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Parking Lot Runoff Quality and Treatment Efficiency of a Stormwater-Filtration Device, Madison, Wisconsin, 2005–07

Scientific Investigations Report 2009–5196

U.S. Department of the Interior
U.S. Geological Survey

Cover: A stormwater-filtration device installed in an employee parking lot in downtown Madison, Wisconsin. (Photograph from Earth Tech, Inc., September 2004.)

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KEN SALAZAR, Secretary

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Marcia K. McNutt, Director

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Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
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)
milliliter per second (mL/s)	.00003531	cubic foot per second (ft^3/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-thousandth of a millimeter.

Concentrations of sieved solids as a dried weight are in milligrams per kilogram (mg/kg).

Abbreviations used in this report

Cl	chloride
COD	chemical oxygen demand
DCRA	Dane County Regional Airport
DCOD	dissolved chemical oxygen demand
DCu	dissolved copper
DP	dissolved phosphorus
DZn	dissolved zinc
EMC	event mean concentration
LOQ	limit of quantification
MCTT	Multi-Chamber Treatment Tank
NOAA	National Oceanic and Atmospheric Administration
NURP	Nationwide Urban Runoff Program
PAH	polycyclic aromatic hydrocarbon
PSD	particle-size distribution
QA/QC	quality-assurance/quality-control
RPD	relative percent difference
SFD	stormwater-filtration device
SOL	summation of loads
SRS	standard reference sample
SS	suspended sediment
TCu	total copper
TDS	total dissolved solid
TP	total phosphorus
TSS	total suspended solid
TZn	total zinc
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources
WisDOT	Wisconsin Department of Transportation
WinSLAMM	Windows Source Load and Management Model
WSLOH	Wisconsin State Laboratory of Hygiene

Parking Lot Runoff Quality and Treatment Efficiency of a Stormwater-Filtration Device, Madison, Wisconsin, 2005–07

By Judy A. Horwatich and Roger T. Bannerman[1]

Abstract

To evaluate the treatment efficiency of a stormwater-filtration device (SFD) for potential use at Wisconsin Department of Transportation (WisDOT) park-and-ride facilities, a SFD was installed at an employee parking lot in downtown Madison, Wisconsin. This type of parking lot was chosen for the test site because the constituent concentrations and particle-size distributions (PSDs) were expected to be similar to those of a typical park-and-ride lot operated by WisDOT. The objective of this particular installation was to reduce loads of total suspended solids (TSS) in stormwater runoff to Lake Monona. This study also was designed to provide a range of treatment efficiencies expected for a SFD. Samples from the inlet and outlet were analyzed for 33 organic and inorganic constituents, including 18 polycyclic aromatic hydrocarbons (PAHs). Samples were also analyzed for physical properties, including PSD. Water-quality samples were collected for 51 runoff events from November 2005 to August 2007. Samples from all runoff events were analyzed for concentrations of suspended sediment (SS). Samples from 31 runoff events were analyzed for 15 constituents, samples from 15 runoff events were analyzed for PAHs, and samples from 36 events were analyzed for PSD.

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 decreased by the SFD include TSS, SS, volatile suspended solids, total phosphorous (TP), total copper, total zinc, and PAHs. The efficiency ratios for these constituents are 45, 37, 38, 55, 22, 5, and 46 percent, respectively. The SOLs for these constituents are 32, 37, 28, 36, 23, 8, and 48 percent, respectively. The SOL for chloride was -21 and the efficiency ratio was -18. Six chemical constituents or properties—dissolved phosphorus, chemical oxygen demand, dissolved zinc, total dissolved solids, dissolved chemical oxygen demand, and dissolved copper—were not included in the efficiency or SOL, because the difference between concentrations in samples from the inlet and outlet were not significant. Concentrations of TP and TSS were inexplicably high in samples at the inlet for one event.

Introduction

An Administrative Rule has been established by the Wisconsin Department of Transportation (WisDOT) (Wisconsin Administrative Code, 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, 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, 2002). The rule requires a performance standard of at least a 40-percent reduction in loads of TSS for highway reconstruction and non-highway redevelopment (Wisconsin Administrative Code, 2002). To evaluate post-construction performance, the WDNR allows the use of a computer simulation model, such as the Windows Source Load and Management Model (WinSLAMM) to determine TSS load reduction. In addition, the U.S. Environmental Protection Agency Phase I and Phase II stormwater regulations result in additional focus on the quality of flow from transportation facilities (U.S. Environmental Protection Agency, 2000).

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. These include street-cleaning devices evaluated in Milwaukee (Waschbusch, 2003) and Madison (Wendy Braun, Wisconsin Department of Transportation, written commun., 2006). Two prefabricated devices were evaluated in Milwaukee; these include a stormwater-filtration device (SFD) (similar to the one used in this study) and a hydrodynamic settling device (U.S. Environmental Protection Agency, 2004; 2005).

[1] Wisconsin Department of Natural Resources

To evaluate the treatment efficiency of a SFD for WisDOT transportation facilities—for example, a park-and-ride lot—a SFD was installed in an employee parking lot. The objective of this particular installation was to reduce loads of TSS in stormwater runoff to Lake Monona. This site has a similar rate of usage as a park-and-ride lot. Because the WisDOT has already tested a SFD that treated runoff from a freeway, it was considered important to select a WisDOT facility with different levels of contaminants and a different distribution of mean particle size from those at the freeway site. Therefore, WisDOT, Madison Gas and Electric Company (MGE) (owner of the parking lot), WDNR, and the U.S. Geological Survey (USGS) developed this cooperative study to determine the reductions of contaminants 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 prefabricated 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-ride lots in highly urbanized areas. Many facilities in highly urbanized areas will need to meet the 40-percent TSS performance standard at redevelopment sites and in 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 newer 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 newer non-structural 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 ft thick and serves drainage areas of less than 2 acres. More study would be needed of the maintenance requirements, filter thicknesses, and mixture 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 contained 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.

Prefabricated devices are an alternative to the non-structural ones. Advantages to using prefabricated devices include technical support from the manufacturer and they are usually designed for easy maintenance. However, the TSS reductions for these devices have not been verified and any testing has been limited by site-specific characteristics of the stormwater runoff.

Prefabricated 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 on a freeway in Milwaukee, Wisconsin (Horwatich and others, 2004; U.S. Environmental Protection Agency, 2004). A prefabricated pressurized sand filter reduced the TSS load by 80 percent in runoff from a hospital parking lot. The SFD at the freeway site reduced the 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-ride lots and maintenance yards. Each type of facility may have different levels of contaminants and particle-size distributions. Testing the SFD at the employee parking lot in Madison will help quantify the efficiencies of using this filter at park-and-ride lots. It also may provide the additional data needed to calibrate and verify the SFD efficiency equations in an urban stormwater-runoff model.

Purpose and Scope

This report describes the process of monitoring stormwater runoff at the inlet, outlet, and bypass pipes of a stormwater-filtration device installed at an employee parking lot in downtown Madison, Wis. 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, antecedent dry days, and peak flow data are presented in appendixes. Precipitation, flow volume, and concentrations of suspended sediment were recorded for 51 storm events. Concentrations in samples collected during 31 runoff events are reported for 15 constituents analyzed including 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 (PAHs) are presented for 15 runoff events.

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

A goal of the current project was to verify the results of the WinSLAMM model. Data from the parking lot study and the Milwaukee freeway studies can be modeled in WinSLAMM using TSS reduction devices. For example, WinSLAMM simulates hydrodynamic settling devices (such as the one evaluated in Milwaukee) utilizing 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 their SFDs in the model. If the calibration and verification are successful, the model could be used to estimate the efficiencies from a SFD at any transportation facility when appropriate source-area data are available.

This report also adds to the understanding of stormwater quality and quantity in an urban environment. 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.

Site Description

In June 2003, MGE installed a stormwater-filtration device called a StormFilter at an employee parking lot in downtown Madison, Wis. (fig. 1). The filter cartridges were replaced 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' cars with a few stalls for visitor parking. On weekends and weeknights, the parking lot is used for overflow parking of downtown businesses. Most contaminants deposited on the parking lot are delivered by cars and atmospheric deposition. Salt is 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 a 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 Company, 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 is 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 that flows to the SFD (fig. 1).

Figure 1. Study area including the drainage area of the parking lot (outlined in red), and location of the islands, manholes, and flow-splitter box and storm-sewer pipes (lined in yellow).

The gravel islands do not have curbs, 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, which could allow additional infiltration through the islands. The gravel islands consist of 0.06 acres. 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, depressions have formed in the pavement. Small depressions have formed in many of the stalls where the wheels of cars sit. Larger 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 bottom upward consists of a fibrous peat and organic soil mixture at 7.5 ft; 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 is 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.

Previous Investigations

The USGS has a 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, Wis., 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 references for these investigations.

Design of the Stormwater-Filtration Device

The SFD removes contaminants through filtration and sedimentation. Filtration, considered the primary method of treatment, is done by means of a filter media that physically removes particles by retaining contaminants through sorption. Each of the 26 filter cartridges in the SFD was 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, phosphorus, oils, and greases. Sedimentation of larger particles occurs in a pretreatment chamber and on the bottom of the cartridge-filter bay.

The device was designed to treat stormwater runoff from an impervious area of 1.3 acres, but runoff coefficients measured during the study indicated that the drainage area had not been determined correctly. The runoff coefficients using the 1.3 acres averaged about 40 percent, which was much lower 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 correct area of the watershed was 0.91 acres; therefore, the SFD was over-sized for the site.

Stormwater from the parking lot enters into a precast 4-ft-long flow-splitter-box manhole (figs. 1 and 2). An adjustable external-weir plate is set in the center of the box at a height of 2.17 ft. At 90 degrees from 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.-diameter 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 SFD 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 enters 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.

Flow rates were controlled through the filter cartridges by a siphon action, and the water exited the cartridge through 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 exceeded 0.87 ft^3/s, water bypassed the filter cartridges by way of the high-flow bypass weir at a height of 1.83 ft (fig. 3). Treated water from the underdrain manifold and untreated internal bypass water entered the outlet bay area (8 ft long by 2.3 ft wide) and then flowed through a 6-in.-diameter outlet pipe (James Bachhuber, Earth Tech, written commun., 2004).

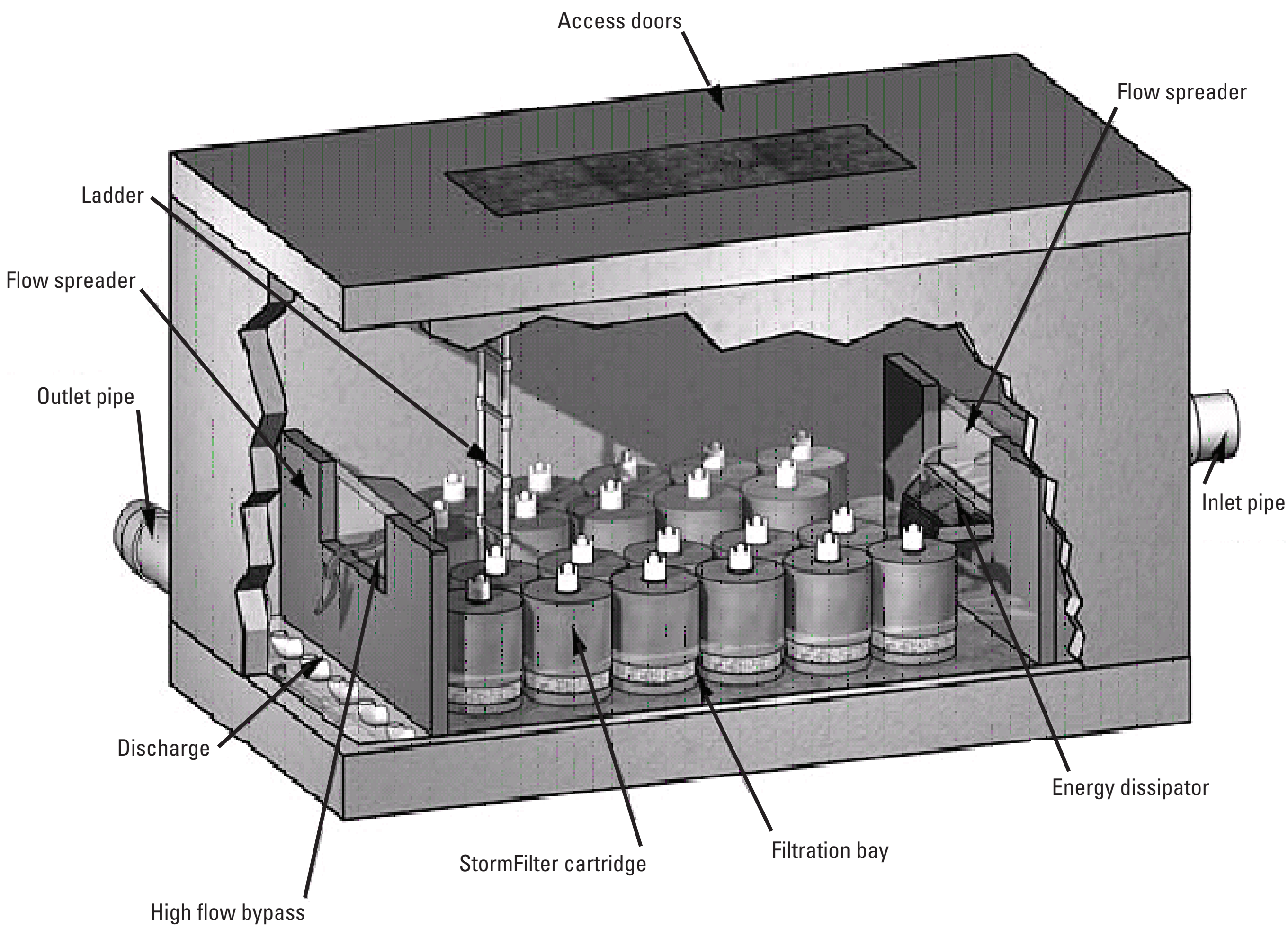

Figure 3. Components of the stormwater-filtration device (U.S. Environmental Protection Agency, 2004).

Figure 4. The flow spreader and the modification made to the internal bypass weir of the stormwater-filtration device. Each black cylinder contains a filter cartridge.

The manufacturer recommended that sediment be removed from the pretreatment chamber as necessary and that the filters be inspected once a year to determine whether replacement was needed. However, the filters did not need replacement during the project in part for the following reasons: (1) the device was designed to treat runoff from 1.3 acres rather than the effective runoff area of 0.91 acres, and (2) the removal efficiencies of the device were not observed to diminish during the monitoring period. Personnel from the manufacturer inspected the SFD on August 17, 2007, the day after sampling was completed, and determined the device remained in good working order.

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 raingage. Measurement, control, and storage of data were done by means of electronic dataloggers. Data were automatically retrieved twice daily using telephone modems. Descriptive statistics for stormwater runoff events from the SFD are detailed in appendixes 2–3 and 2–4.

Water-Quality Sampling and 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, MGE Stormwater Filter Inlet at Madison, Wis.; 430440089223400 MGE Stormwater Filter Outlet at Madison, Wis.; and 430440089223401, MGE Stormwater Filter Bypass at Madison, Wis.

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 event, consisting of numerous subsamples collected 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.

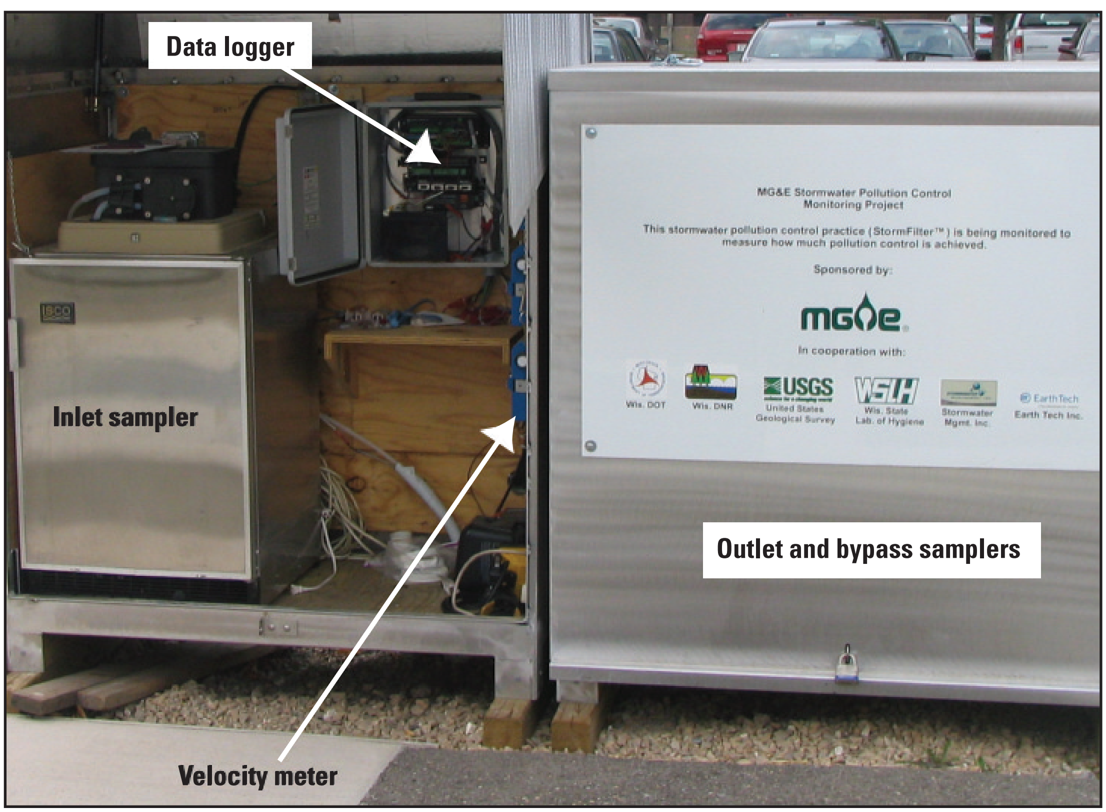

Figure 5. Automatic sampling equipment.

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).

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

Precipitation

A tipping-bucket raingage was used for continuous precipitation measurement. 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 raingage used a built-in polynomial to correct for the intensity, which was based on the tipping bucket's mechanism (Design Analysis Associates, 2001).

The raingage was attached to the back of the monitoring station. It was mounted on a 2-in.-diameter pipe raised 10 ft to avoid interference from nearby structures and to prevent vandalism. During two raingage calibrations, debris was cleaned from inside the raingage.

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

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

Constituent or characteristic	Unit	Limit of detection	Limit of quantification[1]	Method
Dissolved solids, total	mg/L	50	167	[2]SM2540C
Suspended solids, total	mg/L	2	7	[3]EPA 160.2
Volatile solids, total	mg/L	2	7	[3]EPA 160.2
Suspended sediment	mg/L	2	7	[2]ASTM D3977–97
Phosphorus, dissolved	mg/L as P	.005	.016	[3]EPA 365.1
Phosphorus, total	mg/L as P	.005	.016	[3]EPA 365.1
Chemical oxygen demand, total	mg/L	14	28	[3]EPA Method 410.4
Chemical oxygen demand, dissolved	mg/L	14	28	[3]EPA Method 410.4
Chloride, dissolved	mg/L	.6	2	[2,1]SM4500CL
Calcium, total recoverable	mg/L	.02	.07	[2]EPA 200.7
Magnesium, total recoverable	mg/L	.03	.7	[2]EPA 200.7
Zinc, dissolved	µg/L	16	50	[2]EPA 200.9
Zinc, total recoverable	µg/L	16	50	[2,1]EPA 200.9
Copper, dissolved	µg/L	1	3	[2]SM3113B
Copper, total recoverable	µg/L	1	3	[2]SM3113B
Wet-sieve of sediment	NA	NA	NA	[4]Burton
Coulter counter of sediment	NA	NA	NA	[4]Burton
Laser diffraction of sediment	NA	NA	NA	[4]Burton
Microfiltration of sediment	NA	NA	NA	[4]Burton

[1] Limit of quantification is the low standard in the calibration curve.

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

[3] U.S. Environmental Protection Agency, 1986.

[4] 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, Wis.

[All data in micrograms per liter, determined by use of method SW8310 in American Public Health Association and others, 1989[1]]

Constituent or characteristic	Limit of detection	Limit of quantification[2]
1-Methylnaphthalene	0.064	0.2
2-Methylnaphthalene	.049	.16
Fluorene	.52	1.7
Acenaphthene	.064	.20
Acenaphthylene	.11	.34
Anthracene	.031	.1
Benzo[a]anthracene	.093	.30
Benzo[a]pyrene	.16	.52
Benzo[b]fluoranthene	.13	.41
Benzo[g,h,i]perylene	.14	.44
Benzo[k]fluoranthene	.12	.38
Chrysene	.027	.09
Dibenzo[a,h]anthracene	.034	.11
Fluoranthene	.11	.35
Indeno[1,2,3-cd]pyrene	.093	.30
Phenanthrene	.093	.30
Pyrene	.11	.34
Naphthalene	.042	.13

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

[2] Limit of quantification is the low standard in the calibration curve.

Flow Monitoring

Area-velocity flowmeters were installed that use continuous-wave Doppler technology to measure average 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.-diameter inlet pipe, 6-in.-diameter outlet pipe, and 15-in.-diameter bypass pipe. The area-velocity flowmeters 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

Figure 6. Inlet pipe with stabilization bar.

(fig. 4). The recorded depth indicated the height of flow in the filtration bay.

Cameras were installed at five locations to identify problems with sampling equipment or to detect a change in flow regimen 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 that turned the cameras on and off.

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 to make stage corrections throughout 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 rate 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 measure 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

$$Q = q \quad C/c \,, \tag{1}$$

where

- Q is flow being measured, in cubic feet,
- q is injection rate, in milliliters per minute,
- C is concentration of injected dye, in percent by volume, and
- c is concentration of measure, in micrograms per liter.

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 18 percent (fig. 7). To correct the inlet flow measurements, a plot of dye-to-metered-flow data points was used to produce a correction equation with an R^2=0.9825:

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

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.

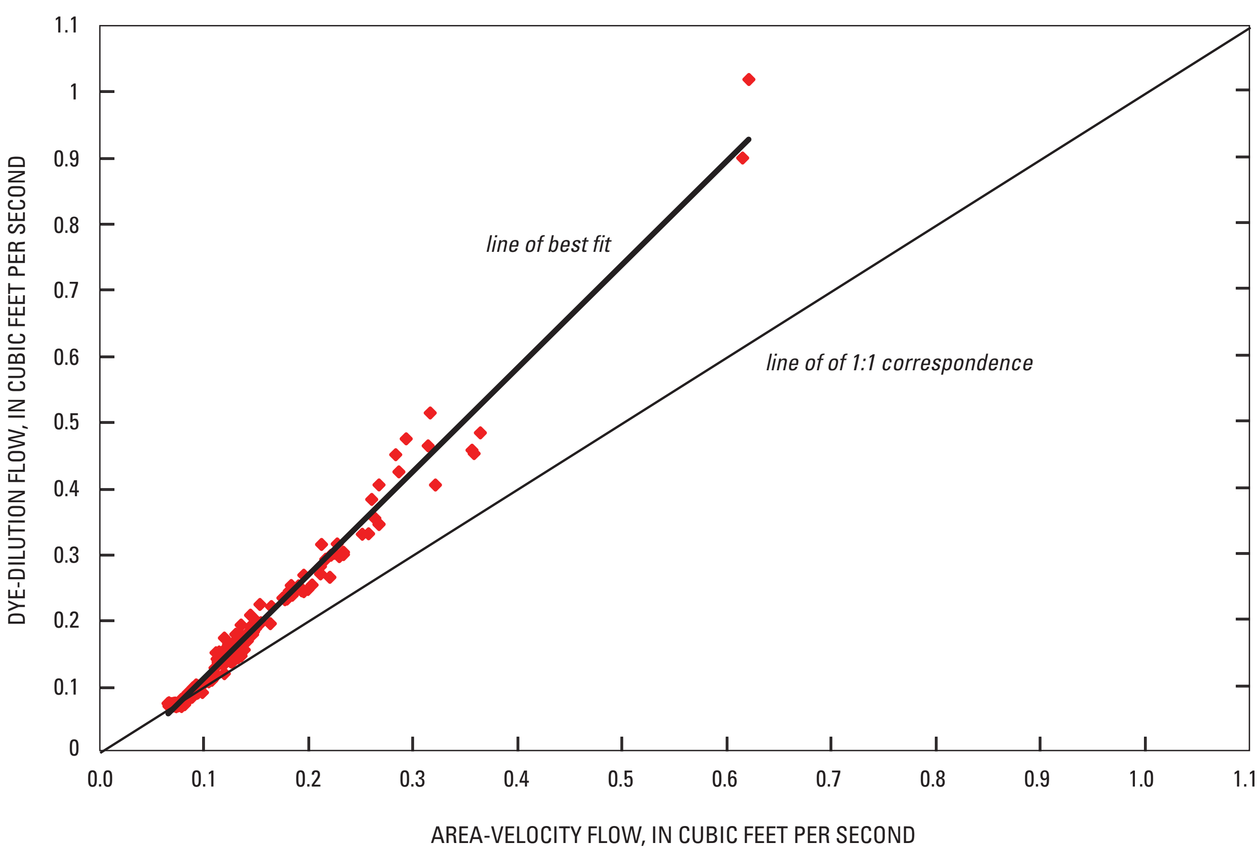

Figure 7. Dye-dilution flow in relation to area-velocity flow at the inlet of the stormwater-filtration device.

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. During 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 the unit was recording negative values.

High-flow weirs. The SFD was designed with external and internal high-flow bypass weirs. During July–October 2005, stormwater runoff was measured for 16 events; 8 of the events produced external bypassing, and 4 produced internal bypassing. The manufacturer decided that additional stormwater could be passed to the filter 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. Programming changes between the datalogger and the velocity meter were added that omitted data spikes during non-events. Communications from the area-velocity meter to the datalogger were managed 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 could not 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 data 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 (fig. 8). 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). The stabilization bar was added on April 29, 2007. Because of the shifting of the inlet pipe during large-volume events, there were probably some errors in the data collected before the inlet pipe was stabilized. Also, during one runoff event, debris became draped over the meter.

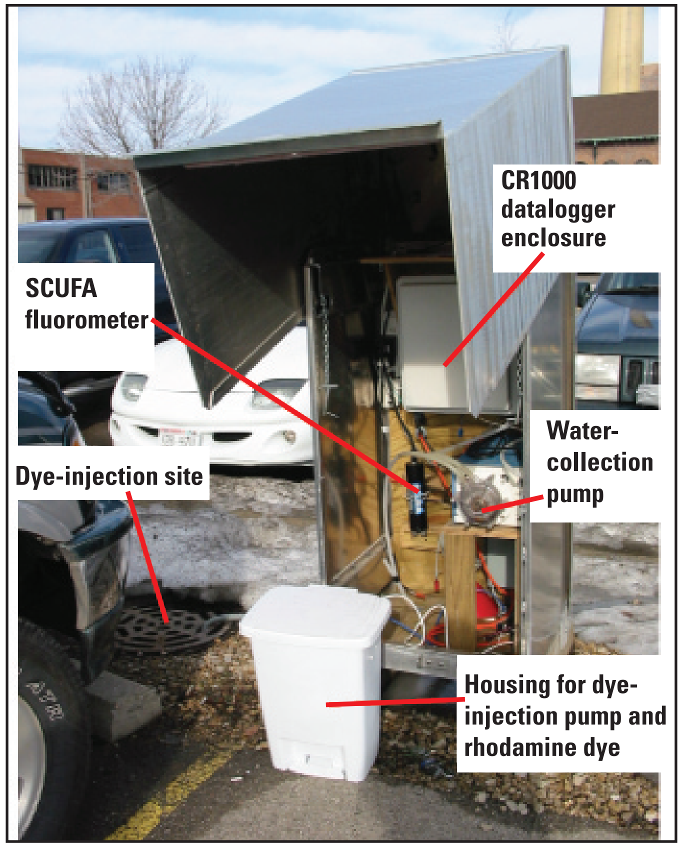

Figure 8. Dye-dilution equipment.

Quality Control

The field-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 (appendix 2–1). The equipment blank procedure passed deionized water through the sampler and processed through the churn to validate clean sampling procedures (Wilde, 2006). Blanks were collected at the beginning and midpoint of the project to validate clean-sampling procedures.

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 contained detectable concentrations of dissolved copper (DCu) and total copper (TCu), but these concentrations were below the limit of quantification (LOQ) for the inlet and outlet. Blank 2 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 (appendix 2–1). Blank 3 had no detectable concentrations.

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

$$\%RPD = [(X_1 - X_2) / \bar{X}] \times 100 \,, \qquad (2)$$

where

X_1 is concentration of constituent in a sample,
X_2 is concentration of a constituent in a duplicate sample, and
$\bar{X}$ is mean value of X_1 and X_2.

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 RPD target was 25 percent or less (appendix 2–2). In replicates for event 9 the RPD 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.

Processing of Water-Quality Samples

A new procedure was used to improve the accuracy and precision of measured quantity of particulate constituents in samples that contained a large amount of sand-sized particles (>125 µm). Previous studies have shown that using a churn to partition samples with large quantities of sand had the potential to cause a positive bias and to lower the precision of constituent concentrations associated with particulates (Horowitz and others, 1997). The use of a wet-sieving process decreased these errors for sediment-associated constituent concentrations (Selbig and others, 2007). This process consisted 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 was then combined and processed for total recoverable metals and phosphorus. This process was used for six events, which were determined by stirring the samples and observing at least 2 g of material at the bottom of the bottle after 1 minute. For samples from these six events, large amounts of material dropped to the bottom of the glass jar within 1 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):

$$C_I = \left(\left(Sm / 1000 \right) \quad Cs \right) / V \,, \qquad (3)$$

where

C_I is concentration of sieved solids, in mg/L,
Sm is mass of sieved solids after drying, in grams,
Cs is concentration of sieved solid, in mg/kg, and
V is volume of sieved water, in liters.

Particle-Size Analysis

In July 2004, the USGS Wisconsin Water Science Center adopted a new method for particle-size analysis. Previous methods 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 has been incorporated into this project. The new particle-size analysis uses a two-step process developed by the SLOH.

The first step was to wet sieve the sample for the particle sizes of 500, 250, 125, 63, and 32 µm. The material on the sieves was then dried and weighed. The second step was to separate the particles less than 32 µm into particle-size fractions of 16, 8, 4, and 2 µm. 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.

Treatment Efficiency of the Stormwater-Filtration Device

Rainfall, flow, particle-size, and water-quality data were important in evaluating the effectiveness of the filtration device. A comparison of monitored event rainfall depths and long-term trends in rainfall depths helped evaluate if the monitoring data were representative of rainfall patterns in Madison. The flow data were needed to determine the volumes of runoff entering and leaving the filtration device. Efficiencies of the SFD were evaluated by first determining if the inlet and outlet concentrations were significantly different. For those that were significantly different, the concentrations and loads were used to determine efficiency ratios 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 data collected by both gages were comparable to the long-term average at DCRA (table 3). DCRA was approximately 4 mi northeast of the SFD.

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

[Precipitation is presented in inches; USGS, U.S. Geological Survey; 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	--	--	--
Partial year 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
Partial year 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
Partial year total 2007	**25.7**	**32.1**	**21.1**

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

The difference between the total from the USGS (on-site) precipitation data and the 2005–07 totals from the DCRA precipitation data was less than 20 percent. Larger differences generally occurred during the 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 precipitation data recorded was 5.9 in. less than the long-term average at DCRA, whereas in 2006 and 2007, the USGS precipitation averages were 5.9 and 4.6 in. higher, respectively, than the long-term average at DCRA.

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 would 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 favored either all small or all large precipitation depths for the observed area (Bachhuber and others, 2001). 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 (1997).

Probability distributions for both data sets were constructed by use of the Weibull plotting position (Helsel and Hirsch, 1992). Precipitation amounts for individual events were computed for both data sets. Precipitation greater than or equal to 0.19 in. (the minimum amount recorded during this project) were ranked from lowest to highest. A cumulative probability distribution then was computed for both data sets by use of the formula

$$P_R = i_R / (n+1), \quad (4)$$

where

R is precipitation event,
P_R is probability of an event having a precipitation less than that of event,
i_R is ranking of event R, and
n is total number of events in the data set.

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).

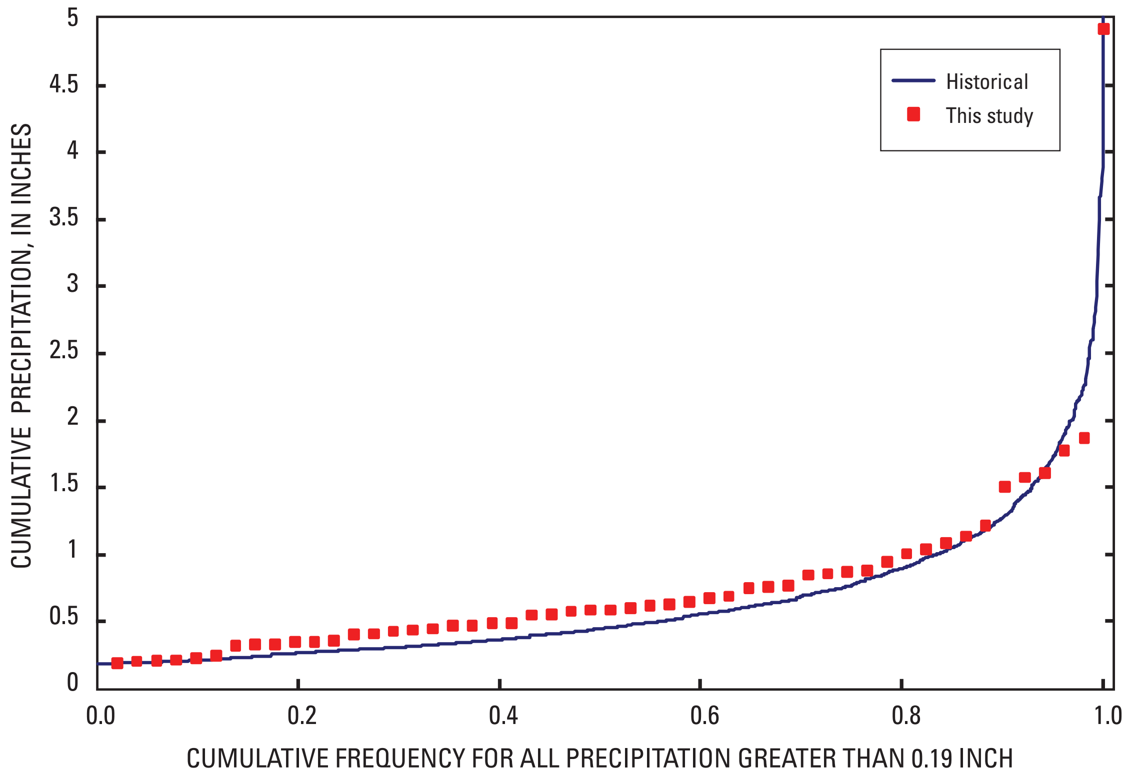

Figure 9. Cumulative precipitation for the study period (2005–07) in relation to the cumulative frequency for all precipitation greater than 0.19 inches (1949–92) based on the National Oceanic and Atmospheric Administration precipitation gage at Dane County Regional Airport, Madison, Wis.

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 entered 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.

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. (appendix 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 ft^3. The volume of stormwater that passed through the filtration system ranged from 235 to 8,210 ft^3 (appendix 2–4). On average, 63 percent of the precipitation resulted in direct runoff from the site. There were two events during which stormwater bypassed the SFD after heights of the weirs were increased, but data from 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 sample was collected; therefore, bypassing events are not included in the report.

Particle-Size Distributions

Sufficient sample volume was available to do particle-size analysis for 36 events (appendix 2–8). The particle-size distributions (PSD) at the inlet and outlet varied for each event. For the inlet samples the portion of silt- and clay-sized particles (<63 µm) ranged from 29 to 80 percent. A similar range occurred for the outlet samples; the portion of silt- and clay-sized particles ranged from 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).

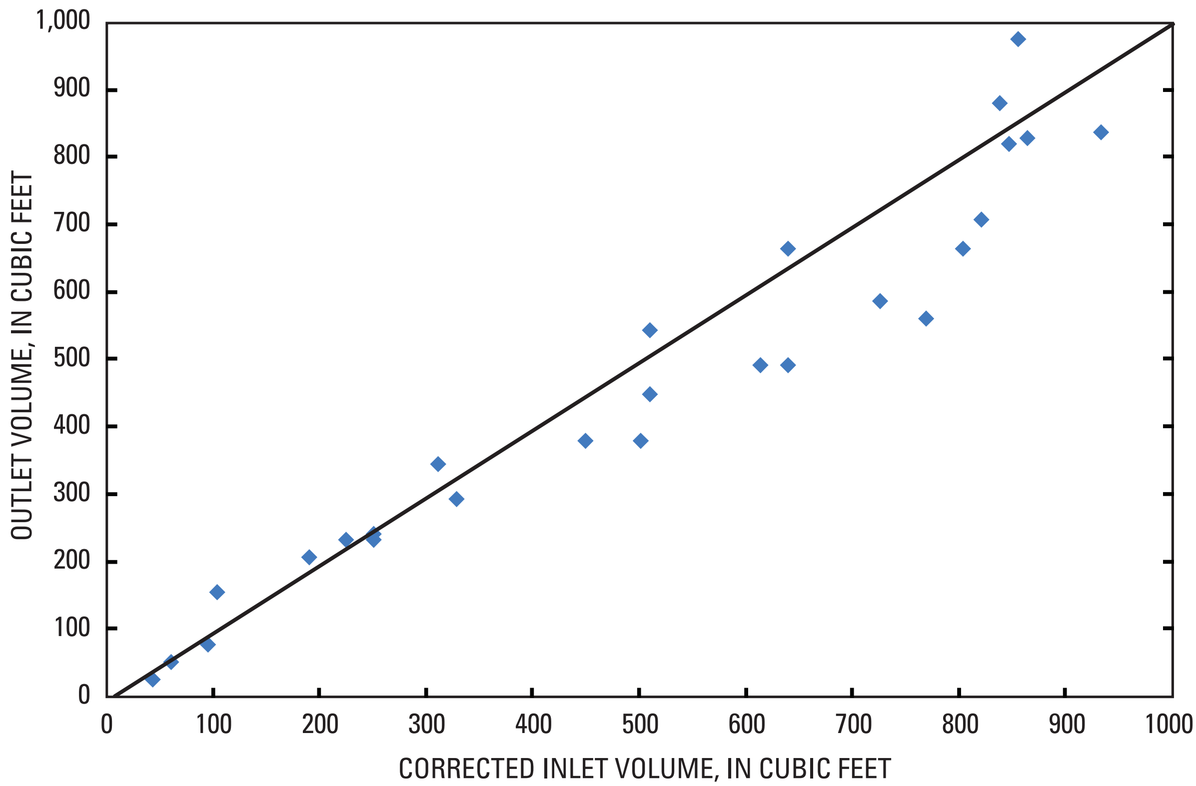

Figure 10. Stormwater volumes at the inlet of the stormwater-filtration device corrected by dye dilution in relation to outlet volumes, Madison, Wis., 2007.

Table 4. Average particle-size distribution in stormwater samples collected from the inlet and outlet of a stormwater-filtration device, Madison, Wis.

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

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

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 µm 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 effect 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 indicated about a 20-percent reduction in concentrations of TSS and SS was possible by controlling all the particles greater than 250 microns. About a 40- and an 80-percent reduction might be possible by trapping all the particles greater than 63 and 4 µm, respectively. The average particle-size distribution is necessary to enter in some models, such as WinSLAMM, which is designed to predict the TSS reduction in stormwater-control devices. A PSD for each transportation facility appears to be a necessary input to determine device efficiency in such models.

Water-Quality Data for the Inlet and Outlet

Constituent concentrations for each stormwater event are listed in appendix 2 (appendixes 2–5 through 2–7). Thirty-three constituents were analyzed for the inlet and outlet samples. Eighteen of the constituents were individual PAH compounds. Samples from 31 runoff events were analyzed for all constituents except PAHs. Samples from 15 stormwater events were analyzed for PAHs.

Non-detectable compounds composed a substantial proportion of the total PAH results. Non-detectable compounds were below detection limits for samples from the outlet more often than samples from the inlet. To calculate summary statistics for individual PAH compounds that had non-detects less than 80 percent, the Kaplan-Meier analysis was used (Helsel, 2004). Non-detectable compounds that were greater than 80 percent detection were the following 7 of the 18 PAHs: 1-methylnaphthalene, 2-methylnaphthalene, acenaphthylene, acenaphthene, fluorene, dibenzo[a,h]anthracene, naphthalene; summary statistics were not computed for these compounds. 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. To be consistent with other USGS studies, the total PAH concentrations were calculated by using zero (Mahler and others, 2005).

Constituent concentrations followed a log-normal distribution from inlet and outlet samples. The Shapiro-Wilk statistic was used to test for normality (Helsel and Hirsch, 1992). Runoff data from many urban sites around the country exhibited similar distributions for event-mean concentrations; these concentrations were either log-normal or could be approximated as log-normally distributed (Driscoll and others, 1990). Data sets that were log-normally distributed are better estimated by the median because it reduces the influence of a few extreme observations. The mean concentrations are also reported because they are used to calculate the efficiency ratio. These are typical reporting methods used to determine removal efficiencies for urban stormwater best-management practices (Strecker and others, 2003). The minimums, maximums, medians, and means for all the constituents are presented in table 5, and the statistics for individual PAHs are presented in table 6.

Table 5. Summary statistics for selected water-quality constituents in samples collected from a stormwater-filtration device, Madison, Wis.

[mg/L, milligrams per liter; <, less than; ( ), number of nondetects; { }, without total suspended solids for runoff event 12 and total phosphorus for runoff event 8—concentrations for these events appeared to be in error; --, not computed; µg/L micrograms per liter; PAHs, polycyclic aromatic hydrocarbons]

Constituent	Number of samples	Minimum		Maximum		Median		Mean	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
[1]Solids, suspended total, mg/L	44	<2.0 (2.0)	<2.0 (2.0)	190	50	15	12	27 {24}	15
Sediment, suspended, mg/L	50	2.0	1.9	82	62	19	9.0	23	14
[1]Solids, volatile suspended, mg/L	28	<2.0 (1.0)	<2.0 (2.0)	55	23	7.0	5.0	10	6.0
[1]Solids, dissolved, mg/L	43	<50 (39)	<50 (39)	55	23	<50	<50	--	--
[1]Chemical oxygen demand, total, mg/L	30	<9.0 (6.0)	<9.0 (3.0)	52	58	18	16	22	20
[1]Chemical oxygen demand, dissolved, mg/L	23	<9.0 (12)	<9.0 (14)	41	46	<9.0	<9.0	--	--
Phosphorus, total, mg/L	31	.019	.022	2.0	.11	.058 {.055}	.050	.12 {.057}	.054
Phosphorus, dissolved, mg/L	31	.0080	.012	.085	.064	.030	.026	.034	.028
Chloride, mg/L	38	.80	.80	39	41	1.8	2.1	4.3	5.1
[1]Copper, dissolved, µg/L	31	<1.0 (15)	<1.0 (14)	4.0	5.0	1.9	1.9	2.1	2.0
[1]Copper, total recoverable, µg/L	31	<2.0 (2.0)	<2.0 (2.0)	13	8.0	4.2	3.5	4.7	3.7
[1]Zinc, dissolved, µg/L	29	<16 (1.0)	<16 (1.0)	22	20	8.0	11	8.6	12
[1]Zinc, total recoverable, µg/L	29	<16	<16	51	54	20	16	24	23
Calcium, total recoverable, mg/L	31	2.6	2.6	8.6	7.1	4.2	4.0	4.6	4.4
Magnesium, total recoverable, mg/L	31	.70	.70	4.0	2.9	1.2	1.0	1.5	1.2
PAHs, total, µg/L	15	--	--	--	--	54	24	64	34

[1]Kaplan-Meier analysis for non-detects was used to calculate summary statistics (Helsel, 2005).

Table 6. Summary statistics for individual polycyclic aromatic hydrocarbons in 15 samples collected from a stormwater-filtration device, Madison, Wis.

[All constituents in micrograms per liter; <, less than; --, not computed]

Constituent	Number of non-detects		Minimum		Maximum		Median		Mean	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
2-Methylnaphthalene	11	13	<0.049	<0.049	0.11	0.12	--	--	--	--
1-Methylnaphthalene	15	15	<.064	<.064	<.64	<.20	--	--	--	--
Acenaphthylene	15	15	<.11	<.11	<1.1	<.33	--	--	--	--
Acenaphthene	9	13	<.064	<.064	.17	.24	--	--	--	--
Anthracene[1]	1	4	.052	<.031	.97	.49	0.25	0.074	0.27	0.13
Benzo[b]fluoranthene	0	0	1.7	.91	18	11	5.2	2.7	6.4	3.8
Benzo[k]fluoranthene	0	0	.68	.36	8.2	4.8	2.4	1.1	2.9	1.6
Benzo[a]pyrene	0	0	.66	.33	12	6.4	3.6	1.1	3.7	1.9
Chrysene	0	0	1.4	.62	17	9.5	4.7	2.3	5.7	3.1
Fluoranthene	0	0	3.7	1.6	47	25	13	5.9	16	3.3
9H-Fluorene	15	15	<.52	<.52	<.52	<.52	--	--	--	--
Indeno[1,2,3-cd]pyrene	0	0	1.1	.61	13	7.6	3.8	1.9	4.3	2.6
Phenanthrene	0	0	1.4	.60	26	13	5.8	2.6	6.8	3.5
Pyrene	0	0	2.5	.99	36	19	9.2	4.0	11	5.9
Benzo[ghi]perylene	0	0	1.2	.53	14	8.4	4.1	2.0	4.8	2.8
Benzo[a]anthracene[1]	3	4	.17	<.093	5.0	2.5	1.5	.38	1.3	.63
Dibenzo[a,h]anthracene	14	14	<.12	<.12	.47	.47	--	--	--	--
Naphthalene	15	15	<.042	<.042	<.042	<.042	--	--	--	--

[1]Kaplan-Meier analysis for non-detects was used to calculate summary statistics (Helsel, 2004).

The mean concentrations for TSS, SSC, TP, DP, TZn, and TCu were lower for this site than those for other parking lots in Wisconsin and Michigan (appendix 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 mean TSS, TP, and TCu concentrations measured at a retail parking lot in Madison, Wis., were 91 mg/L, 0.26 mg/L, and 47 µg/L, respectively (Bannerman and others, 1992), compared to the results of this study: 20 mg/L, 0.11 mg/L, and 25 µg/L, respectively. These were 2 to 7 times greater than the concentrations for the study presented in table 5. Concentrations of PAHs measured during this study were much higher than those measured for retail parking lots in Madison, Wis. (Selbig and others, 2007), but the concentrations were similar to a parking lot in Marquette, Mich. (about 260 mi to the northeast) (Steuer and others, 1997).

Efficiency Calculations

Two of the methods typically used by investigators to determine the removal efficiency of constituents by a SFD are the efficiency ratio and summation of loads (SOL) (National Cooperative Highway Research Program, 2006). The efficiency ratio uses event-mean concentration of contaminants sampled from the study. 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 runoff 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 generated by the methods 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 medians for nonparametric 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 data set because concentrations at the 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 15 inorganic constituents (excluding PSD) analyzed for the 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 different 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, probably owing to winter practices. Eleven of the 18 PAH compounds also were significantly different at the 95-percent confidence level.

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:

$$\textit{Efficiency Ratio} = 1 - (\textit{average outlet concentration} / \textit{average inlet concentration}). \quad (5)$$

Efficiency ratios were calculated for constituents at the 95-percent confidence level (table 7). Efficiencies were calculated for runoff events after November 2005 and did not include bypass events. 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 (appendix 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 were similar or higher than the TSS concentrations for this study. The TP inlet concentrations (2.0 mg/L) for runoff event 8 (appendix 2–6) was at least 20 times that of any other event. A high TP concentration for event 8 was not accompanied by an increase in DP, which would be expected to increase in most instances. Both of these concentrations were inexplicably 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 a stormwater-filtration device, Madison, Wis., 2005–07.

[Significantly different at the 95-percent level; mg/L, milligrams per liter; --, significance could not be determined; ( ), 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; µg/L, micrograms per liter; PAHs, polycyclic aromatic hydrocarbons]

Constituent	Are inlet and outlet pairs significantly different for median concentration?	Efficiency ratio[1], in percent
Total dissolved solids (mg/L)[1]	No	--
Total suspended solids (mg/L)[1]	Yes	45 (37)
Suspended sediment concentrations (mg/L)	Yes	37
Volatile solids (mg/L)	Yes	38
Dissolved phosphorus (mg/L)	No	--
Total phosphorus (mg/L)	Yes	55 (6)
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	46

[1] Efficiency was calculated when the inlet and outlet of that constituent was sampled for a runoff event.

A total PAH is the sum of 18 compounds analyzed for a runoff event. Several of the 18 compounds were reported as “non-detects”; therefore, a method was needed to sum a total PAH. Methods used to fill in non-detects include using the value of the detection limit, using one-half the detection limit, or using a zero for the detection limit. A total PAH concentration was summed by using 11 significant compounds, and excluding the 7 compounds that were insignificant (greater than 50 percent of the values were non-detects), for all 15 events. Substituting zero for non-detect values, the total PAH concentration was 955 µg/L at the inlet and 512 µg/L at the outlet, which resulted in an efficiency ratio of 46 percent—this is the lowest estimate. Substituting a non-detectable concentration for non-detect values, the total PAH concentration was 984 µg/L at the inlet and 531 µg/L at the outlet resulting in the same efficiency ratio—this is the highest estimate. Because there is much debate on which method to use for substitutions of non-detected values, the total PAH is assumed to fall somewhere between these two extremes. To be conservative, this report relies upon the first method, which is a method used in previous USGS reports (Mahlar, 2004).

Summation of Loads

The SOL method of calculating efficiencies is weighted by the runoff volume event. This method puts emphasis on the load of contaminants 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 runoff volume event) for all monitored events.

The equation for calculating the summation of loads is

$$\textit{Summation of loads} = 1 - (\textit{sum of outlet loads}/\textit{sum of inlet loads}). \quad (6)$$

SOLs were calculated for constituents at the 95-percent confidence level for a pair test; results indicated that there was a difference in the median concentration (tables 7 and 8 and appendixes 2–9, 2–10, and 2–11). Non-detectable concentrations were substituted with zero to compute loads. 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 the median; the small volume (770 ft^3) of the event resulted in a relatively small change in the SOL (appendix 2–4). Despite the relatively small volume for runoff event 8 (685 ft^3), removing the inlet TP concentration that was about 33 times the median significantly decreased the SOL (table 9).

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

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

Constituent	Are inlet and outlet pairs significantly different for median concentration?	Efficiency ratio[1], in percent
2-Methylnaphthalene	No	--
1-Methylnaphthalene	No	--
Acenaphthylene	No	--
Acenaphthene	No	--
Anthracene	Yes	56
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	54
Dibenzo[a,h]anthracene	No	--
Naphthalene	No	--

[1] Efficiency was calculated when the inlet and outlet of that constituent was sampled for a runoff event.

Table 9. Summation of loads of selected constituents and percent efficiency for a stormwater-filtration device, Madison, Wis., 2005–07.

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

Constituent	Loads at inlet (lb)	Loads at outlet (lb)	SOL[1], (%)
Total dissolved solids	--	--	--
Total suspended solids	[1]103 (94)	[1]70	32 (26)
Suspended sediment	[1]116	[1]73	37
Volatile solids	21	15	28
Dissolved phosphorus	--	--	--
Total phosphorus	.27 (.18)	.17	36 (6)
Chemical oxygen demand	--	--	--
Dissolved chemical oxygen demand	--	--	--
Dissolved copper	--	--	--
Total copper	.016	.012	23
Dissolved zinc	--	--	--
Total zinc	.080	.074	8
Dissolved chloride	13	16	-21
Total PAHs	[2].087	[2].045	48

[1]Summation of loads was calculated for only those events when both constituents were sampled.

[2]Total PAH was summed using 11 significant compounds and by replacing non-detect values with zero.

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

The SOL for total PAHs (table 9) was computed using the same approach as the efficiency ratio; that is, computing the extreme low and extreme high estimates and assuming that the totals fell somewhere between these extremes. Replacement of non-detects with zero resulted in an inlet load of 0.087 lb and an outlet load of 0.045 lb. Replacement of non-detects with the limit of detection (table 2) resulted in an inlet load of 0.09 lb and an outlet load of 0.047 lb. To be conservative with estimates for total PAH load, table 9 reports the replacement of non-detects with zero.

Summary

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

The SFD is a concrete structure (16 ft long by 8 ft wide and 5.5 ft deep) that was installed underneath the parking lot, and 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 an 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 (PAHs). Samples from 31 runoff events were analyzed for all the constituents except PAHs, which were analyzed in samples from 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 included 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 45, 37, 38, 55, 22, 5, and 46 percent, respectively. The SOLs for these constituents were 32, 37, 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 dissolved phosphorus, total chemical oxygen demand, dissolved chemical oxygen demand, dissolved zinc, total dissolved solids, and dissolved copper, efficiency ratios and SOLs were not calculated because the differences between the inlet and outlet concentrations were determined to be statistically insignificant.

Efficiency ratios and SOLs were similar for total PAHs, TZn, TCu, and Cl. When two inexplicably 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 became 5 and 6 percent, respectively, and the ratios for TSS became 26 and 37 percent, respectively. Only SS and VSS had 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 WisDOT park-and-ride lots. Because of the two inexplicably 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 different 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 WisDOT 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 in the runoff was about 80 percent, but for this study the average percent sand was about 40 percent.

Models can be used as tools for predicting the level of control to be expected for different types of stormwater-control devices, including a 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 contaminant loads from various source areas such as parking lots. Models can also be used to predict reduction in loads from different kinds of stormwater-control devices, such as a SFD. Constituent concentrations in samples from flows to the inlet of the SFD provide 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 relation developed for a SFD. Unfortunately, none of the available urban runoff models, including WinSLAMM, include a pollutant reduction relation for a SFD. Results from this project could be instrumental in developing algorithms to predict the efficiency of a SFD based on inlet concentration, particle size, filter media type, and flow rates.

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Appendix 2. Tables of Sample Analyses Results

Table 2–1. Concentrations of selected constituents in equipment-field-blank data collected from a stormwater-filtration device, Madison, Wis., 2005–07.

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

Constituent	Unit	Blank1 7/7/2005			Blank 2 7/13/2006			Blank 3 6/11/2007			LOD	LOQ
		Inlet	Outlet	Bypass	Inlet	Outlet	Bypass	Inlet	Outlet	Bypass		
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 stormwater-filtration device and sample, Madison, Wis., 2005–07.

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

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 solids, 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 solids, (mg/L)	na	Inlet	--	--	--	9	10	-11	7	7	0	7	7	0
		Outlet	--	--	--	6	6	0	5	5	0	5	5	0
Suspended solids, 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	.062	.061	.16	.02	.02	0	.026	.028	-7	.053	.055	-4
		Outlet	.07	.064	9.0	.012	.012	0	.031	.030	3	.038	.039	-3
Phosphorus, total (mg/L)	30	Inlet	.089	.089	0	.058	.059	-2	.052	.053	-2	.072	.072	0
		Outlet	.079	.079	0	.040	.044	-10	.043	.041	5	.077	.072	-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	--	46	36	24
Chloride, dissolved (mg/L)	25	Inlet	1.7	1.7	0	1.9	1.8	5	.8	.8	0	1.2	1.2	0
		Outlet	2	2	0	2.1	1.9	10	--	--	--	2.1	2	5
Copper, dissolved (µg/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 (µg/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

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

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

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 (%)
Zinc, dissolved (µg/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 (µg/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	.9	.9	0	1.1	1.1	0	.8	.8	0	1.6	1.7	-6

Table 2–3. Precipitation during sampling events from a stormwater-filtration device, Madison, Wis., 2005–07.

[mm, month; dd, day; yyyy, year; hh, hour; mm, min, minute; in., inch; in/h, inch per hour; ft-lb/acre, foot per pound per acre; ft^3, cubic foot]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	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 hh: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
1	11/06/2005 01:33	11/06/2005 05:28	03:55	.23	.14	.11	.21	720	00 01:41
1	11/12/2005 16:14	11/12/2005 17:08	00:54	.09	.25	.14	.11	280	06 10:46
1	11/12/2005 21:47	11/12/2005 22:05	00:18	.07	.22	--	--	220	00 04:39
1	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
2	11/15/2005 21:25	11/16/2005 01:16	03:51	.05	.04	.02	.01	170	00 01:02
2	11/23/2005 08:58	11/23/2005 09:28	00:30	.06	.14	.13	.07	190	07 07:42
2	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
3	12/23/2005 08:45	12/23/2005 12:13	03:28	.17	.11	.11	.15	530	25 01:15
3	01/01/2006 20:21	01/01/2006 22:47	02:26	.10	.07	.05	.04	310	09 08:08
3	01/02/2006 06:58	01/02/2006 14:23	07:25	.73	.29	.25	1.5	2,250	00 08:11
3	01/24/2006 09:06	01/24/2006 10:09	01:03	.10	.18	.14	.12	310	21 18:43
3	01/28/2006 05:16	01/28/2006 06:04	00:48	.08	.18	.13	.08	250	03 19:07
3	01/28/2006 09:02	01/28/2006 09:30	00:28	.05	.14	--	--	170	00 02:58
3	01/28/2006 12:34	01/28/2006 17:22	04:48	.23	.11	.09	.17	720	00 03:04
3	01/28/2006 19:48	01/29/2006 08:42	12:54	.80	.18	.14	.95	2,470	00 02:26
3	02/03/2006 05:29	02/03/2006 06:13	00:44	.05	.11	.09	.04	170	04 20:47
3	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
4	03/12/2006 21:52	03/13/2006 00:10	02:18	.34	.28	.24	.69	1,050	03 23:17
4	03/13/2006 02:35	03/13/2006 03:34	00:59	.11	.16	.12	.11	340	00 02:25
4	03/17/2006 12:07	03/17/2006 13:13	01:06	.10	.24	.18	.15	310	04 08:33
4	03/23/2006 16:00	03/23/2006 17:24	01:24	.10	.16	.12	.10	310	06 02:47
4	03/30/2006 22:42	03/31/2006 02:10	03:28	.18	.16	.12	.18	560	07 05:18
4	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
8	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

Table 2–3. Precipitation during sampling events from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[mm, month; dd, day; yyyy, year; hh, hour; mm, min, minute; in., inch; in/h, inch per hour; ft-lb/acre, foot per pound per acre; ft^3, cubic foot]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Precipi-tation duration (hh:mm)	Total precipi-tation (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 hh:mm)
9	04/19/2006 04:28	04/19/2006 05:47	01:19	0.16	0.56	0.28	0.42	490	02 11:48
9	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
10	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
11	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
12	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
13	05/12/2006 00:44	05/12/2006 03:44	03:00	.07	.07	.05	.03	220	00 01:32
13	05/13/2006 10:40	05/13/2006 11:32	00:52	.05	.11	.07	.03	170	01 06:56
13	05/13/2006 15:38	05/13/2006 16:45	01:07	.10	.14	.11	.09	310	00 04:06
13	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
15	05/24/2006 18:37	05/24/2006 19:03	00:26	1.83	6.13	--	--	5,660	07 02:24
15	05/24/2006 21:11	05/24/2006 21:37	00:26	.10	.36	--	--	310	00 02:08
15	05/30/2006 13:26	05/30/2006 13:33	00:07	.05	--	--	--	170	05 15:49
15	06/06/2006 05:37	06/06/2006 08:16	02:39	.14	.14	.11	.13	440	06 16:04
15	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
16	06/14/2006 11:27	06/14/2006 13:03	01:36	.13	.25	.13	.13	390	04 04:41
16	06/18/2006 07:19	06/18/2006 09:39	02:20	.08	.11	.07	.05	250	03 18:16
16	06/18/2006 12:16	06/18/2006 13:11	00:55	.09	.25	.14	.11	280	00 02:37
16	06/21/2006 05:52	06/21/2006 06:49	00:57	.09	.32	.16	.12	280	02 16:41
16	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
19	07/22/2006 16:31	07/22/2006 17:51	01:20	.16	.48	.28	.39	490	02 09:32
19	07/25/2006 23:47	07/26/2006 01:08	01:21	.05	.11	.05	.02	170	03 05:56
19	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

Table 2–3. Precipitation during sampling events from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[mm, month; dd, day; yyyy, year; hh, hour; mm, min, minute; in., inch; in/h, inch per hour; ft-lb/acre, foot per pound per acre; ft³, cubic foot]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	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 (ft³)	Antecedent dry times (dd hh:mm)
23	08/23/2006 22:26	08/23/2006 23:55	01:29	0.34	0.72	0.58	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
24	08/25/2006 05:11	08/25/2006 06:51	01:40	.26	.32	.28	.61	800	00 14:11
24	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
25	08/26/2006 01:22	08/26/2006 01:30	00:08	.10	--	--	--	310	00 11:42
25	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
26	09/10/2006 14:41	09/10/2006 23:30	08:49	.38	.16	.12	.38	1,170	06 06:21
26	09/11/2006 11:30	09/11/2006 11:57	00:27	.07	.20	--	--	220	00 12:00
26	09/11/2006 15:20	09/11/2006 20:07	04:47	.38	.60	.36	1.2	1,170	00 03:23
26	09/12/2006 02:10	09/12/2006 06:02	03:52	.53	.40	.28	1.3	1,640	00 06:03
26	09/12/2006 09:37	09/12/2006 11:38	02:01	.17	.24	.20	.29	520	00 03:35
26	09/12/2006 13:30	09/12/2006 17:22	03:52	.69	1.04	.86	5.3	2,130	00 01:52
26	09/21/2006 21:39	09/21/2006 22:50	01:11	.06	.08	.06	.03	190	09 04:17
26	09/22/2006 05:16	09/22/2006 06:48	01:32	.11	.16	.12	.11	340	00 06:26
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
27	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
28	10/18/2006 14:36	10/18/2006 16:02	01:26	.07	.08	.08	.05	220	01 07:23
28	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
29	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
30	11/12/2006 11:31	11/12/2006 18:46	07:15	.44	.16	.14	.52	1,360	01 21:04
30	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
32	11/29/2006 02:52	11/29/2006 04:39	01:47	.10	.16	.12	.10	310	00 22:52
32	11/29/2006 18:04	11/29/2006 20:03	01:59	.06	.08	.04	.02	190	00 13:25

Table 2–3. Precipitation during sampling events from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[mm, month; dd, day; yyyy, year; hh, hour; mm, min, minute; in., inch; in/h, inch per hour; ft-lb/acre, foot per pound per acre; ft^3, cubic foot]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Precipi-tation duration (hh:mm)	Total precipi-tation (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 hh:mm)
32	12/20/2006 19:45	12/21/2006 03:39	07:54	0.23	0.08	0.08	0.16	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
34	12/31/2006 07:12	12/31/2006 10:24	03:12	.23	.28	.24	.47	710	08 15:33
34	01/26/2007 13:45	01/26/2007 14:44	00:59	.14	.28	.20	.24	430	26 03:21
34	02/25/2007 06:09	02/25/2007 15:46	09:37	.46	.16	.12	.47	1,420	29 15:25
34	02/26/2007 14:04	02/26/2007 16:04	02:00	.10	.08	.08	.07	310	00 22:18
34	03/01/2007 10:11	03/01/2007 14:34	04:23	.31	.40	.30	.78	960	02 18:07
34	03/09/2007 15:02	03/09/2007 18:38	03:36	.20	.12	.10	.17	620	08 00:28
34	03/14/2007 16:38	03/14/2007 18:37	01:59	.06	.08	.04	.02	190	04 22:00
34	03/21/2007 03:16	03/21/2007 05:45	02:29	.11	.20	.14	.13	340	06 08:39
34	03/21/2007 08:32	03/21/2007 10:33	02:01	.07	.12	.08	.05	220	00 02:47
34	03/21/2007 17:39	03/21/2007 18:37	00:58	.12	.24	.14	.16	370	00 07:06
34	03/22/2007 01:24	03/22/2007 03:14	01:50	.54	1.16	.82	4.1	1,670	00 06:47
34	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
36	04/11/2007 00:03	04/11/2007 06:50	06:47	.20	.08	.08	.14	620	07 16:32
36	04/12/2007 11:20	04/12/2007 14:38	03:18	.18	.12	.08	.13	560	01 04:30
36	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
38	04/25/2007 00:21	04/25/2007 04:43	04:22	.27	.12	.10	.23	830	00 01:03
38	04/25/2007 20:20	04/25/2007 21:13	00:53	.06	.08	.06	.03	190	00 15:37
38	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
39	04/30/2007 20:37	04/30/2007 20:56	00:19	.08	.28	--	--	250	04 07:54
39	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
40	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
41	05/26/2007 14:41	05/26/2007 15:09	00:28	.06	.20	--	--	190	01 20:17
41	06/01/2007 16:44	06/01/2007 17:30	00:46	.20	.64	.38	.71	620	06 01:35
41	06/02/2007 06:36	06/02/2007 08:13	01:37	.23	.40	.28	.55	710	00 13:06

Table 2–3. Precipitation during sampling events from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[mm, month; dd, day; yyyy, year; hh, hour; mm, min, minute; in., inch; in/h, inch per hour; ft-lb/acre, foot per pound per acre; ft^3, cubic foot]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Precipi-tation duration (hh:mm)	Total precipi-tation (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 hh:mm)
41	06/03/2007 16:56	06/03/2007 19:42	02:46	0.70	1.12	0.66	4.3	2,160	01 08:43
41	06/03/2007 20:55	06/03/2007 22:50	01:55	.36	.56	.36	1.1	1,110	00 01:13
41	06/04/2007 06:00	06/04/2007 07:48	01:48	.27	.28	.20	.46	830	00 07:10
41	06/04/2007 08:56	06/04/2007 09:56	01:00	.14	.48	.26	.32	430	00 01:08
41	06/06/2007 15:02	06/06/2007 17:12	02:10	.06	.08	.04	.02	190	02 05:06
41	06/11/2007 09:10	06/11/2007 09:49	00:39	1.21	2.08	2.02	25	3,730	04 15:58
41	06/18/2007 15:46	06/18/2007 16:14	00:28	.09	.24	--	--	280	07 05:57
41	06/18/2007 18:44	06/18/2007 19:02	00:18	.11	.40	--	--	340	00 02:30
41	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
44	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
51	08/22/2007 01:29	08/22/2007 03:47	02:18	.28	.47	.27	.64	860	02 13:13
51	08/22/2007 15:55	08/22/2007 16:32	00:37	.15	.33	.24	.32	480	00 12:08
51	08/22/2007 18:31	08/22/2007 21:19	02:48	.40	.47	.36	1.2	1,220	00 01:59
51	08/23/2007 04:29	08/23/2007 05:11	00:42	.07	.14	.13	.08	220	00 07:10
51	08/23/2007 07:02	08/23/2007 08:38	01:36	.34	.40	.38	1.1	1,060	00 01:51
51	08/23/2007 17:34	08/23/2007 17:43	00:09	.05	--	--	--	170	00 08:56
51	08/24/2007 02:49	08/24/2007 04:22	01:33	.61	1.09	.94	5.3	1,870	00 09:06
51	08/24/2007 16:15	08/24/2007 16:53	00:38	.73	1.87	1.37	9.8	2,250	00 11:53
51	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 a stormwater-filtration device, Madison, Wis., 2005–07.

[mm, month; dd, day; yyyy, year; hh, hour; mm, minute; in., inch; ft^3, cubic foot; ft^3/s, cubic foot per second]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Total precipitation (in.)	Volume (ft^3)	Percent runoff	Peak discharge (ft^3/s)
1	11/05/2005 17:40	11/06/2005 00:39	1.01	2,015	60	0.42
2	11/15/2005 13:38	11/15/2005 20:51	.77	1,640	64	.51
3	11/28/2005 03:18	11/28/2005 08:09	.63	1,165	55	.70
4	03/08/2006 18:08	03/08/2006 22:58	.85	2,240	79	.09
5	04/02/2006 11:19	04/02/2006 13:36	.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	.44	685	46	.84
9	04/16/2006 04:17	04/16/2006 17:10	.95	2,125	67	.10
10	04/29/2006 18:28	04/29/2006 23:41	.33	630	57	.99
11	05/01/2006 21:09	05/01/2006 22:35	.41	1,045	76	.42
12	05/09/2006 14:26	05/09/2006 17:29	.41	770	57	.07
13	05/11/2006 13:32	05/12/2006 06:38	.62	1,840	89	.11
14	05/16/2006 15:23	05/16/2006 18:52	.19	335	53	.77
15	05/17/2006 15:30	05/17/2006 17:01	.36	845	70	.51
16	06/10/2006 00:58	06/10/2006 07:23	.69	985	43	.67
17	06/25/2006 17:57	06/26/2006 09:37	.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	.88	1,850	63	.60
20	08/06/2006 07:21	08/06/2006 11:29	.87	1,020	35	.68
21	08/09/2006 18:49	08/09/2006 19:19	.21	240	35	.71
22	08/17/2006 16:42	08/17/2006 17:23	.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	.59	475	24	.73
27	10/04/2006 06:11	10/04/2006 10:56	.33	620	56	.45
28	10/16/2006 23:28	10/17/2006 07:32	.75	2,110	84	.06
29	10/21/2006 13:08	10/22/2006 01:48	.58	1,020	53	.59
30	11/10/2006 12:28	11/10/2006 14:54	.55	590	32	.08
31	11/26/2006 23:12	11/27/2006 02:05	.21	300	43	.71
32	11/27/2006 20:18	11/28/2006 08:19	.76	2,340	92	.49
33	12/21/2006 07:50	12/21/2006 13:43	.47	1,165	74	.71
34	12/22/2006 14:00	12/22/2006 15:34	.23	615	80	.79
35	03/31/2007 08:46	03/31/2007 23:20	1.04	2,585	74	.87

Table 2–4. Outlet flow volumes, percent runoff, and peak discharge for sampled events at a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[mm, month; dd, day; yyyy, year; hh, hour; mm, minute; in., inch; ft^3, cubic foot; ft^3/s, cubic foot per second]

Sampling event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Total precipitation (in.)	Volume (ft^3)	Percent runoff	Peak discharge (ft^3/s)
36	04/03/2007 00:13	04/03/2007 07:51	1.58	4,085	77	0.67
37	04/23/2007 00:54	04/23/2007 07:10	.49	1,035	63	.05
38	04/24/2007 17:27	04/24/2007 19:44	.35	235	20	.08
39	04/26/2007 09:37	04/26/2007 13:05	.32	665	62	.66
40	05/15/2007 12:39	05/15/2007 17:49	.59	1,235	63	.73
41	05/24/2007 16:43	05/24/2007 18:47	.49	830	51	.69
42	06/21/2007 19:01	06/21/2007 23:09	.43	560	39	.39
43	07/03/2007 20:54	07/03/2007 23:33	.47	590	37	.68
44	07/26/2007 10:28	07/27/2007 01:43	.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	.60	1,805	90	.92
47	08/09/2007 03:13	08/09/2007 07:14	.86	2,755	96	.81
48	08/12/2007 01:04	08/12/2007 02:48	.68	840	37	.88
49	08/14/2007 02:43	08/14/2007 07:03	.56	1,980	107	.10
50	08/15/2007 08:15	08/15/2007 14:32	.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, volatile solids, and dissolved solids in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07.

[All data are in milligrams per liter; --, no sample processed for event; <, less than]

Sampling event number	Suspended solids, total		Suspended sediment		Solids, volatile		Solids, dissolved	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	14	8	22	7	--	--	<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	<2	<50	<50
14	80	12	82	12	--	--	<50	<50
15	102	34	77	30	55	15	--	--
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
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

Table 2–5. Concentrations of suspended solids, suspended sediment, volatile solids, and dissolved solids in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[All data are in milligrams per liter; --, no sample processed for event; <, less than]

Sampling event number	Suspended solids, total		Suspended sediment		Solids, volatile		Solids, dissolved	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
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	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 properties in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07.

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

Sampling event number	Chemical oxygen demand, total (mg/L)		Phosphorus, total (mg/L)		Phosphorus, dissolved (mg/L)		Chloride, dissolved (mg/L)		Copper, dissolved (µg/L)		Copper, total recoverable (µg/L)		Zinc, dissolved (µg/L)		Zinc, total recoverable (µg/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
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

Table 2–6. Concentrations of selected constituents and physical properties in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

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

Sampling event number	Chemical oxygen demand, total (mg/L)		Phosphorus, total (mg/L)		Phosphorus, dissolved (mg/L)		Chloride, dissolved (mg/L)		Copper, dissolved (µg/L)		Copper, total recoverable (µg/L)		Zinc, dissolved (µg/L)		Zinc, total recoverable (µg/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
25	13	19	0.02	0.02	0.01	<0.005	0.80	0.90	<2.0	<2.0	3	3	11	11	18	20	2.9	3.0	0.90	0.90
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. Mean concentrations of selected polycyclic aromatic hydrocarbons in samples collected from a stormwater-filtration device, Madison, Wis., 2005–07.

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

Sampling event number	2-Methylnaphthalene	1-Methylnaphthalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo[b] fluoranthene	Benzo[k]fluoranthene	Benzo[a]pyrene	Chrysene	Fluoranthene	9H-Fluorene	Indeno [1,2,3-cd] pyrene	Phenanthrene	Pyrene	Benzo [ghi] perylene	Benzo [a] anthracene	Dibenzo [a,h] anthracene	Naphthalene
Inlet																		
10	<0.049	<0.064	<0.11	0.08	0.25	5.2	2.4	2.8	4.6	13	<0.52	3.8	5.8	9.2	4.0	1.2	<0.37	<0.042
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
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

Table 2–7. Mean concentrations of selected polycyclic aromatic hydrocarbons in samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

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

Sampling event number	2-Methylnaph-thalene	1-Methylnaph-thalene	Acenaphthylene	Acenaphthene	Anthracene	Benzo[b] fluor-anthene	Benzo[k]fluoran-thene	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—continued																		
19	<0.049	<0.064	<0.11	<0.064	0.12	3.2	1.4	1.1	2.7	7.0	<0.52	2.3	2.6	4.7	2.3	0.38	<0.21	<0.042
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 a stormwater-filtration device, Madison, Wis., 2005–07.

[All data are in percent by mass; <, less than; µm, micrometer]

Sampling event number	<500 µm		<250 µm		<125 µm		<63 µm		<31 µm		<16 µm		<8 µm		<4 µm		<2 µm	
	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
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

Table 2–8. Particle-size distributions in samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[All data are in percent by mass; <, less than; µm, micrometer]

Sampling event number	<500 µm		<250 µm		<125 µm		<63 µm		<31 µm		<16 µm		<8 µm		<4 µm		<2 µm	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
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, suspended sediment, volatile solids, and dissolved solids in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07.

[All data in pounds; --, no sample processed for event]

Sampling event number	Suspended solids, total		Concentrations of suspended sediment		Solids, volatile		Solids, dissolved	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	1.8	1.0	2.8	0.9	--	--	--	--
2	1.0	.7	1.9	.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	11.3
5	.8	.3	.8	.3	--	--	1.6	2.0
6	2.1	2.1	2.4	1.9	--	--	--	--
7	16.8	11.1	18.5	11.1	3.7	2.7	--	--
8	1.1	1.1	1.5	1.1	.3	.3	--	--
9	4.7	2.7	6.0	2.7	1.3	.8	--	--
10	.6	.5	.6	.5	.2	.2	--	--
11	2.8	1.6	3.0	1.6	.9	.5	--	--
12	9.2	.1	.7	.1	.9	.1	--	--
13	.6	.2	.7	.2	.5	--	--	--
14	1.7	.3	1.7	.3	--	--	--	--
15	5.4	1.8	4.1	1.6	2.9	.8	--	--
16	1.5	.9	2.5	.8	.6	.4	--	--
17	.9	.5	1.4	.4	.3	.2	--	--
18	.8	.6	1.4	.5	.3	.2	--	--
19	9.3	7.1	11.8	5.7	3.0	2.3	--	--
20	.9	.5	.8	.3	.3	--	--	--
21	2.6	2.1	2.7	2.1	--	--	--	3.2
22	.3	.2	.3	.2	--	--	--	--
23	.4	.3	.6	.2	.1	.1	--	--
24	3.4	1.2	3.2	1.0	1.0	--	--	--
25	1.9	2.0	1.5	1.4	1.0	.6	--	--
26	.1	.4	1.0	.4	--	--	--	--
27	.0	.7	.8	.7	.3	.2	--	--
28	.2	.2	.2	.2	.1	.1	--	--
29	.1	.1	.3	.3	--	--	--	--
30	.7	.4	2.3	.4	--	--	--	--
31	.3	.1	.3	.1	--	--	--	--
32	.1	.1	.1	.1	.1	.0	--	--
33	2.9	2.2	2.9	1.9	1.2	.9	7.7	8.2
34	2.9	2.8	2.8	2.8	1.2	1.3	--	--
35	2.5	1.9	2.9	2.4	.6	.9	--	--
36	2.4	2.3	3.6	2.6	.8	.6	--	--

Table 2–9. Loads of suspended solids, suspended sediment, volatile solids, and dissolved solids in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[All data in pounds; --, no sample processed for event]

Sampling event number	Suspended solids, total		Concentrations of suspended sediment		Solids, volatile		Solids, dissolved	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
37	4.6	5.7	4.9	5.9	2.1	1.5	--	--
38	.3	.1	.3	.2	--	--	--	--
39	.0	.0	.1	.0	--	--	--	--
40	.8	.5	.8	.4	.3	.2	--	--
41	3.1	1.8	3.4	2.0	1.1	.6	--	--
42	--	--	--	--	--	--	--	--
43	.4	.2	.4	.2	.1	.1	--	--
44	1.1	1.0	.9	.7	.5	.4	--	3.9
45	1.5	1.8	1.8	1.3	1.8	1.3	--	--
46	--	--	1.0	.6	--	--	--	--
47	--	--	.9	.9	--	--	--	--
48	--	--	.7	.5	--	--	--	--
49	--	--	.9	.9	--	--	--	--
50	--	--	.2	.1	--	--	--	--
51	--	--	2.6	3.6	--	--	--	--

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

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

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
25	1.4	2.1	.0022	.0024	.0009	.0003	.09	.10	.00006	.00006	.00033	.00033	.00122	.00122	.00199	.00222
26	--	--	--	--	--	--	--	.06	--	--	--	--	--	--	--	--

Table 2–10. Loads of selected constituents in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

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

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
27	1.6	1.4	0.0037	0.0032	0.0023	0.0020	0.05	0.07	0.00008	0.00012	0.00027	0.00020	0.00035	0.00055	0.00129	0.00117
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	.17	.18	.00031	.00031	.00039	.00023	.00085	.00132	.00210	.00217
41	2.4	1.6	.0063	.0057	.0028	.0021	.15	.19	.00021	.00026	.00042	.00042	.00073	.00099	.00209	.00214
43	1.2	1.3	.0023	.0025	.0015	.0016	.04	.05	.00007	.00007	.00015	.00011	.00030	.00048	.00070	.00070
44	3.3	4.3	.0054	.0057	.0039	.0028	.14	.16	.00030	.00022	.00045	.00030	.00164	.00149	.00246	.00223

Table 2–11. Loads of selected polycyclic aromatic hydrocarbons in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07.

[All data in pounds; --, no sample processed for event]

Sampling event number	2-Methylnaphthalene, water, unfiltered, recoverable	1-Methylnaphthalene, water, unfiltered, recoverable	Acenaphthylene, water, unfiltered, recoverable	Acenaphthene, water, unfiltered, recoverable	Anthracene, water, unfiltered, recoverable	Benzo[b]fluoranthene, water, unfiltered, recoverable	Benzo[k]fluoranthene, water, unfiltered, recoverable	Benzo[a]pyrene, water, unfiltered, recoverable	Chrysene, water, unfiltered, recoverable
					Inlet				
10	--	--	--	--	9.91131E-06	0.000206155	9.51486E-05	0.000111007	0.000182368
11	--	--	--	--	6.3742E-05	.001182841	.00053885	.00078856	.001117127
13	--	--	--	--	6.01522E-06	.000196651	7.86605E-05	7.6347E-05	.000161948
16	--	--	--	--	1.17632E-05	.000247647	.00010525	.000111441	.000222882
17	--	--	--	--	3.21507E-05	.000522448	.000231083	.000190895	.00048226
18	--	--	--	--	5.31464E-05	.001290698	.000569425	.000296101	.001176812
19	--	--	--	--	4.18393E-05	.000871653	.000418393	.000476503	.000813542
23	--	--	--	--	5.0507E-05	.001363688	.000622919	.000925961	.001195332
24	--	--	--	--	3.01087E-05	.000677445	.000313632	.000489266	.000589628
25	--	--	--	--	3.2129E-05	.00053179	.000243737	.000398842	.000476395
37	--	--	--	--	2.28096E-05	.000638669	.000299783	.000371471	.00054743
38	--	--	--	--	8.35809E-07	3.0793E-05	1.61296E-05	1.23172E-05	2.6394E-05
40	--	--	--	--	1.94153E-05	.000497032	.000217452	.000287347	.000427137
41	--	--	--	--	--	.000521362	.000250254	.000318031	.000458799
43	--	--	--	--	1.22194E-06	1.85735E-05	8.79799E-06	1.17307E-05	1.7596E-05
					Outlet				
10	--	--	--	--	5.94679E-06	.00016651	7.13615E-05	8.3255E-05	.000134794
11	--	--	--	--	3.21996E-05	.000722847	.000315424	.000420566	.000624277
13	--	--	--	--	--	.000105266	4.16438E-05	3.81735E-05	7.17199E-05
16	--	--	--	--	4.39574E-06	.000160971	6.81029E-05	5.2625E-05	.000136206
17	--	--	--	--	4.42072E-06	.000231083	9.34379E-05	4.21978E-05	.000200942
18	--	--	--	--	3.22674E-05	.000873119	.000368228	.000144254	.000721272
19	--	--	--	--	1.39464E-05	.000371905	.000162708	.000127842	.000313795
23	--	--	--	--	1.24584E-05	.000454563	.000185192	.000235699	.00038722
24	--	--	--	--	7.02536E-06	.000225815	9.65987E-05	.000137998	.000188179
25	--	--	--	--	1.44026E-05	.000387763	.000177263	.000265895	.000332368
37	--	--	--	--	2.86749E-05	.000625635	.000299783	.000404056	.000521362
38	--	--	--	--	--	1.7596E-05	7.18502E-06	6.15859E-06	1.20239E-05
40	--	--	--	--	8.54274E-06	.000287347	.000132024	.000155323	.00024075
41	--	--	--	--	--	.000323245	.000140768	.000177263	.000271108
43	--	--	--	--	--	5.37655E-06	2.05286E-06	2.24837E-06	3.91022E-06

Table 2–11. Loads of selected polycyclic aromatic hydrocarbons in stormwater samples collected from a stormwater-filtration device, Madison, Wis., 2005–07. —Continued

[All data in pounds; --, no sample processed for event]

Sampling event number	Fluoranthene, water, unfiltered, recoverable	9H-Fluorene, water, unfiltered, recoverable	Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable	Phenanthrene, water, unfiltered, recoverable	Pyrene, water, unfiltered, recoverable	Benzo[ghi]perylene, water, unfiltered, recoverable	Benzo[a]anthracene, water, unfiltered, recoverable	Dibenzo[a,h]anthracene, water, unfiltered, recoverable	Naphthalene, water, unfiltered, recoverable
					Inlet				
10	0.000515388	--	0.000150652	0.000229942	0.000364736	0.000158581	4.75743E-05	--	--
11	.003088528	--	.000854274	.001708548	.002365681	.000919987	.000328567	--	--
13	.000428006	--	.000127245	.000161948	.000289193	.000138813	1.96651E-05	--	--
16	.000681029	--	.000173353	.000253838	.000439574	.000185735	--	--	--
17	.001507063	--	.000381789	.000733437	.001004709	.000411931	--	--	--
18	.003378591	--	.000911081	.001214774	.00223974	.000987004	--	--	--
19	.002208187	--	.000615968	.000836786	.001627085	.000662456	.000220819	--	--
23	.003030418	--	.000993304	.001060646	.002188635	.001060646	.000303042	--	--
24	.001505434	--	.000514356	.000526902	.001129075	.000539447	.000188179	--	--
25	.001218684	--	.000387763	.000443158	.000963869	.000421	.000188342	--	--
37	.001564087	--	.000377988	.000716873	.001107895	.000462709	.000110789	--	--
38	6.59849E-05	--	1.7596E-05	2.78603E-05	4.54563E-05	2.05286E-05	4.98553E-06	--	--
40	.001397903	--	.000279581	.000512564	.000854274	.00034171	8.54274E-05	--	--
41	.001303406	--	.000323245	.000458799	.000886316	.000385808	9.38452E-05	--	--
43	5.37655E-05	--	1.17307E-05	2.00399E-05	3.56807E-05	1.36858E-05	4.74114E-06	--	--
					Outlet				
10	.000344914	--	.000118936	.000174439	.000261659	.000126865	2.25978E-05	--	--
11	.001642834	--	.000499422	.000854274	.001248554	.000551992	.000164283	--	--
13	.000185084	--	7.17199E-05	6.94064E-05	.00011452	6.13089E-05	--	--	--
16	.000365279	--	.000111441	.000167162	.000247647	.000117632	--	--	--
17	.000522448	--	.000160753	.0001708	.000351648	.0001708	--	--	--
18	.002163816	--	.000607387	.000797196	.001404583	.000645349	--	--	--
19	.000813542	--	.000267307	.000302173	.000546236	.000267307	4.41637E-05	--	--
23	.000959632	--	.000319877	.000303042	.000656591	.000336713	6.06084E-05	--	--
24	.000439085	--	.000163089	.000150543	.000326177	.000175634	4.01449E-05	--	--
25	.00074229	--	.000288053	.000288053	.000576105	.000310211	8.53079E-05	--	--
37	.001433746	--	.000404056	.000651703	.001042725	.000469226	.000143375	--	--
38	3.0793E-05	--	8.94462E-06	1.29037E-05	2.05286E-05	1.11441E-05	1.437E-06	--	--
40	.000691185	--	.000163089	.00024075	.000419371	.000201919	4.19371E-05	--	--
41	.000729907	--	.000260681	.000260681	.000500508	.000234613	4.64012E-05	--	--
43	9.77554E-06	--	3.17705E-06	3.37256E-06	6.3541E-06	3.66583E-06	6.3541E-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 Company, Madison	20	21	0.03	0.11	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	.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	--	.22	.21	25	178	--
Commercial strip, Madison (Bannerman 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

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