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Module 3a: Characteristics of Urban Runoff and Sources of Pollutants

Introduction

Stormwaters may pose a potential threat to both surface and subsurface receiving waters. This module summarizes urban runoff quality data. Many studies have investigated stormwater quality, with the EPA's Nationwide Urban Runoff Program (NURP) (EPA 1983) providing the largest and best known data base. Recently, the National Stormwater Quality Database, a compilation of much of the Phase 1 stormwater permit program data from throughout the country, has been developed that contains an updated description of stormwater quality (Maestre and Pitt 2005).

Urban runoff is comprised of many different flow types. These include dry-weather base flows, stormwater runoff, combined sewer overflows (CSOs) and snowmelt. The relative magnitudes of these discharges vary considerably, based on a number of factors. Season (especially cold versus warm weather) and land use have been identified as important factors affecting base flow and stormwater runoff quality, respectively (Pitt and McLean 1986). This module briefly summarizes a number of different observations of runoff quality for these different phases and land uses, along with summaries of observations of source area flows contributing to these combined discharges.

Stormwater Characteristics

Land development increases stormwater runoff volumes and pollutant concentrations. Impervious surfaces, such as rooftops, driveways and roads, reduce infiltration of rainfall and runoff into the ground and degrade runoff quality. The most important hydraulic factors affecting urban runoff volume (and therefore the amount of water available for groundwater infiltration) are the quantity of rain and the extent of impervious surfaces directly connected to a stream or drainage system. Directly connected impervious areas include paved streets, driveways, and parking areas draining to curb and gutter drainage systems, and roofs draining directly to a storm or combined sewer pipe. BOD_5 and nutrient concentrations in stormwater are lower than in raw sanitary wastewater; they are closer in quality to typically treated sanitary wastewaters. However, urban stormwater has relatively high concentrations of bacteria, along with high concentrations of many metallic and some organic toxicants.

Historical Stormwater Quality Data

Table 1 presents older stormwater quality data (APWA 1969) while Table 2 is a summary of the Nationwide Urban Runoff Program (NURP) stormwater data collected from about 1979 through 1982 (EPA 1983). The NURP data has been used as the most comprehensive stormwater data available from throughout the nation. The next section reviews the newer National Stormwater Quality Database that better represents some parts of the country. BOD_5 and nutrient concentrations in stormwater are lower than associated values for raw sanitary wastewater; they are closer in quality to typically treated sanitary wastewaters. However, urban stormwater has relatively high concentrations of bacteria, along with high concentrations of many metallic and some organic toxicants. Land use and source areas (parking areas, rooftops, streets, landscaped areas, etc.) all have important effects on stormwater runoff quality and source area characteristics are also discussed later in this module.

Table 1. Characteristics of Stormwater Runoff

	City	BOD_5 (mg/L)	Total Solids (mg/L)	Suspended Solids (mg/L)	Chlorides (mg/L)	COD (mg/L)
1.	East Bay Sanitary District:					
	Oakland, California					
	Minimum	3	726	16	300	
	Maximum	7,700		4,400	10,260	
	Average	87	1,401	613	5,100	
2.	Cincinnati, Ohio					
	Maximum Seasonal Means	12	260			110
	Average	17		227		111
3.	Los Angeles County					
	Average 1962-63	161	2,909		199	
4.	Washington, D.C.					
	Catch-basin samples					
	during storm	6		26	11	
	Minimum	625		36,250	160	
	Maximum	126		2,100	42	
	Average					
5.	Seattle, Washington	10				
6.	Oxney, England	100[a]	2,045			
7.	Moscow, U.S.S.R.	186-285	1,000-3,500[a]			
8.	Leningrad, U.S.S.R.	36	14,541			
9.	Stockholm, Sweden	17-80	30-8,000			18-3,100
10.	Pretoria, South Africa					
	Residential	30				29
	Business	34				28
11.	Detroit, Michigan	96-234	310-914	102-213[b]		

[a] Maximum [b] Mean

Source: APWA 1969

Table 2. Median Stormwater Pollutant Concentrations for All Sites by Land Use (Nationwide Urban Runoff Program, NURP)

Constituent	Residential		Mixed Land Use		Commercial		Open/Nonurban	
	Median	COV[1]	Median	COV	Median	COV	Median	COV
BOD_5, mg/L	10.0	0.41	7.8	0.52	9.3	0.31	--	--
COD, mg/L	73	0.55	65	0.58	57	0.39	40	0.78
TSS, mg/L	101	0.96	67	1.14	69	0.85	70	2.92
Total Kjeldahl Nitrogen, μg/L	1900	0.73	1288	0.50	1179	0.43	965	1.00
$NO_2 + NO_3$ (as N) μg/L	736	0.83	558	0.67	572	0.48	543	0.91
Total P, μg/L	383	0.69	263	0.75	201	0.67	121	1.66
Soluble P, μg/L	143	0.46	56	0.75	80	0.71	26	2.11
Total Lead, μg/L	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper, μg/L	33	0.99	27	1.32	29	0.81	--	--
Total Zinc, μg/L	135	0.84	154	0.78	226	1.07	195	0.66

[1] COV: coefficient of variation = standard deviation/mean

Source: EPA 1983

National Stormwater Quality Database (NSQD)

Introduction

The University of Alabama and the Center for Watershed Protection were awarded an EPA Office of Water 104(b)3 grant in 2001 to collect and evaluate stormwater data from selected NPDES (National Pollutant Discharge Elimination System) MS4 (municipal separate storm sewer system) stormwater permit holders, mainly in the Chesapeake Bay area and the southeast. The National Stormwater Quality Database (NSQD) contains selected water quality information from the monitoring carried out as part of the U.S. EPA's National Pollutant Discharge Elimination System (NPDES) Phase 1 stormwater permit applications and subsequent permits, during the period of 1992 to 2002 (Maestre and Pitt 2005). Version 1.1 of this database contains about 3,765 events from 360 sites in 65 communities from throughout the U.S. For each site, more additional data, including the percentage of each land use in the catchment, the total area, the percentage of impervious cover, the geographical location, and the season, has been included in the database. The database and associated information is located at: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml. Information about the characteristics of each event is also included. Total precipitation, precipitation intensity, total runoff and antecedent dry period are also included, if collected. The database only contains information for samples collected at drainage system outfalls; in-stream samples (which were a component of some state programs) were not included in the database, although some outfalls were located in open channel conveyances.

There are a number of commonly accepted ideas that are used by stormwater managers and regulators that can have major impacts on local costs and program effectiveness. The NSQD report (Maestre and Pitt 2005) examined a number of these potential misconceptions to see how well they hold up under a comprehensive set of actual monitoring data collected throughout the U.S. as part of the Phase I stormwater permit program.

Several efforts have been performed in the past to describe the water quality characteristics of stormwater constituents at different locations. The interest of this EPA-sponsored project is based on the scarcity of nationally summarized and accessible data from the existing U.S. EPA's NPDES (National Pollutant Discharge Elimination System) stormwater permit program. There have been some local and regional data summaries, but little has been done with nationwide data. A notable exception is the Camp, Dresser, and McGee (CDM) national stormwater database (Smullen and Cave 2002) that combined historical Nationwide Urban Runoff Program (NURP) (EPA 1983) data, available urban U.S. Geological survey (USGS), and selected NPDES data. Their main effort had been to describe the probability distributions of these data (and corresponding EMCs, the event mean concentrations). They concluded that concentrations for different land uses were not significantly different, so all their data were pooled into a single urban land use category.

The Clean Water Act (CWA) of 1972 was the first major national regulation in the U.S. requiring control of conventional point source discharges of water pollutants (affecting municipal and industrial discharges). Section 208 also provided the capability to implement stormwater management plans at the regional level. In 1976, the EPA enlarged the planning initiative through the "Section 208: Areawide Assessment Procedures Manual". However, in the late 1970s, some problems arose with the 208 planning projects due to inadequate data and lack of technological development (Whipple, as quoted by Pitt, *et al*. 1999). Between 1978 and 1983, the EPA conducted the Nationwide Urban Runoff Program (NURP) that examined stormwater quality from separate storm sewers in different land uses (EPA 1983). This program studied 81 outfalls in 28 communities throughout the U.S. and included the monitoring of approximately 2,300 storm events. NURP is still an important reference for water quality characteristics of urban stormwater; however, the collected data poorly represented the southern area of the country and was focused mainly in residential and mixed land use areas. Since NURP, other important studies have been conducted that characterize stormwater. The USGS created a database with more than 1,100 storms from 98 monitoring sites in 20 metropolitan areas. The Federal Highway Administration (FHWA) analyzed stormwater runoff from 31 highways in 11 states during the 1970s and 1980s. Strecker (personal communication) is also collecting information from highway monitoring as part of a current NCHRP (National Cooperative Highway Research Program) funded project. The city of Austin also developed a database having more than 1,200 events. Other regional databases also exist for U.S. data, mostly using local NPDES data. These include the Los Angeles area database, the Santa Clara and Alameda County (California) databases, the Oregon Association of Clean Water Agencies Database, and the Dallas, Texas, area stormwater database. These regional data are included in the NSQD. However, the USGS and historical NURP data are not included in the NSQD due to lack of consistent descriptive information for the older drainage areas and because of the age of the data from those prior studies. Much of the NURP data is available in electronic form at the University of Alabama's student American Water Resources Association web page at: http://www.eng.ua.edu/~awra/download.htm.

Outside the U.S., there have been important efforts to characterize stormwater. In Toronto, Canada, the Toronto Area Watershed Management Strategy Study (TAWMS) was conducted during 1983 and 1984 and extensively monitored industrial stormwater, along with snowmelt in the Toronto urban area, for example. Numerous other investigations in South Africa, the South Pacific, Europe and Latin America have also been conducted over the past 30 years, but no large-scale summaries of that data have been prepared. About 4,000 international references on stormwater have been reviewed and compiled since 1996 by the Urban Wet Weather Flows literature review team for publication in *Water Environment Research* (most recently by Clark, *et al*. 2001, 2002, 2003, 2004). An overall compilation of these literature reviews is available at: http://www.eng.ua.edu/~rpitt/Publications/Publications.shtml. These reviews include short summaries of the papers and are organized by major topics. Besides journal articles, many published conference proceedings are also represented (including the extensive conference proceedings from the 7th International Conference on Urban Storm Drainage held in Germany in 1996, the 8th International Conference on Urban Storm Drainage held in Sydney, Australia, in 1999, the 9th International Conference on Urban Storm Drainage held in Portland, OR, in 2002, and the Urban Water Systems Modeling conference series Toronto meetings organized by Computational Hydraulics, Inc., amongst many other specialty conferences).

In 1987, the amendments to the CWA established a two-phase program to regulate 13 classes of stormwater discharges. Two of these classifications were discharges from large and medium-sized Municipal Separate Storm Sewer Systems. A large MS4 serves an urban population of 250,000 or more, while a medium MS4 serves communities between 100,000 and 250,000. EPA set up a permit strategy for communities complying with NPDES requirements. Monitoring data from this program have been included in some databases. The CDM National Stormwater Runoff Pollution database included 816 NPDES storm events in a database that totals approximately 3,100 events. The Rouge River National Wet Weather Demonstration Program office in Detroit included their NPDES data in their database (Smullen and Cave 2003).

Another important effort has been the development of the International Stormwater Best Management Practices Database (http://www.bmpdatabase.com). This database was created with the purpose to evaluate the performance and effectiveness of stormwater control practices, frequently labeled "best management practices," or BMP's. Detention ponds, street cleaning, and hydrodynamic devices are examples of BMPs (ASCE/EPA 2000).

Data Collection

Data from 3,765 storm events at 360 monitoring sites were collected and are stored in version 1.1 of the NSQD. This version contains the results of approximately one fourth of the total number of communities that participated in the Phase I NPDES stormwater permit monitoring activities.

According to the published sampling guidance (40 CFR 122.21) for the permit application, each community was required to sample at least a residential, a commercial and an industrial watershed. At least three samples should be collected every year at each location. Each storm should be at least one month apart and have at least a 3 days antecedent dry period. Only samples from rain events greater than 0.1 inches, and close to the annual mean conditions, were considered valid for the analysis. It was required to collect a composite sample with subsamples collected during the first three hours of the event. An additional grab sample was required during the first 30 minutes of the event to evaluate the "first flush" effect. "First flush" refers to the hypothesis that the concentrations of stormwater constituents are higher at the beginning of the discharge event than during the complete event. Designated states were able to modify some of these sampling requirements to better address local concerns.

Most communities were required to submit annual reports describing the sampling locations and procedures, the equipment, and the quality control and quality assurance (QA/QC) procedures used during the sampling and analysis of the samples, the analytical methods used in the laboratory, and problems encountered during the sample collection. The reports also included the results of the chemical analyses performed by the laboratories.

Figure 1 is a map showing the 65 communities and 17 states included in the first version of the NSQD. The EPA-funded project was intended to focus on the Chesapeake Bay area and parts of the southern U.S. (specifically Birmingham, AL, and Atlanta, GA) as a demonstration of the usefulness of the data. However, it was possible to obtain some data from other parts of the country during the project period and these data were incorporated in the database, allowing some regional analyses. States representing most of the samples included Virginia (24%) and Maryland (13%). The states with low numbers of observations included Pennsylvania, Massachusetts, and Indiana.

Figure 1 also shows the EPA Rain Zones. Each zone corresponds to a geographical region with similar climatic conditions (EPA 1986). There is at least one community per rain zone indicating some geographical representation for the entire country. However, Table 3 indicates that most of the samples were collected west, south and east of the central part of the country, with few data from EPA Rain Zone 1 included in the database. EPA Rain Zones 8 and 9 have sparse available data from the Phase I monitoring program, due to few large cities in these areas.

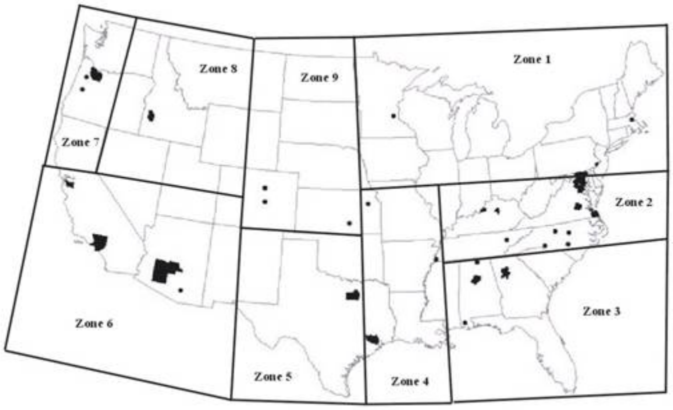


Figure 1. Communities included in the NSQD version 1.1 by rainfall zones

Table 3. Total Samples and Sites by EPA Rain Zone in ver. 1. 1 of the NSQD

EPA Rain Zone	Total Samples	Percentage of Samples	Number of Communities	Number of Sites
1	69	1.8	2	12
2	2000	53	28	185
3	266	7.1	8	30
4	212	5.6	4	21
5	485	13	9	33
6	356	9.5	4	30
7	229	6.1	6	28
8	24	0.63	1	4
9	124	3.3	3	17

About one third of the sites included in the database correspond to residential areas, another third is shared by commercial and industrial land uses. The remaining third correspond to freeways, open space, institutional and all the mixed land uses. Several schools were identified in the sites, however only one site was considered 100% institutional.

Summary of U.S. NPDES Phase I Stormwater Data in the NSQD
Table 4 is a summary of selected data collected and entered into the database. The data are separated into 11 land use categories: residential, commercial, industrial, institutional, freeways, and open space, plus mixtures of these land uses. Summaries are shown for the major land use areas and for the total data set combined. The full database includes all of the data, and is available at http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml. The total number of observations and the percentage of observations above the detection limits are also shown on this summary table. In general, the coefficient of variation (COV) values range from 1.0 to 2.0 for the majority of pollutants across all major land uses.

Supplemental reports were created containing additional information for each community. These site descriptions include (depending on available information) the land use and impervious surfaces for the monitored site, aerial photographs and a topographic map of the area, and descriptions of the sampling procedures and quality control (QA/QC) used during sample collection and analysis. The QA/QC description indicates if blank samples were used during the analysis to check the equipment, the protocols used during the sample collection, and in some cases, the chain of custody of the samples. These supplemental reports also contain descriptions of the sampled parameters, analytical methods, and field instrumentation used by the community.

Table 4. Summary of Available Stormwater Data Included in NSQD, version 1.1

	Area (acres)	% Impervious	Precipitation Depth (in)	Runoff Depth (in)	Conductivity (µS/cm @25ºC)	Hardness (mg/L CaCO3)	Oil and Grease (mg/L)	pH	Tempe-rature (C)	TDS (mg/L)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)
Overall Summary (3765)													
Number of observations	3765	2209	3316	1495	685	1082	1834	1665	861	2956	3493	3105	2750
% of samples above detection	100	100	100	100	100	98.7	66.1	100	100	99.0	97.9	96.2	98.4
Median	57.3	50.0	0.48	0.15	121	38.0	4.3	7.5	16.5	80	59	8.6	53
Coefficient of variation	3.7	0.4	1.0	1.9	1.6	1.4	9.7	0.1	0.4	3.4	1.8	7.4	1.1
Residential (1042)													
Number of observations	1042	614	919	372	104	215	483	286	181	814	978	908	748
% of samples above detection	100	100	100	100	100	100	54.9	100	100	99.1	98.3	97.1	98.7
Median	57.3	37.0	0.48	0.10	102	32.0	4.0	7.2	17.0	72.0	49	9.0	54.5
Coefficient of variation	4.8	0.4	1.0	1.5	1.6	1.1	7.8	0.1	0.4	1.1	1.8	1.5	0.93
Mixed Residential (611)													
Number of observations	611	278	491	262	105	168	283	333	137	491	582	549	465
% of samples above detection	100	100	100	100	100	98.2	70.3	100	100	99.2	98.3	94.2	99.6
Median	150.8	44.9	0.53	0.12	112	40.0	4.0	7.50	15.5	86	66	7.8	43
Coefficient of variation	2.1	0.3	0.8	1.3	1.2	1.1	2.6	0.1	0.3	5.2	1.6	1.3	1.2
Commercial (527)													
Number of observations	527	284	462	146	78	156	331	191	98	418	503	452	393
% of samples above detection	100	100	100	100	100	100	71.9	100	100	99.5	95.2	97.6	98.5
Median	38.8	84.5	0.42	0.29	107	36.5	4.6	7.4	16.0	72	43	11.0	58
Coefficient of variation	1.2	0.1	1.0	1.0	1.0	1.1	3.0	0.1	0.4	1.9	2.0	1.1	1.0
Mixed Commercial (324)													

Number of observations	324	237	305	118	59	98	134	156	98	265	297	277	267
% of samples above detection	100	100	100	100	100	99.0	79.9	100	100	99.6	99.7	98.9	99.6
Median	75.0	60.0	0.47	0.28	100	36.0	5.0	7.60	14.5	69.5	54.5	9.0	60
Coefficient of variation	1.4	0.3	1.0	0.9	0.8	1.8	2.9	0.1	0.4	1.9	1.3	1.7	1.0
Industrial (566)													
Number of observations	566	292	482	215	102	132	315	248	140	431	521	455	386
% of samples above detection	100	100	100	100	100	96.2	64.8	100	100	99.5	97.7	95.4	99.0
Median	39.5	75.0	0.50	0.16	139	39.0	4.8	7.50	17.9	86	81	9.0	58.6
Coefficient of variation	1.1	0.3	0.9	1.2	1.3	1.5	11.8	0.1	0.3	3.6	1.6	10.0	1.2

Table 4. Summary of Available Stormwater Data Included in NSQD, version 1.1 – Continued

	Area (acres)	% Impervious	Precipitation Depth (in)	Runoff Depth (in)	Conductivity (µS/cm @25ºC)	Hardness (mg/L CaCO3)	Oil and Grease (mg/L)	pH	Tempe-rature (C)	TDS (mg/L)	TSS (mg/L)	BOD$_5$ (mg/L)	COD (m
Mixed Industrial (218)													
Number of observations	218	118	193	117	56	75	72	152	57	186	207	178	1
% of samples above detection	100	100	100	100	100	93.3	80.6	100	100	99.5	100	95.5	9
Median	168.0	44.0	0.45	0.29	126	29.3	9.0	7.70	18.0	90	82	7.5	3
Coefficient of variation	1.8	0.3	0.9	1.2	0.8	0.6	1.8	0.1	0.3	0.8	1.4	1.8	
Institutional (18)													
Number of observations	18	18	17	14						18	18	18	
% of samples above detection	100	100	100	100						100	94.4	88.9	88.9
Median	36.0	45.0	0.18	0.00						52.5	17	8.5	50
Coefficient of variation	0	0	0.9	2.1						0.7	0.83	0.7	0.9
Freeways (185)													
Number of observations	185	154	182	144	86	127	60	111	31	97	134	26	67
% of samples above detection	100	100	100	100	100	100	71.7	100	100	99.0	99.3	84.6	98.5
Median	1.6	80.0	0.54	0.41	99	34.0	8.0	7.10	14.0	77.5	99	8	100
Coefficient of variation	1.4	0.13	1.1	1.7	1.0	1.9	0.6	0.1	0.4	0.8	2.6	1.3	1.1
Mixed Freeways (26)													
Number of observations	26		26		21	12	20	17	17	15	23	23	15
% of samples above detection	100		100		100	100	100	100	100	100	100	100.0	100.0
Median	63.1		0.47		353	83	4.5	7.7	16.0	177	88	8.2	47
Coefficient of variation	0.7		0.8		0.6	0.3	1.8	0.1	0.3	0.4	1.1	1.2	0.5
Open Space (49)													
Number of observations	49	37	41	11	2	8	19	19	2	45	44	44	43
% of samples above detection	100	100	100	100	100	100	36.8	100	100	97.8	95.5	86.4	76.74
Median	85	2.0	0.52	0.05	113	150	1.3	7.70	14.6	125	48.5	5.4	42.1
Coefficient of variation	1.5	1.0	1.2	1.4	0.5	0.6	0.7	0.08	0.7	0.7	1.5	0.7	1.5
Mixed Open Space (168)													
Number of observations	168	131	167	93	65	70	90	128	76	148	153	145	145
% of samples above detection	100	100	100	100	100	100	60.0	100	100	99.3	97.4	96.6	96.6
Median	115.4	33.0	0.51	0.10	215	64.2	8.5	7.9	16.0	109	78.0	6.0	34
Coefficient of variation	0.8	0.4	0.8	1.2	1.7	1.3	1.5	0.1	0.3	2.2	1.6	2.7	1.6

Table 4. Summary of Available Stormwater Data Included in NSQD, version 1.1 – Continued

	Fecal Coliform (mpn/100 mL)	Fecal Strepto-coccus (mpn/100 mL)	Total Coliform (mpn/100 mL)	Total E. Coli (mpn/100 mL)	NH3 (mg/L)	N02+NO3 (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Phospho-rus, filtered (mg/L)	Phospho-rus, total (mg/L)	Sb, total (µg/L)	As, total (µg/L)	As, filtered (µg/L)	Be, total (µg/L)
Overall Summary (3765)													
Number of observations	1704	1141	83	67	1908	3075	3191	2477	3285	874	1507	210	947
% of samples above detection	91.2	94.0	90.4	95.5	71.3	97.3	95.6	85.1	96.5	7.2	49.9	27.1	7.7
Median	5091	17000	12000	1750	0.44	0.60	1.4	0.13	0.27	3.0	3.0	1.5	0.4
Coefficient of variation	4.6	3.8	2.4	2.3	1.4	0.97	1.2	1.6	1.5	1.7	2.6	1.0	2.5
Residential (1042)													
Number of observations	402	257		14	572	889	922	690	926		395		282
% of samples above detection	87.8	87.9		100	82.2	97.6	96.5	83.5	96.8		40.8		7.8
Median	7000	24300		700	0.31	0.60	1.5	0.18	0.31		3.0		0.5
Coefficient of variation	5.2	1.7		1.6	1.1	1.1	1.1	0.9	1.1		2.2		2.5

Mixed Residential (611)													
Number of observations	336	178	26	11	282	531	517	430	552		158		97
% of samples above detection	94.3	97.8	84.6	90.9	58.5	97.9	95.0	83.3	96.2		65.9		11.3
Median	11210	27500	5667	1050	0.39	0.57	1.4	0.13	0.28		3.0		0.3
Coefficient of variation	3.2	2.1	1.3	2.1	1.6	0.78	1.7	1.1	1.7		3.9		2.7
Commercial (527)													
Number of observations	253	201			300	445	469	343	466		235		
% of samples above detection	88.9	92.5			83.3	98.0	97.4	81.0	95.9		33.6		
Median	4600	12000			0.50	0.6	1.5	0.11	0.22		2.3		
Coefficient of variation	3.0	2.7			1.2	1.1	0.9	1.3	1.2		2.9		
Mixed Commercial (324)													
Number of observations	116	95			173	284	276	221	290	89	139		
% of samples above detection	94.8	98.9			67.1	96.8	96.0	93.7	98.6	11.9	45.5		
Median	5400	11900			0.60	0.58	1.4	0.12	0.26	15.0	2.0		
Coefficient of variation	3.0	2.6			1.0	0.7	0.9	2.1	1.5	1.0	1.0		
Industrial (566)													
Number of observations	315	189			272	461	483	344	478	152	255		197
% of samples above detection	87.3	93.7			78.3	96.3	96.3	88.1	96.2	14.5	52.9		10.7
Median	2400	12000			0.42	0.69	1.4	0.10	0.25	3.7	4.0		0.38
Coefficient of variation	5.7	7.0			1.3	0.92	1.1	1.2	1.4	1.4	1.4		2.5

Table 4. Summary of Available Stormwater Data Included in NSQD, version 1.1 – Continued

	Fecal Coliform (mpn/100 mL)	Fecal Strepto-coccus (mpn/100 mL)	Total Coliform (mpn/100 mL)	Total E. Coli (mpn/100 mL)	NH3 (mg/L)	N02+NO3 (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Phospho-rus, filtered (mg/L)	Phospho-rus, total (mg/L)	Sb, total (µg/L)	As, total (µg/L)	As, filtered (µg/L)	Be, total (µg/L)
Mixed Industrial (218)													
Number of observations	79	59	14		99	173	160	179	177		93		
% of samples above detection	98.7	96.9	71.4		30.3	98.8	92.5	84.4	95.5		88.2		
Median	3033	11000	2467		0.58	0.59	1.1	0.08	0.20		3.5		
Coefficient of variation	2.5	2.5	1.5		0.8	0.7	1.5	2.3	1.6		0.9		
Institutional (18)													
Number of observations					18	18	18	17	17				
% of samples above detection					88.9	100	100	82.4	94.1				
Median					0.31	0.6	1.35	0.13	0.18				
Coefficient of variation					0.5	0.6	0.5	0.5	1.0				
Freeways (185)													
Number of observations	49	25	16	13	79	25	125	22	128		61	72	
% of samples above detection	100	100	100	100	87.3	96.0	96.8	95.5	99.2		55.7	50.0	
Median	1700	17000	50000	1900	1.07	0.28	2.0	0.20	0.25		2.4	1.4	
Coefficient of variation	2.0	1.2	1.5	2.2	1.3	1.2	1.4	2.1	1.8		0.7	2.0	
Mixed Freeways (26)													
Number of observations	20	16				22	22	11	22		15		
% of samples above detection	85.0	93.8				100	100	100	100		80		
Median	2600	19000				0.9	2.3	0.03	0.34		3.0		
Coefficient of variation	2.3	1.1				0.7	1.3	0.9	0.7		0.7		
Open Space (68)													
Number of observations	23	22			32	44	45	44	46		19		
% of samples above detection	91.3	90.9			18.8	84.1	71.1	79.6	84.8		31.6		
Median	7200	24900			0.18	0.59	0.74	0.13	0.31		4.0		
Coefficient of variation	1.1	1.0			1.24	0.9	0.9	0.9	3.5		0.4		
Mixed Open Space (168)													
Number of observations	86	75			71	152	123	148	152		88		
% of samples above detection	97.7	100			22.5	97.4	90.2	85.8	96.1		44.3		
Median	3000	21000			0.51	0.7	1.1	0.09	0.25		3.0		
Coefficient of variation	2.3	2.4			1.2	0.8	0.9	1.1	1.1		0.9		

Table 4. Summary of Available Stormwater Data Included in NSQD, version 1.1 – Continued

	Cd, total (µg/L)	Cd, filtered (µg/L)	Cr, total (µg/L)	Cr, filtered (µg/L)	Cu, total (µg/L)	Cu, filtered (µg/L)	Pb, total (µg/L)	Pb, filtered (µg/L)	Hg, total (µg/L)	Ni, total (µg/l)	Ni, filtered (µg/L)	Zn, total (µg/L)	Zn, filtered (µg/L)
Overall Summary (3765)													
Number of observations	2574	389	1598	261	2722	411	2949	446	1014	1430	246	3007	381
% of samples above detection	40.6	30.3	70.2	60.5	87.4	83	77.7	49.8	10.2	59.8	64.2	96.6	96.3
Median	1.0	0.50	7.0	2.1	16	8.0	17.0	3.0	0.20	8.0	4.0	116	52
Coefficient of variation	3.7	1.1	1.5	0.7	2.2	1.6	1.8	2.0	2.5	1.2	1.5	3.3	3.9
Residential (1042)													
Number of observations	695		404		771	90	762	108	275	392	25	784	87
% of samples above detection	31.1		53.2		83.1	63.3	69.4	33.3	6.9	44.1	44.0	96.2	89.7
Median	0.5		4.5		12	7.0	12.0	3.0	0.20	5.6	2.0	73	31.5
Coefficient of variation	3.4		1.2		1.8	2.0	1.9	1.9	0.9	1.2	0.5	1.3	0.8
Mixed Residential (611)													
Number of observations	420	30	193	21	432	29	500	30	115	150	25	515	28
% of samples above detection	34.5	40.0	81.3	52.4	83.8	72.4	78.4	46.7	15.7	60	72.0	92.6	100
Median	0.9	0.30	7.0	2.0	16	5.5	16	3.0	0.20	7.8	5.5	95	48
Coefficient of variation	3.6	0.6	1.5	0.8	1.2	0.9	1.4	0.7	0.8	0.8	0.9	0.9	0.9
Commercial (527)													
Number of observations	379	47	257	27	408	48	399	59	170	242	23	414	49
% of samples above detection	41.7	23.4	60.7	40.7	92.9	79.2	85.5	52.5	6.5	60.3	47.8	99.0	100
Median	0.96	0.30	6.0	2.0	17	7.57	18.0	5.0	0.20	7.0	3.0	150	59
Coefficient of variation	2.7	1.3	1.3	0.6	1.5	0.8	1.6	1.6	0.8	1.2	0.8	1.2	1.4
Mixed Commercial (324)													
Number of observations	188	41	128	27	191	41	244	41		102	26	243	39
% of samples above detection	49.5	34.1	88.3	66.7	93.2	80.5	88.1	63.4		78.4	69.2	98.8	100
Median	0.9	0.35	5.0	2.5	17.5	10	17.0	3.5		5.1	3.5	131.4	73
Coefficient of variation	1.1	0.8	1.1	0.7	3.0	0.6	1.4	0.8		1.3	0.6	1.7	0.8
Industrial (566)													
Number of observations	435	42	250	36	455	42	452	51	199	237	36	473	42
% of samples above detection	49.0	54.8	72.0	55.6	88.6	90.5	75.0	52.9	13.9	61.6	58.3	98.9	95.2
Median	2.0	0.60	12.0	3.0	20.8	8.0	24.9	5.0	0.20	14.0	5.0	199	112
Coefficient of variation	2.2	1.1	1.2	0.7	2.0	0.7	1.9	1.6	2.7	1.0	1.4	1.5	3.6

Table 4. Summary of Available Stormwater Data Included in NSQD, version 1.1 – Continued

	Cd, total (µg/L)	Cd, filtered (µg/L)	Cr, total (µg/L)	Cr, filtered (µg/L)	Cu, total (µg/L)	Cu, filtered (µg/L)	Pb, total (µg/L)	Pb, filtered (µg/L)	Hg, total (µg/L)	Ni, total (µg/l)	Ni, filtered (µg/L)	Zn, total (µg/L)	Zn, filtered (µg/L)
Mixed Industrial (218)													
Number of observations	145	25	109	15	150	24	213	25	58	74	15	212	24
% of samples above detection	60.7	92.0	92.7	66.7	90.0	100.0	82.6	92.0	22.4	83.8	100.0	98.6	95.8
Median	1.6	0.60	8.0	2.0	23	6.0	20.0	5.0	0.3	12	5.0	172	2100
Coefficient of variation	1.9	0.6	1.7	0.7	0.8	0.6	1.4	1.0	0.6	0.8	0.6	3.1	1.2
Institutional (18)													
Number of observations							18					18	
% of samples above detection							77.8					100	
Median							5.75					305	
Coefficient of variation							0.8					0.8	
Freeways (185)													
Number of observations	95	114	76	101	97	130	107	126		99	95	93	105
% of samples above detection	71.6	26.3	98.7	78.2	99.0	99.2	100	50.0		89.9	67.4	96.8	99.1
Median	1.0	0.68	8.3	2.3	34.7	10.9	25	1.8		9.0	4.0	200	51
Coefficient of variation	0.9	1.0	0.7	0.7	1.0	1.5	1.5	1.7		0.9	1.4	1.0	1.9
Mixed Freeways (26)													
Number of observations	23		15		23		23					23	
% of samples above detection	56.5		100		100		56.5					100	
Median	0.5		6.0		14		10.0					130	
Coefficient of variation	2.2		1.0		1.0		1.3					0.9	
Open Space (68)													

Number of observations	38	36	39	45			45
% of samples above detection	55.3	36.1	74.4	42.2			71.1
Median	0.38	5.4	10	10.0			40
Coefficient of variation	1.9	1.7	2.0	1.7			1.3
Mixed Open Space (168)							
Number of observations	107	88	108	155	27	51	156
% of samples above detection	18.7	81.8	89.8	74.2	14.8	72.5	98.1
Median	2.0	6.0	9.0	10	0.15	8.0	80
Coefficient of variation	1.4	1.3	1.0	2.3	0.4	1.1	1.1

Figure 2 shows the distribution of the drainage area for each outfall by land use. Commercial, industrial, open space, and residential land uses have approximately the same range of drainage areas for the monitored outfalls, with a range between ten and one thousand acres. The median monitored watershed area for commercial and industrial sites was about 43 acres, while the median watershed area in residential and open space areas was about 65 acres. Freeways had smaller areas than the other land uses, with median areas being about 2 acres, with a range varying between one and one hundred acres.

Figure 2. Outfall drainage areas by land use

Figure 3 shows a box and whiskers plot of the reported impervious surface areas for the predominant land uses. As expected, the open space sites have the lowest percentage of impervious surfaces (mean about 3.3%), while the mean impervious surface value for the freeway sites is 92%. Industrial and commercial area impervious surface values are higher, with means of 67% and 81% respectively. Residential areas cover almost the complete range, from about 7 to 89%. The impervious surfaces for residential areas are intermediate between the values for open space and the industrial/commercial values, as expected. The mean percentage of impervious areas in residential areas is about 41%.

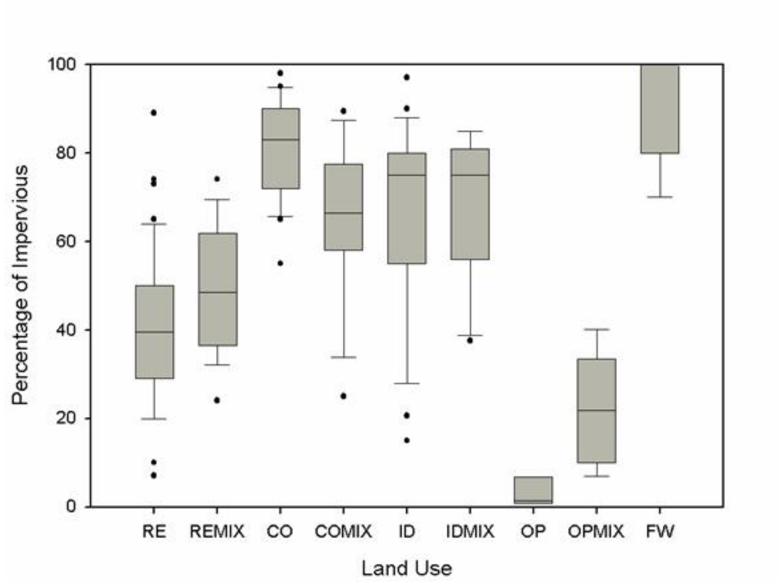


Figure 3. Percentage of impervious surfaces by land use

Figure 4 is a scatter plot of the reported percentage of impervious areas and the reported volumetric runoff coefficient (the ratio of runoff to rainfall volumes), Rv, for 18 sites. As expected, higher volumetric runoff coefficients are reported for heavily paved areas, such as parking lots or freeways, compared to areas having much more landscaped areas, such as residential areas or parks.

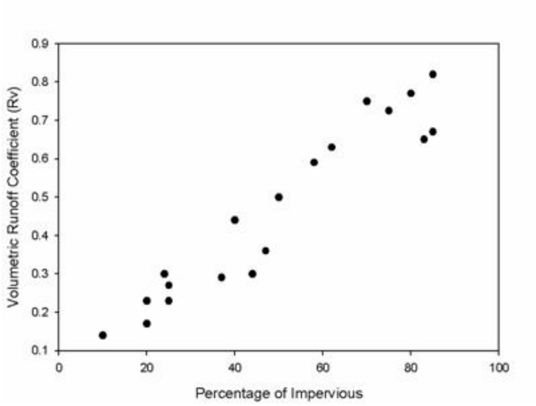
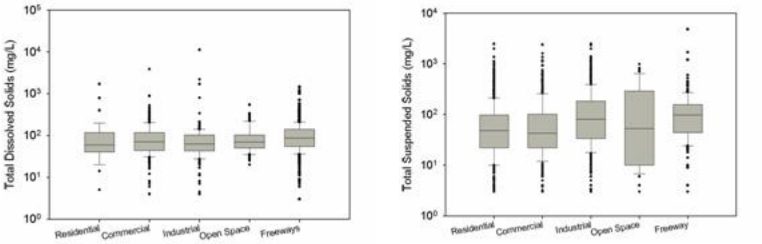


Figure 4. Scatter plot of percentage of impervious and Rv

Figure 5 contains examples of grouped box and whiskers plots for several constituents for different major land use categories. The freeways sites had the highest reported TSS, COD and oil and grease concentrations. Statistical ANOVA analyses for all land use categories found significant differences for land use categories for all constituents except for dissolved oxygen.



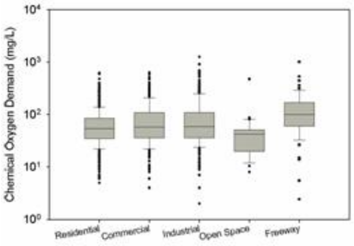


Figure 5. Box and whiskers plots for conventional constituents by single land use

In contrast to the conventional constituents, dissolved and total phosphorus have the highest concentrations in residential land uses. There was no significant difference noted for total nitrogen for the different land uses. The median ammonia concentration in freeway stormwater is almost three times the median concentration observed in residential and open space land uses, while freeways have the lowest orthophosphate and nitrite-nitrate concentrations; almost half of the concentration levels that were observed in industrial land uses. Figure 6 shows box plots for TKN, total phosphorus, and nitrite-nitrate for several land uses. It shows that even if there are differences in the median concentrations by a factor of two or three between the land uses, the extreme range of the concentrations within a single land uses can still vary by two or three orders of magnitude. The large amount of data allows statistical determinations of these differences, even though there appears to be much overlap.

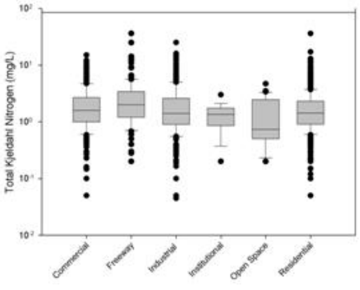


Figure 6. Box and whiskers plots for nutrients by single land use

Industrial land uses have higher median concentrations of heavy metals than any of the other land uses, followed by freeways. As expected, open space and residential land uses have the lowest median concentrations. In almost all cases, the median metal concentrations at the industrial areas were about three times the median concentrations observed in open space and residential areas. Arsenic, cadmium, chromium, copper, lead, nickel, and zinc showed significant differences between the extreme land uses at the 1% level of confidence, or less. Figure 7 contains examples of grouped box and whisker plots for lead, copper, and zinc constituents for different major land use categories. The highest lead and zinc concentrations were found in industrial land uses, while the highest copper concentrations were observed at freeways sites.

Figure 7. Box and whiskers plots for metals by single land use

Comparison of NSQD with Existing Stormwater Databases

The NSQD, with 3,765 events (from the 1992-2002 period) represented sites throughout much of the US for most land uses, and for many constituents. It is therefore the most comprehensive stormwater quality database currently available for US stormwater conditions. The historical NURP database (sampling period in the late 1970s and early 1980s) contains the results from 2,300 national stormwater events. Table 5 compares the results of the pooled EMC's from the NURP (calculated by Smullen and Cave 2002) and NSQD databases.

Table 5. Comparison of Stormwater Databases

Constituent	Units	Source	Event Mean Concentrations		Number of events
			Mean	Median	
Total Suspended Solids	mg/L	NURP	174	113	2000
		NSQD	79.1	49.8	3404
Biochemical Oxygen Demand	mg/L	NURP	10.4	8.4	474
		NSQD	10.9	8.6	2973
Chemical Oxygen Demand	mg/L	NURP	66.1	55.0	1538
		NSQD	71.2	55.6	2699
Total Phosphorus	mg/L	NURP	0.337	0.266	1902
		NSQD	0.373	0.289	3162
Dissolved Phosphorus	mg/L	NURP	0.100	0.078	767
		NSQD	0.107	0.078	2093
Total Kjeldahl Nitrogen	mg/L	NURP	1.67	1.41	1601
		NSQD	1.74	1.37	3034
Nitrite and Nitrate	mg/L	NURP	0.837	0.666	1234
		NSQD	0.767	0.606	2983
Copper	µg/L	NURP	66.6	54.8	849
		NSQD	17.8	14.2	2356
Lead	µg/L	NURP	175	131	1579
		NSQD	24.4	16.5	2250
Zinc	µg/L	NURP	176	140	1281
		NSQD	110	88	2888

The two databases have similar reported median and mean concentrations for COD, BOD, and the nutrients, but are apparently different for TSS and the heavy metals. The pooled event mean concentration (EMC) for TSS was 2.3 times larger in the NURP database compared to the NSQD. The largest reduction in mean EMCs was found for lead (7.9 times larger for NURP) followed by copper (7.9 times larger for NURP) and zinc (1.6 times large for NURP). In an effort to recognize why differences were observed between the NURP and NSQD databases, further examinations of two communities that monitored stormwater during both NURP and the Phase I NPDES program were made. As part of their MS4 Phase I application, Denver and Milwaukee both returned to some of their earlier monitoring stations used during the local NURP projects (EPA 1983). In the time between the early 1980s (NURP) and the early 1990s (MS4 permit applications), they did not detect any significant differences, except for large decreases in lead concentrations. Figure 8 compares suspended solids, copper, lead, and zinc concentrations at the Wood Center NURP monitoring site in Milwaukee. The average site concentrations remained the same, except for lead, which decreased from about 450 to about 110 µg/L, as expected due to the decreased use of leaded gasoline during this period.

Figure 8. Comparison of pollutant concentrations collected during NURP (1981) to MS4 application data (1990) at the same location (personal communication, Roger Bannerman, WI DNR)

The Denver Urban Drainage and Flood Control District performed similar comparisons in the Denver Metropolitan area. Table 6 compares stormwater quality for commercial and residential areas for 1980/81 (NURP) and 1992/93 (MS4 application). Although there was an apparent difference in the averages of the event concentrations between the sampling dates, they concluded that the differences were all within the normal range of stormwater quality variations, except for lead, which decreased by about a factor of four.

Table 6. Comparison of Commercial and Residential Stormwater Runoff Quality from 1980/81 to 1992/93 (Doerfer, 1993)

Constituent	Commercial		Residential	
	1980 - 1981	1992 - 1993	1980 - 1981	1992 - 1993
Total suspended solids (mg/L)	251	165	226	325
Total nitrogen (mg/L)	3.0	3.9	3.2	4.7
Nitrate plus nitrite (mg/L)	0.80	1.4	0.61	0.92
Total phosphorus (mg/L)	0.46	0.34	0.61	0.87
Dissolved phosphorus (mg/L)	0.15	0.15	0.22	0.24
Copper, total recoverable (µg/L)	27	81	28	31
Lead, total recoverable (µg/L)	200	59	190	53
Zinc, total recoverable (µg/L)	220	290	180	180

The differences found in both the NURP and the NSQD databases are therefore most likely due to differences in geographical areas emphasized by each database. Half of the events included in the NSQD database were collected in EPA Rain Zone 2 (Maryland, Virginia, North Carolina, Kentucky and Tennessee), while half of the events contained in the NURP database were collected in EPA Rain Zone 1 (Minnesota, Wisconsin, Michigan, Illinois, New York, Massachusetts and New Hampshire). Only 3% of the events in the NSQD are located in EPA Rain Zone 1, while 50% of the NURP data is from this area. Twenty four percent of the NURP data is located in the Mid-Atlantic and southeast states, while 60% of the NSQD data is from this area (the area that was emphasized by the NSQD research). The NSQD is slightly better representative of other parts of the country compared to NURP. As an example, the percentage of the total event data from the west coast is similar for both databases, but the NSQD represents 10 communities with almost 60 different sites, while NURP has only 3 communities and only 7 sites. The total number of sites, communities and events collected in the NURP study are shown in Table 7.

Table 7. Total Events Monitored During NURP by EPA Rain Zones

EPA Rain Zone	Total Events	Percentage of Events	Number of Communities	Number of Sites
1	804	51	12	42
2	324	20	3	10
3	65	4.1	1	5
4	0	0	0	0
5	24	1.5	1	2
6	45	2.8	2	5
7	136	8.6	1	2
8	0	0	0	0
9	188	12	3	12

Regional Variations

Figure 9 presents example plots for selected residential area data for different EPA Rain Zones for the country as contained in the NSQD. Rain Zones 3 and 7 (the wettest areas of the country) had the lowest concentrations for most of the constituents, while Rain Zone 1 has some of the highest concentrations.

Figure 9. Example of constituents collected in residential land use by EPA Rain Zone

It is likely that the few data from EPA Rain Zone 1 (having relatively high concentrations) in the NSQD and the few data in EPA Rain Zones 2 and 3 (having relatively low concentrations) in NURP are the main reason for the differences in the database summary values for some of the pollutants.

Effects of Stormwater Controls as Measured in the NSQD

Figure 10 shows the observed TSS concentrations in residential areas for EPA Rain Zone 2, for different drainage area stormwater controls (Channel weir: a flow measurement weir in an open channel that forms a small pool; Dry pond: a dry detention pond that drains completely between each storm event; Wet pond: a wet detention pond that retains water between events, forming a small lake or pond; Detention storage: Oversize pipes with small outlet orifices, usually under parking lots).

Figure 10. Effects of stormwater controls on observed outfall TSS concentrations, residential areas in EPA Rain Zone 2 (Maestre and Pitt 2005).

There is a significant reduction in TSS, nitrite-nitrate, total phosphorus, total copper, and total zinc concentration at sites having wet detention ponds, the control practice having the largest concentration reductions. No reductions in TKN concentrations were found using wet ponds, but TKN seems to be reduced by dry ponds. Locations with detention storage facilities had smaller reductions of TSS, BOD_5, COD, total lead and total zinc concentrations compared to wet pond sites. Unfortunately, there were few sites in the database having grass swales that could be compared with data from sites having curbs and gutters.

Seasonal Effects

Another factor that may affect stormwater quality is the season when the sample was obtained. If the few samples collected for a single site were all collected in the same season, the results may not be representative of the whole year. The NPDES sampling protocols were designed to minimize this effect by requiring the three samples per year to be separated by at least 1 month. The few samples still could be collected within a single season, but at least not within the same week. Seasonal variations for residential fecal coliform data are shown in Figure 11 for all residential areas. The bacteria levels are lowest during the winter season and highest during the summer and fall (a similar conclusion was obtained during the NURP, EPA 1983, data evaluations). The database does not contain any snowmelt data, so all of the data corresponds to rain-related runoff only. No other seasonal trends in stormwater quality were identified.

Figure 11. Fecal coliform variations by season (Maestre and Pitt 2005).

Rain Depth Effects

Figure 12 contains several scatter plots showing concentrations plotted against rain depth. There are no obvious trends of concentration associated with rain depth for the NSQD data for any constituents.

Figure 12. Examples of scatter plots by precipitation depth.

No effects on concentration were observed according to precipitation depth. Rainfall energy determines erosion and washoff of particulates, but sufficient runoff volume is needed to carry the particulate pollutants to the outfalls. Different travel times from different locations in the drainage areas results in these materials arriving at different times, plus periods of high rainfall intensity (that increase pollutant washoff and movement) occur randomly throughout the storm. The resulting outfall stormwater concentration patterns for a large area having various surfaces is therefore complex and rain depth is just one of the factors involved.

Interevent Period Effects

Antecedent dry periods before sampling was found to have a significant effect for BOD_5, COD, ammonia, nitrates, TKN, dissolved, and total phosphorus concentrations at residential land use sites. As the number of days increased, there was an increase in the concentrations of the stormwater constituents. This relationship was not observed for freeway sites.

First-Flush Effects

Sample collection conducted for some of the NPDES MS4 Phase I permits required both a grab and a composite sample for each event. A grab sample was to be taken during the first 30 minutes of discharge, and a flow-weighted composite sample for the entire time of discharge (up to three hours). The initial grab sample was used for the analysis of the "first flush effect," which assumes that more of the pollutants are discharged during the first period of runoff than during later periods. The composite sample was obtained with aliquots collected about every 15 to 20 minutes for at least 3 hours, or until the event ended. About 400 paired sets of 30-minute and 3-hour samples were available for comparisons. Table 8 shows the results of the first flush analyses.

Table 8. Significant First Flushes Ratios (first flush to composite median concentration)

Parameter	Commercial				Industrial				Institutional			
	n	sc	R	ratio	n	sc	R	ratio	n	sc	R	ratio
Turbidity, NTU	11	11	=	1.32			X				X	
pH, S.U.	17	17	=	1.03	16	16	=	1.00			X	
COD, mg/L	91	91	≠	2.29	84	84	≠	1.43	18	18	≠	2.73
TSS, mg/L	90	90	≠	1.85	83	83	=	0.97	18	18	≠	2.12
BOD_5, mg/L	83	83	≠	1.77	80	80	≠	1.58	18	18	≠	1.67
TDS, mg/L	82	82	≠	1.83	82	81	≠	1.32	18	18	≠	2.66
O&G, mg/L	10	10	≠	1.54			X				X	
Fecal Coliform, col/100mL	12	12	=	0.87			X				X	
Fecal Streptococcus, col/100 mL	12	11	=	1.05			X				X	
Ammonia, mg/L	70	52	≠	2.11	40	33	=	1.08	18	16	≠	1.66
$NO_2 + NO_3$, mg/L	84	82	≠	1.73	72	71	≠	1.31	18	18	≠	1.70
N Total, mg/L	19	19	=	1.35	19	16	=	1.79			X	
TKN, mg/L	93	86	≠	1.71	77	76	≠	1.35			X	
P Total, mg/L	89	77	≠	1.44	84	71	=	1.42	17	17	=	1.24
P Dissolved, mg/L	91	69	=	1.23	77	50	=	1.04	18	14	=	1.05
Ortho-P, mg/L			X		6	6	=	1.55			X	
Cadmium Total, μg/L	74	48	≠	2.15	80	41	=	1.00			X	
Chromium Total, μg/L	47	22	≠	1.67	54	25	=	1.36			X	
Copper Total, μg/L	92	82	≠	1.62	84	76	≠	1.24	18	7	=	0.94
Lead Total, μg/L	89	83	≠	1.65	84	71	≠	1.41	18	13	≠	2.28
Nickel, μg/L	47	23	≠	2.40	51	22	=	1.00			X	
Zinc, μg/L	90	90	≠	1.93	83	83	≠	1.54	18	18	≠	2.48
Turbidity, NTU			X		12	12	=	1.24	26	26	=	1.26
pH, S.U.			X		26	26	=	1.01	63	63	=	1.01
COD, mg/L	28	28	=	0.67	140	140	≠	1.63	363	363	≠	1.71
TSS, mg/L	32	32	=	0.95	144	144	≠	1.84	372	372	≠	1.60
BOD5, mg/L	28	28	=	1.07	133	133	≠	1.67	344	344	≠	1.67
TDS, mg/L	31	30	=	1.07	137	133	≠	1.52	354	342	≠	1.55
O&G, mg/L			X				X		18	14	≠	1.60
Fecal Coliform, col/100mL			X		10	9	=	0.98	22	21	=	1.21
Fecal Streptococcus, col/100 mL			X		11	8	=	1.30	26	22	=	1.11
Ammonia, mg/L			X		119	86	≠	1.36	269	190	≠	1.54
$NO_2 + NO_3$, mg/L	30	21	=	0.96	121	118	≠	1.66	324	310	≠	1.50
N Total, mg/L	6	6	=	1.53	31	30	=	0.88	77	73	=	1.22
TKN, mg/L	32	14	=	1.28	131	123	≠	1.65	335	301	≠	1.60
P Total, mg/L	32	20	=	1.05	140	128	≠	1.46	363	313	≠	1.45
P Dissolved, mg/L	32	14	=	0.69	130	105	≠	1.24	350	254	=	1.07
Ortho-P, mg/L			X		14	14	=	0.95	22	22	=	1.30
Cadmium Total, μg/L	30	15	=	1.30	123	33	≠	2.00	325	139	≠	1.62
Chromium Total, μg/L	16	4	=	1.70	86	31	=	1.24	218	82	≠	1.47
Copper Total, μg/L	30	22	=	0.78	144	108	≠	1.33	368	295	≠	1.33
Lead Total, μg/L	31	16	=	0.90	140	93	≠	1.48	364	278	≠	1.50
Nickel, μg/L			X		83	18	=	1.20	213	64	≠	1.50
Zinc, μg/L	21	21	=	1.25	136	136	≠	1.58	350	350	≠	1.59

Note: n = number of total possible events. sc = number of selected events with detected values. R = result. Not enough data (X); not enough evidence to conclude that median values are different (=); median values are different (≠).

Generally, a statistically significant first flush is associated with a median concentration ratio of the first 30-minute concentration to the overall storm concentration of about 1.4, or greater (the exceptions are where the number of samples in a specific category is much smaller). The largest ratios are about 2.5, indicating that for these conditions, the first flush sample concentrations are about 2.5 times greater than the composite sample concentrations. More of the larger ratios are found for the commercial and institutional land use categories, areas where larger paved areas are likely to be found. The smallest ratios are associated with the residential, industrial, and open spaces land uses, locations where there may be larger areas of unpaved surfaces.

Approximately 70% of the constituents in the commercial land use category had elevated first flush concentrations, about 60% of the constituents in the residential, institutional and the mixed (mostly commercial and residential) land use categories had elevated first flushes, and only 45% of the constituents in the industrial land use category had elevated first flushes. In contrast, no constituents were found to have elevated first flushes in the open space category.

COD, BOD_5, TDS, TKN and Zn all had first flushes in all areas (except for the open space category). In contrast, turbidity, pH, fecal coliform, fecal streptococcus, total N, dissolved and ortho-P never showed a statistically significant first flush in any category.

This investigation of first flush conditions indicated that a first flush effect was not present for all the land use categories, and certainly not for all constituents. Commercial areas were most likely to show this phenomenon, especially if the peak rainfall occurred near the beginning of the event. It is expected that this effect will be more likely to occur in a watershed with a high level of imperviousness, but even so, the data indicated first flushes for less than 50% of the samples for the most impervious areas. This reduced frequency of observed first flushes in these areas most likely to have first flushes is likely associated with the varying rain conditions during the different events.

Groups of constituents showed different behaviors for different land uses. All the heavy metals evaluated showed higher concentrations at the beginning of the event in the commercial land use category. Similarly, all the nutrients showed higher initial concentrations in residential land use areas, except for total nitrogen and ortho-phosphorus. This phenomenon was not found in the bacteria analyses. None of the land uses showed a higher population of bacteria at the beginning of the event. Conventional constituents showed elevated concentrations in commercial, residential, and institutional land uses.

Effects of Land Use and Geographical Location on Stormwater Quality

All land uses in EPA Rain Zone two (except for freeways) have reduced TSS values when compared with the overall NSQD average. On the other hand, conditions in EPA Rain Zones 4, 6 and 9 have higher TSS values for the land uses noted. Industrial and freeway land uses had elevated TSS concentrations compared with the other land uses, as expected from the one-way ANOVA tests. Of the 45 possible EPA Rain Zone and land use interactions, 21 categories have significantly different TSS concentrations. All of these possible TSS concentrations, based on this ANOVA analysis, are shown in Table 9.

Table 9. TSS Concentrations (mg/L) for Different Land Uses and Rain Zones (if values not shown, use 60 mg/L)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Open space		40		139					
Residential		40		84		92	35		
Commercial		43	33	90	30	120			152
Industrial	25			103	147	206	121		
Freeways		215				86	99		409

Grouping of Data by Land Use and Geographical Area

Table 10 shows the combined groups that had statistically similar TSS concentrations. Figure 13 also indicates that about half of the TSS single land use data in the NSQD database were in the first group (52%). Most of this data are from residential areas and EPA Rain Zone 2. Twenty-four percent of the observations were not affected by the land use – EPA Rain Zone interaction. Only 1.5% of the data are present in groups 4 and 5. These groups are significantly different than groups 1 and 2. Overall, there are three main levels of TSS concentrations in stormwater: Low (1), Medium (2) and High (3). Other minor categories correspond to groups 4 and 5 and contain the unusually high values.

Table 10. Five TSS Concentration Categories in NSQD

	Land use*rain zone interactions (Rain Zone: land uses)	**Concentration (mean; mean – st. dev. and mean + st. dev., mg/L)**	**Number of single land use TSS observations in category in NSQD**
Low	1: residential 2: open space; residential; commercial 3: commercial 5: commercial 7: residential	40 (13 – 123)	1056
Medium	All others not noted elsewhere	56 (18 – 169)	478
High	4: residential; commercial; industrial; open space 5: industrial 6: freeways; residential; commercial 7: freeways; industrial 9: commercial	99 (30 – 330)	460
Unusually high 1	2: freeways 6: industrial	Approx. 250	22
Unusually high 2	9: industrial	Approx. 400	9

Figure 13. Box plots of five groups also showing 5th and 95th percentiles.

Mass Discharge Calculations

A section of the NSQD report demonstrated how the NSQD information can be used to make mass discharge calculations for large drainage areas. This is an example for Maryland's Anne Arundel County, an important tributary of Chesapeake Bay. TSS and nutrient concentrations for the urban land uses in the county were calculated using NSQD data for Maryland and Virginia only. The rural data were obtained from the EPA's Chesapeake Bay program. Various factors were found to influence these concentrations using ANOVA analyses. Specifically, season, rain depth, and impervious cover were examined for each land use category. The resulting coefficients of variation were all significantly reduced with these categories of data, as shown on Tables 11 and 12. Figure 14 shows that most of the suspended solids mass discharges in the county originate from agricultural areas, while urban areas contribute about 30% of the total.

Table 11. Average Concentrations for Urban Land Uses

Land Use	Constituent	Conditions	Average conc. (COV) mg/L
Urban - Residential	TSS		
		Summer rains (between 0.1 and 0.35 inches in depth)	143 (0.71)
		All other rains	58 (0.70)
	TP	Sites having <27% impervious cover:	
		Winter rains	0.28 (0.59)
		All other rains	0.41 (0.65)
		Sites having >27% impervious cover:	
		Winter rains (less than 0.1 inches in depth)	0.16 (0.86)
		All other rains	0.30 (0.63)
	TN	Fall rains (less than 0.1 and greater than 1 inch in depth)	1.4 (0.57)
		Winter rains (0.35 and 1 inch in depth)	1.5 (0.30)
		Fall rains (0.35 and 1 inch) and Winter rains (between 0.1 and 0.35 inches in depth)	1.9 (0.51)
		All other rains	2.4 (0.62)
		Spring and summer rains (between 0.1 and 0.35 inches in depth)	2.6 (0.38)
Urban - Commercial	TSS	Average value for long-term analyses	58
	TN	Average value for long-term analyses	2.6
	TP	Summer rains >1 inch and fall rains between 0.1 and 0.35 inch	0.46 (0.36)
		All other rains	0.23 (0.71)
Urban - Industrial	TSS	Fall, spring, and summer	77 (1.48)
		Winter	81 (0.93)
	TP	Rains less than 0.35 inches	0.29 (0.81)
		Rains greater than 0.35 inches	0.22 (1.05)
	TN	All conditions	2.1 (0.79)

Table 12. Total Suspended Solids Concentrations and Volumetric Runoff Coefficients for Non-urban Land Use Categories in Anne Arundel County, Maryland

Land Use Description	# of acres in 2000	TSS (mg/L)	Concentration reliability?	R_V	R_V reliability?
Extractive	1,686	350	poor	0.3	moderate
Deciduous forest	43,901	90	moderate	0.08	moderate
Evergreen forest	4,891	90	moderate	0.08	moderate
Mixed forest	56,621	90	moderate	0.08	moderate
Brush	2,565	90	poor	0.08	moderate
Wetlands	1,643	0	poor	0.65	moderate
Beaches	29	0	poor	0.1	moderate
Bare ground	224	1000	poor	0.3	moderate
Row and garden crops	300	357	very good	0.2	poor
Cropland	42,368	357	very good	0.2	poor
Orchards / vineyards / horticulture	63	357	very good	0.15	poor
Pasture	4,690	145	very good	0.08	moderate
Feeding operations	49	145	very good	0.2	poor
Agricultural building, breeding and training facilities	163	145	very good	0.5	poor

Figure 14. Calculated sources of TSS for Anne Arundel County, Maryland.

Urban Snowmelt Water Quality

A large percentage of the annual runoff in northern climates comes from snowmelt. In urban areas with seasonal snow cover, snowmelt runoff has the potential to contribute significantly to the pollution of streams, lakes and rivers. Nevertheless, relatively little research attention has been given to the subject of snowmelt runoff quality.

Sources of Contaminants in Snowmelt

Snow can be polluted during three stages of its "life cycle." First, air pollutants can be incorporated into snowflakes as they form and fall to earth. After it falls to earth, snow, unlike other forms of precipitation, receives inputs of contaminants as it accumulates on the ground for sometimes long periods. Lastly, snowmelt runoff picks up additional pollutants as it washes over various surfaces.

Air Pollutants. Snowflakes can remove particulates and gases from the air by in-cloud or below-cloud capture. In-cloud capture of pollutants can occur during snowflake formation as super-cooled cloud water condenses on particles and aerosols that act as cloud condensation nuclei. This is known as nucleation scavenging and is a major pathway for air pollution to be incorporated into snow.

Particles and gases may also be scavenged as snowflakes fall to the ground. During below-cloud capture, snowflakes strike particles and carry them to the surface. Gases can also be absorbed as snow falls. Snowflakes are more effective below-cloud scavengers than raindrops because they are bigger and fall slower. Barrie (1991) reports that large snowflakes capture particles in the 0.2 to 0.4 µm diameter range, not by impaction, but by filtering the air that moves through the crystal as it falls.

Surface Contaminants. Most of the contamination of snow occurs after it lands on the ground. Table 13 shows the flow-weighted mean concentrations of pollutants found in undisturbed falling snow as compared to those found in urban snowcover. Samples of snow were collected as they were falling to establish the contaminant levels that come from airborne sources before snow encountered surface pollutants (Bennett, *et al.* 1981).

Table 13. Comparison of Flow-weighted Means of Snow Samples from Boulder, Colo., mg/L (Bennett, *et al.* 1981)

The pollutant levels in the fresh fallen snow shown in Table 13 are, generally, a small fraction of the levels in the snow from urban study areas. Pierstoff and Bishop (1980) analyzed freshly fallen snow for the same constituents they measured in snow at a snow dump site. From a comparison of the two sets of data, they concluded that "pollutant levels at the dump site are the result of environmental input occurring after the snow falls."

Some pollutants in snowmelt have almost no atmospheric sources. For example, Oliver, *et al*. (1974) found only negligible amounts of chloride in samples of snow from rooftops, indicating chloride comes almost entirely from surface sources, i.e., road salting.

Accumulation of Pollutants in Snowpacks. Ground snowcover accumulates dry weather deposited pollutants. In winter, these pollutants are allowed to accumulate in the snowpack for long periods. In some locations, pollutants accumulate all winter until spring thaw when the contaminants are consolidated and transported during short duration events (Jokela 1990).

Urban snowcovers receive pollutant input from various airborne sources. These sources include emissions from motor vehicles, heating equipment, and industrial activity. Dry deposition of sulfur dioxide from industrial smoke stacks has frequently been studied because of its role in the acid deposition process (Cadle 1991).

Pollutants are also directly deposited on the snowpack. The sources of directly deposited pollutants include debris from deteriorated roadways, vehicles depositing petroleum products and metals, and roadway maintenance crews applying salt and anti-skid grit (Oberts 1994a).

Pollutants Picked up during Snowmelt Runoff. Snowmelt meltwater runoff does not have the capacity that rain runoff does to dislodge and carry particulate matter. Peak flowrates are generally much less for snowmelt events. The lower flow velocities of snowmelt may be one reason Novotny, *et al*. (1986) found that urban soil erosion is reduced or eliminated during winter snowcover conditions. Two other factors that minimize erosion in the winter are that snowflakes have much less energy upon impacting the ground compared to rain droplets and that the soil is often frozen.

Cold Weather Runoff Water Quality at Outfalls

Warm weather runoff (stormwater) characteristics have been fairly well established and can be compared to snowmelt. Table 14 (Oberts 1994a) shows stormwater NURP study averages compared with runoff data from snowmelt events in the St. Paul, Minnesota area. The median concentrations of pollutants in the snowmelt are not strikingly different from the NURP average concentrations.

Table 14. Flow-weighted mean snowmelt concentrations compared to NURP stormwater averages. (Oberts 1994a)

Few studies have reported water quality results of both cold weather and warm weather runoff sampled at the same urban outfall. In general, snowmelts contain the same pollutants as warm weather stormwater runoff, but at lower concentrations. An exception to this generalization is the increase in total dissolved solids in snowmelt over rain runoff. This increase is caused by high chlorides from road salting. Snowmelt is also less polluted by particulate pollutants. Phosphorous concentrations are also consistently lower in snowmelt than in rain runoff.

Pitt and McLean (1986) report that bacteria populations are noticeably lower in cold weather runoff. The Municipality of Anchorage has studied the bacteriological quality of its surface water resources over several years and has found that winter coliform measurements are almost uniformly lower (Jokela 1990).

First Flush Effect. A first flush effect normally occurs as the first portion of snowmelt contains disproportionately higher levels of pollutants than the rest of the snowmelt runoff. Part of the cause of this effect may be that the first portion of snowmelt is enriched with soluble pollutants. The enrichment of the first portion of soluble pollutants can be explained by processes such as snow changes, water percolation and melt-freeze events that occur in the snowpack (Colbeck 1981). These processes cause soluble pollutants to be flushed from throughout the snowpack to concentrate at the bottom of the pack. A “wetted front” of soluble pollutants forms and moves through the pack until it reaches the bottom. When the front intersects with the underlying surface, it leaves the pack as a highly concentrated pulse. Thus, soluble pollutants preferentially leach out from the snowpack early in a melt and predominant the early stages of snowmelts (Oberts 1994a). Also, energy is more evenly distributed throughout snowmelt events, unless accompanied with rainfall.

Rain-on-snow Events. When it rains on snow, heavy pollutant loads can be produced because both soluble and particulate pollutants are flushed from the snowpack simultaneously. Also, the large volume of melt water plus rain runoff can wash off pollutants that have accumulated on various surfaces. The intensity of runoff from a rain-on-snow event is usually greater than a summer thunderstorm because the ground is saturated or frozen and the rapidly melting snowpack provides added runoff volume (Oberts 1994a).

Figure 15 compares the runoff volumes associated with snowmelts alone to those associated with snowmelts mixed with rain. The data is from an industrial drainage basin in Toronto in 1986. As can be seen from the chart, rain with snow events are responsible for much more runoff than snowmelt alone. Rain with snow contributes over 80% of the total cold weather event runoff volume.

Figure 15. Snowmelt and rain on snow discharges in Toronto (Pitt and McLean 1986).

Chlorides. Much of the high concentration of dissolved solids in snowmelt can be attributed to high levels of chloride. Figure 16 is a plot of the chloride concentration in the influent to the Monroe Street detention pond in Madison, Wisconsin. Chloride levels are negligible in the non-winter months. In the winter months when road salting begins, chloride levels increase dramatically.

The use of road salts leads to the most significant difference between winter and non-winter runoff, the elevated chloride concentrations in snowmelt. Maintenance crews attempt to achieve “bare pavement” conditions during winter by spreading salt (sodium and calcium chloride).

Figure 16. Monroe Street detention pond chloride concentration of influent (U.S. Geological Survey - 1986-1988).

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Snowmelt Pollutant Loadings at Outfalls

Table 15 shows the estimated annual pollutant loading to receiving waters from two drainage basins in Toronto (Pitt and McLean 1986). The total loading contributed by cold weather flows was significant for all reported pollutants. The importance of considering baseflow when analyzing runoff pollutant loading is reflected in this table. Base flows (those flows occurring between runoff events) contributed significantly to the annual pollutant loading. For example, about half of the total cold weather loading for total solids came from baseflows, and base flows accounted for 40% of the total runoff volume during the cold weather period. Pitt and McLean (1986) found that snowmelt flows occurred only about 10 to 20% of the time, whereas baseflows occurred 80 to 90% of the time.

Table 15. Estimated Annual Discharges during Different Flow Phases for Toronto Land Uses (Pitt and McLean 1986)

Oberts (1994a) reports that much of the annual pollutant yields from event flows is accounted for by end-of-winter melts. End-of-winter melts yielded 8% to 20% of the total phosphorous and total lead annual load in Minnesota. Small midwinter melts accounted for less than 5% of the total loads.

Some of the data from Table 15 is shown graphically below in Figure 17. Although warm weather runoff contributed slightly more of the annual flow (59%) than cold weather runoff, cold weather runoff was responsible for a majority of the annual total of total solids (63%) and lead (54%) (Pitt and McLean 1986).

Figure 17. Warm weather flows compared to cold weather flows in Toronto (Pitt and McLean 1986).

Effects of Land Uses on Cold Weather Runoff Quality

Source Areas. The effluent from a storm sewer outfall includes flows from the runoff of the different contributing land areas drained by that storm sewer system. Different source areas contribute different amounts of runoff and pollutants. Impervious areas contribute most of the flow during small runoff events and pervious source areas become important contributors during larger runoff events. The results of sampling sheetflows identifies the quantity of pollutants that are being contributed by different types of source areas.

Pollutant Concentrations in Sheetflows. A comparison of the sheetflow data for rain runoff and snowmelt shows that, in general, source areas contribute similar relative quantities of pollutants during rain and snowmelt events. For example, under both conditions, the highest concentrations of lead and zinc were found in samples collected from paved areas and roads. However, there are two constituents, coliforms and total residue, where the two sets of data differ noticeably. Fecal coliforms numbers were significantly higher on sidewalks and on, or near, roads during snowmelt sampling. A possible explanation for this is that these areas are where dogs would likely be walked in winter conditions. In warm weather, dog walking would be less concentrated into these areas.

The concentrations for total residue from grass or bare open areas are reduced drastically during snowmelt compared to rain runoff. This is an indication of the reduction in erosion and the poor deliver of particulate pollutants during snowmelts. Grass and open areas would generally be located relatively far from the drainage system. Particles from these areas may not be easily transported long distances during periods of low energy snowmelt runoff. Cold weather sheetflow median concentrations of particulate residue in the grass and open areas (77 mg/L) were much less than the concentrations observed during warm weather runoff (248 mg/L).

Total residue concentrations also increased at roads during snowmelt. This is attributed to the influence of road salting on dissolved solids concentrations near roads.

In the residential areas, streets are the most significant source of solids including chloride, while yards and open areas are the major source of nutrients. Parking and storage areas contribute the most pollutants in the industrial catchment.

Contributions from Roadways. Roadways are one of the urban land uses that contribute the most pollutants to snowmelt runoff. Analysis of snow samples taken along a transect of a snowpack adjacent to a road shows the pollutant levels as a function of distance from the roadway (Pitt and McLean 1986). Measuring the distribution of contaminants in an urban roadside snowpack shows the extent of snow contamination related to traffic. The concentration of these constituents decreased substantially as the distance from the road increased. At distances greater than 3 to 5 meters from the edge of the snowpack, the concentrations are relatively constant.

Novotony, *et al.* (1986) also sampled along a transect of the snowcover by a freeway in Milwaukee. They also found that the concentration of constituents decreased as the distance from the road increased. In this study, samples were taken at 30 meter intervals. Samples taken at 30 meters or greater was assumed to reflect the deposition of pollutants from the atmosphere. Most of the measured constituents including total solids and lead were at, or near, background levels at 30 meters or more from the road. The samples taken immediately adjacent to the road showed a marked increase over background levels.

Land Use and Snowmelt Quality. Table 16 compares the water quality characteristics from a rural and an urban drainage basin. The table shows that, in general, the relative relationship between cold weather and warm weather runoff quality is similar in both the rural and urban basins. However, the concentration of total phosphorous was higher in the rural cold weather runoff than in rural warm weather runoff, whereas, the opposite was the case in the urban drainage basin.

Table 16. Rural and Urban Snowmelt Quality (Pope and Bevans 1984)

In comparing runoff from an industrial and residential catchment, Pitt and McLean (1986) observed that concentrations of most constituents in runoff from the industrial watershed were typically greater than the concentrations of the same constituents in the residential runoff. The only constituents with a unit area yield that was lower in the industrial catchment were chloride and total dissolved solids. These results can be attributed to the use of road deicing salts in the residential area. It was found that annual yields of several constituents were dominated by cold weather flows irrespective of the land use. These constituents included total solids, total dissolved solids, chlorides, ammonia nitrogen, and phenolics.

Relative Contributions of Urban Runoff Flow Phases

Tables 17 and 18 summarize Toronto residential/commercial and industrial urban runoff characteristics during both warm and cold weather (Pitt and McLean 1986). These tables show the relative importance of wet-weather and dry-weather flows coming from separate stormwater systems. If urban runoff is to be directed to an outfall infiltration device, then the dry-weather flows will also be present at the outfalls. Possibly 25 percent of all separate stormwater outfalls have water flowing in them during dry weather, and as much as 10 percent are grossly contaminated with raw sewage, industrial wastewaters, etc. (Pitt, *et al.* 1993; CWP and Pitt 2005). The EPA's Stormwater Permit program requires municipalities to conduct stormwater outfall surveys to identify, and then correct, inappropriate discharges into separate storm drainage. However, it can be expected that substantial outfall contamination will exist for many years. If stormwater is infiltrated before it enters the drainage system (such as by using French drains, infiltration trenches, grass swales, porous pavements or percolation ponds in upland areas) then the effects of contamination problems in the drainage system on groundwater will be substantially reduced. If outfall waters are to be infiltrated in larger regional facilities, then these periods of dry-weather flows will have to be considered.

Table 17. Median Concentrations Observed at Toronto Outfalls during Warm Weather (Pitt and McLean 1986)

Constituent (mg/L unless noted)	Warm Weather Baseflow		Warm Weather Stormwater	
	Residential	Industrial	Residential	Industrial
Stormwater volume (m^3/ha/season)	--	--	950	1500
Baseflow volume (m^3/ha/season)	1700	2100	--	--
Total residue	979	554	256	371
Total dissolved solids (TDS)	973	454	230	208
Suspended solids (SS)	<5	43	22	117
Chlorides	281	78	34	17
Total phosphorus	0.09	0.73	0.28	0.75
Phosphates	<0.06	0.12	0.02	0.16
Total Kjeldahl nitrogen (organic N plus NH_3)	0.9	2.4	2.5	2.0
Ammonia nitrogen	<0.1	<0.1	<0.1	<0.1
Chemical oxygen demand (COD)	22	108	55	106

Fecal coliform bacteria (#/100mL)	33,000	7,000	40,000	49,000
Fecal strep. bacteria (#/100mL)	2,300	8,800	20,000	39,000
Pseudo. aeruginosa bacteria (#/100mL)	2,900	2,380	2,700	11,000
Arsenic	<0.03	<0.03	<0.03	<0.03
Cadmium	<0.01	<0.01	<0.01	<0.01
Chromium	<0.06	0.42	<0.06	0.32
Copper	0.02	0.05	0.03	0.06
Lead	<0.04	<0.04	<0.06	0.08
Selenium	<0.03	<0.03	<0.03	<0.03
Zinc	0.04	0.18	0.06	0.19
Phenolics (g/L)	<1.5	2.0	1.2	5.1
- BHC (ng/L)	17	<1	1	3.5
- BHC (Lindane) (ng/L)	5	<2	<1	<1
Chlordane (ng/L)	4	<2	<2	<2
Dieldrin (ng/L)	4	<5	<2	<2
Polychlorinated biphenols (PCBs) (ng/L)	<20	<20	<20	33
Pentachlorophenol (PCP) (ng/L)	280	50	70	705

(1) Warm weather samples were obtained during the late spring, summer, and early fall months when the air temperatures were above freezing and no snow was present.

Table 18. Median Concentrations Observed at Toronto Outfalls during Cold Weather (Pitt and McLean 1986)

Constituent (mg/L unless noted)	Cold Weather Baseflow		Cold Weather Snowmelt	
	Residential	Industrial	Residential	Industrial
Stormwater volume (m^3/ha/season)	--	--	1800	830
Baseflow volume (m^3/ha/season)	1100	660	--	--
Total residue	2230	1080	1580	1340
Total dissolved solids (TDS)	2210	1020	1530	1240
Suspended solids (SS)	21	50	30	95
Chlorides	1080	470	660	620
Total phosphorus	0.18	0.34	0.23	0.50
Phosphates	<0.05	<0.02	<0.06	0.14
Total Kjeldahl nitrogen (organic N plus NH$_3$)	1.4	2.0	1.7	2.5
Ammonia nitrogen	<0.1	<0.1	0.2	0.4
Chemical oxygen demand (COD)	48	68	40	94
Fecal coliform bacteria (#/100mL)	9800	400	2320	300
Fecal strep bacteria (#/100mL)	1400	2400	1900	2500
Pseudo. aeruginosa bacteria (#/100mL)	85	55	20	30
Cadmium	<0.01	<0.01	<0.01	0.01
Chromium	<0.01	0.24	<0.01	0.35
Copper	0.02	0.04	0.04	0.07
Lead	<0.06	<0.04	0.09	0.08
Zinc	0.07	0.15	0.12	0.31
Phenolics (mg/L)	2.0	7.3	2.5	15
- BHC (ng/L)	NA^2	3	4	5
- BHC (Lindane) (ng/L)	NA	NA	2	1
Chlordane (ng/L)	NA	NA	11	2
Dieldrin (ng/L)	NA	NA	2	NA
Pentachlorophenol (PCP) (ng/L)	NA	NA	NA	40

(1) Cold weather samples were obtained during the winter months when the air temperatures were commonly below freezing. Snowmelt samples were obtained during snowmelt episodes and when rain fell on snow.

(2) NA: not analyzed

Similar problems occur in areas having substantial snowfalls. Table 18 summarizes Toronto snowmelt and cold weather baseflow characteristics (Pitt and McLean 1986). The bacteria densities during cold weather are substantially less than during warm weather, but are still relatively high (EPA 1983). However, chloride concentrations and dissolved solids are much higher during cold weather. Early spring stormwater events also contain high dissolved solids concentrations (Bannerman, personal communication, WI DNR). Unfortunately, upland infiltration devices do not work well during cold weather due to freezing soils. Outfall flows occur under ice into receiving waters (including detention ponds) and may enter regional infiltration devices if not specifically diverted.

Stormwater Pollutant Sources

Older Monitoring Projects

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. Unfortunately, this information is not readily available and can be expensive and tedious to collect. However, a substantial amount of these data have been collected over the past several decades, but are not well known. This discussion presents summaries of these 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 early source area information was collected in the 1970s and 1980s as part of stormwater research projects for the EPA. This discussion summarizes source area sheetflow quality data obtained from a number of studies conducted in California, Washington, Nevada, Illinois, Ontario, Colorado, New Hampshire, and New York. 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.

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. Other important sources of zinc are galvanized metals. 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 wind transport after the material is resuspended from the road surface by traffic-induced turbulence, or high winds.

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 the 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 Pb, Br, Cl (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% 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 1983).

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 19 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 20. 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 19. Summary of Reported Rain Quality

	1	2	3	4	5	6
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			

Column 1. Rural-Northwest (Quilayute, WA)[1] ; 2. Rural-Northeast (Lake George, NY)[1] ; 3. Urban Northwest (Lodi, NJ)[2] ; 4. Urban-Midwest (Cincinnati, OH)[3] ; 5. Other Urban[3] ; 6. Continental Avg. (32 locations)[1]
Notes: 1.Rubin 1976; 2. Wilbur and Hunter 1980; 3. Manning, *et al.* 1976.

Table 20. 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

Notes: 1. Summarized by Rubin 1976; 2. Spring, et al. 1978

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 21 and 22 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 22 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.

Table 21. 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

Notes: 1. Betson 1978; 2. Malmquist 1978.

Table 22. 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

Note: 1. Average for three Knoxville, KY, watersheds.

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.

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.

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. 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 from the same source.

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.

Sheetflow 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 2001) determined how much of this material would wash off during rains.

The data summarized in this section focus on average concentration values for different pollutants, land uses, and source areas. Generally, each sample comprised 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 small plastic 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 23 and 24. 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.

Table 23. Summary of Observed Street Dirt Mean Chemical Quality (mg constituent/kg solids).

Constituent	Residential	Commercial	Industrial
P	620 (4)		
	540 (6)		670 (4)
	1100 (5)	400 (6)	
	710 (1)	1500 (5)	
	810 (3)	910 (1)	
TKN	1030 (4)		
	3000 (6)		560 (4)
	290 (5)	1100 (6)	
	2630 (3)	340 (5)	
	3000 (2)	4300 (2)	
COD	100,000 (4)		
	150,000 (6)		65,000 (4)
	180,000 (5)	110,000 (6)	
	280,000 (1)	250,000 (5)	
	180,000 (3)	340,000 (1)	
	170,000 (2)	210,000 (2)	
Cu	162 (4)		
	110 (6)	130 (6)	360 (4)

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

References; location; particle size described in above table:
(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 24. 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			130,000	1110	650		
Unpaved	770	1060				930	98
parking/storage			110,000	1120	2050		
Paved footpath	620	700	120,000	280	460	1120	62
Bare ground		1900	70,000	91	135	1300	63
	890	1700				270	38
	700						

Source: Pitt and McLean 1986 (Toronto, Ontario)

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

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 US and Canada as represented by these samples.

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.

Sheetflow Quality
The sheetflow data available are divided into four groups: 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). 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 25 through 27 summarize warm weather sheetflow observations, separated by source area type and land use, from many locations.

Table 25. Source Area Sheetflow Quality, Compilation from Earlier Studies

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)

Table 25. Source Area Sheetflow Quality, Compilation from Earlier Studies (Cont.)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
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)
BOD_5 (mg/L)									
Residential:	3 (4)	22 (4)							13 (4)
Commercial:	7 (4)	11 (1) 4 (8)							

Table 25. Source Area Sheetflow Quality, Compilation from Earlier Studies (Cont.)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
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)
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)

Table 25. Source Area Sheetflow Quality, Compilation from Earlier Studies (Cont.)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
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)
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)

Table 25. Source Area Sheetflow Quality, Compilation from Earlier Studies (Cont.)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
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)
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)

Table 25. Source Area Sheetflow Quality, Compilation from Earlier Studies (Cont.)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
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)
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)

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

Pollutants	Landscaped Areas	Undeveloped Areas	Freeway Paved Lane and Shoulder Areas
Total Solids, mg/L	388 (4)		340 (5)
		588 (4)	
Suspended Solids, mg/L	100 (4)		180 (5)
		400 (1)	
Dissolved Solids, mg/L	288 (4)		160 (5)
BOD_5, mg/L		390 (4)	
	3 (3)		10 (5)
COD, mg/L	70 (3)	193 (4)	
	26 (4)		130 (5)
		- - - -	
Total Phosphorus, mg/L			
	0.42 (3)	72 (1)	- - - -
Total Phosphate, mg/L	0.56 (4)	54 (4)	
TKN, mg/L	0.32 (3) 0.14 (4)	0.40 (1) 0.68 (4)	0.38 (5)
	1.32 (3)	0.10 (1)	2.5 (5)

Ammonia, mg/L	3.6 3.6 (4)	0.26 (4)	
	1.2 1.2 (3)	2.9 (1)	- - - -
Phenols, µg/L	0.4 0.4 (4)	1.8 (4)	
Aluminum, µg/L	0.8 0.8 (4)	0.1 (1) <0.1 (4)	- - - -
Cadmium, µg/L	1.5 1.5 (4)	- - - -	- - - -
Chromium, µg/L	<3 (4)	11 (4)	60 (5)
Copper, µg/L	10 (3)	<4 (4)	70 (5)
	<20 (4)	<60 (4)	120 (5)
Lead, µg/L	30 (2) 35 (3) <30 (4)	40 (1) 31 (3) <20 (4)	2000 (5)
Zinc, µg/L	10 (3)	100 (1) 30 (2) <40 (4)	460 (5)
		100 (1) 100 (4)	

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 27. Bacteria Analyses for Sheetflow Observations Compiled from Prior Studies

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/ Storage	Paved Drives	Unpaved Drives	Dirt Walks	Paved Side walks	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)			

Table 27. Bacteria Analyses for Sheetflow Observations Compiled from Prior Studies (cont.)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/ Storage	Paved Drives	Unpaved Drives	Dirt Walks	Paved Side walks	Streets	Land-scaped	Un-developed	Freeway Lane and Shoulders
Fecal Strep (#/100 mL)												
Residential:	170 (2) 920 (3) 2200 (4) 17 (2)	190,000 (4)	<100 (4)		1900 (4)		1800 (4)		>2400 (3) 7300 (4)	43,000 (4)	16,500 (2) 920 (3)	2200 (7)
Commercial:	690 (4)	11,900 (2) >2400 (3) 770 (1) 1120 (5) 62,000 (6)										
Industrial:		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)			

(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

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, in contrast to outfall data which do not show any obvious relationships of pollutant concentrations with rain depth. Sheetflows from all pervious areas had the highest total solids concentrations for 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 pollutant contributions were not sufficient to explain the concentrations of some the observed outfall stormwater constituents. As an example, high concentrations of dissolved chromium, dissolved copper, and dissolved zinc in the monitored Toronto industrial outfall could not be explained by the wet weather sheetflow observations (Pitt and McLean 1986). Very few detectable chromium observations were obtained in any of the more than 100 surface sheetflow samples analyzed, and were all much less than the outfall chromium concentrations detected. 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 facilities that are inappropriately discharged to the storm drainage system, were the cause of the high dissolved metals concentrations at the outfall and that some sanitary sewage was entering the storm drainage system causing the elevated bacteria levels. Table 28 summarizes the little filterable pollutant concentration data available for different source areas from these earlier tests. Most of the available filterable data are for residential roofs and commercial parking lots.

Table 28. Filterable Pollutants Observed from Many Studies

	Residential			Commercial			Industrial		
	Total	Filterable	Filterable (%)	Total	Filterable	Filterable (%)	Total	Filterable	Filterable (%)
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)

(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)

Recent Sheetflow Monitoring Observations

Two research projects that examined source area sheetflows that were conducted in the 1990s are further described in the following discussion. These are a comprehensive project conducted in Birmingham, AL, as part of a project developing a control strategy for critical source areas (Pitt, *et al.*1995), and a series of related projects conducted in Wisconsin and Michigan as part of the WI DNR's efforts in calibrating the Source Loading and Management Model (WinSLAMM). A bibliography of recent source area monitoring activities by other researchers is also included. These projects are more comprehensive than the earlier monitoring efforts previously described. These large projects included a wide range of land uses, source sources, and pollutants, in coordinated monitoring efforts.

Birmingham, AL, Studies

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 (30 m 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 (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 29 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 29 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 29 lists stormwater toxicants detected in at least 10% of the source area sheetflow samples (Pitt, *et al*. 1995). This table 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).

Table 29. Birmingham, AL, Source Area Sheetflow Toxicant Data (Pitt, *et al.* 1995)

	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
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			

Table 29. Birmingham, AL, Source Area Sheetflow Toxicant Data (Pitt, *et al.* 1995) (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
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			
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**							

Table 29. Birmingham, AL, Source Area Sheetflow Toxicant Data (Pitt, *et al.* 1995) (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
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													
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**

Table 29. Birmingham, AL, Source Area Sheetflow Toxicant Data (Pitt, *et al.* 1995) (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
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 (mg/L)	6.85	0.23	3.21	0.43	2.32	0.18	3.08	0.88	0.78	0.18	0.70	0.17	2.3	1.2	0.62	0.19	0.70	**0.21**
Max. (mg/L)	71.3	1.56	6.48	2.90	6.99	0.74	10.0	4.38	0.93		1.37	0.41	4.6	1.9	3.25	0.50	1.57	**0.36**
Min. (µg/L)	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**
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**

Table 29. Birmingham, AL, Source Area Sheetflow Toxicant Data (Pitt, *et al.* 1995) (continued)

	Roof areas	Parking areas	Storage areas	Street runoff	Loading docks	Vehicle service areas	Landscaped areas	Urban creeks	Detention ponds
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 constituent was detected.
4) Mean values based only on the number of samples with a definite concentration 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.

Out of more than 35 targeted organic compounds analyzed, 13 were detected in more than 10% of all samples, as shown in Table 29. 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.

Wisconsin and Michigan Data

The source area concentrations collected in seven monitoring projects in Wisconsin, and one in Michigan are described below. The monitoring was conducted by the United States Geological Survey (USGS) in cooperation with the Wisconsin Department of Natural Resources (WI DNR). All of these monitoring projects were conducted between 1991 and 1997. Contaminant concentrations for the source areas were used to calibrate WinSLAMM, 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 entire 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 located 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, fecal coliform, BOD, COD, and PAHs, plus total recoverable and dissolved forms of zinc, lead, cadmium, and copper. Sheetflow samples were collected for 12 runoff events at each site. Flow and water quality were measured at the storm drain outfall for the entire 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 WinSLAMM. 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 were measured at the storm drain outfalls for both study areas.

Madison, WI, runoff samples were collected during 1994 and 1995 (Waschbusch, *et al*. in press) to evaluate the effects of various environmental factors on the yields of pollutants washed off city streets. The environmental factors included average daily traffic count, antecedent dry time, rainfall intensity, rainfall depth, season, and tree canopy. Street pollutant concentrations were also used to calibrate WinSLAMM. Sheetflow samples were collected from five streets with different daily traffic counts. The street samplers were grouted into the street approximately 5 ft (1.5m) from the curb. The sample bottles were covered with a 6 inch (150mm) 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 at 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 (1.7ha) 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 WinSLAMM 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, or MCTT). 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 WinSLAMM for industrial parking lots.

Results from the eight Wisconsin studies were combined to create an average concentration for each source area (Table 30). 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.

Table 30. Wisconsin and Minnesota Source Area Sheetflow 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* (m
Residential Roofs								
Sample Count	38	81	38	8	8	8	9	6
Average	112	36.7	60.8	78	590,000	30	19	140,000
COV**	1.12	2.07	1.20	1.34	0.72	0.68	0.49	0.6
Commercial Roofs								
Sample Count	19	34	19	6	6	6	9	4
Average	146	32.8	115	172	740,000	152.3	24	94,000
COV	0.66	1.25	0.85	0.66	1.05	0.69	0.78	0.94
Industrial Roofs								
Sample Count	45	42	42	34	32	34	n/a	n/a
Average	76	15.8	60.8	23	760,000	20	n/a	n/a
COV	0.40	1.7	0.54	0.60	0.88	0.60	n/a	n/a
Commercial Parking								
Sample Count	21	44	21	6	5	6	5	4
Average	246	130	62.7	77	330,000	39	10.5	28,000
COV	0.77	1.15	0.81	0.23	0.32	0.81	0.41	0.52
Industrial Parking Lots								
Sample Count	89	90	89	14	n/d	n/d	15	n/d
Average	1246	244	1002	120	n/d	n/d	18	n/d
COV	3	0.96	3	0.43	n/d	n/d	0.62	n/d
Driveways								
Sample Count	19	69	19	9	9	9	7	6
Average	350	154	111	146	300,000	91.8	16	32,000
COV	0.58	1.10	0.81	1.07	0.84	1.68	0.35	0.45
Small Landscape Areas								
Sample Count	13	40	13	4	4	4	2	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

*Particulate = (total constituent - dissolved constituent)/suspended solids ** COV = coefficient of variation = mean/standard deviation

Table 30. Wisconsin and Minnesota Source Area Sheetflow 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

Table 30. Wisconsin and Minnesota Source Area Sheetflow Data (continued)

Source Area	P, Total (mg/L)	P, Part.* (mg/Kg)	P, Dis. (mg/L)	TKN (mg/L)	Kjeldahl N, Part.* (mg/Kg)	Kjeldahl N, Dis. (mg/L)	Nitrite + Nitrate N (mg/L)	Cd, Total (µg/L)	Cd, Part.* (mg/Kg)	Cd, Dis. (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 30. Wisconsin and Minnesota Source Area Sheetflow Data (continued)

Source Area	P, Total (mg/L)	P, Part.* (mg/Kg)	P, Dis. (mg/L)	TKN (mg/L)	Kjeldahl N, Part.* (mg/Kg)	Kjeldahl N, Dis. (mg/L)	Nitrite + Nitrate N (mg/L)	Cd, Total (µg/L)	Cd, Part.* (mg/Kg)	Cd, Dis. (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 30. Wisconsin and Minnesota Source Area Sheetflow Data (continued)

Source Area	Cr, Total (µg/L)	Cr, Part.* (mg/Kg)	Cr, Dis. (µg/L)	Cu, Total (µg/L)	Cu, Part.* (mg/Kg)	Cu, Dis. (µg/L)	Pb, Total (µg/L)	Pb, Part. * (mg/Kg)	Pb, Dis. (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	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 30. Wisconsin and Minnesota Source Area Sheetflow Data (continued)

Source Area	Cr, Total (µg/L)	Cr, Part.* (mg/Kg)	Cr, Dis. (µg/L)	Cu, Total (µg/L)	Cu, Part.* (mg/Kg)	Cu, Dis. (µg/L)	Pb, Total (µg/L)	Pb, Part. * (mg/Kg)	Pb, Dis. (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 30. Wisconsin and Minnesota Source Area Sheetflow Data (continued)

Source Area	Zn, Total (µg/L)	Zn, Part.* (mg/Kg)	Zn, Dis. (µg/L)	Fluoranthene, Total (µg/L)	Fluoranthene, Part.* (mg/kg)	Pyrene, Total (µg/L)	Pyrene, Part.* (mg/kg)
Residential Roofs							
Sample Count	34	5	6	10	10	10	10
Average	185	2900	278	0.22	6.7	0.15	4.7
COV	1.09	0.56	0.80	1.09	0.75	1.12	0.84

Commercial Roofs							
Sample Count	15	6	6	10.0	10.0	10.0	10.0
Average	322	3500	182	0.85	25	0.6	18
COV	0.54	0.95	0.92	1.21	0.70	1.27	0.72
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	7	6
Average	292	802	51	28	290	17	180
COV	0.91	0.58	0.42	0.77	0.77	0.80	0.67
Industrial Parking Lots							
Sample Count	26	17	19	26	26	26	26
Average	227.7	490	99.5	2.48	10	1.85	7.7
COV	0.67	0.47	1.25	0.74	0.57	0.79	0.57
Driveways							
Sample Count	19	19	15	6	6	6	6
Average	164	650	166	1.1	23	0.8	17
COV	0.79	0.48	0.48	0.9	2.21	0.94	2.21
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 30. Wisconsin and Minnesota Source Area Sheetflow Data (continued)

Source Area	Zn, Total (μg/L)	Zn, Part.* (mg/Kg)	Zn, Dis. (μg/L)	Fluoranthene, Total (μg/L)	Fluoranthene, Part.* (mg/kg)	Pyrene, Total (μg/L)	Pyrene, Part.* (mg/kg)
Commercial Streets							
Sample Count	50	48	37	35	35	35	35
Average	302	1150	60.2	5.0	25	3.4	17
COV	0.95	1.23	1.03	1.4	1.0	1.39	0.93
Residential Streets							
Sample Count	32	26	11	13	13	12	12
Average	151	350	45.0	1.3	9.6	0.9	6.5
COV	0.71	0.55	0.39	1.20	0.78	1.08	0.78
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	1.1	11	0.71	6.6
COV	0.78	0.36	0.42	1.0	0.77	0.94	0.63
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

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 differences 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% 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% of an urban drainage area can contribute 60% of the annual PAH load (Steuer, *et al*. 1997).

Concentrations for some of the pollutants can be compared between roofs and streets for residential, commercial, and industrial land uses. Streets in industrial areas are likely important sources of suspended solids, total phosphorus, and zinc when 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 are compiled in Table 30 to determine pollutant loads from many of the most common urban source areas. However, more monitoring is needed to expand the list of constituents. Also, additional source areas need to be monitored. Pesticides are an example of a pollutant not included in Table 30. 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. Gas stations are an example of a missing specific source area of potential interest. Also missing are runoff concentrations for a range of parking lot types. Parking lots with high automobile turnover are expected to experience higher pollutant concentrations than those used for long-term employee parking, for example, and need to be better represented.

Other Recent Sheetflow Source Area Data

Many other researchers throughout the world have monitored source area runoff. The following discussion is a bibliography of some of these resent studies.

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. 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, BOD5, hydrocarbons, and heavy metals both in dissolved and particulate fractions. The street runoff showed large SS, COD and hydrocarbon loads, and 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 heavy 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-y 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/y, 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/y 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 Switzerland 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) summarized their studies investigating roof runoff as a stormwater pollutant source. 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/y). 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 forms 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 showed 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 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 reductions in the growth rate of green algae. 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 emissions 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 their release. Water repellent coatings 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, CA, 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 PAHs, 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 areas in Madison, Wisconsin. They collected numerous sheetflow runoff samples from throughout the test watersheds and used WinSLAMM, 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 and 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). Highway runoff contains significant loads of heavy metals and hydrocarbons, and according to German regulations, it should be infiltrated to support groundwater recharge. 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 a 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. Laser particle sizing showed that a significant proportion of the sediment in runoff was less than 100 µm in size. 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 concentrations. However, particulate bound PAHs were found to be bimodally distributed. Three-ring PAHs were mostly found 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 rain 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% 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 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 total phosphorus) were inclined to be washed off in heavier rainfall; event mean runoff intensity and cumulative runoff depth were correlated with cumulative runoff load of the constituents except total nitrogen (TN). ADP and traffic flow volume were not correlated with cumulative runoff load (except TN). Sutherland (2003) investigated lead concentrations in six grain-size fractions of road-deposited sediment from Oahu, HI. Significant Pb concentrations were 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.

Summary of Stormwater Characteristics and Sources

Stormwater Characteristics

Statistical ANOVA analyses for all land use categories found significant differences for land use categories for all constituents except for dissolved oxygen. Freeways sites had the highest reported TSS, COD and oil and grease concentrations. Dissolved and total phosphorus have the highest concentrations in residential land uses. There was no significant difference noted for total nitrogen for the different land uses. The median ammonia concentration in freeway stormwater is almost three times the median concentration observed in residential and open space land uses, while freeways have the lowest orthophosphate and nitrite-nitrate concentrations; almost half of the concentration levels that were observed in industrial land uses. Industrial land uses have higher median concentrations of heavy metals than any of the other land uses, followed by freeways. As expected, open space and residential land uses have the lowest median concentrations. In almost all cases, the median metal concentrations at the industrial areas were about three times the median concentrations observed in open space and residential areas. The highest lead and zinc concentrations were found in industrial land uses, while the highest copper concentrations were observed at freeways sites.

The bacteria levels are lowest during the winter season and highest during the summer and fall. Also, there were no obvious trends of concentration associated with rain depth for the NSQD data for any constituents. Antecedent dry periods before sampling was found to have a significant effect for BOD_5, COD, ammonia, nitrates, TKN, dissolved, and total phosphorus concentrations at residential land use sites. As the number of days increased, there was an increase in the concentrations of the stormwater constituents. This relationship was not observed for freeway sites. The investigation of first flush conditions indicated that a first flush effect was not present for all the land use categories, and certainly not for all constituents. Commercial areas were most likely to show this phenomenon, especially if the peak rainfall occurred near the beginning of the event. COD, BOD_5, TDS, TKN and Zn all had first flushes in all areas (except for the open space category). In contrast, turbidity, pH, fecal coliform, fecal streptococcus, total N, dissolved and ortho-P never showed a statistically significant first flush in any category. All the heavy metals evaluated showed higher concentrations at the beginning of the event for the commercial land use category. Similarly, all the nutrients showed higher initial concentrations in residential land use areas, except for total nitrogen and ortho-phosphorus. This phenomenon was not found in the bacteria analyses. None of the land uses showed a higher population of bacteria at the beginning of the event.

Snowmelt Contributions

A large percentage of the annual runoff in northern climates comes from snowmelt. In urban areas with seasonal snow cover, snowmelt runoff has the potential to contribute significantly to the pollution of streams, lakes and rivers. When it rains on snow, heavy pollutant loads can be produced because both soluble and particulate pollutants are flushed from the snowpack simultaneously. Also, the large volume of melt water plus rain runoff can wash off pollutants that have accumulated on various surfaces. The total loading contributed by cold weather flows was significant for all reported pollutants.

Baseflow Contributions

The importance of considering baseflow when analyzing runoff pollutant loading is shown in these summaries. Base flows (those flows occurring between runoff events) contributed significantly to the annual pollutant loading. For example, about half of the total cold weather loading for total solids came from baseflows, and base flows accounted for 40% of the total runoff volume during the cold weather period during monitoring in Toronto. Snowmelt flows occurred only about 10 to 20% of the time, whereas baseflows occurred 80 to 90% of the time. Inappropriate discharges (required to be identified and corrected by the NPDES stormwater regulations) usually have large effects on baseflows. Much more information on inappropriate discharges is available at: http://unix.eng.ua.edu/~rpitt/Research/ID/ID2.shtml and at the Center for Watershed Protection website, where the CWP/UA report on inappropriate discharges is available to download.

Pollutant Sources

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 module 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.

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) 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, although galvanized metals are the dominant zinc source in most cases. 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 % 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% of an urban drainage area can contribute 60% of the annual PAH load.

Many studies throughout the world have investigated stormwater pollutant sources. Pavement is usually identified as the most important source for toxicants (heavy metals and PAHs), while landscaped areas are important sediment and nutrient sources. Stormwater managers need to understand the likely sources of critical pollutants in their areas in order to make reasonable decisions pertaining to source area and outfall controls, and when developing regulations. The information in this module should also be of use to stormwater modelers.

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