Use of a Stormwater Filtration Device for Reducing Contaminants in Runoff from a Parking Lot in Madison, Wisconsin, 2005-07

Judy A. Horwatich, U.S. Geological Survey
Roger T. Bannerman, Wisconsin Department of Natural Resources

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16. Abstract

In June 2003, a proprietary stormwater filtration device (SFD) was installed at an employee parking lot in downtown Madison, Wisconsin. A total of 26 filter cartridges were used to treat stormwater runoff from the 0.91 acre asphalt parking lot. Automated equipment was installed to measure flow and collect water-quality samples during storms at the inlet, outlet, and bypass pipes of the SFD. Thirty-three organic and inorganic constituents or physical properties plus particle-size distributions were analyzed for in samples from the inlet and outlet, 18 of which were polycyclic aromatic hydrocarbons (PAHs). Water-quality samples were collected for 51 runoff events from November 2005 to August 2007. Samples from all runoff events were analyzed for suspended sediment concentrations, whereas samples from 31 of the runoff events were analyzed for 15 of the constituents. Samples from 15 runoff events were analyzed for PAHs, and samples from 36 events were analyzed for particle size.

The treatment efficiency of the SFD was calculated using the summation of loads (SOL) and the efficiency ratio methods. Constituents for which the concentrations and (or) loads were significantly decreased by the SFD include total suspended solids (TSS), suspended sediment, volatile suspended solids, total phosphorous (TP), total copper, total zinc, and PAHs. The efficiency ratios for these constituents were 44, 43, 38, 55, 22, 5, and 45 percent, respectively. The SOLs for these constituents were 32, 39, 28, 36, 23, 8, and 48 percent, respectively. Both the SOL and efficiency ratio were negative for chloride of about 20 percent. Six constituents or physical properties, dissolved phosphorous, chemical oxygen demand, dissolved zinc, total dissolved solids, dissolved chemical oxygen demand, and dissolved copper, were not included, because the difference between concentrations in samples from the inlet and outlet were not determined to be significant.

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Conversion Factors and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
millimeter (mm)	0.03937	inch (in.)
	Area	
Acre	4,047	square meter (m^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Gallon per minute (gal/min)	0.06309	Liter per second (L/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Particle sizes of sediment are given in micrometers (µm). A micrometer is one-thousand of a millimeter.

Concentration of sieved solid, in milligrams per kilogram (mg/kg).

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By Judy A. Horwatich and Roger T. Bannerman

Abstract

In June 2003, a proprietary stormwater filtration device (SFD) was installed at an employee parking lot in downtown Madison, Wisconsin. A total of 26 filter cartridges were used to treat stormwater runoff from the 0.91 acre asphalt parking lot. Automated equipment was installed to measure flow and collect water-quality samples during storms at the inlet, outlet, and bypass pipes of the SFD. Thirty-three organic and inorganic constituents or physical properties plus particle-size distributions were analyzed for in samples from the inlet and outlet, 18 of which were polycyclic aromatic hydrocarbons (PAHs). Water-quality samples were collected for 51 runoff events from November 2005 to August 2007. Samples from all runoff events were analyzed for suspended sediment concentrations, whereas samples from 31 of the runoff events were analyzed for 15 of the constituents. Samples from 15 runoff events were analyzed for PAHs, and samples from 36 events were analyzed for particle size.

The treatment efficiency of the SFD was calculated using the summation of loads (SOL) and the efficiency ratio methods. Constituents for which the concentrations and (or) loads were significantly decreased by the SFD include total suspended solids (TSS), suspended sediment, volatile suspended solids, total phosphorous (TP), total copper, total zinc, and PAHs. The

efficiency ratios for these constituents are 44, 43, 38, 55, 22, 5, and 45 percent, respectively. The SOLs for these constituents are 32, 39, 28, 36, 23, 8, and 48 percent, respectively. Both the SOL and efficiency ratio were negative for chloride of about 20 percent. Six constituents or physical properties, dissolved phosphorous, chemical oxygen demand, dissolved zinc, total dissolved solids, dissolved chemical oxygen demand, and dissolved copper, were not included, because the difference between concentrations in samples from the inlet and outlet were not determined to be significant. For TP and TSS, the concentrations were unexplainably high for one event samples at the inlet.

Introduction

An administrative rule has been established by the Wisconsin Department of Transportation (WisDOT) (Wisconsin Administrative Code Trans 401, 2002) to control the stormwater quality runoff from transportation facilities, such as highways, airports, and railroads. The rule was established to comply with the administrative rules for non-agricultural and runoff management performance standards established by the Wisconsin Department of Natural Resources (WDNR) (Wisconsin Administrative Code NR 151, 2004), A major element of the administrative rule is the control of total suspended solids (TSS) in stormwater runoff from post-construction sites and developed urban areas. For new development, the performance standard requires that loads of TSS be reduced by at least 80 percent for those facilities constructed after January 1, 2003 (Wisconsin Administrative Code Trans 401, 2002). The rule requires a performance standard of at least 40-percent reduction in loads of TSS for highway reconstruction and non-highway redevelopment (Wisconsin Administrative Code Trans 401, 2002). To evaluate post-construction performance, the WDNR allows the use of a computer simulation model, such as WinSLAMM to determine TSS load reduction. In addition, the U.S. Environmental Protection

(2000) Agency Phase I and Phase II stormwater regulations result in additional focus on the quality of flow from WisDOT transportation facilities.

To find the most cost-effective ways of complying with the TSS performance standard, WisDOT has supported evaluations of several devices that reduce contaminants from freeways — street-cleaning programs in Milwaukee (Waschbusch, 2003) and Madison (Wendy Braun Wisconsin Department of Transportation, written commun., 2006) and two proprietary devices used in Milwaukee, which were a stormwater filtration device (SFD) (similar to the one for this study) and a hydrodynamic settling device (U.S. Environmental Protection Agency, 2004; 2005).

To evaluate the treatment efficiency of a SFD for WisDOT transportation facilities, for example a park and ride, Madison Gas and Electric Company (MG&E) installed a SFD in an employee parking lot to reduce loads of TSS in stormwater runoff to Lake Monona. This site is similar to a park and ride with a similar turn-over rate of cars. Because the WisDOT has already tested the SFD that treated runoff from a freeway, it was important to select a WisDOT facility with different levels of contaminates and a different distribution of average particle size from those at the freeway site. Therefore, WisDOT, MG&E, WDNR, and the U.S. Geological Survey (USGS) developed this cooperative study to determine the reductions of contaminates when a SFD is used at a typical parking lot facility. This study also was designed to provide a range of treatment efficiencies expected for a SFD.

A SFD is among the emerging proprietary stormwater-control devices designed to provide at least a 40-percent reduction of TSS without requiring a lot of space. Space can be a limitation at some transportation facilities, such as park and rides in high-density urban areas. Many facilities in high-density urban areas will need to meet the 40-percent TSS performance standard at re-development sites and developed urban areas. To save space most of the devices are installed underground or above ground as a landscaping feature. Because single-chamber settling devices, such as catchment basins, have not achieved TSS reductions of 40 percent (Waschbusch, 1999; U.S. Environmental Protection Agency, 2005), most of the emerging devices incorporate filters to achieve higher levels of TSS reduction in a relatively small space.

Bioretention systems and Multi-Chamber Treatment Tanks (MCTTs) are two examples of emerging non-proprietary stormwater-control devices using filtration as part of the treatment process (Prince George's County, 2002; Pitt and others, 1999). Bioretention systems are a landscaping feature capable of reducing the TSS load by at least 80 percent (Hunt, 2006). This stormwater-control feature usually has a mixture of sand, compost, and native soil that is 3-feet thick and serves drainage areas of less than 2 acres. More study is needed of the maintenance requirements and filter thicknesses and mixes to improve TSS reduction. Bioretention systems are gaining widespread acceptance in Wisconsin as a method for treating stormwater runoff from parking lots. A 98-percent load reduction in TSS was achieved by an MCTT installed underground in a maintenance yard in Milwaukee, Wisconsin (Corsi and others, 1999). The MCTT are tanks that contain a mixture of sand, peat moss, and activated carbon. Because limited technical and maintenance support are available, MCTTs have been installed in only a few places around the country.

Proprietary devices are an attractive alternative to the non-proprietary ones because of the technical support from the manufacturer. In addition, they are usually designed for easy maintenance. However, the TSS reduction for these devices have not been verified and any testing has been limited by site-specific characteristics of the stormwater runoff.

Proprietary filtration devices installed underground have achieved at least a 40-percent reduction in TSS load at a hospital parking lot in Green Bay, Wisconsin, and a freeway in

Milwaukee, Wisconsin (Horwatich and others, 2004; U.S. Environmental Protection Agency, 2004). A proprietary pressurized sand filter reduced the TSS load in runoff from a hospital parking lot by 80 percent. The SFD at the freeway site reduced TSS load by 50 percent.

The ability of the SFD to exceed a 40-percent TSS load reduction at a freeway site does not guarantee that the filter will achieve the same level of TSS load reduction at other types of WisDOT facilities, such as park and rides and maintenance yards. Each type of site will have not only different levels of contaminates but different particle-size distributions. Testing the SFD on the employee parking lot will quantify the benefits of using this filter at park and rides and provide the additional data needed to calibrate and verify the SFD efficiency equations in an urban stormwater runoff model. One goal of the current project was to verify the results of the Windows Source Load and Management Model (WinSLAMM). Data from the parking lot study and the Milwaukee freeway studies can be modeled in WinSLAMM using TSS reduction devices. For example, the hydrodynamic settling device uses Stokes law equation, which is based on particle-size distribution, and flow velocity to determine the particle-size dropout rate through the device (Pitt, 2003). The efficiency of other stormwater-control devices can be affected depending on which particle-size distribution is applied in the model. The manufacturer of the SFD used in the study and the developers of WinSLAMM are cooperatively designing the algorithm to include SFDs in the model. If the calibration and verification are successful, the model could be used to estimate the efficiencies from an SFD at any transportation facility when appropriate source-area data are available.

The results from this study and from the study in Milwaukee eventually may be used to calibrate and verify WinSLAMM. If the calibration and verification are successful, WisDOT may be able to use WinSLAMM to estimate the TSS load reduction for SFD at more types of facilities. Input data on particle-size distributions, flow rates, filter media mixtures, number of cartridges, and type of source areas would be needed to model WisDOT facilities for estimating the TSS load reduction for the many types of SFD designs.

This report also adds to the understanding of stormwater quality and quantity in an urban environment. The USGS and the WDNR have cooperated on many projects to characterize quality and quantity of urban runoff. Concentrations of constituents in samples from storm-sewer inlets are compared with concentrations from other types of source areas, such as a high turnover parking lot at a hospital. These results help identify the relative importance of different source areas and characterize the potential impact of the stormwater on receiving waters.

Purpose and Scope

This report describes the process of monitoring stormwater runoff at the inlet, outlet and bypass pipes of a proprietary stormwater filtration device. The report also describes the methods for determining the efficiency of the device.

Precipitation, flow volume, particle size, and concentration data collected from November 5, 2005 to August 18, 2007 are reported. Precipitation erosivity, peak flow, antecedent dry days and peak flow are presented in appendices. Precipitation, flow volume, and concentrations of suspended sediment were recorded for 51 storms events, Concentrations in samples collected during 31 runoff events are reported for 15 of the 33 constituents analyzed in this study, include dissolved and particulate solids, inorganic compounds, organic compounds and recoverable metals. Particle-size distributions are presented for 36 runoff events and concentrations of 18 polycyclic aromatic hydrocarbons are presented for 15 runoff events.

New methods for determining particle-size distributions and processing samples with a churn splitter are presented. Constituents concentrations in samples from the SFD inlet were compared with concentrations form other source area, such as a high turnover parking lot at a hospital.

Site Description

In June 2003, MG&E installed a stormwater-filtration device called a StormFilter at an employee parking lot in downtown Madison, WI. (fig. 1). The cartridges were replace in May 2005, just before sampling began. The area of the parking lot was originally determined to be 1.3 acres (using an available surface elevation map) but was later revised to 0.91 acres. The asphalt parking lot has 181 parking stalls occupied mostly by employees with a few stalls for visitor parking. On weekends and weeknights the parking lot was used for overflow parking of downtown business. Most contaminates deposited on the parking lot were delivered by the cars and atmospheric deposition. Salt was applied in the winter as needed. Stormwater from the site flows from a 15-in. storm-sewer pipe then into a 48 by 76-in. storm-sewer culvert, and then flows to Lake Monona. The maintenance plan for the parking lot states that layer of seal coat is to be applied periodically. A seal coat of coal tar was last applied in 2000 (James Montgomery, Madison Gas and Electric, oral commun., 2006).

The parking lot is divided into three areas, and each area has about the same number of stalls. A 4-ft-wide gravel island separates the areas from each other, and there was an island at each end of the parking lot. When parked all the cars face an island. Stormwater draining from the parking lot flows into storm-sewer grates in the north and south islands. These grates are attached to a 15 in.-diameter storm-sewer pipe, which flow to the SFD (fig. 1).

No curb is present for the islands, so the stormwater from the parking lot can flow into the islands. Underneath the gravel is a sheet of thick black plastic. An inspection revealed that holes have developed in the plastic. The gravel islands represent 0.06 acres of the total area. The islands probably contribute runoff during large, intense runoff events but store water during small events.

The parking lot was built in 1986. Over time, small and large depressions have formed. The small depressions have formed in many of the stalls where the wheels of cars sit. The large depressions have formed in the driving lanes between stalls. Deposited sediment was observed in most of the depressions. Puddles formed in these depressions after rainfall.

Underneath the parking lot, the soil profile from base upward consists of a fibrous peat and organic soil mixture; above that is 5.5 ft of fill material consisting of dark brown silty sand with pebbles. The next layer is 1.25 ft of fill material, consisting of concrete rubble with sand; above that was a base course 7 in. deep. The parking lot surface layer is 2 in. of asphaltic concrete. The water table is approximately 6 ft below the parking lot.

Figure 1. Study area with a Geographic Information System overlay detailing the drainage area.

Previous Investigations

The USGS has long history of conducting urban water-quality investigations in Wisconsin. In 1978, the U.S. Environmental Protection Agency (USEPA) established the Nationwide Urban Runoff Program (NURP) to assess the water-quality characteristics of urban runoff. When the city of Milwaukee, WI, was chosen by the USEPA as a NURP site, a partnership between the WDNR and the USGS was developed to evaluate urban runoff in Milwaukee. Since the NURP study, the USGS and the WDNR have continued their partnership and have completed more than 15 studies in at least 6 cities to assist the State of Wisconsin in characterization of urban stormwater runoff See appendix 1 for a list of investigations.

Design of the Stormwater Filtration Device

The SFD removes contaminates through filtration and sedimentation. Filtration, considered the primary method of treatment, consists of a filter media to physically remove particles by retaining contaminates through sorption. Each of 26 filter cartridges were filled with ZPG media, a mixture of zeolite, perlite, and granular activated carbon. The filter media was designed to remove sediments, recoverable metals, organic compounds, phosphorous, oils, and greases. Sedimentation of larger particles occurs in a pretreatment chamber and on the bottom of the cartridge-filter bay.

The device designed to treat stormwater runoff from an impervious area of 1.3 acres, but runoff coefficients measured during the study indicated the drainage area had not been determined correctly. The runoff coefficients using the 1.3 acres averaged about 40 percent, which was much lower the than the expected runoff coefficients around 70 percent (Horwatich and others, 2004). The correct drainage-area divides were determined by watching the direction of flow when water was applied with a hose. The corrected watershed was 0.91 acres, so the SFD was too large for this site.

Stormwater from the parking lot enters into a precast 4-ft-long flow-splitter-box manhole. An adjustable external-weir plate is set in the center of the box at a height of 2.17 ft. At 90 degrees south of the weir plate, a 6-in.-diameter low-flow inlet pipe transfers stormwater into the device (fig. 2). If the stormwater rises more than 2.17 ft in the flow-splitter box, it bypasses the SFD through a 15-in.-diamter pipe; this stormwater is not treated.

Figure 2. Flow-splitter-box upstream from the stormwater-filtration device, representing the inlet pipe, the overflow weir, and the bypass pipe. (top view).

The device was housed in a concrete structure that was 6 in. thick, 16 ft long, 8 ft wide, and 5.5 ft. deep (fig. 3). Stormwater enter from the inlet pipe into a 2-ft wide, 1.67-ft deep inlet bay, which acts as a pretreatment chamber and energy dissipater (fig. 4). It then flows through a flow spreader that disperses water evenly into a 7.4 ft-long cartridge bay.

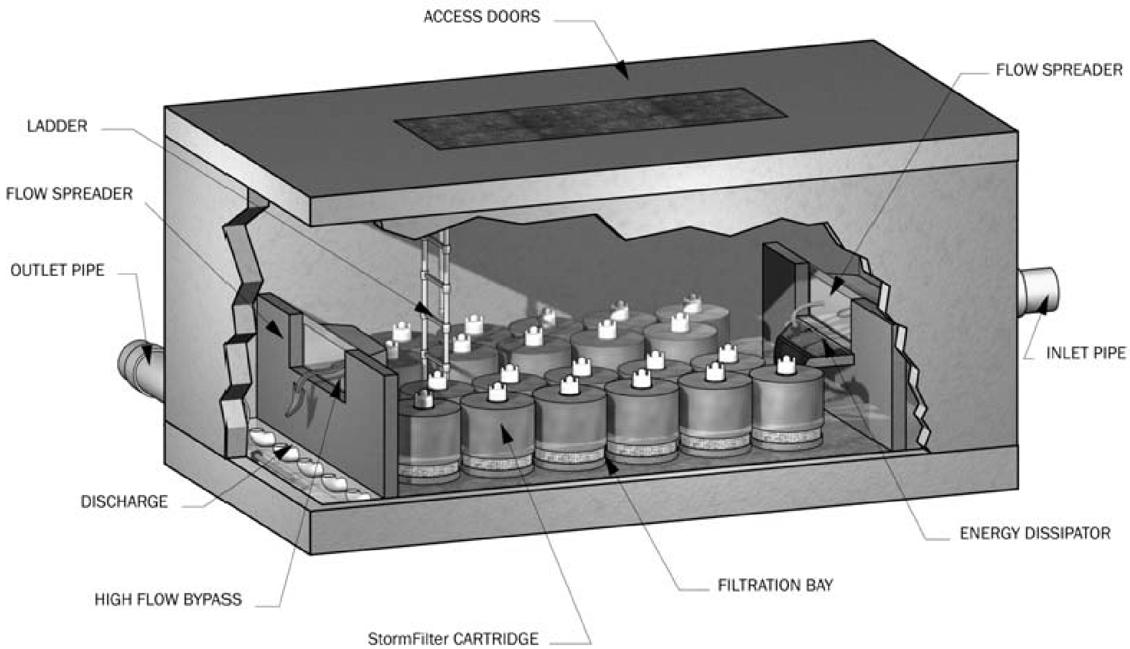

Figure 3. Components of the stormwater filtration device (USEPA, 2004).

Flow was controlled through the cartridges by a siphon action, and the water leaves the cartridge by an underdrain manifold. Each cartridge was designed to treat a peak flow of 0.033 ft^3/s, and combined the cartridges could treat a peak flow of 0.87 ft^3/s. When inlet flows exceed 0.87 ft^3/s, water bypasses the filter cartridges by way of the high-flow bypass weir at a height of 1.83 ft. Treated water from the underdrain manifold and untreated internal bypass water enter into an outlet bay area 8-ft long by 2.3-ft wide and then flow through a 6-in.-diameter pipe (James Bachhuber, Earth Tech, 2004 written commun.).

The manufacturer recommends that sediment be removed from the pretreatment chamber and filters be replaced in the device once a year. However, personnel from the manufacturer observed the SFD on August 17, 2007 and determined the device was still in working order.

Figure 4. The flow spreader and internal bypass weir of the stormwater-filtration device.

Sampling Design and Analytical Methods

Stormwater runoff was measured and collected at the inlet, outlet and bypass pipes of the SFD. Each pipe was equipped with automated stormwater-quality samplers and instruments to measure water level and velocity. Precipitation data was collected by use of a tipping-bucket rain gage. Measurement, control and storage of data were done by way of electronic dataloggers. Data were automatically retrieved twice daily with telephone modems. Descriptive statistics for stormwater runoff events from the SDF are detailed in appendix 2–3 and 2–4.

Water-Quality Sampling and Methods of Analysis

Water-quality samples were collected from the inlet, outlet, and bypass pipes of the SFD over 2.5 years. Station identification numbers and names for each sampling location are 430440089223500, MG&E Stormwater Filter Inlet at Madison, WI; 430440089223400 MG&E Stormwater Filter Outlet at Madison, WI; and 430440089223401, MG&E Stormwater Filter Bypass at Madison, WI.

Automatic samplers (fig. 5) were programmed to collect flow-weighted samples from the three pipes. The datalogger in the monitoring station was programmed to initiate a subsample for a predefined volume of flow; consequently, more subsamples were collected for large-volume runoff events than for small-volume runoff events. Flow-weighted sampling allowed for the collection of one composite sample for a stormwater runoff, consisting of numerous collected subsamples throughout the course of the event. This approach resulted in a single flow-weighted or “event mean” concentration for each runoff event.

The sample tubing of the inlet automatic sampler was installed 1 ft upstream from where the flow entered the device, and the outlet sample line was installed 3 ft downstream from where the flow exits the device. All sample lines were perpendicular to flow and approximately 1 inch from the bottom of the pipe. The bypass area-velocity flowmeter and sample tubing used to collect bypass stormwater were housed in separate pipes. Velocities were too high in the bypass pipe for the sampler to work properly, so the bypass sample tubing was placed 5 ft. upstream from the flow-splitter box.

The volume between subsamples was determined such that a minimum of five 1-L subsamples were collected for each event. The maximum sampler capacity was 40 1-L subsamples. For events greater than or equal to 0.2 in. of precipitation and a minimum of five 1-

L subsamples, the subsamples were processed for all constituents (tables 1 and 2); otherwise, subsamples were processed for concentrations of suspended sediment (SS), total suspended solids (TSS) and total dissolved solids (TDS). Samples were processed according to the churn-splitting procedure described by Horowitz and others (1997).

Figure 5. Automatic sampling equipment.

The constituents investigated were selected on the basis of the performance information from the manufacturer and the regulated constituents WisDOT might want to control in the future (tables 1 and 2). Samples were analyzed at the Wisconsin State Laboratory of Hygiene (SLOH), participators in the USGS Standard Reference Sample (SRS) program (Woodworth and Connor, 2003).

Table 1. Limits of detection and analytical methods for inorganic constituents analyzed in samples collected at the stormwater-filtration device, Madison, WI.

[mg/l, milligrams per liter; µg/L micrograms per liter; NA, not applicable]

Constituent or characteristic	Unit	Limit of detection	Limit of quantification	Method
Dissolved solids, total	mg/L	50	167	[1]SM2540C
Suspended solids, total	mg/L	2	7	[2]EPA 160.2
Volatile solids, total	mg/L	2	7	[2]EPA 160.2
Suspended sediment	mg/L	2	7	[1]ASTM D3977-97
Phosphorus, dissolved	mg/L as P	.005	.016	[2]EPA 365.1
Phosphorus, total	mg/L as P	.005	.016	[2]EPA 365.1
Chemical oxygen demand, total	mg/L	14	28	[2]EPA Method 410.4
Chemical oxygen demand, dissolved	mg/L	14	28	[2]EPA Method 410.4
Chloride, dissolved	mg/L	.6	2	[1]SM4500CL
Calcium, total recoverable	mg/L	.02	.07	[1]EPA 200.7
Magnesium, total recoverable	mg/L	.03	.7	[1]EPA 200.7
Zinc, dissolved	µg/L	16	50	[1]EPA 200.9
Zinc, total recoverable	µg/L	16	50	[1]EPA 200.9
Copper, dissolved	µg/L	1	3	[1]SM3113B
Copper, total recoverable	µg/L	1	3	[1]SM3113B
Wet-sieve of sediment	NA	NA	NA	[3]Burton
Coulter counter of sediment	NA	NA	NA	[3]Burton
Laser diffraction of sediment	NA	NA	NA	[3]Burton
Microfiltration of sediment	NA	NA	NA	[3]Burton

[1]American Public Health Association and others, 1989. SM (Standard Methods).

[2] U.S. Environmental Protection Agency, 1979.

[3] Burton and Pitt. 2002.

Table 2. Limits of detection and analytical methods for polycyclic aromatic hydrocarbons analyzed in samples collected at the stormwater filtration device, Madison, WI.

[µg/L micrograms per liter]

Constituent or characteristic	Unit	Limit of detection	Limit of quantification	Method
1-Methylnaphthalene	µg/L	0.064	0.2	[1]SW8310
2-Methylnaphthalene	µg/L	0.049	0.16	[1]SW8310
Fluorene	µg/L	0.52	1.7	[1]SW8310
Acenaphthene	µg/L	0.064	0.20	[1]SW8310
Acenaphthylene	µg/L	0.11	0.34	[1]SW8310
Anthracene	µg/L	0.031	0.1	[1]SW8310
Benzo[a]anthracene	µg/L	0.093	0.30	[1]SW8310
Benzo[a]pyrene	µg/L	0.16	0.52	[1]SW8310
Benzo[b]fluoranthene	µg/L	0.13	0.41	[1]SW8310
Benzo[g,h,i]perylene	µg/L	0.14	0.44	[1]SW8310
Benzo[k]fluoranthene	µg/L	0.12	0.38	[1]SW8310
Chrysene	µg/L	0.027	0.09	[1]SW8310
Dibenzo[a,h]anthracene	µg/L	0.034	0.11	[1]SW8310
Fluoranthene	µg/L	0.11	0.35	[1]SW8310
Indeno[1,2,3-cd]pyrene	µg/L	0.093	0.30	[1]SW8310
Phenanthrene	µg/L	0.093	0.30	[1]SW8310
Pyrene	µg/L	0.11	0.34	[1]SW8310
Naphthalene	µg/L	0.042	0.13	[1]SW8310

[1]American Public Health Association and others, 1989. SM (Standard Methods).

Processing of Water-Quality Samples

New procedures were used to improve the accuracy and precision of measuring the quantity of particulate constituents in samples containing large amounts of sand-sized particles (>125 µm). The use of a churn to partition samples with large quantities of sand has the potential to cause a positive bias and to lower the precision of the measurement of constituents concentrations associated with particulates (Horowitz and others, 1997). Use of a wet-sieving process decreases these errors for sediment-associated constituent concentrations (Selbig and others, 2007). This process consists of pouring a known quantity of sample through sieves of 125 µm, 250 µm, and 500 µm before churning the aqueous portion. Material collected on sieves was sent to the SLOH in individual bottles to be dried and weighed. Dried material from each of the sieves then was combined and processed for total recoverable metals and phosphorus. This process was used for six events only, which were determined by stirring the samples and observing at least 2 grams of material at the bottom the bottle after 1 minute. For samples from these six events, large amounts of material dropped to the bottom of the glass jar within a minute of stirring the sample. The aqueous portion of the sample that passed through the sieves was processed using typical USGS churning procedures (Horowitz and others, 1997). All concentrations of SS presented in this report include sieved material.

Sample results of the sieved mass were added back to the aqueous portion to determine a mean concentration for the event by using the following equation (Selbig and others, 2007):

$$C1 = ((Sm/1000)*Cs)/V,$$

where

C1 = concentration of sieved solid, in mg/L;

Sm= mass of sieved solids after drying, in grams;

Cs = concentration of sieved solid, in mg/kg; and

V= volume of water sieved, in liters.

Flow Monitoring

Area-velocity flowmeters were installed that use continuous wave Doppler technology to measure mean velocity. The sensor transmits a continuous ultrasonic wave and then measures the frequency shift of returned echoes reflected by air bubbles or particles in the flow (Teledyne Isco, 2004). Three meters were installed to monitor flow in the 6-in. inlet-diameter pipe, 6-in.-diameter outlet pipe, and 15-in.-diameter bypass pipe. The area-velocity flow meters at the inlet and outlet were installed 4 in. downstream from the sample intake tubes.

Because laminar flow was necessary to produce accurate measurements from the area-velocity meter, an additional 3-ft length of pipe was attached to the inlet pipe (fig. 6). The outlet area-velocity flowmeter was 3 ft. downstream from the device in a 6-in.-diameter pipe. The area-velocity meter was placed downstream from the external bypass weir in a 15 in.-diameter pipe that graded at a 29-percent slope.

A stand-alone stage pressure transducer and temperature probe were installed in May 2006. The transducer and probe were installed 2 ft. in front of the SFD internal bypass weir (fig. 4). The recorded depth indicated the height of flow in filtration bay.

Cameras were installed at five locations to identify problems with sampling equipment or to detect a change in flow regime at (1) the flow-splitter box to detect bypass flows, (2) the inlet pipe to detect debris on the meter, (3) the pressure transducer and device weir to detect overflows, (4) the bypass pipe to detect movement of the meter, and (5) the exit manhole, where the bypass pipe and the device outlet pipe flow, to detect back-water flow. Digital recordings were controlled by an inlet stage threshold, which turned the cameras on and off.

Figure 6. Inlet pipe with stabilization bar.

Calibration of Gage Height

Corrections were applied to stage measurements (for June 22, 2005; July 13, 2006; and June 11, 2007) that reflect differences between water-surface elevations measured manually and those measured with the area-velocity flowmeters. To generate two sets of elevations for comparison, the meters were placed in separate buckets. Water levels then were increased in each bucket, and measurements were made at various levels, representing the entire depth of the pipe. Ten to 15 readings were taken at each meter. Results from this procedure were used in making stage corrections through the entire monitored period of record (November 2005 - August 2007); accuracy of the records, on average, was estimated to be within ± 2 percent.

Calibration of Flow

Stormwater runoff was measured at the inlet, outlet and bypass pipes of the SFD. A dye dilution system was installed to calibrate flow at the inlet. The outlet meter was corrected using the calibrated inlet flows. It was not necessary to correct bypass flows because no bypass event samples were processed.

Inlet Flows

In October 2006, an automatic dye dilution system was installed to calibrate flow. A separate gage house for sampling dye, fluorometer, and datalogger to record dye dilution data was located adjacent to the sampling gage houses. The injection site for known dye concentrations was 20 ft upstream from the inlet area-velocity flowmeter (fig. 6). A dye sampling tube was placed 1 in. downstream from the inlet sampling tube for a uniform mixture of stormwater and dye. The mixture was pumped to the fluorometer to measures the concentration of dye fluorescence. A dye dilution occurred when a given stage threshold was reached at the inlet area-velocity flowmeter.

The equation used to convert dye measurements to flow is

$$Q = q*C/c,$$

where

Q = flow being measured;

q = injection rate;

C = concentration of injected dye; and

c = concentration of dye measured.

In 2007, more than 200 sample points were recorded for calibration at the inlet meter from six events (April 25, May 15, July 3 and 26, and August 4 and 5). Comparison of the data points from the inlet area-velocity meter and the dye dilution flow indicated that the inlet area-velocity meter was reading low by an average of 10 percent (fig. 7). To correct the inlet flow measurements, a plot of dye to metered flow data points were used to produce a correction equation with an R^2=0.9825:

Inlet corrected flow = 1.5689 * (Inlet flow measured) – 0.0469

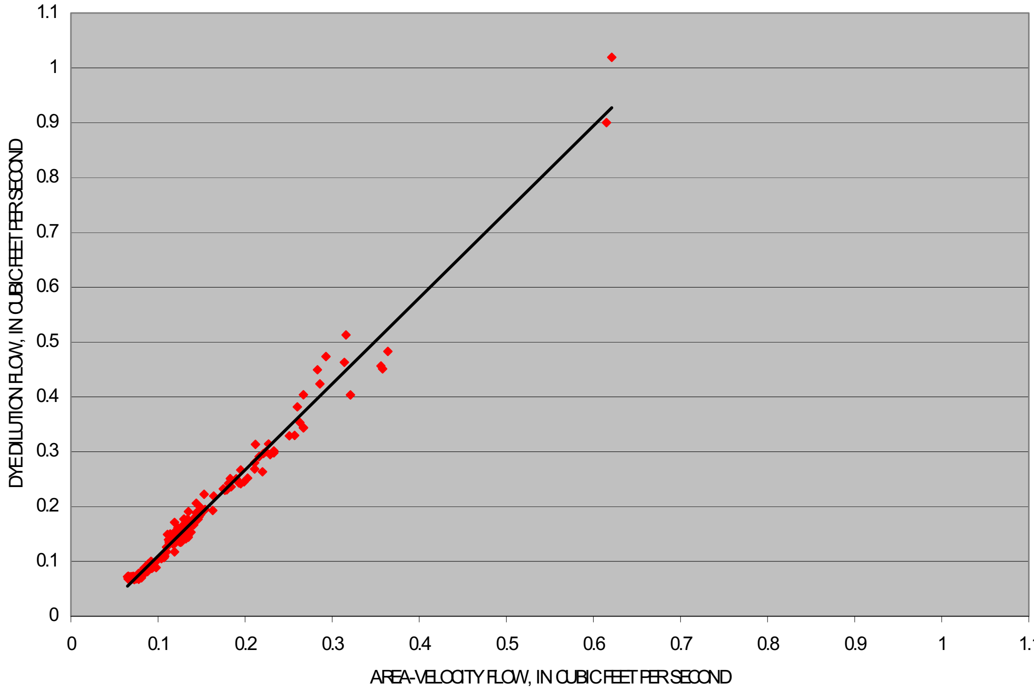

Figure 7. Dye dilution in relation to area-velocity flow at a flow inlet of a stormwater filtration device.

Figure 8. Dye dilution equipment.

Outlet Flows

It was not possible to calibrate the outlet area-velocity meter owing to the short mixing zone between the flow exiting the cartridge bay and the outlet area-velocity meter. Because there was no external bypass through the filtration device for most events, the outlet meter could be corrected using the inlet corrected event volumes.

Monitoring Complications

Bypass meter. The external bypass flow exited through a 15-in.-diameter PVC pipe that was set at a 29 percent slope. The area-velocity meter was attached to a spring band and placed 3 ft. upstream from the exit manhole. After a runoff event on August 25, 2005 the high velocities of runoff forced the meter downstream. Subsequently, screws were used to secure the spring band. On August 21, 2006, the probe of the area-velocity meter was replaced because recorded data were all negative values.

High-flow weirs. The SFD was designed with external and internal high-flow bypass weirs. During July to October 2005, stormwater runoff was measured for 16 events; 8 of the events produced external bypassing, and 4 produced internal bypassing. The manufacturer decided additional stormwater could be treated by increasing the heights of both weir plates. The task of increasing the heights of the weir plates was completed on November 1, 2005. This adjustment reduced the number of bypasses to three during the rest of the study period.

Datalogger. Communications from the area-velocity meter to the datalogger were sent through serial string translation. During non-events, data were recorded for the first minute of the hour. When particles were not available for the area-velocity meter, the meter cannot correctly determine the velocity within that minute; therefore, the datalogger translated the velocity data as an extremely high or low data point. To replace the high or low data point with the last valid velocity recorded by the area-velocity meter, high and low cutoff thresholds were programmed into the datalogger. To validate removal of these high or low data points, the velocity data recorded by the datalogger were compared to velocity recorded by the internal memory of the area-velocity meter. The area-velocity meter stores 15-second data for approximately 2 days then overwrites it with new data. Programming changes were made in April 2006.

Dye dilution system. From October through December 2006, four dye dilution events were recorded. These data were not used because the ratios of dye dilution to area-velocity flow were inconsistent. Review of the video revealed that the stage-flow relation was distorted by large volumes of stormwater that shifted the extended inlet pipe downward. To correct this problem a stabilization bar was attached from the SFD wall to the extended inlet pipe (fig. 6). Stabilization bar was added on April 29, 2007. Because of the shifting of the inlet pipe during large volume events, there was probably some error in the data occurring before the inlet pipe was stabilized. Also, during one runoff event debris became draped over the meter.

Precipitation

A tipping-bucket rain gage was used for continuous measurement of precipitation. A datalogger recorded the number of bucket tips (0.09 in. per tip) every 60 seconds. This gage was not designed to record frozen precipitation, so data during periods of snowfall and freezing rainfall were not used. Calibration data showed there was no need to adjust precipitation data. All precipitation data collected for each site are listed in appendix 2–3. To accurately record precipitation amounts during varying intensities, a microprocessor in the rain gage uses a built-in polynomial to correct for the intensity, which is based on the tipping bucket's mechanism (Design Analysis Associates, 2001).

The rain gage was attached to the back of the monitoring station. It was mounted on a 2-in.-diamenter pipe raised 10 ft to avoid interference from nearby structures and to prevent vandalism. During two calibration, the rain gage was cleaned.

Quality Control

Equipment blank and replicate samples were collected at the inlet and outlet of the SFD and analyzed for the same constituents as those for runoff samples (app. 2–1). Blanks were collected at the beginning and midpoint of the project to validate clean-sampling procedures.

Replicate samples were collected during several stormwater events to quantify the variability or precision of sampling procedures. Analytical precision was a measurement of how much an individual measurement deviates from a mean of replicate measurements. The relative percent difference (RPD) was calculated to evaluate precision in procedures after sample collection.

The relative percent difference equation is

$$\%RPD = \{(x_1 - x_2) / \bar{x}\} \text{ x } 100,$$

where

x_1 = concentration of constituent in a sample;

x_2 = concentration of a constituent in a duplicate sample; and

$\bar{x}$ = mean value of x_1 and x_2.

Three equipment blank samples were collected to validate clean-sampling procedures: the first was collected before sampling began (blank 1), the second between events 18 and 19 (blank 2) and the third between events 40 and 41(blank 3). Blank 1 sample contained detectable concentrations of dissolved copper (DCu), total copper (TCu), and chemical oxygen demand (COD), but both concentrations were below the limit of quantification (LOQ) for the inlet and outlet. Blank 2 sample had detectable concentrations of total phosphorus (TP) and dissolved phosphorus (DP) from the inlet, outlet, and bypass, and dissolved zinc (DZn) from the outlet, but all concentrations were below LOQ. In blank 2, from the outlet, the concentration of DCu exceeded the LOQ. Quality-control samples collected directly from the sampler and from the jar of blank water were analyzed; but analyses resulted in no detects. (app. 2–1). Blank 3 sample had no detectable concentrations.

Replicate samples were collected during events 1, 9, 23, and 44 to quantify variability in the sampling process. The RPD target for TSS was 30 percent or less; for recoverable metals, the RDP target was 25 percent or less (app. 2–2). In replicates for event 9 the RDP target of 25 percent was exceeded for, total zinc (TZn), and for event 23 the RPD target of 25 was exceeded for TCu. For all of the dissolved constituents, a relatively low RPD was reported, but RPDs that were greater than the target were reported for some of the particulate constituents, however no adjustments were made to concentration data.

Particle-Size Analysis

In July 2004, the USGS Wisconsin Science Center adopted a new method for particle-size analysis. Previous methods had required a large sample volume to provide enough sediment for analysis. Previous methods were not designed for the relatively low levels of sediment observed in stormwater samples. The new method requires only about a liter of sample and was used exclusively on this project. The new particle-size analysis uses a two-step process developed by the State Laboratory of Hygiene.

The first step was to wet sieve the sample for the 500, 250, 125, 63, and 32 micrometers particle sizes. The material on the sieves was then dried and weighed. The second step was to separate the particles less than 32 microns into particle-size fractions of 16, 8, 4, and 2 micrometers. For the first 30 samples a Laser counter was used to identify the quantity of the four smaller particle sizes. For later samples a Coulter counter (Beckman Coulter Multisizer 3 particle size counter; Graham, 2003) was used to determine the quantity of smaller particles. Other researchers have used a Coulter counter to evaluate particle sizes in stormwater (Burton and Pitt, 2002). The Coulter counter was calibrated by microfiltering replicate samples with polycarbonate filters.

Evaluation of Stormwater Filtration Device

Efficiencies of the SFD were evaluated by first determining if the inlet and outlet concentrations were significantly different. For concentration significantly different the concentrations and loads were used to determine efficiency-ratio and sum of the loads.

Precipitation Data

Precipitation data collected at the site were compared to National Oceanic and Atmospheric Administration (NOAA) data collected at the Dane County Regional Airport (DCRA). Precipitation collected by both gages was comparable to the long-term average at DCRA (table 3). DCRA was approximately 6 miles northeast of the SFD.

The difference between the total from the USGS rain gage and the 2005-07 totals from the DCRA rain gage was less than 20 percent. Larger differences generally occurred summer months when precipitation amounts can vary substantially over distances as small as 4 mi., owing to a predominance of localized convective events. For precipitation in 2005, the USGS rain gage recorded 5.9 in. less than the long-term average at DCRA, whereas in 2006 and 2007, the USGS precipitation averages was 5.9, in and 4.6 in. higher, respectively, than the long-term average at DCRA.

Table 3. Monthly precipitation at the U.S. Geological Survey rain gage and the National Oceanic and Atmospheric Administration precipitation gage at Dane County Regional Airport Madison, WI, 2005-07.

[Precipitation is presented in inches; NOAA National Oceanic and Atmospheric Administration; DCRA, Dane County Regional Airport; --, no data]

Month	USGS precipitation	NOAA hourly DCRA	NOAA DCRA long term average[1]
July 2005	2.5	3.9	3.9
August 2005	1.5	1.2	4.3
September 2005	2.1	2.0	3.1
October 2005	.6	.76	2.2
November 2005	3.2	3.4	2.3
December 2005	--	--	--
Total 2005	**9.9**	**11.3**	**15.8**
January 2006	--	--	--
February 2006	--	--	--
March 2006	2.0	2.3	2.3
April 2006	6.2	4.2	3.4
May 2006	4.4	4.6	3.2
June 2006	3.0	2.3	4.0
July 2006	7.0	4.2	3.9
August 2006	5.7	5.4	4.3
September 2006	3.2	3.3	3.1
October 2006	2.1	2.2	2.9
November 2006	2.2	2.3	2.3
December 2006	1.2	1.7	1.7
Total 2006	**37.0**	**32.5**	**31.1**
January 2007	--	--	--
February 2007	--	--	--
March 2007	2.5	3.4	2.3
April 2007	3.7	4.7	3.4
May 2007	1.5	1.4	3.2
June 2007	3.9	4.8	4.0
July 2007	1.2	2.7	3.9
August 2007	12.9	15.1	4.3
Total 2007	**25.7**	**32.1**	**21.1**

[1.] Average for 1971 to 2000 data for Dane County Regional Airport, WI.

Because flow rates can affect the performance of a stormwater control practice, a project determining the treatment efficiency of a practice would benefit by sampling a mix of precipitation depths and intensities. Ideally, the distribution of precipitation depths for a project will be comparable to the long-term distribution of precipitation depths. It would not be a valid test of a treatment device if the sampled events had a significant bias to the smaller or larger precipitation observed for the area. To assess how the mix of precipitation events during the project period compared to long-term precipitation patterns, the distribution of monitored precipitation depths from this study was compared to the historical distribution of precipitation depths from the NOAA DCRA site.

Probability distributions for both datasets were constructed by use of the Weibull plotting position (Helsel and Hirsch, 1992). Precipitation amounts for individual events were computed for both datasets. Precipitation greater than or equal to 0.07 in. (the minimum amount recorded during this project) were ranked from lowest to highest. A cumulative probability distribution then was computed for both datasets by use of the formula

$$P_R = i_R/(n+1),$$

where

R = precipitation event;

P_R = probability of an event having a precipitation less than that of event;

R, i_R = ranking of event R; and

n = total number of events in the dataset.

Although the distribution for this study tends to be a little higher than the historical distribution, the distribution for this study would still be considered very similar to the historical distribution (fig. 9).

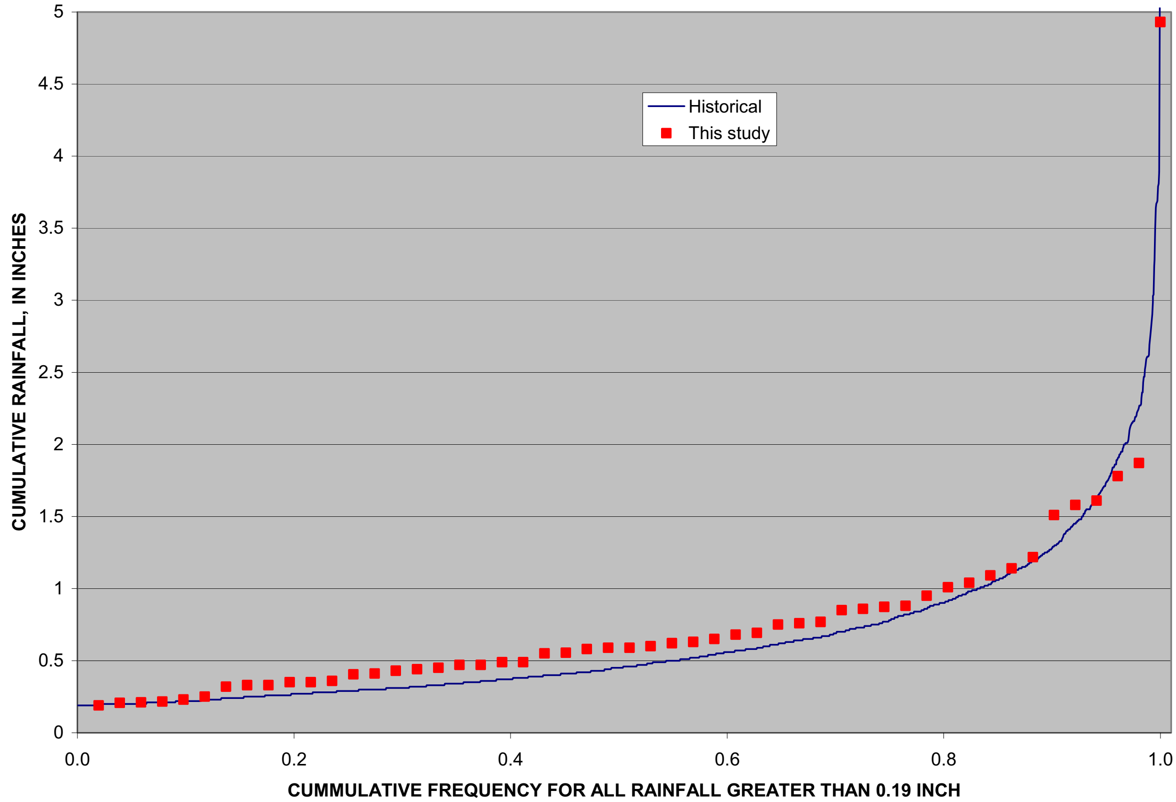

Figure 9. Cumulative precipitation for the study period (2005-07) in relation to the cumulative frequency for all precipitation greater than 0.19 inches (1949-92) based on the National Oceanic and Atmospheric Administration precipitation gage at Dane County Regional Airport, Madison WI.

Number of Events with Water-Quality Data

From November 5, 2005, until August 18, 2007, 51 runoff events were monitored for water-quality and water quantity. The precipitation for these sampled events ranged from 0.19 to 4.93 in. (app. 2–3). The maximum 15- and 60-minute precipitation intensities were 7.01 and 3.79 in/hr, respectively. For the drainage area without gravel islands, the precipitation volumes ranged from 250 to 15,210 cubic feet. The volume of stormwater that passed through the filtration system ranged from 235 to 8,210 cubic feet (app. 2–4). On average, 63 percent of the precipitation resulted in direct runoff from the site. There were two events in which stormwater bypassed the SFD after the weirs heights were adjusted, but those events are not included in the report. For one event, flow at the inlet, outlet, and bypass were poorly sampled. For the second, only one sampled was collected; therefore, bypassing events are not included in the report.

Stormwater Flow Data

Volumes of stormwater measured at the outlet ideally were the same as volumes at the inlet because there was no external bypassing after the flows enter the SFD. To verify that the outlet area-velocity flowmeter was recording flow correctly, volumes from the outlet were compared to corrected inlet volumes (fig. 10). Only 2007 event volumes were used for the comparison, because the inlet meter produced some inconsistencies in the stage-flow relation before the inlet pipe was secured. On average the outlet volumes were 5 percent lower than the inlet volumes, so no correction was applied to the outlet. Flows for the outlet were not affected by a shifting pipe in 2005 and 2006, so the outlet flows were used to calculate event volumes.

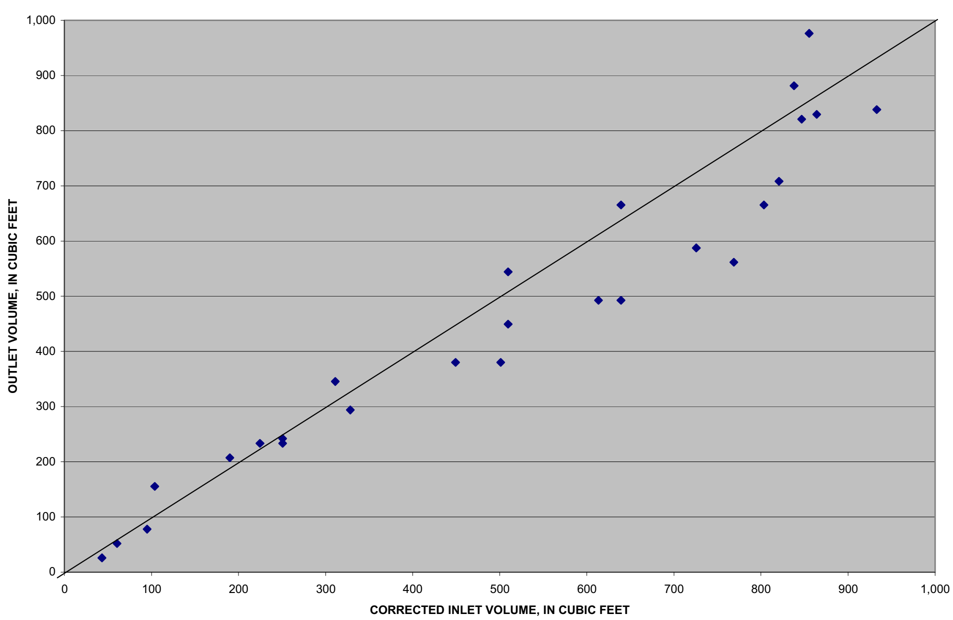

Figure 10. Stormwater volumes at the inlet of the Stormwater Filtration corrected by the dye dilution, in relation to outlet volumes, Madison WI, 2007.

Particle-Size Distributions

Sufficient sample volume was available to do particle-size analysis in 36 events (app. 2–8). The particle-size distributions at the inlet and outlet varied for each event. For the inlet samples the portion of silt- and clay-size particles (<63 micrometers) ranged from 29 to 80 percent. A similar range occurred for the outlet samples; the portion of silt- and clay-size particles ranged 33 to 94 percent. On the basis of average particle sizes for all events, slightly more silt- and clay- sized particles were present in the inlet water than sand-sized particles (table 4). At the Milwaukee SFD site, silt- and clay-sized particles averaged only 20 percent of the sediment (U.S. Environmental Protection Agency, 2004).

Outlet flows contained a greater percentage of fine particles than the inlet flows. There was a shift to a larger percentage of the smaller particles because the larger particles were trapped in the SFD. The average percentage of particles less than 63 microns increased from 57 percent at the inlet to 68 percent at the outlet (table 4).

In previous studies of stormwater control practices, particle-size distribution had some affect on the reduction of TSS and SS achieved by the device (Waschbusch, 1999; Horwatich and others, 2004). The average distribution of particles at the inlet indicates about a 20-percent reduction in concentrations of TSS and SS was possible by controlling all the particles greater than 250 microns. About 40 and 80 percent reduction might be possible by trapping all the particles greater than 63 and 4 microns, respectively. The average particle-size distribution is necessary in some models, such as WinSLAMM, designed to predict the TSS reduction in stormwater-control devices.

Table 4. Average particle-size distribution in stormwater samples from the inlet and outlet of the Stormwater Filtration Device, Madison, WI.

[µm, micrometer; all data are in percent by mass]

Sampling location	Percent of particles less than each particle size								
	500 µm	250 µm	125 µm	63 µm	31 µm	16 µm	8 µm	4 µm	2 µm
Inlet	90	81	71	57	43	36	31	27	17
Outlet	94	87	82	68	54	47	41	35	24

Water-Quality Data for the Inlet and Outlet

Constituent concentrations for each stormwater event are listed in Appendix 2 (app. 2–5 through 2–7). Thirty-three constituents were analyzed for the inlet and outlet samples. Eighteen of the constituents were individual species of polycyclic aromatic hydrocarbon (PAHs). Samples from 31 runoff events were analyzed for all constituents, except PAHs. Samples from at least 15 stormwater events were analyzed for PAHs.

Non-detectable concentrations composed substantial proportion of the total for the PAHs. Non-detectable concentrations were below detection limits for samples from the outlets than for samples from the inlets. Non-detectable concentrations were associated with 6 of the 18 PAHs: 1-methylnaphthalene, 2-methylnaphthalene, fluorene, acenaphthene, acenaphthylene, and naphthalene. To calculate the summary statistics for total PAHs, a method was needed to account for the non-detected concentrations. Methods included using the limit of detections, one-half the limit of detections, and zero. The difference between a total PAH value calculated with one-half the limit of detections and the other methods were only about 5 percent. Therefore, the total PAH concentrations were calculated by using one-half the limit of detections.

Constituent concentrations followed a lognormal distribution from inlet and outlet samples. The Shapiro-Wilk statistic was used to test for normality (Helsel and Hirsch, 1992). Runoff data from many of urban sites around the country exhibit similar distributions for average concentrations; these concentrations were either lognormal or can be approximated as lognormally distributed (Driscoll and others, 1990). Datasets that were lognormally distributed are best described by the median or geometric mean to reduce the influence of a few extreme observations. The averages, geometric means, and coefficients of variations for all the constituents are presented in table 5, and the statistics for individual PAHs are presented in table 6. Since most of the TDS and dissolved chemical oxygen demand (DCOD) concentrations were less than the detection limit, the TDS and DCOD statistics are not included in the table. The average concentrations for TSS, SSC, TP, DP, TZn, and TCu were lower for this site than those for other parking lots in Wisconsin and Michigan (table 2–12) (U.S. Environmental Protection Agency, 2004; Horwatich and others, 2004; Steuer and others, 1997; Bannerman and others, 1992; Bannerman and others, 1983). For example the average TSS, TP, and TZn concentrations measured at a retail parking lot in Madison, WI, were 58 mg/L, 0.2 mg/L, and 178 mg/L, respectively, compared to this studies of 20 mg/l, 0.11 mg/l and 25 μg/l, respectively (Bannerman and others, 1992). These were 2 to 7 times greater than the concentrations for this study presented in table 5. Concentrations of PAHs measured during this study were much higher than those measured for retail parking lots in Madison (Selbig and others, 2007), but the concentrations were similar to a parking lot in Marquette, Michigan (Steuer and others, 1997).

Table 5. Summary Statistics for selected Water-Quality constituents in samples collected from the stormwater filtration device, Madison, WI.

[mg/l, milligrams per liter; µg/L micrograms per liter]

Constituent	Geometric mean		Average		Coefficient of variation	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Solids, suspended total, mg/L	18	11	28	16	1.2	0.80
Sediment, suspended, mg/ L	20	11	26	15	.80	.92
Solids, volatile suspended, mg/ L	7	5	10	6	1.0	.83
Chemical oxygen demand , total, mg/ L	17	18	22	21	0.67	.59
Chemical oxygen demand, dissolved., mg/ L	9	9	12	11	.86	.83
Phosphorus, total, mg/ L	.058	.05	.12	.05	2.9	6.5
Phosphorus, dissolved, mg/ L	.029	.026	.03	.03	.54	.46
Chloride, mg/ L	1.8	2.2	4.4	5.2	1.7	1.7
Copper, dissolved, ug/ L	2.8	2.5	3.2	2.9	.67	.74
Copper, total recoverable, ug/ L	4.2	3.5	4.7	3.7	.52	.40
Zinc, dissolved, ug/ L	8.1	11	8.6	12	.39	.27
Zinc, total recoverable, ug/ L	22	21	24	23	.46	.42
Calcium, total recoverable, mg/ L	4.4	4.3	4.6	4.4	.34	.29
Magnesium, total recoverable, mg/ L	1.3	1.2	1.4	1.2	.51	.41
PAHs, total, ug/ L	53	26	65	35	.70	.87

Table 6. Summary statistics for individual polycyclic aromatic hydrocarbons in samples collected from the stormwater filtration device.

[All constituents in micrograms per liter]

Constituent	Averages		Geometric means		Coefficient of variation	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
2-Methylnaphthalene	0.091	0.062	.068	.057	1.2	0.5
1-Methylnaphthalene	.10	.07	.075	.069	1.5	0.5
Acenaphthylene	.18	.12	.13	.12	1.5	.46
Acenaphthene	.13	.11	.094	.075	1.2	1.5
Anthracene	.29	.14	.23	.098	0.7	1.0
Benzo[b]fluoranthene	6.4	3.8	5.4	2.9	.64	.80
Benzo[k]fluoranthene	2.9	1.6	2.5	1.2	.64	.84
Benzo[a]pyrene	3.7	1.9	2.8	1.2	.78	1.0
Chrysene	5.7	3.1	4.8	2.4	.67	.82
Fluoranthene	16	8.3	13	6.1	.66	.84
9H-Fluorene	.83	.59	.61	.56	1.5	.47
Indeno[1,2,3-cd]pyrene	4.3	2.6	3.6	2.0	.67	.80
Phenanthrene	6.8	3.5	5.3	2.4	.87	1.0
Pyrene	11	5.9	12	5.8	.71	.89
Benzo[ghi]perylene	4.8	2.8	4.0	2.1	.66	.82
Benzo[a]anthracene	1.4	.64	1.1	.39	.80	1.2
Dibenzo[a,h]anthracene	.47	.24	.39	.19	.72	.80
Naphthalene	.07	.05	.049	.045	1.5	.47

Efficiency Calculations

To determine the efficiency of concentration removal by a stormwater SFD device, various methods are used (National Cooperative Highway Research Program, 2006). Two of the methods typically used by investigators are the efficiency ratio and summation of loads. The efficiency ratio uses event mean concentration (EMC) of contaminates over a time period. The SOL is used to evaluate the treatment efficiency on a percentage basis by comparing the sum of the influent and effluent loads (the product of multiplying the constituent concentration by the precipitation volume) for all monitored events.

Each method uses data from the inlet and outlet to produce a single number that is designed to represent removal efficiency of the device. Unfortunately, these methods are not designed to evaluate the statistical differences in the data, so there is insufficient information to determine whether the differences in water-quality measurements for samples from the inlet and outlet are significant. These efficiency calculations can be supplemented with a statistical test, indicating whether the means of the concentrations are statistically significant (Helsel and Hirsch, 1992).

A paired statistical test was used to determine whether the constituent concentrations at the inlet were greater than those at the outlet. A paired statistical test was considered valid for this dataset because concentrations at inlet and outlet were paired for each event. Most of the constituents were log-normally distributed; therefore, the nonparametric one-sided Wilcoxon signed-rank test was applied (Helsel and Hirsch, 1992). A test for significance and efficiency ratios calculations was not done for calcium and magnesium, because these concentrations are only used in the calculation of hardness.

Concentrations of 8 of the 14 constituents analyzed for SFD were significantly different at the 95-percent confidence level for the inlet and outlet samples. Concentrations of DP, DCOD, TCOD, TDS, DCu, and DZn, were not significantly for the inlet and outlet samples. All the constituents that were significantly different were significantly higher in samples from the inlet, except for chloride (Cl), which was significantly higher in the outlet samples probable due to winter practices.

Efficiency Ratio

The efficiency ratio method of calculating efficiencies of a SFD weights all runoff events equally. For example, a large volume of flow with high constituent concentrations has the same weight as a small volume of flow with low constituent concentrations.

The efficiency ratio comparison evaluates treatment efficiency on a percentage basis by dividing the constituent concentration at the outflow by the concentration at the inflow and multiplying the quotient by 100. The efficiency ratio was calculated for each constituent (and physical property) and each individual runoff event.

The calculation is represented by the following equation:

$$\textit{Efficiency Ratio} = 1 - (\textit{average outlet concentration} / \textit{average inlet concentration})$$

Efficiency ratios were calculated for constituents that were significant at the 95 percent confidence level (tables 7 and 8). Efficiencies were calculated for runoff events after November 2005. Runoff events before this date were affected by a lower height of the weir plates for the internal and external bypasses. Efficiency ratios for TSS and TP decreased significantly when the concentrations for one runoff event were removed from the calculations. The inlet TSS concentration (191 mg/L) for runoff event 12 (app. 2-5) was not only 2 to 3 times higher than the closest concentrations, but it was higher than the inlet concentration of SS (14 mg/L). The SS concentrations typically were similar or higher than the TSS concentrations. The TP inlet concentrations (2.0 mg/L) for runoff event 8 (app. 2–6) was at least 20 times that of any other event. Both of these concentrations were unexplainably high, so an alternate efficiency ratio was determined without the concentrations from the two events (table 7). The efficiency ratios for TSS, SSC, TZN, TCU, and Total PAHs for the Madison SFD site were much lower than those for the Milwaukee SFD site (U.S. Environmental Protection Agency, 2004). As with the Milwaukee site, the efficiency ratio for Cl was negative.

Table 7. Efficiency ratios for selected constituents in samples from the stormwater filtration device, Madison, WI, 2005-07.

[Significantly different at the 95 percent level; --, significance could not be determined; %, percent efficiency ratio; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), efficiency ratio without total suspended solids for runoff event 12 and total phosphorus for runoff event 8, concentrations for these events appeared to be in error]

Constituents	Are inlet & outlet pairs significantly different?	[1]Efficiency ratio, %
Total dissolved solids (mg/L)[1]	No	--
Total suspended solids (mg/L) [1]	Yes	44 (33)
Suspended sediment concentrations (mg/L)	Yes	43
Volatile solids (mg/L)	Yes	38
Dissolved phosphorus (mg/L)	No	--
Total phosphorus (mg/L)	Yes	55 (5)
Dissolved chemical oxygen demand (mg/L)	No	--
Total chemical oxygen demand (mg/L)	No	--
Dissolved copper (µg/L)	No	--
Total copper (µg/L)	Yes	22
Dissolved zinc (µg/L)	No	--
Total zinc (µg/L)	Yes	5
Dissolved chloride (mg/L)	Yes	-18
Total PAHs	Yes	45

[1.] Efficiency ratio was calculated when both constituents were sampled for a runoff event.

Table 8. Efficiency ratios for selected polycyclic aromatic hydrocarbons in samples from a stormwater filtration device, Madison, WI, 2005-07.

[Significantly different at the 95 percent level; --, significance could not be determined; all constituents in micrograms per liter; %, percent efficiency ratio]

Constituent	Inlet and outlet pairs significantly different?	[1]Efficiency tatio, %
2-Methylnaphthalene	No	--
1-Methylnaphthalene	No	--
Acenaphthylene	No	--
Acenaphthene	No	--
Anthracene	Yes	44
Benzo[b]fluoranthene	Yes	41
Benzo[k]fluoranthene	Yes	44
Benzo[a]pyrene	Yes	48
Chrysene	Yes	45
Fluoranthene	Yes	49
9H-Fluorene	No	--
Indeno[1,2,3-cd]pyrene	Yes	40
Phenanthrene	Yes	49
Pyrene	Yes	49
Benzo[ghi]perylene	Yes	42
Benzo[a]anthracene	Yes	50
Dibenzo[a,h]anthracene	No	--
Naphthalene	No	--

1. Efficiency ratio was calculated when both constituents were sampled for a runoff event.

Summation of Loads

The summation of loads (SOL) method of calculating efficiencies is weighted by the volume of the runoff events. This method puts the emphasis on the load of contaminates leaving a filtration device rather than the concentration. The outlet volumes were used to calculate both the inlet and outlet loads because of the previously described problem with the shifting of the inlet pipe. The SOL is used to evaluate the treatment efficiency on a percentage basis by comparing the sum of the influent and effluent loads (the product of multiplying the constituent concentration by the precipitation volume) for all monitored events.

The equation calculating the summation of loads is

$$\textit{Summation of loads} = 1 - (\textit{sum of outlet loads}/\textit{sum of inlet loads})$$

SOLs were calculated for constituents that were significance at the 95-percent level (table 8, app. 2–9, 2–10, 2–11). As with the efficiency ratios, the SOL for TSS and TP decreased when the TSS loads for event 12 and the TP loads for event 8 were removed from the calculations. For event 12 the TSS concentration runoff at the inlet was about 11 times geometric mean; the small volume (770 cubic feet) of the event resulted in a relatively small change in the SOL (app. 2–4). Despite the relatively small volume for runoff event 8 (685 cubic feet), removing the inlet TP concentration that was about 33 times the geometric mean significantly decreased the SOL (table 9).

Table 9. Summary of loads of selected constituents and percent efficiency for the stormwater filtration device, Madison, WI, 2005-07.

[lb, pounds; %, percent; SOL, summation of loads; PAHs, polycyclic aromatic hydrocarbon; ( ), SOL without total suspended solids for event 12 and total phosphorus for event 8 for, concentrations for these events appeared to be in error; --, significance could not be determined]

Constituents	Loads at inlet (lb)	Loads at outlet (lb)	[1]SOL, %
Total dissolved solids	--	--	--
Total suspended solids	103[1] (98)	70[1]	32 (31)
Suspended sediment	109[1]	67[1]	39
Volatile solids	21.1	15.1	28
Dissolved phosphorus	--	--	--
Total phosphorus	0.27 (0.18)	0.17	36 (6)
Chemical oxygen demand	--	--	--
Dissolved chemical oxygen demand	--	--	--
Dissolved copper	--	--	--
Total copper	0.016	0.012	23
Dissolved zinc	--	--	--
Total zinc	0.081	0.075	8
Dissolved chloride	13	16	-21
Total PAHs	0.0879	0.0457	48

1. Sum of load was calculated for only those events when both constituents were sampled.

Efficiency ratios and SOL were similar for total PAHs, TZn, TCu, and Cl. If the events with the unexplainably high TSS and TP concentrations were removed from the calculations, efficiency ratios and SOLs are similar for both TSS and TP. Only SS and volatile suspended solids have as much as a 10-percent difference between the efficiency ratio and SOLs. Compared to the SFD site in Milwaukee, the SOLs for TSS, SS, TZn, TCu, and total PAHs were much lower at the Madison site (U.S. Environmental Protection Agency, 2004). As for the Milwaukee site, the SOL for Cl was negative.

Summary

This study was conducted in cooperation with the Wisconsin Department of Transportation (WisDOT) and the Wisconsin Department of Natural Resource to evaluate the performance of a proprietary stormwater filtration device (SFD). An SFD was installed by The Madison Gas and Electric Company (MG&E) in one of the employee parking lots in June 2003. An employee parking lot was chosen for the test site because the constituent concentrations and particle-size distributions are expected to be similar to those at any park and ride operated by the WisDOT. The asphalt parking lot has 181 parking stalls covering 0.91 acres.

The concrete structure (16-ft long by 8-ft wide and 5.5-ft deep) installed under the parking lot contains 26 filter cartridges. Each cartridge was filled with a ZPG media composed of zeolite, perlite, and granular activated carbon. Together the cartridges could treat a peak flow of 0.87 ft^3/s. When inlet flows exceeded the peak flow, the water bypassed the cartridges by way of a internal weir.

Fifty-one runoff events were monitored for flow and water quality from November 5, 2005, to August 18, 2007. The precipitation depths for these sampled events ranged from 0.19 to 4.93 in. The event average runoff coefficient was 63 percent. Thirty-three constituents were analyzed in samples from the inlet and outlet of the device. Eighteen of the constituents were polycyclic aromatic hydrocarbons (PAH). Samples from 31 runoff events were analyzed for all the constituents except PAHs, were analyzed in samples from for 15 events.

Treatment efficiency of the device was calculated using summation of loads (SOL) and the efficiency ratio methods. Constituents for which concentrations and loads were significantly decreased by the SFD include total suspended solids (TSS), suspended sediment (SS), volatile suspended solids (VSS), total phosphorus (TP), total copper (TCu), total zinc (TZn), and total PAHs. The efficiency ratios for these constituents were 44, 43, 38, 55, 22, 5, and 45 percent, respectively. The SOLs for these constituents were 32, 39, 28, 36, 23, 8, and 48 percent, respectively. Both methods resulted in a negative efficiency ratio and SOL for chloride (Cl) (about 20-percent). For the six constituents, dissolve phosphorus (DP), total chemical oxygen demand, dissolved chemical oxygen demand, dissolve zinc, total dissolved solids, and dissolved copper, efficiency ratios and SOLs were not calculated because the differences between the inlet and outlet concentrations were not determined to be significant.

Efficiency ratios and SOLs were similar to each other for total PAHs, TZn, TCu, and Cl. When two unexplainably high inlet concentrations were removed from the calculations, the TSS and TP for SOLs and efficiency ratios were also similar. The SOLs and efficiency ratios for TP become 6 and 5 percent, respectively, and the ratios for TSS become 26 and 33 percent, respectively. Only SS and VSS have as much as a 10-percent difference between the efficiency ratio and SOL.

Results from this study can be used to estimate the ability of cartridge filters to reduce the loads of TSS and other contaminants from WiDOT park and rides. Because of the two unexplainably high inlet concentrations for TSS and TP, the efficiency ratios and SOLs without these high concentrations might better represent the expected reductions for these two contaminants. A higher or lower level of performance would be expected for the cartridge filter at a facility with a different particle size distribution. For example, the cartridge filter tested by

WiDOT in Milwaukee achieved a higher TSS reduction of about 50 percent compared to about 30 percent for this study. For the Milwaukee SFD the average percent sand was about 80 percent, while this study the average percent sand in the runoff for was about 40 percent.

Models are tools for predicting the level of control to be expected for different types of stormwater-control devices including an SFD. By collecting representative field data at a few locations, a model can be calibrated and verified to perform with moderate reliability for similar sites. Results from this study provide an opportunity to calibrate and verify urban watershed models capable of predicting contaminate loads from various source areas, such as parking lots, and predicting reduction using different kinds of stormwater control devices, such as a SFD. Constituent concentrations in samples from flows to the inlet of the SFD provided the data needed to verify the concentrations and runoff predicted by a model. The particle-size distributions, flows, and the reductions in constituent concentrations are needed to evaluate any reduction relationship developed for a SFD. Unfortunately, none of the available urban runoff models including WinSLAMM include a pollutant reduction relationship for SFD. Results from this project could be instrumental in developing algorithms to predicting the efficiency of a SFD based on inlet concentration, particle size, filter media type, and flow rates.

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Appendix 1 Previous Investigations

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Appendix 2 Results of analyses of samples

Table 2–1. Concentrations of selected constituents in field-blank data collected from a storm water filtration device, Madison, WI, 2005-07.

[mg/L, milligrams per liter; µg/L, micrograms per liter; LOD, limit of detection; LOQ, limit of quantification;--, no sample processed for event]

Constituent	Unit	Blank1 7/7/2005			Blank 2 7/13/2006			Blank 3 6/11/2007				
		Inlet	Outlet	Bypass	Inlet	Outlet	Bypass	Inlet	Outlet	Bypass	LOD	LOQ
Suspended solids, total (mg/L)	mg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	2	7
Suspended-sediment concentration	mg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	2	7
Volatile solids, total	mg/L	--	--	--	--	--	--	<2	<2	<2		
Dissolved solids, total	mg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	50	167
Phosphorus, dissolved	mg/L	<.005	<.005	<.005	.012	.011	.011	<.005	<.005	<.005	.005	.016
Phosphorus, total	mg/L	<.005	<.005	<.005	.011	.011	.01	<.005	<.005	<.005	.005	.016
Chemical oxygen demand, total	mg/L	10	<9	<9	<9	<9	<9	<9	<9	<9	9	28
Chemical oxygen demand, dissolved	mg/L	--	--	--	<9	<9	<9	<9	<9	<9	<9	28
Chloride, dissolved	mg/L	<.6	<.6	<.6	<.6	<.6	<.6	<1	<1	<1	2.0	3.3
Copper, dissolved	µg/L	1.3	<1	1.0	<2	<1	<1	<2	<2	<2	1	3
Copper, total recoverable	µg/L	1	1	2	<1	<1	--	<2	<2	<2	1	3
Zinc, dissolved	µg/L	<16	<16	<16	<1	6	<1	<1	<1	<1	16	50
Zinc, total recoverable	µg/L	<16	<16	<16	<3	<3	<3	<3	<3	<3	16	50
Calcium, total recoverable	mg/L	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1	<.1	.200	.070
Magnesium, total recoverable	mg/L	<.2	<.2	<.2	<.1	<.1	<.1	<.1	<.1	<.1	.200	.070

Table 2–2. Relative percent difference for concentrations of selected constituents in field replicate samples collected from a storm water filtration device and sample, Madison, WI, 2005-07.

[Target, minimum criteria for acceptance of quality control sample data without qualification; Rep, replicate; RPD, relative percent difference; %, percent; mg/L, milligrams per liter; µg/L, micrograms per liter; na, not available; --, no sample processed for event; <, less than]

Constituent	Target (%)	Site	Event 1 11/05/2005			Event 9 4/16/2006			Event 23 8/23/06			Event 44 7/26/2007		
			Rep 1a	Rep 1b	RPD (%)	Rep 2a	Rep 2b	RPD (%)	Rep 3a	Rep 3b	RPD (%)	Rep 4a	Rep 4b	RPD (%)
Suspended solid, total (mg/L)	30	Inlet	13	14	-7	34	35	-3	22	23	-4	15	16	-6
		Outlet	8	8	0	20	20	0	11	17	-43	13	12	8
Suspended sediment concentration (mg/L)	na	Inlet	13	13	0	53	45	16	33	32	3	12	14	-15
		Outlet	7	7	0	20	20	0	9	9	0	10	9	11
Volatile suspended solid, (mg/L)	na	Inlet	--	--	--	9	10	-11	7	7	0	7	7	0
		Outlet	--	--	--	6	6	0	5	5	0	5	5	0
Suspended solid, dissolved (mg/L)	30	Inlet	<50	<50	--	<50	<50	--	<50	<50	--	<50	<50	--
		Outlet	<50	<50	--	<50	<50	--	<50	<50	--	52	<50	--
Phosphorus, dissolved (mg/L)	30	Inlet	0.06	.06	2	.02	.02	0	.03	.03	-7	.053	.055	-4
		Outlet	.07	.06	9	.01	.01	0	.03	.03	3	.038	.039	-3
Phosphorus, total (mg/L)	30	Inlet	.09	.09	0	.06	.06	-2	.05	.05	-2	.072	.072	0
		Outlet	.08	.08	0	.04	.04	-10	.04	.04	5	.077	.078	-1
Chemical oxygen demand, total (mg/L)	na	Inlet	19	<9	--	20	26	-26	15	28	-60	44	46	-4
		Outlet	17	15	13	21	13	47	22	33	-40	58	60	-3
Chemical oxygen demand, dissolved (mg/L)	na	Inlet	16	15	6	22	<9	--	41	43	-5	41	43	-5
		Outlet	--	--	--	15	23	-42	<9	20	126	46	36	24
Chloride, dissolved (mg/L)	25	Inlet	1.7	1.7	0	1.9	1.8	5	0.8	0.8	0	1.2	1.2	0
		Outlet	2	2	0	2.1	1.9	10	--	--	--	2.1	2	5
Copper, dissolved (ug/L)	25	Inlet	1.9	1.8	5	<1	<1	--	<2	<2	--	4	3	14
		Outlet	1.8	1.9	-5	1	1	0	<2	<2	--	3	3	0
Copper, total recoverable (ug/L)	25	Inlet	3	3	0	4	4	0	3	4	-29	6	6	0
		Outlet	3	3	0	3	3	0	2	3	-40	4	5	-22
Zinc, dissolved (ug/L)	25	Inlet	<16	<16	--	6	6	0	7	8	-13	22	21	5
		Outlet	<16	<16	--	11	11	0	10	10	0	20	21	-5
Zinc, total recoverable (ug/L)	25	Inlet	<16	<16	--	24	43	-57	24	27	-12	33	34	-3
		Outlet	<16	<16	--	21	20	5	18	19	-5	30	32	-6
Calcium, total recoverable (mg/L)	25	Inlet	4.2	4.2	0	4.5	8.6	-63	3.8	3.9	-3	4.3	4.3	0
		Outlet	4.3	4.2	2	3.6	3.5	3	3.3	3.4	-3	6.1	6.4	-5
Magnesium, total recoverable(mg/L)	25	Inlet	1.2	1.3	-8	1.7	2.2	-26	1.2	1.2	0	1.2	1.2	0
		Outlet	0.9	0.9	0	1.1	1.1	0	0.8	0.8	0	1.6	1.7	-6

Table 2–3. Precipitation during sampling events from the storm water filtration device, Madison, WI, 2005-07.

[in., inches; in/h, inches per hour; ft-lb/acre, foot-pounds per acre; ft3, cubic feet; dd, day; hh:mm, hour; min, minute]

Sampling event	Start date and time	End date and time	Precipitation duration (hh:mm)	Total precipitation (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Precipitation volume (ft^3)	Antecedent dry times (dd hr:mm)
1	11/05/2005 17:27	11/05/2005 23:52	06:25	1.01	0.324	0.27	2.4	3,370	06 01:55
	11/06/2005 01:33	11/06/2005 05:28	03:55	.23	.14	.11	.21	720	00 01:41
	11/12/2005 16:14	11/12/2005 17:08	00:54	.09	.25	.14	.11	280	06 10:46
	11/12/2005 21:47	11/12/2005 22:05	00:18	.07	.22	--	--	220	00 04:39
	11/14/2005 18:38	11/14/2005 21:16	02:38	.08	.07	.07	.05	250	01 20:33
2	11/15/2005 13:09	11/15/2005 20:23	07:14	.77	.32	.31	2.0	2,390	00 15:53
	11/15/2005 21:25	11/16/2005 01:16	03:51	.05	.04	.02	.01	170	00 01:02
	11/23/2005 08:58	11/23/2005 09:28	00:30	.06	.14	.13	.07	190	07 07:42
	11/27/2005 06:58	11/27/2005 11:20	04:22	.16	.11	.07	.10	500	03 21:30
3	11/28/2005 03:09	11/28/2005 07:30	04:21	.63	.54	.43	2.3	1,940	00 15:49
	12/23/2005 08:45	12/23/2005 12:13	03:28	.17	.11	.11	.15	530	25 01:15
	01/01/2006 20:21	01/01/2006 22:47	02:26	.10	.07	.05	.04	310	09 08:08
	01/02/2006 06:58	01/02/2006 14:23	07:25	.73	.29	.25	1.5	2,250	00 08:11
	01/24/2006 09:06	01/24/2006 10:09	01:03	.10	.18	.14	.12	310	21 18:43
	01/28/2006 05:16	01/28/2006 06:04	00:48	.08	.18	.13	.08	250	03 19:07
	01/28/2006 09:02	01/28/2006 09:30	00:28	.05	.14	--	--	170	00 02:58
	01/28/2006 12:34	01/28/2006 17:22	04:48	.23	.11	.09	.17	720	00 03:04
	01/28/2006 19:48	01/29/2006 08:42	12:54	.80	.18	.14	.95	2,470	00 02:26
	02/03/2006 05:29	02/03/2006 06:13	00:44	.05	.11	.09	.04	170	04 20:47
	03/06/2006 14:01	03/06/2006 16:05	02:04	.22	.25	.20	.37	690	31 07:48
4	03/08/2006 17:52	03/08/2006 22:35	04:43	.85	.44	.38	2.7	2,620	02 01:47
	03/12/2006 21:52	03/13/2006 00:10	02:18	.34	.28	.24	.69	1,050	03 23:17
	03/13/2006 02:35	03/13/2006 03:34	00:59	.11	.16	.12	.11	340	00 02:25
	03/17/2006 12:07	03/17/2006 13:13	01:06	.10	.24	.18	.15	310	04 08:33
	03/23/2006 16:00	03/23/2006 17:24	01:24	.10	.16	.12	.10	310	06 02:47
	03/30/2006 22:42	03/31/2006 02:10	03:28	.18	.16	.12	.18	560	07 05:18
	03/31/2006 12:52	03/31/2006 13:32	00:40	.07	.12	.12	.07	220	00 10:42
5	04/02/2006 11:02	04/02/2006 13:10	02:08	.25	.28	.20	.42	770	01 21:30
6	04/02/2006 20:32	04/02/2006 22:06	01:34	.37	.40	.36	1.1	1,140	00 07:22
6	04/02/2006 23:31	04/03/2006 05:25	05:54	.72	.24	.20	1.2	2,220	00 01:25
7	04/06/2006 22:00	04/07/2006 07:54	09:54	1.61	.88	.72	10	4,970	03 16:35
8	04/12/2006 05:06	04/12/2006 07:45	02:39	.44	.48	.36	1.3	1,360	04 21:12

Sampling event	Start date and time	End date and time	Precipitation duration (hh:mm)	Total precipitation (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Precipitation volume (ft^3)	Antecedent dry times (dd hr:mm)
	04/13/2006 21:37	04/13/2006 21:40	00:03	.10	--	--	--	310	01 13:52
9	04/16/2006 03:37	04/16/2006 04:29	00:52	.11	.24	.18	.17	340	02 05:57
9	04/16/2006 09:18	04/16/2006 10:22	01:04	.09	.24	.14	.11	280	00 04:49
9	04/16/2006 13:23	04/16/2006 16:40	03:17	.75	.96	.74	4.9	2,310	00 03:01
	04/19/2006 04:28	04/19/2006 05:47	01:19	.16	.56	.28	.42	490	02 11:48
	04/22/2006 01:26	04/22/2006 01:41	00:15	.09	.36	--	--	280	02 19:39
10	04/29/2006 18:39	04/29/2006 22:22	03:43	.33	.28	.20	.76	1,020	07 16:58
	04/29/2006 23:27	04/30/2006 09:30	10:03	1.19	.44	.36	3.6	3,670	00 01:05
11	05/01/2006 20:34	05/01/2006 21:36	01:02	.41	1.36	.78	3.0	1,270	01 11:04
	05/09/2006 10:37	05/09/2006 12:24	01:47	.05	.07	.05	.02	170	07 13:01
12	05/09/2006 13:46	05/09/2006 17:22	03:36	.41	.29	.25	.84	1,250	00 01:22
	05/11/2006 06:12	05/11/2006 09:18	03:06	.07	.11	.07	.04	220	01 12:50
13	05/11/2006 12:01	05/11/2006 23:12	11:11	.62	.11	.11	.56	1,920	00 02:43
	05/12/2006 00:44	05/12/2006 03:44	03:00	.07	.07	.05	.03	220	00 01:32
	05/13/2006 10:40	05/13/2006 11:32	00:52	.05	.11	.07	.03	170	01 06:56
	05/13/2006 15:38	05/13/2006 16:45	01:07	.10	.14	.11	.09	310	00 04:06
	05/15/2006 15:38	05/15/2006 15:45	00:07	.06	--	--	--	190	01 22:53
14	05/16/2006 14:49	05/16/2006 15:42	00:53	.10	.32	.18	.15	310	00 23:04
14	05/16/2006 17:50	05/16/2006 17:59	00:09	.09	--	--	--	280	00 02:08
15	05/17/2006 15:25	05/17/2006 16:13	00:48	.36	.83	.50	1.7	1,110	00 21:26
	05/24/2006 18:37	05/24/2006 19:03	00:26	1.83	6.13	--	--	5,660	07 02:24
	05/24/2006 21:11	05/24/2006 21:37	00:26	.10	.36	--	--	310	00 02:08
	05/30/2006 13:26	05/30/2006 13:33	00:07	.05	--	--	--	170	05 15:49
	06/06/2006 05:37	06/06/2006 08:16	02:39	.14	.14	.11	.13	440	06 16:04
	06/08/2006 10:50	06/08/2006 11:56	01:06	1.28	1.22	1.19	14	3,940	02 02:34
16	06/09/2006 23:59	06/10/2006 06:46	06:47	.69	.32	.31	1.8	2,140	01 12:03
	06/14/2006 11:27	06/14/2006 13:03	01:36	.13	.25	.13	.13	390	04 04:41
	06/18/2006 07:19	06/18/2006 09:39	02:20	.08	.11	.07	.05	250	03 18:16
	06/18/2006 12:16	06/18/2006 13:11	00:55	.09	.25	.14	.11	280	00 02:37
	06/21/2006 05:52	06/21/2006 06:49	00:57	.09	.32	.16	.12	280	02 16:41
	06/24/2006 08:51	06/24/2006 11:02	02:11	.06	.07	.05	.03	180	03 02:02
17	06/25/2006 17:40	06/26/2006 06:16	12:36	.45	.12	.10	.38	1,390	01 06:38
18	07/11/2006 07:17	07/11/2006 16:08	08:51	1.87	.86	.76	12	5,770	15 01:01
19	07/20/2006 02:33	07/20/2006 06:59	04:26	.88	1.44	.90	7.4	2,720	08 10:25
	07/22/2006 16:31	07/22/2006 17:51	01:20	.16	.48	.28	.39	490	02 09:32

Sampling event	Start date and time	End date and time	Precipitation duration (hh:mm)	Total precipitation (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Precipitation volume (ft^3)	Antecedent dry times (dd hr:mm)
	07/25/2006 23:47	07/26/2006 01:08	01:21	.05	.11	.05	.02	170	03 05:56
	07/27/2006 11:44	07/27/2006 13:42	01:58	4.05	7.01	5.23	106	12,500	01 10:36
20	08/06/2006 05:43	08/06/2006 11:08	05:25	.87	.47	.32	2.3	2,690	09 16:01
21	08/09/2006 18:42	08/09/2006 19:04	00:22	.21	.79	--	--	640	03 07:34
22	08/17/2006 15:02	08/17/2006 17:23	02:21	.22	.61	.36	.67	670	07 19:58
23	08/23/2006 22:26	08/23/2006 23:55	01:29	.34	.72	.58	1.7	1,060	06 05:03
23	08/24/2006 01:22	08/24/2006 06:53	05:31	1.17	1.82	1.14	13	3,610	00 01:27
24	08/24/2006 13:00	08/24/2006 15:00	02:00	1.22	2.28	1.28	16	3,760	00 06:07
	08/25/2006 05:11	08/25/2006 06:51	01:40	.26	.32	.28	.61	800	00 14:11
	08/25/2006 08:23	08/25/2006 08:47	00:24	.07	.20	--	--	220	00 01:32
25	08/25/2006 10:53	08/25/2006 11:09	00:16	.86	3.40	--	--	2,650	00 02:06
25	08/25/2006 13:27	08/25/2006 13:40	00:13	.28	--	--	--	860	00 02:18
	08/26/2006 01:22	08/26/2006 01:30	00:08	.10	--	--	--	310	00 11:42
	08/28/2006 13:59	08/28/2006 16:30	02:31	.07	.08	.06	.04	220	02 12:29
26	09/03/2006 18:29	09/03/2006 21:21	02:52	.36	.28	.20	.61	1,110	06 01:59
26	09/04/2006 05:31	09/04/2006 08:20	02:49	.23	.40	.22	.43	710	00 08:10
	09/10/2006 14:41	09/10/2006 23:30	08:49	.38	.16	.12	.38	1,170	06 06:21
	09/11/2006 11:30	09/11/2006 11:57	00:27	.07	.20	--	--	220	00 12:00
	09/11/2006 15:20	09/11/2006 20:07	04:47	.38	.60	.36	1.2	1,170	00 03:23
	09/12/2006 02:10	09/12/2006 06:02	03:52	.53	.40	.28	1.3	1,640	00 06:03
	09/12/2006 09:37	09/12/2006 11:38	02:01	.17	.24	.20	.29	520	00 03:35
	09/12/2006 13:30	09/12/2006 17:22	03:52	.69	1.04	.86	5.3	2,130	00 01:52
	09/21/2006 21:39	09/21/2006 22:50	01:11	.06	.08	.06	.03	190	09 04:17
	09/22/2006 05:16	09/22/2006 06:48	01:32	.11	.16	.12	.11	340	00 06:26
	09/23/2006 14:17	09/23/2006 16:45	02:28	.17	.20	.16	.23	520	01 07:29
27	10/04/2006 05:36	10/04/2006 07:26	01:50	.24	.52	.34	.76	740	10 12:51
27	10/04/2006 08:43	10/04/2006 10:03	01:20	.09	.20	.10	.08	280	00 01:17
	10/10/2006 19:31	10/11/2006 00:24	04:53	.21	.12	.10	.18	650	06 09:28
28	10/16/2006 22:58	10/17/2006 07:13	08:15	.75	.28	.22	1.4	2,310	05 22:34
	10/18/2006 14:36	10/18/2006 16:02	01:26	.07	.08	.08	.05	220	01 07:23
	10/18/2006 17:11	10/18/2006 18:20	01:09	.07	.16	.12	.07	220	00 01:09
29	10/21/2006 12:30	10/21/2006 14:25	01:55	.08	.12	.06	.04	250	02 18:10
29	10/21/2006 15:32	10/22/2006 01:49	10:17	.50	.12	.12	.51	1,540	00 01:07
	10/26/2006 17:11	10/26/2006 18:59	01:48	.06	.08	.04	.02	190	04 15:22
30	11/10/2006 12:01	11/10/2006 14:27	02:26	.55	.36	.32	1.5	1,700	14 17:02

Sampling event	Start date and time	End date and time	Precipitation duration (hh:mm)	Total precipitation (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Precipitation volume (ft^3)	Antecedent dry times (dd hr:mm)
	11/12/2006 11:31	11/12/2006 18:46	07:15	.44	.16	.14	.52	1,360	01 21:04
	11/26/2006 20:12	11/26/2006 20:55	00:43	.08	.20	.12	.08	250	14 01:26
31	11/26/2006 22:21	11/27/2006 01:36	03:15	.21	.20	.14	.25	650	00 01:26
32	11/27/2006 19:43	11/28/2006 04:00	08:17	.76	.32	.24	1.5	2,340	00 18:07
	11/29/2006 02:52	11/29/2006 04:39	01:47	.10	.16	.12	.10	310	00 22:52
	11/29/2006 18:04	11/29/2006 20:03	01:59	.06	.08	.04	.02	190	00 13:25
	12/20/2006 19:45	12/21/2006 03:39	07:54	.23	.08	.08	.16	710	20 23:42
33	12/21/2006 06:26	12/21/2006 13:52	07:26	.47	.24	.20	.79	1,450	00 02:47
34	12/22/2006 12:54	12/22/2006 15:39	02:45	.23	.36	.28	.54	710	00 23:02
	12/31/2006 07:12	12/31/2006 10:24	03:12	.23	.28	.24	.47	710	08 15:33
	01/26/2007 13:45	01/26/2007 14:44	00:59	.14	.28	.20	.24	430	26 03:21
	02/25/2007 06:09	02/25/2007 15:46	09:37	.46	.16	.12	.47	1,420	29 15:25
	02/26/2007 14:04	02/26/2007 16:04	02:00	.10	.08	.08	.07	310	00 22:18
	03/01/2007 10:11	03/01/2007 14:34	04:23	.31	.40	.30	.78	960	02 18:07
	03/09/2007 15:02	03/09/2007 18:38	03:36	.20	.12	.10	.17	620	08 00:28
	03/14/2007 16:38	03/14/2007 18:37	01:59	.06	.08	.04	.02	190	04 22:00
	03/21/2007 03:16	03/21/2007 05:45	02:29	.11	.20	.14	.13	340	06 08:39
	03/21/2007 08:32	03/21/2007 10:33	02:01	.07	.12	.08	.05	220	00 02:47
	03/21/2007 17:39	03/21/2007 18:37	00:58	.12	.24	.14	.16	370	00 07:06
	03/22/2007 01:24	03/22/2007 03:14	01:50	.54	1.16	.82	4.1	1,670	00 06:47
	03/28/2007 12:36	03/28/2007 14:40	02:04	.09	.16	.10	.08	280	06 09:22
35	03/31/2007 08:31	03/31/2007 09:14	00:43	.09	.28	.16	.12	280	02 17:51
35	03/31/2007 12:10	03/31/2007 14:10	02:00	.35	.64	.34	1.1	1,080	00 02:56
35	03/31/2007 20:37	03/31/2007 22:48	02:11	.60	.68	.54	2.9	1,850	00 06:27
36	04/03/2007 00:03	04/03/2007 07:31	07:28	1.58	1.04	.60	8.2	4,880	02 01:15
	04/11/2007 00:03	04/11/2007 06:50	06:47	.20	.08	.08	.14	620	07 16:32
	04/12/2007 11:20	04/12/2007 14:38	03:18	.18	.12	.08	.13	560	01 04:30
	04/22/2007 20:07	04/22/2007 20:30	00:23	.08	.28	--	--	250	10 05:29
37	04/23/2007 00:25	04/23/2007 05:48	05:23	.49	.40	.32	1.4	1,510	00 03:55
38	04/24/2007 13:23	04/24/2007 23:18	09:55	.35	.16	.12	.35	1,080	01 07:35
	04/25/2007 00:21	04/25/2007 04:43	04:22	.27	.12	.10	.23	830	00 01:03
	04/25/2007 20:20	04/25/2007 21:13	00:53	.06	.08	.06	.03	190	00 15:37
	04/25/2007 23:19	04/26/2007 00:59	01:40	.06	.08	.06	.03	190	00 02:06
39	04/26/2007 08:57	04/26/2007 12:43	03:46	.32	.16	.14	.38	990	00 07:58
	04/30/2007 20:37	04/30/2007 20:56	00:19	.08	.28	--	--	250	04 07:54

Sampling event	Start date and time	End date and time	Precipitation duration (hh:mm)	Total precipitation (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Precipitation volume (ft^3)	Antecedent dry times (dd hr:mm)
	05/13/2007 05:41	05/13/2007 09:50	04:09	.32	.20	.14	.38	990	12 08:45
40	05/15/2007 12:23	05/15/2007 16:06	03:43	.59	.56	.48	2.4	1,820	02 02:33
	05/16/2007 16:56	05/16/2007 17:09	00:13	.08	--	--	--	250	01 00:50
41	05/24/2007 16:38	05/24/2007 18:24	01:46	.49	.84	.70	3.2	1,510	07 23:29
	05/26/2007 14:41	05/26/2007 15:09	00:28	.06	.20	--	--	190	01 20:17
	06/01/2007 16:44	06/01/2007 17:30	00:46	.20	.64	.38	.71	620	06 01:35
	06/02/2007 06:36	06/02/2007 08:13	01:37	.23	.40	.28	.55	710	00 13:06
	06/03/2007 16:56	06/03/2007 19:42	02:46	.70	1.12	.66	4.3	2,160	01 08:43
	06/03/2007 20:55	06/03/2007 22:50	01:55	.36	.56	.36	1.1	1,110	00 01:13
	06/04/2007 06:00	06/04/2007 07:48	01:48	.27	.28	.20	.46	830	00 07:10
	06/04/2007 08:56	06/04/2007 09:56	01:00	.14	.48	.26	.32	430	00 01:08
	06/06/2007 15:02	06/06/2007 17:12	02:10	.06	.08	.04	.02	190	02 05:06
	06/11/2007 09:10	06/11/2007 09:49	00:39	1.21	2.08	2.02	25	3,730	04 15:58
	06/18/2007 15:46	06/18/2007 16:14	00:28	.09	.24	--	--	280	07 05:57
	06/18/2007 18:44	06/18/2007 19:02	00:18	.11	.40	--	--	340	00 02:30
	06/21/2007 16:31	06/21/2007 17:16	00:45	.06	.20	.10	.06	190	02 21:29
42	06/21/2007 18:23	06/21/2007 22:53	04:30	.43	.56	.30	1.1	1,330	00 01:07
43	07/03/2007 20:12	07/03/2007 23:31	03:19	.47	.32	.28	1.1	1,450	11 21:19
44	07/26/2007 10:20	07/26/2007 10:28	00:08	.12	--	--	--	370	22 10:49
44	07/26/2007 22:57	07/27/2007 01:20	02:23	.53	.68	.56	2.6	1,640	00 12:29
	07/27/2007 07:07	07/27/2007 07:20	00:13	.06	--	--	--	190	00 05:47
45	08/04/2007 17:01	08/04/2007 19:52	02:51	.47	.52	.44	1.8	1,450	08 09:41
45	08/04/2007 21:05	08/05/2007 05:10	08:05	1.31	.88	.68	7.6	4,040	00 01:13
46	08/06/2007 21:58	08/07/2007 05:55	07:57	.60	.20	.12	.17	1,850	01 16:48
47	08/09/2007 04:09	08/09/2007 05:54	01:45	.86	1.28	.96	7.5	2,650	01 22:14
48	08/12/2007 00:58	08/12/2007 02:25	01:27	.68	2.04	1.20	8.0	2,100	02 19:04
49	08/14/2007 02:31	08/14/2007 05:09	02:38	.56	.44	.40	1.7	1,710	02 00:06
50	08/15/2007 07:42	08/15/2007 12:58	05:16	.35	.24	.20	.26	1,080	01 02:33
51	08/18/2007 11:34	08/19/2007 12:16	00:42	4.93	1.96	1.64	68	15,210	02 22:36
	08/22/2007 01:29	08/22/2007 03:47	02:18	.28	.47	.27	.64	860	02 13:13
	08/22/2007 15:55	08/22/2007 16:32	00:37	.15	.33	.24	.32	480	00 12:08
	08/22/2007 18:31	08/22/2007 21:19	02:48	.40	.47	.36	1.2	1,220	00 01:59
	08/23/2007 04:29	08/23/2007 05:11	00:42	.07	.14	.13	.08	220	00 07:10
	08/23/2007 07:02	08/23/2007 08:38	01:36	.34	.40	.38	1.1	1,060	00 01:51
	08/23/2007 17:34	08/23/2007 17:43	00:09	.05	--	--	--	170	00 08:56

Sampling event	Start date and time	End date and time	Precipitation duration (hh:mm)	Total precipitation (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Precipitation volume (ft^3)	Antecedent dry times (dd hr:mm)
	08/24/2007 02:49	08/24/2007 04:22	01:33	.61	1.09	.94	5.3	1,870	00 09:06
	08/24/2007 16:15	08/24/2007 16:53	00:38	.73	1.87	1.37	9.8	2,250	00 11:53
	08/27/2007 08:57	08/27/2007 11:41	02:44	.50	.47	.32	1.4	1,560	02 16:04

Table 2–4 Outlet flow volumes, percent runoff, and peak discharge for sampled events at storm water filtration device, Madison, WI, 2005-07

[in, inches; ft^3, cubic feet; ft^3/s, cubic feet per second]

Sampled event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Total precipitation (in)	Volume (ft3)	Percent runoff	Peak discharge (ft3/s)
1	11/05/2005 17:40	11/06/2005 00:39	1.01	2,015	60	.42
2	11/15/2005 13:38	11/15/2005 20:51	0.77	1,640	64	.51
3	11/28/2005 03:18	11/28/2005 08:09	0.63	1,165	55	.70
4	03/08/2006 18:08	03/08/2006 22:58	0.85	2,240	79	.09
5	04/02/2006 11:19	04/02/2006 13:36	0.25	380	46	.49
6	04/02/2006 20:45	04/03/2006 06:15	1.09	2,555	70	.88
7	04/06/2006 10:22	04/07/2006 08:56	1.61	3,930	73	.49
8	04/12/2006 05:36	04/12/2006 07:48	0.44	685	46	.84
9	04/16/2006 04:17	04/16/2006 17:10	0.95	2,125	67	.10
10	04/29/2006 18:28	04/29/2006 23:41	0.33	630	57	.99
11	05/01/2006 21:09	05/01/2006 22:35	0.41	1,045	76	.42
12	05/09/2006 14:26	05/09/2006 17:29	0.41	770	57	.07
13	05/11/2006 13:32	05/12/2006 06:38	0.62	1,840	89	.11
14	05/16/2006 15:23	05/16/2006 18:52	0.19	335	53	.77
15	05/17/2006 15:30	05/17/2006 17:01	0.36	845	70	.51
16	06/10/2006 00:58	06/10/2006 07:23	0.69	985	43	.67
17	06/25/2006 17:57	06/26/2006 09:37	0.45	1,600	106	.85
18	07/11/2006 08:48	07/11/2006 15:39	1.87	6,040	97	.80
19	07/20/2006 02:48	07/20/2006 07:44	0.88	1,850	63	.60
20	08/06/2006 07:21	08/06/2006 11:29	0.87	1,020	35	.68
21	08/09/2006 18:49	08/09/2006 19:19	0.21	240	35	.71
22	08/17/2006 16:42	08/17/2006 17:23	0.22	275	38	.86
23	08/23/2006 22:50	08/24/2006 07:47	1.51	2,680	53	.85
24	08/24/2006 13:11	08/24/2006 15:24	1.22	1,995	49	1.05
25	08/25/2006 10:57	08/25/2006 13:54	1.14	1,765	46	.07
26	09/03/2006 18:38	09/04/2006 08:58	0.59	475	24	.73
27	10/04/2006 06:11	10/04/2006 10:56	0.33	620	56	.45
28	10/16/2006 23:28	10/17/2006 07:32	0.75	2,110	84	.06
29	10/21/2006 13:08	10/22/2006 01:48	0.58	1,020	53	.59
30	11/10/2006 12:28	11/10/2006 14:54	0.55	590	32	.08
31	11/26/2006 23:12	11/27/2006 02:05	0.21	300	43	.71
32	11/27/2006 20:18	11/28/2006 08:19	0.76	2,340	92	.49
33	12/21/2006 07:50	12/21/2006 13:43	0.47	1,165	74	.71
34	12/22/2006 14:00	12/22/2006 15:34	0.23	615	80	.79
35	03/31/2007 08:46	03/31/2007 23:20	1.04	2,585	74	.87
36	04/03/2007 00:13	04/03/2007 07:51	1.58	4,085	77	.67

Sampled event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Total precipitation (in)	Volume (ft3)	Percent runoff	Peak discharge (ft3/s)
37	04/23/2007 00:54	04/23/2007 07:10	0.49	1,035	63	.05
38	04/24/2007 17:27	04/24/2007 19:44	0.35	235	20	.08
39	04/26/2007 09:37	04/26/2007 13:05	0.32	665	62	.66
40	05/15/2007 12:39	05/15/2007 17:49	0.59	1,235	63	.73
41	05/24/2007 16:43	05/24/2007 18:47	0.49	830	51	.69
42	06/21/2007 19:01	06/21/2007 23:09	0.43	560	39	.39
43	07/03/2007 20:54	07/03/2007 23:33	0.47	590	37	.68
44	07/26/2007 10:28	07/27/2007 01:43	0.65	1,185	55	.84
45	08/04/2007 17:30	08/05/2007 07:44	1.78	4,070	68	.76
46	08/06/2007 22:35	08/07/2007 06:33	0.60	1,805	90	.92
47	08/09/2007 03:13	08/09/2007 07:14	0.86	2,755	96	.81
48	08/12/2007 01:04	08/12/2007 02:48	0.68	840	37	.88
49	08/14/2007 02:43	08/14/2007 07:03	0.56	1,980	107	.10
50	08/15/2007 08:15	08/15/2007 14:32	0.35	690	59	1.01
51	08/18/2007 14:21	08/19/2007 13:01	4.93	8,210	50	42

Table 2–5. Concentrations of suspended solids, suspended sediment and volatile solids, and dissolved solids in inlet and outlet samples from a storm water filtration device, Madison, WI, 2005-07.

[All concentrations in milligrams per liter; --, no sample processed for event]

Sampling event	Suspended solids, total		Suspended-sediment concentration		Solids, dissolved		Solids, volatile	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	14.0	8.0	22.0	7.0	--	--	<50	<50
2	10	7	18.2	6	--	--	<50	<50
3	42	27	53	26	--	--	94	96
4	37	45	41	47	--	--	58	80
5	34	13	34	14	--	--	66	82
6	13	13	15	12	--	--	<50	<50
7	68	45	75	45	15	11	<50	<50
8	26	26	35	25	8	7	<50	<50
9	35	20	45	20	10	6	<50	<50
10	14	12	14	12	6	5	<50	<50
11	42	25	46	25	13	8	<50	<50
12	191	3	14	3	19	2	<50	<50
13	5	2	6	2	4	1	<50	<50
14	80	12	82	12	--	--	<50	<50
15	102	34	77	30	55	14	--	--
16	13	8	21	7	5	3	<50	<50
17	14	8	22	7	5	3	<50	<50
18	8	6	14	5	3	2	<50	<50
19	24	19	31	15	8	6	<50	<50
20	8	4	7	3	3	<2	<50	<50
21	41	33	42	33	--	--	<50	50
22	17	16	17	14	--	--	<50	<50

Sampling event	Suspended solids, total		Suspended-sediment concentration		Solids, dissolved		Solids, volatile	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
23	23	17	32	9	7	5	<50	<50
24	20	7	19	6	6	--	<50	<50
25	15	16	12	11	8	5	<50	<50
26	<2	4	9	4	--	--	<100	<50
27	26	24	26	23	10	8	<50	<50
28	5	5	4	5	3	2	<50	<50
29	<2	<2	2	1.9	--	--	<50	<50
30	11	7	36	6	--	--	<50	<50
31	8	4	8	4	--	--	<50	<50
32	6	5	6	4	3	2	<50	<50
33	20	15	20	13	8	6	52	56
34	40	38	38	38	17	18	<50	<50
35	66	50	76	62	16	23	<50	<50
36	15	14	22	16	5	4	<50	<50
37	18	22	19	23	8	6	<50	<50
38	4	<2	4	3	<2	<2	<50	<50
39	3	2	4	3	--	--	<50	<50
40	18	12	18	10	7	4	<50	<50
41	40	23	44	26	14	8	<50	<50
42	--	--	--	--	--	--	--	--
43	10	5	10	5	4	2	<50	<50
44	15	13	12	10	7	5	<50	52
45	6	7	7	5	--	--	<50	<50
46	--	--	9	5	--	--	--	--
47	--	--	5	5	--	--	--	--
48	--	--	13	9	--	--	--	--
49	--	--	7	7	--	--	--	--
50	--	--	5	3	--	--	--	--
51	--	--	5	7	--	--	--	--

Table 2–6. Concentrations of selected constituents and physical property in storm water samples collected from a storm water filtration device, Madison, WI, 2005-07.

[mg/L, milligrams per liter; µg/L, micrograms per liter;--, no sample processed for event; <, less than]

Sampled event number	Chemical oxygen demand, total (mg/L)		Phosphorus, total (mg/L)		Phosphorus, dissolved (mg/L)		Chloride, dissolved (mg/L)		Copper, dissolved (ug/L)		Copper, total recoverable (ug/L)		Zinc, dissolved (ug/L)		Zinc, total recoverable (ug/L)		Calcium, total recoverable (mg/L)		Magnesium, total recoverable (mg/L)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	<9	15	0.09	0.08	0.061	0.06	1.7	2	1.8	1.9	3.0	3.0	<16	<16	<16	<16	4.2	4.2	1.3	0.9
2	22	16	.08	.07	.05	.04	2.1	2.6	<1.0	<1.0	2	3			18	18	3.2	3.4	.90	.80
3	--	--	--	--	--	--	39	41	--	--	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	17	29	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	18	24	--	--	--	--	--	--	--	--	--	--	--	--
6	8.8	43.4	.03	.03	.09	.02	3.8	3.9	1.9	1.7	4	3	--	--	17	18	3.6	3.4	1.0	.80
7	52	29	.09	.07	.02	.02	2.5	2.3	1.8	1.6	7	6	8	10	44	37	8.3	5.7	3.5	2.2
8	24	22	2.0	.05	.02	.02	4.3	4.6	2.7	2.4	5	4	6	11	23	25	5.5	5.1	1.7	1.4
9	26	13	.06	.04	.02	.01	1.8	1.9	<1.0	1.0	4	3	6	11	43	20	8.6	3.5	2.2	1.1
10	13	16	.05	.04	.02	.02	1.5	2.3	<1.0	<1.0	2	2	8	14	18	22	4.2	4.5	1.1	1.0
11	<9.0	17	.02	.05	.07	.02	1.3	1.3	<1.0	<1.0	3	2	6	9	25	22	4.9	3.1	2.0	1.1
12	24	16	.06	.04	.03	.03	1.8	2.2	2.5	2.6	4	4	8	11	19	14	4.4	3.9	1.1	.80
13	<9.0	14	.06	.04	.04	.03	--	1.9	4.0	2.3	3	3	12	13	13	15	3.4	4.3	.70	.90
14	--	--	--	--	--	--	4.1	4.5	--	--	--	--	--	--	--	--	--	--	--	--
15	48	36	.11	.09	.04	.03	1.9	--	2.1	2.0	7	5	8	9	37	31	5.3	4.0	2.2	1.4
16	22	14	.06	.07	.04	.05	1.4	1.6	3.0	3.0	4	4	6	9	17	19	4.1	5.5	1.2	1.3
17	13	12	.05	.06	.03	.02	1.3	1.4	1.9	2.2	8	3	6	11	20	16	4.1	4.0	1.2	1.0
18	<9.0	<9.0	.03	.03	.02	.02	1.0	1.0	3.7	2.5	6	5	8	8	14	13	2.6	2.6	.80	.70
19	32	15	.08	.07	.05	.05	1.1	1.2	2.6	2.5	13	5	8	9	33	21	4.6	3.5	1.6	1.0
20	10	13	.04	.05	.03	.04	1.1	1.3	<2.0	<2.0	3	3	9	9	16	15	3.4	3.7	.90	.90
21	--	--	--	--	--	--	2.1	2.5	--	--	--	--	--	--	--	--	--	--	--	--
22	--	--	--	--	--	--	1.1	1.7	--	--	--	--	--	--	--	--	--	--	--	--
23	28	33	.05	.04	.03	.03	.80	--	<2.0	<2.0	4	3	8	10	27	19	3.9	3.4	1.2	.80

Sampled event number	Chemical oxygen demand, total (mg/L)		Phosphorus, total (mg/L)		Phosphorus, dissolved (mg/L)		Chloride, dissolved (mg/L)		Copper, dissolved (ug/L)		Copper, total recoverable (ug/L)		Zinc, dissolved (ug/L)		Zinc, total recoverable (ug/L)		Calcium, total recoverable (mg/L)		Magnesium, total recoverable (mg/L)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
24	15	--	.03	.03	.02	.02	.80	.90	<2.0	<2.0	3	2	9	9	20	15	3.7	2.8	1.1	.70
25	13	19	.02	.02	.01	<.005	.80	.90	<2.0	<2.0	3	3	11	11	18	20	2.9	3.0	.90	.90
26	--	--	--	--	--	--	--	2.0	--	--	--	--	--	--	--	--	--	--	--	--
27	41	36	.10	.08	.06	.05	1.4	1.7	2.0	3.0	7.0	5	9	14	33	30	5.2	7.0	1.7	2.0
28	<9.0	<9.0	.04	.04	.03	.03	.80	.80	<2.0	<2.0	<2.0	<2.0	4.0	8.0	10	14	2.9	3.2	.80	.80
29	--	--	--	--	--	--	.90	.90	--	--	--	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	1.2	1.1	--	--	--	--	--	--	--	--	--	--	--	--
32	24	14	.02	.03	.02	.01	.90	1.1	<2.0	<2.0	<2.0	<2.0	8	13	14	17	3.5	4.0	.90	1.0
33	18	16	.05	.04	.02	.02	20	18	<2.0	<2.0	5.0	4.0	10	16	31	30	5.0	4.6	1.6	1.3
34	--	--	--	--	--	--	8.8	10	--	--	--	--	--	--	--	--	--	--	--	--
35	46	34	.08	.08	.02	.02	2.9	4.3	<2.0	<2.0	8	7	10	14	51	54	8.5	7.1	4.0	2.9
36	12	13	.03	.03	.01	.01	1.9	2.2	<2.0	<2.0	3	2	7	10	19	22	3.3	3.3	1.3	1.0
37	15	13	.05	.05	.02	.03	--	3.4	<2.0	<2.0	4	4	6	11	22	29	4.2	5.7	1.2	1.7
38	<9.0	<9.0	.02	.02	.02	.02	2.3	2.7	<2.0	<2.0	2	3	5	13	11	19	4.3	5.1	1.0	1.2
40	26	24	.07	.08	.03	.03	2.2	2.3	4.0	4.0	5	3	11	17	27	28	4.9	5.5	1.5	1.5
41	46	31	.12	.11	.05	.04	2.9	3.6	4.0	5.0	8	8	14	19	40	41	6.3	6.7	2.2	2.0
43	33	36	.06	.07	.04	.04	1.2	1.3	2.0	2.0	4	3	8	13	19	19	4.0	6.0	1.1	1.5
44	44	58	.07	.08	.05	.04	1.9	2.1	4.0	3.0	6	4	22	20	33	30	4.3	6.1	1.2	1.6

Table 2–7. Means concentrations of selected polycyclic aromatic hydrocarbon in samples collected from a storm water filter device, Madison, WI, 2005-07.

[All concentrations in micrograms per liter;--, no sample processed for event]

Sampling event number	2-Methylnaph-thalene	1-Methylnaph-thalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo[b] fluo-ranthene	Benzo[k]fluo-ranthene	Benzo[a]pyrene	Chrysene	Fluoranthene	9H-Fluorene	Indeno [1,2,3-cd] pyrene	Phenanthrene	Pyrene	Benzo [ghi] perylene	Benzo [a] an-thracene	Dibenzo [a,h] anthracene	Naphthalene
Inlet																		
10	<0.049	<.064	<0.11	0.08	0.25	5.2	2.4	2.8	4.6	13	<.52	3.8	5.8	9.2	4.0	1.2	<0.37	<.042
11	<.49	<.64	<1.1	<.64	.97	18	8.2	12	17.	47	<5.2	13	26	36	14	5.0	<1.5	<.42
13	<.049	<.064	<.11	<.064	.05	1.7	.68	.66	1.4	3.7	<.52	1.10	1.4	2.5	1.2	.17	<.12	<.042
16	<.049	<.064	<.11	<.064	.19	4.0	1.7	1.8	3.6	11	<.52	2.80	4.1	7.1	3.0	<.59	<.28	<.042
17	<.049	<.064	<.11	.16	.32	5.2	2.3	1.9	4.8	15	<.52	3.80	7.3	10	4.1	<1.0	<.36	<.042
18	<.049	<.064	<.11	<.064	.14	3.4	1.5	.78	3.1	8.9	<.52	2.40	3.2	5.9	2.6	<.57	<.23	<.042
19	<.049	<.064	<.11	.09	.36	7.5	3.6	4.1	7.0	19	<.52	5.30	7.2	14	5.7	1.9	<.53	<.042
23	<.049	<.064	<.11	<.064	.30	8.1	3.7	5.5	7.1	18	<.52	5.90	6.3	13	6.3	1.8	<.60	<.042
24	<.049	<.064	<.11	<.064	.24	5.4	2.5	3.9	4.7	12	<.52	4.10	4.2	9.0	4.3	1.5	<.45	<.042
25	<.049	<.064	<.11	<.064	.29	4.8	2.2	3.6	4.3	11	<.52	3.50	4.0	8.7	3.8	1.7	<.42	<.042
37	.11	<.064	<.11	--	.35	9.8	4.6	5.7	8.4	24	<.52	5.80	11	17	7.1	1.7	<.79	<.042
38	<.049	<.064	<.11	<.064	.06	2.1	1.1	.84	1.8	4.5	<.52	1.20	1.9	3.1	1.4	.34	<.14	<.042
40	.09	<.064	<.11	.17	.25	6.4	2.8	3.7	5.5	18	<.52	3.60	6.6	11	4.4	1.1	.47	<.042
41	.09	<.064	<.11	<.064	<.28	10	4.8	6.1	8.8	25	<.52	6.20	8.8	17	7.4	1.8	<.58	<.042
43	.09	<.064	<.11	.11	.25	3.8	1.8	2.4	3.6	11	<.52	2.40	4.1	7.3	2.8	.97	<.22	<.042

Sampling event number	2-Methylnaph-thalene	1-Methylnaph-thalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo[b] fluo-ranthene	Benzo[k]fluo-ranthene	Benzo[a]pyrene	Chrysene	Fluoranthene	9H-Fluorene	Indeno [1,2,3-cd] pyrene	Phenanthrene	Pyrene	Benzo [ghi] perylene	Benzo [a] an-thracene	Dibenzo [a,h] anthracene	Naphthalene
Outlet																		
10	<.049	<.064	<.11	<.064	.15	4.2	1.8	2.1	3.4	8.7	<.52	3.0	4.4	6.6	3.2	.57	<.31	<.042
11	<.15	<.2	<.33	.24	.49	11	4.8	6.4	9.5	25	<1.6	7.6	13	19	8.4	2.5	<.80	<.13
13	<.049	<.064	<.11	<.064	<.031	.91	.36	.33	.62	1.6	<.52	.62	.60	.99	.53	<.093	<.078	<.042
16	<.049	<.064	<.11	<.064	.07	2.6	1.1	.85	2.2	5.9	<.52	1.8	2.7	4.0	1.9	<.24	<.17	<.042
17	<.049	<.064	<.11	<.064	.04	2.3	.93	.42	2.0	5.2	<.52	1.6	1.7	3.5	1.7	<.11	<.14	<.042
18	<.049	<.064	<.11	<.064	.09	2.3	.97	.38	1.9	5.7	<.52	1.6	2.1	3.7	1.7	<.40	<.15	<.042
19	<.049	<.064	<.11	<.064	.12	3.2	1.4	1.1	2.7	7.0	<.52	2.3	2.6	4.7	2.3	.38	<.21	<.042
23	<.049	<.064	<.11	<.064	.07	2.7	1.1	1.4	2.3	5.7	<.52	1.9	1.8	3.9	2.0	.36	<.17	<.042
24	<.049	<.064	<.11	<.064	.06	1.8	.77	1.1	1.5	3.5	<.52	1.3	1.2	2.6	1.4	.32	<.12	<.042
25	<.049	<.064	<.11	<.064	.13	3.5	1.6	2.4	3.0	6.7	<.52	2.6	2.6	5.2	2.8	.77	<.26	<.042
37	.12	<.064	<.11	.19	.44	9.6	4.6	6.2	8.0	22.	<.52	6.2	10	16	7.2	2.2	.47	<.042
38	<.049	<.064	<.11	<.064	<.031	1.2	.49	.42	.82	2.1	<.52	.61	.88	1.4	.76	.10	<.061	<.042
40	.05	<.064	<.11	<.064	.11	3.7	1.7	2.0	3.1	8.9	<.52	2.1	3.1	5.4	2.6	.54	<.25	<.042
41	<.049	<.064	<.11	<.064	<.15	6.2	2.7	3.4	5.2	14.	<.52	5.0	5.0	9.6	4.5	.89	<.33	<.042
43	<.049	<.064	<.11	<.064	<.031	1.1	.42	.46	.80	2.0	<.52	.65	.69	1.3	.75	.13	<.059	<.042

Table 2–8. Particle-size distributions in samples collected from the storm water filtration device, Madison, WI, 2005-07.

[µm, Micrometer; all data are in percent by mass; <, less than]

	Particle Size (µm)																	
	<500		<250		<125		<63		<31		<16		<8		<4		<2	
Sampling event	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	99	96	98	92	48	80	29	64	18	48	15	32	14	29	12	23	6	14
2	98	90	95	80	49	70	29	36	13	10	10	10	9	10	8	10	5	10
4	97	96	74	91	50	87	48	67	41	58	29	50	26	47	22	42	13	24
7	97	96	84	92	81	88	78	78	70	74	46	48	39	40	29	32	13	12
8	99	99	89	97	86	93	73	79	64	79	37	62	27	53	18	39	5	10
9	79	97	74	94	69	88	57	66	44	45	31	33	27	31	22	27	9	15
10	98	96	78	91	74	87	56	66	38	39	27	33	23	30	16	24	5	12
11	97	96	85	91	76	76	53	45	38	28	21	23	15	21	10	18	3	9
12	88	97	85	94	77	84	59	61	40	38	26	28	19	25	14	20	4	8
13	69	91	62	81	52	72	33	62	25	53	23	43	3	40	3	36	3	21
15	92	88	84	75	64	63	42	50	27	38	22	33	20	28	17	13	8	13
16	66	98	62	96	56	88	43	63	29	43	20	31	16	26	12	22	5	12
17	86	97	78	95	59	92	41	65	29	38	18	29	14	26	9	21	2	9
18	55	94	52	89	47	83	37	72	26	58	23	57	22	53	19	47	9	19
19	81	93	70	86	52	80	45	73	24	50	19	46	17	39	16	34	13	23
20	94	97	67	94	61	90	48	82	35	79	24	62	19	48	15	36	6	20
23	77	96	71	93	54	89	34	67	22	47	18	42	14	35	12	30	8	23
24	95	90	72	80	67	71	53	61	40	51	31	49	22	49	18	47	12	43
25	70	95	68	90	60	78	40	60	24	47	23	47	23	45	22	44	21	40
26	97	92	80	85	77	77	61	62	37	45	34	42	32	40	31	38	29	35
27	98	98	96	96	87	94	78	87	63	76	43	59	32	45	25	34	13	16

	Particle Size (µm)																	
	<500		<250		<125		<63		<31		<16		<8		<4		<2	
Sampling event	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
28	91	93	83	85	74	78	66	70	57	63	31	45	24	39	21	31	9	18
29	89	89	77	77	66	66	55	55	43	43	36	34	34	27	27	11	11	11
30	96	94	82	89	73	89	60	89	48	70	44	64	34	49	27	40	15	20
32	94	90	82	79	76	79	70	79	58	79	53	71	48	63	43	56	35	44
33	89	97	87	94	84	94	80	94	74	87	71	82	65	75	53	65	21	42
34	98	97	91	94	80	82	61	69	49	58	48	55	44	49	38	42	21	25
36	97	97	94	95	91	87	76	70	63	52	59	43	51	32	46	26	36	15
37	91	86	82	71	73	71	73	71	73	71	71	69	67	66	62	63	53	60
38	97	95	84	90	71	90	42	65	27	45	26	44	25	41	24	39	20	35
40	99	98	88	96	79	91	59	71	36	48	34	47	31	45	29	43	20	38
41	97	67	94	33	90	33	79	33	57	33	55	33	52	33	49	33	40	33
42	95	90	90	79	86	79	67	79	52	79	50	73	47	65	46	56	39	40
43	90	95	84	90	77	90	66	70	51	52	48	48	46	41	43	37	26	29
44	90	95	87	90	84	90	71	79	55	60	53	53	51	45	48	39	30	30
45	93	91	87	82	80	82	60	82	45	57	43	54	41	46	39	41	27	30

Table 2–9. Loads of suspended solids, volatile solids, dissolved solids, and suspended sediment in storm water samples collected from a storm water filtration device, Madison, WI, 2005-07.

[All loads in pounds; --, no sample processed for event; SOL, sum of loads]

Event	Suspended solids, total		Suspended-sediment		Solids, volatile		Solids, dissolved	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	1.8	1.0	2.8	.89	--	--	3.2	3.2
2	1.0	.72	1.9	.62	--	--	2.6	2.6
3	3.1	2.0	3.9	1.9	--	--	6.9	7.0
4	5.2	6.3	5.8	6.6	--	--	8.2	11
5	.81	.31	.81	.33	--	--	1.6	2.0
6	2.1	2.1	2.4	1.9	--	--	4.0	4.0
7	17	11	19	11	.50	.36	6.2	6.2
8	1.1	1.1	1.5	1.1	1.5	1.3	1.1	1.1
9	5	3	6	3	.21	.12	3.3	3.3
10	.56	.48	.56	.48	.16	.14	.99	.99
11	2.8	1.6	3.0	1.6	1.6	1.0	1.6	1.6
12	9.2	.15	.68	.15	2.0	.21	1.2	1.2
13	.58	.23	.69	.23	.29	.07	2.9	2.9
14	1.7	.25	1.7	.25	--	--	.53	.53
15	5.4	1.8	4.1	1.6	1.3	.33	--	--
16	1.5	.95	2.5	.83	.80	.48	3.0	3.0
17	.87	.50	1.4	.43	1.2	.74	1.5	1.5
18	.80	.60	1.4	.50	.13	.09	2.5	2.5
19	9.3	7.1	12	5.7	1.1	.80	9.5	9.5
20	.93	.46	.81	.35	.12	.02	2.9	2.9
21	2.6	2.1	2.7	2.1	--	--	1.6	1.6
22	.26	.24	.26	.21	--	--	.38	.38
23	.40	.30	.56	.16	.81	.58	.43	.43
24	3.4	1.2	3.2	1.0	.13	--	4.2	4.2
25	1.9	2.0	1.5	1.4	.43	.27	3.1	3.1
26	.11	.44	1.0	.44	--	--	2.8	2.8
27	.03	.72	.78	.69	.62	.50	.75	.75
28	.20	.20	.16	.20	.30	.20	.98	.98
29	.13	.13	.27	.25	--	--	3.3	3.3
30	.70	.45	2.31	.38	--	--	1.6	1.6
31	.30	.15	.30	.15	--	--	.92	.92
32	.11	.10	.11	.08	.05	.03	.48	.48
33	2.9	2.2	2.9	1.9	.14	.10	7.7	8.2
34	2.9	2.8	2.8	2.8	2.9	3.0	1.8	1.8

Event	Suspended solids, total		Suspended-sediment		Solids, volatile		Solids, dissolved	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
35	2.5	1.9	2.9	2.4	2.0	2.9	1.0	.96
36	2.4	2.3	3.6	2.6	.55	.44	4.1	4.1
37	4.6	5.7	4.9	5.9	.24	.18	6.4	6.4
38	.26	.07	.26	.20	.02	.02	1.6	1.6
39	.04	.03	.06	.04	--	--	.37	.37
40	.75	.50	.75	.42	.45	.26	1.0	1.0
41	3.1	1.8	3.4	2.0	.52	.30	1.9	1.9
42	--	--	--	--	--	--	--	--
43	.37	.18	.37	.18	.59	.29	.92	.92
44	1.1	.97	.89	.74	.51	.37	1.9	3.9
45	1.5	1.8	1.8	1.3	--	--	6.4	6.4
46	--	--	1.0	.57	--	--	--	--
47	--	--	.87	.87	--	--	--	--
48	--	--	.68	.47	--	--	--	--
49	--	--	.87	.87	--	--	--	--
50	--	--	.22	.13	--	--	--	--
51	--	--	2.6	3.6	--	--	--	--
Total	103	70	116	73	21	15	119	126
SOL		32%		37%		28%		-5%

Table 2–10. Loads of selected constituents in storm water samples collected from a storm water filtration device, Madison, WI, 2005-07.

[All loads in pounds; --, not analyzed for that event; SOL, sum of loads]

Sampling event number	Chemical oxygen demand, total		Phosphorus, total		Phosphorus, dissolved		Chloride, dissolved		Copper, dissolved		Copper, total recoverable		Zinc, dissolved		Zinc, total recoverable	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	0.6	1.9	0.011	0.010	0.0077	0.008	0.22	0.25	0.0002	0.0002	0.0004	0.0004	0.0010	0.0010	0.0010	0.0010
2	2.3	1.6	.0086	.0071	.0047	.0043	.22	.27	.00005	.00005	.00021	.00031	--	--	.00186	.00186
3	--	--	--	--	--	--	2.84	3.01	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	2.41	4.08	--	--	--	--	--	--	--	--
5	--	--	--	--	--	--	.44	.57	--	--	--	--	--	--	--	--
6	1.4	7.0	.0050	.0048	.0137	.0024	.61	.63	.00031	.00027	.00064	.00048	--	--	.00273	.00289
7	13	7.2	.0213	.0161	.0054	.0059	.62	.57	.00044	.00040	.00173	.00148	.00198	.00247	.01087	.00914
8	1.0	.94	.0858	.0021	.0009	.0009	.18	.20	.00012	.00010	.00021	.00017	.00026	.00047	.00099	.00107
9	3.5	1.7	.0079	.0059	.0027	.0016	.24	.25	.00007	.00013	.00053	.00040	.00080	.00147	.00574	.00267
10	.52	.63	.0019	.0016	.0009	.0008	.06	.09	.00002	.00002	.00008	.00008	.00032	.00056	.00071	.00087
11	.30	1.1	.0012	.0034	.0045	.0014	.09	.09	.00003	.00003	.00020	.00013	.00039	.00059	.00164	.00145
12	1.2	.77	.0028	.0018	.0016	.0013	.09	.11	.00012	.00013	.00019	.00019	.00039	.00053	.00092	.00068
13	.52	1.6	.0067	.0051	.0049	.0035	--	.22	.00046	.00027	.00035	.00035	.00139	.00150	.00150	.00174
14	--	--	--	--	--	--	.09	.10	--	--	--	--	--	--	--	--
15	2.6	1.9	.0059	.0047	.0021	.0014	.10	--	.00011	.00011	.00037	.00027	.00043	.00048	.00197	.00165
16	1.4	.87	.0037	.0045	.0027	.0029	.09	.10	.00019	.00019	.00025	.00025	.00037	.00056	.00105	.00118
17	1.3	1.2	.0051	.0056	.0031	.0023	.13	.14	.00019	.00022	.00080	.00030	.00060	.00111	.00201	.00161
18	1.7	1.7	.0129	.0125	.0084	.0087	.38	.38	.00140	.00095	.00228	.00190	.00304	.00304	.00531	.00494
19	3.7	1.7	.0094	.0084	.0053	.0059	.13	.14	.00030	.00029	.00151	.00058	.00093	.00105	.00384	.00244
20	.64	.83	.0028	.0034	.0019	.0025	.07	.08	.00006	.00006	.00019	.00019	.00058	.00058	.00103	.00096
21	--	--	--	--	--	--	.03	.04	--	--	--	--	--	--	--	--
22	--	--	--	--	--	--	.02	.03	--	--	--	--	--	--	--	--
23	4.7	5.6	.0089	.0069	.0047	.0051	.13	--	.00006	.00006	.00067	.00051	.00135	.00168	.00455	.00320
24	1.9	--	.0038	.0033	.0020	.0019	.10	.11	.00006	.00006	.00038	.00025	.00113	.00113	.00251	.00188

Sampling event number	Chemical oxygen demand, total		Phosphorus, total		Phosphorus, dissolved		Chloride, dissolved		Copper, dissolved		Copper, total recoverable		Zinc, dissolved		Zinc, total recoverable	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
25	1.4	2.1	.0022	.0024	.0009	.0003	.09	.10	.00006	.00006	.00033	.00033	.00122	.00122	.00199	.00222
26	--	--	--	--	--	--	--	.06	--	--	--	--	--	--	--	--
27	1.6	1.4	.0037	.0032	.0023	.0020	.05	.07	.00008	.00012	.00027	.00020	.00035	.00055	.00129	.00117
28	.60	.60	.0048	.0050	.0038	.0038	.11	.11	.00013	.00013	.00013	.00013	.00053	.00106	.00133	.00186
29	--	--	--	--	--	--	.06	.06	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	.04	.04	--	--	--	--	--	--	--	--
32	3.5	2.1	.0032	.0037	.0022	.0021	.13	.16	.00015	.00015	.00015	.00015	.00118	.00191	.00206	.00250
33	1.3	1.2	.0037	.0032	.0013	.0012	1.45	1.29	.00007	.00007	.00037	.00029	.00073	.00117	.00227	.00220
34	--	--	--	--	--	--	.34	.40	--	--	--	--	--	--	--	--
35	7.5	5.5	.0135	.0130	.0024	.0024	.47	.70	.00016	.00016	.00130	.00114	.00162	.00227	.00828	.00877
36	3.1	3.3	.0080	.0082	.0033	.0036	.49	.57	.00026	.00026	.00077	.00051	.00180	.00257	.00488	.00565
37	.98	.85	.0029	.0030	.0015	.0017	--	.22	.00007	.00007	.00026	.00026	.00039	.00072	.00143	.00189
38	.07	.07	.0004	.0004	.0002	.0003	.03	.04	.00001	.00001	.00003	.00004	.00007	.00019	.00016	.00028
40	2.0	1.9	.0052	.0063	.0023	.0024	0.17	0.18	.00031	.00031	.00039	.00023	.00085	.00132	.00210	.00217
41	2.4	1.6	.0063	.0057	.0028	.0021	0.15	0.19	.00021	.00026	.00042	.00042	.00073	.00099	.00209	.00214
43	1.2	1.3	.0023	.0025	.0015	.0016	0.04	0.05	.00007	.00007	.00015	.00011	.00030	.00048	.00070	.00070
44	3.3	4.3	.0054	.0057	.0039	.0028	0.14	0.16	.00030	.00022	.00045	.00030	.00164	.00149	.00246	.00223

Table 2–11. Loads of selected polycyclic aromatic hydrocarbon in storm water samples collected from a storm water filtration device, Madison, WI, 2005-07.

[All loads in pounds; --, no sample processed for event; SOL, sum of loads E, scientific notation times ten raised to the power]

Sampled event number	2-Methylnaphthalene	1-Methylnaphthalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo[b] fluoranthene	Benzo[k]fluoranthene	Benzo[a]pyrene	Chrysene
					Inlet				
10	9.71E-07	9.71E-07	9.71E-07	3.25E-06	9.91E-06	2.06E-04	9.51E-05	1.11E-04	1.82E-04
11	1.61E-06	1.61E-06	1.61E-06	2.10E-06	6.37E-05	1.18E-03	5.39E-04	7.89E-04	1.12E-03
13	2.83E-06	2.83E-06	2.83E-06	2.83E-06	6.02E-06	1.97E-04	7.87E-05	7.63E-05	1.62E-04
16	1.52E-06	1.52E-06	1.52E-06	1.52E-06	1.18E-05	2.48E-04	1.05E-04	1.11E-04	2.23E-04
17	2.46E-06	2.46E-06	2.46E-06	2.46E-06	3.22E-05	5.22E-04	2.31E-04	1.91E-04	4.82E-04
18	9.30E-06	9.30E-06	9.30E-06	9.30E-06	5.31E-05	1.29E-03	5.69E-04	2.96E-04	1.18E-03
19	2.85E-06	2.85E-06	2.85E-06	2.85E-06	4.18E-05	8.72E-04	4.18E-04	4.77E-04	8.14E-04
23	4.12E-06	4.12E-06	4.12E-06	4.12E-06	5.05E-05	1.36E-03	6.23E-04	9.26E-04	1.20E-03
24	3.07E-06	3.07E-06	3.07E-06	--	3.01E-05	6.77E-04	3.14E-04	4.89E-04	5.90E-04
25	2.71E-06	2.71E-06	2.71E-06	2.71E-06	3.21E-05	5.32E-04	2.44E-04	3.99E-04	4.76E-04
37	5.60E-06	1.60E-06	1.60E-06	--	2.28E-05	6.39E-04	3.00E-04	3.71E-04	5.47E-04
38	3.59E-07	3.59E-07	3.59E-07	3.59E-07	8.36E-07	3.08E-05	1.61E-05	1.23E-05	2.64E-05
40	7.14E-06	1.90E-06	1.90E-06	1.90E-06	1.94E-05	4.97E-04	2.17E-04	2.87E-04	4.27E-04
41	1.28E-06	1.25E-06	1.25E-06	1.25E-06	7.30E-06	5.21E-04	2.50E-04	3.18E-04	4.59E-04
43	1.20E-07	1.56E-07	2.69E-07	5.38E-07	1.22E-06	1.86E-05	8.80E-06	1.17E-05	1.76E-05
					Outlet				
10	9.71E-07	9.71E-07	9.71E-07	1.27E-06	5.95E-06	1.67E-04	7.14E-05	8.33E-05	1.35E-04
11	4.93E-06	1.61E-06	1.61E-06	1.58E-05	3.22E-05	7.23E-04	3.15E-04	4.21E-04	6.24E-04
13	2.83E-06	2.83E-06	2.83E-06	2.83E-06	1.79E-06	1.05E-04	4.16E-05	3.82E-05	7.17E-05
16	1.52E-06	1.52E-06	1.52E-06	1.52E-06	4.40E-06	1.61E-04	6.81E-05	5.26E-05	1.36E-04
17	2.46E-06	2.46E-06	2.46E-06	2.46E-06	4.42E-06	2.31E-04	9.34E-05	4.22E-05	2.01E-04
18	9.30E-06	9.30E-06	9.30E-06	9.30E-06	3.23E-05	8.73E-04	3.68E-04	1.44E-04	7.21E-04
19	2.85E-06	2.85E-06	2.85E-06	2.85E-06	1.39E-05	3.72E-04	1.63E-04	1.28E-04	3.14E-04
23	4.12E-06	4.12E-06	4.12E-06	4.12E-06	1.25E-05	4.55E-04	1.85E-04	2.36E-04	3.87E-04
24	3.07E-06	3.07E-06	3.07E-06	--	7.03E-06	2.26E-04	9.66E-05	1.38E-04	1.88E-04
25	2.71E-06	2.71E-06	2.71E-06	3.55E-06	1.44E-05	3.88E-04	1.77E-04	2.66E-04	3.32E-04
37	3.19E-06	1.60E-06	1.60E-06	--	2.87E-05	6.26E-04	3.00E-04	4.04E-04	5.21E-04
38	3.59E-07	3.59E-07	3.59E-07	4.69E-07	2.27E-07	1.76E-05	7.19E-06	6.16E-06	1.20E-05
40	1.86E-06	1.90E-06	1.90E-06	2.49E-06	8.54E-06	2.87E-04	1.32E-04	1.55E-04	2.41E-04
41	1.28E-06	1.25E-06	1.25E-06	1.67E-06	3.91E-06	3.23E-04	1.41E-04	1.77E-04	2.71E-04
43	1.20E-07	1.56E-07	2.69E-07	1.56E-07	7.58E-08	5.38E-06	2.05E-06	2.25E-06	3.91E-06

Sampled event number	Fluoranthene	9H-Fluorene	Indeno [1,2,3-cd] pyrene	Phenanthrene	Pyrene	Benzo [ghi] perylene	Benzo [a] anthracene	Dibenzo [a,h] anthracene	Naphthalene
					Inlet				
10	5.15E-04	1.03E-05	1.51E-04	2.30E-04	3.65E-04	1.59E-04	4.76E-05	7.33E-06	8.33E-07
11	3.09E-03	1.71E-05	8.54E-04	1.71E-03	2.37E-03	9.20E-04	3.29E-04	4.93E-05	1.38E-05
13	4.28E-04	3.01E-05	1.27E-04	1.62E-04	2.89E-04	1.39E-04	1.97E-05	6.94E-06	2.43E-06
16	6.81E-04	1.61E-05	1.73E-04	2.54E-04	4.40E-04	1.86E-04	1.83E-05	8.67E-06	1.30E-06
17	1.51E-03	2.61E-05	3.82E-04	7.33E-04	1.00E-03	4.12E-04	5.02E-05	1.81E-05	2.11E-06
18	3.38E-03	9.87E-05	9.11E-04	1.21E-03	2.24E-03	9.87E-04	1.08E-04	4.37E-05	7.97E-06
19	2.21E-03	3.02E-05	6.16E-04	8.37E-04	1.63E-03	6.62E-04	2.21E-04	3.08E-05	2.44E-06
23	3.03E-03	4.38E-05	9.93E-04	1.06E-03	2.19E-03	1.06E-03	3.03E-04	5.05E-05	3.54E-06
24	1.51E-03	3.26E-05	5.14E-04	5.27E-04	1.13E-03	5.39E-04	1.88E-04	2.82E-05	2.63E-06
25	1.22E-03	2.88E-05	3.88E-04	4.43E-04	9.64E-04	4.21E-04	1.88E-04	2.33E-05	2.33E-06
37	1.56E-03	1.69E-05	3.78E-04	7.17E-04	1.11E-03	4.63E-04	1.11E-04	2.57E-05	1.37E-06
38	6.60E-05	3.81E-06	1.76E-05	2.79E-05	4.55E-05	2.05E-05	4.99E-06	1.03E-06	3.08E-07
40	1.40E-03	2.02E-05	2.80E-04	5.13E-04	8.54E-04	3.42E-04	8.54E-05	3.65E-05	1.63E-06
41	1.30E-03	1.36E-05	3.23E-04	4.59E-04	8.86E-04	3.86E-04	9.38E-05	1.51E-05	1.09E-06
43	5.38E-05	1.27E-06	1.17E-05	2.00E-05	3.57E-05	1.37E-05	4.74E-06	5.38E-07	1.03E-07
					Outlet				
10	3.45E-04	1.03E-05	1.19E-04	1.74E-04	2.62E-04	1.27E-04	2.26E-05	6.15E-06	8.33E-07
11	1.64E-03	5.26E-05	4.99E-04	8.54E-04	1.25E-03	5.52E-04	1.64E-04	2.63E-05	4.27E-06
13	1.85E-04	3.01E-05	7.17E-05	6.94E-05	1.15E-04	6.13E-05	5.38E-06	4.51E-06	2.43E-06
16	3.65E-04	1.61E-05	1.11E-04	1.67E-04	2.48E-04	1.18E-04	7.43E-06	5.26E-06	1.30E-06
17	5.22E-04	2.61E-05	1.61E-04	1.71E-04	3.52E-04	1.71E-04	5.53E-06	7.03E-06	2.11E-06
18	2.16E-03	9.87E-05	6.07E-04	7.97E-04	1.40E-03	6.45E-04	7.59E-05	2.85E-05	7.97E-06
19	8.14E-04	3.02E-05	2.67E-04	3.02E-04	5.46E-04	2.67E-04	4.42E-05	1.22E-05	2.44E-06
23	9.60E-04	4.38E-05	3.20E-04	3.03E-04	6.57E-04	3.37E-04	6.06E-05	1.43E-05	3.54E-06
24	4.39E-04	3.26E-05	1.63E-04	1.51E-04	3.26E-04	1.76E-04	4.01E-05	7.53E-06	2.63E-06
25	7.42E-04	2.88E-05	2.88E-04	2.88E-04	5.76E-04	3.10E-04	8.53E-05	1.44E-05	2.33E-06
37	1.43E-03	1.69E-05	4.04E-04	6.52E-04	1.04E-03	4.69E-04	1.43E-04	3.06E-05	1.37E-06
38	3.08E-05	3.81E-06	8.94E-06	1.29E-05	2.05E-05	1.11E-05	1.44E-06	4.47E-06	3.08E-07
40	6.91E-04	2.02E-05	1.63E-04	2.41E-04	4.19E-04	2.02E-04	4.19E-05	9.71E-06	1.63E-06
41	7.30E-04	1.36E-05	2.61E-04	2.61E-04	5.01E-04	2.35E-04	4.64E-05	8.60E-06	1.09E-06
43	9.78E-06	1.27E-06	3.18E-06	3.37E-06	6.35E-06	3.67E-06	6.35E-07	1.44E-06	1.03E-07

Table 2–12. Parking lot comparison of geometric concentrations from several studies in Wisconsin.

[mg/L, milligrams per liter; µg/l micrograms per liter; --, no data available]

Study	Total suspended solids (mg/L)	Suspended sediment concentration (mg/L)	Dissolved phosphorus (mg/L)	Total phosphorus (mg/L)	Total copper (µg /L)	Total zinc (µg/L)	Mean Percentage of sand
Madison Gas and Electric, Madison	20	21	.03	.11	4.9	25	43
City of Madison Water Utility, Madison (U.S. Environmental Protection Agency, 2004)	96	121	.088	.20	5.1	47	49
St. Mary's Hospital parking lot, Green Bay (Horwatich, 2000)	36	127	0.021	.082	--	56	26
City maintenance yard, Madison (Waschbusch, 1999)	180	--	.12	.34	17	193	--
City garage & parking lot, Milwaukee							
(Corsi and others, 1999)	259	--	.011	.26	30	154	10
Commercial strip, Madison (Waschbusch and others, 1999)	50	--	.016	.09	--	--	--
Commercial strip, Marquette, Mich.,							
(Steuer and others, 1997)	138	--	0.22	.21	25	178	--
Commercial strip, Madison							
(and others, 1993)	58	--	.05	.19	9	330	--
Commercial strip, Milwaukee (Bannerman and others, 1983; Post Office)	116	--	.05	.26	--	210	--
Shopping Center, Milwaukee (Bannerman and others, 1983; Rustler)	38	--	.026	.101	--	131	50

Wisconsin Department of Transportation
4802 Sheboygan Avenue, Room 104
P.O. Box 7915
Madison, WI 53707-7915