Effectiveness of a Hydrodynamic Settling Device and a Stormwater Filtration Device in Milwaukee, Wisconsin

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16. Abstract

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An efficiency ratio and summation of loads (SOL) calculation were used to estimate the treatment efficiency of each device. Most constituents showed a reduction in average concentration and total load leaving the device, but a few constituents, especially dissolved ones, showed an increase in concentration and load at the outlets. The efficiency ratios for the HSD tend to be higher than the SOLs. In contrast the efficiency ratios and SOLs are about the same for the SFD.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
millimeter (mm)	0.03937	inch (in.)
	Area	
Acre	4,047	square meter (m^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^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-thousand of a millimeter.

Effectiveness of a Hydrodynamic Settling Device and a Stormwater Filtration Device in Milwaukee, Wisconsin

By Judy A. Horwatich[1], Roger T. Bannerman[2], and Robert Pearson[3]

Abstract

The treatment efficiency of two proprietary stormwater treatment devices was tested at a freeway site in an ultra-urban part of Milwaukee, Wis. One treatment device is categorized as a hydrodynamic settling device (HSD) that removes pollutants by sedimentation and flotation. The other treatment device is categorized as a stormwater filtration device (SFD) that removes pollutants by filtration and sedimentation. During runoff events, flow measurements were recorded and water-quality samples were collected at the inlet and outlet of each device.

An efficiency ratio and summation of loads (SOL) calculation were used to estimate the treatment efficiency of each device. Most constituents showed a reduction in average concentration and total load leaving the device, but a few constituents, especially dissolved ones, showed an increase in concentration and load at the outlets. The efficiency ratios for the HSD tend to be higher than the SOLs. In contrast the efficiency ratios and SOLs are about the same for the SFD.

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[1] U.S. Geological Survey.
[2] Wisconsin Department of Natural Resources.
[3] Wisconsin Department of Transportation.

Constituents whose average concentrations and loads decreased passing through by the HSD include total suspended solids (TSS), suspended-sediment (SS) concentration, total phosphorus, total copper, and total zinc,. The efficiency ratios for these constituent were 42, 57, 16, 33, and 23 percent, respectively. Constituents calculated for the SOLs had a loads removal rate of 25, 49, 10, 27, and 16 percent, respectively. Concentrations and loads increased at the outlet for chloride, total dissolved solids, and dissolved zinc. The efficiency ratios for these constituents were -347, -194, and -19 percent, respectively. Four constituents—dissolved phosphorus, chemical oxygen demand, total polycyclic aromatic hydrocarbon, and dissolved copper—are not included in the list of computed loads because the difference between the inlet and outlet for each concentration was determined not to be significant.

Constituents whose average concentrations and total loads decreased by passing through the SFD include TSS, SS, total phosphorus, dissolved copper, total copper, dissolved zinc, total zinc, and chemical oxygen demand. The efficiency ratios for these constituents were 59, 90, 40, 21, 66, 23, 66, and 18, respectively. The SOLs, for these constituents were 50, 89, 38, 16, 66, 20, 68, and 14, respectively. At the SFD, sand-size particles in the inlet water averaging 80 percent, the SOL and efficiency ratios for SS were both about 90 percent, which suggests that the device controlled more than sand-size particles. Similar to the HSD, the average efficiency ratio and SOL for total dissolved solids and dissolved chloride were negative.

Flow rates, high SS, and particle-size distributions all affect the treatment efficiencies of the two devices. When peak flows are near or higher than the design flow for the HSD, the treatment efficiencies for TSS and SS are much lower or negative. The same is true for TSS efficiencies in the SFD, but the treatment efficiencies for SS tend to stay high, even past the design flow. When the TSS and SS concentration were above 200 mg/L, the treatment efficiency for both devices tended to be higher. The average percentage of sand-size particles in the SFD runoff was 71 percent, whereas the runoff to the HSD has an average sand content of 33 percent. A large proportion of the SS load reduction measured for SFD device could be accounted for by the percentage of sand in the inlet runoff. Further evidence for the importance of particle sizes in the treatment efficiency values was the large percentage of sand-size particles in the sediments retained in the bottom of both devices.

Introduction

In Wisconsin, State and Federal regulations apply to the quality of stormwater runoff from the state highway system. The Wisconsin Department of Transportation (WisDOT) finalized a Memorandum of Understanding (MOU) in 1994 with the Wisconsin Department of Natural Resources (WDNR) for the control of stormwater discharges from the highway system (Wisconsin Administrative Code Trans 401.03, 2002). The MOU covers state-owned and-operated systems in Milwaukee and Madison and includes a phased approach to examine stormwater-control opportunities at many other municipal areas. In addition, the U.S. Environmental Protection Agency (2000) Phase II stormwater regulations have additional focus on the quality of water discharged from WisDOT storm sewers.

The MOU requires at least 80 percent reduction in total suspended solids (TSS) for transportation facilities first constructed on or after January 2003, and a maximum extent possible for reconstructive highway projects (Wisconsin Administrative Code TRANS 401.03, 2002). The cost of land in ultra-urban areas can be prohibitive for implementation of traditional stormwater systems such as wet detention basins. Alternatives include more compact (usually installed underground) proprietary treatment devices available from various manufacturers. The pollutant-removal efficiencies of these stormwater-treatment devices have not been tested previously for direct field applications in Wisconsin. The study described in this report evaluated the effectiveness and practical application of two of the many proprietary stormwater-treatment technologies designed to improve the quality of stormwater runoff.

This study builds on a long history of U.S. Geological Survey (USGS) urban water-quality investigation 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 (appendix 1). Results from this study provide additional information to meet the partnership goals of understanding urban runoff.

In 1999, the USEPA established the Environmental Technology Verification (ETV) program, setting a national focus on validating the performance of technologies that includes verifying manufacturers' claims for efficiency of proprietary stormwater treatment devices. The USEPA, in cooperation with the National Sanitation Foundation International (NSF International) as its verification partner, is in charge of the following tasks: (1) create a national protocol to test wet-weather flow technologies, (2) contract independent groups to evaluate the effectiveness of the stormwater-treatment devices of interest, (3) review and implement the verification testing plans, and (4) make study results available to the general public (U.S. Environmental Protection Agency, 2002). Municipalities and other interested parties will then have access to all ETV program results to assist them in making informed decisions on the choice of stormwater-treatment devices for their stormwater-management programs. Results from this study were forwarded to ETV personnel for their final verification reporting (U.S. Environmental Protection Agency, 2004; 2005, a, b).

As part of its efforts to improve the quality of highway runoff, the WisDOT has worked in cooperation with the USGS, WDNR, City of Milwaukee, the Milwaukee Third Ward, Milwaukee County, and within the ETV program to verify the treatment efficiency of two proprietary stormwater treatment devices. The cooperators shared in the either the cost of installing the devices or the cost of monitoring. In December 2001, two devices were installed by contractors in a Milwaukee County parking lot underneath an elevated freeway, Interstate 794 (I–794), in Milwaukee (fig. 1). Both devices were connected to pipes draining a section of the freeway. Both devices had been installed in Wisconsin before but had never been evaluated for their effectiveness in the Wisconsin.

These devices are 2 of 10 such stormwater-treatment devices that the WDNR and USGS have examined to evaluate water-quality effects. A third study was in cooperation with the ETV program (Horwatich and others, 2004). This studies two sampling locations are beneath an elevated freeway I-794, which is next to the Milwaukee River. These sampling sites have been referred to as the “Milwaukee Riverwalk Sites”.

The first device was a hydrodynamic settling device (HSD), the Vortechs System. The HSD has a circular grit chamber that causes a rotating-flow field to remove sediment; an oil baffle wall to entrap surface oil, grease, and floating material; and low-flow and high-flow weirs for discharging flows.

The second device was a stormwater filtration device (SFD), the Stormwater Management StormFilter. The SFD has an inlet bay to remove larger particles, a cartridge bay for filtration of sediment and a variety of pollutants (depending on cartridge media), an overflow baffle wall for flow control, and an outlet bay for discharging treated water from the cartridge bay and untreated bypass water from the cartridge bay that topped the baffle wall.

Purpose and Scope

The primary objective of this report is to describe the effectiveness of two stormwater treatment devices in removing a suite of inorganic and organic water-quality constituents from stormwater runoff. This report also describes methods and techniques used to determine the effectiveness of these devices. Detailed data describing water quality, flow, constituent loads, and efficiencies of removal are presented for inlet and outlet samples collected between June 2002 and September 2004.

Another objective of this report is to add to the understanding of stormwater quality and quantity in an urban environment. The USGS and the WDNR have cooperated in many projects that help characterize quality and quantity of urban runoff. These results have helped State and Federal agencies improve stormwater management decision (Appendix 1).

Site Description

The municipal parking lot where the devices were installed in December 2001 was located beneath an elevated span of I–794 (fig. 1.). The parking lot is west of Water Street, between Clybourn Street and St. Paul Avenue in downtown Milwaukee. Stormwater flowed from the devices directly to the Milwaukee River, upstream from the mouth to Milwaukee Harbor, which flows into Lake Michigan.

The climate of Milwaukee, and Wisconsin in general, is typically continental with some modification by Lakes Michigan. Milwaukee experiences cold, snowy winters and warm to hot summers. Average annual precipitation is approximately 32 in., and average annual snowfall is 47.5 in. (National Oceanic and Atmospheric Administration, 1997 a, b).

The Milwaukee metropolitan area is an USEPA nonattainment area for high ozone levels during the summer, exceeding 85 parts per billion. During the winter, snow and ice is removed from freeways through the use of road salt. The freeway is swept by a conventional (mechanical) sweeper, once per month and by special assignment (such as when a truck spills debris on the freeway).

The eastbound and westbound I–794 decks were originally constructed in 1967 and were last overlaid in 1993 with a bituminous surface. The condition of the elevated freeway was rated as “poor” during the time of the study, and reconstruction of the freeway was planned for 2007. The average daily traffic count during the study period was 47,000.

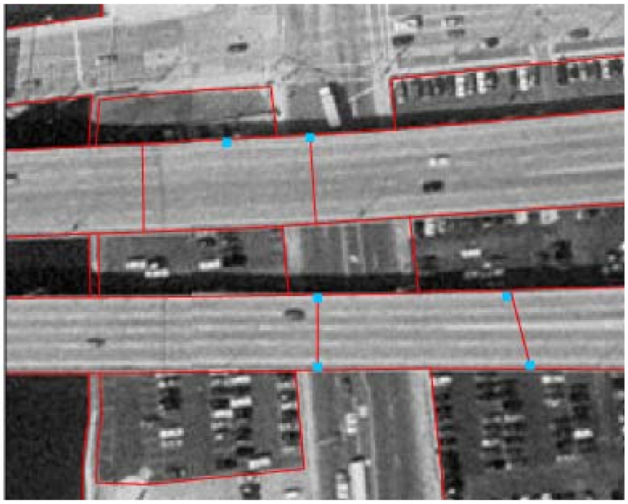

Figure 1. Location of monitored sites for the hydrodynamic settling device and stormwater filtration device in the City of Milwaukee, Wis.

Hydrodynamic Settling Device

The hydrodynamic settling device (HSD) treats a 0.25 acre deck section of westbound I–794 freeway, encompassing five lanes and an outside shoulder (fig. 1). The drainage surface on the westbound freeway slopes gradually eastward (0.5 percent slope) and dips slightly to the north. Runoff flows across the lanes toward the outside edge of the deck into two storm-drain inlets, on the north side of the freeway deck. Two 6-in.-diameter downspouts then connect into 8-in. piping connected to the device. Segments of the 8-in. pipe are on a slope of 5.6 percent approximately 15 ft above the parking lot (fig. 2.).

Figure 2. Piping system from freeway to hydrodynamic settling device.

Stormwater Filtration Device

The stormwater filtration device (SFD) treats 0.19 acre deck section of eastbound I–794 freeway, encompassing four driving lanes and an outside shoulder. The drainage surface slopes gradually westward (1.7 percent) and dips slightly to the south. The two storm drains are across from each other on opposite sides of the deck. Runoff entering the inlets drops into 6-in. diameter downspouts that connect to an 8-in. pipe. The downspouts are on a slope of 5.6 percent and are approximately 15 ft above the parking lot. The 8-in. connection pipe drops 6 ft to the ground surface and then another 4 ft below ground, which drains into a 9-ft length of lateral pipe connected to the device.

Design of the Hydrodynamic Settling Device and Stormwater Filtration Device

These devices use different processes to treat stormwater. The HSD removes pollutants by sedimentation and flotation. This study focused on the process of sedimentation and disregarded floating material, such as large pieces of trash and oil. The SFD removes pollutants by filtration and sedimentation. Filtration is considered the primary method of treatment; a filter media is used to retain the pollutants by sorption. Sedimentation of larger particles occurs in a pretreatment chamber and on the bottom of the cartridge-filter bay.

Hydrodynamic Settling Device

The HSD station was commonly referred to as “Riverwalk North” because it was at the north end of the parking lot. Station identification number and names for the monitoring sites are 430208087543201, Milwaukee Riverwalk North Device inlet at Milwaukee; and 430209087543200, Milwaukee Riverwalk North Device outlet at Milwaukee.

The device was housed in a 6 in. thick concrete structure, 10 ft long, 3 ft wide and 8 ft deep (fig. 3). The 10-ft length of pipe connected to the HSD was considered part of the device because the device created backwater in the pipe allowing sediment to drop out in the pipe. The stormwater flows from the inlet pipe into a 3-ft-diameter grit chamber that is the principal settling unit. Past the grit chamber an oil baffle wall extends from the top of the device to 6 in. above the floor to trap oil and floating material. Two weirs wall control flow out of the device, with a low-flow weir set at an elevation of 3 ft and the high-flow weir set at an elevation of 4.9 ft (U.S. Environmental Protection Agency, September 2005 a). The weirs are designed to create backwater to increase efficiency of the device. All flow exits through an 8-in. pipe.

Peak design capacity is approximately 0.27 ft^3/s per square foot of grit chamber area. This device was designed to treat flows with a peak flow rate of 1.6 ft^3/s. It was not designed with a bypass, so flows exceeding 1.6 ft^3/s go over the high-flow weir wall decreasing settling time through the device.

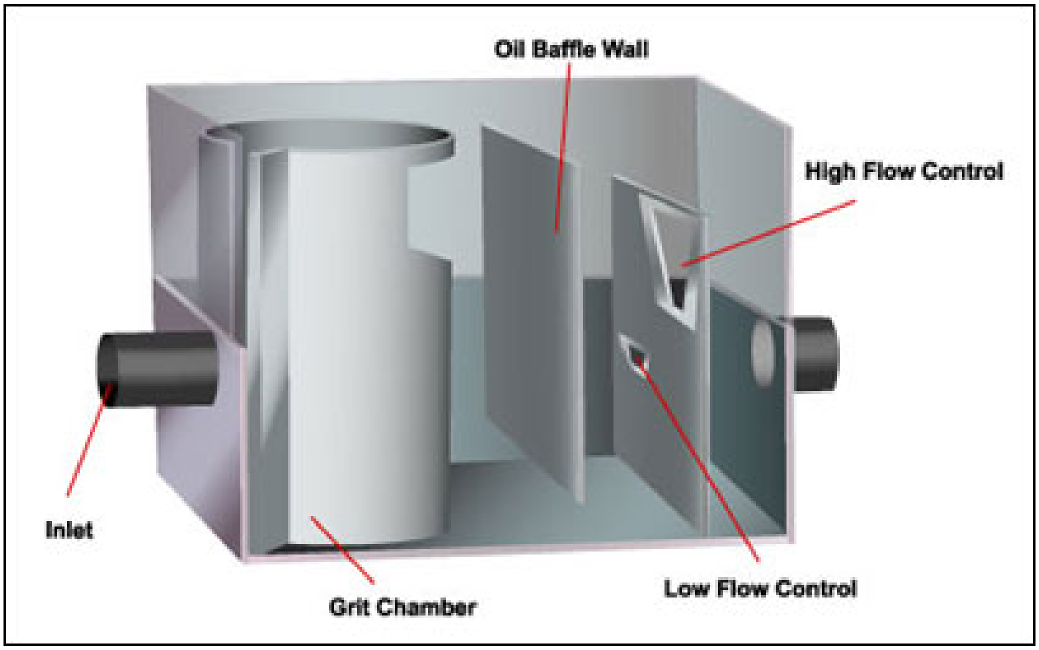

Figure 3. Diagram of hydrodynamic settling device (U.S. Environmental Protection Agency, 2005).

Stormwater Filtration Device

This station was commonly referred to as “Riverwalk South” because it was at the south end of the parking lot. Station identification number and names for the monitoring sites are 430207087543200, Milwaukee Riverwalk South device inlet at Milwaukee; and 430208087543200, Milwaukee Riverwalk South outlet at Milwaukee.

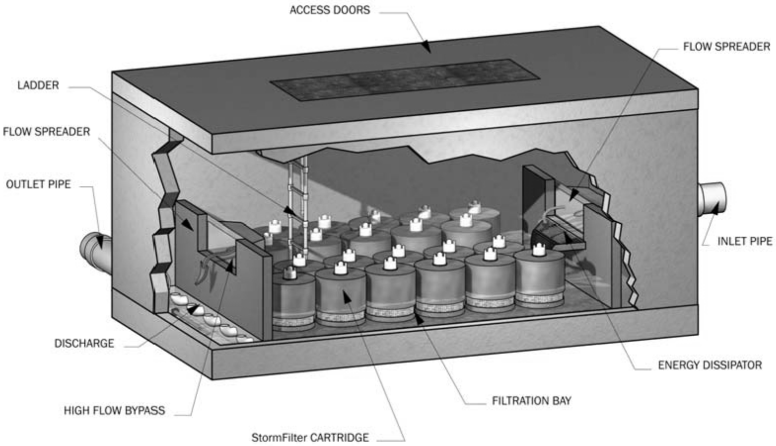

Figure 4. Overview of the stormwater filtration device (U.S. Environmental Protection Agency 2004, b).

The SFD was housed in a 6-in. thick concrete structure that is, 12-ft long, 6-ft wide, and 5.5-ft deep (fig. 4). Inlet flow enters a 2-ft-wide and 1.67-ft-deep inlet bay, where the larger particles are intended to drop out. Stormwater then flows through a flow spreader that disperses water evenly into a 7.4-ft-long cartridge bay. The nine filter cartridges for this study were designed to remove sediments, metals, organics, phosphorous, oils, and greases.

Each cartridge was 1.5 ft high and was filled with ZPG media, a mixture of zeolite, perlite, and granular activated carbon (U.S. Environmental Protection Agency, 2004, b). Flow is controlled through the cartridges by a siphon action, and the water leaves the cartridge by underdrain manifold. Each cartridge was designed to treat a peak flow of 0.03 ft^3/s. The device was designed to treat flows with a peak flow rate of 0.29 ft^3/s. When flows exceed 0.29 ft^3/s, water bypasses the filter cartridges via the high-flow bypass weir at a height of 1.67 ft. Treated water from the underdrain manifold and untreated bypass water enter into the outlet-bay area that is 1.5 ft wide and 1.67 in. deep, then discharge through an 8-in. pipe (U.S. Environmental

Protection Agency, 2004, b). The SFD influent piping system was similar to those shown in figure 2.

Sampling Methods

Selection of sampling methods was based, as much as possible, on what has been learned from previous stormwater monitoring projects in Wisconsin. Although methods for collecting rainfall, flow, and water quality data have been used in previous Wisconsin projects, it was still important to perform quality control tests and to make adjustments when problems were observe with the sampling methods. Extensive calibration efforts insured better quality rainfall and flow data. Blanks and replicate samples were collected to evaluate the quality of the concentration data. Some characteristics of the study sites, such as small diameter pipes, high flow velocities, and pipes with backwater flows, created complications in the sampling methods. These complications had to be solved during the project.

Measurement of Rainfall Depths

A tipping-bucket rain gage was used for continuous measurement of rainfall (fig. 8). A datalogger recorded the number of bucket tips (0.01 in. per tip) every 60 seconds. This gage was not designed to record frozen precipitation, so values during periods of snowfall and freezing rainfall were not used. Calibration data showed no need to adjust rainfall data. All rainfall data collected for each site are in appendix table, 2–1 and 3–1.

The rain gage was 25 ft northeast of the HSD gage house, attached to a barrier wall. It was mounted on a 4-in. x 4-in. plank raised 10 ft to avoid interference of nearby structures and to prevent vandalism. During calibration, the rain gage was cleaned.

Figure 8. Rain gage for both devices.

Flow Monitoring Methods

Electromagnetic area-velocity-flowmeters, which are equipped with a pressure transducer to measure water levels and a velocity probe to measure velocity, were installed at the inlet and outlet of each device

Calibration of Flow

Corrections were applied to stage measurements 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 pipe was first blocked by an inflated ball. Water levels were then increased in the pipe, and measurements were made at various levels representing the entire 8-in. depth of the pipe. Results from this procedure were used in making stage corrections through the entire period of record; accuracy of the record, on average, was estimated to be within ± 2 percent.

Discharge calibrations were performed at the site on April 18 & Nov 8. A 3” Parshall flume was mounted in a level position in the back of a boom truck (fig. 6). Water was pumped from the Milwaukee River, into a 2.5 ft wide, 8 ft, and long 2 ft deep chamber also mounted in the boom truck, just upstream from the flume, at 4 different pumping rates. The pumping rates were approximately 0.1, 0.15, 0.4 and 0.55 cfs. Water levels in the flume were carefully monitored and recorded. The flow left the flume and passed over the flowmeters leading to the devices. Flow rates above 0.55 were not possible due to the chamber capacity and turbulence.

Several steps were taken to correct each area-velocity meter flow. First, meters outputted point velocity, which was converted to an average velocity by applying an equation supplied by the manufacturer. Overall, this conversion lowered flows by an average of 10 percent. Second, the cross-sectional area of the pipe was reduced to the area that could effectively carry flow by excluding the probe area and cord area in the flow calculation; this could be as much as half of the area at depth less then 0.1 ft. Flow was then calculated by multiplying the average velocity by the effective cross-sectional area.

Flow was estimated for each meter after stage corrections were applied, then corrected stage values and flume discharges were plotted. From this plot, a stage-discharge rating was developed that plotted through the flume-recorded points at stages ranging from 0.08 to 0.2. A USGS rating curve for stable channels was used to correct the irregular channel flows at these depths (equation below). The meter acted as a control until a gage height of 0.06-ft. The equation was applied when depths of 0.08 and 0.2-ft. Effective flow ‘E’ was set at 0.08. ‘N’ fell in the ranges suggested by Rantz, 1982 and ‘C’ was adjusted for the best fit through the flume-recorded points. Depths less than 0.08-ft and greater than 0.2-ft were adjusted for flows by using the equation Manning’s.

Figure 6. Flow calibration equipment: (a) boom truck, (b) approach section of the flume, (c) Parshall flume, and (d) discharge to the device.

The following USGS rating curve for stable channels was used, which is a modified form of Manning's equation (Rantz and others, 1982):

$$Q = C\,(G - E)^{N}$$

where

Q is discharge, in cubic feet per second;

C is discharge coefficient;

G is gage height of the water surface, in feet;

E is effective zero control, in feet;

and

N is slope of the rating curve.

Flows were rated by use of Manning's equation when flume discharge could not be used to rate the area-velocity-meter flows. Calibration data were not available for low flows (less than 0.08 ft), because the area-velocity flowmeter does not register velocities until 0.01 ft of depth. In addition, a second Manning's rating was used for flows greater than 0.20 ft, because calibration data were not available beyond 0.2 ft stage, owing to the difficulty in maintaining laminar flow through the flume. Roughness coefficients were adjusted for a high and low rating that fitted through the USGS rating curve. Roughness coefficients for the HSD were 0.0067 for the low rating and 0.0075 for the high rating. Roughness coefficients for the SFD were 0.0162 for the low rating and 0.0207 for the high rating.

The Manning's rating curve is the following equation for inch-pound units:

$$Q = (1.486 / n)\ A\ R^{2/3}\ S^{1/2}$$

where

Q is discharge, in cubic feet per second;

1.486 is a conversion factor to inch-pound;

A is cross-sectional area in square feet, based on the water level;

R is hydraulic radius, in feet, based on the water level;

S is energy slope, in feet per foot;

and

n is Manning's roughness coefficient.

This method of estimating flows seems to be very robust for volume relying only on the area-velocity flowmeter's stage. Results from this project show that calibration of the automatic flow-measurement system is critical for research projects of this type.

Water-Quality Sampling

Automatic samplers (fig. 5) were programmed to collect flow-weighted samples at the inlet and outlet of each treatment device. The data logger in the monitoring station was programmed to initiate a subsample for a predefined volume of flow; consequently, more subsamples were collected for large-volume events than for small-volume events. In this respect, the sampling frequency increased or decreased to reflect the magnitude of flow. Flow-weighted sampling allowed for the collection of one composite runoff-event sample consisting of numerous subsamples throughout the course of the event. This approach resulted in a single average or “event-mean” concentration for each runoff event.

The intake of each inlet sampler was 3 ft upstream from each device and the intake of the outlet sample line was 3 ft downstream from each device. The area-velocity flowmeters were 4 in. above the sample intakes. All sample intakes were perpendicular to flow and approximately 1 in. off the bottom of the pipe. When a sample is initiated the sampler goes thru a purge and rinse cycle before collecting the water quality sample. This purge and rinse cycle is needed to eliminate residual water from 3/8-in.-Teflon-lined sample tubing.

The constituent list was based on the performance information from the manufacturers and the types of constituents WisDOT might want to control in the future (tables 1 and 2). Samples were analyzed at the Wisconsin State Laboratory of Hygiene, participators in the USGS Standard Reference Sample (SRS) program (Woodworth and Connor, 2003).

SS and TSS analysis are two different methods used for the determination of solids concentration. The TSS method, an aliquot of a sample is filtered and weighed to determine solids concentration (Kopp and McKee, 1979). The SS concentration method requires filtering the entire sample (American Public Health Association and others, 1989). SS concentration accounts for all of the solids within the sample and may a yield higher solids concentration than that determined by TSS using an aliquot sample (Gray and others, 2000).

Figure 5. Automatic sampling equipment.

Particle-Size Analysis

Particle-size analysis of runoff-event samples was done in three different ways. The first level particle-size definition was the “sand/silt split,” which was used to determine the percentage of sediment, by mass, with a diameter greater than 62 µm (for simplicity, referred to hereafter as “sand”) and less than 62 µm (referred to hereafter as “silt”). To define the sand fraction of the sample further, a visual-accumulation (VA) tube analysis was completed (Guy, 1977). This analysis determines the percentage of sediment, by mass, with diameters less than 1,000, 500, 250, 125, and 62 µm. To determine the silt fraction of the sample with more definition, a pipet analysis was done (Guy, 1977). This analysis determined the percentage of sediment, by mass, with diameters less than 31, 16, 8, 4, and 2 µm.

Table 1. List of inorganic constituent analyzed, limits of detection, limit of quantification, and analytical methods for samples collected at the hydrodynamic settling device and stormwater filtration device.

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

Constituent or characteristic	Unit	Limit of detection	Limit of quantification	Method
Dissolved solids, total	mg/L	50	167	SM2540C[1]
Suspended solids, total	mg/L	2	7	EPA 160.2[2]
Suspended sediment, total	mg/L	0.1	.05	ASTM D3977-97[1]
Chemical oxygen demand (COD)	mg/L	9	28	ASTM D1252-88(B) [1]
Dissolved phosphorus	mg/L as P	.005	.016	EPA 365.1[2]
Phosphorus, total recoverable	mg/L as P	.005	.016	EPA 365.1[2]
Calcium, total recoverable	mg/L	.02	.07	EPA 200.7[1]
Magnesium, total recoverable	mg/L	.03	.7	EPA 200.7[1]
Dissolved zinc	µg/L	16	50	EPA 200.9[1]
Zinc, total recoverable	µg/L	16	50	EPA 200.9[1]
Dissolved copper	µg/L	1	3	SM3113B[1]
Polycyclic aromatic hydrocarbon	mg/L	varies	varies	SW8310[1]
Copper , total recoverable	µg/L	1	3	SM3113B[1]
Sand/silt split	NA	NA	NA	Guy, 1977
Five-point sedigraph (fall diameter)	NA	NA	NA	U.S. Geological Survey[3]
Sand fractionation	NA	NA	NA	Guy, 1977

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

[2] Kopp and McKee U.S. Environmental Protection Agency (1979).

[3] Knott, J.M., and others U.S. Geological Survey (1993).

Table 2. List of organic constituent analyzed for, limits of detection, and analytical methods for samples collected at the hydrodynamic settling device and stormwater filtration device.

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

Constituent or characteristic	Limit of detection	Limit of quantification
1-Methylnaphthalene	0.046	0.14
2-Methylnaphthalene	.034	.11
Fluorene	.20	.65
Acenaphthene	.060	.19
Acenaphthylene	.072	.23
Anthracene	.021	.067
Benzo[a]anthracene	.062	.20
Benzo[a]pyrene	.070	.22
Benzo[b]fluoranthene	.11	.34
Benzo[g,h,i]perylene	.078	.25
Benzo[k]fluoranthene	.070	.22
Chrysene	.027	.087
Dibenzo[a,h]anthracene	.038	.12
Fluoranthene	.080	.25
Indeno[1,2,3-cd]pyrene	.12	.39
Phenanthrene	.040	.13
Pyrene	.070	.22
Naphthalene	.038	.12

Monitoring Complications

For each device, the monitoring period was extended because of monitoring complications.

The HSD had four sets of problems:

Low-flow weir. Partway into the study, it was noticed that the hydro-break or low-flow weir was not installed properly. The manufacturer replaced it with a 4-in. orifice plate.

Position of inlet pipe and flowmeter. When monitoring began in June 2002, the flowmeter in the inlet pipe was 3 ft from the device. Water elevations in the pipe were the same as in the grit chamber, creating backwater conditions that allowed sediment to drop out in the pipe. Sediment covered the meter and produced errors in stage and flow. To alleviate this problem, a small check dam was placed upstream from the meter in hope of causing the sediment deposition to occur ahead of the meter. However, velocity in the pipe sometimes was too great, and sediment moved past the dam, again covering the meter. It was decided to move the inlet meter farther upstream, out of backwater conditions. The most efficient alternative was to move the piping above ground. The new piping was designed to prevent turbulent flow and to match the existing pipe slope (Appendix 2, fig. 2–1). This moved the meter about 12 ft upstream from the device (fig. 7). The new piping was installed in January 2003. For the 15 events sampled before this date, data are not reported herein because of their unreliability and the reduced sampling frequency.

Replacement of flowmeters. The area-velocity flowmeters had to be replaced at the inlet and outlet. Several events were missed at the inlet due to meter failures.

Low flow at outlet. The outlet meter flow measurements were inaccurate as a result of low flow in the pipe. Because of the difficulty in measuring flow at the outlet, composite sampling was based on inlet flow and outlet sample threshold; this offset the outlet samples to about a minute after the inlet samples, so that approximately the same water was collected.

At the SFD site, the meters at the inlet and outlet were not changed. However, for five events at the inlet and one event at the outlet, there were velocity dropouts (the velocity dropped to zero) during high flows, lasting 1 to 15 minutes. Flows during the dropouts were recorded as zero, and no samples were collected because the sampling routine was based on flow-proportional sampling.

Figure 7. Piping modification of the hydrodynamic settling device.

At the SFD site, the meters at the inlet and outlet were not changed. However, for five events at the inlet and one event at the outlet, there were velocity dropouts (the velocity dropped to zero) during high flows, lasting 1 to 15 minutes. Flows during the dropouts were recorded as zero, and no samples were collected because the sampling routine was based on flow-proportional sampling.

The dropouts may have resulted from larger, sand-size particles covering the meter, air entrainment disrupting the electrodes on the meter, or velocity exceeding meter’s measurement limits because of nearly pipefull conditions. These events were sampled, but analytical results are not reported herein because of inaccuracy of the flow data and failure to sample over the complete hydrograph. A hydrograph displaying velocity drops is footnoted in appendix 3, figure 3–1. In future projects of this type, use of an ultrasonic area-velocity flowmeter may eliminate velocity dropouts.

Quality Control

Equipment blank and replicate samples were collected at the inlet and outlet of both devices and analyzed for the same constituents as those from runoff-event samples. Blanks were collected at the beginning and midpoint of the project to validate clean sampling procedures.

Replicate samples were done for several events to quantify the variability or precision in sampling procedures. Analytical precision is a measurement of how much an individual measurement deviates from a mean of replicate measurements. The relative percent difference (RPD) is calculated to evaluate precision in procedures after sample collection. The targets are set by the Wisconsin State Laboratory of Hygiene.

The relative percent difference equation is

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

where

x_1= concentration of compound in sample,

x_2 = concentration of compound in duplicate,

and

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

Hydrodynamic Settling Device

Two equipment blank samples were collected between events 9 and 10 (blank 1) and events 30 and 31, (blank 2), respectively to validate clean sampling procedures. The blank 1 sample had detectable concentrations of dissolved copper (DCu) and chloride (Cl), but both concentrations were below the limit of quantification (LOQ) at the inlet and outlet. The blank 2 sample had detectable total copper (TCu) and DCu at the inlet, but concentrations were below LOQ. In blank 2, for the outlet, chemical oxygen demand (COD) exceeded the LOQ, but additional QA/QC samples collected directly from the sampler and from the jar of blank water were accidentally discarded; therefore, the particular piece of equipment that may have contributed to the detection could not be determined (table 2–2). A possible source of the COD in the second blank is the methanol used to rinse the 2.5 gallon glass sample containers. Some of the methanol might have remained in the container after the rinse with distilled water. Many studies have used a methanol rinse for the containers and this is the first time a high blank for COD has occurred. This problem requires further testing, but it seems pre-mature to discount all the COD values in this study until further testing is completed.

Replicate samples were collected during events 9, 18, and 42 to quantify variability in the sampling process. The RPD target for TSS was 30 percent or less; for metals, the RDP target was 25 percent or less (table 2–3). In replicates for events 18 and 42 the target of 25 percent was exceeded for total copper TCu, and in replicates for event 42, the RPD target for total zinc (TZn) was exceeded. Additionally, events 9 and 42 Ca and Mg exceeded targets. For all of the dissolved constituents, a relatively low RPD was reported, but high RPDs were reported for some of the particulate constituents. The high RPD for particulate associated constituents might be explained by churn-splitting procedures, where precision is known to decline with increasing sediment concentration and particle sizes (Horowitz and others, 1997). Since the end of the Riverwalk data collection, a new process of sieving samples before churning has been incorporated at the USGS Wisconsin Water Science Center (Selbig and others, 2007).

Stormwater Filtration Device

Three equipment blank samples were collected; the first blank was before event 1 (blank 1), then events 9 (blank 2) and 19 (blank 3). Blank 1 had a detectable concentrations of Cl and Ca, but the values were below the LOQ. Blank 2 had a detectable concentrations of total phosphorus (TP) above the LOQ, but was not in Blank 3. Blank 3 had detectable concentrations of COD, DCu, TCu, and Cl but those values were below the LOQ for inlet and outlet (table 3–2).

Replicate samples were collected during events 9, 14, 19, 26, and 28 to quantify variability in the sampling process. The RPD target for TSS was 30 percent, and for metals, Cl, Ca and Mg the RPD target was 25 percent (table 3–3). Replicates results for events 9, 14 and 28 exceeded the TCu RPD of 25 percent, and those for events 9, 14, and 19 exceeded the RDP target for TZn of 25 percent, and in event 28 DCu was exceeded. The poor precision might have resulted from using the churn while splitting the sample (Selbig and Other, 2007). As stated previously, procedures that involve sieving samples before churning have been shown to increase precision.

Evaluation of Settling and Filtration Treatment Devices

Rainfall, flow, particle size, and concentration data were all important to evaluating the effectiveness of the two treatment devices. A comparison of monitored event rainfall depths and long term trends in rainfall depths helped evaluate if the monitoring data is representative of rainfall patterns in Milwaukee. Rainfall data was also useful in checking the accuracy of the flow data. The flow data was needed to determine the volumes of runoff entering and leaving the treatment devices. Inlet and outlet contaminant loads calculated from volumes and concentrations are the basis for one of the methods used to determine the effectiveness of the two devices. A second method for evaluating the effectiveness of the devices is based just on the concentrations. The particle size data is helpful in the analysis of trends in the concentration data and the treatment effectiveness results.

Rainfall Data

One rain gage was operated for both devices from June 21, 2002, until October 8, 2004 (tables 2–1 and 3–1). Rainfall data collected from June 21, 2002, until December 28, 2003 (18 months) was used for the evaluation of the SFD, and the rainfall data collected from April 30, 2003, until October 8, 2004 (17 months), was used for evaluation of the HSD. Seven months of the rain gage data overlapped for the two devices. The largest rainfall event with water-quality samples was 1.67 in. for the SFD and 1.75 in. for the HSD, whereas the smallest rainfall event sampled for both devices was 0.07 in.

Data from two National Oceanic and Atmospheric Administration (NOAA) rain gages in the Milwaukee area were used to check the monthly rainfall depths recorded at the site for reasonableness. One NOAA site is General Mitchell International Airport (GMIA), about 10 mi. south of the study site, and the other is Milwaukee Mount Mary College about 10 mi. west of the study site (National Oceanic and Atmospheric Administration, 1997a, 1997b). Also, the records at the GMIA sites were used to determine whether the sampled events with reasonably represent the long-term mix of rainfall depths observed in the Milwaukee area.

Monthly rainfall totals measured at the study site compared well with the totals reported for the two NOAA sites (table 3). There was less than a 25-percent difference between the totals for 83 percent of the months. Months with larger differences were generally summer months, when rainfall amounts can vary substantially over distance as small as 10 mi., owing to a predominance of localized convective storms in the summer. All the annual totals compared well between the NOAA sites and the study site. Three of the six annual totals at the NOAA sites were almost identical to the study-site totals. The total rainfall for 2004 was 5.4 in. more than the long-term average rainfall, but the total rainfall for 2003 was about 12.8 in. less than the long-term average (table 3).

Table 3. Comparison of monthly rainfall between the U.S. Geological Survey rain gage at the Riverwalk site and the National Oceanic and Atmospheric Administration precipitation gages at General Mitchell International Airport and Mount Mary College, Milwaukee, Wis.

[Rainfall is in inches; USGS, U.S. Geological Survey; GMIA, General Mitchell International Airport and MMMC, Milwaukee Mount Mary College; NOAA National Oceanic and Atmospheric Administration 1997a, 1997b; --, no data]

Month	USGS rain gage , water year 2002	NOAA GMIA, 2002	NOAA MMMC , 2002	USGS rain gage, water year 2003	NOAA GMIA, 2003	NOAA MMMC , 2003	USGS rain gage, water year 2004	NOAA GMIA, 2004	NOAA MMMC , 2004	NOAA MMMC, Long-term averages
October	--	--	--	2.7	1.7	2.3	1.6	1.5	1.6	2.5
November	--	--	--	1.1	--	--	2.1	3.9	3.0	2.7
December	--	--	--	0.9	0.4	1.1	2.3	2.0	1.4	2.2
March	--	--	--	1.7	1.6	1.0	4.4	4.0	3.3	2.6
April	--	--	--	2.5	2.6	1.5	2.2	1.9	2.4	3.8
May	--	--	--	4.0	3.6	4.7	11.4	8.2	9.8	3.1
June	--	--	--	1.3	1.5	2.0	4.6	4.1	3.5	3.6
July	3.0	2.3	2.9	1.7	2.4	1.8	3.8	3.2	3.6	3.6
August	6.2	4.7	6.6	1.2	0.6	1.4	4.1	3.4	2.6	4.0
September	3.6	2.8	3.3	1.5	1.6	1.9	0.3	0.2	0.2	3.3
Total	12.8	9.8	12.8	18.6	18.6	17.7	36.8	36.5	31.4	31.4

Although the total rainfalls for 2003 and 2004 were not the same as the long-term average rainfalls, the differences in total rainfall depth did not describe how well the distribution of sampled rainfall depths matched the long-term distribution of rainfall depths measured in the Milwaukee area. Because the performance of stormwater treatment devices is usually related to flow, a project determining the efficiency of a stormwater treatment device should sample a mix of storms with a distribution similar to the long-term distribution. It would not be a test that did not include the range of events would be incomplete for a treatment device if the sampled events had a significant bias to the smaller or larger types of rainfalls observed for the area. To assess how the mix of rainfall events during the study period compared to long-term rainfall patterns, the distribution of monitored rainfall depths from this study was compared to the historical (1949-1992) distribution of rainfall depths from the NOAA Mitchell Airport site.

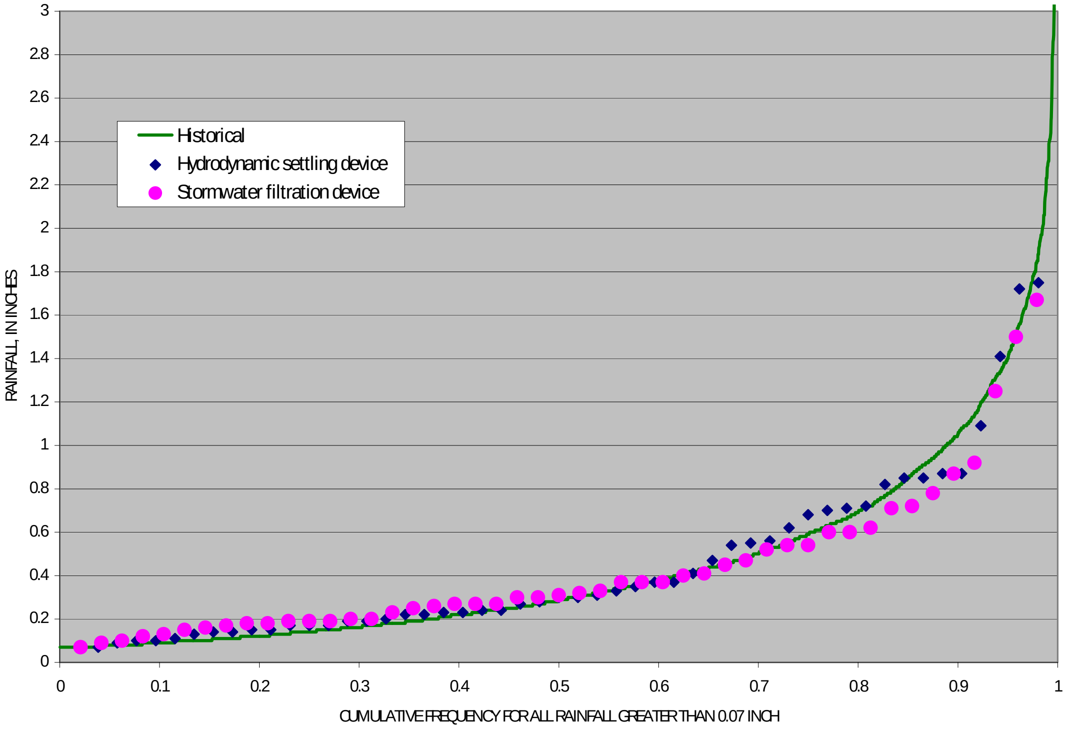

Figure 9. Cumulative rainfall distributions for the study period compared to historical rainfall records (1949–92) for Milwaukee, Wis., based on the National Oceanic and Atmospheric Administration gage at General Mitchell International Airport, Milwaukee, Wis.

Probability distributions for both datasets were constructed by use of the Weibull plotting position (Helsel and Hirsch, 1992). Rainfall amounts for individual events were computed for both datasets. Rainfall depths greater than or equal to 0.07 in. (the minimum event amount sampled during this project) were ranked from lowest to highest depth. A cumulative probability distribution was then computed for both datasets by use of the formula $P_R = i_R/(n+1)$, where R is the rainfall event referred to, P_R is the probability of an event having a rainfall depth less than that of event R, i_R is the ranking of event R, and n is the total number of events in the data set. Except for a moderate deviation for rainfall depths between 0.65 and 0.9 in., the distribution of the sampled events was very similar to the long-term distribution (fig. 9), indicate the data collected for the two devices represents a mix of rainfall characteristics for the Milwaukee area.

Number of Rainfall Events with Water-Quality Data

Water-quality data were collected for a similar number of events at both devices (tables 2–1 and 3–1): 45 events, (47 percent of the 109 total events) for the HSD and 33 events for the SFD (42 percent of 106 total events). These numbers do not represent the actual number of water-quality samples because some event samples were combined with preceding and (or) subsequent event samples to one composite sample. Combining the samples was necessary when the time between the ending of one of rainfall and the beginning of the next one was brief. In all, 45 water-quality event samples were available for inlet-to-outlet comparison for the HSD and 33 for the SFD. For 15 events concurrent water-quality data were available for comparison at both devices.

Most of the unsampled events (60 to 70 percent) for both devices were rainfall events of less than 0.2 in. depth. Not many of the small rainfalls were sampled because the flowmeter needs about 0.08 ft of water to activate. Of the 33 water-quality samples collected for the SFD, 10 were rainfalls of less than 0.2 in., and only 1 sample for the HSD was the runoff from a single rainfall of less than 0.2 in. For rainfall depths of 0.2 in. or greater, the percentage of rainfall events sampled increased to about 70 and 60 percent for the SFD and HSD, respectively.

Flow Data

Neither device has an external bypass flow structure, so the volumes measured at the inlets should be the same as the outlet volumes. Flows at the inlet were selected to calculate the volumes for the HSD. Measurements made with the HSD outlet area-velocity flowmeter were not reliable, because the flows were frequently too low to properly submerse the probe. Volumes for the SFD were calculated at the outlet. Although most of the flows were similar at the outlet and inlet, the flows at the inlet were less reliable. During several large rainfall events, the velocities at the inlet dropped to zero as the flows started to peak. The outlet flows, however were reliable during high-flow events that caused velocity dropouts at the inlet (Appendix 3, fig. 3–1).

Peak flows, percent runoff, and volumes at the HSD inlet and the SFD outlet for sampled events are presented in tables 2–4 and 3–4, respectively. Only 4 out of the 45 events with water-quality data at the HSD site exceeded the design peak flow rate of 1.6 ft^3/s. Exceeding the design peak flow at the HSD site should not reduce the amount of water treated, because all the water goes into the treatment chamber. However, flows greater than the maximum design flow exceed the optimal treatment capacity for which the device has been sized. Because the sampling was done as flow composite, it was not possible to calculate the diminished treatment capacity for the few minutes that the design flow was exceeded (table 4). Nevertheless, because the design flows were exceeded for only a few minutes, the effect on the calculated loads should be minimal.

Table 4. Length of time during four events that flows exceeded the design flow for the hydrodynamic settling device.

Date of event	Peak flow for	Time flow	Total duration	Percentage of

and event number ()	event (cubic feet per second)	exceeds design flow (minutes)	of runoff event (minutes)	time design flow is exceeded (percent)
9/14/03 (19)	2.08	2	412	1
5/21/04 (33)	1.81	3	67	4
6/14/04 (36)	2.64	5	47	11
8/03/04 (41)	2.44	11	230	5

Twelve times the peak flows at the SFD site exceeded the design peak flow of 0.29 ft^3/s (table 5). For events 3 and 28, flow exceeded the design flow and the elevation of the bypass wall. However, each time the design-flow was exceeded or a bypass-flow occurred, it only lasted for a few minutes. Because most of the volume was treated below the design flow, the treatment efficiency for each event does not appear to be affected. Even if the bypass volumes had been sizeable, the efficiency calculations could have been done because the bypass water and treated water are mixed at the outlet.

Table 5. Length of time during 12 events that flows exceeded the design flow for the stormwater filtration device.

Date of event and event number ()	Peak flow for event (cubic feet per second)	Time flow exceeds design flow (minutes)	Total duration of runoff event (minutes)	Percentage of time design flow is exceeded (percent)	Time flows exceeded the bypass wall (minutes)
06/21/02 (1)	1.11	6	46	13	0
07/08/02 (3)	1.06	22	145	15	9
08/21/02 (5)	1.12	11	985	1	0
09/02/02 (6)	0.30	4	25	16	0
09/02/02 (7)	0.38	5	264	2	0
06/08/03 (18)	0.34	3	772	1	0
07/04/03 (20)	0.36	3	2,302	1	0
07/21/03 (22)	0.39	4	31	13	0
08/01/03 (24)	0.33	1	3552	1	0
08/25/03 (25)	0.53	4	26	15	0
09/14/03 (28)	0.52	6	412	1	4
11/04/03 (33)	1.12	5	196	3	0

Runoff coefficients can provide a simple check on the accuracy of the flow measurements. By dividing the volume of rainfall into the runoff volume, it is possible to determine whether the amount of rainfall produced the expected amount of runoff. Runoff measurements done by Pitt (1987) on roadways indicate the largest runoff coefficient observed on the elevated freeway should have been around 85 percent (Pitt, 1987). Many of the runoff coefficients for the HSD and SFD site were much higher or lower than the 85 percent (fig 10). The number of events at the HSD and SFD sites with runoff coefficients 100 percent or greater was 17 and 10, respectively. Only four events with high runoff coefficients at the HSD site corresponded to flows exceeding the design flow, whereas all the events with high runoff coefficients at the SFD site corresponded to flows exceeding the design flow. Nine events at the HSD site had runoff coefficients less than 50 percent, while 5 events at the SFD site had numbers less than 50 percent.

Some reasons for the variability in the runoff coefficients might include errors in rainfall measurements, uncertainties in the rating curves, losses by traffic spray, changes in the drainage areas, and losses during small long duration events. Errors in rainfall measurements probably does not play a small role in the variability, since the comparisons with the local NOAA rainfall stations indicate that the rainfall data collected for the sites were reasonably accurate. A more significant source of the variability in the runoff coefficients could be the lack of high and low flow calibration data needed to extrapolate stage-discharge rating curves. The uncertainty in the high-flow rating curves is more likely to be greater for events with higher discharge rates. High discharge rates were observed for all the runoff coefficients over 100 percent at the SFD site. Also, there is uncertainty in the low-flow rating curves for events with small rain fall depths and long durations. The low-flow rating curve could result in over or under estimate of the runoff volume for these small events. An example of an over estimate is the runoff coefficients of more than 200 percent for very small events at the HSD site (fig. 10).

Losses of water on the freeway surface could also contribute to the variability in the runoff coefficients. This is especially true for the lower runoff coefficients observed at both sites. The most obvious loss is the vehicles spraying the water over the sides of the elevated freeway. Evaporation and depression storage may be sources of loss for the small long duration rainfall events. Although these types of losses were not quantified, the potential for these types of losses might mean the measured runoff volumes are reasonably accurate for some of the events with low runoff coefficients.

Changes in the size of the drainage areas might have contributed to the variability in the runoff coefficients. Each drainage area was fairly flat, and the area was defined by the elevations above the inlet drains. Depending on the size and intensity of the rainfall event, the potential exists for runoff from an adjacent piece of the freeway to jump its inlet and enter the test drainage areas. Plus the size of drainage areas could be reduced by water bypassing the test inlets. Since the area is important to the calculation of rainfall volume, the runoff coefficient would be too high if the area is under estimated and it would be too low if the drainage area is over estimated. It is important to note an error in the size of drainage area affects the runoff coefficient calculation, but it does not affect the accuracy of the runoff volume measured at the site.

All the variability in the runoff coefficients indicates there are potential sources errors for the runoff volumes determined in this study. To reduce the error every effort was made to reduce the uncertainty in the high and low flow rating curves. Nothing could be done during the study to reduce the other potential sources of variability. Given the potential for losses on the freeway surface, there is a possibility that many of the lower runoff coefficients represent reasonably accurate runoff volumes. If the size of the drainage area was changing, the runoff volumes might be reasonably accurate for many of the events with runoff coefficients over 100 percent. Although there is not a defensible method for reducing the variability in the runoff coefficients for this study, it is not certain the unreasonably low or high runoff coefficients always represent an inaccurate flow measurement.

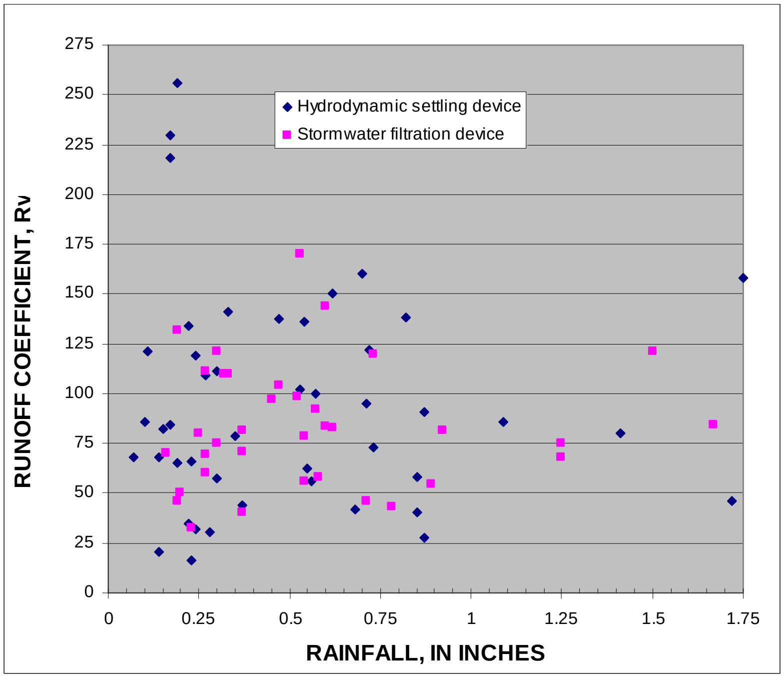

Figure 10. Freeway-runoff coefficients for hydrodynamic settling and stormwater filtration devices.

Particle-Size Distribution

Particle-size distributions measured for this project could be helpful in designing devices to meet TSS and SS reduction goals for other elevated freeways. Proper selection of a particle-size distribution is important decisions in sizing a stormwater-control practice. Water-quality data showing a particle-size distribution with a large percentage of sand-size particles will support the selection of a smaller stormwater-control practice to achieve a reduction goal for SS or TSS, than would a distribution dominated by particles less than 62 μm.

Because the particle-size analysis captures all the particles in a water sample, the particle-size distribution will always represent the SS in the runoff. If the SS and the TSS concentrations are similar, then the particle-size distribution will also represent the TSS. However, the particle-size distribution might not represent the distribution of other constituents, such as TP, because the concentrations tend to be higher on smaller particles (Dong and others, 1979).

Particle-Size Distributions for the Hydrodynamic Settling Device

Sand/silt split data were collected for nine runoff events at the HSD inlet and outlet (table 6). Of those nine events, seven samples at the inlet had sufficient sediment content and sample volume for the VA tube analysis. Three of the inlet samples also had sufficient sediment content to do a complete particle-size distribution (table 7). Outlet samples contained enough sediment and sample volume for the VA tube analysis in two samples and pipet analyses for one sample.

The sand/silt split at 62 µm (Guy, 1977) analyses shows that 8 of 11 inlet samples were composed mostly of silt or smaller particles (table 6). The average percentage of silt or smaller particles in the inlet samples was 70 percent, whereas the average for sand was only 30 percent. The particle-size distributions changed substantially from the inlet to the outlet of the HSD. A large proportion of the sand-size particles appear to be captured by the HSD.

Table 6. Results of sand/silt split sediment analysis at the inlet and outlet of the hydrodynamic settling device for nine events.

[µm, micrometer: %, percent by mass; >, greater than or equal to; < less than--, insufficient sample amount for determination of smaller particle size;]

Event number	Inlet %		Outlet %	
	> 62 (µm)	< 62 (µm)	> 62 (µm)	< 62 (µm)
3	24	76	5	95
8	58	42	2	98
16	17	83	3	97
18	19	81	2	98
19	26	74	2	98
23	36	64	6	94
24	17	83	2	98
25	2	98	0	100
32	17	83	3	97
43	67	33	--	--
44	76	24	--	--
Median	21	79	3	97
Average	30	70	11	89
Maximum	76	98	86	100
Minimum	2	24	0	14

Table 7. Particle-size distribution determined by visual accumulation (VA) and pipet-withdrawal analysis for seven events at the hydrodynamic settling device inlet and outlet sampling sites.

[µm, micrometer; --, insufficient sample amount for determination of smaller particle size; all data are percent by mass; --, not analyzed; <, less than]

Particle Size (µm)	Event number						
	3	16	18	25	32	43	44
Inlet							
<1000	100	98	100	100	100	91	100
<500	96	96	100	99	98	85	84
<250	83	90	93	98	92	78	56
<125	79	86	85	98	86	48	35
<63	76	83	81	97	83	33	24
<31	--	74	74	--	--	--	15
<16	--	60	67	--	--	--	8
<8	--	45	55	--	--	--	5
<4	--	37	43	--	--	--	1
<2	--	29	28	--	--	--	1
Outlet							
<1000	--	--	--	--	--	--	--
<500	--	--	--	--	--	--	--
<250	--	--	--	--	--	--	--
<125	--	--	--	--	--	--	--
<63	--	--		--	--	--	--
<31	--	90	--	--	--	--	--
<16	--	80	--	--	--	--	--
<8	--	61	--	--	--	--	--
<4	--	51	--	--	--	--	--
<2	--	43	--	--	--	--	--

The detailed particle-size results describe the relationships between particle size and percent control at the HSD site (fig. 11 and table 7). Based on the average particle-size distribution in these samples, if all particles greater than 250-µm were completely removed from stormwater there would be a 16 percent reduction in SS and controlling all the particles greater than 63-µm would result in a 32 percent SS reduction. To go beyond 32 percent control at the HSD site, the device would have to control some of the particles in the silt sizes. For example, on average the HSD would have to control all the particles above 31-um to achieve a 46 percent reduction in SS. Given the variability in the particle-size distributions between events, the levels of control for each particle size will vary somewhat with each event.

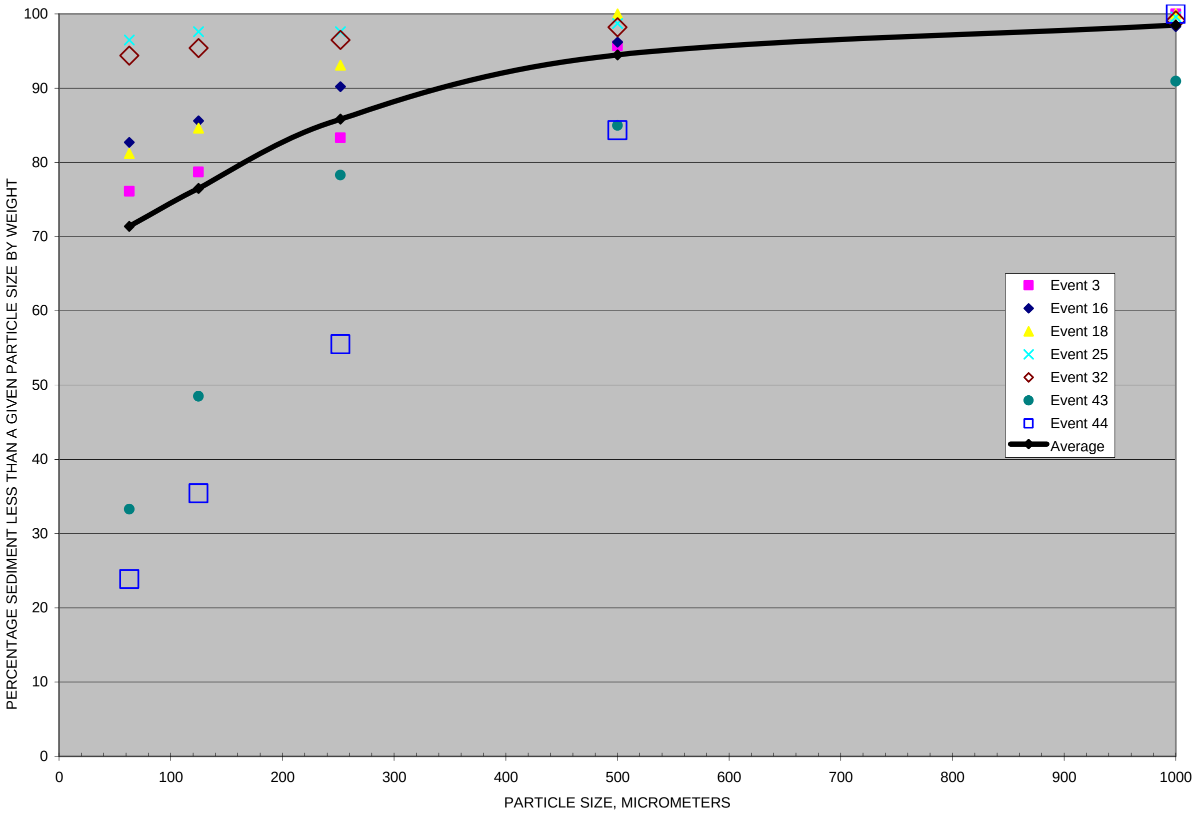

Figure 11. Particle-size distributions from the hydrodynamic settling device inlet samples from six events.

Particle-Size Distributions for the Stormwater Filtration Device

Sand/silt split data were collected for 16 runoff events at the SFD inlet and outlet (table 8). Of those 16 events, 14 at the inlet had sufficient sediment content and sample volume for the VA tube analysis (table 9). The VA tube analysis could be done for only six samples at the outlet. Only 3 of the 16 events contained enough of the smaller-size particles for a pipet analysis at the inlet and outlet (Table 9).

The sand/silt split analyses shows that14 of 16 inlet samples were composed mostly of sand particles (table 8). The average percentage of sand particles in the inlet samples was 71 percent, whereas the average for silt was only 29 percent. The particle-size distributions changed substantially from the inlet to the outlet of the SFD. A large proportion of the sand-size particles appear to be captured by the SFD (table 8). The average percent sand at the inlet is 71 percent and the average is reduced to 15 percent at the outlet.

Table 8. Results of sand-silt split sediment analysis at the inlet and outlet of the stormwater filtration device for 16 events.
[µm, micrometer: %, percent by mass; >, greater than; <, less than; --, insufficient sample amount for determination of smaller particle sizes]

	Inlet %		Outlet %	
Event number	**> 62 (µm)**	**< 62 (µm)**	**> 62 (µm)**	**< 62 (µm)**
1	82	18	9	91
3	88	12	12	88
4	77	23	6	94
5	68	32	18	82
6	92	8	8	92
9	68	32	9	91
10	72	28	0	100
11	60	40	0	100
12	66	34	0	100
14	71	30	0	100
15	85	15	56	44
24	8	92	2	98
25	11	89	4	96
26	97	4	99	1
28	87	13	8	92
30	100	0	--	--
Median	74	26	8	92
Average	71	29	15	85
Maximum	100	92	99	100
Minimum	8	0	0	1

More can be learned about how the particle sizes might influence the percent SS reduction at the SFD site by looking at the more detailed particle size data (table 9). On the basis of average particle-size distribution, a 100 percent control of particles greater than 250-µm would result in a 60-percent reduction in SS, and the control of particles greater than 63-µm would result in about an 80 percent SS reduction (fig 12). The average percent control for the 63-um particles is larger for figure 12 than in table 8, because the two additional events in the sand\split data have a much lower percent sand in the sample. Just the control of sand appears to achieve a very high level of control at the SFD site. Given the variability in the particle-size distributions between events, the levels of control for each particle size would vary somewhat with each event.

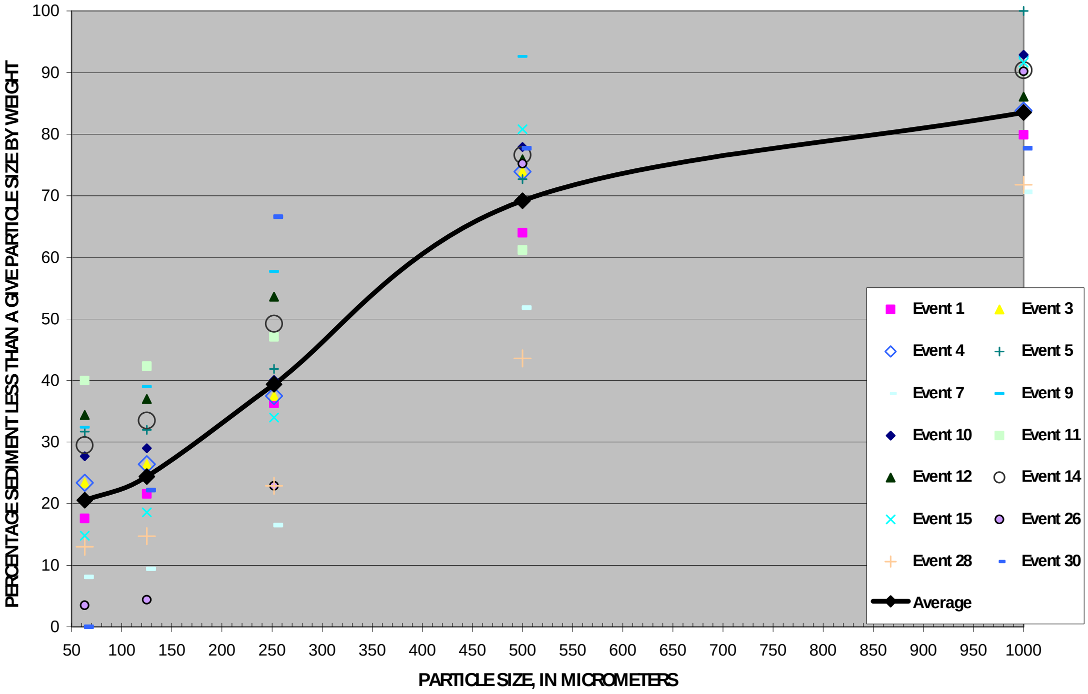

Figure 12. Particle-size distributions from the stormwater filtration device inlet samples from 14 events.

Two very similar sections of freeway produced very different particle-size distributions in the runoff. The average percentage of sand-size particles in the runoff at the HSD site was 30 percent, whereas the SFD site runoff samples contained 71 percent sand. This difference leaves much uncertainty in the selection of a particle-size distribution for freeways. Sand/silt split data was also determined for runoff samples collected from a control and test section of freeway in another part of Milwaukee. The average percentages of sand-sized particles calculated for the test and control sections were 46 and 34 percent, respectively (Waschbusch, 2003; Table A9). Compared to the other three sites the percent sand at the SFD site seems unusually high.

Table 9. Particle-size distribution determined by visual accumulation (VA) and pipet-withdrawal analysis from samples collected during 14 events at the stormwater filtration device inlet and outlet sampling sites.
[µm, micrometer; --, insufficient sample amount for determination of smaller particle sizes; %, all data are in percent by mass; <, less than]

	Event number													
Particle Size (µm)	**1**	**3**	**4**	**5**	**7**	**9**	**10**	**11**	**12**	**14**	**15**	**26**	**28**	**30**
Inlet														
<1000	80	52	84	100	71	93	93	90	86	90	92	90	72	78
<500	64	45	74	73	52	93	78	61	76	77	81	75	44	78
<250	36	25	38	42	17	58	40	47	54	49	34	23	23	67
<125	22	12	26	32	9	39	29	42	37	34	19	4	15	22
<63	18	12	23	32	8	32	28	40	34	30	15	4	13	0
<31	--	--	--	--	--	--	27	38	--	26	--	--	--	--
<16	--	--	--	--	--	--	26	33	--	20	--	--	--	--
<8	--	--	--	--	--	--	25	25	--	14	--	--	--	--
<4	--	--	--	--	--	--	23	16	--	11	--	--	--	--
<2	--	--	--	--	--	--	21	10	--	8	--	--	--	--
Outlet														
<1000	100	100	--	--	--	--	--	100	100	100	100	--	--	--
<500	100	100	--	--	--	--	--	100	100	100	81	--	--	--
<250	98	100	--	--	--	--	--	100	100	100	57	--	--	--
<125	93	96	--	--	--	--	--	100	100	100	50	--	--	--
<63	91	88	--	--	--	--	--	100	100	100	44	--	--	--
<31	--	--	--	--	--	--	--	97	99	96	--	--	--	--
<16	--	--	--	--	--	--	--	96	93	86	--	--	--	--
<8	--	--	--	--	--	--	--	86	80	66	--	--	--	--
<4	--	--	--	--	--	--	--	78	61	55	--	--	--	--
<2	--	--	--	--	--	--	--	65	38	48	--	--	--	--

Summary of Inlet and Outlet Chemical Concentrations

Chemical-constituent concentrations for each runoff event and the summary statistics for all the events, such as averages, medians, and coefficients of variation, are presented in Appendix 2 (tables 2–5 through 2–7) and Appendix 3 (tables 3–5 through 3–7). Thirty-two constituents were analyzed in inlet and outlet samples from both the HSD and the SFD (figs. 13 and 14). Eighteen of the constituents are different types of polycyclic aromatic hydrocarbon (PAHs). Samples from at least 15 runoff events were analyzed for all the constituents except PAHs. Samples from at least seven runoff events were analyzed for PAHs at both sites. Runoff events with rainfall depths less than 0.2 in. were analyzed only for TDS, TSS, and SS, if enough sample volume was collected. The number of samples available for these constituents was about 30 for the SFD and 45 for the HSD. Samples were collected for 17 months between June 21, 2002, and November 04, 2003, at the SFD site, and samples at the HSD site were collected over 14 months between April 30, 2003, and November 15, 2004. All but one of the samples at each site was collected during the non-winter events.

Figure 13. Example of inlet and outlet hydrodynamic settling device event samples.

Nondetectable concentrations were a substantial proportion of the total for the PAHs. More concentrations were below detection limits for the outlets than the inlets. Five of the 18 PAH compounds that had large number of nondetectable concentrations were: 1-methylnaphthalene; 2-methylnaphthalene, fluorene, acenaphthene, and acenaphthylene. To calculate the summary statistics for total PAHs, a method was needed to fill in the nondetected concentrations. Summing of the total PAH for calculation of the event-mean concentration was done in thee ways: (1) using the detection limit for less than detections and (2) using zero for less than detections (3) using one-half the limit of detection value. The three summing methods resulted in means that were in ± 5 percent of one-half of the applicable detection limit. Therefore the total PAH values were calculated by using one-half the limit of detection.

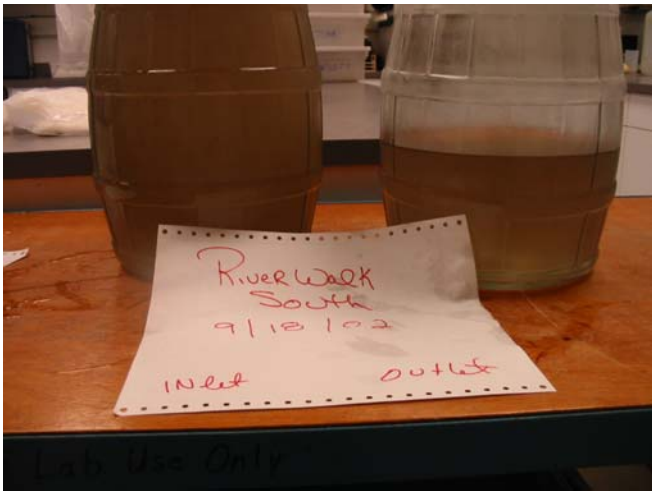

Figure 14. Example of inlet and outlet stormwater filtration device event samples.

Most of the concentrations for the inlet and outlet follow a lognormal distribution. The Shapiro-Wilk statistic was used to test for normality (Helsel and Hirsch, 1992). The outlet concentrations for COD did not follow a lognormal distribution at the HSD site. Also, the SFD data for Cl, COD, TSS, and TDS did not fit a lognormal distribution. Runoff data from a number of highway sites around the country exhibit similar distributions for average pollutant concentrations; that is, they were either lognormal or can be approximated as lognormally distributed (Driscoll and others, 1990). The USEPA NURP study (U.S. Environmental Protection Agency, 1983) reached a similar conclusion for pollutant-concentration data collected from many urban sites around the country. Datasets that are lognormally distributed are better described by the median or geometric mean than the arithmetic mean to reduce the influence of a few extreme observations. Therefore, the geometric means and medians are listed in tables 2–5 through 2–6 and 3–5 through 3–6.

Not all the same events were monitored at both sites, but the inlet medians for the HSD and SFD sites were similar for all the constituents except for SS, TSS, TDS, PAHs, and Cl (table 10). With differences in the range of 40 percent the median inlet concentrations were still relatively small between the PAHs, TSS, and TDS , but the SFD SS median of 389 mg/L was about 3.4 times greater than that of the 114 mg/L for the HSD. Many individual event SS concentrations observed at the SFD site were much higher than any of the observed SS concentrations at the HSD site (fig. 15). It is expected that two similar sections of freeway would produce similar concentrations for the constituents, but large differences in the SS concentrations is probably one consequence of having sites with dramatically different particle- size distributions.

While the inlet SS concentrations at the SFD site were almost always higher than the inlet TSS concentrations, the TSS and SS inlet concentrations were very similar at the HSD site (fig. 16). The median inlet SS concentration at the SFD site was 6 times the median TSS concentration. The differences in the TSS and SS concentration might be explained by the possible exclusion of the larger sand particles from the TSS analysis at the SFD site. The dominance of smaller particles might explain the similarities in TSS and SS concentrations at the HSD site. Gray and others (2000) concluded that the relations of SS and TSS concentrations were comparable when the percentages of sand-size material in the sample were less than 25 percent.

Similarities between both devices for particulate concentrations such as TP, TZn and TCu are partially explained by the type of laboratory procedures. Just like the TSS analyses, the analysis for TP, TZn, and TCu were done on an aliquot of the sample. Since some of the larger particles might not be included in the analysis, these averages can be similar between the sites despite the presence of a greater amount of larger particles in the SFD inlet samples. Dissolved constituents were very similar between the sites.

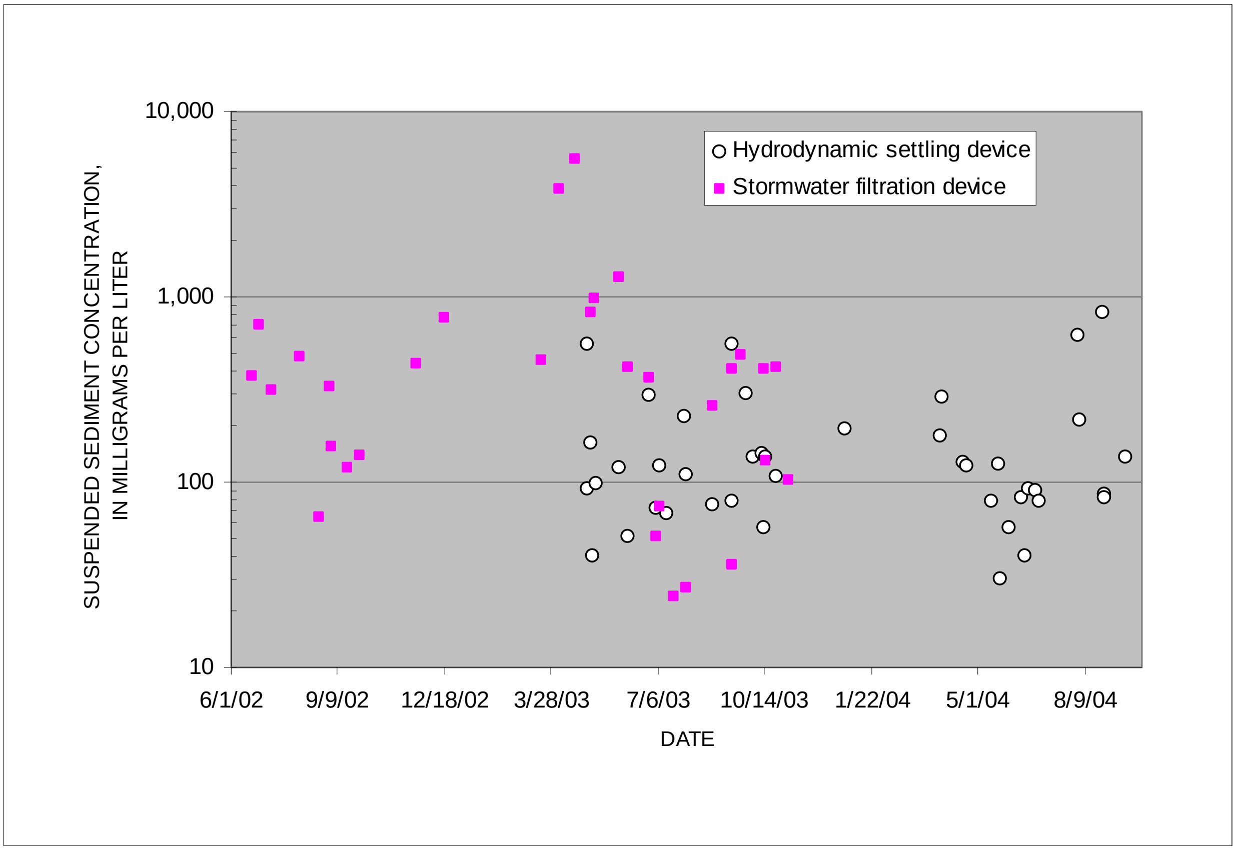

Figure 15. Site comparison of suspended-sediment concentration from device inlets by date.

The median outlet SS concentration for the HSD was 67 mg/L, and the median for TSS was 47 mg/L (table 10). The SFD outlet medians for SS and TSS concentrations were 34 mg/L and 36 mg/L. Outlet median concentrations for TP, DCu, DZn, TZn were lower for the SFD than the HSD when the inlet concentrations were similar were, except dissolved phosphorus (DP) which was lower at the HSD.

It is important to examine why two nearly identical source areas can have such large differences in SS concentration. One possibility was that the SFD site had a source of larger particles because more road-surface repairs were being done in the eastbound direction than in the westbound direction. Another explanation is that some of the sand-size particles were trapped somewhere in the pipe system before the runoff reached the HSD. Comparisons of events sampled on the same date from the SFD and the HFD substantiates that concentrations of suspended sediment were consistently higher at the SFD. There were two horizontal sections of pipe draining the westbound freeway into the HSD. These 8-in. pipes were beneath the freeway deck, about 15 ft above the ground. It is certainly possible that some of the larger material accumulated in this section of the pipe.

Table 10. Median concentrations at the inlets and outlets of the hydrodynamic settling device and stormwater filtration device.

[mg/L, milligrams per liter; µg/L, micrograms per liter; PAH, Polycyclic aromatic hydrocarbon]

Constituent	Hydrodynamic settling device			Stormwater filtration device		
	Number of samples	Inlet	Outlet	Number of samples	Inlet	Outlet
Dissolved solids, total (mg/L)	44	98	167	27	72	110
Suspended solids, total (mg/L)	44	89	47	24	60	36
Suspended-sediment concentration (mg/L)	42	114	67	32	389	34
Chemical oxygen demand (mg/L)	18	63	75	17	51	50
Phosphorus, dissolved (mg/L)	18	0.040	.028	17	.041	.037
Phosphorus, total recoverable (mg/L)	18	.147	.132	17	.152	.098
Copper, dissolved (µg/L)	18	14	15	16	13.6	12.4
Copper, total recoverable (µg/L)	18	53	41	17	44	23

Dissolved zinc (µg/L)	18	52	69	17	59	45
Zinc, total recoverable (µg/L)	18	231	172	17	226	91
Chloride, dissolved (mg/L)	18	20	38	15	9.2	17.0
Total PAHs µg/L	9	14.6	9.2	7	7.90	2.43

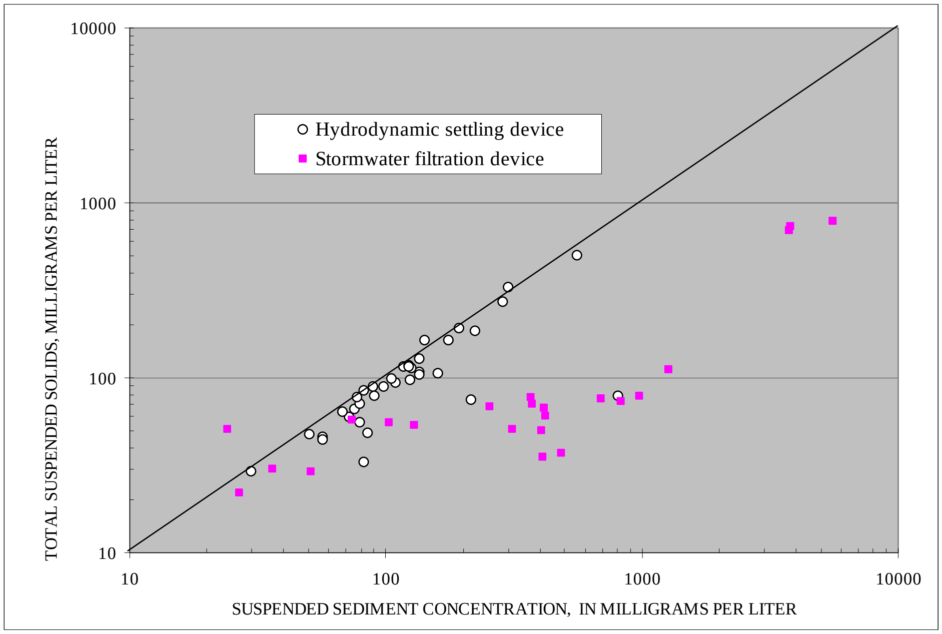

Figure 16. Comparison of suspended-sediment concentration and total-suspended-solids concentration at inlet devices for the hydrodynamic settling and stormwater filtration devices.

Table 11. Comparison of mean influent concentrations at the Riverwalk sites (hydrodynamic settling device and stormwater filtration device) with average runoff concentrations from other highway sites.

[mg/L, milligrams per liter; HSD hydrodynamic settling device; SFD, stormwater filtration device; --, data not collected or not applicable]

Site	Percent impervious	Average daily traffic	Seasons sampled	Suspended solids, total (mg/L)	Chemical oxygen demand (mg/L)	Phosphorus, total (mg/L)	Zinc, total (mg/L)	Copper, total (mg/L)	Chloride (mg/L)
HSD	100	44,000	Nonwinter	117	78	0.18	0.25	0.07	27
SFD	100	44,000	Nonwinter	143	80	0.20	0.40	0.10	59
I-794[1] Milwaukee	100	53,000	Nonwinter	138	105	0.31	0.35	0.10	63
Multiple sites[2]	37-100	>30,000	Nonwinter	165	129	0.52	0.54	0.06	31
I-894 National[3]	63	133,900	All	108	49	0.10	0.21	0.06	511
I-894[3] Oklahoma (nonswept period)	94	133,900	All	197	49	0.19	0.32	0.07	438
I-94[4] Minneapolis	55	114,000	All	118	207	0.56	0.17	0.05	1,802
Arterial St.[5]	100	20,000	Nonwinter	241	--	0.53	0.55	0.05	--

Highway[6] 12 &18 (Beltline)	100	77,000	Nonwinter	106	--	0.32	.125	.041	--

1. Gupta, and others, (1981).
2. Driscoll, and others, (1990), data from 12–16 sites.
3. Waschbusch, (2003).
4. Thomson, and others, (1997).
5. Bannerman, others, (1992).
6. Waschbusch, (1996).

Efficiency Calculations

To determine pollutant removal efficiency of a stormwater-treatment device, various methods are used (National Cooperative Highway Research Program, 2006). Two methods commonly used are the efficiency-ratio and summation-of-loads methods. The efficiency-ratio method is defined in terms of the average event mean concentration (EMC) of pollutants over a time period. The summation of loads method bases the efficiency on the ratio of the summation of all inlet loads to the summation of all outlet loads.

Each method uses data from the inlet and outlet of the device to produce a single number that is designed to represent the pollutant removal-efficiency of the device. However, the methods do not evaluate if there are statistical differences between the set of inlet and outlet concentrations. Therefore, it is very important to supplement the efficiency calculations with a statistical test indicating whether the means of the concentrations are statistically different (Helsel and Hirsch, 1992).

A paired statistical test was used to determine whether the inlet concentrations were higher than the outlet concentrations. Most of the constituents were lognormally distributed; therefore the nonparametric one-sided Wilcoxon signed-rank test was applied (Helsel and Hirsch, 1992). A test for significance was not done for Ca, Mg, and PAHs. Efficiency calculations were not done for Ca and Mg because they are used in the calculation of hardness.

The small number of samples and the occurrence of censored data (values less than detection limit) made it difficult to do a significance test for the PAHs.

A paired statistical test was considered valid for this dataset because the inlet and outlet concentrations are paired for each event. It would be more difficult to defend the idea that the concentrations are paired if more of the outlet concentration reflected the water stored in the devices between events. For most events, the volume of inlet water was sufficient at the HSD site to replace the stored volume of about 30 ft^3 at least 10 times. The same was true for the SFD site, where the stored water of about 20 ft^3 was replaced at least 10 times during most events.

At the HSD concentrations of TP, DP, TCu, TZn, SS, and TSS were significantly higher at the inlet than at the outlet at 95 percent confidence level. Concentrations of three of the dissolved constituents—TDS, Cl, and dissolved zinc (DZn), were significantly lower at the inlet than at the outlet. There was no significant difference between the COD and DCu concentrations.

Concentrations of 9 of the 11 constituents analyzed for at the SFD site were significantly different at the 95-percent confidence level between inlet and outlet, and TP was significantly different at the 90-percent level. Concentrations of DP were not significantly different at the inlet compared to the outlet. All the constituents that were significantly different were significantly higher at the inlet, except for CL and TDS. They were significantly higher at the outlet.

Sufficient differences existed between the means of the inlet, and outlet concentrations to have confidence in the efficiencies calculated for most constituents. Only the efficiencies for DP at the SFD site and the COD and DCu at the HSD site should not be considered significant.

Efficiency Ratio

The efficiency-ratio method of calculating efficiencies of a treatment device weights all events equally. For example, a large-volume event with high concentrations will have the same weight as a small-volume event with low concentrations. The calculation is represented by the following equation (U.S. Environmental Protection Agency, 1999):

EFFICIENCY RATIO AS A PERCENT = 100 (1- (AVERAGE OUTLET EVENT MEAN CONCENTRATION/ AVERAGE INLET EVENT MEAN CONCENTRATION))

Efficiency Ratio for the Hydrodynamic Settling Device

Of those constituents that were significantly different, 6 of the 9 constituents, the positive value of the efficiency ratio showed the HSD was able to decrease the average concentration of those constituents (table 12). Most of the efficiency ratios were about 30 percent or less. The TSS and SS efficiencies ratio were higher, at 42 and 57, respectively. For Cl, TDS, and DZn, the negative values of the efficiency ratios showed that the average event concentrations increased at the outlet of the HSD. Salt pellets from the winter road salting could have produced brine in the sedimentation chamber that increased the outlet concentrations for both Cl and TDS. For example, the inlet concentration of Cl on April 17, 2004, was 40 mg/L, and the outlet concentration was 792 mg/L (table 2–6). It was not clear why the DZn concentration increased at the outlet.

Table 12. Summary of average event-mean concentrations and efficiency ratio for the hydrodynamic settling device.

[%, percent efficiency ratio; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent	In	Out	%
Dissolved solids, total (mg/L)	213	627	-194
Suspended solids, total (mg/L)	117	67	42
Suspended-sediment (mg/L)	170	73	57
Phosphorus, dissolved (mg/L)	0.06	.04	28
Phosphorus, total (mg/L)	.18	.15	16
Copper, total recoverable (µg/L)	71	48	33
Zinc, dissolved (µg/L)	76	91	-19
Zinc, total recoverable (µg/L)	254	196	23
Chloride, dissolved (mg/L)	27	122	-347

The SS and TSS efficiency ratios for individual events (event efficiency ratio) tended to be between 50 and 90 percent when their inlet concentrations were greater than about 200 mg/L (fig. 17). Below this concentration, the event efficiency ratios were much more variable. When concentrations were around 150 mg\L, the SS and TSS event efficiency ratios ranged from 10 to 90 percent. An increase in efficiency ratios above 200 mg/L might be explained by a possible increase in the percentage of larger particles in samples with higher concentrations. This explanation for these tendencies cannot be tested when particle-size distribution data are available for only 8 of the 45 events monitored. All the negative efficiencies were observed for inlet SS and TSS concentrations of less than about 125 mg/L.

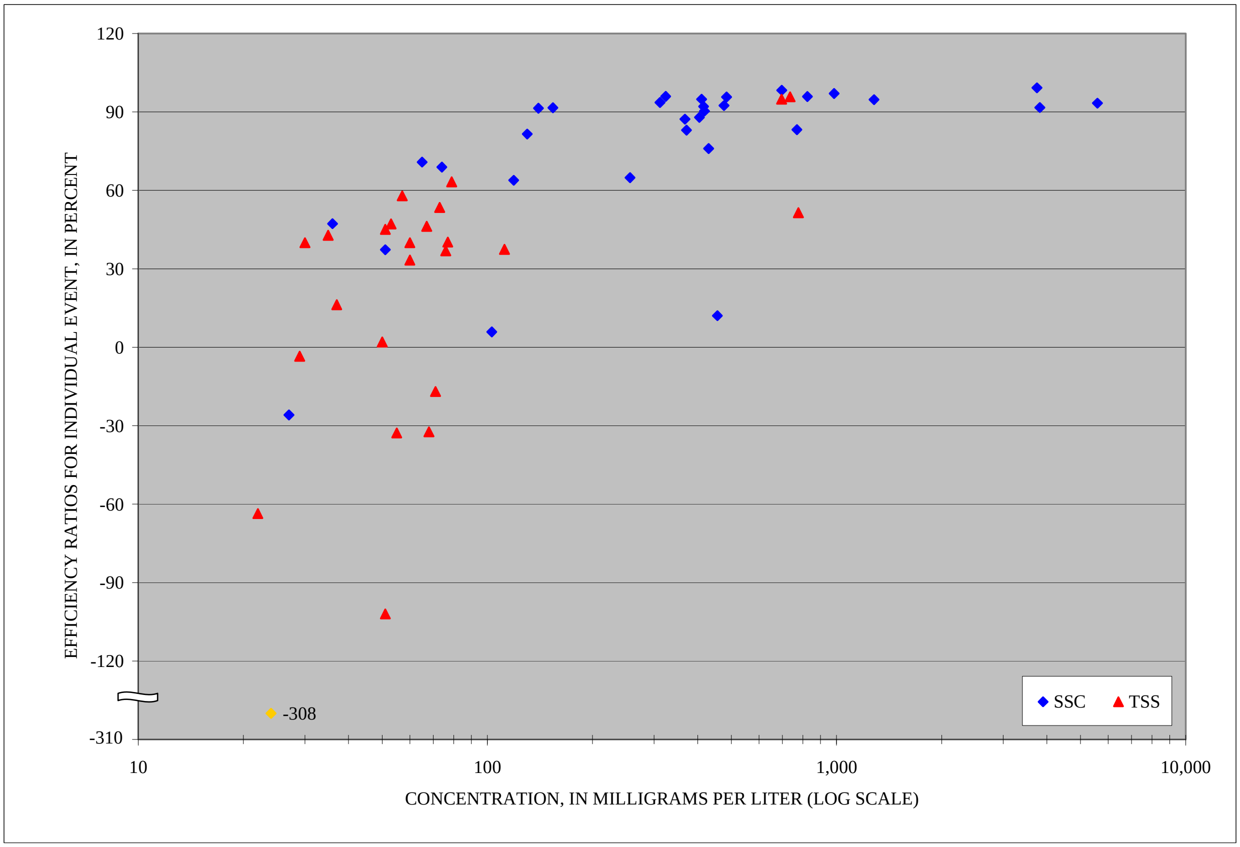

Figure 17. Efficiency ratios for total suspended solids and suspended sediment as a function of concentration for the hydrodynamic settling device.

At relatively low peak flows, there was a wide scatter in the SS and TSS event efficiency ratios (fig. 18). For peak flows less than 0.15 ft^3/s the event efficiency ratios ranged from zero to almost 100 percent. Most of the events were in this area of wide scatter. The peak flows did not seem to be a good predictor of efficiencies except when peak flows were greater than the design flow. When peak flows were greater than the design flow, all of the event efficiency ratios were negative, except for SS in one event. Flows greater than the design flows were more likely to scour some of the sediment already deposited in the device, and the amount removed could be more than that deposited during the event. The HSD had no bypass, so all runoff entered the settling chamber of the HSD.

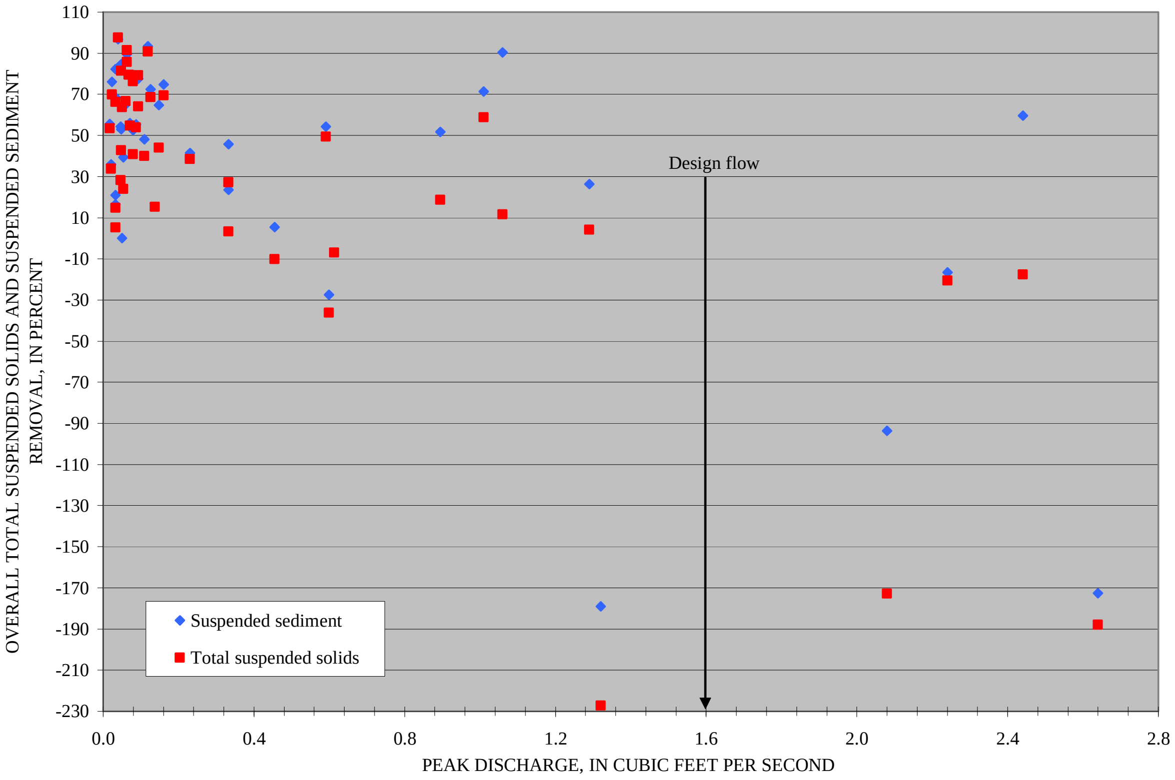

Figure 18. Removal efficiency of total suspended solids and suspended sediment as a function of peak discharge for the hydrodynamic settling device.

Efficiency Ratio for the Stormwater Filtration Device

Eight of the 10 constituents had positive efficiency ratios for the SFD (table 13). All the constituents associated with TSS, such as TP and the total recoverable metals, had efficiency ratios between 40 and 66 percent. These percentages are similar to the efficiency of 59 percent for TSS. Efficiency ratios for the total recoverable metals were given a boost by the 20-percent efficiency ratios for dissolved metals. The efficiency ratio for DP should not be considered because the difference between the inlet and outlet concentrations was not significant.

The SS efficiency ratio of 90 percent was much higher than the TSS ratio of 59 percent. This clearly reflects the large amount of sand-sized particles found in the inlet samples for the SFD (fig. 12). As described before, the sand-size particles are included in the SS concentration analysis, but a large proportion of these particles may not be included in the TSS analysis. Chloride and TDS had negative efficiency ratios for the SFD. Again, road salt brine created from probably caused the increase in the outlet concentrations of these two constituents. The biggest increase in outlet concentration for Cl for event 11, when the inlet concentration was 310 mg/L and the outlet concentration was 2,590 mg/L (table 3–6).

SS and TSS showed increasing efficiency ratio with increasing inlet concentration (fig. 19). For SS and TSS, 95 percent of the events had efficiency ratios over 70 percent when the inlet concentration greater than 200 mg/l. Once inlet SS concentration exceeded above 600 mg/L, the efficiency ratios were always about 90 percent. The presence of a greater number of large particles at the higher concentrations probably contributed to the consistently higher efficiency ratios at higher concentrations. SS and TSS concentrations below about 120 mg/L had a large range in efficiency ratios, some efficiencies being negative. Six of the TSS concentrations were negative, whereas only two efficiency ratios for SS were negative.

Event efficiency ratios for both TSS and SS were reasonably constant when the peak flows are less than the design flow (fig. 20). For almost all the peak flows observed during the project, the SS event efficiency ratios were above 60. This was true even when the peak flow exceeded the design flow of 0.29 ft^3/s. Three of the events with peak flows greater than the design flow had negative or efficiency ratios less than 30 percent for SS. Efficiency ratios for TSS were mostly between 40 and 60 percent until the peak flows exceed the design flow. Six of the twelve TSS event efficiency ratios were either negative or about zero for peak flows that were above the design flow.

Table 13. Summary of average event-mean concentrations and efficiency ratio for the stormwater filtration device.

[%, percent efficiency ratio; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituents	In	Out	%
Dissolved solids, total (mg/L)	141	394	-179
Suspended solids, total (mg/L)	143	58	59
Suspended sediment (mg/L)	743	73	90
Phosphorus, total (mg/L)	.20	.12	40
Chemical oxygen demand (mg/L)	80	65	18
Copper, dissolved (µg/L)	18.3	15.5	21
Copper, total (µg/L)	103	35	66
Zinc, dissolved (µg/L)	74	57	23
Zinc, total (µg/L)	402	135	66
Chloride, dissolved (mg/L)	59	231	-294

Scour of sediment deposited on the bottom of the pre-treatment chamber and cartridge filter bay seems an unlikely reason for the negative ratios for the SFD, because almost all the water entering the SFD was treated by the filters except during two events. Only a few minutes of bypass was observed during these two events. One possible explanation for the negative values might be the remobilization of the clay-sized particles and very-fine silt-sized grained particles already trapped in the filters (J.T.Doerfer, Midwest Regional Regulatory Manager–

Contech, CPI; (Kalamazoo, MI) oral commun., 2008). This is more likely to happen during the first flush of water into the filters after the filters have had a chance to dry between events.

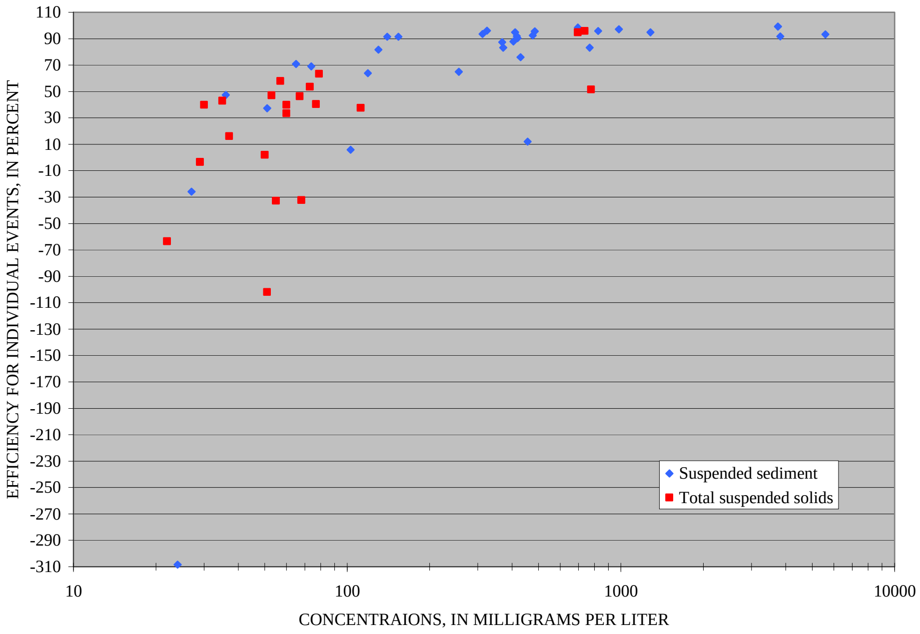

Figure 19. Removal efficiency of total suspended solids and suspended-sediment as a function of concentration for the stormwater filtration device.

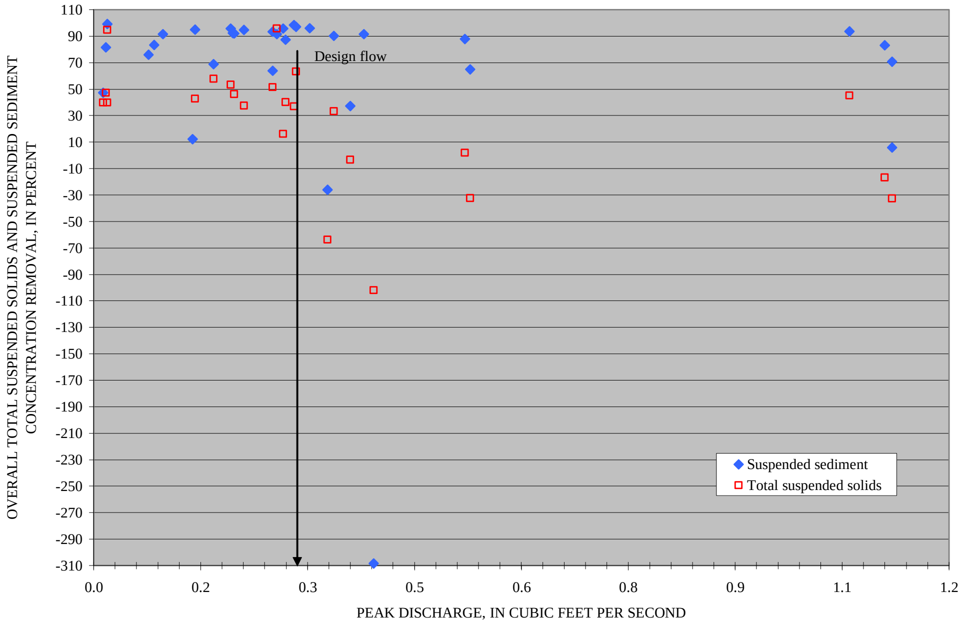

Figure 20. Efficiency ratios of total suspended solids and suspended sediment as a function of peak discharge for the stormwater filtration device.

Summation of Loads

The summation-of-loads (SOL) method of calculating efficiencies is weighted by the size of the events. This method puts the emphasis on the quantity of pollutants entering the receiving water instead of a change in concentration. In many cases, filtration and/or settling devices are installed to achieve a reduction in the pollutant load. The SOL method might be of more interest than the efficiency-ratio method to agencies trying to reduce the total load of a pollutant to receiving waters. It is possible with this method that a small number of large events can dominate the SOLs. As the efficiency-ratio calculations, the water stored in the devices between events is considered too small to affect the SOL calculations. Significant testing was performed on concentrations at the 95 or 90 percent confidence interval using the Wilcoxon signed-rank.

The SOLs was on calculated only for those constituents that had a significant of the concentration.

The device efficiency based on summation of loads is (U.S. Environmental Protection Agency, 1999):

$$\textbf{SUMMATION OF LOADS} = 100 * (1- (\textbf{SUM OF LOADS}_{\textbf{OUTLET}} / \textbf{SUM OF LOADS}_{\textbf{INLET}}))$$

Summation of Loads for Hydrodynamic Settling Device

For about one-half of the constituents, the negative SOLs for the HSD are higher at the outlet than the inlet (table 14): specifically, these constituents are TDS, DP, COD, DCu, DZn, and Cl. However, the difference between the inlet and outlet loads for DP, COD and DCu were not considered significant. SOLs for TP, TZn, TCu, SS, and TSS ranged from 10 to 49 percent (table 14). SS had the largest reduction, at 49 percent, whereas TP had a 10-percent reduction. SOLs for SS were higher than those for TSS because the SS concentration analysis better represents all the sand-size particles that might be deposited in the device. As with the efficiency ratios, it was not clear why the DZn SOL values were negative, but outlet loads were higher than the inlet loads for 12 of the 18 events (table 2–9). Very high outlet loads for four events in December, March, and April accounted for most of the magnitude of the negative SOLs for Cl.

If most of the sand-sized particles are retained in the HSD, the sand could account for over one half of the 49-percent reduction observed for SS load. The average percentage of particles in the sand fraction entering the HSD was 30 percent (table 6). However, to bring the SS efficiency load up to 49 percent, some of the silt-size particles also must be trapped in the HSD. A more precise accounting of the importance of the different particles would be possible, if sufficient particle-size data were available to determine a SOL value for each particle size.

SOLs are weighted by the size of the events, so a large event can have a disproportionate influence on the final efficiency loads. To test the impact of larger events, the events with the two largest inlet loads were omitted from the SOL calculation for TSS and suspended sediment. SOL for SS dropped from 49 to 40 percent, about a 20-percent decrease without the two largest events. SOL for TSS increased from 25 to 30 percent when the two largest events were omitted from in the calculation. This increase was explained by the TSS outlet load for the largest event being larger than the inlet load.

Table 14. Summary of loads and percent efficiency for the hydrodynamic settling device**.**

[lb, pounds; %, percent; SOL, summation of loads]

Constituents	**Inlet (lb)**	**Outlet (lb)**	**SOL %**
Dissolved solids, total	143	417	-192
Suspended solids, total	127	94	25
Suspended sediment, total	182	92	49
Phosphorus, total	0.09	.08	10
Copper, total recoverable	.035	.026	27
Zinc, dissolved	.038	.047	-23
Zinc, total recoverable	.125	.106	16
Chloride, dissolved	.011	.0347	-216

All of the HSD efficiency ratio values were higher than the SOLs for the constituents with positive SOLs. For TSS and TP the efficiency ratios approach twice that of the SOL values. The difference between the efficiency ratio and SOLs seems to be related to the outlet concentrations that are higher than the inlet concentrations. If these events are removed from the efficiency-ratio and SOLs calculations, the TSS and SS efficiency ratios and SOL values would be almost the same. Removing the events with negative removals increases both the efficiency ratios and SOL values, but the relative increase for SOL values is greater. This is because the inlet concentrations for these events are relatively low, but the runoff volumes are relatively high. Although the removal of the events with negative removals explains the differences between the efficiency ratios and SOL values for the HSD, both methods are probably valid depending on the whether the goal is to control concentrations or loads.

Summation of Loads for the Stormwater Filtration Device

All the SOLs for the SFD were significant except that for DP. SS had the highest SOL at 89 percent, whereas the rest of the positive SOLs ranged from 20 to 64 percent (table 15). SOLs for TSS, DZn, and DCu might have been somewhat higher if a few of the outlet loads were not greater than the inlet loads (tables 3–8 and 3–9). Only two outlet loads were greater than the inlet load for SS.

At 50 percent, the SOL for TSS was much lower than that for SS. The reason for the difference was that most of the inlet loads for SS were larger than those for TSS, but outlet loads were very similar for most events (table 3–8). For example, the outlet loads for TSS and SS were the same on event 14, but the inlet suspended sediment load was about 7 times the TSS load. The ability of the SS concentration analysis to include all the larger particles had a major effect on the SOLs. This was especially true at the SFD site because such a large proportion of the inlet particles were in the sand fraction (table 8).

Based on the average percentage of the sand-size particles in the inlet water (table 8), controlling 100 percent of the sand fraction would achieve an SOL for SS of about 70 percent. Some percentage of silt-size particles must have also been removed, because it can not be assumed 100 percent of the sand-sized particles are removed and the SOL for SS is greater than 70 percent. The three events with pipet data for the outlet showed the SFD can remove some of the particles in the range of 8 to 16 µm (table 9). Unfortunately, there was not enough particle-data in this study to calculate a SOL by particle sizes. An ETV evaluation of an SFD in Griffin, Georgia found a SOL value of 40 percent for particles in the silt and smaller-size fraction (U.S. Environmental Protection Agencies, 2005 b). If the SOL for the silt-sized fraction was 40 percent at the Milwaukee site, the silt would account for about 12 percent of the SOL value for TSS and SS. SOLs for TSS would be influenced by the 12 percent for silt, the percentage of sand trapped by the HSD and ability of the TSS analysis to capture all the sand-sized particles in the sample.

SOLs for TP and total metals ranged from 38 to 68 percent (table 15). Factors that might contribute to the high SOLs for these constituents are (1) none of the outlet loads were higher than the inlet load (table 3–9); (2) some of the silt or smaller particles were captured; and (3) significant proportion of the dissolved metals were removed. The DZn and DCu SOLs were about 20 percent. Removing the silt-size particles can increase the removal of TP and metals, because their concentrations tend to be highest on silt-size particles (Dong and others, 1979).

Removing two events with the largest loads from the SOL calculation for TSS, decreased the SOLs for TSS from 52 to 37 percent. These same two events removed from the SOL calculation for SS only reduced the SOL from 89 to 87 percent.

Table 15. Summary of loadings and percent efficiency for the stormwater filtration device.

[lb, pounds; %, percent; SOL, summation of loads]

Constituents	Inlet (lb)	Outlet (lb)	SOL %
Dissolved solids	30	64	-112
Suspended solids, total	52	26	50
Suspended sediment, total	368	40	89
Phosphorus, total	0.064	.040	38
Chemical oxygen demand	24	20	14
Copper, dissolved	.0057	.0048	16
Copper, total	.0314	.0108	66
Zinc, dissolved	.026	.021	20
Zinc, total	.125	.0416	68
Chloride, dissolved	12.1	56.2	-367

Efficiency ratios and SOLs were almost identical for the SFD. This is possible if the events with the higher concentrations also tended to have higher loads. These events would have a similar impact on the final SOLs and efficiency ratios. For example, 4 of the events 13, 14, 16 and 26 not only had much higher SS concentrations than the other 29 events but also had the inlet loads that represent almost 50 percent of the total load for all events (tables 3–5, 3–8). Given the results for the two methods of calculating efficiencies were different at the HSD site and the same at the SFD site, it appears to be important to use both methods at all sites.

Total Suspended Solids Reductions in Other Field Tests of the Hydrodynamic Settling Device and Stormwater Filtration Device

Results from other field-performance studies of the HSD and SFD might help determine how well the results from this study will apply to other sites. Results from this study indicate that SS, TSS concentrations and particle-size distribution affect the level of control for a device (figs.11, 12, 17, and 19). A logical question from this study would be how transferable results from the Riverwalk sites might be to other sites in Wisconsin. A literature review of previous HSD and SFD studies maybe useful in determining how transferable the results from this study maybe. System performance in this review is described for TSS concentration only.

Other Field Verification Studies for the Hydrodynamic Settling Device

Field verification studies of the HSD have been done in the states of Maine, New Jersey, New York, Connecticut, and Washington (Pack, 2003). Flow accuracies in the Maine study make it difficult to draw conclusions from the data (Winkler and Guswa, 2002). Data from only five runoff events were collected during the New Jersey study (Greenway, 2001), again making it difficult to compare results with those from the Milwaukee Riverwalk study.

At 58 runoff events sampled, the study in Connecticut (Clausen and others, 2002) collected more samples than any other study we were able to identify. A HSD was installed to treat the runoff from a 1.95-acre school parking lot. Eighty percent of the parking lot area was impervious. The SOL determined for TSS was 77 percent, much higher than the 25 percent calculated for the Milwaukee Riverwalk study. It is possible that two differences in the monitoring projects contributed to the differences in the SOLs. First, the parking lot was sanded during the winter months; this might be why 22 of 58 inlet TSS concentrations were greater than 250 mg/L, with a maximum value of 3,521 mg/L. The maximum TSS concentration for the Riverwalk study was 494 mg/L, with only four concentrations greater than 250 mg/L. Only 9 percent of the Riverwalk TSS concentrations were greater than 250 mg/L compared to 38 percent for the Connecticut study. When the inlet TSS concentrations exceed about 250 mg/L, the efficiencies of the device improve and are consistently greater than 50 percent (fig. 17). Second, the inlet water-quality sampling was done with a Coshocton Wheel in the Connecticut study. More information is needed on how the Coshocton Wheel data compare with the automatic-sampler data and how the wheel might affect the magnitude of the concentrations.

An HSD was installed in the Village of Lake George, NY, to treat the runoff from 9.3-acres of mixed land use, considered to be 95 percent impervious (West and others, 2001; Winkler and Guswa, 2002). About 30 percent of the drainage area was roadway. Samples were collected for 13 runoff events at the inlet and outlet of the HSD. An external bypass was installed with the device. However, bypass data were not recorded, so the efficiency of the device during bypassing events was unclear. An SOL of 88 percent was calculated for TSS in the New York study, compared to 25 percent calculated for Milwaukee Riverwalk study. The New York, study had an average inlet TSS concentration of 802 mg/L, much higher than the Milwaukee

Riverwalk average of 117 mg/L. In the New York study approximately 70 percent of inlet TSS concentrations were greater than 250 mg/L compared to approximately 9 percent for the Milwaukee Riverwalk study. About 38 percent of the New York inlet TSS concentrations were greater than 1,000 mg/L, with a maximum of 2,492 mg/L. It is not clear why the TSS concentrations were so high in the New York runoff samples, but the high concentrations would certainly play a role in the high efficiency seen in that study.

The field testing on the HDS in Washington State was done on a 28-acre drainage area along State Route 405 in King County (Taylor Associates, 2002). About 66 percent of the drainage area was estimated to be impervious. Inlet and outlet monitoring was done for 11 runoff events between March 2001 and February 2002. This was the only HSD study we reviewed where an effort was made to measure particle-size distributions for the samples. The Washington study efficiency ratio was 20 percent for TSS, much lower than the 42 percent measured in Milwaukee Riverwalk study. Similar results might be expected, because the TSS concentrations were very similar for both studies. The range in TSS concentrations in Washington was 30 to 580 mg/L with an average of 190 mg/L, and the range for the Milwaukee Riverwalk study was 29 to 494 mg/L with an average of 117 mg/L. Only two TSS concentrations were greater than 250 mg/L for the Washington study. One reason the two studies produced such different efficiency ratios might be the large amount of impervious area (18 acres) draining to one device. Also, 11 rainfall events are usually not enough to establish a significant difference between the pairs formed by the inlet and outlet concentrations. If the coefficient of variation for the Washington concentration data were about the same as for the Riverwalk study, then the Washington study would have had to sample about 35 rainfall events to have a 90-percent level of confidence in seeing a 25-percent difference in the inlet-outlet concentration pairs (Burton, 2002).

Field Verification Studies for the Stormwater Filter Device

Brown (2003) reviewed six field verification studies of the SFD: each experienced complications, making a comparison with the Riverwalk study difficult. These issues included the use of a different filter media, such as leaf compost, and monitoring of less than six events. The findings of this study could be compared with two more recent field verification studies conducted by the California Department of Transportation (2004) and NSF International (U.S. Environmental Protection Agencies, 2005 b), because all the studies had similar sampling methods and filter media.

An SFD was installed on a California Department of Transportation maintenance station as part of a BMP retrofit pilot program (California Department of Transportation, 2004). The drainage area of 1.5 acres was 100 percent impervious. A design flow of 2.7 ft^3/s was used for the SFD. A mixture of perlite and zeolite was used for the filter media. Particle-size distributions and SS concentration were not determined for the runoff samples. The average inlet TSS concentration of 175 mg/L was similar to the 143 mg/L observed for the Riverwalk study. Only the efficiency ratio was calculated for TSS; and at 40 percent, it was lower than the 59 percent calculated for the Riverwalk study. Without particle-size data or the TSS concentrations for each event, it is difficult to speculate as to why the efficiency ratio was higher for the Milwaukee Riverwalk study.

The field verification monitoring for the SFD in City of Griffin, Ga, was a part of the USEPA’s Environmental Technology Verification program (U.S. Environmental Protection Agencies, 2005 b), as was the Milwaukee Riverwalk study; hence both studies used the same monitoring protocols. Instead of freeway, the 0.7 acre drainage area of for the SFD in the Georgia was a mixture of parking lot, roadway, and rooftop, with an imperviousness of 85 percent. Perlite was used as a filter media instead of a mixture of perlite and zeolite. The SFD in the Georgia study had a 50 percent SOL for TSS, the same as 50 percent (table 15) found for the Milwaukee Riverwalk study. Similar inlet TSS concentrations observed might be partly responsible for the agreement in the SOLs. The average inlet TSS concentration for the Georgia study was 165 mg/L, and the average for the Riverwalk study was 143 mg/L. The range in inlet TSS concentrations of 90 to 410 mg/L was similar to the range of 22 to 778 mg/L observed at the inlet for the Riverwalk study (table 3–5).

Unlike the large differences found between the SOLs measured for TSS and SS in Milwaukee study, the SOL for both TSS and SS was 50 percent for the Griffin SFD. This can be explained by the very large differences in the particle-size distributions at the two sites. On average only about 10 percent of the particles in the Georgia runoff samples were in the sand fraction, whereas the average percentage of sand in samples from the Riverwalk study was 71 percent.

Despite the differences in the percent sand-sized particles, the similarities between the SOLs for TSS can be explained by how much of the silt-size particles might be retained by a SFD and the limitations of the TSS analysis. The SOL for the silt-sized particles was 40 percent at the Griffin, Georgia site. Since about 90 percent of the particles are in the silt-size fraction and the TSS analysis is very efficient for silt-size particles, the silt-size fraction was largely responsible for the SOL value of 50 percent. Insufficient particle-size data was collected at the Milwaukee site to calculate a SOL by particle size, but the available data indicates some of the silt-sized fraction was trapped by the filter. Particle size information was available for only about one half of the 30 sampled events. If the SOL for the silt-size fraction at the Milwaukee site was 40 percent, the amount of silt in the water samples limits the TSS reduction due to silt to about 12 percent. Assuming a large percentage of the available sand-sized particle would be trapped by the SFD, increasing the SOL for TSS beyond 12 percent would depend on the efficiency of the TSS analysis for larger sand-sized particles.

Mass Balance of Sediment Retained in the Devices

One way of checking the accuracy of the measured loads at the inlet and outlet of a device is to weigh the material that is retained in the treatment chambers. The weight of the sediment retained in the devices should be reasonably close to the calculated reduction in SS load. To complete the mass-balance calculation, the SS loads needed to be computed for all events. Ideally, there would be SS concentration data for every event during the testing period. Unfortunately, because of the monitoring challenges, there were many events without concentration data. The HSD and SFD had 59 and 63 events without concentration data, respectively. The significance of these unmeasured values was diminished somewhat by the fact that rainfall depth for more than one-half of the un-sampled events was less than 0.2 in. The goal was to find a method that calculated a reasonable estimate to the measured events and to apply that method to unmeasured events; the goal was not to match the known sediment retained at the bottom of the devices.

The challenge was to find a method to estimate the inlet and outlet SS concentrations for the un-sampled events. This is all that was missing to calculate the inlet and outlet loads, since the volumes were measured for the un-sampled events. The approach to finding a method for estimating the concentrations for un-sampled events starts with trying to match the concentrations for the sampled events. The SOL for SS using the sampled and un-sampled events could then be compared to the weight of the sediment removed from the bottom of the treatment devices.

Multiple linear regression analysis was applied to the runoff events with suspended sediment concentrations in an attempt to estimate suspended sediment loads for events with no water-quality data. Because flow and rainfall data were available for all events with unmeasured concentrations, the regression analysis used flow and rainfall as predictors of SS concentrations. The list of independent variables included peak flow; average rainfall intensity; peak 5-, 10-, 15-, 30- and 60-minute rainfall intensity erosivity index; rainfall depth; and antecedent dry days. Similar analysis was completed for logtransformed SS concentration data. The regression analysis produced unsatisfactory results in predicting SS concentrations.

The best predictor of the unmeasured SS concentrations data proved to be the average SS concentrations measured at the inlet and outlet of each device. The total SS load determined by multiplying the average SS concentrations by the measured water volumes compared very well with total measured SS load for the same runoff events (table 16). It was decided the average SS concentration were the best way to determine the suspended sediment loads for the events without SS data.

The average SS concentration was not used to estimate the outlet load of the HSD for 5 unmeasured events with peak flows exceeding the design flow of the HSD. Results from four monitored events show the SS efficiency ratios for individual events tend to be negative when the peak flow exceeds the design flow (fig. 16). The average ratio of outlet load to inlet load was about 1.3 for these four monitored events. This ratio was multiplied by the inlet load to estimate the outlet load for the five unmeasured events with peak flows exceeding the design flow. This approach of adjusting outlet loads was not applied to the SFD, because most of the monitored events with peak flows exceeding the design flows did not result in negative efficiency ratios (fig. 20). Only event 22 and 24 had negative efficiency ratios, and both of these events had very low SS concentrations relative to the other monitored events.

Table 16. Comparison of suspended sediment loads estimated with average concentrations and measured suspended sediment loads for the same runoff events.
[lb, pounds; HSD, hydrodynamic settling device; SFD, stormwater filtration device]

Location	Number of Sampled Events	Measured Load (lb)	Estimated Load (lb)	Percent difference
	HSD			
Inlet	42	182	201	10
Outlet	42	92	77	-16
	SFD			
Inlet	32	368	434	16
Outlet	32	40	54	32

Figure 21. Cleanout of the settling chamber for the hydrodynamic settling device.

At the end of the monitoring period, both devices were cleaned out by hand removing all possible sediment. Standing water was decanted to a level of 0.5 ft above the deposited sediment. Samples of the decanted water were collected at numerous water levels and analyzed for SS and

TSS concentrations. Sediment removed from each device were collected then dried and weighed. Subsamples were sent to the USGS Iowa Sediment Laboratory to define the percentage of sediment, by mass, with diameters less than 2,000, 1,000, 500, 250, 125, 62, 31, 16, 8, 4, and 2µm.

Figure 22. Cleanout of the 8 in. inlet pipe for the hydrodynamic settling device.

Mass Balance for Hydrodynamic Settling Device

The HSD was cleaned out on September 24, 2004 (figs. 21 and 22). Sediment was removed from the inlet pipe 4 ft upstream from the HSD, the 3-ft-diameter grit chamber, and the flow-and oil-control chamber. The dry weight of the sediment at each location was 8 lb for the inlet pipe, 106 lb for the grit chamber, and 15 lb for the flow and oil control chamber. The total weight from all the locations was 129 lb. Most of the sediment retained in the HSD was found in the grit chamber. The amount of sediment found in the HSD was about the same as predicted by the monitoring data (table 17). Although about one-half of the SS loads had to be estimated, the similarity in the measured and retained loads gave credibility to the monitoring methods.

About 90 percent of the sediment removed from the bottom of the device was in the sand fraction (table 18). The opposite was observed for the inlet water, where 80 percent of the particles were in the silt fraction or smaller (table 6). The difference between the particle sizes in the water coming in and the sediment retained by the device clearly shows the device preferentially traps the larger particles and may scour of some of the silt particles in subsequent runoff events. A small amount of sediment retained in the inlet pipe and the flow-and-oil control chamber had a particle-size distribution similar to that found in the grit chamber.

Table 17. Comparison of the sediment retained in the device, the calculated sum of loads, and the estimated load from the hydrodynamic settling device and stormwater filtration device.

[lb, pounds; HSD, hydrodynamic settling device; SFD, stormwater filtration device]

Type of suspended sediment load	HSD loads (lb)	SFD loads (lb)
Calculated sum of loads	90	317
Estimated loads retained	58	334
Total of measured and estimated loads retained	148	651
Amount sediment retained from devices	129	638
Difference between monitored loads and amount of sediment retained from the devices:	19	13
In percent	15	-2

Table 18. Particle-size distribution for the sediment samples collected from the hydrodynamic settling device.

[µm, micrometer; % percent by mass; <, less than]

Particle size (µm)	Inlet pipe (%)	Grit chamber subsample 1 (%)	Grit chamber subsample 2 (%)	Flow-and-oil control chamber (%)	Median[1] (%)	Average[1] (%)
<8,000	--	--	--	--	--	--
<4,000	88	95	89	87	89	90
<2,000	83	92	84	82	84	85
<1,000	76	87	69	72	74	76
<500	62	74	58	54	60	62
<250	39	40	41	37	40	39
<125	18	16	20	21	19	19
<63	11	7.2	11	14	11	11
<31	6	5.4	8.3	9.8	7	7
<16	4.6	3.8	6.3	6.9	5	5
<8	3.5	2.6	4.3	4.4	4	4
<4	2.8	2.3	3.1	3.4	3	3
<2	2.0	1.6	2.2	2.5	2	2

[1] Statistic combines on inlet pipe, grit chamber 1 & 2, and flow-and oil-control chamber.

Mass Balance for the Stormwater Filtration Device

The SFD was cleaned out on January 24, 2004 (fig. 23). All the sediment was removed from the inlet bay and the cartridge bay. To determine the amount of material retained by the filters, material from five of the nine cartridges was dried and weighed. The average weight of the cartridges before the study began was subtracted from the total weight at the end of the study. Total sediment retained from the inlet bay was 289 lbs; from the cartridge bay, 145 lbs; and from the filters, 204 lbs; for a total of 638 lbs. The suspended-sediment load reduction calculated for the SFD using the measured and estimated loads was very close to the amount predicted by weighing the amount of sediment retained in the device’s treatment chambers (table 17).

Figure 23. Cleanout of the settling bay and cartridge chamber for the stormwater filtration device. (Photo shows sediment and debris before cleanout.)

Sediment removed from the SFD inlet and cartridge bays contained particles that were mostly in the sand fraction (table 19). On average, the sediment in the inlet bay was 89 percent sand, and the percent sand in the cartridge bay was 84 percent. The percentage sand in the filter cartridges was (about 84 percent) nearly the same as in the cartridge bay. A slightly higher percentage of fine particles were trapped in the cartridge bay and filter cartridges than in the inlet bay. Mostly sand was found in the SFD, similar to the average composition of inlet-water particles was about 71 percent sand (table 8).

Table 19. Particle-size distribution for the sediment samples collected from the stormwater filtration device.

[µm, micrometer; % percent by mass; <, less than]

Particle Size (µm)	Inlet bay, sub-sample 1 (%)	Inlet bay, sub-sample 2 (%)	Inlet bay, sub-sample 3 (%)	Inlet bay, sub-sample 4 (%)	Average, Inlet bay (%)	Cartridges bay sub-sample 1 (%)	Cartridges bay sub-sample 2 (%)	Average, cartridges bay (%)
<8,000	--	--	100	96	98	--	--	--
<4,000	92	95	90	92	92	97	95	96
<2,000	83	89	83	87	85	90	89	89
<1,000	69	81	74	75	75	79	75	77
<500	44	65	54	52	54	78	51	65
<250	24	41	31	27	30	32	37	34
<125	13	21	15	16	16	15	28	21
<63	9	14	9	11	11	10	21	16
<31	6.1	8.3	5.9	7.8	7	6.4	16	11
<16	3.8	5.2	4	5.2	5	4.2	11	7
<8	2	3.2	2.3	3.7	3	2.3	7.6	5
<4	1.7	2.6	2	3.1	2	2	6.6	4
<2	1.2	1.9	1.6	2.5	2	1.5	5.3	3

Summary and Conclusions

As part of their efforts to improve the quality of highway runoff, the Wisconsin Department of Transportation (WisDOT) has worked in cooperation with the U.S. Geological Survey, Wisconsin Department of Natural Resources (WDNR), City of Milwaukee, the Milwaukee Third Ward, Milwaukee County, and the USEPA Environmental Technology Verification Program to verify the treatment efficiency of two stormwater treatment devices. The two devices were installed in December 2001 to treat runoff from a freeway in an ultra-urban part of Milwaukee, Wis., referred to as the “Riverwalk sites”. Runoff events were monitored for flow and water quality at the inlet and outlet of each device.

One treatment device is categorized as a hydrodynamic settling device (HSD) that removes pollutants by sedimentation and flotation. The other treatment device is categorized as a stormwater filtration device (SFD) that removes pollutants by filtration and sedimentation. Filtration is considered the primary method of treatment with sedimentation of larger particles in the pre-treatment chamber and cartridge filter bay. A filter media is selected for each site to retain the dissolved pollutants by sorption.

Thirty-three water-quality samples were collected at both the inlet and outlet of the SFD, and 45 for the HSD. For rains with depths of 0.2 in. or greater, the percentage of rainfall events sampled during the monitoring period was about 70 and 60 percent for the SFD and HSD, respectively. Except for a moderate deviation for rainfall depths between 0.65 and 0.9 in., the distribution of the sampled events was very similar to the long-term distribution. Bypassing the system was not possible for the HSD, so all sampled water entered and exited the system. Only a few minutes of bypassing was observed for two events at the SFD site.

Treatment efficiency of the devices was calculated by means of summation of loads (SOL) and the efficiency-ratio methods. Both methods produced similar treatment efficiencies for the SFD, but the SOLs tended to be somewhat lower than the efficiency ratios for the HSD, especially for total suspended solids (TSS), dissolved phosphorus (DP), and total polycyclic aromatic hydrocarbon (PAH). The SOLs for the HSD were lowered by the five events when the outlet loads were higher than the inlet loads. The five events were able to lower the SOL significantly because they had relatively large loads. In contrast, these events had relatively low concentrations, so they had a relatively small effect on the efficiency ratios.

Constituents whose concentrations and loads decreased by passing through the HSD include TSS, suspended sediment (SS) concentration, total phosphorus (TP), total copper (TCu), and total zinc (TZn). The efficiency ratios for these constituent were 42, 57, 16, 33, and 23 percent, respectively. The SOLs for these constituents were 25, 49, 10, 27, and 16 percent, respectively. Concentrations and loads increased at the outlet for chloride (Cl), total dissolved solids (TDS) and dissolved zinc (DZn). For example, the efficiency ratios for these constituents were -347, -194, and -19 percent, respectively. Sand-sized particles could account for a larger proportion of the efficiency ratio and SOLs for SS than silt-size particles, because the average percentage of sand in the inlet samples was about 30 percent. But some of the silt particles are captured in the HSD to achieve the SS reductions. Three constituents—DP, chemical oxygen demand (COD), and dissolved copper (DCu)—are not included in the list of computed loads, because the difference between the inlet and outlet concentrations for each was not determined to be significant.

Constituents whose average concentrations and total loads were significantly decreased by the SFD include TSS, SS, TP, DCu, TCu, DZn, TZn, and COD. The efficiency ratios for these constituents were 59, 90, 40, 21, 66, 23, 66, and 18, respectively. The SOLs for these constituents were 50, 89, 38, 16, 66, 20, 68, and 14, respectively. With the percentage of sand in the inlet water averaging 71 percent, the SOLs and efficiency ratios for SS could be more a function of the sand particles than the silt particles. But some of the silt-sized particles are retained in the SFD. By controlling some of the dissolved metals, the SFD efficiency ratio and SOL for total metals was higher than the concentrations of TSS. Dissolved metals were not controlled by the HSD, and the total metals reductions were less than the concentrations of TSS. Similar to the HSD, the average efficiency ratios and SOLs for the TDS and Cl were negative.

Road salt brine in both devices appeared to increase the effluent concentrations of both Cl and TDS.

Above a TSS concentration of about 200 mg/L, the efficiency of both devices appeared to be consistently higher. One possible explanation for the higher efficiencies might be the presence of more large particles in samples with higher TSS and SS concentrations. The larger particles are more readily removed by both devices. In contrast the efficiencies for TSS tend to go negative when the peak flow of an event exceeds the design flow of each device. For the HSD most of the SS efficiencies are also negative, but only 2 of the 12 events with the design flows exceeded have negative SS efficiencies for the SFD.

The sediment retained inside both devices was removed, weighed, and analyzed for particle-size distribution. The water-quality data were used to predict the amount of sediment that should be retained in the bottom of each device. The amount of sediment predicted to be trapped in the HDS and SFD was about the same as what was removed from the bottom of each device. Most of the sediment retained in both devices was sand size or larger. The percentage of sand in the grit chamber for the HSD was 90 percent and in the SFD filter cartridges was 84 percent. Although the average percentage of sand-size particles at the HSD inlet was only about 30 percent, the device retained mostly sand-size particles. The high percentage of sand observed in the sediment removed from the bottom of the SFD was reflected in the high percentage of sand measured in the inlet water. The cartridge filters did, however, trap some particles in the size range of 8 to 16 µm.

The WisDOT and the WDNR have an understanding that the WisDOT is to reduce TSS loads in stormwater and this project provides data on the amount of TSS that might be removed by the HSD and the SFD. The SOL of 25 percent for the HSD and 50 percent for the SFD should approximate the treatment efficiencies expected for TSS at other sections of Wisconsin freeways. Sizing of the devices at other sites should reflect careful analysis of the potential peak flows, since the devices are not as efficient when the design flows are exceeded. The SOL values for TSS are probably best applied to urban freeways instead of rural freeways where the TSS concentrations and particle-size distributions might be different.

The efficiencies for individual events can change with increasing TSS concentration, but the TSS concentrations observed at the Milwaukee Riverwalk site support the use of the SOL values at other urban freeways in Wisconsin. The average TSS concentrations measured at the HSD and SFD sites falls within the range of values observed at four other urban freeway monitoring sites in Wisconsin. The range is relatively small with the average TSS concentrations going from 106 to 197 mg/l. Based on average TSS concentrations collected at all six freeway sites, the average TSS concentrations should not vary enough between urban freeway sites to significantly alter the SOL expected for the HSD and SFD.

While the sand\silt split data collected at the HSD site compares favorably with the sand\silt data collected at two other sections of freeway in Milwaukee, the relatively high percent sand observed at the SFD site would indicate the SOL for TSS is too high for other sites. The average percent of sand-size particles in the runoff at the HSD site was 30 percent, whereas runoff at the SFD site was 71 percent sand. Based on the results from another study of a SFD, the SOL for TSS would still be about 50 percent even if the percent sand was as little as 10 percent. The other study of a SFD measured a 40 percent reduction in silt-sized particles, which might keep the SOL for TSS up around 50 percents with just a small amount of sand in the runoff.

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Appendix 2 Hydrodynamic Settling Device

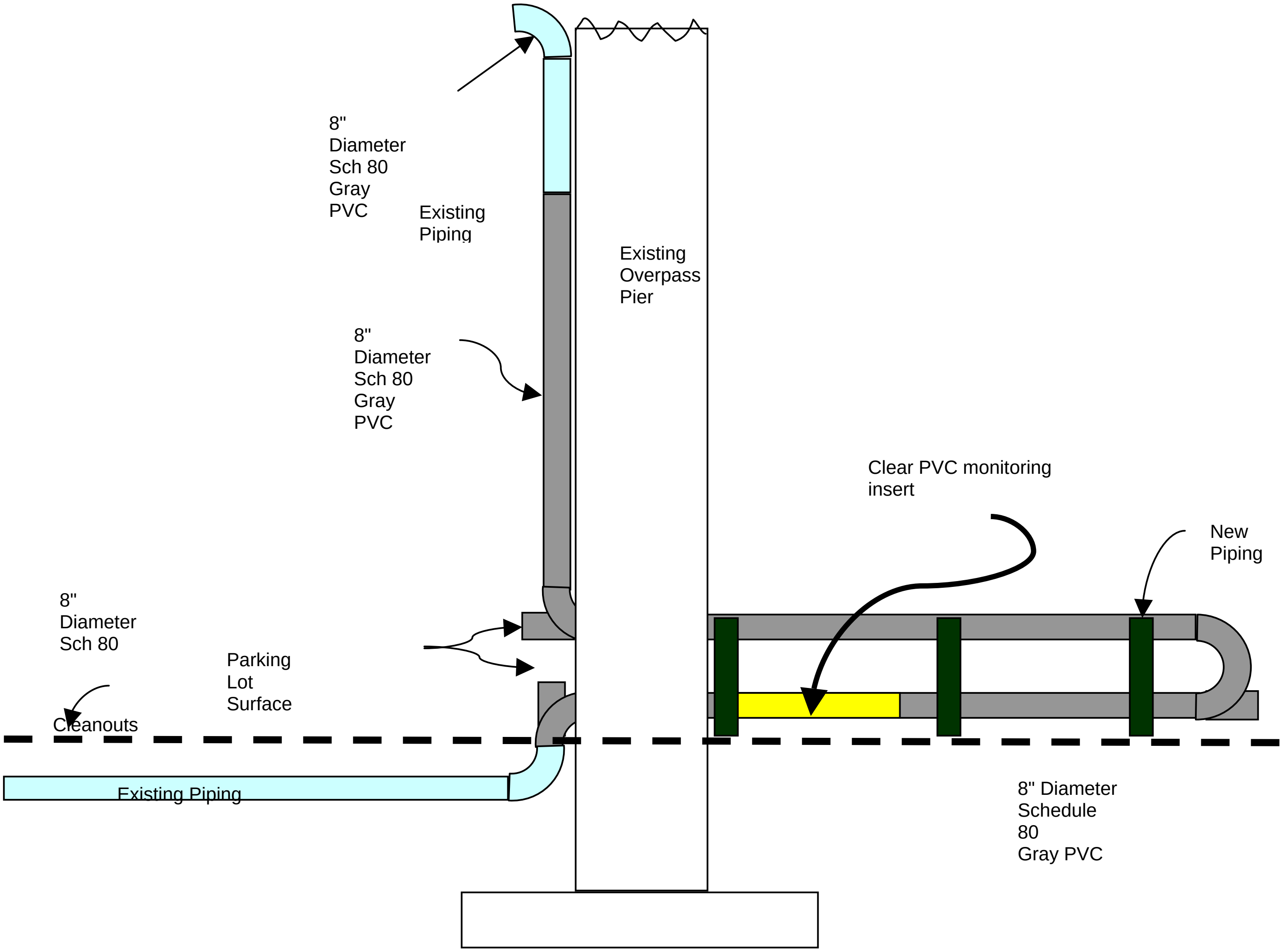

Figure 2–1. Design of new piping for the hydrodynamic settling device.

Table 2–1. Rainfall data for monitored events, hydrodynamic settling device, Milwaukee, Wis.

[in., inches; in/h, inches per hour; ft-lb/acre, foot-pounds per acre; ft^3, cubic feet; dd, day; hh, hour; min, minute; GMIA, General Mitchell International Airport]

Monitored event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Rainfall duration (hh: mm)	Total rainfall (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/hr)	Rainfall volume (ft^3)	Antecedent dry times (dd hh:mm)	Comments
	04/30/2003 07:54	4/30/2003 08:36	00:42	0.08	0.12	0.12	0.08	73	08 21:44	
1	04/30/2003 13:30	4/30/2003 14:30	01:00	.35	.76	.54	1.7	318	00 04:54	
2	04/30/2003 22:08	05/01/2003 01:38	03:30	1.1	1.0	.88	8.4	989	00 07:38	
	05/01/2003 11:19	05/01/2003 14:11	02:52	.08	.12	.08	.05	73	00 09:41	
3	05/04/2003 21:21	05/05/2003 01:26	04:05	.72	.36	.30	1.8	653	03 07:10	
4	05/05/2003 04:14	05/05/2003 09:05	04:51	.17	.24	.20	.29	154	00 02:48	
	05/07/2003 05:36	05/07/2003 06:35	00:59	.12	.16	.14	.14	109	01 20:31	
	05/07/2003 11:54	05/07/2003 17:15	05:21	.26	.16	.12	.26	236	00 05:19	
5	05/09/2003 00:12	05/09/2003 04:39	04:27	.87	.60	.42	3.1	790	01 06:57	
	05/11/2003 12:39	05/11/2003 19:57	07:18	.16	.08	.08	.11	145	02 08:00	
	05/14/2003 11:39	05/14/2003 12:53	01:14	.05	.12	.06	.03	45	02 15:42	
	05/14/2003 16:49	05/15/2003 01:14	08:25	.23	.12	.10	.19	209	00 03:56	
	05/15/2003 06:01	05/15/2003 08:03	02:02	.03	.04	.04	.01	27	00 04:47	
6	05/20/2003 00:16	05/20/2003 02:41	02:25	.19	.16	.14	.22	172	04 16:13	
7	05/30/2003 18:54	05/30/2003 23:01	04:07	.54	.52	.32	1.5	490	10 16:13	
	05/31/2003 05:11	05/31/2003 05:28	00:17	.13	.48	--	--	118	00 06:10	
8	06/08/2003 03:26	06/08/2003 14:35	11:09	.62	.80	.54	2.1	563	07 21:58	
9	06/27/2003 17:30	06/27/2003 20:08	02:38	.37	.60	.40	1.3	336	19 02:55	
9	06/28/2003 08:29	06/28/2003 10:55	02:26	.20	.36	.22	.39	182	00 12:21	
10	07/04/2003 07:25	07/04/2003 08:57	01:32	.15	.52	.26	.35	136	05 20:30	
10	07/05/2003 04:33	07/05/2003 06:14	01:41	.31	.36	.32	.84	281	00 19:36	
10	07/06/2003 09:30	07/06/2003 10:08	00:38	.07	.20	.12	.07	64	01 03:16	
11	07/06/2003 15:06	07/06/2003 16:19	01:13	.14	.36	.20	.24	127	00 04:58	
	07/06/2003 19:49	07/06/2003 20:02	00:13	.03	--	--	--	27	00 03:30	
	07/07/2003 08:20	07/07/2003 08:49	00:29	.10	.32	--	--	91	00 12:18	
12	07/08/2003 09:49	07/08/2003 13:26	03:37	.33	.24	.20	.56	299	01 01:00	
13	07/09/2003 23:14	07/10/2003 00:43	01:29	.07	.24	.12	.08	64	01 09:48	
14	07/15/2003 02:56	07/15/2003 04:46	01:50	.17	.20	.12	.17	154	05 02:13	
	07/21/2003 09:32	07/21/2003 10:14	00:42	.19	.72	.36	.66	172	06 04:46	
15	07/30/2003 15:14	07/30/2003 19:45	04:31	.19	.64	.34	.73	172	09 05:00	
16	08/01/2003 00:30	08/01/2003 02:54	02:24	.13	.40	.22	.26	118	01 04:45	
16	08/01/2003 06:03	08/01/2003 06:10	00:07	.10	--	--	--	91	00 03:09	
16	08/02/2003 17:38	08/02/2003 17:47	00:09	.09	--	--	--	82	01 11:28	
16	08/03/2003 12:34	08/03/2003 14:21	01:47	.41	.64	.50	1.8	372	00 18:47	
	08/11/2003 22:54	08/11/2003 23:41	00:47	.11	.40	.20	.19	100	08 08:33	
17	08/25/2003 18:49	08/25/2003 19:36	00:47	.30	1.2	.58	1.8	272	13 19:08	
18	09/12/2003 15:32	09/12/2003 19:21	03:49	.30	.24	.22	.56	272	17 19:56	
	09/13/2003 07:30	09/13/2003 10:52	03:22	.16	.16	.12	.16	145	00 12:09	
19	09/14/2003 05:22	09/14/2003 11:57	06:35	.47	1.4	.16	.16	427	00 18:30	

	09/22/2003 02:28	09/22/2003 06:05	03:37	.27	.32	.24	.67	245	07 14:31	
20	09/26/2003 16:11	09/26/2003 19:23	03:12	.15	.16	.14	.18	136	04 10:06	
21	10/03/2003 10:15	10/03/2003 12:23	02:08	.14	.12	.12	.14	127	06 14:52	
22	10/11/2003 21:58	10/12/2003 00:02	02:04	.11	.08	.08	.07	100	08 09:35	
23	10/14/2003 00:17	10/14/2003 03:10	02:53	.27	.20	.16	.36	245	02 00:15	
24	10/14/2003 07:08	10/14/2003 09:49	02:41	0.23	0.24	0.20	0.39	209	00 03:58	Rainfall from GMIA
25	10/24/2003 16:45	10/24/2003 22:16	05:31	.71	.36	.34	2.0	644	10 06:56	
	11/01/2003 22:06	11/02/2003 08:05	09:59	.63	.32	.24	1.3	572	07 23:50	
	11/04/2003 16:14	11/04/2003 20:21	04:07	.60	.68	.36	1.4	545	02 08:09	
	11/17/2003 23:10	11/18/2003 12:11	13:01	1.08	.52	.40	3.6	980	13 02:49	
	11/22/2003 17:26	11/22/2003 21:59	04:33	.12	.12	.08	.08	109	04 05:15	
	11/23/2003 05:37	11/23/2003 15:04	09:27	.13	.12	.10	.11	118	00 07:38	
	12/09/2003 12:30	12/10/2003 16:57	04:27	1.9	.32	.24	3.8	1,724	15 21:26	
	12/16/2003 03:29	12/16/2003 04:58	01:29	.11	.16	.12	.11	100	05 10:32	
26	12/28/2003 01:06	12/28/2003 05:34	04:28	.22	.16	.12	.22	200	11 20:08	
	03/01/2004 15:39	03/01/2004 17:10	01:31	.15	.24	.16	.20	136	04 10:05	
	03/04/2004 16:41	03/05/2004 06:22	13:41	1.89	.44	.40	6.4	1,715	02 23:31	
	03/13/2004 23:16	03/14/2004 03:46	04:30	.16	.08	.06	.08	145	08 16:54	
	03/17/2004 11:38	03/17/2004 18:13	06:35	.08	.04	.04	.03	73	03 07:52	
	03/18/2004 09:18	03/18/2004 17:04	07:46	.14	.08	.06	.07	127	00 15:05	
27	03/25/2004 22:59	03/26/2004 03:56	04:57	.85	.48	.36	2.63	771	07 05:55	
28	03/28/2004 15:18	03/28/2004 20:07	04:49	.87	.48	.42	3.12	790	02 11:22	
	03/30/2004 05:21	03/30/2004 12:41	07:20	.13	.08	.06	.07	118	01 09:14	
29	04/17/2004 02:53	04/17/2004 04:11	01:18	.24	.44	.34	.69	218	17 14:12	
30	04/20/2004 16:21	04/21/2004 03:12	10:51	1.41	1.16	.78	9.5	1,280	03 12:10	
	04/24/2004 23:26	04/25/2004 00:21	00:55	.08	.20	.16	.49	73	03 20:14	
	04/25/2004 15:26	04/25/2004 15:33	00:07	.07	--	--	--	64	00 15:05	
	04/30/2004 19:31	04/30/2004 23:09	03:38	.08	.08	.06	.04	73	05 03:58	
	05/07/2004 19:06	05/07/2004 20:10	01:04	.07	.12	.08	.05	64	06 19:57	
	05/08/2004 22:04	05/09/2004 02:53	04:49	.44	1.16	.66	2.7	399	01 01:54	
	05/10/2004 14:46	05/10/2004 18:27	03:41	1.19	1.20	.72	7.7	1,080	01 11:53	
31	05/12/2004 18:22	05/13/2004 03:27	09:05	.55	.44	.34	1.7	499	01 23:55	
	05/13/2004 17:06	05/13/2004 17:49	00:43	1.79	4.96	3.40	47.0	1,624	00 13:39	
	05/14/2004 03:29	05/14/2004 12:31	09:02	1.36	.60	.50	5.9	1,234	00 09:40	
	05/17/2004 22:05	05/18/2004 02:44	04:39	.57	.64	.34	1.67	517	03 09:34	
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33	05/21/2004 17:34	05/22/2004 08:07	14:33	1.78	1.40	.98	15.6	1,615	00 07:31	
	05/22/2004 19:24	05/23/2004 07:24	12:00	1.15	2.28	1.16	13.3	1,044	00 11:17	
	05/25/2004 03:55	05/25/2004 05:34	01:39	.07	.08	.06	.04	64	01 20:31	
	05/29/2004 08:44	05/29/2004 12:48	04:04	.17	.08	.08	.12	154	04 03:10	
34	05/30/2004 10:48	05/30/2004 12:59	02:11	.68	.56	.48	2.8	617	00 22:00	
	05/30/2004 19:00	05/31/2004 05:56	10:56	.18	.36	.18	.29	163	00 06:01	
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	06/14/2004 02:12	06/14/2004 02:26	00:14	.11	--	--	--	100	01 22:22	

36	06/14/2004 11:27	06/14/2004 12:26	00:59	.82	2.96	1.56	13.6	744	00 09:01	
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	06/17/2004 05:06	06/17/2004 08:19	03:13	.22	.20	.18	.33	200	00 09:02	
	06/21/2004 09:37	06/21/2004 15:41	06:04	0.66	.32	.28	1.56	599	04 01:18	
	06/23/2004 12:26	06/23/2004 14:30	02:04	.07	.08	.06	.04	64	01 20:45	
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39	06/27/2004 20:11	06/27/2004 23:22	03:11	.22	.24	.22	.41	200	03 07:22	
	07/03/2004 17:08	07/04/2004 03:12	10:04	1.59	.84	.60	8.30	1,443	05 17:46	
	07/07/2004 00:04	07/07/2004 01:11	01:07	.58	1.08	.96	5.08	526	02 20:52	
	07/11/2004 20:33	07/11/2004 22:13	01:40	1.08	1.84	1.6	17.1	980	04 19:22	
	07/13/2004 16:15	07/13/2004 18:35	02:20	.19	.52	.26	.46	172	01 18:02	
	07/21/2004 09:40	07/21/2004 14:20	04:40	.23	.76	.44	.91	209	07 15:05	
40	08/02/2004 12:00	08/02/2004 12:26	00:26	.17	.56	--	--	154	11 21:40	
41	08/03/2004 20:10	08/03/2004 23:53	03:43	1.75	3.20	2.14	36.0	1,588	01 07:44	
	08/09/2004 04:51	08/09/2004 09:30	04:39	.33	.52	.40	1.14	299	05 04:58	
42	08/24/2004 20:29	08/25/2004 00:01	03:32	.85	1.76	.92	7.39	771	15 10:59	Rainfall from GMIA
43	08/27/2004 01:30	08/27/2004 02:53	01:23	.37	.64	.54	1.79	336	02 01:29	
44	08/28/2004 01:42	08/28/2004 19:54	18:12	.56	.40	.26	.59	508	00 22:49	
45	09/15/2004 16:03	09/15/2004 22:06	06:03	.28	.40	.26	.63	254	17 20:09	
	10/01/2004 17:04	10/01/2004 23:51	06:47	.22	.24	.20	.37	200	15 18:58	
	10/08/2004 02:44	10/08/2004 13:02	10:18	.14	.08	.06	.07	127	06 02:53	

Table 2–2. Field-blank data summary, hydrodynamic settling device.

[mg/L, milligrams per liter; μg/L, micrograms per liter; LOD, limit of detection; LOQ, limit of quantification]

Constituents	Unit	Blank 1 06/30/03		Blank 2 05/03/04		LOD	LOQ
		Inlet	Outlet	Inlet	Outlet		
Dissolved solids, total	mg/L	<50	<50	<50	<50	50	167
Suspended solids, total recoverable	mg/L	<2	<2	<2	<2	2	7
Suspended sediment, total	mg/L	<2	<2	<2	<2	2	7
Chemical oxygen demand, total	mg/L	<9	<9	<9	55	9	28
Phosphorus , total recoverable	mg/L	<0.005	<.005	<.005	<.005	.005	.016
Phosphorus, dissolved	mg/L	<.005	<.005	<.005	<.005	.002	.005
Copper, total recoverable	μg/L	<1	<1	2	1	1	3
Copper, dissolved	μg/L	1.7	1.7	1.6	<1	1	3
Zinc, total recoverable	μg/L	<16	<16	<16	<16	16	50
Zinc, dissolved	μg/L	<16	<16	<16	<16	16	50
Chloride, dissolved	mg/L	.6	1.1	<.6	<.6	.6	2
Calcium , total recoverable	mg/L	<.2	<.2	<.2	<.2	.2	.7
Magnesium , total recoverable	mg/L	<.2	<.2	<.2	<.2	.2	.7

Table 2–3. Hydrodynamic settling device field replicate and sample relative percent difference data summary.

[Rep, replicate; RPD, relative percent difference; %, percent; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no sample processed for event; na, not available]

Parameter	Unit	Site	Event 9			Event 18			Event 42			Objective (%)
			Rep 1a	Rep 1b	RPD (%)	Rep 2a	Rep 2b	RPD (%)	Rep 1a	Rep 1b	RPD (%)	
Dissolved solids, total	mg/L	Inlet	116	116	0	282	286	1	54	60	11	30
		Outlet	178	178	0	394	392	1	128	152	17	
Suspended solids, total recoverable	mg/L	Inlet	186	186	0	312	na	--	70	78	11	30
		Outlet	101	104	3	94	118	23	73	69	6	
Suspended sediment, total	mg/L	Inlet	261	290	11	501	550	9	968	815	17	na
		Outlet	105	102	3	98	100	2	75	79	5	
Chemical oxygen demand, total	mg/L	Inlet	129	133	3	313	362	15	78	53	38	na
		Outlet	119	113	5	223	237	6	84	84	0	
Phosphorus, dissolved	mg/L	Inlet	0.10	0.10	3	0.24	0.24	1	.04	.04	0	30
		Outlet	.03	.03	0	.15	0.15	0	.03	.03	0	
Phosphorus, total recoverable	mg/L	Inlet	.34	.35	3	.73	0.68	7	.20	.23	11	30
		Outlet	.27	.27	1	.49	0.48	1	.14	.14	2	
Copper, dissolved	*µg/L*	Inlet	32.1	32.6	2	75	72.7	3	12.7	13.1	3	25
		Outlet	33.4	32.4	3	34.5	34.9	1	9.9	10	1	
Copper, total recoverable	*µg/L*	Inlet	113	102	10	202	280	32	111	198	56	25
		Outlet	76	75	1	155	123	23	35	60	53	
Zinc, dissolved	*µg/L*	Inlet	113	115	2	335	348	4	51	50	2	25
		Outlet	105	110	5	315	325	3	49	52	6	
Zinc, total recoverable	*µg/L*	Inlet	364	365	0	962	918	5	347	271	25	25
		Outlet	237	247	4	519	523	1	145	172	17	
Chloride, dissolved	mg/L	Inlet	21	21.1	0	78.4	80	2	7	7	0	25
		Outlet	37.3	37.6	1	122	122	0	31.4	31.5	0	
Calcium, total recoverable	mg/L	Inlet	38	47.8	23	48.6	45.3	7	66.4	48	32	25
		Outlet	30.1	31	3	32.3	32.5	1	16.6	16.8	1	
Magnesium, total recoverable	mg/L	Inlet	14.8	20.4	32	20.1	19.3	4	32.2	23.4	32	25
		Outlet	7.4	7.7	4	8.3	8.4	1	4.9	5	2	

Table 2–4. Hydrodynamic settling device inlet event start and end time, event volumes, percent runoff, and peak discharge.

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

Sampled event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Total rainfall (in.)	Inlet volume (ft^3)	Percent runoff	Peak discharge (ft^3/s)
1	04/30/2003 13:38	04/30/2003 14:48	0.35	251	79	0.59
2	04/30/2003 22:16	05/01/2003 02:01	1.09	847	86	.46
3	05/04/2003 21:26	05/05/2003 01:51	.72	795	122	.09
4	05/05/2003 04:17	05/05/2003 07:25	.17	130	84	.06
5	05/09/2003 00:27	05/09/2003 04:57	.87	717	91	.13
6	05/20/2003 00:41	05/20/2003 03:14	.19	441	256	.09

7	05/30/2003 18:55	05/30/2003 23:42	.54	665	136	.23
8	06/08/2003 03:26	06/08/2003 16:18	.62	847	150	.60
9	06/27/2003 17:30	06/28/2003 11:15	.57	518	100	.15
10	07/04/2003 07:25	07/06/2003 09:47	.53	492	102	.33
11	07/06/2003 15:08	07/06/2003 16:21	.14	86	68	.06
12	07/08/2003 09:49	07/08/2003 13:45	.33	423	141	.09
13	07/09/2003 23:16	07/09/2003 23:42	.07	43	68	.07
14	07/15/2003 02:59	07/15/2003 05:00	.17	337	218	.08
15	07/30/2003 15:27	07/30/2003 23:37	.19	112	65	.12
16	08/01/2003 02:46	08/03/2003 13:58	.73	484	73	.33
17	08/25/2003 18:44	08/25/2003 19:10	.30	302	111	1.32
18	09/12/2003 15:37	09/12/2003 19:41	.30	156	57	.03
19	09/14/2003 05:30	09/14/2003 12:22	.47	588	138	2.08
20	09/26/2003 16:28	09/26/2003 20:13	.15	112	83	.04
21	10/03/2003 11:19	10/03/2003 12:49	.14	25.9	20	.02
22	10/11/2003 21:53	10/11/2003 23:17	.11	121	121	.05
23	10/14/2003 01:06	10/14/2003 03:19	.27	268	109	.06
24	10/14/2003 08:44	10/14/2003 10:22	.23	138	66	.05
25	10/24/2003 16:46	10/24/2003 22:49	.71	613	95	.16
26	12/28/2003 01:16	12/28/2003 05:49	.22	268	134	.05
27	03/25/2004 23:03	03/26/2004 03:58	.85	311	40	.03
28	03/28/2004 15:24	03/28/2004 20:15	.87	216	27	.03
29	04/17/2004 03:26	04/17/2004 04:25	.24	69	32	.03
30	04/20/2004 16:39	04/21/2004 02:27	1.41	1,028	80	.61
31	05/12/2004 18:27	05/13/2004 03:34	.55	311	62	.11
32	05/20/2004 16:35	05/20/2004 17:41	.24	259	119	1.29
33	05/21/2004 09:04	05/21/2004 10:11	.70	1,020	160	1.81
34	05/30/2004 11:00	05/31/2004 03:45	.68	259	42	.35
35	06/10/2004 11:16	06/11/2004 12:08	1.72	717	46	.07
36	06/14/2004 11:29	06/14/2004 12:16	.82	1,028	138	2.64
37	06/16/2004 19:47	06/16/2004 20:14	.10	78	86	.02
38	06/24/2004 11:32	06/24/2004 12:18	.23	35	17	.02
39	06/27/2004 21:51	06/27/2004 23:25	.22	69	35	.02
40	08/02/2004 12:03	08/02/2004 12:29	.17	354	230	1.01
41	08/03/2004 20:16	08/04/2004 00:06	1.75	2,514	158	2.44
42	08/24/2004 20:32	08/25/2004 00:09	.85	449	58	1.06
43	08/27/2004 01:39	08/27/2004 03:05	.37	147	44	.90
44	08/28/2004 01:47	08/28/2004 20:13	.56	285	56	.05
45	09/15/2004 16:04	09/15/2004 21:49	.28	78	31	.05
Average			.51	422	94	.44

Table 2–5. Event mean solids and sediment concentrations during testing of the hydrodynamic settling device.

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

Sampled event number	Dissolved solids, total		Suspended solids, total recoverable		Suspended sediment, total	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	224	408	494	250	559	256

2	54	84	79	87	91	86
3	100	118	106	38	161	36
4	68	92	39	13	40	14
5	80	60	89	28	98	27
6	86	186	130	27	--	--
7	88	182	114	70	118	69
8	<50	--	47	64	50.3	64
9	116	178	186	104	290	102
10	80	128	59	43	72	39
11	118	78	70	10	--	--
12	118	128	117	54	123	55
13	108	112	73	15	--	--
14	168	168	63	15	68	14
15	468	200	185	17	223	15
16	64	166	93	90	110	84
17	96	260	66	216	76	212
18	286	394	--	--	550	98
19	<50	--	55	150	79	153
20	202	202	330	8	300	10
21	188	354	108	20	136	21
22	784	746	162	14	142	15
23	82	242	46	33	57	26
24	106	126	128	39	135	34
25	56	128	98	83	106	83
26	2,910	14,500	192	110	194	91
27	184	840	163	139	177	140
28	162	526	272	92	287	90
29	120	1430	113	107	127	106
30	94	440	115	123	123	128
31	80	146	70	42	79	41
32	82	120	97	93	125	92
33	<50	<50	29	35	30	35
34	60	62	44	26	57	27
35	--	<50	84	38	82	36
36	<50	<50	33	95	40	109
37	90	92	73	22	92	22
38	76	172	88	41	90	40
39	60	102	77	51	78	50
40	138	166	432	178	624	178
41	<50	<50	74	87	216	87
42	60	152	78	69	815	79
43	<50	--	48	39	85	41
44	66	60	33	12	82	82
45	178	266	104	79	135	82
Count	44	42	44	44	42	42
Average	213	627	117	67	170	73
Median	98	167	89	47	114	67
Geometric mean	122	205	93	48	124	55
Standard deviation	468	2,326	98	55	170	55
Coefficient of	2.20	3.71	.83	0.82	1.00	.75

variation						
Maximum	2,910	14,500	494	250	815	256
Minimum	<50	<50	29	8	30	10

Table 2–6. Event mean concentrations for specific properties and constituents during testing of the hydrodynamic settling device.

[mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed for event; PAH, Polycyclic aromatic hydrocarbon]

Sampled event number	Phosphorus, dissolved (mg/L)		Phosphorus, total recoverable (mg/L)		Chemical oxygen demand (mg/L)		Copper, dissolved (µg/L)		Copper, total recoverable (µg/L)		Zinc, dissolved (µg/L)		Zinc, total recoverable (µg/L)		Chloride, dissolved (mg/L)		Calcium, total recoverable (mg/L)		Magnesium, total recoverable (mg/L)		Total hardness (mg/L)		[1]PAH (µg/L)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	0.01	0.02	0.06	0.08	27	39	5	9	25	34	46	68	121	157	10	23	20	18	9	7	86	72	9.3	9.2
3	.109	.056	.226	.115	69	69	14	11	64	24	100	78	268	131	32	40	25	14	9	3	99	47	14.6	4.7
5	.016	.007	.086	.041	58	25	8	5	29	13	64	48	158	84	20	17	20	9	7	2	78	33	--	--
7	.029	.023	.171	.120	66	1350	16	19	56	52	78	96	222	171	18	55	18	23	8	5	76	78	9.5	6.6
8	.038	.028	.098	.128	36	60	10	13	26	33	43	62	102	132	11	33	10	21	4	5	39	75	--	--
9	.098	.033	.354	.269	129	119	33	32	102	75	115	110	365	247	21	38	48	31	20	8	203	106	18.7	5.4
18	.241	.154	.679	.484	313	223	73	35	280	123	348	325	918	523	80	122	45	32	19	8	193	115	--	--
19	.032	.024	.113	.203	31	85	9	10	35	64	42	70	151	266	9	35	10	20	5	9	45	89	--	--
23	.072	.030	.128	.152	52	86	26	33	27	33	17	81	117	130	20	81	15	19	4	3	53	48	--	--
24	.053	.048	.184	.116	90	55	75	32	77	31	48	33	243	101	35	37	20	15	8	3	82	60	--	--
25	.042	.111	.140	.174	53	81	12	42	51	51	47	165	182	192	12	37	17	17	7	6	71	65	8.6	12.3
27	.021	.017	.134	.136	76	82	12	16	64	73	35	61	244	280	78	481	29	32	11	10	118	121	26.8	27.0
28	.017	.009	.182	.089	101	55	14	12	99	43	85	59	406	193	56	276	47	24	21	7	202	87	51.1	15.5
29	.056	.019	.161	.165	72	137	25	43	21	36	108	156	240	306	40	792	20	43	7	8	80	141	--	--
31	.058	.028	.131	.121	60	59	13	19	41	39	53	70	188	147	22	51	13	12	5	3	53	43	--	--
32	.037	.012	.153	.140	57	56	16	14	55	46	60	67	247	173	18	38	16	16	7	6	67	63	--	--
41	.024	.071	.098	.109	33	51	8	8	36	28	33	38	126	126	3	6	19	12	10	5	86	52	13.2	15.1
42	.042	.030	.225	.139	78	84	13	10	198	60	50	52	271	172	7	32	48	17	23	5	216	62	20.7	5.6
Count	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	9	9
Average	.056	.040	.185	.154	78	151	21	20	71	48	76	91	254	196	27	122	24	21	10	6	103	75	19.1	11.3
Median	.040	.028	.147	.132	63	75	14	15	53	41	52	69	231	172	20	38	20	18	8	5	81	68	14.6	9.2
Geometric mean	.042	.029	.156	.136	65	84	16	17	54	42	60	77	217	178	20	55	21	19	9	5	89	70	16.2	9.6
Standard deviation	.053	.038	.140	.096	64	303	20	12	67	25	73	68	185	102	23	204	13	9	6	2	59	30	13.4	7.2
Coefficient of variation	.963	.953	.758	.621	0.8	2.0	1.0	0.6	0.9	0.5	1.0	0.8	0.7	0.5	0.8	1.7	0.5	0.4	0.6	0.4	0.6	0.4	.7	.64
Maximum	.241	.154	.679	.484	313	1350	75	43	280	123	348	325	918	523	80	792	48	43	23	10	216	141	51.1	27.0
Minimum	.014	.007	.062	.041	27	25	5	5	21	13	17	33	102	84	3	6	10	9	4	2	39	33	8.6	4.7

[1] Summary statistics were only computed for total PAH not of the individual constituents.

Table 2–7. Event-mean polycyclic aromatic hydrocarbon concentrations during testing of the hydrodynamic settling device.

[All concentrations in micrograms per liter;--, no data]

Sampled event number	1-Methylnaphthalene	2-Methylnaphthalene	Fluorene	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]anthracene	Benzo[a]pyrene	Benzo[b]fluoranthene	Benzo[g,h,i]perylene	Benzo[k]fluoranthene	Chrysene	Dibenzo[a,h]anthracene	Fluoranthene	Indeno[1,2,3-cd]pyrene	Phenanthrene	Pyrene	Naphthalene
	Inlet																	
2	<0.046	<0.034	<0.2	<0.06	<0.07	0.058	0.350	0.52	0.86	0.64	0.39	0.73	1.30	1.70	0.61	0.70	1.20	<0.038
3	<.046	.480	<.2	<.06	<.07	.140	.640	.93	1.50	1.20	.67	1.30	.20	3.00	1.10	1.50	2.10	.075
7	<.046	<.034	<.2	<.06	<.07	.055	.370	.63	1.10	.85	.47	0.89	.13	1.90	.80	.64	1.30	<.038
9	.047	.060	<.2	<.06	<.07	.134	.779	1.30	2.10	1.60	.93	1.80	.25	3.80	1.50	1.42	2.70	.084
25	<.046	.042	--	.092	--	.170	.600	--	--	.91	.55	0.98	--	2.40	.82	--	1.90	.068
27	<.046	.052	<.2	.088	<.07	.320	1.100	1.60	2.70	2.40	1.20	2.30	.40	5.80	2.30	2.10	4.20	.085
28	.076	.096	<.2	.170	<.07	.560	2.200	3.30	5.00	4.40	2.30	4.20	.70	11.0	4.20	4.50	8.10	.170
41	<.046	<.049	<.2	<.06	<.11	.210	.800	1.00	1.20	1.00	.62	1.00	<.20	2.60	0.93	1.10	2.20	<.042
42	<.046	<.049	<.5	<.06	<.11	.410	1.300	1.60	1.80	1.50	.88	1.60	<.30	4.30	1.40	2.10	3.50	.059
	Outlet																	
2	<.046	<.034	<.2	<.06	<.07	.062	.340	.54	1.10	.77	.47	.87	.14	1.90	.75	.70	1.30	.05
3	<.046	<.034	<.2	<.06	<.07	<.021	.160	.25	.53	.39	.22	.44	.10	1.00	.37	.34	.68	<.038
7	<.046	<.034	<.2	<.06	<.07	.036	.260	.42	.77	.59	.33	.62	.10	1.40	.53	.43	.96	<.038
9	<.046	<.034	<.2	<.06	<.07	<.021	--	.36	.93	.68	.38	.75	.10	1.30	.63	--	--	<.038
25	.050	.058	--	--	--	.220	.840	--	--	1.40	.83	1.40	--	3.40	1.30	--	2.70	.09
27	<.046	.078	<.2	.073	<.07	.220	.990	1.50	3.00	2.60	1.30	2.40	.40	5.90	2.50	1.60	4.20	.11
28	<.046	<.034	<.2	<.06	<.07	.150	.640	.98	1.60	1.50	.74	1.30	.25	3.30	1.40	1.00	2.40	.05
41	<.064	<.049	<.5	<.06	<.11	.300	1.000	1.20	1.30	1.20	.70	1.10	<.26	2.90	1.10	1.40	2.40	<.042
42	<.064	<.049	<.5	<.06	<.11	.071	.300	.43	.60	.54	.28	.45	<.1	.96	.49	.35	.78	<.042

Table 2–8. Sum of loads for suspended solids and suspended sediment during testing of the hydrodynamic settling device.

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

Sampled event number	Dissolved Solids, total		Suspended solids, total		Suspended sediment, total	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	3.5	6.4	7.8	3.9	8.8	4.0
2	2.9	4.5	4.2	4.6	4.8	4.6
3	5.0	5.9	5.3	1.9	8.0	1.8
4	0.6	0.7	0.3	0.1	0.3	0.1
5	3.6	2.7	4.0	1.3	4.4	1.2
6	2.4	5.2	3.6	0.7	--	--
7	3.7	7.6	4.8	2.9	4.9	2.9
8	--	--	2.5	3.4	2.7	3.4
9	3.8	5.8	6.1	3.4	9.4	3.3
10	2.5	4.0	1.8	1.3	2.2	1.2
11	0.6	0.4	0.4	0.1	--	--
12	3.1	3.4	3.1	1.4	3.3	1.5
13	0.3	0.3	0.2	0.0	--	--
14	3.6	3.6	1.3	0.3	1.4	0.3
15	3.3	1.4	1.3	0.1	1.6	0.1
16	1.9	5.0	2.8	2.7	3.3	2.6
17	1.8	4.9	1.3	4.1	1.4	4.0
18	2.8	3.9	--	--	5.4	1.0
19	--	--	2.0	5.5	2.9	5.7
20	1.8	1.8	2.9	0.1	2.6	0.1
21	1.4	2.7	0.8	0.2	1.0	0.2
22	13.2	12.6	2.7	0.2	2.4	0.3
23	0.7	2.1	0.4	0.3	0.5	0.2
24	4.1	4.9	4.9	1.5	5.2	1.3
25	3.4	7.7	5.9	5.0	6.4	5.0
26	49.0	244.1	3.2	1.9	3.3	1.5
27	3.6	16.4	3.2	2.7	3.5	2.7
28	2.2	7.1	3.7	1.2	3.9	1.2
29	0.5	6.2	0.5	0.5	0.6	0.5
30	6.1	28.4	7.4	7.9	7.9	8.3
31	1.6	2.9	1.4	0.8	1.5	0.8
32	1.3	2.0	1.6	1.5	2.0	1.5
33	--	--	2.8	3.4	2.9	3.4
34	0.7	0.7	0.5	0.3	0.6	0.3
35	--	--	3.8	1.7	3.7	1.6
36	--	--	2.1	6.1	2.6	7.0
37	0.4	0.4	0.4	0.1	0.4	0.1
38	0.2	0.4	0.2	0.1	0.2	0.1
39	0.3	0.4	0.3	0.2	0.3	0.2
40	3.1	3.7	9.6	4.0	13.9	4.0
41	--	--	11.7	13.7	34.1	13.7
42	1.7	4.3	2.2	1.9	23.0	2.2
43	--	--	0.4	0.4	0.8	0.4
44	1.2	1.1	0.6	0.2	1.47	1.47
45	0.9	1.3	0.5	0.4	0.7	0.4
Total load	143	417	127	94	182	92
SOL	**-192**		**25**		**49**	

Table 2–9. Sum of loads for other constituents during testing of the hydrodynamic settling device.

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

Sampled event number	Phosphorus, dissolved		Phosphorus, total recoverable		Chemical oxygen demand		Copper, dissolved		Copper, total recoverable		Zinc, dissolved		Zinc, total recoverable		Chloride, dissolved		Polycyclic aromatic hydrocarbon, total (1/2 detection)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	0.001	0.001	0.003	0.004	1.4	2.1	0.0003	0.0005	0.0013	0.0018	0.0024	0.0036	0.0064	0.0083	0.0005	0.0012	0.0005	0.0005
3	.0054	.0028	.0112	.0057	3.4	3.4	.0007	.0006	.0032	.0012	.0050	.0039	.0133	.0065	.0016	.0020	.0007	.0002
5	.0007	.0003	.0038	.0018	2.6	1.1	.0004	.0002	.0013	.0006	.0029	.0021	.0071	.0038	.0009	.0008	--	--
7	.0012	.0010	.0071	.0050	2.7	56.1	.0007	.0008	.0023	.0022	.0032	.0040	.0092	.0071	.0007	.0023	.0004	.0003
8	.0020	.0015	.0052	.0068	1.9	3.2	.0005	.0007	.0014	.0017	.0023	.0033	.0054	.0070	.0006	.0017	--	--
9	.0032	.0011	.0115	.0087	4.2	3.9	.0011	.0010	.0033	.0024	.0037	.0036	.0118	.0080	.0007	.0012	.0006	.0002
18	.0023	.0015	.0066	.0047	3.0	2.2	.0007	.0003	.0027	.0012	.0034	.0032	.0089	.0051	.0008	.0012	--	--
19	.0012	.0009	.0041	.0074	1.1	3.1	.0003	.0004	.0013	.0023	.0015	.0026	.0055	.0098	.0003	.0013	--	--
23	.0012	.0005	.0021	.0025	0.9	1.4	.0004	.0005	.0005	.0006	.0003	.0014	.0020	.0022	.0003	.0013	--	--
24	.0005	.0004	.0016	.0010	0.8	0.5	.0006	.0003	.0007	.0003	.0004	.0003	.0021	.0009	.0003	.0003	--	--
25	.0016	.0042	.0054	.0067	2.0	3.1	.0005	.0016	.0020	.0020	.0018	.0063	.0070	.0074	.0004	.0014	.0003	.0005
27	.0004	.0003	.0026	.0026	1.5	1.6	.0002	.0003	.0012	.0014	.0007	.0012	.0047	.0054	.0015	.0093	.0005	.0005
28	.0002	.0001	.0025	.0012	1.4	0.7	.0002	.0002	.0013	.0006	.0011	.0008	.0055	.0026	.0008	.0037	.0007	.0002
29	.0002	.0001	.0007	.0007	0.3	0.6	.0001	.0002	.0001	.0002	.0005	.0007	.0010	.0013	.0002	.0034	--	--
31	.0011	.0005	.0025	.0023	1.2	1.1	.0002	.0004	.0008	.0008	.0010	.0014	.0036	.0029	.0004	.0010	--	--
32	.0006	.0002	.0025	.0023	0.9	0.9	.0003	.0002	.0009	.0007	.0010	.0011	.0040	.0028	.0003	.0006	--	--
41	.0038	.0111	.0154	.0171	5.2	8.0	.0012	.0012	.0056	.0044	.0052	.0060	.0198	.0198	.0005	.0010	.0021	.0024
42	.0012	.0008	.0063	.0039	2.2	2.4	.0004	.0003	.0056	.0017	.0014	.0015	.0076	.0048	.0002	.0009	.0006	.0002
Total	.0276	.0284	.0943	.0847	36.7	95.3	.0087	.0097	.0354	.0259	.0378	.0466	.1249	.1055	.0110	.0347	0.0064	0.0049
SOL	-3.0		10		-160		-11		27		-23		16		-216		23	

[1] Summing of PAH for calculation of the event-mean concentration was done in thee ways: (1) using half the detection limit for less than detections and (2) using zero for less than detections (3) using the limit of detection value. The three summing methods resulted in means that were in + 5 percent of one-half of the applicable detection limit.

Appendix 3 Stormwater filtration device

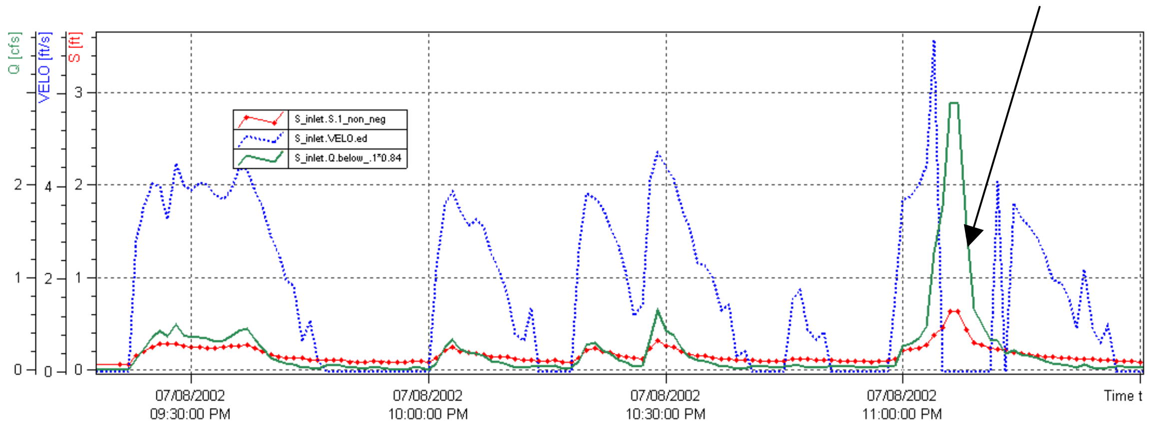

Figure 3–1. Graph showing velocity dropout for the inlet area-velocity flowmeter during a high event flow at the stormwater filtration device. (The dropout lasted for 8 minutes of the event.)

Table 3–1. Rainfall data for monitored event, stormwater filtration device, Milwaukee, Wis.

[in., inches; in/h, inches/hour; dd, day; hr, hour; min, minute;--, not computed for event; GMIA, General Mitchell International Airport]

Monitored event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd/yyyy hh:mm)	Rainfall duration (hh:mm)	Total rainfall (in.)	Max 15-min intensity (in/h)	Max 30-min intensity (in/h)	Erosivity index (hundreds of ft-lb/acre/in/h)	Rainfall volume (ft^3)	Antecedent dry times (dd hr:mm)	Comments
1	06/21/2002 06:54	06/21/2002 07:14	00:20	0.52	0.56	0.40	1.7	359	06 11:06	

	06/21/2002 21:29	06/21/2002 21:49	00:20	.04	.12	--	--	28	00 14:15
	06/26/2002 05:15	06/26/2002 06:23	01:08	.08	.20	.10	0.1	55	04 07:26
2	06/26/2002 21:10	06/26/2002 22:00	00:50	.25	.64	.32	.8	172	00 14:47
3	07/08/2002 21:16	07/08/2002 23:58	02:42	1.5	.12	--	25.1	1,035	11 23:16
	07/20/2002 22:11	07/20/2002 22:22	00:11	.03	--	--	--	21	11 22:13
	07/26/2002 01:26	07/26/2002 03:04	01:38	1.36	2.40	1.44	19.3	938	05 03:04
	07/29/2002 02:29	07/29/2002 03:56	01:27	.08	.16	.10	.07	55	02 23:25
4	08/04/2002 04:33	08/04/2002 05:14	00:41	0.2	.64	.36	.7	138	06 00:37
	08/12/2002 19:39	08/12/2002 23:48	04:09	2.45	2.64	1.92	45.6	1,690	08 14:25
	08/13/2002 14:19	08/13/2002 15:39	01:20	.92	2.52	1.62	14.8	635	00 14:31
	08/13/2002 19:17	08/13/2002 20:49	01:32	.43	.52	.46	1.7	297	00 03:38
	08/17/2002 08:41	08/17/2002 08:55	00:14	.07	--	--	--	48	03 11:52
	08/19/2002 04:07	08/19/2002 04:22	00:15	.03	.12	--	--	21	01 19:12
	08/19/2002 06:37	08/19/2002 07:47	01:10	.05	.12	.06	.0	34	00 02:15
5	08/21/2002 20:08	08/22/2002 12:07	15:59	1.67	2.24	1.46	16.7	1,152	02 12:21
	08/24/2002 03:18	08/24/2002 03:29	00:11	.05	--	--	--	34	01 15:11
6	09/02/2002 05:24	09/02/2002 08:48	03:24	1.25	1.36	.94	10.6	862	09 01:55
7	09/02/2002 23:23	09/02/2002 23:42	00:19	.32	1.16	--	--	221	00 14:35
	09/14/2002 18:45	09/14/2002 18:55	00:10	.04	--	--	--	28	11 19:03
8	09/18/2002 05:25	09/18/2002 10:19	04:54	0.37	.56	.34	1.3	255	03 10:30
	09/19/2002 14:34	09/19/2002 15:37	01:03	.60	1.24	1.00	5.7	414	01 04:15
	09/20/2002 09:33	09/20/2002 12:28	02:55	.10	.12	.06	.1	69	00 17:56
9	09/29/2002 00:49	09/29/2002 08:43	07:54	.78	.40	.34	2.2	538	08 12:21
	10/02/2002 00:45	10/02/2002 05:11	04:26	.79	.84	.70	4.8	545	02 16:02
	10/02/2002 20:12	10/02/2002 23:09	02:57	.09	.16	.10	.1	62	00 15:01
	10/04/2002 09:35	10/04/2002 13:10	03:35	.54	.80	.48	2.3	372	01 10:26
	10/12/2002 14:20	10/12/2002 16:39	02:19	.05	.08	.06	.0	34	08 01:10
	10/18/2002 07:04	10/18/2002 12:54	05:50	.22	.08	.08	.2	152	05 14:25
	10/24/2002 02:25	10/24/2002 08:47	06:22	.13	.04	.04	.0	90	05 13:31
	10/25/2002 01:46	10/25/2002 11:20	09:34	.49	.12	.10	.4	338	00 16:59
	11/05/2002 10:44	11/05/2002 14:51	04:07	.12	.08	.06	.1	83	10 23:24
	11/11/2002 03:51	11/11/2002 04:59	01:08	.05	.08	.06	.0	34	05 13:00
	11/11/2002 09:00	11/11/2002 10:50	01:50	.07	.08	.04	.0	48	00 04:01

	11/18/2002 17:02	11/18/2002 22:08	05:06	.24	.16	.10	.2	166	07 06:12
10	11/21/2002 05:11	11/21/2002 10:24	05:13	.27	.16	.14	.3	186	02 07:03
11	12/18/2002 01:18	12/18/2002 06:39	05:21	.37	.36	.30	1.0	255	26 14:54
	12/18/2002 13:19	12/18/2002 18:38	05:19	.16	.12	.12	.2	110	00 06:40
12	03/19/2003 12:51	03/19/2003 17:21	04:30	.45	.36	.24	.9	310	30 18:13
	03/19/2003 20:51	03/19/2003 21:14	00:23	.03	.08	--	--	21	00 03:30
	03/28/2003 08:44	03/28/2003 15:57	07:13	.32	.36	.28	.8	221	08 11:30
	03/31/2003 19:06	03/31/2003 20:16	01:10	.06	.08	.06	.0	41	03 03:09
13	04/04/2003 00:21	04/04/2003 02:37	02:16	.19	.24	.16	.3	131	03 04:05
13	04/04/2003 07:11	04/04/2003 09:10	01:59	.18	.40	.24	.4	124	00 04:34
	04/04/2003 14:48	04/04/2003 16:06	01:18	.10	.20	.14	.1	69	00 05:38
	04/06/2003 12:47	04/06/2003 16:19	03:32	.06	.04	.02	.0	41	01 20:41
	04/08/2003 11:54	04/08/2003 18:02	06:08	.13	.04	.04	.0	90	01 19:35
	04/09/2003 09:19	04/09/2003 10:54	01:35	.05	.04	.04	.0	34	00 15:17
14	04/19/2003 05:39	04/19/2003 07:59	02:20	.40	.64	.40	1.4	276	09 18:45
14	04/19/2003 15:12	04/19/2003 17:03	01:51	.18	.32	.30	.5	124	00 07:13
	04/20/2003 06:50	04/20/2003 07:10	00:20	.07	.24	--	--	48	00 13:47
	04/21/2003 08:48	04/21/2003 10:10	01:22	.03	.04	.04	.0	21	01 01:38
	04/30/2003 07:54	04/30/2003 08:36	00:42	.08	.12	.12	.1	55	08 21:44
	04/30/2003 13:30	04/30/2003 14:30	01:00	.35	.76	.54	1.7	241	00 04:54
	04/30/2003 22:08	05/01/2003 01:38	03:30	1.09	1.00	.88	8.4	752	00 07:38
	05/01/2003 11:19	05/01/2003 14:11	02:52	.08	.12	.08	.1	55	00 09:41
15	05/04/2003 21:21	05/05/2003 01:26	04:05	.72	.36	.30	1.8	497	03 07:10
15	05/05/2003 04:14	05/05/2003 09:05	04:51	.17	.24	.20	.3	117	00 02:48
16	05/07/2003 05:36	05/07/2003 06:35	00:59	.12	.16	.14	.1	83	01 20:31
16	05/07/2003 11:54	05/07/2003 17:15	05:21	.26	.16	.12	.3	179	00 05:19
16	05/09/2003 00:12	05/09/2003 04:39	04:27	.87	.60	.42	3.1	600	01 06:57
	05/11/2003 12:39	05/11/2003 19:57	07:18	.16	.08	.08	.1	110	02 08:00
	05/14/2003 11:39	05/14/2003 12:53	01:14	.05	.12	.06	.0	34	02 15:42
	05/14/2003 16:49	05/15/2003 01:14	08:25	.23	.12	.10	.2	159	00 03:56
	05/15/2003 06:01	05/15/2003 08:03	02:02	.03	.04	.04	.0	21	00 04:47
	05/20/2003 00:16	05/20/2003 02:41	02:25	.19	.16	.14	.2	131	04 16:13
17	05/30/2003 18:54	05/30/2003 23:01	04:07	.54	.52	.32	1.5	372	10 16:13

	05/31/2003 05:11	05/31/2003 05:28	00:17	.13	.48	--	--	90	00 06:10	
18	06/08/2003 03:26	06/08/2003 14:35	11:09	.62	.80	.54	2.1	428	07 21:58	
19	06/27/2003 17:30	06/27/2003 20:08	02:38	.37	.60	.40	1.3	255	19 02:55	
19	06/28/2003 08:29	06/28/2003 10:55	02:26	.20	.36	.22	.4	138	00 12:21	
20	07/04/2003 07:25	07/04/2003 08:57	01:32	.15	.52	.26	.4	103	05 20:30	
20	07/05/2003 04:33	07/05/2003 06:14	01:41	.31	.36	.32	.8	214	00 19:36	
20	07/06/2003 09:30	07/06/2003 10:08	00:38	.07	.20	.12	.1	48	01 03:16	
	07/06/2003 15:06	07/06/2003 16:19	01:13	.14	.36	.20	.2	97	00 04:58	
	07/06/2003 19:49	07/06/2003 20:02	00:13	.03	--	--	--	21	00 03:30	
	07/07/2003 08:20	07/07/2003 08:49	00:29	.10	.32	--	--	69	00 12:18	
21	07/08/2003 09:49	07/08/2003 13:26	03:37	.33	.24	.20	.6	228	01 01:00	
	07/09/2003 23:14	07/10/2003 00:43	01:29	.07	.24	.12	.1	48	01 09:48	
	07/15/2003 02:56	07/15/2003 04:46	01:50	.17	.20	.12	.2	117	05 02:13	
22	07/21/2003 09:32	07/21/2003 10:14	00:42	.19	.72	.36	.7	131	06 04:46	
23	07/30/2003 15:14	07/30/2003 19:45	04:31	.19	.64	.34	.7	131	09 05:00	Rainfall from GMIA
24	08/01/2003 00:30	08/01/2003 02:54	02:24	.13	.40	.22	.3	90	01 04:45	
24	08/01/2003 06:03	08/01/2003 06:10	00:07	.10	--	--	--	69	00 03:09	
24	08/02/2003 17:38	08/02/2003 17:47	00:09	.09	--	--	--	62	01 11:28	
24	08/03/2003 12:34	08/03/2003 14:21	01:47	.41	.64	.50	1.8	283	00 18:47	
	08/11/2003 22:54	08/11/2003 23:41	00:47	.11	.40	.20	.2	76	08 08:33	
25	08/25/2003 18:49	08/25/2003 19:36	00:47	.30	1.16	.58	1.8	207	13 19:08	
26	09/12/2003 15:32	09/12/2003 19:21	03:49	.30	.24	.22	.6	207	17 19:56	
27	09/13/2003 07:30	09/13/2003 10:52	03:22	.16	.16	.12	.2	110	00 12:09	
28	09/14/2003 05:22	09/14/2003 11:57	06:35	.47	1.36	.16	.2	324	00 18:30	
29	09/22/2003 02:28	09/22/2003 06:05	03:37	.27	.32	.24	.7	186	07 14:31	
	09/26/2003 16:11	09/26/2003 19:23	03:12	.15	.16	.14	.2	103	04 10:06	
	10/03/2003 10:15	10/03/2003 12:23	02:08	.14	.12	.12	.1	97	06 14:52	
	10/11/2003 21:58	10/12/2003 00:02	02:04	.11	.08	.08	.1	76	08 09:35	
30	10/14/2003 00:17	10/14/2003 03:10	02:53	.27	.20	.16	.4	186	02 00:15	
31	10/14/2003 07:08	10/14/2003 09:49	02:41	.23	.24	.20	.4	159	00 03:58	
32	10/24/2003 16:45	10/24/2003 22:16	05:31	.71	.36	.34	2.0	490	10 06:56	
	11/01/2003 22:06	11/02/2003 08:05	09:59	.63	.32	.24	1.3	435	07 23:50	
33	11/04/2003 16:14	11/04/2003 20:21	04:07	.60	.68	.36	1.4	414	02 08:09	Rainfall from

GMIA

11/17/2003 23:10	11/18/2003 12:11	13:01	1.08	.52	.40	3.6	745	13 02:49
11/22/2003 17:26	11/22/2003 21:59	04:33	.12	.12	.08	.1	83	04 05:15
11/23/2003 05:37	11/23/2003 15:04	09:27	.13	.12	.10	.1	90	00 07:38
12/09/2003 12:30	12/10/2003 16:57	04:27	1.90	.32	.24	3.8	1,310	15 21:26
12/16/2003 03:29	12/16/2003 04:58	01:29	.11	.16	.12	.1	76	05 10:32
12/28/2003 01:06	12/28/2003 05:34	04:28	.22	.16	.12	.2	152	11 20:08

Table 3–2. Field-blank data summary, stormwater filtration device.

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

Constituent	Unit	Blank1 4/2/2002		Blank 2 11/11/2002		Blank 3 6/30/2003		LOD	LOQ
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet		
Suspended solids, total recoverable (mg/L)	mg/L	<2	<2	--	--	<2	<2	2	7
Suspended sediment, total	mg/L	--	--	--	--	<2	<2	2	7
Dissolved solids, total	mg/L	<50	<50	<50	<50	<50	<50	50	167
Total chemical oxygen, demand	mg/L	<9	<9	<9	<9	12	14	9	28
Phosphorus, dissolved	mg/L	--	--	<.005	<.005	<.005	<.005	.005	.016
Phosphorus, total recoverable	mg/L	<.005	<.005	0.025	<.005	<.005	<.005	.005	.016
Copper, dissolved	µg/L	<5	<5	<1	<1	1.7	2.3	1	3
Copper, total recoverable	µg/L	<5	<5	<1	<1	2	2	1	3
Zinc, dissolved	µg/L	<16	<16	<16	<16	<16	<16	16	50
Zinc, total recoverable	µg/L	<16	<16	<16	<16	<16	<16	16	50
Chloride, dissolved	mg/L	3.3	<.6	<.6	<.6	0.8	<.6	.6	2
Calcium, total recoverable	mg/L	0.7	<.2	<.2	<.2	<.2	<.2	.200	.070
Magnesium, total recoverable	mg/L	<.2	<.2	<.2	<.2	<.2	<.2	.200	.070

Table 3–3. Stormwater filtration device field replicate and sample relative percent difference data summary.

[Rep, replicate; RPD, relative percent difference; %, percent; mg/L, milligrams per liter; µg/L, micrograms per liter; na, not available; --, no sample processed]

			Event 9			Event 14			Event 19			Event 26			Event 28			
Parameter	**Unit**	**Site**	**Rep 1a**	**Rep 1b**	**RPD (Pct)**	**Rep 2a**	**Rep 2b**	**RPD (Pct)**	**Rep 3a**	**Rep 3b**	**RPD (Pct)**	**Rep 4a**	**Rep 4b**	**RPD (Pct)**	**Rep 5a**	**Rep 5b**	**RPD (Pct)**	**Objective (%)**
Dissolved solids, total	mg/L	Inlet	<50	52	na	516	522	-1	90	86	5	212	224	-6	50	<50	na	30
		Outlet	<50	<50	na	722	728	-1	162	160	1	190	194	-2	74	58	24	
Suspended solids, total recoverable	mg/L	Inlet	--	--	--	778	838	-7	77	96	-22	696	816	-16	35	44	-23	30
		Outlet	--	--	--	378	380	-1	46	47	-2	36	31	15	20	25	-22	
Suspended sediment, total	mg/L	Inlet	501	681	-30	5590	4860	14	368	212	54	3750	2410	44	411	306	29	na
		Outlet	39	39	0	373	373	0	47	48	-2	29	32	-10	21	22	-5	
Chemical oxygen demand. total	mg/L	Inlet	41	45	-9	315	287	9	85	86	-1	298	295	1	51	48	6	na
		Outlet	30	22	31	190	187	2	81	87	-7	162	153	6	50	53	-6	
Phosphorus, dissolved	mg/L	Inlet	0.03	0.031	-3	0.027	0.025	8	0.061	0.063	-3	0.199	0.206	-3	0.04	0.039	3	30
		Outlet	0.027	0.026	4	0.017	0.016	6	0.059	0.058	2	0.193	0.193	0	0.046	0.046	0	
Phosphorus, total recoverable	mg/L	Inlet	0.159	0.109	37	0.502	0.555	-10	0.235	0.32	-31	0.625	0.584	7	0.149	0.105	35	30
		Outlet	0.067	0.065	3	0.292	0.302	-3	0.189	0.188	1	0.298	0.285	4	0.098	0.098	0	
Copper, dissolved	*µg/L*	Inlet	8.9	9.5	-7	27.8	27.6	1	20	21.2	-6	57.5	58.5	-2	49.5	166	-108	25
		Outlet	6.8	8.4	-21	27.1	25.7	5	22.6	23.3	-3	41.7	40.7	2	17.6	18.6	-6	
Copper, total recoverable	*µg/L*	Inlet	139	35	120	277	372	-29	48	52	-8	331	258	25	46	133	-97	25
		Outlet	17	18	-6	139	140	-1	44	46	-4	69	68	1	15	15	0	
Zinc, dissolved	*µg/L*	Inlet	35	31	12	112	119	-6	81	77	5	358	353	1	46	47	-2	25
		Outlet	22	22	0	84	91	-8	96	92	4	158	153	3	42	43	-2	
Zinc, total recoverable	*µg/L*	Inlet	134	328	-84	1,380	2,200	-46	198	324	-48	1,370	1,700	-21	296	281	5	25
		Outlet	61	63	-3	539	544	-1	158	156	1	215	208	3	66	67	-2	
Chloride, dissolved	mg/L	Inlet	na	na	--	468	477	-2	16.7	17.1	-2	34.4	33.4	3	5.4	5.3	2	25
		Outlet	na	na	--	661	673	-2	34.8	34.7	0	35.2	34.9	1	--	8.7	na	
Calcium, total recoverable	mg/L	Inlet	16	20.1	-23	434	475	-9	29.3	32	-9	233	217	7	59.7	62.2	-4	25
		Outlet	6.1	6.2	-2	68.2	68.4	0	17.2	17.5	-2	16.3	15.6	4	7	7.1	-1	
Magnesium, total recoverable	mg/l	Inlet	7.8	10.1	-26	174	201	-14	11.2	11.5	-3	122	111	9	22.2	27.1	-20	25
		Outlet	2.5	2.5	0	25.8	26	-1	4.2	4.2	0	4.4	4.2	5	1.9	2	-5	

Table 3–4. Filtration device outlet event start and end time, event volumes, percent runoff and peak discharge.

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

Sampled event number	**Start date and time (mm/dd/yyyy hh:mm)**	**End date and time (mm/dd/yyyy hh:mm)**	**Total rainfall (in.)**	**Volume (ft^3)**	**Percent runoff**	**Peak discharge (ft^3/s)**
1	06/21/2002 06:54	06/21/2002 07:40	0.52	354	99	1.11
2	06/26/2002 21:10	06/26/2002 22:19	.25	138	80	0.28
3	07/08/2002 21:16	07/08/2002 23:41	1.5	1,253	121	1.06
4	08/04/2002 04:35	08/04/2002 05:01	.20	69	50	.20
5	08/21/2002 20:12	08/22/2002 12:37	1.67	968	84	1.12
6	09/02/2002 05:24	09/02/2002 09:48	1.25	648	75	.30
7	09/02/2002 23:26	09/02/2002 23:51	.32	242	110	.38
8	09/18/2002 05:25	09/18/2002 10:25	.37	207	81	.25
9	09/29/2002 02:49	09/29/2002 09:27	.78	233	43	.01
10	11/21/2002 05:15	11/21/2002 11:26	.27	112	60	.08
11	12/18/2002 01:18	12/18/2002 06:02	.37	104	41	.08
12	03/19/2003 13:51	03/19/2003 17:07	.45	302	97	.14
13	04/04/2003 01:01	04/04/2003 09:12	.37	181	71	.26
14	04/19/2003 05:39	04/19/2003 15:55	.58	233	58	.25
15	05/04/2003 21:26	05/05/2003 07:25	.89	337	55	.19
16	05/07/2003 05:42	05/09/2003 04:57	1.25	588	68	.28
17	05/30/2003 18:55	05/30/2003 23:42	.54	207	56	.21
18	06/08/2003 03:26	06/08/2003 16:18	.62	354	83	.34
19	06/27/2003 17:30	06/28/2003 11:15	.57	363	92	.27
20	07/04/2003 07:25	07/06/2003 09:47	.53	622	170	.36
21	07/08/2003 09:49	07/08/2003 13:45	.33	250	110	.17
22	07/21/2003 09:37	07/21/2003 10:08	.19	173	132	.39
23	07/30/2003 15:27	07/30/2003 23:37	.19	61	46	.02
24	08/01/2003 02:46	08/03/2003 13:58	.73	605	120	.33
25	08/25/2003 18:44	08/25/2003 19:10	.30	250	121	.53
26	09/12/2003 15:37	09/12/2003 19:41	.30	156	75	.02
27	09/13/2003 07:34	09/13/2003 11:28	.16	78	70	.01
28	09/14/2003 05:30	09/14/2003 12:22	.47	337	104	.52
29	09/22/2003 02:29	09/22/2003 04:54	.27	207	111	.27
30	10/14/2003 01:06	10/14/2003 03:19	.27	130	70	.14
31	10/14/2003 08:44	10/14/2003 10:22	.23	52	33	.02
32	10/24/2003 16:46	10/24/2003 22:49	.71	225	46	.20
33	11/04/2003 16:14	11/04/2003 19:30	.60	596	144	1.12
Average			.55	322	84	.33

Table 3–5. Event means solids and sediment concentrations during testing of the stormwater filtration device.

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

Sampled event number	Dissolved solids, total		Suspended solids, total recoverable		Suspended sediment, total	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	--	<50	71	83	372	63
2	<50	<50	76	48	697	12
3	<50	<50	51	28	312	20
4	<50	<50	--	--	476	36
5	<50	<50	--	--	65	19
6	39	38	--	--	324	13
7	<50	<50	--	--	154	13
8	<50	<50	--	--	119	43
9	<50	<50	--	--	140	12
10	--	--	--	--	430	103
11	596	4170	--	--	770	129
12	--	--	--	--	456	401
13	<50	<50	736	31	3,820	318
14	516	722	778	378	5,590	373
15	78	90	73	34	825	34
16	66	64	79	29	984	29
17	66	126	112	70	1,280	68
18	<50	--	60	40	419	40.4
19	90	162	77	46	368	47
20	60	110	29	30	51	32
21	82	108	57	24	74	23
22	68	110	51	103	24	98
23	208	276	60	36	--	--
24	<50	--	22	36	27	34
25	72	124	68	90	256	90
26	212	190	696	36	3,750	29
27	88	168	30	18	36	19
28	<50	--	50	49	405	49
29	50	80	37	31	484	21
30	50	74	35	20	411	21
31	56	78	53	28	130	24
32	<50	--	67	36	416	33
33	<50	<50	55	73	103	97
Count	30	27	24	24	32	32
Average	141	394	143	58	743	73
Median	72	110	60	36	389	34
Geometric mean	96	149	75	43	307	43
Standard deviation	164	986	230	72	1,255	100
Coefficient of variation	1.2	2.50	1.6	1.2	1.7	1.4
Maximum	596	4,170	778	378	5,590	401
Minimum	39	38	22	18	24	12

Table 3– 6. Event-mean concentrations during testing of the stormwater filtration device.

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

Event	Phosphorus, dissolved (mg/L)		Phosphorus, total recoverable (mg/L)		Chemical oxygen demand (mg/L)		Copper, dissolved (µg/L)		Copper, total recoverable (µg/L)		Zinc, dissolved (µg/L)		Zinc, total recoverable (µg/L)		Chloride, dissolved (mg/L)		Calcium, total recoverable (mg/L)		Magnesium, total recoverable (mg/L)		Total hardness (mg/L)		Polycyclic aromatic hydrocarbon, total (µg/L)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Inlet	Outlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	0.041	0.039	0.138	0.097	42	37	<5	<5	41	28	60	34	222	139	5.8	5.2	42.4	14.8	21	6	--	--	--	--
3	.041	.037	.105	.078	39	25	10.0	8.8	34	19	59	51	202	76	4.6	4.6	27.8	6.0	14	2	205	16	--	--
5	.014	.013	.045	.037	18	24	6.1	5.4	15	10	27	20	176	39	4.5	3.4	9.7	4.4	4	2	41	17	1.46	0.99
6	.030	.032	.099	.048	29	24	7.7	7.0	29	10	49	43	198	56	3.2	3.3	54.6	4.4	26	1	242	17	7.90	0.94
8	.059	.046	.135	.101	80	78	21.0	14.2	127	30	87	51	677	109	--	--	16.9	9.7	7	3	72.4	37	--	--
9	.021	.021	.100	.030	28	17	5.0	4.5	16	7	26	16	77	28	3.6	4	9.4	4.0	4	101	40	15	6.56	0.86
11	.035	.029	.327	.202	68	129	13.9	20.4	126	78	59	109	393	302	310	2,590	130.0	47.5	56	9	557	153	--	--
12	.027	.017	.502	.292	315	190	27.8	27.1	277	139	112	84	1,380	539	468	661	434.0	68.2	174	26	1,800	276	138.84	33.49
15	.057	.043	.170	.080	53	38	11.4	8.7	44	20	64	45	230	91	25	31	61.6	10.5	28	3	267	38	23.89	3.44
17	.045	.028	.200	.138	67	61	16.8	15.2	79	42	67	70	243	145	14	32	39.7	16.6	18	5	173	61	11.87	6.89
18	.023	.028	.193	.080	41	36	18.0	7.6	36	23	37	32	117	84	9.4	17	37.3	9.6	18	3	167	36	--	--
19	.061	.059	.235	.189	85	81	20.0	22.6	48	44	81	96	198	158	17	35	29.3	17.2	11	4	119	60	5.26	2.43
21	.048	.049	.162	.107	63	53	13.2	15.1	36	29	57	42	226	79	20	22	12.4	8.9	5	2	51	32	--	--
26	.199	.193	.625	.298	298	162	57.5	41.7	331	69	358	158	1,370	215	34	35	233	16.3	122	4	1,080	59	--	--
28	.020	.027	.100	.095	38	34	5.5	6.2	32	21	26	30	184	106	6.1	9.7	40.8	8.8	20	4	184	37	--	--
29	.043	.054	.152	.098	48	72	9.0	10.5	440	18	42	47	650	69	9	16	73.0	8.3	36	3	331	31	--	--
30	.040	.046	.149	.098	51	50	49.5	17.6	46	15	46	42	296	66	5.4	--	59.7	7.0	22	2	240	25	--	--
Count	17	17	17	17	17	17	16	16	17	17	17	17	17	17	16	15	17	17	17	17	16	16	7	7
Average	.047	.045	.202	.122	80	65	18.3	14.5	103	35	74	57	402	135	58.7	231.3	77.2	15.4	34	11	348	4	27.97	7.01
Median	.041	.037	.152	.098	51	50	13.6	12.4	44	23	59	45	226	91	9.2	17.0	40.8	9.6	20	3	195	37	7.90	2.43
Geomean	.039	.036	.165	.101	58	51	14.1	12.0	61	26	58	48	288	103	14.0	21.9	43.7	10.9	19	4	195	39	10.70	2.85
Standard Deviation	.042	.040	.152	.079	87	50	15.2	9.8	125	33	77	36	401	124	132.4	673.4	106.9	16.9	46	24	464	67	49.41	11.87
Coefficient of variation	0.9	0.9	0.7	0.7	1.1	0.8	0.8	0.7	1.2	0.9	1.0	0.6	1.0	0.9	2.3	2.9	1.4	1.1	1.3	2.3	1.3	18.7	0.57	0.59
Max	0.199	0.193	0.625	0.298	315	190	57.5	41.7	440	139	358	158	1380	539	468.0	2590.0	434.0	68.2	174	101	1,800	276	138.84	33.49
Min	0.014	0.013	0.045	0.030	18	17	5.0	4.5	15	7	26	16	77	28	3.2	3.3	9.4	4.0	4	1	40	15	1.49	0.86

Table 3–7. Event-means concentrations polycyclic aromatic hydrocarbon[1] during testing of the stormwater filter device.

[All concentrations in micrograms per liter]

Sampled event number	1-Methylnaphthalene	2-Methylnaphthalene	Fluorene	Acenaphthene	Acenaphthylene	Anthracene	Benzo[*a*]anthracene	Benzo[*a*]pyrene	Benzo[*b*]fluoranthene	Benzo[*g,h,i*]perylene	Benzo[*k*]fluoranthene	Chrysene	Dibenzo[*a,h*]anthracene	Fluoranthene	Indeno[*1,2,3-cd*]pyrene	Phenanthrene	Pyrene	Naphthalene
	Inlet																	
5	<0.046	<0.034	<0.2	<0.06	<0.072	<0.021	<0.062	<0.07	0.13	0.120	<0.07	0.1	0.04	0.24	0.12	0.13	0.18	<0.038
6	<.046	<.034	<.2	<.06	<.072	.630	.35	.43	.59	.480	0.30	.54	1.0	1.30	.46	.59	1.00	<.038
9	<.046	.035	<.2	<.06	<.072	.071	0.30	.37	.51	.450	.26	.47	.80	1.10	.41	.66	.89	.046
12	.290	<.700	0.9	<.80	<0.72	2.000	7.00	9.30	13.00	9.30	6.10	12.00	<1.8	30.00	8.90	16.00	22.00	.32
15	.074	.081	0.3	<.06	<.072	.480	1.30	1.60	1.90	1.50	.94	1.90	.25	4.90	1.30	3.30	3.9	0.10
17	<.046	<.034	<.2	<.06	<.072	.140	.64	.89	1.20	.920	.55	1.00	.15	2.40	.83	1.1	1.9	<.038
19	<.046	<.034	<.2	<.06	<.072	.044	.25	.38	0.60	.480	.27	.53	.08	1.10	.42	.04	.84	<.038
	Outlet																	
5	<.046	<.034	<.2	<.06	<.072	<.021	<.062	<.07	<0.11	<.078	<.07	.05	.04	.14	.12	.12	.10	<.038
6	<.046	<.034	<.2	<.06	<.072	<.021	<.062	<.07	<.11	0.08	<.07	.05	.04	.13	.12	.04	.09	<.038
9	<.046	<.034	<.2	<.06	<.072	<.021	<.062	<.07	<.11	<.078	<.07	.04	.04	.10	.12	.09	<0.07	<.038
12	0.05	0.066	<.2	<.06	<.072	0.220	1.20	1.70	3.90	2.80	1.70	3.30	.70	7.20	2.7	2.70	5.00	0.09
15	<.046	<.034	<.2	<.06	<.072	<.021	.13	.21	.38	.310	.17	.30	.04	.62	.28	.31	.46	<.038
17	<.046	<.034	<.2	<.06	<.072	.095	.41	.53	.70	.550	.33	.62	.10	1.30	.50	.59	.94	<.038
19	<.046	<.034	<.2	<.06	<.072	<.021	.09	.15	.28	.230	<.07	.22	.04	.44	.20	.18	.33	<.038

[1] Summary statistics were only computed for total PAH not of the individual constituents.

Table 3–8. Sum of loads for solids and sediment during testing of the stormwater filtration device.

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

Sampled event number	Dissolved solids, total		Suspended solids, total		Suspended sediment, total	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	--	--	1.6	1.8	8.3	1.4
2	--	--	0.7	0.4	6.1	0.1
3	--	--	4.0	2.2	24.6	1.6
4	--	--	--	--	2.1	.2
5	--	--	--	--	4.0	1.2
6	1.6	1.5	--	--	13.2	.5
7	--	--	--	--	2.3	.2
8	--	--	--	--	1.6	.6
9	--	--	--	--	2.1	.2
10	--	--	--	--	3.0	.7
11	3.9	27.2	--	--	5.0	.8
12	--	--	--	--	8.7	7.6
13	--	--	8.4	.4	43.6	3.6
14	7.6	10.6	11.4	5.5	82.0	5.5
15	1.7	1.9	1.5	.7	17.5	.7
16	2.4	2.4	2.9	1.1	36.3	1.1
17	0.9	1.6	1.5	.9	16.7	.9
18	--	--	1.3	.9	9.3	.9
19	2.1	3.7	1.8	1.0	8.4	1.1
20	2.3	4.3	1.1	1.2	2.0	1.3
21	1.3	1.7	.9	.4	1.2	.4
22	0.7	1.2	.6	1.1	.3	1.1
23	0.8	1.0	.2	.1	--	--
24	--	--	.8	1.4	1.0	1.3
25	1.1	2.0	1.1	1.4	4.0	1.4
26	2.1	1.9	6.8	.4	36.7	.3
27	.4	.8	.1	.1	.2	.1
28	--	--	1.1	1.0	8.6	1.0
29	.7	1.0	.5	.4	6.3	.3
30	.4	0.6	.3	.2	3.3	.2
31	.2	.3	.2	.1	.4	.1
32	--	--	.9	.5	5.9	.5
33	--	--	2.1	2.7	3.9	3.6
Total Load	30	64	51.8	25.9	368	40
SOL	-112		50		89	

Table 3–9. Sum of loads for other constituents during testing of the stormwater filtration device.

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

Sampled event number	Phosphorus, dissolved		Phosphorus, total recoverable		Chemical oxygen demand		Copper, dissolved		Copper, total recoverable		Zinc, dissolved		Zinc, total recoverable		Chloride, dissolved		Polycyclic aromatic hydrocarbon, total (1/2 detection)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1	0.0009	0.0009	0.003	0.002	0.93	0.82	0.0001	0.0001	0.0009	0.0006	0.0013	0.0008	0.005	0.003	0.13	0.12	--	--
3	.0032	.0029	.008	.006	3.05	1.96	.0008	.0007	.0027	.0015	.0046	.0040	.016	.006	.36	.36	--	--
5	.0008	.0008	.003	.002	1.09	1.45	.0004	.0003	.0009	.0006	.0016	.0012	.011	.002	.27	.20	0.0001	0.0000
6	.0012	.0013	.004	.002	1.17	.97	.0003	.0003	.0012	.0004	.0020	.0017	.008	.002	.13	.13	.0003	.0001
8	.0008	.0006	.002	.001	1.04	1.01	.0003	.0002	.0016	.0004	.0011	.0007	.009	.001	--	--	.0002	.0006
9	.0005	.0005	.002	.001	.60	.37	.0001	.0001	.0003	.0002	.0006	.0003	.002	.001	.08	.09	.0001	.0000
11	.0006	.0005	.006	.004	1.25	2.36	.0003	.0004	.0023	.0014	.0011	.0020	.007	.006	5.68	47.49	--	--
12	.0002	.0001	.003	.002	2.04	1.23	.0002	.0002	.0018	.0009	.0007	.0005	.009	.003	3.03	4.28	.0020	.0005
15	.0008	.0006	.002	.001	.77	.55	.0002	.0001	.0006	.0003	.0009	.0007	.003	.001	.36	.45	.0004	.0001
17	.0008	.0005	.003	.002	1.16	1.05	.0003	.0003	.0014	.0007	.0012	.0012	.004	.003	.24	.55	.0002	.0001
18	.0003	.0004	.002	.001	.53	.47	.0002	.0001	.0005	.0003	.0005	.0004	.002	.001	.12	.22	--	--
19	.0013	.0013	.005	.004	1.88	1.79	.0004	.0005	.0011	.0010	.0018	.0021	.004	.003	.38	.77	.0001	.0000
21	.0011	.0011	.004	.002	1.43	1.20	.0003	.0003	.0008	.0007	.0013	.0010	.005	.002	.45	.50	--	--
26	.0031	.0030	.010	.005	4.66	2.53	.0009	.0007	.0052	.0011	.0056	.0025	.021	.003	.53	.55	--	--
28	.0002	.0003	.001	.001	.37	.33	.0001	.0001	.0003	.0002	.0003	.0003	.002	.001	.06	.09	--	--
29	.0009	.0011	.003	.002	1.01	1.51	.0002	.0002	.0093	.0004	.0009	.0010	.014	.001	.19	.35	--	--
30	.0005	.0006	.002	.001	.66	.65	.0006	.0002	.0006	.0002	.0006	.0005	.004	.001	--	--	--	--
Total	.0173	.0164	.0643	.0401	23.64	20.25	.0057	.0048	.0314	.0108	.0260	.0209	.125	.0416	12.1	56.15	.0034	.0013
SOL	5		38		14		16		66		20		68		-367.53		59	

[1] Summing of PAH for calculation of the event-mean concentration was done in thee ways: (1) using half the detection limit for less than detections and (2) using zero for less than detections (3) using the limit of detection value. The three summing methods resulted in means that were in + 5 percent of one-half of the applicable detection limit

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