Chesapeake Bay Technology Assessment Protocol
For Evaluating Stormwater Manufactured Treatment Devices

Prepared by:

an Expert Panel of the Urban Stormwater Work Group (USWG)
U.S. Environmental Protection Agency
Chesapeake Bay Program

Acronyms and Abbreviations

APHA – American Public Health Association
ASCE – American Society of Civil Engineers
ASTM – American Society for Testing and Materials
AWWA – American Water Works Association
BMP – best management practice
C – Celsius
CAD – computer-aided design
CBTAP – Chesapeake Program Technical Assessment Protocol
CBW – Chesapeake Bay watershed
COC – Chain of Custody
D_{50} – mass median particle diameter
DQA – data quality assessment
DQO – data quality objective
EMC – event mean concentration
EPA – United States Environmental Protection Agency
ER – efficiency ratio
EWRI – Environmental Water Resources institute (a technical institute of ASCE)
ft./sec. – feet per second
ft.^{3} – cubic feet
ft.^{3}/sec. – cubic feet per second
GIS – geographic information system
HDPE – high-density polyethylene
hr – hour
i.e. – Latin *id est*, “that is”
in. – inches
in./hr. – inches per hour
Inc. – Incorporated
mg – milligram (one thousandth of a gram)
mL – milliliter (one thousandth of a liter)
mm/L – millimeter per liter
MQO – measurement quality objective
MS/MSD – matrix spike/matrix spike duplicate
MTD – manufactured treatment device
µm – micron or micrometer (one millionth of a meter)
N – nitrogen
NELAC – National Environmental Laboratory Accreditation Conference
NELAP – National Environmental Laboratory Accreditation Program
NH_3-N -- ammonia nitrogen
NJCAT – New Jersey Corporation for Advanced Technology
NJDEP – New Jersey Department of Environmental Protection
NOAA – National Oceanic and Atmospheric Administration
NPDES – National Pollutant Discharge Elimination System
NRCS – Natural Resources Conservation Service
NSQD – National Stormwater Quality Database
NTIS – National Technical Information Service
O&M – operation and maintenance
%RSD – percent relative standard deviation
PP – particulate phosphorus

PR – pollutant removal
PSD – particle-size distribution
PSEP – Puget Sound Estuary Program
QA – quality assurance
QAPP – quality assurance project plan
QC – quality control
SCM – stormwater control measure
SOL – summation of loads
SRP – soluble reactive phosphorus
SSC – suspended sediment concentration
TAPE – Technology Assessment Protocol – Ecology
TARP – Technology Acceptance Reciprocity Partnership
TDN – total dissolved nitrogen
TER – technology evaluation report
TMDL – Total Maximum Daily Load
TN – total nitrogen
TNI – The NELAC Institute
TP – total phosphorus
TRC – Technical Review Committee
TSP – total soluble phosphorus
TSS – total suspended solids
U.S. EPA – United States Environmental Protection Agency
USGS – United States Geological Survey
V_Et_v – Equal Volume – Variable Time
V_Vt_V – Variable Volume – Variable Time
WA – Washington
WEF – Water Environment Federation
WSDOE – Washington State Department of Ecology

1 -- Introduction

The *Chesapeake Bay Technology Assessment Protocol (CBTAP)* is for evaluating Manufactured Treatment Devices (MTDs) that are used to treat stormwater on urban sites in the Chesapeake Bay watershed. The testing protocol is intended for volume-based and flow-rate-based stormwater MTDs and may not be suitable for all stormwater treatment practices. Assessments conducted by CBTAP are recommendations. Actual credits for sediment, nitrogen, or phosphorus removal from site runoff will be determined by each state or the District of Columbia as part of their 303(d) water quality certification responsibilities.

2 -- Field Monitoring and Data Evaluation

2.1 -- Monitoring Site Selection

The success of the field-monitoring program will depend in large part on locating a suitable test site(s). Applicants should elect test site(s) that incorporate characteristics consistent with the intended application of the MTD, including land use, field conditions, and climate.

Prospective test sites shall initially be evaluated based on engineering and institutional concerns. Engineering concerns would include hydraulic loading, hydraulic grade, types of pollutants, and area and depth limitations. Institutional concerns would include site access, security, and existing permit requirements. Sites should be well established with no on-going land development or land disturbance activities. The stormwater drainage systems should be sufficiently understood to allow a reliable delineation and description of the drainage area (e.g., geographic extent, topography, soils, land uses).

2.2 -- QAPP and Documentation

Prior to conducting testing, a quality assurance project plan (QAPP) shall be submitted, reviewed, and approved by the CBTAP.

2.2.1 -- Preparation of a QAPP

- The QAPP shall specify the procedures to be followed to ensure the validity of the test results and conclusions. A QAPP addresses the basic elements listed in *EPA Requirements for QA Project Plans* (EPA QA/R-5) (U.S. EPA 2001). The QAPP should identify or include:
    - The project manager, test site owner/manager, field personnel, consultant(s) if applicable, technical advisor, and the analytical laboratory that will perform the sample analyses.

  - The roles and responsibilities of key personnel, and provide key personnel resumes.
  - Required training, certifications, or permits needed to complete the testing.
  - Documentation of any certifications received from a national or state agency regulating laboratory certification or accreditation programs for each laboratory participating in the project.
  - Certification by a professional engineer (P.E.) that the structural components of MTDs are properly designed.
  - Project schedule documenting when the field-monitoring equipment is expected to be installed, the expected field-testing start date, projected field sampling completion, and technical evaluation report (TER) submittal.

In general, applicants shall:

- Include the following information about each test site:
  - location of the test site (street, city, state, zip);
  - site map showing drainage area, drainage system layout, and MTD and sampling equipment locations;
  - tributary land uses (e.g., roadway, commercial, high-use site, residential, industrial), and amount of impervious cover, topography, slope, geometry/planimetrics, and all anthropogenic/biogenic activities affecting the drainage area;
  - potential pollutant sources in the drainage area (e.g., parking lots, roofs, landscaped areas, sediment sources, exterior storage, or process areas);
  - particle-size distribution of TSS in runoff (entire distribution, specify D_{50}) for a specific storm event
  - baseline-stormwater-quality information to characterize conditions at the site;
  - location of flow devices and samplers in relation to the inlets and outlets of the MTD (demonstrate that flow devices and samplers are installed and positioned properly to ensure that samples are representative of influent runoff and effluent runoff [i.e., sample the influent as close as possible to the inlet of the system and sample the total treated effluent]);
  - regional climate station for test site and its average number of storms per year, average annual precipitation (in.), and monthly average precipitation (in.)
  - identify design maximum hydraulic loading rate (i.e., peak flow rate);
  - make, model, and capacity of the MTD;
  - evidence of matching unit operations, and hydraulic/volumetric capacity to watershed loads,
  - analysis of rainfall-frequency distributions and their anticipated effect on the treatment unit;
  - location and description of the closest receiving water body;
  - bypass flow rates or flow splitter designs necessary to accommodate the MTD (specify the bypass flow set point). In the CBTAP, bypass refers to flow that enters the MTD but is diverted prior to treatment. External diversions before the inflow is recorded are not considered to be bypasses for CBTAP purposes, however the drainage area up gradient of the diversion shall be provided;
  - pretreatment system set-up and operational details, if required by site conditions or MTD operation;
  - potential adverse site conditions such as tidal influence, high groundwater, rainfall pattern, steep slopes, erosion, high spill potential, illicit connections to stormwater drainage areas, and industrial runoff. Provide any provisions for site abandonment including, safety hazards, excessive meaningless water quality parameters,

        excessive loading of labile materials, e.g. heavy pollen loads, or unusual hydraulic conditions.

- Prepare and coordinate a QAPP and ensure that it includes:
    - data quality objectives (DQOs) (Test objectives should be clear, concise, quantitative, and unambiguous, such that standardized test methods and procedures can be applied and that the entire range of MTD performance capabilities be tested in order to demonstrate the full potential of the MTD.) (See *Guidance on Systematic Planning Using the Data Quality Objective Process* [EPA QA/G4] [U.S. EPA 2006c] available at: http://www.epa.gov/quality/qa_docs.html);
    - sampling equipment and procedures;
    - method of calibrating the flow metering system;
    - description of how any grab samples will be collected and at what intervals they will be collected during the storm event;
    - description of how composite samples will be collected (Samples collected as discrete flow composites may need to be manually composited following the sampling event. If samples will be manually composited, provide a description of the compositing procedures to prevent cross-contamination of samples.);
    - chain-of-custody procedures;
    - sample preservation/holding times;
    - quality control (QC) sample protocol (splits and composites; field, trip, equipment blanks; spikes; duplicates); and
    - sample equipment cleaning and maintenance procedures.
- Prepare and coordinate MQOs
- Have field sampling overseen by the technical advisor (TA) or taken by an qualified independent consultant
    - Independent laboratory analysis and data reports
    - Have an independent TA verify data from laboratories
    - Have an independent TA review and verify all interim and final reports.
    - Report all site visits and all of the associate activities associated with the site visit.
- Use standardized test methods and procedures, where applicable.
    - Have all analyses conducted by an independent laboratory. Use of a laboratory certified under National Environmental Laboratory Accreditation Program (NELAP) is required for all analyses.
    - Use equipment manufacturer’s recommended instrument calibration or certification procedures.

In addition, the QAPP shall address the requirements stated in the other sections of this document (particularly Section 2.3 -- Monitoring Program Design and Section 2.5 -- Sample Collection, Analysis, and Quality Control).

Standardized test methods and procedures shall be used to collect stormwater MTD data. Several sources of test plans, test methods, procedures, and standards are available for testing stormwater technologies. Some examples are provided below:

- *EPA Requirements for QA Project Plans* (EPA QA/R-5) (U.S. EPA 2001, available at http://www.epa.gov/quality/qa_docs.html).
- *National Field Manual for Collection of Water Quality Data, Techniques of Water Resources Investigations Book 9* (USGS, variously dated, available at http://water.usgs.gov/owq/FieldManual/).
- *National Water Quality Handbook* (NRCS 2003, available at http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17843.wba).

- *NPDES Storm Water Sampling Guidance Document* (EPA 833-B-92-001) (U.S. EPA 1992, available at http://www.epa.gov/npdes/pubs/owm0093.pdf).
- *Standard Methods for the Examination of Water* & Wastewater*: Centennial Edition* (American Public Health Association [APHA], the American Water Works Association [AWWA], and the Water Environment Federation [WEF] 2005).
- American Society for Testing and Materials (ASTM) Standards (Website: http://www.astm.org/).
- The National Environmental Laboratory Accreditation Conference (NELAC) Institute (TNI) (Website: http://www.nelac-institute.org/).
- *Caltrans Comprehensive Protocols Guidance Manual* (Stormwater Quality Monitoring Protocols) (California Department of Transportation 2003, available at http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-03-105.pdf).
- *Guidance Manual for Monitoring Highway Runoff Water Quality* (FHWA-EP-01-022) (Federal Highway Administration 2001, available at http://www.fhwa.dot.gov/environment/h2o_runoff/index.htm).
- *Urban Stormwater BMP Performance Monitoring* (provides general advice on selecting monitoring methods and equipment, installing and using equipment, and implementing sampling approaches and techniques; prepared under support from U.S. Environmental Protection Agency, Water Environment Research Foundation, Federal Highway Administration, Environmental and Water Resources Institute of the American Society of Civil Engineers) (Geosyntec Consultants and Wright Water Engineers, Inc. 2009, available at http://www.bmpdatabase.org/MonitoringEval.htm).
- Joint Task Committee for Certification of Manufactured Stormwater BMPs; Guo, Q., *Stormwater manufactured treatment devices certification guidelines*. American Society of Civil Engineers: Reston, Virginia, 2017; p pages cm

2.2.2 -- Modification of a QAPP

In some circumstances it may be necessary to modify an existing QAPP due to unforeseen changes at the monitoring site. All such changes will be documented in a technical memorandum to be prepared by the applicant. The memorandum will describe the issue prompting the change, the planned change, and when the change will take effect. Until such time as the memorandum is approved, all testing performed by the applicant is at their own risk.

2.3 -- Monitoring Program Design

2.3.1 -- MTD Sizing Methodology for Test Sites

MTD sizing is dynamic as a given MTD can be sized across a wide range of loading rates, depending on pollutant removal goals and water quality objectives. This poses a challenge in a testing and evaluation program, i.e. what are the applicability of the results to a range of sizes for that MTD? Sizing of MTDs must be consistent with the sizing/loading rates applicable to the tested MTD to ensure consistent performance. For that reason, it is critical that any approvals granted be consistent with sizing criteria obtained from data gathered during testing and be relevant to the specific unit tested. Specifically, the design hydraulic loading from the test unit should be the approved design hydraulic loading rate assuming favorable test results. If the design loading rate is not achieved during testing, the approved design loading rate should be reduced to reflect performance observed during tested conditions. ~~Thus, peak water quality flow rates shall be calculated from water quality volume using the graphical peak discharge method. Next, approved flows and hydraulic loading rates for each MTD should be established. If laboratory testing of the MTD consistent with NJDEP (2013) is available, use hydraulic loading rates and ranges established during the laboratory testing. If only field testing is available, the hydraulic loading rate shall be established by one of the following methods:~~

1. ~~Three storm events producing peak flows within 75% of the design/stated hydraulic loading rate of the tested unit) are selected. If this desired hydraulic loading rate is not met, it shall be reduced until the data is in compliance with the requirement.~~

   ~~Example: if the stated treatment capacity is 1 gpm/ft^2 of filter surface area~~, ~~then at least 3 monitored storm events must have produced peak treated flows >0.75 gpm/ft^2~~. ~~If this goal is not met~~, ~~the approved treatment capacity is reduced until there are 3 storm events with peak treatment flows within 75% of~~ the reduced treatment capacity.

2. ~~Calculating an average of the 2-3 highest hydraulic loading rates recorded during the study.~~

~~Preliminary water quality data analysis obtained during characterization of the test site(s) may be part of the basis used for sizing the MTD for testing.~~

2.3.2 -- Monitoring and Sampling Parameters

2.3.2.1 -- Qualifying Storm Event Parameters

The following parameters shall be used to define qualifying storm events:

- More than 0.1-inch of total rainfall. If a storm with more than 0.1-inch of rainfall has measurable runoff at the inflow of the MTD but produces no discharge, report the occurrence of the storm and record that the MTD effectively treated all runoff, but the storm does not count towards the minimum number of storms required for testing (see Section 2.3.2.4 -- Minimum Number of Events Required to be Sampled).
- Minimum inter-event period of 6 hours.

2.3.2.2 -- Rainfall Monitoring

Rainfall shall be recorded during every storm event. Measurement sensitivity shall be no greater than 0.01 inch (time stamped to the nearest second), and a maximum intensity measurement capability of no less than 4 in./hr. If the onsite rainfall monitoring equipment fails during a storm event, data from the next-closest, representative rain gaging station may be used to determine whether the event meets the qualifying storm event parameters. Nearby third-party rain gages may be used only in the event of individual rain gage failure, and only for the period of failure. If nearby rain gages are used to fill in missing data, a regression relationship shall be established with the recorded rainfall at the monitoring site, and used to compute the local (monitoring site) rainfall.

2.3.2.3 -- Flow Monitoring

To the extent feasible, all flow (inflow, outflow and overflow, and fugitive bypass) shall be accounted for and monitored. Inflow to and outflow from the test unit shall be measured and recorded on a continuous basis over the duration of each sampling event. The appropriate flow measurement method depends on the nature of the test site and the conveyance system. For those systems with internal bypasses, flows shall be measured at at the inlet and outlet., and some means of documenting that internal bypass has occurred shall be employed. Flow measurement procedures shall be fully described in the QAPP and evidence of equipment calibration provided. The flow data-recording interval shall provide adequate definition of the inflow and outflow hydrograph, but in no case shall flow be logged at an interval greater than 5 minutes.

2.3.2.4 -- Minimum Number of Events Required to be Sampled

Statistical methods may be used to develop an estimate of the required sample size. There are a variety of methods for calculating sample size for various confidence levels (e.g., refer to Burton and Pitt 2002, Sample et al. 2012, Bootstrapping calculation tool at Washington Stormwater Center [http://www.wastormwatercenter.org/tape-program]).

Sampling should continue until the confidence level exceeds 95% computed using tools listed previously; however, in no case should there be less than 18 events. As a guideline, a continuous sequence of qualifying storm events or as close to that as possible should be sampled, thus providing a more complete description of the behavior of the system by sampling the bulk of the mass flux through the MTD during each event and throughout the sampling campaign. At a minimum, three sets of two consecutive qualifying storm events in sequence shall be sampled.

Other criteria include at least two qualified storm event with greater than the 95th percentile for the area being tested, and at least three qualified storm events with greater than 0.5 inches of rainfall shall be sampled during the testing period. A minimum of three qualified storm events where the peak flow rate exceeds 75% of the design capacity of the MTD should be sampled, if feasible. The sampling and performance results for all sampled qualifying storm events shall be reported and included in all performance and maintenance interval computations.

2.3.2.5 -- Sampling Methodology

Sampling protocols shall be fully described in the QAPP, and the approved methods adhered to throughout the testing program. This subsection provides a brief discussion of sampling methods that may be applicable to MTD performance measurements.

- **Grab samples** are discrete, individual samples taken within a short period of time (usually less than 15 minutes). If instantaneous flow data are available, loads may be computed as illustrated in the schematic of Figure 2.1. Assuming that discrete samples were taken at each of the black dots situated along the hydrograph and subsequently analyzed (C_i), the total event load may be estimated as:

  $$\text{Total Load} = \sum_{i=1}^{9} C_i \Delta V_i$$

  where ΔV_i = incremental runoff volume, L^3
  C_i = constituent concentration, m/L^3

The degree to which the total load estimated in the foregoing manner could be said to approach the “true” load would be increased by extracting (and analyzing) more samples at smaller (but not necessarily equal) increments of flow. Using such an approach is expected, in theory, to eventually produce a very fine estimate of the true load of any constituent of interest if the number of samples collected was very high. There are, however, practical limits. For example, most automatic samplers have a total bottle limit of 24 to 28 samples. Using this as the upper limit of the number of samples that could be collected during a storm event, it may be seen that, even for constituents having modest unit analytical costs, load characterizations with the discrete sampling method could very quickly become cost-prohibitive.

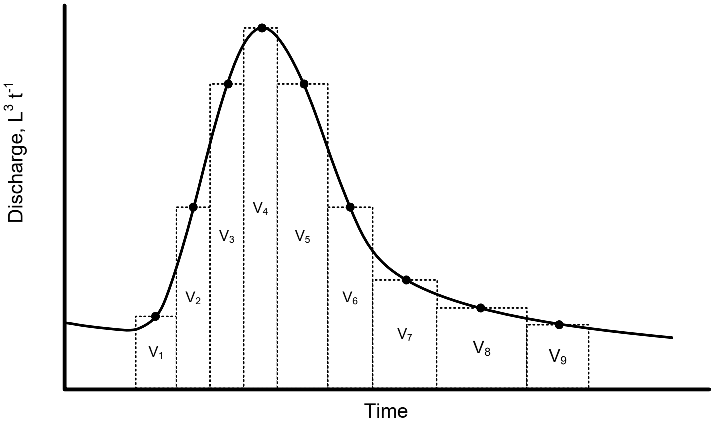

Figure 2.1. Equal volume, variable time, flow-weighted composite (Graphic courtesy of T. Grizzard)

- **Composite samples** are more often better suited to the goals of stormwater sampling or MTD performance assessments that seek to develop a total mass load or an event mean concentration (EMC) for a constituent of interest in the runoff. In such cases, it may be more cost-effective to develop a sampling strategy around flow-weighted-composite samples of the entire runoff event. There are other strategies for constructing composite samples, but only flow-weighted composites are recommended. The potential for undue bias is simply too high with essentially all other methods. The flow-weighting approach is, generally, based on the premise that the volume of any sub-sample (or aliquot) in a composite is proportional to the flow increment that it represents. There are several methods for producing flow-weighted composites, but two of the most common are:
  - Variable Volume – Variable Time ($V_V t_V$)
  - Equal Volume – Variable Time ($V_E t_V$)

Figure 2.1 may again be used to illustrate the $V_V t_V$ compositing approach. Note that there are 9 samples and 9 volumes in Figure 2.1. Assuming that V_1 is the smallest volume increment of the nine sub-samples taken, it may be used as the basis for calculating the aliquot volumes of the remaining eight sub-samples in the overall composite. For example, if the index aliquot for incremental volume V_1 is taken to be 100 mL, then the volume for the aliquot representing V_6 would be 100 x V_6/V_1. After all nine aliquots are placed in a single vessel with similarly computed sub-volumes, the resulting composite may be analyzed to determine the EMCs for constituents of interest. The caveats of the approach include insuring that the index volume is low enough to ensure that there is enough sample for the maximum volume aliquot in the composite. In addition, great care shall be taken in extracting aliquots for the composite from individual sample bottles in a quantitative manner. This diligence is of paramount importance when substantial amounts of suspended matter are present. In fact, if the analytical protocols for suspended sediment concentration (SSC) are observed, the labor involved may make the method time- and cost-prohibitive.

The compositing approach of choice is usually the V_Et_V method illustrated in Figure 2.2. The procedure requires the use of a somewhat more capable flow metering/sampling equipment suite, but initial costs are likely to be far outweighed by savings in staff time and analysis. As may be seen in the schematic, sub-samples of constant volume are withdrawn at equal increments of total stormwater flow volume. These sub-samples are deposited directly into the composite vessel in the field, and at the end of the event, the flow-weighted composite is complete and ready for retrieval and analysis. As may be inferred from Figure 2.2, the total flow volume increment may be reduced to a point so that n is quite large, and the resulting composite represents the entire hydrograph at a very fine scale. An additional advantage of the method is that no post-storm effort is required in the laboratory to make up the composite. The entire composite is constructed in the field, and the measured concentrations in the vessel are representative of the EMCs for constituents of interest.

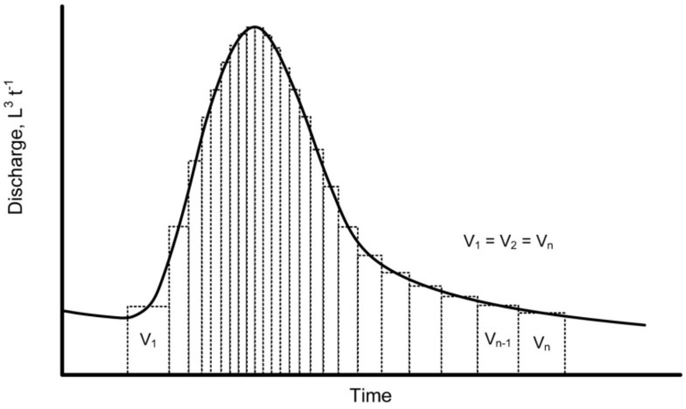

Figure 2.2. Equal volume, variable time, flow-weighted composite (Graphic courtesy of T. Grizzard)

Sampling criteria include the following:

- Flow-weighted composite samples covering a minimum of 70% of the total storm flow, including as much of the first 20% of the storm's runoff volume as feasible shall be collected for all constituents for which pollutant removal credits are to be computed.

- A minimum of 10 aliquots (i.e., 10 influent and 10 effluent aliquots) shall be collected per storm event. Exception: for short duration storms, those less than 1-hour in duration, 6 aliquots are the minimum. One composite sample comprised of 10 aliquots (or 6 aliquots for short duration storms) equals a water quality sample minimum. Use of programmable automatic samplers, which is recommended, will likely result in a larger number of aliquots being taken at a finer scale. This larger number of aliquots, if planned appropriately, does not increase the sampling burden of the applicant.

2.3.2.6 -- Maintenance Monitoring

Applicants shall strive to collect samples through at least a single maintenance cycle to verify maintenance requirements and to document how MTD performance changes over time. Monitoring is therefore required for the qualifying storm event just prior to and immediately after maintenance. If it can be shown that maintenance returns the MTD to its original condition (e.g., total replacement of treatment material), there is no need to show performance past one maintenance cycle (however, the requirement of meeting the minimum number of monitored qualified storm events shall still be met [See **Section 2.3.2.4 -- Minimum Number of Events Required to be Sampled**]). For expected maintenance cycles greater than two years, the applicant shall agree in writing to conduct long-term periodic monitoring to show how performance varies over time and shall monitor the qualifying storm events immediately before and after maintenance.

2.4 -- Monitoring System Design and Installation

2.4.1 -- Monitoring System Design

The physical layout of the monitoring system may have direct impacts on MTD pollutant removal. For example, upstream controls may have an important impact on the pollutant concentration observed. Likewise, if bypass and overflows are not considered, different performance results may be expected for the MTD. Physical management of the system during the study period (e.g., adjustments to the height of an overflow/bypass weir or gate) may also impact the monitoring results. For this reason, static and variable states of the MTD shall be considered when designing the monitoring system.

Flow monitoring stations have the following requirements:

- For monitoring stations where flow is to be measured in open channels, locate the flow measurement facilities where there is suitable primary hydraulic control to support the development of reliable rating curves (i.e., stage-discharge relationships). Suitable primary hydraulic controls for most MTDs most often include a properly calibrated weir or flume. Careful selection of the flow monitoring equipment is necessary to avoid introducing bias into either water quantity or water quality measurements. If other flow measurement technologies are proposed in the study design (e.g., area-velocity meters), provision shall be made for adequate demonstration of precision and accuracy.

- Where possible, locate stations in reaches of a conveyance where flows tend to be relatively stable and uniform for some distance upstream (approximately 6 channel widths or 12 pipe diameters) in order to better approach "uniform" flow conditions. Avoid steep channel slopes, changes in pipe diameter, conduit junctions, and areas of irregular channel shape (e.g., breaks, repairs, roots, debris).

- Locate stations established in pipes, culverts, or tunnels in such a way to avoid surcharging (pressure flow) over the normal range of precipitation.

- Locate sampling stations for the MTD as close as feasibly possible to the MTD inlet and outlet in order to avoid potential sources of pollutants that bias the study results (and the derived MTD pollutant removal data).

- Locate influent sampling stations sufficiently downstream from inflows to the drainage system to better achieve well-mixed conditions across the channel.

- Sampling chambers designed to produce completely-mixed samples are preferable to sampling from pipe inverts.

- If an automated sampler with a peristaltic pump is used and the access point is a manhole, the water surface elevation shall not be excessively deep (i.e., it is recommended to be less than 6 meters, or 20 feet, below the elevation of the pump in the sampler, and preferably less than 4.5 meters or 15 feet deep). This positioning is necessary to avoid unacceptable intake velocity reductions due to increased pump suction lift.

  When locating the sampler intake, consider the expected velocity profile in the type of channel being used; see Figure 2.3 from Chow (1959).

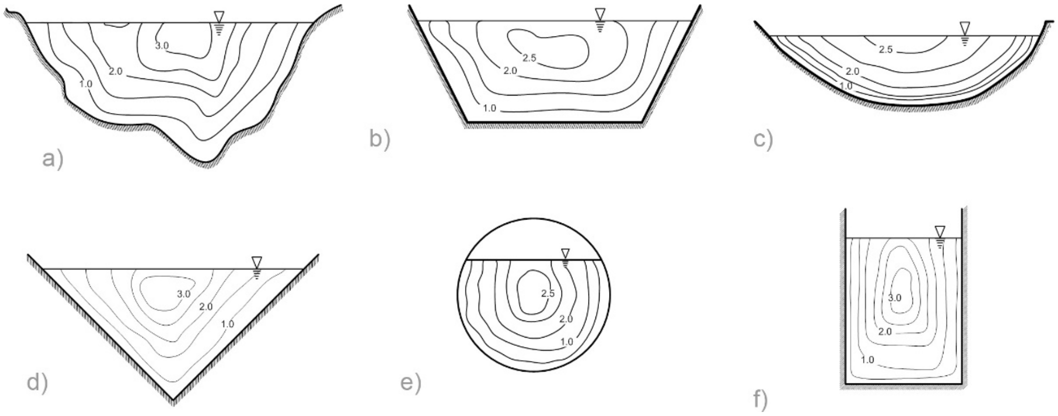

Figure 2.3. Typical velocity distributions (ft./sec.) for a) natural channel, b) trapezoidal channel, c) parabolic channel, d) triangular channel, e) pipe, f) rectangular channel. Modified from Chow (1959) (Graphic courtesy of T. Grizzard)

- In addition, evidence shall be provided to ensure that carry-over of compounds between samples (e.g., adherence to the sampling equipment surfaces) is not taking place.

- For systems that bypass runoff internally, the influent sampling station shall be directly upstream of the system and before the flow is split between the treatment system and the bypass. The outflow sampling location shall be located directly downstream of the treated flow (i.e., the MTD) and after the effluent joins the bypass flow. If the treated effluent flow does not join the bypass, the bypass flow and water quality shall be monitored after the split. Flow that is bypassed externally which exceeds the design water quality event is not required to be sampled.

The following recommendations apply to all monitoring stations:

- Monitoring sites in locations that may be affected by backwater and tidal action shall not be used because such conditions may adversely impact the reliable measurement of flow.

- Where feasible, take TSS measurements from multiple flow-weighted cross-sectional samples at various flows and compare them to the point intake TSS value to ensure that intake location is not creating bias in sample results.

- Locate stations where field personnel may safely access the equipment for construction, maintenance, and sample retrieval, e.g., where surface visibility is good and traffic hazards are minimal, and where monitoring personnel are unlikely to be exposed to explosive or toxic atmospheres.

- If automated equipment is to be used, configure the monitoring system such that confined space entry (for equipment installation, routine servicing, and operation) can be performed safely and in compliance with applicable regulations.

- Locate stations where access and security are good, and vandalism of sampling equipment is unlikely.

- Locate stations where the channel or storm drain is soundly constructed.

- Establish groundwater-monitoring wells if contamination of groundwater is suspected. Establish groundwater flow, direction and elevation as well as soil types before choosing monitoring stations. Locate monitoring stations sufficiently down gradient from the MTD in order to intercept infiltrated water from the MTD.

It is recommended that the applicant visit each candidate site during or after a storm to observe the discharge. A wet-weather site visit can provide valuable information regarding logistical constraints that would not be readily apparent during dry weather.

2.4.2 -- Minimum Monitoring Equipment Requirements

The following list of monitoring equipment is typically the minimum required to conduct field monitoring. Applicants shall address these standards in the QAPP. Deviations from the required standards will only be approved if the applicant's alternative is determined to meet or exceed the requirements in this section.

- **Rainfall Monitoring**: When feasible, locate a rainfall monitoring station at or within 200 feet of the MTD at each test site. A tipping bucket rain gage that measures rainfall volume in no greater than 0.01 inch increments (measurements time stamped to the nearest second) and a maximum intensity measurement capability of no less than 4 in./hr. is required. Rain gages should be installed at least 25 ft from buildings and/or tree canopy. Rain gage data should interface with a data acquisition system that uses the same electronic time base as the flow measurements.

- **Inlet and Outlet Flow Monitoring**: When feasible, locate flow-monitoring equipment at both the MTD inlet and outlet. Use of both primary and secondary flow measurement devices are recommended whenever feasible. Primary flow measurement devices include control sections such as weirs and flumes that create a known stage-discharge relationship. Secondary flow measurement devices include floats, ultrasonic transducers, pressure transducers, and bubblers that provide a means for sensing fluid level and either recording it or routing it to an external data acquisition/data logging device. Flow monitoring equipment should have the capability to measure discharge from near zero to full pipe (or cross-section) conditions. Carefully choose sampling/monitoring sites to be consistent with the requirements of the primary devices selected. Generally, this positioning means maintaining a free discharge (no backwater) through the control section. Designing and equipping a system to provide accurate flow measurements under backwater conditions adds unnecessary complexity, and often reduces reliability, an exception is if an area-velocity meter is used. Evaluate sites carefully and decide to include them only after it has been demonstrated that the impacts on the quality of discharge measurements have been satisfactorily addressed.

- **Stage and Bypass Flow Monitoring**: For MTDs that are predominately filtration devices, stage-discharge shall be measured in the unit tested as specified in the QAPP. The applicant shall assess the potential for periodic clogging of the filter media and develop recommendations for how frequently maintenance is needed. In addition, any internal bypasses shall be sampled and analyzed and their flows reported.

- **Inlet and Outlet Water Sampling**: Flow-weighted composite sampling using automatic samplers is mandatory unless it is demonstrated that alternate methods are superior or where automatic sampling is infeasible. Locate automatic samplers at the MTD inlet and outlet, and configure them to be activated by the data acquisition/control system in accordance with the sampling scheme (discrete, composite) adopted for the study. Where feasible, locate sampler intakes in sampling chambers designed to provide well-mixed conditions. Otherwise mount sampler intakes in a well-mixed section of the conduit close to the inlet and outlet of the test unit. The sampler intake tubing (and strainer, if any) shall be selected to ensure the desired representativeness of the sample. The sampler intake tubing material shall be selected to be consistent with the constituents to be analyzed. Initiate sample aliquot collection by signals from the data acquisition/control system.

- **In-situ Monitoring**: Attachment of in-situ monitoring equipment such as temperature probes and pH probes to internal surfaces of the MTD is recommended where well-mixed conditions exist.

- **Data Acquisition, Recording, and System Control**: The data acquisition system is often included in the same commercial package as the secondary device for flow measurement. Whether integrated or free-standing, it is recommended that the system not only have multiple channels available to record both analog and digital data, but also have sufficient computing capacity to determine aliquot volumes for the compositing protocol being employed, and to route appropriate activation signals to automatic samplers. It is recommended that the data acquisition system have a primary power source, a backup power source, and an online connection via cellular or broadband access.

- **Weatherproof Shelter**: Weatherproof shelters to house the data acquisition system and automatic samplers are recommended, and the shelters should be sized with adequate clearance to easily remove samples, and to permit maintenance activities during storm events without exposing equipment to the elements.

Calibrate and maintain all monitoring equipment in accordance with the recommendations of the equipment providers.

2.5 -- Sample Collection, Analysis, and Quality Control

The following subsections detail the protocol for sample collection, analysis, and quality control.

2.5.1 -- Stormwater Sampling

All stormwater samples shall be collected and analyzed in a manner that supports the construction of a mass-based assessment of MTD performance. Therefore, when feasible, all runoff passing through the MTD (i.e., untreated runoff, treated runoff, and bypassed flows) is to be monitored. While the analytical work is generally undertaken at a laboratory remote from the sampling site(s), it is recommended that care be taken that the sampling protocols in use at the site are consistent with the analyses contemplated.

Required parameters for phosphorus monitoring of stormwater include, at a minimum:

- Total phosphorus (TP)
- Total soluble phosphorus (TSP)
- Soluble reactive phosphorus (SRP(
- Total suspended solids (TSS)
- Suspended Solids Concentration (SSC)
- Particle size distribution (PSD)
- specific gravity.

Since SSC requires a whole sample, the samples must be split for the rest of the analytes. A cone splitter shall be used for splitting samples. Additionally, pH, , temperature, conductivity should be measured in the analytical program, and may be monitored in situ or through sample collection, as appropriate.

Particulate phosphorus (PP) may be calculated by subtracting TSP from TP. TSP is what passes through a 0.45-μm membrane filter, PP is the remainder. The PP load in stormwater is related to the PSD. Generally, the finer fraction of suspended particles contains the highest concentration of PP, which suggests that MTDs capable of removing the finer fraction will be more effective at reducing phosphorus load. Therefore, analyzing for PSD from SSC samples at the inlet and outlet of the MTD will provide important information relative to MTD effectiveness for reducing the PP load. Individual analysis of particle size ranges for PP, and the summation of PP load, can be used to corroborate the PP results taken from subtraction of TSP from TP.

Particle specific gravity provides additional useful information about the ability of a particular MTD to remove PP. In addition, settling velocities of solids are important and may be measured directly or calculated theoretically from specific gravity and PSD data. Settling velocities may give vital information for quantifying the amount of MTD sediment removal (Geosyntec Consultants and Wright Water Engineers, Inc. 2009) and, by extension, PP load reduction.

Required parameters, as described in APHA, AWWA and WEF (2005), for nitrogen monitoring of stormwater include, at a minimum:

- total nitrogen (TN)
- total dissolved nitrogen (TDN)
- ammonia-N
- total oxidized nitrogen (nitrate-N + nitrite-N, also known as NO_x).

- total kjehldal nitrogen (TKN)

2.5.2 -- Accumulated Sediment Sampling

Where appropriate, it is recommended that the sediment accumulation rate in the MTD be measured to help demonstrate MTD performance and to design an operations and maintenance plan. Practical measurement methods would suffice, such as measuring sump sediment depth immediately prior to sediment cleaning and following test completion.

Use several grab samples (at least four) of the accumulated sediment, collected from various locations within the MTD to create a composite sample of the sediment. This method is intended to collect a representative sample of the total sediment volume in the MTD. For QA/QC purposes, collect a field duplicate sample (see **Section 2.5.7 -- Field QA/QC Procedures**). Keep the sediment sample at 4°C during transport and storage prior to analysis. If possible, remove and weigh (or otherwise quantify) the sediment deposited in the MTD during testing. Quantify or otherwise document gross solids (debris, litter, and other particles exceeding 4,750 microns in diameter). Use volumetric sediment measurements and analyses to help determine maintenance requirements, calculate a solids or pollutant mass balance, and determine if the sediment quality and quantity are typical for the application.

The following constituents shall be analyzed from the composite sample of the sediment:
- TP;
- PSD;
- percent total volatile solids; and
- specific gravity.

For applicants seeking approval for the removal of nitrogen, analyze the TN concentration of the sediment sample.

2.5.3 -- Sample Handling and Custody

Sample handling includes retrieval from the sampling device, packaging, shipment from the site, and storage at the laboratory. Documentation includes sample labels, custody forms, and sample-custody logs.

Sample container material, sample preservation, and holding time limits for the analyzed pollutants shall be specified in the QAPP. Whether pre-cleaned sample bottles are obtained directly from the analytical laboratory, or bottles are to be obtained from another source, a detailed bottle-cleaning procedure shall be included in the QAPP.

Provide preservation during sample collection, as well as during transport. Samples shall be preserved in accordance with U.S. EPA-approved methods (U.S. EPA 1983) or *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA and WEF 2005). Automatic samplers shall be cooled to maintain low temperatures throughout the sample collection period.

Samples shall be labeled and tracked from collection through delivery to the analytical laboratory in order to insure sample integrity from time of collection to time of receipt in the laboratory. Whenever samples are removed from the flow, or retrieved from an automatic sampler, they shall be placed in a cooled transportation case (e.g., a cooler) along with the chain-of-custody record form, pertinent field records, and analysis request forms, and transported to the laboratory. Temperature in the storage case shall be recorded when the samples are introduced and when they are removed at the analytical laboratory. When performing composite sampling, the chain-of-custody form shall include a column for entering the time and date of collection of the first and last aliquot so that holding time limits may be determined.

Sample holding times shall be assessed with respect to constituents being evaluated, and how long the "tail" of the hydrograph lasts. PSDs and PP/TSP may require holding times as short as 8 to12 hours. To address this may require an additional sampler for the "tail" of the hydrograph.

When preparing samples for shipment to the laboratory, identify:

- Name of the analytical methodology.
- Approved method identifier.
- Sample matrix (aqueous or solid).
- Required reporting limit with appropriate units.
- Sample preservation technique(s) employed.
- Container type.
- Maximum holding time.

2.5.4 -- Analytical Methods

Proposed analytical methods shall be included in the QAPP.

2.5.4.1 -- Standardized Test Methods

Standardized test methods shall be used to collect MTD performance data. Methods often used for analyses of samples from aquatic treatment systems include:

- *Methods and Guidance for the Analysis of Water* (U.S. EPA 1999),
- *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA and WEF 2005), and
- American Society for Testing and Materials, e.g., D3977-97(2007) and D5612-94(2008) (ASTM 2007, 2008).

In addition, the procedures cited in the following U.S. Geological Survey report, *Comparability of Suspended-sediment Concentration and Total Suspended Solids Data* (Water-Resources Investigation Report No. 00-4191; Gray et al. 2000), are often used in the analysis of SSC and TSS.

Other nationally recognized organizations, such as the American Water Works Association (AWWA) and NSF International, have also published methods that may be used if more broadly applied standard methods are not available. Standardized test methods and procedures have the advantage of being prepared by technology-specific, expert subcommittees, and the methods typically incorporate a rigorous peer-reviewed data QA/QC.

2.5.4.2 -- Analysis of Phosphorus

TP is largely defined on the basis of how much phosphorus in its various forms will be oxidized into orthophosphate by a strong chemical oxidant (i.e., digested). TSP is measured after filtering the sample with a 0.45-micron membrane filter and digesting the filtrate. SRP is measured on the same filtered sample, but without digestion, and represents the phosphorus directly available to participate in the color-producing reaction. While often taken as a surrogate for orthophosphate, SRP generally includes some additional material that is mobilized by the conditions of the test. The filter excludes most particulates, but some colloidal phosphorus may be present in the filtrate. The filtrate contains both organic and inorganic forms that are converted to orthophosphate by the digestion process. PP is defined as the sum of all the phosphorus retained on a 0.45-µm membrane filter during sample filtration and includes particulate and colloidal as well as inorganic and organic phosphorus. Different analytical tests used for digestion and analysis of phosphorus may change the amount of phosphorus reported. It is critically important that the laboratory not deviate from specified and approved analytical procedures.

2.5.4.3 -- Analysis of Nitrogen

“Still to be developed”

2.5.4.4 -- Analysis of Particle-Size Distributions (PSDs)

Due to the potential differences in precision among analytical procedures, it is recommended that the same analytical apparatus and procedures be employed throughout the test program. PSDs shall be determined through an appropriate method or combination of methods, including:

- Wet Sieve Analysis
- Laser Diffraction (less than 62.5 microns)

The recommended PSD analysis method is a modified *Suspended Sediment Concentration (SSC) Method* according to American Society for Testing and Materials (ASTM) Method D3977-97 (ASTM 2007) using wet sieve filtration (Method C) and glass fiber filtration (Method B). The SSC method uses wet sieve filtration (Method C) to measure the sand concentration by passing the entire sample (minimum volume of 1 liter) through a 62.5 micron (No. 230) sieve, and uses glass fiber filtration (Method B) to measure the fines (silt/clay) concentration by passing the wet sieve filtrate through a 1.5 micron glass fiber filter. A modification of this procedure is necessary to measure the concentration of four size categories: clay less than 3.9 microns, silt between 3.9 to 62.5 microns, very fine to fine sand between 62.5 and 250 microns, and medium to coarse sand greater than 250 microns (No. 60 sieve).

A PSD analytical procedure using laser diffraction instrumentation and sieve analysis is attached,

Appendix B – Particle-Size Distribution. .

2.5.5 -- Quality Control

One major function of quality control (QC) is to identify, quantify, and reduce both systematic and random errors encountered in analytical processes, including variability due to sampling, storage, preparation, analysis, and data manipulations. A properly functioning QC program has the benefit of continuous feedback to the analytical system, and is a mainstay of the continuous quality improvement goal in analytical operations. More detailed information on assessing quality control is provided in the following sections: **2.5.6 -- Monitoring Equipment QA/QC Procedures**; **2.5.7 -- Field QA/QC Procedures**; and **2.5.8 -- Laboratory QA/QC Procedures.**

The QC plan shall include the following:

- QC checks that shall be followed for all project activities and the frequency at which each shall occur.
- Control limits for each QC activity and the actions that shall take place when these limits are exceeded.
- Applicable statistics that will be used to estimate sample bias and precision.
- Methodology for measurement of accuracy and precision, including the establishment of criteria based on the data quality objectives for the project.
- Methodology for use of blanks, materials, frequency, criteria for acceptable method blanks and actions to be taken if criteria are not met.
- Procedure for determining samples to be analyzed in duplicate, the frequency, and approximate number.

The QAPP shall provide a table listing all QC sample analyses being performed including the number and type of analyses for each batch of samples. QC activities shall constitute no less than 10% of the samples being analyzed, with at least one of each QC procedure specified per sample batch.

2.5.6 -- Monitoring Equipment QA/QC Procedures

Quality assurance (QA) describes a process meant to prevent problems, such as the use of standardized methods, and QC is a product-based approach used to detect problems that occur. QA and QC are largely interdependent and thus frequently described together.

The following subsections identify procedures that will help ensure monitoring equipment is operating as intended and will help prevent cross-contamination of samples.

2.5.6.1 -- Instrument/Equipment Calibration and Frequency

- **Automated Samplers**. Automated samplers shall be calibrated after installation to ensure that the correct volumes of liquid are being retrieved. The condition of the sampler pump and intake tubing, the vertical distance over which the sample must be lifted, and other factors can affect the volume drawn. Therefore, test the sampler after installation and adjust the sampler programming if necessary to be sure the system consistently draws the correct sample volume

  Flow Metering Systems. Primary devices (e.g., weirs, flume) are often deformed in some way during installation, and small changes in the geometry may have large impacts on the rating relationship. Upon installation, the primary device shall be calibrated using methods such as tracer dilution studies, velocity-area rating studies, or bucket rating. Secondary devices such as bubblers, floats, or pressure transducers shall similarly be calibrated and verified in the field. Establish a stable datum for stage measurements at the time the station is constructed and periodically refer to it for subsequent calibrations and verifications. Most devices have well-developed procedures from the equipment supplier, and it is recommended to carefully follow these procedures.

- **Rain Gages**. Calibration of rain gages should be performed at the time of installation. Periodically inspect/test them throughout the study to ensure that operating characteristics have not changed. It is recommended that tipping bucket rain gages be located where they are not subject to the effects of wind eddy currents and turbulence. In general, obstructions (e.g., buildings, trees), may be no closer to the rain gage barrel than four times the height of the obstruction above the lip of the gage, and in no case may an obstruction be closer than twice the height of the obstruction above the lip of the gage. Rain gages shall be carefully leveled and periodically tested to insure that indicated rainfall is consistent with the depth of rain applied to the gage. A 6 inch gage size shall be used.

2.5.6.2 -- Sampling Equipment Maintenance

Sampling equipment (sampler head and suction tubing) shall be cleaned and maintained between sampling events as necessary and specified under QA/QC procedures to prevent sample cross-contamination. Replace the suction tubing at least once during the test period and more frequently for highly polluted runoff.

2.5.6.3 -- Inspection/Acceptance of Supplies and Consumables

The purpose of this element is to identify necessary supplies and how to make sure they are available when needed. Examples of supplies and consumables are reagent water, reference standards for calibrating instruments, and bottles of known cleanliness (such as for trace metal analysis).

- Maintain a list of project supplies and consumables that may directly or indirectly affect the quality of the results.
- Identify individuals responsible for maintaining these supplies.
- Check products against acceptance criteria before using the product.

2.5.7 -- Field QA/QC Procedures

Field QA/QC procedures shall be carefully integrated with laboratory QA/QC such that the overall program meets the project data quality objectives. When collecting samples from aquatic systems and transporting them to a remote analytical laboratory, field quality control shall include: field blanks, field duplicate samples, field sample volumes, recordkeeping, and chain of custody.

2.5.7.1 -- Field Blanks

Field blanks are prepared after cleaning the equipment by sampling reagent-grade water with the equipment. Field blanks could include sources of contamination introduced by reagent water, sampling equipment, containers, handling, preservation, and analysis. Collection and analysis of field blanks should be performed prior to sample collection. Because the field blank is an overall measure of all sources of contamination, it is used to determine if there are any blank problems. If problems are encountered with the field blank, then it is recommended that the other components of the sampling process be evaluated by preparation of other blanks (e.g., method blanks, source solution blanks, bottle blanks, travel blanks, equipment blanks) in order to identify and eliminate the specific problem (see Geosyntec Consultants and Wright Water Engineers, Inc. [2009] for more information).

Field blanks are used to verify the adequacy of the cleaning and maintenance process (i.e., to verify that the equipment is not a source of sample contamination). Collect field blanks at the inlet monitoring station where stormwater is expected to contain the highest pollutant concentrations. At a minimum, collect two separate field blanks during the initial equipment startup and testing and at least one additional blank midway through the sampling program. Collect more frequent blank samples if site conditions warrant (e.g., following an event with unusually high contaminant concentrations). Collect field blanks after cleaning the equipment and after at least one storm event has been sampled. The field-blank sample volume is to be representative of the volume of stormwater collected during a typical sampling event.

Analyze field blanks as regular samples with all other appropriate quality control activities performed. It is recommended that the equipment-rinsate blanks be below the accepted reporting limit for the constituent of interest. If contamination is observed above the reporting limit for the constituent of interest, corrective actions shall be taken (e.g., modifying equipment cleaning procedures, replacing suction tubing).

2.5.7.2 -- Field Duplicate Samples

A field duplicate sample is a second independent sample collected at the same location and with the same equipment. Duplicates are primarily used to assess the variation attributable to sample collection procedure and sample matrix effects. Duplicates for composite sampling may be obtained by splitting a composite sample of adequate volume into two separate samples, using an acceptable sample splitting technique. Duplicates for grab samples are collected by filling two grab sample bottles at the same location. Field duplicate samples shall be collected at a frequency of 5% or a minimum of one per event, whichever is greater. Field duplicate samples are used to provide a measure of the representativeness of the sampling and analysis procedures.

2.5.7.3 -- Field Sample Volumes

Sufficient sample volumes need to be collected to enable the required laboratory QA/QC analysis to be conducted. A table indicating what sample volumes are needed for regular sampling and for QA/QC sampling shall be included in the QAPP.

2.5.7.4 -- Recordkeeping

Field logbooks shall be maintained to record any relevant information noted at the collection time or during site visits. Notations about any activities or issues that could affect sample quality shall be made (e.g., sample integrity, test site alterations, maintenance activities, and improperly functioning equipment). At a minimum, the field notebook shall 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. Records of sediment accumulation measurements are also appropriately entered into the field logbook. In particular, any conditions in the tributary basin that could affect sample quality shall be noted (e.g., construction activities, reported spills, other pollutant sources). A field data form can be used in place of, or to supplement, the field logbook. If a field data form will be used, a sample form shall be provided in the QAPP.

2.5.7.5 -- Chain of Custody

Sample custody and transfer procedures shall be based on procedures outlined in *NPDES Storm Water Sampling Guidance Document* (EPA 833-B-92-001) (U.S. EPA 1992, available at http://www.epa.gov/npdes/pubs/owm0093.pdf). These procedures emphasize careful documentation of sample collection, labeling, and transfer, and storage procedures. Pre-formatted chain-of-custody forms should be used in order to document the transfer of samples to the laboratory and the analysis to be conducted on each bottle. A sample chain of custody form shall be provided along with the QAPP.

2.5.8 -- Laboratory QA/QC Procedures

QA/QC procedures and standard operating procedures shall be documented in the laboratory quality manual, referenced in the QAPP, and made available for inspection by CBTAP. Project requirements for laboratory QA/QC systems documented in the QAPP shall include, but are not limited to, laboratory control samples, method blanks, matrix spike/matrix spike duplicates (MS/MSDs), laboratory duplicates, surrogates, and proficiency test samples or certified reference materials. Corrective action, management audit, data integrity and ethics policies shall be outlined in the laboratory quality manual.

Laboratory analyses shall be conducted by an independent laboratory certified by NELAP. Analyses that do not have a procedure established under NELAP are not required to be performed by a NELAP certified or accredited laboratory.

2.5.9 -- Data Quality Indicators and Measurement Quality Objectives

The data quality indicators (DQIs) help define the quality and usefulness of the sample data, based on the factors that may impact the overall quality of the data. By defining the limits of the systematic and random errors that can impact data, the quality and usefulness of the data and impacts on decisions can be determined. The measurement quality objectives (MQOs) answer the question of how accurate the measurements need to be in order to get accurate data. For MTD effectiveness monitoring, individual measurement results are combined into data sets for statistical evaluation. The MQOs for accuracy, precision, bias, and required reporting limits shall be presented in the QAPP. Reporting limits shall be provided in the QAPP. In some cases, a laboratory may need to reduce laboratory contamination sources to meet the reporting limits. Report any concentration that is less than the reporting limit as being one-half the reporting limit and note that such value is below the reporting limit. If both input and output values are below the reporting limit, note the storm in the report, but exclude the results from the statistical evaluation.

The following paragraphs define the DQIs and specify the methods used to evaluate them. Additional detail on the use of these methods to evaluate the precision, accuracy, and completeness of data is provided in **Section 2.5.7 -- Field QA/QC Procedures** and **Section 2.5.8 -- Laboratory QA/QC Procedures**.

- **Precision** is a measure of the scatter in the data due to random error and is stated in terms of percent relative standard deviation or relative percent difference. The primary sources of random error are the sampling and analytical procedures. The total precision of results can be estimated from the results of field-duplicate samples. For laboratory analysis, precision is assessed using laboratory duplicates.

- **Bias** is a measure of the difference between the result for a parameter and the true value due to systematic errors. Bias is the difference between the mean of an infinite number of replicate results and the true value of the parameter being measured. Potential sources of bias include: (1) sample collection methods, (2) physical or chemical instability of samples, (3) interference effects, (4) inability to measure all forms of a parameter, (5) calibration of the measurement system, and (6) contamination.

  Previous studies pertaining to the sources of bias due to sampling have led to the recommended procedures currently in use. Thus, careful adherence to established procedures for collection, preservation, transportation, and storage of samples reduces or eliminates most sources of bias. Bias affecting laboratory measurement procedures are assessed by the use of matrix spike recovery, method blanks, and check samples in accordance with the laboratory QA plan. Analysis of split samples provides an estimate of overall sampling bias including variation in concentration due to sample heterogeneity. Matrix spikes are used to detect interference effects due to the sample matrix. An estimate of bias due to calibration is calculated from the difference between the check standard results and the true concentration.

- **Representativeness** is achieved by selecting sampling locations, sampler intakes, methods, and times so that the data describe the conditions that the project seeks to evaluate. The representativeness of project data is achieved by choosing the sampling sites using criteria specified in this document. Additionally, representativeness of the data is assured through definition of target storms and qualifying conditions, and through programming of the automated samplers to collect aliquots at appropriate intervals during the storm events.

- **Comparability** refers to the ability to compare the data from the project to other data sources. Data comparability is assured by selection of standardized procedures, adherence to this protocol, and by clearly stating any non-standard requirements.

- **Completeness** refers to the amount of useable data obtained during the project. Data completeness can be determined primarily by the success of flow data, rainfall data, and water quality sample collection during storm events.

2.6 -- Data Verification, Validation, and Certification

Guidance concerning the data verification and validation processes shall follow http://www.epa.gov/quality/qa_docs.html, *Guidance on Environmental Data Verification and Data Validation* (EPA QA/G-8) (EPA 2002).

2.6.1 -- Data Verification and Certification

The project manager, field collectors, and lab personnel need to coordinate efforts to produce verified data and data verification records. Verified data have been carefully reviewed by a designated independent representative. Any changes in the data from that originally reported shall be accompanied by an initialed/signed note of explanation from the field data collector, the laboratory, or the data verifier. The data verification records summarize the technical non-compliance issues or shortcomings of the data produced, identify deficient data, and document corrective actions. When data are not available to perform verification, it shall be stated in the data verification records that the data could not be verified. Normally, data verification records include checklists, handwritten notes, data tables (electronic or hard copies), definitions, and supporting documentation for any laboratory qualifiers assigned. The data verification records also include a signed and dated certification statement from the verifier. Submit these documents to the data validator.

2.6.2 -- Data Validation and Certification

Data validation is based on the verified data and data verification records and shall be performed by person(s) independent of the activity which is being validated. Validated data are expected to be the same as the verified data with the addition of any data validation qualifiers that were assigned by the data validator. Any corrections or changes noted during the data validator's review of the verified data shall be reflected in the validated data. Data that change as the result of validation shall be re-verified.

The basic steps to validation are listed below:

1. Check that all requested analyses were performed and reported. Check that all requested QA/QC samples were analyzed and reported.
2. Check sample holding times to ensure that all samples were extracted and analyzed within the allowed sample holding times.
3. Check that the laboratory's performance objectives for accuracy and precision were achieved. Include a check of method blanks, detection limits, laboratory duplicates, matrix spikes and matrix spike duplicates, laboratory control samples, and standard reference materials.
4. Check that field QA/QC was acceptable. Include a check of equipment blanks, field duplicates, and chain-of-custody procedures.
5. Check that surrogate recoveries were within laboratory control limits.
6. Assign data qualifiers as needed to alert potential users of any uncertainties to consider during data interpretation.

If the field performance objectives were achieved, further data validation is not generally needed. Specifics of the instrument calibration, mass spectral information, and run logs are not usually recommended for review unless there is a suspected problem or the data are deemed critical. If performance objectives were not achieved (e.g., due to contaminated blanks, matrix interference, or other specific problems in laboratory performance), the resulting data shall be disqualified.

The data validation process results in the following three outcomes: 1) validated data, 2) a data validation report, and 3) a certification statement. A data validation report is the primary means of communication between the data validator and the data user. It is recommended that the report provide sufficient detail for the data user to have an overall idea of the quality of the data and how well the project needs were met. It is recommended that the report be written in easy to read "lay language," as much as is feasible, because it is likely to be read by decision makers that do not have the same level of technical understanding that is typically shared by the researchers and technical advisors. Additionally, the data validation report shall include:

- objectives for sampling and analysis;
- summary of the project record needs as assessed from the QAPP;

- field and laboratory data documentation (e.g., laboratory certification sheets, chain of custody forms);
- deficiencies encountered and the impact of deficiencies on the overall data quality;
- data validation qualifier definitions, assignments, and reasons for the assignments (also include these in the validated data set); and
- updates and corrections to the verified data with explanations for the change.

2.7 -- Data Management

This element gives an overview for managing data generated throughout the project. Data management is an important component of field monitoring. You need to be able to store, retrieve, and transfer the diverse hard copy and electronic information generated by your monitoring program. Before beginning monitoring, establish the following data repositories:

- central file to accommodate and archive hard-copy information expected to be generated and practical dating and filing procedures to help ensure that superseded information is not confused with current information; and
- database to accommodate digital information such as results of laboratory analyses, information recorded by data loggers (e.g., flow, precipitation, in-situ water quality measurements), maps in CAD or GIS, and spreadsheets.

After data from the field have been received, store the originals in the project file. The data reports shall be reviewed for completeness as soon as they are received from the laboratory. Check reports to ensure all requested analyses were performed and all required QA data are reported for each sample batch. If problems with reporting or laboratory performance are encountered, corrective actions (re-submittal of data sheets or sample re-analysis) shall be performed prior to final data reporting or data analysis.

2.8 -- Data Quality Assessment

Data quality assessment (DQA) is the scientific and statistical evaluation of environmental data to determine if they meet the planning objectives of the project, and thus are of the right type, quality, and quantity to support their intended use. EPA's *Data Quality Assessment: A Reviewer's Guide* (EPA QA/G-9R) (U.S. EPA 2006a) is a non-technical guidance that describes broadly the statistical aspects of DQA in evaluating environmental data sets. A more detailed discussion about DQA graphical and statistical tools may be found in the companion guidance document, *Data Quality Assessment: Statistical Methods for Practitioners* (EPA QA/G-9S) (U.S. EPA 2006b). Both documents are available at http://www.epa.gov/quality/qa_docs.html. In general, DQA follows the following steps:

- State well-defined project objectives and criteria.
- Provide the statistical hypotheses, including a null hypothesis as well as an alternative hypothesis. Alternatively, provide confidence intervals or tolerance intervals (e.g., 'We are 95% confident that at least 80% of the population is above the threshold value.').
- Describe the tolerance for uncertainty. For example, list the Type I error (false positive) and Type II error (false negative).
- Calculate basic descriptive statistics of the data and generate graphs of the data.
- Document the test statistical method used and the critical value or *p*-value.
- List the assumptions underlying the statistical method.

- Document the method used to verify each assumption together with the results from the investigations.
- Describe any corrective actions that were taken.
- Report the statistical results at the specified significance level.

An acceptable means of using direct measurements, modeling, and statistical analysis shall be used to assess performance. For an in-depth discussion of appropriate statistical analysis procedures, including hypothesis driven techniques, refer to *Urban Stormwater BMP Performance Monitoring* (Geosyntec Consultants and Wright Water Engineers, Inc. [2009] for EPA and the American Society of Civil Engineers). In addition to the statistical characterization, it is desirable to advance further understanding of the physiochemical treatment processes used by the MTD, and be able to assess and predict how mass moves through the MTD during each event. Both statistical and mechanistic approaches are necessary to fully characterize performance and reliability of the MTD.

2.9 -- Methods for Estimating Pollutant Removal

The following three types of data are particularly valuable for determining the performance of BMPs in removing water quality pollutants: 1) event mean concentrations (EMC); 2) summation of loads (SOL); and 3) Effluent Probability (see **Appendix C -- Pollutant Removal Calculation Methods**).

- **Event Mean Concentrations** -- The EMC is defined as the flow-weighted mean concentration of pollutant in urban runoff

- **Summation of Loads** -- The SOL is determined from concentration and flow data. Loads are particularly important for meeting stormwater management regulations and for meeting total maximum daily load (TMDL) implementation plans. Annual loads of pollutants removed by the MTD and cited in the performance claim shall be calculated.

- **Effluent Probability** -- The effluent probability method provides a statistical view of the influent and effluent water quality. With this method, the data analyzer determines if the influent and effluent mean EMCs or loads are statistically different from one another and develops either a cumulative distribution function of influent and effluent quality or a standard parallel probability plot. For example, the ranked EMC (log scale) can be plotted as a function of the probability. Improvements in water quality will be apparent from the differences in the input and output data. The ability of the MTD to meet a desired performance goal can be determined from this plot, as shown in Figure 2.4, which is an example for suspended sediment reported by Geosyntec Consultants and Wright Water Engineers, Inc. (2009).

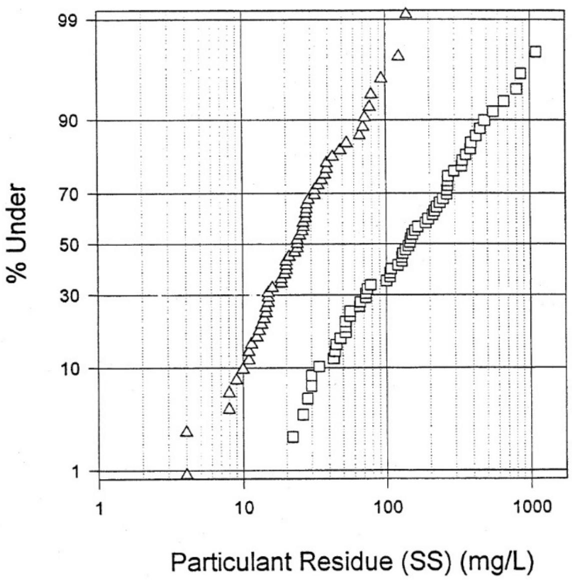

Figure 2.4. Illustration of effluent probability method for assessing pollutant removal of stormwater manufactured treatment devices

3 – Technical Evaluation Report (TER)

The Technical Evaluation Report (TER) is to be written once performance testing is complete and the resulting data have been validated and analyzed.

3.1 -- TER -- Title Page

- Include: "Chesapeake Bay Watershed Stormwater MTD Technical Evaluation Report."
- List the title of the project. Give the same title as that used on the use-designation application form.
- Provide the month and year of report submittal.
- List the name of the applicant and manufacturer (if different than the applicant).
- Include the contact information, including e-mail addresses, of key contacts where questions and correspondences may be addressed.

3.2 -- TER -- Executive Summary

The executive summary shall include the following items:

- MTD name, function, and category (e.g., hydrodynamic separator, filter).
- Desired pollutant removal designation.
- If approval has been previously issued by another state, include the name of the granting agency, the level of approval, the protocol version under which performance testing occurred (if applicable), date of award, and the link to the Web page where the award is listed (if applicable).
- A brief performance claim that identifies the MTD's intended use and predicts the MTD's capabilities to remove specific pollutants or to reduce the volume of stormwater runoff.
- A summary of the test results and conclusions.
- If criteria in the CBTAP have not been addressed, provide an opinion of how relevant such omission(s) may be for consideration.

3.3 -- TER -- Performance Claim

Performance claims should be objective, quantifiable, replicable, and defensible. Wherever possible, include information about anticipated performance in relation to any of the following: design, site conditions, storms or climate. Avoid claims that are overstated, as they might not be achievable and may result in rejection of the TER.

3.3.4 -- TER -- Technology Description

Technology description should include:

1. Description of Practice;
2. Performance Criteria;
3. Site Installation Requirements and Impacts;
4. Design and Sizing;
5. Material Specifications;
6. Construction Sequence and Inspection;

7. Operation and Maintenance;
8. System Longevity; and
9. References.

3.4.1 -- TER -- Description: Description of Practice

Begin the description with the name of the MTD, a photograph, and scale CAD drawing. Include the purpose of the MTD and cite the specific applications of the MTD. Provide detailed descriptions to ensure the reader can understand completely how the MTD works:

- Summarize the underlying scientific and engineering principles for the MTD. Describe any physical, chemical, or biological treatment processes.
- Describe significant modifications and technical advancements in the MTD design.
- Include details on relevant treatment mechanisms, such as those in Table 3.1.

Table 3.1. Measurements for various treatment mechanisms for manufactured treatment devices

Mechanism	Measurement
Exchange Capacity / (dissolved pollutants)	Each medium or soil's anion or cation exchange capacity and target pollutant's overall removal capacity indicated by isotherms (mass/mass) and breakthrough (pollutant load per volume) analyses (capturing typical range of stormwater pollutant concentrations and hydraulic loading rates).
Sorption	Capacity -- Pollutant mass absorbed or adsorbed per mass (mass/mass). Absorbent type -- Each medium's percent organic matter or organic carbon.
Gravity Separation	Detention time, length to width ratio, hydraulic loading rate for design flow, removal efficiency versus flow rate, particle-size distribution, and specific gravity for each system type or size.
Filtration	Filter media grain size distribution, clean media hydraulic conductivity, hydraulic conductivity versus sediment loading (provide sediment grain size distribution and dry density used in analysis), provide typical and maximum operational hydraulic gradient.
Biological	Describe target pollutant's specific degradation mechanisms and estimated half-life versus temperature, provide estimated stormwater contact time (or detention time) for design flow, and provide target pollutant's estimated treatment efficiency versus flow rate.

3.4.2 -- TER -- Description: Performance Criteria

List the expected treatment performance capabilities. Describe the advantages of the MTD compared to conventional stormwater systems providing comparable stormwater control.

3.4.3 -- TER -- Description: Site Installation Requirements and Impacts

Describe the range of site installation characteristics. Address any and all site installation requirements and likely impacts resulting from the installation of the MTD. As a guide, be sure to consider at least the following:

- **Siting location** – Contributing drainage area (including the effects of any diversions), upstream controls (non-structural and structural), available space needed, soil characteristics, hydraulic grade requirements, hydraulic capacity, minimum depth needed from water table, and pretreatment requirements.

- **Land use** – Provide the applications that the manufacturer recommends for the MTD (e.g., land uses such as roadways, high-use sites, commercial, industrial, residential runoff areas). Give the rationale for the recommendations. List restrictions to installations within proximity of underground utilities, overhead wires, and hotspot land uses. Provide needed setbacks from buildings and vehicle loading allowances. Report any utility requirements.

- **Limitations** – Consider the physical constraints to installing the MTD within karst terrain; steep terrain; flat terrain; tidal areas; sites with shallow groundwater tables; cold climates; types of soil; linear highway sites; and proximity to wells, septic systems and buildings. Also include limitations associated with the MTD's weight and buoyancy, transportability, durability, energy requirements, and consumable materials. Describe whether the following safety considerations favor or limit the MTD's use: facility depth limits for access and safety and hazardous materials spill risk. Describe how the limitation factors affect the MTD.

- **Environmental impacts** – Describe likely impacts resulting from the construction, operation, and maintenance of the MTD. Address community and environmental concerns, including safety risks and liability issues, local codes, winter operation, mosquitoes, and aesthetics.

3.4.4 -- TER -- Description: Design and Sizing

Divide this section into specific subsections that adequately describe design and sizing. The use of tables can be helpful to convey information. Follow the table format used in the design specifications information for post-construction, non-proprietary BMPs listed on the website.

Include the following information as applicable:

- Design description and standard drawings (photographs may also be useful):
  - Schematic of the technology;
  - Diagram of the process and functions of the MTD;
  - Description of MTD's potential configurations;
  - Description of each treatment system component (engineering plans/diagrams of functional components, dimensions, description of each component's capacity, media or soil head-loss curves).
- Detailed description of the overall sizing methodology:
  - hydraulics (maximum treatment flow rate, bypass flow, hydraulic grade line, scour velocities);

  - System sizing to meet performance standards and goals (e.g., to handle the water quality volume, rate of runoff, type of storm, or recharge requirements; include sizing chart);
  - Soil infiltration rate testing, specific media surface loading rate and specifications.
- Siting and design specifications to achieve stated performance, include (but not limited to):
  - If applicable: TP, SRP, PP, and sediment;
  - Optional: TN, TDN, ammonia-N, and nitrate-N + nitrite-N;
  - Identify pollutants that may be increased;
  - Stormwater constituent limitations (pollutants and other constituents), including fouling factors;
  - Range of operating conditions for the MTD, including minimal, maximal, and optimal influent conditions to achieve the performance goals and standards, and for reliability of the MTD, including modifications as needed to accommodate Type III (coastal) rainfall conditions;
  - Pollutant removal at water quality design treatment flow rate at the water quality storm event (1-inch in 24 hours) and for representative stormwater characteristics;
  - Design residence time, vertical/horizontal velocities, surface overflow rate, and other parameters relevant to the process, if applicable;
  - Description of any bypasses or diversions processes if applicable; and
  - Description of pretreatment and preconditioning of stormwater if appropriate to achieve stated performance of the MTD.

3.4.5 -- TER -- Description: Material Specifications

When applicable, include a table that lists each construction material. For non-proprietary and patented materials, include specifications. Include raw material specifications for all non-proprietary treatment media.

3.4.6 -- TER -- Description: Construction Sequence and Inspection

List the steps to construction in chronological order. Begin with protection during site construction. Identify who will be responsible for construction oversight.

Describe the following:

- The role the manufacturer/vendor takes in design and construction.
- MTD availability (e.g., where do the major components come from and how much lead time is needed).
- Include estimate of typical installation time.
- Provisions for factors such as structural integrity, water tightness, and buoyancy.
- Types of problems that can occur/have occurred in designing and installing the MTD.
- Methods for diagnosing and correcting potential problems; identify who is responsible to diagnose and correct problems.
- Impacts to the MTD's effectiveness if problems are not corrected.

3.4.7 -- TER -- Description: Operation and Maintenance

Describe special operation instructions and maintenance needed to sustain performance, include:

- Date the manufacturer went into business. If applicant goes out of business or MTD model changes, describe how and where the facility owner will find needed parts, materials, and service.

- Whether the MTD can be damaged due to delayed maintenance, and if so, tell how it is restored.
- How inspections are performed and their frequency. Recommended maintenance schedule and basis for this estimated maintenance frequency.
- How operations and maintenance are performed. Personnel and equipment needs to operate and maintain the MTD. Maintenance checklist. Availability of supplies, replacement materials and parts (e.g., filter media).
- Maintenance area accessibility by people and equipment; describe access ports, including dimensions. List special equipment or methods needed for access and identify any confined space entry areas or other safety issues.
- Generation, handling, removal, and disposal of discharges, emissions, and waste byproducts in terms of mass balance, maintenance requirements, and cost.
- Projected operational and maintenance (O&M) costs. Maintenance service contract availability. Include information about items that affect O&M costs: number of inspection/maintenance visits expected annually, equipment rental and mobilization, solids/spent media disposal, and other items that affect O&M costs.

3.4.8 -- TER -- Description: System Longevity

Provide the expected life span of the MTD, assuming the MTD is designed, installed, and maintained correctly.

List factors that may cause the MTD to not perform as designed by addressing the following questions:
- Is the MTD sensitive to heavy or fine sediment loadings?
- Is pretreatment required?
- Under what circumstances is the MTD likely to add, transform, or release accumulated pollutants?
- If applicable, how long will a soil-based or filter medium last if designed to capture dissolved pollutants?
- If applicable, does the filter medium decompose?
- Is the filter medium subject to slime/bacteria growth?
- How is underperformance diagnosed and treated?

In addition answer the following questions:
- What is the warranty?
- What initial/ongoing user support is provided?
- Does the vendor charge for support?

3.4.9 -- TER -- Description: References

List any sources of published information, including websites, cited in the TER. List sources alphabetically. Follow the format style used for references included within the design specifications information for post-construction, non-proprietary BMPs listed on the website.

3.5 -- TER -- Test Methods and Procedures Used

Include descriptions of how the assessment data were obtained. For all laboratory and field tests, the author of the TER shall provide the following information:

- Specifics of the MTD used in the assessment (model number if applicable, size).
- The testing protocol followed (e.g., CBTAP, TARP [2003], TAPE [2002, 2004, 2008, 2011], NJDEP [2003]); if different protocols were followed, distinguish which protocol was used for each specific lab test or field test site.
- Deviations from the testing protocol; list the deviations that exceed the protocol requirements separately from those that did not meet the protocol standards, and clearly label the two sections.
- All procedures for obtaining data as described in the QAPP, including a description of any deviations from this procedure during the assessment.
- Information on QA/QC as described in approved QAPP(s) and followed during testing.
- Inspection protocols used to determine when maintenance was needed. All maintenance activities shall be logged and included in TER.
- Summary of the maintenance procedures implemented during the course of the performance testing.
- The method used to calculate performance.

For all MTDs, include the requested information below when applicable:

- Influent and effluent requirements of PSD, TSS, and SSC, including representative PSDs and gravimetric TSS and SSC measurements.
- Representative method of sampling and sampling volume to generate a representative PSD; and suspended, settleable and sediment gravimetric fractions.
- Representative gravimetric measurement of the suspended fraction (1 to ~ 25 μm), settleable fraction (~ 25 to 75 μm) and sediment fraction (> 75 μm) for influent and effluent.
- Representative hydrologic, chemical and particulate matter loading rates.
- Representative QA/QC of the testing methods and analytical methods. For example, what does a mass balance result indicate?

For adsorptive-filtration media and soil-based treatment practices, the following information is mandatory.

1. Granulometric media properties:
    a. Representative media size gradation, i.e., media size distribution and statistical indices;
    b. Representative media specific gravity; and
    c. Representative media specific surface area (not surface area of system, i.e., cartridge).
2. Representative mechanisms, i.e., filtration mechanisms that range from straining to physical-chemical phenomena.
3. Geometric and hydrodynamic properties of system including surface loading rates, contact time, and head-loss models. In this case, surface area is geometric surface area of the deployment system for the media, i.e., the area orthogonal to flow paths, as in Darcy's Law.
4. Chemical applications, such as coagulants and flocculants upstream of the filter, if part of the normal process of operation.
5. Backwash criteria based on hydraulics and backwash frequency, if using backwash.
6. Media stratification and inter-mixing.
7. Standardized isotherm, kinetics and breakthrough parameters.

8. Standardized desorption testing.

If field tests were performed, characterize field sites by including the following information:
- General description of where the testing occurred (street, city, state, zip).
- Site information shall include a site map, land-cover type, land-use activities, location of land-use activities, site conditions, site elevations and slopes, location of sampling equipment, location of on-site stormwater collection system, a description of any upstream BMPs, and the name of downstream receiving waters.
- Narrative that describes any special circumstances (e.g., pretreatment, bypass conditions, retention/detention facilities).
- The method used for sizing the MTD for the specific testing location.
- The time period that testing occurred for each test site, the sequence of storms, including missed events.

If laboratory tests were performed, include the following information:
- Detailed test facility descriptions (photos, illustrations, process/flow diagrams).
- Treatment and hydraulic design flow.
- Loading rates on a unit basis.
- Dead storage/detention volumes (if applicable).
- Media type/quantity/thickness (if applicable).

3.6 -- TER -- Monitoring Equipment Used

List the monitoring equipment used to obtain data. If the equipment is standard monitoring equipment, giving the manufacturer's name and model number is appropriate. Show calibration results of flow metering systems.

3.7 -- TER -- Data Verification and Validation

Include the certification statement by the data validator that certifies that the data have been validated. Also, include the data validation report, which is based on the verified and validated data and is to be written by the data validator, who is independent of the activity which is being validated. Refer to EPA's *Guidance on Environmental Data Verification and Data Validation* (U.S. EPA 2002) for practical advice on implementing data verification and validation.

3.3.8 -- TER -- Data Summary

Provide summaries of field testing and laboratory testing as described in the following subsections.

3.8.1 -- TER -- Data Summary: Field Testing

Report the number of storms monitored, longest continuous sequence of storms sampled, and the number of sets of back-to-back storms monitored. Using the validated data, complete a **Stormwater MTD Demonstration Site Summary** form (available from the website) for each field test site. When reporting the PSD, include the entire distribution and specify D_{50}. Include additional data of value for understanding any of the performance results or quality control measures. Include individual storm reports in the appendices of the TER (see **Section 3.11 -- TER – Appendices**). Maintenance data are required. Quantify the impact of maintenance activities or lack thereof on performance.

3.8.2 -- TER -- Data Summary: Laboratory Testing

Include laboratory testing results in the TER at the conclusion of performance testing. Summarize the data obtained from laboratory testing in tables and graphs. Be sure to document data that are needed to prove the effectiveness of the practice in relation to the performance claim.

MTD Lab Test Results (for MTD performance tested in a laboratory)

- Develop a table to summarize the characteristics of the MTD including specifics related to sizing. Characteristics may include the model number, size, treatment capacity, storage capacity, and other characteristics.
- When a synthetic sediment product, such as Sil-Co-Sil 106 or NJDEP particle-size distribution (NJDEP 2009), is used to test the performance of the MTD, include information about the particle-size distribution of the test material (entire distribution, specify D_{50}).
- Report the number of test runs.
- Summarize the specific settings of each test run, e.g., flow rate, run times, and loading rates.
- Include data to show pollutant removals. If the MTD performance was tested under different conditions (e.g., different flow rates, filter material), be sure to show data results for each tested condition. Determine the percent capture of the various sized particles under the performance claim conditions (e.g., flow rate).
- Determine the sediment effluent retention values and the various sized particles retained during higher flow conditions under the performance claim conditions (i.e., maximum design flow rate).

Analytical Lab Test Results (for water, sediment, or other samples analyzed in a laboratory)

- Include data to show pollutant removal of phosphorus and sediment as required for approval according to the specified testing protocol. PR credits may be awarded for TP and TSS.
- At the option of the applicant, the pollutant removal of nitrogen and subspecies may be reported. However, the intent to assess the MTD for removal of nitrogen shall be disclosed in the QAPP. A PR credit may be awarded for TN.
- At the option of the applicant, performance data for additional constituents (such as bacteria, metals, and other pollutants) may be reported.

3.9 -- TER -- Data Quality Assessment

Submit statistical analyses (e.g., paired t-tests, Wilcoxon signed rank tests, sign tests, or effluent probability method) that were performed on the collected data to determine if pollutant concentrations and loadings are significantly lower in effluent samples relative to influent samples. Also submit additional analyses that may have been performed to examine how the MTD performance varies with factors such as antecedent dry period, storm magnitude, or storm intensity. For all systems, address flow balance and provide justification for any loss of flow between the inflow and outflow.

3.10 -- TER -- Conclusions, Recommendations, and Limitations

All MTDs being assessed shall include the conclusions, recommendations, and limitations section in the TER. This section shall include the following information:

- All conclusions related to performance testing.
- Expected MTD performance for typical land uses. Recommendations concerning how best to site the MTD relative to factors such as hydraulic grade and space constraints.
- Recommendations pertaining to the operation and maintenance (O&M) procedures of the MTD.
- Frequency with which maintenance is needed.
- Special disposal requirements.
- Site limitations that would preclude the use of the MTD.
- Limitations on the use or installation of the MTD, including information about anticipated performance in relation to any of the following: design, site conditions, storms, or climate. List any pretreatment requirements.

If the sampling design is to be used again, either in a later phase of the current study or in a similar study, it is recommended that the applicant's technical advisor evaluate the overall performance of the design. The technical advisor shall perform a statistical power analysis that describes the estimated power of the statistical test over the range of possible parameter values. Additional information on power curves (performance curves) is contained in EPA's *Guidance on Systematic Planning using the Data Quality Objectives Process* (EPA QA/G-4) (U.S. EPA 2006c) available at http://www.epa.gov/quality/qa_docs.html.

3.11 -- TER -- Appendices

Include individual storm reports. These reports compare data and provide a detailed description of each storm event monitored in an easy-to-read format. Individual storm reports shall include:

- **General information** -- storm name, site location, system description, event date, date of last maintenance, antecedent conditions, and unusual circumstances associated with the storm (e.g., a large storm that impacts the drainage area).
- **Hydrological information** -- total precipitation (in.); influent peak flow rate (ft.^{3}/sec.); effluent peak flow rate (ft.^{3}/sec.); bypass peak flow rate (ft.^{3}/sec.) if applicable; total influent runoff volume (ft.^{3}); total effluent runoff volume (ft.^{3}); total bypass runoff volume (ft.^{3}) if applicable. Include an event hydrograph with axes of time, flow, and precipitation: time on x-axis (date, time), flow on left-side y-axis (ft.^{3}/sec.); and precipitation on right-side y-axis (in./time). The event hydrograph shall include a graph of precipitation, influent flow, effluent flow, and 75% of the design flow.
- **Pollutant information** -- number of influent aliquots, number of effluent aliquots, parameters monitored, influent mean concentrations, effluent mean concentrations, pollutant removal (calculated per **Appendix C -- Pollutant Removal Calculation Methods**), and reported detection limits.

References

American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF). 2005. *Standard Methods for the Examination of Water and Wastewater, 21st Edition.* APHA, AWWA and WEF, Washington, D.C.

American Society of Testing and Materials (ASTM). 2007. *D3977-97(2007) Standard Test Methods for Determining Sediment Concentration in Water Samples*. ASTM International, West Conschohocken, PA.

ASTM 2008. *D5612-94(2008) Standard Guide for Quality Planning and Field Implementation of a Water Quality Measurement Program*. ASTM International, West Conschohocken, PA.

Burton, G.A., Jr., and R.E. Pitt. 2002. *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists and Engineers.* CRC/Lewis Publishers, Boca Raton, FL. 911 pp.

California Department of Transportation (Caltrans). 2003. *Caltrans Comprehensive Protocols: Guidance Manual*. CTSW-RT-03-105.51.42. California Department of Transportation, Sacramento, CA. 36 pp. http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-03-105.pdf (accessed August 13, 2012).

Center for Watershed Protection (CWP). 2008. *Tool 8: BMP Performance Verification Checklist Appendices.* CWP, Ellicott City, MD. 20 pp. http://www.cwp.org (accessed August 13, 2012).

Chow, Ven Te. 1959. *Open-Channel Hydraulics*. McGraw-Hill, New York, NY. 680 pp.

Federal Highway Administration (FHWA). 2001*. Guidance Manual for Monitoring Highway Runoff Water Quality.* Report No. FHWA-EP-01-022. Office of Natural Environment, FHWA, Washington, D.C. http://www.environment.fhwa.dot.gov/ecosystems/h2o_runoff/index.asp (accessed August 13, 2012).

Geosyntec and Wright Water Engineers, Inc. 2009. *Urban Stormwater BMP Performance Monitoring*. http://www.bmpdatabase.org/MonitoringEval.htm (accessed August 13, 2012).

Gray, J.R., G.D. Glysson, L.M. Turcios, and G.E. Schwarz. 2000. *Comparability of Suspended-sediment Concentration and Total Suspended Solids Data*. U.S. Geological Survey, Water-Resources Investigations Report 00-4191. Reston, VA. 14 pp.

Lenhart, J,H , *BMP performance expectation functions–A simple method for evaluating stormwater treatment BMP performance data*, in: 9th Biennial Conference on Stormwater Research and Watershed Management, 2007, pp. 2-3

Natural Resources Conservation Service (NRCS). 2003. *National Water Quality Handbook*. 450-VI-NWQH. NRCS, U.S. Department of Agriculture. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17843.wba (accessed August 13, 2012).

New Jersey Corporation for Advanced Technology (NJCAT). Verification Process. http://www.njcat.org/ (accessed August 7, 2012).

New Jersey Department of Environmental Protection (NJDEP). 2003. Total Suspended Solids Laboratory Testing Procedure. December 23, 2003. 2 pp. http://www.state.nj.us/dep/dsr/bscit/Documents.htm (accessed August 7, 2012).

NJDEP. 2009. Protocol for Total Suspended Solids Removal Based on Field Testing Amendments to TARP Protocol, Dated August 5, 2009, Revised December 15, 2009. 8 pp. http://www.state.nj.us/dep/stormwater/pdf/field_protocol_12_15_09.pdf (accessed August 13, 2012).

NJDEP. 2013. Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from the New Jersey Corporation for Advanced Technology, January 25, 2013.

Pitt, R. 2008. The National Stormwater Quality Database (NSQD) Version 3 Spreadsheet. Updated: February 3, 2008. http://rpitt.eng.ua.edu/Research/ms4/mainms4.shtml (accessed August 13, 2012).

Sample, D. et al. 2010. Assessing Performance of Manufactured Treatment Devices: State of the Science and Review of Proposed Virginia Testing Protocols. Expert Panel Report. Prepared for: Virginia Department of Conservation and Recreation. Submitted: December 13, 2010.

Sample, D.J., et al. 2012. Assessing performance of manufactured treatment devices for the removal of phosphorus from urban stormwater. *Journal of Environmental Management*, 113: 279-291.

Technology Acceptance Reciprocity Partnership (TARP). 2003. *The Technology Acceptance Reciprocity Partnership Protocol for Stormwater Best Management Practice Demonstrations*. 37 pp. http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/ (accessed August 13, 2012).

U.S. Environmental Protection Agency (U.S. EPA). 1983. *Addendum to Handbook for Sampling and Sample Preservation, EPA-600/4-82-029*. EPA-600/4-83-039. U.S. EPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH. 28 pp.

U.S. EPA. 1992. *NPDES Storm Water Sampling Guidance Document*. EPA 833-B-92-001. Office of Water, U.S. EPA. http://www.epa.gov/npdes/pubs/owm0093.pdf (accessed August 13, 2012).

U.S. EPA. 1999. *Methods and Guidance for the Analysis of Water.* U.S. EPA, National Technical Information Service (NTIS) PB99-500209INQ.

U.S. EPA. 2001. *EPA Requirements for QA Project Plans* (EPA QA/R-5). EPA/240/B-01/003. U.S. EPA, Office of Environmental Information, Washington, D.C. http://www.epa.gov/quality/qa_docs.html (accessed August 13, 2012).

U.S. EPA. 2002. *Guidance on Environmental Data Verification and Data Validation* (EPA QA/G-8). EPA/240/R-02/004. U.S. EPA, Office of Environmental Information, Washington, D.C. http://www.epa.gov/quality/qa_docs.html (accessed August 13, 2012).

U.S. EPA. 2006a. *Data Quality Assessment: A Reviewer's Guide* (EPA QA/G-9R). EPA/240/B-06/002. U.S. EPA, Office of Environmental Information, Washington, D.C. 55 pp. http://www.epa.gov/quality/qa_docs.html (accessed August 13, 2012).

U.S. EPA. 2006b. *Data Quality Assessment: Statistical Methods for Practitioners* (EPA QA/G-9S). EPA/240/B-06/003. U.S. EPA, Office of Environmental Information, Washington, D.C. 190 pp. http://www.epa.gov/quality/qa_docs.html (accessed August 13, 2012).

U.S. EPA. 2006c. *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA QA/G-4). EPA/240/B-06/001. U.S. EPA, Office Environmental Information, Washington, D.C. 111 pp. http://www.epa.gov/quality/qa_docs.html (accessed August 13, 2012).

U.S. Geological Survey (USGS). variously dated. *National Field Manual for the Collection of Water-Quality Data: U.S. Geological Survey Techniques of Water Resources Investigations.* Book 9, Chapters A1-A9. http://water.usgs.gov/owq/FieldManual/ or http://pubs.water.usgs.gov/twri9A (accessed August 13, 2012).

Washington State Department of Ecology (WSDOE). 2002. *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE)*. Publication Number 02-10-037. Washington State Department of Ecology, Water Quality Program, Olympia, WA.

WSDOE. 2004. *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol - Ecology (TAPE).* Publication Number 02-10-037**.** Washington State Department of Ecology, Water Quality Program, Olympia, WA. 48 pp.

WSDOE. 2008. *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE)*. Publication Number 02-10-037. Washington State Department of Ecology, Water Quality Program, Olympia, WA. 51 pp. http://www.ecy.wa.gov/biblio/0210037.html (accessed August 13, 2012).

WSDOE. 2011. *Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE).* August 2011 Revision of Publication Number 02-10-037. Publication Number 11-10-061. Washington State Department of Ecology, Water Quality Program, Olympia, WA. 61 pp. www.ecy.wa.gov/biblio/1110061.html (accessed August 7, 2012).

Glossary

This glossary contains the definitions for some of the technical terms used in this document.

“Accuracy” means the degree to which a measured value agrees with the true value of the measured property. The terms precision and bias are terms that are related to or associated with this term.

“Aliquot” means a discrete sample used for analysis.

“Ammonia nitrogen” (NH_3-N) means the nitrogen fraction of ammonia, an inorganic nitrogen compound.

“Anion Exchange Capacity” means a measure of the ability of an ion exchange resin, media, or soil to adsorb and retain negatively charged ions such as $NO_3^-, PO_4^{3-}, SO_4^{2-}$.

“Assessment” means the evaluation process used to measure performance or effectiveness.

“Automated sampler” means a portable unit that can be programmed to automatically collect discrete sequential samples, time-composite samples, or flow-composite samples during storm events.

“Backwater” means water upstream from an obstruction that is deeper than it would normally be without the obstruction.

“Bias” means a measure of the difference between the result for a parameter and the true value due to systematic errors; usually this is an estimate. True bias is the difference between the mean of an infinite number of replicate results and the true value of the parameter being measured.

“Blank” means a synthetic sample, free of the analyte(s) of interest. Blanks are used to assess possible contamination or inadvertent introduction of analyte(s) during various stages of the sampling and analytical process.

“Bypass” means those flows that are diverted after entering the MTD and after flow measurement.

“Calibration” means, with respect to analytical data, a comparison of a measurement standard, instrument, or item with a standard or instrument of higher accuracy to detect and quantify inaccuracies and to report or eliminate those inaccuracies by adjustments. Calibration is also used as a term in numerical modeling; in this context, it means the process of adjusting the parameters of a numerical model within acceptable ranges until they agree with selected observed data.

“Cation exchange capacity” means a measure of the ability of an ion exchange resin, media, or soil to adsorb and retain positively charged ions such as $NH_4^+, K^+, Ca^{2+}, Fe^{2+}$.

“CBW” means Chesapeake Bay Watershed, the drainage area that drains to the Chesapeake Bay

“Chain-of-custody” means an unbroken trail of accountability that ensures the physical security of samples, data, and records.

“Comparability” means the ability to compare the data from the project to other data sources. It describes the degree to which different methods, datasets and/or decisions agree or can be represented as similar.

“Completeness” means amount of useable data obtained during the project. Completeness is usually expressed as a percentage. For example, during a monitoring period lasting 18 months, there were 20 qualifying storm events; samples were collected from 15 of these events, and 5 of the qualifying storms were not sampled because of various reasons. Thus, these data are 75% complete with respect to the available qualifying storm events.

“Composite sample” means a method used to determine “average” loadings or concentrations of pollutants for an event. Such samples are collected at specified intervals and pooled into one large sample, which can be developed on time, flow volume, or flow rate.

“Confined space entry” means a space that has limited or restricted means for entry or exit where an employee can bodily enter and perform assigned work but is not designed for continuous employee occupancy.

“Data quality assessment” means a statistical and scientific evaluation of the data to determine the validity and performance of the data collection design and statistical test, and to determine the adequacy of the data for its intended use.

“Data quality indicators” means the quantitative and qualitative measures of principal quality attributes, including precision, accuracy, representativeness, comparability, completeness, and sensitivity.

“Data quality objectives” means qualitative and quantitative statements that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

“Data validation” means an analyte-specific and sample-specific process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e., data verification) to determine the analytical quality of a specific data set.

“Data validator” means a person(s), independent of the activity which is being validated, who is responsible for conducting data validation activities.

“Data verification” means the process of evaluating the completeness, correctness, and conformance/compliance of a specific data set against the method, procedural, or contractual requirements.

“Data verifier” means an individual (typically an employee of the field or laboratory organization whose operations are being verified) responsible for conducting data verification activities.

“Design” means specifications, drawings, design criteria, and performance requirements. It also means the result of deliberate planning, analysis, mathematical calculations, modeling, and other processes needed to create a design.

“Detention time” means the theoretical calculated time required for a specific amount of water to pass through a basin, tank or other storage unit at a given rate of discharge (volume divided by rate of discharge).

“Drainage area” means a land area, water area, or both from which runoff flows to a common point.

“Efficiency ratio” (ER) means a method to estimate pollutant removal credit that is calculated by subtracting from one the ratio of the average EMC for the outflow in relation to the average EMC for the inflow.

“Effluent” means the discharge from the outlet of the MTD.

“Equipment rinsate blank” means a quality control sample collected by passing analyte-free water through clean monitoring equipment and collecting samples for chemical analyses. The amount of reagent-grade water used for the sample should represent the volume of stormwater that will be collected during a typical sampling event. The equipment rinsate blank may also detect contamination from the surroundings, contamination from the containers, or from cross-contamination during transportation and storage of the samples and is therefore the most comprehensive type of field blank.

“Field blank” means a sample of analyte-free water poured into a sample container in the field, preserved and shipped to the laboratory with field samples. It is used to assess contamination from field conditions during sampling.

“Field duplicate” sample means a second independent sample collected at the same location and with the same equipment. Field duplicates are used to assess total sample variability (i.e., field plus analytical variability).

“Flow-weighted composite sample” means a composite sample consisting of a mixture of aliquots collected at intervals across the runoff event hydrograph. Weighting is accomplished by either of the following methods: Variable Volume-Variable Time, or Equal Volume-Variable Time. The former method uses a variable time interval, where the volume of each aliquot is proportional to the flow rate of the discharge. The latter method uses a constant volume, where the amount of time within which it is collected is proportional to the flow rate of the discharge.

“Grab sample” means a discrete sample collected at a particular time and place that is intended to represent, at that time and place, the composition of the water or sediment from which it was taken.

“Gradient” means, the change of elevation or slope per unit length (rate of ascent or descent) of a specific surface of interest.

“Groundwater” means water in a saturated zone or stratum beneath the land surface or a surface water body.

“Head” (hydraulics) means the height of water above any plane of reference. The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed.

“Hydrograph” means a graph of runoff rate, inflow rate or discharge rate past a specific point as a function of time.

“Illicit connection” means any man-made conveyance that is connected to a municipal separate storm sewer without a permit, excluding roof drains and other similar type connections. Examples include sanitary sewer connections, floor drains, channels, pipelines, conduits, inlets, or outlets that are connected directly to the municipal separate storm sewer system.

“Impervious cover” means a surface composed of material that significantly impedes or prevents the natural infiltration of water into soil.

“Infiltration” means the downward movement of water from the surface to the subsoil.

“Influent” means stormwater runoff entering the inlet of the MTD.

“Inlet” means the upstream end of the MTD through which water enters.

“In situ” means “in place.”

“Inspection” means an activity such as measuring, photographing, documenting, examining, testing, or gaging one or more characteristics of an entity and comparing the results either over time or with specified requirements in order to establish whether conformance is achieved for each characteristic.

“Karst terrain” means a geographic area generally underlain by soluble bedrock (e.g., limestone, dolostone, marble, or gypsum) at the surface or in the shallow subsurface (less than 50 feet), and characterized by (1) storage and transport of water in voids and conduits produced by bedrock dissolution, (2) such features as sinkholes, caves, closed depressions, sinking and losing streams, large flow springs, and other subsurface drainage, and (3) a relative lack of surface streams.

“Laboratory control sample” means a known sample, usually prepared and certified by an outside agency, which is carried through the preparation and analysis procedures as if it were a sample.

“Laboratory duplicates” means a quality control method used to assess the precision of the analytical method and laboratory handling. One sample will be split by the analytical laboratory into two portions, and each portion is analyzed. The results are evaluated by calculating the relative percent difference between the two sets of results for each constituent.

“Mass median particle diameter” (D_{50}) means the mass median diameter, or the diameter at which 50% of the particles are larger, and 50% are smaller. It is considered to be the average particle diameter by mass.

“Matrix spike/matrix spike duplicate” (MS/MSD) means analyses used to assess the accuracy (MS) and precision (MSD) of the analytical methods in the sample matrix. The analytical laboratory prepares matrix spike samples by splitting off three aliquots of the environmental sample and adding known amounts of target analytes to two of the three environmental sample aliquots. The results of the analysis of the unspiked environmental sample are compared to the MS analysis results, and “percent recovery” of each spike is calculated to determine the accuracy of the analysis.

“Measurement quality objectives” means "acceptance criteria" for the quality attributes measured by project data quality indicators. During project planning, measurement quality objectives are established as quantitative measures of performance against selected data quality indicators, such as precision, bias, representativeness, completeness, comparability, and sensitivity.

“Method” means a body of procedures and techniques for performing an activity (e.g., sampling, modeling, chemical analysis, quantification) systematically presented in the order in which they are to be executed.

“Method blank” means a laboratory blank prepared to represent the sample matrix as closely as possible. The method blank is prepared/extracted/digested and analyzed exactly like the field samples. It is used to assess contamination introduced during sample preparation activities.

“Outlet” means the point at which water discharges from a MTD.

“Parameter” means a specified characteristic of a sample. It also means an analyte or grouping of analytes. It can also be an attribute of a site or media, such as infiltration rate.

“Particle size” means the effective diameter of a particle as measured by sedimentation, sieving, or micrometric methods.

“Particle size distribution” (PSD) means a list of values or a mathematical function that defines the relative amounts of particles (such as soil or sediment particles) present, sorted according to size; also known as grain size distribution.

“Particulate phosphorus” (PP) means the fraction of total phosphorus that does not pass through a 0.45-μm membrane filter. PP is calculated by subtracting TSP from TP.

“Percent relative standard deviation” (%RSD) means a statistic used to evaluate precision in environmental analysis. It is determined in the following manner:
%RSD = (100 * s)/x where s = sample standard deviation, and x = sample mean

“pH” means a measure of the alkalinity or acidity of a substance which is conducted by measuring the concentration of hydrogen ions in the substance. The neutral point is a pH of 7.0. All pH values below 7.0 are acid, and all above 7.0 are alkaline.

“Pollutant” means dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 USC §2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. It does not mean:
1. Sewage from vessels; or
2. Water, gas, or other material that is injected into a well to facilitate production of oil or gas, or water derived in association with oil and gas production and disposed of in a well if the well used either to facilitate production or for disposal purposes is approved by the board and if the board determines that the injection or disposal will not result in the degradation of ground or surface water resources.

“Pollutant load” means the total mass of a pollutant conveyed over a specified duration. The pollutant load from a given storm event can be estimated using pollutant EMCs and flow data.

“Precision” is a measure reflecting the reproducibility of the data. Precision is a measure of the scatter in the data due to random error and is stated in terms of percent relative standard deviation or relative percent difference.

“Pretreatment”means a process used to reduce the pollution of stormwater (especially sediment and other particulate matter) before it is introduced into a stormwater BMP for a reduction of pollution load. Pretreatment is usually performed to reduce constituents, such as sediment, that may interfere or substantially reduce the effectiveness of the stormwater BMP.

“Quality assurance” (QA) means an integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the client.

“Quality control” (QC) means the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfill requirements for quality.

“Rainfall distribution” means a tabular listing or graphical depiction of the typical timing of rainfall quantities over aspecific time duration in a given location. Usually it is collected and aggregated into a 1-hour, 6-hour, or 24-hour increments.

“Rainfall intensity” means the rate at which rain is falling at any given instant, usually expressed in inches per hour.

“Relative percent difference” means the difference between two values divided by their mean and multiplied by 100.

“Representativeness” means the degree to which a sample reflects the population from which it is taken.

“Runoff volume” means the volume of water that runs off the site during a storm event.

“Sediment” means the solid fragmentary material, both mineral and organic, that is transported by, suspended in, or deposited by air, water, wind or ice and has come to rest. Sediment is normally formed by weathering, decomposition, and erosion.

“Sensitivity” means the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit.

“Soluble reactive phosphorus” (SRP) means the fraction of phosphorus in TSP that responds to colorimetric tests in the laboratory without preliminary hydrolysis or oxidative digestion of the sample.

“Specific gravity” means the dimensionless ratio of the density of a substance with respect to the density of water. The specific gravity of water is equal to 1.0 by definition.

“Standard operating procedure” means a document that describes in detail a reproducible and repeatable organized activity.

“Stormwater” or “stormwater runoff” or “runoff” or “surface runoff” means that portion of precipitation that does not infiltrate and either sheet flows across the land surface or flows through conveyances to one or more waterways.

“Summation of loads” (SOL) means a method to estimate pollutant removal credit that is calculated from the sum of the outlet loads in relation to the sum of the inlet loads. Loads are calculated using pollutant concentration and flow volume and are summed for the number of events measured.

“Surrogate” means a substance with properties similar to those of the target analyte(s). Surrogates may be used for quality control purposes to track extraction efficiency or to measure analyte recovery.

“Total dissolved nitrogen” means the fraction of nitrogen remaining in a water sample after all particulate nitrogen has been removed by filtration, through a 0.45-μm membrane filter.

“Total oxidized nitrogen” means the sum of nitrate nitrogen (NO_3^--N) and nitrite nitrogen (NO_2^--N). Nitrate is an essential nutrient for many photosynthetic autotrophs and in some cases has been identified as the grow-limiting nutrient. Nitrite is an intermediate oxidation state of nitrogen, both in the oxidation of ammonia to nitrate and in the reduction of nitrate.

“Total soluble phosphorus” (TSP) means the fraction of total phosphorus that passes through a 0.45-μm membrane filter. It refers to the biologically available form of phosphorus.

“Validation” means confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled. In design and development, validation concerns the process of examining a product or result to determine conformance to user needs.

“Verification” means confirmation by examination and provision of objective evidence that specified requirements have been fulfilled. In design and development, verification concerns the process of examining a result of a given activity to determine conformance to the stated requirements for that activity.

“Water quality” means a description of the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Appendix A -- Particle-Size Distribution

Slightly modified from

Guidance for Evaluating Emerging

Stormwater Treatment Technologies

Technology Assessment Protocol – Ecology
(TAPE)

January 2008 Revision

Publication Number 02-10-037

Washington State Department of Ecology

Particle-Size Distribution

Wet sieve protocol and mass measurement

(Recommended by the Technical Review committee [TRC] that serves in an advisory capacity to provide recommendations to Washington State Department of Ecology)

The intent of providing this protocol is to allow more analytical flexibility for vendors while setting reasonable expectations in terms of results. The purpose of requiring particle-size distribution (PSD) analysis in the TAPE protocols 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 because 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.

This protocol is intended for use with the laser diffraction PSD analysis. Laser diffraction methods are effective for 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.

The mass measurement for the larger-sized particles will also separate out particles between 499 to 250 µm in order to be consistent with the *Guidance for Evaluating Emerging Stormwater Treatment Technologies* definition of TSS (total suspended particles <500 µm).

NOTE: The Technical Review Committee (TRC) recognizes the fact that applying a mathematical constant for density would provide a rough estimate of mass. However, there is concern that the potential error associated with the results due to different soil types and structure might be large.

Wet Sieving and Mass Measurement for Laser Diffraction Analysis

Wet sieving

Sample Collection/Handling

Samples should be collected in HDPE or Teflon containers and held at 4°C during the collection process. If organic compounds are being collected, the sample containers should be glass or Teflon.

Preservation/holding time

Samples should be stored at 4°C and must be analyzed within 7 days (U.S. EPA 1998). Samples may not be frozen or dried prior to analysis, as either process may change the particle-size distribution.

Sonication

Do not sonicate samples prior to analysis to preserve particle integrity and representativeness. Laboratories using laser diffraction will have to be notified not to sonicate these samples at any time during the analysis. This request is to be written on the chain-of-custody form that the analytical laboratory receives in order to assure that sonication is omitted.

Laboratory Procedures

Equipment

__ 2 L of stormwater sample water (total sample required for analysis [ASTM 1997, D 3977])
__ Drying oven (90°C ± 2 degrees)
__ Analytical balance (0.01 mg accuracy)
__ Desiccator (large enough diameter to accommodate sieve)
__ Standard sieves – larger than 2" diameter may be desirable
__ 500 µm (Tyler 32, US Standard 35)
__ 250 µm (Tyler 60, US Standard 60)
__ Beakers – plastic (HDPE)
__ Funnel (HDPE – Large enough diameter to accommodate sieve)
__ Wash bottle
__ Pre-measured reagent-grade water

Sample processing

- Dry 250 µm and 500 µm mesh sieves in a drying oven to a constant weight at 90 ± 2°C.
- Cool the sieves to room temperature in a desiccator.
- Weigh each sieve to the nearest 0.01 mg.
- Record the initial weight of each dry sieve.
- Measure the volume of sample water and record.
- Pour the sample through a nested sieve stack (the 500 µm sieve should be on the top and the sieve stack should be stabilized in a funnel and the funnel should be resting above/inside a collection beaker).
- Use some of the pre-measured reagent-grade water in wash bottle to thoroughly rinse all soil particles from sample container so that all soil particles are rinsed through the sieve.

- Thoroughly rinse the soil particles in the sieve using a pre-measured volume of reagent-grade water.
- The particles that pass through the sieve stack will be analyzed by laser diffraction particle-size distribution (PSD) analysis using the manufacturers recommended protocols (with the exception of no sonication).
- Particles retained on the sieve (>250 μm) will not be analyzed with the laser diffraction PSD.
- Dry each sieve (500 μm and 250 μm) with the material it retained in a drying oven to a constant weight at 90 ± 2°C. The drying temperature should be less than 100°C to prevent boiling and potential loss of sample (PSEP 1986).
- Cool the samples to room temperature in a desiccator.
- Weigh the cooled sample with each sieve to the nearest 0.01 mg.
- Subtract initial dry weight of each sieve from final dry weight of the sample and sieve together.
- Record weight of particles/debris separately for each size fraction (> 500 μm and 499 – 250 μm).
- Document the dominant types of particles/debris found in this each size fraction.

Laser diffraction (PSD)

PSD results are reported in mm/L for each particle-size range. Particle-size gradations should match the Wentworth grade scale (Wentworth 1922).

Mass Measurement

Equipment

__ Glass filter – 0.45 μm (pore size) glass fiber filter disk (ASTM 1997, D 3977) (larger diameter sized filter is preferable)
__ Drying oven (90°C ±2 degrees)
__ Analytical balance (0.01 mg accuracy)
__ Wash bottle
__ Reagent-grade water

Procedure

- Dry glass filter in drying oven at 90 ± 2°C to a constant weight.
- Cool the glass filter to room temperature in a desiccator.
- Weigh the 0.45 μm glass filter to the nearest 0.01mg.
- Record the initial weight of the glass filter.
- Slowly pour the laser diffraction sample water (after analysis) through the previously weighed 0.45 μm glass filter and discard the water.
- Use reagent-grade water in wash bottle to rinse particles adhering to the analysis container onto glass filter.
- Dry glass filter with particles in a drying oven at 90 ± 2°C to a constant weight.
- Cool the glass filter and dried particles to room temperature in a desiccator.
- Weigh the glass filter and particles to the nearest 0.01mg.
- Subtract the initial glass filter weight from the final glass filter and particle sample weight.
- Record the final sample weight for particles <250 μm in size.

Quality Assurance

Dried samples should be cooled in a desiccator and held there until they are weighed. If a desiccator is not used, the particles will accumulate ambient moisture and the sample weight will be overestimated. A color-indicating desiccant is recommended so that spent desiccant can be detected easily. Also, the seal on the desiccator should be checked periodically, and, if necessary, the ground glass rims should be greased or the “O” rings should be replaced.

Handle sieves with clean gloves to avoid adding oils or other products that could increase the weight. The weighing room should not have fluctuating temperatures or changing humidity. Any conditions that could affect results such as doors opening and closing should be minimized as much as possible.

After the initial weight of the sieve is measured, the sieve should be kept covered and dust free. Duplicate samples should be analyzed on 10% of the samples for both wet sieving and mass measurements.

Reporting

Visual observations should be made on all wet sieved fractions and recorded. For example if the very coarse sand fraction (2,000-1,000 µm) is composed primarily of beauty bark, or cigarette butts, or other organic debris this should be noted. An option might also be for a Professional Geologist to record the geological composition of the sediment as well.

References

ASTM. 1997. *Standard Test Methods for Determining Sediment Concentration in Water Samples*. Method D 3977. American Society for Testing and Materials, Philadelphia, PA.

Puget Sound Estuary Program (PSEP). 1986. *Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound*. Prepared by Tetra Tech, Inc. for U.S. Environmental Protection Agency and Puget Sound Water Quality Authority. Tetra Tech Inc., Bellevue, WA.

U.S. EPA. 1998. *Analysis of Total Suspended Solids by EPA Method 160.2*. Region 9, Revision 1. SOP 462. 12 pp.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology* 30: 377-392.

Appendix B -- Pollutant Removal Calculation Methods

Modified from

Center for Watershed Protection's

Tool 8: BMP Performance Verification Checklist Appendices
2008

Pollutant Removal Calculation Methods

The pollutant removal efficiency of a BMP refers to the pollutant reduction that is achieved by comparing the influent and effluent of a BMP or treatment train. To fully understand stormwater treatment, all of the runoff needs to be accounted for (e.g., untreated runoff, treated runoff, and bypassed flows).

The Efficiency Ratio method and the Summation of Loads methods are recommended for use by ASCE and EPA (2002) (Table C.1). Use of either method should be supplemented with an appropriate statistical test indicating if the differences in mean EMCs between the outflow and inflow are statistically significant.

References

American Society of Civil Engineers (ASCE) and United States Environmental Protection Agency (EPA). 2002. *Urban Stormwater BMP Performance Monitoring: a Guidance Manual for Meeting the National Stormwater BMP Database Requirements*. EPA-821-B-02-001. Office of Water, U.S. Environmental Protection Agency, Washington DC. http://water.epa.gov/scitech/wastetech/guide/stormwater/monitor.cfm (accessed January 14, 2011).

Center for Watershed Protection (CWP). 2008. *Tool 8: BMP Performance Verification Checklist Appendices.* CWP, Ellicott City, MD. 20 pp. http://www.cwp.org (accessed January 14, 2011).

Winer, R. 2000. *National Pollutant Removal Database for Stormwater Treatment Practices*. Second edition. Center for Watershed Protection, Ellicott City, MD.

Table C.1. Pollutant Removal Calculation Methods

Method	Formula	Comments
Efficiency Ratio (ER)	$ER = 1 - \frac{Average\ outlet\ EMC}{Average\ inlet\ EMC}$ Where the EMC = $\frac{\sum_{j=1}^{n} CiVi}{\sum_{j=1}^{n} Vi}$ Where: *Ci* = event inflow concentration; *Vi* = event inflow volume	• Most useful when loads are directly proportional to the storm volume. • Weights EMCs from all storms equally. • The accuracy varies with BMP type. • Minimizes impacts of smaller/cleaner storms on performance calculations. • Can apply log normalization to avoid equal weighting of events.
Summation of Loads (SOL)	$SOL = \frac{sum\ of\ outlet\ loads}{sum\ of\ inlet\ loads}$ Where the Load = C*i*V*i* *Ci = average concentration within period i;* *Vi = volume of flow during period i*	• Loads are calculated using concentration and flow volume and are summed for the number of events measured. • A small number of large storms can significantly influence results. • Removal of material is most relevant over entire period of analysis • Uses a mass balance approach. • Effluent concentration may still be high despite high removal efficiency