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

A Review of Semivolatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater

Open-File Report 98-409

A Contribution to the
National Highway Runoff Data and Methodology Synthesis

U.S. Department
of Transportation

USGS
science for a changing world

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

A Review of Semivolatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater

By THOMAS J. LOPES and SHANNON G. DIONNE

Open-File Report 98-409

A Contribution to the
National Highway Runoff Data and Methodology Synthesis

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, *Acting Director*

For additional information write to:	Copies of this report can be purchased from:
District Chief U.S. Geological Survey 1608 Mt. View Road Rapid City, SD 57702	U.S. Geological Survey Branch of Information Services Box 25286, Federal Center Denver, CO 80225-0286

PREFACE

Knowledge of the characteristics of highway runoff (concentrations and loads of constituents and the physical and chemical processes which produce this runoff) is important for decision makers, planners, and highway engineers to assess and mitigate possible adverse-impacts of highway runoff on the Nation's receiving waters. In October, 1996, the Federal Highway Administration and the U.S. Geological Survey began the National Highway Runoff Data and Methodology Synthesis to provide a catalog of the pertinent information available; to define the necessary documentation to determine if data are valid (useful for intended purposes), current, and technically supportable; and to evaluate available sources in terms of current and foreseeable information needs. This paper is one contribution to the National Highway Runoff Data and Methodology Synthesis and is being made available as a U.S. Geological Survey Open-File Report pending its inclusion in a volume or series to be published by the Federal Highway Administration. More information about this project is available on the World Wide Web at http://mass1.er.usgs.gov/fhwa/runwater.htm

Fred G. Bank
Team Leader
Natural and Cultural Resources Team
Office of Environment and Planning
Federal Highway Administration

Patricia A. Cazenas
Highway Engineer
Natural and Cultural Resources Team
Office of Environment and Planning
Federal Highway Administration

Gregory E. Granato
Hydrologist
U.S. Geological Survey

CONTENTS

ILLUSTRATIONS

TABLES

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

---

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

A Review of Semivolatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater

By Thomas J. Lopes *and* Shannon G. Dionne

Abstract

Many studies have been conducted since 1970 to characterize concentrations of semivolatile organic compounds (SVOCs) in highway runoff and urban stormwater. To a lesser extent, studies also have characterized concentrations of volatile organic compounds (VOCs), estimated loads of SVOCs, and assessed potential impacts of these contaminants on receiving streams. This review evaluates the quality of existing data on SVOCs and VOCs in highway runoff and urban storm–water and summarizes significant findings. Studies related to highways are emphasized when possible. The review included 44 articles and reports that focused primarily on SVOCs and VOCs. Only 17 of these publications are related to highways, and 5 of these 17 are themselves review papers. SVOCs in urban stormwater and sediments during the late 1970's to mid-1980's were the subject of most studies.

Criteria used to evaluate data quality included documentation of sampling protocols, analytical methods, minimum reporting limit (MRL) or method detection limit (MDL), quality-assurance protocols, and quality-control samples. The largest deficiency in documenting data quality was that only 10 percent of the studies described where water samples were collected in the stream cross section. About 80 percent of SVOCs in runoff are in the suspended solids. Because suspended solids can vary significantly even in narrow channels, concentrations from discrete point samples and contaminant loads estimated from those samples are questionable without information on sample location or how well streamflow was mixed. Thirty percent or fewer of the studies documented the MRL, MDL, cleaning of samplers, or use of field quality-control samples. Comparing results of different studies and evaluating the quality of environmental data, especially for samples with low concentrations, is difficult without this information.

The most significant factor affecting SVOC concentrations in water is suspended solids concentration. In sediment, the most significant factors affecting SVOC concentrations are organic carbon content and distance from sources such as highways and power plants. Petroleum hydrocarbons, oil and grease, and polycyclic aromatic hydrocarbons (PAHs) in crankcase oil and vehicle emissions are the major SVOCs detected in highway runoff and urban stormwater.

The few loading factors and regression equations that were developed in the 1970's and 1980's have limited use in estimating current (1998) loads of SVOCs on a national scale. These factors and equations are based on few data and use inconsistent units, and some are independent of rainfall. Also, more cars on the road today have catalytic converters, and fuels that were used in 1998 are cleaner than when loading factors and regression equations were developed.

Comparisons to water-quality and sediment-quality criteria and guidelines indicate that PAHs, phenolic compounds, and phthalates in runoff and sediment exceeded U.S. Environmental Protection Agency drinking-water and aquatic-life standards and guidelines. PAHs in stream sediments adjacent to highways have the highest potential for adverse effects on receiving streams.

Few data exist on VOCs in highway runoff. VOCs were detected in precipitation adjacent to a highway in England, and chloromethane, toluene, xylenes, 1,2,4-trimethylbenzene, and 1,2,3-trichloropropane were detected in runoff from a highway in Texas. In urban stormwater, gasoline-related compounds were detected in as many as 23 percent of the samples. Land use could be the most significant factor affecting the occurrence of VOCs, with highest concentrations of VOCs found in industrial areas. Temperature is another factor affecting the occurrence and concentrations of VOCs. Urban land surfaces are the primary nonpoint source of VOCs in stormwater. However, the atmosphere is a potential source of hydrophilic VOCs in stormwater, especially during cold seasons when partitioning of VOCs from air into water is greatest. Tetrachloroethene, dichloromethane, and benzene were the only VOCs detected in stormwater that exceeded U.S. Environmental Protection Agency drinking-water standards.

INTRODUCTION

Runoff from highways and urban areas has long been recognized as a source of contaminants that could affect the Nation's water resources. Federal, State, and local agencies and universities have conducted or sponsored research since about 1970 to characterize runoff quality, estimate contaminant loads, and assess impacts on receiving streams. Sampling protocols, analytical methods and detection limits, and quality-assurance/quality-control (QA/QC) protocols have improved during this time. In addition, new contaminants are being released into the environment, more is known about their toxic effects, and water-quality criteria for contaminants have been established or changed. In light of these changes, highway-runoff and urban-stormwater studies need to be periodically reviewed for quality of data and whether the results address current water-quality issues.

Semivolatile organic compounds (SVOCs) and volatile organic compounds (VOCs) are two groups of contaminants that have been measured in runoff from highways and urban areas. SVOCs are operationally defined as solvent-extractable organic compounds that can be determined by gas chromatography/mass spectrometry (GC/MS) (Furlong and others, 1996). Examples of SVOCs include phthalates, phenols, and polycyclic aromatic hydrocarbons (PAHs). Smith and others (1988) reviewed the sources of several types of SVOCs and processes affecting their fate and distribution in surface water. SVOCs are present in many products, including plastics, dyes, and disinfectants, and PAHs are produced by burning gasoline, oil, wood, and other fuels. SVOCs typically are hydrophobic and by definition have a moderate tendency to volatilize (Karickhoff and others, 1979; Lucius and others, 1989). These properties control how SVOCs are distributed among air, water, and soil when released into the environment. Because they are hydrophobic and moderately volatile, SVOCs preferentially distribute into organic phases, such as tissue and sediments containing organic carbon (Witkowski and others, 1987; Smith and others, 1988).

SVOCs are an environmentally significant group of contaminants because they may accumulate to concentrations that will adversely affect aquatic organisms. Benthic organisms that live in contaminated sediment are most affected because sediments have the largest fraction of SVOCs; however, organisms that feed on benthic species also may be affected. Adverse effects could include mortality, reduced fecundity, and inhibited or abnormal growth. Recently, scientists have become aware of compounds that disrupt the endocrine system and reproduction of fish, reptiles, and mammals (Colborn and others, 1993). Endocrine disruption occurs when a compound either mimics natural hormones or blocks their function. Certain phthalates and PAHs are among the organic compounds that cause endocrine disruption, although their effect is weaker than the effect of some pesticides. In a national survey, concentrations of phenols in bottom sediment were found to correlate with concentrations of 11-ketotestosterone in male carp at an alpha-level of 0.05, suggesting these SVOCs also could cause endocrine disruption (Goodbred and others, 1997).

VOCs are operationally defined as organic compounds that can be extracted from water by purging with an inert gas, then trapped and determined by GC/MS (Connor and others, 1998). VOCs are present in many products including fuels, solvents, refrigerants, paints, adhesives, and deodorants. VOCs also are present in vehicle exhaust and chlorinated water. In contrast to SVOCs, VOCs can be either hydrophobic or hydrophilic, have a high tendency to volatilize, and distribute preferentially into air because of their volatility.

VOCs have low aquatic toxicity (Rowe and others, 1997). Except for spills, concentrations found in highway runoff and urban stormwater are too low to cause a toxic response in aquatic species. However, VOCs in highway runoff and urban stormwater could enter drinking-water supplies and have chronic effects on the consumers. For example, ground water in Tucson, Arizona, was contaminated with low concentrations of VOCs in urban stormwater (Pritt and others, 1996).

Objectives and Scope

The objectives of this review are to evaluate the quality of existing data on SVOCs and VOCs and to summarize significant findings. This is not an exhaustive review of all studies that contain information on SVOCs and VOCs, but a review of studies that focused primarily on SVOCs and VOCs in highway runoff, urban stormwater, precipitation, and sediments. Studies related to highway runoff are emphasized when possible. Measures of extractable organic compounds, such as petroleum hydrocarbons and oil and grease, are included in the discussion of SVOCs, but pesticides and polychlorinated biphenyls are not within the scope of this report.

A total of 44 articles and reports published between 1976 to 1998 were reviewed. Only 17 of these publications were related to highways, and 5 of these 17 are themselves review papers. SVOCs in urban stormwater and sediments were the subjects of most studies.

Criteria for Data Quality

Studies done since 1970 are useful if they were documented such that the quality, interpretations, and limits of the data can be qualified. Documentation should be able to answer several important questions, such as: Where, when, and how were samples collected? What analytical methods were used to identify and quantify contaminants, and what was the minimum reporting limit (MRL) or method detection limit (MDL)? What QA/QC steps were taken to assure data are representative, accurate, and precise? These questions comprise the criteria for evaluating the quality of existing data.

MONITORING TRACE ORGANIC CHEMICALS

Because of their physical and chemical properties, different samplers and sampling procedures are needed for SVOCs and VOCs. SVOCs can be sampled using a variety of samplers because analyte loss during sampling is not a significant issue. The choice and use of a sampler depends on sampling objectives and logistical considerations. For example, discrete point samplers are adequate for obtaining occurrence data, but do not obtain accurate concentrations of SVOCs unless the stream is well mixed and suspended solids are evenly distributed in the stream cross section. The best techniques to obtain accurate data are equal-width-increment (EWI) and equal-discharge-increment (EDI) sampling using samplers that collect depth-integrated samples (Wells and others, 1990). However, these sampling techniques are difficult in flashy runoff from urban areas and highways, which is why automatic samplers commonly are used in stormwater studies. Regardless of the sampler type, the sampler should be made of noncontaminating materials. Generally, metal and glass are the best materials for sampling trace concentrations of organic compounds. Teflon is the preferred material when metal and glass cannot be used, such as for sampling lines for automatic samplers.

In contrast, analyte loss during sampling is a significant issue for VOCs because of their volatility. Three types of samplers and sampling techniques are used to collect VOC samples, all three of which collect discrete point samples. If point sources are not nearby, point sampling for VOCs is not as significant an issue as for SVOCs because VOCs are mostly in the dissolved phase and not sorbed to sediments (Rathbun, 1998). The two most common sampling techniques are to manually dip a 40-mL (milliliter) glass vial directly into the stream or to obtain a sample with another container and then transfer the water to a vial. Vials are then quickly sealed with a Teflon-lined septum cap.

Dipping a vial directly into the stream eliminates potential contamination from sampling equipment. However, this technique is limited to the length of the sampler's arm and can be hazardous during high-flow conditions. A stainless steel and copper sampler (Shelton, 1997) is more versatile and safer than dip sampling because it collects samples at greater depths and can be suspended from bridges. Sample water is collected directly into sample vials, which are sealed when the sampler is retrieved from the stream. Laboratory and field testing has shown that this sampler collects accurate data (Gregory Delzer, U.S. Geological Survey, written commun., 1997). VOCs should not be collected using automatic samplers with peristaltic pumps that do not quickly seal vials because the negative pressure created by the pumps and volatilization from open vials can bias sample results. Recently, ISCO Inc. developed the model 6100 automatic sampler for sampling VOCs in streams. This sampler uses a positive-displacement pump and quickly seals vials. Laboratory testing of this sampler indicates it produces accurate data with less than 2 μg/L (micrograms per liter) of carryover between samples (Gregory Delzer, written commun., 1997).

Preservation of water samples for analysis of SVOCs and VOCs depends on laboratory requirements. SVOC samples usually are chilled at 4˚C. VOC samples usually are chilled and may be acidified to a pH of less than 2 using hydrochloric acid. Some laboratories require addition of ascorbic acid to VOC samples if free chlorine is present.

GC/MS is the most accurate method of identifying and quantifying most SVOCs and VOCs. Even if laboratories use the same analytical method, they may report varying MRLs and MDLs that can create difficulties in data interpretation (Cole and others, 1984). MRLs and MDLs can vary because of the sample matrix, study objectives require different values, and analytical methods improve with time. For example, MRLs and MDLs that meet current regulatory requirements may be satisfactory for compliance monitoring. However, organic compounds in stormwater commonly occur at concentrations below water-quality criteria (Makepeace and others, 1995), so regulatory requirements may be inadequate to determine if compounds are present, to estimate loads, to identify causal factors and emerging problems, and to use data in the future if water-quality criteria are lowered. The National Water-Quality Laboratory of the U.S. Geological Survey (USGS) reports SVOCs in water as low as 5 μg/L (Fishman, 1993), SVOCs in sediment as low as 50 μg/Kg (micrograms per kilogram) (Furlong and others, 1996), and VOCs in water as low as 0.05 μg/L (Connor and others, 1998). Extraction and recovery efficiencies are lower for SVOCs than for VOCs, which is why SVOCs have higher MRLs and MDLs. Extraction and recovery efficiencies less than 90 percent are common for compounds that sorb to sediments (Furlong and others, 1996), whereas extraction and recoveries for most VOCs are 95 percent or greater (Connor and others, 1998).

Results of water-quality studies can form the basis of or alter agency policies and have significant economic and social implications. Studies should be supported by a QA/QC plan to ensure that these results are based on quality data. QA is the precautionary actions used to prevent systematic bias. Examples of QA are using noncontaminating materials and sample containers, cleaning equipment, preserving samples soon after collection, and shipping samples overnight. QC includes the steps used to check that QA is effective and to evaluate variability due to random error. Examples of QC are equipment blank samples to ensure that equipment is clean, replicates to assess sample variance and analytical precision, and samples spiked with analytes to evaluate analyte degradation and recovery. QC samples generally comprise 10 to 15 percent of all samples. The QA/QC plan usually is an unpublished document, but should be briefly described with study results. For large studies, the QA/QC plan often is a published document, such as that by Mueller and others (1997).

Sample Collection

Documentation of sample collection should include where, when, and how highway runoff and urban stormwater samples were collected. Documenting sample location is important so sampling can be repeated to evaluate apparent anomalies and to define changes with time. All studies answered the question of where samples were collected (table 1, at back of report), although the level of detail varied. Some studies provided maps showing precise sample locations; however, most studies included generalized maps or described sample locations. An extreme case of generalizing was Line and others (1997), who only stated that samples were collected in North Carolina.

Studies included in this review were conducted in the United States (fig. 1) and in Canada, Germany, Japan, Norway, Spain, Switzerland, and the United Kingdom. Most studies in the United States were conducted along the northeast coast and in southern states where population densities are greatest. Few studies have been conducted in the Great Lakes region and the central and western states.

Seventeen studies were related to SVOCs and VOCs in highway runoff or in rain, snow, and sediment near highways. Ten of the 17 studies related to highways were in the United States (Wiland and Malina, 1976; Zawlocki and others, 1980; Gupta, 1981; Hoffman and others, 1983, 1984, 1985; Hoffman and Quinn, 1987; Latimer and others, 1990; Barrett and others, 1993; Baldys and others, 1997); four were in England (Butler and others, 1984; Johnston and Harrison, 1984; Harrison and Johnston, 1985; Hewitt and Rashed, 1990); and one was in each of Canada (Boom and Marsalek, 1988), Norway (Gjessing and others, 1984), and Germany (Stotz, 1987). PAHs were the topic of most highway-related studies.

The priority pollutant monitoring project of the Nationwide Urban Runoff Program (NURP) had the widest geographic distribution and is the most frequently cited study of organic contaminants in urban stormwater. The U.S. Environmental Protection Agency's (USEPA) priority pollutants, including SVOCs and VOCs, were monitored in 15 cities in 14 states (Cole and others, 1984). Concentrations of the priority pollutants were measured in 86 stormwater samples collected from drainage basins with residential, commercial, or industrial land use.

Marsalek and Schroeter (1988) conducted a study similar to NURP in 12 Canadian cities in the Great Lakes region. Up to 125 stormwater and sediment samples from 81 sites with residential, commercial, industrial, or transportation land use were analyzed for 50 priority pollutants, including PAHs and chlorinated benzenes.

A set of independent urban stormwater studies conducted by the USGS comprise another type of study with a wide geographic distribution. In 1991, USEPA required cities with a population of 100,000 or more to monitor stormwater quality and obtain municipal National Pollutant Discharge Elimination System (NPDES) permits. The USGS monitored stormwater from drainage basins with residential, commercial, or industrial land use in 16 of these cities in 11 states (Delzer and others, 1996). Most of these

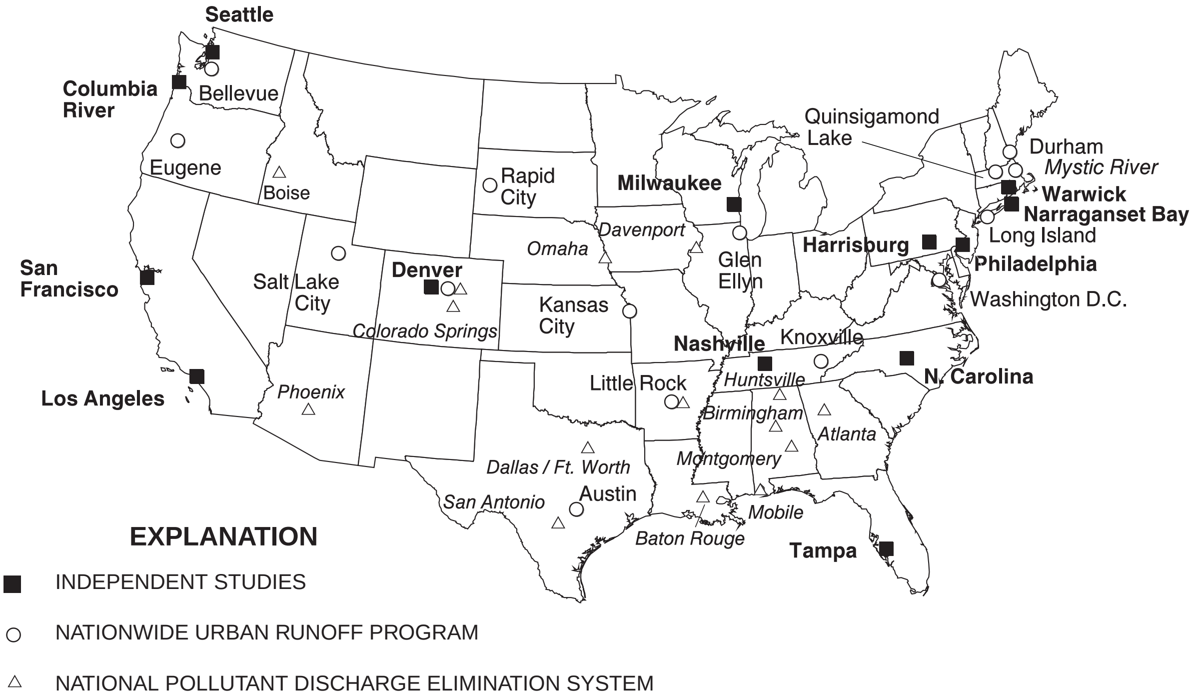

Figure 1. Cities in the United States where semivolatile and volatile organic compounds have been studied in highway runoff and urban stormwater.

cities are in southern and central states (fig. 1). A total of 642 stormwater samples were analyzed for up to 210 properties and constituents, including the priority pollutants. VOC data were compiled to characterize the occurrence of VOCs in stormwater (Delzer and others, 1996) and identify nonpoint sources (Lopes and Bender, 1998). Data on SVOCs and other contaminants that were measured in stormwater samples were not compiled.

Documenting when samples were collected is necessary to know if unusual weather occurred during the respective studies and to determine if state-of-the-art sampling and analytical methods were used. The question of when samples were collected was answered in about 84 percent of the studies. The majority of data were collected during the late 1970's to mid-1980's, including data related to highway runoff. Only 20 percent of studies, most of which were NPDES studies, collected data after 1990. Typically, the time between data collection and publication was about 2 to 4 years, although Latimer and others (1990) was published 10 years after data were collected. Studies that did not report when data were collected were published between 1982–91; therefore, data probably were collected prior to the mid-1980's.

The validity and comparability of data depend on several criteria, including documented sampling protocols. Description of the sampling protocol should include information on the type and material of the sampler; where in the stream cross section samples were collected; if discrete or composite samples were analyzed; and if whole water, suspended solids, or filtrates were analyzed. Most studies provided some, but none provided all information on the sampling protocol.

About 80 percent of studies reported the type of sampler. Water samples were collected with buckets, bottles, trays, cans, storage tanks, drums, and automatic samplers. Snow and sediment were sampled with corers, trowels, ponar samplers, jars, and lysimeters. Atmospheric deposition and rain were sampled with funnels. Line and others (1997) collected samples for VOCs with automatic samplers that were not designed for these contaminants; therefore, volatilization from sample water probably biased results.

About 60 percent of studies reported the sampler material. Most samplers were made of metal or glass, which are good materials to use for sampling organic contaminants. Studies that used flow splitters and samplers made of fiberglass and plastics included Zawlocki and others (1980), Gjessing and others (1984), Johnston and Harrison (1984), and Harrison and Johnston (1985). Sorption to these materials may have biased the SVOC and VOC data of these studies. Hewitt and Rashed (1990) conducted a study in the same area as Johnston and Harrison (1984) and Harrison and Johnston (1985) and may have used the same equipment, but there is insufficient information to determine this from the article. Seven studies used automatic-pumping samplers. Three NPDES studies (Lopes and others, 1995; von Guerard and Weiss, 1995; and Baldys and others, 1998) noted that sampling lines were made of Teflon. The other studies did not document the sampler-line material.

The largest deficiency in documenting data quality was that only 10 percent of studies described where water samples were collected in the stream cross section, if streamflow was well mixed, or if equal-width increment or depth-integrated techniques were used. The representativeness of discrete point samples and interpretations based on those data, especially load estimates, are questionable without this information. Sample location could have affected results because SVOC concentrations depend on suspended solids concentrations (Hunter and others, 1979; Hoffman and Quinn, 1987; and Barrett and others, 1993). Suspended solids concentrations can have significant horizontal and vertical variations (Horowitz and others, 1989) even in channels less than 5 ft wide (Edwards and Glysson, 1986). Samplers do not need to be sophisticated devices like electronically activated point samplers to obtain representative samples. However, the water samplers used in these studies and lack of information on flow conditions suggest most studies sampled surficial streamflow along the streambank. Stream velocity and suspended sediment concentrations typically are lowest along the banks, so point samples collected along the streambanks may result in biased (low) contaminant concentrations and load estimates. This may not be a significant issue in stormwater drainages where streamflow usually is fast and shallow.

About 90 percent of studies described whether samples were discrete or composite samples. About 70 percent of studies that described sampling methods manually collected discrete water samples. Eight studies composited stormwater samples, but two of these studies did not document whether these were time-weighted or flow-weighted composites. Composite samples were obtained using cone or churn splitters (Lopes and others, 1995; von Guerard and Weiss, 1995) and a flow splitter (Zawlocki and others, 1980). Other studies did not describe how samples were composited. About 90 percent of studies described whether bottom-sediment samples were point samples or composites and the depth interval of bottom sediment that was sampled. Most samples were point samples collected from the upper 10 centimeters of bottom sediment. Ellis and others (1985) and Brown and others (1985) composited surficial bottom-sediment samples from several sites. Gavens and others (1982) and Butler and others (1984) sieved bottom sediment and Hoffman and others (1984) sieved suspended solids for a consistent grain size among samples. Comparing bottom-sediment concentrations is difficult because most studies did not analyze for organic carbon, which is the most common way of normalizing organic contaminant concentrations in sediments.

About 90 percent of studies described whether whole-water samples were analyzed or if suspended solids and filtrates were analyzed separately. Unless stated otherwise, it was assumed that whole-water samples were analyzed. About 30 percent of studies separated suspended solids and analyzed the filtrate, solids, or both. Separation was done by filtration with glass fiber filters or by centrifugation.

Analytical Methods and Minimum Reporting and Detection Limits

Documenting the analytical methods, MRLs, and MDLs is important to use data from different studies for a common objective. About 90 percent of studies described the analytical method for contaminant identification and quantitation. Gas chromatograph/flame-ionization detection (GC/FID) was the most commonly used analytical method. GC/MS was used to identify analytes or confirm GC/FID results in about 30 percent of the studies. About 30 percent of studies documented analytical precisions and recoveries. Generally, precision was less than 25 percent and recoveries were greater than 80 percent.

About 30 percent of studies, most of which were conducted in the 1990's, documented the MRL or MDL. The MRL is the lowest concentration that can accurately be quantified. The MDL is the lowest concentration that the method can detect. For studies done in the 1980's, Brown and others (1985) reported an MRL of 1 μg/L for petroleum hydrocarbons, Schondorf and Herrmann (1987) reported MDLs ranging from 0.03 to 0.15 ng/L (nanograms per liter) for PAHs, Zawlocki and others (1980) reported an MRL of 100 μg/L for a variety of SVOCs, and Boom and Marsalek (1988) and Marsalek and Schroeter (1988) reported an MRL of 0.05 μg/L for PAHs. Except for Zawlocki and others (1980), these limits compare well with current (1998) limits of the U.S. Geological Survey. The high MRLs ranging from 5 to 100 μg/L used by Line and others (1997) could explain why few SVOCs and VOCs were detected in stormwater from industrial sites.

Quality Assurance and Quality Control

The validity and use of data depend on documenting the procedures used to ensure that high-quality data were collected. Most studies described some precautionary action to ensure sample integrity, but few studies described thorough QA/QC procedures. Only Cole and others (1984) described a QA/QC plan, although they were unable to evaluate the effectiveness of the plan for NURP.

As previously noted, about 60 percent of studies used noncontaminating materials such as glass and metal. However, only 30 percent of studies documented that equipment was cleaned before sampling or that samples were preserved. Chilling samples at 4°C was the most commonly used method for preserving samples. Infrequently described precautionary steps included use of Teflon-lined or metal lids, covering jars with aluminum foil, homogenizing samples before splitting into equal portions, slowly melting snow samples to minimize volatilization, sampling in well-mixed parts of a storm drain, shipping samples overnight, and using nitrogen to filter samples for SVOCs. Studies that retrieved samples up to 2 weeks after collection without chilling were Johnston and Harrison (1984) and Harrison and Johnston (1985). Latimer and others (1990) left samples at room temperature for up to 2 days before analysis. Line and others (1997) used automatic samplers for VOCs and retrieved and chilled samples sometimes hours after they were collected.

Both laboratory and field QC samples are needed to evaluate sample and analytical quality. About 30 percent of studies reported analyzing laboratory QC samples and 15 percent analyzed field QC samples.

Laboratory QC samples included blanks, lab-split duplicates, surrogate recoveries, and performance-evaluation samples. Four studies reported using laboratory blanks and surrogate recoveries to correct environmental concentrations. The use of field QC samples became prevalent after most of the studies in this review were conducted. Except for NURP, the only studies that reported analyzing field QC samples were conducted in the 1990's. Field QC samples included equipment blanks, trip blanks, replicates, and spikes. Evaluating the quality of environmental data, especially low concentrations, is difficult because few studies collected QC data and documented that samplers were cleaned.

SUMMARY OF STUDY RESULTS

Most highway-runoff and urban-stormwater studies were conducted to address regional or local issues. However, results from all studies could provide useful qualitative information to answer some general questions of national importance. For example, do certain SVOCs and VOCs occur more frequently and at higher concentrations in particular regions of the country? If so, do factors such as climate affect occurrence and concentrations of these compounds? What are the sources of SVOCs and VOCs? Can loads of SVOCs be estimated on a national scale? Could SVOCs and VOCs have an adverse effect on water resources? These questions are the focus of this summary.

Semivolatile Organic Compounds

SVOCs were the subjects of most highway runoff and urban stormwater studies. Much has been learned about these compounds, especially the extractable organic compounds and polycyclic aromatic hydrocarbons (PAHs).

Occurrence

Characterizing the occurrence of SVOCs in highway runoff and urban stormwater for the entire United States is not possible because few studies reported detection frequencies or were conducted in the Great Lakes region and the central and western states. Studies that reported detection frequencies are Cole and others (1984), Boom and Marsalek (1988), Marsalek and Schroeter (1988), Lopes and others (1995), von Guerard and Weiss (1995), and Baldys and others (1998). SVOC concentrations vary by several orders of magnitude, which is typical of stormwater quality (table 7 at back of report). Table 7 was compiled assuming that unknown sample types and samples described as sediment samples, but reported in milligrams per liter or nanograms per liter, were whole-water samples. Thirty SVOCs were measured but not detected in stormwater (table 2, at back of report).

Total oil and grease and hydrocarbon concentrations in runoff ranged from less than 1 to 480 milligrams per liter (mg/L) (table 7). In suspended sediment, bottom sediment, and soils, oil and grease and hydrocarbon concentrations ranged from 8 to 507,000 micrograms per gram (µg/g). The highest concentrations in water and solid phases were associated with highways and industrial land use.

Studies that analyzed petroleum hydrocarbons and oil and grease for the classes of organic compounds that comprise these measurements were Zawlocki and others (1980), Eganhouse and Kaplan (1981b), Brown and others (1985), Fam and others (1987), Hoffman and Quinn (1987), Marsalek and Schroeter (1988), and Barrett and others (1993). Comparing results is difficult because fractions were separated using non-standard procedures (Hoffman and Quinn, 1987). Most extractable organic compounds in stormwater are aliphatic compounds and, except for polar compounds, about 80 percent or more are in the solid phase. The high solubilities of polar compounds, such as phenols, ketones, and alcohols, explain the large percentages measured in filtrates. Generally, aromatic compounds, phenolic compounds, PAHs, alcohols, and ketones comprise less than 1 percent to about 15 percent of the extractable organic compounds.

Concentrations of individual PAHs in runoff ranged from less than 1 to 120 µg/L. Highest concentrations were associated with industrial land use; few data exist for individual PAHs in highway runoff. In solid phases, concentrations of individual PAHs ranged from less than 1 to 200 µg/g. Of the few studies that reported total PAH concentrations, the maximum concentrations were 18,210 µg/L in whole water and 1,100 µg/g in solid phases. The maximum detection frequency of PAHs in both urban stormwater and snow was 90 percent. Most PAHs were detected in less than 25 percent of samples (Cole and others, 1984;

Boom and Marselak, 1988; Marsalek and Schroeter, 1988; Lopes and others, 1995; von Guerard and Weiss, 1995; and Baldys and others, 1998).

Johnston and Harrison (1984) tentatively identified 2-chlorophenol and 2,4-dichlorophenol in bulk deposition adjacent to a highway. Baldys and others (1997) detected phenolic compounds at concentrations between 1 and 16 µg/L in 90 percent of highway runoff samples. Phenolic compounds were detected in 15 percent or less of urban stormwater samples from NURP (Cole and others, 1984), 55 percent for urban stormwater samples from Phoenix (Lopes and others, 1995), and were not detected in urban stormwater samples from Colorado Springs (von Guerard and Weiss, 1995) and Dallas-Fort Worth (Baldys and others, 1998). When detected, concentrations of phenolic compounds in urban stormwater generally were less than 20 µg/L.

Related Factors

Of the factors that affect SVOC concentrations in water, the most significant is suspended solids concentration. About 80 percent or more of SVOCs in stormwater are associated with the solid phase due to the hydrophobic character of these contaminants (Hunter and others, 1979; Zawlocki and others, 1980; Eganhouse and Kaplan, 1981a; Brown and others, 1985; Hoffman and Quinn, 1987; and Barrett and others, 1993).

Organic carbon content is the most significant factor affecting SVOCs in the solid phase (Butler and others, 1984; Ellis and others, 1985; and Witkowski and others, 1987). Mineral particles are less effective at sorbing nonionic SVOCs (Witkowski and others, 1987), thus grain size does not appear to be a significant factor affecting SVOC concentrations in sediments unless small grains have an organic coating (Witkowski and others, 1987; Gavens and others, 1982). In contrast, trace-element concentrations in sediments are strongly correlated with grain size because ionic elements adsorb to small particles that have charged surfaces (Horowitz and Elrick, 1987).

Sorption of SVOCs to solids is reflected in the high concentration of SVOCs in the initial runoff from a storm and correlation between concentrations of solids and SVOCs throughout a storm (Hunter and others, 1979; Stenstrom and others, 1984; Brown and others, 1985; Hoffman and others, 1984, 1985; and Hoffman and Quinn, 1987). The initial runoff, commonly called first flush, can have concentrations of suspended solids and sorbed SVOCs that are several factors higher than concentrations in composite samples. Suspended solids concentrations typically decrease during a storm due to flushing of particles that accumulated on the land surface (Novotny, 1995).

Land use also affects SVOC concentrations. Most studies found higher SVOC concentrations in runoff, snow, and bottom sediment from highways or industrial areas compared to residential and commercial areas (Hoffman and others, 1983, 1984; Hoffman and Quinn, 1987; Evans and others, 1990; Latimer and others, 1990; Bomboi and Hernandez, 1991; and Baldys and others, 1998). For example, PAH concentrations in snow near highways and a steel plant were similar, and PAHs were more frequently detected and concentrations were higher than NURP stormwater data (Boom and Marsalek, 1988). Gjessing and others (1984) found PAHs in snow up to 50 meters from a highway, the furthest of all contaminants they measured, and that PAHs were fractionated during atmospheric transport. Johnston and Harrison (1984) found PAHs in rain up to 70 meters from a highway and that concentrations decreased with distance. Butler and others (1984) found that PAH concentrations in bottom sediment decreased with distance from highways.

Storm characteristics, such as rainfall intensity and volume of runoff, are important factors affecting SVOC concentrations and loads in stormwater and sediments. As rainfall intensity increases, stream velocity and sediment-carrying capacity increase, resulting in increased SVOC concentrations in stormwater (Hoffman and Quinn, 1987; Barrett and others, 1993). In bottom sediment, Evans and others (1990) found that PAH concentrations weakly correlated with monthly rainfall and that concentrations increased about 4 to 30 days after a storm. Gupta (1981) observed higher concentrations of oil and grease in highway runoff and Prahl and others (1984) observed higher PAH concentrations in atmospheric particulates during winter compared to summer months. Schondorf and Herrmann (1987) found that freezing can concentrate organic compounds in water. During thaws, soluble organic compounds elute in the first and last parts of the melt and that about 90 percent of PAHs elute with the particulates during the last 20 percent of the melt. These observations indicate that concentrations and loads of SVOCs could vary seasonally.

Not all studies found a relation between storm characteristics and SVOC concentrations and loads. Stenstrom and others (1984) found no correlation between oil and grease concentrations and streamflow rates, total rainfall, time since beginning of storm, rainfall intensity, or antecedent dry days. Hunter and others (1979), Herrmann (1981), and Hoffman and others (1984) found that SVOC concentrations did not correlate with antecedent conditions. Zawlocki and others (1980) found no correlation between SVOC loads and rainfall, traffic volume, or runoff volume, although they noted that traffic volume during the storm had a greater effect than rainfall.

Conclusions have been mixed whether highway surface type significantly affects SVOC concentrations (Barrett and others, 1993). Gupta (1981) measured oil and grease concentrations from paved surfaces that were 20 times greater than from grass-covered surfaces, but concluded that land use was the most important factor. Strenstrom and others (1984) measured oil and grease concentrations 25 times greater from parking lots compared to residential areas. Wakeham and others (1980) concluded that PAHs in street dust were from asphalt. Zawlocki and others (1980) noted that higher suspended solids concentrations occurred in highway runoff at a site with a median barrier and side railings compared to another site without these features. Other variables, such as traffic volume and drainage, may be more important factors affecting SVOC concentrations than surface type (Stotz, 1987; Barrett and others, 1993).

Sources

Crankcase oil and vehicle emissions were consistently identified as the primary source of SVOCs in stormwater (Hunter and others, 1979; Zawlocki and others, 1980; Stenstrom and others, 1984; Brown and others, 1985; Hoffman and Quinn, 1987; Fam and others, 1987; Yamane and others, 1990; Latimer and others, 1990; and Bomboi and Hernandez, 1991). The significance of PAHs in automobile emissions is indicated by concentrations in sediment, snow, and rain that decrease with distance from highways (Butler and others, 1984; Johnston and Harrison, 1984; Gjessing and others, 1984; Harrison and Johnston, 1985; and Hewitt and Rashed, 1990).

Emission of most PAHs from automobiles is directly related to their concentration in gasoline (Westerhold and others, 1988). Naphthalene and its alkylated homologues comprise about 0.5 percent by weight of gasoline (Canadian Petroleum Institute, 1994); 13 other PAHs occur in gasoline at less than 0.01 to 54 mg/L (Westerhold and others, 1988). About 95 percent of PAHs in gasoline are decomposed during gasoline combustion. However, in gasoline with low PAH content, a large percentage of the PAHs emitted are formed during combustion, including 70 to 80 percent of cyclopenta[*cd*]pyrene and benzo[*b*&*k*]fluoranthene. Gasoline exhaust contains about 1 to 2 parts per million of phenol and o-cresol (Lucius and others, 1989) and is a possible source of phenolic compounds in stormwater.

Load Estimates

Estimates of SVOC loads and mass balances have been made on different scales to evaluate the relative importance of different sources and transport mechanisms. For example, Edwards (1983) estimated that forest and agricultural fires comprise 75 percent of the annual global release of PAHs. Hoffman and Quinn (1987) estimated 470,000 tons per year of petroleum hydrocarbons are released to waters of the United States and that up to 50 percent of this amount could be discharged in urban stormwater. Bjorseth and Ramdahl (1985) estimated that automobile emissions comprise one-third of the 6,000 tons of PAHs emitted each year in the United States. In contrast, Edwards (1983) estimated that automobiles, buses, and trucks comprise only 1.6 percent of benzo(a)pyrene emissions in the United States. The difference could be because Bjorseth and Ramdahl (1985) did not correct for catalytic converters, which were in about 50 percent of cars.

At a regional scale, Hoffman and others (1983, 1984) estimated hydrocarbon and PAH loads to Narraganset Bay, and Marsalek and Schroeter (1988) estimated SVOC loads to the Great Lakes. Estimates by Hewitt and Rashed (1990) and Stotz (1987) indicated that 30 percent or less of the PAHs emitted along highways is transported in runoff and the remainder is dispersed. Other estimates have been made at a local scale (Butler and others, 1984; Gjessing and others, 1984; Johnston and Harrison, 1984; Harrison and Johnston, 1985; Boom and Marsalek, 1988; and Hewitt and Rashed, 1990).

Few regression equations or loading factors have been developed for SVOCs compared to other constituents such as suspended solids and nutrients.

Most equations and factors were based on few data and have little statistical power and large uncertainties, especially for regional and national application. Also, studies reported loading factors with inconsistent units so comparisons are difficult or with units that limit their application (table 3, at back of report). For example, Hoffman and Quinn (1987), Stotz (1987), and Barrett and others (1993) report loading factors that are independent of rainfall and, therefore, apply only to areas with climates similar to their study areas. Gupta (1981) estimated loads from highways using regression equations for runoff, pollutant build-up and wash-off, and loads of suspended solids. Correlations between other contaminants and suspended solids were used to convert loads of suspended solids into loads of the other contaminants. However, conversion equations were developed for individual sites and have only site-specific application. Marsalek and Schroeter (1988) used a procedure similar to Gupta (1981) to estimate loads to the Great Lakes.

Using study results to develop equations and factors of SVOC loads and concentrations at a national level, particularly from highways, is not possible because ancillary information was not documented, raw data were rarely reported, laboratory reporting levels varied, and few studies were related to SVOCs from highways. In addition, vehicles emit fewer SVOCs and VOCs today than when most studies were conducted (U.S. Environment Protection Agency, 1996a). The lower emissions are probably due to catalytic converters and to the use of cleaner-burning fuels. Gasoline-powered cars without catalytic converters emit 25 times more total aerosol PAHs in comparison to cars with catalytic converters, and diesel trucks emit 7 times more PAHs than cars with catalytic converters (Rogge and others, 1993). Therefore, the few loading factors that are available in the literature probably have limited application for estimating current loads of SVOCs and VOCs.

Comparison to Water-Quality and Sediment-Quality Standards and Guidelines

The potential for SVOCs to adversely affect water resources can be made by comparing SVOC concentrations in urban stormwater, snowmelt, and sediment to water-quality and sediment-quality standards and guidelines. Makepeace and others (1995) and Boom and Marsalek (1988) concluded that certain PAHs, phenol, *m*- and *p*-cresols, pentachlorophenol, and phthalates in stormwater were a concern for drinking water and aquatic life. Of the PAHs, total PAH, acenaphthene, fluoranthene, and benzo(a)pyrene in urban stormwater exceeded drinking-water standards of the United States, Canada, and World Health Organization (WHO). Concentrations of fluoranthene in stormwater exceeded acute and chronic aquatic regulation values of the United States.

For this report, SVOC concentrations in sediments were compared to recently developed sediment-quality guidelines (U.S. Environmental Protection Agency, 1996b) as another assessment of their potential adverse effects. No single set of sediment-quality guidelines is universally accepted in the United States. Therefore, the method of USEPA (1996b) was used to determine an upper threshold concentration for selected SVOCs above which there is a high probability of adverse effects on aquatic life. However, guidelines do not exist for all SVOCs detected in urban stormwater and upper threshold concentrations may be over- or under-protective depending on site-specific conditions.

Briefly, USEPA (1996b) used several sets of sediment-quality guidelines that were developed using different methods and have considerable inconsistencies among them. Rather than select one set of guidelines over another, USEPA (1996b) used all available sediment guidelines for a contaminant to classify sites into one of three tiers based on the probability of adverse effects on aquatic life. Tier 1 sites have a high probability of adverse effects on aquatic life, Tier 2 sites have an intermediate probability of adverse effects on aquatic life, and Tier 3 sites have no indication of adverse effects on aquatic life. USEPA (1996b) used lower threshold guidelines, above which adverse effects occasionally occur, to define the Tier 2/Tier 3 boundary, and upper threshold guidelines, above which effects may be frequent or severe, to define the Tier 1/Tier 2 boundary. For a site to be designated as Tier 1, the measured contaminant concentration at that site must exceed at least two of the upper threshold guidelines for that contaminant.

The guideline used in this comparison was the Tier 1/Tier 2 boundary concentration (table 4, at back of report). The upper threshold values used were (1) the effects range-median (Long and Morgan, 1991; Long and others, 1995); (2) the apparent effects threshold-high (Barrick and others, 1988); (3) the probable effect level used by the Florida Department of

Environmental Protection (1994); (4) the probable effect level used by the Canadian Council of Ministers of the Environment (1995); (5) the USEPA sediment-quality criterion (U.S. Environmental Protection Agency, 1996b); and (6) the USEPA sediment-quality advisory level (U.S. Environmental Protection Agency, 1996b).

In the future, guidelines for PAHs are likely to change to PAH mixtures because PAHs typically co-occur in the environment. Testing and modeling is being conducted to determine the toxicity of PAH mixtures in sediment, which will form the basis for sediment-quality criteria for PAH mixtures (U.S. Environmental Protection Agency, 1998).

About 70 percent of surface-soil samples near a highway exceeded upper threshold concentrations of benz(a)anthracene, benzo(a)pyrene, chrysene, or pyrene, or of more than one of these PAHs, indicating adverse effects are probable (Butler and others, 1984). About 60 percent of bottom sediments from an urban stream exceeded upper threshold concentrations of fluoranthene, anthracene, pyrene, or benzo(a)pyrene, or of more than one of these PAHs (Ellis and others, 1985). Other studies had samples that exceeded upper threshold values, but the percentage of exceedence is unknown. For example, particulates in vehicle emissions and in the atmosphere exceeded upper threshold concentrations of benzo(a)pyrene (Prahl and others, 1984; Bjorseth and Ramdahl, 1985). Suspended sediments and street dust from highways and commercial areas exceeded upper threshold concentrations of fluoranthene, phenanthrene, pyrene, acenapthlyene, and benzo(a)pyrene (Hoffman and others, 1984 and 1985; Marsalek and Schroeter, 1988).

Volatile Organic Compounds

Few studies have been done on VOCs in highway runoff and urban stormwater. This summary of VOCs is mostly from the National Urban Runoff Program (NURP) and National Pollutant Discharge Elimination System (NPDES) studies.

Occurrence

Harrison and Johnston (1985) and Baldys and others (1997) were the only studies of VOCs in highway runoff. Harrison and Johnston (1985) sampled 2-week composites of atmospheric deposition at three sites near a highway in England. A total of 48 compounds were identified and quantified on a relative basis. Toluene and C_2-alkylbenzene were the major components in atmospheric deposition. No variation with distance from the highway was observed. Twenty-one highway runoff samples were collected at four sites between 1992-94 and analyzed for VOCs and other contaminants in the Dallas–Fort Worth area (Baldys and others, 1997). Chloromethane, toluene, xylenes, 1,2,4-trimethylbenzene, and 1,2,3-trichloropropane were detected in about 5 to 28 percent of samples at concentrations between 0.2 and 4.0 μg/L.

Most of the data on VOCs were collected during the NURP and NPDES studies. Together, these studies provide information on the occurrence of VOCs in most regions of the United States. For the NURP, the most frequently detected VOCs were dichloromethane, naphthalene, and chloroform, detected in 10 to 12 percent of all samples (Cole and others, 1984). In contrast, the most frequently detected VOCs for NPDES studies were toluene, xylenes, chloroform, and trimethylbenzene, detected in 12 to 23 percent of all samples (table 5, at back of report) (Delzer and others, 1996). A lower MRL for the NPDES studies could account from the greater frequencies of detection. Comparing VOC detections among regions of the United States may be possible using the NURP and NPDES data, but would be difficult because of the different reporting limits. Most detected concentrations of VOCs in urban stormwater for the NURP and NPDES studies were less than 10 μg/L and ranged from 0.2 to 43 μg/L.

The prevalence of gasoline-related compounds in NPDES data compared to NURP data probably is because stormwater was sampled closer to its source at NPDES monitoring sites and because the NURP did not measure xylenes, trimethylbenzenes, methyl *tert*-butyl ether (MTBE). MTBE and other ether oxygenates are added to gasoline to reduce vehicle emissions and enhance octane ratings. MTBE usage as an octane enhancer started about 1979. The use of MTBE to produce cleaner burning gasoline increased considerably during the late 1980’s. In 1996, 17.6 billion pounds of MTBE were produced, making it the VOC with the third highest production (Chemical and Engineering News, April 8, 1996). MTBE’s widespread use, high solubility, and resistance to degradation (Squillace and others, 1997) could account for its frequent occurrence in urban stormwater (Delzer and others, 1996) and in shallow urban ground water (Squillace and others, 1996).

Related Factors

Land use could be the most significant factor affecting the occurrence of VOCs. Lopes and Bender (1998) found that concentrations of gasoline-related and chlorinated VOCs were significantly higher in industrial areas as compared to commercial and residential areas and that MTBE was detected more frequently in commercial areas. Most VOCs have industrial applications (Pankow and Cherry, 1996), which probably is why concentrations were higher in industrial areas. The frequent detection of MTBE in commercial areas could be from spills at gas stations, which typically are located in commercial areas. Line and others (1997) infrequently detected VOCs in first-flush samples from industrial sites in North Carolina; sampling methods and high MRLs could account for the few detections.

Temperature is a significant factor affecting the occurrence of VOCs. A study by von Guerard and Weiss (1995) observed that more detections of VOCs occurred during snowmelt than during storm runoff. For all NPDES data, MTBE, benzene, xylenes, and 1,2,4-trimethylbenzene were detected more frequently during winter than summer (Delzer and others, 1996; Lopes and Bender, 1998). This higher detection of VOCs could be caused by the increased partitioning of VOCs from air into precipitation or slower volatilization from stormwater during cold months.

Sources

Lopes and Bender (1998) concluded that urban land surfaces are the primary nonpoint source of VOCs in stormwater. Most VOC concentrations in NPDES samples were higher than those in equilibrium with concentrations measured in urban air, indicating the atmosphere was not the source. VOCs associated with certain products, such as gasoline, frequently occurred together, and concentrations were significantly correlated and different among urban land uses. Model results indicated that VOC concentrations near the reporting limits evolved by volatilization. The primary source of VOCs probably was spills and VOCs sorbed to organic particulates and impervious surfaces, although partitioning between precipitation and VOCs in the atmosphere could be a source for MTBE.

The seasonal detection of some VOCs suggests that the atmosphere could be a nonpoint source. Measurements by Kawamura and Kaplan (1983), Pankow and others (1984), Harrison and Johnston (1985), Ligocki and others (1985), and Adachi and Kobayashi (1994) support the hypothesis that the atmosphere near highways and urban areas is a source of VOCs, although concentrations in precipitation were less than or equal to 0.2 µg/L. Concentrations of MTBE in precipitation estimated from concentrations in air range from less than 1 to about 4 µg/L (Squillace and others, 1996). These estimated concentrations of MTBE are why Squillace and others (1996) hypothesized precipitation could be a major source of MTBE detected in shallow urban ground water. Pankow and others (1997) demonstrated that MTBE and other VOCs in the atmosphere can be transported in recharge into sandy aquifers.

Comparison to Water-Quality Standards

From the NURP data, Makepeace and others (1995) concluded that tetrachloroethene, dichloromethane, and benzene could be a concern if stormwater entered drinking-water supplies. For the NPDES data, Delzer and others (1996) found that concentrations of MTBE in urban stormwater were less than the lower limit of the USEPA draft lifetime health advisory of 20 µg/L. Other VOCs detected in NPDES samples were compared to drinking-water standards (U.S. Environmental Protection Agency, 1996c) in table 6 (at back of report) because VOCs have low aquatic toxicities (Rowe and others, 1997) and primarily are a threat to drinking-water supplies. Less than 0.5 percent of NPDES samples exceeded drinking-water standards of dichloromethane and tetrachloroethene, similar to the NURP study (Makepeace and others, 1995).

INFORMATION NEEDS

This review has shown that highways can be major sources of SVOCs detected in water and sediment. However, there is insufficient information to determine if highways are sources of VOCs or to estimate loads and concentrations of SVOCs and VOCs from highways. Nationally consistent data are needed to (1) characterize the regional occurrence and concentrations of SVOCs and VOCs in highway runoff, (2) determine which are the most important factors affecting runoff quality, (3) estimate contaminant loads and concentrations on regional and national scales, and (4) identify water resources that potentially are affected.

A strategy is needed so that the distribution of information adequately represents factors affecting highway runoff in the United States. This strategy should define regions that have different values of factors that are expected to significantly correlate with water and sediment quality. For example, streams in drainage basins with residential and commercial land use are being monitored in regions with significantly different climate (Lopes and Price, 1997) because urban stormwater quality is significantly correlated with mean annual precipitation (Driver and Tasker, 1990). Other factors, such as highway-surface type, drainage, and traffic load, could be incorporated into this plan to develop a similar strategy for highways.

Information that is needed includes chemical data on SVOCs and VOCs in runoff, precipitation, and sediment to characterize their occurrence and ranges in concentrations. PAHs, oil and grease, and petroleum hydrocarbons are the primary classes of SVOCs associated with highway runoff. However, phenolic compounds and VOCs are in vehicle exhaust and could also be in highway runoff, precipitation, and sediment along highways. Parameters that could be related to chemical concentration, such as pH, dissolved oxygen, and total organic carbon, should also be measured. These data should be collected using appropriate procedures and materials and documented in a QA/QC plan.

Factors that are significantly related to water quality need to be characterized to estimate contaminant loads and concentrations from unmonitored sites and to identify potentially affected water resources. Factors that clearly affect concentrations and loads of SVOCs in highway runoff include suspended solids and organic carbon concentrations, total rainfall, rainfall intensity, traffic loads, and how runoff is drained. It is unclear if the type of surface has a significant effect, how much temperature affects concentrations and loads of SVOCs, and if surrounding land use has an effect. These and other factors may affect VOCs in highway runoff and precipitation. Relations between water quality and significant factors can be characterized by statistical analysis of ancillary data associated with monitoring sites and storms. From these relations, techniques similar to those of Driver and Tasker (1990) can be developed to estimate constituent loads and concentrations in highway runoff throughout the United States.

Geographic information on factors included in the estimation techniques can be used to obtain a national distribution of estimated contaminant loads and concentrations. These estimates and geographic information on water resources, including ground water, could then be used to determine which water resources could be adversely affected by highways. Ground water that is shallow and is used or has the potential of being used for drinking water could be affected by water-soluble compounds like MTBE.

Deterministic studies and modeling are also needed to understand the physical and chemical processes controlling highway-runoff quality, contaminant transport and fate, and impacts on biological and drinking-water resources. For example, Hewitt and Rashed (1990) and Stotz (1987) found that 70 percent of PAHs from highways are dispersed and 30 percent are transported in runoff. The majority of PAHs could be transported through the atmosphere into water-supply reservoirs. Modeling could help determine the transport and fate of dispersed PAHs and potentially affected waters.

SUMMARY

This review evaluated the quality and geographic distribution of existing data on SVOCs and VOCs, summarized significant findings, compared concentrations in highway runoff and urban stormwater with current (1998) water-quality criteria, and identified areas where additional information is needed. A total of 44 articles and reports were reviewed. Only 17 studies were related to highways, and 5 of these are review papers. Most of the data were collected during the late 1970’s to mid-1980’s. SVOCs in urban stormwater and sediments was the subjects of most studies.

Only 10 percent of studies described where in the stream cross section water samples were collected. This was the largest deficiency in documenting the sampling protocol. About 80 percent of SVOCs in runoff are in the suspended solids. Because suspended solids can vary significantly in the stream cross section even in narrow channels, the representativeness of discrete point samples and interpretations based on those data, especially load estimates, are questionable without information regarding sample location, how samplers were used, or how well the streamflow was mixed.

Only 30 percent of studies documented the MRL or MDL of the analytical method and only 15 percent of studies used field quality-control samples. The lack of MRL and MDL documentation hinders the ability to compare stormwater quality from different parts of the country. Evaluating the quality of environmental data, especially low concentrations, is difficult because few studies collected QC data and documented that samplers were cleaned.

PAHs, petroleum hydrocarbons, and oil and grease are the major SVOCs in urban stormwater and highway runoff. Suspended solids concentrations is the most significant factor affecting SVOCs in water. In sediment, the most significant factors affecting SVOC concentrations are organic carbon content and distance from sources, such as highways and power plants. Rainfall intensity, storm volume, and land use also are important factors affecting concentrations and loads of SVOCs. The highest SVOC concentrations in runoff, snow, and bottom sediment were measured from highways and industrial areas. Crankcase oil and vehicle emissions are the primary sources of SVOCs. The few loading factors and regression equations that were developed in the 1970's and 1980's are inadequate to estimate current (1998) loads of SVOCs because they use inconsistent units, some are independent of rainfall and have limited application, and they are based on few data. Also, more cars have catalytic converters and fuels are cleaner than when loading factors and regression equations were developed. PAHs, phenolic compounds, and phthalates in runoff exceeded drinking-water and aquatic-life standards. PAHs exceeded upper threshold concentrations in sediments near highways, indicating adverse effects on receiving streams.

VOCs were detected in precipitation adjacent to a highway in England, and chloromethane, toluene, xylenes, 1,2,4-trimethylbenzene, and 1,2,3-trichloropropane were detected in runoff from a highway in Texas. VOCs were detected in as many as 23 percent of the urban stormwater samples; gasoline-related compounds were the most frequently detected VOCs. Land use could be the most significant factor affecting the occurrence of VOCs. The highest concentrations of VOCs were found in industrial areas, suggesting urban land surfaces are the primary nonpoint source of most VOCs. Temperature is another important factor affecting the occurrence of VOCs. MTBE, benzene, xylenes, and 1,2,4-trimethylbenzene were detected more frequently during winter than summer. The seasonal detection could be due to the increased partitioning of VOCs in air into water at cold temperatures, suggesting that the atmosphere could be a nonpoint source of some VOCs. Tetrachloroethene, dichloromethane, and benzene were the only VOCs in stormwater that exceeded drinking-water standards.

Information deficiencies identified during the review included a need to determine if highways are a source of phenolic compounds and VOCs and if the occurrence and concentrations of SVOCs and VOCs vary regionally. A better understanding of the factors that affect SVOCs and VOCs is needed to estimate contaminant loads and concentrations at unmonitored sites and to identify potentially affected water resources. Deterministic studies and modeling also are needed to understand the physical and chemical processes controlling highway-runoff quality and contaminant transport and fate.

REFERENCES CITED

Adachi, Atsuko, and Kobayashi, Tadashi, 1994, Volatile chlorinated organic compound levels in rain water from Kobe City in Japan: Bulletin of Environmental Contaminants and Toxicology, v. 52, p. 9–12.

Baldys, Stanley, III, Raines, T.H., Mansfield, B.L., and Sandlin, J.T., 1997, Hydrologic data for urban stormwater studies in the Dallas-Fort Worth Area, Texas, 1992–94: U.S. Geological Survey Open-File Report 96-482, 256 p.

Baldys, Stanley, III, Raines, T.H., Mansfield, B.L., and Sandlin, J.T., 1998, Urban stormwater quality, event-mean concentrations, and estimates of stormwater pollutant loads, Dallas-Fort Worth area, Texas, 1992–93: U.S. Geological Survey Water-Resources Investigation Report 98-4158, 51.

Barrett, M.E., Zuber, R.D., Collins, E.R., III, Malina, J.F., Charbeneau, R.J., and Ward, G.H., 1993, A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction: Austin, Tex., Center for Research in Water Resources Technical Report CRWR 239.

Barrick, R.S., and others, 1988, Sediment quality values refinement—1988 update and evaluation of Puget Sound, AET, v. 1: Prepared for the Puget Sound Estuary Program, Office of Puget Sound.

Bjorseth, Alf, and Ramdahl, Thomas, 1985, Sources and emissions of polycyclic aromatic hydrocarbons, *in* Bjorseth, A., and Ramdahl, T., eds., Handbook of polycyclic aromatic hydrocarbons, v. 2: New York, Marcel Dekker Inc., p. 1–20.

Bomboi, M.T., and Hernandez, A., 1991, Hydrocarbons in urban runoff—Their contribution to the wastewater: Water Research, v. 25, no. 5, p. 557–565.

Bomboi, M.T., Hernandez, A., Marino, F., and Hontoria, E, 1990, Distribution of hydrocarbon concentrations from urban runoff: The Science of the Total Environment, v. 93, p. 465–480.

Boom, A., and Marsalek, J., 1988, Accumulation of polycyclic aromatic hydrocarbons (PAHs) in an urban snowpack: The Science of the Total Environment, v. 74, p. 133–148.

Brown, R.C., Pierce, R.H., and Rice, S.A., 1985, Hydrocarbon contamination in sediments from urban stormwater runoff: Marine Pollution Bulletin, v. 16, no. 6, p. 236–240.

Butler, J.D., Butterworth, Valerie, Kellow, S.O., and Robinson, H.G., 1984, Some observations on the polycyclic aromatic hydrocarbon (PAH) content of surface soils in urban areas: The Science of the Total Environment, v. 33, p. 75–85.

Canadian Council of Ministers of the Environment, 1995, Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life: Report CCME EPC-98E, March 1995.

Canadian Petroleum Products Institute, 1994, Composition of Canadian summer and winter gasolines–1993: Alberta, Canada, Canadian Petroleum Products Institute Report 94-5.

Colborn, Theo, vom Saal, F.S., and Soto, A.M., 1993, Developmental effects of endocrine-disrupting chemicals in wildlife and humans: Environmental Health Perspectives, v. 101, no. 5, p. 378–384.

Cole, R.H., Frederick, R.E., Healy, R.P., and Rolan, R.G., 1984, Preliminary findings of the priority pollutant monitoring project of the Nationwide Urban Runoff Program: Journal of the Water Pollution Control Federation, v. 56, no. 7, p. 898–908.

Connor, B.F., Rose, D.L., Noriega, M.C., Murtagh, L.K., and Abney, S.R., 1998, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of 86 volatile organic compounds in water gas chromatography/mass spectrometry, including detections less than reporting limits: U.S. Geological Survey Open-File Report 97-829, 78 p.

Delzer, G.C., Zogorski, J.S., Lopes, T.J., and Bosshart, R. L., 1996, Occurrence of the gasoline oxygenate MTBE and BTEX compounds in urban stormwater in the United States, 1991–95: U.S. Geological Survey Water-Resources Investigations Report 96-4145, 6 p.

Driver, N.E., and Tasker, G.D., 1990, Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2363, 44 p.

Edwards, N.T., 1983, Polycyclic aromatic hydrocarbons (PAH’s) in the terrestrial environment—A review: Journal of Environmental Quality, v. 12, no. 4, p. 427–441.

Edwards, T.K., and Glysson, G.D., 1986, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.

Eganhouse, R.P., and Kaplan, I.R., 1981a, Extractable organic matter in urban stormwater runoff, 1. Transport dynamics and mass emission rates: Environmental Science and Technology, v. 15, no. 3, p. 310–315.

Eganhouse, R.P., and Kaplan, I.R., 1981b, Extractable organic matter in urban stormwater runoff, 2. Molecular characterization: Environmental Science and Technology, v. 15, no. 3, p. 315–326.

Ellis, J.B., Revitt, D.M, and Angela Gavens, 1985, Polyaromatic hydrocarbon distributions in sediments of an urban catchment: International Journal of Environmental Analytical Chemistry, v. 21, no. 3, p. 161–170.

Evans, K.M, Gill, R.A., and Robotham, P.W.J., 1990, The source, composition and flux of polycyclic aromatic hydrocarbons in sediment of the River Derwent, Derbyshire, United Kingdom: Water, Air, and Soil Pollution, v. 51, p. 1–12.

Fam, Sami, Stenstrom, M.K., and Silverman, Gary, 1987, Hydrocarbons in urban runoff: Journal of Environmental Engineering, v. 113, no. 5, p. 1032–1046.

Fishman, M.J., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, p. 27–45.

Florida Department of Environmental Protection, 1994, Approach to the assessment of sediment quality in Florida coastal waters, Vol. 1. Development and evaluation of sediment quality assessment guidelines: Tallahassee, Fla., Prepared for Florida Department of Environmental Protection, Office of Water Policy, by MacDonald Environmental Sciences Ltd., Ladysmith, British Columbia.

Furlong, E.T., Vaught, D.G., Merten, L.M., Foreman, W.T., and Gates, P.M., 1996, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of semivolatile organic compounds in bottom sediment by solvent extraction, gel permeation chromatographic fractionation, and capillary-column gas chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 95-719, 67 p.

Gavens, A., Revitt, D.M., and Ellis, J.B., 1982, Hydrocarbon accumulation in freshwater sediments of an urban catchment: Microbiologia, v. 91, p. 285–292.

Gjessing, E., Lygren, E., Berglind, L, Gulbrandsen, T., and Skaane, R., 1984, Effects of highway runoff on lake water quality: The Science of the Total Environment, v. 33, p. 245–257.

Goodbred, S.L., Gilliom, R.J., Gross, T.S., Denslow, N.P., Bryant, W.L., and Schoeb, T.R., 1997, Reconnaissance of 17B-Estrodial, 11-ketotestosterone, vitellogenin, and gonad histopathology in common carp of the United States Streams—Potential for contaminants-induced endocrine disruption: U.S. Geological Survey Open-File Report 96-627, 47 p.

Gupta, M.K., 1981, Constituents of highway runoff, vol. VI, Executive Summary: Washington, D.C., Federal Highway Administration Report FHWA/RD-81/047, Offices of Research and Development, Environment Division, 10 p.

Harrison, R.M., and Johnston, W.R., 1985, Deposition fluxes of lead, cadmium, copper and polynuclear aromatic hydrocarbons (PAH) on the verges of a major highway: The Science of the Total Environment, v. 46, p. 121–135.

Herrmann, Reimer, 1981, Transport of polycyclic aromatic hydrocarbons through a partly urbanized river basin: Water, Air, and Soil Pollution, v. 16, p. 445–467.

Hewitt, C.H., and Rashed, M.B., 1990, An integrated budget for selected pollutants for major rural highway: The Science of the Total Environment, v. 93, p. 375–384.

Hoffman, E.J., Latimer, J.S., Hunt, C.D., Mills, G.L., and Quinn, J.G., 1985, Stormwater runoff from highways: Water, Air, and Soil Pollution, v. 25, no. 4, p. 349–364.

Hoffman, E.J., Mills, G.L., Latimer, J.S., and Quinn, J.G., 1983, Annual input of petroleum hydrocarbons to the coastal environment via urban runoff: Canadian Journal of Fisheries and Aquatic Sciences, v. 40, supplement no. 2, p. 41–53.

Hoffman, E.J., Mills, G.L., Latimer, J.S., and Quinn, J.G.,1984, Urban runoff as a source of polycyclic aromatic hydrocarbons to coastal waters: Environmental Science and Technology, v. 18, no. 8, p. 580–587.

Hoffman, E.J., and Quinn, J.G., 1987, Chronic hydrocarbon discharges into aquatic environments—II-Urban runoff and combined sewer overflows, *in* Vandermeulen, J.H, and Hrudey, S.E, eds., Oil in freshwater—Chemistry, biology, countermeasure technology: Pergamon Press, New York, Proceedings of the Symposium of Oil Pollution in Freshwater, Edmonton, Alberta, Canada, p. 114–137.

Horowitz, A. J., and Elrick, K.A., 1987, The relation of stream sediment surface area, grain size and composition to trace element chemistry: Applied Geochemistry, v. 2, p. 437–451.

Horowitz, A.J., Rinella, F.A., Lamothe, Paul, Miller, T.L., Edwards, T.K., Roche, R.L, and Rickert, D.A., 1989, Cross-sectional variability in suspended sediment and associated trace element concentrations in selected rivers in the U.S.: Wallingford, Oxfordshire, United Kingdom, IAHS Press, Sediment and the Environment (Proceedings of the Baltimore Symposium, May 1989), IAHS Publication no. 181, p. 57–65.

Hunter, V., Sabatino, R., Gomperts, R., and MacKenzie, M.J., 1979, Contribution of urban runoff to hydrocarbon pollution: Journal of Water Pollution Control Federation, v. 51, no. 8, p. 2129–2138.

Johnston, W.R., and Harrison, R.M., 1984, Deposition of metallic and organic pollutants alongside the M6 motorway: The Science of the Total Environment, v. 33, p. 119–127.

Karickhoff, S.W., Brown, D.S., and Scott, T.A., 1979, Sorption of hydrophobic pollutants on natural sediments: Water Research, v. 13, p. 241–248.

Kawamura, Kimitaka, and Kaplan, I.R., 1983, Organic compounds in rainwater of Los Angeles: Environmental Science and Technology, v. 17, p. 497–501.

Latimer, J.S., Hoffman, E.J., Hoffman, Gerald, Fasching, J.L, and Quinn, J.G., 1990, Sources of petroleum hydrocarbons in urban runoff: Water, Air, and Pollution, v. 52, p. 1–21.

Ligocki, M.P., Leuenberger, C., and Pankow, J.F., 1985, Trace organic compounds in rain, II. Gas scavenging of neutral organic compounds: Atmospheric Environment, v. 19, p. 1609–1617.

Line, D.E., Wu, J., Arnold, J.A., Jennings, G.D., and Rubin, A.R., 1997, Water quality of first flush runoff from 20 industrial sites: Water Environment Research, v. 69, no. 3, p. 305–310.

Long, E.R., and Morgan, L.G., 1991, The potential for biological effects for sediment-sorbed contaminants tested in the National Status and Trends Program: Seattle, NOAA Technical Memorandum NOS OMA 52.

Long, E.R., and others, 1995, Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments: Environmental Management, v. 19, no. 1, p. 81–97.

Lopes, T.J., and Bender, D.A., 1998, Nonpoint sources of volatile organic compounds in urban areas—relative importance of land surface and air: Environmental Pollution (in press).

Lopes, T.J., Fossum, K.D., Phillips, J.V., and Monical, J.E., 1995, Statistical summary of selected physical, chemical, and microbial characteristics, and estimates of constituent loads in urban stormwater, Maricopa County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 94-4240, 62 p.

Lopes, T.J., and Price, C.V., 1997, Study plan for urban stream indicator sites of the National Water Quality Assessment Program: U.S. Geological Survey Open-File Report 97-25, 15 p.

Lucius, J.E., Olhoeft, G.R., Hill, P.L., and Duke, S.K., 1989, Properties and hazards of 108 selected substances: U.S. Geological Survey Open-File Report 89-491, 538 p.

Makepeace, D.K, Smith, D.W., and Stanley, S.J., 1995, Urban stormwater quality—Summary of contaminant data: Critical Reviews in Environmental Science and Technology, v. 25, no. 2, p. 93–139.

Marsalek, Jiri, and Schroeter, Harold, 1988, Annual loadings of toxic contaminants in urban runoff from the Canadian Great Lakes Basin: Water Pollution Research Journal of Canada, v. 23, no. 3, p. 360–378.

Mueller, D.K., Martin, J.D., and Lopes, T.J., 1997, Quality-control design for surface-water sampling in the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 97-223, 17 p.

Novotny, Vladimir, ed., 1995, Nonpoint Pollution and Urban Stormwater Management: Lancaster, Pa., TECHNOMIC Publishing, 434 p.

Pankow, J.F., and Cherry, J.A., 1996, Dense chlorinated solvents and other DNAPLS in groundwater: Portland, Oreg., Waterloo Press, 522 p.

Pankow, J.F., Isabelle, L.M., and Asher, W.E., 1984, Trace organic compounds in rain, 1. Sampler Design and Analysis by Adsorption/Thermal Desorption (ATD): Environmental Science and Technology, v. 18, p. 310–318.

Pankow, J.F., Thomson, N.R., Johnson, R.L., Baehr, A.L., and Zogorski, J.S., 1997, The urban atmosphere as a non-point source for the transport of MTBE and other volatile organic compounds (VOCs) to shallow groundwater: Environmental Science and Technology, v. 31, no. 10, p. 2821–2828.

Prahl, F.G., Cvexellus, E., and Carpenter, R., 1984, Polycyclic aromatic hydrocarbons in Washington coastal sediments—An evaluation of atmospheric and riverine routes of introduction: Environmental Science and Technology, v. 18, no. 9, p. 687–693.

Pritt, Robert, Clark, S., Parmer, K., and Field, R., 1996, Groundwater contamination from stormwater infiltration: Chelsea, Mich., Ann Arbor Press, 219 p.

Rathbun, R.E., 1998, Transport, behavior, and fate of volatile organic compounds in streams: U.S. Geological Survey Professional Paper 1589, 151 p.

Rogge, W.F., Hildemann, L.M., Mazurek, M.A., Cass, G.R., and Simoneit, B.R.T., 1993, Sources of fine organic aerosol. 2. Noncatalyst and catalyst-equipped automobiles and heavy-duty diesel trucks: Environmental Science and Technology, v. 27, no. 4, p. 636–651.

Rowe, B.L., Landrigan, S.J., and Lopes, T.J., 1997, Summary of published aquatic toxicity information and water-quality criteria for selected volatile organic compounds: U.S. Geological Survey Open-File Report 97-563, 60 p.

Schondorf, Thomas, and Herrmann, Reimer, 1987, Transport and chemodynamics of organic micropollutants and ions during snowmelt: Nordic Hydrology, v. 18, p. 259–278.

Shelton, L.R., 1997, Field guide for collecting samples for analysis of volatile organic compounds in stream water for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 97-401, 14 p.

Smith, J.A., Witkowski, P.J., and Fusillo, T.V., 1988, Manmade organic compounds in the surface waters of the United States—A review of current understanding: U.S. Geological Survey Circular 1007, 92 p.

Squillace, P.J., Pankow, J.F., Korte, N.E., and Zogorski, J.S., 1997, Review of the environmental behavior and fate of Methyl *tert*-Butyl Ether: Environmental Toxicology and Chemistry, v. 16, no. 9, p. 1836–1844.

Squillace, P.J., Zogorski, J.S., Wilber, W.G., and Price, C.V., 1996, Preliminary assessment of the occurrence and possible sources of MTBE in groundwater in the United States, 1993-94: Environmental Science and Technology v. 30, no. 5, p. 1721–1730.

Stenstrom, M.K., Silverman, G.S., and Bursztynsky, T.A., 1984, Oil and grease in urban stormwater: Journal of Environmental Engineering, v. 110, no. 1, p. 58–72.

Stotz, G., 1987, Investigations of the properties of the surface water run-off form federal highways in the FGR: The Science of the Total Environment, v. 59, p. 329–337.

U.S. Environmental Protection Agency, 1996a, National air pollutant emission trends, 1990–1995: Office of Air Quality Planning and Standards, Research Triangle Park, N.C., EPA-454/R-96-007.

U.S. Environmental Protection Agency, 1996b, The National Sediment Quality Survey—A report to Congress on the extent and severity of sediment contamination in surface waters of the United States: Office of Science and Technology, U.S. Environmental Protection Agency, EPA-823-D-96-002.

U.S. Environmental Protection Agency, 1996c, Drinking water regulations and health advisories: Washington, D.C., Office of Water, EPA 822-B-96-002, October 1996.

U.S. Environmental Protection Agency, 1998, Contaminated sediment news: Office of Water, EPA 823-N-97-007, no. 20, 11 p.

von Guerard, Paul, and Weiss, W.B., 1995, Water quality of storm runoff and comparison of procedures for estimating storm-runoff loads, volume, event-mean concentrations, and the mean load for a storm for selected properties and constituents for Colorado Springs, southeastern Colorado, 1992: U.S. Geological Survey Water-Resources Investigations Report 94-4194, 68 p.

Wakeham, S.G, Schaffner, Christian, and Giger, Walter, 1980, Polycyclic aromatic hydrocarbons in recent lake sediments, I. Compounds having anthropogenic origins: Geochemica et Cosmochemica Acta, v. 44, p. 403–413.

Wells, F. C., Gibbons, W.J., and Dorsey, M.E., 1990, Guidelines for collection and field analysis of water-quality samples from streams in Texas: U.S. Geological Survey Open-File Report 90-127, 79 p.

Westerhold, R.N., Alsberg, T.E., Frommelin, A.B., and Strandell, M.E., 1988, Effect of fuel polycyclic aromatic hydrocarbon content on the emissions of polycyclic aromatic hydrocarbons and other mutagenic substances from a gasoline-fueled automobile: Environmental Science and Technology, v. 22, no. 8, p. 925–930.

Wiland, Bruce, and Malina, J.F., 1976, Oil, grease, and other pollutants in highway runoff: Texas Department of Transportation Final Report FHWA-TX-77-16-1F, 76 p.

Witkowski, P.J., Smith, J.A., Fusillo, T.V, and Chiou, C.T., 1987, A review of surface-water sediment fractions and their interactions with persistent manmade organic compounds: U.S. Geological Survey Circular 993, 39 p.

Yamane, A., Nagashima, I., Okubo, T., Okada, M., and Murakami, A., 1990, Stormwater runoff of hydrocarbons in the Tama River Basin in Tokyo (Japan) and their fate in the river: Water Science Technology, v. 22, no. 10/11, p. 119–126.

Zawlocki, K.R., Ferguson, J.F., and Mar, B.W., 1980, A survey of trace organics in highway runoff in Seattle, Washington: Washington State Department of Transportation Report WA-RD-39.9, 43 p.

TABLES 1–7

Table 1. Documented quality criteria of data on semivolatile and volatile organic compounds in urban stormwater and highway runoff

[°C, degrees Celsius; cm, centimeters; m, meters; µg/L, micrograms per liter; mg/L, milligrams per liter; ng/L, nanograms per liter; ng/g, nanograms per gram; ppb, parts per billion; NA, not applicable; ND, not described; SS, stainless steel; O+G, oil and grease; GC/FID, gas chromatography/flame-ionization detector; GC-MS, gas chromatography-mass spectrometry; HCl, hydrochloric acid; HPLC, high performance liquid chromatography; IR, infrared spectrometry; EWI, equal-width increment; MRL, minimum reporting limit; NaCl, sodium chloride; NPDES, National Pollutant Discharge Elimination System; NURP, Nationwide Urban Runoff Program; %, percent; ~, approximate; ---, no comment]

Reference	Where	Years data were collected	Water sampling protocol					Sediment and soil sampling protocol				Comment
			Sampler type	Material	Manual or automatic	Discrete or composite	Where in stream	Sampler type	Material	Discrete or composite	Depth (cm)	
Baldys and others, 1997	Dallas–Ft. Worth, Texas	1992–94	auto-sampler + bottles	Teflon, steel, glass	both	both	ND	NA	NA	NA	NA	Flow-weighted composites; not known if splitter used. Sampled where storm drain well mixed.
Baldys and others, 1998	Dallas–Ft. Worth, Texas	1992–93	auto-sampler + bottles	Teflon, steel, glass	both	both	ND	NA	NA	NA	NA	Flow-weighted composites; not known if splitter used. Sampled where storm drain well mixed.
Barrett and others, 1993	Review paper	1976–92	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bjorseth and Ramdahl, 1985	Review paper	1775–84	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bomboi and others, 1990	Madrid, Spain	1985–86	tray	metal	manual	discrete	assume all flow	NA	NA	NA	NA	Simulated rain for runoff samples; extracted water, solids separately.
Bomboi and Hernandez, 1991	Madrid, Spain	ND	tray	metal	manual	discrete	assume all flow	NA	NA	NA	NA	Same data as Bomboi and others, 1990.
Boom and Marsalek, 1988	Ontario, Canada	1986–87	corer for snow	SS	manual	discrete	NA	NA	NA	NA	NA	NA
Brown and others, 1985	Tampa	1982–83	ND	ND	ND	both	ND	ponar	ND	composite	0–5	Discrete samples of first flush, composite-type unknown; whole water and suspended solids analyzed.
Butler and others, 1984	England	ND	NA	NA	NA	NA	NA	ND	ND	discrete	0–4, 4–8	Samples sieved to 18 mesh.
Cole and others, 1984	15 NURP cities	1979–82	ND	ND	ND	both	ND	NA	NA	NA	NA	Compilation of coordinated studies; low-weighted composites.
Delzer and others, 1996	16 NPDES cities	1991–95	vials	glass	manual	discrete	ND	NA	NA	NA	NA	Compilation of independent studies; sampling procedures varied.
Edwards, 1983	Review paper	1956–82	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Eganhouse and Kaplan, 1981a	Los Angeles, California	1978	ND	steel	manual	discrete	center, below surface	NA	NA	NA	NA	Whole and filtered water analyzed.
Eganhouse and Kaplan, 1981b	Los Angeles, California	1978	ND	steel	manual	discrete	center, below surface	NA	NA	NA	NA	Same data as Eganhouse and Kaplan, 1981a.
Ellis and others, 1985	London, England	ND	NA	NA	NA	NA	NA	grab sampler	SS	composite	surface	NA

Table 1. Documented quality criteria of data on semivolatile and volatile organic compounds in urban stormwater and highway runoff—*Continued*

Reference	Where	Years data were collected	Water sampling protocol					Sediment and soil sampling protocol				Comment
			Sampler type	Material	Manual or automatic	Discrete or composite	Where in stream	Sampler type	Material	Discrete or composite	Depth (cm)	
Evans and others, 1990	United Kingdom	1987–88	NA	NA	NA	NA	NA	jars	glass	discrete	0–10	Collected bottom sediment monthly for 1 year.
Fam and others, 1987	San Francisco, California	ND	bottles + buckets	glass + metal	manual	discrete	ND	NA	NA	NA	NA	Particulates and filtrate analyzed.
Gavens and others, 1982	London, England	ND	ND	ND	ND	ND	ND	corer	SS	discrete	0–10, 290–300	Whole water analyzed; sediment samples sieved into several fractions.
Gjessing and others, 1984	Norway	1981–82	cans	aluminum	manual	discrete	ND	gravity corer	acrylic	discrete	0–2	NA
Gupta, 1981	Milwaukee, Harrisburg, Nashville, Denver	1975–78	ISCO	ND	both	both	ND	NA	NA	NA	NA	Oil and grease sampled manually; whole water analyzed. Flow-weighted composites.
Harrison and Johnston, 1985	England	1981–83	funnel	plastic, glass	passive auto-sampler	composite	NA	NA	NA	NA	NA	Includes data from Johnston and Harrison, 1984.
Herrmann, 1981	Germany	1979	auto-sampler	ND	auto	discrete	ND	pan	ND	NA	surface	Sampled stream, snow, street dust, bed load, rain. Mostly whole water analyzed.
Hewitt and Rashed, 1990	England	ND	funnel, auto-samplers	ND	passive auto-sampler	discrete	NA	trowel	ND	discrete	0–10, 10–20, 20–30	Bulk deposition sampled; autosampler for SWRO.
Hoffman and others, 1983	Narraganset Bay	1979–81	bucket	metal	manual	discrete	ND	NA	NA	NA	NA	Samples collected at about 30-minute intervals; suspended solids and filtrate analyzed.
Hoffman and others, 1984	Narraganset Bay	1979–81	bucket	metal	manual	discrete	ND	NA	NA	NA	NA	Same data as Hoffman and others, 1983.
Hoffman and others, 1985	Rhode Island	1979–81	bucket	metal	manual	discrete	ND	NA	NA	NA	NA	Samples collected at about 30-minute intervals; suspended solids and filtrate analyzed.
Hoffman and Quinn, 1987	Review paper	1969–87	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hunter and others, 1979	Philadelphia, Pennsylvania	1974	ND	ND	manual	both	ND	NA	NA	NA	NA	Flow-weighed composites; centrifuged water and particulates analyzed separately.
Johnston and Harrison, 1984	England	1982–83	funnel	plastic	passive auto-sampler	composite	NA	NA	NA	NA		Bulk deposition sampled biweekly.
Latimer and others, 1990	Warwick, Rhode Island	1979–81	bucket	metal	manual	discrete	ND	trowel	SS	discrete	ND	Suspended solids and filtrate analyzed. Soil, vegetation, street dust sampled.
Line and others, 1997	North Carolina	1993–94	auto-sampler	ND	auto-sampler	discrete	ND	NA	NA	NA	NA	Only first-flush samples. Samples iced after collection and preserved at lab.

Table 1. Documented quality criteria of data on semivolatile and volatile organic compounds in urban stormwater and highway runoff—*Continued*

Reference	Where	Years data were collected	Water sampling protocol					Sediment and soil sampling protocol				Comment
			Sampler type	Material	Manual or automatic	Discrete or composite	Where in stream	Sampler type	Material	Discrete or composite	Depth (cm)	
Lopes and Bender, 1998	16 NPDES cities	1991–95	vials	glass	manual	discrete	ND	NA	NA	NA	NA	Includes data from Delzer and others, 1996.
Lopes and others, 1995	Phoenix, Arizona	1991–93	auto-samplers	Teflon, steel, glass	both	both	ND, EWI for stream	NA	NA	NA	NA	Discrete manual samples for VOCs, phenols, O+G. Flow-weighted composites from churn splitter.
Makepeace and others, 1995	Review paper	1970–94	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Marsalek and Schroeter, 1988	Canada, Great Lakes region	1979–83	auto-samplers	metal, glass	pumping and passive auto-samplers	flow-weight composite	bank, ND	filtered water	ND	ND	ND	Filtered at 5 micron due to high solids. Also collected street sediments.
Prahl and others, 1984	Seattle, Washington and Columbia River	1979–80	pump	glass	manual	discrete	middle, 1–2 m deep	filtered water	NA	NA	NA	Only analyzed suspended sediment filtered from water using nitrogen. Also sampled air.
Schondorm and Herrmann, 1987	Germany	1986	snow lysimeter	Aluminum foil covered plywood	manual	discrete	NA	NA	NA	NA	NA	NA
Stenstrom and others, 1984	Richmond, California	1980–81	bottles	glass	manual	discrete	ND	NA	NA	NA	NA	Sampled at turbulent locations for uniform sample.
Stotz, 1987	Germany	1978–81	ND	ND	ND	composite	ND	NA	NA	NA	NA	Whole water and centrifuged samples analyzed; unknown composite type.
von Guerard and Weiss, 1995	Colorado Springs, Colorado	1992	auto-samplers	Teflon, glass	both	depth integrated manual	ND, flow turbulent, mixed	NA	NA	NA	NA	Discrete manual samples for VOCs, phenols, O+G. Flow-weighted composites from churn and cone splitter.
Wakeham and others, 1980	Switzerland, Seattle, Washington	1976–77	NA	NA	NA	NA	NA	gravity, piston corers	ND	NA	max 6.4 m	Gravity cores for shallow (<1 m) cores, piston for deep cores.
Wiland and Malina, 1976	Austin, Texas	1976	bottle	glass	manual	discrete	ND	NA	NA	NA	NA	Simulated rainfall for runoff
Yamane and others, 1990	Tokyo, Japan	ND	bottle	glass	manual	discrete	ND	ND	ND	ND	ND	Whole water analyzed; sediment, street dust and highway dust analyzed.
Zawlocki and others, 1980	Seattle, Washington	1979–80	tank, drum	poly-ethylene	automatic	composite	used flow-splitter	NA	NA	NA	NA	Samples taken from well-mixed tank, drum. Flume, flow splitter made of fiberglass, contamination assumed negligible. Filtrate, particulates analyzed.

Table 1. Documented quality criteria of data on semivolatile and volatile organic compounds in stormwater and highway runoff—*Continued*

Reference	Laboratory methods			Quality assurance				Quality control		
	Instrument	MRL	Comment	Cleaned sampler?	Container	Preser-vation	Comment	Field QC	Lab QC	Comment
Baldys and others, 1997	ND	mostly 0.2–10 mg/L	USGS analytical methods	ND	ND	ND		equipment, trip blanks, matrix spikes, replicates	ND	QC data provided
Baldys and others, 1998	ND	mostly 0.2–10 µg/L	USGS analytical methods	ND	ND	ND	---	blanks, replicates, spikes	reference	No QC results discussed
Barrett and others, 1993	NA	NA	---	NA	NA	NA	---	NA	NA	---
Bjorseth and Ramdahl, 1985	NA	NA	---	NA	NA	NA	---	NA	NA	---
Bomboi and others, 1990	GC-FID, GC-MS	ND	---	ND	ND	ND	---	ND	ND	---
Bomboi and Hernandez, 1991	GC-FID, GC-MS	ND	---	ND	ND	ND	---	ND	ND	---
Boom and Marsalek, 1988	GC-FID	0.05 µg/L	---	ND	stainless steel	ND	Slowly melted snow	ND	ND	---
Brown and others, 1985	GC-FID	ND	1 µg/L	ND	glass	chilled 4°C	Teflon-lined lids	ND	all analyses duplicated, blanks, recovery samples	Teflon-lined lids
Butler and others, 1984	GC-fluorescence	ND	---	ND	ND	ND	---	ND	ND	---
Cole and others, 1984	ND	varied	Many labs used	ND	ND	ND	Guidelines for consistent sample collection, but details not given	blanks, replicates, spikes	performance evaluation samples, surrogates	Summarized QC evaluation
Delzer and others, 1996	GC-MS	0.2–1 µg/L	USGS analytical methods	ND	glass	ND	---	ND	ND	---
Edwards, 1983	NA	NA	---	NA	NA	NA	---	NA	NA	---
Eganhouse and Kaplan, 1981a	gravimetric	ND	---	ND	glass	ND	Samples shaken and split into 2 bottles	ND	ND	---
Eganhouse and Kaplan, 1981b	gravimetric	ND	---	ND	glass	ND	Samples shaken and split into 2 bottles	ND	ND	---
Ellis and others, 1985	GC-FID, GC-MS	ND	---	yes	ND	ND	---	ND	ND	---
Evans and others, 1990	HPLC, GS-MS	ND	Recovery 83–131%	yes	glass	chilled	Covered w/ foil, capped w/metal lid	ND	blanks, recovery samples	Blank, recovery corrections made
Fam and others, 1987	GC-FID	ND	Standard methods	ND	glass	acidify, chill	---	ND	ND	---

Table 1. Documented quality criteria of data on semivolatile and volatile organic compounds in stormwater and highway runoff—*Continued*

Reference	Laboratory methods			Quality assurance				Quality control		
	Instrument	MRL	Comment	Cleaned sampler?	Container	Preservation	Comment	Field QC	Lab QC	Comment
Gavens and others, 1982	GC-FID, GC-MS	ND	---	yes	ND	sediment frozen; water ND	---	ND	ND	Suggest naphthalene lost during workup
Gjessing and others, 1984	GC-ND, reference	ND	---	ND	ND	ND	---	ND	ND	---
Gupta, 1981	Standard methods	ND	---	ND	ND	chilled	Overnight shipping	ND	ND	---
Harrison and Johnston, 1985	HPLC, GC-MS	ND	---	yes	glass	ND	Plastic samplers, 2 weeks w/o chilling	ND	blanks	Blank corrections made
Herrmann, 1981	HPLC, fluorescence	ND	ND	ND	ND	ND	Snow, street dust frozen in polyethylene bags	ND	ND	---
Hewitt and Rashed, 1990	HPLC	ND	---	ND	ND	ND	---	ND	ND	---
Hoffman and others, 1983	GC-FID, GC-MS	ND	Precision ~15%	ND	glass	ND	Teflon-lined lids	ND	blanks	No blank corrections needed
Hoffman and others, 1984	GC-FID, GC-MS	ND	Precision mostly 11–25%	ND	glass	ND	Teflon-lined lids	ND	blanks	---
Hoffman and others, 1985	GC-FID, GC-MS	ND	Precision mostly 11–25%	ND	glass	ND	Teflon-lined lids	ND	blanks	---
Hoffman and Quinn, 1987	NA	NA	---	NA	NA	NA	---	NA	NA	---
Hunter and others, 1979	GC-FID	ND	85–95% recovery	ND	glass	ND	---	ND	ND	---
Johnston and Harrison, 1984	HPLC	ND		yes	glass	ND	Plastic samplers, 2 weeks w/o chilling	ND	ND	43–87% recovery, corrections made
Latimer and others, 1990	GC-FID	ND	Relative deviation <20%	yes	glass	none	---	ND	blanks	Blank data given
Line and others, 1997	Standard methods	5 to 100 µg/L	---	yes	ND	chilled	Sometimes hours before samples were retrieved, chilled; autosampler for VOCs	Automatic sampler blanks	lab-split duplicates, spikes for about 10% of samples	---

Table 1. Documented quality criteria of data on semivolatile and volatile organic compounds in stormwater and highway runoff—*Continued*

Reference	Laboratory methods			Quality assurance				Quality control		
	Instrument	MRL	Comment	Cleaned sampler?	Container	Preservation	Comment	Field QC	Lab QC	Comment
Lopes and Bender, 1998	GC-MS	0.2–1 µg/L	USGS analytical methods	ND	glass	ND	---	ND	ND	---
Lopes and others, 1995	ND	mostly 0.2–10 µg/L	USGS analytical methods	yes	ND	chilled	Autosampler checked with concurrent manual samples	Automatic sampler and trip blanks, matrix spikes, replicates	ND	Some compounds may degrade; blanks clean
Makepeace and others, 1995	NA	NA	---	NA	NA	NA	---	NA	NA	---
Marsalek and Schroeter, 1988	GC/FID, ECD	water MDL 0.001–0.05 ppb. sediment 5–50 ppb	Recovery 60–110%, precision 12–83%	ND	reference	reference	---	ND	ND, but done	---
Prahl and others, 1984	GC-FID air samples, HPLC sediment samples	ND	---	yes	glass	air samples refrigerated, sediment frozen	Nitrogen used for filtering	ND	ND	GC, HPLC ± 15%
Schondorm and Herrmann, 1987	HPLC, fluorescense	MDL 0.03–0.15ng/L	85-90% recovery	ND	ND	ND	---	ND	ND	---
Stenstrom and others, 1984	IR, GC-FID	ND	---	yes	glass	ND	Sampled turbulent area for well mixed sample	ND	ND	---
Stotz, 1987	reference	ND	---	ND	ND	ND	---	ND	ND	---
von Guerard and Weiss, 1995	ND	mostly 0.2–10 µg/L	USGS analytical methods	yes	ND	chilled	Manual samples from turbulent, well-mixed flow	blanks, spikes	ND	Low spike recovery, blanks clean
Wakeham and others, 1980	GC-FID	1-2 ng/g	Reproducibility ± 25%	ND	ND	frozen or chilled at 4˚C	Preservation for samples from 2 lakes not described	ND	blanks	Data blank and recovery corrected
Wiland and Malina, 1976	IR	ND	---	ND	glass	chilled at 4˚C	Plastic sheet under truck used for simulated rain	ND	ND	---
Yamane and others, 1990	GC-FID, HPLC	ND	---	ND	glass	NaCl, HCl pH<2.0	Preserved on site	ND	ND	---
Zawlocki and others, 1980	GC/MS, Standard Methods	100 µg/L for trace organics	Trace organics precision ± 50%, results summed into compound class	ND	glass	chilled	Samples well mixed, but don't know if they are of entire storm	ND	lab-split replicates, system blanks, recoveries	Particulate replicates ± 5%, total organic extracts within 20%

Table 2. Semivolatile and volatile organic compounds not detected in stormwater

[IUPAC, International Union of Pure and Applied Chemistry; NURP, Nationwide Urban Runoff Program; NR, not reported]

IUPAC compound name (common name)	Minimum reporting limit (range), in micrograms per liter	Location	Reference
Semivolatile organic compounds			
Benzidine	40	Maricopa County, AZ	Lopes and others, 1995
	40	Colorado Springs, CO	von Guerard and Weiss, 1995
	40	Dallas/Fort Worth, TX	Baldys and others, 1998
4-Bromophenyl phenyl ether	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
0-Chlorobenzene	5	Colorado Springs, CO	von Guerard and Weiss, 1995
4-Chloro-3-methylphenol	30	Dallas/Fort Worth, TX	Baldys and others, 1998
bis(2-Chloroethoxy)methane	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
bis(2-Chloroethyl)ether	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
bis(2-Chloroisopropyl)ether	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
4-Chlorophenyl phenyl ether	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
1,2,5,6-Dibenzanthracene	10	Colorado Springs, CO	von Guerard and Weiss, 1995
3, 3'-Dichlorobenzidine	20	Maricopa County, AZ	Lopes and others, 1995
	20	Colorado Springs, CO	von Guerard and Weiss, 1995
	20	Dallas/Fort Worth, TX	Baldys and others, 1998
2,4-Dichlorophenol	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
Dimethylphthalate	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
4,6-Dinitro-2-methylphenol	30	Dallas/Fort Worth, TX	Baldys and others, 1998
4,6-Dinitro-ortho-cresol	30	Colorado Springs, CO	von Guerard and Weiss, 1995
	NR	Summary–NURP	Cole and others, 1984
2,4-Dinitrophenol	20	Maricopa County, AZ	Lopes and others, 1995
	20	Colorado Springs, CO	von Guerard and Weiss, 1995
	20	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
2,4-Dinitrotoluene	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
2,6-Dinitrotoluene	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
1,2-Diphenyl hydrazine	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998

Table 2. Semivolatile and volatile organic compounds not detected in stormwater—*Continued*

IUPAC compound name (common name)	Minimum reporting limit (range), in micrograms per liter	Location	Reference
Semivolatile organic compounds—*Continued*			
Hexachlorobutadiene	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2–10	Dallas/Fort Worth, TX	Baldys and others, 1998
Hexachlorocyclopentadiene	5	Maricopa County, AZ	Lopes and others, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
Hexachloroethane	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
Isophorone	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
Nitrobenzene	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
2-Nitrophenol	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
n-nitrosodi-n-propylamine	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
n-nitrosodiphenylamine	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
n-nitrosodimethylamine	5	Maricopa County, AZ	Lopes and others, 1995
	5	Colorado Springs, CO	von Guerard and Weiss, 1995
	5	Dallas/Fort Worth, TX	Baldys and others, 1998
Parachlorometacresol	30	Colorado Springs, CO	von Guerard and Weiss, 1995
Phenol	3	Colorado Springs, CO	von Guerard and Weiss, 1995
	3	Dallas/Fort Worth, TX	Baldys and others, 1998
2,4,6-Trichlorophenol	20	Maricopa County, AZ	Lopes and others, 1995
	20	Colorado Springs, CO	von Guerard and Weiss, 1995
	20	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1984
Volatile organic compounds			
Bromobenzene	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
Bromochloromethane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
Bromomethane	0.2	Maricopa County, AZ	Lopes and others, 1995
(Methyl bromide)	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
Chloroethane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
2-Chloroethyl vinyl ether	1.0	Maricopa County, AZ	Lopes and others, 1995
	1.0	Colorado Springs, CO	von Guerard and Weiss, 1995
	1.0 - 50	Dallas/Fort Worth, TX	Baldys and others, 1998
Chloromethane	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
1-Chloro-2-Methylbenzene	0.2	Maricopa County, AZ	Lopes and others, 1995
(0-Chlorotoluene)	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995

Table 2. Semivolatile and volatile organic compounds not detected in stormwater—*Continued*

IUPAC compound name (common name)	Minimum reporting limit (range), in micrograms per liter	Location	Reference
	Volatile organic compounds—*Continued*		
1,2-Dibromo-3-chloropropane	1.0	Maricopa County, AZ	Lopes and others, 1995
(Dibromochloropropane)	1.0	Colorado Springs, CO	von Guerard and Weiss, 1995
	1.0 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
1,2-Dibromoethane	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
1,2-Dichlorobenzene	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
1,3-Dichlorobenzene	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
1,4-Dichlorobenzene	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
Dichlorodifluoromethane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
1,3-Dichloropropane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
2,2-Dichloropropane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
1,1-Dichloropropene	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
cis-1,3-Dichloropropene	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
trans-1,3-Dichloropropene	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
(1,1-Dimethylethyl)benzene	0.2	Maricopa County, AZ	Lopes and others, 1995
(tert-Butylbenzene)	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
1,1,2,3,4,4-Hexachloro-1,3-butadiene	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
(hexachlorobutadiene)	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
(1-Methylpropyl)benzene	0.2	Maricopa County, AZ	Lopes and others, 1995
(sec-Butylbenzene)	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
Parachlorotoluene	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
2-Propenal	20	Maricopa County, AZ	Lopes and others, 1995
(Acrolein)	20	Colorado Springs, CO	von Guerard and Weiss, 1995
	20 - 1000	Dallas/Fort Worth, TX	Baldys and others, 1998
2-Propenenitrile	20	Maricopa County, AZ	Lopes and others, 1995
(Acrylonitrile)	20	Colorado Springs, CO	von Guerard and Weiss, 1995
	20 - 1000	Dallas/Fort Worth, TX	Baldys and others, 1998
1,1,1,2-Tetrachloroethane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998

Table 2. Semivolatile and volatile organic compounds not detected in stormwater—*Continued*

IUPAC compound name (common name)	Minimum reporting limit (range), in micrograms per liter	Location	Reference
	Volatile organic compounds—*Continued*		
1,2,3-Trichlorobenzene	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
1,2,4-Trichlorobenzene	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998
	NR	Summary–NURP	Cole and others, 1995
1,2,3-Trichloropropane	0.2	Maricopa County, AZ	Lopes and others, 1995
	0.2	Colorado Springs, CO	von Guerard and Weiss, 1995
	0.2 - 10	Dallas/Fort Worth, TX	Baldys and others, 1998

Table 3. Loading factors for semivolatile organic compounds as a function of land use

[kg, kilogram; km^2, square kilometer; km, kilometer; yr, year; cm, centimeter; m^2, square meter; PAHs, polycyclic aromatic hydrocarbons; µg, microgram; m, meter; hwy, highway; E-5, 10 to the exponent -5; --, factors were not estimated]

Compound class	Residential	Commercial	Industrial	Highway	Bridges	Reference
			Stormwater			
Petroleum hydrocarbons	180 (kg/km^2)/yr	580 (kg/km^2)/yr	14,000 (kg/km^2)/yr	7,800 (kg/km^2)/yr	--	Hoffman and Quinn, 1987
	--	--	--	2.5E-5 (kg/vehicle)/km	--	Hoffman and others, 1985
	--	--	--	126 (kg/km^2)/cm rain	--	Hoffman and others, 1985
	2,560 (kg/km^2)/yr	--	--	--	--	Hunter and others, 1979
Oil and grease	--	--	--	485-76,700 (kg/km^2)/yr	4.1 kg/yr	Barrett and others, 1993
	--	--	--	9-16 (kg/km^2)/event	--	Barrett and others, 1993
	--	--	--	27-298 (kg/km^2)/cm rain	--	Wiland and Malina, 1976
	9.8 (kg/km^2)/cm rain	239 (kg/km^2)/cm rain	--	--	--	Stenstrom and others, 1984
PAHs	[1]0.009 (kg/km^2)/yr	[1]0.100 (kg/km^2)/yr	[1]2.42 (kg/km^2)/yr	[1]1.22 (kg/km^2)/yr	--	Hoffman and Quinn, 1987
	[2]0.258 (kg/km^2)/yr	[2]0.589 (kg/km^2)/yr	[2]3.97 (kg/km^2)/yr	[2]16.9 (kg/km^2)/yr	--	Hoffman and Quinn, 1987
	--	--	--	0.5-1.8 (kg/km^2)/yr	--	Stotz, 1987
	--	--	--	5.8E-8 (kg/vehicle)/km	--	Hoffman and others, 1985
	--	--	--	0.151 (kg/km^2)/cm rain	--	Hoffman and others, 1985
			Bulk deposition			
Petroleum hydrocarbons	61.4 (summer) (µg/m^2)/day	--	1,130 (winter) 4,120 (summer) (µg/m^2)/day	--	--	Latimer and others, 1990
Oil and grease	--	--	--	--	8.1 kg/yr	Barrett and others, 1993
PAHs	--	--	--	[3]15.6-48 µg/m of hwy/day	--	Hewitt and Rashed, 1990
	--	--	--	29-71 (µg/m^2)/yr	--	Harrison and Johnston, 1985

[1] Low-molecular-weight PAHs.

[2] High-molecular-weight PAHs.

[3] Within 50 meters of highway.

Table 4. Upper threshold concentrations of selected semivolatile organic compounds in sediment

[CAS, Chemical Abstracts]

Compound name	CAS number	Threshold concentration, in micrograms per kilogram of sediment
Acenaphthene	83-32-9	[1]1,300
Acenaphthylene	208-96-8	640
Anthracene	120-12-7	1100
Benz[a]anthracene	218-00-9	693
Benzo[a]pyrene	50-32-8	782
Bis(2-ethylhexyl)phthalate	117-81-7	2,650
Butylbenzylphthalate	85-68-7	11,000
Chrysene	218-00-9	862
Dibenz[a,h]anthracene	53-70-3	260
1,2-Dichlorobenzene	120-83-2	350
1,4-Dichlorobenzene	95-50-1	340
Diethylphthalate	84-66-2	630
Di-n-butylphthalate	84-74-2	11,000
Fluoranthene	206-44-0	[1]6,200
Naphthalene	91-20-3	470
Phenanthrene	85-01-8	[1]1,800
Pyrene	129-00-0	1,398
1,2,4-Trichlorobenzene	120-82-1	9,200

[1] Assumes 1 percent sediment organic carbon.

Table 5. Comparison of volatile organic compounds detected in the NURP and NPDES studies

[NURP, Nationwide Urban Runoff Program; NPDES, National Pollutant Discharge Elimination System; NA, not analyzed]

Compound	Frequency of detection, in percent, NURP[1]	Frequency of detection, in percent, NPDES[2]
Toluene	2	23
Xylenes	NA	17.5
Chloroform	12	13
Trimethylbenzene	NA	12
Tetrachloroethene	5	8
Naphthalene	11	7
methyl-*tert* butyl ether	NA	7
Dichloromethane	10	6
Bromodichloromethane	1	6
Ethylbenzene	4	5

[1] Cole and others, 1984.

[2] Delzer and others, 1996.

Table 6. Comparison of volatile organic compounds in stormwater to drinking-water standards

[µg/L, micrograms per liter; IUPAC, International Union of Pure and Applied Chemistry; CAS, Chemical Abstracts; NPDES, National Pollutant Discharge Elimination System; MCL, maximum contaminant level; HAL, health advisory level (U.S. Environmental Protection Agency, 1996c)]

IUPAC name	CAS number	Maximum concentration in NPDES samples	Standard, in µg/L	Type of standard
Methylbenzene	108-88-3	6.6	1,000	MCL
Dimethylbenzenes	1330-20-7	15	10,000	MCL
Trichloromethane	67-66-3	7.0	[1]100	MCL
Tetrachloroethene	127-18-4	42	5	MCL
Naphthalene	91-20-3	5.1	20	HAL
Methyl *tert*-butyl ether	1634-04-4	8.7	[2]20	HAL
Dichloromethane	75-09-2	13	5	MCL
Bromodichloromethane	75-27-4	2.8	[1]100	MCL
Ethylbenzene	100-41-4	2.0	700	MCL
Benzene	71-43-2	0.8	5	MCL

[1] Total for all trihalomethanes combined cannot exceed the 100 µg/L.

[2] Standard varies from 20 to 40 µg/L.

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil

[NPDES, National Pollutant Discharge Elimination System; NURP, Nationwide Urban Runoff Program; NR, not reported; ND, not detected; <, less than reporting limit; --, no data]

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter																	
Acenaphthene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.97	Marsalek and Schroeter, 1988
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.098	NR	--	--	--	Boom and Marsalek, 1988
Acenaphthylene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	NR	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	NR	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.96	Marsalek and Schroeter, 1988
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.153	NR	--	--	--	Boom and Marsalek, 1988
Anthracene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	9	NR	<5	10	NR	--	--	NR	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	7	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	10	--	Cole and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Anthracene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.009	10	NR	Makepeace and others, 1995
	Norway																
	Oslo	ND	0.379	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
Benz(*a*) anthracene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	<10	NR	<10	<10	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	<10	NR	<10	<10	NR	<10	37	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	13	NR	<10	26	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0003	10	NR	Makepeace and others, 1995
	Japan																
	Tokyo	--	--	--	NR	NR	5	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	Norway																
	Oslo	ND	0.677	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1.1	Bomboi and Hernandez, 1991
Benzo(*b*) fluoranthene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	19	NR	<10	<10	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	15	NR	<10	11	--	<10	73	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	15	NR	<10	23	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	2	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0034	1.9	NR	Makepeace and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Benzo(*b*) fluoranthene	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.1	0.647	NR	--	--	--	Boom and Marsalek, 1988
	Norway																
	Oslo	1	1.171	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
Benzo(*k*) fluoranthene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	<10	NR	<10	<10	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	14	NR	<10	<10	NR	<10	90	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	28	NR	<10	13	NR	<10	22	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	4	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0012	10	NR	Makepeace and others, 1995
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.1	0.99	NR	--	--	--	Boom and Marsalek, 1988
	Japan																
	Tokyo	--	--	--	NR	NR	5	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	Norway																
	Oslo	1	1.171	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.6	Bomboi and Hernandez, 1991
Benzo(*b*) fluorene	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.7	Bomboi and Hernandez, 1991
Benzo(*ghi*) perylene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	<10	NR	<10	16	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	<10	--	<10	11	NR	<10	31	NR	--	--	--	von Guerard and Weiss, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Benzo(*ghi*) perylene	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	15	NR	<10	25	NR	--	--	--	Baldys and others, 1998
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0024	1.5	NR	Makepeace and others, 1995
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.1	0.466	NR	--	--	--	Boom and Marsalek, 1988
	Japan																
	Tokyo	--	--	--	NR	NR	1.2	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	Norway																
	Oslo	ND	0.551	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.3	Bomboi and Hernandez, 1991
Benzo(*a*) pyrene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	<10	NR	<10	<10	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	11	NR	<10	<10	NR	<10	46	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	11	NR	<10	20	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0025	10	NR	Makepeace and others, 1995
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.1	0.558	NR	--	--	--	Boom and Marsalek, 1988
	Germany																
	Bayreuth	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	52	Herrmann, 1981
	Japan																
	Tokyo	--	--	--	NR	NR	NR	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	Norway																
	Oslo	ND	0.602	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Benzo(*a*) pyrene	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1.1	Bomboi and Hernandez, 1991
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	ND	4.75	NR	Bomboi and others, 1990
Benzo(*e*) pyrene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.4	0.609	NR	Makepeace and others, 1995
	Norway																
	Oslo	ND	0.609	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
Butylbenzyl phthalate	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	11	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	10	NR	<5	8	NR	<5	14	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	10	NR	Cole and others, 1984
p-Chloro-*m*-cresol	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	1.5	NR	Cole and others, 1984
2-Chloro naphthalene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.5	0.5	NR	--	--	--	Boom and Marsalek, 1988
B-Chloro naphthalene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.97	Marsalek and Schroeter, 1988
2-Chloro phenol	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
2-Chloro phenol	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	2	NR	Cole and others, 1984
Chrysene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	17	NR	<10	<10	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	--	NR	<10	12	NR	<10	61	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	23	NR	<10	49	3.2	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.6	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0038	10	NR	Makepeace and others, 1995
	Norway																
	Oslo	ND	1.147	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1.4	Bomboi and Hernandez, 1991
Dibenzanthracene	United States																
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	<10	NR	<10	<10	NR	--	--	--	Baldys and others, 1998
	Norway																
	Oslo	ND	0.214	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
Dibenz(*a*,*h*) anthracene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0006	0.9	NR	Makepeace and others, 1995
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.5	Bomboi and Hernandez, 1991
Dibenzofuran	Norway																
	Oslo	ND	0.001	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Dibenzothiophene	Norway																
	Oslo	ND	0.136	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
1,2-Dichloro benzene	United States																
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<5	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.39	Marsalek and Schroeter, 1988
1,3-Dichloro benzene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<5	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0074	Marsalek and Schroeter, 1988
1,4-Dichloro benzene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<5	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0089	Marsalek and Schroeter, 1988

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Diethylphthalate	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	2	10	NR	Cole and others, 1984
9,10-Dimethyl-anthracene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	1	1.4	NR	Makepeace and others, 1995
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1	Bomboi and Hernandez, 1991
2,4-Dimethyl phenol	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	10	NR	Cole and others, 1984
Di-n-butyl phthalate	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	15	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.5	11	NR	Cole and others, 1984
Di-n-octyl phthalate	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	<10	NR	<10	<10	NR	--	--	--	Lopes and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
	Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																
Di-n-octyl phthalate	Colorado																
	Colorado Springs	--	--	--	<10	11	NR	<10	11	NR	<10	11	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	<10	NR	<10	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.4	1	NR	Cole and others, 1984
bis(2-Ethyl hexyl) phthalate	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	8	NR	<5	9	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	7	13	NR	11	100	NR	9	24	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	24	5.7	<5	20	NR	<5	140	6.9	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	7	39	NR	Cole and others, 1984
Fluoranthene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	18	NR	<5	7	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	32	NR	10	25	NR	<5	120	NR	--	--	--	von Guerard and Weiss, 1995
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	0.1609	NR	--	--	--	--	--	--	Hoffman and others, 1984
	Texas																
	Dallas–Fort Worth	--	--	--	<5	13	NR	<5	23	3.6	<5	52	6.5	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.3	12	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.03	56	NR	Makepeace and others, 1995
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1	Marsalek and Schroeter, 1988
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.5	2.95	NR	--	--	--	Boom and Marsalek, 1988
	Germany																
	Bayreuth	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.106	Herrmann, 1981

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Fluoranthene	Norway																
	Oslo	4	2.665	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	2.7	Bomboi and Hernandez, 1991
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	0.4	10.65	NR	Bomboi and others, 1990
Fluorene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	1	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.096	1	NR	Makepeace and others, 1995
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.135	NR	--	--	--	Boom and Marsalek, 1988
	Norway																
	Oslo	ND	0.96	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
Hexachloro benzene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<5	--	NR	<5	<5	NR	<5	<5	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.00073	Marsalek and Schroeter, 1988
Indene	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.05	NR	--	--	--	Boom and Marsalek, 1988

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Indeno (1,2,3-cd) pyrene	United States																
	Arizona																
	Maricopa County	--	--	--	<10	<10	NR	<10	<10	NR	<10	27	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<10	11	NR	<10	13	NR	<10	38	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<10	<10	NR	<10	15	NR	<10	27	NR	--	--	--	Baldys and others, 1998
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.31	0.5	NR	Makepeace and others, 1995
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.1	0.496	NR	--	--	--	Boom and Marsalek, 1988
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.2	Bomboi and Hernandez, 1991
1-Methyl anthracene	Norway																
	Oslo	ND	0.133	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
2-Methyl anthracene	Norway																
	Oslo	ND	0.036	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.7	Bomboi and Hernandez, 1991
1-Methyl naphthalene	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.177	NR	--	--	--	Boom and Marsalek, 1988
	Norway																
	Oslo	ND	0.045	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
2-Methyl naphthalene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.01	1.6	NR	Makepeace and others, 1995
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.95	Marsalek and Schroeter, 1988
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.251	NR	--	--	--	Boom and Marsalek, 1988
	Norway																
	Oslo	ND	0.025	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Methylphen anthrene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	2.9	3.4	NR	Makepeace and others, 1995
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	2.9	Bomboi and Hernandez, 1991
Naphthalene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<5	NR	<0.2	<5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.8	2.3	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.036	2.3	NR	Makepeace and others, 1995
	Norway																
	Oslo	ND	0.067	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
4-Nitrophenol	United States																
	Arizona																
	Maricopa County	--	--	--	<30	<30	NR	<30	<30	NR	<30	<30	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<30	<30	NR	<30	<30	NR	<30	<30	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<30	<30	NR	<30	<30	NR	<30	<30	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	19	NR	Cole and others, 1984
PAH (total)	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.24	13	NR	Makepeace and others, 1995
	Germany																
	Obereisesheim	NR	NR	2.97	--	--	--	--	--	--	--	--	--	--	--	--	Stoltz, 1987
	Pleidelsheim	NR	NR	2.61	--	--	--	--	--	--	--	--	--	--	--	--	Stoltz, 1987
	Ulm	NR	NR	2.51	--	--	--	--	--	--	--	--	--	--	--	--	Stoltz, 1987
	United Kingdom																
	NW London	--	--	--	--	--	--	--	--	--	--	--	--	5830	18210	NR	Gavens and others, 1983

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Pentachloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.001	Marsalek and Schroeter, 1988
Pentachloro phenol	United States																
	Arizona																
	Maricopa County	--	--	--	<30	<30	NR	<30	<30	NR	<30	<30	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<30	<30.	NR	<30	<30	NR	<30	<30	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<30	<30	NR	<30	<30	NR	<30	<30	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	115	NR	Cole and others, 1984
Perylene	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.05	0.5	NR	Makepeace and others, 1995
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.5	Bomboi and Hernandez, 1991
Phenanthrene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	23	NR	<5	14	NR	<5	67	NR	--	--	--	von Guerard and Weiss, 1995
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	0.0906	NR	--	--	--	--	--	--	Hoffman and others, 1984
	Texas																
	Dallas–Fort Worth	--	--	--	<5	10	NR	<5	10	NR	<5	33	3.6	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.3	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.045	10	NR	Makepeace and others, 1995
	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	3.56	NR	--	--	--	Boom and Marsalek, 1988
	Norway																
	Oslo	3	1.385	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Phenanthrene	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	2.9	Bomboi and Hernandez, 1991
Phenol	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	3	10	NR	Cole and others, 1984
0-Phenyl enepyrene	Norway																
	Oslo	ND	0.432	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
Pyrene	United States																
	Arizona																
	Maricopa County	--	--	--	<5	<5	NR	<5	13	NR	<5	<5	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<5	24	NR	8	19	NR	<5	94	NR	--	--	--	von Guerard and Weiss, 1995
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	0.1367	NR	--	--	--	--	--	--	Hoffman and others, 1984
	Texas																
	Dallas–Fort Worth	--	--	--	<5	10	NR	<5	18	NR	<5	43	5.4	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.3	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.045	10	NR	Makepeace and others, 1995
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1	Marsalek and Schroeter, 1988
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	3.75	NR	--	--	--	Boom and Marsalek, 1988
	Norway																
	Oslo	5	2.002	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1.9	Bomboi and Hernandez, 1991
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	0.5	8.5	NR	Bomboi and others, 1990
Quinoline	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.124	NR	--	--	--	Boom and Marsalek, 1988
1,2,3,4-Tetra hydronaphthalene	Canada																
	Sault Ste Marie	--	--	--	--	--	--	--	--	--	<0.05	0.05	NR	--	--	--	Boom and Marsalek, 1988

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, whole water, in micrograms per liter—*Continued*																	
1,2,4-Trichloro benzene	United States																
	Colorado																
	Colorado Springs	--	--	--	<5	<5	NR	<5	<5	NR	<5	<5	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<5	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0015	Marsalek and Schroeter, 1988
1,3,5,-Trichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.00099	Marsalek and Schroeter, 1988
Semivolatile organic compounds, filtered/centrigured water, in micrograms per liter																	
Fluoranthrene	United States																
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	0.0034	NR	--	--	--	--	--	--	Hoffman and others, 1984
Phenanthrene	United States																
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	0.0263	NR	--	--	--	--	--	--	Hoffman and others, 1984
Pyrene	United States																
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	0.0056	NR	--	--	--	--	--	--	Hoffman and others, 1984
Semivolatile organic compounds, suspended sediment, in micrograms per gram																	
Acenaphthylene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.7	Marsalek and Schroeter, 1988
Benzo(*b*) fluoranthene	United States																
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.021	0.35	0.07	Prahl and others, 1984
Benzo(*k*) fluorenthene	United States																
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.008	0.14	NR	Prahl and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, suspended sediment, in micrograms per gram—*Continued*																	
Benzo(*ghi*) perylene	United States																
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.007	0.15	0.019	Prahl and others, 1984
Benzo(*a*) pyrene	United States																
	Rhode Island																
	Cranston	0.28	7.78	1.35	--	--	--	--	--	--	--	--	--	--	--	--	Hoffman and others, 1985
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.005	0.097	0.016	Prahl and others, 1984
1,2-Dichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.12	Marsalek and Schroeter, 1988
1,3-Dichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.027	Marsalek and Schroeter, 1988
1,4-Dichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.4	Marsalek and Schroeter, 1988
Fluoranthene	United States																
	Rhode Island																
	Cranston	3.2	45.7	12	--	--	--	--	--	--	--	--	--	--	--	--	Hoffman and others, 1985
	Cranston	--	--	--	--	--	--	NR	3.32	NR	--	--	--	--	--	--	Hoffman and others, 1984
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.025	0.38	0.052	Prahl and others, 1984
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	2.4	Marsalek and Schroeter, 1988
Hexachloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.075	Marsalek and Schroeter, 1988
Indene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.44	Marsalek and Schroeter, 1988
2-Methylnaph-thalene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.53	Marsalek and Schroeter, 1988

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, suspended sediment, in micrograms per gram—*Continued*																	
Pentachloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0098	Marsalek and Schroeter, 1988
Perylene	United States																
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.021	0.17	0.051	Prahl and others, 1984
Phenanthrene	United States																
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	1.35	NR	--	--	--	--	--	--	Hoffman and others, 1984
Phenanthrene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1.7	Marsalek and Schroeter, 1988
Pyrene	United States																
	Rhode Island																
	Cranston	--	--	--	--	--	--	NR	2.76	NR	--	--	--	--	--	--	Hoffman and others, 1984
	Washington																
	Columbia River	--	--	--	--	--	--	--	--	--	--	--	--	0.026	0.41	0.056	Prahl and others, 1984
	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	2.2	Marsalek and Schroeter, 1988
1,2,3,5-Tetra chloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.005	Marsalek and Schroeter, 1988
1,2,3,4-Tetra chloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0044	Marsalek and Schroeter, 1988
1,2,4,5-Tetra chloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.005	Marsalek and Schroeter, 1988
1,2,3-Trichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0076	Marsalek and Schroeter, 1988
1,2,4-Trichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.0085	Marsalek and Schroeter, 1988
1,3,5-Trichloro benzene	Canada																
	Canadian Great Lakes	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	0.019	Marsalek and Schroeter, 1988

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, bottom material/soil, in micrograms per gram																	
Anthracene	Norway																
	Olso	ND	0.16	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.25	2.1	NR	Ellis and others, 1985
Benzo(*a*) anthracene	Japan																
	Tokyo	--	--	--	NR	NR	0.075	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	United Kingdom																
	Midlands	0.169	2.97	1.165	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
Benzo(*b*)fluor anthene	Norway																
	Olso	0.03	0.096	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.5	4	NR	Ellis and others, 1985
Benzo(*k*)fluor anthene	Japan																
	Tokyo	--	--	--	NR	NR	0.14	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.5	4	NR	Ellis and others, 1985
Benzo(*ghi*) perylene	Japan																
	Tokyo	--	--	--	NR	NR	0.42	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.1	4.5	NR	Ellis and others, 1985
Benzo(*a*) pyrene	US–summary	--	--	--	--	--	--	--	--	--	--	--	--	0.04	7	NR	Edwards, 1983
	Canada–summary	NR	0.866	NR	--	--	--	--	--	--	--	--	--	--	--	--	Edwards, 1983
	Czechoslovakia–summary	--	--	--	--	--	--	--	--	--	--	--	--	0.0083	0.0421	--	Edwards, 1983
	Germany–summary	--	--	--	--	--	--	--	--	--	0.8	650	NR	0.0015	0.004	NR	Edwards, 1983
	Japan																
	Tokyo	--	--	--	NR	NR	0.08	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	Russia																
	Moscow–summary	--	--	--	--	--	--	--	--	--	0.058	0.2997	NR	ND	200	--	Edwards, 1983
	Switzerland																
	Greifebsee	--	--	--	--	--	--	--	--	--	--	--	--	ND	2	NR	Wakeham and others, 1980
	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.2	2.9	NR	Ellis and others, 1985

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, bottom material/soil, in micrograms per gram—*Continued*																	
Benzo(*a*) pyrene	Midlands	0.165	3.196	0.781	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
	Yugoslavia–summary	--	--	--	--	--	--	--	--	--	--	--	--	0.029	0.9	--	Edwards, 1983
Benzo(*e*) pyrene	Norway																
	Olso	ND	0.8	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	United Kingdom																
	Midlands	0.164	2.293	0.731	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
Chrysene	Norway																
	Olso	0.02	0.1	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	United Kingdom																
	Midlands	0.251	2.703	1.949	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
Coronene	United Kingdom																
	Midlands	0.032	0.322	0.117	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
Fluoranthene	Norway																
	Olso	0.066	0.248	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Switzerland																
	Greifebsee	--	--	--	--	--	--	--	--	--	--	--	--	ND	3.5	NR	Wakeham and others, 1980
	United Kingdom																
	Midlands	0.2	3.734	1.313	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
Fluorene	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.3	3.9	NR	Ellis and others, 1985
PAH (total)	United States																
	Washington																
	Lake Washington	--	--	--	--	--	--	--	--	--	--	--	--	1	6.5	NR	Wakeham and others, 1980
	Canada–summary	--	--	--	--	--	--	--	--	--	--	--	--	NR	1.109	NR	Edwards, 1983
	Switzerland																
	Greifensee	--	--	--	--	--	--	--	--	--	--	--	--	0.3	6	NR	Wakeham and others, 1980
	Lake Lucerne	--	--	--	--	--	--	--	--	--	--	--	--	1	5.5	NR	Wakeham and others, 1980
	Lake Zurich	--	--	--	--	--	--	--	--	--	--	--	--	0.4	15	NR	Wakeham and others, 1980

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Semivolatile organic compounds, bottom material/soil, in micrograms per gram—*Continued*																	
PAH (total)	Summary	5	300	NR	--	--	--	--	--	--	--	--	--	4	8	NR	Edwards, 1983
	United Kingdom																
	Derwent River	1.51	26.76	8.32	0.02	2.45	0.58	2.65	63.75	34.55	2.91	209.59	25.75	--	--	--	Evans and others, 1990
	NW London	--	--	--	--	--	--	--	--	--	--	--	--	310	1100	NR	Gavens and others, 1983
Phenanthracene	Norway																
	Olso	0.07	0.18	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	Switzerland																
	Greifebsee	--	--	--	--	--	--	--	--	--	--	--	--	ND	5	NR	Wakeham and others, 1980
Pyrene	Norway																
	Olso	0.11	0.122	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gjessing and others, 1984
	United Kingdom																
	N.W. London	--	--	--	--	--	--	--	--	--	--	--	--	0.1	3.3	NR	Ellis and others, 1985
	Midlands	0.145	4.515	1.386	--	--	--	--	--	--	--	--	--	--	--	--	Butler and others, 1984
Extractable organic compounds, whole water, in milligrams per liter																	
Hydrocarbons	United States																
	California																
	Los Angeles	--	--	--	--	--		--	--	--	--	--	--	0.99	19.5	NR	Eganhoues and Kaplan. 1981
	San Francisco Bay	--	--	--	--	--	--	--	--	--	2.98	9.75	NR	1.606	10.83	NR	Fam and others, 1987
	Florida																
	Tallahassee	--	--	--	--	--	--	0.064	16.4	3.44	--	--	--	0.17	1.35	0.58	Hoffman and Qunin, 1987
	Pennsylvania																
	Philadelphia	--	--	--	--	--	--	--	--	--	--	--	--	2.18	5.3	3.69	Hunter and others, 1979
	Rhode Island	0.03	6.85	3.28	0.02	1.95	1.09	0.04	5.71	0.99	0.32	58.4	19.82	--	--	--	Hoffman and Qunin, 1987
	Cranston	2	6	NR	--	--	--	--	--	--	--	--	--	--	--	--	Hoffman and others, 1983
	Cranston	--	--	--	--	--	--	--	1.14	--	--	--	--	--	--	--	Hoffman and others, 1984
	Washington																
	Seattle	--	--	--	--	--	--	--	--	--	--	--	--	6	24	NR	Hoffman and Qunin, 1987

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Extractable organic compounds, whole water, in milligrams per liter—*Continued*																	
Hydrocarbons	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.64	19.71	NR	Makepeace and others, 1995
	Japan																
	Tokyo	--	--	--	NR	NR	0.75	--	--	--	--	--	--	--	--	--	Yamane and others, 1990
	Spain																
	Madrid	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	1.154	Bomboi and Hernandez, 1991
	Switzerland	1.7	10	3.9	--	--	--	--	--	--	--	--	--	--	--	--	Hoffman and Qunin, 1987
	United Kingdom																
	NW London	--	--	--	--	--	--	--	--	--	--	--	--	0.36	1.1	NR	Gavens and others, 1983
Extractable organic compounds, filtered/centrigured water, in milligrams per liter																	
	United States																
	California																
	Los Angeles	--	--	--	--	--	--	--	--	--	--	--	--	0.302	0.49	NR	Eganhouse and Kaplan, 1981
	San Francisco Bay	--	--	--	--	--	--	--	--	--	1.29	4.32	NR	1.18	3.98	NR	Fam and others, 1987
	Pennsylvania																
	Philadelphia	--	--	--	--	--	--	--	--	--	--	--	--	0.67	0.16	0.4	Hunter and others, 1979
	Rhode Island																
	Cranston	ND	0.5	NR	--	--	--	--	--	--	--	--	--	--	--	--	Hoffman and others, 1983
	Cranston	--	--	--	--	--	--	--	0.0954	--	--	--	--	--	--	--	Hoffman and others, 1984
Extractable organic compounds, suspended sediment, in micrograms per gram																	
	United States																
	Rhode Island	8,750	51,800	24,800	15,700	59,800	42,000	16,400	34,000	24,800	61,900	507,000	211,000	--	--	--	Latimer and others, 1990
	Cranston	--	--	--	--	--	--	--	21,900	--	--	--	--	--	--	--	Hoffman and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	8.75	507	NR	Makepeace and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Extractable organic compounds, bottom material/soil, in micrograms per gram																	
Hydrocarbons	United States																
	Florida																
	Tampa	--	--	--	--	--	--	--	--	--	--	--	--	152	485	258	Brown and others, 1985
	Japan																
	Tokyo	--	--	--	--	--	--	--	--	--	--	--	--	NR	NR	69	Yamane and others, 1990
	United Kingdom																
	NW London	--	--	--	--	--	--	--	--	--	--	--	--	43	690	NR	Gavens and others, 1983
Extractable organic compounds, whole water, in milligrams per liter																	
Oil and grease	United States																
	Arizona																
	Maricopa County	--	--	--	<1	10	NR	<1.0	5	NR	<1	6	NR	<1	8	NR	Lopes and Fossum, 1995
	California																
	Richmond	4.2	89.09	16.05	0.57	24.55	3.92	1.98	--	10.9	1.49	21.11	7.26	2.1	71.97	7.87	Stenstrom and others, 1984
	Colorado																
	Boulder	--	--	--	1.7	25.9	NR	8.9	155	NR	--	--	--	--	--	--	Hoffman and Qunin, 1987
	Colorado Springs	--	--	--	<1	10	NR	<1.0	10	NR	<1	6	NR	--	--	--	von Guerard and Weiss, 1995
	Michigan																
	Southeast Michigan	--	--	--	--	--	--	--	--	--	--	--	--	ND	0.28	NR	Hoffman and Qunin, 1987
	North Carolina	--	--	--	--	--	--	--	--	--	<5	51	6	--	--	--	Line and others, 1997
	Texas																
	Austin	1.4	7.8	3.65	--	--	--	--	--	--	--	--	--	--	--	--	Wiland and Malima, 1976
	Dallas–Fort Worth	--	--	--	<1	19	2.2	<1.0	8	2.3	1	1.2	3.5	--	--	--	Baldys and others, 1998
	Washington																
	Seattle	146	480	NR	--	--	--	--	--	--	--	--	--	--	--	--	Zawlocki and others, 1980
	Wisconson																
	Milwaukee	1	20	NR	--	--	--	--	--	--	--	--	--	--	--	--	Gupta, 1981
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.001	110	NR	Makepeace and others, 1995
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	2.7	27	NR	Barrett and others, 1993

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use: Highway			Residential			Commercial			Industrial			Unspecified			Reference
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Extractable organic compounds, bottom material/soil, in micrograms per gram																	
Oil and grease	United States																
	Arizona																
	Maricopa County	--	--	--	--	--	--	--	--	--	--	--	--	<100	2,200	NR	Lopes and Fossum, 1995
Volatile organic compounds, whole water, in micrograms per liter																	
Benzene	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	0.4	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<0.2	NR	<0.2	0.8	0.12	<0.2	0.6	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	3.5	13	NR	Cole and others, 1984
Bromodichloromethane	United States																
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.2	NR	<0.2	<10	NR	<0.2	0.5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	2	NR	Cole and others, 1984
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	2.8	NR	Delzer and others, 1996
n-Butylbenzene	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	0.4	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.2	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
Chlorobenzene	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Chlorobenzene	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	10	NR	Cole and others, 1984
Chloroethene (vinyl chloride)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	110	NR	--	--	--	Baldys and others, 1998
1,2-Chloro toluene	United States																
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	0.2	NR	--	--	--	Baldys and others, 1998
1,4-Chloro toluene	United States																
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	0.2	NR	--	--	--	Baldys and others, 1998
Dibromochloro-methane (chloro dibromo-methane)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<0.2	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	2	2	NR	Cole and others, 1984
Dibromo methane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Dibromo methane	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.2	NR	<0.2	0.4	NR	<0.2	0.7	NR	--	--	--	Baldys and others, 1998
1,1-Dichloro ethane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	8.3	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1.5	3	NR	Cole and others, 1984
1,2-Dichloro ethane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	4	NR	Cole and others, 1984
1,1-Dichloro ethene (1,1-Dichloro ethylene)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	5.9	NR	<0.2	<10	NR	<0.2	13	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1.5	4	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	1.5	4	NR	Makepeace and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use: Highway			Residential			Commercial			Industrial			Unspecified			Reference
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
cis-1,2-Dichloro ethene	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	1200	25.7	--	--	--	Baldys and others, 1998
trans-1,2-Dichloro ethene (*trans*-1,2-Dichloro ethylene)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	27	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	3	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	1	3	NR	Makepeace and others, 1995
Dichloro methane (methylene chloride)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<20	NR	<0.2	0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.8	NR	<0.2	<0.2	NR	<0.2	0.09	0.09	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	4	14.5	NR	Cole and others, 1984
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	13	NR	Baldys and others, 1998
1,2-Dichloro propane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
1,2-Dichloro propane	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	NR	3	NR	Cole and others, 1984
1,3-Dichloro propene (isomer not specified)	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	2	NR	Cole and others, 1984
Ethenyl benzene (Styrene)	United States																
	Arizona	--	--	--	<0.2	<0.2	NR	<0.2	<20	NR	<0.2	0.5	NR	--	--	--	Lopes and others, 1995
	Maricopa County																
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	0.6	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
Ethylbenzene	United States																
	Arizona	--	--	--	<0.2	<0.2	NR	<0.2	<20	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Maricopa County																
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.6	NR	<0.2	0.6	NR	<0.2	1.5	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	2	NR	Cole and others, 1984
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	2	NR	Delzer and others, 1996
Isopropyl benzene	United States																
	Arizona	--	--	--	<0.2	<0.2	NR	<0.2	<20	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Maricopa County																
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Isopropyl benzene	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	--	NR	<0.2	<10	NR	<0.2	4.6	NR	--	--	--	Baldys and others, 1998
1-Isopropyl-4-methyl benzene (P-isopropyltoluene)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<20	NR	<0.2	0.7	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	0.9	NR	<0.2	0.2	NR	--	--	--	Baldys and others, 1998
Methyl benzene (Toluene)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<1	0.2	NR	<0.2	0.3	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	1.2	NR	<0.2	1.7	NR	<0.2	0.4	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	1.8	0.08	<0.2	2.4	0.25	<0.2	1.8	0.11	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	9	12	NR	Cole and others, 1984
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	6.6	NR	Delzer and others, 1996
2-Methoxy-2-methyl-propane (Methyl *tert*-butyl ether)	United States																
	Alabama																
	Birmingham	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	1.9	NR	Delzer and others, 1996
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<5	2.5	NR	<0.2	0.3	NR	--	--	--	Lopes and others, 1995
	Phoenix	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	2.5	NR	Delzer and others, 1996
	Colorado																
	Colorado Springs	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	3	NR	Delzer and others, 1996
	Denver	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	1.5	NR	Delzer and others, 1996

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
2-Methoxy-2-methyl-propane (Methyl *tert*-butyl ether)	Georgia																
	Atlanta	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	1.5	NR	Delzer and others, 1996
	Louisana																
	Baton Rouge	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	0.4	NR	Delzer and others, 1996
	Texas																
	Dallas–Fort Worth	--	--	--	<1	<25	NR	<1	8.7	1.2	<0.2	5.4	NR	--	--	--	Baldys and others, 1998
	San Antonio	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	1.8	NR	Delzer and others, 1996
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	8.7	NR	Delzer and others, 1996
Naphthalene	United States																
	Colorado																
	Colorado Springs	--	--	--	<0.2	0.4	NR	<0.2	--	NR	<0.2	1.1	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.6	NR	<0.2	<5	NR	<0.2	1.3	NR	--	--	--	Baldys and others, 1998
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	5.1	NR	Delzer and others, 1996
n-Propyl benzene	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	0.5	NR	--	--	--	Baldys and others, 1998
1,1,2,2-Tetra chloro ethane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<01	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	2	3	NR	Cole and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Tetrachloroethene (Tetrachloroethylene)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	42	1.2	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	4.5	43	NR	Cole and others, 1984
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	42	NR	Delzer and others, 1996
Tetrachloromethane (Carbon tetrachloride)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1	2	NR	Cole and others, 1984
Tribromomethane (Bromoform)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<10	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	NR	1	NR	Cole and others, 1984
1,1,1-Trichloroethane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	0.7	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
1,1,1-Trichloro ethane	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<0.2	NR	<0.2	0.2	NR	<0.2	5.4	<0.24	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	1.6	10	NR	Cole and others, 1984
1,1,2-Trichloro ethane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<5	NR	<0.2	<10	NR	<0.2	<0.2	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	2	3	NR	Cole and others, 1984
Trichloro ethene (Trichloro ethylene)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.2	NR	<0.2	<10	NR	<0.2	28	1.3	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.3	10	NR	Cole and others, 1984
	Summary	--	--	--	--	--	--	--	--	--	--	--	--	0.3	10	NR	Makepeace and others, 1995
Trichloro fluoro methane	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.5	<13	NR	<0.5	<25	NR	<0.2	<25	NR	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.6	0.27	NR	Cole and others, 1984

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Trichloro methane Chloroform	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<0.2	<0.2	NR	<0.2	<0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	2.1	NR	<0.2	<0.2	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.7	0.06	<0.2	1.1	NR	<0.2	0.7	0.15	--	--	--	Baldys and others, 1998
	Summary–NURP	--	--	--	--	--	--	--	--	--	--	--	--	0.2	12	NR	Cole and others, 1984
	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	7	NR	Delzer and others, 1996
1,1,2-Trichloro-1,2,2-trifluoro ethane	United States																
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	0.4	NR	<0.2	<10	NR	<0.2	<0.2	NR	--	--	--	Baldys and others, 1998
1,2,4-Trimethyl benzene	United States																
	Colorado																
	Colorado Springs	--	--	--	<0.2	0.9	NR	<0.2	2.8	NR	<0.2	0.4	NR	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	2	NR	<0.2	0.4	NR	<0.2	15	NR	--	--	--	Baldys and others, 1998
1,3,5-Trimethyl benzene	United States																
	Colorado																
	Colorado Springs	--	--	--	<0.2	<0.2	NR	<0.2	0.9	NR	<0.2	<0.2	--	--	--	--	von Guerard and Weiss, 1995
	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	<0.2	NR	<0.2	<10	NR	<0.2	6.3	NR	--	--	--	Baldys and others, 1998
Trimethyl benzene	Summary–NPDES	--	--	--	--	--	--	--	--	--	--	--	--	<0.2	15	NR	Delzer and others, 1996
Dimethyl benzene (total xylenes) (isomer not specified)	United States																
	Arizona																
	Maricopa County	--	--	--	<0.2	<0.2	NR	<1	0.3	NR	<0.2	0.2	NR	--	--	--	Lopes and others, 1995
	Colorado																
	Colorado Springs	--	--	--	<0.2	1.5	NR	<0.2	4.4	NR	<0.2	0.7	NR	--	--	--	von Guerard and Weiss, 1995

Table 7. Concentrations of detected semivolatile and volatile organic compounds in stormwater, suspended sediment, and bottom material/soil—*Continued*

Compound name	Location	Land use															Reference
		Highway			Residential			Commercial			Industrial			Unspecified			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
Volatile organic compounds, whole water, in micrograms per liter—*Continued*																	
Dimethyl benzene (total xylenes) (isomer not specified)	Texas																
	Dallas–Fort Worth	--	--	--	<0.2	3.7	0.12	<0.2	1.9	0.23	<0.2	<0.2	0.43	--	--	--	Baldys and others, 1998
	Summary–NPDES	--	--	--	--	--	--	--	--	--	<0.2	10	--	<0.2	15	NR	Delzer and others, 1996
Volatile organic compounds, suspended sediment, in micrograms per gram																	
Benzene	United States																
	New York																
	Love Canal	--	--	--	--	--	--	--	--	--	--	--	--	NR	0.232	NR	Makepeace and others, 1995

District Chief,
South Dakota District
U.S. Geological Survey
Water Resources Division
1608 Mt. View Road
Rapid City, SD 57702

Lopes and Dionne—A REVIEW OF SEMIVOLATILE AND VOLATILE ORGANIC COMPOUNDS IN HIGHWAY RUNOFF AND URBAN STORMWATER—OFR 98-409