Product Evaluation

Sandy loam TSS removal efficiency of a stormwater BMP:

Coarse perlite StormFilter cartridge at 57 L/min (15 gpm)

ABSTRACT: This experiment assesses the ability of a Stormwater Management StormFilter® (StormFilter) cartridge configured with coarse perlite to remove total suspended solids (TSS) with a sandy loam texture (55% sand, 40% silt, 5% clay) at a filtration rate of 57 L/min (15 gpm) (100% design, per cartridge, operating rate for this configuration). Under controlled conditions, 21 runoff simulations were performed using influent TSS event mean concentrations (EMCs) between non-detect and 301 mg/L. A strong relationship between influent and effluent TSS EMC was observed. Based upon this observation, the mean TSS (sandy loam) removal efficiency for this StormFilter cartridge configuration was determined using regression statistics and found to be 79% (with 95% confidence, 78% lower limit and 80% upper limit) over the range of influent EMCs tested. Optical particle size observations indicated noticeable removal of silt-sized particles (2 to 50 µm as per USDA definitions).

Introduction

Stormwater BMPs are often chosen through direct comparison of reported total suspended solids (TSS) removal efficiencies. However, these values are rarely accompanied by data identifying flow velocity, particle size, particle density, and influent TSS concentration. Without addressing these variables, true comparison of TSS removal efficiency data resulting from different systems is impossible. For example, a system encountering large, high-density, sand-type solids would operate more efficiently than the same system encountering small, low-density, organic solids. The purpose of this experiment is to generate TSS removal efficiency data, in accordance with existing protocols, that is accompanied by the previously mentioned variables so as to provide the means for more accurate system comparison and performance prediction. This experiment assesses the ability of the Stormwater Management StormFilter® system (StormFilter) to remove TSS with a particle size distribution (PSD) characteristic of a sandy loam material.

The StormFilter system is typically comprised of a vault that houses rechargeable, media-filled, filter cartridges (StormFilter cartridges). Stormwater from storm drains is percolated through these media-filled cartridges, which trap and remove pollutants such as solids, dissolved metals, nutrients, and hydrocarbons. During the filtering process, the StormFilter system also removes surface scums and floating oil and grease. Once filtered through the media, the treated stormwater is directed to a collection pipe or discharged to an open channel drainage way.

The StormFilter cartridge configuration chosen for this experiment was the coarse perlite StormFilter cartridge operating at 57 L/min (15 gpm). Twenty-one, cartridge-scale tests were conducted in the laboratory environment using simulated stormwater with influent TSS event mean concentrations (EMCs) ranging between non-detect (ND) and 301 mg/L. Composite samples representing true TSS EMC values were used to characterize the influent and effluent and ultimately used to estimate mean TSS removal efficiency. One corresponding pair of influent and effluent TSS samples was taken for particle size assessment using optical methods.

Apparatus

Test Apparatus

The typical precast StormFilter system is composed of three bays: the inlet bay, the filtration bay, and the outlet bay. Stormwater first enters the inlet bay of the StormFilter vault through the inlet pipe. Stormwater in the inlet bay is then directed through the flow spreader, which traps some floatables, oils, and surface scum, and over the energy dissipator into the filtration bay where treatment will take place. Once in the filtration bay, the stormwater begins to pond and percolate horizontally through the media contained in the StormFilter cartridges. After passing through the media, the treated water in each cartridge collects in the cartridge's center tube from where it is directed into the outlet bay by an under-drain manifold. The treated water in the outlet bay is then discharged through the single outlet pipe to a collection pipe or to an open channel drainage way.

The test apparatus used for this experiment simulates the filtration bay component of a full-scale StormFilter system, including the energy dissipator. Since the design of full-scale StormFilter systems varies, and since the operation of a full-scale system in the laboratory environment would require very large volumes of water, the use of the most common components among all of the possible designs, the StormFilter cartridge and the associated volume of filtration bay area, were selected so as to provide a very conservative estimate of StormFilter performance.

Unlike chemical removal testing, suspended solids removal testing is challenging due to the relatively large, dense, insoluble nature of the contaminant. Care must be taken to maintain the suspension of solids within the influent and effluent reservoirs, maintain the suspension of solids within the conveyance system, avoid the fouling of flow metering devices, avoid the destruction of individual solids by the pumping system, and avoid the destruction of the pumping system by the solids.

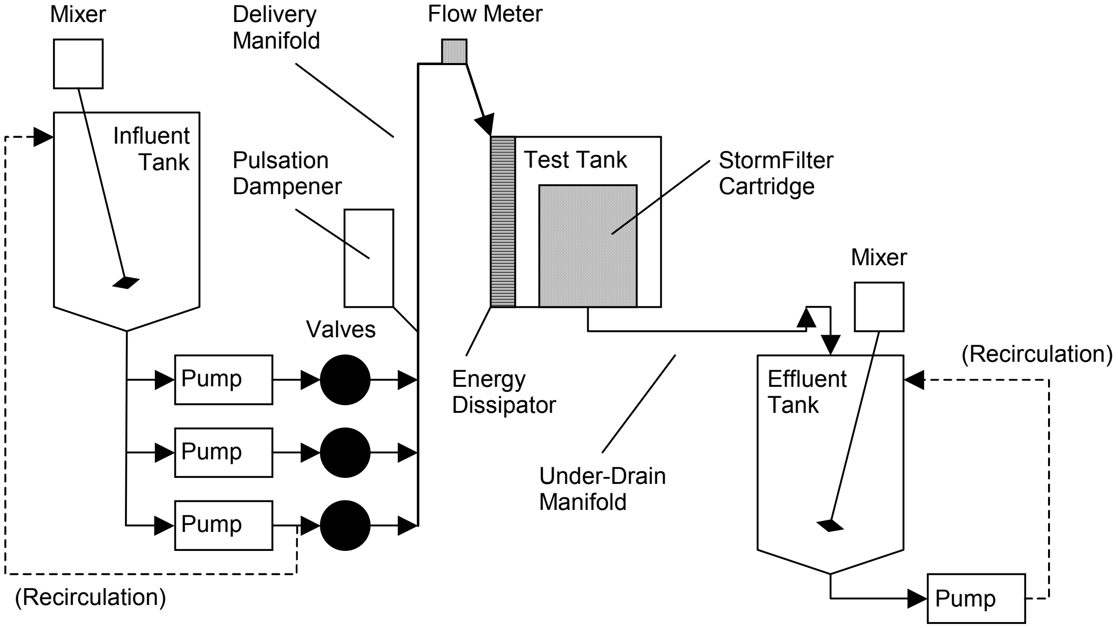

Figure 1. Schematic diagram of the test apparatus. Arrows indicate flow pathways. Dashed arrows indicate recirculation pathways employed during influent and effluent sampling.

The apparatus used for this experiment was carefully designed to meet these challenges. Figure 1 demonstrates the layout of the test apparatus. Influent and effluent storage was provided by individual 950-L (250 gallon), conical bottom, polyethylene tanks (Chem-Tainer). The conical bottom design ensured full drainage of the tanks, in addition to the movement of all solids out of the tanks. Suspension of solids within the tanks was maintained by individual, 1/2-hp, electric, propeller mixers (J.L Wingert, B-3-TE-PRP/316). The propeller design maximized the vertical circulation of solids within the tank and ensured the homogeneity of the mixture. Peristaltic-type pumps (Vanton, 19 L/min (5 gpm) Flex-i-liner) were used to recirculate water through the underlying manifolds of both tanks during sampling so as to eliminate any possibility of sediment accumulation in the manifolds.

Influent was carried from the influent tank by three peristaltic-type pumps (Vanton, two 38 L/min (10 gpm) and one 19 L/min Flex-i-liner) plumbed into a common PVC intake manifold below the influent tank and discharged into a common delivery manifold of 25 mm (1 in) PVC pipe. The peristaltic pumps specified for use in this experiment were selected because of their ability to handle solids to 1 mm without breaking down the solids themselves. Also, despite the associated head loss, 25 mm diameter pipe was selected to ensure high flow velocities to maintain the suspension of solids during transfer. The pulsating flow generated by the pumps also helped to eliminate settling within the piping.

Discharge from the delivery manifold into the 56 cm x 56 cm x 62 cm (22 in x 22 in x 24.5 in) (LxWxH) polypropylene StormFilter cartridge test tank was by free discharge into the tank-mounted energy dissipator, which consisted of a vertical length of 76 mm (3 in) PVC pipe with an open bottom and multiple 3 mm (1/8 in) wide horizontal slots along its entire length. The energy dissipator was used to minimize the re-suspension of settled material within the test tank by restricting turbulence to the region within the dissipator. Discharge from the StormFilter cartridge test tank into the effluent tank was through direct discharge from the under-drain manifold component of the test tank over the top of the effluent tank.

Flow into the StormFilter cartridge test tank was controlled by individual ball valves placed between each pump and the delivery manifold, and flow was monitored with a paddle-wheel type electronic flow meter (GF Signet, Rotor-X Low Flow) coupled with a flow transmitter with totalizer (GF Signet, Processpro). A pulsation dampener, consisting of a constant air pocket constructed out of a capped length of 76 mm PVC pipe, was fitted to the delivery manifold to dampen the pulsating flow generated by the peristaltic-type pumps. An empty 1-L polypropylene sample bottle was floated in the influent tank to prevent cavitation of the mixer by blocking the intake of air by potential vortices.

Media

The media chosen for this experiment was coarse perlite. Perlite is a naturally occurring volcanic mineral product and is a common raw material obtainable from a variety of suppliers. The grade of perlite specified by Stormwater360 for use with the StormFilter cartridge was selected for its superior physical characteristics. Lightweight, chemically inert, coarse, and granular, it is an effective physical filtration media.

Prior to testing, the coarse perlite StormFilter cartridge was flushed to remove the residual dust within the media left over from the cartridge production process, as well as to allow the media to approach a typical, wet operating condition. Individual, ~800-L, tap water flushes were performed according to the operation segment of the procedure section. Flushing was ceased after 3200-L of tap water was passed through the system, at which point the effluent TSS EMC stabilized at 2 mg/L from an initial value of 8 mg/L.

Contaminant

For the purpose of this experiment, TSS is defined according to EPA method 160.2 with the additional constraint of a maximum particle size of 1000 µm. This definition of TSS is in accordance with APWA (1999) and Portland BES (2001) protocols for the laboratory testing of stormwater treatment technologies.

In the interest of generating a conservative result, synthetic or refined silica-based materials were not used for testing due to their high density and uniform sphericity. Instead, actual soil was used, thus providing the range of particle sizes, shapes, and densities of a material that might actually erode or otherwise become entrained by stormwater runoff.

The suspended solids used in the experiment were supplied through the addition of a sandy loam soil to the influent. The soil was collected in collaboration with J. H. Huddleson, Soil Specialist with Oregon State University, and originated in the Willamette Valley, OR. A bulk sample, "OSU Loam GPS W.P. #13," was collected in the field and prepared for use by air-drying followed by de-aggregation. De-aggregation was accomplished by tumbling the dried sample in a clean cement mixer in the presence of several 51 mm (2 in) diameter PVC cylinders of various lengths.

Following preparation of the bulk sample, particle size analysis was performed internally using hydrometer and sieve techniques (Gee and Bauder, 1986), revealing the particle size distribution shown in Figure 2. This particle size distribution is slightly finer than that recommended by APWA (1999), and within the range recommended by Portland BES (2001), for laboratory performance testing. The approximate 55% sand, 40% silt, and 5% clay content (hereafter presented as a 55:40:5) indicated a more coarse texture than the loam textural classification derived in the field.

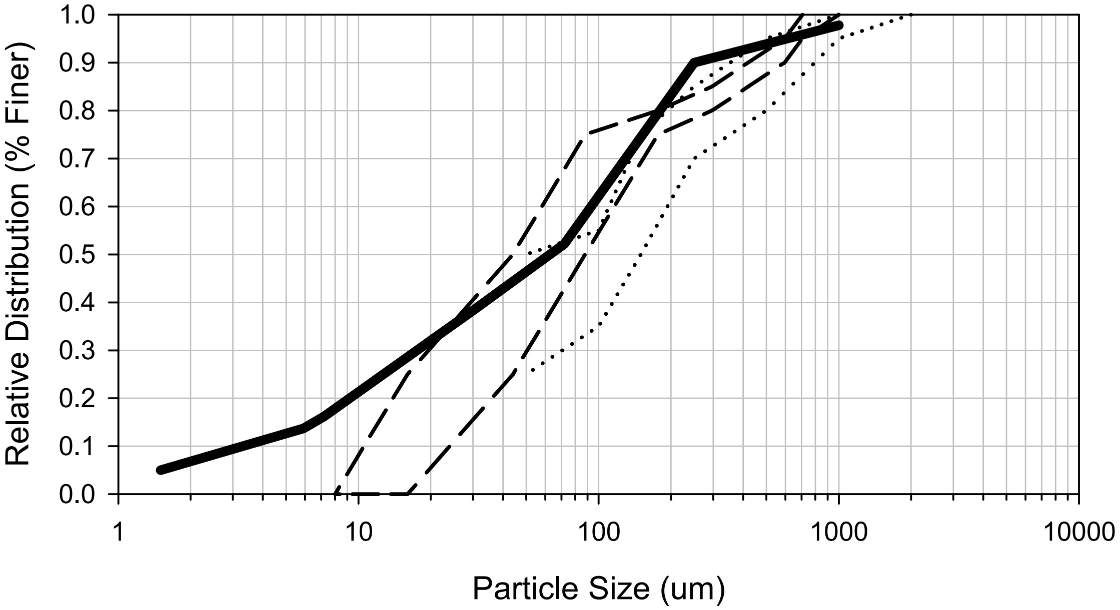

Figure 2. Particle size distribution (shown as solid line) for bulk soil sample "OSU Loam GPS W.P. #13" used for testing. Sand/silt/clay fractions according to USDA definitions are approximately 55%, 40%, and 5%, indicating that the texture corresponds to a sandy loam material. Dashed and dotted lines indicate particle size distribution range recommended by Portland BES (2001) and APWA (1999), respectively, for materials used for laboratory evaluation of TSS removal efficiency.

In addition to the de-aggregation process employed during the preparation of the bulk sample, the solids were also given the opportunity to hydrate prior to experimentation so as to further promote the disintegration of fine aggregate particles. Based upon an 800-L influent volume, target TSS EMCs were determined for each planned contaminated simulation and associated masses of contaminant were placed in 1-L HDPE bottles of tap water--one bottle of concentrate per planned contaminated simulation. Target TSS EMCs between 0 and 300 mg/L and the order in which they were to be used were randomly selected using random number techniques so as to provide a good range of influent TSS EMCs and performance conditions. These concentrates were then left out at room temperature for a day and periodically shaken to encourage the dissolution of any aggregates. Following this initial equilibration period, the concentrates were refrigerated until needed.

During addition to the influent reservoir, each concentrate solution was passed through a 1000 µm sieve to ensure the utilization of TSS <1000 µm in size. Material captured on the sieve screen was agitated and washed repeatedly in the influent to ensure the breakup of any remaining aggregates. Since the fraction of particles >1000 µm present in the 55:40:5 sandy loam (<5% by mass) were not passed through the system, the actual PSD of the TSS in the influent was slightly finer than that reported in Figure 2; however, the PSD was not adjusted so as to further add an element of conservatism to the overall result.

Procedure

Operation

The operational procedure consisted of performing multiple runoff simulations, tests, or runs using the same StormFilter cartridge test tank and apparatus described in the Test Apparatus section above. Runs proceeded as follows.

The influent tank was filled with ~800-L of tap water, and the predetermined contaminant concentrate was added to the influent tank. The influent tank was then mixed thoroughly with the mechanical mixer while influent was re-circulated through the lowest port in the underlying manifold and allowed to equilibrate for 5 to 10 minutes before sampling.

Following influent sample collection, re-circulation was stopped and the influent was pumped into the test tank energy dissipator via the delivery manifold. Flow rate was controlled through periodic adjustment of the influent flow valves so as to maintain a constant flow rate reading of 57 L/min ± 4 L/min (15 gpm ± 1 gpm). Mixing and re-circulation of the effluent reservoir was started towards the end of a run to allow effluent equilibration prior to sample collection.

The influent pumps were operated until as much of the influent had been pumped from the influent reservoir and underlying manifold as was possible, at which point the influent pumps were shut down and the StormFilter cartridge test tank was allowed to drain. Once the float valve within the StormFilter cartridge closed, effluent was sampled and the total run volume reported by the totalizer was recorded.

Sampling

Composite samples of entire influent and effluent volumes were collected for both TSS and particle size analysis; six of the 21 events were sampled in duplicate to increase the overall accuracy of the experiment. Sample handling was performed in accordance with standard techniques; all samples were promptly refrigerated following collection, shipped in ice-packed coolers to the appropriate laboratories for analysis within seven days, and accompanied by chain-of-custody documentation. Severn Trent Services (Tacoma, WA) was employed to provide TSS analysis according to a "whole-sample" variation of EPA method 160.2

(Stormwater360, 2001), and Chemoptix Microanalysis (West Linn, OR) was used to perform the particle size analysis according to ASTM method F312-97, an optical technique.

Samples were collected in 1-L HDPE, wide-mouthed bottles using a 0.5-L PE, 1.2-m (4-ft) ladle to extract individual sample volumes using a sweeping motion across and through the center of the reservoir. Care was taken to transfer all solids from the ladle, and when necessary, very small volumes (<10 mL) of deionized water were sprayed into the ladle using a fine-stream squeeze bottle to aid the removal of any remaining visible solids. This rinse was used on an as needed basis under the following assumptions: 1) invisible quantities of TSS would have an insignificant impact on overall TSS mass; 2) the volume of water occasionally used to aid the transfer of solids was insignificant relative to the overall sample volume. The sampling ladle was subject to a high-pressure wash between uses.

Results

Table 1. Summary of influent and effluent TSS concentrations and removal results for a coarse perlite StormFilter cartridge test unit operating at 57 L/min for TSS with a sandy loam texture (55% sand, 40% silt, 5% clay by mass), in order of increasing influent TSS EMC. Data collected using the "whole sample" variation of EPA method 160.2. Non-detect (ND) values include associated practical quantitation limit value in parenthesis. Duplicate samples are presented as replicate runs followed by duplicate sample number.

Influent TSS EMC (mg/L)	Effluent TSS EMC (mg/L)	Run	Run Volume (L)	Discrete TSS Removal Efficiency (%)
ND (1)	3	21	847	-200
13	4	12	849	69
19	4	3	847	79
27	7	11.1	847	74
30	7	11.2	847	77
37	7	4	847	81
48	10	13.2	845	79
50	10	13.1	845	80
60	13	16	844	78
71	15	7	845	79
74	16	18	838	78
96	20	14.1	842	79
101	20	14.2	842	80
112	22	6	840	80
119	29	20.1	835	76
121	29	20.2	835	76
128	28	17	842	78
140	32	8.2	841	77
142	33	8.1	841	77
169	35	15	838	79
172	39	10	833	77
180	39	1	835	78
183	42	9.2	839	77
184	41	9.1	839	78
203	47	19	839	77
221	46	5	837	79
301	59	2	830	80

Table 2. Summary of categorized influent and effluent particle observations for a coarse perlite StormFilter cartridge test unit operating at 57 L/min for TSS with a sandy loam texture (55% sand, 40% silt, 5% clay by mass). Results represent Run 17 of the experiment, which was randomly selected for analysis. Removal of particles as small as 5-15 µm in size was observed. Analysis was performed using ASTM method F312-97.

Particle Size Range (um)	Categorized Particle Count per mL		Removal Efficiency (%)
	Influent	Effluent	
1 to 2	2020	2260	(-)
2 to 5	11500	11500	0
5 to 15	10900	9480	13
15 to 25	2480	1710	31
25 to 50	1800	790	56
50 to 100	490	100	80
100 to 200	90	10	89

TSS EMC results for each run are shown in Table 1. A very good distribution of influent TSS EMCs was obtained, and a direct relationship between influent and effluent TSS EMC was observed. Calculation of discrete TSS removal efficiencies, efficiencies based upon individual pairs of associated influent and effluent TSS EMCs, revealed a wide variety of results that generally increased with increasing influent TSS EMC.

The particle size data shown in Table 2 indicate that removal of particles as small as 5-15 µm was observed. Due to the limitations of the analytical technique, particle counts in the particle size range above 200 µm were not available. A clear relationship between particle size and particle removal efficiency by count is observable; particle size removal efficiency increases with increasing particle size category.

Using the TSS EMC and associated run volume data shown in Table 1, influent and effluent TSS loads can be compared to determine that 1.95 kg of the 2.50 kg of 55:40:5 sandy loam introduced into the system was retained by the StormFilter cartridge test tank. The TSS load captured outside of the StormFilter cartridge, but within the StormFilter cartridge test tank, was manually extracted from the StormFilter cartridge test tank, dried, and determined to be 0.72 kg. Comparison of these values reveals that 63% of the cumulative TSS load retained by the system was removed by the filtration media, with the remaining 37% settling outside the StormFilter cartridge due to the flow rate control provided by the cartridge.

Discussion

Statistical estimation of mean TSS removal efficiency

Linear regression of influent and effluent TSS EMC pairs was used to estimate mean TSS removal efficiency. Previous use of this approach by Stormwater360 (2001) for a similar system was shown to be both feasible and less prone to error than methods employing the use of discrete efficiency calculations. Further interpretation of the results from the Stormwater360 (2001) study indicates that the linear regression method of mean TSS removal efficiency estimation is more accurate than estimation based upon the geometric mean of discrete removal efficiencies.

As shown in Figure 3, the coefficient of determination (r^2) of 0.98 associated with the linear regression indicates a very strong dependence of effluent TSS EMC on influent TSS EMC. Thus TSS removal efficiency, the relationship between influent and effluent TSS EMCs, can be said to be independent of influent TSS EMC, and the regression coefficient (the slope of the linear regression) can be interpreted as the mean TSS removal inefficiency demonstrated by the system for any given influent TSS EMC. Subtracting the regression coefficient from 1 yields the mean TSS removal efficiency demonstrated by the system for any given influent TSS EMC, which in this case is 79% with 95% upper and lower confidence limits of 80% and 78%, respectively. The mean irreducible effluent TSS EMC, observed as the y-intercept of the linear regression, is ~1 mg/L with 95% upper and lower confidence limits of ~3 mg/L and <1 mg/L, respectively.

Estimation of particle size removal efficiency

Based upon the particle size removal efficiency estimates shown in Table 2, particle size removal efficiency increases with increasing particle size category. This relationship makes intuitive sense, however previous observation of this relationship based upon the same analysis for a similar system by SMI (2001) produced less clear results. These differing observations suggest that the error associated with ASTM method F312-97 is such that more than one analysis is necessary to generate data subject to quantitative interpretation. Thus, while Table 2 clearly allows the observation of particle size removal trends as well as the minimum particle size range removed by the system under evaluation, it would be more conservative to interpret the data qualitatively and perhaps state that the system demonstrated the ability to remove a substantial portion of the silt mass entering the system.

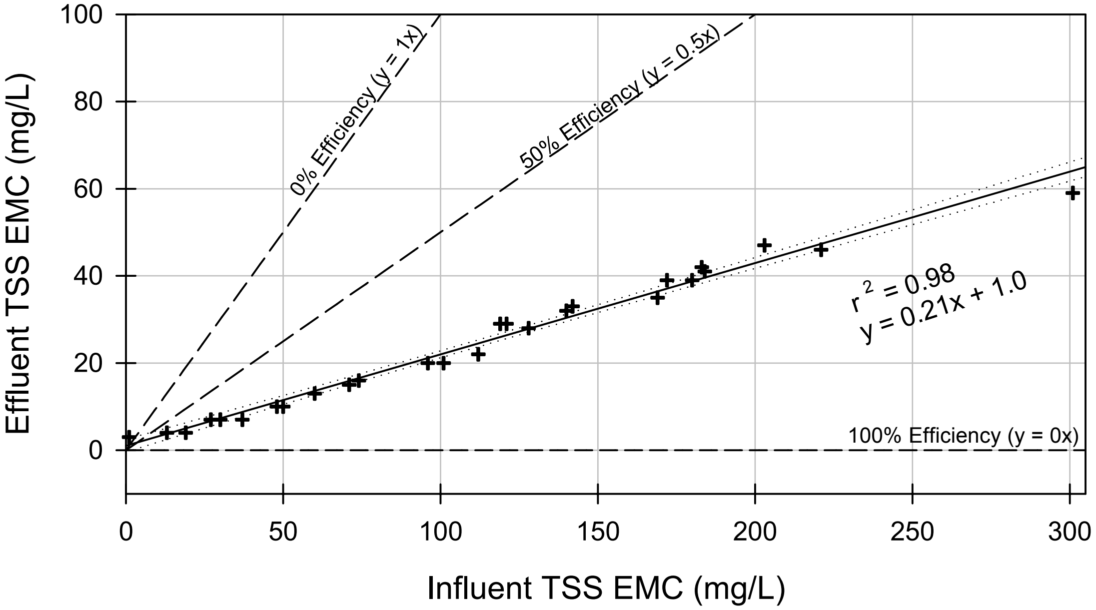

Figure 3. Plot of influent TSS EMC and corresponding effluent TSS EMC observations for a coarse perlite StormFilter cartridge test unit operating at 57 L/min for TSS with a sandy loam texture (55% sand, 40% silt, 5% clay by mass). The regression coefficient yields the mean TSS removal inefficiency, 21%. Subtracting this value from 1 yields the mean TSS removal efficiency, 79%. Dotted lines represent upper and lower 95% confidence intervals for the regression. 0, 50, and 100% efficiency lines, with ideal irreducible effluent TSS concentrations of zero, have been provided for comparison.

Conclusion

This experiment successfully measured the 55:40:5 sandy loam TSS removal efficiency of a coarse perlite StormFilter Cartridge operating at 57 L/min. A mean TSS removal efficiency estimate of 79% was calculated based upon the linear regression of influent and effluent TSS EMCs. Also the removal of silt-sized particles as small as 5-15 µm was observed.

The measurement of influent and effluent TSS EMCs for 21 simulated runoff events covering a wide range of influent TSS EMCs revealed a very strong relationship between these two variables. This observation corresponds well with previous work by SMI (2001), and supports their conclusion that the true TSS removal efficiency of the StormFilter is independent of influent TSS EMC.

The mean TSS removal efficiency estimate calculated for the system under evaluation is very conservative, not only for the reasons stated earlier in the apparatus and procedures sections, but also because of the constant flow rate used during testing. The 57 L/min filtration rate would represent the 100% design filtration rate specified per cartridge for the treatment of a design storm event by an actual StormFilter system employing the StormFilter cartridge configuration used in this experiment. In an actual StormFilter system, an appropriate number of cartridges would be used such that each cartridge would be treating 57 L/min during the peak of the design storm event. Thus during most storm events, as well as during the head and tail end of the design storm event, the filtration rate per cartridge would be less than 57 L/min, with a higher mean TSS removal efficiency resulting from the lower filtration rate (see SMI (2002) for details regarding full-scale system hydraulics).

It should be kept in mind that the mean TSS removal efficiency estimate ultimately only holds true for the system under evaluation. The addition or absence of settling, the presence of dead storage, and the location and design of the sampling ports within a similar system can have significant implications on overall system performance such that results observed for similar systems might differ from those observed in this experiment. This will be most pronounced in systems that are “volume-based” or located downstream of a detention system.

Stormwater360, Stormwater Management Inc, and Vortechnics Inc. are now CONTECH Stormwater Solutions Inc.

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Revision Summary

PE-B023
Document rebranded.

PE-B022
Document number changed; document rebranded; no substantial changes.

PD-01-002.1
Updated paper format; updated Stormwater360 references and in-text citations.

PD-01-002.0
Original.