GREEN INFRASTRUCTURE MONITORING PLAN

FEBRUARY 2019

CITY OF
LANCASTER
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Chapter 1

1. INTRODUCTION

1.1 GREEN INFRASTRUCTURE IN THE CITY OF LANCASTER

The City of Lancaster (City) is served by a combined sewer system and a municipal separate storm sewer (MS4). Both systems convey polluted urban runoff and excessive storm volumes, which can lead to flooding, stream erosion and water quality problems downstream. Since 2010, the City has been implementing an integrated Green Infrastructure (GI) Program that allows it to incorporate GI in a cost-effective, adaptive, and systematic manner into public capital improvement projects and into private projects that are identified outside of formal public capital improvement planning.

In December 2017, the City entered into a Consent Decree with the U.S. Environmental Protection Agency (EPA), the U.S. Department of Justice, and the Pennsylvania Department of Environmental Protection (PA DEP) to prepare an Amended Long Term Control Plan, including the identification of sensitive areas, sewer modeling, characterization of the collection area and receiving waters, development of a public participation plan, an alternatives analysis, a financial capability analysis, and GI program plans and manuals, including the development of a GI Monitoring Plan.

The GI Monitoring Plan is based on the requirements of the Consent Decree. According to the Consent Decree, "Green Infrastructure Monitoring or GI Monitoring shall mean those processes and procedures necessary to evaluate the performance of GI Projects over time. Green Infrastructure Monitoring shall include physical testing, data collection, recordation in an asset management system, and long-term analysis to evaluate the infiltration (volume reduction) performance of GI Projects within the City's Combined Sewer System. GI Monitoring shall include Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing. Monitoring may also include sample collection, advanced chemical testing, or biological studies."

Figure 1.1-1. Bioretention Facility

1.2 PURPOSE

The purpose of the GI Monitoring Plan is to comply with the requirements of the Consent Decree and improve the runoff retention and detention of GI facilities across the City. By monitoring existing sites, the City will gather lessons learned regarding GI siting, design, construction, and maintenance. This Monitoring Plan describes the monitoring activities under the City's Monitoring Program, the rationale for monitoring, and the plan for implementation. Based on the Consent Decree requirements, the GI Monitoring Plan includes three types of GI monitoring: Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing.

1.3 OBJECTIVES AND APPROACH

The monitoring objectives help focus the GI Monitoring Plan and integrate the monitoring requirements of the Consent Decree. Table 1.3-1 presents the monitoring related requirements identified in the Consent Decree and mentioned in the Draft GI Performance Evaluation Strategy (GIPES).

Monitoring Objectives

The following are the objectives for the GI Monitoring Plan that integrate the requirements listed in Table 1.3-1:

- Evaluate performance of GI projects.
- Confirm compliance with design criteria and technical standards for representative GI project types.

TABLE 1.3-1. CONSENT DECREE MONITORING REQUIREMENTS

Monitoring Requirements	Consent Decree Source
Evaluate performance of GI projects	IV.7.s
Evaluate the infiltration (volume reduction) performance of GI projects within the City's Combined Sewer System	IV.7.s
Demonstrate initial and continued performance of project not constructed by the City	VI.34
Evaluate the performance of representative GI projects constructed by the City	App A, II.D
Confirm compliance with design criteria and technical standards for representative GI project types included in the GI Plan	App A, II.D.a

1.4 REPORT ORGANIZATION

The remainder of this document is organized as follows.

TABLE 1.4-1. HOW TO USE THE GREEN INFRASTRUCTURE MONITORING PLAN	
Chapter	How to Use
Chapter 1 – Introduction and Purpose	Brief description of the City's current stormwater system, GI practices, and description of objectives and purpose of the GI Monitoring Plan.
Chapter 2 – Stormwater Management and Green Infrastructure Background	Summary of the GI background, regulatory requirements, and previous GI monitoring efforts in the City undertaken by Department of Public Works.
Chapter 3 – Selection of Monitoring Sites	GI types and project types to be monitored based on the Consent Decree and an overview of the site selection process.
Chapter 4 – Monitoring Protocols and Procedures	Monitoring procedures to be used for Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing. This chapter also includes a subsection on green roofs that addresses specific monitoring requirements.
Chapter 5 – Implementation Schedule	Recommendations for scheduling, reporting, and implementation of the monitoring program.
Chapter 6 – Data Management	Data management considerations.
Chapter 7 – Quality Assurance and Quality Control	Quality assurance and quality control activities.
Appendices	The appendices include the status of the City's GI sites by construction year, forms to be used for site selection and monitoring, and monitoring procedures.

1.5 PEER REVIEW

The Draft GI Monitoring Plan was reviewed by City's staff and Dr. Robert Traver of Villanova University. The reviewers were asked to review the draft document to ensure alignment with the monitoring objectives and requirements, as well as to provide comments on the overall strategy, protocols, and procedures. Comments from the City and Dr. Traver have been incorporated in this GI Monitoring Plan. The GI Monitoring Plan has been developed to aid in evaluating the performance of the program from various levels, for example program level or best management practices (BMP) level. The plan outlines strategies for monitoring BMP metrics, which will inform standards set forth in the GI Design Manual and the GI Operations and Manentance (O&M) Plan.

2. STORMWATER MANAGEMENT AND GREEN INFRASTRUCTURE BACKGROUND

2.1 CITY OF LANCASTER REGULATORY REQUIREMENTS

The City captures and conveys stormwater in part through the use of a combined sewer system which collects and transports a combination of stormwater runoff and domestic sewage for approximately 45 percent of the City's total area. During typical conditions, the City's Advanced Wastewater Treatment Facility is able to manage and treat water collected by the combined sewer system. However, heavy storm events create flow volumes that exceed the treatment facility's capacity, resulting in combined sewer overflow (CSO) discharges into the Conestoga River and eventually into the Chesapeake Bay.

The Clean Water Act of 1972 established water quality standards for surface waters in the United States. The Co ion System Municipal Separate Storm Sewer System (MS4) permit holder, the City must adhere to certain pollution reduction requirements set by the PA DEP. The City has outlined an approach to mitigating pollution loads in their Chesapeake Bay Pollution Reduction Plan.

2.2 GREEN INFRASTRUCTURE MONITORING PROGRAM TO-DATE

The City has been conducting surface infiltration monitoring, soil testing, and visual inspections of GI installations since 2015. As of December 2018, the City has conducted 65 surface infiltration tests on eight bioinfiltration projects. They have also conducted 27 surface infiltration tests, 15 porous asphalt installations and 12 porous pavement installations, on 12 porous pavement projects. The porous pavement testing was done using the ASTM method for porous pavement surface infiltration using a 12-inch diameter double ring infiltrometer.

3. SELECTION OF MONITORING SITES

Figure 3.0-1. Brandon Park Bioretention Facility (Sept. 7, 2018)

The Monitoring Plan presents methods and procedures to evaluate the performance of representative GI projects constructed by the City. Figure 3.0-1 presents an example of the type of GI project (Bioretention) in the City. The selection of representative sites will be performed in accordance with Section II.E of Appendix A of the Consent Decree. Therefore, it is important to choose monitoring sites that are representative of the entire portfolio of GI projects built and planned for the future, not only to meet the Consent Decree requirements, but also to use the insights gained during monitoring to improve GI design and performance.

Criteria. The following criteria are aligned with the GI Consent Decree requirements and will be used to select representative sites to implement the Monitoring Plan:

- Coverage of representative GI types and project types to be monitored (see Table 3.1-1);
- Time period and effort required to implement the monitoring requirements and verify draindown time through visual observation of surface ponding or observation wells;
- Specific locations to set up monitoring equipment for measuring infiltration and flows entering and leaving the GI facility;
- Specific locations for performing water quality sampling, if needed, of influent and effluent;
- Site characteristics such as site access and ownership, GI type, site slopes, maintenance issues, etc.; and
- Design characteristics such as hydraulic loading ration, contributing impervious area, GI facility size, underdrain information, vegetation type, etc.

Site Selection Steps. The following are the steps that the City will follow to select monitoring sites: 1) The first step is to identify project types and criteria, described above, to be used in identifying and selecting the monitoring sites. 2) Once a preliminary site selection is completed, the following step is to check the construction drawings and as-built drawings, if available, to further evaluate the design characteristics which factor in the decision to monitor a site. These steps will facilitate site selection by narrowing down the list to a representative set of preliminary sites. 3) Next, the preliminary sites are field validated to collect information about the site characteristics, such as surrounding land use, street slope, depression storage, physical condition of the practice, etc. 4) After the field validation data is assessed, the site selection can be finalized.

The City followed these steps to do a preliminary selection of sites for the initial monitoring season as described in Section 3.3. The sites selected during the initial monitoring season will be used to kickoff the monitoring program, train City staff on the protocols, and refine any procedures, if needed. After the initial monitoring season, the City will evaluate the results of the monitoring activities and develop plans for future monitoring seasons as described in Section 3.4. The following sections delve into the factors to consider during site selection.

3.1 GREEN INFRASTRUCTURE TYPES AND PROJECT TYPES

Table 3.1-1 presents the number of current GI sites organized by GI type and project type in the City. The Consent Decree requires that at minimum, one site from each category must be monitored. The City may, at its discretion, monitor more than one site per category and sites that do not fit into the current categorization scheme (e.g., a site with different GI type).

3.2 SITE SELECTION PROCESS

The Consent Decree requires three types of monitoring: Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing. Monitoring protocols and procedures for these testing requirements are presented in Chapter 4. This section describes the process that the City will follow for selecting sites. In addition, this section includes a description of the selection of sites for the initial monitoring season and future monitoring seasons. The site selection process includes the following elements:

- Monitoring effort required
- Monitoring setup opportunities
- Site characteristics
- Design characteristics
- Field verification

3.2.1 Site Characteristics

Monitoring sites should be chosen to reflect the full range of site and drainage area characteristics associated with the City's GI portfolio. To understand the variability of site characteristics, the monitoring team should conduct a field validation and desktop analysis of sites prior to finalizing site selection. Common site characteristics to consider include property ownership, age of the practice, geotechnical conditions, drainage area characteristics (e.g., land use, street slope, sediment loading to the site), and maintenance practices and frequency. These factors may affect performance of the GI facility in ways that may be difficult to quantify. For instance, street slope may increase the velocity of runoff entering the GI facility, which in turn may cause higher levels of runoff bypass, lowering inflow. Also, a site located in an area with considerable traffic may have a higher sediment loading, which may decrease surface infiltration rates at the site.

When choosing representative sites for monitoring, these differing site characteristics should be thought of as independent variables that could influence GI performance in developing the monitoring procedure. It may be beneficial to vary them, in order to cover a variety of real-world conditions.

TABLE 3.1-1. GI INSTALLATIONS CONSTRUCTED AND UNDER CONSTRUCTION IN CSO AREAS BY SITE CATEGORY					
Project Types	Green Infrastructure Type				
	Porous Pavement	Bioretention	Green Roof	Subsurface Infiltration	Total
Parking Lots	9	10	-	5	24
Parks	4	2	-	-	6
Public Schools	1	1	-	-	2
Streets/Alleys	17	19	-	15	51
Roofs	-	-	5	-	5
Total	31	32	5	20	88

Figure 3.1-1 shows the geographic distribution of the sites tallied in Table 3.1-1.

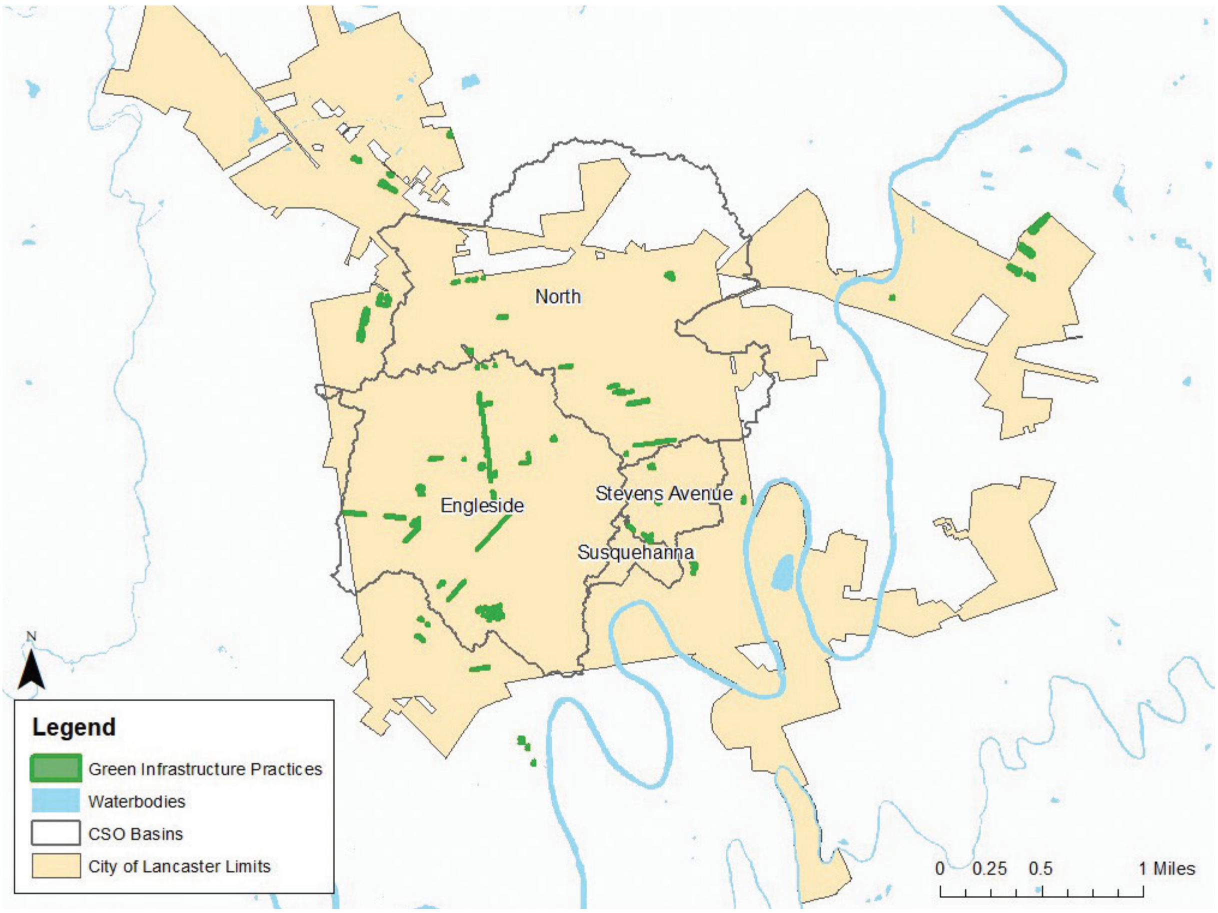


Figure 3.1-1. Map of Green Infrastructure Practices in the City of Lancaster

3.2.2 Monitoring Setup Opportunities

GI monitoring can be conducted most efficiently in sites that are designed and constructed with a site-specific monitoring setup. Sites may also be retrofitted to accommodate observation wells, inflow flumes, water quality wells, and other monitoring instruments but the cost will be significantly higher. Established vegetation may need to be replaced and the functionality of the site will be affected by the resulting re-establishment period. Therefore, when retrofitting GI installations for monitoring purposes, it is important to select sites with favorable conditions for monitoring. This means that the site must have specific locations available to measure the inflow and outflow. It should also have specific locations for performing water quality sampling of the influent and effluent, when applicable. Therefore, during site selection, sites that were constructed with monitoring wells and other monitoring setups must be prioritized over sites that would require retrofitting.

3.2.3 Optimizing Monitoring Effort

Representative sites will be chosen to optimize the time and resources required to complete monitoring data collection. For surface infiltration testing, selected sites should be large enough to accommodate the equipment, (e.g., 24-inch double ring infiltrometers), without damaging vegetation or tree root balls. This would minimize the effort required to replant sites after testing is completed. In addition, selected sites should be sites in which water balance measurements can be easily done. For instance, sites that have unknown geotechnical characteristics should be avoided. It is also more resource intensive to conduct flow monitoring on large sites with multiple inlet and outlet points. Although monitoring difficulty and effort should not impede testing, it should be taken into consideration in order to obtain the most useful data possible.

3.2.4 Design Characteristics

Design characteristics of GI installations can affect the performance of the installation. Some examples of design characteristics include hydraulic loading ratio, construction materials, construction quality, and applied designs/technology. The hydraulic loading ratio of a GI facility is the tributary drainage area managed divided by the area of the GI facility. For instance, if a green roof manages only the rainfall that falls directly onto it, the hydraulic loading ratio is 1. However, if the roof managed its own area plus the area of a connected roof of equal size, the hydraulic loading ratio is 2. GI is designed to manage the expected runoff volumes and peak rates from the tributary drainage area. Therefore, key design characteristics are important factors to consider when choosing sites for performance monitoring.

Furthermore, the results from GI monitoring studies will be used by the City to compare GI technologies, designs, materials, siting practices, and maintenance regimes. Performance of GI facilities should be evaluated according to the design specifications and design intent. Therefore, design drawings, specifications, and calculations must be reviewed prior to finalizing site selection. Selected sites should have design characteristics that are commonly constructed in the City or that will be commonly constructed in the future. For instance, if most bioretention practices have curb cut inlets and underdrains, monitored sites should also have these characteristics.

3.2.5 Field Validation

The purpose of field validation is to collect information about the site characteristics of potential monitoring sites. Figure 3.2.5-1 shows City staff conducting field validation activities. The Consent Decree requires the completion of a site and treatment characterization worksheet to document:

- Specific site characteristics
- Contributing land use characteristics
- Field points to be monitored (potential locations for measuring flow entering and leaving the GI facility and potential locations for performing water quality sampling of the influent and effluent, if needed)
- Site security information
- Treatment characterization:
    - Hydraulic loading rate at design capacity/flow
    - For filtration systems, media type (media samples will be taken at the beginning and end of the clogging of the media)
    - For vegetated systems, vegetation type and age

The Site and Treatment Characterization Worksheet can be found in Appendix B: Forms. The field validation visits can be coordinated with maintenance visits or construction management oversight for efficiency. Photos should be taken of the site, and a site drawing or map should be marked up with field measurements. Data should be uploaded to Lucity™. The results of the field validation can be presented in a table comparing important site characteristics and considerations. This information will be used in finalizing the site selection.

Figure 3.2.5-1. Field Validation Involves the Collection of Site Characerization Data

Chapter 3

3.3 SITE SELECTION FOR INITIAL MONITORING SEASON

This section presents the list of the portfolio of sites available for monitoring. Figure 3.3-1 shows an example of a constructed GI facility in the City that could be included in the monitoring plan for the initial season. As described below and in Chapter 4 of this Plan, the Consent Decree requires three types of GI monitoring: Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing.

Field Acceptance Testing. In order to choose representative sites for Field Acceptance Testing, it is recommended that sites be selected during the concept and design stages of the projects. This is needed because a specification for Field Acceptance Testing must be included in the final Construction Documents. Table A-1 in Appendix A: Site Selection includes a list of sites that are under construction in 2019.

There are five sites under construction, and four out of the five sites are on land owned by the City. Property ownership is an important site characteristic since site access must be safe and permanent in order to commit to the monitoring program for a site. Out of the four sites, three are bioretention installations in a street or alley, and one site is a porous pavement installation in a street or alley, and one site is a porous pavement installation in a parking lot. It may be possible to choose these sites for piloting Field Acceptance Testing, but final selection will depend on construction completion timing and site design, as well as all the considerations presented in this section that address the Consent Decree requirements.

Baseline Performance Testing. Sites chosen for Baseline Performance Testing would ideally be sites that have undergone Field Acceptance Testing. These sites are advantageous because there would be more data for determining the change in site performance over time. A site's baseline performance should be determined within 60 days of construction. However, if it becomes necessary to choose sites that are already constructed, it would be beneficial to choose recently constructed sites.

Table A-2 in Appendix A: Site Selection includes a list of 11 sites that were constructed in 2017 or 2018. Out of the 11 sites, four are in land owned by the City and in the CSO area. Out of the four sites, three are bioretention installations in a street or alley, and one site is a porous pavement installation in a street or alley. Site visits to select sites for baseline performance testing were conducted with the City and informed this document.

Figure 3.3-1 Bioretention Facility in a Parking Lot at Community Mennonite Church

Ongoing Field Performance Testing. Site selection for Ongoing Field Performance Testing should be sites for which the Baseline Testing was completed. Therefore, the 2019 site selection will be determined once the baseline performance sites are identified as indicated above. Alternatively, the City may include sites for which a baseline was not obtained.

An inventory of sites that already have observation wells installed will be prepared by the City, since they are good candidates for monitoring, and will complement other field verification activities.

Initial Site Selection and Monitoring Season. The City conducted a preliminary selection of potential monitoring sites for the initial season using the criteria and steps described above. Once the Monitoring Plan is approved, the City will use the site selection steps and information described this section to finalize selection of sites for the three types of GI monitoring: Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing.

The dates for the first monitoring season (year) will be selected to align with other Consent Decree reports and requirements, as well as the recommendations in Section 5.1, Monitoring Frequency and Reports.

3.4 FUTURE SITE SELECTION

After the first monitoring season is completed, the City will evaluate the results of the monitoring activities and develop a plan for each subsequent season (year). The monitoring season (year) will be selected to align with other Consent Decree reports and requirements, as well as the recommendations in Section 5.1.

4. MONITORING PROTOCOLS AND PROCEDURES

The Consent Decree requires protocols for the three elements of the GI Monitoring Plan: Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing. This chapter describes the types of tests that were considered for inclusion in the monitoring program and the strategy recommended for each of the three monitoring elements. Table 4.0-1 presents the pros and cons of each type of monitoring test.

TABLE 4.0-1. MONITORING TESTS CONSIDERATIONS

Monitoring Test	Example	Pros	Cons
Surface Infiltration Testing (measure infiltration rates)	Single or double ring infiltrometer testing	• Well-established standards available with reliable equations that have been thoroughly vetted	• Cost and weight of equipment (ASTM double ring)
		• Easy comparison to other GI systems	• Provides limited knowledge of performance of entire GI system
		• Equipment is readily available	• May damage plants (applies only to vegetated practices)
		• Does not require permits	• Testing requires constant attention
		• Does not require permanently installed equipment	• May require pedestrian and traffic control
Simulated Runoff Techniques (measure drawdown, surface infiltration, inflow and outflow quantity and quality)	Hydrant test, flood test	• Can be used to test underdrain	• Requires observation well
		• Testing does not require constant attention	• Requires high precision flow meter and pressure transducer(s) (which must be calibrated)
		• Can test for "design storm" and other flow rates of interest (e.g. 90th percentile storm, different contributing areas, etc.)	• Requires heavy and costly hydrant equipment
		• Does not require permanently installed equipment	• May require permits • May require pedestrian and traffic control

TABLE 4.0-1. MONITORING TESTS CONSIDERATIONS (cont.)			
Monitoring Test	**Example**	**Pros**	**Cons**
Continuous Water Level Monitoring (measure surface drawdown, infiltration, inflow and outflow quantity and quality)	Instrumenting observation wells and recording data during real storms	• Can be used to test underdrain • Testing does not require constant attention • May be done with permanently installed equipment or portable equipment that is secured at the GI installation • May be most accurate way to document real performance	• Costly equipment • Needs frequent equipment maintenance and calibrations • May require hiring a contractor to install monitoring setup • More difficult to establish water balance than simulated test, especially if rain gauges are far away and/or contributing area is uncertain
Visual Inspection (observe performance characteristics)	Visual inspection of a GI asset following a checklist	• Can be incorporated into maintenance activities • Good way to monitor plant health and sediment accumulation • Good way to inspect hardscape materials • Fast and inexpensive	• Knowledge about GI asset is limited to what can be seen from the surface • Cannot be used to measure water quality and quantity
CCTV Inspection (observe performance of underground components)	Underdrain inspection	• Typically done for underdrain systems to ensure that they will function as designed	• Costly, should only be used for very large scale projects
Field Sampling and Laboratory Testing (measure inflow and outflow quantity and quality, soil/media characteristics)	Soil sampling, water quality monitoring, inflow and outflow monitoring	• Facilitates determination of whether engineered soil is to specification • Analysis of soil cores are a good way to monitor changes in sediment composition in a vegetated practice • Provides accurate water quality data	• Laboratory testing is costly and requires a waiting period to obtain results • Water quality and soil samples must be collected correctly and sent to the laboratory within a short period of time • Water quality samples should be collected during first flush of storm. This requires an automated sampler or sending a person out during the beginning of a storm event. Both options are difficult to implement.

Based on an evaluation of this table and the planned monitoring process, as well as the Consent Decree requirements, the following monitoring tests have been selected and are further described in Chapter 4:

- Field Acceptance Testing will be done using surface infiltration testing and simulated runoff testing, for complex GI installation. In addition, visual inspections will be conducted and will include verification of grades, plantings, soil mixes, energy dissipation and erosion control features, etc. Section 4.2, Field Acceptance Testing, and Appendix C: Monitoring Procedures provide additional information.
- Performance Baseline Testing will be done through surface infiltration testing. In addition, visual inspections will be conducted prior to the start of the surface infiltration test. Section 4.3, Performance Baseline Testing, and Appendix C provide additional information.
- Ongoing Field Performance Testing will include a repeat of the same surface infiltration tests conducted during Performance Baseline Testing. In addition, a visual inspection will be conducted prior to surface infiltration testing. Section 4.4, Ongoing Field Performance Testing, and Appendix C provide additional information.

4.1 GENERAL MONITORING PROCEDURES

Monitoring procedures vary depending on the type of GI facility and the testing type. This section provides a description of monitoring procedures that will be necessary at most or all sites to ensure data quality and continuity. Unforeseen equipment requirements and site-specific issues (e.g., access) may require adaptation of these procedures.

4.1.1 Site Investigation

Prior to the start of monitoring, the sites that have been shortlisted must be investigated. The Site and Treatment Characterization Worksheet in Appendix B: Forms serves as a starting point for both desktop and field evaluation of potential sites. The investigation begins by looking at the construction drawings, specifications, and as-built drawings, if available. Then, a field visit is scheduled to “field evaluate” the site and determine the monitoring setup.

4.1.2 Health and Safety

A health and safety plan should be written and followed for the monitoring program. It should include the following components:

- Emergency Action Plan
- Personal Protective Equipment requirements
- Traffic and Pedestrian Safety Plan
- Job Safety Analysis
- Permits
- Incident Reporting and Investigation procedures
- City of Lancaster Health and Safety Standards, if applicable

4.1.3 Calibration and Instrument Maintenance

Calibration improves sensor performance by removing structural errors in the output values. Structural error is the repeatable and consistent difference between the sensor's expected output and its measured output. Any repeatable error can be calculated during calibration, so that when the sensor is being used for monitoring, the errors can be removed in real time. Manufacturers calibrate their products before sending them to consumers. However, these "factory calibrations" are not permanent and sensor readings may begin to "migrate." Therefore, intermittent calibrations may be needed.

Pressure transducers are usually calibrated using a bucket test. A sensor is connected to a computer with the appropriate sensor software. Then, it is placed into a bucket with a known water depth and the depth is recorded in the calibrating software. Similar approaches are used to calibrate pH sensors, soil moisture sensors, etc. Instruments should be calibrated and maintained according to the manufacturer's instructions.

4.1.4 Coordination with Design Team and Contractor

Field Acceptance Testing requires coordination with the Design Team and the Contractor. The specification for Field Acceptance Testing must be finalized by the Design Team. This should include a Field Acceptance Inspection checklist that is customized to the specific design scheme for a site. A template for this form can be found in Appendix B: Forms. If a simulated runoff test will be performed as part of Field Acceptance Testing, the Design Engineer must determine the site-specific parameters defined in Appendix C: Monitoring Procedures.

The City will coordinate with the Contractor to perform the Field Acceptance Inspection. The Contractor must also submit all submittals required for Field Acceptance prior to the inspection. The inspection may result in a punchlist of items for the Contractor to correct or amend. The City will then re-inspect the site in order to "accept" it. This will be documented in a corrected Field Acceptance Inspection form.

4.1.5 Coordination with Operation & Maintenance Staff

Ongoing Field Performance Testing will require coordination with City and Contractor maintenance staff. Coordination should be expected and planned in advance. Before finalizing site selection, monitoring staff should interview maintenance staff about the specific sites under consideration. Maintenance staff are commonly in the best position to understand possible performance issues in GI sites. It is recommended that sites chosen for the monitoring program as "representative sites" be sites that experience average conditions. This means that a site that is exceptional or out of the ordinary may not be the right choice. For instance, if a site receives much more sediment in its runoff than other similar sites, it may not be representative of all sites of its type. The information received from maintenance staff on typical sites should be balanced with the need to have representative sites based on design and site characteristics. In future years, the City may consider selecting sites for monitoring with a range of conditions to better understand how site characteristics relate to GI performance.

Once monitoring of a site is scheduled, maintenance staff should be notified. Sites should be maintained as usual before the monitoring test takes place. This will ensure that the monitoring test reflects the typical conditions of the GI asset.

Finally, monitoring staff should review their results with the maintenance staff in order to guide their efforts. For example, if a permeable pavement site has an unsatisfactory surface infiltration rate, the maintenance staff should be informed, and vacuuming of the site should be scheduled.

4.2 FIELD ACCEPTANCE TESTING

4.2.1 Goals and Approach

The goal of field acceptance testing is to ensure that completed GI projects meet design criteria to ensure the installations appropriately manage stormwater runoff. City staff will coordinate monitoring requirements with the Design Team and the contractor as indicated in Section 4.1.4 during construction (see Figure 4.2.1-1) to ensure appropriate planning and timely completion of the Field Acceptance Testing.

Figure 4.2.1-1 GI Facility During Construction

The City will choose between two options for Field Acceptance Testing:

- The first option is to conduct the surface infiltration testing as done under the Pennvest project and conduct visual inspections. In-place density testing for planting soils may also be appropriate. This is the option best suited for most GI installations. Surface infiltration testing is discussed in more detail in Appendix C: Monitoring Procedures.
- The second option is to perform simulated runoff testing to gather more information about the performance of sites, especially bioinfiltration sites. Simulated Runoff Testing is discussed in more detail in Appendix C: Monitoring Procedures.

4.2.2 Regulatory Requirements and Reporting

The Consent Decree defines field acceptance testing as "an assessment performed by the contractor to demonstrate that the completed GI project satisfies contract design criteria". For purposes of the Monitoring Plan, field acceptance testing will also include an assessment to demonstrate that the completed GI project satisfies performance specifications.

The Consent Decree requires that Field Acceptance Testing and Performance Baseline Testing be performed at each representative GI project within 60 days after completion of construction. Representative facilities will be selected by the City as part of the site selection process for the initial monitoring season described in Section 3.3 and in Section 3.4 for future seasons.

The City will submit the results in an Annual GI Performance Report summarizing the field acceptance, performance baseline testing, and field performance testing conducted for representative sites. See Section 5.1, Monitoring Frequency and Reports, and Section 6.3, Coordination with Annual Performance Report, for additional reporting information.

4.2.3 Monitoring Setup

Field Acceptance Testing consists of two parts: performance testing and visual inspections. Performance testing should not be conducted until field acceptance visual inspection and remedial action have been completed. Both surface infiltration testing procedures and the simulated runoff testing procedure can be found in Appendix C: Monitoring Procedures.

Performance Testing

Surface Infiltration Testing – Porous Pavement

The surface infiltration procedure for permeable pavement and pavers consists of adhering a 12-inch infiltration ring to the permeable surface and applying water to pre-wet the area. After the media is saturated, a specified mass of water is poured into the ring and the time for the water to be infiltrated is used to calculate a surface infiltration rate. This is repeated across multiple locations in the practice to arrive at an average infiltration rate. The monitoring procedure was developed in accordance with the following standards: ASTM C1781/C1781M-15 Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems and ASTM C1701/C1701M–17a Standard Test Method for Infiltration Rate of In Place Pervious Concrete.

Surface Infiltration Testing – Bioretention

The surface infiltration procedure for soil varies according to type of double ring setup. A 12-inch inner diameter, 24-inch outer diameter double ring is required by ASTM D3385 – 09 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer. The ASTM method requires at least six hours of testing and has rigorous requirements for documentation of volume introduced into the rings. For this reason, the ASTM procedure is usually accomplished using Mariotte Tubes. The PA DEP BMP Manual suggests that ring sizes as small as 4 inches may be suitable for soil infiltration testing.[1] Smaller sizes make monitoring easier and faster. The smaller size also allows for infiltration testing in tight areas with clearance less than 24 inches. This may be especially useful in landscaped areas, since the smaller sizes cause less destruction of plants and tree root balls. The other two available double ring infiltrometers are Turf-Tec Infiltrometer (2 ³⁄₈-inch inner ring diameter, 4 ¼-inch outer ring diameter) and 6-inch Double Ring.

Simulated Runoff Test

Lastly, the City may choose to perform a simulated runoff test or “hydrant test” as the Field Acceptance Test for complex GI installations. A simulated runoff test verifies that water flows through the project as designed and can be used to measure both surface and subsurface infiltration rates. Measuring the flow that returns to the combined sewer system is important, since it must be considered to determine the correct volume of runoff managed by the practice. The test works by applying a measured flow of water from a nearby fire hydrant upstream of the GI, while monitoring water levels within the system. This allows the monitoring team to perform a water balance to calculate how much runoff the practice stores, the rate of infiltration into the engineered soil, and the drain down time out of the GI system through the native soil.

[1] StormwaterPA.org. Pennsylvania Department of Environmental Protection Bureau of Watershed Management. BMP Manual – Appendix C. 30 December 2016. http://www.stormwaterpa.org/bmp-manual-appendix-c.html

Chapter 4

The monitoring setup consists of two piezometers installed during construction. One piezometer is installed at the bottom of the practice to measure the rate of drawdown of the water within the practice through the native soil. The other piezometer is installed in the cleanout for the underdrain, if applicable.

Testing locations should be chosen based on site area. Unless otherwise specified, use the following to determine the locations and number of tests to perform:

- Three test locations for areas up to 25,000 square feet (SF).
- Add one test location for each additional 10,000 SF.
- Provide at least 3 feet clear distance between test locations, unless at least 24 hours have elapsed between tests.
- One of the locations tested should be located within an area that is expected to experience significant sediment deposition.
- Measure the distance from the testing locations to a reference point and note it on the site diagram, which is included in the form presented in Appendix C.

It is recommended that two trials be performed per location, and the results averaged. For more information on the monitoring setup, see Appendix C: Monitoring Procedures.

4.2.4 Instrumentation and Visual Inspections

After construction of the GI installation is complete, it is necessary to conduct a visual inspection. The construction manager and a member of the monitoring team must ensure that all design specifications have been met. This includes the installation of the piezometers, if applicable. If the specifications are not met, remedial action must be taken by the Contractor. Field acceptance will be done in accordance with the as-built requirements in the Design Manual and typically includes verification of grades, plantings, soil mixes, energy dissipation, and erosion control features, etc.

Documentation of the field acceptance visual inspection is key, and the documents and photos should be stored in a central monitoring database. After all remedial action has been completed, the monitoring portion can be conducted. The template to be used for developing a form for the visual inspection for specific projects is included as part of Appendix B: Forms. These forms should integrate the acceptance procedures presented in the Design Manual with the visual inspection.

4.2.5 Procedure and Contractor Oversight

Contractor Oversight and Coordination

Field acceptance monitoring must be done by the Contractor in the presence of a City representative trained in GI monitoring. It is recommended to require the Contractor to submit a Field Acceptance Monitoring Plan to the City for approval before testing occurs. It is also recommended that the Design Engineers review the plan in order to ensure that all important items are accounted for and testing parameters match design criteria. The Contractor must determine the root cause of the non-compliance and provide a remedy.

Acceptable Infiltration Rate

The acceptable surface infiltration rate must be derived from the minimum surface infiltration rate as established in the Construction Specifications for all GI types. If a minimum rate is not specified for a porous pavement practice, the following requirement from the Design Manual Section 5.3.1 applies, "The design surface infiltration rate through the porous pavement surface shall be a minimum 60 inches per hour."

If a minimum rate is not specified for a biorientation practice, then the following requirement from the Design Manual Section 4.1, Step 8 applies, "Any water stored at the surface must drain-down within 24 hours from the end of the design storm." The equation below can be used to calculate the minimum acceptable surface infiltration rate for a bioretention practice.

$$i_{SURF,min} = \frac{V_{SURF}}{A_{SURF} \times 2}$$

(Equation 4.2-1)

Where,

$i_{SURF,\ min}$ = *Minimum acceptable surface infiltration rate (inches per hour)*

V_{SURF} = *Total surface volume managed (cubic feet), from Equation 4.1-12 of the Design Manual*

A_{SURF} = *Surface Area (square feet)*

If the surface infiltration test for a bioretention site does not meet the specified or calculated minimum acceptable surface infiltration rate, it is possible that the soil installed in the practice did not meet the texture specification. It is recommended to take a sample of the soil and send it to a laboratory for analysis per ASTM C136 / C136M - 14 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. The City monitoring team will present results to City management, Design Team, and Contractor to identify alternatives to solve the observed problems with the site. If the surface infiltration test for a porous pavement site does not meet the specified or Design Manual minimum infiltration rate, the Contractor must determine the root cause of the non-compliance and provide a remedy.

4.2.6 Data Analysis

The data collected for each site during the year along with documents and photos should be stored in a central monitoring database. Quantitative performance data obtained during field acceptance testing should be compared to the surface infiltration rate calculated during Performance Baseline Testing. The results, as described in Section 4.2.5, should also be compared to the permeability rate specified by the Design Engineer in the Contract Specifications. This information will be used to prepare the Annual GI Performance Report.

4.3 PERFORMANCE BASELINE TESTING

4.3.1 Goals and Approach

The goal of Performance Baseline Testing, which is performed by the City, is to establish the baseline performance of GI projects in order to track the change in performance over time. Factors such as sediment accumulation, traffic, erosion, plant establishment, and maintenance change the infiltration potential of GI facilities. Generally, it is believed that GI performance decays over time. For example, porous pavements become clogged over time as interstitial spaces fill up with sediment previously suspended in the stormwater runoff. This reduces the surface infiltration rate, which in turn causes the practice to retain a smaller percentage of the runoff from its tributary drainage area. Likewise, sediment accumulation clogs the pores of the engineered soil in vegetated practices. Appropriate maintenance of GI projects reduces or eliminates these problems. Therefore, it is important to track how performance changes over time in representative GI projects.

The primary component of baseline performance testing is surface infiltration testing. It is vital to take seasonal variations in soil permeability into account when establishing a baseline surface infiltration rate for bioretention sites. Research suggests that soil permeability rates are lower at the beginning of the growing season (early spring), and higher at the end of the growing season (late summer into fall). Therefore, when comparing soil infiltration rates from one time period to another, it is important to note when in the growing season a measurement was taken. It is recommended that two baseline measurements be taken, one at the beginning and one at the end of the growing season.

4.3.2 Regulatory Requirements and Reporting

The Consent Decree defines Performance Baseline Testing as follows:

"Performance Baseline Testing' shall mean the testing to determine the baseline performance of GI Projects upon completion of construction. Lancaster shall perform such tests in accordance with applicable American Society for Testing and Materials ('ASTM'), including but not limited to C1701 (ASTM 2009) and C1781 (ASTM 2013), as soon as reasonably feasible following completion of construction in order to establish a performance baseline against which future performance shall be evaluated."

The Consent Decree requires that Field Acceptance Testing and Performance Baseline Testing be performed at each representative GI project within 60 days after completion of construction. The City will submit the results in an Annual GI Performance Report summarizing the field acceptance, performance baseline testing, and field performance testing conducted for representative sites. See Sections 5.1, Monitoring Frequency and Reports, and Section 6.3, Coordination with Annual Performance Report, for additional reporting information.

4.3.3 Monitoring Setup

Performance baseline testing consists of surface infiltration testing. The surface infiltration tests are used to determine whether there are changes in the permeability of the various practices due to clogging over time and allow for adjustment of maintenance practices and frequency.

The monitoring setup for each test shall follow the guidelines and requirements set in the applicable ASTM Standard Test Method. For more information, see Section 4.2.3 and Appendix C: Monitoring Procedures.

It is recommended that the same equipment be used for performance baseline testing and ongoing field performance testing. For example, if a Turf-Tec infiltrometer will be used for Ongoing Field Performance Testing on bioretention sites, it is important that a baseline measurement be taken with the Turf-Tec, in order to compare that measurement with subsequent infiltration measurements taken with the same instrument, following the same methodology.

4.3.4 Instrumentation and Visual Inspections

Prior to the start of the surface infiltration test, a visual inspection must be performed for the practice. Since a thorough inspection was performed during Field Acceptance Testing, this inspection will only note any changes that have occurred to the site since the last inspection.

There is no permanent instrument installation at sites required for surface infiltration testing. Monitoring instruments that must be purchased for each test are outlined in the respective ASTM standard and Appendix C: Monitoring Procedures.

4.3.5 Procedure

Figure 4.4.1-1. 6-inch and 12-inch Double Ring Infiltrometer

Performance Baseline Testing will be performed following Field Acceptance Testing and after the City takes possession of the assets. The testing will follow the procedure outlined inAppendix C: Monitoring Procedures. Surface infiltration testing should be performed in more than one area of a GI practice, if possible. This should be determined according to the size of the practice and the spacing requirements in the ASTM standard. For instance, a large bioretention practice may require two separate double ring infiltrometer tests. One located at the inlet of the practice and another at the low point, where sediment is expected to be deposited. In a permeable pavement system, the edges of the system that receive the runoff flow first would be expected to have the most clogging, therefore surface runoff testing should be performed there and at another location. It is important that the testing locations be carefully measured out and documented in the monitoring documents. This is so that the locations can be replicated in future monitoring.

4.3.6 Data Analysis

The data analysis for each site is outlined in the respective ASTM standard. After the surface infiltration rate is calculated, it should be compared to the surface infiltration rate calculated during Field Acceptance Testing. The results should also be compared to the permeability rate specified by the Design Engineer in the Contract Specifications. This information will be used to prepare the Annual GI Performance Report.

4.4 ONGOING FIELD PERFORMANCE TESTING

4.4.1 Goals and Approach

The goal of Ongoing Field Performance Testing is to determine the performance of a representative GI facility over time and monitor changes in order to learn about the factors that cause the changes. These tests are performed by the City. In going above and beyond the Consent Decree requirements, the City's goal is to monitor a set of approximately one third of all GI projects each year such that every GI project is tested at least once every five years.

The Ongoing Field Performance Testing will enable the City to modify design and maintenance requirements for sites, if needed, to maintain good stormwater management in existing and future GI projects.

4.4.2 Regulatory Requirements and Reporting

The Consent Decree defines field performance testing as "an assessment performed to determine the performance of a GI Project over the service life of the Project".

The Consent Decree requires that long-term Ongoing Field Performance Testing be conducted at a minimum once every five years after the completion of construction of representative sites. The City will submit the results in an Annual GI Performance Report summarizing the field acceptance, performance baseline testing, and field performance testing conducted for representative sites. See Sections 5.1, Monitoring Frequency and Reports, and Section 6.3, Coordination with Annual Performance Report, for additional reporting information.

4.4.3 Monitoring Setup

The Ongoing Field Performance Testing will consist of the same surface infiltration testing procedure as was performed for the Performance Baseline Testing. Comparison of surface infiltration testing results over time will be used to evaluate changes in the permeability of the various practices due to clogging over time and allow for adjustment of maintenance practices and frequency. For surface infiltration monitoring setup, see Section 4.2.3 and Appendix C: Monitoring Procedures.

4.4.4 Instrumentation and Visual Inspections

A visual inspection must be conducted prior to the surface infiltration test. The inspector must complete the Site and Treatment Characterization Worksheet (see Appendix B: Forms) to document:

- Specific site characteristics
- Contributing land use characteristics
- Field points to be monitored
- Site security information
- Treatment characterization
- Hydraulic loading rate at design capacity/flow
- For filtration systems, media type
- For vegetated systems, vegetation type and age

One or more samples of engineered soil media (depending on the BMP size) may also be required to screen for sediment accrual, soil fertility, and evidence of contaminants. This would be sent to a laboratory for testing. For surface infiltration instrumentation, see Section 4.2.4, Instrumentation and Visual Inspections.

4.4.5 Procedure

For surface infiltration procedure, see Section 4.2.5, Procedure and Contractor Oversight, and Appendix C: Monitoring Procedures. Surface infiltration test results and associated monitoring documentation will be stored in Lucity™.

4.4.6 Data Analysis

The data must be compared with the surface infiltration values for previous years to determine whether infiltration rates are declining over time. If that is the case, the root cause must be analyzed in order to apply the correct remedial action.

Figure 4.5-1. Green Roof at Lancaster City Hall

Research suggests that soil permeability rates are lower at the beginning of the growing season (i.e., early spring), and higher at the end of the growing season (i.e., fall). For bioretention sites, it is vital to take seasonal variations in soil permeability into account when comparing ongoing surface infiltration testing results to the baseline surface infiltration rate. Therefore, when comparing soil infiltration rates from one time period to another, it is important to note when in the growing season a measurement was taken.

Moreover, infiltration test results should only be compared if the same instrument type and data collection method were used. For instance, infiltration rate data recorded using a Turf-Tec should not be compared with a 12-inch and 24-inch double ring infiltrometer baseline infiltration rate.

4.5 GREEN ROOFS

As described in Chapter 3, the Consent Decree requires that, at minimum, one site from each category must be monitored. Monitoring green roofs is more difficult and resource-intensive than any other type of GI monitoring. Monitoring setups for green roof monitoring typically consist of the following components:

A. Rain gauge

B. Outlet flow monitoring setup

C. Weather station

Equipment Setup

Quantifying runoff reduction requires the first two components at minimum. A weather station is usually installed on the roof and connected to a data logger. The logger records rainfall, air temperature, solar radiation, wind speed, and relative humidity. This enables the monitoring team to determine the rainfall onto the green roof and the environmental conditions that affect evapotranspiration. The weather station and other types of sensors can be purchased as a package from vendors such as Onset HOBO[2].

[2] Onset HOBO Green Roof Monitoring System: http://www.onsetcomp.com/products/kits/sys-rx-grms-a

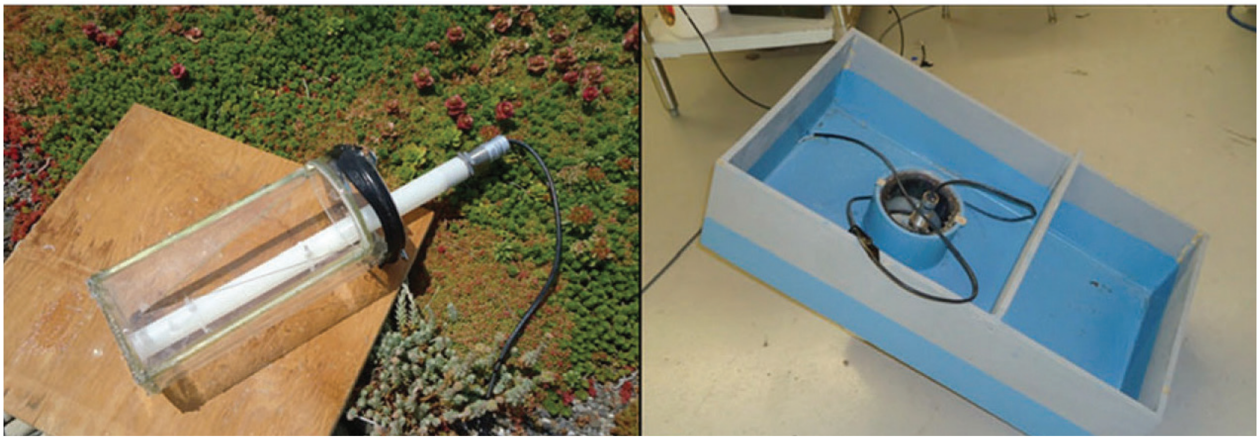


Figure 4.5-2. Example of Monitoring Setup for Overflow Weir

Photo 1: Runoff monitoring weir device, built with V-notch weir and Senix ultrasonic distance measure, prior to downspout instalation. Photo 2: Calibration champer used to simulate rooftop runoff.[3]

The outlet monitoring system measures the flow rate leaving the green roof via outflow, and is therefore an important part of computing the full water balance for a green roof system. The runoff flow monitoring device allows the monitoring team to calculate both the retention and detention of the green roof, including runoff volume and peak discharge attenuation. The outlet flow monitoring device usually must be custom made to fit the site's downspout and cannot be purchased from a vendor. Figure 4.5-2 shows an example of a flow monitoring device. This device is constructed with a v-notch weir outlet and an acoustic sensor to continuously read the water level within the device. The depth of water can be fed into a reference weir equation or a laboratory-calibrated weir equation to determine the runoff flow rate at any time interval. The device can be tailored to different downspout configurations; for instance, a round device to fit inside an interior downspout or a rectangular device to fit around the outlet of an exterior wall downspout. Different sensor setups can be selected such as pressure transducers or acoustic sensors.

Monitoring and Frequency

Green roof monitoring typically spans a minimum of one growing season, about seven months. The instruments and data loggers require weekly data checks to ensure there are no quality issues, monthly maintenance, annual recalibrations after the winter period, or as needed based on data issues.

In general, green roof monitoring is resource-intensive due to the the need for specialized, research grade and customized equipment. Because of the complexity of monitoring setup, maintenance, and data analysis, the City plans to partner with a university to monitor one representative green roof according to Consent Decree requirements.

[3] Figure obtained from T B Carson et al 2013 Environ. Res. Lett. 8 024036. Accessed at the following link: http://www.greengridroofs.com/wp-content/uploads/2018/01/ Hydrological-performance-of-extensive-green-roofs-Carson-et-al.pdf

Chapter 5

5. IMPLEMENTATION SCHEDULE

5.1 MONITORING FREQUENCY AND REPORTS

Field Acceptance Testing and Performance Baseline Testing must be completed for selected GI facilities within 60 days following the completion of construction. Ongoing Field Performance Testing must be performed at each GI project no less frequently than once every five years after the completion of construction for the service life of the GI installation. Once site selection for the first monitoring season is finalized, a detailed schedule for testing can be established. The monitoring season begins in spring when ground temperatures are consistently well above freezing and ends in autumn when temperatures become too cold for field activities.

Reports. The City will submit the results in an Annual GI Performance Report summarizing the field acceptance, performance baseline testing, and field performance testing conducted for representative sites, as well as the results of the green roof monitoringt

February/ March

- Purchase monitoring equipment
- Train monitoring team
- Work with A/E firms on current GI design projects to include Field Acceptance Testing specifications into Design Documents
- Meet with O&M staff to familiarize them with monitoring program
- Perform field validation for sites to be monitored and finalize site selection

April

- Calibration and testing of monitoring equipment
- Begin Ongoing Field Performance Testing on representative sites (sites already constructed)
- Meet with possible university partners to discuss green roof monitoring

May

- Continue Ongoing Field Performance Testing on representative sites
- Perform Field Acceptance Tests (on newly constructed sites), if possible

June/July/ August

- Continue Ongoing Field Performance Testing on representative sites
- Perform Field Acceptance Tests, if possible
- Perform Performance Baseline Tests (on newly constructed sites), if possible
- Communicate needed remedial actions to O&M staff

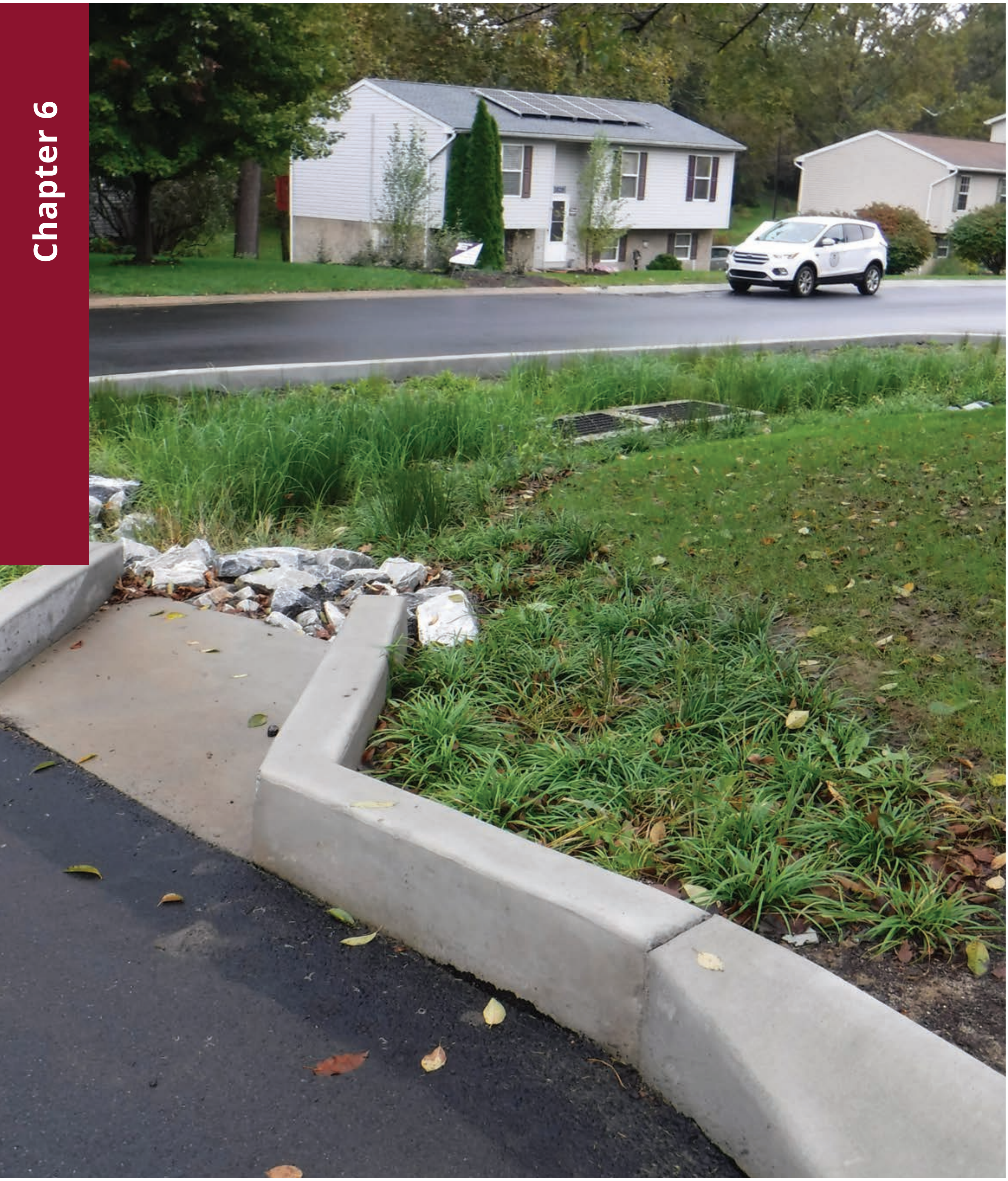
September/ October

- Meet with university researchers to kick-off green roof monitoring partnership
- Finish remaining monitoring for the season and begin data analysis
- Perform maintenance activities on equipment before storing it for the winter
- Present first year results to O&M and Design City staff with proposed improvements to maintenance practices and design standards

November/ December/ January

- Prepare plan for next monitoring season
- Prepare and submit Annual GI Performance Report incorporating the monitoring results

Figure 5.1-1. Preliminary Schedule for First Monitoring Season



6. DATA MANAGEMENT

6.1 MONITORING DATA DOCUMENTATION AND RECORDS

During field testing, data will be collected using paper forms or digital forms within a tablet application which will be archived. For surface infiltration testing, the forms include all data required by the ASTM standards. The data will then be transcribed into an Excel file with formulas set up to calculate surface infiltration rates following the ASTM equations. This Excel file must include a tab which contains all pertinent metadata. For simulated runoff testing, it is important to save the water level logger file as an unedited or "raw" file. A separate Excel file should include any calibrations or transformations that were performed to the data.

Monitoring data may also be saved in the City's ArcGIS geodatabase. It is important to include metadata within the geodatabase. This should include the date in which testing occurred in order to track changes over time.

All records should be kept in a central location within the City's network. The data should be backed up physically to a hard drive or stored in cloud storage. The data must not be saved on local computers or exist only in paper copies. It is crucial for the availability of the data to not be impacted by employee turnover.

6.2 LUCITY™

Data collected as part of the GI Monitoring Program will be stored alongside maintenance data in Lucity™. This is recommended because performance data drives maintenance practices. The data formatting of the table with the final results will follow the Infiltration Data table formatting in Lucity™.

6.3 COORDINATION WITH ANNUAL PERFORMANCE REPORT

Monitoring data will be included in the City's Annual GI Performance Report. The GI Performance Report will include a description of the results of implementation of the GI Monitoring Plan, including the results of all Ongoing Field Performance Testing performed in the previous 12 months. The results will be presented as a table displaying the average surface infiltration rate for each site.

The report will also include a summary of Performance Baseline Testing and Field Performance Testing results from representative sites completed since the effective date of the consent decree, including an explanation of any deviation from the 1.0-inch retention standard.

6.4 INTERNATIONAL BEST MANAGMENT PRACTICE DATABASE

The City plans to submit portions of the monitoring data into the International Stormwater BMP database. The database is a cooperative project between the EPA and several non-profit organizations and public agencies. The BMP Database encompasses a broad range of parameters including test site and watershed characteristics, design and layout characteristics, monitoring instrumentation, and monitoring data for precipitation, flow, and water quality.

The BMP Data Entry Spreadsheet package contains 34 spreadsheets for data entry; however, most users typically require less than half of these to enter their data. For example, 17 of the spreadsheets request BMP-specific design information for various BMP types; therefore, if only one BMP type is present, then only one of these design spreadsheets would need to be completed (plus site related information and monitoring data). Data elements are categorized by relative importance for evaluating BMP performance; some data elements are "required" for evaluation of BMP performance, others are "important" but may not currently be commonly reported information, and others are supplemental or variable.[4] The data collected during field validation and monitoring are sufficient for submission into the database.

[4] International Stormwater Best Management Practices (BMP) Database. User's Guide for BMP Data Entry Spreadsheets. Release Version 3.3. October 2016. http://www.bmpdatabase.org/Docs/2016_BMP_Database_Users_Guide.pdf

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Chapter 7

7. QUALITY ASSURANCE AND QUALITY CONTROL

7.1 DATA QUALITY OBJECTIVES

The purpose of the monitoring program is to evaluate the performance of GI practices over time through field inspections and infiltration testing. The data will be used to revise and improve maintenance, design, siting, and construction practices to optimize long-term performance of GI across the City. The following are the main data quality objectives:

- Consistent application of monitoring procedures across sites, field personnel, and monitoring seasons;
- Adherence to ASTM Standards;
- Consistent calibration and maintenance of field equipment, as needed; and
- Consistent quality control for data management and analysis, as well as reporting.

If surface or groundwater monitoring and/or the collection and analysis of water samples is added to the scope of this Monitoring Plan, it will be amended with a Quality Assurance Project Plan that meets EPA requirements.

7.2 QUALITY ASSURANCE RESPONSIBILITIES

The City will appoint a Quality Assurance Manager (QAM) for the monitoring program who will be responsible for quality assurance. The QAM will coordinate with the Monitoring Manager prior to initiation of field activities to ensure that sensor calibration, training, and required maintenance have been performed. It is the responsibility of the QAM to ensure that any variance with the ASTM standards is properly documented and remediated. Additionally, the QAM will review analytical data and results before they are finalized.

7.3 MEASUREMENT PERFORMANCE CRITERIA

Measurement performance criteria for the GI Monitoring Plan and associated monitoring activities include the following:

- Precision – the agreement between numeric values for two or more assessments that have been obtained in an identical manner (i.e., duplicate samples);
- Accuracy – the degree of agreement of a measurement with its accepted or true value (obtained through field calibration, laboratory control samples, etc.);
- Completeness – the quantity of valid data obtained via measurement compared to the quantity that was expected based on the monitoring plan;
- Comparability – the consistency between sampling and analytical procedures that ensures that one data set can be compared to another; and
- Sensitivity – the ability of a method or instrument to detect a constituent of concern at the expected concentration/level of interest.

7.4 TRAINING REQUIREMENTS

Prior to the start of the initial monitoring season, City monitoring staff will attend a training workshop in which they will be trained on the monitoring procedures and ASTM standards. They will also be trained to calibrate and maintain equipment, conduct field inspections, and properly manage field data.

Field staff working on the monitoring program will be required to review the Health and Safety Plan (HASP) prior to performing any field work. The QAM and the Site Health and Safety Officer will be responsible for ensuring that the safety procedures outlined in the HASP are followed by field staff. The HASP will be updated as needed.

Any subcontracted laboratories are required to maintain the required state/agency certifications and accreditation for the provided analytical services.

7.5 EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

Maintenance of field equipment will be performed by field staff and overseen by the QAM. Field work will not proceed until the properly-working condition of all equipment has been verified. Maintenance will consist of decontamination and calibration (to be carried out at the time of equipment use or per the manufacturer's recommendations).

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APPENDIX A – SITE SELECTION

Appendix A contains three tables that categorize GI sites by "status" and construction year.

Table A-1 Green Infrastructure Sites Under Construction in 2019

Table A-2 Green Infrastructure Sites Constructed in 2017 and 2018

Table A-3 Green Infrastructure Sites Constructed before 2017

The City will use these tables to select sites for their initial monitoring season, as described in Section 3.3, Site Selection for Initial Monitoring Season.

TABLE A-1. GREEN INFRASTRUCTURE SITES UNDER CONSTRUCTION IN 2019

Project ID#	Project Name	Basin	Status	Owner	Porous Pavement Parking Lot	Porous Pavement Parks	Porous Pavement Schools	Porous Pavement Streets/ alleys	Bioretention Parking Lot	Bioretention Parks	Bioretention Schools	Bioretention Streets/Alleys	Green Roof	Subsurface Infiltration Standard Asphalt
P-055	East Fulton St.	North	Under Construction	City								X		X
P-162	Walnut Street	Engleside	Under Construction	City								X		X
P-177	J.L.Clark	North	Under Construction	Private	X									
P-195	Charlotte St Two-way Conversion	North/ Engleside	Under Construction	City				X				X		
P-198	East Ocean Ave.	Engleside	Under Construction	City										X

Appendix A

TABLE A-2. GREEN INFRASTRUCTURE SITES CONSTRUCTED IN 2017 AND 2018

Project ID#	Project Name	Basin	Status	Owner	Porous Pavement Parking Lot	Porous Pavement Parks	Porous Pavement Schools	Porous Pavement Streets/ Alleys	Bioretention Parking Lot	Bioretention Parks	Bioretention Schools	Bioretention Streets/ alleys	Green Roof	Subsurface Infiltration Standard Asphalt
P-142	North Marshall Street	North	Complete	City				X				X		
P-149	Median at N. Pine and Harrisburg Ave	North	Complete	City								X		
P-166	West Ross Street	North	Complete	City								X		
P-171	Morton Lane	Engleside	Complete	City										X
P-057	North Jefferson	Engleside	Complete	Private								X		X
P-178	Clipper Magazine Stadium	North	Complete	Private					X					X
P-180	Brian Donnelly Studio	North	Complete	Private					X					
P-187	Shelly Road	MS4	Complete	City				X				X		
P-165	Hershey Ave.	MS4	Complete	City								X		
P-189	Alley NW 8	MS4	Complete	City										X
P-199	McCaskey HS	North	Complete	Private			X				X			

TABLE A-3. GREEN INFRASTRUCTURE SITES CONSTRUCTED BEFORE 2017

Project ID#	Project Name	Basin	Status	Owner	Porous Pavement Parking Lot	Porous Pavement Parks	Porous Pavement Schools	Porous Pavement Streets/ Alleys	Bioretention Parking Lot	Bioretention Parks	Bioretention Schools	Bioretention Streets/ alleys	Green Roof	Subsurface Infiltration Standard Asphalt
P-001	6th Ward Park	North	Complete	City		X								
P-003	Brandon Park	Engleside	Complete	City	X	X				X		X		
P-004	Crystal Park	Engleside	Complete	City		X						X		
P-005	Rodney Park	Engleside	Complete	City		X		X		X		X		
P-009	Streetscape, Phase III	Engleside	Complete	City				X				X		
P-031	Public Parking Lot: South Plum Street	Stevens Ave	Complete	City	X			X	X					
P-034	Public Parking Lot: Dauphin Street	Stevens Ave	Complete	City					X					X
P-035	Public Parking Lot: Penn Ave.	Stevens Ave	Complete	City					X					X
P-036	Public Parking Lot: East Mifflin Street	Stevens Ave	Complete	City	X				X					
P-050	Walnut & Plum Intersection/ Lancaster Brewery Company	North	Complete	City				X				X		
P-061	East Fulton	North	Complete	City										X
P-062	East Grant	North	Complete	City				X						

TABLE A-3. GREEN INFRASTRUCTURE SITES CONSTRUCTED BEFORE 2017 (cont.)

Project ID#	Project Name	Basin	Status	Owner	Porous Pavement Parking Lot	Porous Pavement Parks	Porous Pavement Schools	Porous Pavement Streets/ Alleys	Bioretention Parking Lot	Bioretention Parks	Bioretention Schools	Bioretention Streets/ alleys	Green Roof	Subsurface Infiltration Standard Asphalt
P-064	East Grant	North	Complete	City				X						
P-069	City Hall Annex Expansion	Engleside	Complete	City					X				X	
P-073	Ocean Avenue	Engleside	Complete	City										X
P-088	Green Alley- SW 56	Engleside	Complete	City										X
P-089	Green Alley- SW 52	Engleside	Complete	City										X
P-090	Green Alley- SW 101	Engleside	Complete	City										X
P-092	Green Alley- SW 105	Engleside	Complete	City										X
P-096	Green Alley- SW 114	Engleside	Complete	City										X
P-115	James Street Greening	North/ Engleside	Complete	City								X		
P-124	Fire Station #3- Green Roof	North/ Stevens Avenue	Complete	City									X	
P-127	Charlotte St. Curb Extension	Engleside	Complete	City								X		
P-133	Recycling Center	North	Complete	City					X					

TABLE A-3. GREEN INFRASTRUCTURE SITES CONSTRUCTED BEFORE 2017 (cont.)

Project ID#	Project Name	Basin	Status	Owner	Porous Pavement Parking Lot	Porous Pavement Parks	Porous Pavement Schools	Porous Pavement Streets/ Alleys	Bioretention Parking Lot	Bioretention Parks	Bioretention Schools	Bioretention Streets/ Alleys	Green Roof	Subsurface Infiltration Standard Asphalt
P-134	W. Liberty restriping Project	North	Complete	City								X		
P-135	Mulberry St. Two-way Conversion	North/ Engleside	Complete	City				X				X		
p-170a	Hand Ave	North	Complete	City				X						
P-170b	Reynolds Ave	North	Complete	City				X						
P-021	Two Dudes Painting Company	Engleside	Complete	Private	X				X					
P-075	Mulberry Studios	Engleside	Complete	Private										X
P-077	Mulberry Partners, LLC	North/ Engleside	Complete	Private										X
P-116	Tec Centro	Engleside	Complete	Private	X									
P-120	Brewery Alley- Alley 45	North	Complete	Private	X									
P-131	Alley 117 (NW)	Engleside	Complete	Private				X						
P-143	Alley 42 (NW)	North	Complete	Private				X						
P-146	317 N. Mulberry	Engleside	Complete	Private	X									

TABLE A-3. GREEN INFRASTRUCTURE SITES CONSTRUCTED BEFORE 2017 (cont.)

Project ID#	Project Name	Basin	Status	Owner	Porous Pavement Parking Lot	Porous Pavement Parks	Porous Pavement Schools	Porous Pavement Streets/ Alleys	Bioretention Parking Lot	Bioretention Parks	Bioretention Schools	Bioretention Streets/ Alleys	Green Roof	Subsurface Infiltration Standard Asphalt
P-147	Steeple View Lofts	Engleside	Complete	Private	X									
P-150	Alley NE 10 - Spruce St.	North	Complete	Private										X
P-159	Community Mennonite	Engleside	Complete	Private	X				X					
P-102	Green Alley - 148 SW		Complete	City				X						
P-173	Green Alley - 142 SW	MS4	Complete	City				X						
P-172	Green Alley - 156 SW	MS4	Complete	City										X
P-13	Dewatering Building	MS4	Complete	City									X	
P-137	Chlorination Building	MS4	Complete	City									X	
P-139	Oxidation Building	MS4	Complete	City									X	
P-121	New Dauphin and S. Broad St.	MS4	Complete	City								X		

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APPENDIX B – FORMS

Appendix B contains forms to be used for site selection and monitoring activities. The list below explains the purpose of each form.

B.1 Site and Treatment Characterization Worksheet

The purpose of this form is to collect information about the site characteristics of potential monitoring sites. will be filled out during field validation.

B.2 Post-Construction Inspection Checklist for Green Infrastructure

This form is a template for inspection checklists to be used during field acceptance inspections. This form is to be customized for each constructed GI site by the Design Engineer or Construction Management team. The following document will serve as a template for guidance: United States Environmental Protection Agency. Green Infrastructure Checklists and Renderings. Appendix B2: Post-Construction Inspection Checklist for Green Infrastructure. September 2016.

B.3 Data Collection Sheet - Surface Infiltration Testing on Permeable Pavements

This data collection form will be filled out during surface infiltration tests on permeable pavements. For more information, see Section 4.3: Performance Baseline Testing and Section 4.4: Ongoing Field Performance Testing.

B.4 Data Collection Sheet - Surface Infiltration Testing on Soils

These data collection forms will be filled out during surface infiltration tests on bioretention sites. The forms cover two different surface infiltration methods: Turf-Tec Infiltrometer and Double Ring Infiltrometer. City of Lancaster staff will choose the test method used for each site. For more information, see Section 4.3: Performance Baseline Testing and Section 4.4: Ongoing Field Performance Testing.

B.5 Data Collection Sheet - Simulated Runoff Testing on Bioretention

This data collection form will be filled out during simulated runoff tests on bioretention sites. For more information, see Section 4.2: Field Acceptance Testing.

B.1 Site and Treatment Characterization Worksheet

Site and Treatment Characterization Worksheet

City of Lancaster Green Infrastructure Program

CITY OF LANCASTER
A City Authentic

Date: ____________________ Time: ____________________

Employee Name: ____

Site Characteristics

Project ID: ____________________ Asset ID: ____________________

Project Name: ____

Site Owner: ____________________ Parcel ID: ____________________

Address: ____

Basin (circle one): **North** **Engleside** **Susquehanna** **Stevens Ave** **MS4**

GI Type(s) – Select all that apply

- ☐ Porous Asphalt
- ☐ Porous Concrete
- ☐ Permeable Pavers
- ☐ Cistern – Rain Barrel
- ☐ Green Roof
- ☐ Bioretention/Bioinfiltration – Stormwater Bumpout
- ☐ Bioretention/Bioinfiltration – Stormwater Planter
- ☐ Bioretention – Rain Garden
- ☐ Infiltration Trench
- ☐ Tree Trench
- ☐ Naturalized Basin

Site Land Use – Select all that apply

- ☐ Parking Lot
- ☐ Park
- ☐ School
- ☐ Street
- ☐ Alley
- ☐ School
- ☐ Roof

Construction Year: ______________________

Maintenance Status: ______________________

Street slope or slope of contributing area (%): ______________________

Describe site access and potential safety issues/concerns:

Design Parameters

Hydraulic loading ratio at design capacity/flow: ______________________

Est. Annual Runoff Captured (gallons):

Impervious Area Contributing (Drainage Area) Sq. Ft.: ______________________

GI/BMP Area Sq. Ft.: ______________________

Storage Volume Cu. Ft.: ______________________

Depression Storage Depth: ______________________

Geotechnical Conditions of Existing Soil:

Design Characteristics

Underdrain? Select one. **Yes** **No** **If yes, describe underdrain characteristics below.**

Inlet types - include number of each type of inlet:

Contributing area land use – Select all that apply

- ☐ Residential
- ☐ Commercial
- ☐ Industrial

Describe any sediment observed, potential sediment sources, and anticipated deposition locations:

Media Types (if applicable):

Vegetation types and age (if applicable):

Current Conditions and Monitoring Opportunities

Piezometers installed: **Yes** **No**

Other type of well/piezometer installed: ______________________

Depression storage depth, if applicable: ______________________

Space restrictions:

Monitoring Diagram

Sketch a Monitoring Diagram below, include inlets and outlets, trees, monitoring wells, drains, catch basins, barriers, adjacent streets, GI site measurements, and any other important GI components.

Potential Water Quality Monitoring Opportunities

[Placeholder for steps needed to identify potential locations for measuring flow entering and leaving the GI facility and potential locations for performing water quality sampling of the influent and effluent]

Photo Log

Take photographs of the entire site and its components. Include the following:

- ☐ Full site from multiple angles
- ☐ Inlets and outlets
- ☐ Pavement or Paving units
- ☐ Vegetation
- ☐ Sediment

Photo Name	Description

B.2 Post-Construction Inspection Checklist for Green Infrastructure

PROJECT INFORMATION	Green Infrastructure Post-Construction Inspection Checklist
Project name:	**Inspection date:**
Site address:	**Weather at time of inspection (rainy, cloudy, sunny, etc.):**
Inspector(s):	**Date of last rainfall:**

Bioretention/Bioinfiltration			
Type(s) present:	☐ Stormwater Bumpout	☐ Stormwater Planter	☐ Rain Garden
Inspection summary:			

Tree Trench/Tree Pit		
Type(s) present:	☐ Tree Trench	☐ Tree Pit
Inspection summary:		

Porous Pavement (Green Alley)		
Type(s) present:	☐ Permeable Interlocking Concrete Pavers (PICP) ☐ Concrete Grid Pavement	☐ Porous Gravel ☐ Reinforced Grass
Inspection summary:		

Appendix B

BIORETENTION/BIOINFILTRATION Stormwater Bumpout, Stormwater Planter, and Rain Garden				Green Infrastructure Post-Construction Inspection Checklist
Inspection Item	**Yes**	**No**	**N/A**	**Corrective action (if "no")**
1. Will site runoff enter the practice as intended?	☐	☐	☐	
2. Will flow be evenly dispersed following the inlet? Are there signs of or potential for concentrated flow?	☐	☐	☐	
3. Is pretreatment in place according to construction drawings?	☐	☐	☐	
4. Do the bioretention dimensions match those specified in the construction drawings?	☐	☐	☐	
5. Are step-out zone dimensions (if applicable) according to plans?	☐	☐	☐	
6. Are pedestrian barriers in place and sized according to plans?	☐	☐	☐	
7. Are underdrains installed? If so, are the slots oriented and sized according to the plans?	☐	☐	☐	
8. If applicable, are underdrain cleanouts visible and sealed? If in a valve box, ensure filter material has also been placed between the valve box and cleanout.	☐	☐	☐	
9. If applicable, are cleanouts configured according to plans and located a maximum of every 300 feet? Are riser pipes solid (not slotted)?	☐	☐	☐	
10. Are walls and spillway constructed as planned?	☐	☐	☐	
11. Is the distance from the surface of the filter area to the outflow (spillway and top of the weir inside the water control structure) appropriate to provide the ponding depth per the construction drawing?	☐	☐	☐	
12. Is the outlet control weir set to the elevation shown on the construction drawings?	☐	☐	☐	
13. Does the bioretention media match the description of the media provided in the submittal?	☐	☐	☐	
14. Has the bioretention media infiltration rate been tested according to the plans and specifications? Verify infiltration rate test records.	☐	☐	☐	
15. If applicable, is mulch finely shredded hardwood and 3 inches in depth?	☐	☐	☐	
16. If plans include a liner, is it sufficiently covered by media and not visible?	☐	☐	☐	
17. If applicable, ensure weed barrier is not used under mulch or rock.	☐	☐	☐	
18. Is the vegetation the type, size, and maturity as specified in the plans? (e.g., grasses versus plantings, seed versus sod)	☐	☐	☐	
19. If sod is used, it is sand-grown sod?	☐	☐	☐	
20. Is the vegetation planted and staked properly according to the plans? (e.g., orientation, proximity, overall placement)	☐	☐	☐	
21. Does vegetation appear healthy?	☐	☐	☐	

TREE TRENCH/PIT				Green Infrastructure Post-Construction Inspection Checklist
Inspection Item	**Yes**	**No**	**N/A**	**Corrective action (if "no")**
1. Will site runoff enter the practice as intended?	☐	☐	☐	
2. Is pretreatment filter in place according to construction drawings? Is there at least 6 inches of fall from the invert of the chase to the top of the aggregate?	☐	☐	☐	
3. Do dimensions of the tree trench/tree pit match those specified in the construction drawings?	☐	☐	☐	
4. Are step-out zone dimensions according to plans?	☐	☐	☐	
5. Are underdrains installed? If so, are the slots oriented and sized according to the plans?	☐	☐	☐	
6. If applicable, are underdrain cleanouts visible and sealed? If in a valve box, ensure filter material has also been placed between the valve box and cleanout.	☐	☐	☐	
7. If applicable, are cleanouts configured according to plans and located a maximum of every 300 feet, with cleanouts at every junction and bend in the pipe? Are riser pipes solid (not slotted)?	☐	☐	☐	
8. Is the distance from the surface of the tree area (filter area) to the tree gate as specified in the plans?	☐	☐	☐	
9. Is the outlet control weir set to the elevation shown on the construction drawings?	☐	☐	☐	
10. Does the bioretention media match the description of the media provided in the submittal?	☐	☐	☐	
11. Has the bioretention media infiltration rate been tested according to the plans and specifications? Verify infiltration rate test records.	☐	☐	☐	
12. If applicable, is mulch finely shredded hardwood and 3 inches in depth?	☐	☐	☐	
13. If plans include a liner, is it sufficiently covered by media and not visible?	☐	☐	☐	
14. If applicable, ensure weed barrier is not used under mulch or rock.	☐	☐	☐	
15. Is the tree type, size, and maturity as specified in the plans?	☐	☐	☐	
16. If multiple trees, are the trees spaced according to the plans?	☐	☐	☐	
17. Does the tree(s) appear healthy?	☐	☐	☐	

3

POROUS PAVEMENT					Green Infrastructure Post-Construction Inspection Checklist
	Inspection Item	**Yes**	**No**	**N/A**	**Corrective action (if "no")**
Common Elements	1. Does the alley drainage area appear to drain centrally towards the porous pavement (away from buildings)?	☐	☐	☐	
	2. Is the width of the porous pavement as specified in the plans?	☐	☐	☐	
	3. Is the surface even with no evidence of cracks or depressions?	☐	☐	☐	
	4. Is the storage or structural layer firm and unyielding?	☐	☐	☐	
	5. Is a transition strip of standard concrete provided at all transitions from asphalt to porous pavement unless otherwise specified in the plans?	☐	☐	☐	
	6. Are underdrains installed? If so, are the slots oriented and sized according to the plans?	☐	☐	☐	
	7. If applicable, are underdrain cleanouts visible and sealed? If in a valve box, ensure filter material has also been placed between the valve box and cleanout.	☐	☐	☐	
	8. If applicable, are cleanouts configured according to plans and located a maximum of every 300 feet, with cleanouts at every junction and bend in the pipe? Are riser pipes solid (not slotted)?	☐	☐	☐	
	9. Is the outlet constructed per construction drawings?				
Permeable Interlocking Concrete Pavers (PICP)	1. Is a leveling layer of washed No. 8 stone included between the structural layer and the permeable interlocking concrete paver?	☐	☐	☐	
	2. Are all voids filled with washed No. 8 stone to the surface of the interlocking concrete paver?	☐	☐	☐	
	3. Is the pavement surface firm and unyielding?	☐	☐	☐	
	4. If for vehicular use, is the outer edge of PICP area bordered by concrete, and are uncut blocks used adjacent to the concrete border?	☐	☐	☐	
	5. Are cut pavers at least 40% of their uncut size?	☐	☐	☐	
	6. Is a herringbone pattern used for PICP areas intended for vehicular traffic?	☐	☐	☐	
Concrete Grid Pavers	1. Is the outer edge of the paver area bordered by concrete?	☐	☐	☐	
	2. If uncut blocks are used, are they adjacent to the concrete border?	☐	☐	☐	
	3. If visible, does the bedding layer consist of No. 8 stone unless otherwise specified in the plans?	☐	☐	☐	
	4. If vegetation is specified, is the grid paver filled with a soil media or seeded according to the plan?	☐	☐	☐	

D

B.3 Data Collection Sheet – Surface Infiltration Testing on Porous Pavements

Data Collection Sheet –
Surface Infiltration Testing on Porous Pavements

City of Lancaster Green Infrastructure Program

Date: ____________________ Time: ____________________

Site: ____________________ BMP Type: ____________________

Location: ____

Weather: ____

Field Personnel: ____

Material Condition

Material Type:

Age:

Thickness:

Site Diagram (next page)

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers, if present
- Testing locations and distances to reference points
- North arrow and surrounding street(s)
- Include a photograph of the immediate area that was tested to document the pavement pattern and layout and a photograph of the circumscribed chalk or temporary marking to document the placement of the ring relative to the pavement pattern and layout

Site Diagram

Time Elapsed during Pre-wetting (s):

Location 1:

Location 2:

Location 3:

(add more if needed)

Surface Infiltration Testing

Location	Trial	Weight of infiltrated water (lb)	Time Elapsed (s)	Notes

B.4 Data Collection Sheet – Surface Infiltration Testing on Soils

Data Collection Sheet –
Surface Infiltration Testing on Soils
TURF-TEC INFILTROMETER

City of Lancaster Green Infrastructure Program

CITY OF LANCASTER
A City Authentic

Date: ______________________ Time: ______________________

Site: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers, if present
- Testing locations and distances to reference points
- North arrow and surrounding street(s)

Penetrometer Readings

Location				
Penetrometer Reading (PSI)				

Pre-wetting

Start time: End time:

Moisture Sensing Method

		Soil Moisture Reading		
Trial	Time Elapsed (min)	Location 1	Location 2	Location 3

Soil Infiltration Testing

Location	Trial	Start time (min)	End time (min)	Infiltrometer Ruler Reading (in)	Infiltration Rate (in/hr)	Notes

Data Collection Sheet –
Surface Infiltration Testing on Soils
DOUBLE RING INFILTROMETER

City of Lancaster Green Infrastructure Program

CITY OF LANCASTER
A City Authentic

Date: ______________________ Time: ______________________

Site: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers, if present
- Testing locations and distances to reference points
- North arrow and surrounding street(s)

Penetrometer Readings

Location				
Penetrometer Reading (PSI)				

Pre-wetting

Start time: End time:

Moisture Sensing Method

		Soil Moisture Reading		
Trial	Time Elapsed (min)	Location 1	Location 2	Location 3

Soil Infiltration Testing

Ground Temperature:

Location	Trial	Start/ end time (min)	Inner Ring Reading (cm)	Inner Ring Mariotte Tube Flow (mL)	Annular Space Reading (cm)	Annular Space Mariotte Tube Flow (mL)	Water Temp. (°C)	Notes

B.5 Data Collection Sheet – Simulated Runoff Testing on Bioretention/Bioinfiltration

Data Collection Sheet –
Simulated Runoff Testing on Bioretention/Bioinfiltration

City of Lancaster Green Infrastructure Program

CITY OF LANCASTER
A City Authentic

Date: ______________________ Time: ______________________

Site: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers
- Pressure transducer locations with logger serial or ID number
- Location of diffuser
- Location of fire hydrant selected for the test
- North arrow and surrounding street(s)

Hydrant and Flow Meter Operation

Inlet Capacity Flow Rate:

Design Flow Rate:

Design Volume:

Bypass Threshold Flow Rate:

Final Total Volume:

Units	Time	Flow Rate	Total Volume	Bypass?	Outflow?	Overtopping?	Notes

Pressure Transducer Operation

Pressure Transducer ID	Piezometer or Well	Location	Depth from soil surface to bottom of pressure transducer	Notes

Pressure Transducer Operation

	Time	Piezometer 1 Water Level	Piezometer 2 Water Level	Piezometer 3 Water Level	Notes
Units					

APPENDIX C – MONITORING PROCEDURES

Appendix C contains the monitoring procedures for surface infiltration testing and simulated runoff testing. The list below explains the purpose of each procedure.

C.1 Surface Infiltration Testing on Porous Pavements

This procedure is suitable for surface infiltration testing on porous concrete, porous asphalt, and permeable unit pavement systems. The method has been adopted from two ASTM standards, as required by the Consent Decree. It may be used during Performance Baseline Testing and Ongoing Field Performance Testing.

C.2 Surface Infiltration Testing on Soils

This procedure is suitable for surface infiltration testing on bioretention/bioinfiltration sites. Two different methods are presented.

a. Turf-Tec Infiltrometer Method

This procedure is suitable for surface infiltration testing on soil in order to establish changes in infiltration over time. Turf-Tec infiltration rates must only be compared to other Turf-Tec infiltration rates. It may be used during Field Acceptance Testing, Performance Baseline Testing and Ongoing Field Performance Testing.

b. Double Ring Infiltrometer Method

This procedure is suitable for surface infiltration testing on soil in order to establish changes in infiltration over time. The 12-inch and 24-inch Double Ring Infiltrometer method complies with the ASTM D3385. It may be used during Field Acceptance Testing, Performance Baseline Testing, and Ongoing Field Performance Testing.

C.3 Simulated Runoff Test

This procedure is used to monitor performance of GI facilities under controlled conditions. It provides monitoring information on inlet capacity and efficiency, bypass characteristics, infiltration, and discharges to an underdrain, if used.

C.1 Surface Infiltration Testing on Permeable Pavements

The method presented below has been adapted from the following ASTM Standards:

1. ASTM C1701/C1701M − 17a Standard Test Method for Infiltration Rate of In Place Porous Concrete
2. ASTM C1781/C1781M – 15 Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems

The first standard may be used for testing infiltration rates on porous concrete and asphalt. The second may be used for testing surface infiltration rates on solid concrete paving units, concrete grid paving units, and clay paving brick.

Set Up

Antecedent Conditions:

- Do not perform test if conditions are deemed unsafe or if rain is forecasted for the scheduled day of testing.
- Ensure that there is no surface ponding in the site at the initiation of testing.
- Do not test if there is standing water on top of the pervious surface.
- Do not test within 24 hours of the last precipitation.

Health and Safety:

- The Project Health and Safety Plan must include procedures for the surface infiltration test and any other monitoring activities.
- Set up appropriate traffic control and safety equipment in accordance with the Health and Safety Plan for the specific site.

Instrumentation and Equipment

- Traffic signage and cones, as required by the Health and Safety Plan
- Protective equipment, as required by the Health and Safety Plan
- 12-inch diameter infiltration ring*
- Water or access to water source
- 5-gallon bucket and pails
- Balance or scale accurate to 0.1lb
- Stopwatch
- Non-hardening plumber’s putty
- Broom
- Chalk
- Ruler and tape measure

*Note: The infiltration ring must open at both ends, watertight, and sufficiently rigid to retain its form when filled with water. Ring materials that have been found to be suitable include steel, aluminum, rigid plastic, and PVC. It must have a diameter of 12 inches with a minimum height of 2 inches. The bottom edge of the ring must be even. The inner surface of the ring should be marked or scored with two lines at a distance of 10 and 15 millimeters (0.40 and 0.60 inches) from the bottom of the ring. Measure and record the inner diameter of the ring to the nearest 1 millimeter (0.05 inches).

It is recommended, but not required, to run all pre-soaking and infiltration testing on a site concurrently. This would require multiple infiltrometers.

1. For documentation purposes, photograph the site and fill out site diagram, including all testing locations.
2. Testing locations should be chosen based on site area. Unless otherwise specified, use the following to determine the number of tests to perform: Three test locations for areas up to 25,000 SF. Add one test location for each additional 10,000 SF. Provide at least 3 feet clear distance between test locations, unless at least 24 hours have elapsed between tests. One of the locations tested should be the point that is expected to experience significant sediment deposition. Measure the distance from the testing locations to a reference point and note it on the site diagram. It is recommended that 2 trials be performed per location, and the results averaged.
3. Infiltration ring installation
   A) Pavers. Clean the pavement surface by only sweeping off trash, debris, and other non-seated material. Take a photograph of the immediate area to be tested to document the pavement pattern and layout.
      i. Move the ring over the surface of the pavement until the pattern, drainage joints and drainage voids framed within the infiltration ring are representative of the entire paving pattern, drainage joints and drainage voids across the pavement surface. Set the ring on the pavement surface and mark its location by circumscribing it with chalk or other temporary marking. Take a photograph of the circumscribed chalk or temporary marking to document the placement of the ring relative to the pavement pattern and layout.
      ii. For solid interlocking concrete paving units and clay brick paving, remove aggregate to a depth of no greater than 0.5 inches in any joint or drainage void that will be directly below the test ring and fill these areas with plumber’s putty so that a positive seal can be made to the test ring once it is placed on the surface. Take care not to extend the plumber’s putty more than 0.5 inches inside the perimeter of the chalk line or other temporary marking. For concrete grid paving units, center as much of the ring as possible on the webs. For ring locations over openings, remove any vegetation, if present, directly below the test ring to a depth of no greater than 0.5 inches and apply plumber’s putty to the surface of the soil, or to the aggregate, if present, so that a positive seal can be made to the test ring once it is placed on the surface. Take care not to extend the plumbers putty more than 0.5 inches inside the perimeter of the chalk line or other temporary marking.

iii. Apply plumber's putty around the bottom edge of the ring and place the ring onto the surface being tested. Press the putty into the surface and around the bottom edge of the ring to create a watertight seal making sure that the putty does not extend more than 0.5 inches inside the perimeter of the ring. Place additional putty as needed to ensure a watertight seal.

B) All others. Clean the pavement surface by only brooming off trash, debris, and other non-seated material. Apply plumber's putty around the bottom edge of the ring and place the ring onto the porous pavement surface being tested. Press the putty into the surface and around the bottom edge of the ring to create a watertight seal. Place additional putty as needed.

4. Pre-wet the testing area. Pour water into the ring at a rate sufficient to maintain a head between the two marked lines. When testing on paving units, take care to not pour the water onto the joints. This minimizes displacement of jointing aggregate and any accumulated sediment in the joints during the test. Use a total of 8 pounds of water. Begin timing as soon as the water impacts the surface. It is recommended that the pour height be limited to a maximum of 6 inches. Stop timing when free water is no longer present on the pervious surface. Record the amount of elapsed time to the nearest 0.1 seconds.
5. The test shall be started within 2 minutes after the completion of the prewetting. If the elapsed time in the prewetting stage is less than 30 seconds, then use a total of 40 pounds of water. If the elapsed time in the prewetting stage is greater than or equal to 30 seconds, then use a total 8 pounds of water. Record the weight of water to the nearest 0.1 pound. Pour the water onto the ring at a rate sufficient to maintain a head between the two marked lines and until the measured amount of water has been used. If a sloped pavement is being measured, maintain head between the two marked lines at the lowest point of the slope. Take care to pour the water such that it falls directly on the surface of a paving unit and not onto the joints. This minimizes displacement of jointing aggregate and any accumulated sediment in the joints during the test. Begin timing as soon as the water impacts the porous pavement surface. Stop timing when free water is no longer present on the surface. Record the testing duration to the nearest 0.1 second.
6. If a test is repeated at the same location, the repeat test does not require pre-wetting if conducted within 5 minutes after completion of the first test. If two tests are conducted at a location on a given day, the infiltration rate at that location on that day shall be calculated as the average of the tests. No more than two tests shall be conducted at the same location on the same day.
7. When completed with testing, remove plumber's putty from the joints and surface, reinstate the removed aggregate jointing materials, and sweep test area clean.

Demobilization

8. Ensure conditions on site are safe prior to departure.
9. All documentation and photographs generated during experiment should be managed according to the procedures established in Section 6 of the Monitoring Plan.

Sample Data Collection Sheet

Includes Example Data Entry

Date: ______________________ Time: ______________________

Site: ______________________ BMP Type: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers, if present
- Testing locations and distances to reference points
- North arrow and surrounding street(s)
- Include a photograph of the immediate area that was tested to document the pavement pattern and layout and a photograph of the circumscribed chalk or temporary marking to document the placement of the ring relative to the pavement pattern and layout

Material Condition

Material Type:

Age:

Thickness:

Time Elapsed During Pre-wetting(s):

Location 1: 138 s

Location 2: 123 s

Location 3: 111 s

Surface Infiltration Testing

Location	Trial	Weight of infiltrated water (lb)	Time Elapsed (s)	Notes
1	1	8.1	144s	
1	2	8.0	142s	
2	1	8.0	125s	
2	2	8.1	129s	
3	1	8.0	130s	

C.2 Surface Infiltration Testing on Soils

Three methods are presented in this Appendix for surface infiltration testing on soils:

1. Turf-Tec Infiltrometer Method
2. 6-inch and 12-inch Double Ring Infiltrometer Method
3. ASTM 3385 12-inch and 24-inch Double Ring Infiltrometer Method

Note the Turf-Tec Infiltrometer and 6-inch and 12-inch Double Ring Infiltrometer do not comply with ASTM D3385. Only the 12-inch and 24-inch Double Ring Infiltrometers comply with the ASTM D3385.

Definitions

- Infiltration rate – Infiltration rate is the velocity at which water enters the soil. It is affected by the degree of saturation the soil.
- Saturated Hydraulic Conductivity – Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement.[1] It is a function of both the fluid and the porous medium through which the fluid is flowing. It is a soil property, not a rate.
- Permeability – Permeability or “intrinsic permeability” is a quantitative property of porous material and is controlled solely by soil pore geometry. Unlike saturated hydraulic conductivity, intrinsic permeability is independent of fluid viscosity and density. It is the soil’s hydraulic conductivity after the effect of fluid viscosity and density are removed.

Although the units of infiltration rate and hydraulic conductivity of soils are similar, there is a distinct difference between these two quantities. They cannot be directly related unless the hydraulic boundary conditions are known, such as hydraulic gradient, and the extent of lateral flow of water can be reliably estimated. The ASTM Double Ring Infiltrometer Test is the preferred method since the outer rings helps to reduce the error resulting from lateral flow in the soil. Saturated hydraulic conductivity of the surface layer can be estimated when the rate of water flow in the inner ring is at steady state. The rate of infiltration is determined by the amount of water that infiltrates into the soil per surface area, per unit of time.

[1] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053573

Turf-Tec Infiltrometer Method

Adapted from Turf-Tec International's Infiltrometer Instructions[2]

Set Up

Antecedent Conditions – Do not perform test if conditions are deemed unsafe or if rain is forecast for the scheduled day of testing. Ensure that there is no surface ponding in the bioinfiltration site at the initiation of testing. If the engineered soil at the surface of the site seems to have very low permeability, consider taking a soil core to be sent to a laboratory for particle size analysis. See Section 4.2 of Monitoring Plan.

Health and Safety – The Project Health and Safety Plan must include procedures for the surface infiltration test and any other monitoring activities. Set up appropriate traffic control and safety equipment in accordance with the Health and Safety Plan for the specific site.

<u>Instrumentation and Equipment</u>

- Traffic signage and cones, as required by the Health and Safety Plan
- Protective equipment, as required by the Health and Safety Plan
- Penetrometer
- Turf-Tec Infiltrometers
- Water or access to water source
- Buckets and pails
- Garden trowel
- Ruler or tape measure
- Digital soil moisture sensor (optional)
- AA batteries, AAA batteries, and silicone spray, as needed

It is recommended, but not required, to run all pre-soaking and infiltration testing on a site concurrently. This would require multiple infiltrometers.

1. For documentation purposes, photograph the site and fill out site diagram, including all testing locations.
2. Testing locations should be chosen based on site area. It is recommended that at minimum 3 testing locations be tested per 100SF of site area. One of the locations tested should be the lowest point in the practice, or any other point that is expected to experience significant sediment deposition. Measure the distance from the testing locations to a reference point and note it on the site diagram. It is recommended that 6 trials be performed per location, and the results averaged.
3. Take a penetrometer reading at each testing location and note the results in the data collection sheet.

[2] Available at the following web address: http://www.turf-tec.com/Instructions/IN2-W-Instructions.pdf

4. Place double ring cutting blades on the area to be tested. Silicone spray may be applied to the cutter edges to allow easier removal of tool.
5. Push down on handle grips while slightly turning instrument back and forth until the Saturn ring is against the soil surface. Do not move the instrument side to side while turning.
6. Pre-wet the testing area. Follow one of the two procedures below.
   A. Saturated Test. Fill the rings at least 3 times by filling the inner ring and allowing it to overflow into the area of the second ring until it is also full to the edge. Allow the water to infiltrate into the soil between fillings. It is recommended that the pre-wetting period should last at least one hour. Once the soil is saturated, proceed with the test.
   B. Moisture Sensing. Prior to soaking the testing area, place the probe of a soil moisture sensor into the soil between the two rings. Record the reading in the Data Collection Sheet. Fill the rings with water by filling the inner ring and allowing it to overflow into the area of the second ring until it is also full to the edge. Then, test and record the moisture percentage once again. Moisture Sensor readings should be taken at the same depth each time, between 3-4 inches deep, and the readings should be recorded. Continue filling and recording the moisture level until the soil moisture readings have stabilized, i.e. the last 3 moisture readings are within 3% of each other. This method should be repeated for each test area. In addition, the next time the same area is to be tested for infiltration, be sure the moisture sensor readings are in the same range before testing. This will eliminate any variables and still produces a reliable test. The infiltration test can then be performed on that area.
7. To begin a test, fill both the outer and inner ring with clean water until they slightly overflow. This is accomplished easiest by filling the inner ring first and allowing it to spill over and fill the outer ring to the edge.
8. When the pointer reaches the beginning of the inch scale, start the timer immediately by pressing the start button. To set the timer, press the Stop/Reset Button once to reset the timer to read “00 00”. Set the timer for 15 minutes by pressing minutes 15 times until 15:00 is displayed.
9. As the water seeps into the soil, the plastic ball attached to the tube will measure the water in inches and register it on the scale with the pointer located just below the timer.
10. At fifteen minutes, the timer will start beeping. Stop the beeper by depressing the stop/reset button on the timer.
11. Note the position of the pointer on the scale. Record this number on the monitoring record. This scale is in inches. Multiply the inches registered on the scale by four to give you the water infiltration in one hour. Also record this information on the record chart.
12. Repeat the procedure for all trials and testing locations. To start timer again, repeat step #1. It is best to get several readings on an area to get the average infiltration rate.
13. If the infiltration rate is slow, a thirty minute or an hour-long test may be desired. If the infiltration rate is fast, a five-minute test may be sufficient.
14. To remove the instrument from the soil, use the hand grips to rotate the cups in a twisting motion.
15. The handles may also require a slight but constant turning while lifting the tool out of the ground.

16. If any soil is removed use the plug pusher that is provided with the Turf-Tec Infiltrometer to remove the plug in one piece.
17. After using your Turf-Tec Infiltrometer, wash the cutter blades, dry, and spray with silicone (this will help prevent rust).

Demobilization

18. Ensure conditions on site are safe prior to departure.
19. All documentation and photographs generated during experiment should be managed according to the procedures established in Section 6 of the Monitoring Plan.

Sample Data Collection Sheet

Includes Example Data Entry

Date: ______________________ Time: ______________________

Site: ______________________ BMP Type: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers, if present
- Testing locations and distances to reference points
- North arrow and surrounding street(s)

Penetrometer Readings

Location	1	2	3
Penetrometer Reading (PSI)	122	217	306

Pre-wetting

Start time: End time:

Moisture Sensing Method

		Soil Moisture Reading		
Trial	Time Elapsed (min)	Location 1	Location 2	Location 3
1	10	10%	12%	9%
2	10	23%	34%	30%
3	10	25%	41%	25%

Soil Infiltration Testing

Location	Trial	Start time (min)	End time (min)	Infiltrometer Ruler Reading (in)	Infiltration Rate (in/hr)	Notes
1	1	0	15	2.75	11	
1	2	0	15	2.75	11	
1	3	0	15	2.5	10	
1	4	0	15	2.5	10	
1	5	0	15	2.5	10	Infiltration rate stabilized
2	1	0	15	15/16	3.75	

Double Ring Infiltrometer Method

This procedure may be used for:

- 6-inch and 12-inch double ring infiltrometer, and
- 12-inch and 24-inch double ring infiltrometer.

Adapted from Turf-Tec International “IN8P-W Turf-Tec Heavy Duty Tall Infiltration Rings with Ports” and ASTM D3385-09.

Set Up

Antecedent Conditions – Do not perform test if conditions are deemed unsafe or if rain is forecast for the scheduled day of testing. Ensure that there is no surface ponding in the bioinfiltration site at the initiation of testing. If the engineered soil at the surface of the site seems to have very low permeability, consider taking a soil core to be sent to a laboratory for particle size analysis. See Section 4.2 of Monitoring Plan.

Health and Safety – The Project Health and Safety Plan must include procedures for the surface infiltration test and any other monitoring activities. Set up appropriate traffic control and safety equipment in accordance with the Health and Safety Plan for the specific site.

<u>Instrumentation and Equipment</u>

- Traffic signage and cones, as required by the Health and Safety Plan
- Protective equipment, as required by the Health and Safety Plan
- Penetrometer
- Double ring Infiltrometers
- Sledgehammer
- Rubber mallet
- Level
- Piece of wood or driving plate, for driving the infiltrometer into the soil without damaging the metal
- Water or access to water source, 60 gallons minimum
- 2 Mariotte Tubes (one large, one small) per infiltrometer
- Rubber tubing
- Thermometer for soil and water
- Buckets, pails, or and/or graduated cylinders
- Garden trowel and/or shovel
- Stopwatch
- Ruler or tape measure
- Waterproof tape, such as duct tape

- Splash guards, such as burlap or other thin fabric
- Digital soil moisture sensor (optional)
- AA batteries, AAA batteries and silicone spray, as needed

It is recommended, but not required, to run all pre-soaking and infiltration testing on a site concurrently. This would require multiple double ring infiltrometers.

1. For documentation purposes, photograph the site and fill out site diagram, including all testing locations.
2. Testing locations should be chosen based on site area. It is recommended that at minimum 3 testing locations be tested per 100SF of site area. One of the locations tested should be the lowest point in the practice, or any other point that is expected to experience significant sediment deposition. Measure the distance from the testing locations to a reference point and note it on the site diagram. It is recommended that more than 3 trials be performed per location, and the results averaged.
3. Take a penetrometer reading at each testing location and note the results in the data collection sheet.
4. Place the double ring cutting blades on the area to be tested. (Silicone spray may be applied to the cutter edges to allow easier and cleaner removal of tool.)
5. Push down on handle while slightly turning instrument back and forth until the rings are approximately two inches into the soil. (Do not move the instrument side to side or twist too much because the soil will be disturbed.
6. If harder soils are being tested, you can use a Driving Plate or a board and dead blow hammer to insert the rings into the soil. Be sure to use care as to not damage or bend the rings with excessive force. If you are using the Turf-Tec IN6-W Infiltration Test Ring Driving Plate, a pickup truck bumper can be placed over the ring with the driving plate and a bottle jack can be used to apply downward pressure on the plate and rings insuring an even insertion into the soil.
7. If using the larger double ring size, a second person standing on the wood block and driving cap will usually facilitate driving the ring and reduce vibrations and disturbance.
8. Use a level to ensure that the double rings are vertically and horizontally level.
9. Cover the soil surface inside the inner ring and between the rings with a splash guard. Pre-wet the testing area. Follow one of the two procedures below.
   A. Saturated Test. Fill the rings at least 3 times by filling the inner ring and allowing it to overflow into the area of the second ring until it is also full to the edge. Allow the water to infiltrate into the soil between fillings. It is recommended that the pre-wetting period should last at least one hour. Once the soil is saturated, proceed with the test.
   B. Moisture Sensing. Prior to soaking the testing area, place the probe of a soil moisture sensor into the soil between the two rings. Record the reading in the Data Collection Sheet. Fill the rings with water by filling the inner ring and allowing it to overflow into the area of the second ring until it is also full to the edge. Then, test and record the moisture percentage once again. Moisture Sensor readings should be taken at the same depth each time, between 3-4 inches deep, and the readings should be recorded. Continue filling and recording the moisture level

until the soil moisture readings have stabilized, i.e. the last 3 moisture readings are within 3% of each other. This method should be repeated for each test area. In addition, the next time the same area is to be tested for infiltration, be sure the moisture sensor readings are in the same range before testing. This will eliminate any variables and still produces a reliable test. The infiltration test can then be performed on that area.

10. There are basically three ways to maintain a constant head (liquid level) within the inner ring and annular space between the two rings: manually controlling the flow of liquid, the use of constant-level float valves, or the use of a Mariotte tube. When manually controlling the flow of liquid, a depth gauge is required to assist the investigator visually in maintaining a constant head. Use a depth gauge such as a steel tape or rule for soils having a relatively high permeability; for soils having a relatively low permeability use a hook gauge or simple point gauge. This methodology will assume the use of Mariotte Tubes.
11. Record the ground temperature at a depth of about 300 mm (12 inches), or at the mid-depth of the test zone.
12. Prepare the Mariotte Tubes. For detailed directions on the preparation of the Mariotte Tubes, see the product manual.
13. Install the large Mariotte Tube to the port in the infiltration rings that leads to the annual space between the two rings. Attach the small Mariotte Tube to the port on the infiltration rings that leads to the inner ring.
14. Fill both Mariotte Tubes with water to the top of the site glass. This is accomplished easiest by attaching a ½ inch inner diameter by 5/8 inch outer diameter vinyl tubing from an elevated water supply to the top valve located on the top cap of the Mariotte Tube.
15. Next, the top valve is fully opened as well as opening the petcock also located on the top cap (Figure 1 below).

Figure 3C
Photo showing the Petcock on the top of the Mariotte tube.

Figure 3D
Photo showing opening the Petcock on the top of the Mariotte tube to vent air while filling.

Figure 1. Top of Mariotte tube (Courtesy of Turf-Tec.)

16. Proceed filling the Mariotte tube through the top valve allowing air to escape through the petcock. Do not fill the unit while testing unless the bottom valve is completely closed. After re-filling close the top valve and the petcock fully before opening the bottom valve and restart testing.
17. Install the Mariotte tubes in such a manner that the reference head will be at least 25 mm (1 inch) and not greater than 150 mm (6 inches) above the soil surface. Select the head on the basis of the permeability of the soil, the higher heads being required for lower permeability soils.
18. Cover the soil surface within the center ring and between the two rings with splash guards, pieces of burlap or rubber sheet, to prevent erosion of the soil when the initial liquid supply is poured into the rings.
19. Use a pail to fill both rings with liquid to the same desired depth in each ring; do not record this initial volume of liquid. Remove the splash guards.
20. Start flow of fluid from the Mariotte Tubes. As soon as the fluid level becomes basically constant, determine the fluid depth in the inner ring and in the annular space to the nearest 2 mm (1/8 inch) using the ruler or a tape measure. Record these depths. Also, record the water temperature inside the inner ring. If the depth between the inner ring and annular space varies more than 5 mm (¼ inch), raise the depth gauge or Mariotte tube having the shallowest depth.
21. Maintain the liquid level at the selected head in both the inner ring and annular space between rings as near as possible throughout the test, to prevent flow of fluid from one ring to the other.
22. Determine and record the volume of liquid that is added to maintain a constant head in the inner ring and annular space during each timing interval by measuring the change in elevation of liquid level in the Mariotte tube by reading the site glass. After recording how much water was been siphoned from the Mariotte tube, move the rubber water height marker to the new water level position. Also, record the temperature of the liquid within the inner ring.
23. For average soils, record the volume of liquid used at intervals of 15 minutes for the first hour, 30 minutes for the second hour, and 60 minutes during the remainder of a period of at least 6 hours, or until after a relatively constant rate is obtained. The appropriate schedule of readings may be determined only through experience. For high permeability materials, readings may be more frequent, while for low permeability materials, the reading interval may be 2 hours or more. In any event, the volume of liquid used in any one reading interval should not be less than approximately 25 mL.
24. Place the driving cap or some other covering over the rings during the intervals between liquid measurements to minimize evaporation.
25. To remove the smaller double ring infiltrometer from the soil, use the hand grips to lift the instrument straight out of the soil. The handles may also require a slight turning while lifting the tool out of the ground. For the larger double ring infiltrometer, remove the rings assisted by light hammering on the sides with a rubber mallet. Extract the tool slowly in order not to disturb the soil surface.
26. After using your infiltration rings, wash the rings, dry them and spray with silicone spray.

Demobilization

27. Ensure conditions on site are safe prior to departure.
28. All documentation and photographs generated during experiment should be managed according to the procedures established in Section 6 of the Monitoring Plan.

Sample Data Collection Sheet

Includes Example Data Entry

Date: ______________________ Time: ______________________

Site: ______________________ BMP Type: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers, if present
- Testing locations and distances to reference points
- North arrow and surrounding street(s)

Penetrometer Readings

Location	1	2	3	
Penetrometer Reading (PSI)	122	217	306	

Pre-wetting

Start time: End time:

Moisture Sensing Method

		Soil Moisture Reading		
Trial	Time Elapsed (min)	Location 1	Location 2	Location 3
1	10	10%	12%	9%
2	10	23%	34%	30%
3	10	25%	41%	25%

Soil Infiltration Testing

Ground Temperature: 14 ºC

Location	Trial	Start/end time (min)	Inner Ring Reading (cm)	Inner Ring Mariotte Tube Flow (mL)	Annular Space Reading (cm)	Annular Space Mariotte Tube Flow (mL)	Water Temp. (ºC)	Notes
1	1	0	3	114	2.2	389	15	
		15	4.45		4.4		15	
1	2	0	4.45	212	4.4	795	15	
		15	7.15		8.9		15	
1	3	0	7.15	263	8.9	848	15	
		15	10.5		13.7		15.5	
1	4	0	10.5	306	13.7	945	15.5	
		15	14.4		19.05		15.5	
1	5	0	14.4	758	19.05	2324	16	Refilled tubes
		30	24.05		32.2		16.5	
								Refilled tubes

C.3 Simulated Runoff Test

Definitions

The following terms are used in the protocol below.

- Inlet Bypass – Inlet bypass is defined as the runoff flow passing the inlet, instead of entering the inlet, along the curb line. This may be caused by irregularities in street conditions or construction (e.g. where concrete and asphalt meet on a concrete apron, bumps along the road, etc.) These conditions are not considered as causing inlet bypass if the bypass flow is a small fraction of the runoff flow presenting itself at the inlet.
- Uniform Flow – Uniform flow is defined as flow that does not change velocity or depth with position along the flow direction.
- Steady Flow – Steady flow is defined as flow that does not change velocity or depth with time.
- Bypass Threshold Flow Rate – Bypass threshold flow rate is defined as the minimum flow rate at which inlet bypass commences for a particular inlet. It is estimated during simulated runoff testing.
- Inlet Capacity Flow Rate – Inlet capacity flow rate is defined as the minimum flow rate at which an inlet must be able to convey all of the flow presenting itself at the inlet into the GI installation. This is a flow rate at which no inlet bypass occurs. This is specified by the Design Engineer.

Set Up

Antecedent Conditions:

- Do not perform test if conditions are deemed unsafe or if rain is forecast for the scheduled day of testing.
- Ensure that there is no surface ponding in the bowl of the bioinfiltration site at the initiation of testing. If the GI facility becomes “full” during testing, such that inlet bypass appears partly or fully impacted by water in the site (i.e. because the water level is too high inside the bioinfiltration site, rather than inlet configuration), stop testing and either reduce the water level in the site to accommodate the next trial by pumping or allowing the site to drain or attempt to find the root cause of the fast “filling up” of the facility.
- If the engineered soil at the surface of the site seems to have a low permeability, the hydrant test should be stopped and a laboratory sample of a soil core of the site should be sent to a laboratory for particle size analysis. See Section 4.2 of Monitoring Plan.

Health and Safety – The Project Health and Safety Plan must include procedures for the hydrant test and any other Field Acceptance Testing activities. It must include a hydrant operation permit, if applicable, and procedures for safe operation of the hydrant and all associated accessories. Set up appropriate traffic control and safety equipment in accordance with the Health and Safety Plan for the specific site.

Site Specific Hydrant Test Procedure – The following Hydrant Test Protocol must be adapted for a particular site prior to the start of testing. The Hydrant Test Procedure for a specific project site must be included in the Field Acceptance Testing Plan and approved by the City of Lancaster. Deviations and additions to the following protocol may be necessary and must be approved by the City of Lancaster.

<u>Instrumentation and Equipment</u>

- Traffic signage and cones, as required by the Health and Safety Plan
- Protective equipment, as required by the Health and Safety Plan
- Hydrant wrench and key
- Hydrant flow meter
- Firehose (length to be specified in Field Acceptance Testing Plan)
- Hose ramps (if required)
- Backflow preventer (if required by permit)
- Diffuser
- Piezometer pipes and caps
- Submersible pressure transducer with water level logger and computer cable
- Batteries for water level logger (if applicable)
- Field Laptop
- Tape Measure or Water Level Meter
- Sand bags

1. Prior to start of testing, ensure that the computer software for the water level loggers has been installed and tested on the field laptop(s) per the manufacturer's user manual. The water level logger must also be calibrated and configured according to the manual. This must be done in a controlled setting, before the hydrant test is scheduled. The sampling intervals and start times must be synced on all loggers, to simplify data analysis.
2. Measure the distance between the GI inlet and the nearest functional fire hydrants. Choose a fire hydrant for the test. If it is across the street, hose ramps may be required. See project-specific HASP for further instructions.

Field Setup Protocol

3. Before starting the hydrant test, clean the inlet, outlet, and rain garden free of debris to isolate the effect of the rain garden construction on the GI performance.
4. For documentation purposes, photograph the site, the curb upstream of the site, the inlet, and the outlet. If there is a concrete apron, it should be included as well.
5. Set up the connection to the fire hydrant, backflow preventer (if applicable), and high precision flow meter in accordance with any applicable permit or City standard. Ensure that the public, both pedestrians and vehicles, can safely travel the perimeter of work or around the equipment installed. Please refer to the site-specific Health and Safety Plan. Clearly isolate areas where equipment is in operation using cones or other traffic signage.
6. Before monitoring begins, connect the firehose to the hydrant and flush the hydrant away from the rain garden until water is relatively clean. Ensure the water is not flowing into the testing area.

7. Connect the hose to the flow meter. Connect additional hose from the flow meter to the hydrant diffuser to better simulate runoff flow and restrain the firehose.
8. Position the hydrant diffuser in the street gutter upstream of the rain garden inlet. The diffuser must be positioned at least 30 feet upstream of the inlet, so uniform flow conditions can be achieved for the duration of the simulated runoff test. A distance of 50 feet or more is recommended. Remove debris from the gutter of the street between the location where the diffuser is positioned and the site inlet to avoid flow irregularities.
9. Drop the submersible pressure transducers into their respective piezometers and/or shallow wells. Ensure that the water level logger is secured to a dry, shaded, and secure location. Care should be taken to minimize the risk of vandalism or damage to the water level logger.

Inlet Conveyance Testing (if applicable)

10. To test the inlet efficiency of a specific inlet, the hydrant flow rate must be set to the minimum inlet capacity as identified in the specifications. If a minimum inlet capacity is not specified, use the Inlet Capacity rate calculated in Section 4.3 of the Design Manual. The rate to be tested must be justified in the Field Acceptance Monitoring Plan. Ensure that the flow meter volume is set to zero at the beginning of the testing period**.** Record the time at which flow starts, and record the time, instantaneous flow rate and total volume every 5 minutes and every time the flow rate is changed. Starting from a low flow rate near zero, carefully increase the hydrant flow rate until the flow meter displays the minimum inlet capacity flow rate identified for that inlet in the Contractor’s Field Acceptance Monitoring Plan. The hydrant flow must be allowed to stabilize to reach uniform and steady flow conditions. This may vary depending on the hydrant used, however, it is preferred for the flow to only fluctuate +/- 5% from the target flow rate.
11. Once the flow is stabilized, a visual determination is made of whether bypass occurs at that flow rate. Inlet bypass is defined as flow passing the inlet along the curb line. If outflow or overtopping occurs, make note of the time, flow rate, and total volume at which it started.
12. If bypass occurs at that flow rate, the Contractor must determine the root cause of the non-compliance and provide a remedy. It may be beneficial to the project team to determine the bypass threshold rate during the hydrant test.
    a. Determine the bypass threshold flow rate for the site by lowering the hydrant flow rate until bypass stops and all simulated runoff flow enters the inlet. When observing the flow condition at the inlet, allow each flow rate to reach a uniform, steady state condition, and run for at least three minutes beyond stabilizing before deciding regarding inlet bypass and moving to the next flow rate.
    b. Initially, flow rates may be decreased incrementally by as much as 5 cubic feet per minute (CFM). Once no bypass conditions have been reached, increase the flow rate such that inlet bypass can be approximated to a resolution of at least 0.5 CFM. That is, by increasing or decreasing the flow rate by roughly 0.5 CFM, or less, the flow will or will not generate inlet bypass. For each flow rate tested, record the determination of inlet bypass or no bypass. Determine the flow rate corresponding to the initiation of bypass or “bypass threshold.” Take photographs and video of the inlet bypass occurring at the inlet for the inlet capacity and bypass threshold flow rate while bypass is occurring.

13. If bypass does not occur at the inlet capacity flow rate, take photographs and video and proceed to water balance testing. Do not reset the total volume reading on the flow meter.

Water Balance

14. Set the hydrant flow rate to the design storm flowrate as specified in the Field Acceptance Testing Plan. If that flow rate causes bypass, place sandbags to prevent bypass and ensure that all water enters the practice. Sandbags must also be used to prevent flow out of the practice through the outlets.
15. The flowrate should be sustained until the high precision flow meter indicates that the total volume of the design storm has been applied to the practice. If the elapsed time required exceeds a reasonable testing period, a higher flow rate may be recommended in the Contractor's Field Acceptance Monitoring Plan and approved by the City of Lancaster.
16. Record the time, instantaneous flow rate and total volume every 5 minutes and every time the flow rate is changed. Every 10 minutes, manually measure and record the water level in the piezometers using a water level meter or tape measure to corroborate the pressure transducer readings.
17. If overtopping of the practice occurs, the time and total volume at the time of overtopping must be recorded and the flow rate must be lowered until overtopping stops.
18. Once the design volume has been reached, turn off the hydrant. The pressure transducers measuring the water level must be left inside the piezometers for the duration of the drawdown period as defined by the Design Manual. Afterwards, the data from the water level logger is downloaded and analyzed to determine the surface infiltration rate and the subsurface infiltration rate into the surrounding native soil.

Demobilization

19. Ensure conditions on site are safe prior to departure.
20. Leave sandbags blocking the inlet(s) and outlet(s) to ensure that water not accounted for enters the GI practice during the drawdown period.
21. Protect water level loggers from vandalism, sun, and water during drawdown period.
22. Return after the end of the drawdown period to retrieve the pressure transducers and water level loggers, and the sandbags. Cap the piezometer wells.
23. All documentation and photographs generated during experiment should be managed according to the procedures established in Section 6 of the Monitoring Plan.

Sample Data Collection Sheet

Includes Example Data Entry

Date: ______________________ Time: ______________________

Site: ______________________ BMP Type: ______________________

Location: ____

Weather: ____

Field Personnel: ____

Site Diagram

Include design drawing to mark the following items:

- Inlet(s) and outlet(s)
- Underdrain
- Piezometers
- Pressure transducer locations with logger serial or ID number
- Location of diffuser
- Location of fire hydrant selected for the test
- North arrow and surrounding street(s)

Hydrant and Flow Meter Operation

Inlet Capacity Flow Rate: 6 CFM

Design Flow Rate: 0.85 CFM

Design Volume: 200 CF

	Time	Flow Rate	Total Volume	Bypass?	Outflow?	Overtopping?	Notes
Units		CFM	CF				
	9:00 AM	1.027	0.864	No	No	No	
	9:05	6.002	10.239	No	No	No	
	9:10	5.994	30.232	No	No	No	

Bypass Threshold Flow Rate: 7.53 CFM

Final Total Volume: 210.88 CF

Pressure Transducer Operation

Pressure Transducer ID	Piezometer or Well	Location	Depth from soil surface to bottom of pressure transducer	Notes
1	Surface Well	Lowest point of depression, in the center of the site	1.0 ft	Measures surface drawdown
2	Piezometer	Bottom of stone layer	5.0 ft	Measures exfiltration out of the GI system
3	Piezometer	Underdrain	4.7 ft	Measures flow out of the underdrain

	Time	Piezometer 1 Water Level	Piezometer 2 Water Level	Piezometer 3 Water Level	Notes
Units		inches	inches	inches	
	9:00 AM	0	0	0	
	9:05	0.25	0	0	
	9:10	1	0	0	

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