Post-Construction Stormwater Technology Assessment Protocol

Metropolitan North Georgia Water Planning District
July 2023

Version 2.0

Post-Construction Stormwater Technology Assessment Protocol

Objectives of the Protocol

The objectives of this protocol are to characterize a technology's effectiveness in removing pollutants from stormwater runoff for an intended application and to compare test results with vendors' claims.

Requesting a Pilot Use Designation or Technology Review

Vendors may submit their proprietary systems for Pilot Use Designation or inclusion on the Post-Construction Stormwater Technology Assessment Protocol (PCSTAP) Concurrence List by submitting a complete application package and review fee to the Metropolitan North Georgia Water Planning District (District). Additional information about the review fee can be found at https://northgeorgiawater.org/. This fee covers the time to provide a review of the application package but does not guarantee issuance of a Pilot Use Designation or Concurrence.

Within two months of the submittal date of a complete application package, the review will be finalized, and the vendor will be notified of Pilot Use Designation, Concurrence, or denial.

Protocol Limitations, Release of Liability, and Disclosure

The District, including its volunteer Technology Review Committee (TRC) and consultants, ***makes no representation, endorsements, or warranties, express or implied***, concerning the validity or suitability of this assessment method for any particular technology or product, or of the accuracy of the evaluation results produced using this protocol; and does not endorse, approve, make or permit to be made any claims based in whole or in part on these results to be asserted by the manufacturers of the systems or equipment assessed using this protocol. Purchasers and users of any technologies or products presented by a manufacturer or other entity using this protocol should make their own independent analyses and evaluations concerning the usefulness or value of any stormwater technologies or combinations of technologies in considering whether to use any particular technology or product for post-construction stormwater treatment. Use of the information generated under this protocol constitutes acceptance of this limitation of liability.

Appeals

Vendors may appeal a letter of denial by contacting the District's Stormwater Planning Manager at comments@northgeorgiawater.org. Appeals will be reviewed by District staff and the TRC, which is comprised of engineers from local jurisdictions within the District. There is no fee or timeframe for the review of appeals.

1.0 PURPOSE OF THIS DOCUMENT

The objective of the PCSTAP is to characterize a proprietary system's effectiveness in removing total suspended solids (TSS) from post-construction stormwater runoff for an intended application (land use) and to compare test results with vendor performance claims. The PCSTAP is structured for conditions within the District and is only meant to collect information about TSS removal. It is not intended for use in evaluation of erosion and sedimentation control technologies or products for use during construction or land-disturbing activities.

Stormwater treatment technologies and products that have been tested according to this protocol can receive consideration to have their results evaluated and made available publicly on the District website (https://northgeorgiawater.org). The review of vendor data and subsequent concurrence and public dissemination using the PCSTAP guideline is not an approval process or an endorsement of any product by the District.

Local governments and other entities may use PCSTAP information as part of their process to evaluate the suitability of these technologies or products for site-specific applications under local conditions. In considering whether to use any particular technology or product, purchasers and users should make their own independent analyses and evaluations of site conditions and post-construction stormwater management requirements. PCSTAP information related to the usefulness or value of any stormwater technologies or combinations of technologies may be incorporated into these evaluations.

2.0 STORMWATER TREATMENT TECHNOLOGY EVALUATION PROCESS

2.1 Overview

The technology performance evaluation process consists of the following elements (illustrated in the flowchart in Figure 1):

- Preparation of a technology engineering report by the vendor;
- Implementation of performance testing of the technology in the field with environmental conditions similar to Georgia;
- Submission of technology engineering report and testing results to the District;
- Review of technology engineering report and testing results by the District; and
- Posting of vendor information and determinations on the District website.

Typically, the vendor will submit the technology engineering report and testing results at the same time, unless requesting a Pilot Use Designation (see Section 2.2).

The District will maintain a list on its website to assist local jurisdictions in identifying stormwater technologies and products that have verifiable performance information after review.

A technology must meet both of the following criteria to receive a letter of concurrence from the District:

- A demonstrated ability to meet the stormwater performance claims outlined in the technology engineering report, verified by field testing performed in accordance with the PCSTAP; and
- A demonstrated capability for sustainable performance with respect to factors other than treatment performance (e.g., maintenance requirements, potential for failure, durability, etc.).

Comments are based solely upon the information presented in the engineering report and testing results provided to the District. Vendors found not to have provided sufficient technology information and/or performance data may submit additional information to the District if requested. If the review finds the information submitted to be wholly insufficient, a full resubmittal may be warranted at a later date. Any submission with an incomplete or unusable checklist will not be considered and will be returned to the vendor for resubmission. A resubmission will require a new review fee and will be considered on its own merits as a new application with no consideration given to previous materials or reviews.

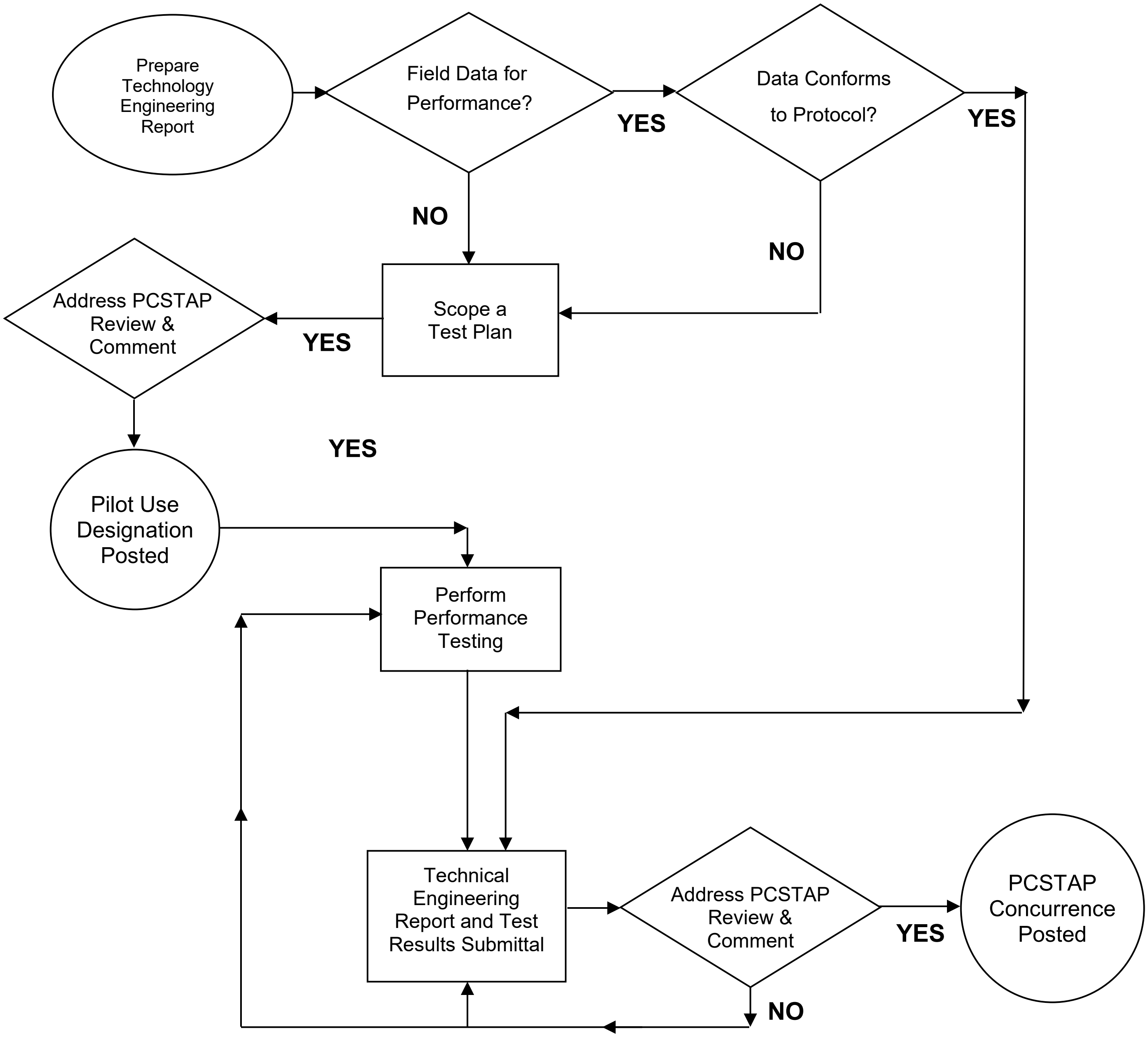

Figure 1: Technology Performance Evaluation Process

2.2 Pilot Use Designation

A Pilot Use Designation is a special sub-category of PCSTAP concurrence, which allows a vendor to scope a test plan and conduct performance testing within the District to collect field performance data. An applicant may submit a Test Plan and review fee to the District for consideration to obtain a Pilot Use Designation. These technologies will be listed with the Pilot Use Designation on the District website along with the relevant details of the Test Plan. Appendix B provides the technology and experimental design details to include in the Test Plan.

Local jurisdictions have full discretion to allow or reject Pilot Use Designation technologies for installation in new development or redevelopment. Upon receipt of a Pilot Use Designation, the vendor and/or developer must agree to conduct field testing based on the criteria in the PCSTAP and agrees to retrofit installations that fail to meet performance claims. Vendors can re-use information required for the pilot use designation application for the PCSTAP concurrence application. A PCSTAP concurrence application will require a new review fee and will be considered on its own merits as a new application.

2.3 Roles and Responsibilities

2.3.1 PCSTAP Administration and Review of Application Packages

District

The District establishes strategies for water supply and conservation, watershed, and wastewater management for 15 counties and 96 cities in metro Atlanta. This includes the administration of the PCSTAP Program. The District ‘s duties are:

- Management of the PCSTAP review process;
- Making review information publicly available;
- Interacting with other state, regional and local government agencies to evaluate the process and ensure it is meeting objectives; and
- Revising the PCSTAP and website as needed.

Technology Review Committee (TRC)

The TRC is a group of volunteers comprised of stormwater and water resource professionals from local jurisdictions in the District. The TRC’s duties are:

- Reviewing technology engineering reports and testing results submitted by vendors for conformity to the PCSTAP;
- Reviewing reports and summaries prepared by consultants that assess conformity to the PCSTAP for vendor submittals; and
- Reviewing appeals from vendors that have received a letter of denial.

2.3.2 Submittal of PCSTAP Application Packages

Vendor/Manufacturer of the Technology

Vendors/ Manufacturers (applicants) provide a variety of commercially available proprietary post-construction stormwater management technologies for both water quality treatment and quantity control. Many proprietary systems are useful on small sites and space-limited areas where there is not enough land or room for other stormwater treatment alternatives. Proprietary systems can also be used as pretreatment in a treatment train. Each applicant will have information about the best use and application of the technology that they manufacture. For review of this technology under the PCSTAP, the applicant must submit a complete PCSTAP application package that includes the technology engineering report and performance testing and reporting. Additional information about these elements can be found below.

Technology Engineering Report

The applicant prepares a technology engineering report on their technology or product following the PCSTAP criteria. The report must clearly identify the performance claims including:

- Reduction of pollutants from stormwater runoff;
- Applications of the technology to be verified, including siting, location, land use, and land activity limitations or restrictions;
- Full range of operating conditions for the technology;
- Minimum maintenance requirements to sustain performance; and
- Capital and projected annual costs, including operation and maintenance (O&M) costs.

Performance claims must include quantitative data (e.g., load reductions and removal efficiencies for specific pollutants or categories of pollutants, application and design criteria, costs, etc.). Applicants may include additional qualitative claims (e.g., advantages over other technologies, installation or maintenance considerations) provided there is evidence to support those claims. The TRC will focus on quantitative claims as they relate to pollutant load reductions. See Section 4 for the complete list of requirements for the technology engineering report.

Performance Testing and Reporting

The vendor/manufacturer completes performance field testing of the technology that meets the PCSTAP criteria. This includes:

- Performance testing project plan;
- Testing data including rainfall data, and influent & effluent concentrations;
- Statistical analysis of the data;
- Data quality assurance summary;
- Documentation of maintenance performed during the study period; and
- Evaluation of the results.

See Section 5.1 for the complete list of requirements for performance testing reporting.

Performance testing should be performed or managed in person by a qualified independent engineering or testing firm (as consistent with state law on professional qualifications), or an accredited academic institution. If the performance testing was performed by the applicant, include a written certified review by such a firm or academic institution certifying that the methodology and evaluation of data was managed in person by such firm or academic institution and was performed in accordance with accepted standards.

Consideration of data and verifiable technology claims which will and/or have occurred outside of the state of Georgia may be accepted for performance claim verification by the TRC (see Section 5.2).

3.0 TREATMENT PERFORMANCE GOALS

The District has a Water Resources Management Plan (Plan) that identifies action items for integrated water resource planning and management. These action items are implemented by local jurisdictions within the District, which are required to comply with it. Within the Plan, the Watershed-1 action item states, "… that each local government shall adopt the Model Ordinance or an equivalent ordinance at least as effective based on the guidance in the latest Georgia Stormwater Management Manual (GSMM) and Municipal Separate Storm Sewer System (MS4) permit as applicable."

The 2019 Model Ordinance for Post-Construction Stormwater Management for New Development and Redevelopment (District Model Ordinance) was drafted for use by local jurisdictions in the District and was adopted by the District Board on December 4, 2019. It contains stormwater performance standards that match the substance and language of the Georgia Environmental Protection Division (EPD) MS4 permit and the GSMM.

3.1 Stormwater Performance Standards

3.1.1 PCSTAP and the Water Quality Standard

The Water Quality Standard states that the stormwater management system shall be designed to remove at least 80% of the calculated average annual post-development total suspended solids (TSS) load or equivalent as defined in the GSMM for runoff from a 1.2 inch rainfall event. The PCSTAP is more closely aligned with the water quality standard. It characterizes a proprietary system's effectiveness in removing TSS from stormwater runoff for an intended application (land use) and compares test results with vendor performance claims.

3.1.2 PCSTAP and the Runoff Reduction Standard

The District Model Ordinance states that stormwater runoff quality/reduction shall be provided by runoff reduction and/or water quality based on site conditions. Runoff reduction practices are stormwater best management practices (BMPs) used to disconnect impervious and disturbed pervious surfaces from the stormwater management system, thereby reducing post-construction stormwater runoff rates, volumes, and pollutant loads. Stormwater management systems should first be designed for the Runoff Reduction Standard which states, "The stormwater management system shall be designed to retain the first 1.0 inch of rainfall on the site using runoff reduction methods, to the maximum extent practicable." If this standard can be met, then additional water quality shall not be required. To the extent runoff reduction has been determined to be infeasible for all or a portion of the site, then the water quality standard shall apply for the remaining runoff from a 1.2 inch rainfall event and must be treated to remove at least 80% of the calculated average annual post-development TSS load or equivalent as defined in the GSMM.

The PCSTAP will not provide a letter of concurrence to proprietary systems for volume or runoff reduction. A literature review of published studies and evaluation of existing protocols for established proprietary device evaluation programs was conducted to evaluate whether runoff reduction should be incorporated into the PCSTAP to meet the updated runoff reduction standard in the District Model Ordinance.

The literature review identified two sources that address runoff reduction in stormwater technologies. Battiata et al. (2010) noted that the "the runoff reduction method further accounts for volume reduction through the use of various BMPs that have a demonstrated capability to reduce the overall volume of runoff based on the post-development condition. Runoff can be reduced via canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration. The use of these practices in conjunction with the site design incentives noted above will reduce the volume of runoff used to compute the annual pollutant load generated by the site." Stormwater technologies typically do not provide these functions, with the exception of soil infiltration that must be evaluated at the site scale. Braswell et al. (2018) noted that "the [proprietary system] does not have significant mechanisms for volume reduction" indicating that there would be no runoff reduction benefit.

The established proprietary device evaluation programs incorporated into the evaluation of existing protocols were Washington's Department of Ecology Technology Assessment Protocol (TAPE) (Washington Stormwater Center, 2023) and the New Jersey Corporation for Advanced Technology (NJCAT) (NJDEP, 2023). TAPE and NJCAT do not certify that stormwater treatment technologies provide volume or runoff reduction. These established programs instead certify treatment for TSS, total petroleum hydrocarbons (TPH), dissolved copper, dissolved zinc, total phosphorus, and turbidity.

Based on this research, the PCSTAP will not provide a letter of concurrence to proprietary systems for volume or runoff reduction.

3.2 Treatment Train, Retrofits, and Pretreatment Applications

Vendors/manufacturers may also provide claims and evaluate their products for use in treatment trains, pretreatment (including gross solids removal), and retrofit applications where an 80% TSS removal may not be required. Some considerations might include:

- Provides mostly coarse solids removal (> 500 μm) including all litter and debris;
- Improves the effectiveness, extends the useful life, or extends the maintenance cycle of a downstream treatment device or infiltration facility; or
- Results in a more cost-effective treatment system.

4.0 TECHNOLOGY ENGINEERING REPORT REQUIREMENTS

At a minimum, the technology engineering report must contain the following information:

4.1 Technology / Product Specifications

The technology specifications must include physical, chemical, and biological processes; O&M requirements; process flow diagrams and algorithms; equipment drawing and specifications;

existing test plans, performance data, certifications; and a description of process inputs and outputs. More specifically, the following information should be provided in the specifications:

1. General description of the technology, including all components and processes;
2. Underlying scientific and engineering principles for the technology. Describe how the technology functions in treating stormwater runoff. Include information about physical, chemical, or biological treatment processes such as filtration, adsorption/absorption, settling, or inertial separation that may be involved in the treatment process;
3. Minimum siting and design requirements specific to environmental conditions in Georgia (e.g., soil, rainfall patterns) in order to achieve the stated performance, including pollutants that should and could be addressed; minimum and maximum influent concentrations; pollutants that will not be addressed or that may be increased; and siting, location, land use, and land activity limitations or restrictions;
4. A discussion of the advantages of the technology when compared to conventional stormwater systems providing comparable stormwater control;
5. Standard drawings, including a schematic of the technology and a process flow diagram;
6. A discussion of technology hydraulics and system sizing to meet performance standards and goals with respect to the District Model Ordinance and the GSMM (e.g., ability to handle the water quality volume, rate of runoff, type of storm, or recharge requirements);
7. Clear specifications of the sizing process with respect to the District Model Ordinance and the GSMM, including appropriate flow rates if applicable;
8. If applicable, recommendations for appropriate vegetation to plant in the technology;
9. Full range of operating conditions for the technology, including minimal, maximal, and optimal conditions to achieve the performance goals and standards, and for reliability of the technology;
10. The technology's expected lifespan and bypass requirements;
11. Maintenance requirements to sustain performance and safe operation;
12. Technology limitations, such as performance limits for control of certain water quality parameters, and predicted impacts from construction, operation, and maintenance of the technology;
13. Identified secondary impacts (e.g., toxicity to aquatic life);
14. Discussion of the generation, handling, removal, and disposal of discharges, emissions, and waste byproducts in terms of mass balance, maintenance requirements, and cost;
15. Discussion of pretreatment and preconditioning of stormwater, if appropriate to achieve stated performance of the technology or product;
16. Identification of any special licensing or hauling requirements, safety issues, and access requirements associated with operation or maintenance of the technology;
17. Capital and projected annual costs, including O&M costs; and
18. Executive summary.

4.2 Specific Performance Claims

An applicant must make a performance claim that identifies the technology's intended use and predicts the technology's capabilities to remove contaminants and/or control the quantity of stormwater runoff for a given flow rate. Performance claims should be objective, quantifiable, replicable, and defensible. Claims that are overstated should be avoided, as they may not be achievable.

A sample stormwater treatment performance claim might be structured as follows:

> *"The Model T system can capture and treat the WQ volume for up to a 1 acre runoff area that is up to 100% impervious. Under these conditions, a total suspended solid (TSS) removal rate of W% ± X% (at a 95% confidence level) can be achieved with inflow TSS concentrations greater than 100 mg/L for flow rates of Y cfs with a median or d_{50} particle size of Z µm."*

Appendix A provides the permitted methods for calculating pollutant removal.

5.0 PERFORMANCE TESTING REPORTING

Performance testing includes the use of standardized test methods and procedures, a data quality assurance and control plan, data collection, and statistical tests of the data. The procedures for performance testing will be reviewed and validated to ensure that the procedures for collecting, handling, and analyzing samples and data will be accurate, precise, representative, complete, and comparable.

5.1 Reporting Requirements

All performance testing reporting must include the following:

1. Statement of performance testing objectives;
2. Performance testing project plan (see below);
3. Standardized test methods and procedures used to collect and analyze data;
4. Quality assurance/quality control (QA/QC) objectives and procedures;
5. Date and time when event-based flow-weighted samples were collected;
6. Rainfall data (include antecedent dry period, total rainfall during sampling event, and rainfall intensity and duration);
7. Comparison of rainfall data to Georgia rainfall criteria included in the GSMM;
8. Comparison of collected aliquots to sampling criteria;
9. Comparison of influent to effluent pollutant concentrations;
10. Particle size distribution (PSD) analysis including the d_{50} for event-based flow-weighted influent samples;
11. Demonstration of scour prevention (if applicable);
12. An estimation of annual average TSS removal;
13. Statistical data evaluation including the coefficient of variation (CV) for TSS removal;
14. Discussion of whether the QA/QC objectives were met;
15. Discussion on deviations from any sampling procedures;
16. Data quality assurance summary (field and laboratory QA/QC results);

17. Maintenance performed during the study period, including activities and frequency;
18. Total amount (estimated dry weight) of sediment and floatables removed and sediment depth prior to each cleaning;
19. Media replacement and/or cleaning, if applicable;
20. Evaluation of results; and
21. Executive summary.

The performance testing project plan should include the following:

- Describe and provide a scaled plan view of the testing site, indicating all buildings, land uses, storm drain inlets, and other control devices;
- Include a description of the site drainage area, percent impervious area, percent impervious area directly connected to the test site, description of the path of storm water flow to the test site, type of activities conducted, pollutant sources, soil type, geological and hydrological conditions, existing control structures, and a site drainage plan;
- Estimate the impervious area within the drainage area and show sample inflow and outflow points;
- Describe how the treatment technology was selected, designed, and appropriately sized for the specific field test site;
- Specify the location of flow devices and samplers in relationship to the inlets and outlets of the stormwater technology; and
- Demonstrate that flow devices and samplers are installed and positioned properly to ensure that samples are representative of influent runoff and effluent runoff.

5.2 Use of Other Performance Testing Data

Field testing and the resulting data and verifiable technology claims which will and/or have occurred outside of the state of Georgia may be accepted for performance claim verification by the TRC with the following conditions:

1. Adherence to the protocol’s performance testing reporting requirements under 5.1 (above);
2. Hydrological differences between the actual field test location(s) versus a representative location within Georgia must be accounted for with proper engineering design using rainfall data analyses and appropriate water quality volume treatment criteria. Only field test data from other regions within North America which have a Type II rainfall pattern will be considered; and
3. Appropriate PSD that is applicable to the soil conditions for a representative location within Georgia (for consideration of potential applications where the site conditions are less than 90% impervious cover). This includes showing 80% (or whatever the claim being made is) removal of TSS with a d_{50} of ≤ 44 μm.

Performance claims submitted to TAPE, NJCAT, or North Carolina’s New Stormwater Technology (NEST) Program (NCDEQ, 2023) for verification are examples of field studies occurring outside the state of Georgia.

6.0 SAMPLING DESIGN CONSIDERATIONS

This section describes test procedures that can be used to evaluate a technology's performance.

6.1 Test Site Selection Considerations

Select field test sites that are consistent with the technology's intended applications (land uses) and geographical location in Georgia (e.g., Piedmont region) that will provide influent concentrations typical of stormwater for those land use types. Testing at multiple sites is recommended. Additional test site considerations include:

- Field test site drainage area, tributary impervious cover, and land uses (roadway, commercial, high-use site, residential, industrial, etc.);
- Potential pollutant sources in the drainage area (e.g., parking lots, roofs, landscaped areas, sediment sources, exterior storage, or process areas);
- Availability of baseline stormwater quality information to characterize conditions at the site. For sites that have already been developed, it is recommended that baseline data be collected to provide a sizing basis for the device and to determine whether site conditions and runoff quality are conducive to performance testing;
- Drainage area flow rates (i.e., water quality design flow, 2-year, 10-year, and 100-year peak flow rates) at 15 minute and 1 hour time steps as provided by an approved continuous runoff model;
- Bypass requirements with flow rates and/or flow splitter designs necessary to accommodate the treatment technology;
- Site adequacy for sampling, flow measurement access, and telephone/AC power, if needed; and
- Any potential adverse site conditions such as climate, tidal influence, high ground water, rainfall pattern, erosion, high spill potential, illicit connections to stormwater drainage areas, industrial runoff, etc.

6.1.1 Sampling Locations

To accurately measure system performance, samples must be collected from both the inlet and outlet from the testing site. The influent to the treatment technology should be sampled as close as possible to the treatment device inlet. Samples should represent the total runoff from the drainage area and should not include debris and large particles. To ensure that samples represent site conditions, design the test site so that influent samples can be collected from a pipe that conveys the total influent to the unit. To avoid skewing influent pollutant concentrations, the influent should be sampled at a location unaffected by accumulated or stored pollutants in, or adjacent to, the treatment device.

The effluent should be sampled at a location that best represents the treated effluent. If bypass occurs, bypass flows must be measured, and bypass loadings calculated using the pollutant concentrations measured at the influent station. In addition, be aware that the settleable or floating solids, and their related bound pollutants, may become stratified across the flow column in the absence of adequate mixing. Samples should be collected at a location where the stormwater flow is well-mixed.

6.1.2 Stormwater Test Site Design and Sizing

Sizing of the test site must be based on meeting applicable performance goals by treating the water quality volume or the design flow rate coinciding with treating the water quality volume in accordance with the Water Quality Standard in the District Model Ordinance and the GSMM.

6.2 Storm Event Criteria for Sampling

A minimum number of 15 storms or discrete flow-weighted sampling events is required per test site. The storms should be representative of the entire annual hydrologic range of storm events and constitute at least 20% of the total annual rainfall. It is recommended that sampling events be evenly distributed over the testing period to capture seasonal influences on storm conditions and system performance. Each storm event for sampling must meet the following criteria:

- At least 0.15 inches of total rainfall;
- A minimum inter-event period of 6 hours, where cessation of flow from the system begins the inter-event period;
- A minimum storm duration of 1 hour;
- Flow-weighted composite samples covering a minimum of 70% of the total storm flow, including as much of the first 20% of the storm as possible. *Note: composite samples are not appropriate for all parameters (see below);*
- A minimum of 10 water quality samples (i.e., 10 influent and 10 effluent samples) should be collected per storm event. For composite samples, a minimum of 5 aliquots is acceptable (i.e., 2 composites with 5 aliquots = 10 water quality sample minimum or 1 composite sample with 10 aliquots = water quality sample minimum). If a storm is too small for 10 samples, an average of 10 samples per storm may be substituted. However, more than 10 samples per storm event should be collected wherever possible;
- Flow measurements must be taken to predict or calculate pollutant loads. The mass of pollutants in the discharge should be based on flow rates and pollutant concentrations or another reasonable approach; and
- At least two storm events should be greater than 75% of the design storm used to size the technology.

6.3 Stormwater Sampling Methods

Programmable automatic flow samplers with continuous flow measurements should be used unless it is demonstrated that alternate methods are superior or that automatic sampling is infeasible. Grab samples should only be used for certain constituents, in accordance with accepted standard sampling protocols, unless it is demonstrated that alternate methods are superior. Constituents that typically require grab sampling include pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, TPH, *Escherichia coli*, total coliform, fecal coliform, fecal streptococci, and enterococci. Grab samples analyzed for TSS will not be accepted as substitutions for event-based flow-weighted composite samples analyzed for TSS.

Note: Time-weighted composite samples are not acceptable, unless flow is monitored and the event mean concentration (EMC) can be calculated from the data.

6.4 Sampling for Total Suspended Solids (TSS)

6.4.1 Sampling Considerations

To determine percent TSS reduction, the samples must represent the vertical cross section (be a homogeneous or well-mixed sample) of the sampled water at the influent and the effluent of the device. The selection of the sampling location, its homogeneity, and placement of and sizing of the sampler tubing in the stormwater must be conducted with care to ensure accurate representativeness of the samples.

6.4.2 Particle Size Distribution (PSD)

Treatment technologies must be capable of removing TSS across the size fraction range typically found in urban runoff.

For field testing performance results, an analysis of the inflow PSD is required. The purpose of the requirement is to collect consistent information on particle size that will aid in evaluating system performance. PSD measurements will provide a frame of reference for comparing variability in performance between storms and between different sites. These measurements are an important tool with which to assess performance since performance is likely to be affected by particle size. For example, it is likely that performance will drop with a substantial increase in fine soil particles. Conversely, it is anticipated that performance will be high with sandy sediments. Therefore, all TSS analysis and particle size distribution shall include only particles that are smaller than 500 µm. Any removal efficiencies for particles above 500 µm should NOT be included in the 80% TSS claim but should be included as a separate removal for information purposes. It is assumed particles above 500 µm will receive a greater than 80% removal efficiency.

Laser diffraction methods are effective for analyzing particles smaller than 250 µm. Therefore, particles greater than 250 µm must be removed with a sieve prior to PSD analysis. These large-sized particles will be analyzed separately to determine the total mass of particulates greater than 250 µm. This protocol functions as a supplement to the existing protocols provided by the manufacturers of laser diffraction instruments such that the larger-sized particles in the sample can also be measured.

For consideration of potential applications where the site conditions are less than 90% impervious cover, a treatment technology must show the capability of removing TSS with a d_{50} of ≤ 44 µm. For sites in the Piedmont region of Georgia with less than 90% impervious cover, the assumed PSD is 20-60-20 or the lab surrogate Sil-Co-Sil 106 (Table 1).

Table 1: Typical Gradation for Sil-Co-Sil (US Silica, 2023)

U.S. Mesh	Sieve Size (µm)	Percent Cumulative Retained (%)
100	150	0
140	105	0.2 to 0.5
200	75	0.6 to 3.4
325	44	4.4 to 21

6.4.3 Accumulated Sediment Sampling Procedures

As appropriate to demonstrate facility performance, and to confirm the stormwater sampling-based percent removal data, the sediment accumulation rate can be measured. Practical measurement methods may be utilized, such as measuring sediment depth.

The following sediment constituents should be analyzed:

- Percent total solids;
- Total volatile solids; and
- PSD.

The sediment sample should be a composite from several samples (at least four) collected from various locations within the treatment system to ensure that the sample represents the total sediment volume in the treatment system. For QA/QC purposes, collect a field duplicate sample (see following section on field QA/QC). The sediment sample should be kept at 4°C during transport and storage prior to analysis. If possible, remove and weigh (or otherwise quantify) the sediment deposited in the system.

Analyze the grain size using the methods described for the PSD analysis above. Quantify or otherwise document gross solids (debris, litter, and other particles exceeding 500 microns in diameter). Volumetric sediment measurements and analyses should be useful in determining maintenance requirements, TSS mass balance, and whether the sediment quality and quantity are typical for the application.

7.0 DATA QUALITY ASSURANCE AND QUALITY CONTROL

QA/QC describe the measures that will be employed to ensure the representativeness, comparability, and quality of field samples for the performance testing of stormwater technologies. The following elements should be included in the QA/QC plan and procedures:

1. Equipment decontamination;
2. QC samples;
3. Preservation and handling;
4. QA on sampling equipment (e.g., calibration of automatic samplers and flow measurement devices);
5. Recordkeeping; and
6. Health and safety plan.

Appendix D has resources for developing QA/QC plans.

7.1 Equipment Decontamination

Describe how sampling equipment (sampler head and suction tubing) will be decontaminated between sampling events to prevent sample cross-contamination. It is recommended that the suction tube be replaced at least once during the test period and more frequently if runoff is highly contaminated.

7.2 Quality Control Samples

1. Equipment rinsate blanks: Equipment rinsate blanks should be collected to verify that equipment is not a source of sample contamination. Equipment rinsate blanks are collected by passing reagent-grade water through monitoring equipment and collecting samples for chemical analyses. These samples are to be analyzed as regular samples with all appropriate quality control performed.

   It is recommended that equipment rinsate blanks be collected at the inlet monitoring station where stormwater is expected to contain the highest contaminant concentrations. However, if the inlet station is difficult to access (e.g., confined space entry required), the rinsate blank may be collected from the outlet station. Two separate rinsate blanks should be collected during the initial equipment startup and testing, and at least one additional blank should be collected midway through the sampling program. More frequent blank samples may need to be collected if site conditions warrant (e.g., following an event with unusually high contaminant concentrations).

   The equipment rinsate blank collection procedure should be described in the QA/QC plan. Include a description of the location and number of samples that will be collected, sample collection and processing procedures, and sample documentation (e.g., length of time that sampler was in place prior to collecting the blank, how much stormwater passes through the sample prior to collecting the rinsate blank). At a minimum, rinsate blanks should be collected after at least one storm event has been sampled (to "contaminate" the equipment) and after the equipment has been decontaminated according to the procedures specified in the QA/QC plan. The two initial blanks may be collected after a volume of stormwater similar to the volume that will be collected during a typical sampling event has been passed through the sampling equipment during the equipment testing process.

   It is recommended that the equipment rinsate blank should be at a "not detected" level. If they are not, then they will have to be taken into account in determining whether the measurement quality objectives (MQO's) have been met. In the QA/QC plan, describe corrective actions that will be taken (e.g., modifying decontamination procedures, replacing suction tubing) if contamination is found in the blank.

2. Field duplicate samples: A field duplicate is a second independent sample collected at the same location. Field duplicates are primarily used to assess the variation attributable to sample collection procedure and sample matrix effects. The QA/QC plan must include a description of techniques used to collect duplicate samples and specify the collection frequency. At a minimum, collect field duplicate samples for 10% of the sampled storm events.

7.3 Sample Preservation and Handling

Samples are to be preserved in accordance with US EPA-approved methods (US EPA 1983), or Standard Methods (APHA, AWWA, WEF 1999). Preservation must be provided during sample collection, as well as during transport. Describe how cooling the automatic samplers will be conducted to maintain low temperatures throughout the sample collection period.

Provide a table in the QA/QC plan that lists sample container material, sample preservation, and holding time limits for the analyzed pollutants. EPA methods should be followed for sample container selection, preservation requirements, and target pollutant holding time limits. Precleaned sample bottles should be obtained directly from the analytical laboratory. If the vendor proposes to obtain bottles from another source, provide a detailed bottle-cleaning procedure. Also, describe procedures that will be employed to label and track samples from collection through delivery to the analytical laboratory. Provide a sample chain of custody form in the QA/QC plan.

Samples collected as discrete flow-weighted aliquots may need to be manually composited following the sampling event. If samples will be manually composited, describe compositing procedures to prevent sample cross-contamination. Also, certain parameters may not be able to be composited, and must be collected as grab samples using an approved method. Describe how these samples will be collected and at what intervals they will be collected during the storm event.

7.4 Equipment Calibration

Describe the field equipment calibration schedule and methods, including automatic samplers, flow monitors, and rainfall monitors. The accuracy of the flow meters is very important so their calibration should be carefully conducted by the site professional in accordance with manufacturer's recommendations.

7.5 Recordkeeping

Maintain a field logbook to record any relevant information noted at the collection time or during site visits. Include notations about any activities or issues that could affect the sample quality (e.g., sample integrity, test site alterations, maintenance activities, and improperly functioning equipment). At a minimum, the field notebook should include the date and time, field staff names, weather conditions, number of samples collected, sample description and label information, field measurements, field QC sample identification, and sampling equipment condition, as well as any measurements tracking sediment accumulation. In particular, note any conditions in the tributary basin that could affect sample quality (e.g., construction activities, reported spills, other pollutant sources). Provide a sample field data form in the QA/QC plan.

7.6 Health and Safety Plan

A health and safety plan should be developed and included with the QA/QC plan covering installation, operation and maintenance of the technology. Specifically, the plan should address hazard identification and mitigation, engineered controls and procedures, personal protective equipment, and training. Where related to the stormwater technology, the health and safety plan should also cover the collection of stormwater samples in confined spaces (manholes, storm sewer lines, and utility vaults); collection of high flow stormwater samples from culverts, drainage channels, and sedimentation basins during storms; and chemical, biological or physical hazards associated with the technology.

8.0 STATISTICAL TESTING OF DATA AND DATA REDUCTION

Statistical testing should be performed on performance claim data to ensure that data are reliable, significant, and within confidence limits. When testing at specified ranges of flow and contaminant concentrations and when normal parametric statistical analysis is performed, CV should be within ±10% for efficiency data, wherever possible. A larger range of CV may be allowed where justified. The vendor must demonstrate that the data set is normally distributed prior to using normal parametric statistical analysis. Data sets that are not normally distributed will need to be evaluated using nonparametric statistical analysis and may require further analysis and review.

The *Data Quality Assessment Guidance Manual* (EPA QA-G9) includes an array of statistical methods, e.g., parametric analysis (mean, standard deviation, confidence intervals, and Z-statistic), comparison of populations (analysis of variance, box-whisker plots, and Tukey-tests), which can be used to compare and validate data sets. EPA QA-G9 can be found at: https://www.epa.gov/sites/production/files/2015-08/documents/g9s-final.pdf.

Recommended steps for analyzing the data include:

1. Determine a level of significance (α),
2. Test the paired influent and effluent data's distributions using the Anderson-Darling test,

If the paired influent and effluent data have a normal distribution:

3. Determine if the variance for the influent and effluent data is equal,
4. Use the student's t-test (with equal or unequal variance) to determine if there are significant differences between the influent and effluent data, and
5. Calculate the confidence interval for the average or mean difference between the influent and effluent data using the student's t-test.

If the paired influent and effluent data do not have a normal distribution:

3. Determine if the differences between the influent and effluent data are symmetrical,
4. For symmetrical data, use the Wilcoxon sign rank test to determine if the influent and effluent data are significantly different,
5. For non-symmetrical data, use the sign test to determine if the influent and effluent data are significantly different, and
6. Calculate the confidence interval for the mean difference between the influent and effluent data using the sign test.

The bootstrap method can be used to identify a more definitive confidence interval for the mean difference between paired influent and effluent data. The permutation method can be used to identify a more definitive p-value for any hypothesis test (e.g., student's t-test, Wilcoxon sign rank test, sign test).

9.0 References

Atlanta Regional Commission. (2016). *Georgia Stormwater Management Manual: Volume 2*. Retrieved from www.georgiastormwater.com

Battiata, J., Collins, K., Hirschman, D., & Hoffmann, G. (2010). The runoff reduction method. *Journal of Contemporary Water Research & Education*, *146*: 11-21. https://doi.org/10.1111/j.1936-704X.2010.00388

Braswell, A.S., Anderson, A.R., & Hunt, W.F. (2018). Hydrologic and water quality evaluation of a permeable pavement and biofiltration device in series. *Water*, *10*(33). https://doi.org/10.3390/w10010033

New Jersey Department of Environmental Protection. (2023). *Stormwater manufactured treatment devices*. https://dep.nj.gov/stormwater/stormwater-manufactured-treatment-devices/

North Carolina Department of Environmental Quality. (2023). *2023 North Carolina stormwater control measure credit document*. Retrieved from https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/stormwater/stormwater-program/stormwater-design-manual

US Silica. (2023). *Sil-Co-Sil® ground silica*. https://www.ussilica.com/products/sil-co-silr

Washington Stormwater Center. (2023). *TAPE*. https://www.wastormwatercenter.org/stormwater-technologies/tape/

APPENDIX A: TREATMENT EFFICIENCY CALCULATION

- For technologies sized for long residence times (hours versus minutes), cumulative performance of several storms, wet season or annual time periods must be considered.
- For short residence times (several minutes), event mean comparisons are recommended. For discrete short-time step residence times (few minutes), lag times should be considered for influent/effluent comparisons.

Individual storm reduction in pollutant concentration.

Calculate the reduction in pollutant concentration during each individual storm as:

> *100 (flow-weighted influent concentration – flow-weighted effluent concentration) / flow-weighted influent concentration*

Individual storm reduction in pollutant loading.

Calculate the reduction in pollutant loading during each individual storm as:

> *100(A-B)/A*
>
> where: A= (Storm 1 Influent concentration) * (Storm 1 total volume)
>
> B= (Storm 1 Effluent concentration) * (Storm 1 total volume)

Aggregate pollutant loading reduction.

Calculate the aggregate pollutant loading removal for all storms sampled as:

> *100(A-B)/A*
>
> where: A= (Storm 1 Influent concentration) * (Storm 1 volume) + (Storm 2 Influent concentration) * (Storm 2 volume) +…(Storm n influent concentration) * (Storm n volume)
>
> B = (Storm 1 Effluent concentration) * (Storm 1 volume) + (Storm 2 Effluent concentration) +…(Storm n Effluent concentration) * (Storm n volume)
>
> Note: Concentrations are flow-weighted, and flow = or total storm volume (vendor's choice)

Annual average pollutant loading estimation

Estimate the annual average pollutant by developing a function of storm volume vs. pollutant loading reduction and using either accumulated daily rainfall data or accumulated 15-minute intensity data for a typical year to calculate the total and annual average pollutant reduction.

APPENDIX B: PILOT USE DESIGNATION PROTOCOL

Applicants shall incorporate into the Test Plan and submit as much of the following information as possible to be considered for pilot use designation:

Technology Description

- The applicant shall describe the device's biological, chemical, or physical treatment mechanisms. Example treatment mechanisms include nitrification, adsorption, and sedimentation. The description shall include a summary of the technology's full range of operating conditions, expected lifespan, performance limitations, and secondary toxic impacts (e.g., toxicity to aquatic life).
- The applicant shall provide standard drawings of the device. The drawings should include the construction materials and a table or description of the device's typical dimensions. If the device is custom-built for each project site, the applicant should note this on the drawings. The applicant shall also note if any of the construction materials may leach pollutants (e.g., copper, zinc, etc.).
- The applicant shall provide a detailed description of the hydraulic loading and system sizing calculations. These calculations must follow the GSMM (e.g., ability to handle the water quality volume, rate of runoff, type of storm, or recharge requirements). The applicant may provide an example calculation for a typical project site in Georgia. The applicant can find a copy of the most current GSMM at www.georgiastormwater.com.
- The applicant shall describe the device's bypass mechanisms and provide any applicable calculations for sizing the bypass mechanism.
- If applicable, the applicant shall provide a list of recommended plants to include in the technology.
- The applicant shall describe any site installation (e.g., location, in-situ soils, etc.) and pre-treatment requirements. The applicant shall also describe any site requirements (e.g., AC power, constant access to monitoring equipment, etc.) to ensure hydrologic and water quality data are collected correctly.
- The applicant shall provide expected treatment capabilities and/or a list of pollutants the device is expected to treat.
- The applicant shall quantify the expected capital constructions associated with device. An expected range of costs is acceptable.
- The applicant shall provide expected operation and maintenance (O&M) costs, requirements, frequencies, and durations associated with the device.

Experimental Design

- The applicant shall describe the device's typical monitoring locations (e.g., inlet, outlet, bypass) as well as the equipment used and how the data are collected at these monitoring locations. The applicant shall identify the types of data collected at the typical monitoring locations. The applicant shall explain how the typical monitoring locations avoid backwater, tidal, and groundwater influences. The applicant may provide photos of previous monitoring studies as examples for a typical monitoring setup.

- The applicant shall describe how sediment and floatables accumulated in the device will be measured and sampled.
- The applicant shall describe how precipitation data (e.g., depth, intensity) will be collected.
- The applicant shall provide an expected duration of monitoring. Note the applicant must sample a minimum of 15 storm events to receive PCSTAP concurrence. PCSTAP defines a storm as a precipitation event with at least 0.15 inches of rainfall over the course of at least one hour and has an inter-event period of at least six hours. The storms should be representative of the entire annual hydrologic range of storm events and constitute at least 20% of the total annual rainfall. It is recommended that sampling events be evenly distributed over the testing period to capture seasonal influences on storm conditions and system performance.
- The applicant shall list all applicable test methods and procedures used to collect and analyze the data.
- The applicant shall describe the anticipated statistical methods that will be used to analyze the data.
- The applicant shall provide general quality assurance and quality control (QA/QC) objectives and tasks for field and laboratory results. QA/QC tasks and objectives should discuss equipment decontamination and calibration, sample preservation and handling, recordkeeping, and the health and safety of project team members. The applicant may submit a previous quality assurance project plan (QAPP) as an example.
- The applicant shall provide a sample field logbook and chain of custody form.
- The applicant shall provide a timeline for designing, installing, and monitoring the technology. This timeline should describe anticipated tasks and durations.
- The applicant may provide results from previous laboratory and/or field studies as supporting documentation.

APPENDIX C: APPLICABLE TEST METHODS AND PROCEDURES

American Society for Testing and Materials (ASTM) Methods

D3370, Practices for Sampling Water.

D4840, Guide for Sampling Chain of Custody Procedures.

D4841, Practice for Estimation of Holding Time for Water Samples Containing Organic and Inorganic Constituents.

D5612-94 (1998), Standard Guide for Quality Planning and Field Implementation of a Water Quality Measurement Program.

D5847-99a , Standard Practice for Writing Quality Control Specifications for Standard Test Methods for Water Analysis.

D5851-95, Standard Guide for Planning and Implementing a Water Monitoring Program.

D6145097, Standard Guide for Monitoring Sediments in Watersheds.

D3977-97, Standard Test Method for Determining Sediment Concentration in Water Samples.

D5907-96a, Standard Test Method for Filterable and Non-filterable Matter in Water.

D4841-88 (1998), Standard Practice for Estimation of Holding Time for Water Samples containing Organic and Inorganic Constituents.

PS74-98, Provisional Standard Test Method for Oil and Grease (Solvent Extractable Substances in Water by Gravimetric Determination.

D5790-95, Standard Test Method for Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectroscopy.

D6362-98, Standard Practice for Certificates of Reference Materials for Water Analysis.

D6104-97, Standard Practice for Determining the Performance of Oil/Water Separators Subjected to Surface Water Run-off.

F625-94, Standard Practice for Classifying Water Bodies for Spill Control Systems.

D5906-96, Standard Guide for Measuring Horizontal Positioning During Measurements of Surface Water Depths.

D5073-90 (1996), Standard Practice for Depth Measurement of Surface Water.

D5413-93 (1997), Standard Test Methods for Measurement of Water Levels in Open-Water Bodies.

D5243-92 (1996), Standard Test Method for Open-Channel Flow Measurement of Water Indirectly at Culverts.

D5130-95, Standard Test Method for Open-Channel Flow Measurement of Water Indirectly by Slope-Area Method.

D5129-95, Standard Test Method for Open Channel Flow Measurement of Water Indirectly by Using Width Constrictions.

D3858-95, Standard Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method.

D5614-94 (1998), Standard Test Method for Open Channel Flow Measurement of Water with Broad-Crested Weirs.

D5242-92 (1996), Standard Test Method for Open-Channel Flow Measurement of Water with Thin-Plate Weirs.

D5640-955, Standard Guide for Selection of Weirs and Flumes for Open-Channel Flow Measurement of Water.

D5089-95, Standard Test Method for Velocity Measurements of Water in Open Channels with Electromagnetic Current Meters.

D4409-95, Standard Test Method for Velocity Measurements of Water in Open Channels with Rotating Element Current Meters.

D5390-93 (1997), Standard Test Method for Open Channel Flow Measurement of Water with Palmer-Bowlus Flumes.

D1941-91 (1996), Standard Test Method for Open Channel Flow Measurement of Water with the Parshall Flume.

D4375-96, Standard Practice for Basic Statistics in Committee D-19 on Water.

E178, Practice for Dealing with Outlying Observations.

F1779-97, Standard Practice for Reporting Visual Observations of Oil on Water.

F1084-90 (1995), Standard Guide for Sampling Oil/Water Mixtures for Oil Spill Recovery Equipment.

Table 2: Typical Analyses and Practical Quantitation Limits (PQLs) for Constituents (US EPA 1983, 1993,1994, 2007, 2018a, 2018b; USGS 2014)

Constituent	Pollutant name	Analysis method	PQL	Maximum holding time
Nutrients and sediment				
NH_3	Ammonia-nitrogen	EPA Method 350.1 Rev. 2.0	0.50 mg/L	28-days
$NO_{2,3}$	Nitrate-nitrite nitrogen	EPA Method 353.2 Rev. 2.0	0.50 mg/L	28-days
$O\text{-}PO_4^{3-}$	Ortho-phosphate	EPA Method 365.1, Rev. 2.0	0.02 mg/L	48-hours
ON	Organic nitrogen	$ON = TKN - NH_3$	-	-
PBP	Particulate-bound phosphorus	$PP = TP - O\text{-}PO_4^{3-}$	-	-
SSC	Suspended sediment concentration	SM 2540 E-1997	2.5 mg/L	7-days
TP	Total phosphorus	EPA Method 365.1	0.20 mg/L	28-days
TKN	Total Kjeldahl nitrogen	EPA Method 351.2 Rev. 2.0	1.5 mg/L	28-days
TN	Total nitrogen	$TN = TKN + NO_{2,3}$	-	-
TSS	Total suspended solids	SM 2540 D-1997	2.5 mg/L	7-days
Turbidity	-	SM 2130 B- 2001	1 NTU	48-hours
Metals				
Cd	Cadmium	EPA Method 200.8 Rev. 5.4 EPA Method 200.9 Rev. 2.2	0.50 µg/L	6-months
Cu	Copper	EPA Method 200.7 Rev. 4.4	20 µg/L	6-months
		EPA Method 200.8 Rev. 5.4 EPA Method 200.9 Rev. 2.2	2.0 µg/L	
Cr	Chromium, Total	EPA Method 200.7 Rev. 4.4	10 µg/L	24-hours
		EPA Method 200.8 Rev. 5.4	5 µg/L	
Fe	Iron	EPA Method 200.7 Rev. 4.4	50 µg/L	6-months
Pb	Lead	EPA Method 200.7 Rev. 4.4	25 µg/L	6-months
		EPA Method 200.8 Rev. 5.4 EPA Method 200.9 Rev. 2.2	2 µg/L	6-months

Constituent	Pollutant name	Analysis method	PQL	Maximum holding time
Zn	Zinc	EPA Method 200.7 Rev. 4.4	20 µg/L	6-months
		EPA Method 200.8 Rev. 5.4	10 µg/L	6-months
Other				
BOD	Biological oxygen demand	SM 5210 B-2001	2 mg/L	18-hours
Cl	Chloride	EPA 300.0, Rev. 2.1	1 mg/L	28-days
Conductivity	-	SM 2510 B-1997	14.9 umhos/cm	28-days
PAHs	Polycyclic aromatic hydrocarbons	EPA Method 625 SW-846 8270 E	10- 30 µg/L	7-days
pH	-	SM 2320 B-1997	1 mg/L	Analyze immediately
Total hardness	-	SM 2340 C-2011	1 mg/L	6-months
TPHs	Total petroleum hydrocarbons	SW-846 8015 C	0.5- 1 mg/L	7-days
Indicator bacteria				
E. coli	Escherichia Coli	SM 9222 D-1998	1 cfu/100 mL	6-hours
Fecal coliform	-	SM 9222 D-1997	1 cfu/100 mL	6-hours
Total coliform	-	SM 9222 B-1997	1 cfu/100 mL	6-hours

Monitoring Equipment Installation Guides

Hach Company. (2021). *AS950 portable sampler installation and maintenance* (7th ed.). https://www.hach.com/p-portable-samplers-as950-standard/ASP.CXXXS141XX#resources

Teledyne ISCO. (2019). *6712 Portable samplers installation and maintenance guide*. https://store.teledyneisco.com/products/sampler-user-manuals

Teledyne ISCO. (2023). *Sampler user manuals*. https://store.teledyneisco.com/products/sampler-user-manuals

YSI. (2018). *ProSample user manual*. https://www.ysi.com/prosample

Water Flow Measurement Methods

Camp, T.R. (1946). Design of sewers to facilitate flow. *Sewage Works Journal*, *18*(1). https://www.jstor.org/stable/25030187

Teledyne ISCO. (2017). *Teledyne ISCO open channel flow measurement handbook* (8th ed.). https://www.teledyneisco.com/water-and-wastewater/open-channel-flow-measurement-handbook-request

Saatci, A. (1990). Velocity and depth of flow calculations in partially filled pipes. *Journal of Environmental Engineering*, *116*(6). https://doi.org/10.1061/(asce)0733-9372(1990)116:6(1202)

Water Quality and Hydrology Analyses and Statistical Methods

Bolks, A., DeWire, A., & Harcum, J.B. (2014). *Baseline assessment of left-censored environmental data using R: Tech Notes 10*. Prepared for the United States Environmental Protection Agency. https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_10_jun2014_r.pdf

Driscoll, E.D., Palhegyi, G.E., Strecker, E.W., & Shelley, P.E. (1989). *Analysis of storm event characteristics for selected rainfall gauges throughout the United States*. Prepared for the United States Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100F7F7.TXT

Helsel, D.R. (2012). *Statistics for censored environmental data using Minitab® and R* (2nd ed.). John Wiley & Sons. https://doi.org/10.1002/9781118162729

Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., & Gilroy, E.J. (2020). A3. Statistical methods in water resources. In *U.S. Geological Survey book 4, hydrologic analysis and interpretation*. United States Geological Survey. https://doi.org/10.3133/tm4A3

Thel-mar LLC. (2023). *Flow charts*. https://thel-mar.com/flow-charts

Water Quality Sample Analysis Methods

American Public Health Association, American Water Works Association, & Water Environment Federation. (2017). *Standard methods for the examination of water and wastewater* (L. Bridgewater, Ed.) (23rd ed.). American Public Health Association.

US Environmental Protection Agency. (1983). *Methods for chemical analysis of water and wastes*. Report No. EPA 600/4-79/020. United States Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30000Q10.TXT

US Environmental Protection Agency. (1993). *Methods for the determination of inorganic substances in environmental samples.* Report No. EPA 600/R-93/100. United States Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30002U3P.TXT

US Environmental Protection Agency. (1994). *Methods for the determination of metals in environmental samples*. Report No. EPA-600/R-94/111. United States Environmental Protection Agency. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300036HL.TXT

US Environmental Protection Agency. (2007). Method 8015C: Nonhalogenated organics by gas chromatography. In *US EPA hazardous waste test methods/SW-846*. United States Environmental Protection Agency. https://www.epa.gov/hw-sw846/sw-846-compendium#chapters

US Environmental Protection Agency. (2018a). Chapter 4: Organic analytes. In *US EPA hazardous waste test methods/SW-846*. United States Environmental Protection Agency. https://www.epa.gov/hw-sw846/sw-846-compendium#chapters

US Environmental Protection Agency. (2018b). Method 8270E: Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS). In *US EPA hazardous waste test methods/SW-846*. United States Environmental Protection Agency. https://www.epa.gov/hw-sw846/sw-846-compendium#8000series

Water Quality Sample Collection Methods

US Department of Agriculture-Natural Resources Conservation Service. (2003). *National water quality handbook*. United States Department of Agriculture. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17843.wba

US Environmental Protection Agency. (1982). *Handbook for sampling and sample preservation of water and wastewater.* Report No. EPA-600/4-82-029. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NERL&dirEntryId=40765

US Environmental Protection Agency. (1992). *NPDES storm water sampling guidance document*. Report No. EPA 833-8-92-001. United States Environmental Protection Agency. https://www3.epa.gov/npdes/pubs/owm0093.pdf

US Geological Survey. (2005). A6.7 turbidity (version 2.0). In *U.S. Geological Survey national field manual for the collection of water-quality data*. United States Geological Survey. https://doi.org/10.3133/twri09A6.7

US Geological Survey. (2006a). A4. Collection of water samples (version 2.0). In *U.S. Geological Survey national field manual for the collection of water-quality data*. United States Geological Survey. https://doi.org/10.3133/twri09A4

US Geological Survey. (2006b). A6.1 temperature (version 2.0). In *U.S. Geological Survey national field manual for the collection of water-quality data*. United States Geological Survey. https://doi.org/10.3133/twri09A6.1

US Geological Survey. (2014). A7. 7.1 fecal indicator bacteria (version 1.2). In *U.S. Geological Survey national field manual for the collection of water-quality data*. United States Geological Survey. https://doi.org/10.3133/twri09A7.1

APPENDIX D: RESOURCES FOR DEVELOPING QA/QC PLANS

Table 3: Typical Margins of Error for Stormwater Physical Characteristics

Parameter	Measurement range	Accuracy	Resolution	Equipment	Resource
Level	0.010 to 10 ft	0.01 ft between 0.01 to 5.0 ft; 0.035 ft between 0.01 to 10 ft	0.001 ft	Teledyne ISCO bubbler	Teledyne ISCO (2013b)
	0 to 30 ft	± 0.2% (0.06 ft)	< 0.007 ft	Onset HOBO pressure transducer (U20L-01)	Onset (2023c)
	0.05 to 10 ft	± 0.008 ft/ft between 0.033 to 5.0 ft; ± 0.012 ft/ft > 5.0 ft	0.002 ft	Teledyne ISCO standard area velocity meter	Teledyne ISCO (2013c)
Velocity	- 5 to + 20 ft/s	± 0.1 ft/s (2% of reading) for -5 to +5 ft/s	0.024 ft/s		
Pressure	0 to 30 psia	± 0.3% FS (0.09 psi)	< 0.003 psi	Onset HOBO pressure transducer (U20L-01)	Onset (2023c)
Temperature	32 to 230°F	-	0.20°F	Teledyne ISCO temperature probe	Teledyne ISCO (2013a)
	-4 to 122°F	± 0.79°F from 32 to 122°F	0.18°F at 77°F	Onset HOBO pressure transducer	Onset (2023c)
Rainfall intensity	0 to 10 in/hr	± 5%	0.01 in	Davis Aerocone	Davis Instruments (2023)
Rainfall depth	-	± 3% of total or ± 0.01 in (whichever is greater)	0.01 in	Davis Aerocone	Davis Instruments (2023)
	0 to 4 in	± 4.0% or ± 1 rainfall count (0.01 in) for rainfall between 0 and 2 in; ± 5% or ± 1 rainfall count (0.01 in) for rainfall between 2 and 4 in	0.01 in	Onset HOBOnet® Rainfall Sensor rain gauge, Davis® Rain Gauge Smart Sensor	Onset (2023a; 2023b)

American Society for Testing and Materials (ASTM) Standards - List, Title & Description for ASTM Methods (see ASTM appendix for specific methods applicable to Stormwater Technologies) http://www.astm.org/

Rainfall Depth and Intensity Measurement Range, Accuracy, and Resolution
Davis Instruments. (2023). *AeroCone rain collector with flat base for Vantage Pro2 and Enviromonitor (tipping spoon)*. https://www.davisinstruments.com/products/aerocone-rain-collector-with-flat-base-for-vantage-pro2

Rainfall Depth Measurement Range, Accuracy, and Resolution
Onset. (2023a). *Davis® 0.01" rain gauge smart sensor*. https://www.onsetcomp.com/products/sensors/s-rge-m002

Onset. (2023b). *HOBOnet rainfall (inches) sensor*. https://www.onsetcomp.com/products/sensors/rxw-rge-xxx

Water Level Measurement Range, Accuracy, and Resolution
Teledyne ISCO. (2013b). *730 bubbler module installation and operation guide*. https://store.teledyneisco.com/products/sampler-user-manuals

Water Level, Pressure, and Temperature Measurement Range, Accuracy, and Resolution
Onset. (2023c). *HOBO U20L water level logger (U20L-0x) user's manual*. https://www.onsetcomp.com/resources/documentation/17153-u20l-manual

Water Quality and Hydrology Monitoring Guidance
Strecker, E., Mayo, L., Quigley, M., & Howell, J. (2001). *Guidance manual for monitoring highway runoff water quality*. Prepared for the Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/41888

Strecker, E., Urbonas, B., Quigley, M., Howell, J., & Hesse, T. (2002). *Urban stormwater BMP performance monitoring: A guidance manual for meeting the National Stormwater BMP Database requirements*. https://www3.epa.gov/npdes/pubs/montcomplete.pdf

Water Temperature Measurement Range, Accuracy, and Resolution
Teledyne ISCO. (2013a). *ISCO 701 pH/temperature module installation and operation guide*. https://store.teledyneisco.com/products/sampler-user-manuals

Water Turbidity Logger QC Tasks
Campbell Scientific. (2022). *ClariVUE10*. https://www.campbellsci.com/clarivue10

Water Velocity Measurement Range, Accuracy, and Resolution
Teledyne ISCO. (2013c). *750 area velocity module installation and operation guide*. https://store.teledyneisco.com/products/sampler-user-manuals

Table 4: Typical Field Quality Control Activities and Frequencies

Activity	QC procedure	Purpose	Frequency	Reference(s)
Verify rainfall data	Measure and record rainfall depth in manual rain gauge	Correct tipping bucket rain gauge data	Every site visit	Strecker et al. (2001, 2002)
Inspect rain gauges	Inspect tipping bucket and manual rain gauges for clogging; remove clogging material as needed	Ensure future rainfall data is collected	Every site visit	
Measure water level	Check level recorded by automated sampler or pressure transducer and record measurement(s); for automated sampler with weir- measure depth of water level above (+) or below (-) weir invert; for automated sampler with area velocity meter (AVM) or using Manning's equation- measure depth of water above (+) or below (-) AVM/bubbler; for pressure transducer- measure depth of water above (+) or below (-) the reference point using a well meter or tape measurer, use bucket with known water depth to verify logger accuracy if ponded water is not present during field visit	Verify monitoring equipment is recording water level data correctly	Every site visit measure water level; for pressure transducers- verify logger accuracy at each data download	
Inspect automated sampler's desiccant	Replace desiccant when desiccant becomes saturated (i.e., pink and/or white)	Absorb moisture and prevent corrosion of equipment	As needed	Hach (2021); Teledyne ISCO (2019); YSI (2018)
Check automated sampler's peristaltic pump tubing	Inspect pump tubing for cracks and nicks and replace if present; clean pump rollers and housing	Ensure functionality of automated sampler	Pump tube alarm	

Activity	QC procedure	Purpose	Frequency	Reference(s)
Collect field blanks	Program automated sampler to collect grab samples from de-ionized water brought to field from laboratory; use sampler intake to collect grab samples; replace sampler and peristaltic pump tubing if pollutant concentrations in water quality samples ≥ practical quantitation limit	Verify monitoring equipment not contaminating water quality samples	Minimum 1 per 5 sampling events (20% of all sampled storm events)	Strecker et al. (2001, 2002)
Collect field duplicates	Split composite sample collected by automated sampler into two samples; adjust field and laboratory procedures if pollutant concentrations in water quality samples are different	Verify field and laboratory procedures not contaminating water quality samples		

Hach Company. (2021). *AS950 portable sampler installation and maintenance* (7th ed.). https://www.hach.com/p-portable-samplers-as950-standard/ASP.CXXXS141XX#resources

Strecker, E., Mayo, L., Quigley, M., & Howell, J. (2001). *Guidance manual for monitoring highway runoff water quality*. Prepared for the Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/41888

Strecker, E., Urbonas, B., Quigley, M., Howell, J., & Hesse, T. (2002). *Urban stormwater BMP performance monitoring: A guidance manual for meeting the National Stormwater BMP Database requirements*. https://www3.epa.gov/npdes/pubs/montcomplete.pdf

Teledyne ISCO. (2019). *6712 Portable samplers installation and maintenance guide*. https://store.teledyneisco.com/products/sampler-user-manuals

YSI. (2018). *ProSample user manual*. https://www.ysi.com/prosample