infiltration}(ft^3) + V_{slow\ release}(ft^3)\right)}{DCIA(ft^2)} * 12\left(\frac{in}{ft}\right)$$

If the processes of infiltration and slow release are not accounted for where applicable, the current calculation method will underestimate the runoff volume that is managed by GSI. This concept is demonstrated in Figure 2-2 below.

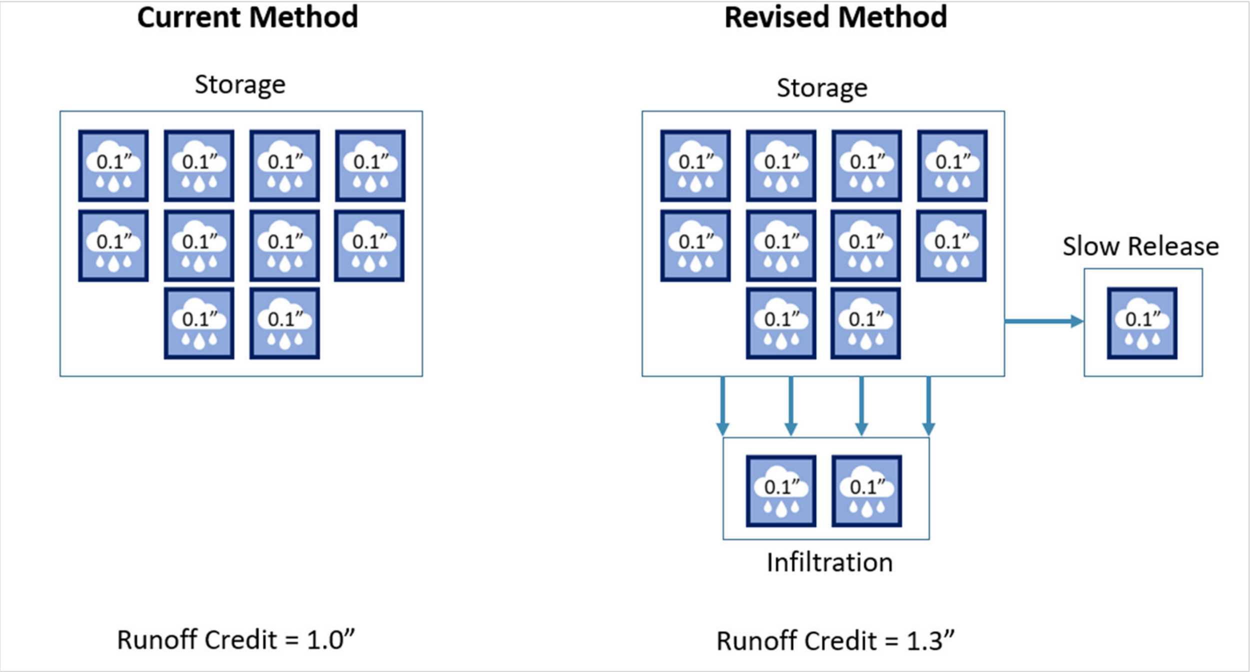

Figure 2- 2: Diagram representing the accounting of runoff using the current method as compared to the revised method

2.6.1 Greened Acre Program Summary

The City of Philadelphia continues to accrue GAs through the following public and private implementation approaches:

- **(Re)Development Regulations:** stormwater management on new and redevelopment projects required for compliance with the *Philadelphia Water Department Stormwater 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 stormwater grants.

(Re)Development Regulations

The *City of Philadelphia Stormwater Regulations* for new development and redevelopment, hereafter called (Re)Development, have remained a major source of GSI implementation. Land development projects that propose an earth disturbance of 15,000 square feet or more must provide on-site stormwater management. Projects must submit plans for conceptual review to obtain 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 (O&M) agreement. PWD periodically performs post-construction inspections to confirm compliance with the O&M agreement. By the close of Year 10, (Re)Development provided 700 GAs from 439 projects toward the City's compliance with the WQBEL Performance Standard.

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 (ROW) 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 investment produced 690 GAs from 288 projects by the close of Year 10.

Incentivized Retrofits

Incentivized Retrofit projects are the result of property owners applying for PWD-sponsored incentives opportunities that are aimed at retrofitting private properties to manage stormwater through green infrastructure. All participants are eligible for credits to reduce the stormwater service charge on their bills. 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 O&M agreement. Incentives projects delivered 806 GAs from 108 projects by the close of Year 10.

2.7 Assessment of Receiving Water Conditions

This section includes an updated assessment of receiving water conditions as required in the COA for Year 10.

2.7.1 Overview of 2013-2015 COA Water Quality Reports

Section 3) a) of the Consent Order and Agreement (COA) requires submission of four deliverables related to water quality models:

Tributary Water Quality Model – Bacteria

Tributary Water Quality Model – Dissolved Oxygen

Tidal Waters Water Quality Model – Bacteria

Tidal Waters Water Quality Model – Dissolved Oxygen

The models described in these deliverables provide the basis for the simulations performed to assess receiving water conditions in COA Year 10. Much of the information in these deliverables remains applicable in Year 10 and will not be duplicated in this Year 10 EAP. The reader is encouraged to refer to the detailed supporting information in these documents.

The Tributary Water Quality Model for Bacteria Report documented data collected, described model setup and validation, and characterized bacteria conditions in the receiving waters through comparison of predicted and observed fecal coliform and *E. coli* concentrations during past wet weather events.

The Tributary Water Quality Model Report for Dissolved Oxygen documented existing dissolved oxygen (DO) conditions and underlying stream processes in the receiving waters through comparison of predicted and observed DO concentrations and benthic algal densities during past events. In particular, spring and summer benthic algal bloom conditions, and DO during wet weather, were simulated.

The Tidal Waters Water Quality Model – Bacteria and Dissolved Oxygen Report documented existing bacteria and DO conditions and the underlying hydrodynamic and water quality processes in the tidal receiving waters, through comparison of predicted and observed bacteria and DO concentrations overlying benthic conditions during the recent past.

COA Appendix G provides additional details on the required contents of these deliverables, which can also be found in Appendix D of this EAP. PWD submitted each of these deliverables on time and has them posted online (https://water.phila.gov/reporting/ltcp/).

2.7.2 Receiving Waters and Receiving Water Segments

The Year 10 receiving water condition was evaluated with the results of water quality simulations of the receiving waters. The evaluation was based on segments of the receiving waters defined by established regulatory boundaries, geography, and tidal extent as shown in **Table 2-10: Receiving Water Segmentation for Year 10 Evaluation and Adaptation Plan** and **Figure 2-3: Receiving Water Segmentation for Year 10 Evaluation and**

Adaptation Plan. The tidal receiving waters were defined by seven segments while the non-tidal Tacony/Frankford Creek and non-tidal Cobbs Creek were each defined by one segment. The applicable Designated Use and regulatory agency for each receiving water segment are included in **Table 2-10.**

Applicable Delaware River Basin Commission (DRBC) and Pennsylvania Department of Environmental Protection (PADEP) water quality criteria for these receiving water segments are summarized below and can be referenced in Appendix D.

In this EAP, water quality simulation results in the non-tidal portions of Cobbs Creek and Tacony/Frankford Creek will be compared to Pennsylvania numeric criteria for bacteria and dissolved oxygen in effect as of June 2020. The applicable numeric criteria are provided in PA Code Title 25, Chapter 93 Water Quality Standards and can be referenced in Appendix D.

Water quality standards for the tidal Delaware estuary are established in the DRBC Administrative Manual – Part III, Water Quality Regulations. Relevant criteria for fecal coliform bacteria and DO in the tidal Delaware River can be referenced in Appendix D.

Table 2- 10: Receiving Water Segmentation for Year 10 Evaluation and Adaptation Plan

Segment	Water Body	Upstream Boundary	Downstream Boundary	Length (mi)	Regulatory Agency	Designated Use
D-6	Tidal Delaware Mainstem	DRBC RM 81.8 (Commodore Barry Bridge)	DRBC RM 71.8	10.0	DRBC	Recreation Maintenance of resident fish and other aquatic life Passage of anadromous fish
D-5	Tidal Delaware Mainstem	DRBC RM 88.4	DRBC RM 81.8 (Commodore Barry Bridge)	6.6	DRBC	Recreation - Secondary Contact Maintenance of resident fish and other aquatic life Passage of anadromous fish
D-4	Tidal Delaware Mainstem	DRBC RM 95.0 (Zone 3/4 Boundary)	DRBC RM 88.4	6.6	DRBC	Recreation - Secondary Contact Maintenance of resident fish and other aquatic life Passage of anadromous fish
D-3	Tidal Delaware Mainstem	DRBC RM 102.0	DRBC RM 95.0 (Zone 3/4 Boundary)	7.0	DRBC	Recreation - Secondary Contact Maintenance of resident fish and other aquatic life Passage of anadromous fish
D-2	Tidal Delaware Mainstem	DRBC RM 108.4 (Zone 2/3 Boundary)	DRBC RM 102.0	6.4	DRBC	Recreation - Secondary Contact Maintenance of resident fish and other aquatic life Passage of anadromous fish
D-1	Tidal Delaware Mainstem	DRBC RM 117.8	DRBC RM 108.4 (Zone 2/3 Boundary)	9.4	DRBC	Recreation Maintenance and propagation of resident fish and other aquatic life Passage of anadromous fish
S-1	Tidal Schuylkill	Fairmount Dam	Schuylkill/Delaware Confluence	8.0	DRBC	Recreation - Secondary Contact Maintenance of resident fish and other aquatic life Passage of anadromous fish
C-1	Non-tidal Cobbs Creek	City Line	Woodland Avenue	6.6	PADEP	Water Contact Sports Warm Water Fishes
T-1	Non-tidal Tacony/ Frankford Creek	Adams Ave	Torresdale Avenue	4.6	PADEP	Water Contact Sports Warm Water Fishes

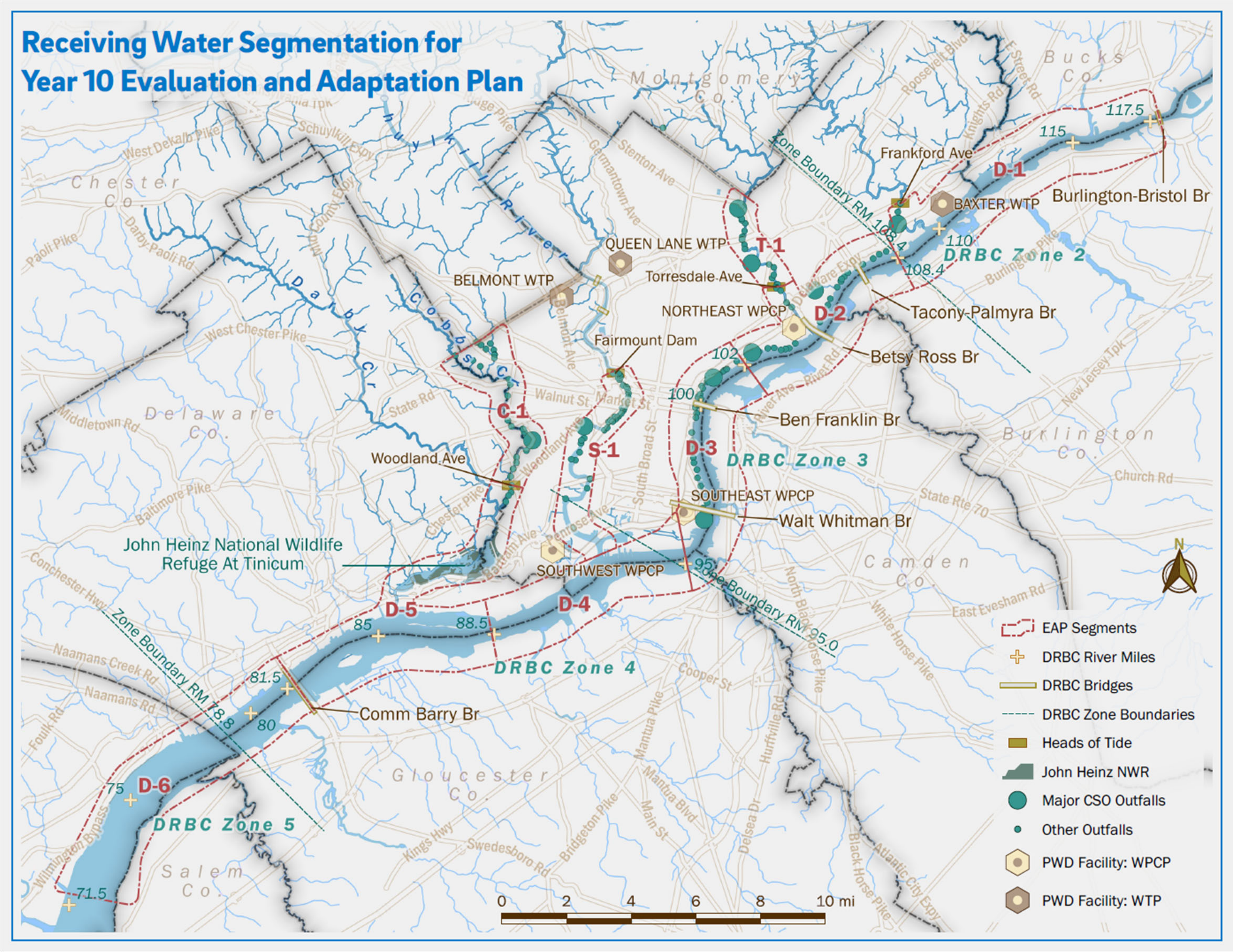

Figure 2- 3: Receiving Water Segmentation for Year 10 Evaluation and Adaptation Plan

2.7.3 Receiving Water Model Summary

2.7.3.1 Receiving Water Model Updates and Typical Year Model Setup

The receiving water models were developed for the Philadelphia Water Department (PWD) *Year 10 Evaluation and Adaptation Plan* for the tidal Delaware River, non-tidal Cobbs Creek, and non-tidal Tacony/Frankford Creek. The receiving water models developed for the COA deliverables outlined in **2.7.1 Overview of 2013-2015 COA Water Quality Reports** and further described in Appendix D were adapted to evaluate the water quality condition of the CSO impact to receiving waters at Year 10. This section summarizes updates made to the models described in the 2013-2015 deliverables. Model inputs and process representations not discussed below remain the same as those documented in the 2013-2015 deliverables, and the reader is encouraged to refer to those documents. Additional information about the receiving water model updates and typical year setup used for the Year 10 EAP can be found in Appendix D. For the Year 10 EAP simulation, the typical year rainfall (See Philadelphia Combined Sewer Overflow Long Term Control Plan Update: Supplemental Documentation Volume 5 Precipitation Analysis, 2011), was used. The tidal Delaware River model is based on 2005 flow conditions, and receives CSO inputs that represent land use, land cover, collection and treatment system configuration at Year 10 conditions. The non-tidal tributary models use the typical year rainfall to define the watershed hydrologic conditions for these water quality assessments at Year 10.

2.7.3.2 Evaluating the Effects of CSO Discharges on Water Quality Criteria Compliance

Analysis of the Year 10 receiving water quality models provides evidence of the extent to which combined sewer overflows from Philadelphia's collection system cause or contribute to exceedance of numerical water quality criteria in a receiving water. As the causes of water quality impairment are typically multiple and complex, they should be studied within a larger watershed or integrated planning context. The approach described here is focused on the compliance requirements of the National CSO Control Policy. It is intended to determine the extent to which Philadelphia's CSOs cause or contribute to water quality impairments "… under the assumption that if other sources were remediated by the appropriate responsible parties, then the CSO control goals would be stringent enough for water quality goals to be met" (USEPA, 1995, *Combined Sewer Overflows: Guidance for Long-Term Control Plan*, p. 1-20).

2.7.3.3 Year 10 Implementation in Receiving Water Models

To represent the Year 10 condition, the receiving water models were simulated with an assumed background water quality loading. The wet weather CSO inputs that represent the Year 10 condition were loaded to the modeled receiving waters in addition to this background assumption. The model results allow evaluation of the extent to which Philadelphia CSOs cause or contribute to water quality impairments.

Year 10 Tidal Delaware River Bacteria Model

The tidal Delaware River Year 10 bacteria model is based on the validated COA Tidal Bacteria Model with 2005 flow conditions, and receives PWD CSO inputs that represent land use, land cover, collection system and the treatment system configuration at Year 10 under historical average annual, or "typical," precipitation conditions. For these efforts, the tidal Delaware River model was subjected to calendar year 2005 atmospheric and wind conditions from observed data at the Philadelphia International Airport National Oceanic and Atmospheric Administration (NOAA) station, and calendar year 2005 United States Geologic Survey (USGS) water temperature data. The predicted water level for 2005 was applied to the downstream boundary to represent tidal forcing (Tide Predictions, Tides and Currents-NOAA NOS CO-OPS). The water level at the downstream boundary was adjusted to reflect the mean sea level condition projection for the year 2021, in addition to the year 2005 tidal forcing.

Since pollution sources other than CSOs may cause non-attainment of water quality standards, evaluating the impact of CSO control requires an assumption that concentrations of bacteria in the receiving water due to other sources have been controlled by others beyond PWD's CSO control program. This is evaluated in the tidal and non-tidal bacteria models by assuming that all sources of bacteria other than Philadelphia's permitted CSO outfalls were capped at a background fecal coliform bacteria concentration.

For the Year 10 EAP simulation, all non-CSO flow inputs to the tidal Delaware River model were based on either calendar year 2005 observed conditions or average condition assumptions. The bacteria inputs from the non-CSO inputs were based on available observed data or average conditions that were capped at the background value. The non-CSO discharge and bacteria loading inputs include: the upper boundary condition at Trenton; all tributaries between Trenton and Delaware City; the lower tidal boundary at Delaware City; permitted direct dischargers; and areas yielding runoff directly to the Delaware River from Pennsylvania, New Jersey, and Delaware. Fecal coliform bacteria boundary conditions for the tributaries to the tidal Delaware River were based on long term grab sample data prepared for the COA bacteria model. Any bacteria values greater than the background value were capped at the background. This method was also used for the upper boundary Delaware River at Trenton. For tributaries with no monitored bacteria data, ungaged portions of tributaries, and direct runoff areas, the same reference creek method was used to assign bacteria concentration as was used in the 2015 COA deliverable. At the downstream Delaware River open boundary, the long term fecal coliform bacteria median value from grab samples collected from 1999-2014 was used to represent the lower boundary in the model. Fecal coliform bacteria loading for municipal and industrial wastewater dischargers were estimated by calculating a median of 2012-2016 reported data from Discharge Monitoring Reports (DMR). For dischargers that did not report fecal coliform bacteria for this time period, a median of all available municipal and industrial data was used, based on multiple years of data from all available DMRs. The flow and bacteria inputs to the tidal Delaware River for the CSO receiving tributaries Cobbs Creek and Tacony/Frankford Creek were represented by the Year 10 Environmental Fluid Dynamics Code (EFDC) model outputs at the downstream non-tidal boundary of the respective EFDC models. Input and boundary assumptions for tidal Delaware River bacteria model are listed in Table 2-11.

For the Year 10 EAP simulation, flow and bacteria loads from the CSOs in the City of Philadelphia that discharge to tidal waters were estimated from the H&H model simulations of the combined and separate sanitary sewer collection system representing the Year 10 condition. Pollutant loads from CSOs in the Year 10 H&H models were simulated by calculating flow-weighted concentrations of the runoff and base wastewater flow components of combined sewer overflow at each time step for the average annual condition. The untreated stormwater fecal coliform Event Mean Concentration (EMC) was assigned 100,000 cfu/100mL and the base wastewater fecal coliform concentration to represent bacteria in the sanitary flow was assigned 1,450,000 cfu/100mL, consistent with the COA. The H&H model is used to mix and transport bacteria from stormwater and sanitary flow through the collection system. This mix of bacteria from the wet and dry sources is discharged through the CSO outfalls during an overflow event. The H&H model simulated bacteria concentration and flow discharge at the outfall represent the CSO input to the receiving water.

The Year 10 conditions were simulated by applying the CSO fecal coliform bacteria loads from the wet-weather CSO inputs that represent the Year 10 condition, to the modeled receiving waters, in addition to the background bacteria assumption as described above. These tidal Delaware River EFDC bacteria model results are intended to estimate the extent to which Philadelphia CSOs cause or contribute to bacteria water quality impairments, assuming other sources of pollution are controlled as described in US EPA's Guidance for Long Term Control Plan.

Table 2- 11: Input and Boundary Assumptions for Tidal Delaware River Bacteria Model

Tidal Delaware River Bacteria Model Input	Fecal Coliform Bacteria (FCB)
Upstream boundary (Trenton)	Wet weather = background Dry weather = median of sampling data
Downstream open boundary	Median of PWD/DRBC/USGS grab samples 1999-2014
Non-tidal creeks and runoff	
Cobbs Creek - inflow to tidal Darby Creek	Timeseries output from non-tidal Year 10 EFDC bacteria model
Tacony Creek - inflow to tidal Frankford Creek	Timeseries output from non-tidal Year 10 EFDC bacteria model
Other tributary surface waters and runoff discharging to Delaware River	Seasonal median of dry weather data where available, capped at background; nearby reference watershed used when no data available

CSOs	
PWD - wastewater baseflow portion of CSO	1,450,000 cfu/100 mL - COA Appendix E, Document #2, Table 1
PWD - stormwater portion of CSO	1,000,000 cfu/100 mL - COA Appendix E, Document #2, Table 1
CCMUA (Camden CSOs)	background
DELCORA (Chester CSOs)	background
Wilmington	background
Other Point Sources	
PWD water pollution control plants	5 year (2012-2016) median value, capped at background
CCMUA treatment plant	5 year (2012-2016) median value, capped at background
Miscellaneous municipal/industrial point sources	5 year (2012-2016) median value, capped at background

Year 10 Non-tidal Tributary Bacteria Models

The Year 10 bacteria condition of the non-tidal tributary creeks was evaluated with US EPA EFDC models, that were developed to simulate fecal coliform bacteria. The non-tidal tributary EFDC model development is described in further detail in Appendix D. The Year 10 EFDC bacteria models for the non-tidal Tacony/Frankford Creek and Cobbs Creek were simulated with these updated EFDC models to estimate fecal coliform bacteria for the Year 10 condition. In the model used for the EAP, the atmospheric inputs were derived from calendar year 2005 observed meteorological conditions at the Philadelphia International Airport (National Weather Service, NOAA). Since the USGS water quality monitors were not active on the creeks in 2005, observed water temperature from calendar year 2005 at the USGS station Delaware River at Trenton was used to represent water temperature. The upstream boundary and runoff from non-CSO catchments that discharge to the creek were estimated from the watershed models simulated with typical year rainfall. Stream baseflow for the typical year was represented by the average monthly baseflow over the period of record at the USGS discharge gage locations for the creeks.

The EFDC models were simulated with background fecal coliform concentrations assigned to the upstream boundary, non-CSO stormwater sheds, and to the baseflow. Input and boundary assumptions for the non-tidal tributary bacteria models are listed in Table 2-12. The Year 10 condition was simulated by assigning CSO fecal coliform bacteria loads from the wet weather CSO inputs that represent the Year 10 condition, to the modeled receiving waters, and includes the addition of the background bacteria assumption as described previously. These EFDC tributary bacteria model results are intended to estimate the extent to which Philadelphia CSOs cause or contribute to bacteria water quality impairments of the non-tidal tributaries, assuming other sources of pollution are controlled.

Table 2- 12: Input and Boundary Assumptions for Non-tidal Tributary Bacteria Models

Non-tidal Tributary Bacteria Model Input	Fecal Coliform Bacteria
Upstream boundary at city line	background
Baseflow	background
Stormwater runoff from non-CSO areas	background
CSOs	
PWD - wastewater baseflow portion of CSO	1,450,000 cfu/100 mL - COA Appendix E, Document #2, Table 1
PWD - stormwater portion of CSO	100,00 cfu/100 mL - COA Appendix E, Document #2, Table 1

Year 10 Non-tidal Tributary Dissolved Oxygen Models

The Year 10 DO condition of the non-tidal tributary creeks was evaluated with EFDC models developed to simulate DO conditions. The hydrodynamic setup of the DO models was similar to that of the bacteria models. The atmospheric and wind inputs include the calendar year 2005 observed meteorological conditions at the NOAA Philadelphia International Airport gage, and the water temperature was derived from calendar year 2005 at the USGS station Delaware River at Trenton. The upstream flow boundary and non-CSO runoff were estimated from watershed models simulated with the typical year rainfall. Stream baseflow used for the model was represented by the average monthly baseflow over the period of record at the USGS discharge gage locations on the creeks. The EFDC models were simulated with background water quality parameters assigned to the upstream boundary, non-CSO stormwater sheds, and baseflow loads. The background values for nutrients include estimates for nitrogen species, phosphorus species, and carbon species, from observed dry weather data upstream of the City boundary. Dry weather simulations of the background condition verified that the model configuration adequately simulated macroalgae periphyton and instream DO dynamics. The model also incorporates sediment oxygen demand (SOD), periphyton scour, and dissolved organic carbon decay, which are important processes for these creeks.

The Year 10 condition was simulated by applying the CSO water quality loads, from the wet weather CSO inputs that represent Year 10 to the modeled receiving waters in addition to the background water quality assumptions. Water quality assumptions in the Year 10 collection system models simulating CSO loads are included in Table 2-13. The non-tidal tributary EFDC

DO model results allow analysis of the extent to which Philadelphia CSOs cause or contribute to dissolved oxygen water quality impairments in the non-tidal tributaries, assuming other sources of pollution are controlled.

Table 2- 13: Year 10 EAP Pollutant Concentrations Applied to CSO Models

Type	BOD$_5$ (mg/L)	TSS (mg/L)	Fecal Coliform (cfu per 100 mL)	Ammonia (NH_3) (mg /L as N)	Nitrate+Nitrite (NO_X) (mg /L as N)
Untreated Stormwater	8.445	65.679	100,000	0.44	0.6
Green Infrastructure Treated Stormwater	4.5	8.8	200	0.06	0.6
Sanitary Sewage	134	116	1,450,000	8.45	0.88
GSI removal rate	*46.7%*	*86.6%*	*99.8%*	*86.4%*	*0.0%*

Type	Total Nitrogen (TKN) (mg/L)	Orthophosphate (oPO_4) (mg /L as P)	Total Phosphorus (TP) (mg/L)	Dissolved Oxygen (DO) (mg/L)	
Untreated Stormwater	1.43	0.126	0.27	8.2	
Green Infrastructure Treated Stormwater	1.43	0.126	0.27	8.2	
Sanitary Sewage	19.98	1.69	3.44	2	
GSI removal rate	*0.0%*	*0.0%*	*0.0%*	*0.0%*	

2.7.3.4 Overview of the Water Quality Comparison Tool

In-stream water quality sampling data typically are used to assess water quality criteria attainment. While the frequency of sampling and number of locations of water quality sampling programs can be limited by the cost of sample collection and analysis, water quality models can provide continuous simulations of in-stream concentrations across the extent of the modeling domain. A water quality assessment tool, referred to as the comparison tool, was developed to evaluate the attainment of the fecal coliform and dissolved oxygen criteria using the water quality model results. This comparison tool compares water quality model results to applicable water quality criteria, by sampling numerical simulation results in an analogous way to a field sampling program and consists of two parts. Part one is used to evaluate fecal coliform conditions and part two is used to evaluate DO conditions.

Part one of the comparison tool utilizes a sampling algorithm to generate a series of 10,000 random sample sets extracted from the model results for each segment. The sampling protocol is applied to the average hourly water quality timeseries model output for each model segment. For each sample, 5 observations are randomly selected from the hourly timeseries on different days over a 30-day window. The geometric mean of each sample group is then calculated for comparison with the DRBC and PADEP geometric mean-based numeric criteria. In addition, to evaluate the PADEP statistical threshold value criteria, the percent of samples exceeding 400 cfu per 100 ml in each sample group during the swimming season was calculated for comparison to the PADEP criteria for the non-tidal tributaries. The results are sampled over the model results for the entire year in the tidal waters where the DRBC criteria apply and sampled separately within the swimming and non-swimming season for the non-tidal waters where the PADEP water quality standards apply. For each water body segment, the tool calculates the frequency the numeric criteria were exceeded in the 10,000 sample sets by dividing the number of sample groups exceeding each criterion by the total number of sample groups (10,000). The frequency of exceedance was considered representative of the probability of not attaining the numeric water quality criteria.

Part two of the comparison tool focuses on PADEP “Warm Water Fishes” criteria for DO in the non-tidal tributaries. Like part one of the tool, part two is applied to the average hourly DO timeseries result for each water body segment, which is sampled over the model results for the year. The tool computes both frequency of DO exceedances below 5.0 mg/l for the average hourly timeseries and below 5.5 mg/l for a 7-day moving average.

2.7.3.5 Tidal Delaware River DO Model Sensitivity Analysis to CSO

For the evaluation of DO in the tidal receiving waters, the validated tidal Delaware River EFDC DO model was used to estimate the extent to which CSO discharges from the PWD collection system cause or contribute to the DO concentrations observed in the tidal Delaware River downstream of Philadelphia, especially in the zone of minimum DO (the “DO sag” area). For the purposes of evaluating the contribution of CSOs to DO concentrations, analysis was based on the evaluation of the DO model validated for the years 2012 and 2013. The results of the analysis suggest that removing Philadelphia CSOs from the system has a negligible effect on the DO conditions within the tidal Delaware River. Additional details about this analysis and a summary of the results can be found in Appendix D.

2.7.4 Year 10 Water Quality Comparison Tool Results

Water quality model results were evaluated with the water quality comparison tool to estimate the extent to which CSOs at Year 10 cause or contribute to any non-attainment of fecal coliform bacteria criteria in the tidal and non-tidal receiving waters and DO criteria in the non-tidal receiving waters. The percent exceedance of the applicable water quality standard was calculated for each water body segment. The fecal coliform bacteria results for each water body segment are in Table 2-14 that includes the percent exceedance of fecal coliform water quality criteria at Year 10 by receiving water segment. Dissolved oxygen results for the non-tidal tributaries are in

Table 2-15 that includes the percent exceedance of dissolved oxygen water quality criteria at Year 10 by receiving water segment.

Table 2- 14: Percent Exceedance of Fecal Coliform Water Quality Criteria at Year 10 by Receiving Water Segment

		Fecal Coliform Criteria Percent Exceedance				
Segment	**Water Body**	**DRBC Recreation**	**DRBC Recreation - Secondary Contact**	**PADEP Water Contact Sports Swimming Season – Geometric Mean**	**PADEP Water Contact Sports Swimming Season – Statistical Threshold Value**	**PADEP Water Contact Sports Non-Swimming Season**
D-6	Tidal Delaware River and tidal reaches of adjacent tributaries: RM 71.8 to RM 81.8 (Commodore Barry Bridge)	0.0 %	-	-	-	-
D-5	Tidal Delaware River and tidal reaches of adjacent tributaries: RM 81.8 to RM 88.4	-	0.0 %	-	-	-
D-4	Tidal Delaware River and tidal reaches of adjacent tributaries: RM 88.4 to RM 95.0 (DRBC Zone 3/4 Boundary)	-	0.0 %	-	-	-
D-3	Tidal Delaware River and tidal reaches of adjacent tributaries: RM 95.0 to RM 102.0	-	0.0 %	-	-	-
D-2	Tidal Delaware River and tidal reaches of adjacent tributaries: RM 102.0R to RM 108.4 (DRBC Zone 2/3 Boundary)	-	0.0 %	-	-	-
D-1	Tidal Delaware River and tidal reaches of adjacent tributaries: RM 108.4 to RM 117.8	0.0 %	-	-	-	-
S-1	Tidal reaches of the Schuylkill River	-	0.1 %	-	-	-
C-1	Non-tidal reaches of the Cobbs Creek	-	-	5.7 %	30.3 %	0.0 %
T-1	Non-tidal reaches of the Tacony/Frankford Creek	-	-	18.6 %	48.8 %	0.3 %

*Consistent with US EPA guidance, results provide evidence of the extent to which combined sewer overflows from the Philadelphia collection system cause or contribute to exceedance of numerical water quality criteria in a receiving water segment. These results assume that sources other than Philadelphia's permitted CSO outfalls have been remediated by the appropriate responsible parties.

Table 2- 15: Percent Exceedance of Dissolved Oxygen Water Quality Criteria at Year 10 by Receiving Water Segment

		Dissolved Oxygen Criteria Percent Exceedance	
Segment	**Water Body**	**PADEP Fresh Water Fishes Minimum**	**PADEP Fresh Water Fishes 7-Day Average**
C-1	Non-tidal reaches of the Cobbs Creek	0.0 %	0.0 %
T-1	Non-tidal reaches of the Tacony/Frankford Creek	0.0 %	0.0 %

*Consistent with US EPA guidance, results provide evidence of the extent to which combined sewer overflows from the Philadelphia collection system cause or contribute to exceedance of numerical water quality criteria in a receiving water segment. These results assume that sources other than Philadelphia's permitted CSO outfalls have been remediated by the appropriate responsible parties.

3.0 Assessment of Program Performance

3.1 Introduction

This section summarizes the Philadelphia Water Department's (PWD) continued extensive data collection and analyses performed during this implementation period. Additional plots associated with this assessment of program performance are provided in Appendix E to this Evaluation and Adaptation Plan (EAP).

3.2 The Role of Monitoring in Understanding Program Performance

Since the submission of the Year 5 EAP, PWD has continued to develop, maintain, and refine the processes associated with green stormwater infrastructure (GSI) monitoring. This evolution involves a dynamic effort to create new processes for collecting and analyzing data and to manage and execute fieldwork and data analysis protocols with the purpose of understanding performance and trends, and actively seeking out and implementing efficiencies. These updated processes positively impact the regularity and constructiveness of feedback to associated PWD groups, such as the GSI Design, Construction, and Operations teams. GSI monitoring data provides analytical insight to each group regarding their contribution to the program and this coordination and feedback loop is key to the success of future implementation. Monitoring data and field observations are also useful for the prioritization of maintenance activities. These data are also used in evaluating GSI performance in the field as they help to identify stormwater management practice (SMP) components that exhibit high levels of performance, as well as components that exhibit low performance or require corrective maintenance to function effectively. Considering this type of information is advantageous for the planning and design of GSI systems that maintain long-term effectiveness and cost-efficiency.

GSI monitoring and testing is performed using methods described in the *Comprehensive Monitoring Plan* (CMP) submitted to PADEP on January 10, 2014. Refinements and new approaches have been incorporated into the monitoring program activities, which allowed for an expansion in monitoring capabilities. These updated standard operating procedures were submitted as Appendix 4 to the FY2019 Consent Order and Agreement (COA) Annual Report. The GSI monitoring program provides PWD with a representative set of performance data that can be utilized to determine efficient monitoring processes, consider improvements to existing projects, plan designs and locations of future projects, and evaluate overall progress of the GSI program. These data also inform refinements in GSI design based on lessons learned, as well as the hydrologic and hydraulic (H&H) model inputs to better assess how GSI implementation affects the Combined Sewer System (CSS) as a whole. Collaboration with associated PWD groups regarding performance data contributes programmatic feedback that allows for more optimized GSI design standards, fine-tuning of construction techniques, refinement of standard maintenance activities and frequencies, more informed H&H model inputs, and improvement of overall program implementation efficiency.

The monitoring data management structure underwent a major overhaul to manage the increasing amount of monitoring data, which included the development of tools to automate data analyses, performance tracking, and synchronization with other GSI databases. Several enhancements were pursued to add, replace, and modernize analytical tools. Tools were also developed to more effectively use information that is stored in other PWD databases. These updates increased the speed with which the monitoring team can access GSI system characteristics and performance metrics and perform more in-depth analyses as the program grows.

The core mission of PWD's monitoring program is to assess the overall effectiveness of the GSI systems in reducing the volume of stormwater entering the City's combined sewers through performance evaluations of individual systems. To that end, this document presents summary statistics from raw data collection, an overview of calculated performance metrics, and various conclusions related to meta-analyses of those metrics.

3.3 Data Collection

Substantial amounts of raw data from a variety of sources are collected as part of the GSI monitoring program. These raw data streams are combined to create composite datasets that are then analyzed to produce GSI performance metrics. All monitoring efforts—routine and specialized, pre-construction and post-construction, short-term and long-term—contribute to one or more raw data streams. The following raw data streams contributed to the calculation of performance metrics that were used for the Year 10 program-wide assessment.

3.3.1 Continuous Water Level Monitoring Data (CWL)

The continuous water level (CWL) monitoring program has proceeded through Year 10 of implementation. Since the monitoring program began in 2013, 39,400,840 data points have been collected through CWL monitoring at over 400 distinct public SMPs. A summary of CWL monitoring per SMP type can be referenced in Table 3-1.

CWL deployments last between 5 and 6 months. At the end of that time, the data is downloaded and assessed to determine whether the system should continue to receive monitoring. In most cases, systems are monitored for a year or more. Subsurface systems can be monitored year-round. For weather-related reasons, sensors are removed from surface systems before first frost, and typically are redeployed in the spring. Some systems have received long-term CWL monitoring since the beginning of the monitoring program in 2013.

Table 3- 1: CWL Monitoring SMP Types and Number of SMPs Monitored

SMP Type	Number of SMPs
Basin	1
Bumpout	8
Drainage Well	4
Infiltration/Storage Trench	108
Pervious Paving	2
Planter	23
Rain Garden	55
Swale	6
Tree Trench	215

3.3.2 Barometric Pressure Data

A spatially distributed network of barometric pressure sensors is maintained which allows for more accurate water level measurements than relying on pressure data from a single source. Barometric pressure data have been collected from a variety of locations, which have been standardized to collect from the same locations since mid-2017. Sites currently in the barometric pressure sensor network have collected 4,075,378 data points.

3.3.3 Gage-Adjusted Radar Rainfall Data (GARR)

GSI performance metrics are associated with individual rain events, which are characterized by processing rainfall data from gage-adjusted radar rainfall (GARR) time series. The time series are converted into distinct events defined by an inter-event time of six hours. For each distinct event, summary statistics such as duration, peak intensity, and total rainfall depth are calculated. These events are paired with spatially-linked SMP monitoring records to assess individual “station-storms.” In that way, a single notional “storm” is used to analyze responses from many SMPs.

A total of 7,843,579 data points have been collected from the GARR dataset that cover the analyzed period for this report. There were 33,126 distinct station-storms that were analyzed during this period.

3.4 Performance Evaluation Toolkit

In the time since the submission of the Year 5 EAP, the methods for evaluating GSI performance have been refined. The most important change was the development of the PWDGSI R Package, described in Section 3.4.1. Another significant refinement was the selection of performance metrics that balance simplicity and utility. These metrics include saturated infiltration rate, storage utilization percentage, draindown time, and frequency of storage capacity exceedance (*i.e.*, “overtopping”).

The performance metrics calculated for each SMP depend on whether the design is categorized as either surface or subsurface. Subsurface SMPs include storage media below the impervious cover from which the runoff is collected. These SMPs often feature simple, rectangular designs with water level measured via observation wells. All available performance metrics are able to be calculated for subsurface SMPs. Surface SMPs primarily manage stormwater by routing runoff through vegetated features. These features are more irregular and are monitored via freestanding sensors that measure ponding depth. The performance metrics calculated for surface SMPs are overtopping frequency and draindown time. The irregular geometry of surface SMPs makes storage utilization unreliable, whereas overtopping is more straightforward. The combination of lower storage depth and less time spent ponding makes it difficult to ensure the surrounding media is at saturation. Draindown time is a reliable-enough measure of the infiltration behavior of these systems.

Event draindown simulations were completed for all qualifying rain events. These simulations created an inflow time series for the simulated SMP using GARR records and directly connected impervious area (DCIA) measurements. The DCIA was then used to estimate the runoff volume influent to that SMP during that timestep's rainfall. A mass balance was created using this estimated runoff volume influent and estimated losses. Infiltration losses were estimated using the pre-construction infiltration rate and slow-release losses were estimated using the submerged orifice equation. The result was a simulated water level time series that could be compared to the observed time series measured by water level sensors. Storage utilization percentage, overtopping assessments, and draindown times are calculated with these simulated time series and are attached to the same rain events as metrics calculated with observed data. Infiltration rates are not calculated with simulated series, because they are assumed to be constant, in keeping with typical design assumptions.

3.4.1 PWDGSI R Package

R is a programming language used for data analysis and visualization. The PWDGSI R package is a collection of R functions and related documentation that assist in calculating GSI performance metrics. The PWDGSI R package contains tools for data access, data plotting, rain event simulation, metrics calculation, and data archival. These tools are involved in every step of the data analysis pipeline and support integration of lessons-learned since the submission of the Year 5 EAP.

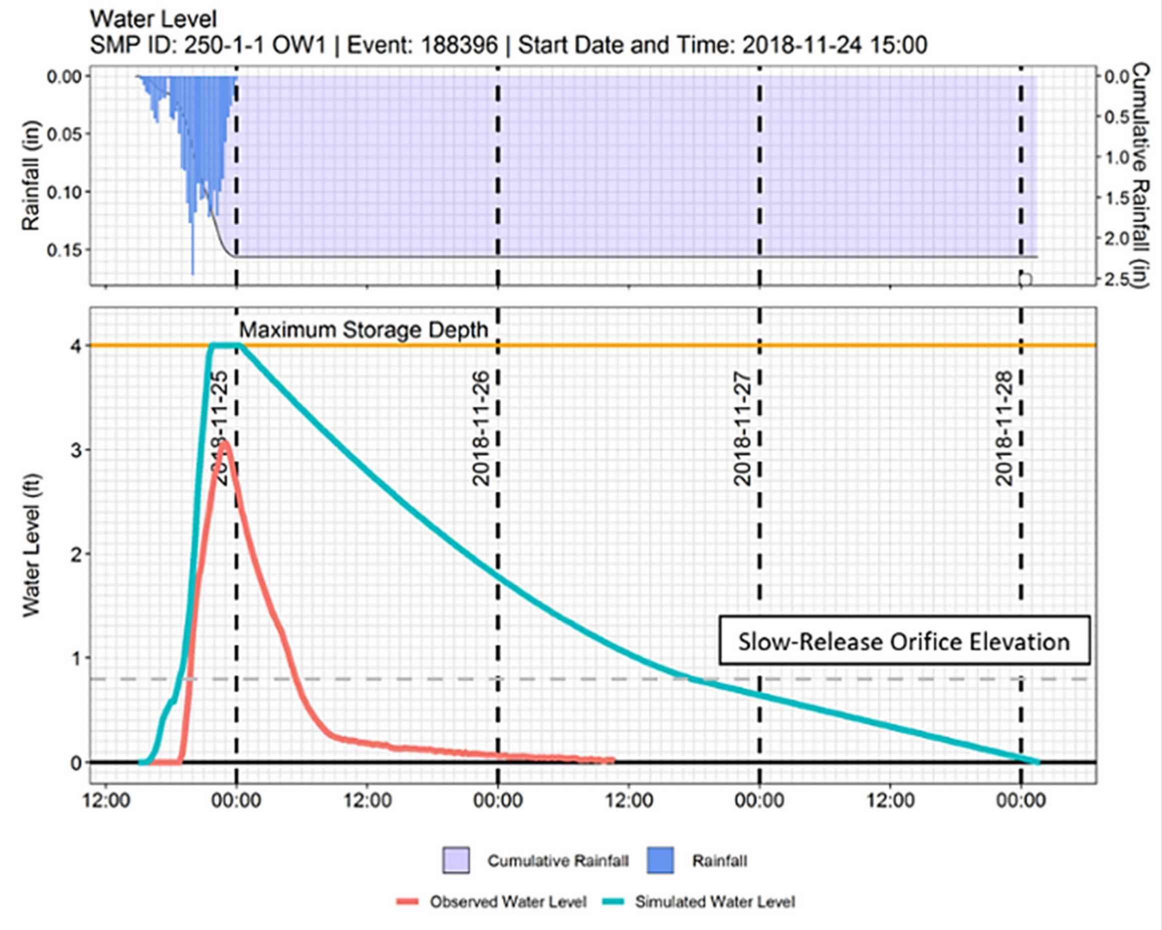

Figure 3- 1: Example of graphic generated from the PWDGSI R package

Figure 3-1 includes an example of a typical hydrograph that is generated with the PWDGSI R package. Each hydrograph is visually inspected to find irregularities that are difficult to systematically identify. Each hydrograph features a simulation of expected performance based on design assumptions. The simulated SMP in this example is a tree trench installed at Belmont Charter School.

Figure 3-1 includes a hyetograph in the upper section, with instantaneous and cumulative rainfall measurements along the left and right axes, respectively. The water level plot features observed and simulated water levels, in red and blue, respectively. The simulation is a mass-balance model with inflow based on the impervious drainage area and the rainfall at each time step; outflow governed by infiltration and slow release based on the pre-construction infiltration test result, orifice dimensions, and head above the orifice; and change in storage as the difference between the inflow and outflow. The simulation routinely overpredicts the water level response when compared to observed water level values. This above-expectations water management phenomenon is a common occurrence and forms the basis of many conclusions in this section. Table 3-2 contains design attributes, some of which inform the simulated water level. Table 3-3 contains metrics comparing simulated and observed water level.

Table 3- 2: Design Attributes for SMP 250-1-1

250-1-1 Design Metrics	
Drainage Area (ft^2)	18,471
Footprint (ft^2)	1,248
Orifice Diameter (in)	0.5
Storage Volume (ft^3)	1,997

Table 3- 3: Performance Metrics for SMP 250-1-1

Metric	Simulated	Observed
Peak Water Level (ft)	4	3.06
Maximum Relative Storage Used (%)	100	76.5
Draindown Time (hr)	72	19
Saturated Infiltration Rate (in/hr)	0.12	2.35

3.4.2 Saturated Infiltration Rate (inches/hour)

The PWDGSI R package calculates saturated infiltration rate by first identifying the water level that reaches equilibrium – a water level where the subsequent drop in level is minimal (less than 0.04 ft/hr) and is assumed to be the bottom of storage for that SMP. The function then calculates the slope of the draindown curve from 6 inches above this level to the assumed bottom of storage. This bottom vertical range represents the portion of the storage volume that spends the most time fully submerged during events and is the most likely to have fully saturated conditions in the adjacent surrounding soil. Water level data have shown that observed infiltration rates vary depending on how full the system is, consistent with infiltration under positive head pressure theory. Calculating the infiltration rate for the lowest 6 inches above the bottom of storage is used to minimize head-dependent impacts on the infiltration rate. This metric is calculated for subsurface SMPs, and for some subsurface wells at surface SMPs. SMP simulations use a constant infiltration rate equal to the observed pre-construction infiltration rate at that site.

3.4.3 Storage Utilization Percentage

Storage utilization represents the proportion of the SMP storage volume that fills up during a storm event. The maximum water level during the event represents the maximum utilization. Percent-of-storage-used (PSU) is an absolute measurement of such, relative to the bottom of storage. The percent of available storage used, also known as relative percent-of-storage-used (RPSU), is measured relative to the initial water level at the beginning of the event and is considered more indicative of SMP performance. This metric is calculated for subsurface SMPs. Surface SMP topography makes uniform estimate of storage utilization challenging.

3.4.4 Draindown Time (hours)

Draindown time is a measurement of the length of time required for an SMP to fully drain, re-establishing available storage volume after rain events. The elapsed time between the conclusion of the rain event and the water level reaching approximate equilibrium is the draindown time. Draindown time is one of the performance criteria defined in PWD's GSI Design Guidelines; subsurface SMPs are designed to drain in 72 hours or less and surface SMPs are designed to drain in 24 hours or less. This metric is calculated for all SMPs.

3.4.5 Overtopping Percentage

This metric is a simple Boolean assessment of whether the water level within an SMP reached or exceeded the maximum storage level during an event. Overtopping is used to assess probable SMP overflows. This metric is calculated for subsurface SMPs; this metric is not calculated for surface SMPs because their topography makes uniform estimate of storage utilization challenging.

3.5 Program-Wide Performance Assessments through Year 10

With the refined performance calculations and updated list of performance metrics adopted during the last five years, judgments can be made about the overall program performance at Year 10. With the help of the tools described above, performance metrics were aggregated in a variety of ways. Through these aggregations, several conclusions about program-wide performance were made.

The aggregations that were chosen to use for these analyses fall into two main categories. The first category aggregates performance metrics for all events monitored at a single SMP. This aggregation technique was used to compute ranges and scatter plots of performance results over time. The second category involves grouping by the function of the SMP. This aggregation level is best suited for boxplots that examine performance across the SMP function type, in a variety of circumstances. The aggregations by SMP function type include the following:

- **Bumpout:** A vegetated curb extension that intercepts gutter flow.
- **Drainage Well:** 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.
- **Planter:** A structure filled with soil media and planted with vegetation or trees.
- **Rain Garden:** A shallow vegetated area designed to detain and release stormwater runoff and/or infiltrate where feasible.
- **Swale:** A vegetated depression designed to convey stormwater.

- **Tree Trench:** A subsurface infiltration/storage trench that is planted with trees. They are typically long rectilinear features that are constructed between the curb and the sidewalk.
- **Trench:** Like the above, with no trees planted in the media.

Within these aggregations, performance metrics were also further subdivided into bins based on rain event characteristics. Two rain event characteristics were used for binning – absolute storm size and relative storm size. Absolute storm size is a straightforward binning structure where metrics are categorized by the depth of the storm that produced them. Relative storm size normalizes the storm depth against the designed storage volume of the SMP expressed in inches over the impervious drainage area. Instead of binning storms of similar sizes, this method bins storms relative to SMP design guidelines by similar amounts.

When applicable, linear mixed-effect regression (LMER) models were used to assess observed performance metrics. LMER models are typically used in research when multiple observations are recorded at the same location. An LMER model, like a typical linear regression model, returns a single slope and an R^2 value for a dataset. The primary difference between an LMER and a typical linear regression model is the inclusion of a random effects term. For our purposes, the random effects term is used to adjust the y-intercept of the regression for each SMP. Using LMER models, linear relationships between performance metrics and suspected predictor variables (e.g., event depth, SMP age) were assessed while accounting for randomness in the data introduced by site and design factors unique to each SMP.

3.5.1 Storage Utilization Relative to Design Assumptions

The most persistent observation across the calculated performance metrics is related to how much systems fill during rain events. The results showed that the monitored SMPs fill less than design assumptions predict they would. This was the case for events of every size, and SMPs of every function type.

Simulated event responses were analyzed with the same tools that were used to compute performance metrics for observed CWL monitoring data. The aggregated results for trench and tree trench SMP function types are shown below in Figure 3-2.

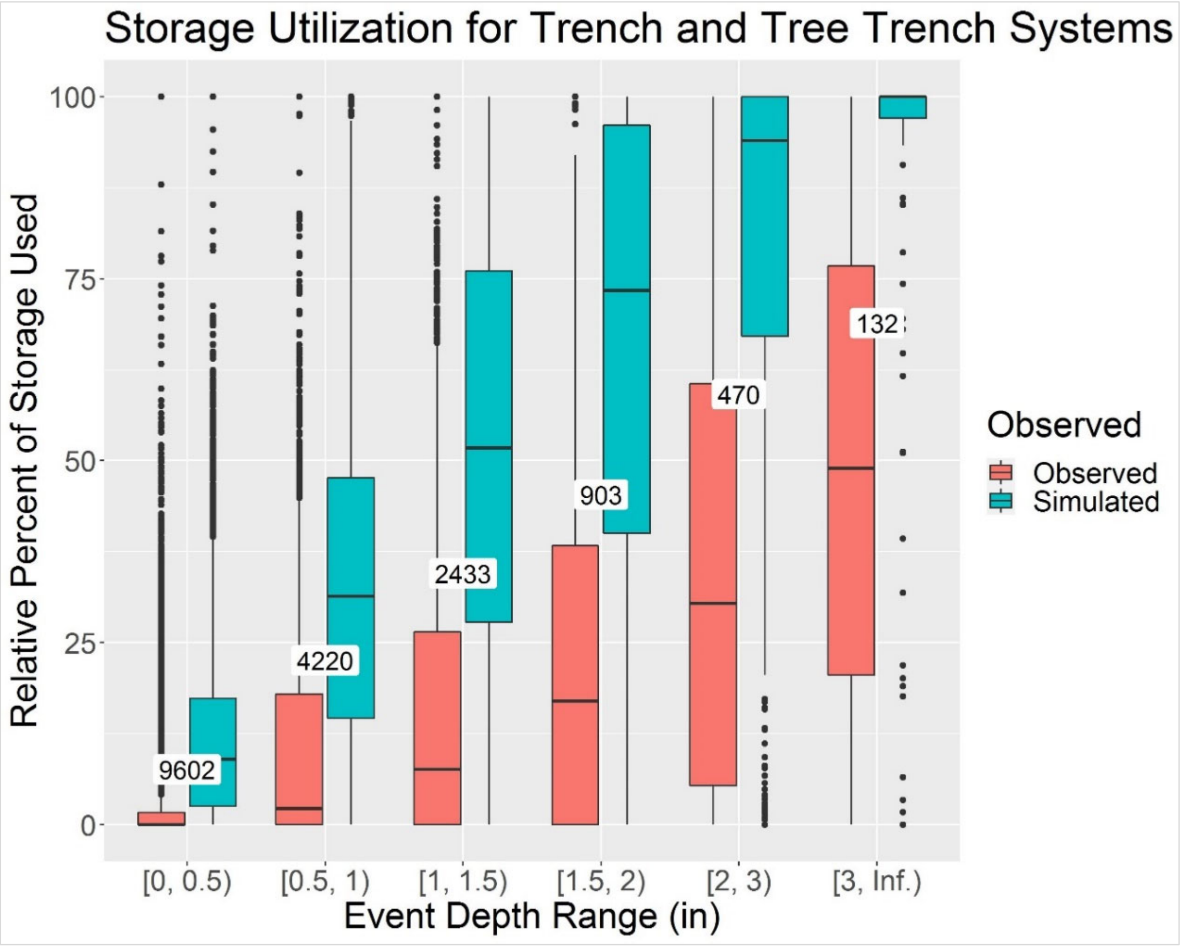

Figure 3- 2: RPSU boxplots for all observed and simulated events at Trench/Tree Trench function types. The number associated with each boxplot is the number of station-storms analyzed.

As seen in Figure 3-2, the observed Relative Percent of Storage Used (RPSU) was consistently less than what was simulated as the expected performance given design assumptions. In total, 77.94% of all station storms measured at subsurface SMPs met or exceeded the RPSU metric for simulated results using design assumptions. One explanation for this phenomenon could be that unsaturated conditions in the soil surrounding SMPs allow for rapid intra-event exfiltration of water that conservative design assumptions do not account for.

Relatively low RPSU values could potentially be caused by poor capture efficiency, where an SMP does not capture the assumed stormwater volume from its drainage area, or alternative preferential flow paths that allow water to drain from the system more quickly than the infiltration and/or slow-release orifice assumptions. This performance metric is useful for identifying SMPs that require further investigation, such as capture efficiency testing or simulated runoff testing, to determine if the SMP is functioning properly or requires corrective maintenance measures.

Current design assumptions are that infiltration occurs at the pre-construction infiltration test rate only through the bottom footprint of the system. The more likely case is that infiltration is occurring laterally through the side walls as well as vertically through the bottom. Infiltration rates also appear to be variable based on saturation level and hydraulic head, with much higher rates of infiltration at the beginning of rain events and when the system is full. The design assumptions are meant to be conservative, and these results provide evidence that the systems are exceeding design expectations when it comes to the amount of runoff managed.

3.5.2 Overtopping Percentage Relative to Design Assumptions

Monitored systems also exhibited fewer instances of overtopping than design assumptions would have anticipated. This phenomenon is attributable to the same performance characteristics as the overperformance in section 3.5.1. Tables 3-4 and 3-5 show the results of a simulation analysis designed to investigate this reduction.

Table 3- 4: Results of simulation analysis designed to compare observed overtopping frequency to the simulated design expectations for Tree Trenches and Trenches

SMP Type	Total Systems Monitored	Total Events	Overtopping Events – Simulated	% of Events Overtopping – Simulated	Overtopping Events - Observed	% of Events Overtopping – Observed
Tree Trench	216	10,780	612	5.68%	69	0.64%
Trench	107	7,087	535	7.65%	62	0.87%

In order to compare the observed overtopping frequency to the simulated design expectations, the events with sufficient data to be simulated were assessed. Events that were able to be simulated required a sufficient rain event depth (at least 0.1 in), as well as the availability of all necessary system design characteristics to calculate a mass balance. The same sample of station storm events used to perform storage utilization analysis described in section 3.5.1 was used for overtopping analysis. The results indicated an order of magnitude fewer overtopping events observed during the GSI monitoring program to date compared to design assumptions. The simulated overtopping events correspond to the events where simulated absolute storage utilization reached 100%. As expected, observed overtopping became more common at greater event depth.

Continuous water level monitoring was also conducted at the three drainage well systems that have been constructed to test their viability for implementation across the city. These systems have been designed with less storage volume than typical GSI systems (between 0.3 and 0.6 inches of storage) and are only located in areas with highly permeable soils. For this reason, these SMPs are expected to reach maximum storage capacity with high frequency. Drainage wells are expected to capture and infiltrate runoff quickly through the sides of the well structure as it fills during an event, requiring less storage to manage most rainfall events. In this way, drainage well SMPs are meant to rapidly fill and rapidly drain down, reaching peak storage level more frequently than other SMPs. As such, the overtopping metric is expected to be higher for SMPs of this kind, even for those behaving as expected.

Table 3- 5: Results of simulation analysis designed to compare observed overtopping frequency to the simulated design expectations for Drainage Wells

SMP Type	Total Systems Monitored	Total Events	Overtopping Events – Simulated	% of Events Overtopping – Simulated	Overtopping Events – Observed	% of Events Overtopping – Observed
Drainage Well	3	274	213	77.74%	1	0.36%

Table 3-5 shows the simulated and observed overtopping results for the three drainage wells. The simulation is conservative in that it assumes a constant infiltration rate over the wetted area of the system and does not account for head-dependent effects on infiltration. Due to the smaller storage volumes, this results in simulations being sensitive to spikes in rainfall intensity filling the system quickly. The majority of event simulations resulted in overtopping due to this sensitivity at the peak rainfall intensity. It should be noted that after systems reach inundation in the simulation, they nevertheless drain relatively quickly and still manage a significant portion of the simulated inflow.

Despite these simulated overtopping results, only one instance of overtopping has been observed in drainage wells during monitoring. This suggests that they are infiltrating much more quickly than assumed, with substantial head-dependent effects on infiltration rates that were not accounted for in the simulations. This result is encouraging evidence that drainage wells are effective stormwater management systems and are viable solutions for sites with limited available footprint but also with appropriate geotechnical conditions.

3.5.3 Observed Infiltration Rates by Storm Size

Estimations of saturated infiltration rates yielded another insight when aggregating by storm size. When aggregating performance metrics for subsurface SMPs, an analysis was completed to determine whether saturated infiltration rates varied with storm depth. It was discovered that individual systems' range of saturated infiltration rates did not tend to vary with storm depth, as seen in Figure 3-3 for tree trench SMPs. The entire sample of measured station storms for subsurface SMPs had very similar infiltration rates across all monitored storm size categories. Tree trenches are depicted here as a representative example, but this behavior was consistent across all subsurface SMPs. This metric suggests that meaningful assessments of a system's saturated performance can be made using data for storm events smaller than the system was designed to manage. Saturated infiltration rate calculations appeared to be equally valid in small storms as in larger storms with more volume. The initial assessment of trends in Figure 3-3 was further supported by an LMER model created to assess significance of infiltration rate as a function of event depth. System locations were used as a random effect to adjust intercepts of the model and account for multiple observations at the same location. Infiltration rate data were transformed using a $\log_{10}$ function to ensure normality. Normality was checked through visual inspection of plots and histograms. Results indicated a statistically significant trend between event depth and $\log_{10}$(infiltration rate) ($p > .05$), but a marginal R^2 of 0.001 implying poor fit. This is relevant information for designing a set of monitoring criteria.

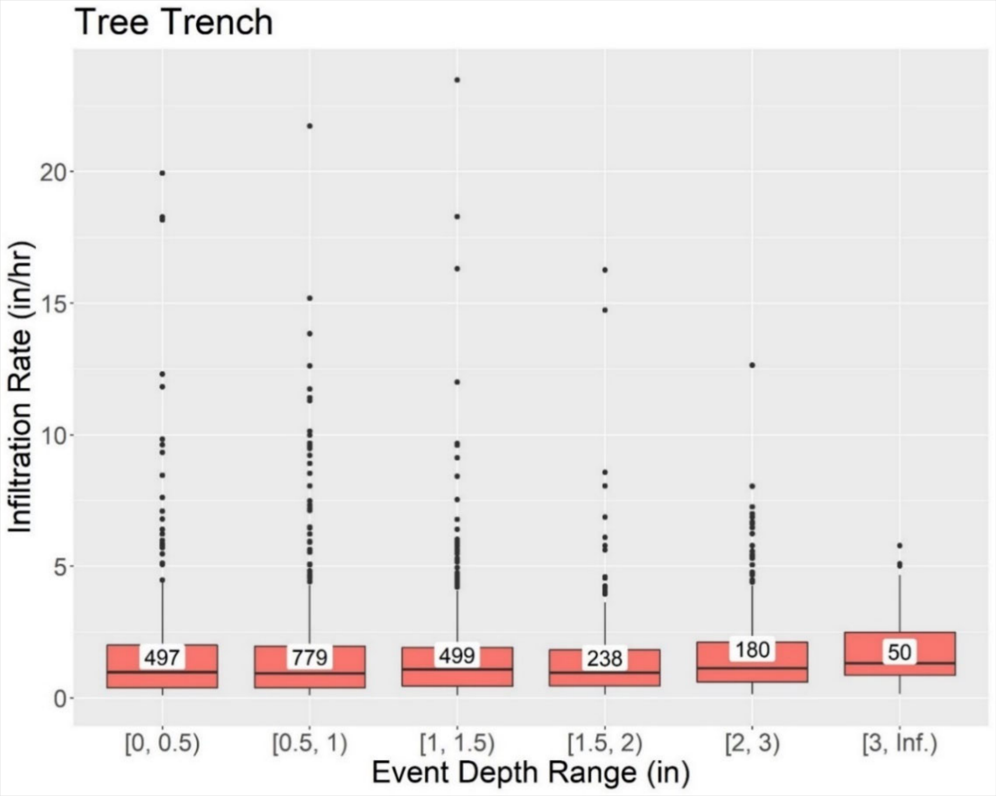

Figure 3- 3: Infiltration rates by storm depth as measured for Tree Trench SMPs

3.5.4 Observed Infiltration Rates v. Pre-construction Infiltration Test Results

The observed pattern of SMP overperformance can be explained in part by an assessment of observed infiltration rates compared to pre-construction infiltration test results. Observed infiltration rates routinely exceeded pre-construction infiltration test results, sometimes by an order of magnitude or more, even when no infiltration could be measured during the pre-construction test. These measurements take place below the slow-release orifices in systems that have them. Table 3-6 illustrates some summary statistics about how often these exceedances occurred.

Table 3- 6: Observed Infiltration Rates v. Pre-construction Infiltration Test Results

Monitored Infiltrating SMPs	SMPs with Observed > Pre-Con	Percentage	Mean Increase (in/hr)
151	126	83.44	1.8850

This is not a direct comparison with the methodology of the pre-construction infiltration rate tests. However, these post-construction rate measurements are measuring the infiltration rate at the lowest vertical stage, when the rate is at its lowest, meaning they are the most conservative averages of our monitored systems' observed infiltration rates. This method ensures that the surrounding soil is as saturated as possible and hydraulic pressure head influence is minimized. Figure 3-4 displays observed mean infiltration rates compared to each SMP's corresponding pre-construction infiltration test result. A $\log_{10}$-$\log_{10}$ scale is used for the sake of displaying data points that would otherwise be visually layered on top of each other.

Systems with a pre-construction infiltration rate of 0 were recoded to 0.01 to allow the points to display on the log axes. A 1:1 line of agreement is plotted as well. Points above this line represent systems that drain more quickly than their pre-construction infiltration tests predict. Points below the 1:1 agreement line have an observed infiltration rate less than their pre-construction infiltration rate.

Figure 3- 4: Log-log scale scatter plot of pre-construction infiltration rates and measured saturated infiltration rates from GSI monitoring

The 17% of SMPs with observed infiltration rates lower than their pre-construction rates were all properly managed by their slow-release underdrains, as evidenced by SMP overtopping analyses. As noted above, SMP overtopping events were found to be exceedingly rare compared to the expectations of design assumptions. This shows that storage and slow release is still an effective management tool for subsurface SMPs, even when infiltration rates are less than expected values.

3.5.5 Draindown Time for Subsurface SMPs

Analysis of draindown times concluded that subsurface systems consistently drain in less than the target design draindown time of 72 hours. The interquartile range of observed draindown times spanned 2 hours to 16 hours. The range of draindown times were generally inelastic respective of event depth and system storage volume. This suggests that unsaturated infiltration conditions allow for substantially more stormwater management than accounted for by simulations with conservative design assumptions. SMP simulations exhibited draindown times that scaled with storm size, since design assumptions utilize a constant infiltration rate at all storage levels. Observed responses for larger rainfall events resulted in greater differences between the simulated and observed performance for this reason (Figure 3-5). This was determined by an analysis including all subsurface SMPs (trenches, tree trenches, and drainage wells) without impermeable liners. The analysis consisted of categorizing storm events for the selected SMPs into bins for comparison. The events were binned by storm size, and the observed/simulated draindown times were displayed in boxplots.

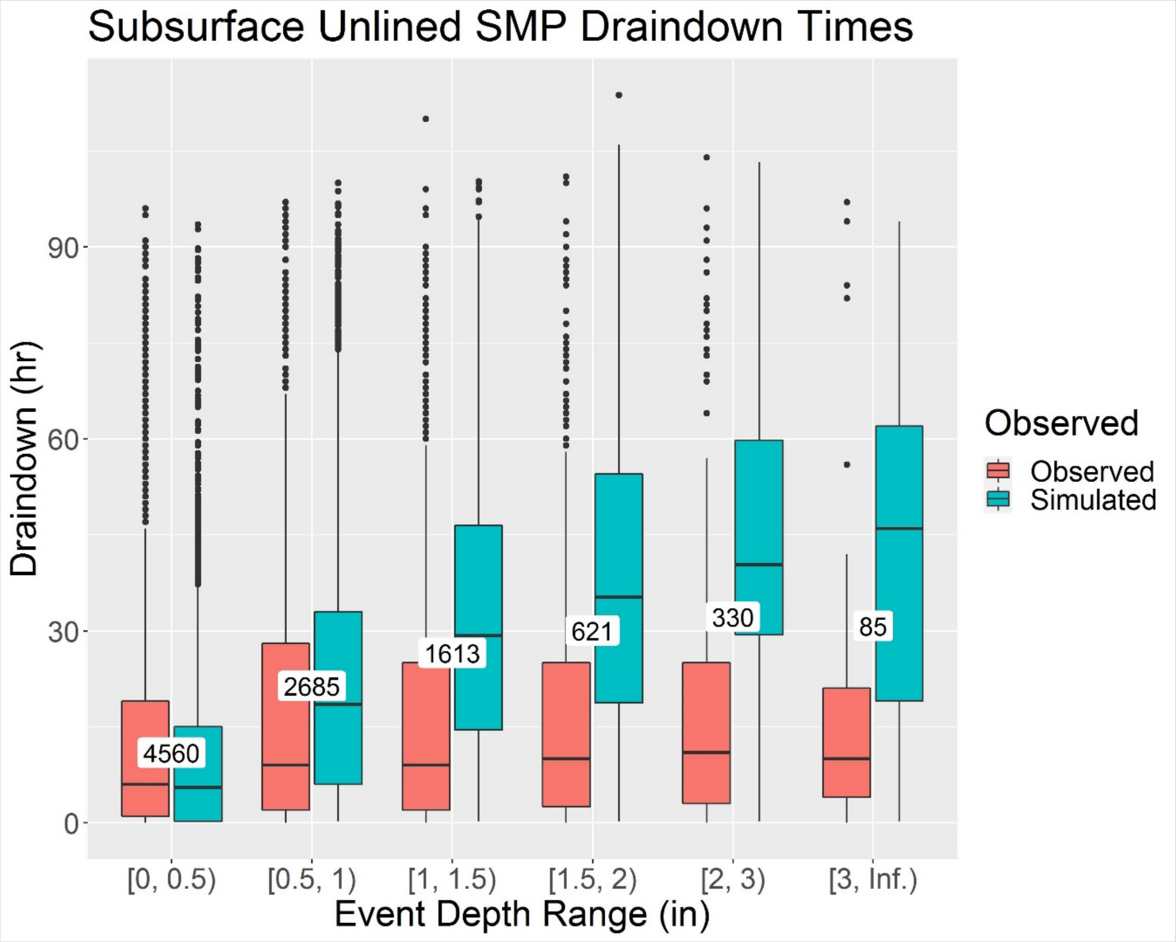

Figure 3- 5: Draindown times for subsurface SMPs

In addition to nearly all observed station storms meeting the 72-hour subsurface draindown guidelines, the monitored systems exceeded this guideline by 1-2 full days in most cases. 94.27% of observed events drained down within 48 hours of the storm ending. This suggests resilience in the face of increased storm depth or frequency due to, for example, climate change.

3.5.6 Draindown Time for Surface SMPs

Surface SMPs were found to consistently meet their 24-hour target draindown time. Monitored rain gardens showed a small number of exceedances of this 24-hour window, with only a few outliers even in the largest storm size range. Most surface SMPs consistently drained within 12 hours, even for storms in the 2–3-inch depth range. Figure 3-6 shows a distribution of monitored rain garden SMPs demonstrating these criteria.

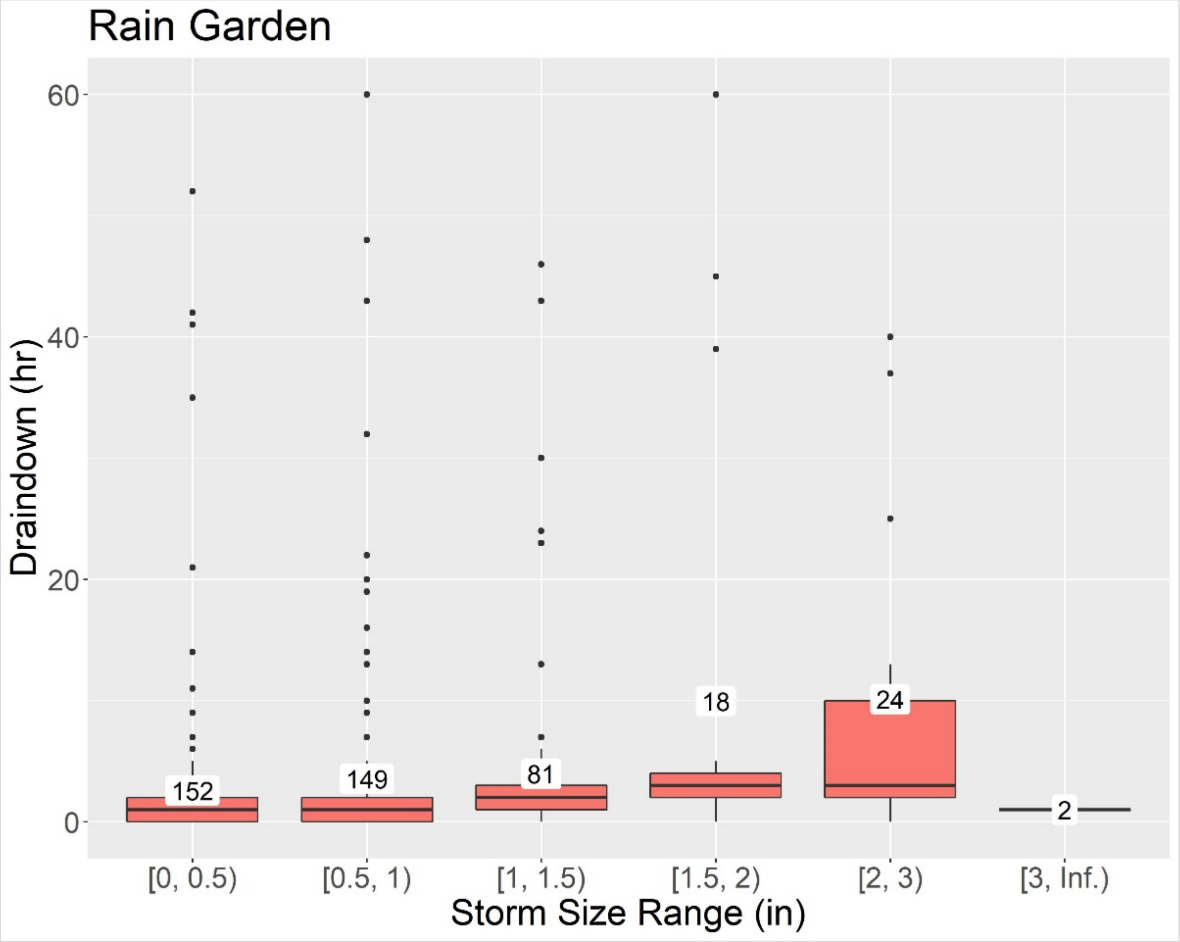

Figure 3- 6: Draindown Times for Rain Gardens

There were fewer station-storms in the surface draindown time analysis than in the subsurface analyses due to fewer rain gardens being monitored than subsurface systems. Surface wells are also removed during the fall and winter months due to the operating temperatures in our monitoring equipment, so there is data coverage for only 6-8 months of the year. Surface SMPs are more subject to seasonal variation in performance metrics for this reason.

3.5.7 Observed Infiltration Rate Trends Over Time

A small group of systems have been continuously monitored since the early stages of the GSI monitoring program for observation of long-term trends. This group includes 52 SMPs in total, consisting of 48 subsurface and 4 surface SMPs with an average monitoring period of 4 years. These SMPs continue to exceed their design expectations. In all cases, they manage larger storms than those for which they were designed, drain down in less than 72 hours, and overtop less than design assumptions would predict.

Among all the long-term monitoring sites, no universal temporal performance trends were observed. Figures 3-7 show consistent performance of SMPs over time, which is the most common long-term performance trend that was observed.

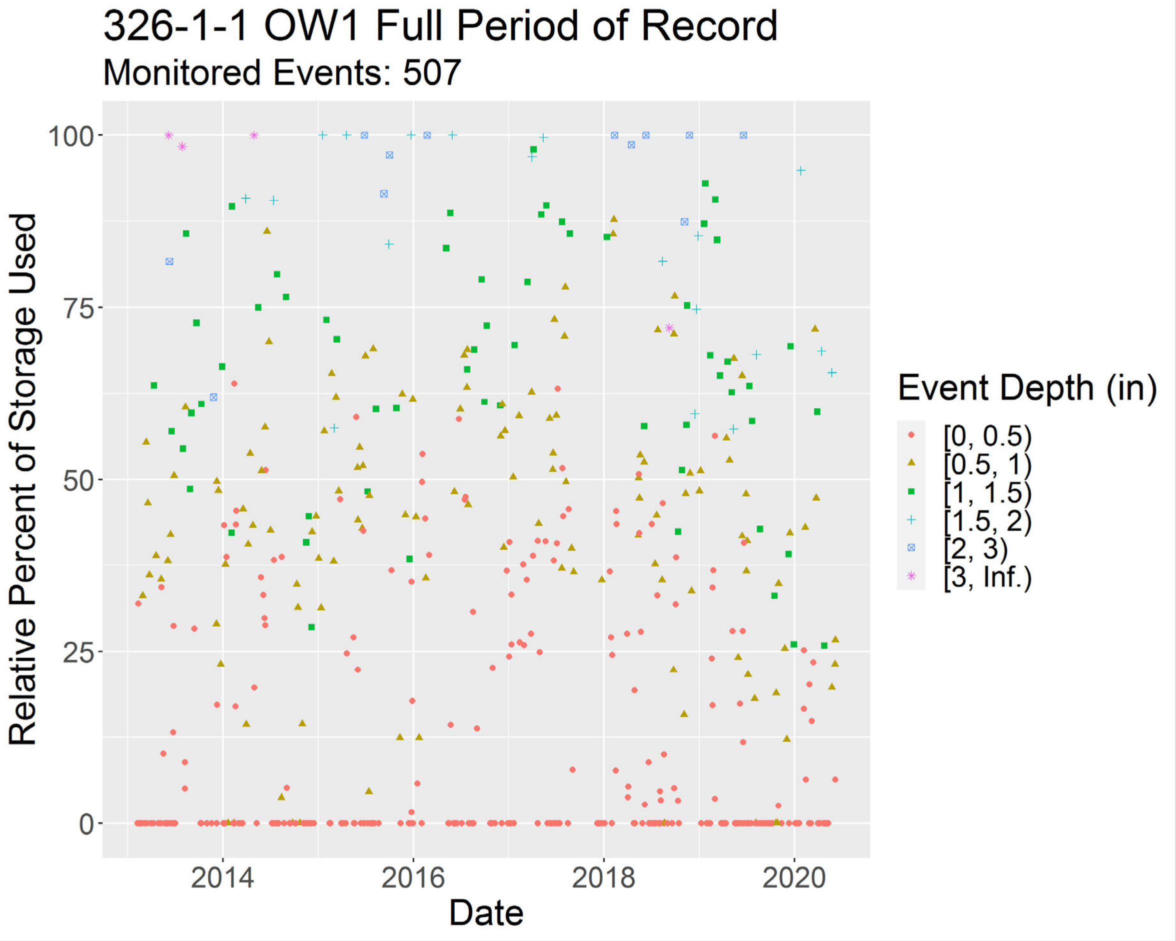

Figure 3- 7: Example of consistent long-term performance for SMP 326-1-1 – RPSU over time

An LMER model was created to assess the relationship between the observed infiltration rate and the age of the monitoring site at the time of a storm event. Infiltration rate data were transformed using a $\log_{10}$ function to create a normal distribution. This distribution was confirmed through visual inspection of histograms and qqplots. Monitoring site location was used as a categorical random effect to account for multiple observations at the same site. Relationship between site age and infiltration was proven to be insignificant ($p > 0.05$) with a Marginal R^2 of 0.00. Some individual SMPs' performance metrics trended towards managing water more quickly, and others trended towards managing water more slowly. Some extreme trends in the data are indicative of a functional issue for a specific system that can be addressed with restorative maintenance, but do not necessarily indicate any widespread issues or systematic phenomena. The CWL monitoring program will continue in perpetuity, including the monitoring of these long-term sites. As more data is collected, further reviews will be conducted for the sake of investigating long-term trends within the monitored sample of constructed GSI.

In Figure 3-8, the system's infiltration rate appears to increase over time, and the variance in the measurements appears to also increase. If these measurements reflect a long-term trend, the SMP is draining more quickly as it ages.

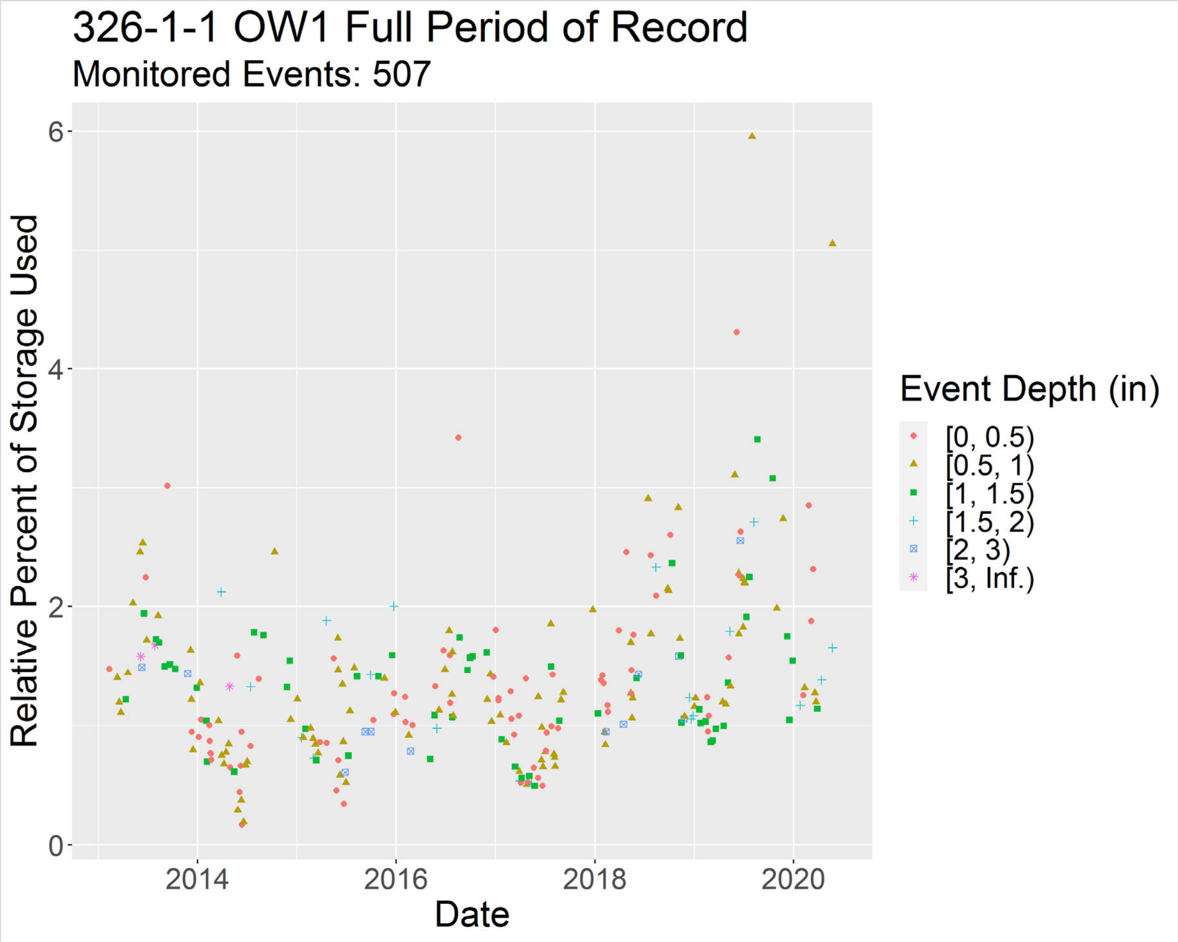

Figure 3- 8: Example of long-term SMP performance – infiltration rates

In Figure 3-9, the RPSU appears to increase with time, implying that the SMP is filling more readily during events of comparable size.

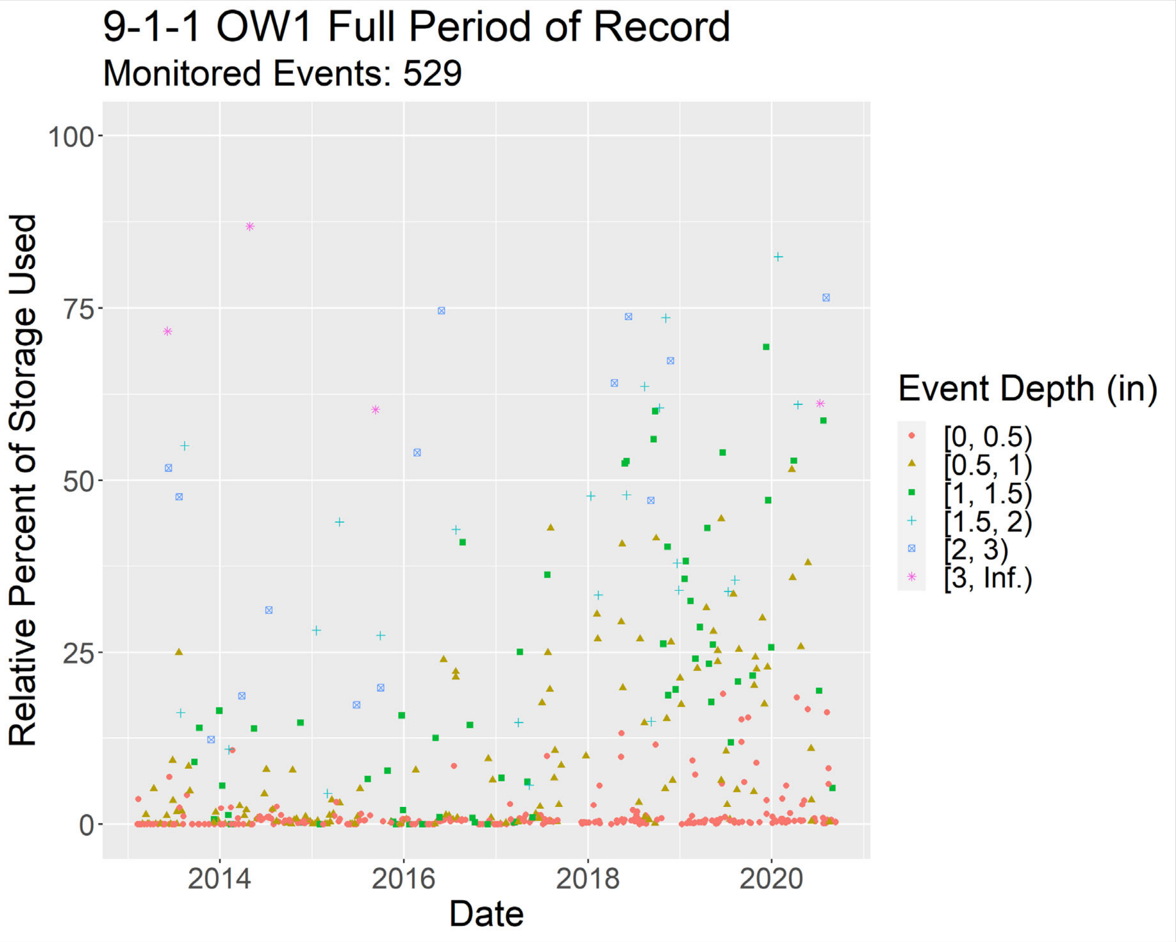

Figure 3- 9: Example of long-term SMP performance – RPSU over time

Some trends in performance over time have been observed, but the systems are still effectively managing runoff as expected and there has not been any evidence of consistent deterioration of performance. A set of subsurface long-term performance plots for the SMPs that made up this dataset is available in Appendix E.

3.6 Conclusion

PWD’s GSI monitoring program has expanded in scope since the Year 5 EAP, with continuous water level data collected at over 400 GSI systems. Performance metrics were developed to assess stormwater management performance with the available data. With such a robust dataset that was collected over the past five years, conclusions can be made about the performance of GSI being implemented by PWD. The data show that GSI systems are consistently infiltrating more quickly than expected and managing runoff volumes greater than the designed storage volume. Systems are overtopping much less frequently than would be expected compared to design assumptions, and draindown times are consistently less than the 72-hour design target for subsurface systems and 24-hour design target for surface systems. These lessons learned can be utilized to update GSI design and runoff crediting methods to maximize efficiency and account for the dynamic processes of infiltration and slow release during rainfall events. These results have informed the department's understanding of GSI performance and revisions to the Greened Acre calculation method, specifically the calculation for depth of runoff managed or Wd, to account for slow-release and infiltration in addition to storage. More information about the revised method can be referenced in Section 2.6 and Appendix B of this EAP. The results may also be used to inform H&H model inputs to represent GSI performance more accurately on a city-wide scale. Overall, GSI monitoring has demonstrated that PWD GSI systems are meeting and exceeding design expectations in most cases, confirming that GSI is an effective tool for reducing the amount of stormwater runoff entering the combined sewer system and contributing to CSOs.

4.0 Program Adaptations

As described in the *Implementation and Adaptive Management Plan*, adaptations and enhancements to implementation tools are expected throughout each five-year implementation period to ensure that program goals are met while the Philadelphia Water Department (PWD) seeks to maximize benefits and minimize program costs. Within this section, PWD has highlighted a number of within-program adaptations and enhancements initiated during this five-year period to address challenges and support achievement of the Water Quality Based Effluent Limit (WQBEL) Performance Standards. In addition to the on-going enhancements that PWD has pursued, additional within-program modifications (some temporary, others permanent) have been necessary as PWD has managed and continued to implement this complex program during the COVID-19 pandemic.

4.1 Green Program Adaptations

Implementation of Green Stormwater Infrastructure (GSI) across the City of Philadelphia has continued to evolve, however the three program implementation approaches remain the same. These include, 1) (Re)Development Regulations (via the *Philadelphia Water Department Stormwater Regulations)*, 2) Public Investment, which include both the PWD-initiated GSI projects and GSI following public works, and 3) Incentivized Retrofits. These approaches continued to develop and mature leading up to the Year 10 milestone.

Much of the evolution of the program during the most recent implementation period can be attributed to a commitment to feedback loops and iterative processes informed by lessons learned. These processes have aided in identifying challenges and resulted in program enhancement and optimization, as well as within-program adaptations, when applicable. The specific impacts of these feedback loops within each GSI project approach are outlined below.

4.1.1 (Re)Development Regulations Adaptations

(Re)Development Regulations continue to contribute to the program's Greened Acres (GAs). PWD's Development Services Unit (DSU) has been responsible for administering the Department's stormwater regulations through review, construction inspection, and maintenance inspection of development sites. Since 2016, PWD has made additional within-program adaptations to maximize the benefit of the regulations. This section includes a description of the milestones, updates, and major accomplishments associated with the regulations during this implementation period. The most notable of these program enhancements are recent updates to the *Philadelphia Water Department Stormwater Regulations* and the release of the *Stormwater Management Guidance Manual, Version 3.2*.

Regulation Updates

The *Philadelphia Water Department Stormwater Regulations* have been in place since 2006 and have undergone updates since 2016. Effective July 2, 2018, PWD made changes to how streets are regulated to better align with the Chapter 102 requirements in the Pennsylvania Code. Street maintenance activities no longer count towards the earth disturbance threshold for triggering the stormwater regulations. Development projects that propose the installation of a new street, whether public or private in designation, are required to also manage the runoff from the street in a stormwater management practice (SMP) on the development site.

Development of Manuals and Tools

During the implementation period leading up to the Year 10 milestone, some of the most notable adaptations within the (Re)Development approach include the development and updating of manuals and tools to help guide processes and align with other programmatic enhancements.

In addition to the regulatory changes, a number of administrative process enhancements were made over the last five years. These improvements include:

1. **Updated application materials:**
    - *Philadelphia Stormwater Guidance Manual, Version 3.1* released on July 2, 2018 and Version 3.2 released on October 1, 2020 and available online
    - New Online Technical Worksheet for Post-Construction Stormwater Management Plan (PCSMP) technical submission – This includes options for resubmissions, field changes during construction, and submission of record drawings following construction completion.
    - New standardized Maintenance Guide to expand on and standardize the existing requirement that applicants provide Operations and Maintenance Schedules
2. **Accessible information and online resources:**
    - An updated Online Project Portal which allows for online submission for all project stages
    - Translated Factsheets – several factsheets have now been translated into Spanish

PWD also updated the review fee schedules for all projects submitted for stormwater management approval, as well as the calculation for the Stormwater Management Fee in Lieu.

Stormwater Management Guidance Manual Update

The most prominent change within the new *Stormwater Management Guidance Manual, Version 3.2* is the incorporation of instructions for Stormwater Retrofits to create one design guide for stormwater management on all private property in Philadelphia. Stormwater Retrofits are defined as the voluntary rehabilitation and/or installation of SMPs on a property to better manage stormwater runoff as opposed to other regulated development. Stormwater Retrofits encompass most of the Incentivized Retrofits discussed in Section 4.1.3. The review procedures were updated to better reflect a largely online process, as well as some selected technical guidance changes. Most of the updates, outlined below, focused on how the program can ensure that SMPs are able to be maintained, function, and persist over time.

- Greater continuity between design and construction requirements for regulated and voluntary retrofit projects
- Detailed instructions on the review process for regulated Development projects, voluntary Stormwater Retrofit projects, and hybrid projects
- Updates to account for an almost completely virtual review and permitting process at PWD and between PWD and the City's Department of Licenses & Inspections (L&I) – This includes guidance for online plan submission through www.pwdplanreview.org.
- Detailed information and critical considerations for Stormwater Retrofit projects, as well as updates on the Stormwater Credits program
- An increase in the maximum loading ratio for all subsurface infiltration systems (regulated and voluntary retrofit projects) to 10:1
- Reorganization of Sections 3.1 and 3.2 for ease in locating specific design requirements, such as Disconnected Impervious Cover, Stormwater Management Practice (SMP) Hierarchy, and Stormwater Management Banking and Trading
- A modification of the SMP Hierarchy to remove porous asphalt and porous concrete as highest-preference SMPs – Any new Existing Resources and Site Analysis (ERSA) Applications received on or after October 1st, 2020 cannot use these materials to qualify for Expedited PCSMP Reviews.
- An expanded suite of Standard Details, now included under a new Appendix to the Manual, Appendix L
- Formalized standards for the required creation of an SMP Maintenance Guide, with associated documents now included under a new Appendix to the Manual, Appendix G
- Expanded basin setback requirements and exceptions for bioinfiltration/biorentention, subsurface infiltration, and subsurface detention
- Modified requirements for soil sampling, cased borehole soil characterization borings, and cased borehole infiltration testing
- Other updates to clarify existing policies and better reflect current design requirements and review procedures

PWD will continue to engage the development community to collect feedback on a rolling basis and incorporate that feedback, as appropriate, into the Manual and future policy updates.

Website Updates

The DSU website is geared toward the applicant and the development community at large and is the best place to find applicant resources. PWD has continued to regularly update the website, which now features additional resources to improve the experience for applicants, including expanded online submission capabilities that streamline the application process, a new

Geographic Information System (GIS) based tool, *Reg Finder,* that automatically imports site specific information into the ERSA application, as well as new website content. The new content consists of guidance targeted to the entire project lifecycle, including a dedicated page about the long-term maintenance of SMPs, a daily project status tracker, direct links to other PWD Unit websites and review process information, an expanded Project Dashboard to assist firms in managing multiple submissions, and a condensed Resource Guide. Through the website, applicants can access these technical resources and download documents, such as process flow charts, Standard Details, the Online Technical Worksheet, Online Pre-Application Meeting Request Form, information fact sheets, and the Manual.

A continued focus of these website improvements has been to establish an intuitive application process based on regulatory logic that streamlines data inputs for applicants. The purpose is for users to clearly identify required fields and plan their submissions by using the tools within the website to complete and meet the requirements. The switch to online submissions has proven to expedite the review process, further supporting that the time and resources invested in improving these online resources is benefitting overall implementation progress.

Additional information about the *Philadelphia Water Department Stormwater Regulations* and related resources can be accessed at this link: https://www.pwdplanreview.org/

COVID-19 Pandemic Impacts

On March 6, 2020, the Governor of Pennsylvania issued a Proclamation of Disaster Emergency in response to the 2019 novel coronavirus disease (COVID-19), which subsequently led to an order prohibiting operation of businesses that were considered non-essential. This led to a shutdown of all construction activities in Philadelphia beginning on March 22, 2020. Specific construction projects were permitted to resume in April 2020 and all construction activities were allowed to be restored by May 2020. Due to the remaining guidelines to prevent further spread of COVID-19, as well as other factors, many sites remained inactive for an extended period or construction activities were not being performed at previous levels. PWD adapted quickly to successfully manage new procedures within the remote work setting and to take full advantage of recent improvements to online processes, but external factors such as lower construction initiation rates, contractor delays, labor and supply shortages, and project funding impacted and are still impacting anticipated project timelines.

4.1.2 Public Investment Adaptations

PWD's Public Investment approach funds, designs, constructs, inspects, and maintains SMPs through a capital GSI program with a district-based planning framework. These projects typically occur in the public right-of-way (ROW) but can also be built on publicly owned property, such as City-owned parks, facilities, or vacant lots. In addition to new installation of GSI, this program also includes Renew and Replace projects that add GSI to water and sewer linear asset replacement projects. PWD continued to develop, enhance, and standardize its GSI implementation process for public investments.

Strengthening Post-Construction Processes

In the first five years of the program and as reported in the Year 5 Evaluation and Adaptation Plan (EAP), PWD primarily focused on implementing and tracking GSI compliance through four project stages: planning, design, construction, and post-construction. After five years of implementing GSI across the City of Philadelphia, tracking post-construction statuses became a prominent factor to strengthen and improve GSI operations, monitoring, and maintenance processes. The PWD implemented a post-construction problem-solving process that is administered by a multi-unit team which presents observations from the field so that lessons learned can be shared and used to consistently improve and strengthen program implementation. This process outlined in Figure 4-1 has contributed to substantial successes in addressing post-construction challenges throughout the past five years.

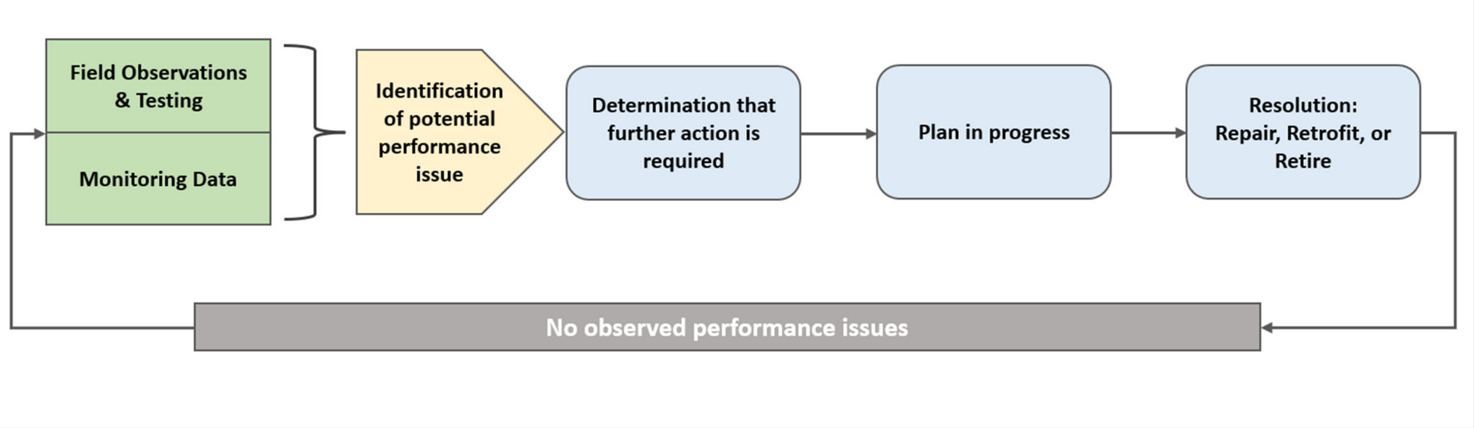

Figure 4- 1: Process for identification and resolution of observed potential post-construction issues

This multi-unit collaboration has allowed the Department to identify, diagnose, and streamline workflows for repairs and the design of retrofit plans. It has led to improved clarity on both proactive and reactive means to handling GSI in a post-construction setting. Some examples of GSI issues confronted include impacts from development, conflicts with abandoned infrastructure, inlet capture rates, and impermeable liner performance.

Some examples of process improvements realized through collaboration and the resolution of issues provided above include:

- Development of a repair matrix to standardize how identified issues are addressed
- Development of workflows to create retrofit plans for constructed GSI systems
- Development of processes to retire/abandon GSI systems in the rare case a repair or retrofit is not suitable or cost effective
- Integration of contractual mechanisms for specialized GSI repairs and retrofits
- Proactive testing of liner performance during construction
- Modification of design standards to improve capture efficiency of surface inlets and to improve conveyance of flow from surface SMPs to subsurface SMPs

This process also inspired improved communication and reporting protocols to keep the Department informed of decisions and policies focused on GSI implementation. Departmental databases and tools were enhanced to track the revised workflows.

GSI Operations and Maintenance

The scope, scale, and magnitude of PWD's responsibilities associated with operations and maintenance have increased exponentially since the start of the program.

At the close of Year 5, PWD public investments had produced 409 SMPs. At Year 10 the public investment approach has now produced 1,405 SMPs. In order to meet the growing demands of the program, PWD has developed feedback processes to support standardization of designs and SMP components when possible. PWD also coordinates with other entities that perform work, such as excavation for utility connections or street paving, within ROWs and other areas that may impact GSI sites; this is a key component of preventative maintenance. Development of robust tracking systems to manage field processes, including inspections, surface and subsurface maintenance, and elevating observed issues that cannot be resolved through standard maintenance, has become an integral aspect of the PWD operations and maintenance program as the number of SMPs in operation continues to grow.

To ensure the function and sustainability of stormwater management infrastructure investments, PWD has continued to implement a robust GSI maintenance program in accordance with the *Green Stormwater Infrastructure Maintenance Manual, Version 2.0*. Protection and management of GSI assets may take several forms, such as replacement of worn, damaged, or stolen components, or determining risk factors for system failure. The surface asset maintenance staff work to keep SMPs maintained within a specified timeframe according to prescribed site-specific maintenance requirements and apply a consistent maintenance standard to both in-house and contracted labor. Most surface components are inspected and maintained monthly or quarterly depending on the SMP type. Subsurface inspection and maintenance procedures ensure that all SMPs with inlets and piping are cleaned on average once annually followed by a post-maintenance inspection. Green inlets have pretreatment devices installed such as filters and screens, but deposits of debris can still become obstructions that must be identified by subsurface inspection and maintenance staff and subsequently removed in order to regain full SMP functionality.

The ability of PWD to inspect and maintain a large number of GSI systems and their associated assets has become increasingly reliant on database and tool enhancements. Depending on how the project was initiated, GSI assets are often tracked in different databases, managed by different units, and facilitated through the construction and inspection processes via different units and workflows. In some cases, the design standards and concepts may vary between the implementation approaches, which can pose challenges related to onboarding projects into the inspection and maintenance queue and implementing cost controls for the associated maintenance requirements. A continued focus on standardization and alignment of workflows, including improved tracking of work orders and the associated follow-up monitoring, will remain a vital component of PWD's GSI operations and maintenance approach.

Workforce Development

Over the past decade, the City and PWD implemented new strategies to address the City's workforce development priorities. In support of this goal, PWD entered a partnership with Power Corp PHL (PCPHL), which is a City of Philadelphia and AmeriCorp initiative designed to engage at-risk Philadelphia youth, ages 18-26, in workforce development training and public service, while also addressing environmental stewardship and violence prevention objectives. The PWD operations team continually worked with PCPHL leadership to develop logistics and operational efficiencies that allowed PCPHL to scale their operation and perform at levels comparable to that of contractors to address the increasing demands on maintenance resources. Some of these modifications included a reduction in crew sizes, increased use of mechanized equipment and specialized vehicles, as well as the use of data management structures to distribute and track work orders.

PCPHL has developed into an invaluable program asset during this period of program growth. More than 90% of Power Corps graduates enter the "green industry," including stormwater management. During any given year, managing PWD's GSI assets may require more than 20,000 individual work orders distributed among PWD, PowerCorps, and contractors. As of 2021, PCPHL has trained more than 700 people, many of whom have moved on to full-time employment with the City and local maintenance contracts. The following link provides more information about the success of the PCPHL program, including testimonials from participants:

https://water.phila.gov/blog/gccw10-jobs?fbclid=IwAR2Z1wTD73Az1kuOZoZ-Y24iYAeYn4koRTfKpkp3be113TII9-6n-sue-RU

Development of Manuals and Standards

Additional within-program adaptations and enhancements were incorporated during Years 5 through 10 to improve process efficiency within the Public Investment approach. These improvements are informed through observations collected during program implementation. PWD anticipates continuing the practice of updating these documents and standards as additional enhancements are identified.

Green Stormwater Infrastructure Maintenance Manual Update

In the Summer of 2016, the original *Green Stormwater Infrastructure Maintenance Manual* was revised to include adjustments influenced by lessons learned and field experience of staff and maintenance personnel. New additions at that time included updated guidance for the maintenance of porous and pervious pavement and guidance on procedures for maintenance for new SMP types. At the end of FY2017, the addition of a substantial number of SMPs dispersed over a much larger geographic distribution area, as well as further maturation of existing SMPs, necessitated PWD to implement additional processes and strategic protocols to adapt to the growing scale of required surface and subsurface maintenance. In response to this growth, the *Green Stormwater Infrastructure Maintenance Manual, Version 2.0* was developed, which improved upon the original version with the inclusion of a section dedicated to inspections. The addition of this section allowed PWD to formally transition from monthly inspection frequencies to a "need based" regime. This modification aligned with the programmatic adjustments that needed to occur in order to maintain the scale of operations required to manage the increasing number of SMPs. The shift to a reduced number of prescribed maintenance inspections considers the need for less intensive maintenance frequencies as vegetated GSI systems become established and reach maturity, which promotes efficiency of process and reduces costs.

The current version of the *Green Stormwater Infrastructure Maintenance Manual, Version 2.0* can be found at the following link: https://water.phila.gov/pool/GSI-Maintenance-Manual_v2_2016.pdf

Planning & Design Guidance Update

PWD's planning and design guidance documentation is part of a robust technical library of resources and standards established during the first phase of the program, creating a clear and documented planning and design approach to GSI in Philadelphia. Since 2016, the planning and design guidance for the Public Retrofits and Renew and Replace programs underwent significant updates. Lessons learned each year, along with feedback from PWD's construction, monitoring, and maintenance teams, provided critical insights that PWD used to improve guidance resources to streamline the planning and design process. Most recently, guidance for vacant lots and for reusing park infrastructure on off-street projects was developed. In 2018, PWD added improved language and better detail on initial siting of GSI to the manual. In January 2021, PWD released a new version, *Green Stormwater Infrastructure Planning & Design Manual, Version 3.0*, which included additional changes. Some of these updates include expanded guidance on system placement and impermeable liners, a reduction in the target storm size to 1.5 inches, and the introduction of new numbering systems to help link potential system footprints to potential project locations tracked in the databases.

The updated *GSI Planning & Design Manual, Version 3.0* can be found at this link: http://documents.philadelphiawater.org/gsi/GSI_Planning_and_Design_Manual.pdf

PWD maintains a constant feedback loop between planning, design, construction, monitoring, and operations and maintenance, leading to success in improving planning and design guidelines, construction specifications, and implementation workflows. Continuous efforts are in place to align planning and design across water/sewer and GSI projects through improved communication and collaboration among units and documentation of lessons learned from teams participating in the implementation of GSI. The collaboration among teams within the department led to a significant effort to document and standardize the guidance for the Public Investment approach and make these standards transparent and readily available to the development community.

Partner Coordination

Significant improvements to coordination within PWD and with other City agencies played a large role in the consistent enhancement of the *GSI Planning & Design Manual, Version 3.0,* and other reference materials. The Department has successfully collaborated with many partners on projects throughout all stages, including the Streets Department, Philadelphia Parks

& Recreation, Public Property, Philadelphia Housing Authority, Philadelphia Redevelopment Authority, Southeastern Pennsylvania Transportation Authority, Philadelphia City Planning Commission, City Council, and Commerce, which has led to the expansion of available land use types for GSI installation and the strengthening of relationships across City agencies. The Mayor's initiative, Rebuild Community Infrastructure (Rebuild), continued to work with PWD as an implementation partner, which included closely coordinating to integrate stormwater management into Rebuild projects. Relationship building with partners is noted as both a success during this implementation period and an opportunity for continuous improvement.

COVID-19 Pandemic Impacts

The March 22, 2020 Order had similar impacts on public project implementation as those documented in the (Re)Development section. As construction activities were permitted to resume in April and May 2020, PWD worked with contractors on timely reviews of updated health and safety plans, requesting and assisting with revisions to resume construction in compliance with governmental orders and guidance. Delays during the beginning of the pandemic impacted anticipated project development timelines, but PWD expedited the transition from fully in-person to a fully remote setting quickly and effectively, which allowed for the department to catch up and remain functional. Unfortunately, as the COVID-19 pandemic is ongoing, there are external factors that are outside of PWD's control that are still impacting project development schedules, such as delays in contracted work and supply chain issues.

4.1.3 Incentivized Retrofits Adaptations

The PWD Incentivized Retrofits programs use innovative approaches to incentivize private commercial and industrial property owners to manage stormwater through green infrastructure. This program is administered by PWD Stormwater Billing and Incentives and provides financial incentives to customers who help the City meet its stormwater management goals. These actions include mitigating stormwater runoff using SMPs and preserving existing conditions on the parcel that are favorable for stormwater management, such as high-quality vegetated area and disconnecting impervious area from the sewer system. Stormwater grants are available and can pay for the design and construction of stormwater retrofit projects on non-residential properties in Philadelphia. Once a stormwater management system is installed, the property owner is eligible for credits to reduce their stormwater service charge on their monthly bill. Both incentivized retrofits and development projects constructed in accordance with the *Philadelphia Water Department Stormwater Regulations* are eligible for a reduction in their stormwater charge upon completion of construction. Property owners are responsible for renewing their credits every four years.

Evolution of Incentivized Retrofits

The Incentivized Retrofits program has been successful to date. Property owners that have participated over the course of the program include large commercial and industrial entities, private parks, and schools. Application and technical guidance materials have been updated as the program evolved into a formal GA delivery approach.

Since 2016, PWD has seen a slow shift away from large, industrial sites toward more community focused parcels owned by entities such as schools, churches, and non-profits. Maintenance of the SMPs and long-term viability of the projects has also become more of a focus during this phase.

To support this shift and diversify project and property types, while increasing transparency in the selection process, a rubric was created to assist in ranking applicants for award from one of the three grant opportunities outlined below. More information about the rubric can be found on Page 4-11. The Stormwater Billing and Incentives Team is actively working to stabilize the timing of grant announcements and deadlines to be more predictable and sustainable in the long-term.

Stormwater Management Incentives Program (SMIP)

The SMIP was launched in 2011 and provides funding to non-residential property owners to design and construct SMPs. Under the SMIP project model, the property owner or the tenant is the applicant. The applicant works with at least one stormwater management vendor to create a concept plan and apply for funding. If the project is awarded a grant, the property owner or tenant becomes the Grant Manager.

Though SMIP 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. Limitations associated with the original SMIP prompted the creation of the Greened Acre Retrofit Program (GARP) and Alternative-SMIP options.

Greened Acre Retrofit Program (GARP)

PWD launched the GARP project model in 2014 after developing an understanding of lessons learned after the SMIP launch. GARP 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 and the aggregator then manages the application, design, construction, and maintenance of the SMPs. This model reduces the administrative burden on the property owners and encourages growth in the private sector.

Alternative Stormwater Management Incentives Program (Alt-SMIP)

The Alt-SMIP model was launched in 2018 and is very similar to the GARP model except that a community group, non-profit organization, or a vendor manages the grant for one project rather than aggregating several. This model has become more popular in recent years because it allows an entity other than the property owners to handle the administrative responsibilities of the grant. As with the GARP model, this option reduces the administrative burden on the property owners and encourages more applicants to take advantage of the opportunity.

Development Incentives

At Year 5, PWD considered prioritizing funding for projects that maximize management through right-of-way capture. The Department recently initiated the Developer ROW Incentive, which targets ROW capture adjacent to redevelopment projects. While there has been limited outreach thus far, the Department plans to continue to pilot this incentive. In addition, Disconnection grants have also been offered, which enable property owners to connect their drainage to new public stormwater systems.

Development of Manuals and Tools

PWD made additional changes to the existing manuals and tools within the Incentivized Retrofits program since the Year 5 EAP. Some of the documents that were updated include the recently released *Stormwater Management Guidance Manual, Version 3.2,* and the *Stormwater Grants Application Guide*. These resources encourage participation from property owners and standardize the administration of the Incentives Program.

Stormwater Management Guidance Manual Update

Stormwater Retrofit guidance was officially added to the recently released *Stormwater Management Guidance Manual, Version 3.2*. Guidance from the Incentives Program is now included throughout the manual to aid applicants and vendors who are developing Stormwater Retrofit projects in navigating the Manual and additional relevant resources. The *Stormwater Management Guidance Manual, Version 3.2* can be accessed at the following link: https://www.pwdplanreview.org/manual-info/guidance-manual

Stormwater Grants Application Guide Update

The *Stormwater Grants Application Guide*, now Version 3.0, underwent changes in the last five years, including the addition of several tools to support applicants in the submission process. A *Common Mistakes: Pre-application Checklist* is now included to help project teams to evaluate their application before submission. A series of templates were also developed and are now provided to applicants, including a template for the *Proof of Consent*, which confirms that the property owner will sign PWD's Subgrant Agreement and O&M Agreement, as well as a template for the *Letter of Intent* for projects applying under the Alt-SMIP and GARP models, which confirms that the property owner will work with the applicant as part of the project team. These templates, as well as other supporting materials, can be found in the Appendix of the guide.

The updates to the *Stormwater Grants Application Guide, Version 3.0* provide more flexibility to project teams when deciding which project delivery model to select. The guide deemphasizes SMIP/Alt-SMIP/GARP as project models and focuses on which entity will serve as the Grant Manager and receive the stormwater grant funds.

In an effort to provide more transparent information to grant applicants in FY2021, PWD published specific criteria that were used to make grant award decisions. The updated FY2022 rubric can be found on Page 20 of the *Stormwater Grants Application Guide, Version 3.0*. The aim of this rubric is to provide applicants with the information they need to develop strong, competitive, quality applications. Some of the criteria categories include Greening, Cost

Effectiveness, Project Funding, Community Impacts, Right-of-Way Impervious Area Capture, and Strong Property Owner Involvement. This rubric solidified greening and additional benefits as key features of a competitive grant application to aid in equitable project selection.

The application guide can be accessed at this link: https://water.phila.gov/pool/files/stormwater-grants-application-guide.pdf. This guide and supplementary materials are also available for download on the Stormwater Grants website: https://water.phila.gov/stormwater/incentives/grants/

Website Updates

The Stormwater Grants website underwent significant updates. An Incentives page was created which outlines the different incentives offered for stormwater management projects in Philadelphia, including Stormwater Credits, Stormwater Grants, and Development Incentives. The page provides links to all relevant technical resources and web content was added to provide a comprehensive overview of the available programs. An online submission process was created to streamline the application process and provide improved project tracking capabilities. The new website can be found at the following link: https://water.phila.gov/stormwater/incentives/.

COVID-19 Pandemic Impacts

As with the other implementation approaches, the Incentivized Retrofits Program also experienced delays related to the construction shut down in March 2020. All grant projects under construction were impacted. Some projects received exemptions to continue work, while others remained inactive until Summer 2020. Some companies also expressed hardship during the pandemic, especially smaller contractors. Additional funds were administered in some cases to aid implementors that expressed a need for more support.

5.0 Strategy for Achievement of Year 15 WQBEL Performance Standards

The program adaptations and enhancements described in Section 4 are intended to support the Philadelphia Water Department (PWD) in meeting future program obligations, including the Year 15 Water Quality Based Effluent Limits (WQBEL) Performance Standards (Table 5-1). There are a number of compounding complexities that PWD faces. In the coming years, PWD anticipates an increase in capital and operating expenditures for Green Stormwater Infrastructure (GSI) implementation as the annual expected delivery of GSI projects increases. It is also expected that GSI implementation opportunities will become more constrained as siting opportunities become limited and complex. The City continues to navigate the impacts of the COVID-19 pandemic, while also managing other compliance obligations that continue to grow in magnitude and complexity. As PWD looks toward the future of the program, there are potential risks to be monitored and navigated. PWD is committed to monitoring potential impacts and proposing adjustments to the program as necessary during subsequent implementation periods. This commitment includes systematic review of program data, costs, and feasibility, as well as considering holistic opportunities to meet Clean Water Act (CWA) requirements while integrating departmental priorities.

PWD presents some of the observed program impacts of the pandemic in this report, but the full duration and potential long-term impacts remain unknown. Tracking the impacts of the pandemic and other challenges on program goals will be a priority as PWD enters the next five-year implementation phase.

Table 5- 1: Year 15 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	14.5
Overflow Reduction Volume	million gallons per year	3,619
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	3,812

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 outlined in the

Green City, Clean Waters Wet Weather Facility Plan submitted in June 2016. PWD continues to conduct research and evaluate tools and technologies used within the Collection System and at the WPCPs to enhance performance when possible. PWD studies and evaluates potential collection system and WWFP projects to determine feasibility and cost effectiveness for inclusion in a Combined Sewer Overflow (CSO) mitigation program.

5.2 Miles of Interceptor Lined and Rehabilitated

In preparation for the Year 15 WQBEL Performance Standards, there are currently 2.6 miles of interceptor lining in construction or contract management and 3.3 miles in design (Table 5-2). Prior to scoping rehabilitation efforts, each interceptor segment is inspected to determine condition and need for rehabilitation. The Frankford High Level Interceptor (FHL) was studied to determine the condition of the interceptor prior to scoping rehabilitation efforts. This segment is labeled as "Tacony Creek Intercepting Sewer Lining Phase 3" in the table below. The section of the FHL evaluated is approximately 6,000 linear feet in length originating just downstream of Regulator T-14 and terminating near the intersection of O Street and Erie Avenue. The evaluation confirms that this segment of the FHL is in serviceable condition and any observed defects, such as root intrusion or surface spalling, can be corrected with spot repairs and debris removal. The report concludes that application of a continuous liner to the FHL, as has been pursued with the other segments listed in the WQBEL Performance Standards, is not recommended to correct infiltration or exfiltration in this case; the rehabilitation work can be completed at a much lower cost by pursuing the recommended spot repairs and debris removal rather than relining the full section of the interceptor.

Table 5- 2: Interceptor Lining and Rehabilitation Progress

Project Name	Extents	Length (Miles)
In Contract Management		
Cobbs Creek Intercepting Sewer Lining Phase 2	61st and Baltimore to 60th and Warrington	1.0
Total		**1.0**
In Design		
Tacony Creek Intercepting Sewer Lining Phase 3	I & Ramona to O & Erie	1.0
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**
In Construction		
Cobbs Creek Intercepting Sewer Lining Phase 4 (Indian Creek Branch)	City Avenue to Drainage Right of Way in former 67th Street	1.6
Total		**1.6**

5.3 Volume and Equivalent Mass Capture

Projects implemented to date and a cumulative of 3,812 Greened Acres (GAs) along with WPCP modifications planned for the coming five years are anticipated to meet or exceed the Year 15 WQBEL Performance Standards.

5.3.1 42nd Street Pump Station Expansion

Based on evaluation of the collection system, as well as considering the necessary operation upgrades, it was determined that there are advantages to replacing the combined sewer pump station located at 42nd Street with a station with expanded pumping capacity. To support this expansion, regulating chamber S50 would also be modified; this regulating chamber modification is considered part of the pump station expansion project. A preliminary feasibility study has been completed to determine the constructability and sizing of the pump station. The study determined that the current 8 MGD (peak flow) pump station could be expanded to 60-100 MGD. This upgrade would accommodate increased flow to the SW WPCP and help reduce CSO volume. The project is currently in the design phase.

5.4 Greened Acres

During the coming five years, the program must realize at least 1,664 additional GAs to achieve the Year 15 WQBEL Performance Standard of 3,812 GAs. During the past five years, PWD analyzed each of the GA implementation approaches, which include (Re)Development Regulations, Public Investment, and Incentivized Retrofits, to understand process improvements and challenges, duration of project phases, and general trends for each approach. This analysis informed PWD’s projections for the coming five-year period, all of which are presented with the understanding that there are unknown factors associated with the COVID-19 pandemic that could affect the outcomes.

5.4.1 (Re)Development Approach

PWD continues to gain a deeper understanding of development trends and the GA potential through the (Re)Development implementation approach. As reported in Year 5, there are many challenges to establishing trends and projecting forward the performance of the (Re)Development approach as the number and size of projects constructed per year varies and is influenced by a variety of external factors. These factors include the economic market within the city, project financing, and other independent economic forces. For example, a significant reduction to the local real estate tax abatement for new construction went into effect on January 1, 2022, which may affect future development rates. In addition, the COVID-19 pandemic revealed the potential for additional impacts, the extent of which are largely still unknown. Early impacts were detected by a decrease in projects initiating construction following the 2020 shut-down of construction activities and broader impacts of the pandemic on the workforce and economy, which could reveal longer-term impacts to production goals. The impacts of the pandemic can be multifaceted and PWD will work to identify, monitor, and mitigate where possible. However, it is likely that the full economic impact will not be understood until several years into the next implementation period.

At present, there are 374 projects representing at least 580 acres in the (Re)Development queue. Pre-pandemic trends show an average of 65 acres were developed annually via this approach and projects took an average of 4.9 years to complete (from technical submittal to complete construction). These trends do not account for project size and market variability and are especially unreliable as we look ahead due to the uncertainty of long-term pandemic impacts on the economy.

PWD is in the process of developing an evaluation process to enhance stormwater management options for development projects that involve residential single-family lots and other small sites. PWD anticipates continuing to expand opportunities for maximizing stormwater management of regulated sites through ongoing and continuous outreach to the development community and incorporation of feedback into future materials and policy updates.

5.4.2 Public Investment

PWD will continue to generate GAs through the Public Investment implementation approach. This approach underwent several within-program adaptations and enhancements leading up to the Year 10 milestone, but PWD has maintained a thorough understanding of the process and continually monitors the expected duration for implementation of public projects. PWD anticipates that moving forward more resources will be dedicated to the post-construction phase, which is integral for long-term program success and will continue to generate feedback and adjustments on operations and maintenance protocols as appropriate.

At present, PWD has 293 projects representing at least 1480 acres in progress within the queue. With the extension granted for Year 10, the timeline for achieving the Year 10 obligations has now encroached on the timeline for Year 15 implementation by approximately six months. Pre-pandemic, public projects took on average 4 years from the point that they initiated design through construction completion and 46 acres were developed annually, but pandemic impacts such as the suspension on bidding for public projects, supply chain issues, labor shortages, and economic constraints make it challenging to project the anticipated trend for the next implementation period.

5.4.3 Incentivized Retrofits

The Incentivized Retrofits approach continues to be a major contributor of GAs toward program goals. At present, there are approximately 120 acres from 57 projects in progress. There are also applications from the fall 2021 submission period that were recently processed and awarded. The average project size this year (FY2021) is 5.2 GAs and the FY2022 budget is $20 million. PWD will consider expanding outreach to extend the program's reach in the coming years. With the shift from larger sites toward more community focused parcels in recent years, project size and associated reduction on stormwater bills for participants in the grant programs will be important to monitor in the upcoming implementation period. Prior to the pandemic, PWD observed that the average project size was 6.3 GAs On average, 65 acres were developed annually, and projects had an average implementation duration of 1.8 years. It is not possible to identify project schedule or delivery trends at this time due to evolving programs, project sizes, and project types.

For the past five years of implementation, PWD has been operating the Incentivized Retrofits approach with a budget of approximately $15-25 million per year. However, funding for the Incentives budget must be requested and approved annually. Tools such as the newly developed rubric for effectively and fairly selecting grantees, as well as the improved online resources and guidance documents, will continue to support the selection of eligible, high-quality projects in light of uncertainty in available future funds.

To support the further maturation of this program, a Grant Manager role associated with incentives opportunities has been developed. The Grant Manager can be the property owner or tenant, a stormwater management vendor, or a third-party organization, and is responsible for filling out and submitting the grant application form and all supplementary materials. This role will guide the project models moving forward and this shift will create flexibility as the program continues to mature.

5.5 Conclusion

PWD has met or exceeded all Year 10 WQBEL Performance Standards as required by the COA, with the seven-month extension granted by the Pennsylvania Department of Environmental Protection (PADEP). 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, PWD GSI systems are meeting and exceeding design expectations in most cases, confirming that GSI is an effective tool for reducing the amount of stormwater runoff entering the combined sewer system and contributing to combined sewer overflows.

However, PWD anticipates challenges ahead as we enter the next implementation period. The City is still contending with the COVID-19 pandemic in addition to other challenges highlighted herein, and only time will reveal the full impacts on the program. The adaptive management process continues to guide PWD towards programmatic enhancements as new information and efficiencies are discovered. As PWD progresses toward the Year 15 WQBEL Performance Standards, the department will continue evaluating the most cost-effective and feasible CSO strategies for achieving program targets. PWD anticipates that additional enhancements, implementation adjustments, and evaluations will be a part of that process. The department will continue monitoring risks in the coming years and will also continue the monitoring program as described in the *Comprehensive Monitoring Plan* until a CMP update is initiated.