Green Stormwater Infrastructure and Source Control Monitoring Guide

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Acronyms and Abbreviations

ALCOSAN	Allegheny County Sanitary Authority
AV	Area-velocity
DCIA	Directly connected impervious area
DSIR	Direct stream inflow removal
FPS	Feet per second
GROW	Green Revitalization of Our Waterways
GSI	Green stormwater infrastructure
GWI	Groundwater infiltration
H&H	Hydrologic and hydraulic
I&I	Inflow/infiltration controls
PWD	Philadelphia Water Department
PWSA	Pittsburgh Water and Sewer Authority
RDII	Rainfall-dependent inflow/infiltration
3RWW	3 Rivers Wet Weather
SO	System Optimization
SRT	Simulated runoff test
SSOAP	Sanitary sewer overflow analysis and planning
SSP	Sewer Separation Project
USGS	US Geological Survey

SECTION 1

Introduction

This document provides guidance to facilitate successful performance monitoring of source control projects implemented to reduce inflow into the regional collection system within the ALCOSAN service area. It is intended to be used by ALCOSAN, municipalities, and municipal sewer authorities in planning for, developing, and implementing monitoring plans for projects funded under ALCOSAN's Green Revitalization of Our Waterways (GROW) grant program. It is not intended to provide detailed monitoring protocols, required equipment lists, or monitoring training. There is a wealth of information available that provides more detailed guidance to supplement this document and a list of resources is provided in Section 2.

How to Use this Manual

Section 1 provides an introduction to the guide and information on GROW program monitoring requirements, as well as an overview of monitoring types. **Section 2** discusses source control monitoring planning and procedures. It includes general recommendations for site analysis, data collection and management, quantifying results, and documentation.

1.1 Purpose and GROW Requirements

This guide includes information on general methods and procedures to conduct pre- and post-construction hydrologic and hydraulic performance monitoring for GROW funded projects to demonstrate project performance and effectiveness. This manual covers monitoring for green stormwater infrastructure (GSI), Inflow/Infiltration controls (I&I), direct stream inflow removal (DSIR), and sewer separation projects (SSP).

System optimization projects are not specifically covered in this guide, as they will require project-specific monitoring plans developed by an experienced professional (although some of the techniques covered such as in-sewer flow monitoring may be applicable to many system optimization projects).

1.1.1 Monitoring Goals

As detailed in the ALCOSAN GROW Program Guidelines, pre- and post-construction monitoring is generally required to quantify the flow reduction achieved and to assess the overflow reduction benefit provided by GROW funded projects. The primary goal of monitoring GROW funded source controls is to assess the effectiveness of the constructed project and to demonstrate that source control projects are meeting performance standards and flow reduction goals. Monitoring is also beneficial in confirming initial modeling estimates, evaluating project performance following construction, and can be helpful to assessing the causes of observed system problems or deficiencies.

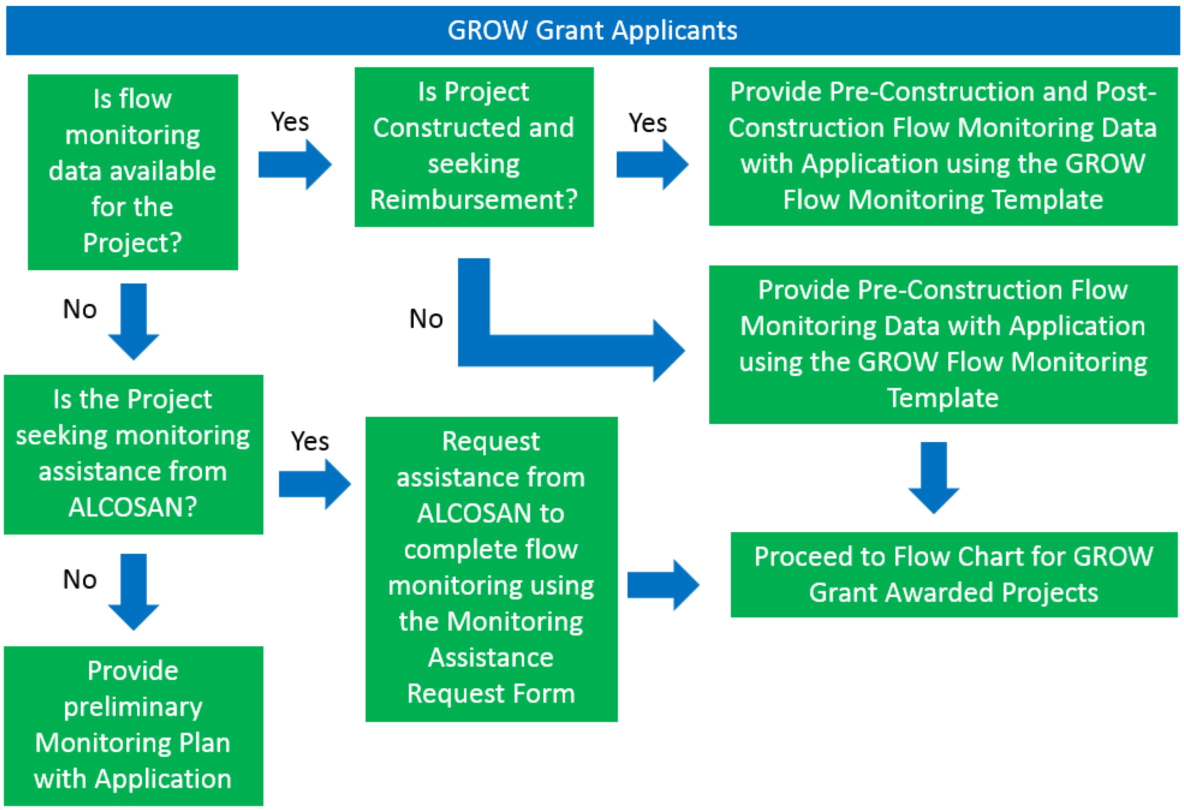
1.1.2 Overview of Monitoring Process for GROW Funding

GROW funded projects are required to provide flow monitoring data at the time of application (if available) or after construction is complete. During the application stage, program applicants are required to provide all available pre-construction flow monitoring. GROW funded projects that do not submit flow monitoring data at the time of application are required to complete pre- and post-construction flow monitoring to evaluate system performance. Following construction, all flow monitoring data is to be provided to ALCOSAN in a Final Monitoring Report that includes an assessment of sewer flow reductions. Synthetic design storms derived from flow monitored data are not permitted as a surrogate for flow data and/or summaries of flow monitoring data; evaluation of performance should be made on the observed data without conversion to a design storm. Further information on Final Monitoring Report requirements are provided in Section 1.1.3.

Flow monitoring is required for all GROW projects, including the following types:

- Green Stormwater Infrastructure (GSI)
- Inflow/Infiltration Control (I&I)
- Direct Stream Inflow Removal (DSIR)
- Sewer Separation Projects (SSP)

The following flow charts provide an overview of flow monitoring requirements for the GROW funded source control projects listed above.



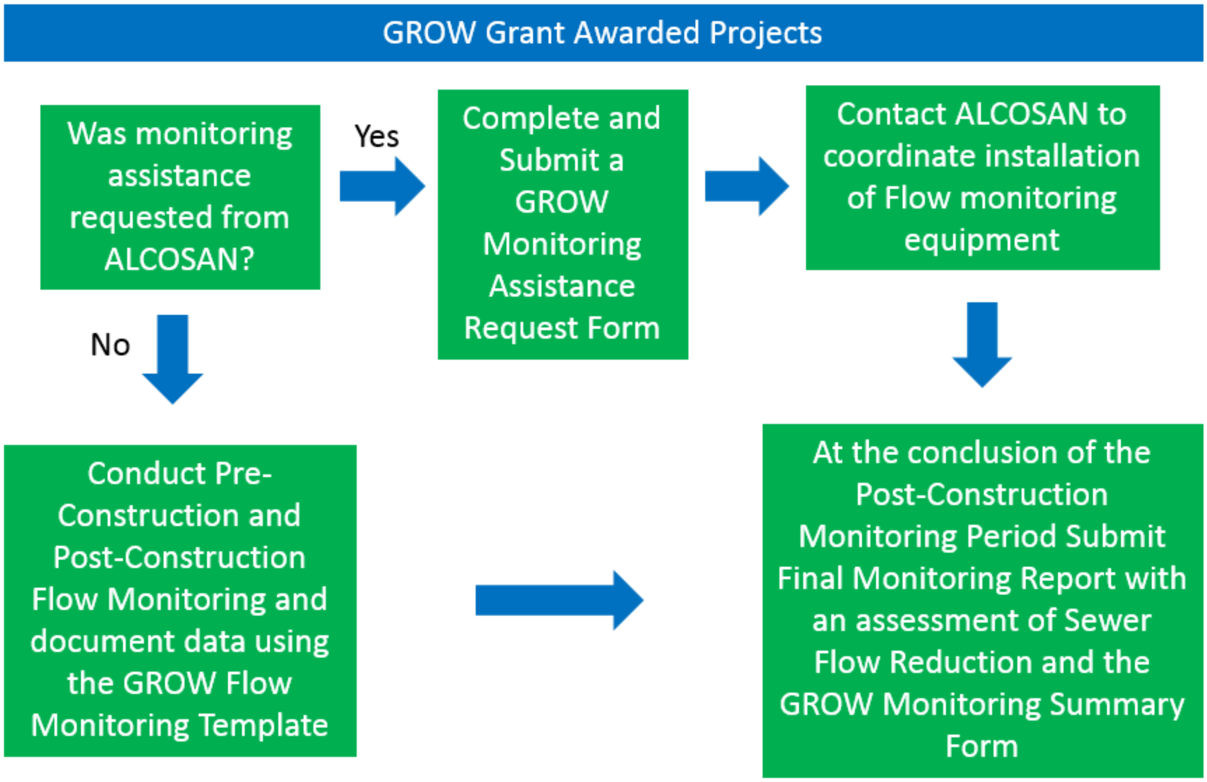


Figure 1-1. Monitoring Process Flowcharts for Pre- and Post-Construction Monitoring

Flow monitoring data should be provided as QA/QC'd flow data in the format indicated in the GROW Flow Monitoring Template. Data collection should be performed for the following minimum time periods.

Flow Monitoring Type	Required Monitoring Duration	Recommended Monitoring Duration
Pre-construction	3 months	6 months
Post-construction	6 months	12 months

GROW program applicants may request assistance from ALCOSAN to complete pre- and post-construction flow monitoring, and ALCOSAN will perform monitoring if resources allow. Requests should be submitted with the GROW application using the Monitoring Assistance Request Form provided in Appendix A. Requests should include a project description, a map of the desired meter location, and the anticipated construction start date. Applicants should complete a field visit prior to submitting the request to verify the manhole or other monitoring location is correct, accessible, and able to be opened.

Applicants should also complete a Monitoring Summary Form, provided in Appendix B, that is specific to their GROW project type. The information needed to complete the Monitoring Summary Forms is covered throughout Section 2.

1.1.3 Pre- and Post-Construction Flow Monitoring Requirements

Pre-construction flow monitoring should be performed for all projects to establish a baseline to compare with post-construction flow data. Baseline pre-construction monitoring ideally should be performed prior to submitting a GROW application, however, GROW applicants may also include a description of proposed pre-construction monitoring including the proposed monitoring schedule in a Preliminary Monitoring Plan submitted with the application.

Post-construction monitoring is a requirement for all GROW funded projects and is to be described along with pre-construction flow monitoring data in a Final Monitoring Plan as described below. For projects that are seeking consideration to use rainfall-dependent inflow/infiltration (RDII) or groundwater infiltration (GWI) reduction percentages that are higher than ALCOSAN's modeled/default values, both pre- and post-construction flow monitoring data that demonstrates the alternate percentage values must be submitted.

Source Control Monitoring Plan Requirements

A key step at the outset is to develop a monitoring plan for the pre- and post-construction periods. At least three months of pre-construction and six months of post-construction monitoring are required, however longer durations (six and twelve months, respectively) are recommended.

The Preliminary Source Control Monitoring Plan should include a brief description of the following:

- Background information
  - Site information and study area description and mapping
  - Project deliverables: Reporting requirements
  - Project schedule: Determine the timeline and include important dates, such as when construction and monitoring will start
- Monitoring purpose and objectives: specific targets for water quantity
- Monitoring approach (see Table 2-1) including requests for ALCOSAN assistance with pre- and post-construction monitoring
- Monitoring location and infrastructure to be included

The Final Source Control Monitoring Plan should include detailed information on the following:

- Background information
  - Site information and study area description and mapping
  - Project deliverables: Reporting requirements
  - Project schedule: Determine the timeline and include important dates, such as when construction and monitoring will start
- Monitoring purpose and objectives: specific targets for water quantity
- Monitoring approach (see Table 2-1)
- Monitoring location and infrastructure to be included
- Schedule of site visits and data extraction
- Data management, communication strategies and reporting
- Approach to data analysis and quantifying flow reduction
- Budget/cost

1.2 Types of Monitoring Overview

1.2.1 Hydrologic Performance Monitoring for GSI

This document offers guidance for monitoring the hydrologic performance of GSI practices that are currently eligible for GROW funding. The types of GSI practices addressed in this Guide are listed in Table 1-1. Since green roofs are typically not eligible for GROW funding and may require specialized monitoring techniques, they are not explicitly included in this guide (although some of the techniques covered such as in-sewer flow monitoring may be applicable to some green roofs).

Table 1-1. Types of GSI Addressed in this Guide

GSI Practice	Examples/Variations
Bioretention/Rain Garden	Bioretention Cell/Basin
	Flow-Through Planter
	Infiltration Planter
	Rain Garden
	Curb Extensions
	Vegetated Infiltration Basin
Infiltration Trenches	Tree Trench
	Vegetated Infiltration Trench
	Surface Flow Infiltration Trench
	Infiltration Trench Under Pavement
Permeable Pavement	Porous Asphalt
	Porous Concrete
	Permeable Paver Units
	Open Grid Pavers

The types of GSI monitoring data that can be collected, and the objectives supported, are listed in Table 1-2. Rainfall data can be obtained from the 3 Rivers Wet Weather (3RWW) calibrated radar rainfall data program or from the network of rain gauges managed by ALCOSAN. Flow can be monitored at inflow and outflow points of the GSI, or in the collection system. Water level data can be obtained from GSI monitoring wells. Infiltration tests can be performed following construction to compare measured infiltration rates to either assumed rates or rates measured before or during construction.

Table 1-2. GSI Monitoring Data and Objectives

Type of Monitoring Data	Data Objective
Rainfall	Estimate runoff volume for the drainage area Estimate flow entering GSI Comparisons to typical year rainfall
Inflow to GSI	Measure flow entering GSI
Outflow from GSI	Measure flow leaving GSI

Table 1-2. GSI Monitoring Data and Objectives

Type of Monitoring Data	Data Objective
	Calculate runoff volume/rate controlled by GSI
Flow in collection system	Use flow measurements to estimate reduction in collection system wet weather flow due to GSI installation
Water level in GSI	Measure water level in GSI throughout a storm event and drain-down period Calculate infiltration rate Calculate slow release rate Measure drain-down duration Calculate storage utilization Calculate overtopping
Infiltration test of GSI	Measure infiltration rate of GSI under controlled conditions

1.2.2 In-Sewer Flow Monitoring

In-sewer flow monitoring at the proper locations in the collection system can provide valuable data on the effectiveness of GROW project types, such as I&I control, direct stream inflow removal, sewer separation, and GSI. GROW participants should inquire about the presence of existing flow meters in their project area, and data availability, prior to deploying meters. Note that a dye test can be done as an additional post-construction measure to confirm the proper installation of SSP and DSIR projects.

Table 1-3. In-Sewer Flow Monitoring Data and Objectives

GROW Project Type	Data	Data Objective
I&I control Direct stream inflow removal Sewer Separation GSI	Flow in collection system	Use flow measurements to estimate reduction in collection system flow due to project installation
		GSI inflow and/or outflow may be measurable at catch basin service line depending on conveyance network configuration

In addition to in-sewer flow monitoring data, rainfall data is needed to:

- Estimate runoff volume for the drainage area
- Provide input to RDII analysis
- Estimate flow entering GSI
- Allow for comparisons to typical year rainfall

Source Control Monitoring Planning

I&I control, direct stream inflow removal, and sewer separation projects must be monitored through in-sewer flow meters. Identifying the right location for placement of flow meters is described in Section 2.1

GSI monitoring can primarily be conducted through measurements of flow or water level, or a combination of both, with flow monitoring occurring in the sewer or in the GSI practice. Below is a figure to help determine which approach is most suitable for your GSI site. In-GSI monitoring is encouraged to gain a more direct understanding of GSI performance.

The content of each box in Figure 2-1 is further described in section 2.1.1 by Steps 1, 2, and 3.

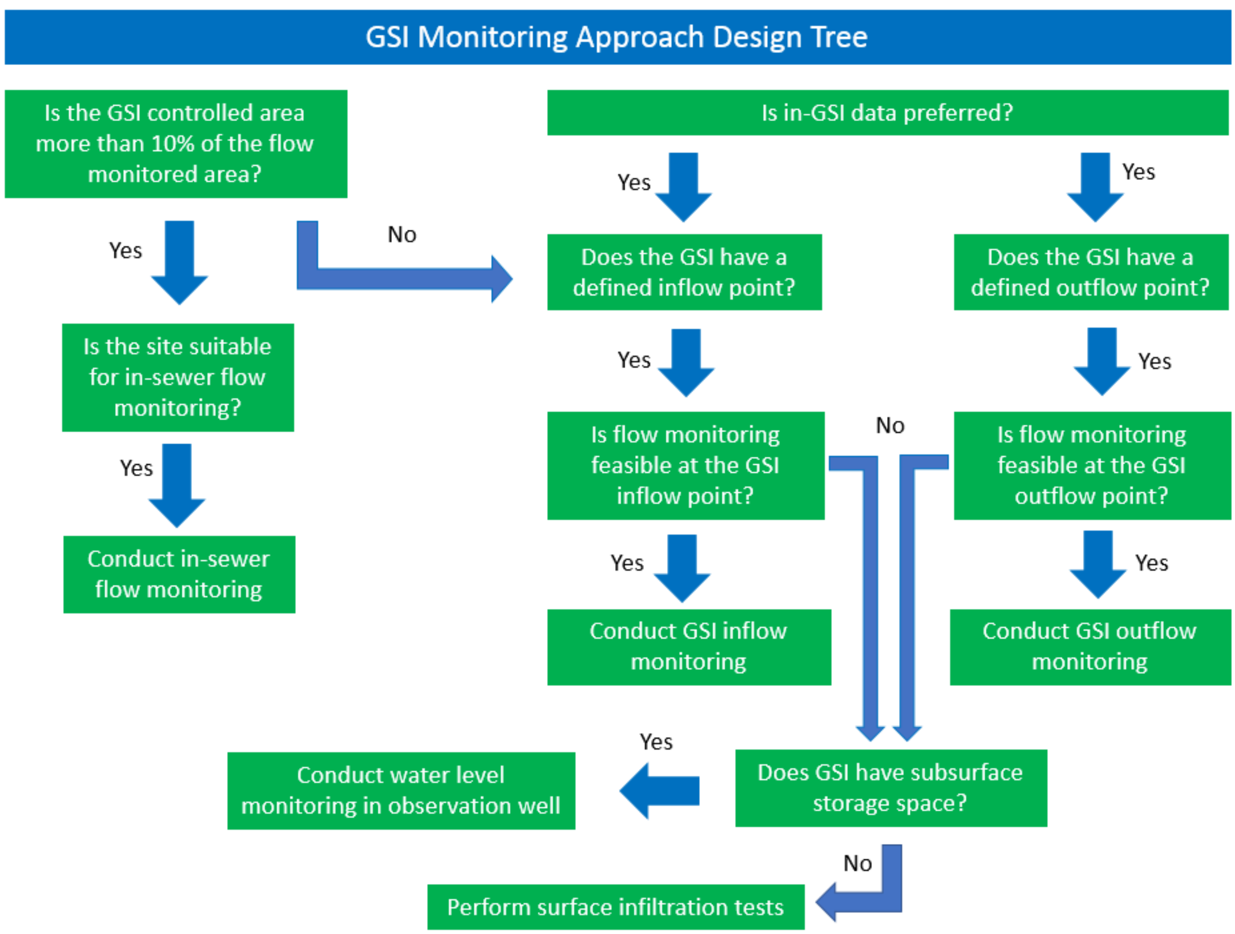


Figure 2-1. GSI Monitoring Approach Decision Tree

A variety of long-term monitoring approaches for GSI are listed in Table 2-1. Note that the spatial and temporal evaluation approaches are also applicable to I&I and DSIR projects. Sewer separation projects should monitor a point in the combined sewer downstream of the separation, before and after construction of the new separate storm sewer.

Table 2-1. GSI Continuous Monitoring Approaches

Evaluation Approach	Benefits	Challenges	Ideal Scenario	ALCOSAN Preferred Approach
Spatial (monitoring a control or reference basin in addition to the project site)	Provides a comparison to a "reference basin" that does not include GSI Comparisons for specific rain events can be made	Reference basins can be difficult to select due to environmental and spatial differences The reference basin should be of comparable drainage area or larger; if the reference basin is too small, it might not capture smaller events that are important in characterizing a variety of storm events	The reference basin exists in very close proximity to the GSI feature being monitored	
Temporal	Provides a comparison between conditions before GSI and conditions at the same location once GSI has been installed	Environmental and climactic conditions change from year to year, using this method requires normalizing of event runoff volume by drainage area and event rainfall to make comparisons. To collect data representative of long-term climactic conditions, at least 6 months of pre-construction, and 12 months of post-construction conditions should be monitored.	Apply a validated hydrologic and Hydraulic (H&H) model of the drainage area to quantify post-construction flow reduction for the typical year	✓
Inflow vs. outflow	Considered the most preferred option for in-GSI monitoring as it provides results without introducing temporal or spatial bias	Difficult to conduct when GSI inflows occur as sheet flow or surface infiltration	Whenever possible, monitor inflow in conjunction with outflow	✓
Continuous water level	Usually the most practical method for in-GSI monitoring when inflow vs. outflow is not feasible	Relies on estimate of inflow based on either an H&H model, or basic approach such as Simple Method or Rational Method	Uncertainty regarding inflow can be mitigated with Simulated Runoff Test	✓

Each GROW GSI practice type can also be monitored using the following rapid assessment protocols to verify performance (Table 2-2).

Table 2-2. GSI Rapid Assessment Monitoring Protocols

GSI Type	Protocol	Objectives Supported
Permeable pavement	Surface infiltration test	Evaluate surface clogging of permeable pavement by evaluating surface infiltration where surface drainage problems are observed or suspected and/or to verify performance following installation
Bioretention	Measure infiltration rate	Verify the infiltration rate of the media/soil in the GSI to determine if the GSI is infiltrating at the designed infiltration rate and if clogging is occurring
Bioretention or Infiltration trench	Simple test of inlet capture efficiency.	Confirm that surface runoff is not excessively bypassing inlet to GSI

Infiltration test methods are further described in Table 2-12.

The simple test of inlet capture efficiency consists of visually observing inlet performance during wet weather or discharging water towards the inlet at low flow, and visually assessing if water enters the inlet. Shown in figure 2-2, this a simple but important way to check if runoff is entering or bypassing the GSI practice.

Figure 2-2. Water bypassing the trench drain inlet due to an improperly constructed concrete apron

2.1 Monitoring Protocols

The intent of this section is to provide basic guidelines for monitoring protocols to meet minimum requirements for GROW funding. Further detailed information in other local and national guidance documents can be accessed through the references in Section 2.1.5.

2.1.1 Site Analysis & Monitoring Equipment

This subsection describes Steps 1 through 5 of the process for conducting pre- and post-construction monitoring.

2.1.1.1 STEP 1: Catchment Area Analysis

For GSI projects, defining the contributing drainage area is important for understanding the size and scope of the project area and the most suitable monitoring equipment. Defining the drainage area typically consists of conducting a desktop GIS / CAD analysis and a field investigation for verification, prior to and after construction.

The information in Table 2-3 should be gathered and documented. A detailed map and site photographs should be part of the documentation, along with observations of any surface drainage anomalies.

Table 2-3. Catchment Area Analysis

Drainage Area Analysis	Information Needed	Tips/Suggestions
Desktop GIS/CAD	• Delineate the drainage area to each proposed GSI inlet • Quantify the impervious and pervious area in each drainage area • Quantify the area and slope of each drainage area	This should be known from the initial design phase
Field Investigation	Verify the desktop GIS/CAD analysis	Perform during rain event Note any topographic barriers that are not detected in the GIS analysis Determine if roof downspouts drain to pervious or impervious area, or directly to sewer

For I&I control projects, define:

- total catchment area
- total amount of public sewer pipe in the catchment
- total amount of sewer pipe that is undergoing rehabilitation.

For direct stream inflow removal projects, define:

- Average annual stream base flow that would be removed by the project
- Total area and total impervious area that contributes wet weather runoff to the DSI location

For sewer separation projects, define:

- total amount of public combined sewer pipe in the catchment
- length of new separate storm sewer pipe installed
- Total drainage area separated
- Impervious area separated

2.1.1.2 STEP 2: Define sewer conveyance network in source control drainage area

If GSI will be monitored with flow meters, it is important to understand the sewer conveyance network in the proposed GSI drainage area, and how it connects to existing stormwater inlets, catch basins, and manholes. This will facilitate the proper selection and placement of flow monitoring equipment.

For I&I control, SSP, and direct stream inflow removal projects, manhole information may be more important to gather than information on catch basins or service pipes.

The information in Table 2-4 should be gathered and documented.

Table 2-4. Sewer Network Information to Gather

Sewer Network	Information Needed	Tips/Suggestions/Criteria
Catch basins (for GSI projects)	Location Dimensions Condition	Open, inspect, measure, photograph each stormwater inlet Clean and remove debris if needed
Service pipe (for GSI projects)	Location Dimensions Material Slope Condition Connection configuration to sewer main	If the service pipe from the catch basin to main sewer connects via a: • direct manhole tap-in, flow monitoring devices can be installed at the either the inlet within the catch basin or the outlet at the location of the manhole tap-in • direct sewer connection, flow monitoring devices must be installed at the inlet within the catch basin
Manholes (for all source control projects)	Location Evidence of surcharging	Surcharging evidence includes water lines or rings on manhole walls or evidence of paper or debris on ladder rungs or the manhole lid. The level of surcharge should be measured if evidence is found.

2.1.1.3 STEP 3: Evaluate site conditions and identify monitoring location(s)

For GSI projects, Table 2-5 provides guidance on whether a GSI site is suitable for in-sewer flow monitoring. Most flow meters have an accuracy of +/- 5% to 10%, so to reliably to measure the effect of GSI on flow reduction, the GSI impervious drainage area should be at least 10% of the total impervious drainage area at the flow monitoring point (25% or more is recommended).

Table 2-5 also describes the sewer hydraulics criteria that are necessary for accurate in-sewer flow monitoring, which apply to all source control types.

Table 2-5. Suitability of In-sewer Flow Monitoring of GSI

Flow Monitoring Location Selection Factors	Considerations/Calculations	Criteria
Relative size of GSI and flow monitored drainage areas	A = Total impervious area managed by GSI B = Total impervious area draining to flow monitoring point	A / B should be > 10% (25% or more recommended)
Hydraulics and connectivity of collection system. *Applies to all GROW source control types.*	• Monitoring in drop manholes should be avoided • Areas of observed or suspected turbulence in the collection system should be avoided, examples include incoming drops from side connections, offset joints, bends in sewer, or other flow turbulence caused by pipe/manhole deficiencies • Areas with observed or suspected heavy sediment or debris should be avoided • Monitoring inlet sewers of manholes is preferable over the outlet sewer of manholes • Monitoring inlets of catch basins can be challenging due to turbulent nature of catch basin hydraulics. Monitoring catch basin	Water level sensor readings should be greater than 1 inch Velocity sensor readings must be 0.5 to 10 feet per second (fps), and ideally between 2 to 5 fps

Table 2-5. Suitability of In-sewer Flow Monitoring of GSI

Flow Monitoring Location Selection Factors	Considerations/Calculations	Criteria
	connections is also challenging due to dry pipe conditions between events, and typically steep slopes. • In challenging flow locations such as combined sewer overflow structures with weirs, leaping weirs and gate structures, redundant depth sensors and/or multiple flow meters may be required	
Proximity to nearest CSO (if quantifying overflow reduction is a program goal)	Identify nearest downstream CSO location A = Calculate total impervious area managed by GSI C = Calculate total impervious area upstream of CSO diversion Activation behavior of CSO diversion: • minimum observed rainfall event to trigger combined sewer overflow activation • typical overflow volume on a storm event basis • number of activations in a typical year	A / C should be > 10% (25% or more recommended) Trigger rainfall should be less than amount of rainfall targeted by GSI design

For all GROW project types, information described in Table 2-6, adapted from Philadelphia Water Department (PWD), can be used for flow monitoring site selection.

Table 2-6. Example Form to Assess Flow Monitoring Site

Category	Factor	Notes
Initial evaluation	Access	Ability to access site
	Safety	Traffic, depth, sewer gas, manhole structural integrity, etc.
	Adequate space to install sensors	
Pipe	Proximity to change in pipe	Must be more than 5 diameters from pipe attribute change, and ideally more than 10
	Pipe shape	Note if the pipe is flat bottom
	Pipe slope	Avoid steep slopes
Flow	Depth measurement	Flow depth must be > 1” and ideally > 4”
	Velocity measurement	Must be between 0.5 to 10 fps, and ideally between 2 to 5 fps
	Depth of silt	Should be none to minimal to avoid sensor clogging, and altering the area profile
	Dry weather turbulence amplitude	Must be <= 3”, and ideally <= 0.25”
	Evidence of surcharging	Avoid if possible

For GSI projects, if in-sewer flow monitoring is not suitable, or if in-GSI data is preferred, Table 2-7 offers guidance on screening of in-GSI monitoring locations.

Table 2-7. Site Selection for In-GSI Monitoring

GSI Site Conditions	Factors	Tips/Suggestions
General location	• Land use • Social impacts • Opportunity to get pre-construction monitoring data, or reference conditions	• Consider implications related to whether the GSI site is located in a residential area, school, public park, or commercial area • Investigate site access requirements to install and maintain any monitoring equipment
Health and safety	• Ease of access • Traffic hazards • Confined space entry	• Select sites with less vehicle traffic • If needed, implement a traffic control plan and obtain a road occupancy permit • Design monitoring to mitigate need for confined space entry (e.g., establish measurement datum to record water level from street level) • If confined space entry is needed, make sure sufficient trained staff and equipment is available to carry out monitoring
Vandalism / security	• Location of monitoring equipment • Potential to attract unwanted attention • Acceptance from local community	• Subsurface installation of monitoring equipment in manhole or well decreases visibility • Above ground equipment should be secured in a concealed, locked enclosure

An in-GSI monitoring layout which incorporates basic elements of Steps 1, 2, and 3 (such as identifying impervious drainage area, and location of GSI site, inlets, and monitoring wells) is shown below.

Figure 2-3. Layout of Observation Wells for in-GSI Monitoring of Three Tree Trenches (PWD)

2.1.1.4 STEP 4: Determine flow monitoring approach and identify appropriate monitoring equipment based on site conditions

Once the monitoring locations have been identified, the monitoring approach and appropriate monitoring equipment can be selected based on site conditions. The three general approaches to measuring flow including the typical equipment required are shown in Table 2-8. The velocity-based approach offers the most versatility, but needs a stable and constant cross section, such as a pipe or concrete channel.

Table 2-8. Approaches to Measuring Flow

Measurement Type	Example	Open Channel	Partially Full Conduit	Full Conduit
Depth	Depth sensor in pipe (flow calculated by Manning's Equation)	x	x	
Depth	Depth sensor with Flumes, Weirs	x	x	
Velocity based	Acoustic Doppler	x	x	x

The primary equipment types used to collect monitoring data are briefly described below. These equipment types and other auxiliary equipment such as scissor rings, sheet flow concentrators, etc. are summarized in Table 2-9.

Weirs

A weir is a designed vertical structure placed across an open channel that allows water to flow through a flow rated notch. The three most common geometries of weir notches are: rectangular, triangular, and trapezoidal. Each type of weir notch opening has a specific discharge equation for determining the flow rate through the weir opening. Compound weirs feature notch combinations to measure flow variations, such as triangular for low flow and rectangular for higher flow. The flow rate is calculated based on the discharge equation and the measured water level (via a pressure transducer or bubbler) behind the weir.

Figure 2-4. Rectangular Weir (PWD)

Figure 2-5. V-notch Weir (PWSA)

The primary advantage to a weir is that it can be used to regulate flow in a channel with irregular geometry. Irregular channels are common occurrences within GSI facilities, and great care must be taken to accurately monitor flow where feasible.

When evaluating a GSI practice for the placement of a weir, determine the expected flow rates and associated water levels for a range of expected rainfall events both upstream and downstream of the weir. If calculations indicate that the water level on the downstream side of the weir is greater than the crest of the weir (i.e., the weir is submerged), a different stage-flow relationship for the weir will apply and flow calculations must be adjusted accordingly under these conditions. Generally, weirs are most effective in locations where there is no influence from downstream submergence.

In addition, calculations such as minimum approach length, maximum velocity, and required slope will be required for installation. Guidelines for these parameters will vary depending on the manufacturer and weir geometry. The guidelines should be strictly followed to promote an adequate flow regime for accurately collecting level and flow data.

Flumes

Like weirs, there are many variants of flume sizes and shapes for conducting open channel flow monitoring in GSI facilities. A weir and flume operate on the same hydraulic principles, where flow through a known geometric area is calculated using the recorded depth (via a pressure transducer or bubbler) and a depth-flow rating equation for the flume. The rating equation differs by the type and size of flume.

A flume is typically chosen over a weir when there is potential for sedimentation impacts behind a weir. A flume does not have a flow restricting weir plate, and therefore is able to better convey sediment through the opening thereby minimizing maintenance and sensor fouling.

The most common types of flumes are the Parshall, Palmer-Bowlus, HS, H, and HL flumes, and the trapezoidal flume. As with weirs, the downstream side of the flume should maintain free flow with no backwater conditions. The installation of a flume will require the same hydraulic calculation checks and requirements as outlined above for weirs.

Figure 2-6. Parshall Flume (www.openchannelflow.com)

Figure 2-7. H-Flume (Villanova University)

Flow Meters

Area-velocity (AV) flow meters are typically used for flow monitoring in sewers. AV flow meters use sensors that monitor and record the mean velocity and depth. To measure mean velocity, the sensor uses continuous Doppler wave technology. Depth can be recorded either by using submerged pressure sensors that detect the height of water over the sensor, or by using unsubmerged ultrasonic wave depth measurements; both sensors are often used simultaneously to provided redundant backup capabilities. Flow is calculated based on the cross-sectional area of the flow stream and the velocity.

It is important to note that accuracy can be lost under dry conditions between runoff events. AV meters are susceptible to error under high velocity flow and lose accuracy in highly turbid water. The pressure sensor can become clogged with high concentrations of sediment and must be cleared as needed to maintain accuracy.

Figure 2-8. Area Velocity Meter Installation Setup in Sewer (RJN Group)

Figure 2-9. Area-Velocity Meter Installation Setup in Sewer (Flow-Tronic)

Level Monitoring Equipment

Level monitoring equipment is often utilized in GSI monitoring wells to determine the depth of water within storage reservoirs. This is useful for understanding the filling and draining cycles within the GSI practice during and between storm events. The data is used for many purposes including monitoring overall performance and changes over time, signaling potential failures or required maintenance, and calculating infiltration rates and drain-down durations.

Level sensors (e.g., pressure transducers and bubblers) are also paired with weirs or flumes installed at the surface or subsurface (e.g., manholes) to determine flow rates. Level sensors are susceptible to error under high velocity flow and therefore not appropriate for steep pipes/channels.

Figure 2-10. Example showing monitor installed at the top of the pipe

When selecting a pressure transducer level sensor, it is important to determine if the pressure transducer is capable of functioning when dry. Some pressure transducers require constant submergence within a liquid for accurate data collection. Pressure transducer level sensors for GSI monitoring should consider transducers that can function under dry (un-submerged) conditions. Another approach is to construct the monitoring well with a known sump depth, where the sensor can be submerged in a reservoir of water. An accurate datum measurement of the bottom of the well in relation to the GSI storage area should be recorded prior to installing the pressure transducer.

A Bubbler (or bubbler tube) is a simple to use level sensor that is not typically affected by wind, turbulence, or air-temperature gradients. Accuracy is not lost under dry conditions between runoff events.

Figure 2-11. Onset HOBO Pressure Transducer (PWD)

Figure 2-12. Pressure transducer installed in monitoring well (PWSA)

Figure 2-13. Bubbler Level Sensor Installed on Flume for Inflow Measurement (Kansas City)

Figure 2-14. Channel and Weir Serving as a Sheet Flow Concentrator (Gwinnett County)

Table 2-9. Monitoring Equipment Types

Type	Pros	Cons	Description	Potential Supplier/ Manufacturer	Estimated Material Cost*
Weir (V-notch, rectangular, compound)	• Accurate • Simple to use • Wide range of flow measurements • Can be manufactured	• High head requirement • Clogging issues • May act as sediment trap • May be expensive to construct	The smaller the angle, the more accurate the measurement Must be paired with a secondary device (e.g., level sensor) for flow monitoring	Isco Tracom Science Direct Thel-Mar	Material for fabrication: $150 - $200 Purchased: $800 - $1,000
Flume (H-flume, 60-degree trapezoidal, Palmer-Bowlus, Parshall)	• Lower head requirement than weirs • Fairly accurate • Lower clogging concerns • Level measurement only	• Expensive • More complex than weirs/ intricate discharge relationships • Difficult to fabricate (usually bought from manufacturer)	Must be paired with a secondary device (e.g., level sensor) for flow monitoring	Isco Tracom Science Direct	Purchased: $1000- $10,000 depending on flume type, size, and installation
Pressure transducer	• Accurate • Low power requirement	• Cable susceptible to damage (rodents). • Sensitive to temperature extremes • May require constant submergence	Must be combined with a primary device (e.g., weir, flume) to measure flow	Isco Hach Science Direct Onset HOBO	$300 - $500
Bubbler	• Suitable for extended dry conditions • Fairly accurate • Tolerates environmental extremes • Rodent "hardy" • Inexpensive to repair if damaged	• High power requirement • May get fouled if submerged for extended periods	Must be combined with a primary device (e.g., weir, flume) to measure flow	Isco Hach	$2,000 - $2,500 Mounting bracket: $150-$200
Area-velocity meter	• Can be used with variable tail water conditions • Can measure both positive and negative flow	• Less reliable performance in low flows • High power requirement • Susceptible to environmental extremes	Must be combined with a secondary device (e.g., depth sensor) to measure flow	Isco Hach	$3,000 - $8,000

Table 2-9. Monitoring Equipment Types

Type	Pros	Cons	Description	Potential Supplier/ Manufacturer	Estimated Material Cost*
		• Susceptible to film forming on sensor face			
Scissor ring	• More stable in large diameter pipes and/or pipes with smooth inner surfaces	• Not suitable for pipes smaller than 16”	Mounting rings are used to secure area-velocity meters and other related equipment to the interior of pipes and culverts	Isco Prefabricated at a typical machine shop	$500 - $1,000
Spring ring	• Can be installed in pipes 15” in diameter and smaller	• Under high flow conditions, may not have sufficient outward force to maintain a tight fit • Not suitable for pipes larger than 15”	Mounting rings are used to secure area-velocity meters and other related equipment to the interior of pipes and culverts	Isco Prefabricated at a typical machine shop	$100 - $250
Sheet flow concentrator	• Allows GSI inlet sampling that would otherwise be difficult due to diffuse flow	• May increase erosive forces. • May short circuit buffer strip or other diffuse flow pretreatment	Often entails a curb or other raised structure to direct all inflow to a single inlet location rather than allowing sheet flow into the GSI	Constructed for the site	$1,000 - $3,000
Trench drain inlet	• Allows GSI inlet sampling that would otherwise be difficult due to diffuse flow • Less clogging of permeable pavement pores if preventing run-on	• Increased cost • May not provide adequate pretreatment	Trench drains provide an inlet for diffuse flow directly into the treatment and storage layers of a GSI structure.	NDS Drainage Direct Aco Drain	$75 - $300 per linear foot depending on traffic rating

*Cost figures are based on 2017 Gwinnett County BMP Monitoring Guide

Alternate Monitoring Methods and Equipment: Simulated runoff test

In-GSI monitoring is often conducted without direct inflow monitoring due to site or resource constraints. Instead, a level sensor in a monitoring well records water level response to storm events, and inflow is estimated based on a rainfall-runoff model or equation. The continuous water level data is used to calculate infiltration rate, drain-down duration, and outflow through an underdrain, as described further in Section 2.1.2.4.

To mitigate the uncertainty of using an estimate for inflow, a 'Simulated Runoff Test' (SRT) can be conducted as needed in GSI systems that do not contain inflow monitoring equipment. During the SRT, a storm of pre-selected intensity and duration is simulated by a metered flow rate from a hydrant or water tank that is discharged directly into the flow path to the GSI inlet. The water level response in the monitoring well is recorded, with the inflow as a known quantity. The SRT can also be used to determine whether bypass or overflows are occurring.

Basic Equipment for Simulated Runoff Test

- Hydrant equipment
  - Pipe Fittings - Hydrant Reducer, Couplings, and Y Connectors
  - Multiple sections of 2 1/2" Diameter x 100' Long Fire Hose
- Portable water meter (e.g., Sensus W-1250)
- Diffuser and associated pipe fittings to be attached to flow meter outflow
- Full details in the PWD SOP

Figure 2-15. Simulated Runoff Test Equipment (PWD)

Figure 2-16. Simulated Runoff Test in Progress (Seattle Public Utilities)

2.1.1.5 STEP 5: Install Monitoring Equipment and Perform Initial Calibration

Monitoring Equipment Placement for GROW Source Control Projects

Table 2-10 lists the types of monitoring equipment and placement for each GROW project type. Note that the first three entries (Bioretention, Infiltration Trench, Permeable Pavement) refer to in-GSI monitoring.

Table 2-10. GROW Project Types and Corresponding Monitoring Equipment

Type	Monitoring Equipment	Placement	Notes
Bioretention	Pressure transducer	Monitoring well – deep and shallow	Deep well pressure transducer can provide **direct** in-GSI measurements of: Infiltration rate, drain-down duration. Deep well pressure transducer can provide **indirect** in-GSI measurements of: outflow. Shallow well pressure transducer can provide **direct** in-GSI measurement of ponding depth and duration. Bypass flow and evapotranspiration can be further estimated as part of the water balance.
	Flow measurement device	Depending on design: in-GSI measurements of inflow/outflow; measurement in catch basin service line impacted by GSI	Depending on site and design conditions, in-GSI flow measurement might be feasible • Inflow: weir/flume at inlet, paired with level sensor; or flow meter in subsurface inlet line • Outflow: weir installed in manhole, paired with level sensor; or AV flow meter in service line to sewer
	Infiltrometer tests	Single to multiple test locations	

Table 2-10. GROW Project Types and Corresponding Monitoring Equipment

Type	Monitoring Equipment	Placement	Notes
Infiltration Trench	Pressure transducer	Monitoring well	Pressure transducer can provide **direct** in-GSI measurements of: Infiltration rate, drain-down duration. Pressure transducer can provide **indirect** in-GSI measurements of: outflow. Bypass flow and evapotranspiration (if vegetated) can be further estimated as part of the water balance.
	Flow measurement device	Depending on design: in-GSI measurements of inflow/outflow; measurement in catch basin service line impacted by GSI	Depending on site and design conditions, in-GSI flow measurement might be feasible • Inflow: weir in subsurface inlet line, paired with a level sensor; or flow meter in subsurface inlet line • Outflow: weir installed in a manhole, paired with level sensor; or AV flow meter in service line to sewer
Permeable Pavement	Pressure transducer (if subsurface storage is part of design)	Monitoring well (if subsurface storage is part of design)	If subsurface storage is part of design, then Pressure transducer can provide **direct** in-GSI measurements of: Infiltration rate, drain-down duration. Pressure transducer can provide **indirect** in-GSI measurements of outflow if an underdrain is present.
	Infiltrometer tests	Multiple locations	Expect great heterogeneity in results across the site, can be used to look at changes in permeability over time and impacts of maintenance activities
	Flow measurement device	Depending on design: in-GSI measurements of outflow; measurement in catch basin service line impacted by GSI	Depending on site and design conditions, in-GSI flow measurement might be feasible • Outflow: weir installed in a manhole, paired with level sensor; or AV flow meter in service line to sewer
I&I control	AV flow meter	Sewer line, downstream of change	Monitor a point in the combined sewer downstream of the separation
Direct stream inflow removal	AV flow meter	Sewer line, downstream of change	Monitor a point in the combined sewer downstream of the separation
Sewer separation	AV flow meter	Sewer line, downstream of change	Monitor a point in the combined sewer downstream of the separation
GSI (in-sewer monitoring)	AV Flow meter	Sewer line, downstream of GSI outlet to sewer	Verify that conditions in Table 2-5 indicate suitability for in-sewer flow monitoring of GSI

GSI Monitoring Wells

Monitoring wells are useful in performance monitoring for bioretention, infiltration trenches, and permeable pavement with subsurface storage. The use of monitoring wells for in-GIS monitoring offers the following benefits:

- Pressure transducers are less expensive than flow meters, and simpler to operate
- Uncertainty regarding inflow can be mitigated with simulated runoff test
- Provides insight on GSI performance at practice or site scale
- No confined space entry required
- Installation & Monitoring Tips:
  - Plan the well during the design phase
  - If there is a sump, then the depth of the sump will need to be accounted for. Sump depth should be based on an As-Built drawing, with the sump depth field confirmed and documented during construction.
  - A second pressure sensor that is left unsubmerged is needed to correct the monitoring well sensor for barometric pressure. One barometric pressure sensor is sufficient to correct all monitoring well sensors within a one-mile radius.
    - Alternatively, vented pressure sensors can reference atmospheric pressure, which eliminates the need to install a second unsubmerged pressure sensor.

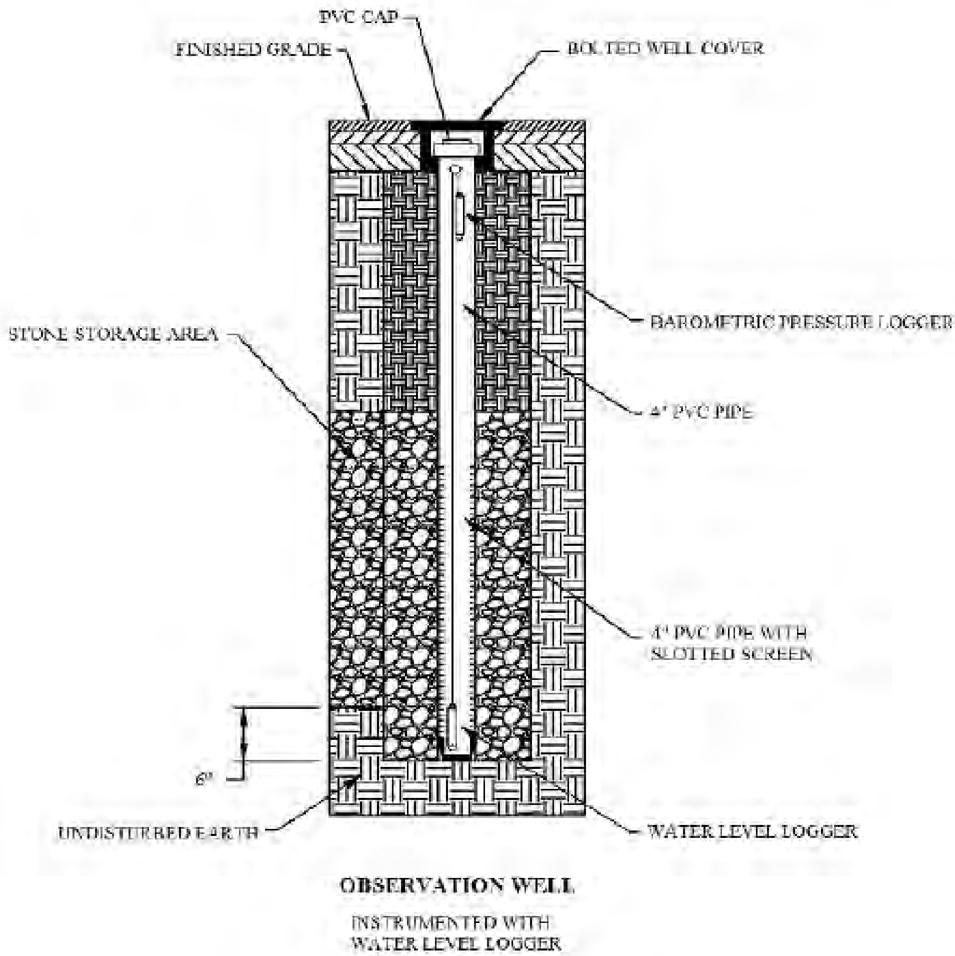


Figure 2-17. Example Monitoring Well Schematic (PWD).
Includes Water Level and Barometric Pressure Sensors. Note the sump depth is 6".

The use of both deep and shallow monitoring wells in bioretention systems allows separate measurements of infiltration and ponding:

- Deeper wells are perforated throughout and installed to the bottom of the bioretention cells. Data is used to quantify the infiltration of water through the bioretention practice and the overall drain-down time of the system.
- Shallow wells are perforated above the surface, but solid below the surface. These wells measure the depth of surface water ponding as well as the duration of ponding.

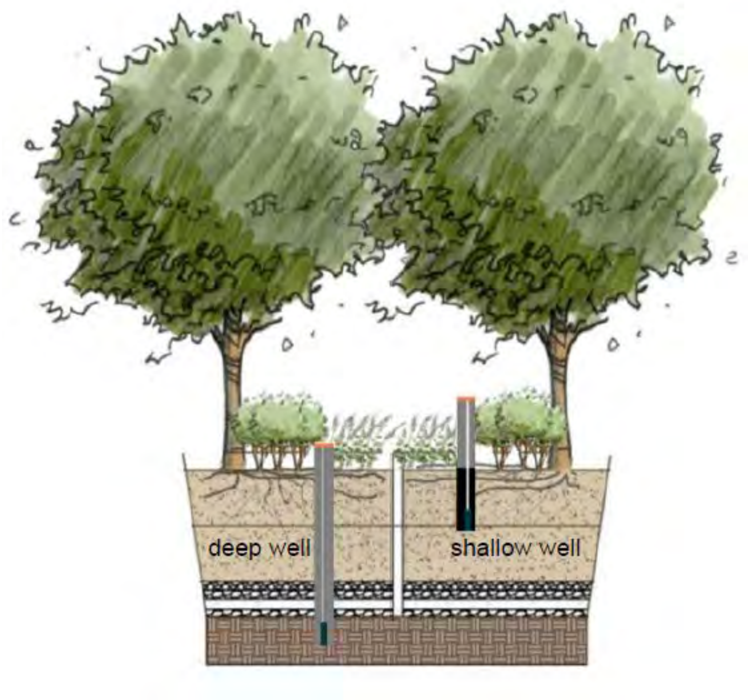


Figure 2-18. Use of a Deep Well and Shallow Well at a Bioretention Site (CVC)

Monitoring Equipment Placement Examples for GSI and In-sewer Monitoring

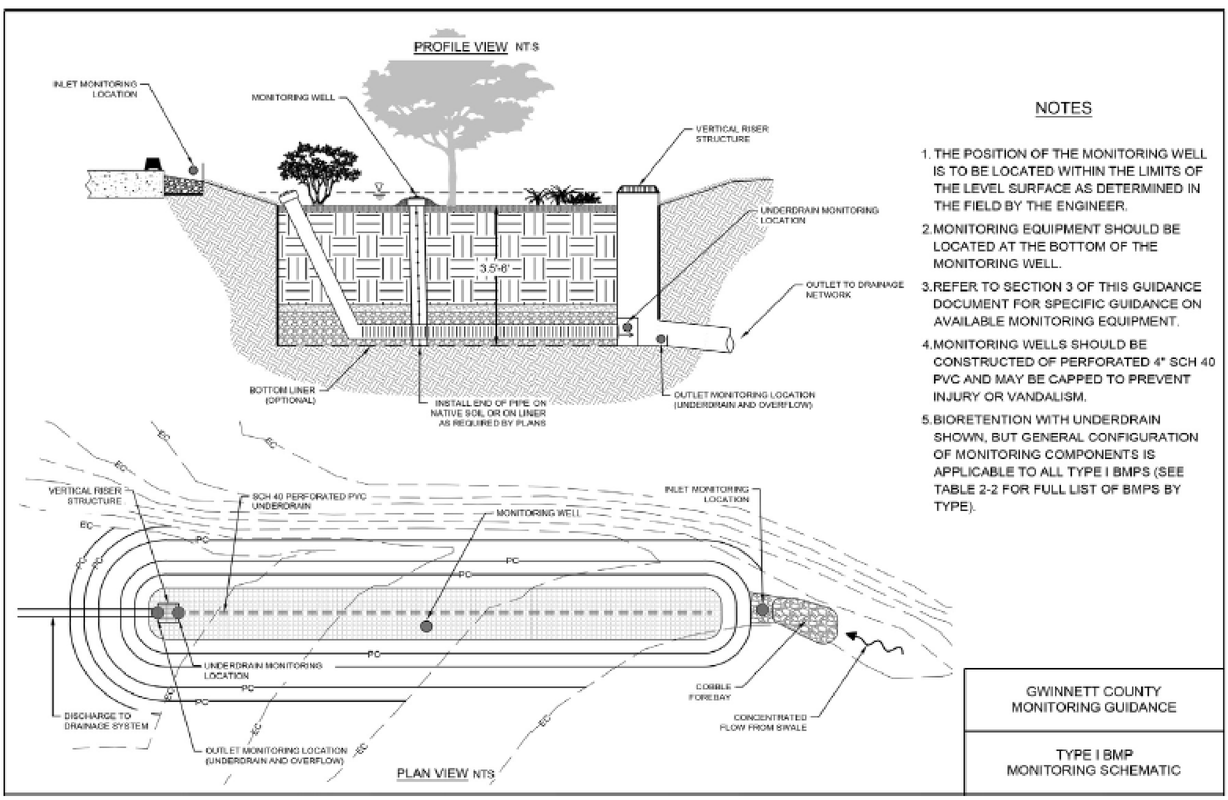


Figure 2-19. Example Schematic of a Bioretention Site (Gwinnett County)
In-GSI Monitoring Locations at the Inlet, Outlet, and Well

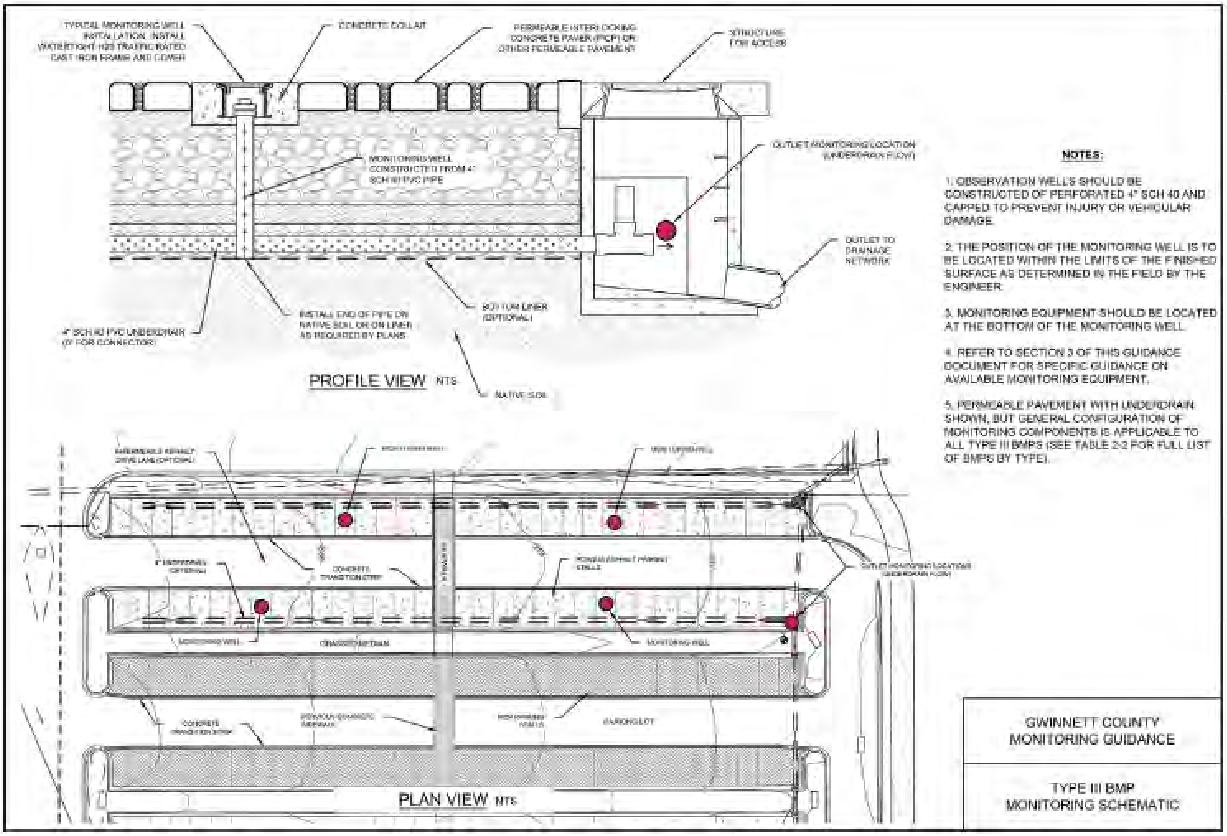


Figure 2-20. Example Schematic of a Permeable Pavement Site (Gwinnett County)
In-GSI Monitoring Locations at the Outlet and Multiple Wells

Figure 2-21. Weir Installed in Manhole for in-GSI Monitoring of Outflow. (CVC)
Level sensor is mounted on upstream side of weir.

Figure 2-22. In-sewer Monitoring with Area-Velocity Flow Meter (ALCOSAN)

Monitoring Equipment Installation

An important step of the installation procedure is to complete a thorough inspection ahead of time for each monitoring location. Collecting pipe and chamber dimensions, and photographing all areas of interest are helpful in planning for the installation and can reduce the amount of time needed for each site installation.

General Guidance

- All data loggers on the proposed site should be configured using an identical time clock and day light savings time setting. Ensure that no data are lost by checking the manufacturer's manual to determine the maximum period of record before new data overwrites previous data in the memory module.
- Prior to installation, test the functionality of monitoring equipment either in-house or in the field.
- Install equipment securely. Choose a location where little or no debris will interfere with readings or damage any sensors.
- Secure all excess cables and or tubing using wire clamps or zip-ties to fixed parts of the monitoring chamber or location. Make sure cables do not interfere with flow but still allow maintenance and data retrieval.
- For GSI projects that measure outflow, low flows typically make up the greater proportion of all volume leaving the GSI practice. Low flow measurement confidence is essential to the success of subsequent data analysis and interpretation. At the start of a study, establish a good depth/level measurement reference point that is accessible from the surface. Use this point of reference as a base for all equipment installation measurements, along with all probe calibration settings.
- Calibration can include, but is not limited to:
  - Measurement brackets or fixed points to act as datum reference points
  - Measurement pipes and piezometers for calibrating in manholes

Weirs

- Ensure weirs are sized properly to accommodate the drainage area and that all seams are sealed with cement or adhesive. Make sure a variety of measurements are conducted including weir height, weir notch height, and volume behind the weir.
- Calculations such as minimum approach length, maximum velocity, and required slope will be required for installation. Guidelines for these parameters will vary depending on the manufacturer and weir geometry. The guidelines should be strictly followed to promote an adequate flow regime for accurately collecting level and flow data.
- If the weir is installed in a manhole, establish a measurement datum to accurately measure water level at each visit. This allows staff to measure the water level in relation to the weir notch based on a standard measurement point. This reduces the chance of human error in measurement and does not require confined space entry.

Flumes

- Calculations such as minimum approach length, maximum velocity, and required slope will be necessary upon selection of the flume and proposed location. The manufacturer's installation guidelines for these parameters will vary depending on the manufacturer, flume size, and flume type. The installation guidelines should be strictly followed to promote a laminar flow regime for accurately collecting level and flow data calculations.

Level Sensors

- Program the equipment to record depth at a set 5-minute interval.
- Prior to installation, calibrate the sensor according to manufacturer instructions.
- Pressure transducers are often installed in perforated PVC monitoring wells that allows for the water to enter and surround the sensor. When installing the monitoring well it is important to understand the bottom of the well in relation to the GSI facility design, and the sump depth if applicable. An accurate datum measurement of the bottom of the well in relation to the GSI storage area should be recorded prior to installing the pressure transducer.
- When using pressure transducers to measure water level, a barometric pressure logger should be installed near to any observation wells to compensate for barometric pressure.

Bubblers

- Program the equipment to record depth at a set 5-minute interval.
- At the flume or weir box, affix the bubbler line so that is not moved out of position either by accident or by debris in the flow stream.
- Record the distance between the bottom of the weir/flume and the bottom of the bubbler tube to use as a reference datum.
- Calibrate the bubbler according to manufacturer instructions.

Flow Meters

- Follow the equipment manufacturer's specifications governing installation and set-up.
- Place the sensor according to the hydraulic characteristics of each site to obtain a repeatable field confirmation of depth and velocity. Redundant depth measurement is preferred where site conditions and equipment requirements permit.
- Install equipment on the influent line of the monitoring manhole where feasible.

- Program the equipment to record depth, velocity, and flow at a set 5-minute interval.
- Prepare a detailed field sketch and/or schematic drawing of the monitoring manhole and equipment installation configuration.
- Document site set-up information such as measured sensor offsets, measured depths, measured velocities and flows, and equipment calibration data on field sheets.
- During the initial 'settling-in' period, check the monitor installation for debris accumulation and/or other conditions that could impact data quality. Report any installation problems and attempt to resolve in the field.
- Perform initial field calibration of the flow monitoring devices as applicable to the monitor type and in accordance with the manufacturer's instructions.
- Compare field depth and velocity measurements with real-time monitor readings to determine if the monitor is recording data representative of field measurements.
- Document the initial calibration data, subsequent calibration verification, and any necessary adjustments on field sheets.

Winter Monitoring Considerations

- Location
  - If your equipment is located within a manhole, snow cover can make it difficult to find and gain access to the equipment.
  - Sloped edges that are slippery and icy can make it hazardous to open the manhole.
- Monitoring equipment
  - If you are using a probe with a pressure transducer, water should continue to flow over the probe for it to function properly. Check that the depth is far enough underground that the water does not freeze
  - Most loggers should not be exposed to temperatures below -20 degrees Celsius (-4 F) or the temperature recommended by the manufacturer.

2.1.2 Data Collection, Management, and Analysis

2.1.2.1 STEP 6: Data collection

Depending on the type of data logging equipment, data retrieval can be done manually or with wireless telemetry. Requirements for each are shown in Table 2-11.

Table 2-11. Data Retrieval Method and Requirements

Data retrieval	Requirements
Manual download from data logger	Durable laptop or tablet
Wireless telemetry	Pre-configured database Optional data quality screening against pre-set criteria

For data loggers that require manual download:

- Data should be downloaded in the field once every two to four weeks.
- Record all tasks and observations made onsite in a field notebook.

- Check the amount of memory available on the logger.
- Check the battery status on the logger. Change batteries in the logger if necessary. If the battery cannot be changed in the field, install a new logger and bring the old one back to be serviced.
- Check that data has been saved to the computer or other device used to download the logger prior to leaving the site or clearing the logger's memory.
- Review data (if possible) by viewing graphs of downloaded data in the applicable equipment program.
- For level sensors, other tasks to complete during a data download visit:
  - Take a manual water level reading just before removing the water level sensor.
  - Check calibration of level probes and calibrate probe if necessary.
  - If equipment requires desiccant, check if the desiccant needs to be recharged.
  - Take a manual water level reading just after installing the water level sensor.

Flow meter calibration should be checked in conjunction with each field visit for data downloading:

- Schedule field measurement of flow points at different times of the day and under both wet and dry weather conditions to provide a representative range of depths and flows.
- Obtain and record field-measured flow points and verify that the monitoring equipment is properly calibrated and providing reliable results.
- Measure wastewater depths from the crown of the pipe using a ruler.
- Check the calibration of pressure transducers and sonic depth sensors by measuring the actual flow depth and comparing it to monitored depths.
  - Adjust the calibration of the sensors if the observed calibration error exceeds the manufacturer's tolerance specifications.
- Measure average velocities through the pipe using a portable meter.
  - Glass weirs may also be used for low flow conditions. These make it easier to identify and measure the depths of low flows.

For "Rapid Assessment" of GSI (Table 2-2), the following infiltration testing methods can be used for permeable pavement and bioretention practices.

For permeable pavement, multiple test locations are needed to capture the expected variance across the site. In bioretention practices, a double ring infiltrometer minimizes lateral infiltration from the measurement.

Table 2-12. Infiltration Testing Methods

Method	GSI Type	Description
ASTM C1781/C1781-M15	Permeable pavement	Covers permeable pavement systems surfaced with solid interlocking concrete paving units, concrete grid paving units, or clay paving brick. Surface infiltration test with single infiltration ring. Three test locations for areas up to 25,000 ft^2. Add one test location for each additional 10,000 ft^2 or fraction thereof.
ASTM C1701/C1701-M17a	Permeable pavement	Similar method to above; applies to pervious concrete

Table 2-12. Infiltration Testing Methods

Method	GSI Type	Description
ASTM D3385	Bioretention	Double ring infiltrometer test for soils. Test may be conducted at ground surface or at discrete depths in test pits above the groundwater table.

Figure 2-23. GSI Infiltrometer Testing. (PWD)
Single Ring Infiltrometer Test on Permeable Pavement;
Double Ring Infiltrometer Test on Bioretention Soils

Rainfall data

- Projects should evaluate the availability of local rain gauges managed by ALCOSAN and utilize those data if applicable. Calibrated radar rainfall data is also available from 3RWW (http://www.3riverswetweather.org/municipalities/calibrated-radar-rainfall-data).

2.1.2.2 Equipment Maintenance

Flow Meters

Check the battery charge, desiccants and vent tubes. Inspect sensors to check for the presence of debris and solids that may have hung-up on the sensors and/or oily substances that may have deposited. Where possible, remove debris, grit, gravel, and/or sediment buildup from the sensor head(s) during each site visit. Check equipment to verify that it has been functioning properly, that any problems and malfunctioning equipment are identified, and required corrections and equipment substitutions are made as soon as possible.

Weirs

Maintenance of weirs of consists of cleaning the approach channel due to the settling of sediment particles above the weir, particularly during low flow conditions. Sediments and debris that accumulate behind a weir can alter the hydraulic conditions, changing the empirical relationship between flow depth and discharge rate. Weirs should be inspected regularly to remove accumulated sediment or debris. If high amounts of sediment or debris occur in the flow, then use of a flume may be more appropriate as flumes generally avoid sedimentation problems.

It is also important to check for signs of leakage, bypass flow, and scouring around the sides of the weir/flume structure. For accurate measurements all upstream flow should pass through the weir/flume structure. If signs of bypass flows are present, it should be corrected immediately.

Level Sensors

When using a pressure transducer to measure water level behind a subsurface weir (e.g., weir installed in manhole), a piezometer pipe and water level meter allows staff to perform calibration and obtain accurate measurements of the level of water in relation to the weir notch without confined space entry. The team can conduct all measurements in this way from the surface.

Further notes on equipment maintenance are listed in Table 2-13.

Table 2-13. Equipment Maintenance

Equipment Type	Notes
General equipment	• Follow manufacturer guidelines for maintenance and re-calibration of monitoring equipment • Synchronize the date and time on computers, level loggers, meteorological equipment, and all other monitoring equipment to improve accuracy and ease of analysis • Check battery life on each field visit • Maintain ideal operating power on all equipment by changing batteries regularly • Replace or recharge desiccant packs if applicable • Maintenance records for all equipment should be kept in a standardized form and uploaded to a central database or shared site • If troubleshooting, do not do anything that may delete data if the logger has not been downloaded

Table 2-13. Equipment Maintenance

Equipment Type	Notes
Level sensor	General: • Once or twice per month compare manually measured depth to sensor output and calibrate if necessary Pressure transducers: • Remove and test level probes if significant level fluctuations are observed this may be a sign of a probe fouled by sediment or debris • Clean the housing unit and replace the desiccant if fouled Bubblers: • Periodic purging with compressed air is recommended to prevent sediment and organic material from plugging bubbler tubes • May be susceptible to breaking in below freezing temperatures
Flow meter	• Check and clear of debris bi-weekly • Check for depth accuracy monthly • Check after very large storm events
Weir	• Clean the approach channel by removing sediment and debris above the weir • Check for leaks if water depth rapidly decreases, especially during dry periods • Check for signs of bypass flow and scouring around the sides of the weir structure
Flume	• Remove any sediment or debris, although less likely to accumulate than with weirs • Check for signs of bypass flow and scouring around the sides of the flume

2.1.2.3 Data management guidelines

For all GROW project types, a comprehensive monitoring program will collect information on watershed/drainage area, and existing and proposed sewer network features (pipes, inlets, and manholes). In addition, direct stream inflow removal, sewer separation, and GSI projects should document the percent imperviousness of the drainage area.

For GSI projects, GSI design characteristics are important. GSI variables such as storage volume, inlet and outlet design, vegetation, and bottom lining or soil infiltration characteristics should be documented. Additional watershed characteristics such as land use and slope should also be documented.

General guidelines for data management for data collected using monitoring equipment

An effective data management system is needed to handle the large quantities of data that will be collected. The data management system should be as simple and straightforward to use as possible, promote data reporting and plotting standardization, and provide ready access to the data for the people who will be involved in collecting, reviewing, and analyzing the data. Excel spreadsheets, Access databases, and/or automated program scripts in Python or R are typical platforms used for data management. Recommendations for data management include the following:

- Use tracking sheets to record when the dataset was last analyzed or updated and which staff member completed the task.
- Use a logical file naming convention that identifies the meter or sensor location, and the time period of data collection.

- Use separate files, or separate sheets within a spreadsheet file, to track rainfall data, sensor data, field measurement data, site/source control characteristics.
- Store raw data in separate files or sheets from processed data.
- For each storm event at each project site, keep track of:
  - Antecedent conditions
  - Rainfall intensity, duration, accumulation, and volume
  - Runoff rates, duration, and total volume into the source control

Data Management for GSI Sites

The following information and data is representative of what is typically collected and recorded as part of a GSI monitoring program, depending on specific site and GSI design conditions. Items 1-8 should be documented for all GSI sites; in addition, Items 9-18 are documented for sites with in-GSI monitoring via observation wells.

(Sites with in-GSI monitoring of inflow/outflow via level sensors paired with flumes or weirs are discussed in the next subsection. GSI sites with AV flow meters, either in-GSI or in-sewer, are described in the last portion of 2.1.2.3.)

1) Nearest rain gage
2) System ID
3) GSI type
4) Design rainfall event
5) System footprint
6) Directly connected impervious area
7) Loading ratio
8) Monitoring start date
9) Effective porosity
10) Storage volume (accounts for porosity)
11) Total volume (does not account for porosity)
12) Storage depth
13) Stage-storage relationship
14) Ponded storage volume (for bioretention)
15) Pre-construction infiltration rate
16) Design drain-down duration
17) Planned outlet for storage dewatering (infiltration, combined sewer, or storm sewer)
18) Underdrain characteristics (if present)
    - Depth of underdrain relative to bottom of GSI subsurface storage space
    - Underdrain diameter
    - Volume of GSI storage space below underdrain

Data management for continuous water level monitoring:

In addition to the "Data Management for GSI Sites" list above, the following data should be tracked for GSI sites with continuous water level monitoring, either in observation wells or from level sensors paired with weirs or flumes.

Site info:

- Datum
- Battery level at field check
- Water surface at field check

Monitoring equipment:

- Observation well ID
- Monitoring well depth
- Sump depth in well, if applicable, based on As-Built drawing. Sump depth should be field confirmed and documented during construction, since it is very difficult to determine post-construction (Figure 2-24).
- Sensor ID
- Depth of water level sensor
- Weir or flume type and discharge equation

Time series data:

- Time
- For bubbler, use measured water depth
- For pressure transducer
  - Absolute barometric pressure (sensor 1)
  - Submerged sensor pressure (sensor 2; records the sum of barometric and water pressure)
  - Temperature of sensor 2
  - Calculate water depth based on correction for barometric pressure
- Calculated flow, for weirs or flumes.

Figure 2-24. Field measurement of sump depth
(East Liberty Presbyterian Church monitoring program [John Buck, CEC])

Data management for a simulated runoff test:

If a simulated runoff test is performed, the data in Table 2-14 should be collected and tracked. Note that a dye test can be done in conjunction to identify possible short circuiting of runoff through the GSI and into the sewer.

Table 2-14. Data Management for Simulated Runoff Test

Category	Data to Record
Data specific to the GSI	1. Site name 2. Site ID 3. Drainage area 4. Directly connected impervious area (DCIA) 5. Storage Volume 6. Loading Ratio 7. Nearest rain gage 8. Date and amount of most recent rainfall
Runoff simulation data	1. Target volume at target storm magnitude 2. Target flow rate at target intensity
Data specific to the sensor	1. Serial ID # 2. Location (Well ID) 3. Barometric pressure sensor ID and location
Incremental data collection	1. Time 2. Accrued time since start of testing 3. Instantaneous Flow 4. Total Flow 5. Water Level in Observation Well
Observation notes	Examples: Any evidence of flow anomalies or bypass, dye observations in location of interest (e.g., underdrain orifice or nearby sewer), maintenance needs.

Data Management for Monitoring Performed with AV Flow Meters

The following apply to I&I control, direct stream inflow removal, and sewer separation projects; and to GSI sites where AV flow monitoring is used (either in the GSI inlet/outlet lines, or in the main sewer if the GSI controlled area is sufficiently large relative to the total flow monitored area).

- Nearest rain gage
- Site ID
- Catchment total area and impervious area
- Monitoring start date
- Sensor ID
- Sensor recorded time series of flow, depth, velocity
- Field measured depth and velocity
- Total amount of public sewer pipe in catchment, and total amount rehabilitated (for I&I control projects); Length of new separate storm sewer pipe installed (for SSP)

- Average annual stream baseflow (for direct stream inflow removal projects)

2.1.2.4 STEP 7: Data QA/QC and Analysis

Quality assurance and quality control steps should be followed prior to undertaking data analysis.

Below is an example QA/QC list applicable to in-sewer and in-GSI monitoring:

- Site ID
- Name of Reviewer
- Name of staff that performed data entry/upload
- Period of data reviewed
- Datum
- Field measurements and notes
- Verify all columns containing formulas
- Verify accuracy of all manual entries
- Verify all units of measure
- Review of graphs and data for any errors in values and date/times
  - Identify any data points that are missing, appear to be errant, or otherwise unusable.
  - If the error appears random, it may be possible to replace or fill using averaging techniques.
  - If the error appears systematic, data should be removed from subsequent analysis.
    - An exception is that systematic errors in flow meter velocity measurements can usually be corrected if the corresponding depth measurements are reliable. Estimate the flow based on rating curve of flow to depth.
- For in-GSI monitoring:
  - Review barometric pressure graphs to check for any sensors that may have been malfunctioning when compared to other sensors
  - Review water level and/or flow response to rainfall data

Data analysis general guidelines:

- Data review is important to make sure equipment is functioning properly, and to perform accurate data analysis
- There are multiple methods and programs that can be used to analyze data. The method and program used should correspond to monitoring program goals and objectives, the type of feature being monitored, and the data collected.
- For GSI sites, a water balance is a valuable tool to understand where water is coming from, how it gets to the site, and to determine if the site is performing as designed or if performance has declined over time.

I&I control, direct stream inflow removal, and sewer separation projects: flow monitoring data analysis

- If the monitoring location involves combined sewer flow, import the sewer flow data and rainfall data into the USEPA Sanitary Sewer Overflow Analysis and Planning (SSOAP) software package designed to analyze sewer flow monitoring data
- Use the software to determine average daily weekend and weekday dry weather flow patterns
  - Separate the base wastewater flows from groundwater infiltration
- Analyze rainfall events to determine the wet weather flow hydrograph

- Separate the rainfall dependent infiltration and inflow from stormwater runoff using 'RTK' shape analysis of wet weather hydrographs
- A more detailed description of RTK analysis is in Section 5.2.2 of PWD (2014)

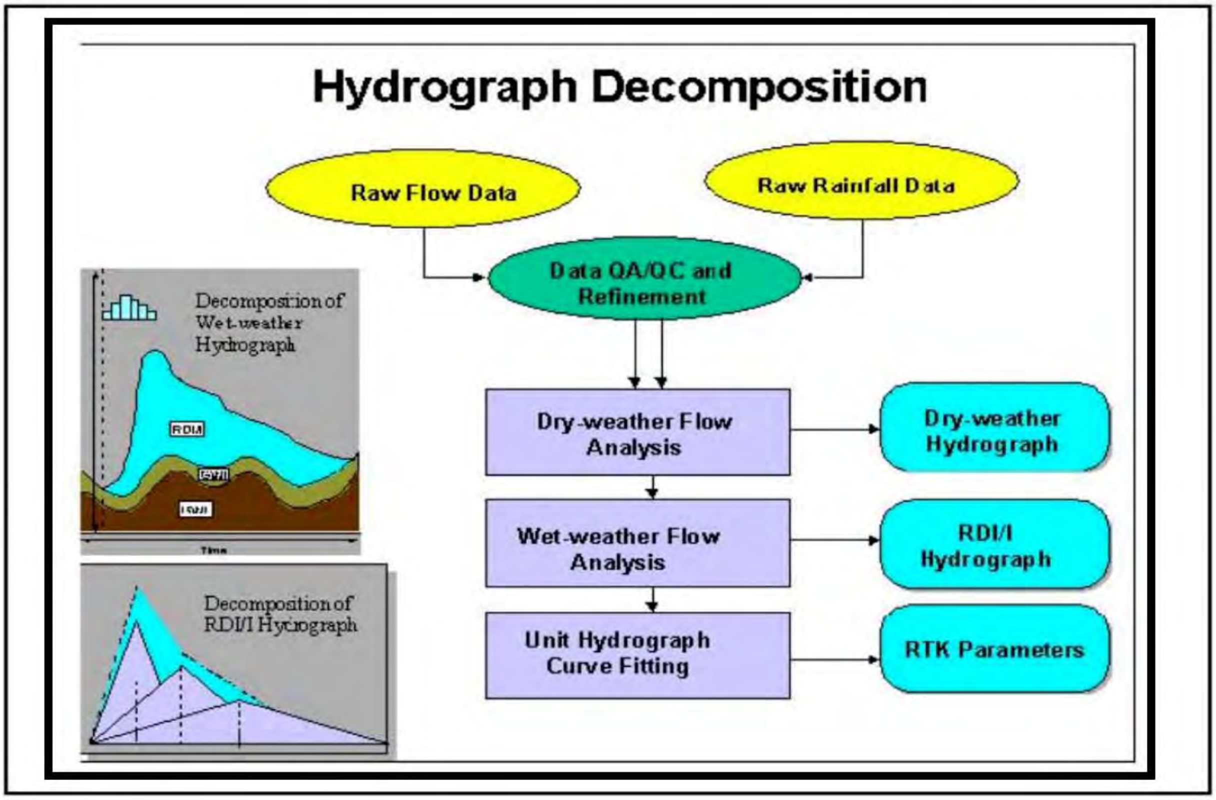


Figure 2-25. SSOAP Analysis Processing Steps and Output

Plots are a valuable tool in data analysis and can communicate complex information in a clear and concise manner. Table 2-15 lists the different types of plots that are most commonly used for GROW source control types.

Table 2-15. Plot Types for Data Analysis

Plot Type	Description	Applications
Hyetograph	Variation of rainfall over time	Calculate individual rain event statistics such as event start and end times; event duration; total rainfall depth; peak rainfall intensity; frequency return interval of the storm; antecedent dry time from previous storm event
Hydrographs (including those decomposed using SSOAP)	Variation of flow over time	For all source control types: calculate total volume; time to peak; peak flow rate For in-sewer monitoring: calculate time of concentration; storm event "R-Coefficient" of effective rainfall
Scatter plot	X-Y plot of one dataset against another dataset	Compare sensor data against field measurements and other data QA/QC checks
Water level time series	For GSI sites: variation of water level over time	Calculate: infiltration rate; infiltration volume; slow release (underdrain) volume; drain-down duration; storage utilization; overtopping

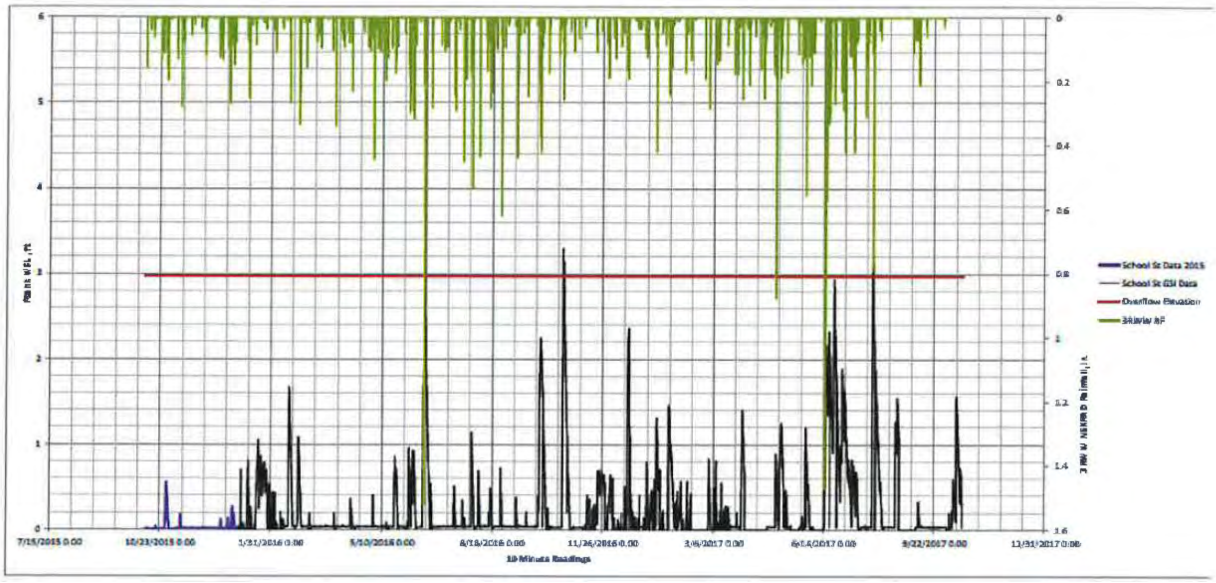


Figure 2-26. Rainfall (green) and water level response (black) time series in a biofiltration facility.
The red line represents the overflow elevation. Three overflow events occurred in two years (Borough of Etna GROW project).

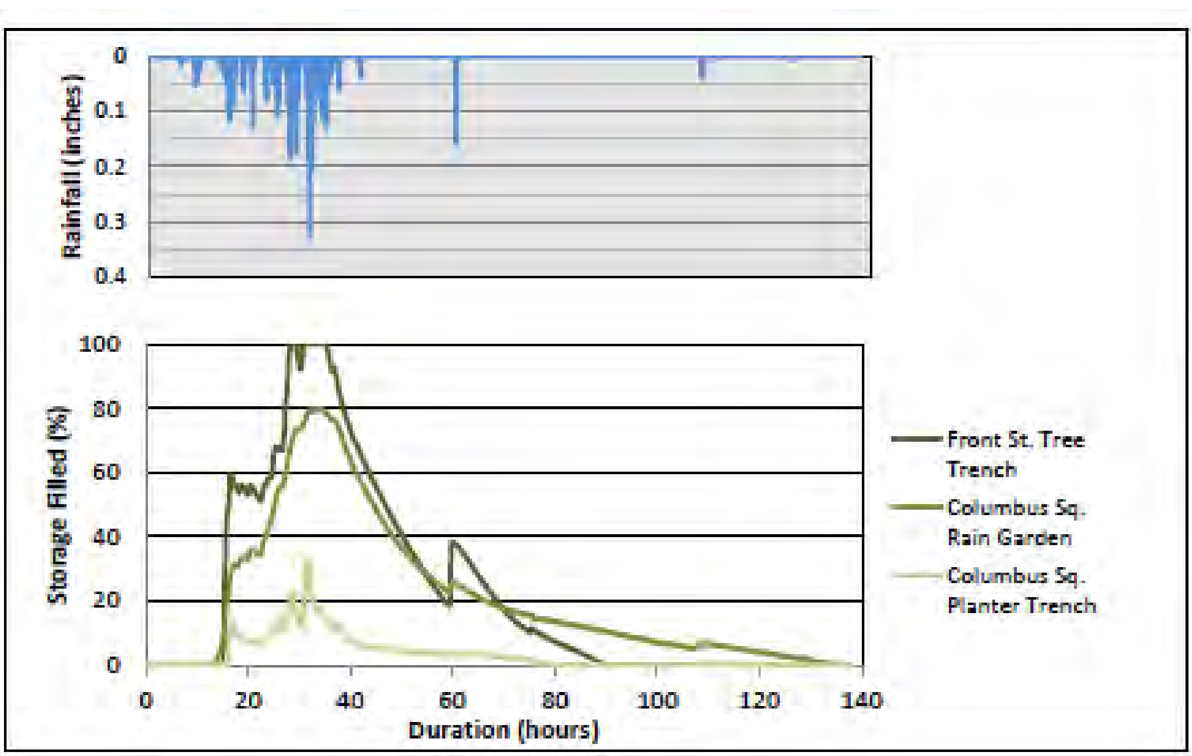


Figure 2-27. Rainfall and GSI response over time (PWD).

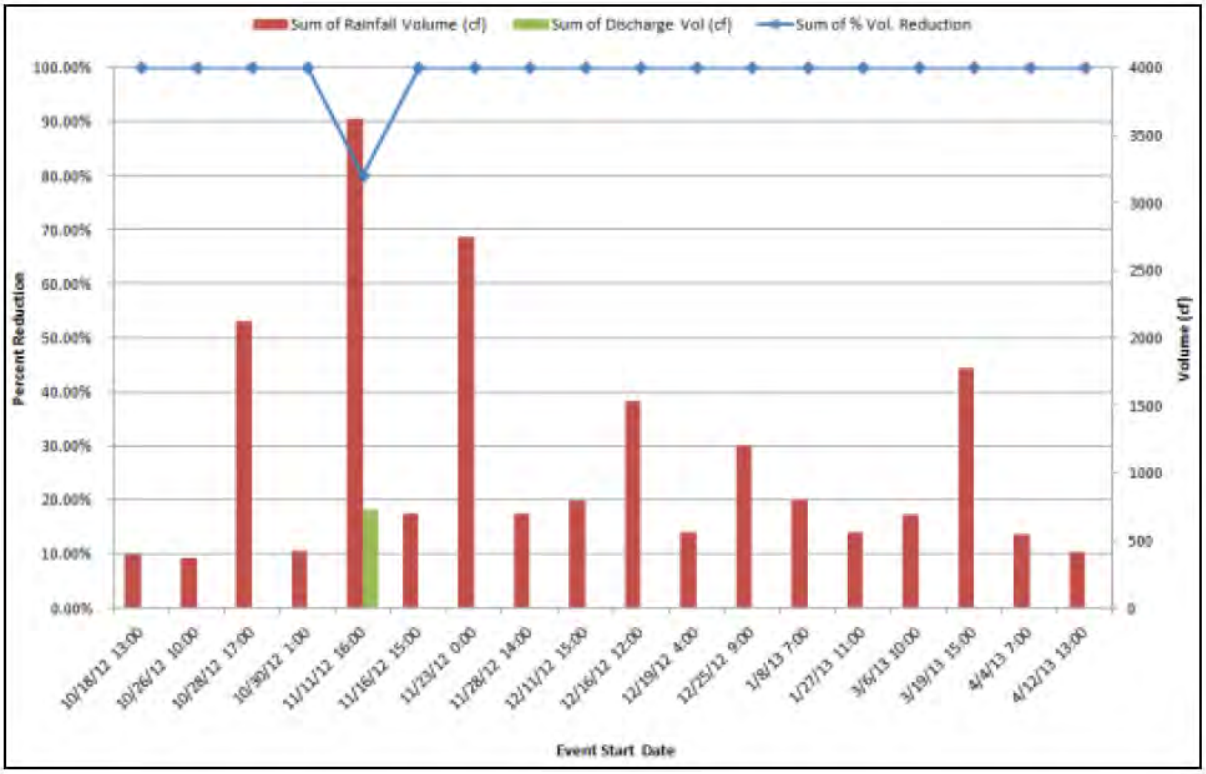


Figure 2-28. Rainfall volume, discharge volume, and percent volume reduction from a rain garden.
Data recorded over a six-month period (Seattle Public Utilities)

Rainfall and water level data at three proximate GSI sites with subsurface storage are shown in Figure 2-27. The top half is a one-inch rain event, and the bottom half is a five-inch rain event. The drain-down durations of each GSI site can be determined from the plot. Also, the water level has been converted to its relative depth in the subsurface storage, so that the lower panel y-axes are shown as percentage of storage filled; this lets stakeholders know if the subsurface space is adequately sized.

Rain garden performance over eighteen events in a six-month period is shown in Figure 2-28, with rainfall and discharge volume plotted along with percent reduction data.

When using level sensor data, the infiltration rate can be calculated by examining the recession limb (when there is not discharge from the underdrain) and dividing the change in water level over a given time interval.

For GROW source control types, measurement of **inflow** from runoff may not be feasible, depending on site conditions. In those cases, inflow must be estimated as a precursor to quantifying flow reduction.

Table 2-16. Methods of Inflow Estimation

Method	Description	Notes
Hydrologic and Hydraulic (H&H) Model	Calibrated and validated model of the site area based on catchment area, slope, pervious fraction, impervious fraction, soil type, depression storage, and conveyance network. Generates event or continuous time series of runoff based on rainfall input.	To mitigate the effort needed for model development, the ALCOSAN H&H collection system model should be used if made available

Table 2-16. Methods of Inflow Estimation

Method	Description	Notes
Rational Method	Calculates peak discharge runoff based on runoff coefficient, rainfall intensity and drainage area	PWD uses a variant of this method, where the product of the precipitation and directly connected impervious area at each recorded interval of rainfall is summed for the entire rain event to get the total runoff volume and the runoff calculation begins after the total rainfall has exceeded the depression storage of the drainage area
Simple Method	Calculates runoff coefficient based on impervious fraction of drainage area. Calculates runoff volume based on runoff coefficient, rainfall depth, and watershed area.	CVC monitoring guide has a Modified Simple Method for LID that distinguishes between the GSI drainage area and the GSI area itself
EPA National Stormwater Calculator	Targeted for 1-12 acre sites Uses national databases on soils, topography, land use, and weather to characterize site. Runs SWMM in background to produce estimates of runoff based on rainfall input data.	EPA designed screening tool for non-technical professionals

For GSI projects, methods to measure or estimate **outflow** leaving the GSI practice include:

- If site and hydraulic conditions are suitable, GSI outflow can be measured with:
  - Flow meter in the service line from catch basin to main sewer
  - Weir installed in a manhole that is located along the outflow line
- GSI outflow can also be estimated using a pressure transducer in a monitoring well.
  - The measured depth above the underdrain orifice can be input into the orifice equation to calculate the flow through the underdrain orifice.
  - PWD uses this method to estimate 'slow release' volume of outflow into the collection system, without the need to directly monitor it.

Direct measurements of flow, via flow meters, weirs, or flumes, are subject to measurement error. For example, flow meters have an error of +/- 5% to 10%, and weirs or flumes are optimized for greater accuracy within a certain range of depths. Instrument fouling and installation issues can also contribute to measurement error.

Methods that rely on estimation, rather than measurement, of GSI inflow and/or outflow are subject to other sources of error or uncertainty. It is important to understand these sources and reduce uncertainty where possible. The total error can be quantified by checking for inconsistencies in the water balance.

Table 2-17. Sources of Error when Estimating GSI Inflow and/or Outflow

Source of Error	Description
Measurement Uncertainty of GSI Elements	Uncertainty in measurement of GSI physical elements, such as constructed dimensions, elevations, inlet configurations, porous media properties, sump depth, and stage-storage relationships
Runoff Uncertainty	Uncertainty in spatial and temporal measurement of environmental data, including rainfall, water depth, and drainage area characteristics.
Mathematical Representation of Physical Processes	Simplifications in mathematical representation of complex physical processes, such as rainfall-runoff, infiltration, unsaturated and saturated flow in porous media, evapotranspiration, soil moisture, and flow control structures.
Numerical Error	Numerical errors in time-step based computation that affect volume calculations of inflow, infiltration, and outflow.

For GSI projects that rely on water level data without measurements of flow, PWD has developed the following water balance approach. Below is a summary, and full details are in Baldridge et al. (2016)

It is assumed that the water level has been recorded at a 5-minute interval, and rainfall data from a nearby gage is available. The rainfall data is discretized to a 5-minute interval if needed.

The water balance equation is calculated at each 5-minute interval of water level data:

$$Volume\ in = Volume\ out + \ \Delta Storage$$

$$Volume\ in = \frac{P}{12} * DCIA$$

Where

Volume in = runoff volume entering the GSI over the 5 minute interval;

P is the precipitation in inches over the 5 minute interval;

DCIA = Directly Connected Impervious Area (square feet);

Δ Storage = determined from the change in water level from the previous timestep.

$$Volume\ out = Infiltration + Slow\ Release + Overflow$$

Infiltration = volume of water that infiltrates to surrounding soils over the 5-minute interval, based on the infiltration rate multiplied by the infiltration area;

Slow release = volume of water released to the collection system via the GSI underdrain orifice.

Slow release volume = $Cd * a * \sqrt{2gh} * 60 \left(\frac{seconds}{minute}\right) * 5\ (minutes)$

Cd is the coefficient of discharge (0.62 assumed), *a* is the cross-sectional area of the orifice (square feet), *g* is 32.2 ft/s^2, and *h* is the head above the orifice centerline which is the water level minus the depth from the bottom of storage to the orifice centerline.

Overflow is assumed to occur when the water level reaches the top of storage. At that point, there is no change in storage (unless the system temporarily stages above the overflow), and

$$Overflow = Volume\ in - Infiltration - Slow\ Release$$

The error is the difference between the total volume in and the total volume out for the event duration. The sources of error are attributed to factors listed in Table 2-17. Using this method, +/- 15% error is considered reasonable.

The advantages to this approach are that in-GSI monitoring can be done economically using only pressure transducers without flow monitoring devices or confined space entry.

2.1.3 Quantifying Flow Reduction

STEP 8: Quantifying flow reduction. This final step helps to determine the effectiveness of the GROW source control project. An understanding at the project start of the desired approach to quantifying flow reduction can aid the development of the monitoring plan.

As mentioned in Section 2.0, at least 6 months of pre-construction monitoring data and 12 months of post-construction monitoring data should be collected.

Pre-construction flow can be measured in-sewer, or estimated using the methods outlined in Table 2-16:

- H&H model
- Simple Method
- Rational Method
- EPA National Stormwater Calculator

Post-construction flow can be measured in-sewer, or in the case of GSI, measured at the GSI inflow/outflow points, or estimated using in-GSI water level data and the orifice equation, as described in Section 2.1.2.

A variety of methods to compare pre- and post-construction data, along with key steps for each method, are listed in Table 2-18.

Table 2-18. Methods to Compare Pre- and Post-Construction Data

Method	Main Steps	Notes
Develop H&H Model	1. Calibrate model using pre-construction monitoring data 2. Simulate rainfall events from post-construction period, without source controls in model. 3. Compare model results at catch basin/flow monitoring point to observed post-construction data.	Recommend using at least 3 rainfall events of varying event sizes for calibration, and 2 separate events for validation. Use ALCOSAN model and/or monitoring data as appropriate. Can apply to GSI, I&I, DSIR, or SSP.
Direct comparison of pre- and post-construction in-sewer monitoring data	1. Monitor flow at the same location pre- and post-construction 2. Normalize the observed runoff volume by the flow monitored drainage area and rainfall volume. This yields the "effective rainfall" or "R-coefficient" of drainage area 3. Compare R-coefficients from pre- and post-construction to quantify collection system reduction benefits in total runoff removed.	Use existing ALCOSAN monitoring data if applicable. Can apply to GSI, I&I, DSIR, or SSP. Make sure to consider differences between pre- and post-construction storms (intensity, antecedent rainfall, season, temperature, etc.).
Reference basin approach	1. Identify a nearby comparable reference basin to monitor simultaneously with the basin that will be changed through source control 2. Monitor both basins simultaneously in the post-construction period 3. Ideally, also monitor both basins simultaneously in the pre-construction period, to account for differing	Finding two drainage areas that are similar can be difficult. Ideally, the reference basin is a sewered area that is nearby, and similar in age, size, land use, and pipe materials to the rehabilitated area. The reference area would not have had any rehabilitation work performed.

Table 2-18. Methods to Compare Pre- and Post-Construction Data

Method	Main Steps	Notes
	hydrological and environmental conditions between the two monitoring periods and basins.	Any differences between the basins should be noted to help inform the analysis. Consider the time and cost needed to perform monitoring in two watersheds. Can apply to GSI, I&I, DSIR, or SSP.
EPA National Stormwater Calculator	1. Go to https://swcweb.epa.gov/stormwatercalculator 2. Enter site address and draw polygon around drainage area to be controlled 3. Adjust as needed the default values on soils, topography, land use, weather data 4. To get a baseline estimate, do not enter any LID controls 5. Run simulation to get baseline runoff estimates 6. Compare baseline runoff estimates at discrete rainfall amounts to GSI post-installation monitored data	Only applies only to GSI source controls EPA designed screening tool for non-technical professionals Targeted for 1-12 acre sites Uses national databases on soils, topography, land use, and weather to characterize site Runs SWMM in background to produce estimates of runoff
Dynamic water budget	1. Calculate water balance at each time step of water level data 2. Estimate inflow based on DCIA and precipitation 3. Calculate infiltration and slow release based on water level time series data 4. Compare infiltrated and slow released volume to inflow volume and quantify the runoff volume that has been controlled	Only applies only to GSI source controls Subject to uncertainties shown in Table 2-17 Measuring inflow can reduce the largest uncertainties (either through inflow monitoring, or simulated runoff test) Full details in Baldridge et al., 2016

2.1.4 Documentation and Reporting

GROW funded projects are required to conduct pre- and post-construction flow monitoring and to summarize the results of the monitoring and the flow removal efficiency of the project in a Final Monitoring Report as described in Section 1.1.3. QA/QC'd flow data should be provided using the GROW data template along with any supporting information and summary charts and graphs. Supporting information may include the following items:

- Schedule of site visits and data extraction
- Equipment lists and maintenance logs
- Monitoring Field Logs
- Budgeting and costing data

Guidelines for field logs of monitoring sites

Monitoring field logs should contain the following documentation:

- Date, time, and purpose of visit
- Staff members present and equipment used to download data
- Field measured depths/velocities. and sensor measured depths/velocities
- Remaining battery power
- Document any discrepancies or required calibration adjustments

- Document depth of any in-sewer debris
- Document any maintenance problems and remediation measures, and equipment damage

2.1.5 Additional Information and Resources

Allegheny County Sanitary Authority (ALCOSAN). 2007. Flow Monitoring Program Protocols for Data Quality Assurance.

Pittsburgh Water and Sewer Authority (PWSA). DRAFT Pittsburgh Regional Green Stormwater Infrastructure Monitoring Guidebook. http://apps.pittsburghpa.gov/pwsa/Monitoring_for_Grants.pdf

Philadelphia Water Department (PWD). 2014. Green City, Clean Waters Comprehensive Monitoring Plan. http://phillywatersheds.org/ltcpu/GCCW%20Comprehensive%20Monitoring%20Plan%20Sections%201-10.pdf

PWD. 2016. Green City, Clean Waters Year 5 Evaluation and Adaptation Plan, Appendix B. http://phillywatersheds.org/doc/Year5_EAPCombinedAppendices_website.pdf

Baldridge, A., E. Mannarino, D. Myers, M. Vanaskie, J. Cruz, S. White, C. Bergerson, and T. Heffernan, 2016. Methods for Assessing Green Stormwater Infrastructure Hydrologic Water Budgets Using Continuous Water Level Monitoring Data. WEFTEC 2016 Proceedings, pp. 362-376.

Gwinnett County Department of Water Resources. 2017. Monitoring Guidance and Equipment Evaluation.

Credit Valley Conservation Authority. 2015. Lessons Learned: CVC Stormwater Management and Low Impact Development Monitoring and Performance Assessment Guide. https://cvc.ca/wp-content/uploads/2016/05/Monitoring_Guide_with-app_s.pdf

US EPA. 2002. Urban Stormwater BMP Performance Monitoring Guide. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100170R.TXT

US EPA. 2012. CSO Post Construction Compliance Monitoring Guide. https://www.epa.gov/sites/production/files/2015-10/documents/final_cso_pccm_guidance.pdf

US Geological Survey (USGS). 1999. Basic Requirements for Collecting, Documenting, and Reporting Precipitation and Stormwater-Flow Measurements. https://pubs.er.usgs.gov/publication/ofr99255

Appendix A
ALCOSAN Monitoring Assistance Form

Save Form

Clear Form

ALCOSAN GROW Program
Request for Flow Monitoring Services Form

Requests for ALCOSAN to provide flow monitoring services can be made by completing this form. Submission of the form does not guarantee ALCOSAN will be able to provide flow monitoring services. Requests will be fulfilled based on the availability of equipment, staff and the project's potential to reduce sewer overflow volume. The completed form, meter location map and other requested material should be submitted to GROW@alcosan.org.

1. Municipality/Sewer Authority:

2. Municipal Contact Information:

Name:

Title:

Email:

Phone Number:

3. Project Type:

☐ Green Stormwater Infrastructure
☐ Sewer Separation
☐ Infiltration/Inflow Reduction
☐ Direct Stream Inflow Removal
☐ Other:

4. Brief Project Description.
Please provide a site plan for the project being described, if available: ☐ Plan Attached ☐ Not available

5. Will this project be submitted for GROW funding consideration? ☐ Yes ☐ No

6. What type of monitoring are you requesting?

☐ Pre-construction ☐ Post-construction ☐ Both

7. Schedule:

Anticipated construction start date: Month: Year:

Anticipated construction end date: Month: Year:

8. Sewer System Type Where Meter Would be Installed (select all that apply):

☐ Combined ☐ Sanitary Sewer ☐ Storm Sewer

9. Sewer pipe diameter at installation site: inches

10. Map: Provide a location map showing the desired installation location for the flow meter. The map should include road names and other landmarks to help identify the proper location. Please provide a drawing or sketch of the manhole to be monitored, if available.

TO BE COMPLETED BY ALCOSAN PERSONNEL

Determination: ☐ Approved ☐ Unable to fulfill request

	Date Completed	Completed By
Site evaluation date:		
Meter installation date:		
Removal date:		
Data QA/QC complete:		
Access to data provided:		

Appendix B
GROW Monitoring Summary Forms

GROW Monitoring Summary Form - In-GSI monitoring

Project Information

Project Name: ______________________________ Date: ______________

Project Description: (including GSI Type) [ ]

Project as-built Costs: ______________ GSI Footprint [ft^2]: ______________

DCIA [ft^2]: ______________ Loading Ratio: ______________

GSI subsurface depth of storage [in.]: ________ Design rainfall event used for system sizing [in.]: ________

Infiltration rate[a,b]: ________ ☐ Assumed ☐ Pre-Construction ☐ During- Construction

a. 0.1 in/hr default. Use site-specific info if available, must be based on geotech report
b. Enter zero if GSI has impermeable liner

Monitoring Setup/Methods

Gauge Location:

Rainfall: ______________

Flow/Water Level: ______________

Number of Gauges:

Rainfall: ______________

Flow/Water Level: ______________

Equipment Type: ______________
(Flow/Water Level)

Site Conditions: [ ]

	Start Date:	**End Date:**
Pre-Implementation Monitoring period:	________	________
Post-Implementation Monitoring period:	________	________

Data QA/QC Performed? Y N

Precipitation Monitoring Summary

Pre-Implementation

Number of Events: ______________ Median Rainfall Event [in.]: ______________

Total Rainfall[1]: ________ Inches ________ Gallons Max. Rainfall Event [in]: ______________

Post-Implementation

Number of Events: ______________ Median Rainfall Event [in.]: ______________

Total Rainfall[1]: ________ Inches ________ Gallons Max. Rainfall Event [in]: ______________

1. For In-GSI monitoring, total rainfall volume [gallons] = total rainfall [inches] * DCIA [ft^2] *0.623 [unit conversion factor]

In-GSI Monitoring

Runoff Volume[a] [gallons]: ______________________
(from DCIA entering GSI)

____

Infiltration Volume[b] [gallons] ______________________

% Runoff volume managed by GSI ______________________
= (Infiltration + Slow release volumes)/Runoff volume

Infiltration Rate[b] [in/hr]: ______________________
(avg. or median)

____

Slow Release Volume[c] [gallons]: ______________________
(from GSI underdrain to sewer)

Number of times GSI storage depth was exceeded: ______________________

Largest rain event fully captured within GSI storage depth [in.]: ______________________

a. Indicate if measured, or calculated (e.g., Rational Method or Simple Method)
b. Indicate if derived from monitoring well water level data, or based on direct measurement of infiltration test
c. Indicate if derived from monitoring well water level data, or directly measured

GROW Monitoring Summary Form - In-sewer monitoring of GSI

Project Information

Project Name: ______________________ Date: __________

Project Description: (including GSI Type)

Project as-built Costs: __________ GSI Footprint [ft^2]: __________

DCIA [ft^2]: __________ Loading Ratio: __________

GSI subsurface depth of storage [in.]: __________ Design rainfall event used for system sizing [in.]: __________

Infiltration rate[a,b]: __________ ☐ Assumed ☐ Pre-Construction ☐ During- Construction

a. 0.1 in/hr default. Use site-specific info if available, must be based on geotech report
b. Enter zero if GSI has impermeable liner

Monitoring Setup/Methods

Gauge Location:

Rainfall: __________

Flow/Water Level: __________

Number of Gauges:

Rainfall: __________

Flow/Water Level: __________

Equipment Type: __________
(Flow/Water Level)

Site Conditions:

	Start Date:	**End Date:**
Pre-Implementation Monitoring period		
Post-Implementation Monitoring period		

Flow Monitored drainage area [acres]: __________

Data QA/QC Performed? Y N

Precipitation Monitoring Summary

Pre-Implementation

Number of Events: __________ Median Rainfall Event [in.]: __________

Total Rainfall[1]: __________ Inches __________ Gallons Max. Rainfall Event [in]: __________

Post-Implementation

Number of Events: __________ Median Rainfall Event [in.]: __________

Total Rainfall[1]: __________ Inches __________ Gallons Max. Rainfall Event [in]: __________

1. For In-sewer monitoring, total rainfall volume [gallons] = total rainfall [inches] * flow monitored drainage area [acres] * 27,154 [unit conversion factor]

In-Sewer Flow Monitoring Summary[a]

	Pre-Implementation	Post-Implementation
Rainfall dependent inflow & infiltration[b] (RDII) [gallons]:	__________	__________
R value[c] (RDII vol/ Rainfall vol):	__________	__________

Performance Metrics

Total RDII Flow removed [gallons]: ____________________

Percent Change in Total RDII (Pre to Post): ____________________

a. Flow Monitoring Summary should be based on the entire monitored period, not on a design storm derived from the data
b. Derived value
c. Also known as Percent Rainfall Capture Rate

GROW Monitoring Summary Form - Sewer Separation Projects

Project Information

Project Name: ______________________ Date: __________

Project Description: [ ]

Project as-built Costs: __________

Total amount of sewer pipe in catchment [inch-miles]: __________

New amount of separate storm sewer installed [inch-miles]: __________

New length of separate storm sewer installed [feet]: __________

Total drainage area separated [acres]: __________

Impervious area separated [acres]: __________

Monitoring Set/Up Methods

Gauge Location:

Rainfall: __________

Flow: __________

Number of Gauges:

Rainfall: __________

Flow: __________

Flow Monitored drainage area [acres]: __________

Site Conditions: [ ]

	Start Date:	End Date:
Pre-Implementation Monitoring period:		
Post-Implementation Monitoring period:		

Data QA/QC Performed? Y N

Precipitation Monitoring Summary

Pre-Implementation

Number of Events: __________

Total Rainfall: __________ Inches **Gallons**[1]

Post-Implementation

Number of Events: __________

Total Rainfall: __________ Inches **Gallons**[1]

1. total rainfall volume [gallons] = total rainfall [inches] * flow monitored drainage area [acres] * 27,154 [unit conversion factor]

Flow Monitoring Summary[a,d]

	Pre-Implementation	Post-Implementation
Wastewater Flow [gallons]:		
Rainfall dependent inflow & infiltration[b] (RDII) [gallons]:		
GW infiltration[b] (GWI) [gallons]:		
Total I/I[b] (sum of RDII and GWI) [gallons]:		
R value[c] (RDII vol/ Rainfall vol):		

a. Flow Monitoring Summary should be based on the entire monitored period, and not on a design storm derived from the data
b. Derived value
c. Also known as Percent Rainfall Capture Rate
d. For sewer separation projects, monitor the affected combined sewer pre- and post-implementation

Performance Metrics

Total RDII Flow removed [gallons]:__________

Volume I/I Reduced [gallons]:__________

Total GWI Flow removed [gallons]:__________

Percent Change in Total I/I (Pre to Post):__________

GROW Monitoring Summary Form- I/I control projects

Project Information

Project Name: ______________________________ Date: ____________

Project Description:

Project as-built Costs: ____________________

Total amount of sewer pipe in catchment [inch-miles]: ____________________

Total amount of sewer rehabilitated [inch-miles]: ____________________

Total length of sewer rehabilitated [feet]: ____________________

Monitoring Setup/Methods

Gauge Location:

Rainfall: ____________________

Flow: ____________________

Number of Gauges:

Rainfall: ____________

Flow: ____________

Flow Monitored drainage area [acres]: ____________________

Site Conditions:

Data QA/QC Performed? Y N

	Start Date:	**End Date:**
Pre-Implementation Monitoring period:	________	________
Post-Implementation Monitoring period:	________	________

Precipitation Monitoring Summary

Pre-Implementation

Number of Events: ____________________

Total Rainfall: __________ Inches __________ **Gallons**[1]

Post-Implementation

Number of Events: ____________________

Total Rainfall: __________ Inches __________ **Gallons**[1]

1. total rainfall volume [gallons] = total rainfall [inches] * flow monitored drainage area [acres] * 27,154 [unit conversion factor]

Flow Monitoring Summary[a]

	Pre-Implementation	Post-Implementation
Wastewater Flow [gallons]:		
Rainfall dependent inflow & infiltration[b] (RDII) [gallons]:		
GW infiltration[b] (GWI) [gallons]:		
Total I/I[b] (sum of RDII and GWI) [gallons]:		
R value[c] (RDII vol/ Rainfall vol):		

a. Flow Monitoring Summary should be based on the entire monitored period, not on a design storm derived from the data
b. Derived value
c. Also known as Percent Rainfall Capture Rate

Performance Metrics

Total RDII Flow removed [gallons]:________________ Volume I/I Reduced [gallons]:________________

Total GWI Flow removed [gallons]:________________ Percent Change in Total I/I (Pre to Post):________________

GROW Monitoring Summary Form - Direct Stream Inflow Removal (DSIR) Projects

Project Information

Project Name: ______________________ Date: __________

Project Description: [ ]

Project as-built Costs: __________ Avg annual stream baseflow [gallons]: __________

Monitoring Setup/Methods

Gauge Location:

Rainfall: __________

Flow: __________

Number of Gauges:

Rainfall: __________

Flow: __________

Flow Monitored drainage area [acres]: __________

Site Conditions: [ ]

	Start Date:	End Date:
Pre-Implementation Monitoring period:	__________	__________
Post-Implementation Monitoring period:	__________	__________

Data QA/QC Performed? Y N

Precipitation Monitoring Summary

Pre-Implementation

Number of Events: __________

Total Rainfall: __________ Inches __________ **Gallons[1]**

Post-Implementation

Number of Events: __________

Total Rainfall: __________ Inches __________ **Gallons[1]**

1. total rainfall volume [gallons] = total rainfall [inches] * flow monitored drainage area [acres] * 27,154 [unit conversion factor]

Flow Monitoring Summary[a]

	Pre-Implementation	**Post-Implementation**
Wastewater Flow [gallons]:	__________	__________
Rainfall dependent inflow & infiltration[b] (RDII) [gallons]:	__________	__________
GW infiltration[b] (GWI) [gallons]:	__________	__________
Total I/I[b] (sum of RDII and GWI) [gallons]:	__________	__________
R value[c] (RDII vol/ Rainfall vol):	__________	__________

a. Flow Monitoring Summary should be based on the entire monitored period, not on a design storm derived from the data
b. Derived value
c. Also known as Percent Rainfall Capture Rate

Performance Metrics

Total RDII Flow removed [gallons]:____________________

Volume I/I Reduced [gallons]:__________________________

Total GWI Flow removed [gallons]:____________________

Percent Change in Total I/I (Pre to Post):__________________________