New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device

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Contents

1. Overview

This document specifies the laboratory testing procedures required for hydrodynamic sedimentation (HDS) manufactured treatment devices (MTDs) seeking verification in the State of New Jersey, as required by the Stormwater Management Rules, N.J.A.C. 7:8. This document shall be adhered to by manufacturers, New Jersey Corporation for Advanced Technology (NJCAT) and entities performing or overseeing the testing of a HDS MTD to meet that verification requirement.

2. Definitions

Geometrically Proportional

For the purposes of scaling, a MTD is considered geometrically proportional to a reference MTD when the ratios of the inside dimensions of length, width, and depth are the same as the ratios of the inside dimensions of length, width and depth of the reference MTD.

Example 1: A reference MTD is a rectangular vault with inside dimensions of length, width, and depth of six feet, four feet, and three feet, respectively. The dimensional ratios are 2:1.33:1. A geometrically proportional MTD has the same dimensional ratios as the reference MTD

Example 2: A reference MTD is a cylindrical structure with inside dimensions of diameter and depth of four feet and six feet, respectively. The dimensional ratio is 1:1.5. A geometrically proportional MTD has the same dimensional ratio as the reference MTD.

Maintenance Sediment Storage Depth and Volume

The maintenance sediment storage depth and volume of a HDS MTD represents the amount of sediment that can accumulate in the MTD prior to maintenance, as recommended by the manufacturer and confirmed via scour testing.

Maximum Hydraulic Flow Rate (MHFR)

The maximum hydraulic flow rate (MHFR) of a HDS MTD is the highest flow rate that can be conveyed through the MTD with specified head loss. This value is primarily designed to provide maximum flows that can be safely conveyed through the unit to protect against backup during extreme events where overland flooding is a concern. The MHFR is determined or estimated from hydraulic characterization tests that are not described in these protocols.

3. Laboratory Testing Criteria

A. Laboratory Qualifications

Information regarding laboratory testing qualifications can be found at: http://www.njcat.org/ in the document entitled "Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from New Jersey Corporation for Advanced Technology: For use in accordance with the Stormwater Management Rules, N.J.A.C. 7:8" dated January 25, 2013.

B. Analysis of TSS Samples

Analysis of all Total Suspended Solids (TSS) samples shall be done in accordance with ASTM: D3977-97 (re-approval 2007) "Standard Test Methods for Determining Sediment Concentrations in Water

Samples." TSS is defined as any particulate test sediment that is transported to the MTD during flow conditions.

C. Temperature

The temperature of the water for all testing shall not exceed 80 degrees Fahrenheit.

D. Background TSS Levels

Background levels of TSS shall be no more than 10% of the target influent concentration in all tests. The maximum allowable background concentration is 20 mg/L. The use of flocculants is not an acceptable means to reduce background TSS levels.

E. MTD Size and Availability

A full scale, commercially available MTD must be tested in the laboratory in the same configuration and with the same components as typically used in actual installations. See Section 6 for the scaling of HDS MTDs.

4. Scour Testing

For MTDs intended to be installed off-line, the scour testing shall be conducted at a minimum 125% of the maximum treatment flow rate (MTFR). MTFR is defined as the highest flow rate that can be conveyed through the MTD while still achieving the performance claim based on the TSS Removal Efficiency Testing procedures described later in this protocol. Testing performed at this flow rate or higher is necessary to ensure that re-suspension and washout of previously captured sediment within the MTD is not excessive. To determine if a MTD can be located on-line, scour testing shall be conducted at a minimum 200% of the MTFR. The flow rate used for scour testing must include only flows that passed through the MTD and may not include any externally bypassed flow.

The average effluent concentration must be less than 20 mg/L above the background concentration regardless of which of the above minimum MTFRs is used; however, if this benchmark is achieved during scour testing at a minimum 200% MTFR, separate scour testing at a minimum 125% of the MTFR is not required.

A. Scour Testing Procedure

This test shall be performed utilizing a full-scale, commercially available MTD. The sedimentation chamber(s) corresponding to the Effective Treatment Area, which is defined as the entire area within the MTD where sedimentation occurs, shall be pre-loaded to 50% of the manufacturer's recommended maximum sediment storage volume. The pre-load shall be consistent with the particle size distribution for particles 50 microns and greater found in Column 3 in Table 1: Test Sediment Particle Size Distribution. Three samples of the test sediment shall be obtained for particle size distribution (PSD) analysis and the results reported accordingly. The average of the three samples shall be used to assess compliance with the target PSD.

A false floor may be placed in the sedimentation chamber at a level below the 50% maximum sediment storage volume and then covered with sufficient test sediment to achieve 50% of the maximum sediment storage volume. In doing so, the level of the false floor shall be at least four inches below the 50% maximum sediment storage volume. Following pre-load and before commencing the testing, the test sediment layer shall either be leveled or placed in a condition documented to be similar to actual field observations (e.g., cone or favored to inlet side and sloped). A non-level sediment layer is acceptable if the contoured shape is documented through TSS Removal Efficiency Testing described herein. However, the minimum four inch pre-load depth is still required before contouring.

The MTD shall be filled with clear water to its normal, dry weather operating depth. Clear water is defined as water free of test sediment (i.e. with a background TSS concentration of less than 20 mg/L). Commencement of the scour test shall start within 96 hours of pre-loading of the unit.

Following pre-loading and the addition of clear water, the test shall commence by conveying clear water through the MTD at increasing flow rates up to either the minimum 125% or 200% MTFR scour tests. Effluent samples shall be collected and time stamped every two minutes after achieving the maximum target flow rate. A minimum of 15 effluent samples shall be taken over the duration of the test. The flow rate shall be recorded continuously so that the effluent samples can be compared to corresponding flow rate values. The flow rate shall be increased to the target flow rate within five minutes of commencement of the test. The flow rate shall then remain constant at the target maximum flow rate for the remainder of the test duration. Samples shall only be taken from the effluent of the MTD and shall not include any externally bypassed flow.

A minimum of eight background samples of the clear water shall be collected at evenly spaced intervals throughout the duration of the target maximum flow rate testing. All samples (background and effluent) shall be analyzed for TSS in accordance with ASTM D3977-97 (re-approval 2007) "Standard Test Methods for Determining Sediment Concentrations in Water Samples." The maximum allowable background concentration shall not exceed 20 mg/L. If any of the background concentrations exceed 20 mg/L the clear water must be replaced or filtered to reduce background concentration to acceptable levels.

If the minimum 200% MTFR scour testing is conducted subsequent to the minimum 125% MTFR scour testing, the existing sediment bed must be either replaced with fresh sediment or replenished with fresh sediment that is added to the surface of the sediment bed to restore the 50% sediment depth.

B. Sampling Procedures

Effluent samples may be collected by any of the methods cited in association with the Effluent Sampling Test Method, Section 5D, including the Effluent Grab Sampling, Isokinetic or Automatic Effluent Sampling Methods.

C. Scour Testing Results

All effluent sample results from a scour test must be adjusted for background concentration [effluent sample = recorded effluent sample – background (maximum allowable background is 20 mg/L)]. The time each background and effluent sample is collected shall be recorded. The background data shall be plotted on a curve for use in adjusting the effluent samples for background concentration. All adjusted effluent samples from a scour test shall be included in the calculation of the average effluent TSS concentration. As stated above, there must be a minimum of 15 effluent sample results used to determine the average effluent TSS concentration.

For scour testing using the minimum 125% MTFR, the selected MTFR is deemed acceptable if the average effluent TSS concentration is no more than 20 mg/L above the average background concentration. Under these circumstances, the selected MTFR or rate lower than the MTFR may be utilized.

For scour testing performed to determine whether a MTD qualifies for on-line installation, the MTD is deemed acceptable for on-line installation if the average effluent TSS concentration is no more than 20 mg/L above the average background concentration. As mentioned previously, the minimum MTFR that can be used for this type of scour test is 200%.

5. Total Suspended Solids Removal Efficiency

A. Test Sediment Particle Size Distribution

Test sediment particle size distribution must be consistent with Column 2 in Table 1: Test Sediment Particle Size Distribution. PSD of the actual test (feed) sediment shall be determined using ASTM D 422-63 (Reapproved 2007) "Standard Test Method for Particle-Size Analysis of Soils." Three samples of the test sediment shall be obtained for PSD analysis and the results reported accordingly. The average of the three samples shall be used to assess compliance with the target PSD.

Table 1: Test Sediment Particle Size Distribution[1]

	TSS Removal Test PSD	Scour Test Pre-load PSD
Particle Size (Microns)	**Target Minimum % Less Than[2]**	**Target Minimum % Less Than[2 and 3]**
1,000	100	100
500	95	90
250	90	55
150	75	40
100	60	25
75	50	10
50	45	0
20	35	0
8	20	0
5	10	0
2	5	0

1. The material shall be hard, firm, and inorganic with a specific gravity of 2.65. The various particle sizes shall be uniformly distributed throughout the material prior to use.
2. A measured value may be lower than a target minimum % less than value by up to two percentage points, a measured value may be lower than a target minimum % less than value by up to two percentage points (e.g., at least 3% of the particles must be less than 2 microns in size [target is 5%]), provided the measured d50 value does not exceed 75 microns.
3. This distribution is to be used to pre-load the MTD's sedimentation chamber for off-line and on-line scour testing.

B. TSS Removal Efficiency Testing

TSS Removal Efficiency must be determined through the use of either the Mass Balance Test Method (preferred) or the Effluent Sampling Test Method. TSS Removal Efficiency testing shall be performed at constant flow rates of 25%, 50%, 75%, 100%, and 125% of the MTD's MTFR and a TSS influent concentration of 200 mg/L.

For all TSS Removal Efficiency Testing a false floor shall be installed to simulate the 50% sump full condition, but no sediment shall be added to the sump prior to the test run.

All testing must include, at minimum, the following:

1. Background Sampling:
   a. Background TSS samples must be obtained at a pre-determined location upstream from the introduction of the test sediment;
   b. Influent background samples shall be taken in correspondence with the odd numbered effluent samples (first, third, fifth, etc.);
   c. The time each background and effluent sample is collected shall be recorded. The background data shall be plotted on a curve for use in adjusting the effluent samples for background concentration;
   d. Background TSS concentrations shall not exceed 20 mg/L.

2. Test Sediment Feed:
   The test sediment feed must include a method to introduce the test sediment within the following parameters:
   a. The test sediment feed rate and total mass of test sediment introduced during each test run must be a known quantity;
   b. The test sediment feed rate must be introduced at a rate within 10% of the targeted value of 200 mg/L (180 – 220 mg/L) influent concentration;
   c. Test sediment shall be injected using an auger, vibratory hopper, well-mixed slurry injection system or other suitable means of sediment addition that provides a consistent, calibrated concentration of solids. Six calibration samples shall be taken from the injection point at evenly spaced intervals over the total duration of the test for each constant flow rate (i.e. 25%, 50%, etc. of the MTD's MTFR). Each sample shall be collected in a clean one-liter container over an interval timed to the nearest second and shall be a minimum 0.1 liter or the collection interval shall not exceed one minute, whichever comes first. In general the sample collection time should be as short as possible. Samples shall be weighed to the nearest milligram and the concentration coefficient of variance (COV) shall not exceed 0.10. Note that the mass extracted for calibration samples should be subtracted from the total mass introduced to the system when calculating removal efficiency.

3. Flow Measurements:
   a. A flow meter or equivalent device must be located either upstream or downstream of the MTD;
   b. All flow meters used in this protocol must be calibrated as required by the instrument manufacturer. Copies of flow meter calibrations shall be included in the final report. The flow meter data logger must record flows at a minimum of once per minute and the average flow rate reported;
   c. During all test runs, the allowable variation of any of the five target flow rates listed above shall be $\pm$10% for targeted flow rates. The COV shall be within 0.03.

C. Mass Balance Test Method

The Mass Balance Test Method compares the total known mass introduced and the mass collected in the MTD after completion of the test (or test run).

The Mass Balance Test Method procedure is as follows:

1. Dry and determine the moisture content of a well-mixed feed sample in accordance with ASTM Method D 4959- 07, "Standard Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating."
2. A minimum of 25 pounds (dry mass) of test sediment shall be fed into the influent pipe;
3. After attaining a constant target flow rate through the test unit, feeding of the sediment shall begin at the target concentration of 200 mg/L;
4. Sediment injection point shall be at the crown of the influent pipe at a distance of 10 feet or three to five pipe diameters, whichever is less, along the centerline of the pipe upstream of the inlet to the MTD. Any remaining sediment not added must be accounted for in the Mass Balance Test Method. The times for sediment feed start, feed stop, end of flush, flow stop and when draining begins shall be recorded;
5. Any sediment that accumulates in the inlet pipe shall be collected and included with the amount of sediment that collected in the MTD;
6. The test MTD shall be decanted by means of either a sump pump or a drain into storage containers;
7. After sediment is allowed to settle in the storage container(s), the remaining water from the containers shall be decanted and discarded. Additional filtering of discarded water is at the manufacturer's discretion;
8. The residual mixture of water and test sediment shall be removed from the storage container(s) and sump of the test MTD into pre-weighed non-ferrous trays;
9. Trays shall be placed into a vented drying oven at no more than 100ºC (212ºF) until a constant weight is obtained when cooled to room temperature, as determined by two successive measurements taken no less than two hours apart which show no more than a 0.1% difference in measured mass weighed to a precision of 10 grams. Weights obtained for all sediments shall be added;
10. Removal efficiency for that test run will then be computed as follows:

$$\textbf{Removal Efficiency (\%)} = \left(\frac{\text{Total Mass Collected}}{\text{Total Mass Input During Run}} \right) \times 100$$

D. Effluent Sampling Test Methods

Effluent sampling shall be performed through the use of one of the following methods, depending on flow rate: the Effluent Grab Sampling Method, Isokinetic Sampling Method or the Automatic Effluent Sampling Method. For flows less than 0.5 cfs (225 gpm), the Effluent Grab Sampling Method must be utilized. For flow greater than 0.5 cfs, either the Isokinetic Sampling Method or the Automatic Effluent Sampling Method may be employed. These sampling methods are used to establish an MTD's TSS removal efficiency under the following conditions:

1. The average influent TSS concentration shall be calculated using the total mass of the test sediment added during dosing divided by the volume of water that flowed through the MTD during dosing as follows:

$$\textbf{Average Influent Concentration} = \frac{\text{Total mass added}}{\text{Total volume of water flowing through the MTD during addition of test sediment}}$$

The volume of water that flows through the MTD shall be calculated by multiplying the average flow rate by the time of sediment injection only.

2. Once a constant feed of test sediment and flow rate are established, the first effluent sample shall be collected after a minimum of three MTD detention times have passed;
3. The time interval between sequential samples shall be evenly spaced during the test sediment feed period to achieve 15 samples. However if the test sediment feed is interrupted for measurement, the next effluent sample shall be collected following a minimum of three MTD detention times;
4. A minimum of 15 effluent samples shall be taken downstream of the MTD such that any internally bypassed water is also sampled; and
5. All effluent samples shall be analyzed for TSS in accordance with ASTM D3977-97 (re-approval 2007) "Standard Test Methods for Determining Sediment Concentrations in Water Samples."

Removal efficiency shall be calculated as follows:

$$\textbf{Removal Efficiency (\%)} = \frac{\left(\begin{array}{c}\text{Average Influent}\\ \text{Concentration}\end{array} - \begin{array}{c}\text{Adjusted}\\ \text{Average Effluent*}\\ \text{Concentration}\end{array}\right)}{\text{Average Influent Concentration}} \times 100$$

* Adjusted for background concentration

Effluent Grab Sampling Method

This method allows for conducting manual sample collection procedures. The effluent sample location shall be either end of pipe or in-line, and should consider the distance from the MTD, sample container size to minimize the potential for spilling, and sediment capture method (e.g., sweeping motion).

Isokinetic Sampling Method

The use of isokinetic sampling procedures may be applicable for this method depending on water depth in the effluent piping. This procedure must include a minimum of three evenly spaced, vertically and centrally aligned sampling tubes. Flows from the tubes shall be composited. With isokinetic sampling, the tube intake flow velocity is equal to the pipe flow velocity at the sample tube location. For flows greater than 0.5 cfs (225 gpm), three intake points must be used in the pipe. For flows less than 0.5 cfs, only the Effluent Grab Sampling Method is acceptable.

Automatic Effluent Sampling Method

This method allows for the use of automated sampling equipment positioned downstream of the MTD. This procedure requires three automatic samplers each having its own inlet tube. The three inlet tubes shall be evenly spaced, vertically aligned and centrally located. The intake elevations shall be at approximately 25, 50 and 75% of flow depth. The samples from each sample time interval may be composited for analysis.

The sampling equipment shall be positioned at a distance of no more than three feet from the outlet of the MTD. Each sample container within the automatic sampler shall be at least one liter in size.

The automatic sampler equipment shall be calibrated and properly cleaned in compliance with the manufacturer's recommendations.

6. Scaling of HDS MTDs

The TSS removal rate determined for the tested full scale, commercially available MTD may be applied to similar MTDs with different (MTFR). Scaling the tested MTD to determine other model sizes and performance without completing additional testing is acceptable provided that:

A. The ratio of the MTFR to the Effective Treatment Area for the similar MTD is the same or less than the tested MTD; **and**
B. For similar MTDs with MTFRs within 250% of the tested unit's MTFR, surface area scaling is acceptable provided that the depth of the similar MTD is equal to or geometrically proportioned within 15% variation of the depth of the tested MTD; **or**
C. For a similar MTD with an MTFR that exceeds 250% of the tested unit's MTFR, the similar MTD must be scaled geometrically proportional to the tested unit; a MTD is considered geometrically proportional to a reference MTD when the ratios of the inside dimensions of length, width and depth is the same as the ratios of the inside dimensions of length, width and depth of the reference MTD; a deviation of 15 % is allowable in any dimension.

If requirements (A) and (B), or (A) and (C) are met, the TSS removal efficiencies of the similar MTD will be equal to the tested MTD's removal efficiency determined in Section 5.

If requirements (A) and (B), or (A) and (C) are not met, then a second full scale, commercially available MTD with an MTFR difference of at least 250% is required to be tested to validate the alternative scaling methodology. Testing of the similar model shall follow the same TSS Removal Efficiency Testing procedures as described in Section 5. The scaling methodology shall be deemed valid if the weighted TSS removal efficiency of the similar MTD is within five percentage points of the weighted TSS removal efficiency of the first tested MTD.

7. Units of Measure

All dimensions must be consistent with the following:

- **Area**: square feet
- **Concentration**: milligrams/liter
- **Flow Rate**: cubic feet per second, gallons per minute
- **Hydraulic Loading Rate**: gallons per minute per square foot
- **Length/Distance**: inches, feet
- **Velocity**: feet per second
- **Volume**: cubic feet, milliliter, liter, gallons

Appendix A - Requirements for HDS MTDs

A. Annualized Weighted TSS Removal Efficiency

The rainfall weighting factors in Table 1 are based on the total volume of annual runoff in an average year in New Jersey. The annual TSS removal rate shall be computed by multiplying the average TSS removal efficiency for each flow rate for the particulate concentration by the weighting factors in Table 1.

The annualized weighted TSS removal efficiency for the HDS MTD shall be calculated in accordance with Section 5 and the below chart.

Table 1

Tested Flow Rate as a Percentage of Maximum Treatment Flow Rate (MTFR)	Annual Weighting Factor
25%	0.25
50%	0.30
75%	0.20
100%	0.15
125%	0.10

B. Sediment Removal Interval Equation

Following determination of the HDS MTD's annualized weighted TSS removal efficiency; the HDS MTD's required sediment removal interval must be computed using the Required Sediment Removal Interval Equation shown below.

$$Sediment\ Removal\ Interval\ (months) = \frac{(50\%\ of\ HDS\ MTD\ Maximum\ Sediment\ Storage\ Volume * 3.57)}{(MTFR * TSS\ Removal\ Efficiency)}$$

$$Sediment\ Removal\ Interval\ (years) = \frac{(50\%\ of\ HDS\ MTD\ Maximum\ Sediment\ Storage\ Volume\ )}{(3.366 * MTFR * TSS\ Removal\ Efficiency)}$$

This equation estimates the time required to accumulate a sediment depth and volume equal to 50% of the HDS MTD's maximum sediment storage depth and volume utilizing the HDS MTD's annualized weighted TSS removal efficiency rate, annual average New Jersey rainfall, an estimated runoff coefficient, sediment loading rate, wet sediment density, and an appropriate safety factor. The interval can be no more frequent than twice a year, and the sediment must be removed on or before it reaches a maximum depth of 50% of the MTD's maximum sediment storage depth and volume. For information on the Verification requirements for Maintenance refer to the "Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from New Jersey Corporation for Advanced Technology: For use in accordance with the Stormwater Management Rules, N.J.A.C. 7:8" dated January 25, 2013 for details on the submittal process which is available at http://www.njcat.org/.

Appendix B – Sediment Removal Equation Derivation

A. Constants

62.4 lbs/cubic foot	Density of Water
2.65	Specific Gravity of Dry Sediment
2	Wet Sediment Bulking Factor
50%	Maximum Available Sediment Storage Volume
400 lbs/acre	Sediment Loading Rate
3.2 in/hr	Maximum Stormwater Quality Storm Rainfall Intensity for 10 Minutes
0.90	HDS MTD Drainage Area Runoff Coefficient
10 minutes	HDS MTD Drainage Area Time of Concentration

B. Volume of Sediment per Acre per Year

Density of Dry Sediment	= (62.4 LBS/CF)(2.65)	= 165 LBS/CF
Density of Wet Sediment	= (165 LBS/CF)/2 Bulking Factor	= 82.5 LBS/CF
Annual Sediment Volume per Acre	= (400 LBS/Acre)/(82.5 LBS/CF)	= 4.85 CF/Acre
Apply Safety Factor	= (4.85 CF/Acre)(2 Safety Factor)	= 9.70 CF/Acre
MTD Drainage Area in Acres	= MTFR/((3.2 Inches/Hour)(0.9))	= (0.347)(MTFR)

Annual Sediment Volume Captured = (9.70 CF/Acre)(0.347)(MTFR)(TSS Removal Efficiency)
= (3.366)(MTFR)(TSS Removal Efficiency)