Sources of Pollutants in Urban Areas

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Abstract

Information concerning source area runoff characteristics during wet weather events can be very important when developing stormwater management plans that incorporate source area controls, or changes in development patterns. This information is also important when calibrating or testing many stormwater models. This information is not readily available and can be expensive and tedious to collect. However, a substantial amount of this data has been collected over the past several decades, but is not well known. This paper presents a summary of this data, specifically source area sheetflow and particulate quality for a variety of areas. Information is presented for many source areas, including urban wet and dry atmospheric deposition, roofs, urban soils, streets and other pavements. Information showing concentrations of conventional pollutants, heavy metals, and selected organic compounds is summarized for major land use categories.

Much of the information was collected in the 1970s and 1980s as part of stormwater research projects for the EPA. Two more recent research projects conducted in the 1990s are high-lighted, a comprehensive project conducted in Birmingham, AL, as part of a project developing a control strategy for critical source areas, and a series of related projects conducted in Wisconsin as part of the DNR's efforts in calibrating the Source Loading and Management Model (SLAMM). A bibliography of recent source area monitoring activities by other researchers is also included.

This paper summarizes source area sheetflow quality data obtained from a number of studies conducted in Alabama, California, Washington, Nevada, Wisconsin, Illinois, Ontario, Colorado, New Hampshire, and New York since the 1970s. Most of the early data obtained were for street dirt chemical quality as part of street cleaning research projects, but a relatively large amount of parking area runoff and roof runoff quality data was also obtained during these early projects. However, only a few of these studies evaluated a broad range of source areas or land uses. The more recent projects conducted in Alabama and Wisconsin are more comprehensive than the earlier monitoring efforts and have included a wide range of land uses, source sources, and pollutants.

Source Area Pollutant Generation Processes

The following discussion stresses stormwater pollutants originating from automobile activities and atmospheric deposition. More limited information is available for other source areas, such as roof runoff and runoff from landscaped areas.

Automotive Activities

Most of the street surface dust and dirt materials (by weight) are local soil erosion products, while some materials are contributed by motor vehicle emissions and wear (Shaheen 1975). Minor contributions are made by erosion of street surfaces in good condition. The specific makeup of street surface contaminants is a function of many conditions and varies widely (Pitt 1979).

Pitt (1979) found that automobile tire wear is a major source of zinc in urban runoff and is mostly deposited on street surfaces and nearby adjacent areas. About half of the airborne particulates lost due to tire wear settle out on the street and the majority of the remaining particulates settle within about six meters of the roadway. Exhaust particulates, fluid losses, drips, spills and mechanical wear products can all contribute lead to street dirt. Many heavy metals are important pollutants associated with automobile activity. Most of these automobile pollutants affect parking lots and street surfaces. However, some of the automobile related materials also affect areas adjacent to the streets. This occurs through the wind transport mechanism after being resuspended from the road surface by traffic-induced turbulence.

Automobile exhaust particulates contribute many important heavy metals to street surface particulates and to urban runoff and receiving waters. The most notable of these heavy metals has been lead. However, since the late 1980s, the concentrations of lead in stormwater has decreased substantially (by about ten times) compared to early 1970 observations. This decrease, of course, is associated with significantly decreased consumption of leaded gasoline.

Solomon and Natusch (1977) studied automobile exhaust particulates in conjunction with a comprehensive study of lead in the Champaign-Urbana, IL area. They found that the exhaust particulates existed in two distinct morphological forms. The smallest particulates were almost perfectly spherical, having diameters in the range of 0.1 to 0.5 μm. These small particles consisted almost entirely of PbBrCl (lead, bromine, chlorine) at the time of emission. Because the particles are small, they are expected to remain airborne for considerable distances and can be captured in the lungs when inhaled. The researchers concluded that the small particles are formed by condensation of PbBrCl vapor onto small nucleating centers, which are probably introduced into the engine with the filtered engine air.

Solomon and Natusch (1977) found that the second major form of automobile exhaust particulates were rather large, being roughly 10 to 20 μm in diameter. These particles typically had irregular shapes and somewhat smooth surfaces. The elemental compositions of these irregular particles were found to be quite variable, being predominantly iron, calcium, lead, chlorine and bromine. They found that individual particles did contain aluminum, zinc, sulfur, phosphorus and some carbon, chromium, potassium, sodium, nickel and thallium. Many of these elements (bromine, carbon, chlorine, chromium, potassium, sodium, nickel, phosphorus, lead, sulfur, and thallium) are most likely condensed, or adsorbed, onto the surfaces of these larger particles during passage through the exhaust system. They believed that these large particles originate in the engine or exhaust system because of their very high iron content. They found that 50 to 70 percent of the emitted lead was associated with these large

particles, which would be deposited within a few meters of the emission point onto the roadway, because of their aerodynamic properties.

Solomon and Natusch (1977) also examined urban particulates near roadways and homes in urban areas. They found that lead concentrations in soils were higher near roads and houses. This indicated the capability of road dust and peeling house paint to contaminate nearby soils. The lead content of the soils ranged from 130 to about 1,200 mg/kg. Koeppe (1977), during another element of the Champaign-Urbana lead study, found that lead was tightly bound to various soil components. However, the lead did not remain in one location, but it was transported both downward in the soil profile and to adjacent areas through both natural and man-assisted processes.

Atmospheric Deposition

Wind transported materials are commonly called "dustfall." Dustfall includes sedimentation, coagulation with subsequent sedimentation and impaction. Dustfall is normally measured by collecting dry samples, excluding rainfall and snowfall. If rainout and washout are included, one has a measure of total atmospheric fallout. This total atmospheric fallout is sometimes called "bulk precipitation." Rainout removes contaminants from the atmosphere by condensation processes in clouds, while washout is the removal of contaminants by the falling rain. Therefore, precipitation can include natural contamination associated with condensation nuclei in addition to collecting atmospheric pollutants as the rain or snow falls. In some areas, the contaminant contribution by dry deposition is small, compared to the contribution by precipitation (Malmquist 1978). However, in heavily urbanized areas, dustfall can contribute more of an annual load than the wet precipitation, especially when dustfall includes resuspended materials.

Atmospheric processes affecting urban runoff pollutants include dry dustfall and precipitation quality. These have been monitored in many urban and rural areas. In many instances, however, the samples were combined as a bulk precipitation sample before processing. Automatic precipitation sampling equipment can distinguish between dry periods of fallout and precipitation. These devices cover and uncover appropriate collection jars exposed to the atmosphere. Much of this information has been collected as part of the Nationwide Urban Runoff Program (NURP) and the Atmospheric Deposition Program, both sponsored by the USEPA (EPA 1983a).

Urban atmospheric deposition information must be interpreted carefully, because of the ability of many polluted dust and dirt particles to be resuspended and then redeposited within the urban area. In many cases, the atmospheric deposition measurements include material that was previously residing and measured in other urban runoff pollutant source areas. Also, only small amounts of the atmospheric deposition material would directly contribute to runoff. Rain is subjected to infiltration and the dry fall particulates are likely mostly incorporated with surface soils and only small fractions are then eroded during rains. Therefore, mass balances and determinations of urban runoff deposition and accumulation from different source areas can be highly misleading, unless transfer of material between source areas and the effective yield of this material to the receiving water is considered. Depending on the land use, relatively little of the dustfall in urban areas likely contributes to stormwater discharges.

Dustfall and precipitation affect all of the major urban runoff source areas in an urban area. Dustfall, however, is typically not a major pollutant source but fugitive dust is mostly a mechanism for pollutant transport. Most of the dustfall monitored in an urban area is resuspended particulate matter from street surfaces or wind erosion products from vacant areas (Pitt 1979). Point source pollutant emissions can also significantly contribute to dustfall pollution, especially in industrial areas. Transported dust from regional agricultural activities can also significantly affect urban stormwater.

Table 1 summarizes rain quality reported by several researchers. As expected, the non-urban area rain quality can be substantially better than urban rain quality. Many of the important heavy metals, however, have not been detected in rain in many areas of the country. The most important heavy metals found in rain have been lead and zinc, both being present in rain in concentrations from about 20 µg/L up to several hundred µg/L. It is expected that more recent lead rainfall concentrations would be substantially less, reflecting the decreased use of leaded gasoline since these measurements were taken. Iron is also present in relatively high concentrations in rain (about 30 to 40 µg/L).

The concentrations of various urban runoff pollutants associated with dry dustfall are summarized in Table 2. Urban, rural and oceanic dry dustfall samples contained more than 5,000 mg iron/kg total solids. Zinc and lead were present in high concentrations. These constituents can have concentrations of up to several thousand mg of pollutant per kg of dry dustfall. Spring, *et al.* (1978) monitored dry dustfall near a major freeway in Los Angeles, CA. Based on a series of samples collected over several months, they found that lead concentrations on and near the freeway can be about 3,000 mg/kg, but as low as about 500 mg/kg 150 m (500 feet) away. In contrast, the chromium concentrations of the dustfall did not vary substantially between the two locations and approached oceanic dustfall chromium concentrations.

Table 1. Summary of reported rain quality.

	Rural-Northwest (Quilayute, WA)[1]	Rural-Northeast (Lake George, NY)[1]	Urban-Northwest (Lodi, NJ)[2]	Urban-Midwest (Cincinnati, OH)[3]	Other Urban[3]	Continental Avg. (32 locations)[1]
Suspended solids, mg/L				13		
Volatile suspended solids, mg/L				3.8		
Inorganic nitrogen, mg/L as N				0.69		
Ammonia, mg/L as N					0.7	
Nitrates, mg/L as N					0.3	
Total phosphates, mg/L as P					<0.1	
Ortho phosphate, mg/L as P				0.24		
Scandium, µg/L	<0.002	nd				nd
Titanium, µg/L	nd	nd				nd
Vanadium, µg/L	nd	nd				nd
Chromium, µg/L	<2	nd	1			nd
Manganese, µg/L	2.6	3.4				12
Iron, µg/L	32	35				
Cobalt, µg/L	0.04	nd				nd
Nickel, µg/L	nd	nd	3			43
Copper, µg/L	3.1	8.2	6			21
Zinc, µg/L	20	30	44			107
Lead, µg/L			45			

1) Rubin 1976
2) Wilbur and Hunter 1980
3) Manning, *et al.* 1976

Much of the monitored atmospheric dustfall and precipitation would not reach the urban runoff receiving waters. The percentage of dry atmospheric deposition retained in a rural watershed was extensively monitored and modeled in Oakridge, TN (Barkdoll, *et al.* 1977). They found that about 98% of the lead in dry atmospheric deposits was retained in the watershed, along with about 95% of the cadmium, 85% of the copper, 60% of the chromium and magnesium and 75% of the zinc and mercury. Therefore, if the dry deposition rates were added directly to the yields from other urban runoff pollutant sources, the resultant urban runoff loads would be very much overestimated.

Tables 3 and 4 report bulk precipitation (dry dustfall plus rainfall) quality and deposition rates as reported by several researchers. For the Knoxville, KY, area (Betson 1978), chemical oxygen demand (COD) was found to be the largest component in the bulk precipitation monitored, followed by filterable residue and nonfilterable residue. Table 4 also presents the total watershed bulk precipitation, as the percentage of the total stream flow output, for the three Knoxville watersheds studies. This shows that almost all of the pollutants presented in the urban runoff streamflow outputs could easily be accounted for by bulk precipitation deposition alone. Betson concluded that bulk precipitation is an important component for some of the constituents in urban runoff, but the transport and resuspension of particulates from other areas in the watershed are overriding factors.

Rubin (1976) stated that resuspended urban particulates are returned to the earth's surface and waters in four main ways: gravitational settling, impaction, precipitation and washout. Gravitational settling, as dry deposition, returns most of the particles. This not only involves the settling of relatively large fly ash and soil particles, but also the

settling of smaller particles that collide and coagulate. Rubin stated that particles that are less than 0.1 μm in diameter move randomly in the air and collide often with other particles. These small particles can grow rapidly by this coagulation process. These small particles would soon be totally depleted in the air if they were not constantly replenished. Particles in the 0.1 to 1.0 μm range are also removed primarily by coagulation. These larger particles grow more slowly than the smaller particles because they move less rapidly in the air, are somewhat less numerous and, therefore, collide less often with other particles. Particles with diameters larger than 1 μm have appreciable settling velocities. Those particles about 10 μm in diameter can settle rapidly, although they can be kept airborne for extended periods of time and for long distances by atmospheric turbulence.

Table 2. Atmosphere Dustfall Quality

Constituent, (mg constituent/kg total solids)	Urban[1]	Rural/ suburban[1]	Oceanic[1]	Near freeway (LA)[2]	500' from freeway (LA)[2]
pH				4.3	4.7
Phosphate-Phosphorous				1200	1600
Nitrate-Nitrogen, μg/L				5800	9000
Scandium, μg/L	5	3	4		
Titanium, μg/L	380	810	2700		
Vanadium, μg/L	480	140	18		
Chromium, μg/L	190	270	38	34	45
Manganese, μg/L	6700	1400	1800		
Iron, μg/L	24000	5400	21000		
Cobalt, μg/L	48	27	8		
Nickel, μg/L	950	1400			
Copper, μg/L	1900	2700	4500		
Zinc, μg/L	6700	1400	230		
Lead, μg/L				2800	550

1) Summarized by Rubin 1976
2) Spring 1978

The second important particulate removal process from the atmosphere is impaction. Impaction of particles near the earth's surface can occur on vegetation, rocks and building surfaces. The third form of particulate removal from the atmosphere is precipitation, in the form of rain and snow. This is caused by the rainout process where the particulates are removed in the cloud-forming process. The fourth important removal process is washout of the particulates below the clouds during the precipitation event. Therefore, it is easy to see that re-entrained particles (especially from street surfaces, other paved surfaces, rooftops and from soil erosion) in urban areas can be readily redeposited through these various processes, either close to the points of origin or at some distance away.

Table 3. Bulk precipitation quality

Constituent (all units mg/L except pH)	Urban (average of Knoxville St. Louis & Germany)1	Rural (Tennessee)1	Urban (Guteburg, Sweden)2
Calcium	3.4	0.4	
Magnesium	0.6	0.1	
Sodium	1.2	0.3	
Chlorine	2.5	0.2	
Sulfate	8.0	8.4	
pH	5.0	4.9	
Organic Nitrogen	2.5	1.2	
Ammonia Nitrogen	0.4	0.4	2
Nitrite plus Nitrate-N	0.5	0.4	1
Total phosphate	1.1	0.8	0.03
Potassium	1.8	0.6	
Total iron	0.8	0.7	
Manganese	0.03	0.05	
Lead	0.03	0.01	0.05

Mercury	0.01	0.0002	
Nonfilterable residue	16		
Chemical Oxygen Demand	65		10
Zinc			0.08
Copper			0.02

1) Betson 1978
2) Malmquist 1978

Pitt (1979) monitored airborne concentrations of particulates near typical urban roads. He found that on a number basis, the downwind roadside particulate concentrations were about 10% greater than upwind conditions. About 80% of the concentration increases, by number, were associated with particles in the 0.5 to 1.0 μm size range. However, about 90% of the particle concentration increases by weight were associated with particles greater than 10 μm. Pitt found that the rate of particulate resuspension from street surfaces increases when the streets are dirty (cleaned infrequently) and varied widely for different street and traffic conditions. The resuspension rates were calculated based upon observed long-term accumulation conditions on street surfaces for many different study area conditions, and varied from about 0.30 to 3.6 kg per curb-km (one to 12 lb per curb-mile) of street per day.

Murphy (1975) described a Chicago study where airborne particulate material within the city was microscopically examined, along with street surface particulates. The particulates from both of these areas were found to be similar (mostly limestone and quartz) indicating that the airborne particulates were most likely resuspended street surface particulates, or were from the same source.

Table 4. Urban bulk precipitation deposition rates (Betson 1978)[1]

Rank	Constituent	Average Bulk Deposition Rate (kg/ha/yr)	Average Bulk Prec. as a % of Total Streamflow Output
1	Chemical oxygen demand	530	490
2	Filterable residue	310	60
3	Nonfilterable residue	170	120
4	Alkalinity	150	120
5	Sulfate	96	470
6	Chloride	47	360
7	Calcium	38	170
8	Potassium	21	310
9	Organic nitrogen	17	490
10	Sodium	15	270
11	Silica	11	130
12	Magnesium	9	180
13	Total Phosphate	9	130
14	Nitrite and Nitrate-N	5.7	360
15	Soluble phosphate	5.3	170
16	Ammonia Nitrogen	3.2	1,100
17	Total Iron	1.9	47
18	Fluoride	1.8	300
19	Lead	1.1	650
20	Manganese	0.54	270
21	Arsenic	0.07	720
22	Mercury	0.008	250

1) Average for three Knoxville, KY, watersheds.

PEDCo (1977) found that the re-entrained portion of the traffic-related particulate emissions (by weight) is an order of magnitude greater than the direct emissions accounted for by vehicle exhaust and tire wear. They also found that particulate resuspensions from a street are directly proportional to the traffic volume and that the suspended particulate concentrations near the streets are associated with relatively large particle sizes. The medium particle size found, by weight, was about 15 μm, with about 22% of the particulates occurring at sizes greater than 30 μm. These relatively large particle sizes resulted in substantial particulate fallout near the road. They found that about 15% of the resuspended particulates fall out at 10 m, 25% at 20 m, and 35% at 30 m from the street (by weight).

In a similar study Cowherd, *et al.* (1977) reported a wind erosion threshold value of about 5.8 m/s (13 mph). At this wind speed, or greater, significant dust and dirt losses from the road surface could result, even in the absence of traffic-induced turbulence. Rolfe and Reinbold (1977) also found that most of the particulate lead from automobile emissions settled out within 100 m of roads. However, the automobile lead does widely disperse over a large area. They found, through multi-elemental analyses, that the settled outdoor dust collected at or near the curb was contaminated by automobile activity and originated from the streets.

Particulate Quality

A number of early stormwater studies collected dry soil samples from various urban surfaces for gravimetric, particle size, and quality analyses. Many of these data are summarized in this section. Burton and Pitt (2002) describe how these samples were obtained. In general, they were vacuumed from hard surfaces in very specific patterns in order to determine the accumulation rates. Related tests (such as conducted by Pitt, 1987, and summarized in Burton and Pitt, 2002) determined how much of this material would washoff during rains. The accumulation rates and washoff conditions are summarized in another chapter of this book.

The data summarized in this section focus on average concentration values for different pollutants, land uses, and source areas. Ranges or variations are not presented due to the vast amount of data obtained and how the samples were composited before chemical analyses. Generally, each sample was comprised of 12 to 40 subsamples for each collection. Collections were usually made several times a week for up to several years from 5 to 10 areas per project. Therefore, each project typically included data from hundreds to thousands of samples. Normally, each sample was separated into several particle sizes using standard sieves. Each sample fraction was retained, usually in zip lock bags. Seasonal composites were then made of all similar sized samples for each source area for the chemical analyses. The data shown in this section are averages of the chemical analyses for the smallest particle sizes for all samples representing each land use for each project.

Particulate potency factors (usually expressed as mg pollutant/kg dry particulate residue) for many samples are summarized on Tables 5 and 6. These data can help recognize critical source areas, but care must be taken if they are used for predicting runoff quality because of likely differential effects due to washoff and erosion from the different source areas. These data show the variations in chemical quality between particles from different land uses and source areas. Typically, the potency factors increase as the use of an area becomes more intensive, but the variations are slight for different locations throughout the country. Increasing concentrations of heavy metals with decreasing particle sizes was also evident, for those studies that included particle size information. However, phosphorus concentrations typically increased with increasing particle sizes. Only the quality of the smallest particle sizes are shown on these tables because they best represent the particles that are washed off during rains.

Table 5. Summary of observed street dirt mean chemical quality (mg constituent/kg solids).

Constituent	Residential	Commercial	Industrial
P	620 (4)		670 (4)
	540 (6)	400 (6)	
	1100 (5)	1500 (5)	
	710 (1)	910 (1)	
	810 (3)		
TKN	1030 (4)		560 (4)
	3000 (6)	1100 (6)	
	290 (5)	340 (5)	
	2630 (3)	4300 (2)	
	3000 (2)		
COD	100,000 (4)		65,000 (4)
	150,000 (6)	110,000 (6)	
	180,000 (5)	250,000 (5)	
	280,000 (1)	340,000 (1)	
	180,000 (3)	210,000 (2)	

	170,000 (2)		
Cu	162 (4)		360 (4)
	110 (6)	130 (6)	
	420 (2)	220 (2)	
Pb	1010 (4)		900 (4)
	1800 (6)	3500 (6)	
	530 (5)	2600 (5)	
	1200 (1)	2400 (1)	
	1650 (3)	7500 (2)	
	3500 (2)		
Zn	460 (4)		500 (4)
	260 (5)	750 (5)	
	325 (3)	1200 (2)	
	680 (2)		
Cd	<3 (5)	5 (5)	
	4 (2)	5 (2)	
Cr	42 (4)		70 (4)
	31 (5)	65 (5)	
	170 (2)	180 (2)	

References; location; particle size described:
(1) Bannerman, *et al.* 1983 (Milwaukee, WI) <31μm
(2) Pitt 1979 (San Jose, CA) <45 μm
(3) Pitt 1985 (Bellevue, WA) <63 μm
(4) Pitt and McLean 1986 (Toronto, Ontario) <125 μm
(5) Pitt and Sutherland 1982 (Reno/Sparks, NV) <63 μm
(6) Terstriep, *et al.* 1982 (Champaign/Urbana, IL) <63 μm

Table 6. Summary of observed particulate quality for other source areas (means for <125 μm particles) (mg constituent/kg solids).

	P	TKN	COD	Cu	Pb	Zn	Cr
Residential/Commercial Land Uses							
Roofs	1500	5700	240,000	130	980	1900	77
Paved parking	600	790	78,000	145	630	420	47
Unpaved driveways	400	850	50,000	45	160	170	20
Paved driveways	550	2750	250,000	170	900	800	70
Dirt footpath	360	760	25,000	15	38	50	25
Paved sidewalk	1100	3620	146,000	44	1200	430	32
Garden soil	1300	1950	70,000	30	50	120	35
Road shoulder	870	720	35,000	35	230	120	25

Industrial Land Uses							
Paved parking	770	1060	130,000	1110	650	930	98
Unpaved parking/storage	620	700	110,000	1120	2050	1120	62
Paved footpath	890	1900	120,000	280	460	1300	63
Bare ground	700	1700	70,000	91	135	270	38

Source: Pitt and McLean 1986 (Toronto, Ontario)

Sheetflow Quality

The data presented in this section are divided into four sections: data from early sheetflow monitoring projects in the early 1980s, data from the Birmingham, AL, source area project conducted for the EPA in the mid 1990s, data from a series of related projects conducted in Wisconsin by the WI DNR and the USGS used to calibrate the Source Loading and Management Model (SLAMM) from the early and mid 1990s, and a bibliography of more recent source area runoff studies conducted throughout the world during the late 1990s and early 2000s.

Early Sheetflow Monitoring Results

Sheetflow data, collected during actual rain events, are probably more representative of runoff conditions than the previously presented dry particulate quality data because they are not further modified by washoff mechanisms. Pitt (1987) conducted numerous washoff tests to supplement early tests conducted by Sartor and Boyd (1972), and accumulation and washoff data are presented in a related chapter of this book. These data, in conjunction with source area flow quantity information, can be used to predict outfall conditions and the magnitude of the relative sources of critical pollutants (as done in the Source Loading and Management Model, SLAMM, http://rpitt.eng.ua.edu/SLAMMDETPOND/MainSLAMMDETPOND.html and Pitt and Voorhees 1995). Tables 7 through 10 summarize warm weather sheetflow observations, separated by source area type and land use, from many locations. The major source area categories examined are listed below:

1. Roofs
2. Paved parking areas
3. Paved storage areas
4. Unpaved parking and storage areas
5. Paved driveways
6. Unpaved driveways
7. Dirt walks
8. Paved sidewalks
9. Streets
10. Landscaped areas
11. Undeveloped areas
12. Freeway paved lanes and shoulders

Table 7. Sheetflow quality summary for other source areas (mean concentration and source of data).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Total Solids (mg/L)									
Residential:	58 (5) 64 (1) 18 (4)	1790 (5)	73 (5)		510 (5)		1240 (5)	49 (5)	325 (5) 235 (4)
Commercial:	95 (1) 190 (4)	340 (2) 240 (1) 102 (7)							325 (4)
Industrial:	113 (5)	490 (5)	270 (5)	1250 (5)	506 (5)	5620 (5)		580 (5)	1800 (5)
Suspended Solids (mg/L)									
Residential:	22 (1) 13 (5)	1660 (5)	41 (5)		440 (5)		810 (5)	20 (5)	242 (5)
Commercial:		270 (2) 65 (1) 41 (7)							242 (5)
Industrial:	4 (5)	306 (5)	202 (5)	730 (5)	373 (5)	4670 (5)		434 (5)	1300 (5)
Dissolved Solids (mg/L)									
Residential:	42 (10 5 (5)	130 (5)	32 (5)		70 (5)		430 (5)	29 (5)	83 (5) 83 (4)
Commercial:		70 (2) 175 (1) 61 (7)							83 (5)
Industrial:	109 (5)	184 (5)	68 (5)	520 (5)	133 (5)	950 (5)		146 (5)	500 (5)

Table 7. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
BOD_5 (mg/L)									
Residential:	3 (4)	22 (4)							13 (4)
Commercial:	7 (4)	11 (1) 4 (8)							
COD (mg/L)									
Residential:	46 (5) 27 (1) 20 (4)	173 (5)	22 (5)		178 (5)			62 (5)	174 (5) 170 (4)
Commercial:	130 (4)	190 (2) 180 (4) 53 (1) 57 (8)							174 (5)
Industrial:	55 (5)	180 (5)	82 (5)	247 (5)	138 (5)	418 (5)		98 (5)	322 (5)
Total Phosphorus (mg/L)									
Residential:	0.03 (5) 0.05 (1) 0.1 (4)				0.36 (5)		0.20 (5)	0.80 (5)	0.62 (5) 0.31 (4)
Commercial:	0.03 (4) 0.07 (4)	0.16 (1) 0.15 (7) 0.73 (5) 0.9 (2) 0.5 (4)							0.62 (5)
Industrial:	<0.06 (5)	2.3 (5)	0.7 (5)	1.0 (5)	0.9 (5)	3.0 (5)		0.82 (5)	1.6 (5)

Table 7. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Total Phosphate (mg/L)									
Residential:	<0.04 (5) 0.08 (4)				<0.2 (5)		0.66 (5)	0.64 (5)	0.07 (5) 0.12 (4)
Commercial:	0.02 (4)	0.03 (5) 0.3 (2) 0.5 (4) 0.04 (7) 0.22 (8)	<0.02 (5)						0.07 (5)
Industrial:	<0.02 (5)	0.6 (5)	0.06 (5)	0.13 (5)	<0.02 (5)	0.10 (5)		0.03 (5)	0.15 (5)
TKN (mg/L)									
Residential:	1.1 (5) 0.71 (4)				3.1 (5)		1.3 (5)	1.1 (5)	2.4 (5) 2.4 (4)
Commercial:	4.4 (4)	3.8 (5) 4.1 (2) 1.5 (4) 1.0 (1) 0.8 (8)							2.4 (5)
Industrial:	1.7 (5)	2.9 (5)	3.5 (5)	2.7 (5)	5.7 (5)	7.5 (5)		4.7 (5)	5.7 (5)
Ammonia (mg/L)									
Residential:	0.1 (5) 0.9 (1) 0.5 (4)	0.1 (5)	0.3 (5)		<0.1 (5)		0.5 (5)	0.3 (5)	<0.1 (5) 0.42 (4)
Commercial:	1.1 (4)	1.4 (2) 0.35 (4) 0.38 (1)							<0.1 (5)
Industrial:	0.4 (5)	0.3 (5)	0.3 (5)	<0.1 (5)	<0.1 (5)	<0.1 (5)		<0.1 (5)	<0.1 (5)

Table 7. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Phenols (mg/L)									
Residential:	2.4 (5)	12.2 (5)	30.0 (5)		9.7 (5)		<0.4 (5)	8.6 (5)	6.2 (5)
Industrial:	1.2 (5)	9.4 (5)	2.6 (5)	8.7 (5)	7.0 (5)	7.4 (5)		8.7 (5)	24 (7)
Aluminum (µg/L)									
Residential:	0.4 (5)	3.2 (5)	0.38 (5)		5.3 (5)		<0.03 (5)	0.5 (5)	1.5 (5)
Industrial:	<0.2 (5)	3.5 (5)	3.1 (5)	9.2 (5)	3.4 (5)	41 (5)		1.2 (5)	14 (5)
Cadmium (µg/L)									
Residential:	<4 (5) 0.6 (1)	2 (5)	<5 (5)		5 (5)		<1 (5)	<4 (5)	<5 (5)
Commercial:		5.1 (7) 0.6 (8)							<5 (5)
Industrial:	<4 (5)	<4 (5)	<4 (5)	<4 (5)	<4 (5)	<4 (5)		<4 (5)	<4 (5)
Chromium (µg/L)									
Residential:	<60 (5) <5 (4)	20 (5) 71 (4)	<10 (5)		<60 (5)		<10 (5)	<60 (5)	<60 (5) 49 (4)
Commercial:	<5 (4)	19 (7) 12 (8)							<60 (5)
Industrial:	<60 (5)	<60 (5)	<60 (5)	<60 (5)	<60 (5)	70 (5)		<60 (5)	<60 (5)

Table 7. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Copper (µg/L)									
Residential:	10 (5) <5 (4)	100 (5)	20 (5)		210 (5)		20 (5)	20 (5)	40 (5) 30 (4)
Commercial:	110 (4)	40 (2) 46 (4) 110 (7)							40 (5)
Industrial:	<20 (5)	480 (5)	260 (5)	120 (5)	40 (5)	140 (5)		30 (5)	220 (5)
Lead (µg/L)									
Residential:	<40 (5) 30 (3) 48 (1) 17 (4)	250 (5)	760 (5)		1400 (5)		30 (5)	80 (5)	180 (5) 670 (4)
Commercial:	19 (4) 30 (1)	200 (2) 350 (3) 1090 (4) 146 (1) 255 (7) 54 (8)							180 (5)
Industrial:	<40 (5)	230 (5)	280 (5)	210 (5)	260 (5)	340 (5)		<40 (5)	560 (5)

Table 7. Sheetflow quality summary for other source areas (mean concentration and source of data) (Continued).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
Zinc (µg/L)									
Residential:	320 (5) 670 (1) 180 (4)	520 (5)	390 (5)		1000 (5)		40 (5)	60 (5)	180 (5) 140 (4)
Commercial:	310 (1) 80 (4)	300 (5) 230 (4) 133 (1) 490 (7)							180 (5)
Industrial:	70 (5)	640 (7)	310 (5)	410 (5)	310 (5)	690 (5)		60 (5)	910 (5)

References:
(1) Bannerman, *et al.* 1983 (Milwaukee, WI) (NURP)
(2) Denver Regional Council of Governments 1983 (NURP)
(3) Pitt 1983 (Ottawa)
(4) Pitt and Bozeman 1982 (San Jose)
(5) Pitt and McLean 1986 (Toronto)
(6) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(7) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)

Table 8. Sheetflow quality summary for undeveloped landscaped and freeway pavement areas (mean observed concentrations and source of data).

Pollutants	Landscaped Areas	Undeveloped Areas	Freeway Paved Lane and Shoulder Areas
Total Solids, mg/L	388 (4)	588 (4)	340 (5)
Suspended Solids, mg/L	100 (4)	400 (1) 390 (4)	180 (5)
Dissolved Solids, mg/L	288 (4)	193 (4)	160 (5)
BOD_5, mg/L	3 (3)	----	10 (5)
COD, mg/L	70 (3) 26 (4)	72 (1) 54 (4)	130 (5)
Total Phosphorus, mg/L	0.42 (3) 0.56 (4)	0.40 (1) 0.68 (4)	----
Total Phosphate, mg/L	0.32 (3) 0.14 (4)	0.10 (1) 0.26 (4)	0.38 (5)
TKN, mg/L	1.32 (3) 3.6 (4)	2.9 (1) 1.8 (4)	2.5 (5)
Ammonia, mg/L	1.2 (3) 0.4 (4)	0.1 (1) <0.1 (4)	----
Phenols, µg/L	0.8 (4)	----	----
Aluminum, µg/L	1.5 (4)	11 (4)	----
Cadmium, µg/L	<3 (4)	<4 (4)	60 (5)
Chromium, µg/L	10 (3)	<60 (4)	70 (5)
Copper, µg/L	<20 (4)	40 (1) 31 (3) <20 (4)	120 (5)
Lead, µg/L	30 (2) 35 (3) <30 (4)	100 (1) 30 (2) <40 (4)	2000 (5)
Zinc, µg/L	10 (3)	100 (1) 100 (4)	460 (5)

References:
(1) Denver Regional Council of Governments 1983 (NURP)
(2) Pitt 1983 (Ottawa)
(3) Pitt and Bozeman 1982 (San Jose)
(4) Pitt and McLean 1986 (Toronto)
(5) Shelly and Gaboury 1986 (Milwaukee)

Table 9. Source area bacteria sheetflow quality summary (means).

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/ Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets	Land-scaped	Un-developed	Freeway Paved Lane and Shoulders
Fecal Coliforms (#/100 ml)												
Residential:	85 (2) <2 (3) 1400 (4)	250,000 (4)	100 (4)		600 (4)			11,000 (4)	920 (3) 6,900 (4)	3300 (4)	5400 (2) 49 (3)	1500 (7)
Commercial	9 (3)	2900 (2) 350 (3) 210 (1) 480 (5) 23,000 (6)										
Industrial:	1600 (4)	8660 (6)	9200 (4)	18,000 (4)	66,000 (4)	300,000 (4)		55,000 (4)	100,000 (4)			
Fecal Strep (#/100 ml)												
Residential:	170 (2) 920 (3) 2200 (4)	190,000 (4)	<100 (4)		1900 (4)		1800 (4)		>2400 (3) 7300 (4)	43,000 (4)	16,500 (2) 920 (3)	2200 (7)
Commercial:	17 (2)	11,900 (2) >2400 (3) 770 (1) 1120 (5) 62,000 (6)										
Industrial:	690 (4)	7300 (4)	2070 (4)	8100 (4)	36,000 (4)	21,000 (4)		3600 (4)	45,000 (4)			
Pseudo, Aerug (#/100 ml)												
Residential:	30,000 (4) 50 (4)	1900 (4)	100 (4)		600 (4)		600 (4)		570 (4)	2100 (4)		
Industrial:		5800 (4)	5850 (4)	14,000 (4)	14,300 (4)	100 (4)		3600 (4)	6200 (4)			

References:

(1) Bannerman, *et al.* 1983 (Milwaukee, WI) (NURP)
(2) Pitt 1983 (Ottawa)
(3) Pitt and Bozeman 1982 (San Jose)
(4) Pitt and McLean 1986 (Toronto)
(5) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(6) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)
(7) Kobriger, *et al.* 1981 and Gupta, *et al.* 1977

Table 10. Source area filterable pollutant concentration summary (means).

	Residential			Commercial			Industrial		
	Total	Filterable	Filterable (%)	Total	Filterable	Filterable (%)	Total	Filterable	Filt. (%)
Roof Runoff									
Solids (mg/L)	64 58	42 45	66 (1) 77 (3)				113	110	97 (3)
Phosphorus (mg/L)	0.054	0.013	24 (1)						
Lead (µg/L)	48	4	8 (1)						
Paved Parking									
Solids (mg/L)				240 102 1790	175 61 138	73 (1) 60 (4) 8 (3)	490	138	28 (3)
Phosphorus (mg/L)				0.16 0.9	0.03 0.3	19 (1) 33 (2)			
TKN (mg/L)				0.77	0.48	62 (5)			
Lead (µg/L)				146 54	5 8.8	3 (1) 16 (5)			
Arsenic (µg/L)				0.38	0.095	25 (5)			
Cadmium (µg/L)				0.62	0.11	18 (5)			
Chromium (µg/L)				11.8	2.8	24 (5)			
Paved Storage									
Solids (mg/L)				73	32	44 (3)	270	64	24 (3)

References:

(1) Bannerman, *et al.* 1983 (Milwaukee) (NURP)
(2) Denver Regional Council of Governments 1983 (NURP)
(3) Pitt and McLean 1986 (Toronto)
(4) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(5) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)

Toronto warm weather sheetflow water quality data were plotted against the rain volume that had occurred before the samples were collected to identify any possible trends of concentrations with rain volume (Pitt and McLean 1986). The street runoff data obtained during the special washoff tests were also compared with the street sheetflow data obtained during the actual rain events (Pitt 1987). These data observations showed definite trends of solids concentrations verses rain volume for most of the source area categories. Sheetflows from all pervious areas combined had the highest total solids concentrations from any source category, for all rain events. Other paved areas (besides streets) had total solids concentrations similar to runoff from smooth industrial streets. The concentrations of total solids in roof runoff were almost constant for all rain events, being slightly lower for small rains than for large rains. No other pollutant, besides SS, had observed trends of concentrations with rain depths for the samples collected in Toronto. Lead and zinc concentrations were highest in sheetflows from paved parking areas and streets, with some high zinc concentrations also found in roof drainage samples. High bacteria populations were found in

sidewalk, road, and some bare ground sheetflow samples (collected from locations where dogs would most likely be "walked").

Some of the Toronto sheetflow contributions were not sufficient to explain the concentrations of some constituents observed in stormwater at the outfall. High concentrations of dissolved chromium, dissolved copper, and dissolved zinc in a Toronto industrial outfall during both wet and dry weather could not be explained by wet weather sheetflow observations (Pitt and McLean 1986). As an example, very few detectable chromium observations were obtained in any of the more than 100 surface sheetflow samples analyzed. Similarly, most of the fecal coliform values observed in sheetflows were significantly lower than those observed at the outfall. It is expected that some industrial wastes, possibly originating from metal plating operations, were the cause of the high concentrations of dissolved metals at the outfall and that some sanitary sewage was entering the storm drainage system. Table 10 summarizes the little filterable pollutant concentration data available for different source areas from these earlier tests. Most of the available data are for residential roofs and commercial parking lots.

Recent Sheetflow Monitoring Results

Summary of Birmingham, AL, Sheetflow Monitoring

Pitt, *et al.* (1995) studied stormwater runoff samples from a variety of source areas under different rain conditions in Birmingham, AL. All of the samples were analyzed in filtered (0.45 µm filter) and non-filtered forms to enable partitioning of the toxicants into "particulate" (non-filterable) and "dissolved" (filterable) forms.

Samples were taken from shallow flows originating from homogeneous source areas by using several manual grab sampling procedures. For deep flows, samples were collected directly into the sample bottles. For shallow flows, a peristaltic hand operated vacuum pump created a small vacuum in the sample bottle, which then gently drew the sample directly into the container through a Teflon™ tube. About one liter of sample was needed, split into two containers: one 500 ml glass bottle with Teflon™ lined lid was used for the organic and toxicity analyses and another 500 ml polyethylene bottle was used for the metals and other analyses.

All samples were handled, preserved, and analyzed according to accepted protocols (EPA 1982 and 1983b). The organic pollutants were analyzed using two gas chromatographs, one with a mass selective detector (GC/MSD) and another with an electron capture detector (GC/ECD). The pesticides were analyzed according to EPA method 505, while the base neutral compounds were analyzed according to EPA method 625 (but only using 100 ml samples). The pesticides were analyzed on a Perkin Elmer Sigma 300 GC/ECD using a J&W DB-1 capillary column (30m by 0.32 mm ID with a 1 µm film thickness). The base neutrals were analyzed on a Hewlett Packard 5890 GC with a 5970 MSD using a Supelco DB-5 capillary column (30m by 0.25 mm ID with a 0.2 µm film thickness). Sample extraction was critical for these organic analyses. Liquid-liquid separation funnel extractions were necessary to provide acceptably high recoveries of the organic toxicants. Burton and Pitt (2002) describe the method development for the sample handling and analyses in detail.

Metallic toxicants were analyzed using a graphite furnace equipped atomic absorption spectrophotometer (GFAA). EPA methods 202.2 (Al), 213.2 (Cd), 218.2 (Cr), 220.2 (Cu), 239.2 (Pb), 249.2 (Ni), and 289.2 (Zn) were followed in these analyses. A Perkin Elmer 3030B atomic absorption spectrophotometer was used after nitric acid digestion of the samples. Previous research (Pitt and McLean 1986; EPA 1983a) indicated that low detection limits were necessary in order to measure the filtered sample concentrations of the metals, which would not be achieved by use of a flame atomic absorption spectrophotometer, or ICP unit most commonly available in commercial laboratories. Low detection limits would enable partitioning of the metals between the solid and liquid phases to be investigated, an important factor in assessing the fates of the metals in receiving waters and in treatment processes.

Table 11 summarizes the source area sample data for the most frequently detected organic toxicants and for all of the metallic toxicants analyzed. The organic toxicants analyzed, but not reported, were generally detected in five, or less, of the non-filtered samples and in none of the filtered samples. Table 11 shows the mean, maximum, and minimum concentrations for the detected toxicants. Note that these values are based only on the observed concentrations. They do not consider the non-detectable conditions. Mean values based on total sample numbers for each source area category would therefore result in lower concentrations. The frequency of detection is therefore an

important consideration when evaluating organic toxicants. High detection frequencies for the organics may indicate greater potential problems than infrequent high concentrations.

Table 11. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (μg/L, unless otherwise noted) (Pitt, *et al.* 1995).

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	NF.[1]	F.[2]	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Base neutrals (detection limit = 0.5 μg/L)																		
1,3-Dichlorobenzene detection frequency = 20% N.F. and 13% F.																		
No. detected[3]	3	2	3	2	1	1	1	1	0	0	3	2	3	2	2	0	1	1
Mean[4]	52	20	34	13	16	14	5.4	3.3			48	26	29	5.6	93		27	21
Max.	88	23	103	26							72	47	54	7.5	120			
Min.[5]	14	17	3.0	2.0							6.0	4.9	4.5	3.8	65			
Fluoranthene detection frequency = 20% N.F. and 12% F.																		
No. detected	3	2	3	2	1	0	1	1	0	0	3	2	3	2	1	0	2	1
Mean	23	9.3	37	2.7	4.5	0	0.6	0.5			39	3.6	13	1.0	130		10	6.6
Max.	45	14	110	5.4							53	6.8	38	1.3			14	
Min.	7.6	4.8	3.0	2.0							0.4	0.4	0.7	0.7			6.6	
Pyrene detection frequency = 17% N,F, and 7% F.																		
No. detected	1	0	3	2	1	0	1	1	0	0	3	2	2	0	1	0	2	1
Mean	28		40	9.8	8		1.0	0.7			44	4.1	5.3		100		31	5.8
Max.			120	20							51	7.4	8.2				57	
Min.			3.0	2.0							0.7	0.7	2.3				6.0	
Benzo(b)fluoranthene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean	76		53				14				98		30		36			
Max.	260		160								110				64			
Min.	6.4		3.0								90				8.0			
Benzo(k)fluoranthene detection frequency = 11% N.F. and 0% F.																		
No. detected	0	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean			20				15				59		61		55			
Max.			1								103				78			
Min.			3.0								15				31			
Benzo(a)pyrene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean	99		40				19				90		54		73			
Max.	300		120								120				130			
Min.	34		3.0								60				19			

Table 11. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (µg/L, unless otherwise noted).Continued.

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[1]	F.[2]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Bis(2-chloroethyl) ether detection frequency = 12% N.F. and 2% F.																		
No. detected	3	1	2	0	0	0	1	0	0	0	1	1	1	0	1	0	1	0
Mean	42	17	20				15				45	23	56		200		15	
Max.	87	2	39															
Min.	20		2.0								6.0	4.9	4.5	3.8	65			
Bis(chloroisopropyl) ether detection frequency = 13% N.F. and 0% F.																		
No. detected	3	0	3	0	0	0	0	0	0	0	2	0	1	0	2	0	0	0
Mean	99		130								120		85		59			
Max.	150		400								160				78			
Min.	68		3.0								74				40			
Naphthalene detection frequency = 11% N.F. and 6% F.																		
No. detected	2	0	1	1	0	0	0	0	0	0	2	1	1	0	1	1	2	2
Mean	17		72	6.6							70	82	49		300	6.7	43	12
Max.	21										100						68	17
Min.	13										37						18	6.6
Benzo(a)anthracene detection frequency = 10% N.F. and 0% F.																		
No. detected	1	0	3	0	0	0	0	0	0	0	2	0	1	0	1	0	0	0
Mean	16		24								35		54		61			
Max.			73								39							
Min.			3.0								31							
Butylbenzyl phthalate detection frequency = 10% N.F. and 4% F.																		
No. detected	1	0	2	1	0	0	0	0	0	0	2	2	1	0	1	0	1	0
Mean	100		12	3.3							26	9.8	130		59		13	
Max.			21								48	16						
Min.			3.3								3.8	3						
Pesticides (detection limit = 0.3 µg/L)																		
Chlordane detection frequency = 11% N.F. and 0% F.																		
No. detected	2	0	2	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0
Mean	1.6		1.0		1.7		0.8			0.8								
Max.	2.2		1.2		2.9													
Min.	0.9		0.8		1.0													

Table 11. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (μg/L, unless otherwise noted).Continued.

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	NF.[1]	F.[2]	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.	NF.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Metals (detection limit = 1μg/L)																		
Lead detection frequency = 100% N.F. and 54% F.																		
No. detected	12	1	16	8	8	7	6	4	3	1	5	2	6	1	19	15	12	8
Mean	41	1.1	46	2.1	105	2.6	43	2.0	55	2.3	63	2.4	24	1.7	20	1.4	19	1.0
Max.	170		130	5.2	330	5.7	150	3.9	80		110	3.4	70		100	1.6	55	1.0
Min.	1.3		1.0	1.2	3.6	1.6	1.5	1.1	25		27	1.4	1.4		1.4	<1	1	<1
Zinc detection frequency = 99% N.F. and 98% F.																		
No. detected	12	12	16	16	8	7	6	6	2	2	5	5	6	6	19	19	12	12
Mean	250	220	110	86	1730	22	58	31	55	33	105	73	230	140	10	10	13	14
Max.	1580	1550	650	560	13100	100	130	76	79	62	230	230	1160	670	32	23	25	25
Min.	11	9	12	6	12	3.0	4.0	4.0	31	4.0	30	11	18	18	<1	<1	<1	<1
Copper detection frequency = 98% N.F. and 78% F.																		
No. detected	11	7	15	13	8	6	6	5	3	2	5	4	6	6	19	17	12	8
Mean	110	2.9	116	11	290	250	280	3.8	22	8.7	135	8.4	81	4.2	50	1.4	43	20
Max.	900	8.7	770	61	1830	1520	1250	11	30	15	580	24	300	8.8	440	1.7	210	35
Min.	1.5	1.1	10	1.1	10	1.0	10	1.0	15	2.6	1.5	1.1	1.9	0.9	<1	<1	0.2	<1
Aluminum detection frequency = 97% N.F. and 92% F.																		
No. detected	12	12	15	15	7	6	6	6	3	1	5	4	5	5	19	19	12	12
Mean	6850	230	3210	430	2320	180	3080	880	780	18	700	170	2310	1210	620	190	700	210
Max.	71300	1550	6480	2890	6990	740	10040	4380	930		1370	410	4610	1860	3250	500	1570	360
Min.	25	6.4	130	5.0	180	10	70	18	590		93	0.3	180	120	<5	<5	<5	<5
Cadmium detection frequency = 95% N.F. and 69% F.																		
No. detected	11	7	15	9	8	7	6	5	3	3	5	3	4	2	19	15	12	9
Mean	3.4	0.4	6.3	0.6	5.9	2.1	37	0.3	1.4	0.4	9.2	0.3	0.5	0.6	8.3	0.2	2	0.5
Max.	30	0.7	70	1.8	17	10	220	0.6	2.4	0.6	30	0.5	1	1	30	0.3	11	0.7
Min.	0.2	0.1	0.1	0.1	0.9	0.3	0.4	0.1	0.7	0.3	1.7	0.2	0.1	0.1	<0.1	<0.1	0.1	0.4
Chromium detection frequency = 91% N.F. and 55% F.																		
No. detected	7	2	15	8	8	5	5	4	3	0	5	1	6	5	19	15	11	8
Mean	85	1.8	56	2.3	75	11	9.9	1.8	17		74	2.5	79	2.0	62	1.6	37	2.0
Max.	510	2.3	310	5.0	340	32	30	2.7	40		320		250	4.1	710	4.3	230	3.0
Min.	5.0	1.4	2.4	1.1	3.7	1.1	2.8	1.3	2.4		2.4		2.2	1.4	<0.1	<0.1	<0.1	<0.1

Table 11. Stormwater toxicants detected in at least 10% of the source area sheetflow samples (μg/L, unless otherwise noted).Continued.

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F.[1]	F.[2]	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Nickel detection frequency = 90% N.F. and 37% F.																		
No. detected	10	0	14	4	8	1	5	0	3	1	5	1	4	1	18	16	11	8
Mean	16		45	5.1	55	87	17		6.7	1.3	42	31	53	2.1	29	2.3	24	3.0
Max.	70		130	13	170		70		8.1		70		130		74	3.6	70	6.0
Min.	2.6		4.2	1.6	1.9		1.2		4.2		7.9		21		<1	<1	1.5	<1
Other constituents (always detected, analyzed only for non-filtered samples)																		
pH																		
Mean	6.9		7.3		8.5		7.6		7.8		7.2		6.7		7.7		8.0	
Max.	8.4		8.7		12		8.4		8.3		8.1		7.2		8.6		9.0	
Min.	4.4		5.6		6.5		6.9		7.1		5.3		6.2		6.9		7.0	
Suspended solids																		
Mean	14		110		100		49		40		24		33		26		17	
Max.	92		750		450		110		47		38		81		140		60	
Min.	0.5		9.0		5.0		7.0		34		17		8.0		5.0		3.0	

1) N.F.: concentration associated with a non-filtered sample.
2) F.: concentration after the sample was filtered through a 0.45 μm membrane filter.
3) Number detected refers to the number of samples in which the toxicant was detected.
4) Mean values based only on the number of samples with a definite concentration of toxicant reported (not on the total number of samples analyzed).
5) The minimum values shown are the lowest concentration detected, they are not necessarily the detection limit.

Table 11 also summarizes the measured pH and SS concentrations. Most pH values were in the range of 7.0 to 8.5 with a low of 4.4 and a high of 11.6 for roof and concrete plant storage area runoff samples, respectively. This range of pH can have dramatic effects on the speciation of the metals analyzed. The SS concentrations were generally less than 100 mg/L, with impervious area runoff (e.g., roofs and parking areas) having much lower SS concentrations and turbidities compared to samples obtained from pervious areas (e.g., landscaped areas).

Out of more than 35 targeted organic compounds analyzed, 13 were detected in more than 10% of all samples, as shown in Table 11. The greatest detection frequencies were for 1,3-dichlorobenzene and fluoranthene, which were each detected in 23% of the samples. The organics most frequently found in these source area samples (i.e., polycyclic aromatic hydrocarbons (PAH), especially fluoranthene and pyrene) were similar to the organics most frequently detected at outfalls in prior studies (EPA 1983a).

Roof runoff, parking area and vehicle service area samples had the greatest detection frequencies for the organic toxicants. Vehicle service areas and urban creeks had several of the observed maximum organic compound concentrations. Most of the organics were associated with the non-filtered sample portions, indicating an association with the particulate sample fractions. The compound 1,3-dichlorobenzene was an exception, having a significant dissolved fraction.

In contrast to the organics, the heavy metals analyzed were detected in almost all samples, including the filtered sample portions. The non-filtered samples generally had much higher concentrations, with the exception of zinc, which was mostly associated with the dissolved sample portion (i.e., not associated with the SS). Roof runoff generally had the highest concentrations of zinc, probably from galvanized roof drainage components, as previously reported by Bannerman, *et al.* (1983). Parking and storage areas had the highest nickel concentrations, while vehicle service areas and street runoff had the highest concentrations of cadmium and lead. Urban creek samples had the highest copper concentrations, which were probably due to illicit industrial connections or other non-stormwater discharges.

Summary of Source Area Pollutant Concentrations Observed in Wisconsin Urban Runoff
Described below are the source area concentrations collected in seven monitoring projects in Wisconsin, and one in Michigan. The monitoring was conducted by the United States Geological Survey (USGS) in cooperation with the Wisconsin Department of Natural Resources (WI DNR). All of the monitoring projects were conducted between 1991 and 1997. Contaminant concentrations for the source areas were used to calibrate SLAMM, the Source Loading and Management Model (Pitt and Voorhees 1995).

Madison, WI, runoff samples were collected during three months of 1991 (Bannerman, *et al.* 1993) to identify the relative pollutant loads from the most common source areas in two study areas. One study area was mostly residential with some commercial land use, while the second area was all light industrial land use. Sheetflow samples were collected from 46 sites representing roofs, streets, driveways, parking lots, and lawns in residential, commercial, and light industrial land uses. The sheetflow samplers were simple in design and were positioned to isolate the runoff from each type of source area. Runoff was delivered to the sample bottles by gravity and the bottles for most of the source areas were installed below the surface of the ground. An effort was made in all the projects to use sample collection methods and equipment that prevented the sample bottles from over-filling before the end of the runoff event. To a large extent, the source area concentrations represented a composite of the runoff occurring during the sampled events. Automated flow meters and water samplers were installed at the storm sewer outfalls for each study area for outfall verification. The sheetflow samples were analyzed for total suspended solids, total solids, total phosphorus, dissolved phosphorus, dissolved and total recoverable zinc, copper, cadmium, chromium, and lead, hardness, and fecal coliform bacteria. Between 7 and 10 runoff samples were collected at all the sites, except for lawns and commercial parking areas where fewer samples were collected.

Milwaukee and Madison, WI, runoff samples were collected during 1993 (Roa-Espinosa and Bannerman 1994) to evaluate different methods for collecting source area runoff samples at industrial sites. As part of this evaluation, a total of 50 sampling locations at roofs, paved areas, and lawns were sampled at five industrial facilities. The sheetflow samplers were simple in design and they were located to isolate the runoff from each type of source area. Runoff was delivered to the sample bottles by gravity and the bottles

for most of the source areas were installed below the surface of the ground. The samples were analyzed for chemical oxygen demand, suspended solids, total solids, total recoverable zinc, lead, nickel, and copper, and hardness. Depending on the location, samples were collected during 5 to 7 runoff events.

Marquette, MI, runoff samples were collected during 1993 and 1994 (Steuer, *et al.* 1997) to characterize contaminant concentrations for eight sources in one study area. The study area (297 acres) contained a mixture of land uses including residential, open space, commercial and institutional. A total of 33 sheetflow sampling sites were installed at streets, parking lots, driveways, rooftops, and grass areas. Samples were analyzed for total solids, suspended solids, ammonia N, nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, dissolved phosphorus, hardness, total recoverable and dissolved zinc, lead, cadmium, and copper, fecal coliform, BOD, COD, and PAHs. Sheetflow samples were collected for 12 runoff events. Flow and water quality was measured at the storm sewer outfall for the study area.

Madison, WI, runoff samples were collected during 1994 and 1995 (Waschbusch, *et al.* 1999) to estimate the sources of phosphorus in two residential areas for further detailed calibration of SLAMM. All the source areas were in two drainage areas. One was 232 acres, with mostly residential and some commercial land uses, while the other was 41 residential acres. Sheetflow samples were collected from roofs, streets, driveways, parking lots, and lawns in residential and commercial land uses. Twenty five storms were sampled in both basins. The sheetflow samples were analyzed for total suspended solids, total solids, dissolved phosphorus, and total phosphorus. Flow and water quality was measured at the storm sewer outfall for both study areas.

Madison, WI, runoff samples were collected during 1994 and 1995 (Waschbusch, *et al.* in press) to evaluate the effect of various environmental factors on the yields of pollutants washed off city streets. The environmental factors include average daily traffic count, antecedent dry time, rainfall intensity, rainfall depth, season, and tree canopy. Street pollutant concentrations were also used to calibrate SLAMM. Sheetflow samples were collected from five streets with different daily traffic counts. The street samplers were grouted into the street approximately 5 feet from the curb. The sample bottles were covered with a 6 inch concave polycarbonate cap, set flush with the street surface. A drain hole in the cap could be constricted to control the flow into the bottle. At total of 11 or 12 runoff samples were collected for each site. Samples were analyzed for suspended solids, PAHs, hardness, and total and dissolved cadmium, lead, copper, zinc, and phosphorus.

Superior, WI, runoff samples were collected during 1995 and 1996 (Holstrom, *et al.* 1995 and 1996) to measure flow rates and water quality for runoff from an undeveloped site. The drainage area of the wooded lot is 76.2 acres. Flow was measured with a Parshall flume and runoff samples were collected with a volume activated water quality sampler. Sixteen storm-composite samples were analyzed for suspended solids, total solids, and total phosphorus. Samples were less frequently analyzed for COD, BOD, sulfate, chloride, nitrogen compounds, and total copper, lead, and zinc.

Madison, WI, runoff samples were collected during 1996 and 1997 (Waschbusch, *et al.* 1999) to verify the pollutant removal efficiency of a stormwater treatment device (Stormceptor). The device was located to treat the runoff from a 4.3 acre city maintenance yard. Inlet and outlet runoff samples were collected for 45 runoff events. Samples were analyzed for total solids, suspended solids, total and dissolved phosphorus, nitrate plus nitrite, ammonia N, chloride, hardness, alkalinity, organic carbon, particle sizes, PAHs, and total and dissolved copper, cadmium, lead, and zinc. Automated sampling equipment was used to measure flow and collect flow–weighted composite samples. The inlet pollutant concentrations were used to calibrate SLAMM for industrial parking lots.

Milwaukee, WI, runoff samples were collected during 1996 (Corsi, *et al.* 1999) to measure the pollutant removal efficiency of a stormwater treatment device (the Multi-Chamber Treatment Train). The device was located to treat the runoff from 0.10 acres of parking lot at a city maintenance facility. Inlet and outlet samples were collected for 15 runoff events. Flow meters and automatic water samplers were used to measure flow rates and collect flow-weighted composite water samples in the inlet and outlet pipes. Samples were analyzed for total solids, suspended solids, alkalinity, BOD, COD, volatile suspended solids, ammonia as N, nitrate plus nitrite as N, chloride, sulfate, hardness, PAHs, TOC, total and dissolved

phosphorus, total and dissolved zinc, cadmium, lead, chromium, and copper. The inlet pollutant concentrations were used to calibrate SLAMM for industrial parking lots.

Results from the eight studies were combined to create an average concentration for each source area (Table 12). Almost all of the average concentration values represent the results from more than one study. Because the constituent list was different for each study, the sample count varies considerably between the types of source areas. Sample counts are high for suspended solids and phosphorus, since they were analyzed during all the studies. Only one project (Marquette, MI) analyzed COD and PAHs for all the source areas, so these constituents have a low sample count. Censored values (samples having less than the detection limit) are included as one-half the detection limit for some of the constituents having low sample counts.

Although loads from a source area are greatly influenced by the volume of runoff, the large differences in some of the source area concentrations can decrease the importance of volume when comparing the loads from different source areas. For example, the volume of runoff from lawns is expected to be relatively low, but concentrations of phosphorus in lawn runoff are 2 to 10 times higher than for other source areas. Because of these relatively high concentrations, lawns can contribute as much as 50 percent of the annual total phosphorus load in a residential area (Washbusch, *et al.* 1999). With PAH levels from commercial parking lots 10 to 100 times higher than from any other source area, commercial parking lots representing only 3 percent of an urban drainage area can contribute 60 percent of the annual PAH load (Steuer, *et al.* 1997.

Concentrations for some of the pollutants can be compared between roofs and streets for all three land uses. Streets in industrial areas are likely important sources of suspended solids, total phosphorus, and zinc whenever they are compared to commercial and residential streets. But concentrations of these three pollutants in industrial roof runoff is similar to, or lower than, the other two land uses.

Enough data is compiled in Table 12 to determine pollutant loads from many of the typical urban source areas. However, more monitoring is needed to expand the list of constituents, especially in areas having low sample counts. Additional source areas also need to be monitored. Pesticides are an example of a pollutant not included in Table 12. Both lawns and undeveloped areas do not have any concentrations for PAHs. The sample count is very low for source areas having PAH, COD, and BOD data. Sample counts are less than five for 40 out of the 334 concentrations on the table. Gas stations are an example of a missing specific source area. Also missing are runoff concentrations from a range of parking lot types. Parking lots with high turnover are expected to experience higher pollutant concentrations than those used for long-term employee parking, for example, and need to be better represented.

Table 12. Wisconsin Source Area Monitoring Data

Source Area	Total Solids (mg/L)	Suspended Solids (mg/L)	Dissolved Solids (mg/L)	COD Total (mg/L)	COD Particulate* (mg/Kg)	COD Dissolved (mg/L)	BOD_5, Total (mg/L)	BOD_5, Particulate* (mg/Kg)	BOD_5, Dissolved (mg/L)
Residential Roofs									
Sample Count	38	81	38	8	8	8	9	6	7
Average	112	36.7	60.8	78	590,000	30	19	140,000	9.6
COV	1.12	2.07	1.20	1.34	0.72	0.68	0.49	0.6	0.54
Commercial Roofs									
Sample Count	19	34	19	6	6	6	9	4	6
Average	146	32.8	115	172	740,000	152.3	24	94,000	17.5
COV	0.66	1.25	0.85	0.66	1.05	0.69	0.78	0.94	0.84
Industrial Roofs									
Sample Count	45	42	42	34	32	34	n/a	n/a	n/a
Average	76	15.8	60.8	23	760,000	20	n/a	n/a	n/a
COV	0.40	1.7	0.54	0.60	0.88	0.60	n/a	n/a	n/a
Commercial Parking Lots									
Sample Count	21	44	21	6	5	6	5	4	5
Average	246	130	62.7	77	330,000	39	10.5	28,000	7.5
COV	0.77	1.15	0.81	0.23	0.32	0.81	0.41	0.52	0.63
Industrial Parking Lots									
Sample Count	89	90	89	14	n/d	n/d	15	n/d	n/d
Average	1246	244	1002	120	n/d	n/d	18	n/d	n/d
COV	3	0.96	3	0.43	n/d	n/d	0.62	n/d	n/d
Driveways									
Sample Count	19	69	19	9	9	9	7	6	7
Average	350	154	111	146	300,000	91.8	16	32,000	7.71
COV	0.58	1.10	0.81	1.07	0.84	1.68	0.35	0.45	1.05
Small Landscape Areas									
Sample Count	13	40	13	4	4	4	2	1	1
Average	657	227	183	172.5	380,000	90.5	25	12,000	1.6
COV	0.62	1.25	1.10	0.23	0.63	0.50	0.55	n/a	n/a

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Total Solids (mg/L)	Suspended Solids (mg/L)	Dissolved Solids (mg/L)	COD Total (mg/L)	COD Particulate* (mg/Kg)	COD Dissolved (mg/L)	BOD_5, Total (mg/L)	BOD_5, Particulate* (mg/Kg)	BOD_5, Dissolved (mg/L)
Commercial Streets									
Sample Count	50	75	50.0	16	14	14	12	11	12
Average	345	176	123	88	200,000	47.9	14	21,000	10.6
COV	0.89	1.17	1.05	0.45	0.84	0.63	0.51	0.81	0.54
Residential Streets									
Sample Count	32	131	32	5	3	4	4	2	4.0
Average	521	183	116	46.2	200,000	25	6.7	25,000	6.6
COV	1.16	1.7	0.92	0.39	0.78	0.75	0.95	0.24	0.97
Industrial Streets									
Sample Count	15	15	15	n/a	n/a	n/a	n/a	n/a	n/a
Average	1064	894	170	n/a	n/a	n/a	n/a	n/a	n/a
COV	0.58	0.69	0.64	n/a	n/a	n/a	n/a	n/a	n/a
Freeways									
Sample Count	11	66	11	n/a	n/a	n/a	n/a	n/a	n/a
Average	201	138	94.4	n/a	n/a	n/a	n/a	n/a	n/a
COV	0.51	1.17	0.39	n/a	n/a	n/a	n/a	n/a	n/a
Undeveloped Areas									
Sample Count	6	5	5	8	8	8	7	5	5
Average	260	16	186.2	87	720,000	69	26	67,000	20
COV	0.54	0.43	0.06	0.72	2.0	0.74	0.50	1.38	0.66

*Particulate = (total constituent - dissolved constituent)/suspended solids

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Phosphorus, Total (mg/L)	Phosphorus, Particulate* (mg/Kg)	Phosphorus, Dissolved (mg/L)	Kjeldahl N, Total (mg/L)	Kjeldahl N, Particulate* (mg/Kg)	Kjeldahl N, Dissolved (mg/L)	Nitrite + Nitrate N (mg/L)	Cadmium, Total (µg/L)	Cadmium, Particulate* (mg/Kg)	Cadmium, Dissolved (µg/L)
Residential Roofs										
Sample Count	87	76	82	7	7	7	8	21	5	14
Average	0.17	4600	0.07	1.1	18,000	0.80	0.68	0.54	9.0	0.15
COV	1.22	1.11	1.25	0.67	1.3	0.82	0.97	1.78	0.67	0.67
Commercial Roofs										
Sample Count	19	29	31	7	7	7	9.0	12	5	9
Average	0.18	9400	0.061	2.0	26,000	1.65	0.75	0.65	12.45	0.73
COV	0.67	1.24	1.09	0.56	1.55	0.73	0.86	1.03	1.00	1.06
Industrial Roofs										
Sample Count	9	9	9	n/a	n/a	n/a	n/a	4	1	4
Average	0.13	3400	0.021	n/a	n/a	n/a	n/a	0.30	1.56	0.28
COV	0.72	1.41	0.54	n/a	n/a	n/a	n/a	0.47	n/a	0.75
Commercial Parking Lots										
Sample Count	42	36	39	5	5	5	7	19	16	19
Average	0.2	1900	0.055	1.2	3900	0.58	0.4	0.95	4.65	0.48
COV	1.02	0.89	1.08	0.40	0.42	0.43	0.60	0.69	0.59	1.33
Industrial Parking Lots										
Sample Count	40	34	36	n/a	n/a	n/a	19	27	20	24
Average	0.39	1300	0.09	n/a	n/a	n/a	0.41	1.5	4.2	0.49
COV	0.58	0.66	1.1	n/a	n/a	n/a	0.62	0.53	0.55	1.11
Driveways										
Sample Count	69	66	65	9	9	9	9	19	14	14
Average	1	3400	0.290	2.6	9500	0.69	0.45	0.91	2.88	0.25
COV	1.24	0.79	1.76	0.73	0.69	0.90	1.03	1.06	0.79	0.74
Small Landscape Areas										
Sample Count	42	39	39	4	4	4	4	3	3	3
Average	2.2	7400	1.35	10.5	30,000	1.97	0.45	0.63	1.51	0.30
COV	1.08	1.23	1.63	0.53	0.69	0.52	0.53	0.40	0.69	0.99

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Phosphorus, Total (mg/L)	Phosphorus, Particulate* (mg/Kg)	Phosphorus, Dissolved (mg/L)	Kjeldahl N, Total (mg/L)	Kjeldahl N, Particulate* (mg/Kg)	Kjeldahl N, Dissolved (mg/L)	Nitrite + Nitrate N (mg/L)	Cadmium, Total (µg/L)	Cadmium, Particulate* (mg/Kg)	Cadmium, Dissolved (µg/L)
Commercial Streets										
Sample Count	74.0	67	65	16	15	15	16	39	36	38
Average	0.31	1900	0.060	3.7	19,500	0.9	0.49	1.03	4.81	0.38
COV	1.11	0.72	1.21	2.18	2.95	0.70	0.56	0.67	0.74	1.54
Residential Streets										
Sample Count	132	127	127	5	4	4	5	14	9	9
Average	0.66	2800	0.298	1.0	5000	0.52	0.40	0.6	2.25	0.14
COV	1.39	0.83	1.78	0.15	0.65	0.19	0.35	0.85	0.80	0.37
Industrial Streets										
Sample Count	15	15	15	n/a	n/a	n/a	n/a	13	10	10
Average	1.3	1300	0.46	n/a	n/a	n/a	n/a	1.1	1.15	0.29
COV	0.37	0.59	0.77	n/a	n/a	n/a	n/a	0.82	0.88	0.60
Freeways										
Sample Count	21	20	20	10	10	10	10	21	11	11
Average	0.24	1700	0.08	1.3	7900	0.49	0.78	0.71	4.64	0.22
COV	0.56	0.60	0.93	0.32	0.64	0.45	0.83	0.36	0.34	0.39
Undeveloped Areas										
Sample Count	5	3	3	5	5	5	2	n/a	n/a	n/a
Average	0.08	400	0.01	1.1	1500	0.88	0.033	n/a	n/a	n/a
COV	0.30	0.49	0.82	0.09	0.70	0.10	0.24	n/a	n/a	n/a

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Chromium, Total (µg/L)	Chromium, Particulate* (mg/Kg)	Chromium, Dissolved (µg/L)	Copper, Total (µg/L)	Copper, Particulate* (mg/Kg)	Copper, Dissolved (µg/L)	Lead, Total (µg/L)	Lead, Particulate * (mg/Kg)	Lead, Dissolved (µg/L)
Residential Roofs									
Sample Count	n/a	n/a	n/a	34	28	29	23	21	21
Average	n/a	n/a	n/a	21	160	10.2	43	870	8.47
COV	n/a	n/a	n/a	1.60	1.32	1.37	2.19	0.77	1.52
Commercial Roofs									
Sample Count	n/a	n/a	n/a	18	12	13	13	13	14
Average	n/a	n/a	n/a	19	180	12.9	58	750	27.1
COV	n/a	n/a	n/a	0.81	1.01	1.17	1.06	0.53	1.40
Industrial Roofs									
Sample Count	n/a	n/a	n/a	43	n/a	n/a	4	4	4
Average	n/a	n/a	n/a	9	n/a	n/a	8.25	220	1.50
COV	n/a	n/a	n/a	0.57	n/a	n/a	0.30	1.09	0.0
Commercial Parking Lots									
Sample Count	13	11	14	19	18	19	19	18	19
Average	9.8	47	2.46	30	100	14.4	51.1	320	1.72
COV	0.81	0.40	0.83	0.81	0.69	0.89	0.81	0.35	0.35
Industrial Parking Lots									
Sample Count	27	12	13	41	33	34	25	11	11
Average	11	24	1.26	33	83	11.0	53	180	2.06
COV	0.84	0.42	0.75	0.50	0.48	1.05	0.49	0.46	1.14
Driveways									
Sample Count	9	2	2	19	17	17	19	19	8
Average	1.94	11	1.5	37	89	13.0	57	240	3
COV	0.47	0.01	0.00	1.02	1.04	0.74	1.3	0.81	0.55
Small Landscape Areas									
Sample Count	1	1	1	11	10	11	3	3	3
Average	19.00	20	1.5	12	14	7.4	54	250	2.83
COV	n/a	n/a	n/a	0.36	0.42	0.51	0.90	1.07	0.64

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Chromium, Total (µg/L)	Chromium, Particulate* (mg/Kg)	Chromium, Dissolved (µg/L)	Copper, Total (µg/L)	Copper, Particulate* (mg/Kg)	Copper, Dissolved (µg/L)	Lead, Total (µg/L)	Lead, Particulate * (mg/Kg)	Lead, Dissolved (µg/L)
Commercial Streets									
Sample Count	10	10	10	50	47	48	49	47	37
Average	18	38	8.6	34	140	12.0	39	210	1.9
COV	0.47	0.28	0.81	0.57	1.26	0.86	0.69	0.47	0.44
Residential Streets									
Sample Count	16	14	16	32	29	29	32	31	23
Average	6	11	1.5	18	39	7.05	24.4	87	1.55
COV	0.64	0.82	0.00	0.57	0.56	0.72	0.68	0.57	0.49
Industrial Streets									
Sample Count	15	15	15	15	15	15	15	15	15
Average	20	24	3	22	74	21.7	87	100	1.5
COV	0.53	0.56	0.86	0.61	0.43	0.61	0.68	0.33	0
Freeways									
Sample Count	n/a	n/a	n/a	57	21	21	21	8	8
Average	n/a	n/a	n/a	59	300	13	34	230	1.56
COV	n/a	n/a	n/a	0.59	0.54	0.56	1.2	0.38	2.33
Undeveloped Areas									
Sample Count	n/a	n/a	n/a	1	n/a	n/a	1	1	n/a
Average	n/a	n/a	n/a	5	n/a	n/a	1.3	48	n/a
COV	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Zinc, Total (µg/L)	Zinc, Particulate* (mg/Kg)	Zinc, Dissolved (µg/L)	Fluoranthene, Particulate* (mg/kg)	Fluoranthene, Total (µg/L)	Pyrene, Particulate* (mg/kg)	Pyrene, Total (µg/L)
Residential Roofs							
Sample Count	34	5	6	10	10	10	10
Average	185	2900	278	6.7	0.22	4.7	0.15
COV	1.09	0.56	0.80	0.75	1.09	0.84	1.12
Commercial Roofs							
Sample Count	15	6	6	10.0	10.0	10.0	10.0
Average	322	3500	182	25	0.85	18	0.6
COV	0.54	0.95	0.92	0.70	1.21	0.72	1.27
Industrial Roofs							
Sample Count	44	n/a	n/a	n/a	n/a	n/a	n/a
Average	319	n/a	n/a	n/a	n/a	n/a	n/a
COV	1.49	n/a	n/a	n/a	n/a	n/a	n/a
Commercial Parking Lots							
Sample Count	20	7	7	7	7	6	7
Average	292	802	51	290	28	180	17
COV	0.91	0.58	0.42	0.77	0.77	0.67	0.80
Industrial Parking Lots							
Sample Count	26	17	19	26	26	26	26
Average	227.7	490	99.5	10	2.48	7.7	1.85
COV	0.67	0.47	1.25	0.57	0.74	0.57	0.79
Driveways							
Sample Count	19	19	15	6	6	6	6
Average	164	650	166	23	1.1	17	0.8
COV	0.79	0.48	0.48	2.21	0.9	2.21	0.94
Small Landscape Areas							
Sample Count	10	2	2	n/a	n/a	n/a	n/a
Average	67	160	34.0	n/a	n/a	n/a	n/a
COV	0.39	1.28	0.37	n/a	n/a	n/a	n/a

Table 12. Wisconsin Source Area Monitoring Data (continued)

Source Area	Zinc, Total (µg/L)	Zinc, Particulate* (mg/Kg)	Zinc, Dissolved (µg/L)	Fluoranthene, Particulate* (mg/kg)	Fluoranthene, Total (µg/L)	Pyrene, Particulate* (mg/kg)	Pyrene, Total (µg/L)
Commercial Streets							
Sample Count	50	48	37	35	35	35	35
Average	302	1150	60.2	25	5.0	17	3.4
COV	0.95	1.23	1.03	1.0	1.4	0.93	1.39
Residential Streets							
Sample Count	32	26	11	13	13	12	12
Average	151	350	45.0	9.6	1.3	6.5	0.9
COV	0.71	0.55	0.39	0.78	1.20	0.78	1.08
Industrial Streets							
Sample Count	15	15	15	n/a	n/a	n/a	n/a
Average	593	540	167	n/a	n/a	n/a	n/a
COV	0.48	0.42	0.51	n/a	n/a	n/a	n/a
Freeways							
Sample Count	57	21	21	11	11	11	11
Average	233	1330	22.6	11	1.1	6.6	0.71
COV	0.78	0.36	0.42	0.77	1.0	0.63	0.94
Undeveloped Areas							
Sample Count	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Average	n/a	n/a	n/a	n/a	n/a	n/a	n/a
COV	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Other Recent Source Area Stormwater Investigations

General Sources

Nowakowska-Blaszezyk, *et al.* (1996) studied the sources of wet-weather pollutants in Poland. It was found that storm runoff from parking areas and streets had the greatest concentrations of suspended solids (SS), chemical oxygen demand (COD), five-day biochemical oxygen demand (BOD_5), and Pb, while phosphorus was mostly contributed from landscaped-area storm runoff. Storm runoff from roofs covered with roofing paper was also a significant contributor of many pollutants.

Gromaire-Mertz, *et al.* (1999) collected stormwater runoff from 4 roofs, 3 courtyards and 6 streets on an experimental catchment in central Paris, France, and analyzed the samples for SS, VSS, COD, BOD_5, hydrocarbons, and heavy metals both in dissolved and particulate fractions. The street runoff showed large SS, COD and hydrocarbon loads, but the roof runoff had high concentrations of heavy metals.

Davis, *et al.* (2001) presented loading estimates of lead, copper, cadmium, and zinc in stormwater from different sources. They reviewed available data from the literature, and conducted controlled experiments and other sampling. Specific sources that they examined included building siding and roofs; automobile brakes, tires, and oil leakage; and wet and dry atmospheric deposition. The most important sources they identified were building siding for all four metals, vehicle brake emissions for copper, and tire wear for zinc. Atmospheric deposition was an important source for cadmium, copper, and lead.

Atmospheric Deposition Studies

Jordan, *et al.* (1997) estimated that 40% of the nitrogen (N) loading to the Chesapeake Bay watershed comes from atmospheric deposition, 33% from livestock waste, and 27% from fertilizer. Ahn and James (2001) reported that atmospheric deposition is a substantial source of phosphorus to the Florida Everglades. Phosphorus has been measured on a weekly basis since 1974, but the results were highly variable: the average mean and standard deviation of the calculated P deposition rates for 13 sites were 41± 33 mg P m^{-2} yr^{-1}. They found that the atmospheric P deposition load showed high spatial and temporal variability, with no consistent long-term trend. Because of the random nature of P deposition, the estimated P deposition loads have a significant amount of uncertainty, no matter what type of collection instrument is used, and replicate sampling is highly recommended.

Atasi, *et al.* (1999 and 2001) conducted source monitoring using specialized sampling equipment and ultra-clean analytical methodology to quantify the concentrations and fluxes of mercury, cadmium, and polychlorinated biphenyl in ambient air, precipitation, runoff, sanitary sewer, and wastewater treatment plant influent. The relationships between the atmospheric deposition and runoff on controlled surfaces were also examined. Atmospheric deposition was found to be the primary source of these pollutants in runoff. They concluded that wet weather flows, not atmospheric deposition, contributed the main portion of these pollutants to the Detroit Wastewater Treatment Plant. Garnaud, *et al.* (1999) studied heavy metal concentrations in dry and wet atmospheric deposits in Paris, France, for comparison with urban runoff. Samples were continuously collected for 2 to 13 months at each of four test sites. Comparisons of median values of metal concentrations showed that rainwater contamination with heavy metals was only slightly higher in the center of Paris than at Fontainebleau (48 km SE of the city) which illustrates the medium range transport of atmospheric contamination. Glass and Sorensen (1999) examined a six-year trend (1990-1995) of wet mercury deposition in the Upper Midwest of the United States. The annual wet mercury deposition averaged 7.4 µg Hg/m^2-yr and showed significant variations between sites and illustrated significant increasing trends over the monitoring period. Warm (rain) season wet mercury deposition was found to average 77% of total annual wet deposition.

Tsai, *et al.* (2001) described their pilot study, conducted from August 1999 through August 2000, that estimated the loading of heavy metals from the atmosphere to San Francisco Bay. Dry deposition flux of copper, nickel, cadmium, and chromium was approximately 1100 +/- 73, 600 +/- 35, 22 +/- 15, and 1300 +/- 90 µg/m^2/year, respectively. The volume-weighted average concentrations of these trace metals in the rain water were 1.2, 0.4, 0.1, and 0.2 µg/L, respectively. Direct atmospheric deposition onto Bay waters, from both dry deposition and rainfall, contributed approximately 1900, 930, 93 and 1600 kg/yr of copper,

nickel, cadmium and chromium, respectively. Stormwater runoff contributed approximately twice as much as the loading from direct atmospheric deposition. Direct atmospheric deposition was therefore found to be a minor contributor to the total load of these pollutants to the Bay. A mass balance of all known sources and sinks for heavy metals (Ag, Cd, Cu, and Pb) in New Haven Harbor, CT, was conducted by Rozan and Benoit (2001). Sources included direct atmospheric deposition, rivers, treated sewage effluent, combined sewer overflows, and permitted industrial discharges. All of the fluxes were directly measured, and the uncertainties were quantified. River inputs accounted for most of the total yearly metal discharges, while the salt marshes removed about 20 to 30% of the metals from the rivers before reaching the harbor. Atmospheric deposition is of minor importance, and is comparable to sewage effluent discharges. Schiff and Stolzenbach (2003) investigated the heavy-metal contribution of atmospheric deposition to Santa Monica Bay and compared the atmospheric deposition loading to the loading from other sources. The annual atmospheric deposition of chromium, copper, lead, nickel and zinc exceeded the estimated annual effluent loads from industrial and power generating stations to Santa Monica Bay.

Roof Runoff and Other Building Materials

Sakakibara (1996) investigated roof-runoff quality in Ibaraki prefecture, Japan, in order to determine the feasibility of using roof runoff in urban areas for various beneficial uses. Eighty three samples were collected during one year and analyzed for pH (averaged 6.1), BOD_5 (averaged 1.6 mg/L), COD (averaged 3.2 mg/L), and SS (averaged 12 mg/L). It was concluded that roof-runoff could be used for toilet flushing and landscaping watering with minimal treatment or problems.

Heavy metals and major ions in roof-runoff were investigated by Förster (1996) in Bayreuth, Germany. It was found that the major ions were from the rain, while very high Cu and Zn concentrations were from metal flashings used on the roofs. It was concluded that the best option would be to abandon the use of exposed metal surfaces on roofs and walls of buildings. Pesticides present in rainwater do not pose a greater groundwater contamination problem during artificial roof runoff infiltration (a practice in Switz. to reduce runoff) than does the direct application in agriculture (Bucheli, *et al.* 1998a); however, the herbicide (R,S)-mecoprop, a root protection agent in Preventol B 2 commonly applied to roofs, is of the same order of magnitude as loads from agricultural applications (Bucheli, *et al.* 1998b). Förster (1999) and Förster, *et al.* (1999) reported on studies investigating roof runoff as stormwater pollutant sources. Runoff samples were taken from an experimental roof system containing five different roofing materials and from house roofs at five different locations in Bayreuth, Germany. It was found that local sources (e.g. PAH from heating systems), dissolution of the roof systems' metal components, and background air pollution were the main sources of the roof-runoff pollution. They found that the first flush from the roofs often was heavily polluted and should be specially treated. They concluded that roofs having metal surfaces should not be connected to infiltration facilities as concentrations of copper and zinc far exceed various toxicity threshold values. They also examined a green (vegetated) roof for comparison. These roofs were found to act as a source of heavy metals which were found to be in complexes with dissolved organic material. Leaching from unprotected zinc sheet surfaces on the green roofs resulted in extremely high zinc concentrations in the runoff. In contrast, the green roofs were a trap for PAHs.

Davis and Burns (1999) examined lead concentrations in runoff from painted surfaces. In many tests, high lead concentrations were found (using 100 mL of wash water over 1600 cm^2 of surface). Lead concentrations from 169 different structures followed the following order (median concentrations in the wash water): wood (49 µg/L) > brick (16 µg/L) > block (8.0 µg/L). Lead concentration depended strongly on paint age and condition, with the lead levels from washes of older paints being much higher than from freshly painted surfaces. Lead from surface washes were found to be 70%, or greater, in particulate lead form, suggesting the release of lead pigments from the weathered paints.

Zobrist, *et al.* (2000) examined the potential effects of roof runoff on urban stormwater drainage from three different types of roofs: an inclined tile roof, an inclined polyester roof and a flat gravel roof. Runoff from the two inclined roofs showed initially high ("first flush") concentrations of the pollutants with a rapid decline to lower levels. The flat gravel roof showed lower concentrations of most of the pollutants because of the ponding of the water on the roof surface acting like a detention pond. Pollutant loadings were similar to atmospheric deposition, with the exception of copper from drain corrosion (rate about 5 $g/m^2/yr$). Tobiason and Logan (2000) used the whole effluent toxicity (WET) test to characterize stormwater runoff

samples from four outfalls at Sea-Tac International Airport. Three of the four outfalls met standards; the source of the toxicity at the fourth outfall was found to be zinc-galvanized metal rooftops. Typically, more than 50% of the total zinc in the runoff was in dissolved form and likely bioavailable. Polkowska, *et al.* (2002) presented the results of testing roof runoff waters from buildings in Gdafisk, Poland. More than half of the samples (25) were found to be toxic, with inhibition exceeding 20%. The toxicity was weakly correlated to the levels of organonitrogen and organophosphorus pesticides in runoff waters. It was established that at least in some cases the roofing material affected the levels of the pollutants found in the samples. Heijerick, *et al.* (2002) investigated the bioavailability of zinc in runoff from roofing materials in Stockholm, Sweden. Chemical speciation modeling revealed that most zinc (94.3-99.9%) was present as the free Zn ion, the most bioavailable speciation form. These findings were confirmed by the results of the biosensor test (Biomet™), which indicated that all zinc was indeed bioavailable. Analysis of the ecotoxicity data also suggested that the observed toxic effects were due to the presence of Zn^{2+} ions. Gromaire, *et al.* (2002) investigated the impact of zinc roofing on urban pollutant loads in Paris. On an annual basis, runoff from Parisian zinc roofs would produce around 34 to 64 metric tons of zinc and 15 to 25 kg of cadmium, which is approximately half the load generated by runoff from all of Paris.

Karlen, *et al.* (2002) investigated runoff rates, chemical speciation and bioavailability of copper released from naturally patinated copper roofs in Stockholm, Sweden. The results show annual runoff rates between 1.0 and 1.5 g/m^2 year for naturally patinated copper of varying age with rates increasing slightly with patina age. The total copper concentration in investigated runoff samplings ranged from 0.9 to 9.7 mg/l. The majority (60 – 100%) of the released copper was present as the free hydrated cupric ion, $Cu(H_2O)6^{2+}$, the most bioavailable copper species. The copper-containing runoff water, sampled directly after release from the roof, caused significant reduction in growth rate of the green alga. Wallinder, *et al.* (2002) studied the atmospheric corrosion of naturally and pre-patinated copper roofs in Singapore and Stockholm. Measured annual runoff rates from fresh and brown prepatinated were 1.1-1.6 g/m^2 and 5.5-5.7 g/m^2, in Stockholm and Singapore, respectively. Naturally aged copper sheet (130 years old) and green pre-patinated copper sheet showed slightly higher (1.6-2.3 g/m^2), but comparable runoff rates in Stockholm. In Singapore, runoff rates from green pre-patinated copper sheet were 8.4-8.8 g/m^2. Comparable runoff rates between fresh and brown-patinated copper sheet and between green naturally patinated and green pre-patinated copper sheet at each site were related to similarities in patina morphology and composition. Boller and Steiner (2002) investigated the emission and control of copper from roofs and roads in urban surface runoff. A large copper façade was used to investigate the concentrations of copper emitted. The concentrations ranged from 1 – 10 mg/L. Michels, *et al.* (2003) investigated the environmental impact of stormwater runoff from a copper roof. It was shown that the runoff became less toxic as it passed through the drainage system.

Clark, *et al.* (2003) studied the potential pollutant contributions from commonly-used building materials (roofing, siding, wood) using a modified Toxicity Characteristic Leaching Procedure (TCLP) test. Results of particular interest included evidence of elevated levels of phosphate, nitrate and ammonia in the leachant following exposure of common roofing and siding materials to simulated acid rain.

Lebow, *et al.* (2003) investigated the release of preservatives, primarily arsenic, from CCA-treated wood under simulated rainfall and the ability of wood finishes to prevent/reduce the release. Water repellent significantly decreased the amounts of these elements in the runoff, while UV exposure increased the leaching of preservatives from the wood.

Highway and other Roadway Runoff

Wada and Miura (1996) examined storm runoff from a heavily traveled highway in Osaka, Japan. A significant "first-flush" for COD was found and the amount of small rubber pieces from tire wear in the highway storm runoff was more than 20 times greater than for an "ordinary" road. The primary factors affecting storm runoff concentrations were the amount of traffic (and related exhaust emissions and tire wear) and the fraction of the total traffic that was comprised of trucks and buses. Montrejaud-Vignoles, *et al.* (1996) collected storm runoff from a heavily used six-lane motorway in the Mediterranean area of France. The very irregular rainfall in this area and associated very-long dry periods can result in storm runoff that is much more polluted than elsewhere in France. As an example, during the one-year study, a single rain of only 10 mm but having an antecedent-dry period of 35 days produced more than 12% of the annual COD discharges. Ball, *et al.* (1996) and Ball 2000 examined roadway pollutant accumulations in a

suburb of Sydney, Australia. It was concluded that the local heavy winds have a significant effect on pollutant accumulations that commonly available stormwater models do not consider, and that historical United States' data on roadway-pollutant accumulations are much greater than found in their area.

Sansalone and Buchberger (1996) studied metal distributions in stormwater and snowmelt from a major highway in Cincinnati, OH. Zn and Cd were mostly in filterable (dissolved solids) forms in the storm runoff, while lead was mostly associated with particulates. A receptor-source model was used to apportion source contributions for PAH in street and creek sediments. The model showed that vehicles along with the coke ovens, are the major contributors to PAH in street sediments (Sharma *et al.,* 1997). Measurements of conductivity and turbidity taken in a study of the Crum Creek which runs through the suburbs of Philadelphia, Pa. indicated two stages during the first three hours of wet weather runoff: a dissolved solids flush followed by a suspended solids (SS) flush (Downing and McGarity 1998). In San Francisco, Calif., vehicle emissions of both ultrafine (< 0.12 μm) and accumulation mode (0.12 —2 μm) particulate polycyclic aromatic hydrocarbons (PAH) are derived from diesel vehicles while gasoline vehicles emit higher molecular weight PAH primarily in the ultrafine mode. Heavy duty diesel vehicles were found to be important sources of fine black carbon particles (Miguel, *et al.* 1998). In a European study, 90% of the particles from a contaminated highway runoff catchment were smaller than 100 μm. The constituents of the contaminants smaller than 50 μm were further analyzed by X-ray diffraction, thermogravimetry and specific mass and contained 56% clay, 15% quartz, 12% chalk, 9% organic matter, 5% feldspars, and 2% dolomite (Roger, *et al.* 1998).

Waschbusch, *et al.* (1999) investigated sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin. They collected numerous sheetflow runoff samples from throughout the test watersheds and used SLAMM, an urban stormwater quality model, to quantify the significance of the different phosphorus sources. Lawns and streets were found to be the most significant sources of phosphorus in the test basins, contributing about 80% of the total annual loading. In the Kerault Region of France, the effects of pollution were studied using solid matter from a section of the A9 motorway. This study analyzed both settled sediments from collecting basin and characteristics of sediments in the water column during and after eight storm events between October 12, 1993, and February 6, 1994. Settled sediments were used to measure particle sizes, mineral content, and related characteristics, whereas water samples were used to document total suspended solids, mineral content, and heavy metals (Andral, *et al.* 1999). Runoff from highways contains significant loads of heavy metals and hydrocarbons, according to German regulations it should be infiltrated over embankments to support groundwater recharge. To investigate the decontaminating effect of greened embankments, soil-monoliths from highways with high traffic densities were taken. Soils were analyzed to characterize the contamination in relation to distance and depth for lead, zinc, copper, cadmium, PAH and MOTH (Dierkes and Geiger 1999).

An investigation by Drapper, *et al.* (2000) showed that the pollutant concentrations (heavy metals, hydrocarbons, pesticides, and physical characteristics) in 'first flush' road runoff in Brisbane in southeast Queensland, Australia was within the ranges reported internationally for highways. Traffic volumes were the best indicator of road runoff pollutant concentrations, with interevent duration also being statistically significant factor. Exit-lane sites were found to have higher concentrations of acid-extractable copper and zinc, likely due to brake pad and tire wear caused by rapid deceleration, and laser particle sizing showed that a significant proportion of the sediment in runoff was less than 100 um. Krein and Schorer (2000) investigated heavy metals and PAHs in road runoff and found that, as expected, an inverse relationship existed between particle size and particle-bound heavy metals concentration existed. However, particulate-bound PAHs were found to be bimodally distributed. Three-ring PAHs were mostly find in the fine sand fraction, while six-ring PAHs were mostly concentrated in the fine silt fraction. Sutherland, *et al.* (2000) investigated the potential for road-deposited sediments in Oahu, Hawaii, to bind contaminants, and thus transporting these bound contaminants to the receiving water as part of the runoff. In the sediment fractions less than 2 mm in diameter, the origins of the aluminum, cobalt, iron, manganese and nickel were determined to be geologic. Three of the metals concentrations, copper, lead and zinc, were found to be enhanced by anthropogenic activities. Sequential extraction of the sediment determined the associations of the metals with the following fractions: acid extractable, reducible, oxidizable, and residual).

Stenstrom, *et al.* (2001) studied freeway runoff from three sites in the west Los Angeles area. Each site was sampled for 14 storms during the 1999-2000 rainy season. Samples were collected very early in the storm in order to compare water quality from the first runoff to water quality from the middle of the storm. A large range of water quality parameters and metals were analyzed. The data showed large first flushes in concentration and moderate first flushes in mass emission rates. Neary, *et al.* (2002) studied the pollutant washoff and loadings from parking lots in Cookeville, Tennessee. The monitoring results indicated that the washoff response from small parking lot catchments was also affected by other factors that included antecedent dry conditions and rainfall intensity. Ma, *et al.* (2002) investigated the first-flush phenomenon for highways. Most pollutants showed median mass first flushes where 30 percent of the mass is released in the first 20% of the runoff. Pollutants representing organic contaminants had the highest first flush ratios. Lau, *et al.* (2002) studied whether a first flush of organics (COD, oil and grease, and PAHs) would be seen in highway runoff. The three highway sites exhibited a first flush in most cases for most parameters. The mass first flush ratio (the ratio of the normalized transported mass of pollutant to the normalized runoff volume) generally was above 1.8 for the first 25% of the runoff volume, and in some cases as high as 2.8.

Vaze and Chiew (2003) studied pollutant washoff from small impervious experimental plots and showed that the energy of the falling raindrops was important at the beginning of the event where the concentration/prevalence of easily detachable pollutants is greatest. The authors suggest that meaningful characteristic curves that relate event total suspended solids (TSS) and total phosphorus (TP) loads to storm durations for specific rainfall intensities could be developed from the experimental data. Kayhanian, *et al.* (2003) investigated the relationships between annual average daily traffic (AADT) numbers and highway runoff pollutant concentrations from California Department of Transportation highway sites. No direct linear correlation was found between highway runoff pollutant event mean concentrations (EMCs) and AADT, but multiple linear regression showed that AADT, as well as antecedent dry period (ADP), drainage area, maximum rain intensity and land use, influenced most highway runoff constituent concentrations. Mishra, *et al.* (2003) developed hysteresis and normal mass rating curves were developed for runoff rate and mass of 12 dissolved and particulate-bound metal elements from Cincinnati, OH. Zinc was found to increase with antecedent dry period (ADP). Shinya, *et al.* (2003) evaluated the factors influencing diffusion of highway pollutant loads in urban highway runoff. Particulates (suspended solids, iron and TP) were inclined to be washed off in heavier rainfall; event mean runoff intensity and cumulative runoff height were correlated with cumulative runoff load of the constituents except TN. ADP and traffic flow volume were not correlated with cumulative runoff load (except TN). Sutherland (2003) investigated the lead in six grain-size fractions of road-deposited sediment from Oahu, HI. Significant Pb concentration was seen in all samples and the median labile Pb concentration was 170 mg/kg (4 to 1750 mg/kg), with the silt plus clay fraction containing 38% of the total sediment in this fraction.

Landscaped Areas

Emerson (2003) discussed Plymouth, MN restrictions on the use of lawn fertilizers containing phosphorus. The result of the program has been an improvement in water quality due to reducing phosphorus in the runoff. Strynchuk, *et al.* (2003) studied the decomposition of grass and leaves and the subsequent input of nutrients to receiving waters in Brevard County, FL. Release rates for these nutrients have been calculated, which can then be used to select and determine maintenance frequencies of stormwater control practices that treat nutrients.

Conclusions

Source area sheetflow data can be used to identify critical source areas that should receive special attention when designing a stormwater management program. This information is also useful when calibrating stormwater quality models, especially when it has simultaneous outfall data. The information presented in this paper are summaries from a large number of separate monitoring projects conducted in many locations of the US, and represent a wide range of land uses and source area types. The total number of samples is also relatively large. However, this data is presented as simple averages, along with some variations, for the source areas and no significant statistical analyses have been conducted. This may be suitable for model calibration, especially in areas where the data has been collected, but a complete database containing all data and comprehensive analyses would add greatly to our understanding of stormwater problems. The authors are in the process of collecting this data together for such a database.

The past studies also have tremendous guidance information concerning sample collection and analysis. These activities require special attention when attempting to monitor a large number of locations simultaneously. Burton and Pitt (2002) have recently summarized these sampling (and experimental design) approaches suitable for source area monitoring, along with many other elements of a comprehensive monitoring program.

Many studies have concluded that automobiles contribute many important heavy metals to street surface particulates and to urban runoff and receiving waters. Tire wear is an important zinc source. The role of atmospheric deposition is less clear and is frequently confused. Urban atmospheric deposition information must be interpreted carefully, because of the ability of many polluted dust and dirt particles to be resuspended and then redeposited within the urban area. In many cases, the atmospheric deposition measurements include material that was previously residing and measured in other urban runoff pollutant source areas. Also, only small amounts of the atmospheric deposition material would directly contribute to runoff. Rain is subjected to infiltration and the dry fall particulates are likely mostly incorporated with surface soils and only small fractions are then eroded during rains. Therefore, mass balances and determinations of urban runoff deposition and accumulation from different source areas can be highly misleading, unless transfer of material between source areas and the effective yield of this material to the receiving water is considered. Depending on the land use, relatively little of the dustfall in urban areas likely contributes to stormwater discharges.

Data observations of sheetflow suspended solids showed definite trends of decreasing concentrations verses increasing rain volumes for most of the source area categories. However, sheetflows from pervious areas had the highest total solids concentrations observed for any source category, and for all rain events.

The greatest detection frequencies for organic toxicants were for 1,3-dichlorobenzene and fluoranthene, which were each detected in 23% of the Birmingham area samples. The organics most frequently found in these source area samples (i.e., fluoranthene and pyrene) were similar to the organics most frequently detected at outfalls in prior studies. In contrast to the organics, the heavy metals analyzed were detected in almost all samples, including the filtered sample portions.

The volume of runoff from Wisconsin lawns is expected to be relatively low, but concentrations of phosphorus in lawn runoff are 2 to 10 times higher than for other source areas. Because of these relatively high concentrations, lawns can contribute as much as 50 percent of the annual total phosphorus load in a residential area. Similarly, with PAH levels from commercial parking lots 10 to 100 times higher than from any other source area, commercial parking lots representing only 3 percent of an urban drainage area can contribute 60 percent of the annual PAH load

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