Pollutant Loading to Stormwater Runoff from Highways: Impact of a Highway Sweeping Program

Phase II, Madison, Wisconsin

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16. Abstract

This report describes the methods used to collect stormwater runoff and evaluate a street sweeping program on U.S. Highway 151 in Madison, Wisconsin. The study was a cooperative effort among the Wisconsin Department of Transportation (WisDOT), U.S. Geological Survey, and Wisconsin Department of Natural Resources. In a swept highway section, samples were collected to determine street dirt yields before and after a cleaning from either a vacuum-assisted or a mechanical-broom sweeper machine. Sweeping frequencies of twice per day, once per week, and once every two weeks were used during the study. On an unswept highway section of the study, street dirt yields are presented as weekly collections, and before and after runoff events. Water quality concentrations and flows are also presented for the unswept highway section. Average concentrations of selected contaminants are compared to concentrations measured in other studies of highway runoff.

Changes in street dirt yields before and after sweeping and runoff events will be used to calibrate and verify the WinSLAMM model. By modifying the accumulation, event wash off, and street cleaning productivity equations in the model with the data from this study, WisDOT will be able to evaluate street sweeping programs on urban highways with curbs. A sweeping program is proposed as a best management practice to attain some of the 40% reduction in TSS prescribed in Wisconsin stormwater regulations. This report includes estimated daily-accumulation rates of street-dirt yields and percent of street-dirt washed off during a runoff event. Seasonal estimates of street-dirt yield reductions due to street sweeping are also presented.

Concentrations and flows measured in the unswept highway section were used to calculate contaminant loads for each event. Loads were calculated for particulate and dissolved solids, inorganic compounds and trace metals. Sediment loads measured with a water quality sampler are augmented with the weights of sediment captured in a bedload sampler. Loads will be used to calibrate and verify the contaminant loads predicted at a highway outfall by the model by altering concentration files from this study.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
Flow rate		
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day per square mile [(gal/d)/mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
Mass		
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Vertical Datum of 1988 (NAVD 88).”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1983 (NAD 83).”

Pollutant Loading to Storm Water Runoff from Highways: Impact from a Highway Sweeping Program-Phase II, Madison, Wisconsin

Abstract

The Wisconsin Department of Transportation (WisDOT) is required to control the quality of runoff from roadways under their control according to the National Pollution Discharge Elimination System (NPDES) as authorized by the Clean Water Act. WisDOT also have an agreement with the Wisconsin Department of Natural Resources (WDNR) to attain at least a 40% reduction in total suspended solids from runoff that enters state waters from developed urban areas by 2013 (Trans 401). A sweeping program is proposed as a best management practice to accomplish the stormwater regulations of the WDNR (Administrative Code NR216). Street sweeping could be a cost effective option because it can effectively cover several miles of roadways. Several structural practices, requiring additional land and several structures, would be needed to cover the same area which could be cost prohibitive. This study is the second highway sweeping study by WisDOT to understand the effectiveness of street sweeping on urban freeways. The two main goals of this study were to evaluate a high efficiency sweeper under varying sweeping frequencies and to determine highway street-dirt characteristics such as accumulation rate and wash-off rates.

WisDOT evaluated the effectiveness of street cleaning on highways in ultra-urban areas by simulating contaminant loads from highway runoff. Windows Source Load and Management

Model (WinSLAMM) software was selected for its ability to calculate contaminant loads on the municipal street and at the outfall of the storm sewer pipe and simulate the effectiveness of street cleaning. WinSLAMM is used to evaluate the water-quality and cost benefits of street-cleaning frequency: for example, weekly, bi-monthly, or spring clean-up. The U.S. Geological Survey in cooperation with WisDOT and WDNR collected the data necessary to calibrate and verify the model's methods for simulating street cleaning effectiveness and contaminant loads for highways in ultra-urban areas. The WinSLAMM model will eventually be calibrated using data from this study and verified using data from pervious studies after modifications to the model's highway landuse section have been made. These modifications are to add equations that are similar to municipal streets, which assist in evaluating contaminant loads and street cleaning effectiveness.

For the model to simulate contaminant loads from municipal streets it must track both the accumulation of street dirt between runoff or street cleaning events and the amount of street-dirt washed off after a precipitation event. Changes in street-dirt yield were measured on two half mile sections of U.S. Highway 151 (USH151) from East Springs Drive to the on-ramp of Interstate Highway 90/94/39 in Madison, Wisconsin. Data from one of the sections measure street-dirt yields before and after a street-sweeper cleaning and data from the other section was use to measure street-dirt yields without being swept. Final street-dirt accumulation equations have not been developed for highways, but will be similar to those in the model for municipal streets. This study indicated street-dirt accumulation rates after cleaning or precipitation event decreased from 9 lbs/curb-mile/day for the first four days, to 2 lbs/curb-mile/ day between four and nine days, and to zero lbs/curb-mile/day after ten days or greater. Changes in street-dirt wash off after precipitation events had a median change of 14 percent for the section of highway not cleaned with a street sweeper. Wash off equations in the model will be modified using the results from this study.

A vacuum-assisted street sweeper was used for most of the testing. Street cleaning was usually performed on a once per week schedule. Changes in the municipal street-dirt yields due to street cleaning are expressed in the model as a productivity equation. The equation is sensitive to street-dirt yield, parking density, and street texture. The coefficients in the equation have not been developed for the highway landuse section of the model, but street cleaning removal efficiencies were greater in the spring than in the summer. Spring had median street-dirt removal rates near 60 percent, and summer median removal rates near 30 percent.

After the accumulation, wash off, and productivity equations have been developed for the highway landuse section, the model will be calibrated and verified using the street-yield data and water- quality loads data collected during the study. Contaminant loads measured from the unswept section will be compared to the simulated loads for each monitored event. The average concentrations of total suspended solids (157 mg/l) and total phosphorus (0.23 mg/l) were similar to averages observed for other highway monitoring sites in Wisconsin. Average concentrations of zinc 0.2 mg/l, copper 0.05mg/l, and chemical oxygen demand 47 mg/l were slightly lower than those from other sampled highway sites.

Introduction

The Wisconsin Department of Transportation (WisDOT) is required to control the quality of runoff from roadways under their control according to the National Pollution Discharge Elimination System (NPDES) as authorized by the Clean Water Act. WisDOT also have an agreement with the Wisconsin Department of Natural Resources (WDNR) to attain at least a 40% reduction in total suspended solids from runoff that enters state waters from developed

urban areas by 2013 (Trans 401). Wisconsin maintains approximately 1,300 miles of urban highways that are in close proximity to waters of the state. Impervious surfaces, such as highways, are a source of stormwater that convey contaminants to surface waters and groundwater (Driscoll and others 1990). In 2002, WisDOT prepared Wisconsin Administrative Code Trans 401 to minimize and control the quality of stormwater runoff caused by adverse environmental effects on transportation facilities such as highways, airports, and railroads.
A major element of Trans 401 is to control the level of total suspended solids (TSS) in stormwater runoff from post construction sites and developed urban areas. Highway reconstruction, non-highway redevelopment performance standard (Trans 401.106 (3) (b)) and the developed area performance standard (Trans 401.107 (1) (b), 2002) require at least a 40 percent reduction in TSS.

To determine cost effective techniques of achieving the TSS performance standards, WisDOT, US Geological Survey (USGS) and the Wisconsin Department of Natural Resources (WDNR) evaluated an improved street-sweeping program on an urban freeway in Milwaukee (Waschbusch, 1993) and two proprietary devices in Milwaukee (US Environmental Protection Agency, 2005 a b). The Waschbusch (1993) study (recognized by WisDOT as the Phase I study) used a paired site design (Clause and Spooner, 1993) to determine if an improved street-sweeping program using a regenative air sweeper reduced contaminant loads in runoff. If street sweeping could achieve a 40 percent reduction in the TSS load from the highway, it might be a more cost effective way for WisDOT to achieve the TSS performance standards than the alternative structural practices, such as proprietary settling or filtration devices. Data in Phase I did not adequately support the benefits of the regenerative-air sweeper because of quality-control problems, limited data, contributions of contaminants from the area between the median jersey barriers, limited area swept, and possible sweeper problems.

Because of the problems encountered in the first study and the difficulty in finding a suitable paired site in Dane County, this study (recognized by WisDOT as the Phase II study) did not attempt to evaluate the TSS reduction of an improved street-sweeping program by comparing the TSS loads measured for a swept and unswept portion of highway. Instead, the goal of this study was to evaluate the new technology of vacuum-assisted sweeping by testing the benefits of weekly or monthly sweeping. Another goal was to collect the necessary data to modify the Windows Source Load and Management Model (WinSLAMM) for highway sections. The model can simulate surfaces TSS reductions for different street sweeping programs and estimate contaminant loads. To simulate municipal streets loads the model manipulates coefficients for street-dirt accumulation rates, street-dirt wash off of by runoff events, and the removal of street dirt by street sweeping. Those coefficients must be modified to simulate changes in street-dirt yields on highways in order to predict TSS reduction for highway outfall. These modifications to the street sweeping coefficients are only applicable to highways with curbs.

The recently released WinSLAMM version 9.2 has been updated to simulate the water-quality benefits of applying improved street-sweeping programs to all landuses except highways. This version of the model has the most recent improvements for street cleaning on municipal streets. Accumulation, wash off, and street-sweeping productive equations were calibrated using street-dirt yield data from a street-sweeping study in Madison, WI (Selbig and others, 2007a).

Loads for other contaminants beside TSS can be added to the model after the street-dirt accumulation and wash off equations are working for highways. Water-quality data collected in this study will be used to create files for particulate and dissolved concentrations in highway runoff. The pollutant parameter file has particular pollutants as milligrams per kilogram that produces a contaminant load when multiplied times the TSS concentration and the water volume.

This study is an example of the many studies conducted in Wisconsin that have helped calibrate and verify such modeling programs as WinSLAMM. As of 1975 the Wisconsin Department of Natural Resource (WDNR) and the U.S. Geological Survey (USGS) have partnered to complete more than 15 studies in at least 6 different cities to assist the State of Wisconsin in characterization of urban stormwater runoff and evaluation of stormwater control measures (Appendix A). For example, between 1978 and 1983 the WDNR and USGS participated in the Nationwide Urban Runoff Program (NURP) to assess the water-quality characteristics of urban runoff and the water-quality benefits of street sweeping in the cities around Milwaukee, Wis. Results from all these studies have been used to calibrate and verify such modeling programs as WinSLAMM.

Purpose and Scope

This report describes the methods used to collect stormwater runoff and evaluate street sweeping program on U.S. Highway 151 (USH151) in Madison, Wisconsin. The study was a cooperative effort among the WisDOT, USGS, and WDNR. The swept-highway section collected street-dirt yields obtained before and after a cleaning from either vacuum-assisted or mechanical-broom machines. Sweeping frequencies of twice per day, once per week, and once every two weeks were used during the study. On the unswept-highway section of this study, street-dirt yields are presented as weekly collections and before and after runoff events. Water-quality concentrations and flows are also presented for the unswept-highway section. Average concentrations of selected contaminants are compared to concentrations measured in other studies of highway runoff.

Changes in street-dirt yields before and after sweeping and runoff events will be used to calibrate and verify WinSLAMM. By modifying the accumulation, event wash off, and street cleaning productivity equations in the model with the data from this study the WisDOT will be able to evaluate street sweeping programs on urban highways with curbs. A sweeping program is proposed as a best management practice to attain some of the 40% reduction in TSS prescribed in the stormwater regulations (Trans 401). This report includes estimated daily-accumulation rates of street-dirt yields and percent of street-dirt washed off during a runoff event. Seasonal estimates of street-dirt yield reductions due to street sweeping are presented.

Concentrations and flows measured in the unswept-highway section were used to calculate contaminant loads for each event. Loads were calculated for particulate and dissolved solids, inorganic compounds and trace metals. Sediment loads measured with water-quality sampler are augmented with the weights of sediment captured in a bed-load sampler. Loads will be used to calibrate and verify the contaminant loads predicted at a highway outfall by the model by altering concentration files this study.

Description of Study Area

The study site is located on USH 151 from East Spring Drive to the on-ramp of Interstate Highway (IH) 90/94/39 in Madison, WI (fig. 1, 2). The section was re-constructed in 1999 as a divided highway with up to four lanes in each direction. USH151 has curbed and gutter cross-section that directs highway runoff into storm sewers system. The Eastbound lanes have merge lane from traffic enter into a frontage road and an on-ramp to IH 90/94/39. Westbound has a merge lane for off-ramp traffic from IH 90/94/39 and frontage road traffic. There is approximately 5000 feet of curb. A 3-ft wide grassed median separates the east and west bound lanes.

The study site has three areas: an unswept section, a swept section, and a buffer section. The buffer section allow vehicles entering the project area to travel over pavement that had been either swept or not swept with intention that street dirt the vehicle would be comparable to either swept or unswept condition. There is no on street parking in the entire study area. The average daily traffic count is 39,650. Salting of the highway occurs when ice or snow would cause unsafe driving conditions. Before the study, the highway was swept once per week with a mechanical broom sweeper. Sweeping occurred throughout the seasons except in winter months.

Figure 1. Arial view of the study area USH 151.

The unswept section drainage area was 2.27 ac. Seventy percent drained highway and 30 percent drained lawn from a hillside and median. This section was located 100-ft east of the intersection of USH 151 and East Springs Drive, both the eastbound and westbound lanes are 525-ft long. The highway pavement was concrete that has 1/8-in grooves that are perpendicular to traffic flow. These grooves provide pavement drainage and traction for vehicles under slippery conditions. Before this project sweeping occurred throughout the seasons, except in winter months.

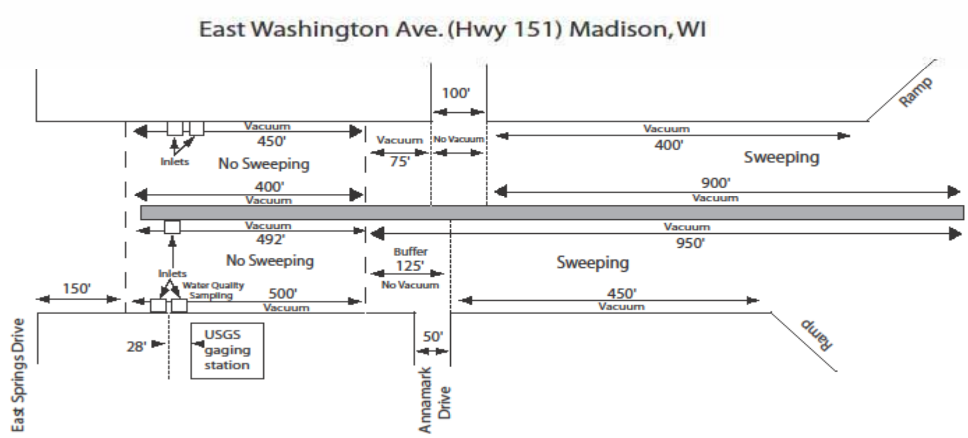

Figure 2. Diagram of the study area USH 151.

The swept section is east of the water-quality section on USH151 (fig. 2 and 3). The total area is 2.87 acres which includes a small section of grassed median. Both the eastbound and westbound lanes are the lanes are 935 ft long. Eastbound and westbound outer lanes are gravel, one foott of concrete curb-and-gutter, adjoined four foot width of asphalt that abuts the inner lanes of grooved concrete.

Pavement textures varied near the curbs where the street-dirt samples were collected. In the swept section, the texture changed from 100 percent grooved-concrete near the East Spring Drive to an increasing amount of blacktop as it approached the 90/94/30 ramps. Overall, the street-dirt samples collected in the swept section were from about 70 percent blacktop and 30 percent concrete. The unswept section street-dirt samples were collected from areas with about 80 percent grooved concrete and 20 percent blacktop.

Description of the sweeper

WisDOT maintains urban highways by contracting street cleaning through city and county municipalities. Primarily sweeping is done in spring to remove high street-dirt yields, usually by a mechanical broom sweeper. The mechanical broom has been around since the early 20th century. It removes particles from the street-curbed area by the uses of a rotating broom that pushes the material into the path of a large cylindrical broom which sends the material to a conveyor belt and then offloads the material into a hopper. (Novotny and Olem, 1994). It is best at removing wet or dry street-dirt and/or vegetative particles that are greater than 250 μm (Selbig and others, 2007a).

In Phase I of the study, a regenerative-air sweeper was evaluated This type of sweeper is used infrequently on urban highways. The regenerative-air sweeper has been around since 1970, and was intended to meet the new regulatory terms of the Clean Water Act. To capture sediments, these sweepers are equipped with gutter brooms and a pick-up head. The gutter brooms direct materials towards the pick-up head. The regenerative-air process blows air into one end of the horizontal pick-up head and onto the pavement dislodging materials entrained within cracks and uneven pavement. The other end of the pick-up head has a suction hose that immediately vacuums out the materials within the pick-up head into a hopper (Schilling, 2005). It is best at removing dry street-dirt or vegetative particles that are greater than 125 µm (Selbig and others, 2007a).

Phase II of the study evaluated the vacuum-assisted sweeper to determining if this new technology has improved sweeping efficiency. Again this type of sweeper is not typically used on urban highways. The vacuum-assisted technology was new in 2004. It improves on the regenerative-air sweeper by adding a powerful vacuum placed along the vehicle chassis such that it was is able to overlapping of the curb swept by the broom. It is best at removing dry street-dirt or vegetative particles that are greater than and less than 63 µm (Selbig and others, 2007a). Maintenance and operation comments for the vacuum-assisted sweeper used for Phase II of the study and a brochure for the vacuum-assisted sweeper are presented in Appendix 4.

Figure 3. Surface area of the unswept section; swept section of USH-151.

Description of WinSLAMM

WinSLAMM is a computer model approved by the WDNR. It was chosen for this study because of it capabilities of predicting the benefits of street cleaning in removal of TSS. A short description of WinSLAMM's predictive capabilities is presented in Appendix 3.

Methods of Data Collection

This study measured quantities of dirt on the street from a swept and unswept section of highway. Street-dirt samples were dried, weighed, and sieved for particle-size analysis. The changes in street-dirt yields were used to determine pickup efficiencies of the street cleaners, the accumulation rates of street dirt, and the amounts of street-dirt wash off by a runoff event. Pickup efficiencies were determined for a mechanical broom street cleaner and a vacuum-assisted street cleaner called the Pelican and Whirlwind respectively and manufactured by Elgin Inc. From October to December 2004 the mechanical-broom machine was tested at a cleaning frequency of once per week. Three different cleaning frequencies were tested for the vacuum assisted machine. From April to August 2005 the cleaning frequency was once per week. The frequency was dropped to twice per month from August to November 2005. Cleaning was increased to twice per day on July 18 and 25, 2005 and August 1, 2005. Additional pickup efficiency during periods of high street-dirt yields that tested the vacuum-assist machine continued in the spring of 2006 and 2007.

Table 1. Cleaning frequencies schedule on USH 151.

Sweeping Format	Start date	End date	Average Frequency (days)	Number of Sweeping
Mechanical broom	10/19/04	12/8/04	Weekly	8
Winter Break	None			
Vacuum-assisted	4/18/05	8/1/05	Weekly	15
Vacuum-assisted	8/15/05	11/7/05	Bimonthly	6
Vacuum-assisted	4/5/06	4/24/06	Spring	2
Vacuum-assisted	3/20/07	5/7/07	Spring	2

Accumulation rates of street dirt were calculated for periods without rainfall or street-cleaning events and wash off estimates depended on obtaining street-dirt samples immediately before and after runoff events. Street dirt measured at both the swept and unswept sections from 2004 to 2007 were used to estimate street-dirt accumulation rates. Estimates of wash off amounts were determined from street yield collected in the unswept section. Wash off yields were collected in the spring months of 2006 and 2007. Due to the logistics of collecting wash off samples before and after a runoff event, the larger swept section was not included in the wash off monitoring.

Water-quality concentrations and flows were collected in the outfall of a storm-sewer pipe draining the unswept section. Data was collected in order to calibrate and verify methods for predicting volumes and loads in highway runoff. Automatic water-quality samplers were used to collect the samples and the flow was measured with flow meters. Samples were collected from April 2005 to May 2007. Bedload samples were also collected in the pipe to characterize the amount of solids that might not be represented in the automatic sampler.

Quality-assurance and quality-control methods were followed during the entire project. Both field blanks and replicate samples were collected for the water-quality samples collected at the unswept section.

Street Dirt Collection and Processing

Street-dirt samples were collected with four vacuum cleaners mounted on a trailer (fig. 4). The vacuums had a 15 gal. wet/dry stainless-steel tank with a 9.2 amp motor. These were housed on a 5x8-ft 1000-lb trailer with 4 latched openings near each vacuum. Each vacuum was mounted on a metal flange that enabled each vacuum to be tipped and cleaned without it being removed from the trailer. Vacuums were powered by a generator that provided 2000 watts of power. Each vacuum head had a small piece of the neoprene hose that was connected to a quick-disconnect fitting mounted to the back of the trailer. A 25-ft black neoprene, wire-reinforced hose could be hooked to any of the vacuum instantly. This designed made it possible to measure the street yield separately for the east and west bound lanes of both sections without having to stop and remove the street dirt as you would with a single vacuum cleaner.

Figure 4. Vacuum trailer set-up; sub-sampling of the freeway.

Figure 5. Street-dirt at the swept sections median; the un-sweep east bound curb near the water-quality manhole.

The vacuums were used to collect sub-samples of street dirt along the outside curb and the curb along the median strip. For a pre-determined number of times, the vacuum wand was placed in the curb and pulled across the pavement until it was about 8-ft from the curb (fig. 4). Places to pull the wand across the pavement were randomly selected. Sometimes the swept and unswept sections were further divided into west and east bound street-dirt yields.

For both sections, the number of sub-samples taken was more than was needed to achieve an allowable error of 20 percent. To calculate the number of sub-samples needed to achieve a 20 percent error, 14 individual sub-samples were collected and weighed from one of the east and west bound curbs in the swept section. The number of sub-samples, N, was determined as follows (Hansen and others, 1984):

$$N = 4.25\,(s\text{-}1)^2/(r\bar{y}\,)^2$$

where,

N is the estimated number of subsamples required to estimate residential street dirt yield;

$\bar{y}$ is the average mass of measured subsamples; s is the standard deviation of measured subsamples mass; and

r is the allowable error.

Forty-two sub-samples were needed to achieve a 20 percent error for the swept section. For the two outer curbs, the number of samples required each curb was 15 and the two median curbs needed 6 sub-samples for each curb. An allowable error analysis was not done for the unswept section.

Fifty-six sub-samples were collected for the swept section. This was broken down into 10 sub-samples per curb for the two outer lanes and 18 sub-samples per curb for the two inner lanes. For the unswept section, 40 sub-samples were collected with 10 sub-samples per curb.

Distribution of Street-Dirt Yields

A study of street cleaning effectiveness on residential streets in Madison, Wis. has shown about 75 percent of street dirt resides within 3 feet of the curb face (Selbig and others, 2007a). On a street in Bellevue, WA that is similar to USH151 (relatively busy with no parking), about 90 percent of the street dirt was found within 8-ft of the curb face (Pitt, 1985). To verify most of the street dirt was located within 8 feet of the curbs for the swept section, a special set of sub-samples were collected on 04/14/2005 and 06/22/2006. The highway was segmented in four sections: starting at the curb face and going for 1-ft (curb segment); starting 1-ft from the curb face and going for 7-ft (shoulder segment); starting 8-ft from the curb and going to the edge of the outside lane (lane segment); and just the width of the center lane (lane segment). The four segments were sub-sampled four times. Twice each on the east and west bound lanes of the swept section. Each segment was sampled with a different vacuum cleaner and the vacuum was emptied after each site. Ninety percent of street-dirt mass was collected in the curb and shoulder with the majority of particles in each segment being greater than 250 micrometers (table 2).

Since the street-dirt yield in this study is represented by the area between the curb to shoulder, the measured street-dirt yield is probably a 10 percent underestimate for most days. The street-dirt collected was the amount of street dirt reduced by the street cleaner. Because this yield is not included in the estimates of street cleaner effectiveness, any benefits of street cleaning based on this data are probably small overestimates.

Table 2. Distribution of street-dirt collected across USH151, Madison Wis.
[(µm), micrometers; <,less than, (g), all data in grams]

Segments	Detritus	2000 (µm)	1000 (µm)	500 (µm)	250 (µm)	125 (µm)	63 (µm)	<63 (µm)	Total Mass
Curb	8	346	181	281	422	251	118	110	1,717
Shoulder	0	132	72	141	232	168	115	128	988
Lanes	0	79	53	55	53	28	16	12	296

Safety Procedures

County safety trucks were used to provide a safe environment for sample street-dirt collection and the street sweeper. Before sampling street-dirt collection, the county crew put up traffic safety signs. The USGS van and trailer used safety lights and the crew wore bright orange vest. Two Dane County safety trucks followed the two-person-vacuum crew positioning one truck about 25-ft behind followed be the second truck in the adjacent lane forcing traffic to be one lane over from the vacuum crew. Three safety trucks were used when the entire highway was sampled.

Street Dirt Processing

Sub-samples were brought back to the USGS Wisconsin Water Science Center's Southwest Field Office for processing. The gate on the trailer next to the vacuum was opened so vacuums could be maneuvered for cleaning. Vacuums were empted by removing the top motor of the unit and the filter knocked with the bottom of soft paint brush to remove the dirt. The filter was then lifted slightly so that the remaining dust on the filter could be brushed off. Material inside the stainless steel tank was lightly brushed then the vacuum was tipped forward and material was carefully transferred into a drying canister to prevent loss of finer dust particles. The sub-samples were dried overnight in an over at 105°C. Samples were weighed and separated into eight particle-size fractions in the range large detritus, and these ranges in micrometers: greater than 2000; 2000-1000; 1000-500; 500-250; 250-125; 125-63;<63.

Unswept Section Collection of Flow, Precipitation and Runoff

Stormwater runoff was measured and collected at the storm sewer pipe to the unswept section (fig. 2). To gain accesses to the storm sewer, a section of the eastbound curb area was excavated and reconstructed into approximately 5-ft long, 3-ft. wide, 4-ft. deep manhole (fig. 5). The top quarter of the storm-sewer pipe was removed for a length of 3-ft. The 18-in. pipe was equipped with a water-quality sampler tube and instruments to measure water level and velocity. An electronic data logger was used to control the instruments and record the data. Precipitation data was collected using a tipping bucket rain gage calibrated to 0.01 inch.

Precipitation Measurement

A tipping-bucket rain gage was used for continuous measurement of rainfall. A data logger recorded the number of bucket tips (0.009 in. per tip) every 60 seconds. Calibration data showed there was no need to adjust rainfall data. There were periods of missing records but a near by rain gage provided the missing information. Winter months are excluded from monthly total because the rain gage was not designed to measure snowfall.

Flow Measurement

Stage and velocity were measured by two area-velocity meters inside the 18-in. circular storm sewer pipe. One was installed 3 feet upstream of the storm sewer pipe opening and a backup meter 3 feet downstream storm sewer pipe opening. To calibrate stage the two meters were removed from the pipe and placed inside a 5 gallon buckets. Time and stages were recorded as the bucket was filled at approximately 0.1-ft depth increments. Stage measurements were adjusted by applying correction based on the observed differences between manually measured water-surface elevation and those measured by each meter.

To calibrate flow an automatic dye-dilution system was installed in June, 2005. The known dye concentrations injection site was located 20 ft upstream of the area-velocity meter. Location for drawing a diluted dye mixture of stormwater to the fluorometer was located 5 feet downstream of water-quality sampling point. A dye-dilution event occurred when a given stage threshold was reached at the inlet area/velocity meter. Storms from June 9, July 21, 23, 25th sample points of calibration at the area-velocity meter were taken. The equation to convert dye recordings to flow is:

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

where

Q is the flow being measured;

q is the injection rate;

C is the concentration of injected dye; and

c is the concentration of dye measured.

A 30 percent discrepancy was computed when comparing discharge from the dye-dilution to the metered. Low reading from meter was corrected a low and high rating curve. Discharges at the lower depths were affected by the area\velocity probe and cord that disrupted a normal flow profile in the 1.5-ft pipe. The USGS rating curve for stable channels was used to correct irregular channel flow at lower depths (equation below). The meter acted as a control until a gage height of 0.06-ft was reached. This was considered effective flow ‘E’. The ‘N’ and the ‘C’, from the USGS equation below, were adjusted to plot through the dye dilution stage discharge relationship. ‘C’ was based on the range of discharges at a 1-ft depth, and ‘N’ fell in the ranges suggested by Rantz, 1982. The dye dilution rating was valid at depths less than 1.2-ft. A high flow rating (greater than 1.2 ft) was developed using Manning’s equation that match the higher end of the USGS rating curve.

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

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

where

Q	is the discharge, in cubic feet per second;
C	is the discharge coefficient;
G	is the gage height of the water surface, in feet;
E	is the effective zero control, in feet; and
N	is the slope of the rating curve.

The Manning's rating curve is an empirical equation for uniform channels. The best fit for this site was to use a slope of 0.0355 and a roughness coefficient of 0.011. The following flow equation:

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

where

Q	is the discharge, in cubic feet per second;
1.486	is a conversion factor to inch-pound;
A	is the cross-sectional area in square feet, based on the water level;
R	is the hydraulic radius, in feet, based on the water level;
S	is the energy slope, in feet per foot; and
n	is Manning's roughness coefficient.

WinSLAMM predicts that there is no lawn runoff until a rainfall is greater than 0.5-in. A lawn runoff sampler was installed June, 2006 to indicate when runoff from the grass occurred; it was not a volumetric measurement. This indicated when flow thought the storm sewer pipe was runoff from just the highway or from both areas. A new highway runoff curve for smaller runoff events could be developed in the model if no lawn runoff occurred. For events with lawn runoff WinSLAMM could be used to estimate a volume from the lawn. A new highway runoff curve for higher runoff events could be developed by subtracting the models lawn runoff from the volume measured in the pipe.

Collection of Water-Quality Samples

A refrigerated automatic sampler was used to collect the water-quality samples from the unswept section. The 3/8-in. sampling tube was installed 1-in. off the bottom of the 18 inch storm sewer pipe. This was placed 3 feet upstream from the opening of the pipe. The intake tube was placed perpendicular to the direction of flow. The sampler was programmed to collect flow-weighted samples when the water volume exceeded a threshold level. Flow-weighted sampling allowed for the collection of one composite runoff-event sample consisting of numerous sub-samples throughout the hydrograph. This approach resulted in a single average or “event mean” concentration for each runoff event. The data logger in the monitoring station was programmed to initiate a sub-sample for a predefined volume of flow; consequently, more sub-samples were collected for large-volume events than for small-volume events.

Figure 6. Manhole constructed for water-quality sampling of the highway runoff; bedload sample.

The constituent list was based on the types of contaminants that may be regulated in the future (tables 3 and 4). The constituents list for the water-quality samples include suspended sediment (SS), TSS, volatile suspended solids (VSS), total dissolved solids (TDS), total phosphorus (TP), dissolved phosphorus (DP), chemical oxygen demand (COD), chloride (Cl), total recoverable copper (TCu), dissolved copper (DCu), total recoverable zinc (TCu), dissolved zinc (DZn), total recoverable calcium (TCa), total recoverable magnesium (TMg), and polycyclic aromatic hydrocarbons (PAHs). Particle size distributions (PSD) were also determined for as many events as possible. Events with 0.2-in of rainfall and a minimum of five 1-L subsamples collected were processed for all constituents, otherwise sub-samples were processed just for SSC, TSS and TDS. Samples were analyzed at the Wisconsin State Laboratory of Hygiene, participators in the USGS Standard Reference Sample (SRS) program (Woodworth and Connor, 2003).

Table 3. List of inorganic constituent analyzed, limits of detection, limit of quantification, and analytical methods for samples collected at USH151, Madison Wis.

[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]
Wet-sieve of sediment	NA	NA	NA	[3]Burton
Coulter counter of sediment	NA	NA	NA	[3]Burton
Laser diffraction of sediment	NA	NA	NA	[3]Burton
Microfiltration of sediment	NA	NA	NA	[3]Burton

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

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

[3] Burton and Pitt. 2002.

Table 4. List of organic constituent analyzed for, limits of detection, and analytical methods for samples collected at USH151, Madison Wis.

[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	0.140
2-Methylnaphthalene	.034	.110
Fluorene	.200	.650
Acenaphthene	.060	.190
Acenaphthylene	.072	.230
Anthracene	.021	.067
Benzo[a]anthracene	.062	.200
Benzo[a]pyrene	.070	.220
Benzo[b]fluoranthene	.110	.340
Benzo[g,h,i]perylene	.078	.250
Benzo[k]fluoranthene	.070	.220
Chrysene	.027	.087
Dibenzo[a,h]anthracene	.038	.120
Fluoranthene	.080	.250
Indeno[1,2,3-cd]pyrene	.120	.390
Phenanthrene	.040	.130
Pyrene	.070	.220
Naphthalene	.038	.120

SS concentrations and TSS analysis are two different methods used for the determination of solids concentration. The TSS method samples an aliquot that 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).

New procedures to improve the accuracy and precision of measuring the quantity of particulate pollutants in samples containing large amounts of sand-sized particles (>125 μm) were incorporated in obtaining samples. The USGS determined using a churn to split samples with large concentrations of sand has the potential to cause a positive bias and to lower the precision in the measurement of pollutant concentrations associated with particulates (Horowitz, 1997). A wet-sieving process decreases these errors for sediment-associated constituent concentrations (Selbig and others, 2007b). This process consists of pouring a known quantity of event sample through sieves of 125, 250 and 500 microns before churning the aqueous portion. Material collected on sieves was sent to the Wisconsin State Laboratory of Hygiene (WSLOH) in individual bottles to be dried and weighed. Dried material from each of the sieves was then combined and processed for total metals and phosphorus. This process was only used on six events. These six events had large amounts of material drop to the bottom of the glass jar within a minute of stirring the sample. The portion of the sample passing thru the sieves was processed through normal USGS churning procedures (Horowitz, 1997). All concentrations of SSs presented in this report include sieved material.

Sieved masses are added back into the aqueous portion to determine an event mean concentration by using the following equation (Selbig and others, 2007b):

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

where

C1	is the concentration of sieved solid represented in mg/L;
Sm	is the mass of sieved solids after drying, in grams;
Cs	is the concentration of sieved solid, in mg/kg;

and

V	is the volume of water sieved in liter.

Quality Control

Equipment blank and replicate samples were collected and analyzed for the same constituents as those from water-quality samples. Blanks were collected at the beginning and midpoint of the project to validate clean sampling procedures. Four equipment blank samples were collected and all the contaminants concentrations were below detection except for DCu and TCu (table 2-2). Blank 1 and 3 had concentrations of dissolved copper (DCu) and TCu just at the limits of detection, but below the limit of quantification (LOQ).

Replicate samples were done for three 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 WSLOH.

The relative percent difference equation is

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

where

x_1 is the concentration of compound in sample,

x_2 is the concentration of compound in duplicate,

and

$\overline{x}$ is the mean value of x_1 and x_2..

Replicate samples were collected during events 5, 19, and 49 to quantify variability in the sampling process. The RPD target for TSS and TP was 30 percent or less and for metals the RDP target was 25 percent or less (table 2–3). Event 5 replicates the target of 25 percent was exceeded for TCu, and the 30 percent goal for TP was exceeded slightly. Dissolved zinc exceeded the RPD target in event 49. A relatively low RPD was reported for most contaminants and none of the contaminants exceeded the RPD target for event 19.

Particle-Size Distribution

July 2004, the USGS Wisconsin Science Center adopted a new method for particle-size analysis. Previous methods had always required a large sample volume to have enough sediment for analysis. They were not designed for the relatively low levels of sediment observed in stormwater samples. The new method only required about a liter of sample. The new particle size analysis used a two-step process performed by WSLOH.

The first step is to wet sieve the sample for the 500, 250, 125, 63 and 32 micron particle sizes. The material on the sieves is then dried and weighed. The second step is to separate the particles less than 32 microns into particle size fractions of 16, 8, 4 and 2 microns. For the first 65 samples, a Laser counter was used to identify the quantity of the four smaller particle sizes. For samples in 2007, a Coulter counter (Beckman Coulter Multisizer 3 particle size counter, Graham 2003) was used to identify the quantity of smaller particles. Others have used a Coulter counter to evaluate particle sizes in stormwater (Burton and Pitt 2002). The Coulter counter is calibrated by micro-filtering replicate samples with polycarbonate filters.

Collection of Bedload Samples

In order to determine size and the mass of the sediment missed by the automatic sampler, a bedload sampler was installed at the bottom of the opened portion storm-sewer pipe. The polypropylene tank for the bedload sampler was 18-in. long, 6-in. wide, 24-in. deep (fig. 6). A cover placed over the sediment trap had 14 slits that were ¼ inch in width. Material from the bedload sampler was usually removed after each event dried, weighted, and sieved at the same particle sizes as the water samples.

Characterization of Highway Street Dirt

Street-dirt samples were collected from both the swept and unswept sections of the study site. The swept section was sampled immediately before and after a street cleaning event. Eight of the street cleanings were done with a mechanical-broom street sweeper, seven cleanings at a frequency of once a week from October to December 2004 and one on May 8, 2006 (table 2–11). Twenty-five street cleanings were done with a vacuum-assisted machine between April, 2005 and May, 2007 (table 2–12). Seven of those vacuum-assisted samples were differentiated between the east and west bound lanes by collecting street dirt into separate vacuum cleaners. For these seven dates, a combined street yield was calculated for entire section by adding together the street-dirt yields measured at the east and west bound lanes. Twelve street-dirt samples were also collected from the swept section without the section being swept.

To characterize street-dirt accumulation and wash off rates at the unswept section, street-dirt samples were collected almost weekly or more frequently from between October 2004 and June, 2007. Seventy-one times street-dirt samples were collected in the unswept section and 53 of those times the east and west bound lanes were sampled separately (table 2–10).

To properly characterize the street dirt, the weight of the samples collected in the vacuum cleaners must be extrapolated to a total street-dirt yield for the swept or unswept section. Street-dirt yield is represented as pounds per curb-mile. With a divided roadway, there would be 4 curb miles per mile of road, compared to 2 curb miles for an undivided road per road mile. If the samples are taken as strips across the entire street, then that represents both curbs and the lbs/mile may be divided by 2 to calculate lbs/curb-mile. The yields are not adjusted at all, if the vacuum wand is pulled only halfway across the street. In this study, the samples were collected from all four curbs and each curb was represented by a sample taken less than halfway across the street. The mass from all the curbs was divided by the total length of the curbs, so the result was in lbs/curb-mile. If the mass was divided by just the length of the street, the final number would have been in lbs/mile and the value should be divided by four.

Street-dirt yields, in pounds per curb mile, for all samples collected from both sections were calculated using the following formula:

$$P = \left[\left(\frac{\frac{(M \times 0.0022)}{W \times \sum D} \times \sum_{i=1}^{n} A}{\sum_{i=1}^{n} L} \right) \right]$$

where

P	is the mass of dirt on a street, in pounds per curb-mile;
M	is the total mass of sampled street-dirt, in grams;
W	is the width of the vacuum nozzle, in feet;
D	is the linear distance wand was pulled across the street for each pull;
A	is the area of each zone of street, in square feet;
L	is the length of each zone of street, in miles;
n_t	is the total number of zones in basin;
i	is an index to each zone in a study basin;
0.22	is a unit conversion factor between grams and pounds.

The characteristics of the street dirt are needed to adjust the accumulation, wash off, and street cleaning pickup efficiency equations in WinSLAMM. The accumulation rates, wash off percentages, and pickup efficiencies presented in this part of the report are not the final algorithms to be used in the model. Instead, the street-dirt characteristics presented in this section represent a first step in improving the algorithms in the model. The first step supports the idea that enough street-dirt data was collected to add street cleaning routines for ultra-urban highways into the model. A description of how the model calculates accumulation, wash off, and street cleaner pickup efficiencies is included in Appendix 3. Future efforts will complete the modifications to the algorithms in the model.

Summary Statistics for Street-Dirt Yields in Swept and Unswept Sections

Mean and median combined street-dirt yields were higher at the unswept section than both pre and post cleaning street yields measured at the swept section (tables 5 and 6). The lower yields for the swept section might reflect the street cleaning to reduce the amount of dirt stored on the street. This is supported by all the post cleaning street yields being lower than the pre cleaning yields in the swept section. The summary statistics for the eastbound lanes have higher yields than the westbound lanes in the unswept section. There is no obvious explanation for the differences between the lanes except the presence of a construction site near the eastbound lanes and maybe material bouncing off of trucks coming from a construction site west of the study area.

Table 5. Summary statistics for combined street dirt yields in the swept section.
[All values given in pounds pre curb-mile]

Statistic	Yield in pounds pre curb-mile, by sweeper type			
	Vacuum assist pre sweeper	Vacuum assist post sweeper	Mechanica l broom pre sweeper	Mechanica l broom post sweeper
Number of samples	37	25	8	8
Maximum	1,488	486	487	429
Minimum	142	111	237	227
Median	217	159	304	288
Mean	333	194	361	317

Table 6. Summary statistics for street-dirt yields in the unswept section.

[All values given in pounds pre curb-mile]

Statistic	Yield in pounds pre curb-mile		
	Combined east and west	East bound	West bound
Number of samples	71	53	53
Maximum	1,750	2,757	984
Minimum	132	130	107
Median	404	494	352
Mean	540	718	399

Average Distribution of Particles in Street Dirt

On average, the largest percentage by mass of the street-dirt particles is in the 250 to 500 micron size range for both the swept and unswept sections (fig. 7). The clay and silt size particles (< 63 microns) are a small percentage of the total mass of street dirt. About 25 percent of the particles are in the 250 to 500 micron size and the less than 63 micron size for the swept and unswept sections represent 7 and 12 percent of the particles, respectively. About 60 percent of the particles for both the swept and unswept sections are accounted for by adding the 125 to 250 microns and 500 to 1000 micron sizes to the 250 to 500 micron sizes. Similar results were found in analysis of residential street dirt in previous studies. The residential streets in the Madison, and Milwaukee WI study had about 66 and 34 percent of the particles in the range of 125 to 1000 microns, respectively (Selbig and others, 2007a; Bannerman and others, 1983).

The biggest difference between the particles distribution between the swept and unswept section came in the coarse-sand sized (greater than 1000 microns) and the finer particles (less than 125 microns). The percent of coarse-sand particles in the unswept section was about 40 percent greater than the percent of the same sized particles in the swept section. In contrast, the percent of fine particles in the unswept section was about 40 percent less than the percent fine particles measured for the swept section (fig. 6). Since the only difference in the two sections is the street cleaning activity, the vacuum assisted street cleaner might be selectively removing some of the larger particles from the swept section. If the machine does not proportionally remove the same amount of fine particles, the percentage of fine particles would increase.

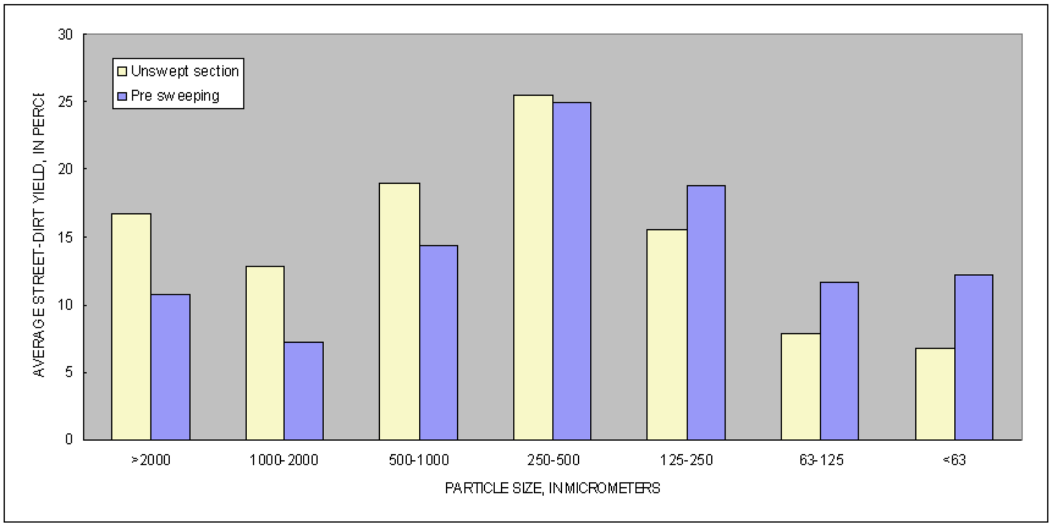

Figure 7. Average particle-size distributions in the street dirt at the swept and unswept sections.

Comparison of Street Yields with Other Sites

Previous studies that used similar methods to measure street dirt have observed a large variability in mean street dirt yields between sites (Bannerman and others, 1983, Selbig and others, 2007a; Breault and others, 2005). Factors affecting the differences between sites include street condition, street texture, traffic counts, and availability of contaminant sources near the street. Streets in poor condition or with a rough texture tend to have higher street dirt yields, because they accumulate more dirt in the pores and cracks. Street dirt appears to accumulate at a faster rate for streets with higher traffic counts. Cars and trucks can track in dirt from surrounding areas (Bannerman and others, 1992). Vegetative debris from trees is a direct input to the total street dirt and street with more tree canopy can higher street dirt yields (Waschbusch and others, 1999). During runoff events, sediment can wash on to the street from surrounding sources, such as eroding lawns and result in higher street-dirt yields (Selbig and others, 2007a).

Given all the factors affecting street yields it was not certain that the street yields from previous highway studies would compare well with this study. If similar street yields were observed for other highway sites, it would support the idea of extrapolating the results from this study to other highways. Although an attempt was made to find street yield data from previous studies on highways, all the comparable data seemed to be for studies on residential streets. A comparison of the street yields from this study with residential-street yields from previous studies reveals the numbers from this study are in the same range as number from previous studies (table 7). For example, the mean street yield for the unswept section is 540 lbs\curb-mile, which is close to the unswept numbers of 614 and 776 lbs\curb-mile for the Madison, WI study. The similarity in average street yields is especially strong between the swept section and the Madison residential street when the street is swept with the vacuum assisted street cleaner. Despite the differences in land use, it appears using the same street cleaning machine on two streets in the same general condition can produce similar average street-dirt yields. Average street dirt yields will certainly vary between sites, but the similarities between the average residential and highway street yields might indicate the factors controlling the street yields will limit all streets to the ranges observed (table 6).

Table 7. Comparison of street-dirt yields from this study with street-dirt yields observed on other streets in the United States.
[All values in pounds per curb-mile]

Statistic	Study Site			Madison, WI[1]			Broom Sweeper		
	Vacuum-assisted unswept section	Vacuum-assisted swept section	Broom Sweeper swept section	Control Site	Vacuum-assisted site, swept	Vacuum-assisted site, unswept	Champaign, Ill.[2]	San Jose, CA.[3]	Bellevue, WA[4]
Median	404	217	304	569	116	672	--	--	705
Mean	540	333	361	614	304	776	408	310	815

[1.] Selbig and others, 2007a

[2]. Bender and Terstriep, 1984
[3]. Pitt, 1979
[4]. Pitt, 1985

Accumulation Rates of Street Dirt

Changes in street dirt during periods of no street cleaning or runoff events were used to determine highway accumulation rates (table 2–13). Twenty-eight accumulation periods were available for the unswept section and 12 for the swept section. Although most street-dirt samples were collected on roughly a once a week schedule, some samples were collected on a one to four day schedule to document accumulation rates for shorter time intervals. There were two instances when over a four day period the sampling was done everyday. A minimal number of samples were collected to support a daily average accumulation rate, several accumulation days were grouped. Accumulation ranged from 1 to 4 days for a sample count 18. Accumulation days of 5 days had 9 samples. Accumulation days ranging from 6 to 9 days were grouped for 8 samples. Accumulation days greater than 10 were grouped for a sample count of 5; including the longest accumulation period of 20 days.

Although some detail is lost by grouping the accumulation periods, a trend was observe of decreasing accumulation rates with increasing number of days (fig. 8). The plot only includes the composite street dirt for each section and does not include the separate street dirt from east and west bound lanes. The median accumulation rate decrease from about 9 lbs/curb-mile/day for 1 to 4 days to a negative number for accumulation periods over 10 days. An equation describing the changes in accumulation rates would have to have a decay coefficient reducing the rate after 4 days. Other studies on non-highways had accumulation rate for the relatively busy street in Bellevue, WA was less than 1 lb/curb-mile/day (Pitt, 1985). The average accumulation rate measured for a mixture of residential and commercial streets in Milwaukee during the

Nationwide Urban Runoff Study (NURP) was about 12 lb/curb-mile/day (Bannerman and others, 1983). Calculations of street-dirt accumulation rates need to be amended in WinSLAMM for highway. This procedure is described in WinSLAMM Appendix 3–1.

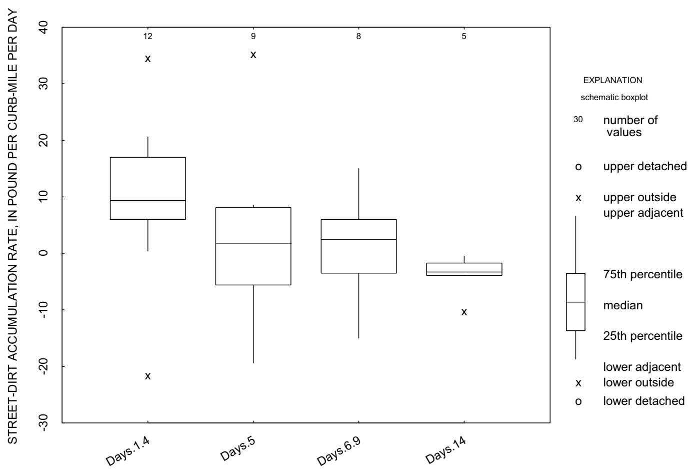

Figure 8. Street-dirt accumulation rates for USH 151.

Wash Off of Street Dirt

Street-dirt samples were collected 11 times before and after a runoff event from dried streets (table 2–14). Ten samples were collected in the unswept section and the 1 sample was collected in swept section. For 10 of these runoff events the east and west bound lanes samples were collected. Collections of street-dirt wash off samples were limited by the difficulty of forecasting runoff events and coordinating with safety trucks availability.

The median percent of the street-dirt washed off was 14 percent using the data separated for the east and west bound lanes (fig. 9). Calculated street-dirt mass composed of both the east and westbound lanes, the median percent wash off the same at 14 percent. The average wash off mass observed for a mixture of streets for NURP was also low at 17 percent (Bannerman and other, 1983). Amounts wash off averaged about 15 percent for street dirt collected in Bellevue, WA (Pitt, 1985). Two factors seem to contribute to the low percent wash off observed for all the studies. One factor is the street dirt can actually increase after a runoff event, especially for the larger particles. This phenomenon has been documented as the result of material being washed off other surfaces and being deposited on the street (US Environmental Protection Agency, 1982). Six of the 11 runoff events in this study produced increases in street dirt for the east and west bound lanes. It is possible that the median strip and the grass area next to the unswept section could have contributing sediment for some of the runoff events. In the absence of street cleaning larger particles might armor the smaller particles and therefore the small particles are not as available to be washed off the street (Burton and Pitt, 2002).

Although the larger particles might armor the smaller particles, a higher percentage of the silt and clay particles are washed off the street surface than any other particle size (fig. 10). Median reductions were less than 10 percent for particles greater than 125 microns. Without the effect of armoring the amount of the particles less than 63 microns and between, 63 and 125 microns might have been greater than about 40 and 20 percent respectively. The average reductions for particles between 31 and 63 microns were 40 and 60 percent after a runoff event. For particles between 63 and 125 microns the average reductions were 28 and 52 percent.

Sufficient wash off data was collected in this study to adjust the street-dirt wash off when WinSLAMM is modified for highways. Calculations of street-dirt wash off in WinSLAMM are explained in Appendix 3–2.

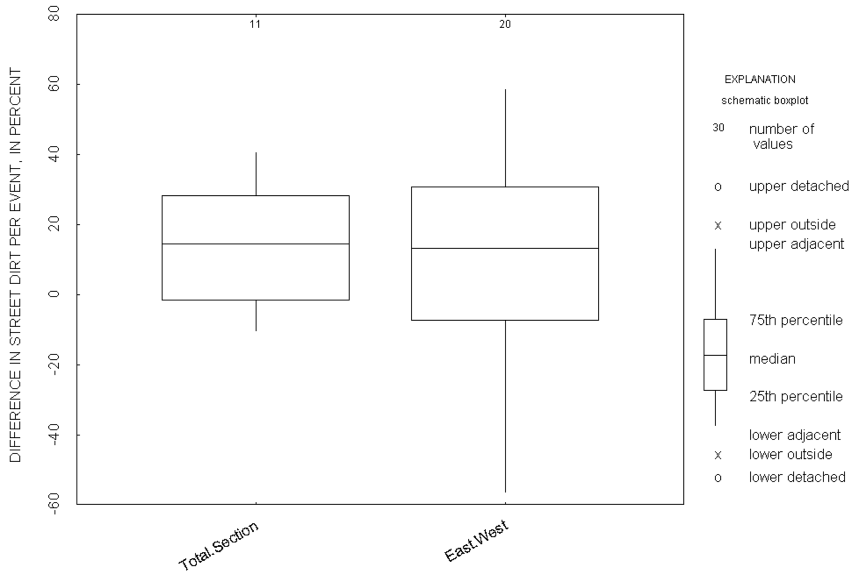

Figure 9. Change in street-dirt yields after a runoff event for the east and west bound lanes and the total highway. A negative number indicates an increase in the street-dirt yield after a runoff event.

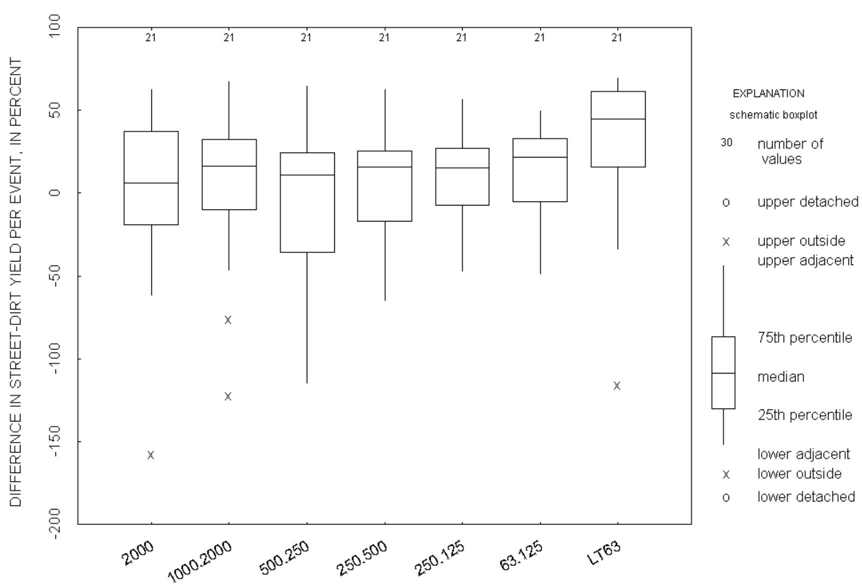

Figure 10. Changes in street dirt yields after runoff events for the east and west bound lanes in the unswept section. Negative values indicate an increase in street-dirt yield.

Street Cleaning Efficiencies

Efficiencies for the vacuum-assisted machine were higher in the spring than the rest of the year (fig. 11). Street-cleaning events in the spring were used to calculate an average spring pickup efficiencies of 55 percent (table 2–12). Overall efficiencies range from 19 percent to 77 percent with median reduction around 32 percent (table 8). A similar median efficiency of 30 percent was observed for the same vacuum assisted machine used on residential streets in Madison, WI (Selbig and others, 2007a).

Greater street cleaning efficiencies in the spring are probably related to the higher street-dirt yields typically observed in the spring. Street-dirt yields over 1000 lbs/curb-mile in the swept section were observed in the March and April (table 2–12). Street-dirt yields in the warm weather months were the range of 150 to 350 lbs/curb-mile. Efficiencies for the larger street-dirt yields are in the range of 60 to 80 percent, while the lower street dirt yields are usually associated with efficiencies in the range of 20 to 30 percent (fig. 12).

Table 8. Comparison of street-dirt yields for the vacuum assist, and mechanical broom sweeper test at USH-151.

[A negative value indicates an increase in street-dirt yield after sweeping]

Statistic	Yield reduction in percent, by sweeper type	
	Vacuum assist	Mechanical broom
Number of samples	25	8
Maximum	77	29
Minimum	19	-14
Median	32	7
Mean	36	8

In 2005, the vacuum-assisted sweeper was tested weekly and monthly frequency (table 1). The yield reductions by the sweeper for both frequencies are comparable (table 9). The increase in efficiency on the monthly sweeping is because street-dirt accumulated between cleanings.

Table 9. Comparison of street-dirt yields for the vacuum assist weekly and monthly sweeping.

Statistic	Yield reduction in percent, by vacuum -assist sweeper	
	Weekly	**Monthly**
Number of samples	15	7
Median	29	32
Average	30	32

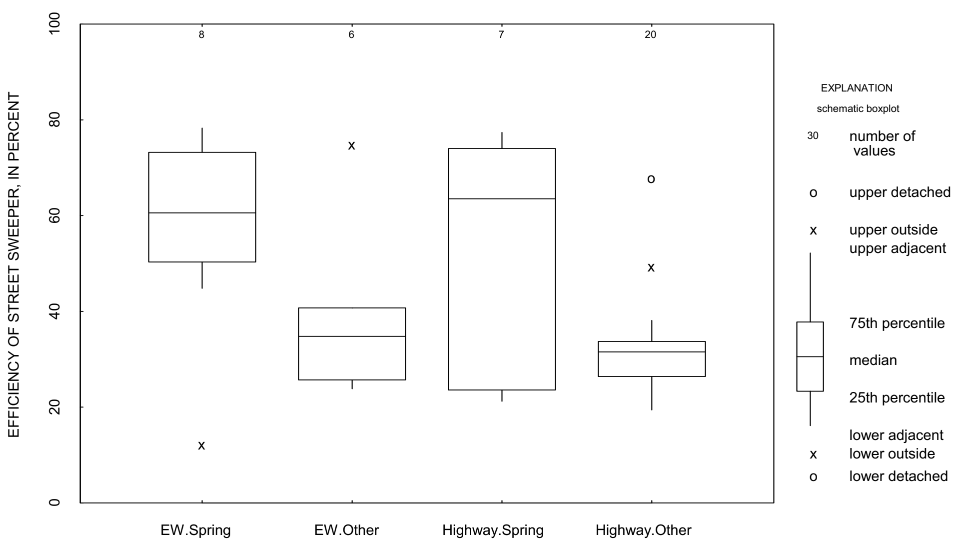

Figure 11. Seasonal reductions in street dirt yields using the vacuum assisted machine in the swept section.

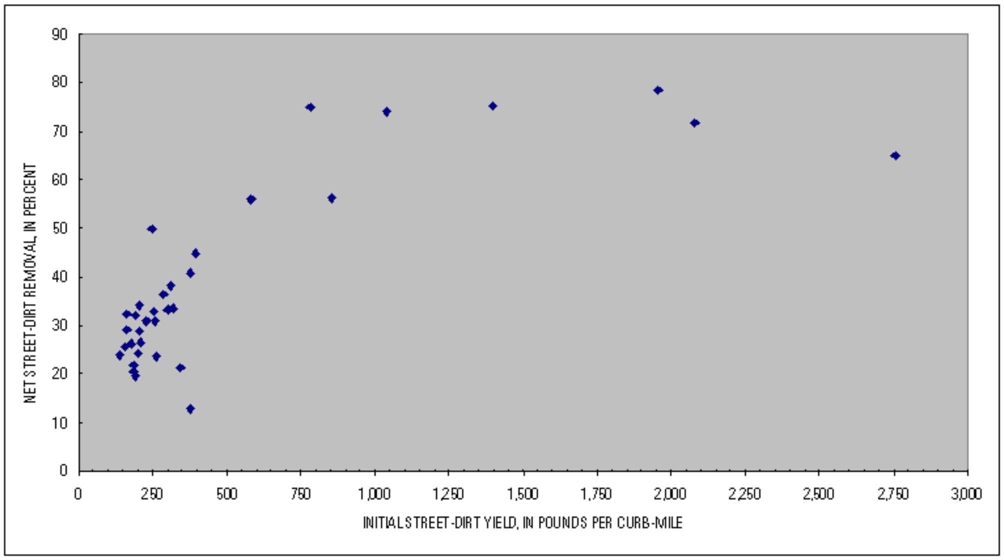

Figure 12. Change in street cleaning efficiency of the vacuum assisted machine with increasing street-dirt yields.

Efficiencies increase with increasing particle sizes. Silt and clay size particles had median efficiency was 18 percent, but the median efficiency increases to 49 percent for the gravel sized particles (fig. 13). All particle sizes except for those in the silt and clay fractions have efficiencies a few percentage points higher than a street cleaning study on residential streets in Madison, WI (Selbig and others, 2007a). The median efficiency for the particles less than 63 um was 9 percent in the Madison, WI study, which is less than the 18 percent observed in this study. A study by Zarriello and others (2002) found higher percent removals efficiencies than this study for all particle-sizes.

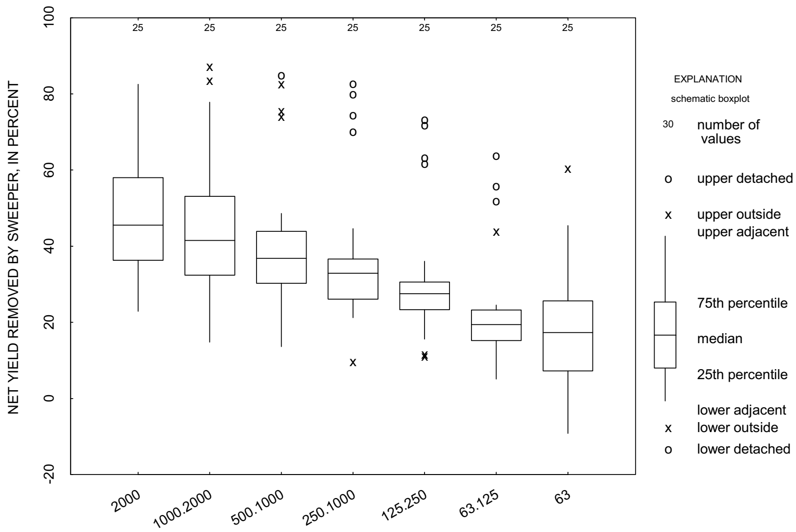

Figure 13. Street cleaning removal for the vacuum assisted machine by particle-size distribution in the swept-section.

Since the vacuum-assisted machine removed street dirt in each particle size, the street cleaning only brings slight changes to the particle size distribution on the street (table 10). A slight increase occurred for particles less than 125 microns and there was a 3 percent decrease in particles greater than 2000 microns. A similar result was observed for two types of street cleaners used in the Madison, WI The regenerative-air and vacuum-assisted machines produced slight increases in the particles less than 125 microns and slight decreases in particles greater than 500 microns(Selbig and others, 2007a).

Table 10. Median particles size in percent by mass for pre and post cleaning for the vacuum-assisted sweeper.

Statistic	Highway section	Percent						
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)
Median pre sweeping	Entire swept section	11	7	14	25	19	12	12
Median post sweeping	Entire swept section	8	6	13	24	20	14	15

In the Fall of 2004, a mechanical-broom sweeper was tested weekly in the swept section for two months. The median weekly efficiency for the seven street cleaning events was 7 percent (fig. 14, table 8). The median efficiency might have been somewhat greater during the period of high street-dirt yields as in the spring. Low median efficiencies of 5 percent were found for a mechanical-broom sweeper used on residential streets in Madison, WI (Selbig and others, 2007a). However, the mechanical-broom cleaner did better in the NURP study conducted on many different streets in Milwaukee, Wis. The average pickup efficiency of about 22 percent was measured for a combination of commercial and residential streets (Bannerman and others, 1983).

Most of the reductions in street-dirt yield by the mechanical broom were for particles greater than 500 microns (fig. 15). Median reductions dropped from at least 19 percent for particles greater than 500 microns to 5 percent or less for particles between 125 and 500 microns. This low efficiency for particles in the range of 125 to 500 microns is very significant, since a large percentage of the particles on the street are found in this range. Particles less than 125 microns increase the street yield when using the mechanical-broom machine. Previous studies have discovered the mechanical broom street cleaners are not very effective in picking up smaller particles (U.S. Environmental Protection Agency, 1983; Bender and Terstriep, 1984; Pitt, 1985; Weaton and others, 1999; Shoemaker and others, 2000). Although both the mechanical broom and vacuum-assisted machines have a gutter broom that dislodges fine particles from the street surface and creates smaller particles from larger particles, only the vacuum assisted machine appears capable of picking up a significant percentage of these finer particles.

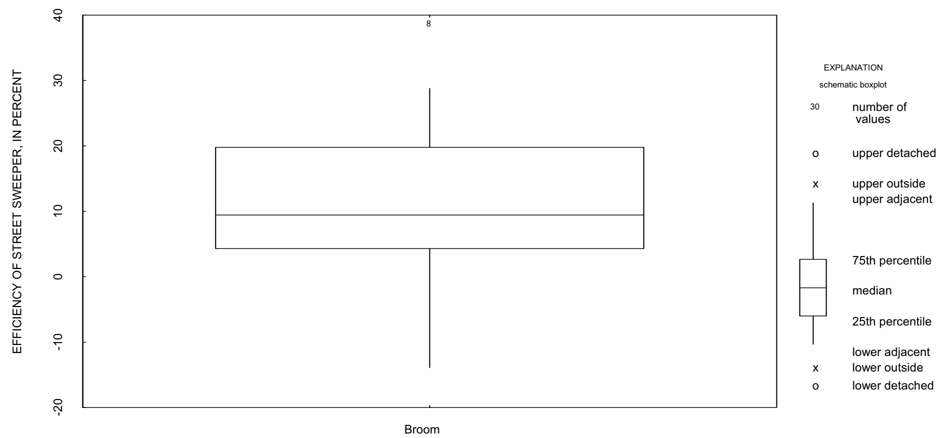

Figure 14. Broom sweeper removal efficiency of street-dirt yields for the east and west bound highway sections and the entire highway.

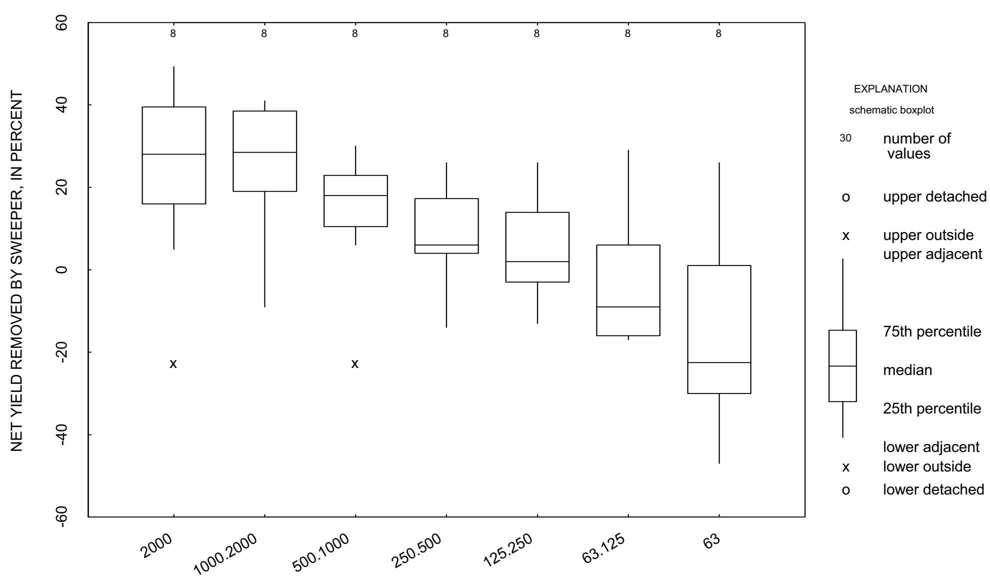

Figure 15. Street cleaning removal for the mechanical broom machine by particle-size distribution in the swept-section.

A tandem street cleaner operation may improve removal efficiencies (Pitt and others, 2004). The approach would be to use a broom machine to pickup the larger particles followed by a vacuum machine to remove some of the finer particles. Another approach might be to make two passes with the same vacuum machine. Three different street cleaning events including a second pass with the vacuum assisted machine were scheduled. The pickup efficiency was always less for the second pass (table 11). The pickup efficiency of the machine did not drop significantly with a second pass. The first pass might have reduced the street-dirt yield reducing the machine effectiveness the second pass (Selbig and other, 2007a).

Table 11. Effect of Second Pass on Cleaning Efficiency.
[yields, lbs/curb-mile]

Date	First Pre Cleaning Street Dirt Yields	Percent Efficiency First Sweeping	Second Pre Cleaning Street Dirt Yields	Percent Efficiency Second Sweeping
07/18/2005	187	21.7	146	15.9
07/25/2005	164	32.4	111	-3.6
08/01/2005	162	29.0	115	5.2

Previous studies have determined the performance of street cleaners is affected by the amount of street dirt, street texture, parking densities, parking controls, and how the street cleaner is operated (Pitt, 1979). If these factors are similar for different urban highway sites, the pickup efficiencies from this study should be transferable to other sites. Assuming all urban highways would have similar parking densities and all the street cleaners are operated by standard guidelines, the factors that might vary significantly between sites is the amount of street-dirt and texture. Since the highway in this study had more intermediate texture, the pickup efficiencies might have to be adjusted for sites with either smooth or rough textures. This is best done using data from previous studies (Pitt, 1979). As discussed before, the street dirt yields in this study are similar to those from other studies with comparable street-dirt yield.

Sufficient data was collected in this study to modify the efficiency coefficients in WinSLAMM to evaluate street cleaning for highways. The adjustments to the efficiency equations will be tested by simulating the changes in street dirt over time in the swept section. The model will be run using the once per week street cleaning frequency and the measured rainfall data. Once the efficiency coefficients are able to provide a reasonable match to the measured street-dirt yields, the model is ready for some final adjustments based on the water-quality data from the unswept section. Calculations of street cleaner effectiveness in WinSLAMM are included in Appendix 3–3.

Characteristics of Highway Runoff Flows and Water-quality

Precipitation, flow and contaminant concentration data was collected from the unswept section of the study site. Precipitation and flow data were collected from November 2004 until June 2007 (table 2–1). Water-quality samples were collected for 69 of those events between April 2005 and May 2007. Most of the samples were collected by September 2006, with four additional events sampled in the spring of 2007 to support the wash off analysis. Events with 0.2-in of rainfall and a minimum of five 1-L subsamples collected were processed for additional constituents. Otherwise, subsamples were processed just for SS concentrations, TSS and TDS. Sixty-seven the samples were analyzed for SS concentrations and 63 samples were analyzed for TSS (table 2–5). All other contaminants are represented by at least 25 events except for VSS and PAHs (table 2–6 and table 2–7). The numbers of VSS samples are lower, because it was added to the constituent list later in the project. The high cost for each sample reduced the number of events with PAH numbers to eleven. Particle-size distribution analysis was done for 36 events (table 2–8).

Sufficient flow and water-quality data was collected in this project to improve the way WinSLAMM estimates runoff volumes and contaminant loads from urban highways. After using the rainfall and flow data to add estimates of highway runoff to the model, the model will be run to generate runoff volumes for the measured rainfall data. The estimated runoff volumes will be compared to the measured runoff volumes (table 2–1). Event-mean concentrations collected in this project will be applied to the concentration files in WinSLAMM. The calibration of the concentrations will be completed by comparing the estimated and measured contaminant loads for each event (tables 2–15 and 2–16).

Precipitation Data

Precipitation was recorded for 261 depths at the site between November 2004 and June 2007 (table 2–1). The end of a runoff event was determined by the end of the flow in the pipe or additional rainfall had not occurred for six hours. These criteria led to the combining of a number of smaller rainfalls into one runoff event. The average pipe discharge lasted about 50 minutes after precipitation ended. Depths range from 0.02 to 2.03 inches with an average of 0.26 inches for the 261 precipitation recorded amounts.

Precipitation data collected at the site were compared to National Oceanic and Atmospheric Administration (NOAA) data collected at the Dane County Regional Airport (DCRA). Precipitation collected by both gages was comparable to the long-term average at DCRA (table 12). DCRA is approximately 2 miles due west of the USH 151 study area.

The difference between the total from the USGS rain gage and the 2005-07 totals from the DCRA rain gage was less than 10 percent. Larger differences generally occurred during summer months when precipitation amounts can vary substantially over distances as small as 2 mi., owing to a predominance of localized convective events. For precipitation in 2005, the USGS rain gage recorded 10.6 in. less than the long-term average at DCRA, whereas in 2006, the USGS rain gage averages was 0.8, in higher, respectively, than the long-term average at DCRA.

Table 12. Monthly precipitation at the U.S. Geological Survey rain gage and the National Oceanic and Atmospheric Administration precipitation gage at Dane County Regional Airport Madison, WI, 2005-07.
[Precipitation is presented in inches; NOAA National Oceanic and Atmospheric Administration; DCRA, Dane County Regional Airport; --, no data]

Month	USGS rain gage	NOAA hourly DCRA	NOAA DCRA long term average[1]
November 2004	0.8	1.5	2.3
December 2004	1.0	1.5	1.7
Total 2004	**1.8**	**3.0**	**4.0**
January 2005	--	--	--
February 2005	--	--	--
March 2005	0.8	1.6	2.3
April 2005	1.9	1.7	3.4
May 2005	3.6	4.0	3.2
June 2005	1.4	1.6	4.0
July 2005	3.6	3.9	3.9
August 2005	1.1	1.2	4.3
September 2005	2.2	2.0	3.1
October 2005	0.7	.76	2.2
November 2005	2.8	3.4	2.3
December 2005	--	--	--
Total 2005	**18.1**	**20.2**	**28.7**
January 2006	--	--	--
February 2006	--	--	--
March 2006	2.6	2.3	2.3
April 2006	4.5	4.2	3.4
May 2006	1.8	4.6	3.2
June 2006	4.8	2.3	4.0
Partial Total 2006	**13.7**	**13.4**	**12.9**

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

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

Probability distributions for both datasets were constructed by use of the Weibull plotting position (Helsel and Hirsch, 1992). Precipitation amounts for individual events were computed for both datasets. Precipitation depths greater than or equal to 0.09 in. (the minimum amount recorded during this project) were ranked from lowest to highest. A cumulative probability distribution then was computed for both datasets by use of the formula

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

where

R	is the precipitation event,
P_R	is the probability of an event having a precipitation less than that of event,
R, i_R	is the ranking of event R,

and

n	is the total number of events in the dataset.

Although the distribution for this study tends to be a higher than the historical distribution up to 0.9 inches of depth, the distribution for this study would still be considered very similar to the historical distribution (fig. 16).

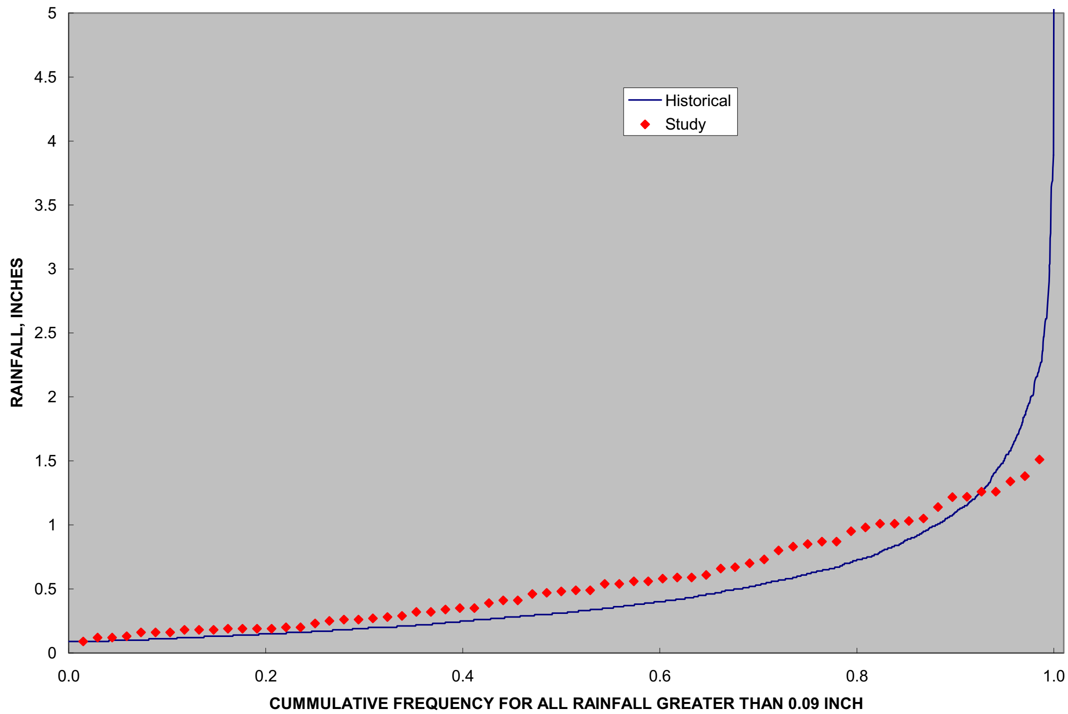

Figure 16. Cumulative precipitation for the study period (2005-07) in relation to the cumulative frequency for all precipitation greater than 0.09 inches (1949-92) based on the National Oceanic and Atmospheric Administration precipitation gage at Dane County Regional Airport, Madison Wis.

Flow Data

Sufficient rainfall occurred in 216 of the 256 runoff events to produce measurable flow in the pipe draining the unswept section (table 2–4). Peak flows for the 69 events with water-quality samples ranged from 0.07 to 7.73 cfs (table 2–4). Runoff volumes from the 2.27 acre study area ranged from 310 to 14,620 cf.

Runoff coefficients calculated for the events with water-quality samples provide a simple check on the quality of the flow data. 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. Eight of the runoff coefficients are greater than 100 percent (fig. 17). Although errors in flow and precipitation measurements might explain greater than 100 percent runoff coefficients, the study area had a 2 percent slope consequently flow from another part of the paved highway could have jumped the watershed boundaries into the study area.

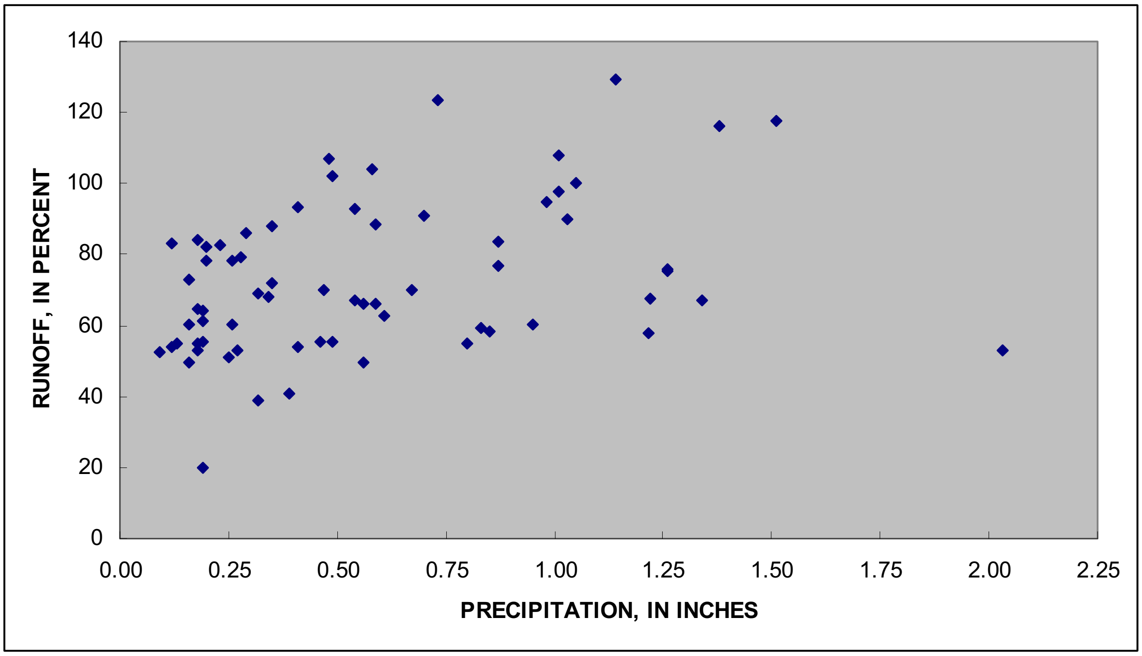

Figure 17. Highway-runoff for sampled events.

With rainfall and runoff volumes for 216 events there is sufficient data to predict runoff volumes for highways. To predict runoff coefficients for just the highway surface the runoff volumes were adjusted for the lawn area as described above. The adjusted runoff coefficients were grouped by 10 rainfall depths between 0.08 and 2.1 inches. Some of the runoff coefficients could not be included in the selected rainfall depths. Some of the 40 rainfalls with no runoff were included in the calculation of average runoff coefficients as a zero runoff. The average runoff coefficient was calculated for the runoff coefficients representing each rainfall depth. A plot of rainfall depth versus average runoff coefficient showed the rainfall depth to be a reasonable predictor of the runoff coefficients (fig. 18). Even at small rainfall depths of about 0.10 in., the runoff coefficient for the roadway is still over 30 percent. Over 90 percent runoff is achieved by the time the rainfall depth is over 1.1 inches. The runoff coefficient curve developed for this studies highway will added to WinSLAMM. Calculations of runoff volumes in WinSLAMM are in Appendix 3–4.

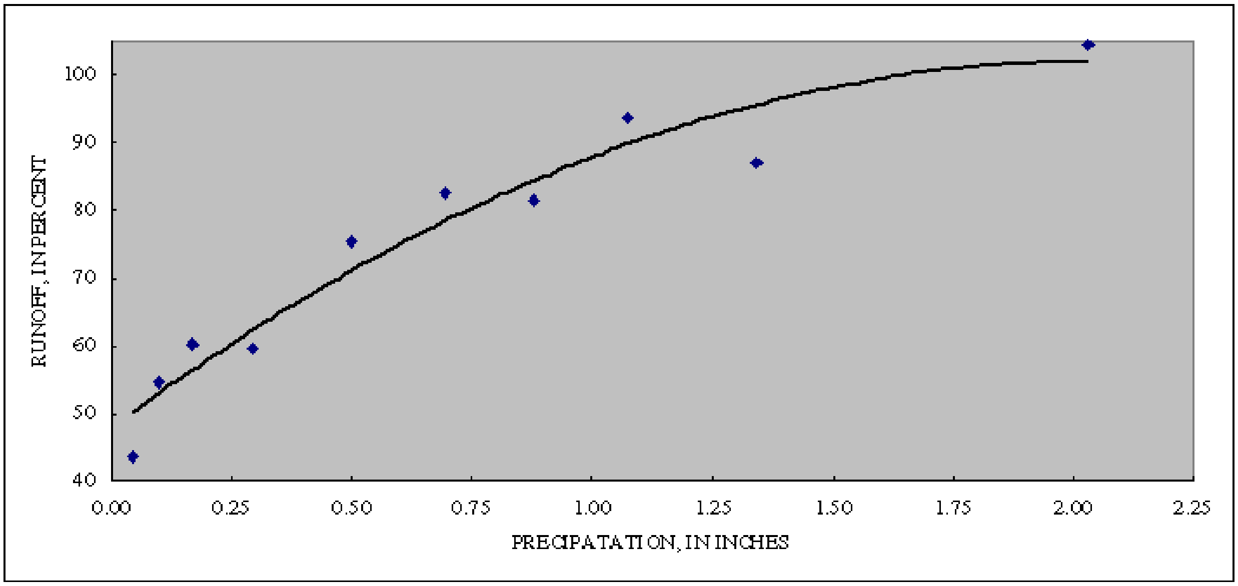

Figure 18. Average runoff coefficients for highways as a function of selected rainfall depths for all precipitation collected.

Contaminant Concentrations in Highway Runoff

Thirty-three constituents plus particle-size distributions were analyzed in water-quality samples collected (fig. 20) from the unswept section storm sewer pipe (tables 2–5, 2–6, and 2–7). Eighteen of the constituents were individual species of PAHs (table 2–7). Sixty-seven of the samples were analyzed for SS concentrations and 62 samples were analyzed for TSS (table 2–5). Calcium and magnesium were included in the analysis for the determination of hardness. The summary statistics for each constituent except PAHs is presented in table 13. Median concentrations for the individual PAHs with species above the limits of detection are presented in figure 19.

Non-detectable compounds composed substantial proportion of the total PAHs results. To calculate summary statistics for individual PAHs compounds that had non-detects less than 80 percent the Kaplan-Meier analysis was used (Helsel, 2004). To calculate summary statistics for individual PAHs compounds that had non-detects less than 50 percent the Kaplan-Meier analysis was used (Helsel, 2004). Non-detectable compounds that were greater than 80 percent detection were 7 of the 18 PAHs: 1-Methylnaphthalene, 2-Methylnaphthalene, Fluorene, Acenaphthene, Acenaphthylene, Dibenzo[a,h]anthracene, Naphthalene summary statistics were not computed for these compounds (table 2–7). To calculate the summary statistics for total PAHs, a method was needed to account for the non-detected concentrations. Methods included using the limit of detections, one-half the limit of detections, and zero. To be consistent with other USGS studies, the total PAH concentrations were calculated by using zero (Mahler and others, 2005).

Table 13. Summary statistics for each constituent and total PAHs.

[COD; Chemical oxygen demand, total; PAH; polycyclic aromatic hydrocarbon, COV, coefficient of variation]

Statistic	Suspended sediment (mg/L)	Suspended solids, total (mg/L)	[1]Solids, dissolved (mg/L)	Solids, Volatile (mg/L)	COD (mg/L)	Phosphorus, total (mg/L)	Phosphorus, dissolved (mg/L)	Chloride, dissolved (mg/L)	[1]Copper, dissolved (µg/L)	Copper, total recoverable (µg/L)	[1]Zinc, dissolved (µg/L)	Zinc, total recoverable (µg/L)	[1]PAH (µg/L)
Count	67	62	49	13	27	28	28	30	28	28	25	28	11
Minimum	21	22	56	8	16	0.07	0.036	2	<2.0	8	6.6	53	2
Maximum	5,114	1,353	1,770	31	157	1.28	0.110	1,070	7.6	374	26.0	806	99
Median	107	83	92	12	48	.15	.056	18	3.9	22	13.0	120	6
Mean	430	152	224	19	47	.23	0.061	92	4.1	46	13.5	199	22
COV	2.3	2	2	0.7	1	1.08	0.319	3	0.4	2	0.4	1	1.4

1. Calculated by using a modification to Kaplan-Meier method (Helsel, 2005).

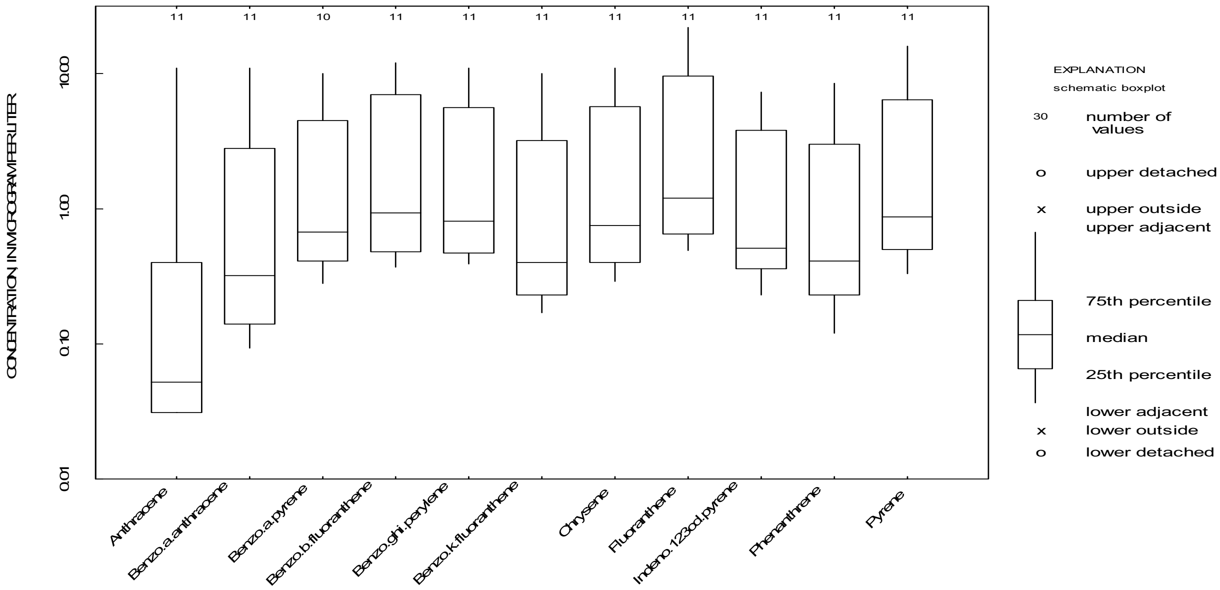

Figure 19. Median concentrations of PAHs species that either have concentration above the limits of detection.

Figure 20. Example of stormwater collected from unswept site.

Other constituents with just a few non-detectable concentrations are DZn and TDS (table 2–5 and 2–6). As with the PAHs the event mean concentrations for events with non-detectable concentrations were filled in using the Kaplan-Meier method (table 13).

Runoff data from a number of highway sites around the country exhibit 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. A test for normality was done for all the constituents analyzed in this study. The test revealed all the concentrations follow a lognormal distribution. Lognormally distributed datasets are better described by the median or geometric mean, which reduces the influence of a few extreme observations.

Fifteen of the sixty-two TSS concentrations were increased, because the samples had been pre-sieved before submittal to the laboratory for analysis. The pre-sieving is performed on all samples when a substantial amount of solids is observed on the bottom of the sample bottle a few seconds after shaking. This procedure significantly reduces the bias and improves the precision of the SS analysis (Selbig and others, 2007b). Because of the pre-sieving, a certain percentage of the material on the sieves must be added back into the TSS number the laboratory determines in the water that passes through the sieves. The adjustment factors are specific to particle size ranges of 125 to 250, 250 to 500, and greater than 500 microns (table 14). All of the adjusted TSS concentrations are less than or similar to the SS concentrations.

Table 14. Percent of the particles in the sand size fractions when the difference in the TSS and SS concentration is about 10 percent or less.
[SS, suspended sediment; TSS, total suspended solids; mg/L, milligrams per liter; %, percent]

Runoff Event Number	SS Concentration, mg/L	TSS Concentration, mg/L	Difference Concentrations, %	Particles > 63 microns, %
49	23	23	0	31
57	32	32	0	25
42	175	179	2	10
47	40	39	2	27
45	115	111	3	22
32	23	24	4	35
43	212	197	7	34
44	77	71	8	34
50	161	149	7	35
65	995	928	7	40
68	72	67	7	30
22	45	49	9	83
24	61	54	11	56
33	28	25	11	30
58	37	33	11	63
66	56	49	12	20

Median concentrations for SS are higher than TSS (table 2–5 and fig. 21). The median SS concentration is 1.3 times higher than the TSS (table 15). The differences in the TSS and SS concentrations might be explained by the possible exclusion of the larger sand particles from the TSS analysis. The TSS method filters an aliquot of a sample (Kopp and McKee, 1979), while the SS concentration method requires filtering the entire sample (American Public Health Association and others, 1989). The 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). Gray and others (2000) concluded the SS and TSS concentrations were comparable when the percentages of sand-size material in the sample are less than 25 percent. When the difference between the SS and TSS concentrations were only 5 percent or less in this study, the average percentage of sand sized particles is also 25 percent. (tables 11, 2–5, and 2–8). The average percentage of sand sized particles increased to 34 percent, if the differences between TSS and SS concentrations were 7 or 8 percent. For differences in TSS and SS between 9 and 12 percent the average percentage of sand-sized particles increased again to 50 percent.

Table 15. TSS concentrations adjusted for the pre-sieving sample preparation.

[mg/L, milligrams per liter]

Runoff Event Number	Un-adjusted TSS Concentration, mg/L	Adjusted TSS Concentration, mg/L	SS Concentration, mg/L
5	57	293	472
6	45	209	513
7	39	1353	2392
8	227	711	1060
11	42	157	243
19	102	198	244
20	55	89	109
24	40	54	61
32	20	24	23
33	21	25	28
42	175	179	175
43	160	197	212
44	62	71	77
52	228	721	1064
65	800	928	995

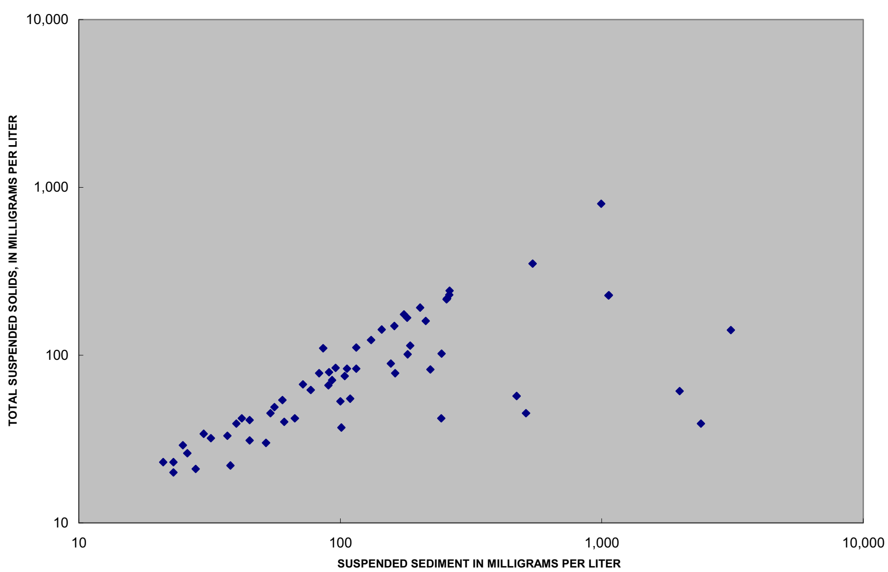

Figure 21. Comparison of SS and TSS concentrations.

VSS concentrations were measured in 13 water-quality samples to determine the amount of the TSS that might have its origins in vegetative material. For those 10 runoff events not affected by the pre-sieving process, the percent of the TSS that was VSS had a median concentration of 30 percent. It appears there can be a significant percentage of organic matter in the runoff for a watershed with just a few trees and about 30 percent of the area in turf. Concentrations from this study will be put into a WinSLAMM file for highway pavement as a source area in the “freeway” land use.

Loads were computed for all concentrations, except PAH’s, with detects. Summary statistics were computed for median, average, geometric mean, standard deviation and coefficient of variation (2–15, and 2–16). Calculations of contaminant concentrations and loads in WinSLAMM are in appendix 3–5.

Comparison of Concentrations with Other Highway Sites

Mean concentrations for the runoff samples from this project were similar to the mean concentrations observed for runoff samples from other urban highways (table 16). Only urban highways were used for comparison, because the runoff quality was significantly different between rural and urban highways (Driscoll and others, 1990). For example, the average concentration for TSS is 157 mg/l, which falls in the range of 106 to 197 mg/l observed for the other highway sites. Comparing this study to recent highway runoff studies in Wisconsin (Waschbusch 2003, US Environmental Protection Agency 2005 a,b), the averages for TP, TZn, and TCu measured for this study are very similar to most of the other values. Chloride concentrations are highest for the sites with winter-runoff. Data from the arterial streets indicate that the results from this study might also apply to busy city streets. The similarity in runoff quality among the urban highways increases the possibility of extrapolate the concentration results from this study to other highways.

Table 16. A comparison of mean runoff concentrations at the USH151 site with concentrations from other highway sites.
[All data in milligrams per liter; IH, Interstate Highway; 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	Chemical oxygen demand	Phosphorus, total	Zinc, total	Copper, total	Chloride
USH-151	70	39,650	Nonwinter	157	47	0.23	0.20	0.05	95
I–794 HSD[1]	100	44,000	Nonwinter	117	78	0.18	0.25	0.07	27
I–794 SFD[2]	100	44,000	Nonwinter	143	80	0.20	0.40	0.10	59
I-794[3] Milwaukee	100	53,000	Nonwinter	138	105	0.31	0.35	0.10	63
Multiple sites[4]	37-100	>30,000	Nonwinter	165	129	0.52	0.54	0.06	31
I-894 national[5]	63	133,900	All	108	49	0.10	0.21	0.06	511
I-894[5] Oklahoma (nonswept period)	94	133,900	All	197	49	0.19	0.32	0.07	438
I-94[6] Minneapolis	55	114,000	All	118	207	0.56	0.17	0.05	1,802
Arterial St.[7]	100	20,000	Nonwinter	241	--	0.53	0.55	0.05	--
Highway[8] 12&18 (Beltline)	100	77,000	Nonwinter	106	--	0.32	.12	.041	--

1. U.S. Environmental Protection Agency 2005 b.
2. U.S. Environmental Protection Agency 2005 a.
3. Gupta, and others, (1981).
4. Driscoll, and others, (1990), data from 12–16 sites.
5. Waschbusch, (2003).
6. Thomson, and others, (1997).
7. Bannerman, others, (1992).
8. Waschbusch, (1996).

Particle-Size Distributions in Water-quality Samples

This study analyzed 37 water-quality samples for particle-size distribution in the unswept section. This is more samples analyzed than for any other highway study in Wisconsin (table 17). The distribution of the particles varied between study areas done by WisDOT. Particles having less than 63 microns the USH151 and I-894 study (Waschbusch, 2003) areas had similar distributions, but they differed for all the other particle sizes. The I-794 (US Environmental Protection Agency, 2005 a, b) particle-size distribution was very different than the other two sites until the particle sizes reach greater than about 250 microns. There could be a difference between the study areas or and sampling errors. For example, deposition of some larger particles might have occurred in the pipe draining the freeway at the I-794 HSD site (US Environmental Protection Agency, 2005 b). This site also had a low number of PSD samples.

Table 17. Comparison of median particle size distributions in water-quality samples collected for WisDOT study areas in Milwaukee and Madison, Wis.

[All data in percent; IH, Interstate Highway; HSD hydrodynamic settling device; SFD, stormwater filtration device]

Site	Count	Percent less than				
		<1000	<500	<250	<125	<63
USH151, East Wash. Ave.	37	--	99	83	63	37
I–794 SFD[1]	14	88	75	39	24	21
I–794 HSD[2]	7	100	96	90	85	81
I-894 National[3]	22	90	78	63	41	34
I-894[3] Oklahoma (nonswept period)	18	81	73	57	50	43

1. U.S. Environmental Protection Agency 2005b.

2. U.S. Environmental Protection Agency 2005a.

3. Waschbusch, 2003.

The difference in particle-size distributions between the street dirt and the water-quality samples clearly demonstrates the finer particles were washed off the streets (figs. 7 and 22). Most of the particles in stormwater runoff are smaller than 125 microns, while most of the particles in the street dirt are greater than 125 microns.

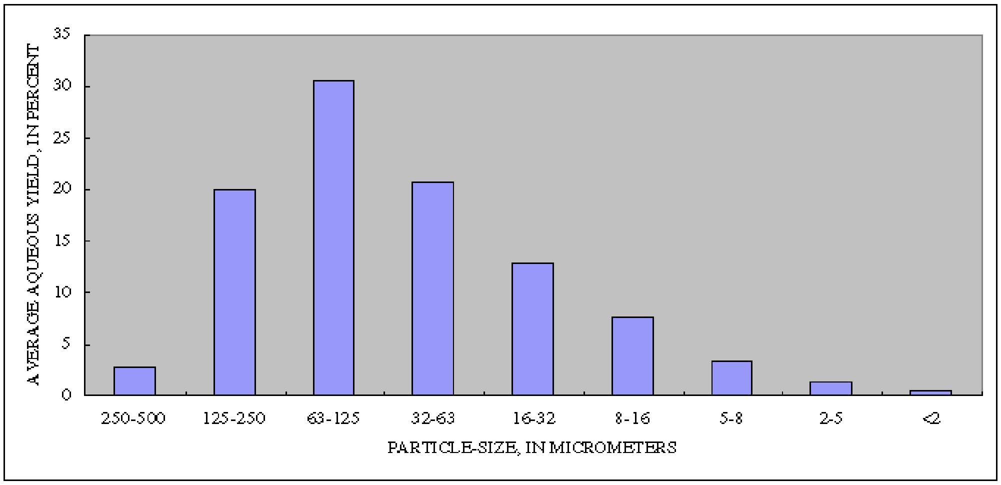

Figure 22. Average percent mass in each particle size for sediment in the water-quality samples.

Bedload Contribution to Suspended-Sediment Loads

Bedload samples were collected for 49 runoff events (table 2–9). Heavier particles were trapped in the bedload sampler that moved along the bottom of the pipe. Some of these solids might be too large to be captured efficiently by the automatic sampler or the bulk of the bedload might move below the depth of the intake tube. Sampling bedload was done to understand the role of the bedload in the amount of sediment moving in the pipe. If the water-quality sampler measures a SS concentration that excludes the bedload material, the SS load calculated with samples from the automatic sampler could significantly underestimate the SS load for each runoff event.

The median load of sediment collected in the bedload sampler was always significantly less than the SS load calculated with the water-quality samples (fig. 23). The median loads for those 49 events were 16.5 lbs for SS, and 2.2 lbs for bedload. Average SS loads are also much higher than the average sediment load in the bedload sampler (table 18). The bedload appears to be a relatively small percentage of the total sediment load moving in the pipe.

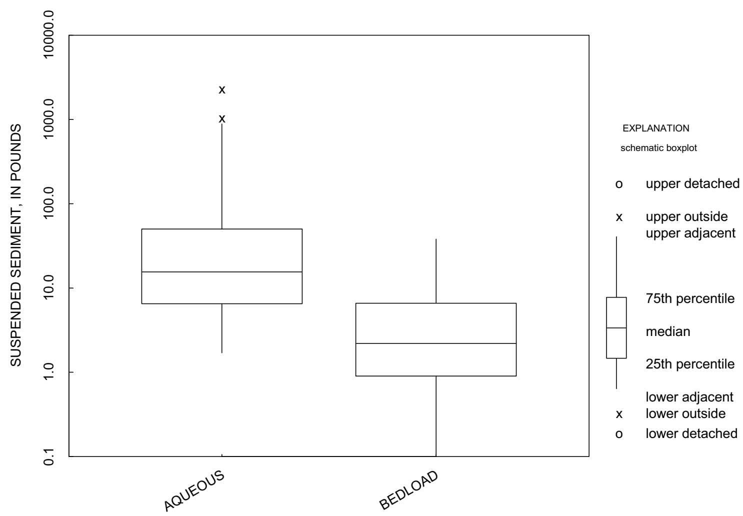

Figure 23. Suspended-sediment loads for aqueous and bedload.

Table 18. Load comparison of water-quality and bedload samples collected for 49 events.

[All data in pounds.]

Statistics	**Sum**	**Maximum**	**Minimum**	**Median**	**Average**
Aqueous	6,871	2,452	1.7	16.5	140.2
Bedload	278	38	0.1	2.2	5.7

More than 50 percent of the bedload material was found in the particles sizes between 250 and 1000 microns (fig. 24). Particles less than 250 microns in size only represented 13 percent of the particles trapped in the bedload sampler. These results support the existence of a stratum of larger particles moving along the bottom of the pipe. The particle-size distribution is very different in water-quality samples collected just about 1-inch off the bottom of the pipe. Most of the particles collected in that stratum are less than 250 microns in size (fig. 24). The particle-size distribution in the bedload material was similar to the distributions measured in street dirt (fig. 7). Street dirt percent average of particles in the less than 250 microns and greater than 2000 microns was larger. The bedload sampler was not expected to trap the finer particles washed off the street, and particles greater than 2000 might have been too big for the bedload sampler to capture and less likely to be transported off the street.

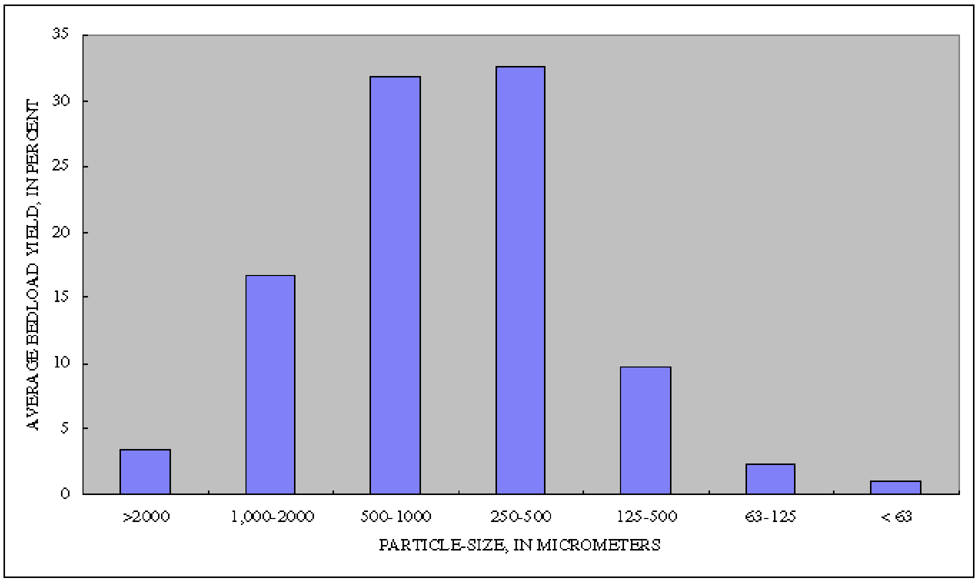

Figure 24. Average percent mass in each particle size for sediment collected in the bedload sampler.

Discussion of Data Collection

WisDOT did a highway sweeping research project in 1999-2000, in cooperation with the USGS to study the effectiveness of an improved sweeping program on an urban freeway (Phase I study). Because of the high variability and loss of data, results from the first sweeping study would not support conclusions for the effectiveness of street sweeping at a 95 percent confidence level. The variability was due to the uncontrollable source of pollutants between the Jersey Barriers at the test section. In addition, utility construction in the grassy right-of-way adjacent to the test section caused several data points to be discarded. Also, due to limited sweeper access to the freeway median, not enough street dirt data was collected to support an accumulation and pick-up functions for modeling purposes. Wash-off data was not collected at this site. Because of the logistics of the site, it was not possible to collect data before and after runoff events (Waschbusch, 1993). This study (Phase II) was designed to overcome some of the problems in the Phase I study.

The purpose of Phase II was to collect the data necessary to fill in the short comings of the first study. From the 34 data points collected, the street-dirt accumulation rate was estimated at 9 lbs/curb-mile/day the first four days. The accumulation rate then diminished for the next consecutive dry days. From the collection of 11 data points, the median percent washoff rate of street-dirt was estimated at 14 percent. By collecting 25 data points, the pick-up function was determined for overall street-dirt removal efficiency as 30 percent. Once modifications are made to WinSLAMM's highway landuse, this information can be used to calibrate loads for urban highways.

Samples were analyzed from at least 62 data points for TSS and SSC concentrations. All other contaminants were represented by at least 25 events except for VSS and PAHs. Particle size distribution analysis was done for 36 events. Once the WinSLAMM model is calibrated for urban highways, concentration can be used to calibrate loads at an outfall pipe and data collected from other Wisconsin urban highways can be used to verify the results from this study.

Determining water-quality benefits of street sweeping was not part of this study, but the WinSLAMM model will be able to estimate the benefits after it has been modified to include street cleaning on highways. When WinSLAMM was calibrated and verified for the vacuum-assist street cleaning unit using the Madison, Wisconsin residential streets study, it simulated an estimated TSS removal of 20 percent at a watershed outfall. Slightly higher pick-up efficiencies were observed for this study than for the Madison, Wisconsin residential study (table 19). Simulating WinSLAMM on a highway sites may produce a 20 percent TSS removal or greater.

Table 19. Median percent removal efficiencies.

Mechanical broom		
Site	**Spring**	**Summer/Fall**
USH-151	--	7
Previous residential study[1]	7	1
Vacuum-assisted		
USH-151	65	26
Previous residential study[1]	37	26

1. Selbig and others, 2007a

Summary

In Wisconsin there are approximately 1,300 miles of urban highway that are in close proximity to waters of the state. To minimize the adverse environmental effects from transportation activities the WisDOT has prepared Administrative Rule Trans 401 (2002) to control the quality of stormwater runoff from transportation facilities, such as highways, airports, and railroads. A major element of the Administrative Rule is to control the level of total suspended solids (TSS) in stormwater runoff from post construction sites and developed urban areas. The Administrative Rules has been approved by WDNR. To reduce levels of TSS, WisDOT can utilize street sweeping as a best practice on ultra-urban highways. This is the second study that WisDOT, WDNR, and the United States Geological Survey (USGS) have complete to test the effectiveness of highway sweeping. The first study was designed to capture the water-quality benefits of this type of a best practice by comparing two watersheds, one unswept, and one swept using a vacuum-assist sweeper. Because of issues related to data quality control problems, limited data, contributions of contaminants from the area between the freeway Jersey Barriers, limited area swept, and possible sweeper problems, the data did not adequately support any conclusions about the benefits of street sweeping. This is the second study used by

WisDOT to determine the benefits of sweeping. This study was designed to collect data needed to calibrate and verify the equations used by WinSLAMM to simulate TSS reductions for different street sweeping programs and to estimate contaminant yields from highway surfaces. WinSLAMM is a model approved by WDNR. By simulating the approximately 1,300 miles of urban highway in Wisconsin, once the model has been recalibrated, WisDOT can demonstrate the percentage of TSS that is being controlled.

The study site was located on divided USH 151 in Madison, Wisconsin. There was approximately 5,000 feet of curb. A three foot wide grassed median separated the east and west bound lanes. The average daily traffic count was 39,650. Two sections of USH 151 were studied. One was a swept section and one was an unswept section. Both sections had street dirt collected to determine washoff from a runoff event and/or accumulation rates on the highway pavement. To maximize the number of street-dirt samples collected, in April of 2005, the east and west bound lanes of the divide highway were sampled into separated vacuum canisters then combined for the entire highway. Fifty-three samples were collected in the unswept section, and thirteen samples in the swept section with seven of those vacuum-assisted samples.

Changes in street dirt during periods of no street cleaning or runoff events were used to determine accumulation rates. Twenty eight accumulation periods were available for the unswept section and twelve for the swept section. Accumulation periods were put into four grouping: 1–4 days, 5 days, 6–10 days, and those greater than 10 days. The median accumulation rate for the first group (1–4 days) was 9 lbs/curb-mile/day. The rate decreased to a negative number for the 10 day grouping. The negative accumulation rate is explained by traffic turbulence and wind blown conditions on the highway after a threshold of street dirt was reached.

Street-dirt samples were collected eleven times from dried streets before and after a runoff events. The median percent of the street-dirt washed off was 8 percent using the data separated for the east and west bound lanes. Five of the eleven runoff events in this study produced increases in street dirt for the east bound lanes which is reflected in the composite highway mass. It is possible that the median strip and the grass area next to the unswept section could have contributing sediment for some of the runoff events.

In the Fall of 2004, eight weekly cleanings tested the pickup efficiency of the mechanical-broom sweeper. The median pickup efficiency was 7 percent. The mechanical broom removed the larger particles, greater than 500 micrometers, and produced an increase in street-dirt yield after sweeping of less than 125 micrometers. In the swept section, there were 25 street-cleaning tests using a vacuum-assist machine at different frequencies. The median pickup efficiency was 31 percent, however in March and April, the median pickup efficiency was near 70 percent. The vacuum-assist sweeper removed particles in all seven fractions tested, even those less than 63 micrometers.

During November 2004 till May 2007, precipitation, flow, water-quality and bedload samples were collected in the unswept section for the purpose of characterizing of highway runoff. At the site, 261 precipitation depths were recorded. Historical data and this studies data for frequency distributions of precipitation depths greater than 0.09 inches were compared, resulting in an increase in frequencies of smaller rainfalls for this study. There were 216 precipitations depths where runoff produced flow in the sampled pipe. Flows were corrected by installing an automatic dye-dilution system. A 30 percent discrepancy was determined when comparing the dye-dilution discharge to the metered discharge.

Samples were collected for 69 runoff events that had an average runoff coefficient of 74 percent. Sixty-seven of the samples were analyzed for SS concentrations and 62 samples were analyzed for TSS. The median concentrations were 107 mg/L and 83 mg/L, respectively.

Comparing average concentration data to pervious studies, measured chemical oxygen demand, total phosphorus, total zinc, and total copper were similar. The average concentrations for these constituents in milligrams per liter were 157, 47, 0.23, 0.20, and 0.05 respectfully.

Particle-size data was collected at four main locations. In the swept and unswept sections, street-dirt samples were collected then sieved into seven particle size fractions ranging from greater than 2,000 micrometers to less than 63 micrometers. Also, samples from the bedload sampler that was installed below the water-quality sampling point were collected and sieved for the same size factions. Water-quality samples were processed for particle-size distributions ranging from 1000 micrometers to less than 2 micrometers. Bedload to water-quality sample comparisons were made for 49 runoff events

The study collected sufficient data so that WisDOT could evaluate the effectiveness of street sweeping on highways in ultra-urban areas, and calculate the contaminant loads in highway runoff. This data will also be used to calibrate Windows Source Load and Management Model (WinSLAMM). The model was selected because of its ability to calculate the effectiveness of street cleaning for municipal streets and highways and the loads of contaminants from different urban source areas such as municipal streets and highways. By modifying the accumulation, wash off, and productivity equations in the model with the data from this study, WisDOT will be able to evaluate the effectiveness of improved sweeping programs on urban highways with curbs. WinSLAMM can calculate mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development characteristics and rainfalls.

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Appendix 2 Field Data

Table 2–1. Summaries of rainfall characteristics for USH 151 in Madison Wis.

[mm/dd/yyyy hh:mm, month/day/year hour:minutes; in., inches; hr, hours; ppt, precipitation; cf, cubic feet; NA, not applicable]

Sample ID	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Duration (hours)	Precipitation (in)	15-min. ppt Intensity (in/hr)	30-min. ppt Intensity (in/hr)	Intensity (ppt/duration)	Total rainfall volume (cf)	Erosivity index (hundreds of ft-lbs/acre/in/hr	Antecedent dry time (hours)
	11/19/2004 08:39	11/19 16:33	7.90	0.22	0.04	0.04	0.01	1,623	0.03	202:37
	11/26/2004 13:56	11/26 15:38	1.70	.03	.04	.04	.02	227	.01	165:23
	11/27/2004 03:04	11/27 16:40	13.60	.53	.08	.08	.02	3,964	.19	11:26
	12/05/2004 22:08	12/06 06:39	8.52	.19	.16	.08	.02	1,435	.13	197:28
	12/07/2004 01:11	12/07 10:42	9.52	.56	.16	.12	.03	4,228	.28	18:32
	12/09/2004 18:37	12/10 19:15	24.63	.23	.04	.04	.01	1,737	.08	55:55
	12/30/2004 19:44	12/30 20:26	.70	.03	.08	.04	.04	227	.01	480:29
	03/18/2005 11:09	03/18 12:09	1.00	.15	.24	.20	.15	1,133	.25	1862:43
	03/19/2005 09:12	03/19 12:58	3.77	.18	.16	.12	.05	1,359	.18	21:03
	03/30/2005 16:05	03/30 19:35	3.50	.39	.40	.20	.05	2,945	.31	267:07
	03/31/2005 04:47	03/31 05:15	.47	.03	.04	NA	.04	227	NA	9:12
1	04/06/2005 19:28	04/06 21:35	2.12	.98	1.08	.84	.28	7,399	4.48	158:13
2	04/12/2005 05:58	04/12 14:16	8.30	.49	.84	.48	.06	3,700	2.18	128:23
	04/17/2005 05:42	04/17 06:03	.35	.02	.04	NA	.06	151	NA	111:26
3	04/19/2005 23:08	04/20 00:25	1.28	.23	.36	.22	.18	1,737	.45	65:05
	04/22/2005 19:43	04/22 21:23	1.67	.03	.08	.04	.02	227	.01	67:18
4	04/25/2005 17:05	04/25 20:07	3.03	.16	.24	.12	.05	1,208	.18	67:42
	04/27/2005 01:21	04/27 03:24	2.05	.03	.04	.04	.01	227	.01	29:14
	05/06/2005 06:12	05/06 09:45	3.55	.37	.72	.46	.10	2,794	1.49	218:48
	05/06/2005 18:10	05/06 18:17	.12	.09	NA	NA	.77	680	NA	8:25
	05/09/2005 12:24	05/09 12:28	3.07	.04	.48	.24	.01	302	.38	66:07
5	05/11/2005 02:47	05/11 10:26	7.65	.87	.56	.42	.11	6,569	3.13	38:19
	05/12/2005 15:05	05/12 15:14	.15	.02	NA	NA	.13	151	NA	28:39
6	05/13/2005 01:43	05/13 07:04	5.35	.54	.76	.60	.10	4,077	2.83	10:29
	05/14/2005 15:34	05/14 15:45	.18	.02	NA	NA	.11	151	NA	32:30
7	05/18/2005 22:16	05/19 04:02	5.77	.66	.40	.34	.11	4,983	1.90	102:31
8	05/19/2005 16:26	05/19 18:08	1.70	.73	2.32	1.38	.43	5,512	10.10	12:24
9	05/22/2005 05:36	05/22 05:42	.10	.09	NA	NA	.90	680	NA	59:28
10	05/27/2005 02:21	05/27 02:45	.40	.16	.44	NA	.40	1,208	NA	116:39
10	05/29/2005 18:34	05/29 18:43	.15	.04	NA	NA	.27	302	NA	63:49
11	06/04/2005 23:53	06/05 04:45	4.87	.35	.52	.30	.07	2,643	.91	149:10
12	06/09/2005 17:30	06/09 18:01	.52	.19	.56	.36	.37	1,435	.58	108:45
13	06/10/2005 19:51	06/10 20:02	.18	.12	NA	NA	.65	906	NA	25:50
14	06/13/2005 13:24	06/13 13:31	.12	.05	NA	NA	.43	378	NA	65:22
14	06/14/2005 19:46	06/14 21:23	1.62	.07	.20	.10	.04	529	.06	30:15
15	06/25/2005 00:55	06/25 05:09	4.23	.21	.12	.12	.05	1,586	.21	243:32
15	06/25/2005 21:31	06/26 00:31	3.00	.11	.12	.10	.04	831	.09	16:22
16	06/28/2005 03:05	06/28 03:19	1.23	.26	2.08	2.04	.99	1,963	25.23	50:34

Sample ID	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Duration (hours)	Precipitation (in)	15-min. ppt Intensity (in/hr)	30-min. ppt Intensity (in/hr)	Intensity (ppt/duration)	Total rainfall volume (cf)	Erosivity index (hundreds of ft-lbs/acre/in/hr	Antecedent dry time (hours)
17	07/04/2005 03:25	07/04 08:06	4.68	.15	.44	.26	.03	1,133	.33	144:06
17	07/04/2005 15:13	07/04 17:59	2.77	.12	.36	.20	.04	906	.20	7:07
18	07/12/2005 23:06	07/13 01:00	1.90	.19	.32	.18	.10	1,435	.29	197:07
19	07/20/2005 09:33	07/20 10:54	2.25	1.05	1.56	1.50	.47	7,928	15.39	176:33
20	07/21/2005 09:15	07/21 11:14	1.98	1.01	2.52	1.70	.51	7,626	16.99	22:21
21	07/23/2005 14:08	07/23 15:41	4.58	.37	.68	.44	.08	2,794	1.55	50:54
21	07/25/2005 01:19	07/25 02:12	.88	.12	.44	.22	.14	906	.23	33:38
22	07/25/2005 15:21	07/26 02:29	11.13	.61	1.08	.58	.05	4,606	3.27	13:09
	07/26/2005 12:48	07/26 13:03	.25	.03	.12	NA	.12	227	NA	10:19
	08/04/2005 03:34	08/04 05:18	1.73	.04	.12	.06	.02	302	.02	206:31
	08/10/2005 00:27	08/10 01:03	.60	.04	.08	.06	.07	302	.02	139:09
23	08/11/2005 22:45	08/12 00:15	15.87	.26	.52	.32	.02	1,963	.88	45:42
24	08/18/2005 07:02	08/18 10:41	3.65	.47	.40	.24	.13	3,549	.37	150:47
25	08/18/2005 18:18	08/19 18:48	7.82	.13	.40	.24	.02	982	.37	7:37
	08/26/2005 20:02	08/26 22:31	2.48	.12	.28	.14	.05	906	.15	169:14
26	09/19/2005 05:28	09/19 07:25	7.25	.28	.40	.26	.04	2,114	.83	558:57
27	09/22/2005 01:44	09/22 04:07	2.38	.59	1.40	.86	.25	4,455	4.82	66:19
	09/22/2005 12:43	09/22 17:22	4.65	.04	.12	.06	.01	302	.02	8:36
28	09/25/2005 09:14	09/25 13:15	4.02	.86	1.48	.88	.21	6,493	6.88	63:52
28	09/25/2005 15:37	09/25 16:09	.53	.02	.04	.02	.04	151	.00	2:22
28	09/25/2005 20:13	09/25 21:36	1.38	.15	.16	.14	.11	1,133	.18	4:04
29	09/28/2005 13:04	09/28 16:17	4.52	.25	.24	.16	.06	1,888	.36	63:28
30	10/05/2005 20:10	10/06 01:46	5.60	.32	.76	.38	.06	2,416	1.12	171:53
31	10/17/2005 08:14	10/17 09:43	1.48	.19	.36	.22	.13	1,435	.36	270:28
	10/23/2005 08:04	10/23 09:39	3.47	.09	.22	.14	.03	680	.12	142:21
	10/30/2005 15:32	10/30 17:54	2.37	.12	.14	.13	.05	964	.12	173:53
32	11/05/2005 03:03	11/05 07:16	16.22	1.34	.32	.27	.08	10,118	3.00	129:09
	11/12/2005 16:21	11/12 22:09	5.80	.14	.16	.10	.02	1,057	.12	177:05
	11/14/2005 18:58	11/14 20:27	2.60	.07	.08	.06	.03	529	.05	44:49
33	11/15/2005 12:38	11/15 20:07	11.82	.56	.24	.22	.05	4,228	1.22	16:11
	11/23/2005 08:49	11/23 09:27	.63	.06	.12	.10	.09	453	.05	180:42
34	11/27/2005 07:24	11/27 16:13	10.07	.19	.08	.06	.02	1,435	.10	93:57
35	11/28/2005 01:17	11/28 10:12	6.30	.41	.24	.22	.07	3,096	.70	9:04
36	01/01/2006 18:39	01/02 00:12	5.55	.18	.12	.08	.03	1,359	.12	824:27
37	01/02/2006 06:38	01/02 14:21	7.72	.56	.32	.24	.07	4,228	1.13	6:26
38	01/28/2006 05:34	01/28 06:05	.52	.04	.12	.06	.08	302	.02	615:13
38	01/28/2006 09:10	01/28 09:37	.45	.05	.12	NA	.11	378	NA	3:05
38	01/28/2006 12:48	01/28 17:24	4.60	.20	.12	.08	.04	1,510	.14	3:11
39	01/28/2006 19:55	01/29 08:31	12.60	.70	.12	.12	.06	5,285	.71	2:31
40	03/08/2006 18:01	03/08 23:06	5.08	.58	.28	.24	.11	4,379	1.17	921:30
41	03/12/2006 18:16	03/13 03:37	9.35	.48	.28	.22	.05	3,624	.89	91:10
	03/16/2006 13:29	03/16 16:37	3.13	.15	.12	.08	.05	1,133	.10	81:52
42	03/30/2006 22:20	03/31 01:58	3.63	.20	.16	.10	.06	1,510	.17	341:43
	03/31/2006 12:56	03/31 13:29	.55	.05	.12	.08	.09	378	.03	10:58
43	04/02/2006 11:06	04/02 13:47	2.68	.16	.12	.12	.06	1,208	.16	45:37
43	04/02/2006 20:32	04/03 10:04	13.53	1.06	.76	.46	.08	8,003	4.17	6:45
44	04/06/2006 21:28	04/07 08:14	13.57	.95	.48	.30	.07	7,173	2.45	83:24

Sample ID	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Duration (hours)	Precipitation (in)	15-min. ppt Intensity (in/hr)	30-min. ppt Intensity (in/hr)	Intensity (ppt/duration)	Total rainfall volume (cf)	Erosivity index (hundreds of ft-lbs/acre/in/hr	Antecedent dry time (hours)
	04/12/2006 05:17	04/12 08:02	2.75	.33	.32	.26	.12	2,492	.72	117:03
45	04/16/2006 03:55	04/16 04:38	.72	.08	.20	.14	.11	604	.09	91:53
45	04/16/2006 09:40	04/16 10:15	.58	.02	.04	.02	.03	151	.00	5:02
45	04/16/2006 12:56	04/16 16:54	3.97	.70	.60	.44	.18	5,285	2.67	2:41
46	04/19/2006 04:56	04/19 05:52	.93	.18	.36	.24	.19	1,359	.36	60:02
	04/22/2006 01:33	04/22 02:49	1.27	.11	.36	.20	.09	831	.19	67:41
	04/25/2006 02:05	04/25 04:02	1.95	.06	.04	.04	.03	453	.02	71:16
47	04/29/2006 14:48	04/30 09:53	19.08	1.26	.40	.30	.07	9,514	3.19	106:46
	04/30/2006 15:26	04/30 16:25	.98	.05	.12	.06	.05	378	.03	5:33
	05/01/2006 15:31	05/01 16:36	1.08	.02	.04	.02	.02	151	.00	23:06
	05/01/2006 19:00	05/01 19:09	.15	.02	NA	NA	.13	151	NA	2:24
	05/01/2006 21:15	05/01 22:07	.87	.30	.72	.56	.35	2,265	1.50	2:06
48	05/09/2006 10:36	05/09 17:01	6.42	.41	.24	.20	.06	3,096	.69	180:29
49	05/11/2006 05:54	05/11 07:58	2.07	.08	.08	.08	.04	604	.05	36:53
49	05/11/2006 11:39	05/12 06:30	18.85	.79	.12	.10	.04	5,965	.67	3:41
	05/13/2006 02:56	05/13 07:38	4.70	.06	.04	.02	.01	453	.01	20:26
50	05/13/2006 15:15	05/13 15:28	.22	.08	NA	NA	.37	604	NA	7:37
50	05/13/2006 21:21	05/14 04:47	7.43	.09	.08	.06	.01	680	.05	5:53
50	05/15/2006 12:55	05/15 13:06	.18	.02	NA	NA	.11	151	NA	32:08
50	05/15/2006 15:37	05/15 17:13	1.60	.15	.32	.16	.09	1,133	.21	2:31
	05/16/2006 06:51	05/16 08:27	1.60	.04	.04	.04	.03	302	.01	13:38
51	05/16/2006 15:08	05/16 17:50	2.70	.21	.40	.22	.08	1,586	.42	6:41
51	05/17/2006 15:19	05/17 16:11	.87	.14	.36	.22	.16	1,057	.26	21:29
52	05/24/2006 18:40	05/24 19:09	.48	1.38	4.08	NA	2.86	10,420	NA	170:29
	05/24/2006 21:37	05/24 21:43	.10	.02	NA	NA	.20	151	NA	2:28
	05/25/2006 13:40	05/25 14:02	.37	.05	.12	NA	.14	378	NA	15:57
	05/25/2006 17:01	05/25 17:21	.33	.03	.08	NA	.09	227	NA	2:59
	05/30/2006 13:40	05/30 13:51	.18	.03	NA	NA	.16	227	NA	116:19
	05/30/2006 16:18	05/30 17:03	.75	.07	.24	.12	.09	529	.08	2:27
53	06/02/2006 14:30	06/02 14:48	.30	.16	.60	NA	.53	1,208	NA	69:27
54	06/06/2006 05:48	06/06 08:48	4.38	.18	.20	.16	.04	1,359	.26	87:00
55	06/09/2006 21:06	06/10 06:17	10.55	.54	.24	.20	.05	4,077	.93	84:18
56	06/14/2006 11:40	06/14 13:11	1.52	.16	.60	.30	.11	1,208	.47	101:23
	06/18/2006 07:29	06/18 09:40	2.18	.07	.08	.06	.03	529	.04	90:18
	06/18/2006 12:22	06/18 12:55	.55	.14	.48	.26	.25	1,057	.34	2:42
	06/21/2006 12:26	06/21 13:03	.62	.02	.04	.02	.03	151	.00	71:31
	06/24/2006 23:50	06/25 00:10	.33	.02	.04	NA	.06	151	NA	82:47
57	06/25/2006 17:28	06/25 21:26	3.97	.46	.40	.28	.12	3,473	1.09	17:18
57	06/26/2006 03:19	06/26 08:32	5.22	.39	.24	.20	.07	2,945	.66	5:53
58	07/11/2006 08:43	07/11 15:01	7.03	2.03	.92	.72	.29	15,327	12.56	360:11
59	07/19/2006 21:11	07/19 21:27	.27	.25	.96	NA	.94	1,888	NA	198:10
59	07/20/2006 02:28	07/20 05:25	2.95	.73	1.96	1.10	.25	5,512	7.70	5:01
59	07/20/2006 06:47	07/20 07:00	.22	.28	NA	NA	1.29	2,114	NA	1:22
	07/25/2006 23:45	07/25 23:58	.22	.04	NA	NA	.19	302	NA	136:45
	07/26/2006 01:00	07/26 01:25	.42	.02	.04	NA	.05	151	NA	1:02
	07/27/2006 12:37	07/27 13:50	1.22	.32	.80	.54	.26	2,416	1.53	35:12
	07/30/2006 08:58	07/30 09:13	.25	.10	.40	NA	.40	755	NA	67:08

Sample ID	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Duration (hours)	Precipitation (in)	15-min. ppt Intensity (in/hr)	30-min. ppt Intensity (in/hr)	Intensity (ppt/duration)	Total rainfall volume (cf)	Erosivity index (hundreds of ft-lbs/acre/in/hr	Antecedent dry time (hours)
	08/01/2006 18:47	08/01 19:01	.23	.06	NA	NA	.26	453	NA	57:34
	08/02/2006 14:55	08/02 14:58	.05	.02	NA	NA	.40	151	NA	19:54
60	08/06/2006 05:56	08/06 11:12	5.27	.83	.48	.28	.16	6,267	2.00	86:58
	08/09/2006 18:42	08/09 19:04	.37	.21	.79	NA	.57	1,563	NA	79:30
	08/17/2006 15:02	08/17 17:23	2.35	.22	.61	.36	.09	1,631	.67	187:58
61	08/23/2006 22:26	08/23 23:55	1.48	.34	.72	.58	.23	2,582	1.72	149:03
61	08/24/2006 01:22	08/24 06:53	3.63	1.17	1.67	1.14	.32	8,826	7.62	1:27
62	08/24/2006 13:00	08/24 15:00	2.00	1.22	2.28	1.28	.61	9,189	15.54	6:07
	08/25/2006 05:11	08/25 06:51	1.67	.26	.32	.28	.16	1,963	.61	14:11
	08/25/2006 08:23	08/25 08:47	.40	.07	.20	NA	.18	529	NA	1:32
63	08/25/2006 10:53	08/25 11:09	.27	.86	3.40	NA	3.23	6,493	NA	2:06
63	08/25/2006 13:27	08/25 13:40	.22	.28	NA	NA	1.29	2,114	NA	2:18
	08/26/2006 01:22	08/26 01:30	.13	.10	NA	NA	.75	755	NA	11:42
	08/28/2006 13:59	08/28 16:30	2.52	.07	.08	.06	.03	529	.04	60:29
	08/31/2006 12:01	08/31 12:03	.03	.07	NA	NA	2.10	529	NA	67:31
64	09/03/2006 18:29	09/03 21:21	2.87	.36	.28	.20	.13	2,718	.61	78:26
64	09/04/2006 05:31	09/04 08:20	1.90	.31	.40	.22	.12	2,341	.38	8:10
	09/07/2006 11:32	09/07 12:29	.95	.40	.80	.60	.42	3,020	2.56	75:12
	09/10/2006 14:46	09/10 23:12	8.43	.38	.12	.08	.05	2,869	.26	74:17
	09/11/2006 02:30	09/11 03:39	1.15	.03	.08	.04	.03	227	.01	3:18
	09/11/2006 05:54	09/11 07:09	1.25	.07	.12	.08	.06	529	.05	2:15
	09/11/2006 11:53	09/11 12:33	.67	.05	.12	.08	.08	378	.03	4:44
	09/11/2006 15:30	09/11 18:13	2.72	.33	.56	.36	.12	2,492	1.01	2:57
	09/11/2006 19:30	09/11 21:18	1.80	.06	.08	.08	.03	453	.04	1:17
	09/12/2006 02:42	09/12 06:16	3.57	.40	.28	.20	.11	3,020	.67	5:24
	09/12/2006 08:14	09/12 08:26	.20	.03	NA	NA	.15	227	NA	1:58
	09/12/2006 10:15	09/12 10:49	.57	.09	.20	.16	.16	680	.12	1:49
	09/12/2006 12:05	09/12 12:57	.87	.02	.04	.02	.02	151	.00	1:16
	09/12/2006 14:58	09/12 17:21	2.38	.37	.60	.36	.16	2,794	1.15	2:01
	09/17/2006 05:56	09/17 06:01	.08	.03	NA	NA	.36	227	NA	108:35
	09/17/2006 17:59	09/17 18:06	.12	.02	NA	NA	.17	151	NA	11:58
	09/21/2006 21:49	09/21 23:59	2.17	.08	.08	.06	.04	604	.04	99:43
	09/22/2006 05:18	09/22 06:47	1.48	.07	.12	.10	.05	529	.06	5:19
	09/23/2006 14:19	09/23 16:47	2.47	.18	.16	.12	.07	1,359	.18	31:32
	09/23/2006 20:48	09/23 21:11	.38	.04	.08	NA	.10	302	NA	4:01
	09/27/2006 03:44	09/27 03:49	.08	.04	NA	NA	.48	302	NA	78:33
	10/02/2006 19:13	10/02 19:27	.23	.04	NA	NA	.17	302	NA	135:24
	10/02/2006 21:47	10/02 22:39	.87	.09	.28	.16	.10	680	.12	2:20
	10/04/2006 05:29	10/04 06:49	1.33	.63	1.00	.76	.47	4,757	4.54	30:50
	10/10/2006 19:51	10/11 00:45	4.90	.22	.08	.08	.05	1,661	.15	157:02
	10/11/2006 01:45	10/11 05:59	4.23	.07	.04	.04	.02	529	.02	1:00
	10/11/2006 07:09	10/11 07:47	.63	.03	.04	.04	.05	227	.01	1:10
	10/11/2006 08:54	10/11 09:46	.87	.06	.08	.06	.07	453	.03	1:07
	10/11/2006 11:41	10/11 12:28	.78	.02	.04	.02	.03	151	.00	1:55
	10/16/2006 05:12	10/16 05:50	.63	.04	.08	.06	.06	302	.02	112:44
	10/16/2006 19:13	10/16 20:14	1.02	.04	.08	.06	.04	302	.02	13:23
	10/16/2006 22:52	10/17 06:53	8.02	.79	.28	.24	.10	5,965	1.60	2:38

Sample ID	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Duration (hours)	Precipitation (in)	15-min. ppt Intensity (in/hr)	30-min. ppt Intensity (in/hr)	Intensity (ppt/duration)	Total rainfall volume (cf)	Erosivity index (hundreds of ft-lbs/acre/in/hr	Antecedent dry time (hours)
	10/18/2006 14:44	10/18 16:29	1.75	.11	.12	.10	.06	831	.09	31:51
	10/18/2006 17:55	10/18 18:39	.73	.05	.08	.08	.07	378	.03	1:26
	10/21/2006 10:07	10/21 14:31	4.40	.15	.12	.08	.03	1,133	.10	63:28
	10/21/2006 15:38	10/21 20:09	4.52	.21	.12	.10	.05	1,586	.18	1:07
	10/22/2006 02:47	10/22 06:17	3.50	.18	.08	.08	.05	1,359	.12	6:38
	10/22/2006 09:12	10/22 13:02	3.83	.13	.08	.06	.03	982	.07	2:55
	10/26/2006 17:29	10/26 21:02	3.55	.07	.04	.04	.02	529	.02	100:27
	11/10/2006 12:05	11/10 14:27	2.37	.60	.40	.36	.25	4,530	1.82	351:03
	11/11/2006 11:14	11/11 16:05	4.85	.20	.12	.08	.04	1,510	.14	20:47
	11/12/2006 09:38	11/12 12:58	3.33	.13	.12	.10	.04	982	.11	17:33
	11/13/2006 08:07	11/13 08:33	.43	.02	.04	NA	.05	151	NA	19:09
	11/26/2006 20:34	11/27 01:38	5.07	.32	.24	.18	.06	2,416	.49	324:01
	11/27/2006 17:57	11/28 04:04	10.12	.82	.24	.24	.08	6,191	1.66	16:19
	11/28/2006 06:39	11/28 07:34	.92	.05	.12	.06	.06	378	.03	2:35
	11/29/2006 03:03	11/29 05:13	2.17	.08	.12	.08	.04	604	.05	19:29
	11/29/2006 10:28	11/29 10:38	.17	.02	NA	NA	.12	151	NA	5:15
	11/29/2006 18:06	11/29 19:29	1.38	.06	.08	.06	.04	453	.03	7:28
	12/02/2006 11:17	12/02 12:14	.95	.03	.08	.04	.03	227	.01	63:48
	12/12/2006 05:12	12/12 05:27	.25	.06	.24	NA	.24	453	NA	232:58
	12/20/2006 19:50	12/21 04:09	8.32	.24	.08	.06	.03	1,812	.12	206:23
	12/21/2006 06:30	12/21 13:21	6.85	.52	.28	.22	.08	3,926	.96	2:21
	12/22/2006 14:00	12/22 14:49	.82	.07	.12	.10	.09	529	.06	24:39
	12/31/2006 07:26	12/31 10:06	2.67	.24	.32	.24	.09	1,812	.49	208:37
	01/07/2007 17:04	01/07 17:22	.30	.02	.04	NA	.07	151	NA	174:58
	01/26/2007 12:12	01/26 13:16	1.07	.07	.08	.08	.07	529	.05	450:50
	02/25/2007 08:48	02/25 15:37	6.82	.57	.20	.16	.08	4,304	.77	715:32
	02/26/2007 11:26	02/26 16:04	4.63	.17	.16	.10	.04	1,284	.14	19:49
	03/01/2007 00:38	03/01 01:25	.78	.02	.04	.02	.03	151	.00	56:34
	03/01/2007 10:21	03/01 11:27	1.10	.08	.12	.10	.07	604	.07	8:56
	03/01/2007 12:42	03/01 14:48	2.10	.23	.40	.30	.11	1,737	.58	1:15
	03/02/2007 11:50	03/02 12:20	.50	.02	.04	.04	.04	151	.01	21:02
	03/09/2007 14:51	03/09 18:55	4.07	.27	.16	.12	.07	2,039	.27	170:31
	03/14/2007 17:02	03/14 18:59	1.95	.04	.04	.04	.02	302	.01	118:07
65	03/21/2007 03:34	03/21 04:59	1.42	.09	.16	.10	.06	680	.08	152:35
65	03/21/2007 08:20	03/21 11:42	3.37	.09	.12	.06	.03	680	.05	3:21
65	03/21/2007 17:45	03/21 18:03	.30	.03	.08	NA	.10	227	NA	6:03
65	03/21/2007 21:55	03/21 22:26	.52	.03	.08	.04	.06	227	.01	3:52
65	03/22/2007 01:18	03/22 03:44	2.43	.77	.96	.86	.32	5,814	5.98	2:52
	03/24/2007 22:25	03/24 22:30	.08	.06	NA	NA	.72	453	NA	66:41
	03/28/2007 05:29	03/28 05:40	.18	.07	NA	NA	.38	529	NA	78:59
	03/30/2007 13:38	03/30 15:13	1.58	.03	.04	.02	.02	227	.01	55:58
	03/31/2007 08:42	03/31 09:04	.37	.08	.24	NA	.22	604	NA	17:29
	03/31/2007 12:19	03/31 13:58	1.65	.20	.28	.22	.12	1,510	.38	3:15
	03/31/2007 15:34	03/31 15:43	.15	.04	NA	NA	.27	302	NA	1:36
	03/31/2007 18:54	03/31 19:09	.25	.06	.24	NA	.24	453	NA	3:11
	03/31/2007 20:32	03/31 22:50	2.30	.39	.52	.34	.17	2,945	1.15	1:23
	04/01/2007 00:08	04/01 00:27	.32	.02	.04	NA	.06	151	NA	1:18

Sample ID	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Duration (hours)	Precipitation (in)	15-min. ppt Intensity (in/hr)	30-min. ppt Intensity (in/hr)	Intensity (ppt/duration)	Total rainfall volume (cf)	Erosivity index (hundreds of ft-lbs/acre/in/hr	Antecedent dry time (hours)
	04/01/2007 11:13	04/01 13:18	2.08	.05	.08	.04	.02	378	.02	10:46
	04/03/2007 00:11	04/03 07:18	7.12	1.47	.48	.42	.21	11,099	5.22	34:53
	04/10/2007 23:46	04/11 01:16	1.50	.06	.08	.06	.04	453	.03	184:28
	04/11/2007 12:57	04/11 16:18	3.35	.28	.20	.16	.08	2,114	.38	11:41
	04/12/2007 10:05	04/12 13:32	3.45	.27	.28	.18	.08	2,039	.42	17:47
	04/22/2007 20:15	04/22 20:28	.22	.02	NA	NA	.09	151	NA	246:43
	04/23/2007 00:31	04/23 05:52	5.35	.45	.36	.26	.08	3,398	.99	4:03
	04/24/2007 13:36	04/25 04:51	15.25	.86	.32	.18	.06	6,493	1.30	31:44
	04/25/2007 20:27	04/25 21:35	1.13	.07	.12	.08	.06	529	.05	15:36
	04/26/2007 00:25	04/26 01:35	1.17	.06	.12	.08	.05	453	.04	2:50
	04/26/2007 04:59	04/26 05:40	.68	.02	.04	.02	.03	151	.00	3:24
66	04/26/2007 08:49	04/26 12:45	3.93	.39	.24	.18	.10	2,945	.59	3:09
	04/27/2007 01:38	04/27 02:03	.42	.02	.04	NA	.05	151	NA	12:53
	04/30/2007 20:09	04/30 21:01	.87	.47	1.32	.90	.54	3,549	4.03	90:06
	05/05/2007 03:48	05/05 04:25	.62	.04	.08	.06	.07	302	.02	102:47
67	05/13/2007 06:20	05/13 10:09	3.82	.46	.52	.46	.12	3,473	1.78	193:55
68	05/15/2007 12:29	05/15 16:24	3.92	.59	.60	.48	.15	4,455	2.42	50:20
	05/15/2007 17:34	05/15 18:01	.45	.04	.12	NA	.09	302	NA	1:10
	05/16/2007 16:48	05/16 16:59	.18	.13	NA	NA	.71	982	NA	22:47
	05/24/2007 16:44	05/24 18:28	1.73	.39	.72	.46	.23	2,945	1.61	191:45
	05/26/2007 14:47	05/26 15:03	.27	.03	.08	NA	.11	227	NA	44:19
	05/29/2007 16:15	05/29 16:22	.12	.07	NA	NA	.60	529	NA	73:12
	06/01/2007 16:58	06/01 18:40	1.70	.18	.44	.30	.11	1,359	.47	72:36
	06/02/2007 06:49	06/02 07:46	.95	.18	.44	.28	.19	1,359	.45	12:09
	06/02/2007 11:27	06/02 12:09	.70	.04	.08	.06	.06	302	.02	3:41
	06/03/2007 03:01	06/03 03:08	.12	.02	NA	NA	.17	151	NA	14:52
	06/03/2007 10:21	06/03 11:31	1.17	.09	.24	.16	.08	680	.12	7:13
	06/03/2007 17:43	06/03 19:33	1.83	1.25	3.64	2.40	.68	9,438	31.10	6:12
	06/03/2007 20:46	06/03 22:58	2.20	2.03	2.20	2.02	.92	15,327	39.87	1:13
	06/04/2007 05:38	06/04 09:11	3.55	.6	.80	.56	.17	4,530	2.97	6:40
	06/05/2007 03:16	06/05 03:34	.30	.04	.12	NA	.13	302	NA	18:05
	06/06/2007 15:08	06/06 16:22	1.23	.06	.08	.06	.05	453	.03	35:34
	06/18/2007 15:54	06/18 16:22	.47	.05	.12	NA	.11	378	NA	287:32
69	06/18/2007 18:25	06/18 19:07	.70	.18	.64	.34	.26	1,359	.58	2:03
	06/18/2007 21:20	06/18 22:58	1.63	.07	.16	.10	.04	529	.06	2:13

Table 2–2. Field-blank data summary from the unswept section of USH 151 in Madison Wis.

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

Constituent	Unit	Blank1 04/15/2005	Blank 2 06/27/2005	Blank 3 05/18/2006	Blank 4 07/12/2007	LOD	LOQ
Suspended solids, total (mg/L)	mg/L	<2	<2	<2	<2	2	7
Suspended-sediment concentration (mg/L)	mg/L	<2	<2	<2	--	2	7
Solids, volatile (mg/L)	mg/L	--	--	<2	<2	2	7
Solids, dissolved (mg/L)	mg/L	<50	<50	--	<50	50	167
Phosphorus, dissolved (mg/L)	mg/L	<.005	<.005	<.005	<.005	.005	.016
Phosphorus, total (mg/L)	mg/L	<.005	<.005	<.005	<.005	.005	.016
Chemical oxygen demand, total (mg/L)	mg/L	<9	<9	<9	<9	9	28
Chloride, dissolved (mg/L)	mg/L	<0.6	<.6	--	<1	2.0	3.3
Copper, dissolved (ug/L)	µg/L	1.3	<1	1	<2	1	3
Copper, total recoverable (ug/L)	µg/L	1	<1	1	<2	1	3
Zinc, dissolved (ug/L)	µg/L	<16	<16	2	<1	16	50
Zinc, total recoverable (ug/L)	µg/L	<16	<16	3	4	16	50
Calcium, total recoverable (mg/L)	mg/L	<.2	<.2	<.1	<.1	.200	.070
Magnesium, total recoverable (mg/L)	mg/L	<.2	<.2	<.1	<1	.200	.070

Table 2–3. Field replication and sample relative percent difference data summary from the unswept section on USH151, Madison Wis.

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

Parameter	Objective (%)	Event 05/11/2005 Rep 1			Event 07/20/2005 Rep 2			Event 05/11/2006 Rep 3		
Suspended solid, total (mg/L)	30	57	63	10	102	93	9	23	20	14
Suspended sediment concentration (mg/L)	na	472	423	11	106	138	2	23	23	0
Volatile suspended solid, (mg/L)	na	--	--	--	--	--	--	12	11	9
Suspended solid, dissolved (mg/L)	30	94	90	4	<50	<50	0	56	58	1
Phosphorus, dissolved (mg/L)	30	0.053	.052	2	.072	.072	0	.051	.05	2
Phosphorus, total (mg/L)	30	.242	.171	34	.147	.139	6	.101	.099	2
Chemical oxygen demand, total (mg/L)	na	48	41	16	56	62	10	25	38	41
Chloride, dissolved (mg/L)	25	22.7	22.7	0	3.1	3.1	0	11.1	11.2	1
Copper, dissolved (ug/L)	25	4.3	4.2	2	3.2	3.5	9	4.4	5.3	19
Copper, total recoverable (ug/L)	25	15	16	6	16	20	22	12	11	9
Zinc, dissolved (ug/L)	25	9.88	9.14	8	15.4	14.8	4	26	18	36
Zinc, total recoverable (ug/L)	25	115	85	30	103	106	3	71	67	6

Parameter	Objective (%)	Event 05/11/2005 Rep 1			Event 07/20/2005 Rep 2			Event 05/11/2006 Rep 3		
Calcium, total recoverable (mg/L)	25	34.6	32.1	8	14	15	7	7.7	7.4	4
Magnesium, total recoverable(mg/L)	25	12.1	10.1	18	5.7	6.1	7	1	0.9	10

Table 2-4. Runoff event start and end time, event volumes, percent runoff and peak discharge from the unswept section on USH 151, Madison Wis.

[mm/dd/yyyy hh:mm, month/day/year hour:minute; 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 hh:mm)	Total rainfall (in.)	Volume (ft^3)	Percent runoff	Peak discharge (ft^3/s)
1	04/06/2005 19:28	04/06 22:14	0.98	7,672	95	4.15
2	04/12/2005 05:58	04/12 15:09	.49	4,121	102	.70
3	04/19/2005 23:08	04/20 00:58	.23	1,564	83	.82
4	04/25/2005 17:05	04/25 20:36	.16	657	50	.34
5	05/11/2005 02:47	05/11 11:02	.87	5,979	83	1.09
6	05/13/2005 01:43	05/13 08:20	.54	2,989	67	1.14
7	05/18/2005 22:16	05/19 04:20	.66	7,387	136	1.24
8	05/19/2005 16:26	05/19 18:20	.73	7,422	123	7.03
9	05/22/2005 05:36	05/22 06:02	.09	389	52	.93
10	05/29/2005 18:34	05/29 19:15	.20	1,287	78	.73
11	06/04/2005 23:53	06/05 04:49	.35	2,074	72	1.41
12	06/09/2005 17:30	06/09 18:19	.19	959	61	.93
13	06/10/2005 19:51	06/10 20:21	.12	536	54	1.29
14	06/14/2005 19:46	06/14 21:55	.12	821	83	.52
15	06/25/2005 21:31	06/26 00:56	.32	1,823	69	.30
16	06/28/2005 03:05	06/28 03:40	.26	1,287	60	2.79
17	07/04/2005 15:13	07/04 18:28	.27	1,175	53	.76
18	07/12/2005 23:06	07/13 01:18	.19	1,002	64	.72
19	07/20/2005 09:33	07/20 11:15	1.05	8,683	100	4.68
20	07/21/2005 09:15	07/21 11:49	1.01	8,977	108	7.73
21	07/25/2005 01:19	07/25 02:32	.49	2,246	56	1.73
22	07/25/2005 15:21	07/26 02:32	.61	3,154	63	2.79
23	08/11/2005 22:45	08/12 00:27	.26	1,676	78	1.35
24	08/18/2005 07:02	08/18 11:03	.47	2,704	70	.85
25	08/18/2005 18:18	08/18 19:09	.13	588	55	1.17
26	09/19/2005 05:28	09/19 07:44	.28	1,832	79	1.37
27	09/22/2005 01:44	09/22 04:28	.59	4,311	89	4.18
28	09/25/2005 20:13	09/25 22:02	1.03	7,629	90	3.93
29	09/28/2005 13:04	09/28 16:47	.25	1,054	51	.34
30	10/05/2005 20:10	10/06 02:04	.32	1,020	39	1.43
31	10/17/2005 08:14	10/17 09:57	.19	864	55	.58
32	11/05/2005 03:03	11/06 07:48	1.34	7,413	67	.43
33	11/15/2005 12:38	11/15 20:34	.56	2,290	50	.29
34	11/27/2005 07:24	11/27 16:40	.19	311	20	.07
35	11/28/2005 01:17	11/28 10:33	.41	1,823	54	.31
36	01/01/2006 18:39	01/02 02:19	.18	812	55	.12
37	01/02/2006 06:38	01/02 14:59	.56	3,050	66	.41
38	01/28/2006 12:48	01/28 17:48	.29	2,056	86	.20
39	01/28/2006 19:55	01/29 09:26	.70	5,253	91	.24
40	03/08/2006 18:01	03/09 08:45	.58	4,977	104	.51
41	03/12/2006 18:16	03/13 04:27	.48	4,225	107	.52

Sampled event number	Start date and time (mm/dd/yyyy hh:mm)	End date and time (mm/dd hh:mm)	Total rainfall (in.)	Volume (ft^3)	Percent runoff	Peak discharge (ft^3/s)
42	03/30/2006 22:20	03/31 02:39	.20	1,356	82	.28
43	04/02/2006 20:32	04/03 06:39	1.22	6,791	68	1.51
44	04/06/2006 21:28	04/07 08:41	.95	4,700	60	.80
45	04/16/2006 12:56	04/16 17:23	.80	3,629	55	.83
46	04/19/2006 04:56	04/19 06:17	.18	786	53	.53
47	04/29/2006 14:48	04/30 10:26	1.26	7,845	76	.64
48	05/09/2006 10:36	05/09 17:46	.41	3,154	93	.44
49	05/11/2006 11:39	05/14 07:09	.87	5,512	77	.24
50	05/15/2006 15:37	05/16 18:26	.34	1,909	68	1.00
51	05/17/2006 15:19	05/17 16:58	.35	2,540	88	1.32
52	05/24/2006 18:40	05/24 20:14	1.38	13,236	116	7.54
53	06/02/2006 14:30	06/02 15:07	.16	959	73	1.59
54	06/06/2006 05:48	06/06 09:17	.18	1,244	84	.51
55	06/09/2006 21:06	06/10 07:02	.54	4,121	93	.50
56	06/14/2006 11:40	06/14 13:36	.16	795	60	2.07
57	06/26/2006 03:19	06/26 08:58	.85	4,095	58	.76
58	07/11/2006 08:43	07/11 15:25	2.03	8,856	53	1.30
59	07/20/2006 06:47	07/20 07:18	1.26	7,871	76	5.39
60	08/06/2006 05:56	08/06 11:30	.83	4,044	59	1.64
61	08/24/2006 01:22	08/24 06:11	1.51	14,619	117	7.70
62	08/24/2006 13:00	08/24 15:25	1.22	5,780	58	6.13
63	08/25/2006 13:27	08/25 14:12	1.14	12,165	130	7.51
64	09/04/2006 05:31	09/04 08:53	.67	3,871	70	3.14
65	03/22/2007 01:18	03/22 03:57	1.01	8,130	98	2.45
66	04/26/2007 08:49	04/26 13:04	.39	1,305	41	.30
67	05/13/2007 06:20	05/13 10:29	.46	2,100	55	.78
68	05/15/2007 12:29	05/15 16:47	.59	3,214	66	.97
69	06/18/2007 18:25	06/18 19:07	.18	959	65	2.22

Table 2–5. Event mean concentrations of solids analyzed in water-quality samples collected from the unswept section of USH 151, Madison Wis.

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

Event	Suspended sediment	Total Suspended Solids	Dissolved Solids	Volatile Suspended Solids
1	5,033	--	--	--
2	67	42	--	--
3	544	351	--	--
4	73	--	--	--
5	472	293	94	--
6	513	209	80	--
7	2,392	1353	104	--
8	1,060	711	60	--
9	3,119	141	--	--
10	1984	61	--	--
11	243	157	82	--

Event	Suspended sediment	Total Suspended Solids	Dissolved Solids	Volatile Suspended Solids
12	90.64	79	--	--
13	181	101	--	--
14	104	75	--	--
15	38	22	--	--
16	274	--	--	--
17	86	110	98	--
18	60	54	112	--
19	244	198	<50	--
20	109	89	<50	--
21	115	83	80	--
22	45	49	60	--
23	106	83	102	--
24	61	54	na	--
25	256	218	na	--
26	93	71	80	--
27	185	114	<50	--
28	5,114	--	na	--
29	26	26	66	--
30	101	37	132	--
31	21	23	92	--
32	23	24	<50	--
33	28	25	na	--
34	90	66	1,770	--
35	96	84	174	--
36	131	123	676	--
37	180	167	178	--
38	202	192	1,230	--
39	42	42	168	--
40	262	242	596	--
41	144	142	162	--
42	175	179	352	--
43	212	197	104	--
44	77	71	98	11
45	115	111	88	22
46	83	78	228	--
47	40	39	66	11
48	54	45	196	18
49	23	23	56	12
50	161	149	--	--
51	255	215	92	--
52	1,064	721	<50	31
53	261	229	118	--
54	30	34	138	--
55	25	29	60	10
56	331	--	--	--
57	32	32	80	10
58	37	33	<50	8
59	221	82	<50	16
60	52	30	<50	--
61	156	89	<50	23
62	100	53	<50	--

Event	Suspended sediment	Total Suspended Solids	Dissolved Solids	Volatile Suspended Solids
63	162	78	<50	--
64	45	31	<50	--
65	995	928	308	60
66	56	49	66	18
67	--	--	--	--
68	72	67	106	--
69	--	--	--	--

Table 2–6. Event-mean concentrations for constituents analyzed in water-quality samples collected from the unswept section on USH 151, Madison Wis.

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

Sampled event number	Chemical oxygen demand, total (mg/L)	Phosphorus, total (mg/L)	Phosphorus, dissolved (mg/L)	Chloride, dissolved (mg/L)	Copper, dissolved (ug/L)	Copper, total recoverable (ug/L)	Zinc, dissolved (ug/L)	Zinc, total recoverable (ug/L)	Calcium, total recoverable (mg/L)	Magnesium, total recoverable (mg/L)	Hardness (mg/L)
1	--	--	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--	--
5	48	0.242	.053	22.7	4.3	15	9.9	115	34.6	12.1	136
6	50	.17	.046	19	3.3	14	7.3	60	12.7	3.3	45.3
7	55	1.28	.069	26	4.7	374	<16	806	11.2	2.2	36.8
8	65	.48	.042	10.5	4	109	9.6	527	33.3	13.7	140
9	--	--	--	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--	--	--	--
11	48	.142	.074	13.9	4.1	47	6.6	119	9	2.2	31.6
12	--	--	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--	--
16	65	.16	.069	--	4	40	<16	258	18.3	7.2	75.3
17	--	--	--	--	--	--	--	--	--	--	--
18	--	--	--	--	--	--	--	--	--	--	--
19	56	.21	.072	3.1	3.2	28	15.4	148	14	5.7	58.6
20	29	.182	.107	5.5	2.5	14	10.3	74	8.7	3	34.1
21	--	--	--	--	--	--	--	--	--	--	--
22	16	.26	.053	13.9	2.5	104	<16	787	8.9	2.5	32.7
23	69	.163	.079	23.3	4.3	17	<16	151	10.7	3.4	40.8
24	52	.165	.104	9.7	6.4	12	<16	68	7.3	1.6	24.9
25	--	--	--	--	--	--	--	--	--	--	--
26	--	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--
32	20	.079	.055	4	2.9	8	<16	53	7.1	1	21.8
33	37	0	.044	--	2	11	--	71	7	1	22.1
34	--	--	--	1070	--	--	--	--	--	--	--
35	--	--	--	54.9	--	--	--	--	--	--	--
36	--	--	--	391	--	--	--	--	--	--	--
37	--	--	--	67.6	--	--	--	--	--	--	--
38	--	--	--	729	--	--	--	--	--	--	--
39	--	--	--	--	--	--	--	--	--	--	--
40	--	--	--	--	--	--	--	--	--	--	--
41	--	--	--	--	--	--	--	--	--	--	--
42	--	--	--	--	--	--	--	--	--	--	--

43	44	.133	.036	26	3.6	35	--	189	31.8	9.1	117
44	37	.102	.05	25.5	3.8	15	12.0	88	17	3.9	58.5
45	43	.17	.056	17.4	4.4	21	11.0	124	20.9	6.1	77.3
46	--	--	--	--	--	--	--	--	--	--	--
47	22	.101	.046	12.7	2.2	10	16.0	77	12.3	2.2	40.0
48	52	.156	.06	17.5	7.6	22	22.0	120	9.3	2	31.4
49	25	.101	.051	11.1	4.4	12	26.0	71	7.7	1	23.3
50	--	--	--	--	--	--	--	--	--	--	--
51	--	--	--	--	--	--	--	--	--	--	--
52	48	.50	.11	4.3	3.6	83	13.0	271	71	31	132
53	--	--	--	--	--	--	--	--	--	--	--
54	--	--	--	--	--	--	--	--	--	--	--
55	34	.103	.051	--	3.3	13	8.0	66	6.4	1.2	21.0
56	--	--	--	--	--	--	--	--	--	--	--
57	<9	.103	.059	17.5	4	12	9.0	87	8.5	1.5	27.3
58	20	.069	.037	4.3	3.8	51	8.0	69	8	1.7	27.0
59	37	.137	.051	4.4	2.4	19	7.0	121	18.6	7.8	78.7
60											
61	32	.127	.049	1.9	<2	38	8.0	86	15.7	6.3	65.2
62	--	--	--	--	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--	--	--	--	--
64	--	--	--	--	--	--	--	--	--	--	
65	157	.560	.063	112	7	111	22.0	687	133	42	504
66	--	--	--	--	--	--	--	--	--	--	--
67	--	--	--	--	--	--	--	--	--	--	--
68	--	.150	0.60	27	7	142	20	142	14.5	3.7	51.2
69	--	--	--	--	--	--	--	--	--	--	

Table 2–7. Event mean concentrations of polycyclic aromatic hydrocarbon measured in water-quality samples collected from the unswept section of USH151, Madison Wis.
[mm/dd/yyyy, month/day/year; all concentrations in micrograms per liter;--, no sample processed for event]

Sampled event number	Dates (mm/dd/yyyy)	1-Methylnaphthalene	2-Methylnaphthalene	9H-Fluorene	Acenaphthene	Acenaphthylene	Anthracene	Benzo[a]anthracene	Benzo[a]pyrene	Benzo[b]fluoranthene	Benzo[ghi]perylene	Benzo[k]fluoranthene	Chrysene	Dibenzo[a,h]anthracene	Fluoranthene recoverable	Indeno[1,2,3-cd]pyrene	Phenanthrene	Pyrene	Naphthalene	Total PAH
5	05/11/2005	<0.064	<.049	<.52	<.064	<.11	<.031	<.093	0.17	.24	.27	<.12	.20	<.060	.49	.23	.12	.33	<.042	3.2
8	05/19/2005	<.064	<.049	<.52	.16	<.11	.56	4.0	6.8	12	7.7	4.8	9.1	<1.2	22	7.3	8.5	16	.042	99.4
19	07/20/2005	<.064	<.049	<.52	<.064	<.11	.31	1.9	3.7	5.1	4.2	2.4	4.3	<1.0	9.6	3.8	3.0	6.4	<.042	45.2
20	07/21/2005	<.064	<.049	<.52	<.064	<.11	.079	.44	.81	1.2	.99	.56	1.0	<.17	2.2	.90	.64	1.5	<.042	10.8
47	04/29/2006	<.064	<.049	<.52	<.064	<.11	.043	.25	.41	.67	.56	.30	.54	<.076	1.2	.51	.37	.87	<.042	6.2
48	05/09/2006	<.064	<.049	<.52	<.064	<.11	.052	.32	.56	.93	.81	.40	.75	<.096	1.6	.72	.42	1.2	<.042	8.3
49	05/11/2006	<.064	<.049	<.52	<.064	<.11	<.031	.14	.32	.48	.47	.23	.40	<.064	.89	.38	.22	.67	<.042	4.8
52	05/24/2006	<.064	<.049	<.52	.13	<.11	.40	2.8	4.5	7.0	5.6	3.2	5.7	<.68	13	5.3	5.0	10	.053	63.1
55	06/09/2006	<.064	<.049	<.52	<.064	<.11	<.031	<.093	--	.37	.39	.17	.29	<.054	.59	.31	.24	.40	<.042	3.8
57	06/25/2006	<.064	<.049	<.52	<.064	<.11	<.031	.12	.28	.44	.46	.19	.33	<.081	.65	.36	.23	.50	<.042	4.1
58	07/11/2006	<.064	<.049	<.52	<.064	<.11	.047	.23	.47	.56	.55	.25	.44	<.058	.88	.44	.41	.69	<.042	5.5

Table 2–8. Particle-size distributions in the water-quality samples collected from the unswept section of USH 151 in Madison Wis.

[um, micrometers--, no event sample processed]

Event sampled	Percent less than								
	500 um	250 um	125 um	63 um	32 um	14 um	8 um	5 um	<2 um
1	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--
5	99.9	99.8	9.6	6.6	3.1	2.0	1.6	1.4	0.6
6	99.8	13.2	7.9	3.4	1.5	1.4	1.4	1.2	0.7
7	100.0	13.3	1.3	0.8	0.4	0.3	0.2	0.2	0.1
8	100.0	38.7	19.5	12.7	7.9	6.6	5.4	4.1	1.4
9	--	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--	--
11	99.8	22.2	12.9	6.5	4.3	3.2	2.9	2.6	1.4
12	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--
16	99.8	99.6	40.6	16.7	8.3	5.7	4.6	3.4	1.3
17	--	--	--	--	--	--	--	--	--
18	--	--	--	--	--	--	--	--	--
19	99.8	99.6	28.8	9.6	5.8	4.0	3.6	2.9	1.3
20	99.5	99.1	48.4	27.3	13.5	11.3	9.5	7.4	2.7
21	--	--	--	--	--	--	--	--	--
22	98.6	97.3	62.9	16.9	1.4	1.4	1.4	1.4	1.4
23	99.5	71.0	59.1	26.9	15.9	9.5	7.7	5.8	2.8
24	99.2	75.3	59.2	43.8	30.6	23.1	21.1	18.3	10.3
25	--	--	--	--	--	--	--	--	--
26	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--
28	100.0	100.0	0.7	0.5	0.4	0.3	0.3	0.2	0.1
29	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--
32	98.7	97.3	84.1	64.8	55.0	43.0	31.2	27.5	19.7
33	98.0	85.1	72.3	70.3	60.3	41.5	35.5	30.3	17.2
34	--	--	--	--	--	--	--	--	--
35	--	--	--	--	--	--	--	--	--
36	--	--	--	--	--	--	--	--	--
37	--	--	--	--	--	--	--	--	--
38	--	--	--	--	--	--	--	--	--
39	--	--	--	--	--	--	--	--	--
40	--	--	--	--	--	--	--	--	--
41	--	--	--	--	--	--	--	--	--
42	99.7	97.3	96.0	90.0	84.1	71.0	54.8	36.9	7.9
43	99.7	82.3	66.3	66.1	38.8	28.8	22.0	13.6	2.7
44	99.4	88.6	79.9	65.6	46.4	33.0	26.0	17.2	4.1
45	95.3	92.9	87.6	78.4	67.2	38.3	24.9	16.8	4.7
46	--	--	--	--	--	--	--	--	--

Event sampled	Percent less than								
	500 um	250 um	125 um	63 um	32 um	14 um	8 um	5 um	<2 um
47	98.6	90.8	85.4	72.6	56.4	27.6	21.1	14.4	5.4
48	91.0	90.0	85.9	76.7	62.7	36.5	29.8	23.1	10.0
49	92.6	86.6	77.9	69.1	51.2	29.5	24.0	18.4	7.8
50	96.0	93.0	79.5	64.7	51.7	20.0	13.6	8.6	2.7
51	--	--	--	--	--	--	--	--	--
52	100.0	32.2	15.1	9.5	7.1	4.5	3.2	2.1	0.5
53	94.0	84.8	60.7	31.6	18.6	11.4	10.0	7.7	2.7
54	--	--	--	--	--	--	--	--	--
55	93.2	91.3	85.7	70.2	53.6	42.3	37.0	29.1	9.4
56	95.9	88.3	66.1	36.7	17.4	11.8	6.0	4.0	2.0
57	98.2	93.4	85.3	75.0	39.0	33.1	29.0	26.5	22.8
58	98.4	84.2	69.6	37.0	26.7	22.0	15.5	12.7	9.3
59	99.7	65.9	45.3	29.1	16.2	12.9	9.5	7.6	4.9
60	98.8	82.8	64.8	36.8	22.0	21.3	20.3	20.1	18.9
61	86.0	67.1	46.5	28.7	12.8	11.0	8.1	6.5	4.3
62	88.6	71.6	47.0	32.8	22.8	20.2	15.7	12.6	8.8
63	90.6	68.8	46.2	31.4	19.5	17.0	12.4	9.5	5.0
64	--	--	--	--	--	--	--	--	--
65	99.9	91.8	76.1	59.7	51.5	48.7	37.8	24.2	6.9
66	99.0	96.4	90.4	79.9	66.1	57.4	38.6	25.9	11.0
67	--	--	--	--	--	--	--	--	--
68	99.3	94.2	86.4	69.6	51.7	47.9	40.9	38.6	34.5
69	87.6	71.9	53.5	36.4	27.2	26.3	25.3	24.9	21.7

Table 2–9. Particle size distributions for sediment samples collected in the bedload sampler located in the pipe draining the unswept section of USH 151 in Madison Wis.

[mm/dd/yyyy, month/day/year; µm, micrometer; >, greater than; <, less than; lb, pounds; --, no event sample processed]

Date (mm/dd/yyyy)	Event sampled	Percentages of Total Mass on Sieve							Total sediment trapped (lb)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
05/11/2005	5	2.2	9.5	29.1	36.4	13.6	4.7	4.4	0 .7
05/13/2005	6	5.1	19.0	33.2	34.5	7.3	.6	.4	7.1
05/18/2005	7	1.4	13.5	37.0	4.8	6.8	.3	.2	38.1
05/19/2005	8	2.2	11.5	37.0	41.6	6.6	.7	.4	21.8
05/22/2005	9	2.4	21.0	58.1	17.6	.6	.2	.2	6.6
05/27/2005	10	3.0	19.0	49.4	26.8	1.3	.2	.2	5.8
06/04/2005	11	2.9	23.8	51.9	19.0	1.8	.4	.3	3.4
06/09/2005	12	4.0	33.0	45.3	15.1	1.9	.4	.3	4.6
06/10/2005	13	2.8	27.3	48.0	19.6	1.9	.2	.2	6.9
06/14/2005	14	4.7	26.8	40.4	22.1	4.5	.9	.7	.9
06/25/2005	15	4.3	17.1	34.3	28.6	10.0	2.9	2.9	.2
06/28/2005	16	2.9	30.7	46.6	16.3	2.2	.7	.5	6.1
07/04/2005	17	3.9	32.3	42.5	15.9	3.5	1.2	.7	1.0
07/12/2005	18	3.0	24.7	46.4	20.9	3.2	1.0	.7	.9
07/21/2005	19&20	1.1	16.5	42.8	30.3	6.6	1.7	.9	2.1
07/23/2005	21	1.8	12.2	34.6	36.9	11.1	2.3	1.1	1.0
07/25/2005	22	1.3	13.5	37.6	35.4	9.7	1.7	.7	2.2
08/11/2005	23	1.5	8.8	27.8	37.6	18.0	4.4	2.0	.5

Date (mm/dd/yyyy)	Event sampled	Percentages of Total Mass on Sieve							Total sediment trapped (lb)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
08/18/2005	24	.9	10.4	28.9	41.9	13.2	2.4	2.3	1.3
09/19/2005	26	1.1	11.8	33.9	37.3	11.2	3.1	1.7	.8
09/21/2005	27	.4	7.5	38.7	46.1	6.0	.9	.5	4.6
09/25/2005	28	.3	12.9	48.0	33.9	3.8	.6	.4	5.0
09/28/2005	29	3.8	11.3	24.5	35.8	15.1	5.7	3.8	.1
10/17/2005	31	3.3	22.8	35.3	27.2	7.5	2.4	1.5	.7
10/23/2005	--	5.2	19.0	24.1	25.9	13.8	6.9	5.2	.1
10/30/2005	--	6.3	25.0	25.0	25.0	12.5	6.3	.0	.0
11/05/2005	32	5.2	34.4	27.1	14.6	8.3	4.2	6.3	.2
11/12/2005	--	3.6	17.9	21.4	21.4	17.9	10.7	7.1	.1
11/15/2005	33	11.1	24.7	29.6	17.3	8.6	3.7	4.9	.2
03/30/2006	42	2.9	13.9	20.0	22.6	26.5	9.0	5.2	.7
04/02/2006	43	20.2	18.9	26.3	28.2	5.3	.6	.5	10.8
04/06/2006	44	24.7	21.6	25.6	23.5	3.9	.4	.4	11.1
04/16/2006	45	22.2	20.3	26.3	26.2	4.2	.4	.4	12.8
04/19/2006	46	1.7	10.5	19.9	31.0	24.1	8.2	4.8	1.1
04/22/2006	--	2.0	9.8	26.8	38.6	17.0	3.3	2.6	.3
04/29/2006	47	2.3	16.9	38.3	35.5	5.0	1.0	1.0	3.2
05/01/2006	--	1.0	13.7	35.4	36.4	10.3	2.4	1.0	3.0
05/13/2006	50	.9	10.5	34.7	35.5	12.6	3.4	2.4	1.0
05/16/2006	51	.7	9.0	33.5	39.3	11.5	3.3	2.7	2.2
05/24/2006	52	1.9	16.8	44.4	33.7	2.9	.2	.2	12.0
05/25–05/29/2006	--	2.1	9.3	27.1	37.1	16.4	5.0	2.9	.3
06/06/2006	54	7.2	9.5	25.9	38.0	13.9	3.8	1.8	1.4
06/09–06/10/2006	55	2.3	9.3	27.9	27.9	16.3	9.3	7.0	.1
06/14/2006	56	3.8	21.8	30.8	28.8	9.5	3.0	2.5	.9
06/17–06/18/2006	--	5.4	15.8	28.8	33.3	11.3	3.6	1.8	.5
06/21/2006	--	4.0	8.0	16.0	32.0	24.0	12.0	4.0	.1
06/25–06/26/2006	57	3.5	19.3	41.1	28.7	5.0	1.4	.9	1.2
07/11/2006	58	2.9	14.5	35.1	34.7	10.0	1.9	.9	3.4
07/19/2006	59	13.4	29.5	37.6	16.9	2.1	.4	.2	33.8
07/25–07/26/2006	--	6.8	11.9	27.1	35.6	13.6	3.4	1.7	.1
07/27/2006	--	3.0	12.0	32.6	42.3	8.2	1.3	.6	2.0
07/30/2006	--	3.3	9.9	28.6	40.7	12.1	3.3	2.2	.2
08/06/2006	60	2.8	11.6	31.1	40.2	10.1	2.5	1.7	1.2
08/17/2006	--	4.6	9.2	24.6	35.4	15.4	6.2	4.6	.1
08/23/2006	61	7.0	25.6	39.0	22.7	4.3	.9	.5	15.7
08/24–08/28/2006	62 & 63	6.4	18.9	33.8	31.8	7.3	1.2	.6	7.2
08/28/2006	--	4.1	8.2	22.4	38.8	20.4	4.1	2.0	.1
09/03–09/04/2006	64	6.9	16.7	30.8	33.7	8.9	1.8	1.1	2.8
09/10–09/12/2006	--	2.7	9.4	26.9	45.5	12.3	2.1	1.1	2.4
03/09/2007	--	16.6	21.5	18.5	19.8	12.0	5.8	5.9	2.0
03/21/2007	65	9.7	17.0	28.7	29.7	11.0	2.4	1.6	18.6
04/24/2007	--	5.6	11.8	25.9	39.6	12.2	2.8	2.0	1.6
05/05/2007	--	8.7	20.7	37.2	28.5	3.9	.6	.3	26.7
05/13/2007	67	5.8	12.0	30.9	39.7	9.9	1.1	0.6	5.0
05/15/2007	68	3.8	17.5	34.2	36.9	6.5	0.6	0.4	8.4
06/18/2007	69	7.9	20.0	28.0	29.2	10.8	2.7	1.5	1.5

Table 2–10. Particle size distributions for street-dirt collected in the unswept section (sampled from curb to shoulder) of USH 151 in Madison Wis.

[mm/dd/yyyy, month/day/year; µm, micrometer; >, greater than; <, less than; lb, pounds; lb/cu-mi, pounds per curb-mile; US, unswept section; EB, east bound; WB, west bound; --, no event sample processed]

Date (mm/dd/yyyy)	Highway section	Percentages of Total Mass on Sieve							Total mass (lb/cu-mi)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
10/19/2004	Entire US section	15	15	20	26	16	6	3	331
10/25/2004	Entire US section	13	14	21	26	15	6	3	345
11/03/2004	Entire US section	22	13	19	24	14	6	2	281
11/08/2004	Entire US section	15	15	20	25	16	7	3	321
11/22/2004	Entire US section	23	14	22	23	11	4	2	183
11/29/2004	Entire US section	11	12	23	28	16	7	4	253
12/08/2004	Entire US section	11	11	21	28	17	8	5	244
04/04/2005	US EB	11	8	15	28	17	9	13	1,314
04/04/2005	US WB	9	9	18	24	14	9	16	771
04/04/2005	Entire US section	11	8	16	26	16	9	14	1,061
04/07/2005	US EB	16	8	14	25	18	10	10	892
04/07/2005	US WB	7	8	17	29	19	10	9	536
04/07/2005	Entire US section	13	8	15	26	18	10	10	726
04/11/2005	US EB	14	7	13	25	18	10	12	824
04/11/2005	WB	7	9	16	28	18	11	11	392
04/11/2005	Entire US section	12	8	14	26	18	10	12	623
04/18/2005	US EB	17	9	16	25	16	8	9	761
04/18/2005	US WB	7	10	23	34	15	7	4	695
04/18/2005	Entire US section	12	9	19	29	16	8	7	730
04/25/2005	US EB	25	10	15	24	14	6	5	900
04/25/2005	US WB	8	11	19	28	15	9	10	500
04/25/2005	Entire US section	20	10	17	25	14	7	7	714
05/04/2005	US EB	21	10	18	21	14	8	8	668
05/04/2005	US WB	8	13	21	24	13	9	11	513
05/04/2005	Entire US section	16	12	19	22	13	8	9	596
05/16/2005	US EB	22	11	18	24	14	7	5	1,123
05/16/2005	US WB	13	11	22	26	13	7	8	668
05/16/2005	Entire US section	19	11	19	24	14	7	6	911
05/23/2005	US EB	20	11	16	24	16	7	6	1,273
05/23/2005	US WB	14	9	17	26	19	9	6	387
05/23/2005	Entire US section	19	11	16	25	16	7	6	860
06/01/2005	US EB	25	13	17	20	13	6	5	1,041
06/01/2005	US WB	12	16	20	23	14	8	7	368
06/01/2005	Entire US section	22	14	18	21	13	7	5	728
06/06/2005	US EB	22	11	18	24	14	6	5	1,106
06/06/2005	US WB	14	16	25	44	34	24	25	318
06/06/2005	Entire US section	21	12	19	28	18	10	9	739
06/13/2005	US EB	28	15	20	20	10	5	3	808
06/13/2005	US WB	21	22	23	21	10	5	8	352
06/13/2005	Entire US section	26	16	21	20	10	5	4	596
06/20/2005	Entire US section	20	12	18	23	13	7	7	860
06/27/2005	Entire US section	28	15	19	55	10	4	3	670
07/06/2005	Entire US section	25	13	17	21	12	6	5	859
07/11/2005	Entire US section	20	11	18	24	14	7	5	1,037
07/18/2005	Entire US section	16	11	17	24	16	9	7	537

Date (mm/dd/yyyy)	Highway section	Percentages of Total Mass on Sieve							Total mass (lb/cu-mi)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
07/25/2005	Entire US section	22	18	19	21	12	5	3	285
08/01/2005	Entire US section	11	11	17	26	19	9	6	395
08/15/2005	Entire US section	17	12	18	24	16	8	6	304
08/22/2005	Entire US section	14	13	19	25	16	8	5	398
08/29/2005	Entire US section	14	13	19	25	16	8	6	408
09/07/2005	Entire US section	14	12	18	24	17	9	7	451
09/12/2005	Entire US section	17	13	18	22	15	9	6	353
09/26/2005	US EB	19	15	18	23	15	6	3	297
09/26/2005	US WB	17	27	26	20	6	2	3	404
09/26/2005	Entire US section	18	21	22	21	10	4	3	347
09/29/2005	US EB	16	13	18	26	16	7	4	375
09/29/2005	US WB	26	17	18	22	11	4	2	207
09/29/2005	Entire US section	19	14	18	25	14	6	3	297
10/10/2005	US EB	14	13	18	22	17	9	6	434
10/10/2005	US WB	20	15	19	23	13	6	5	194
10/10/2005	Entire US section	16	14	18	23	15	9	6	322
10/19/2005	US EB	14	14	19	23	16	9	5	420
10/19/2005	US WB	17	16	20	25	13	7	4	200
10/19/2005	Entire US section	15	14	19	24	15	8	5	317
10/24/2005	US EB	16	16	21	23	14	8	3	280
10/24/2005	US WB	21	15	19	23	13	6	4	176
10/24/2005	Entire US section	17	15	20	23	13	7	3	232
10/31/2005	US EB	19	16	20	21	13	7	4	332
10/31/2005	US WB	22	15	19	22	12	6	4	153
10/31/2005	Entire US section	20	15	20	22	13	7	4	249
11/07/2005	US EB	15	14	21	25	14	7	4	452
11/07/2005	US WB	25	15	19	22	11	5	3	136
11/07/2005	Entire US section	17	15	21	24	13	7	4	305
11/14/2005	US EB	14	13	18	24	16	9	5	339
11/14/2005	US WB	24	15	19	21	11	6	5	203
11/14/2005	Entire US section	17	14	18	23	15	8	5	276
04/06/2006	US EB	19	10	15	22	15	8	12	2,416
04/06/2006	US WB	12	9	16	24	12	8	20	984
04/06/2006	Entire US section	17	9	15	23	14	8	14	1,750
04/10/2006	US EB	10	7	13	23	19	12	16	2,393
04/10/2006	US WB	21	17	30	43	24	15	33	911
04/10/2006	Entire US section	15	11	20	31	21	13	23	1,703
04/17/2006	US EB	8	5	8	10	52	3	3	2,043
04/17/2006	US WB	17	13	24	39	22	11	10	976
04/17/2006	Entire US section	11	8	13	19	43	5	5	1,546
04/24/2006	US EB	16	10	17	26	15	8	9	2,757
04/24/2006	US WB	14	11	21	23	12	7	11	581
04/24/2006	Entire US section	16	10	17	25	15	7	9	1,743
04/24/2006	US EB – US section post sweeping	11	8	14	23	16	11	16	968
04/24/2006	US WB - section post sweeping	11	12	20	22	11	8	14	257
04/24/2006	Entire US section post sweeping	11	9	15	23	15	10	16	637
04/26/2006	US EB	15	10	14	21	14	10	17	890

Date (mm/dd/yyyy)	Highway section	Percentages of Total Mass on Sieve >2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	Total mass (lb/cu-mi)
04/26/2006	US WB	11	12	18	23	12	8	15	259
04/26/2006	Entire US section	14	10	15	21	14	10	16	596
04/27/2006	US EB	16	13	17	22	15	8	8	454
04/27/2006	US WB	13	13	19	22	12	8	13	232
04/27/2006	Entire US section	15	13	18	22	14	8	10	351
04/27/2006	US Piles EB	15	8	11	19	14	11	21	1,747
04/27/2006	Entire US section	15	10	13	20	14	10	18	958
05/03/2006	US EB	15	11	15	24	18	10	8	394
05/03/2006	US WB	8	12	21	27	14	8	11	234
05/03/2006	Entire US section	13	11	17	25	16	9	9	320
05/08/2006	US EB	13	10	17	28	17	9	7	403
05/08/2006	US WB	10	13	21	24	12	8	10	227
05/08/2006	Entire US section	12	11	18	27	16	9	8	321
05/10/2006	US EB	15	15	19	24	14	8	4	314
05/10/2006	US WB	17	14	20	25	12	6	4	180
05/10/2006	Entire US section	16	14	20	25	14	7	4	252
05/10/2006	US Piles EB	34	17	16	18	10	4	1	89
05/10/2006	US Piles WB	6	13	29	30	11	6	6	107
05/10/2006	Both Piles	19	15	22	24	11	5	4	299
05/10/2006	Entire US section & piles	17	14	21	24	13	6	4	325
05/22/2006	US EB	16	12	17	25	16	9	5	652
05/22/2006	US WB	13	11	21	25	13	8	8	301
05/22/2006	Entire US section	15	12	18	25	15	9	6	488
05/24/2006	US EB	15	11	15	23	16	10	9	618
05/24/2006	US WB	10	11	20	25	14	9	11	260
05/24/2006	Entire US section	14	11	17	23	15	10	10	451
05/25/2006	US EB	11	8	13	25	22	14	7	325
05/25/2006	US WB	7	13	22	32	17	5	3	323
05/25/2006	Entire US section	9	10	17	29	20	10	5	324
06/05/2006	US EB	15	10	14	24	19	11	6	373
06/05/2006	US WB	9	14	21	30	16	6	4	441
06/05/2006	Entire US section	12	12	18	27	18	9	5	404
06/07/2006	US EB	20	10	15	23	17	10	5	377
06/07/2006	US WB	11	15	24	30	14	5	3	436
06/07/2006	Entire US section	15	13	19	26	15	7	4	404
06/13/2006	US EB	13	10	18	30	17	8	5	547
06/13/2006	US WB	9	14	21	29	16	7	4	355
06/13/2006	Entire US section	11	11	19	29	17	7	5	458
06/14/2006	US EB	16	7	12	18	13	7	5	587
06/14/2006	US WB	9	14	22	29	15	6	5	354
06/14/2006	Entire US section	14	10	15	22	14	7	5	478
06/20/2006	US EB	20	12	17	24	15	7	3	388
06/20/2006	US WB	11	17	23	28	13	5	3	284
06/20/2006	Entire US section	17	14	20	26	15	6	3	339
06/20/2006	Large pile	30	19	23	19	7	2	1	1,107
06/20/2006	Entire US section & pile	22	16	21	23	11	4	2	592
06/21/2006	US EB	21	12	18	24	14	8	4	321
06/21/2006	US WB	10	16	23	27	14	5	4	314
06/21/2006	Entire US section	16	13	21	25	14	7	4	318
06/22/2006	US EB	21	12	18	25	14	7	3	426

Date (mm/dd/yyyy)	Highway section	Percentages of Total Mass on Sieve							Total mass (lb/cu-mi)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
06/22/2006	US WB	11	16	24	28	13	5	3	269
06/22/2006	Entire US section	17	13	20	26	14	6	3	353
08/14/2006	US EB	11	11	17	25	19	10	6	272
08/14/2006	US WB	15	15	20	25	14	6	5	216
08/14/2006	Entire US section	13	13	18	25	17	9	5	246
08/14/2006	*US EB - section post sweeping*	*14*	*12*	*15*	*21*	*17*	*12*	*8*	*130*
08/14/2006	*WB - US section post vacuum-assist sweeping*	*15*	*15*	*20*	*24*	*14*	*7*	*5*	*117*
08/14/2006	*Entire US section post vacuum-assist sweeping*	*14*	*13*	*17*	*23*	*16*	*10*	*7*	*124*
08/15/2006	US EB	12	12	16	24	17	11	7	130
08/15/2006	US WB	16	14	18	24	14	7	6	134
08/15/2006	Entire US section	14	13	17	24	16	9	7	132
08/16/2006	US EB	13	12	16	22	18	11	8	163
08/16/2006	US WB	12	14	19	24	14	8	7	139
08/16/2006	Entire US section	12	13	17	23	16	9	8	152
08/17/2006	US EB	13	10	14	23	18	12	8	166
08/17/2006	US WB	14	13	18	23	15	9	9	144
08/17/2006	Entire US section	13	11	15	23	17	11	8	156
03/20/2007	US EB	9	7	14	25	19	10	15	1,056
03/20/2007	US WB	14	10	18	24	12	6	14	933
03/20/2007	Entire US section	11	8	16	25	16	9	15	999
03/22/2007	US EB	11	7	12	23	20	14	13	437
03/22/2007	US WB	10	8	17	27	16	9	12	772
03/22/2007	Entire US section	11	8	15	25	17	11	13	593
03/23/2007	US EB	11	7	16	28	20	10	8	970
03/23/2007	US WB	9	8	18	29	15	8	12	889
03/23/2007	Entire US section	10	7	17	29	18	9	10	932
04/24/2007	US EB	15	10	19	26	15	8	6	776
04/24/2007	US WB	9	11	6	24	12	8	12	455
04/24/2007	Entire US section	13	10	15	25	14	8	8	627
04/24/2007	US Piles EB	32	15	18	21	10	3	1	627
04/24/2007	Entire US section & piles	20	12	16	24	13	6	6	849
04/25/2007	US EB	17	11	18	25	14	7	6	881
04/25/2007	US WB	11	11	23	27	14	8	7	408
04/25/2007	Entire US section	15	11	19	26	14	7	6	661
05/07/2007	US EB	14	11	20	28	16	7	5	782
05/07/2007	US WB	11	12	21	25	14	8	7	622
05/07/2007	Entire US section	13	11	20	27	15	8	6	708
05/14/2007	US EB	12	11	19	27	16	8	7	454
05/14/2007	US WB	8	11	23	29	13	7	16	362
05/14/2007	Entire US section	10	11	21	28	15	8	11	411
05/14/2007	US EB-pile	17	16	20	22	13	7	5	219
05/14/2007	Entire US section & piles	12	12	20	27	14	8	10	484
05/16/2007	US EB	18	13	19	25	13	7	5	494
05/16/2007	US WB	13	14	25	24	11	6	7	409
05/16/2007	Entire US section	16	13	22	24	12	6	6	454
05/16/2007	EB-pile	28	20	16	17	11	5	2	938
05/16/2007	Entire US section	17	14	21	24	12	6	6	453

Date (mm/dd/yyyy)	Highway section	Percentages of Total Mass on Sieve >2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	Total mass (lb/cu-mi)
06/18/2007	US EB	11	10	16	28	18	10	7	241
06/18/2007	US WB	16	18	19	21	13	7	6	249
06/18/2007	Entire US section	13	14	17	25	15	8	7	245
06/19/2007	US EB	13	12	19	29	16	7	4	293
06/19/2007	US WB	12	22	22	23	14	6	3	198
06/19/2007	Entire US section	12	18	21	25	14	7	3	249

Table 2–11. Particle size distributions for street dirt collected during the test of the mechanical broom street cleaner in the swept section (sampled from curb to shoulder) of USH 151 in Madison Wis.

[mm/dd/yyyy, month/day/year; µm, micrometer; >, greater than; <, less than; lb, pounds; lb/cu-mi, pounds per curb-mile ; SW, swept section; EB, east bound; WB, west bound; --, no event sample processed]

Date (mm/dd/yyyy)	Sweeper cleaning	Percentage of Total Mass on Sieve >2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	Total mass (lb/cu-mi)
10/19/2004	Pre	16	9	18	27	18	7	4	487
10/19/2004	Post	13	7	17	27	20	10	6	429
10/25/2004	Pre	16	10	18	25	19	8	3	342
10/25/2004	Post	12	7	18	28	20	9	5	288
11/03/2004	Pre	12	7	19	29	20	9	4	291
11/03/2004	Post	10	7	20	30	19	9	4	332
11/08/2004	Pre	8	7	19	29	21	10	5	304
11/08/2004	Post	6	6	18	29	22	12	5	289
11/22/2004	Pre	8	10	24	31	17	7	3	237
11/22/2004	Post	10	8	20	31	19	8	4	229
11/29/2004	Pre	6	8	20	31	21	10	5	293
11/29/2004	Post	5	6	18	31	22	12	7	273
12/08/2004	Pre	5	7	20	31	20	10	6	319
12/08/2004	Post	4	6	19	33	21	10	6	227
05/08/2006	Pre-EB	9	7	16	30	20	10	9	450
05/08/2006	Pre-WB	10	7	11	16	14	14	28	162
05/08/2006	Pre-combined SW	9	7	14	26	18	11	14	611
05/08/2006	Post-EB	5	5	14	30	21	11	12	325
05/08/2006	Post-WB	6	5	11	17	15	15	29	141
05/08/2006	Post- combined SW	6	5	13	26	19	13	17	466

Table 2–12. Particle size distributions for street dirt samples collected during the test of the vacuum assisted street cleaner in the swept section of USH 151 in Madison Wis.
[mm/dd/yyyy, month/day/year; µm, micrometer; >, greater than; <, less than; lb, pounds; ; SW, swept section; EB, east bound; WB, west bound; --, no event sample processed]

Date (mm/dd/yyyy)	Sweeper cleaning	Percentage of Total Mass on Sieve							Total mass (lb/cu-mi)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
04/04/2005	Pre	13	8	15	27	14	9	15	1,338
04/11/2005	Pre	14	7	14	27	16	9	13	1,120
04/14/2005	Pre	150	79	126	190	121	72	84	824
04/18/2005	Pre	14	9	17	27	15	8	10	1,038
04/18/2005	Post	9	4	11	20	16	14	25	270
04/25/2005	Pre	9	6	15	25	16	11	18	345
04/25/2005	Post	8	5	13	22	15	13	25	272
05/04/2005	Pre	7	6	12	19	14	13	29	262
05/04/2005	Post	7	5	11	17	14	13	32	200
05/16/2005	Pre	12	7	14	24	18	11	13	317
05/16/2005	Post	7	5	12	23	19	14	19	211
05/23/2005	Pre	9	6	14	27	21	13	10	312
05/23/2005	Post	7	5	11	25	22	15	14	193
06/01/2005	Pre	10	6	13	24	19	13	15	258
06/01/2005	Post	8	6	12	23	19	15	18	179
06/06/2005	Pre	9	7	14	24	19	13	14	190
06/06/2005	Post	6	5	12	24	20	16	17	129
06/13/2005	Pre	12	7	13	22	19	14	13	208
06/13/2005	Post	8	6	12	23	20	16	14	152
06/20/2005	Pre	12	7	14	23	19	13	12	203
06/20/2005	Post	7	6	13	23	19	15	17	144
06/27/2005	Pre	12	7	15	25	20	12	10	202
06/27/2005	Post	10	7	13	25	19	13	12	153
07/06/2005	Pre	11	7	15	26	20	12	9	193
07/06/2005	Post	10	6	13	25	21	14	10	155
07/11/2005	Pre	9	6	13	25	20	14	12	188
07/11/2005	Post	6	6	13	25	22	15	13	150
07/18/2005	Pre	11	6	14	24	20	14	11	187
07/18/2005	Post	9	7	13	24	21	16	11	146
07/25/2005	Pre	14	8	14	27	23	11	4	164
07/25/2005	Post	11	5	13	30	24	12	5	111
08/01/2005	Pre	8	5	13	28	23	13	9	162
08/01/2005	Post	6	5	13	28	24	14	9	115
08/15/2005	Pre	9	6	14	29	22	12	9	175
08/15/2005	Post	8	5	13	28	24	14	8	129
08/22/2005	Pre	9	6	13	29	23	12	8	221
08/29/2005	Pre	12	7	15	29	21	10	6	252
08/29/2005	Post	8	5	13	27	24	13	8	169
09/07/2005	Pre	8	6	13	26	22	13	12	196
09/12/2005	Pre	10	6	13	24	21	13	13	239
09/21/2005	Pre-EB	12	8	14	26	22	12	7	288
09/21/2005	Pre-WB	13	6	13	22	21	14	11	140
09/21/2005	Pre-entire SW	12	7	14	25	22	12	8	217
09/21/2005	Post-EB	10	7	14	26	23	14	7	183
09/21/2005	Post-WB	11	5	13	22	20	16	12	107

Date (mm/dd/yyyy)	Sweeper cleaning	Percentage of Total Mass on Sieve							Total mass (lb/cu-mi)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
09/21/2005	Post-entire SW	10	7	13	24	22	14	9	146
09/26/2005	Pre-EB	13	8	15	28	21	10	5	225
09/26/2005	Pre-WB	15	8	15	28	21	9	4	101
09/26/2005	Pre-entire SW	8	7	16	27	23	13	6	165
10/03/2005	Pre-EB	12	8	15	27	22	11	6	377
10/03/2005	Pre-WB	12	8	16	28	22	10	5	159
10/03/2005	Pre-entire SW	13	7	14	24	21	13	9	272
10/03/2005	Post-EB	7	6	14	28	25	13	6	224
10/03/2005	Post-WB	9	6	14	25	22	14	10	118
10/03/2005	Post-entire SW	8	6	14	27	24	13	7	173
10/10/2005	Pre-EB	9	7	14	25	23	14	8	296
10/10/2005	Pre-WB	10	7	14	26	22	13	8	158
10/10/2005	Pre-entire SW	6	6	14	24	26	17	8	230
10/19/2005	Pre	9	7	16	26	22	13	7	230
10/19/2005	Post	9	6	14	25	22	15	9	159
10/25/2005	Pre-EB	11	8	16	28	21	11	5	214
10/25/2005	Pre-WB	9	6	14	24	24	16	7	119
10/25/2005	Pre-entire SW	10	8	16	26	22	13	5	168
10/31/2005	Pre	8	7	16	27	21	13	7	162
11/07/2005	Pre	10	8	16	26	20	12	7	203
11/07/2005	Post	9	5	14	25	22	15	10	134
11/08/2005	Pre	8	6	14	25	23	16	8	142
11/09/2005	Pre	8	6	15	26	22	14	9	142
11/14/2005	Pre-EB	10	8	16	25	20	14	9	194
11/14/2005	Pre-WB	11	6	13	20	22	17	11	111
11/14/2005	Pre-entire SW	10	7	15	23	20	15	9	154
04/05/2006	Pre-EB	12	9	17	27	16	8	12	1,953
04/05/2006	Pre-WB	15	11	14	16	13	11	20	783
04/05/2006	Pre-entire SW	13	10	16	24	15	9	14	1,390
04/05/2006	Post-EB	10	6	10	20	19	13	21	423
04/05/2006	Post-WB	12	8	10	13	13	14	30	197
04/05/2006	Post-entire Swept	11	7	10	18	17	13	24	315
04/06/2006	Pre-EB	10	6	11	22	18	12	20	367
04/06/2006	Pre-WB	10	8	11	13	13	13	33	403
04/06/2006	Pre-entire SW	10	7	11	17	15	12	27	384
04/10/2006	Pre-EB	10	7	13	23	19	12	16	452
04/10/2006	Pre-WB	9	6	8	12	13	15	37	339
04/10/2006	Pre-entire SW	10	7	11	18	16	13	24	398
04/24/2006	Pre-EB	11	8	15	24	16	11	15	378
04/24/2006	Pre-WB	11	8	10	13	11	13	34	394
04/24/2006	Pre-entire SW	11	8	13	19	14	12	23	386
04/24/2006	Post-EB	9	9	15	25	16	10	16	330
04/24/2006	Post-WB	8	5	9	13	13	15	38	217
04/24/2006	Post-entire SW	9	8	13	20	15	12	24	276
03/20/2007	Pre-EB	10	10	17	27	17	8	11	2,080
03/20/2007	Pre-WB	15	13	17	19	13	8	15	852
03/20/2007	Pre-entire SW	12	11	17	25	15	8	12	1,488
03/20/2007	Post-EB	7	6	11	25	21	11	19	591
03/20/2007	Post-WB	12	10	14	18	13	9	23	373

Date (mm/dd/yyyy)	Sweeper cleaning	Percentage of Total Mass on Sieve							Total mass (lb/cu-mi)
		>2000 (µm)	1,000-2000 (µm)	500-1000 (µm)	250-500 (µm)	125-500 (µm)	63-125 (µm)	< 63 (µm)	
03/20/2007	Post-entire SW	9	7	12	22	18	10	20	486
05/07/2007	Pre-EB	11	10	18	32	16	7	6	1,400
05/07/2007	Pre-WB	20	12	13	16	13	13	13	302
05/07/2007	Pre-entire SW	12	10	17	30	16	8	7	871
05/07/2007	Post-EB	8	6	14	26	19	12	14	346
05/07/2007	Post-WB	10	8	12	16	13	14	14	201
05/07/2007	Post-entire SW	9	7	13	22	17	13	14	276

Table 2–13. Street-dirt accumulation rates for the unswept section and swept sections of USH151 in Madison Wis.

[mm/dd/yyyy, month/day/year; EB, east bound; WB, west bound; UW, water-quality section; SW, swept section;--, no sample processed for event]

Start Date (mm/dd/yyyy)	Site	Accumulation days	Pounds per curb-mile						Season
			EB yield on start date	EB yield after accumulation days	WB yield on start date	WB yield after accumulation days	Entire section of highway yield on start date	Entire section of highway yield after accumulation days	
10/19/2004	US	6	--	--	--	--	331	345	Fall
10/19/2004	US	15	--	--	--	--	331	281	Fall
11/03/2004	US	5	--	--	--	--	281	321	Fall
10/19/2004	US	20	--	--	--	--	331	321	Fall
10/25/2004	US	9	--	--	--	--	345	281	Fall
10/25/2004	US	14	--	--	--	--	345	321	Fall
11/08/2004	US	14	--	--	--	--	321	183	Fall
04/07/2005	US	4	892	824	536	392	726	623	Spring
04/11/2005	US	7	824	761	392	695	623	730	Spring
07/06/2005	US	5	--	--	--	--	859	1037	Summer
08/29/2005	US	9	--	--	--	--	408	451	Summer
08/29/2005	US	14	--	--	--	--	408	353	Summer
09/07/2005	US	5	--	--	--	--	451	353	Fall
10/19/2005	US	5	420	280	200	176	317	232	Fall
04/24/2006	US	2	968	890	257	259	637	596	Spring
04/26/2006	US	1	890	454	259	232	596	351	Spring
05/03/2006	US	5	394	403	234	227	320	321	Summer
05/22/2006	US	2	652	618	301	260	488	451	Summer
06/13/2006	US	1	547	587	355	354	458	478	Summer
06/20/2006	US	1	388	321	284	314	339	318	Summer
06/21/2006	US	1	321	426	314	269	318	353	Summer
08/14/2006	US	1	130	130	117	134	124	132	Summer
08/15/2006	US	1	130	163	134	139	132	152	Summer
08/16/2006	US	1	163	166	139	144	152	156	Summer
08/14/2006	US	2	130	163	117	139	124	152	Summer
08/15/2006	US	2	130	166	134	144	132	156	Summer
08/14/2006	US	3	130	166	117	144	124	156	Summer

Start Date (mm/dd/yyyy)	Site	Accumulation days	Pounds per curb-mile						Season
			EB yield on start date	EB yield after accumulation days	WB yield on start date	WB yield after accumulation days	Entire section of highway yield on start date	Entire section of highway yield after accumulation days	
04/24/2007	US	1	776	881	455	408	627	661	Spring
10/19/2004	SW	6	--	--	--	--	429	342	Fall
10/25/2004	SW	9	--	--	--	--	288	291	Fall
11/03/2004	SW	5	--	--	--	--	332	304	Fall
08/29/2005	SW	9	--	--	--	--	169	196	Fall
09/07/2005	SW	5	--	--	--	--	196	239	Fall
10/19/2005	SW	5	--	--	--	--	159	168	Fall
11/07/2005	SW	1	--	--	--	--	134	142	Fall
11/08/2005	SW	1	--	--	--	--	142	142	Fall
11/07/2005	SW	1	--	--	--	--	134	142	Fall
04/05/2006	SW	1	423	367	197	403	315	384	Spring
06/13/2005	SW	7	--	--	--	--	152	203	Summer
07/06/2005	SW	5	--	--	--	--	155	188	Summer

Table 2–14. Street-dirt wash-off yields from USH 151 in Madison Wis.

[mm/dd/yyyy, month/day/year; in., inches; lb/curb-mi, pounds per curb-mile; SS, suspended sediment; lb,pound; US, unswepted section; SW, swept section]

Vacuum or rain date(mm/dd/yyyy)	Highway Section	Accumulation days	Event Sample	Precipitation (in.)	Intense (rain/ duration)	SS (lb)	Street dirt yielding (lb/curb-mi.)			Difference after washoff event (lb/curb-mi.)		
							Entire Highway	East Bound	West Bound	Entire Highway	East Bound	West Bound
04/04/2005	US	6.6					1,061	1,314	771			
04/06/2005			1	0.98	0.28	2,427				335	422	234
04/07/2005							726	892	536			
04/11/2005	SW						1,120					
04/12/2005		5.3	2	0.49	0.06					296		
04/14/2005							824					
9/26/2005	US	.2					347	297	404			
9/28/2005			29	.25	1.4	2				50	78	197
9/29/2005							297	375	207			
04/24/2006	US						637	968	257			
04/25/2006		3.0	na	0.06	0.03	na				41	78	-2
04/26/2006							596	890	259			
05/08/2006	US						321	403	227			
05/09/2006		7.5	48	0.41	0.06	11				69	89	47
05/10/2006							252	314	180			
05/24/2006	US						451	618	260			
05/24/2006		7.1	52	1.38	2.86	885				127	293	-63
05/25/2006							324	325	323			
06/05/2006	US						404	373	441			
06/06/2006		3.6	54	0.18	0.04	2				0	-4	5
06/07/2006							404	377	436			
03/20/2007	US						999	986	933			
03/21/2007		6.4	65	1.01	0.32	508				406	578	161
03/22/2007							593	408	772			
04/24/2007	US						627	725	455			
04/24/2007		1.3	na	0.86	0.06					-34	-98	47
04/25/2007							661	823	408			
05/14/2007	US						411	424	362			
05/15/2007		2.1	68	0.63	0.15	15				-43	-67	-204
05/16/2007							454	357	566			
06/18/2007	US						245	241	249			
06/18/2007		12.0	69	0.3	0.26	3				-4	-95	77
06/19/2007							249	336	172			

Table 2–15. Event load for solids analyzed in water-quality samples collected from the unswept section of USH151 in Madison Wis.

[All loads in pounds]

Event	Suspended sediment	Suspended solids, total	Solids, dissolved	Solids, Volatile
1	2427	--	--	--
2	17	11	--	--
3	53	35	--	--
4	3	--	--	--
5	204	126	41	--
6	96	39	15	--
7	1111	628	48	--
8	495	332	28	--
9	76	3	--	--
10	161	5	--	--
11	32	20	11	--
12	5	5	--	--
13	6	3	--	--
14	5	4	--	--
15	4	3	--	--
16	22	--	--	--
17	6	8	7	--
18	4	3	7	--
19	133	56	--	--
20	62	50	--	--
21	16	12	11	--
22	9	10	12	--
23	11	11	11	--
24	10	9	--	--
25	9	8	--	--
26	11	8	9	--
27	50	31	--	--
28	2452	--	--	--
29	2	2	4	--
30	6	2	8	--
31	1	1	5	--
32	11	11	--	--
33	4	4	--	--
34	1	0.5	13	--
35	11	10	20	--
36	7	6	35	--
37	35	32	34	--
38	26	25	159	--
39	14	14	55	--
40	82	76	186	--
41	38	38	43	--
42	15	15	30	--
43	90	84	44	--
44	23	21	29	3
45	26	27	20	5
46	4	4	11	--
47	20	21	33	5
48	11	10	39	3

Event	Suspended sediment	Suspended solids, total	Solids, dissolved	Solids, Volatile
49	8	9	19	3
50	19	20	--	--
51	15	14	21	--
52	41	34	--	27
53	921	624	22	--
54	16	17	7	--
55	2	3	11	2
56	6	8	16	--
57	17	--	--	3
58	8	9	--	5
59	21	22	--	8
60	109	67	--	--
61	13	10	--	22
62	143	123	--	--
63	36	29	--	--
64	124	96	--	--
65	11	8	6	--
66	508	474	157	--
67	5	4	--	--
68	--	--	--	--
69	--	--	--	--

Table 2–16. Event Loads for constituents analyzed in water-quality samples collected from the unswept section of USH 151 in Madison Wis.
[All values in pounds;--, no sample processed for event]

Sampled event number	Chemical oxygen demand, total	Phosphorus, total	Phosphorus, dissolved	Chloride, dissolved	Copper, dissolved	Copper, total recoverable	Zinc, dissolved	Zinc, total recoverable	Calcium, total recoverable	Magnesium, total recoverable
1	--	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--
5	20.7	0.10	.02	9.79	.0019	.0065	.0043	.0496	14.9	5.2
6	9.4	.03	.01	3.57	.0006	.0026	.0014	.0113	2.4	.6
7	25.5	.59	.03	12.07	.0022	.1738	--	.3740	5.2	1.0
8	3.3	.22	.02	4.90	.0019	.0509	.0045	.2459	15.5	6.4
9	--	--	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--	--	--
11	6.3	.02	.01	1.81	.0005	.0061	.0009	.0156	1.2	.3
12	--	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--	--	--
16	5.3	.01	.01	--	.0003	.0033	.0006	.0209	1.5	.6
17	--	--	--	--	--	--	--	--	--	--

Sampled event number	Chemical oxygen demand, total	Phosphorus, total	Phosphorus, dissolved	Chloride, dissolved	Copper, dissolved	Copper, total recoverable	Zinc, dissolved	Zinc, total recoverable	Calcium, total recoverable	Magnesium, total recoverable
18	--	--	--	--	--	--	--	--	--	--
19	30.6	.12	.04	1.69	.0017	.0155	.0084	.0808	7.6	3.1
20	16.4	.10	.06	3.10	.0014	.0077	.0058	.0415	4.9	1.7
21	--	--	--	--	--	--	--	--	--	--
22	3.2	.05	.01	2.76	.0005	.0206	--	.1560	1.8	.5
23	7.3	.02	.01	2.45	.0005	.0018	--	.0159	1.1	.4
24	8.8	.03	.02	1.65	.0011	.0020	--	.0116	1.2	.3
25	--	--	--	--	--	--	--	--	--	--
26	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--
32	9.3	.04	.03	1.86	.0014	.0037	.--	.0247	3.3	.5
33	5.3	.02	.01	--	.0003	.0016	--	.0102	1.0	.2
34	--	--	--	7.75	--	--	--	--	--	--
35	--	--	--	6.29	--	--	--	--	--	--
36	--	--	--	19.96	--	--	--	--	--	--
37	--	--	--	12.96	--	--	--	--	--	--
38	--	--	--	94.23	--	--	--	--	--	--
39	--	--	--	--	--	--	--	--	--	--
40	--	--	--	--	--	--	--	--	--	--
41	--	--	--	--	--	--	--	--	--	--
42	--	--	--	--	--	--	--	--	--	--
43	18.8	.06	.02	11.10	.0015	.0150	--	.0805	13.6	3.9
44	10.9	.03	.01	7.53	.0011	.0044	.0035	.0260	5.0	1.2
45	9.8	.04	.01	3.97	.0010	.0048	.0025	.0283	4.8	1.4
46	--	--	--	--	--	--	--	--	--	--
47	10.8	.05	.02	6.26	.0011	.0049	.0079	.0380	6.1	1.1
48	10.3	.03	.01	3.47	.0015	.0044	.0044	.0238	1.8	.4
49	8.7	.03	.02	3.85	.0015	.0042	.0090	.0246	2.7	.3
50	--	--	--	--	--	--	--	--	--	--
51	10.1	.03	.01	5.45	.0014	.0051	.0040	.0287	2.9	.7
52	--	--	--	--	--	--	--	--	--	--
53	41.5	.43	.10	3.72	.0031	.0715	.0113	.2343	61.3	26.8
54	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--
56	8.8	.03	.01	--	.0009	.0034	.0021	.0171	1.7	.3
57	--	--	--	--	--	--	--	--	--	--
58	1.2	.03	.02	4.50	.0010	.0031	.0023	.0224	2.2	.4
59	11.1	.04	.02	2.39	.0021	.0284	.0045	.0384	4.5	.9
60	18.3	.07	.03	2.18	.0012	.0094	.0035	.0599	9.2	3.9
61	--	--	--	--	--	--	--	--	--	--
62	29.4	.12	.05	--	.0009	.0349	.0074	.0790	14.4	5.8
63	--	--	--	--	--	--	--	--	--	--
64	--	--	--	--	--	--	--	--	--	--

Sampled event number	Chemical oxygen demand, total	Phosphorus, total	Phosphorus, dissolved	Chloride, dissolved	Copper, dissolved	Copper, total recoverable	Zinc, dissolved	Zinc, total recoverable	Calcium, total recoverable	Magnesium, total recoverable
65	--	--	--	--	--	--	--	--	--	--
66	80.2	.29	.03	57.24	.0036	.0569	.0112	.3513	68.0	21.4
67	--	--	--	--	--	--	--	--	--	--
68	--	--		--	--	--	--	--	--	--
69	--	--		--	--	--	--	--	--	--

Appendix 3 Description of the WinSLAMM Model

The primary capabilities of WinSLAMM, a software modeling program, include predicting volumes and contaminant loads that reflect a broad variety of development conditions and the use of many combinations of common urban runoff control practices (Pitt and Voorhees, 2002). WinSLAMM calculates mass balances for both particulate and dissolved pollutants and runoff volumes for different development characteristics and rainfalls. Control practices evaluated by WinSLAMM include disconnections of pavements and roofs, rain gardens, amended soils, detention ponds, infiltration devices, porous pavements, rain barrels and cisterns for on-site re-use, grass swales, catchbasin cleaning, and street cleaning. These controls can be evaluated in many combinations and at many source areas as well as the outfall location. WinSLAMM also predicts the relative contributions or volumes of different source areas (roofs, streets, parking areas, landscaped areas, undeveloped areas, etc.) for each land use investigated. WinSLAMM is based on actual field observations, with minimal reliance on pure theoretical processes that have not been adequately documented or confirmed in the field.

Special emphasis has been placed on small storm hydrology and particulate washoff in WinSLAMM. Many currently available urban runoff models have their roots in drainage design where the emphasis is with very large and rare rainfalls. In contrast, stormwater quality problems are mostly associated with common and relatively small rainfalls. The assumptions and simplifications that are legitimately used with drainage design models are not appropriate for water-quality models. WinSLAMM incorporates small storm hydrology and stormwater control practices to predict the sources of volumes and runoff pollutants for each event. WinSLAMM needs to be accurately calibrated and verified as part of any local stormwater management effort.

WinSLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rainfalls, development characteristics, and stormwater control practices. Some of the major users of WinSLAMM have been associated with the Nonpoint Source Pollution Control Program of the Wisconsin Department of Natural Resources, where WinSLAMM has been used for a number of years to support their extensive urban stormwater planning and cost-sharing program (Thum and others, 1990, Kim, et al. 1993a and 1993b, Ventura and Kim 1993, Bachhuber 1996, Bannerman, et al. 1996, Haubner and Joeres 1996, and Legg, et al. 1996). Many of these applications have included the integrated use of SLAMM with GIS models.

Appendix 3–1. Calculations of Street-Dirt Accumulation Rate in WinSLAMM

Version 9.2 of WinSLAMM does not calculate an accumulation rate for highways (the landuse is freeway in the WinSLAMM model), but for the other land uses the initial rate after a street cleaning or runoff event is 15 lb/cu-mi/day. A decay coefficient reduces the accumulation rate after 15 days for residential and 5 days for non-residential. The decay coefficient is an attempt to account for losses due to wind and turbulence caused by cars. Daily accumulations for smooth and intermediate textures are reduced by 0.75 and 0.5 for rough streets. A winter load can be added to the model to account for street dirt build-up over the winter months. WDNR has prescribed loads set at 2500 lb/cu-mi for smooth and intermediate streets and 2750 lb/cu-mi for rough streets. Accumulation does not occur in the model if the street loads are above at 675 lb/cu-mi for smooth and intermediate streets and 825 for rough streets. The following is the street-dirt accumulation rate equation in the model that needs to be added for highways is:

$$SDLoad_i = SDLoad_{i-1} + SDDepRate * \mathrm{AccRateReduFrac}^{(i-1)} * (PerNum-1) * NumDays$$

where

$SDLoad_i$	is the street dirt load at the end of a given time period (lbs/curb-mi);
$SDLoad_{i-1}$	is the street dirt load at the end of the pervious time period (lbs/curb-mi);

i	is the time period number that a given street dirt accumulation rate is applied;
SDDepRate	is the street dirt deposition rate (lbs/curb-mi);
AccRateReduFrac	is the fraction of deposition rate is reduced by, for each time period due to fugitive dust losses;
PerNum	is the time period number;
NumDays	is the number of days per time period.

This equation would be modified for highways using the street-dirt data collected during this study. Sufficient data was collected to determine a starting street load each spring (winter load), an initial street load after each rainfall and cleaning event, and a decay coefficient.

Appendix 3–2 Calculation of Street-Dirt Washoff in WinSLAMM

The washoff routine in WinSLAMM produces a particulate solids load transported from the street to be added with the other source area loads to compute a final watershed particulate load. Washoff is dependent on the available street dirt, rainfall intensity, and runoff capacity to loosen and transport street dirt. Pervious studies have shown only a portion of the street dirt is available for washoff and the amount available for washoff is dependent on the street texture condition (Pitt and others, 2004). For each runoff event, the model produces an availability factor and proportionality constant (K) based on high (12 mm/hr) and low rainfall intensity (3 mm/hr) and high and low street-dirt load (defined by this study for highways). These two factors are used in the following equations to produce a final washoff load.

$$N_0 = \text{Beforeeventload} * \text{Availability Factor}$$

$$N^* = N_0 \exp(-K^*\text{Rain}^*25.4)$$

$$\text{Unavailafterrain} = \text{Beforeeventload} - N_0$$

$$\text{Afteventload} = \text{unavailafterain} + N^*$$

Washoff = beforeventload - afterventload

where

N_0	is the portion of the total street dirt available for washoff (lb/cu-mi);
Before eventload	is the street dirt immediately before rainfall or street clean event (lb/cu-mi);
Availability Factor	is the street dirt available for load based on rainfall intensity
$N*$	is the residual street dirt after rainfall (lb/cu-mi);
K	is the proportionality constant
Unavailafterrain	is the total loading unavailable for washoff after a rainfall (lb/cu-mi);
Afteventload	is the total loading on the street after the event (lb/cu-mi); and
Washoff	is the street dirt contained in runoff (lb/cu-mi).

Sufficient washoff data was collected in this study to adjust the street-dirt washoff when equations are added to WinSLAMM for highways. The changes in the accumulation and washoff equations will be tested by plotting the changes in street dirt over time using the measured precipitation. This plot will be compared to a plot of the measured data (fig. 3–2). Once the accumulation and washoff equations provide a reasonable match to the measured street-dirt yields, changes in the models productivity equations that predict street cleaner efficiency can be made.

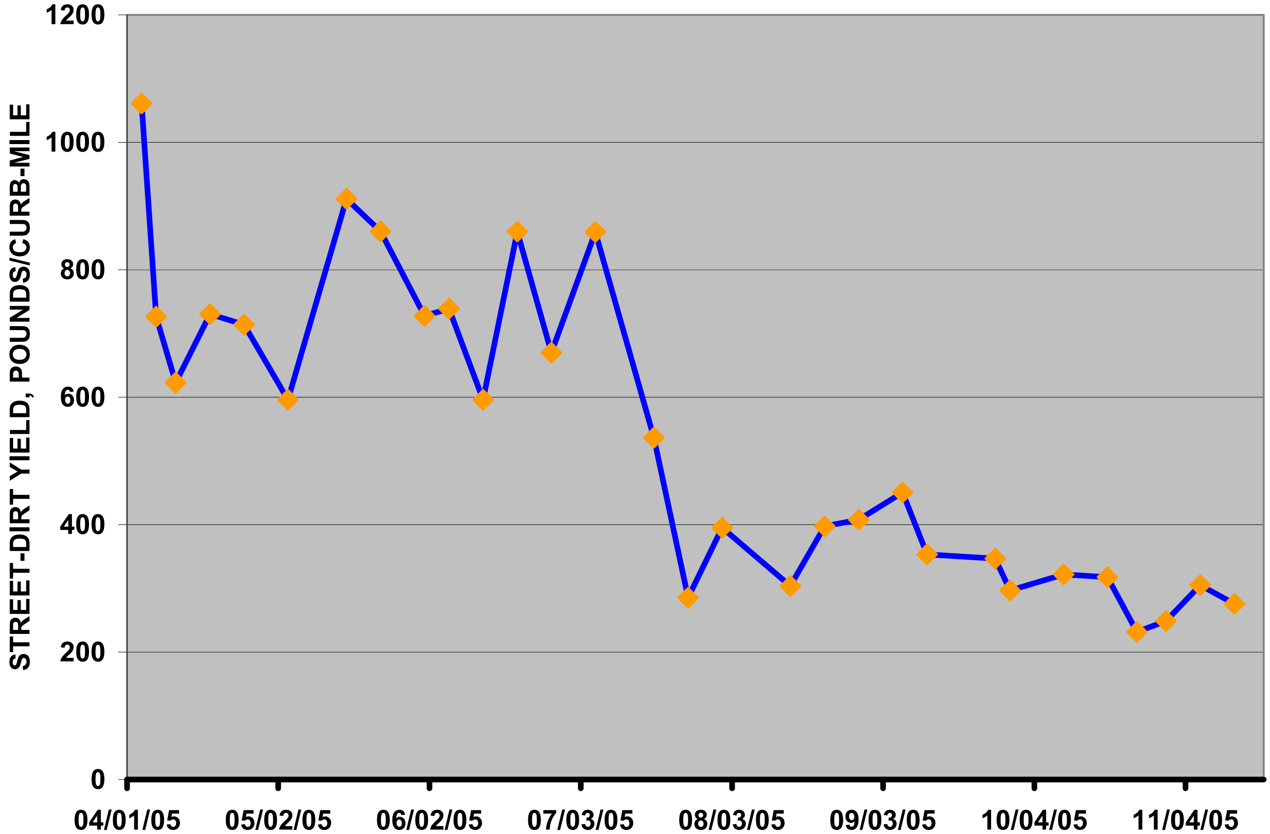


Figure 3-1. Measured changes in street-dirt yield over time at the unswept section.

Appendix 3–3 Calculations of Street Cleaner Effectiveness in WinSLAMM

WinSLAMM calculates a reduction in TSS loads and concentrations for a variety of street cleaning programs. For both a broom and vacuum assisted street cleaner the model will vary TSS loads and concentrations with cleaning frequency, parking density, parking controls, and landuse. The model tracks changes in street dirt based on the amount of accumulation, washoff by runoff events and removal by street cleaning. The accumulation and washoff equations are already described in previous sections. Pickup efficiency data from previous street cleaner studies (Pitt, 1985; Selbig and others, 2007a) have been used to develop a set of 40 productivity coefficients for the model. The coefficients were derived from plots of before and after street cleaning street dirt loads. Some combination of street texture, parking density, parking controls, and landuse is unique street cleaning productivity. A linear equation is used in the model to describe the street cleaning productivity for each combination. That equation is:

$$Y = Mx + B$$

where

Y is the residual street-dirt yield after street cleaning (lbs/curb-mile);

X is the before street cleaning yield (lbs/curb-mile);

M is the slope based street-dirt cleaning (less than 1); and

B is the intercept street yield below which sweeping has no beneficial impact (> or = to 1).

Pickup efficiency data from this study could be used to develop plots of before and after street cleaning street dirt yields. Linear equations describing the plots will provide coefficients to modify the existing coefficients in the model (fig. 17). These new coefficients will be unique to urban highways. Since the data for this study does not support a plot for every combination of street texture, parking density, and parking controls, the coefficients for some of the street sweeping productivities will be modified to follow the trends the existing coefficients for residential and commercial streets. Trends in landuse will not be a factor, because urban highways are one landuse. Changes in parking density and parking control are usually not a factor for urban highways, so it is probably more important to carefully modify the coefficients for street texture.

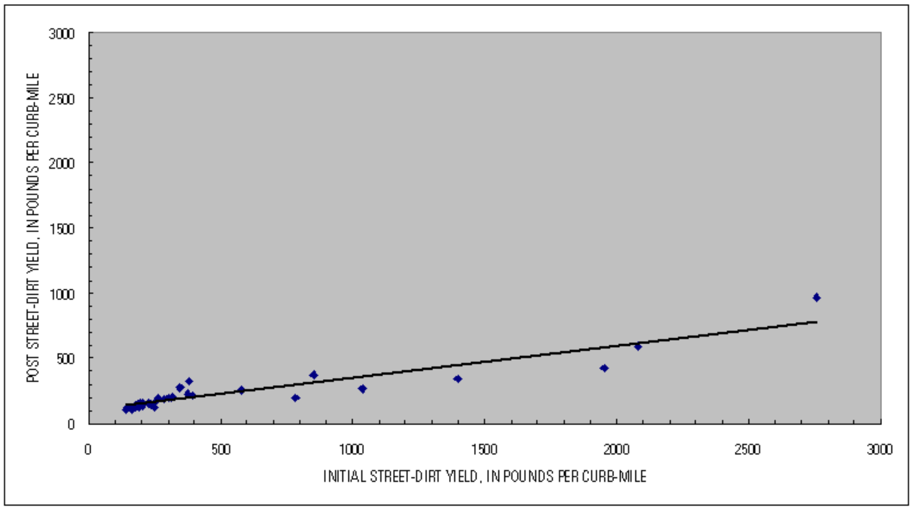


Figure 3-2. Post cleaning street dirt yields as a function of initial street dirt yields for the vacuum assisted street cleaner.

Appendix 3–4 Calculations of Runoff Volumes in WinSLAMM

WinSLAMM calculates volume by volumetric runoff coefficient curves developed for 13 source areas, such as textured streets, parking lots and pervious area. Each runoff coefficient curve was developed using 17 rainfall depths and the model produces runoff by interpolates between the 17 rainfalls depths. Each rainfall depth includes an initial abstraction that represents losses due to interception, infiltration or surface storage. The runoff curve for pervious areas (such as lawn) on a silt soil has a 100 percent abstraction until 0.39 inches of precipitation, whereas runoff curve for street has produces volume at the lowest rainfall depth that increases that gradually increases with rainfall depth. The runoff coefficient curve developed for highways will probably be similar to the curve already in WinSLAMM for intermediate streets (fig. 22). Precipitation depths at 0.1 in. produce a runoff coefficient of 30 percent and a precipitation of 2 in. produces a runoff coefficient of about 90 percent.

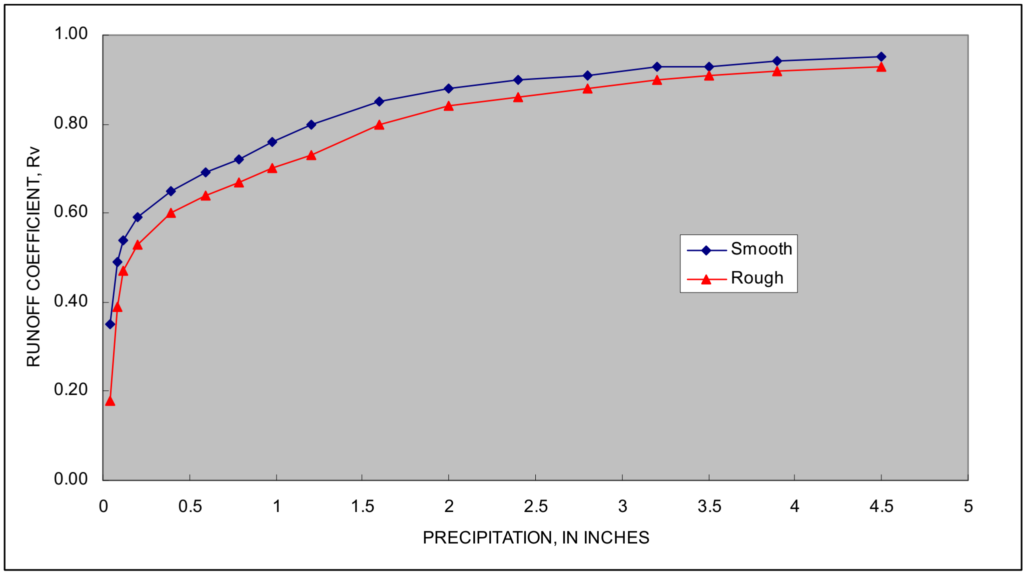


Figure 3-3. Street-runoff coefficients used in WinSLAMM.

Appendix 3–5 Calculation of Contaminant Concentrations & Loads in WinSLAMM

The highway pavement is one source area in the highway (freeway) land use in WinSLAMM. The wash off and accumulation method used for calculation streets loadings in WinSLAMM is a necessity for the highways landuse. The existing method depends on average traffic counts and paved area concentration to estimate TSS concentrations. Once the freeway section of the model has been modified to include the accumulation and wash-off equations, the model will be calibrated and verified using the runoff events monitored at the unswept section. Modeled TSS concentrations and loads will be compared to measured concentrations and loads (tables 2–5 and table 2–15). If the modeled numbers are not reasonably close to the measured numbers, the modeled numbers will be modified using the street delivery parameter file in the model. Because the TSS concentration measured in the pipe does not usually account for all the larger particles included in the wash-off equation, the street delivery file is sometimes needed to reduce the concentrations predicted by the wash-off equation. Also, the file will help adjust the TSS concentration to account for any deposition of sediment that might have occurred in the pipe.

For other constituents in highway pavement runoff, such as TZn and TP, WinSLAMM has a pollutant probability distribution file (extension .ppd) that contains a concentration for the particulate and dissolved form of each constituent. The particulate form is in units of mass (mg/kg) determined by dividing measured TSS concentration into measured constituent concentrations. The dissolved form is put in the model as a concentration (mg/l). The geometric mean of these measured concentrations is put into the probability distribution (.ppd) file. A particulate constituent load for each event is calculated by multiplying the event volume times constituent concentrations in the ppd file times the TSS mass estimated for the event. Dissolved loads for each constituent are computed by multiplying the geometric mean of the measured dissolved concentrations in the ppd file by an event volume. The dissolved and particulate loads are added together to produce the total constituent load.

Concentrations from this study will be put into the pollutant probability distribution file for highway pavement as a source area in the freeway land use. Other source areas, such as lawns, will not have their concentrations changed. The loads and concentrations estimated by the model will be compared to the loads observed for the unswept section of the study area (table 2–6 and table 2–16). It is unlikely any of geometric means determined from the measured values will be changes. If a large difference is observed between the measured and estimated load for the other constituents, the adjustment will be accomplished with the street delivery file. This has not been necessary for previous calibration efforts for the model, because the model is usually working well after the calibration of the volume and TSS loads.

Appendix 4 Street Sweeping Maintenance & Literature

Street Sweeper Maintenance and Operations Questions

What is the fuel usage? – 10-1-06 to 10-1-07 fuel cost was $7377

How often do you have to empty the sweeper? – 15 times per 8 hours in spring, 3 times per 8 hours in summer, and 25 to 35 times per longer 10 hour shift in fall.

Is there a tipping fee to waste the spoils? – No, during spring and summer months when most of the material is soil, the material is used for landfill cover. During the fall, the material which is mostly leaves is taken to a compost site.

How long do brooms last? What type of brooms are used? – Approximately 4 weeks when running 8 hour days. Broom replacements are bid out and are generally Elgin or Zarnoth.

Any problems with the vacuum? – No, only issue is with leaves or sticks plugging especially in fall.

How much water is used? – Water is always used in the vacuum sweepers to help control dust. They use 3 to 4 125 gallon fills during 8 hour shift.

How often is the machine down? – 3 months during winter lay-up, otherwise minor.

What is the cost of maintenance? – 10-1-06 to 10-1-07, $18657

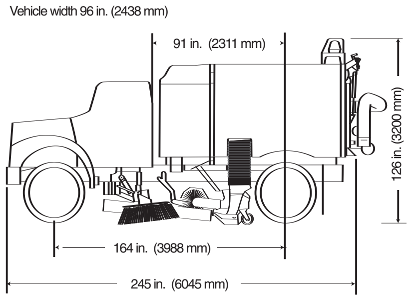
What is the cost of operation? – 10-1-06 to 10-1-07, 770 hours. Using the above figures of $7377 for fuel, and $18657 for repairs, the 770 hours equates to $33.81 per hour for the sweeper. Average operator wages, including benefits, would add $35 per hour, making the total cost of operation $68.81 per hour.

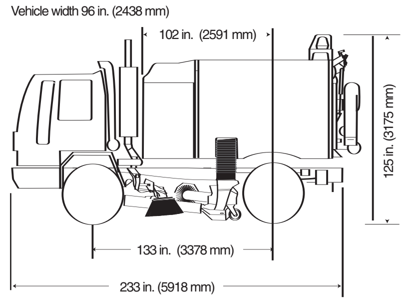
What type of traffic control is needed? –Moving traffic control used occasionally on busy streets.

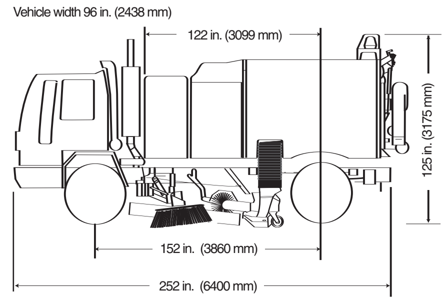
What types of streets are swept? All city streets except those with a gravel surface.

Are there any seasonal problems? No, except for in the fall when leaves tend to plug vacuum.

Do you run a mechanical then vacuum sweeper at any time of year? No







Whirlwind MV

Sweep System–Components

General Specifications

Measured sweeping path (with 36" side broom):
- **Suction nozzle only**
  35 in. (890 mm)
- **Suction nozzle and one side broom**
  52 in. (1320 mm)
- **Suction nozzle and extension broom**
  78 in. (1981 mm)
- **Suction nozzle, extension, and one side broom**
  95 in. (2413 mm)
- **Dual suction nozzles, side brooms and extension broom** 144 in. (3658 mm)

Blower

Drive Fluid coupler and 5-groove banded power belt with adjustable idler pulley
Speed 3400 RPM
Blower Rating 20,000 CFM (562 m^3/min.) @4000 RPM
Blower Construction Abrasion resistant steel
Blower Housing 10 gauge (3.4 mm) steel, linatex lined for extended wear

Vacuum Nozzle and Hoses

Nozzle Width 30 in. (762 mm)
Pickup Area 174 in^2 (1119 cm^2)
Construction Abrasion resistant steel components
Hose Connection Quick disconnect type at lower area near vacuum nozzle
Hose Construction Flexible rubber, steel reinforced
Hose 11 in. (280 mm) inside diameter

Side Broom

Diameter
28 in (711 mm) on 133" WB Sterling SC8000
36 in (914 mm) on 152" WB Sterling SC8000
36 in (914 mm) on 164" WB Freightliner M2 **Disc Construction** Steel plate
Speed Constant
Drive Hydraulic motor, protected by relief valve
Mounting Free floating trailing arm
Motion Pneumatically inward/outward, raised/lowered
Tilt Adjustment Inward/outward, forward/backward
Digging Pressure/Wear Control Pneumatic in cab
Type Segment set disposable
Material Oil tempered steel wire

Extension Broom

Diameter 16 in. (406 mm)
Length 54 in. (1372 mm)
Speed Constant
Drive Hydraulic motor, protected by relief valve
Digging Pressure/Wear Control Pneumatic outside cab
Lift Control Pneumatic from control panel
Type Polypropylene prefab, disposable
Location Center of sweeper

Debris Hopper

Volumetric Capacity 8.0 yds^3 (6.0 m^3)
Floor Angle 10°
Dump Angle 50°
Construction 10 gauge (3.4 mm) steel sides and top, 1/4" gauge (6.4 mm) steel floor
Lifting Double acting hydraulic cylinder
Hopper Dump Door Hydraulic open/close and lock/unlock
Full Load Indicator Weight actuated with in-cab warning light
Hopper Screens Hinged, quick release, steel
Safety Prop Steel bar under body and inside rear door
Hopper Dumping Controls Hydraulic levers on right side of unit

Spray Water System

Water Tank Construction Dual polyethylene, removable
Water System Capacity 335 gal. (1268 L) standard
Pump Type Twin diaphragm with run-dry capability
System Flow 8 GPM (30 LPM) (2 - 4 GPM Pumps)
System Pressure 40 PSI (2.8 bar)
Spray Nozzles (Quick Disconnect Type)
7 inside each suction nozzle
4 at extension broom
2 at each side broom
Controls On/off at control panel
Filter 100 mesh, cleanable
Anti-Siphon Fill Standard
Hydrant Fill Hose 16 ft. 8 in. (5080 mm) with coupling

Hydraulic System

Purpose: Powers hydraulic motors on side broom, extension broom, and hopper cycle
Hydraulic Pump Capacity 8.3 GPM (31 LPM) @ 2500 RPM, each section (16.6 GPM Total)
Hydraulic Pump Direct gear driven, tandem type
Reservoir Capacity 23 gal (87 L)
Filter 10 micron, spin-on type with in-cab restriction indicator

ELGIN
Subsidiary of Federal Signal Corporation

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(847) 741-5370 Phone
(847) 741-3035 Fax
www.elginsweeper.com
P/N 0705335E

Sweep System–Power

Engine

Make John Deere 4045 TF275
Type 4 cylinder Turbocharged Diesel
Displacement 276 in^3 (4.5 L)
Horsepower 115 (86 kW) @ 2500 RPM
Fuel Tank Capacity 50 gal (189 L)
Air Cleaner Two stage, dry type
Oil Filter Spin-on, full flow

Electrical System

Alternator 95 amperes
Battery 12 volt, 1000 CCA
Lights Side broom, rear clearance, rear identification
Reversing Safety Electric back-up alarm, sweep components raise automatically
Circuit Breakers Manual reset
Wiring Harnesses Color coded, function stamped and labeled every 4 in (100mm)

Major Options

Extra 280 Gallon Water For total of 615 gal
High Volume 13 inch Leaf Suction Hose(s)
Wandering Hose
Side Broom Tilt
Front Spray Bar
Stainless Steel Hopper Floor, Sides & Rear Door
LifeLiner® Hopper Liner
Inspection Doors
Rear Flood Light(s)
Rotating Beacon Light
Automatic Lubrication System
Variable Broom Speed
PM-10 Compliant
LED Clearance Lighting
10yd^3 Hopper
Auxiliary Hydraulic System
In Cab Dumping Controls
High Pressure Washdown

Your local Elgin Dealer is:

Photo illustrations in this brochure include optional components
Specifications subject to change without notice.

More debris. Heavier objects. Gone in one pass.

No other vacuum air sweeper is as efficient at removing dust, dirt, debris and larger objects from any street surface than the Whirlwind MV®. With its extremely powerful vacuum, fan and 36-inch diameter side brooms (that can operate simultaneously for the widest sweeping path in the industry), you can cover more street at one time. Which significantly reduces return trips and increases the number of streets cleaned in a single day. In addition, greater power allows the Whirlwind MV's Tier 2 standard auxiliary engine (power provided by John Deere®) to be run at lower RPM—reducing fuel consumption and noise levels.

The benefits are tremendous. More power means less time on the same street. Less time on the same street means you cover more ground. Covering more ground means you maximize the operator's time and productivity. And while most vacuum air sweepers can sweep well enough at 1 to 2 mph, the Whirlwind MV's unique fan (rated to produce 20,000 cfm of airflow) can sweep up more material and heavier items up to 5 mph—reducing time and money required to cover a route.

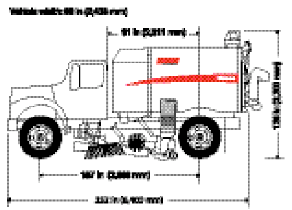
Whirlwind MV. Nothing like it.

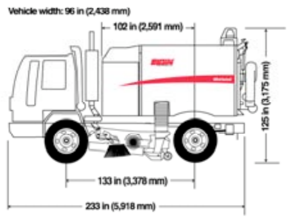
Whirlwind MV Clean more streets in less time.

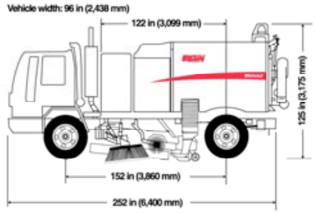
In-Cab Side Broom Tilt
Electrically operated tilting mechanism allows the operator to change the inward/outward tilt of the side broom. The angle can be changed from the cab while sweeping to allow efficient sweeping of irregular surfaces without stopping the sweeper to manually change the broom setting.

Optional Wandering Hose
The Whirlwind MV handles up to four tubes for deep catch basin cleaning. Each 4-foot tube is lightweight, yet sturdy, and constructed out of noncorrosive aluminum. A hydraulic assist makes operation easy and reduces operator fatigue.

Hopper Deluge System
Provides easy, fast and thorough hopper cleanout. Connects with standard water hose to fire hydrant. Includes quick-disconnect coupling.







General Specifications

Measured Sweeping Path (with 36-inch side broom):

Suction Nozzle Only – 35 in (890 mm)

Suction Nozzle and One Side Broom – 52 in (1,320 mm)

Suction Nozzle and Extension Broom – 78 in (1,981 mm)

Suction Nozzle, Extension and One Side Broom – 95 in (2,413 mm)

Dual Suction Nozzles, Side Brooms and Extension Broom – 144 in (3,658 mm)

Options

- Variable Broom Speed
- Additional 280-Gallon (1,060 L) Water Tank for a Total of 615 Gallons (2,328 L)
- High-Volume, 13 in (330 mm) Leaf Suction Hose(s)
- 10 yd^3 Hopper (7.6 m^3)
- Hydraulic Wandering Hose
- Side Broom Tilt
- Front Spray Bar
- Lifeliner®
- Inspection Doors
- Rear Flood Light(s)
- Rotating Beacon/Strobe Light
- Automatic Lubrication System
- Hopper Deluge
- In-Cab Hopper Dump
- Auxiliary Hydraulic System
- High-Pressure Washdown
- Low-Pressure Washdown
- Fuel/Water Separator
- Auto Nozzle Shutter
- PM-10 Package

(Photos and illustration shown with optional equipment.)

Your local Elgin Dealer is:

Warranty
Elgin Sweeper Company backs the Whirlwind MV sweeper with a one-year limited warranty. The Whirlwind MV is warranted against defects in material or workmanship for a period of 12 months from the date of delivery to the original purchaser. Optional extended warranty packages are available. Consult your Elgin dealer for complete warranty details.

1300 West Bartlett Road • Elgin, Illinois 60120-7529
Phone: 847-741-5370 • Fax: 847-742-3035
E-mail: sales@elginsweeper.com
www.elginsweeper.com

Subsidiary of Federal Signal Corporation

THE WHIRLWIND MV AT A GLANCE.

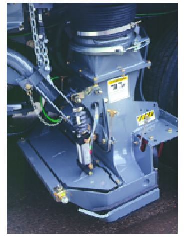
Unique on several points, the Whirlwind MV offers superior fan performance, an outstanding sweep system, efficient dust suppression, maximum maneuverability, quick, complete dumping and simple operation with easy access maintenance. Giving you the most complete air sweeper ever built.

1 Superior Fan Performance

It's all about the fan. Airflow is necessary to carry the debris from the suction nozzle into the hopper. A vacuum is required to overcome any restrictions to that airflow (dirt, rocks, bulky debris). A simple propeller fan may be capable of high airflow but produces little vacuum. Small vacuum pumps can produce incredible vacuum but little airflow. The Whirlwind MV fan is rated to produce an amazing 20,000 cfm of airflow and up to 87 inches of vacuum (in. H_2O). This ability to produce airflow and vacuum simultaneously is why the Whirlwind MV cleans streets more efficiently—at speeds the others simply can't match.

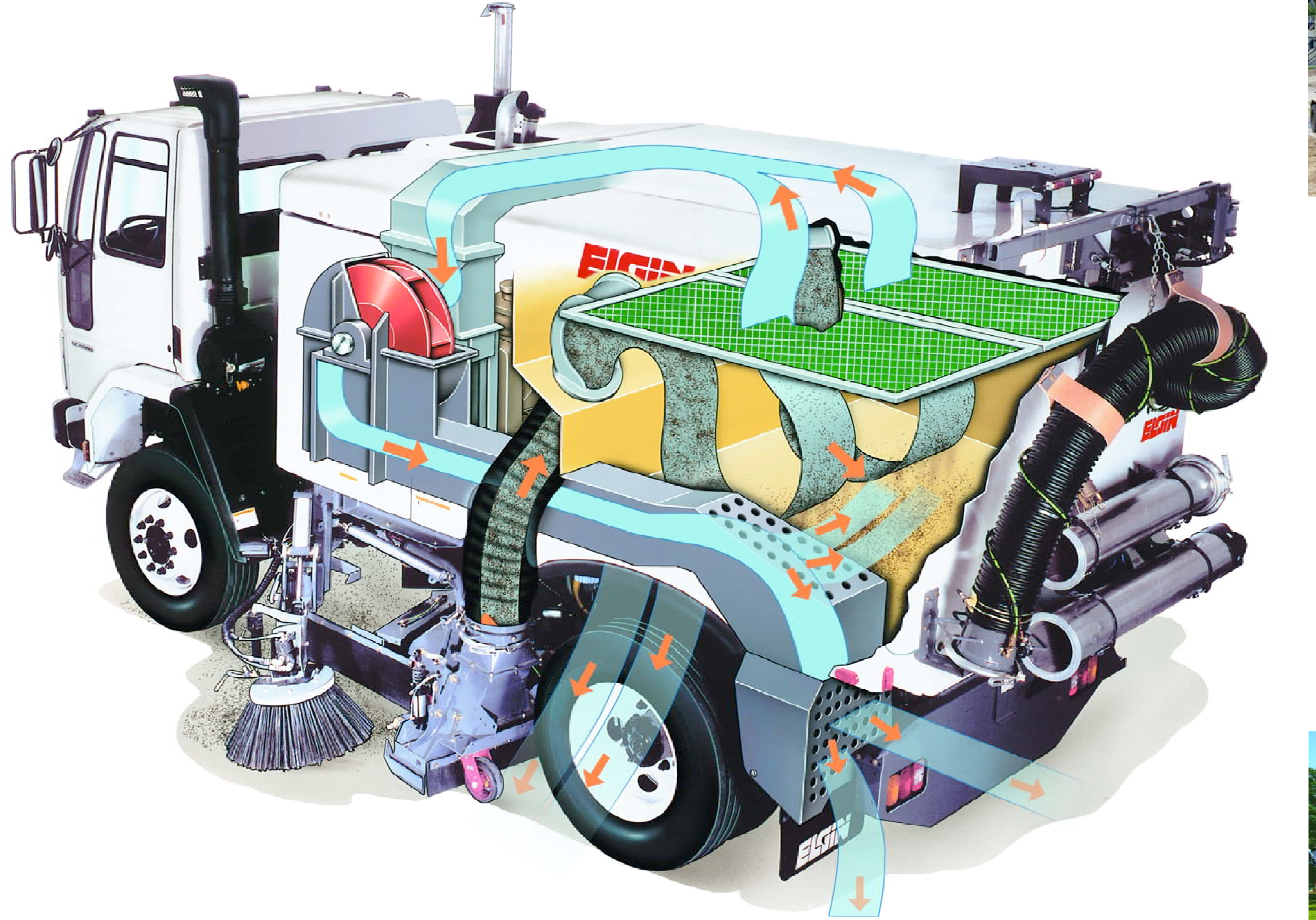
2 Productive Sweeping System

The Whirlwind sweep system includes a suction nozzle, trailing arm side brooms and a centrally mounted extension broom. You can choose between a single 30-inch (762 mm), abrasion-resistant suction nozzle or dual nozzles. The 11-inch (279 mm) suction hose accepts large debris and extends 15 inches (381 mm) beyond the track of the tire for increased performance closer to the curb. Quick disconnect allows an operator to inspect and clean the hose intake tube without raising the hopper.



The 54-inch (1,372 mm) hydraulically driven extension broom operates at an 18-degree windrow angle, directing the material into the path of the nozzle. Down pressure is adjustable outside the cab, giving the operator good visibility of the adjustment.

And you can now choose between 28-inch (711 mm) or 36-inch (914 mm) diameter trailing arm side brooms that can be operated individually or simultaneously for the widest sweeping path in the industry, up to a full 12 feet.



To learn more about the Whirlwind MV difference, talk with your Elgin dealer or visit www.elginsweeper.com.

Wide sweeping path and maximum maneuverability

Easy-access, centrally-mounted console

3 Efficient Dust Suppression

Two corrosion-proof tanks supply the dust suppression system with 335 gallons (1,268 L) of clean water. Optional water tanks provide 280 additional gallons (1,060 L). Spray nozzles with lifelong, quick-disconnect fittings ensure years of maximum dust control and debris conveyance.

4 Maximum Maneuverability

Its compact design and short wheelbase on a conventional or cab-over chassis provide exceptional maneuverability and a tight turning radius as small as 19.2 feet (5.85 m). Standard on the Whirlwind, auto pickup in reverse allows an operator to quickly change sweeping locations.

5 Quick, Complete Dumping

The Whirlwind's large, 8-cubic-yard (6.1 m^3) hopper is constructed with a 1/4-inch-thick floor, 10-gauge steel walls and 2 easy drop-down screens for quick cleanup. A 50-degree tilt angle ensures efficient dumping. Hopper controls are safely accessible on the curb-side of the sweeper in good view of the debris body (in-cab dumping controls available).

6 Operator-Friendly Controls

All sweep and water functions use simple rocker switches and are controlled from a centrally-mounted console for easy operation. New features on the control console include larger air regulators to provide positive side broom down pressure, separate switches to control the side broom in/out and up/down functions, a simple rotary switch for throttle control instead of a push-pull cable and high/low water spray flow rate as standard. Easy-to-read gauges provide a quick assessment of all sweep and engine system conditions.

7 Easy Maintenance Access

Major system components are protected from the elements and are easily accessible for service and inspection without tilting the hopper. The engine oil can be checked, hydraulic filter changed, pneumatic pressure verified and fan bearings greased from the ground or an optional work platform. An engine diagnostic plug and flash codes have been provided to increase troubleshooting capabilities on the Tier II engines.

Easy maintenance access

New standard features on all Whirlwind MVs.

- Auto-shutdown of auxiliary engine (low oil pressure/high temperature)
- Sweep resume with idle down
- Automatic pick-up in reverse
- Electric throttle for auxiliary engine control
- Two-speed (high/low) flow water pumps

ISO-9001 and PM-10 Advantages

The Whirlwind MV is manufactured in an ISO-9001 facility and offers an optional package to meet PM-10 requirements for compliance with SCAQMD Rule 1186.

Quick, complete dumping

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