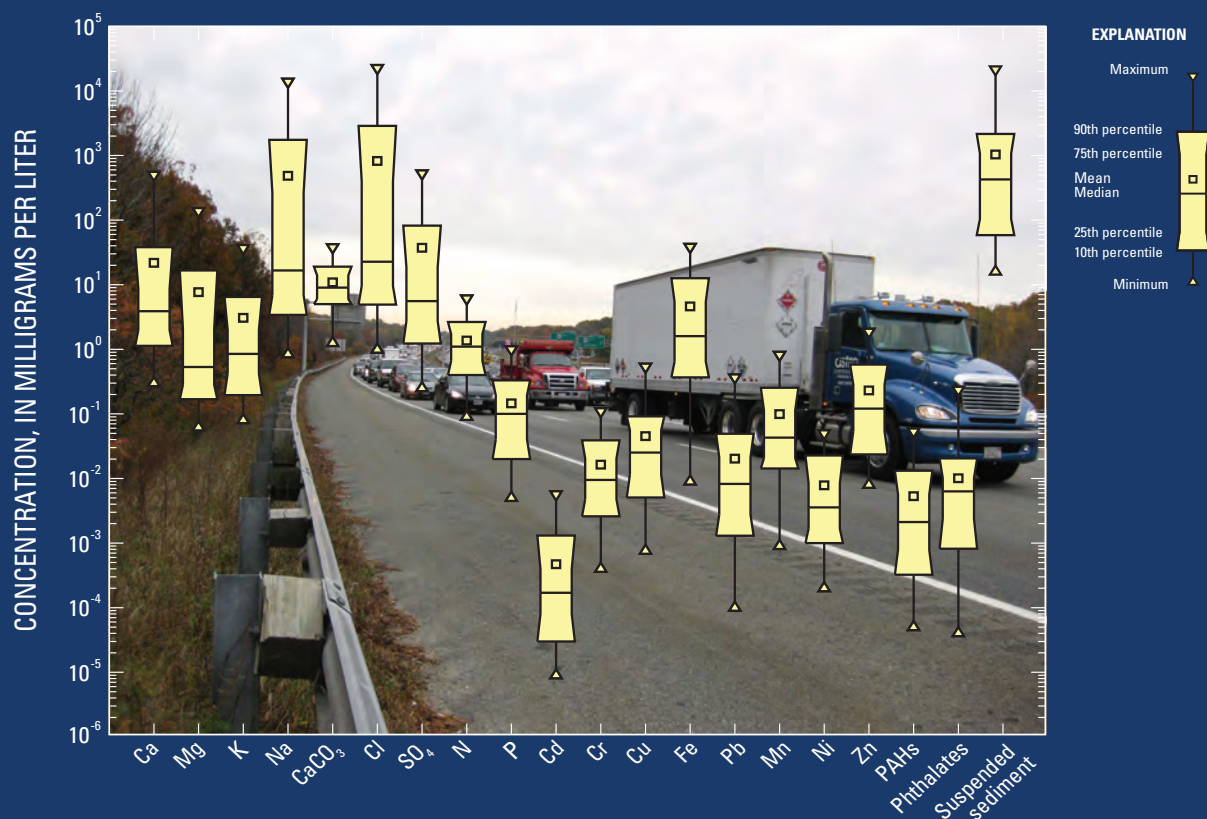


Prepared in cooperation with the U.S. Department of Transportation Federal Highway Administration and the Massachusetts Department of Transportation

Quality of Stormwater Runoff Discharged from Massachusetts Highways, 2005–07



Scientific Investigations Report 2009–5269

Cover. Distribution of event-mean concentrations for selected constituents in approximately 140 composite samples of highway runoff collected at 12 highway-monitoring stations on 8 highways in Massachusetts; background photograph of rush-hour traffic on Interstate 95 in Lexington by Kimberly W. Campo, U.S. Geological Survey.

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By Kirk P. Smith and Gregory E. Granato

Prepared in cooperation with the U.S. Department of Transportation Federal
Highway Administration and the Massachusetts Department of Transportation

Scientific Investigations Report 2009–5269

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

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2010

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PREFACE

Knowledge of the characteristics of highway runoff (concentrations 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 2004, the Federal Highway Administration, the Massachusetts Department of Transportation, and the U.S. Geological Survey began an investigation to characterize the concentrations of selected dissolved major ions, total nitrogen and phosphorus, selected total-recoverable metals, suspended sediment, and semivolatile organic compounds measured in flow-weighted composite samples of stormwater collected from typical highway-drainage conveyance structures on eight highways in Massachusetts during a 2-year sampling period.

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Conversion Factors and Abbreviations

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft ²)	929.0	square centimeter (cm ²)
square foot (ft ²)	0.09290	square meter (m ²)
square inch (in ²)	6.452	square centimeter (cm ²)
square mile (mi ²)	259.0	hectare (ha)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m ³)
gallon (gal)	3.785	cubic decimeter (dm ³)
million gallons (Mgal)	3,785	cubic meter (m ³)
cubic inch (in ³)	16.39	cubic centimeter (cm ³)
cubic inch (in ³)	0.01639	cubic decimeter (dm ³)
cubic inch (in ³)	0.01639	liter (L)
cubic foot (ft ³)	28.32	cubic decimeter (dm ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

ABBREVIATIONS AND ACRONYMS

AADT	Average annual daily traffic
An	Anthracene
Ba	Benzo[<i>a</i>]anthracene
Bghi	Benzo[<i>ghi</i>]perylene
BMP	Best management practice
Chr	Chrysene
DOT	Department of Transportation
EMC	Event-mean concentration
Fl	Fluoranthene
HRDB	Highway Runoff Database
Ip	Indeno[1,2,3- <i>cd</i>]pyrene
LTMDL	Long-term method detection level
NWQL	National Water Quality Laboratory
PAH	Polyaromatic hydrocarbon
Phe	Phenanthrene
Py	Pyrene
RPD	Relative percent difference
SELDL	Stochastic Empirical Loading and Dilution Model
SVOC	Semivolatile organic compound
TOC	Total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Quality of Stormwater Runoff Discharged from Massachusetts Highways, 2005–07

By Kirk P. Smith and Gregory E. Granato

Abstract

The U.S. Geological Survey (USGS), in cooperation with U.S. Department of Transportation Federal Highway Administration and the Massachusetts Department of Transportation, conducted a field study from September 2005 through September 2007 to characterize the quality of highway runoff for a wide range of constituents. The highways studied had annual average daily traffic (AADT) volumes from about 3,000 to more than 190,000 vehicles per day. Highway-monitoring stations were installed at 12 locations in Massachusetts on 8 highways. The 12 monitoring stations were subdivided into 4 primary, 4 secondary, and 4 test stations. Each site contained a 100-percent impervious drainage area that included two or more catch basins sharing a common outflow pipe. Paired primary and secondary stations were located within a few miles of each other on a limited-access section of the same highway. Most of the data were collected at the primary and secondary stations, which were located on four principal highways (Route 119, Route 2, Interstate 495, and Interstate 95). The secondary stations were operated simultaneously with the primary stations for at least a year. Data from the four test stations (Route 8, Interstate 195, Interstate 190, and Interstate 93) were used to determine the transferability of the data collected from the principal highways to other highways characterized by different construction techniques, land use, and geography.

Automatic-monitoring techniques were used to collect composite samples of highway runoff and make continuous measurements of several physical characteristics. Flow-weighted samples of highway runoff were collected automatically during approximately 140 rain and mixed rain, sleet, and snowstorms. These samples were analyzed for physical characteristics and concentrations of 6 dissolved major ions, total nutrients, 8 total-recoverable metals, suspended sediment, and 85 semivolatile organic compounds (SVOCs), which include priority polycyclic aromatic hydrocarbons (PAHs), phthalate esters, and other anthropogenic or naturally occurring organic compounds. The distribution of particle size of suspended sediment also was determined for composite samples of highway runoff. Samples of highway runoff were collected year round and under various dry antecedent conditions throughout the 2-year sampling period. In addition to samples of highway

runoff, supplemental samples also were collected of sediment in highway runoff, background soils, berm materials, maintenance sands, deicing compounds, and vegetation matter. These additional samples were collected near or on the highways to support data analysis.

There were few statistically significant differences between populations of constituent concentrations in samples from the primary and secondary stations on the same principal highways (Mann-Whitney test, 95-percent confidence level). Similarly, there were few statistically significant differences between populations of constituent concentrations for the four principal highways (data from the paired primary and secondary stations for each principal highway) and populations for test stations with similar AADT volumes. Exceptions to this include several total-recoverable metals for stations on Route 2 and Interstate 195 (highways with moderate AADT volumes), and for stations on Interstate 95 and Interstate 93 (highways with high AADT volumes). Supplemental data collected during this study indicate that many of these differences may be explained by the quantity, as well as the quality, of the sediment in samples of highway runoff.

Nonparametric statistical methods also were used to test for differences between populations of sample constituent concentrations among the four principal highways that differed mainly in traffic volume. These results indicate that there were few statistically significant differences (Mann-Whitney test, 95-percent confidence level) for populations of concentrations of most total-recoverable metals and organic compounds among the stations on the four principal highways. There were significant differences between most populations of concentrations in samples from Route 119 (the highway with the lowest AADT volume) and those from the three principal highways with higher AADT volumes. Nevertheless, the median concentrations and upper interquartile ranges for populations of many total-recoverable metals collected from the 12 stations increased with increasing AADT volume, indicating a positive correlation between the two variables. The frequency of detection for various organic compounds also increased with traffic volume for the four principal highways. Furthermore, results for Kendall's Tau correlation coefficient and Spearman rank correlation coefficient tests indicate that correlations between the median concentrations for total nitrogen (N), total phosphorus (P), all total-recoverable metals, benzo[*a*]anthracene,

benzo[*b*]fluoranthene, fluoranthene, and pyrene to the respective AADT volumes of the eight highways were significantly different at a 95-percent confidence level.

Concentrations of nearly all constituents measured in samples of highway runoff in this study increased substantially during January 2006 through April 2006 and March 2007 through April 2007 compared to the concentrations in samples collected during months without snowfall. Average concentrations of total P, total-recoverable metals, and suspended sediment in samples of highway runoff collected during the winter were about 3 to 11 times the average concentrations observed in samples of non-winter runoff. Results for single-tail Mann-Whitney tests of nearly all populations of constituents between winter composite samples and non-winter composite samples collected from each principal highway indicate that the winter concentrations were significantly higher at a 99-percent confidence interval. Deicing compounds, which contain trace amounts of total N and many total-recoverable metals, account for only a small fraction of the difference between winter and non-winter concentrations. Furthermore, results of analyses of 1,381 runoff events indicate that estimated event-mean concentrations (EMCs) of chloride (Cl) in excess of 10,000 mg/L, which would contain relatively marginal amounts of N and many total-recoverable metals, occurs in less than about 2 percent of the runoff events. Many of the same constituents are associated with sand applied to the highways during the winter. Data from this study indicate that highway-maintenance sand can account for a substantial amount of the difference between winter and non-winter concentrations of P, iron (Fe), and manganese (Mn). For the monitoring stations on Interstate 495, highway maintenance sand was estimated to account for about 94, 38, and 53 percent of the increase in winter EMCs for total P, Fe, and Mn, respectively.

Results of principal component analysis of all data and data subsets for total-recoverable metals and for PAHs from the principal highways were inconclusive. However, the proportions of most highway constituents originating from likely sources were estimated from the ratios of certain PAH compounds in samples of highway runoff to known ratios of the same PAHs in different matrixes and from ratios of the dominant particulate-associated PAHs to selected elements in exhaust emissions. These analyses indicate that the dominant sources of most PAHs are consistent with automobile emissions. The source for P and most total-recoverable metals other than copper (Cu) and zinc (Zn) are largely local soils, berm materials, vegetation matter, and maintenance sands, and sources of Cu, Zn, and many phthalate compounds are likely tire and brake wear. Conservative contributions of P, Fe, Mn, nickel (Ni), and lead (Pb) from soils proximate to the highways were estimated to account for on average about 37 percent of the median P concentration, 53 percent of the median Fe concentration, 54 percent of the median Mn concentration, 15 percent of the median Ni concentration, and 44 percent of the median Pb concentration in samples of highway runoff from the principal highways. Many of the SVOCs that were detected in samples of highway runoff in this study are associated with fuels, lubricants, antifreeze, windshield

fluids, and chemical treatments of engine compartments, finish-paint coats, automotive panels, and other vehicle components. However, other SVOCs in the same samples indicate plant materials, tobacco products, wood preservatives, fecal bacteria, and potential leachates from highway litter, including compounds associated with common beverages and personal-care products.

Concentrations of suspended sediment in composite samples of highway runoff were examined as a potential surrogate for concentrations of sediment-affiliated constituents measured in samples of highway runoff. Relations between suspended sediment and total P, and suspended sediment and many total-recoverable metals indicate that it is possible to estimate reasonable planning-level concentrations for many constituents on the basis of the concentration of a constituent affiliated with suspended sediment and from the average gradated concentrations (concentrations that include suspended sediment of specific size ranges) of suspended sediment from the principal highways in this study. For many applications, the average gradated concentrations of suspended sediment from this study may be used in the absence of site-specific data because results of statistical tests of concentrations of suspended sediment among the four principal highways, and between the principal highways and most test highways, were not significantly different, except for Route 119, which had the lowest AADT volume. Relations between gradated concentrations of suspended sediment and concentrations of total P and many total-recoverable metals also indicate that a disproportional amount of the concentration for most constituents is associated with fine-grained sediments less than 0.063 millimeters in diameter.

Introduction

Stormwater discharges from Massachusetts highways can adversely affect the quality of the receiving water and may result in the failure of a water body to meet the Massachusetts surface-water-quality standards. Many studies have shown that stormwater runoff can be a source of suspended solids, nutrients, metals, and polycyclic aromatic hydrocarbons (Kayhanian and others, 2003; Smith, 2002; Breault and Granato, 2000; Davenport, 1990). The variation of contaminants in highway runoff is, however, poorly understood, partly because highway runoff is a complex mix of contaminants from multiple sources, including atmospheric deposition; deposition of local soils and automobile residuals on pavement surfaces, highway-construction residuals, and highway maintenance materials; and other sources. As a result, the quantity of constituents reported and the quality of highway runoff reported in studies may vary by orders of magnitude within a storm and between storms (Smith, 2002; Granato and Smith, 1999; Spangberg and Niemczynowicz, 1992). The wide variation of study results are also caused, at least in part, by inadequate or poorly documented data-collection methods, variation in site characteristics, and limited and out-of-date field data, which can lead to differ-

ent conclusions about the magnitude of the highway-runoff problem (Transportation Research Board, 1997).

Because little highway-runoff data have been collected in the northeastern United States and because the validity of existing data is questionable (Breault and Granato, 2000), the U.S. Geological Survey (USGS), in cooperation with the Federal Highway Administration and the Massachusetts Department of Transportation, began a study in September 2004 to document the presence of a wide range of constituents in runoff from highways with annual average daily traffic (AADT) volumes ranging from about 3,000 to about 191,000 vehicles per day.

The data presented in this report are integrated in the Highway-Runoff Database (HRDB Version 1.0.0a) (Granato and Cazenias, 2009), which serves as a preprocessor for the Stochastic Empirical Loading and Dilution Model (SELDL) (Granato, 2007). The integration of these data with a technically sound highway-runoff model can be used to guide, substantiate, and support highway planning, design, and maintenance decisions. The study findings may be useful toward meeting total maximum daily load (TMDL) requirements (as outlined by the National Pollutant Discharge Elimination System (NPDES) phase II program) and can aid in the interpretation of local, regional, and national highway-runoff data including flows, concentrations, loads, potential effects on receiving waters, and the potential effectiveness of various best management practices (BMPs).

Purpose and Scope

This report documents concentrations of selected dissolved major ions, total nitrogen (N) and phosphorus (P), selected total-recoverable metals, suspended sediment, and semivolatile organic compounds (SVOCs) measured in flow-weighted composite samples of stormwater collected from typical highway-drainage conveyance structures on eight highways in Massachusetts during a 2-year sampling period. The physiochemical characteristics of samples of highway sediment, highway-berm soil, and local soils adjacent to the highways are described, and the monitoring and sample-collection methods for all data within the report are documented.

The report presents a discussion of the relation between populations of constituent concentration data among the 12 highway-monitoring stations and AADT volumes. The report also presents the methods used to estimate event-mean concentrations (EMCs) of elements used in deicing materials from continuous records of flow and specific conductance, and the methods used to calculate planning-level estimates for various constituents associated with suspended sediment. Concentrations of dissolved major ions, total nutrients, total-recoverable metals and other elements, natural and anthropogenic organic compounds, and suspended sediment in highway runoff, roadside materials, and highway-maintenance materials are presented in tables and illustrations. In addition, an overview is presented of HRDB and SELDL.

Site Selection

A systematic approach was used to select 12 monitoring locations on 8 highways in Massachusetts. These locations were selected on the basis of published AADT volumes; proximity of sites to each other; similarities in surficial geology, soils, vegetation, and land use as identified by the U.S. Environmental Protection Agency (USEPA) level III ecoregions (U.S. Environmental Protection Agency, 2003); highway and drainage construction; site accessibility and safety; and suitability of sites for hydrologic and meteorologic monitoring, and collection of stormwater samples. The 12 sites were subdivided into 4 primary, 4 secondary, and 4 test sites (table 1). Most of the stormwater samples were collected at the primary and secondary sites, which were located on four principal highways in the eastern region of the State (fig. 1). Paired primary and secondary sites were located within a few miles of each other on a section of highway with limited access to ensure comparable levels of traffic volume and density. Although both the design and operation of the primary and secondary monitoring stations were similar, the monitoring period and number of samples of highway runoff collected at the primary stations were greater than at the secondary stations. Stormwater samples collected at the test sites were used to assess the transferability of the data collected from the principal highways to other highways that have different construction methods, land use, and geography.

The primary- and secondary-monitoring stations were located on Route 119 in Ashburnham (424209071545201 and 42415507154320); Route 2 in Littleton (423027071291301 and 423027071291302); Interstate 495 in Boxborough (422821071332001) and Bolton (422716071343901); and Interstate 95 in Lexington (422620071153301) and Waltham (422420071153302). The monitoring locations on these highways represent relatively low, moderate, high, and very high AADT volumes, respectively (table 1). These sites were chosen in part by analyzing available traffic volumes compiled by the Massachusetts Department of Transportation (DOT) (2007). Because the EMCs of constituents attributed to vehicular wear and operation are functions of traffic volume, density, and the amount of stormwater, which is directly related to amount of highway-surface area, the number of lanes for each highway also was considered along with the AADT during the site selection. Therefore, normalized AADT volumes (AADT divided by the total number of lanes) that were each incrementally different by about 30 percent or more also were used for site selection.

The proximity of the sampling stations on the principal highways was an additional factor in site selection because the quality of highway runoff can be affected by atmospheric deposition, the composition of soils adjacent to the highways, and land-use characteristics. To determine whether populations of concentrations of highway-related constituents were significantly different between highways with different AADTs, it was important to choose sites that were close enough to

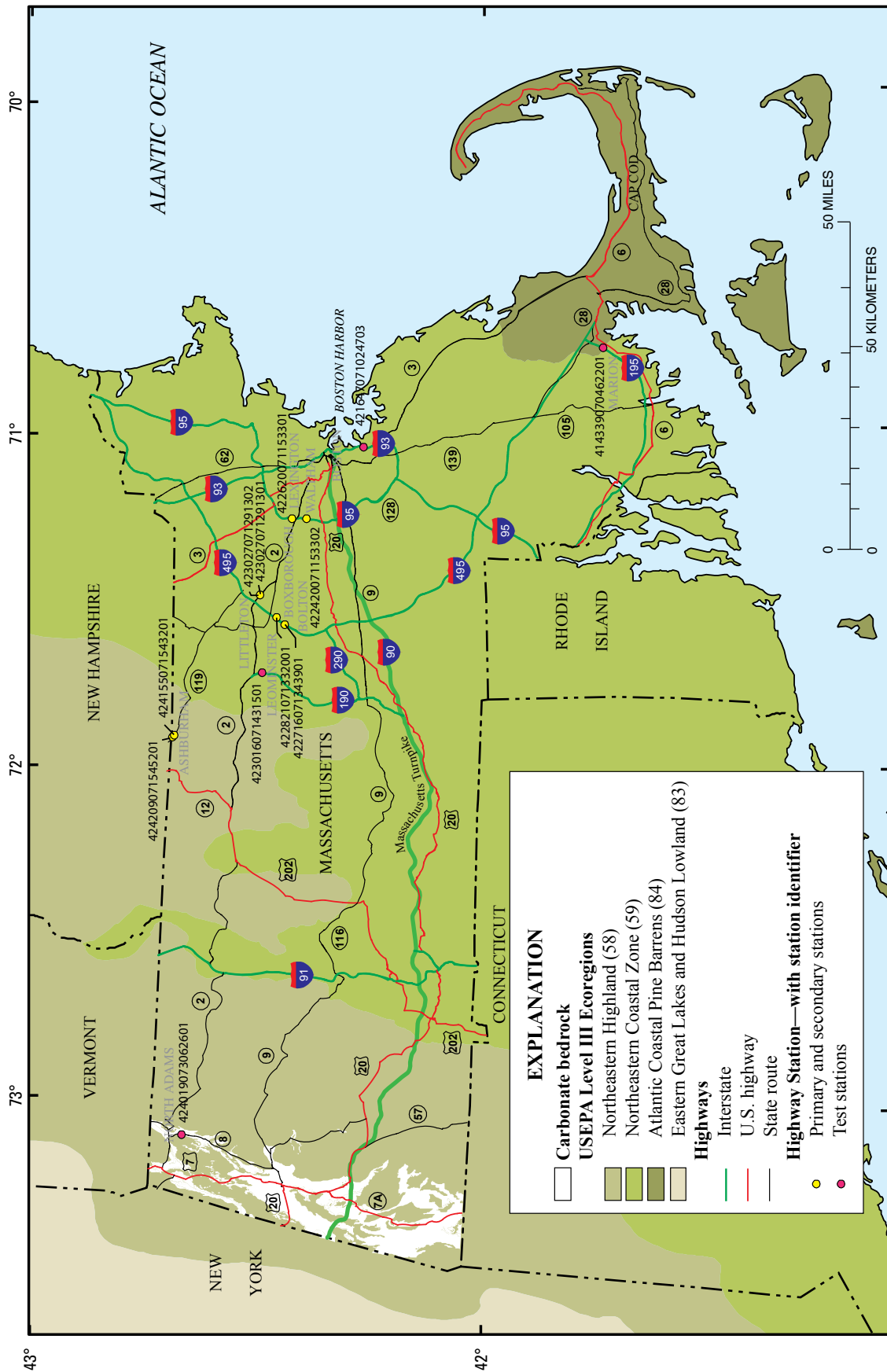
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Table 1. Names, locations, and other highway attributes for U.S. Geological Survey monitoring stations in Massachusetts.

[USGS, U.S. Geological Survey; latitude and longitude: in degrees and decimal minutes; ADT, average daily traffic (values in parenthesis represent year of measurement); MPH, miles per hour; NA, not applicable; MTC, modified top course; T1TC, type one top course; OGFC, open-grade friction course; traffic volume source: Massachusetts Department of Transportation, 2007]

USGS station number	Highway	Town or city	Site designation	Annual ADT	Annual ADT per lane	Number of the total lanes monitored	Latitude	Longitude
424209071545201	Route 119	Ashburnham	Primary	3,000 (2004)	1,500	2 of 2	42 42.155	71 54.867
423027071291301	Route 2	Littleton	Primary	39,700 (2004)	9,923	2 of 4	42 30.448	71 29.223
422821071332001	Interstate 495	Boxborough	Primary	81,900 (2006)	13,650	3 of 6	42 28.351	71 33.333
422620071153301	Interstate 95	Lexington	Primary	154,500 (2006)	19,313	8 of 8	42 26.337	71 15.554
424155071543201	Route 119	Ashburnham	Secondary	3,000 (2004)	1,500	1 of 2	42 41.917	71 54.527
423027071291302	Route 2	Littleton	Secondary	39,693 (2004)	9,923	2 of 4	42 30.448	71 29.223
422716071343901	Interstate 495	Bolton	Secondary	81,900 (2006)	13,650	2 of 4	42 27.267	71 34.645
422420071153302	Interstate 95	Waltham	Secondary	180,600 (2000)	22,576	2 of 8	42 24.341	71 15.553
424019073062601	Route 8	North Adams	Test	15,532 (2006)	3,883	4 of 4	42 40.317	73 06.433
414339070462201	Interstate 195	Marion	Test	25,700 (2006)	6,425	2 of 4	41 43.65	70 46.367
423016071431501	Interstate 190	Leominster	Test	41,168 (2004)	10,292	2 of 4	42 30.275	71 43.250
421647071024703	Interstate 93	Boston	Test	191,000 (2004)	23,874	8 of 8	42 16.78	71 02.78

USGS Station number	Highway	Drainage area (square feet)	Posted speed limit (MPH)	Paved median	Age of pavement at start of study (years)	Pavement type
424209071545201	Route 119	26,000	50	NA	15	MTC
423027071291301	Route 2	11,500	55	Yes	15	MTC
422821071332001	Interstate 495	16,600	65	No	21	T1TC
422620071153301	Interstate 95	31,500	55	No	5	OGFC
424155071543201	Route 119	13,800	50	NA	15	MTC
423027071291302	Route 2	13,590	55	Yes	15	MTC
422716071343901	Interstate 495	17,900	65	No	21	T1TC
422420071153302	Interstate 95	12,700	55	No	12	MTC
424019073062601	Route 8	23,500	50	No	13	T1TC
414339070462201	Interstate 195	12,400	65	No	18	T1TC
423016071431501	Interstate 190	25,100	65	No	0	OGFC
421647071024703	Interstate 93	64,500	55	No	13	OGFC



Base from U.S. Environmental Protection Agency, digital data, 1:250,000, 2003
 Massachusetts stateplane projection, 1983 North American datum
 Ecoregions from U.S. Environmental Protection Agency (USEPA), 2003

Figure 1. Locations of highway-monitoring stations and U.S. Environmental Protection Agency level III ecoregions in Massachusetts.

each other that these attributes (atmospheric deposition, soils, and land use) were broadly similar so that a practical level of experimental control could be achieved. As a result, all of the primary and secondary monitoring stations were located within a 38-mi swath in eastern Massachusetts and were located in or near USEPA level III Northeastern Coastal Zone ecoregion 59 (fig. 1) in areas consisting of sand and gravel, till, or bedrock (fig. 2).

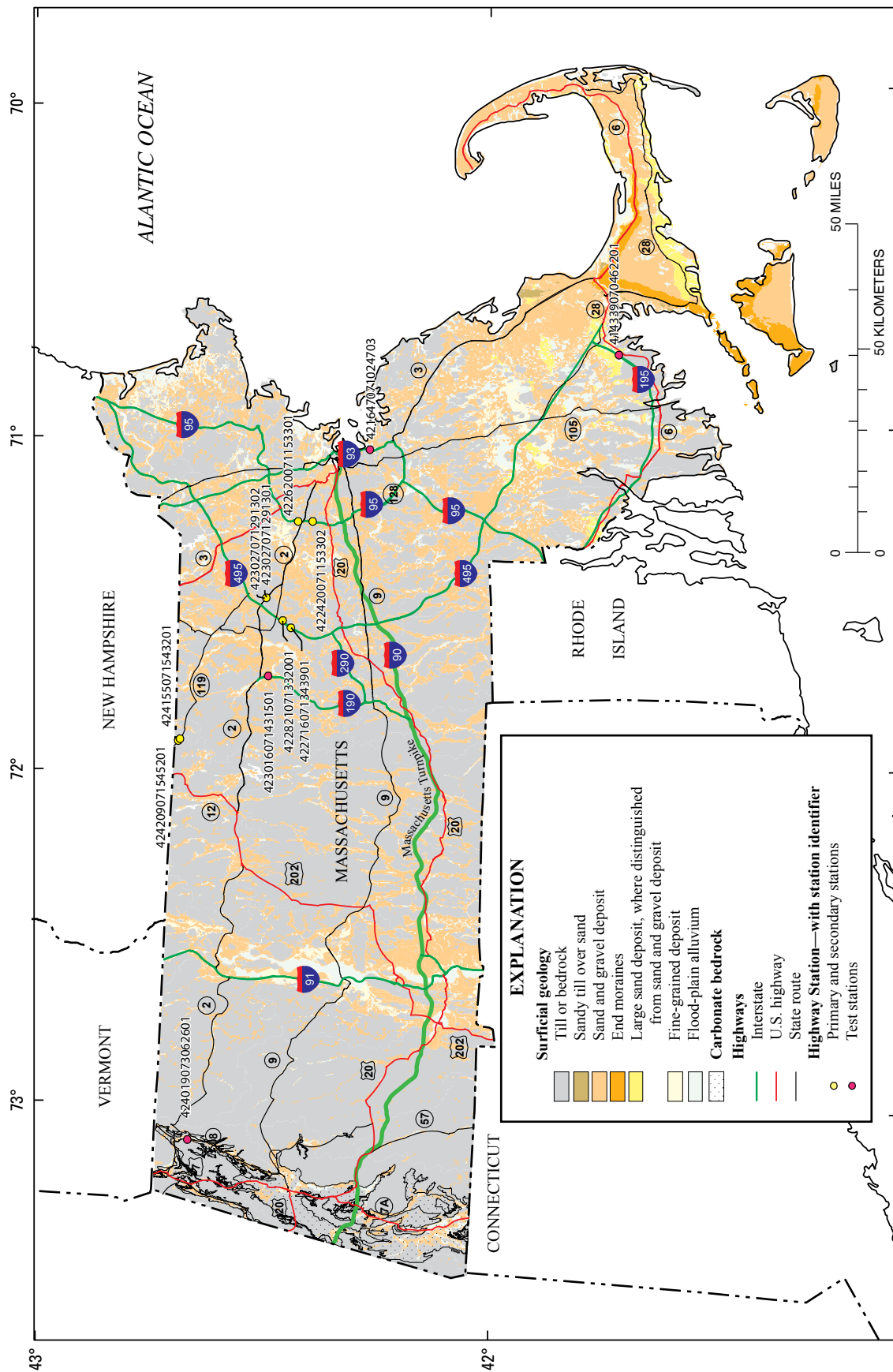
USEPA level III ecoregions are areas that are similar in geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Griffith and others, 1999). Massachusetts contains three level III ecoregions. These include ecoregion 58 (Northeastern Highlands), 59 (Northeastern Coastal Zone), and 84 (Atlantic Coastal Pine Barrens) (fig. 1). In general, ecoregion 58 is more mountainous and less populated than ecoregions 59 and 84. The climate, surficial geology, soils, vegetation, and physiography of ecoregion 84 are much different than those of ecoregions 58 and 59.

The highway attributes for the primary and secondary monitoring stations are relatively similar (table 1). The impervious drainage areas for these sites range from about 13,000 to 31,000 ft². Posted speed limits range from 50 to 65 mi/h. The age of the pavement for the principal highways ranged from 5 to 21 years. The wearing surface for all highways, including the highways where the test sites were located, was constructed of bituminous concrete; however, the type of pavement surface varied among sites. Type I-1 top course and modified top course are standard wearing surfaces composed of a mix of a specific blend and gradation of aggregates with bituminous cement. The primary difference between the two types of pavement is the gradation of the aggregates used in the mix. The gravel in aggregates used in a modified top course is slightly coarser (95–100 percent of the gravel had a diameter less than or equal to 0.75 in.) than the gravel used in a type I-1 course (a diameter of 0.5 in.). Open-grade friction course (OGFC), also referred to as “popcorn pavement,” is a more permeable surface than the other types; the macrotexture of the OGFC pavement facilitates the drainage of water from the tire-pavement interface to improve tire contact with the pavement and reduce the potential for hydroplaning (U.S. Department of Transportation Federal Highway Administration, 1990). In general, the dominant land uses surrounding the monitoring stations on the principal highways are forested and residential (table 2). However, the amount of surrounding impervious area increased with the highway AADT because the larger highways are in areas that contain more residential, commercial, industrial, and other transportation-related land uses than highways with lower AADTs.

The test sites were located on Route 8 in North Adams (424019073062601), Interstate 195 in Marion (414339070462201), Interstate 190 in Leominster (423016071431501), and Interstate 93 in Boston (421647071024703; fig. 1). Some of the characteristics of the test sites were similar to those of the primary and secondary monitoring stations with similar AADTs (tables 1 and 2); however, at least one explanatory variable at each of the test sites

differed from that of the corresponding sites on the principal highways. These explanatory variables for a site include one or more of the following categories: pavement age, surficial geology, land use, and climate. The site on Route 8 in western Massachusetts is similar to the sites on Route 119. The site on Route 8 was selected because the chemistry of local soils was often reflected in the runoff chemistry, and a distinguishing feature of this part of western Massachusetts is the carbonate bedrock, which affects the soil characteristics of this area. The test site on Interstate 190 had similar AADT volume, land-use characteristics, and surficial geology to the sites on Route 2. The Interstate 190 site was selected because this section of Interstate 190 was resurfaced at the start of the study period and, therefore, provided a unique opportunity to compare samples of highway runoff collected from new OGFC pavement to those collected from aged pavement in a similar setting. The third test site was located on Interstate 195 near the coast in southeastern Massachusetts. This site had AADT volume and land-use characteristics similar to those at the sites on Route 2 (tables 1 and 2). This site was selected because the surficial materials there consist largely of sand whereas those at the sites on Route 2 consist mostly of till or bedrock (fig. 2). This location also has a slightly milder climate than elsewhere in Massachusetts, and the quality of precipitation may be affected as a result of the proximity to the coast. A milder climate may affect the level and duration of winter maintenance activities, and coastal precipitation can differ in concentrations of various constituents, including N and chloride (Cl) (National Atmospheric Deposition Program, 2008). The last test site is on Interstate 93 in Boston. Although this site has an AADT volume similar to those at the sites on Interstate 95, the highway site is located in a highly urbanized area near the Boston Harbor. Thus, the quality of highway runoff also may be affected by differences in precipitation, in addition to differences in land use.

The suitability for hydrologic and meteorologic monitoring and for the collection of water-quality samples was the final factor in the selection of each site. Each site contained a well-defined 100-percent impervious drainage area. At each site, the drainage area encompassed the entire cross section of each highway in one or both directions, with the exception of the secondary site on Interstate 95. The sites selected in this study do not contain or receive drainage from the median strip, emergency pull-off areas, driveways, or parking lots. These features ultimately reduce chemical and hydrologic bias associated with local soil chemistry and extraneous drainages not characteristic of stormwater runoff from highways. In this study, all samples of stormwater were collected from the outlets of catch basins because these are commonly used along Massachusetts highways, provide a physical means for metering flows during storms, and are often the final discharge points to receiving water bodies.



Base from Executive Office of Energy and Environmental Affairs, 1:250,000, 1999 Massachusetts mainland stateplane projection. 1983 North American datum

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Table 2. Land-use characteristics for a one-half mile radius around each of the 12 highway-monitoring stations in Massachusetts.

[Land use and total impervious area are expressed as percentages of the total area; Data source: Massachusetts GIS Land Use (1951–99) - January 2002 accessed on March 9, 2009, at <http://www.mass.gov/mgis/lus.htm>]

Surrounding land use	U.S. Geological Survey station number and highway					
	424209071545201	424155071543201	424019073062601	423027071291301	423027071291302	423016071431501
	Route 119	Route 119	Route 8	Route 2	Route 2	Interstate 190
Cropland	0.0	0.0	20.2	4.0	4.0	0.0
Commercial	0.0	0.0	6.0	0.0	0.0	0.3
Forest	85.6	91.6	44.7	69.3	69.3	64.5
Industrial	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.0	0.0	1.2	0.0	0.0	1.3
Open land	2.7	2.1	9.2	1.0	1.0	4.2
Other transportation	0.0	0.0	0.3	4.5	4.5	8.6
Parks, cemeteries, vacant undeveloped land	0.6	0.6	14.3	0.2	0.2	0.0
Participation recreation	0.0	0.0	0.0	0.0	0.0	3.2
Pasture	0.0	0.0	0.2	1.5	1.5	4.2
Residential	0.5	0.8	2.4	10.0	10.0	10.8
Salt wetland	0.0	0.0	0.0	0.0	0.0	0.0
Water (fresh and (or) salt)	4.5	0.4	1.5	0.0	0.0	1.7
Wetland	6.1	4.4	0.0	9.3	9.3	1.2
Total impervious area	1.1	1.1	11.2	6.0	6.0	13.1

Surrounding land use	U.S. Geological Survey station number and highway					
	414339070462201	422821071332001	422716071343901	422620071153301	422420071153302	421647071024703
	Interstate 195	Interstate 495	Interstate 495	Interstate 95	Interstate 95	Interstate 93
Cropland	0.0	1.5	1.4	1.2	0.0	0.0
Commercial	0.6	0.0	0.0	10.7	0.0	5.3
Forest	42.3	49.1	68.7	34.7	13.2	0.5
Industrial	0.7	3.4	0.0	0.0	25.2	12.8
Mining	2.1	0.9	0.0	0.0	0.0	0.0
Open land	2.0	1.4	1.1	6.1	2.5	5.2
Other transportation	12.5	8.1	8.0	12.4	6.0	13.8
Parks, cemeteries, vacant undeveloped land	0.8	0.0	2.9	0.3	0.0	6.6
Participation recreation	0.9	0.0	0.0	0.4	0.5	2.1
Pasture	0.1	0.0	2.8	0.0	0.0	0.0
Residential	25.8	17.3	14.5	25.4	11.3	21.6
Salt wetland	0.5	0.0	0.0	0.0	0.0	12.1
Water (fresh and (or) salt)	0.0	2.1	0.0	6.7	40.5	19.9
Wetland	3.7	16.2	0.6	2.1	0.7	0.0
Total impervious area	10.1	6.3	5.3	18.5	28.6	41.4

Methods

This section includes a description of the design of each highway-monitoring station and the collection and analysis methods used for samples of highway runoff, sediment transported in highway runoff, background soils, berm soils, and other miscellaneous samples.

Continuous Monitoring of Highway Drainage Systems

Automatic monitoring equipment was used extensively to make continuous measurements of several physical characteristics and to collect composite samples of highway runoff. The primary monitoring stations and the monitoring station on Interstate 190 were operated from about April 2005 through September 2007, and secondary monitoring stations were operated for a year or more during the same period. The monitoring stations on the remaining three test sites were operated from December 2005 through July 2007. Prior to the monitoring period, the catch basins within the drainage area of each site were drained and cleaned with a vacuum truck (fig. 3). Runoff coefficients were calculated, in part, to determine practical flow thresholds for triggering the automatic samplers. Samples of highway runoff were collected by the automatic samplers on a flow-weighted basis. Finally, continuous records of flow and specific conductance were used to calculate an event-mean value for specific conductance for each storm.

Design of Highway-Drainage Monitoring Systems

The design of the monitoring stations at the primary and test sites was identical. These sites contained sensors for the measurement of water level, water temperature, specific conductance, air temperature, and rainfall. The secondary monitoring stations were similarly equipped; however, these sites did not contain sensors for measuring air temperature or rainfall. Measurements of water levels were made in order to estimate flow. Water temperature was measured to correct conductivity values to 25°C. Precipitation was measured to estimate the total runoff for the drainage area of each station. Air temperature was measured to determine whether the precipitation was rain or snow. Prior to the installation of equipment in monitoring shelters, all equipment was tested under controlled conditions at the USGS Massachusetts Water Science Center. Water-level sensors were tested in a stand-pipe assembly where the water level was artificially manipulated in the expected operational range, temperature sensors were tested in a water bath, specific conductance sensors were tested against laboratory standards in the range of 50 to 50,000 $\mu\text{S}/\text{cm}$, and rain gages were volumetrically tested.

Monitoring equipment was installed in small shelters, most measuring $2 \times 2 \times 4$ ft and located near the highway

drainage outfall and along the highway shoulder. The monitoring shelter was used to house the datalogger (the measurement, control, and data-storage module), a digital modem, 12-volt power supply, solar regulator, and the automatic sampler. The assembly of a typically equipped monitoring station is shown in figure 4. Conductivity and water temperature probes were mounted inside each discharge pipe. A submersible water-level probe was mounted below the outlet in the most downstream catch basin or behind a volumetric weir mounted in the catch basin outlet. The submersible water-level probe was mounted within a perforated 3-in. diameter acrylic tube designed to minimize water-level fluctuations resulting from water falling in the catch basin. The air temperature sensor and tipping-bucket rainfall gage were mounted on a mast attached to the shelter and about 10 to 12 ft above ground surface to reduce bias from vehicular spray.

Each monitoring installation was programmed to record measurements every minute. Baseline data (data that are recorded regardless of the state of runoff), including water level, water temperature, specific conductance, and rainfall, were recorded every 2 hours. Average air temperature was computed from 60 consecutive 1-minute measurements and recorded every hour. Water level, water temperature, specific conductance, and rainfall were recorded on a 1-minute basis whenever the water level exceeded a water-level threshold or when rainfall was measured. Recorded values were retrieved automatically on a daily basis by a computer at the USGS Massachusetts Water Science Center. The telemetry at each site allowed for remote activation of the sampling algorithm and access to measured and recorded values.

Calculation of Discharge

Discharge from the catch basins was calculated by applying a stage-discharge relation specific to the geometry of the outlet of each catch basin to continuous water-level measurements recorded in the sump of the catch basin. For sites where calibrated weirs were not used, this relation was developed by simultaneously measuring pump flow with in-line flowmeters on as many as three 9,600-gal/h centrifugal pumps and measuring catch-basin-sump level. Paired stage and discharge values were recorded after both pump flow and catch-basin-sump level were stable across a range of pumping rates. This process was repeated until all of the pumps reached their maximum rate of flow. The stage-discharge relations were based on 20 or more discrete discharge measurements and were mathematically extended above the greatest flow rate (about 0.85 ft^3/s) on the basis of research performed by Lager and others (1977). Depending on the specific site, 80 to 100 percent of the recorded peak discharges were less than 0.85 ft^3/s .

Calculation of Runoff Coefficients

A runoff coefficient is the ratio of the volume of runoff to the volume of rainfall. Runoff coefficients for each event in



Figure 3. A catch basin at the highway-monitoring station on Interstate 495 being cleaned by Massachusetts Department of Transportation personnel with a vacuum truck prior to the start of monitoring.



Figure 4. A typical highway-monitoring station used to collect measurements of water level, water temperature, air temperature, specific conductance, and rainfall, and composite samples of highway runoff.

this study were calculated by dividing the sum of all 1-minute flows with instantaneous discharges greater than 0.009 ft³/s by the product of the measured rain total and the drainage area for each respective monitoring station. These runoff coefficients were helpful in selecting appropriate flow thresholds for triggering the automatic samplers and identifying potential errors related to measurements of rainfall or water level. Ideally, the ratio of the volume of runoff to the volume of rainfall will range from zero (no runoff) to one (100 percent of the precipitation is measured in the runoff); however, runoff coefficients can exceed a value of one as a result of errors in the measurement of precipitation, flow, and (or) contributing area (Church and others, 1999). Runoff coefficients greater than one also can occur when flow from an upgradient drainage area is diverted into the drainage area of interest. This often results when the inlet of one or more upgradient catch basins is partially blocked by deposits of sand, debris, or slush around the catch-basin grate (fig. 5). In such cases, some or all of the water from a neighboring drainage area can be diverted to a downgradient drainage system. Similarly, obstructions to the inlet of catch basins in the monitored drainage area result in low runoff coefficients. Runoff coefficients also can be decreased when stormwater that leaks from the drainage area as a result of highway curbs that are too low or damaged is not measured. The point in the drainage system where runoff flow is measured also can affect these ratios. In this study, flows were measured at the outlet of the catch basins. Because runoff water leaked from the sump of many catch basins between storms (particularly the sites of Route 2 and Interstate 495), the initial volume of runoff that was required to fill the catch basin to the level of the outlet pipe was not measured. Runoff coefficients can vary more during the winter months on the basis of available snowmelt water. In mixed precipitation events, the removal of snow or slush from plowing operations serves to lower the runoff coefficient.

In large drainage areas, many of these factors tend to average out. For example, flow that bypasses one catch basin often is accounted for in the next downgradient catch basin, resulting in a zero net loss measurement of stormwater volume. However, because the drainage areas in this study are relatively small, a large amount of variability in the runoff coefficients is not unreasonable. While runoff coefficients are an important quality-assurance tool, they are also useful for estimating constituent loads in the absence of flow data. Specifically, flows can be estimated by multiplying the amount of precipitation from a nearby monitoring station by the size of the drainage area of interest, and finally by the runoff coefficient.

Calculation of Event-Mean Values of Specific Conductance

Specific conductance is the measure of the capacity of water to conduct an electrical current. The measurement is affected by the type and quantity of dissolved solids in water.

Because conductivity sensors are robust and measurements of specific conductance are often relatively accurate under most conditions, continuous records of discharge and specific conductance were used in this study to supplement and expand the number of event-mean measurements of the physical characteristics of samples of highway runoff.

Event-mean specific conductance values were calculated for each highway site on the basis of calculated values of discharge and corresponding measurements of specific conductance. Specifically, for each runoff event (rain, mixed precipitation, and snowmelt) with instantaneous values of discharge greater than 0.009 ft³/s, the event-mean specific conductance was calculated by dividing the sum of flow-weighted 1-minute specific conductance values (that is, the specific conductance multiplied by the instantaneous rate of flow) by the sum of the 1-minute values of flow. For values of discharge less than or equal to 0.009 ft³/s, measurements of specific conductance were often erroneous because the water level at the location of measurement was too low to adequately submerge the sensor. Furthermore, flows less than or equal to 0.009 ft³/s accounted for little of the total event flow. The accuracy of measurements of specific conductances depend primarily on the rate of sensor drift, sensor fouling, and debris collection. In most cases, corrections for fouling and drift were applied to the data to improve the accuracy (Wagner and others, 2006). These corrections were made on the basis of the performance of the sensor before and after sensor maintenance and by the response of the clean sensor after it was placed in three or more standardized conductance solutions in the field.

Collection and Analysis of Samples

Samples of highways runoff were collected automatically during storms and analyzed for concentrations of selected dissolved major ions, total N and P, selected total-recoverable metals, suspended sediment, and SVOCs (tables 3 and 4). Samples of sediment in highway runoff were sieved into specific particle-size ranges, and analyzed for concentrations of 32 total-recoverable elements, total organic carbon (TOC), and selected SVOCs. Samples of soil adjacent to the highways, samples of highway-berm soil, and samples of highway-maintenance materials were collected and analyzed for concentrations of 32 elements. Finally, miscellaneous samples of highway-berm vegetation and catch-basin debris greater than 250 micrometers in diameter were collected and analyzed for concentrations of 32 total-recoverable elements, TOC (catch-basin debris only), and selected SVOCs (highway-berm vegetation only).

Samples of Highway Runoff

About 140 flow-weighted composite samples of highway runoff were collected automatically throughout the year during rain and mixed precipitation storms from September 2005 to September 2007 at the 12 monitoring stations.



Figure 5. Sand debris around a catch basin on Route 2 in Littleton, Massachusetts, that may divert highway runoff to the next downgradient catch basin.

Table 3. Physical characteristics of, and constituents analyzed in, samples of highway stormwater collected in Massachusetts during 2005–07 with respective long-term method detection limits, analytical techniques, and Chemical Abstract Service numbers.

[CAS, Chemical Abstract Service; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; LTMDL, long-term method detection limit; mg/L , milligrams per liter; NTRU, nephelometric turbidity ratio units, $\mu\text{g}/\text{L}$, micrograms per liter; IC, ion chromatograph; ICP, inductively coupled plasma; ICP-MS, inductively coupled plasma-mass spectrometry; ICP-AES, inductively coupled plasma-optical emission spectrometry; cICP-MS, collision/reaction cell inductively coupled plasma-mass spectrometry; MCEGC/MS, methylene chloride extraction and gas chromatograph/mass spectrometry; USEPA, U.S. Environmental Protection Agency; --, not available]

Characteristic or constituent	LTMDL	Analytical technique	Reference	CAS number ¹
Turbidity, unfiltered, NTRU	0.05	USEPA 180.1	Anderson, 2004	--
pH in standard units	0.1	Glass electrode	Wilde and others, 2006	--
Specific conductance in $\mu\text{S}/\text{cm}$	8	Wheatstone Bridge	Radtke and others, 2005	--
Calcium, filtered, mg/L	0.01	ICP-AES	Fishman, 1993	7440-70-2
Magnesium, filtered, mg/L	0.007	ICP-AES	Fishman, 1993	7439-95-4
Potassium, filtered, mg/L	0.08	ICP-AES	Fishman and Friedman, 1989	7440-09-7
Sodium, filtered, mg/L	0.1	ICP-AES	Fishman, 1993	7440-23-5
Alkalinity, filtered, laboratory, mg/L as calcium carbonate	5	Titration	Fishman and Friedman, 1989	471-34-1
Chloride, filtered, mg/L	0.1	IC	Fishman and Friedman, 1989	16887-00-6
Sulfate, filtered, mg/L	0.09	IC	Fishman and Friedman, 1989	14808-79-8
Total nitrogen (nitrate + nitrite + ammonia + organic-N), unfiltered, mg/L	0.03	Alkaline persulfate digestion	Patton and Kryskalla, 2003	17778-88-0
Phosphorus, unfiltered, mg/L	0.01	Alkaline persulfate digestion	Patton and Kryskalla, 2003	7723-14-0
Cadmium, unfiltered, $\mu\text{g}/\text{L}$	0.02	ICP-MS	Garbarino and Struzeski, 1998	7440-43-9
Chromium, unfiltered, $\mu\text{g}/\text{L}$	0.3	cICP-MS	Garbarino and others, 2006	7440-47-3
Copper, unfiltered, $\mu\text{g}/\text{L}$	0.6	cICP-MS	Garbarino and others, 2006	7440-50-8
Iron, unfiltered, $\mu\text{g}/\text{L}$	3	ICP-AES	Garbarino and Struzeski, 1998	7439-89-6
Lead, unfiltered, $\mu\text{g}/\text{L}$	0.03	ICP-MS	Garbarino and Struzeski, 1998	7439-92-1
Manganese, unfiltered, $\mu\text{g}/\text{L}$	0.3	ICP-MS	Garbarino and Struzeski, 1998	7439-96-5
Nickel, unfiltered, $\mu\text{g}/\text{L}$	0.08	cICP-MS	Garbarino and others, 2006	7440-02-0
Zinc, unfiltered, $\mu\text{g}/\text{L}$	1	cICP-MS	Garbarino and others, 2006	7440-66-6
Fluorene, unfiltered, $\mu\text{g}/\text{L}$	0.17	MCEGC/MS	Fishman, 1993	86-73-7
Acenaphthene, unfiltered, $\mu\text{g}/\text{L}$	0.14	MCEGC/MS	Fishman, 1993	83-32-9
Acenaphthylene, unfiltered, $\mu\text{g}/\text{L}$	0.15	MCEGC/MS	Fishman, 1993	208-96-8
Anthracene, unfiltered, $\mu\text{g}/\text{L}$	0.19	MCEGC/MS	Fishman, 1993	120-12-7
Benzo[<i>a</i>]anthracene, unfiltered, $\mu\text{g}/\text{L}$	0.13	MCEGC/MS	Fishman, 1993	56-55-3

Table 3. Physical characteristics of, and constituents analyzed in, samples of highway stormwater collected in Massachusetts during 2005–07 with respective long-term method detection limits, analytical techniques, and Chemical Abstract Service numbers.—Continued

[CAS, Chemical Abstract Service; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; LTMDL, long-term method detection limit; mg/L , milligrams per liter; NTRU, nephelometric turbidity ratio units, $\mu\text{g}/\text{L}$, micrograms per liter; IC, ion chromatograph; ICP, inductively coupled plasma; ICP-MS, inductively coupled plasma-mass spectrometry; ICP-AES, inductively coupled plasma-optical emission spectrometry; cICP-MS, collision/reaction cell inductively coupled plasma-mass spectrometry; MCEGC/MS, methylene chloride extraction and gas chromatograph/mass spectrometry; USEPA, U.S. Environmental Protection Agency; --, not available]

Characteristic or constituent	LTMDL	Analytical technique	Reference	CAS number ¹
Benzo[a]pyrene, unfiltered, $\mu\text{g}/\text{L}$	0.16	MCEGC/MS	Fishman, 1993	50-32-8
Benzo[b]fluoranthene, unfiltered, $\mu\text{g}/\text{L}$	0.9	MCEGC/MS	Fishman, 1993	205-99-2
Benzo[k]fluoranthene, unfiltered, $\mu\text{g}/\text{L}$	0.32	MCEGC/MS	Fishman, 1993	191-24-2
Benzo[k]fluoranthene, unfiltered, $\mu\text{g}/\text{L}$	0.23	MCEGC/MS	Fishman, 1993	207-08-9
Benzyl n-butyl phthalate (butylbenzyl phthalate), unfiltered, $\mu\text{g}/\text{L}$	0.63	MCEGC/MS	Fishman, 1993	85-68-7
Bis(2-ethylhexyl) phthalate, unfiltered, $\mu\text{g}/\text{L}$	0.53	MCEGC/MS	Fishman, 1993	117-81-7
Chrysene, unfiltered, $\mu\text{g}/\text{L}$	0.16	MCEGC/MS	Fishman, 1993	218-01-9
Dibenzof[a,h]anthracene, unfiltered, $\mu\text{g}/\text{L}$	0.35	MCEGC/MS	Fishman, 1993	53-70-3
Diethyl phthalate, unfiltered, $\mu\text{g}/\text{L}$	0.31	MCEGC/MS	Fishman, 1993	84-66-2
Dimethyl phthalate, unfiltered, $\mu\text{g}/\text{L}$	0.3	MCEGC/MS	Fishman, 1993	131-11-3
Di-n-butyl phthalate, unfiltered, $\mu\text{g}/\text{L}$	0.44	MCEGC/MS	Fishman, 1993	84-74-2
Di-n-octyl phthalate, unfiltered, $\mu\text{g}/\text{L}$	0.93	MCEGC/MS	Fishman, 1993	117-84-0
Fluoranthene, unfiltered, $\mu\text{g}/\text{L}$	0.15	MCEGC/MS	Fishman, 1993	206-44-0
Indeno[1,2,3-cd]pyrene, unfiltered, $\mu\text{g}/\text{L}$	0.11	MCEGC/MS	Fishman, 1993	193-39-5
Nitrobenzene, unfiltered, $\mu\text{g}/\text{L}$	0.11	MCEGC/MS	Fishman, 1993	98-95-3
Phenanthrene, unfiltered, $\mu\text{g}/\text{L}$	0.16	MCEGC/MS	Fishman, 1993	85-01-8
Pyrene, unfiltered, $\mu\text{g}/\text{L}$	0.18	MCEGC/MS	Fishman, 1993	129-00-0
Naphthalene, unfiltered, $\mu\text{g}/\text{L}$	0.16	MCEGC/MS	Fishman, 1993	91-20-3
Perylene, unfiltered, $\mu\text{g}/\text{L}$	0.2	MCEGC/MS	Fishman, 1993	198-55-0
Suspended sediment, mg/L	1	Filtration/gravimetry	Guy, 1969; Shreve and Downs, 2005	--
Suspended sediment gradation, percent	0.1	Filtration/sieving/gravimetry	Guy, 1969; Shreve and Downs, 2005	--

¹This table contains CAS Registry Numbers[®], which collectively compose a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CAS Registry Numbers through CAS Client Services.

Table 4. Anthropogenic organic compounds in unfiltered samples of highway runoff determined by solid-phase extraction and capillary-column gas chromatography/mass spectrometry, and respective long-term method detection limits in micrograms per liter and CAS numbers.

[CAS, Chemical Abstract Service; LTMDL, long-term method detection limit]

Constituent	LTMDL	CAS number ¹
1-Methylnaphthalene	0.03	90-12-0
2,6-Dimethylnaphthalene	0.05	581-42-0
2-Methylnaphthalene	0.03	91-57-6
3,4-Dichlorophenyl isocyanate	0.06	102-36-3
3 <i>beta</i> -Coprostanol	0.38	360-68-9
3-Methyl-1H-indole	0.07	83-34-1
3- <i>tert</i> -Butyl-4-hydroxyanisole	0.16	25013-16-5
4-Cumylphenol	0.13	599-64-4
4- <i>n</i> -Octylphenol	0.11	1806-26-4
4-Nonylphenol	1.2	84852-15-3
4- <i>tert</i> -Octylphenol	0.11	140-66-9
5-Methyl-1H-benzotriazole	0.35	136-85-6
Acetophenone	0.07	98-86-2
Acetyl hexamethyl tetrahydro naphthalene	0.11	21145-77-7
Anthracene	0.08	120-12-7
9,10-Anthraquinone	0.08	84-65-1
Atrazine	0.08	1912-24-9
2,2',4,4'-Tetrabromodiphenyl ether	0.1	5436-43-1
Benzo[<i>a</i>]pyrene	0.06	50-32-8
Benzophenone	0.1	119-61-9
<i>beta</i> -Sitosterol	0.11	83-46-5
<i>beta</i> -Stigmastanol	0.22	19466-47-8
Bis(2-ethylhexyl) phthalate (DEHP)	0.85	117-81-7
Bisphenol A	0.22	80-05-7
Bromacil	0.1	314-40-9
Caffeine	0.06	58-08-2
Camphor	0.09	76-22-2
Carbaryl	0.13	63-25-2
Carbazole	0.12	86-74-8
Chlorpyrifos	0.12	2921-88-2
Cholesterol	0.3	57-88-5
Cotinine	0.29	486-56-6
N,N-diethyl-meta-toluamide (DEET)	0.12	134-62-3
Diazinon	0.11	333-41-5
Dichlorvos	0.11	62-73-7

Table 4. Anthropogenic organic compounds in unfiltered samples of highway runoff determined by solid-phase extraction and capillary-column gas chromatography/mass spectrometry, and respective long-term method detection limits in micrograms per liter and CAS numbers.—Continued

[CAS, Chemical Abstract Service; LTMDL, long-term method detection limit]

Constituent	LTMDL	CAS number ¹
Diethoxynonylphenol (4-Nonylphenol diethoxylate; NP2EO)	1.2	26027-38-2
Diethoxyoctylphenol (4- <i>tert</i> -Octylphenol diethoxylate; OP2EO)	0.05	26636-32-8
Diethyl phthalate (DEP)	0.1	84-66-2
<i>d</i> -Limonene	0.02	5989-27-5
Fluoranthene	0.08	206-44-0
Hexahydrohexamethyl cyclopentabenzopyran (HHCB)	0.1	1222-05-5
Indole	0.08	120-72-9
Isoborneol	0.05	124-76-5
Isophorone	0.08	78-59-1
Isoquinoline	0.09	119-65-3
Menthol	0.05	89-78-1
Metalaxyl	0.13	57837-19-1
Methyl salicylate	0.07	119-36-8
Metolachlor	0.12	51218-45-2
Monoethoxynonylphenol (4-Nonylphenol monoethoxylate (sum of all isomers); NP1EO)	1.35	104-35-8
Monoethoxyoctylphenol (4- <i>tert</i> -Octylphenol monoethoxylate; OP1EO)	0.5	26636-32-8
<i>p</i> -Cresol	0.08	106-44-5
Pentachlorophenol	0.33	87-86-5
Phenanthrene	0.07	85-01-8
Phenol	0.07	108-95-2
Prometon	0.08	1610-18-0
Pyrene	0.08	129-00-0
Tributyl phosphate	0.11	126-73-8
Triclosan	0.09	3380-34-5
Triethyl citrate (ethyl citrate)	0.07	77-93-0
Triphenyl phosphate	0.1	115-86-6
Tris(2-butoxyethyl) phosphate	0.05	78-51-3
Tris(2-chloroethyl) phosphate	0.08	115-96-8
Tris(dichloroisopropyl) phosphate	0.05	13674-87-8
1,4-Dichlorobenzene	0.03	106-46-7
Isopropylbenzene (cumene)	0.02	98-82-8
Naphthalene	0.03	91-20-3
Tetrachloroethene	0.22	127-18-4
Tribromomethane (Bromoform)	0.03	75-25-2

¹This table contains CAS Registry Numbers®, which collectively compose a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CAS Registry Numbers through CAS Client Services.

Composite samples of runoff were collected during storms that represented the range of antecedent dry periods (0–45 days), event-mean specific conductances calculated for individual runoff events (figs. 6–9), and rain totals of 0.1 to 6 in. (fig. 10) throughout the sampling period. Water samples were analyzed for concentrations of selected dissolved major ions, total N and P, selected total-recoverable metals, suspended sediment, and SVOCs.

Sample Populations

Composite samples of highway runoff were collected during 16 to 18 storms at the primary monitoring stations, 10 to 11 storms at the secondary monitoring stations, and 5 to 6 storms at the monitoring stations at the test highways over the 2-year sampling period and analyzed for the constituents in table 3. For three storms, composites of highway runoff collected at the four primary sampling stations and at the test station on Interstate 93 also were analyzed for the selected anthropogenic and naturally occurring organic compounds listed in table 4 using the methods described by Zaugg and others (2006a). The size of the anticipated population of storms that would be sampled at sites on the principal highways was determined on the basis of research presented by Thomson and others (1997). Their concept was tested using EMCs of suspended sediment collected during 50 storms from a catch basin on Interstate 93 in Boston (Smith, 2002). Concentrations of suspended sediment from this data set were selected randomly to form 320 discrete populations ranging in size from 3 to 48 samples. This resulted in 20 populations each containing 3 samples, 20 populations each containing 6 samples, 20 populations each containing 9 samples, and so on. Normalized median concentrations of suspended sediment (the median for each discrete population divided by the median of all 50 EMCs) for a randomly generated set of sub-populations are shown in figure 11. These data indicate that the risk of over- and under-estimating suspended-sediment concentrations at a site increases with fewer samples, but the risk of overestimating concentrations increases more rapidly because suspended sediment and constituents affiliated with suspended sediment in highway runoff are lognormally distributed. The range of samples collected from the sites on principal highways in this study should provide reasonable estimates of mean concentrations for many constituents, and the collection of additional samples at these highways may not necessarily provide greater precision. In contrast, the size of the sample population for the test highways is small and less precise, and therefore, analyses between data from the test sites and primary and secondary sites on the principal highways may be improved by collection of additional data.

Selection of Storms

Storms were selected to reflect seasonal and antecedent dry variations existing throughout the study period. Precipitation totals ranged from about 0.1 to 5.1 in. for storms that were sampled at the principal highways. In general, most of

the storms that were sampled during this study were within the interquartile range of precipitation totals greater than 0.10 in. recorded from 1967 through 2007 by the National Climatic Data Center near Worcester, Massachusetts (Granato, 2007, fig. 10). In this study, storms are defined in terms of measured wet precipitation as one or more measurements of wet precipitation equal to or greater than 0.01 in. (the minimum resolution of the rain gages), separated by a period of 6 hours of antecedent dry time. Because some sites did not contain rain gages and because rain gages are susceptible to plugging from snow and other debris, storms are primarily defined in this study by a function of flow where sequential measurements of discharge greater than or equal to 0.01 ft³/s are separated by 6 hours or more of discharge less than 0.01 ft³/s. A discharge of 0.01 ft³/s was chosen as a cutoff because it was the minimum value that was discernable between the presence of flow and no flow on the basis of the resolution of level sensor, the stage-discharge relation for most sites, and reliable concurrent measurements of specific conductance.

Sample Collection

Samples of highway runoff for the analysis of water chemistry and suspended-sediment concentration were collected in the outlet pipe of a single catch basin or the drainage pipe that received discharge from multiple catch basins, using an automatic sampler controlled by a datalogger. The first sample was collected when flow exceeded 0.009 ft³/s, and subsequent samples were collected at flow-proportional intervals. Approximately 60 samples of stormwater were collected for equivalent runoff of 1 in. of rain. Flow-proportional thresholds, at which point the datalogger triggered the automatic water sampler, were fixed at each site throughout the study irrespective of expected storm characteristics; only the volume for each subsample was altered. Generally, a composite of stormwater consisted of multiple 220-mL aliquots; however, the aliquot volume for the subsamples was reduced for storms with forecasted rain amounts greater than 1.5 in. so that the total number of samples could be increased and the 20-L sample bottle would be adequate in size to represent the entire storm. For small storms with forecasted rainfall amounts less than 0.5 in., the aliquot volume for each subsample was increased to ensure that sufficient water volume was collected to satisfy analytical requirements. Because the frequency of the collection of the subsamples was a function of a flow threshold derived from an equivalent runoff of 1 in. of rain from each site, the density of subsamples forming the composite of stormwater was comparable from site to site. Various factors were considered during the selection and construction of the sites to ensure the best possible performance of the automatic samplers. Vertical distances from fixed sampling points to the sampler-pump heads were within optimal suction limits (Bent and others, 2001) and for most sites were less than about 5 ft, but were as much as 8 ft for the monitoring station on Route 8, Interstate 93, and the primary station on Interstate 95. All sampler lines were mounted in a sloping

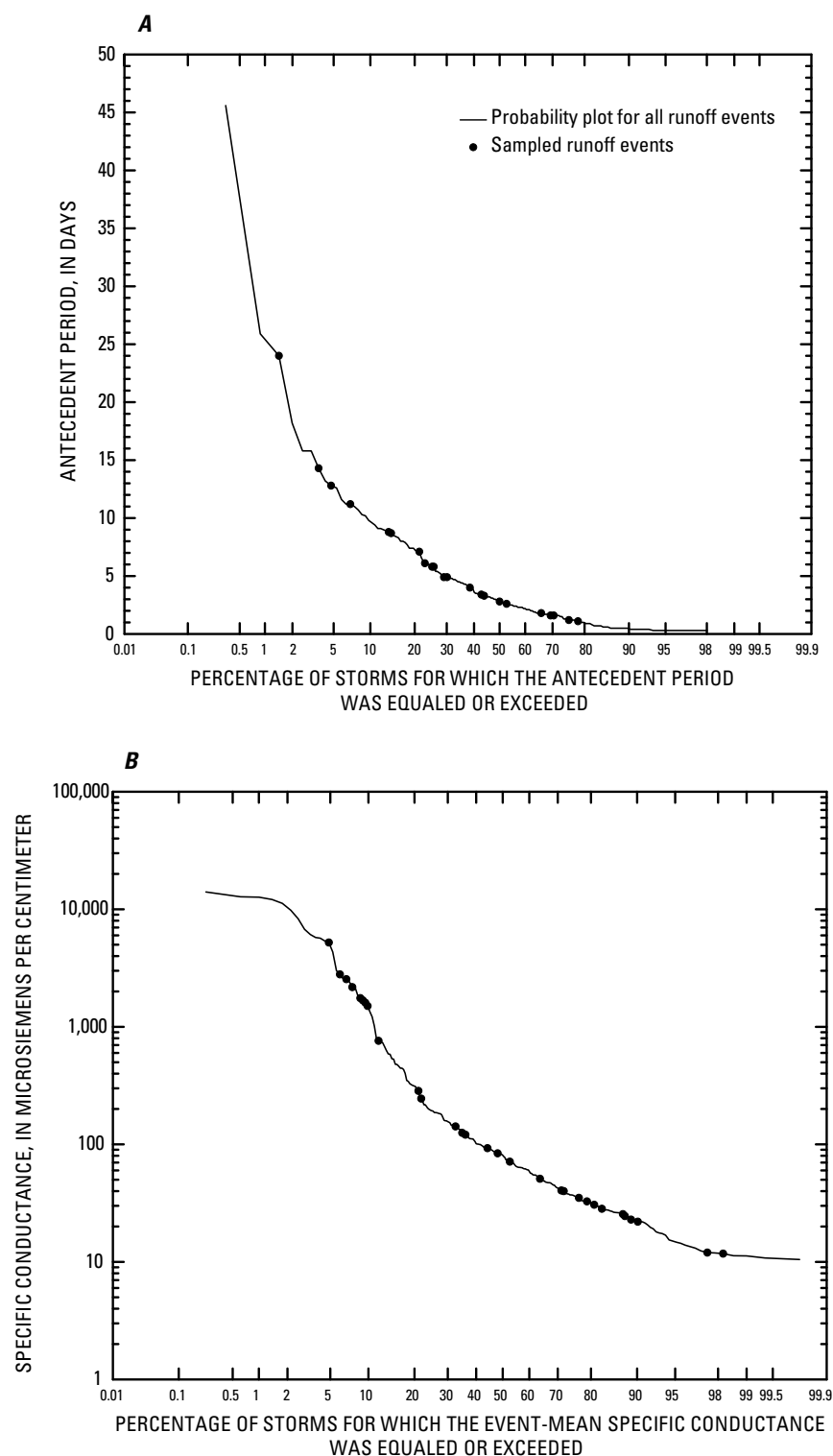


Figure 6. (A) Percentage of storms for which antecedent dry periods were equaled or exceeded in relation to the antecedent dry periods for storms during which runoff samples were collected from monitoring stations on Route 119, Ashburnham, Massachusetts, 2005–07; (B) percentage of storms for which the event-mean values of specific conductance were calculated from continuous records of flow and specific conductance in relation to specific conductance measured in runoff samples collected from the monitoring stations on Route 119, Ashburnham, Massachusetts, 2005–07.

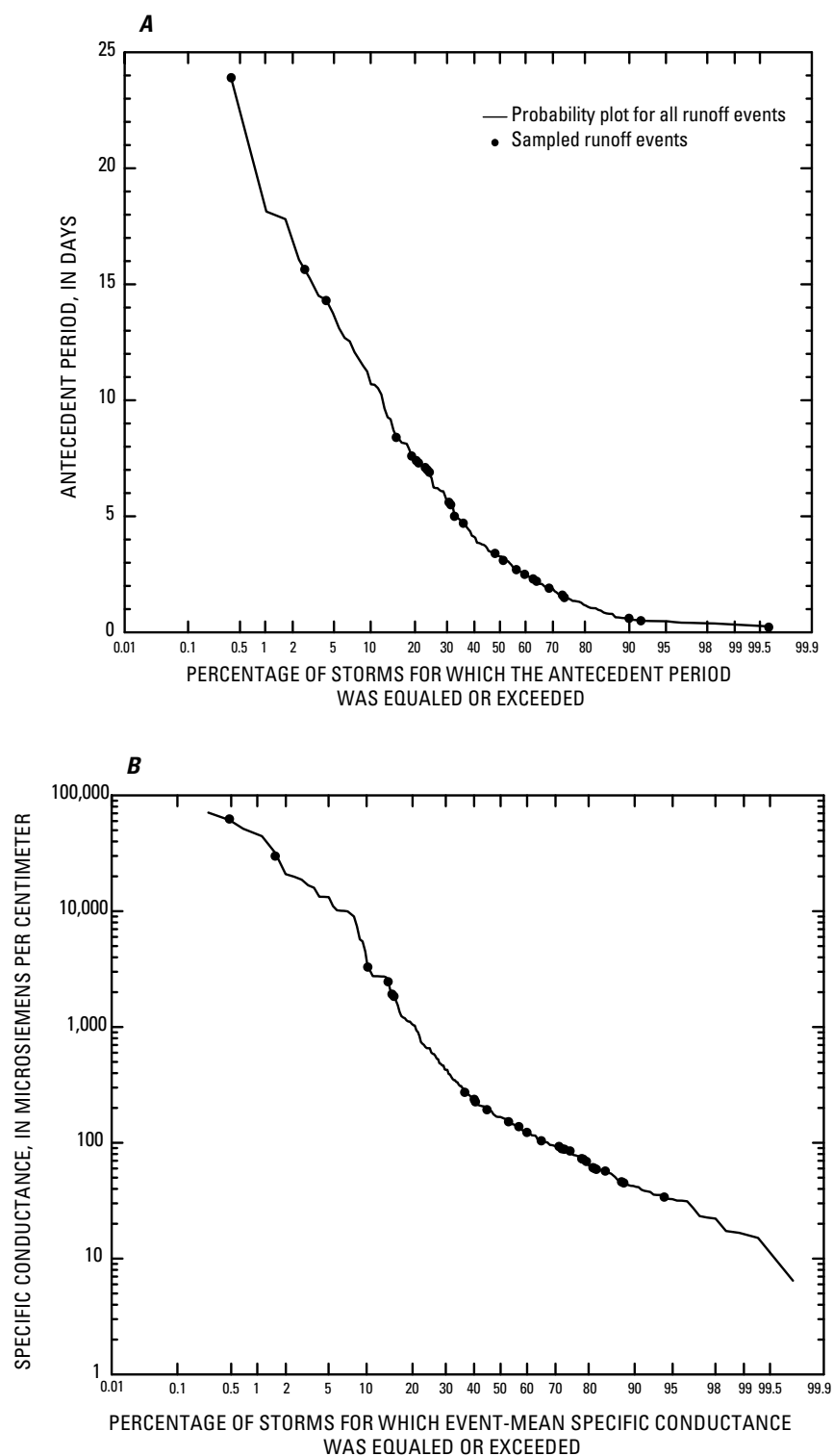


Figure 7. (A) Percentage of storms for which antecedent dry periods were equaled or exceeded in relation to the antecedent dry periods for storms during which runoff samples were collected from monitoring stations on Route 2 in Littleton, Massachusetts, 2005–07; (B) percentage of storms for which the event-mean values of specific conductance were calculated from continuous records of flow and specific conductance in relation to specific conductance measured in runoff samples collected from the monitoring stations on Route 2 in Littleton, Massachusetts, 2005–07.

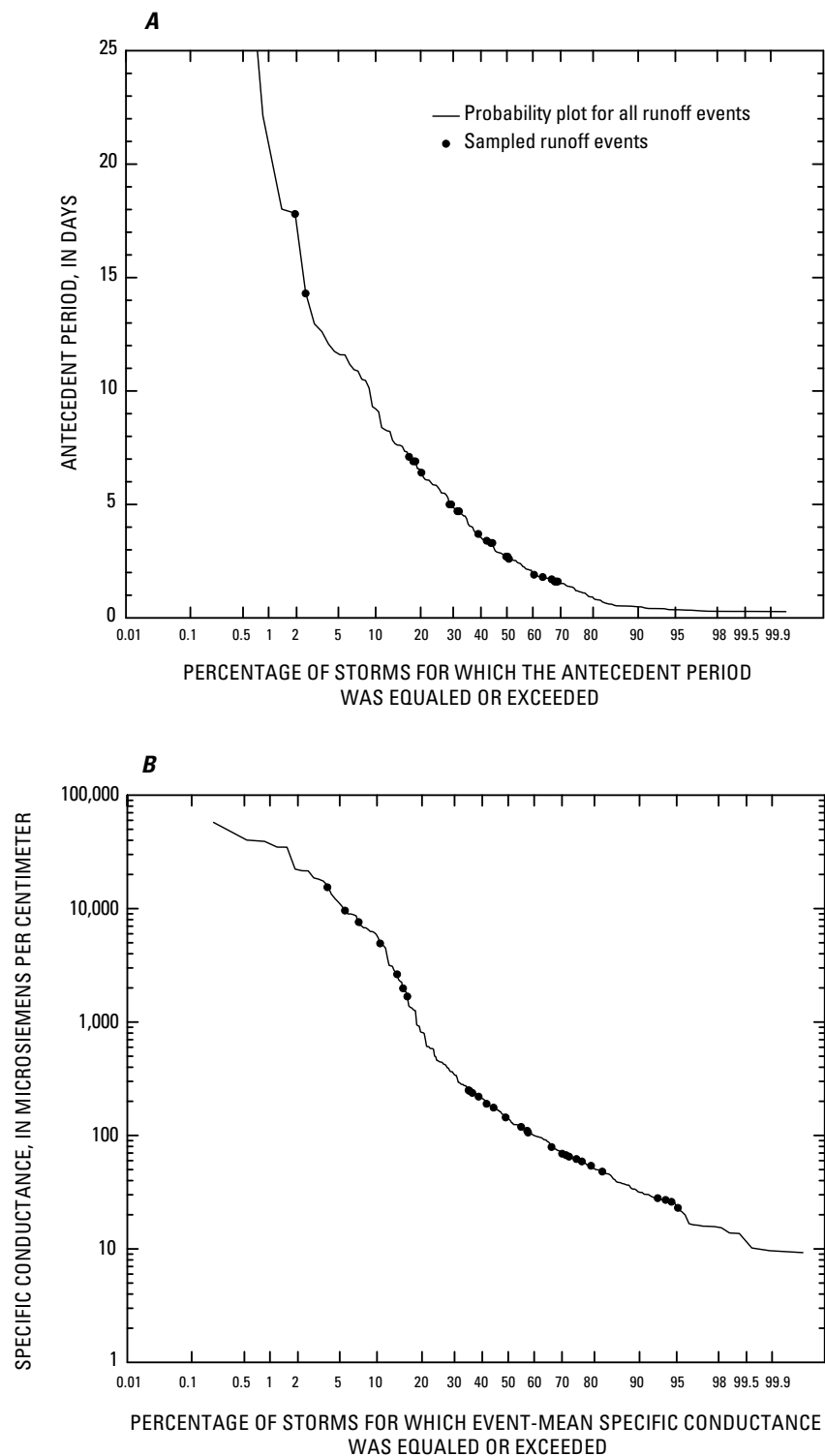


Figure 8. (A) Percentage of storms for which antecedent dry periods were equaled or exceeded in relation to the antecedent dry periods for storms during which runoff samples were collected from monitoring stations on Interstate 495 in Boxborough and Bolton, 2005–07; (B) percentage of storms for which the event-mean values of specific conductance were calculated from continuous records of flow and specific conductance in relation to specific conductance measured in runoff samples collected from the monitoring stations on Interstate 495 in Boxborough and Bolton, Massachusetts, 2005–07.

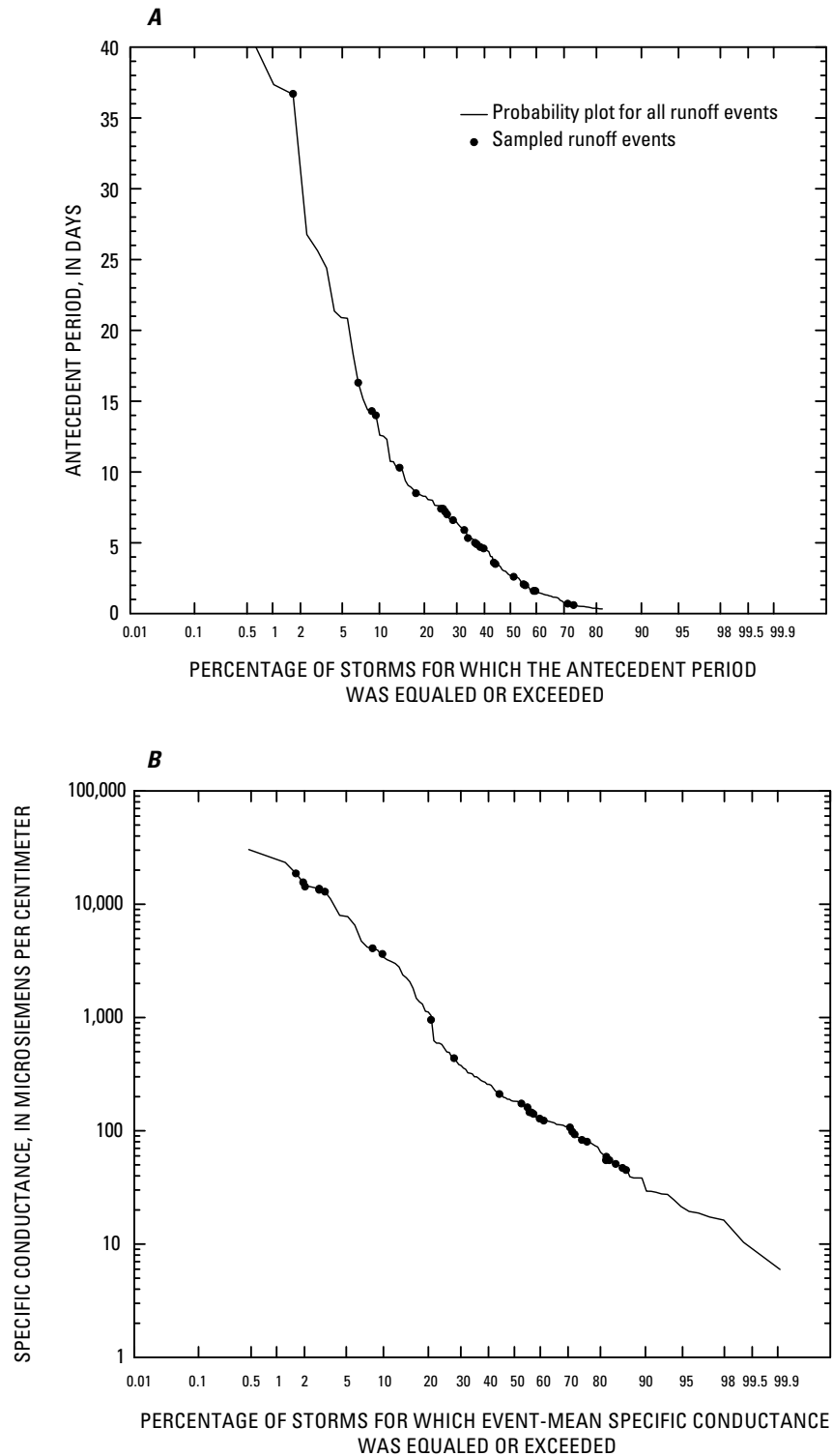


Figure 9. (A) Percentage of storms for which antecedent dry periods were equaled or exceeded in relation to the antecedent dry periods for storms during which runoff samples were collected from monitoring stations on Interstate 95 in Lexington and Waltham, Massachusetts, 2005–07; (B) percentage of storms for which the event-mean values of specific conductance were calculated from continuous records of flow and specific conductance in relation to specific conductance measured in runoff samples collected from the monitoring stations on Interstate 95 in Lexington and Waltham, Massachusetts, 2005–07.

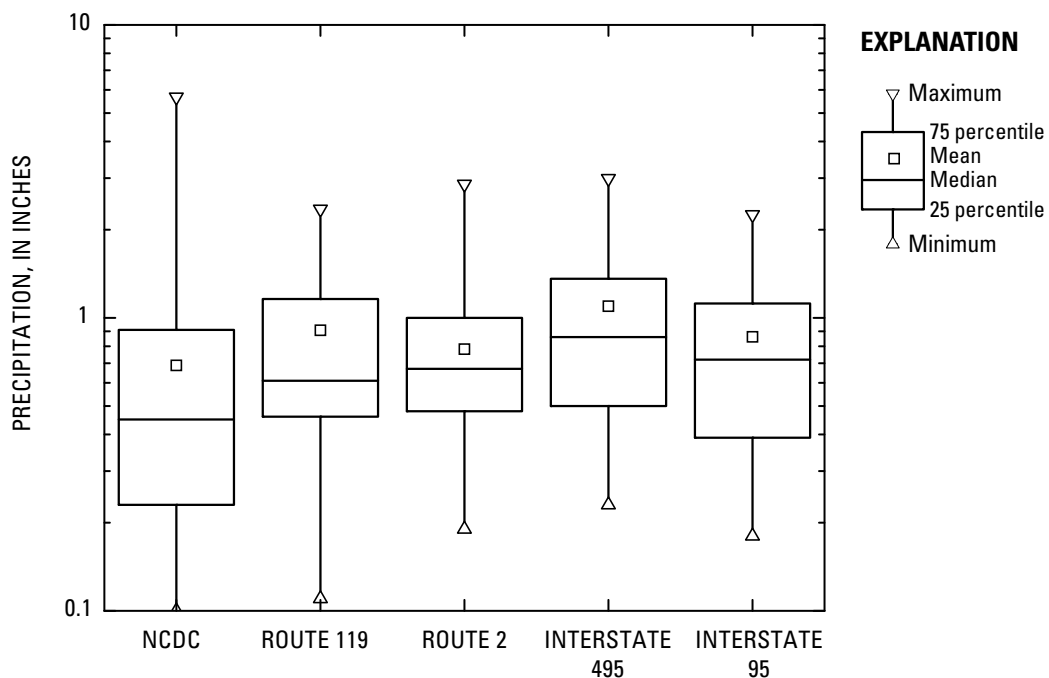


Figure 10. Distribution of precipitation totals greater than 0.10 inch recorded by the National Climatic Data Center near Worcester, Massachusetts, and of precipitation totals for storms during which samples were collected at each of the primary highway sites in Massachusetts, 2005–07.

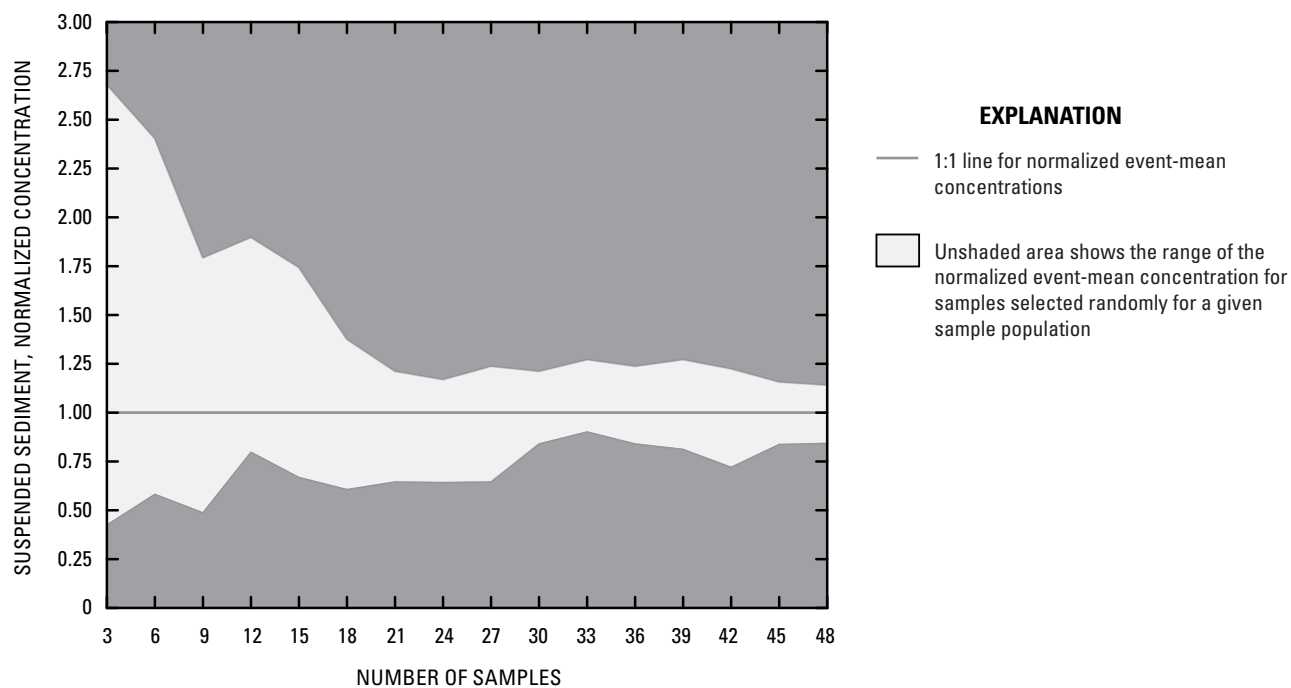


Figure 11. Results of a statistical resampling experiment indicating uncertainty in the median of event-mean concentrations of suspended sediment using a set of 20 randomly selected sample subpopulations ranging from 3 to 48 samples. Samples were collected along Interstate 93 during 50 storms (Smith, 2002). Subsample concentrations are normalized using the median concentration of suspended sediment for all 50 storms.

manner to allow for the complete purging and draining of sample water between samples. Sampler intakes were fixed to static mixers (fig. 12) designed specifically for this project at each sampling point for all sampling locations. The static mixer provides a secure and consistent mount for the sampler intake, reduces transport velocity, and provides agitation to produce a sample that represents the average concentration of suspended sediment (Smith, 2002). Sampler intakes were oriented in a horizontal and downstream direction. This configuration minimizes debris accumulation by forming a small eddy that captures sand particles at the intake and thus allows the sampler to collect a more representative sample of the coarse load (Edwards and Glysson, 1999). The static mixers were constructed from a 0.75-in. low-density polyethylene. The performance of the static mixers was evaluated at a test site prior to, and concurrent with, field sampling at the primary-monitoring station on Interstate 495. These tests were done to document the effectiveness of using the static mixers in conjunction with the automatic samplers for the collection of coarse particles representative of the distribution of particle sizes expected in the highway runoff.

Pre-cleaned wetted components for the sampling system were installed prior to each sampled storm. Each automatic sampler was configured to hold one 20-L Teflon-lined plastic bottle. The Teflon lining consisted of a double wall Teflon

pouch constructed in a clean room without the use of glue or adhesives. The sampler's intake lines consisted of 0.5-in. Teflon tubing attached to silicon pump-head tubing with a custom made Teflon discharge tube. A multi-step process was used to clean all wetted parts associated with the automatic sampler and the processing equipment before collecting trace-level constituents. The initial cleaning consisted of washing the interior and exterior with a phosphate-free laboratory grade soap and tap water, scrubbing surfaces with a plastic brush, and rinsing with tap water. Circulating the solution through the tubing cleaned the interior of the sampler tubing. Lint-free wipes were forced hydraulically through the tubing to remove internal deposits or films that were difficult to remove by circulating solution alone. After the components dried, they were placed in a large stainless steel pan in a fume hood and immersed in a 1-to-1 hexane-to-acetone solution. A Teflon diaphragm pump was used to circulate the solution through the sampler tubing. The components were allowed to soak, with occasional agitation, for a period of about 6 hours. After appropriately dispensing the waste solution, all components except the tubing were rinsed with a 1-to-1 hexane-to-acetone solution from a Teflon squeeze bottle and air dried in a fume hood overnight. Because the rate of cleaning-solution volatilization was limited within the sampler tubing, the tubing was purged with purified air for approximately 20 minutes. The



Figure 12. Static mixer mounted in a cut-out section of 12-inch-diameter plastic pipe.

final steps involved immersing the components in a 5-percent solution of hydrochloric acid for a period of at least 6 hours. The same solution was slowly circulated through each sampler tube for 6 hours or more. All components were thoroughly rinsed with deionized water until the specific conductance of the waste rinse water was less than 1 $\mu\text{S}/\text{cm}$.

Sample Processing

Most samples for chemical analysis were processed within 12 to 24 hours of the completion of each storm in a mobile field unit. Subsamples for the analysis of suspended sediment, nutrients, metals, and SVOCs were split directly from the Teflon-lined bottle into laboratory designated bottles in a positive-pressure hood. This method eliminated sample contact with additional processing equipment and reduced the potential for contamination. Subsamples were dispensed under low pressure directly from the sample bottle with a specialized cap, which included a 6.35-mm (inner diameter) Teflon dispensing tube, a pressure port, and a relief valve. Compressed nitrogen gas applied to the pressure port filled the interior area between the bottle wall and the pouch, compressing the pouch and dispensing the sample. Homogenization of the sample was accomplished by fastening the bottle to a cradle assembly capable of rotating 210 degrees. The sample bottle was rocked the full 210 degrees several times prior to dispensing, and the rocking motion was continued throughout dispensing for all samples except those analyzed for dissolved constituents. Dissolved constituents were filtered through a 600-cm capsule filter with a 0.45- μm pore size.

Sample Analysis

Samples to be analyzed for dissolved cations and total-recoverable metals were preserved with Optima-grade nitric acid. Samples to be analyzed for total N and P were preserved with sulfuric acid. Other samples required no special preservation other than refrigeration. Samples collected for the analysis of major ions, nutrients, total-recoverable metals, and SVOCs were double bagged after processing and stored on ice for overnight delivery to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, where they were analyzed. Samples were analyzed for concentrations of suspended sediment and distribution of particle size at the USGS Kentucky Water Science Center Sediment Laboratory.

Samples of Highway-Runoff Sediment

Suspended sediment, especially fine-grained suspended sediment, is an important transport mechanism for many elements and SVOCs in highway runoff. Several recent studies in Massachusetts have documented the affiliation of various elements and SVOCs with sediment, and the corresponding effect of concentrations with specific particle sizes, in samples of sediment collected from oil-grit separators (Smith 2002), streambeds (Smith 2005), and street sweepings (Breault and

others, 2005). In general, sediment surface area and element concentrations tend to increase with a decrease in sediment grain size. To understand these relations, which are important to the selection and implementation of both structural and nonstructural BMPs to improve the quality of water discharged from highways, the relation of sediment quality to particle size is measured.

Samples of suspended sediment for analysis of sediment quality were collected as separate aliquots from the highway-runoff composite samples that were collected during storms at the sites on the principal highways during the 2-year sampling period. These subsamples, which were separate from samples for the analysis of suspended-sediment concentrations, were wet sieved into specific particle-size ranges, and each size range was analyzed for concentrations of 32 inorganic elements, TOC, and selected SVOCs.

Sample Collection and Processing

Samples of sediment in highway runoff for analysis of sediment quality were collected during storms from the sites on the principal highways using automatic samplers and methods described earlier. Samples for highway-runoff sediment quality were composited from the flow-weighted composites of highway runoff during two separate 8 and 9 month periods. Thus, the sediment samples represent the quality of suspended sediment in highway runoff during multiple storms. Samples were composited because of the relatively large amounts of sediment required by analytical methods; individual flow-weighted composite samples of highway runoff from individual storms did not contain enough suspended sediment for analysis. Samples of sediment were temporarily frozen until sufficient material was available for analysis. Recent tests indicate that samples of sediment can be stored frozen for up to a year with little degradation of the sample (U.S. Environmental Protection Agency, 2005), thus it is unlikely that the integrity of the samples was affected during the compositing stage.

For analysis of inorganic constituents, water containing sediment and obtained from composite samples of highway stormwater was wet-sieved through pre-cleaned 0.250-mm and 0.062-mm nylon-mesh sieves. The sieves were cleaned by immersing them in a 5-percent solution of hydrochloric acid for a period of about 6 hours and thoroughly rinsing them with deionized water. Sediment from 0.063 mm to 0.250 mm in diameter and sediment greater than 0.250 mm in diameter for each principal highway were set aside in separate clean polyethylene bags. Sediment particles less than 0.063 mm in diameter were collected in Teflon bags with native water and allowed to settle undisturbed in a laboratory refrigerator in the USGS Massachusetts Water Science Center for several days. After the sediment settled, the supernatant was decanted and discarded, and the sediment was retained for chemical analysis. Composite samples of suspended sediment to be analyzed for elements were collected over an 8-month period during 2006 and 2007.

The amount of sediment required for the analysis of SVOCs was large, relative to the amount of available sediment in the samples, even after compositing; thus, samples of suspended sediment for analysis of SVOCs were sieved only through a pre-cleaned 0.063-mm stainless-steel sieve. The sieve was cleaned by immersing it in optima-grade methanol and thoroughly rinsing it with deionized water. Sediment greater than or equal to 0.063 mm in diameter from each principal highway was set aside in a separate pre-cleaned baked glass jar. Sediment particles less than 0.063 mm in diameter were collected in Teflon bags with native water and allowed to settle undisturbed in a laboratory refrigerator in the USGS Massachusetts Water Science Center for several days. After the sediment settled, the supernatant was decanted and discarded, and the sediment was retained for chemical analysis. Samples of suspended sediment for the analysis of SVOCs were composited over a 9-month period during 2005 and 2006.

Sample Analysis

Samples of sediment containing particles less than 0.063 mm in diameter, from 0.063 mm to 0.250 mm in diameter, and greater than or equal to 0.250 mm in diameter were submitted to XRAL Laboratory of Ontario, Canada, for analysis of 32 inorganic elements and TOC. Samples were not milled prior to analysis. Total-recoverable concentrations of inorganic constituents were determined with the use of USEPA method 3050B (U.S. Environmental Protection Agency, 1996) and ICP emission spectroscopy. Concentrations of TOC were determined by infrared spectroscopy. A separate set of sediment samples containing particles less than 0.063 mm in diameter and particles greater than or equal 0.063 mm, in diameter was submitted to the USGS NWQL in Denver, Colorado, for analysis of organic compounds by accelerated solvent extraction and gas chromatography (Zaugg and others, 2006b).

Samples of Background Soil, Highway-Berm Soil, and Other Miscellaneous Materials

Samples of background soil, highway-berm soil, and highway-maintenance materials were collected and analyzed for concentrations of 32 inorganic elements. Samples of highway-berm vegetation and catch-basin debris greater than 250 micrometers also were collected and analyzed for concentrations of 32 elements and TOC (except for highway-berm vegetation), and selected SVOCs (except for catch-basin debris).

Sample Collection

Five samples of background soil were collected at a distance of about 100 ft from each of the principal and test highways in the vicinity of the monitoring stations, except for Interstate 190 where no samples were collected. Samples were collected at a distance of about 30 ft from Interstate 93

in Boston because of the lack of available undeveloped land. Where possible, samples of soil were collected near trees with diameters greater than 1 ft because those trees were presumed to be in areas that were undisturbed for the last several decades. Samples were collected through successive soil horizons to a maximum depth of 1 ft with a stainless-steel soil-recovery probe equipped with a precleaned plastic liner. The plastic liners were cleaned by immersing the tubes in a 5-percent solution of hydrochloric acid for a period of about 6 hours and thoroughly rinsing them with deionized water until the specific conductance of the waste rinse water was less than 1 $\mu\text{S}/\text{cm}$.

Samples of surficial highway-berm soil were collected within 1 ft of the highway shoulder and at a depth of about 0.1 ft at five locations along each principal highway in the vicinity of the monitoring stations. Samples were collected with an acid-washed polyethylene scoop and stored in clean polyethylene bags prior to shipment to the laboratory. Two samples of highway maintenance sand also were collected at each of the Massachusetts DOT maintenance depots servicing the principal highways because the materials are procured from different local sources at each depot. In contrast, because the salt used on all Massachusetts highways is from the same source, a single sample of maintenance salt (sodium chloride) and a single sample of liquid calcium chloride were collected from the Massachusetts DOT maintenance depot in Lexington, Massachusetts. The solid-matrix samples were collected with a stainless-steel soil-recovery probe equipped with a precleaned plastic liner. The sample of liquid calcium chloride was dispensed into an acid-cleaned bottle.

Two samples of highway-berm vegetation were collected along Interstate 495 after mowing operations. These samples mainly consisted of roadside grass and weeds. While berm vegetation was available near all the highways sites, it was most plentiful along Interstate 495 in the vicinity of the primary monitoring station. A sample of dry pine needles also was collected along Route 119 because the needles commonly accumulated on the road shoulder and were often found in composite samples of stormwater. Nine samples of catch-basin debris, consisting of particles greater than 250 micrometers, also were collected from a plankton net installed at the outfall of the primary station on Interstate 495.

Sample Processing

Samples of soil, highway-berm soil, and highway-maintenance materials were processed similarly. For soil samples, the soil from each core was separated from the organic-litter layer and homogenized. The organic litter composed of leaves and twigs was discarded. For highway-berm soils, the soil was homogenized, and the contents were inspected for nonhomologous materials (for example, plastic and foil wrappers) that could bias chemical analysis. Such materials were subsequently removed. Each homogenized sample of soil, highway-berm soil, or highway-maintenance sand was split into a minimum of two subsamples. One subsample was used

to determine the particle-size distribution of the sample and the other subsample was analyzed for 32 inorganic elements. Samples of roadside vegetation, pine needles, and catch-basin debris were homogenized and reduced to fine particles with an electric chopper consisting of a stainless steel blade and an acrylic housing.

Sample Analysis

A particle-size gradation and an analysis for inorganic elements were performed for each sample of background soil, highway-berm soil, and highway-maintenance sand. Only an analysis for inorganic elements was performed on the samples of salt. Subsamples of soil, highway-berm soil, and highway-maintenance sand were evaluated for the percentage of particles less than 0.063 mm in diameter, from 0.063 mm to 0.250 mm in diameter, and greater than or equal to 0.250 mm in diameter at the USGS Kentucky Water Science Center Sediment Laboratory. Samples of soil, highway-berm soil, highway-maintenance sand and salt, roadside vegetation and pine needles, and catch-basin debris were submitted to XRAL Laboratory for analysis of 32 inorganic elements. Samples were not milled prior to analysis. Concentrations of inorganic constituents in solid-matrix samples were determined with the use of USEPA method 3050B (U.S. Environmental Protection Agency, 1996) and ICP emission spectroscopy. The sample of liquid calcium chloride was submitted to the USGS NWQL in Denver, Colorado, for analysis of major ions, total nutrients, and selected total-recoverable metals. Samples of roadside vegetation and pine needles also were submitted to the USGS NWQL for analysis of PAHs. These compounds were determined by accelerated solvent extraction and gas chromatography (Zaugg and others, 2006b).

Estimation of Constituents Contributed to Runoff from Road Salt

The primary constituents of road salt, sodium (Na), calcium (Ca), and Cl, were measured directly in the composite samples of highway runoff but also were estimated from the more frequent in-situ measurements of specific conductance. The data set includes 129 EMCs for these dissolved ions, specific conductances of the composite samples ranging from 7 to 62,500 $\mu\text{S}/\text{cm}$, and Cl concentrations ranging from less than 1 to 22,600 mg/L. Specific conductance was measured instantaneously for 1,555 runoff events (rain, mixed precipitation, and snowmelt), and estimated event-mean in-situ measurements of specific conductance ranged from about 6 to 105,600 $\mu\text{S}/\text{cm}$. (Only four storms had specific conductance values greater than 62,500 $\mu\text{S}/\text{cm}$.) Specific conductance measurements, which commonly are used to determine concentrations of dissolved major ions (Hem, 1982, 1992; Miller and others, 1988; Church and others, 1996; Granato and Smith, 1999), were used to estimate concentrations of dissolved Na, Ca, Cl, and sulfate (SO_4) in highway runoff to improve estimates of the populations of

concentrations and loads of these constituents in runoff from Massachusetts highways.

Concentrations of dissolved Na, Ca, Cl, and SO_4 in highway runoff were estimated using the adjusted superposition technique (Granato and Smith, 1999) over the full range of flow-weighted in-situ measurements of specific conductance. The theoretical conductance for each major ionic species in solution is summed to calculate the superposition estimate. Specifically, the theoretical conductance of a solution is the product of each ion in milliequivalents per liter multiplied by the equivalent ionic conductance at infinite dilution (table 5). However, as the concentrations of dissolved constituents increase, superposition will increasingly overestimate the specific conductance measured in a water sample because of interactions among ions in high-ionic strength solutions (Harned and Owen, 1958; Smedley, 1980; Hem, 1982; Miller and others, 1988). The adjusted superposition technique is a semi-empirical method that improves the quantitative relations among estimated and measured specific conductance to account for the attenuating effects of the interactions in high-ionic strength solutions that cannot be adequately quantified using purely theoretical approaches (Granato and Smith, 1999). In this study, nonparametric regression techniques (Granato, 2006) were used to develop an equation using the logarithms of the measured event-mean specific conductance (CM) and the logarithms of the specific conductance estimated by superposition (CC) for the 129 EMCs in the highway runoff data set to account for interionic effects on measured concentrations. This equation, retransformed from log space is

$$CC = 0.829 \times CM^{1.033757}, \quad (1)$$

where CC is the specific conductance (in microsiemens per centimeter) that would be calculated by superposition, and CM is the measured specific conductance (in microsiemens per centimeter). Equation 1 indicates that CM is slightly greater than CC at low concentrations (potentially because the contributions of some ions were not included in the calculation of the superposition values), and CM can be substantially less than CC for measured specific conductance values greater than about 5,000 $\mu\text{S}/\text{cm}$. The standard error of this estimate is 0.126 percent, as calculated for all the regression models using the equation

$$SE = 100 \times \left(e^{(MSE^2 \times 5.302)} - 1 \right)^{\left(\frac{1}{2} \right)}, \quad (2)$$

where SE is the standard error of estimate, in percent, and MSE is the mean square error in log (base 10) units (Driver and Tasker, 1990). The nonparametric coefficient of efficiency E (Legates and McCabe, 1999) also indicates the predictive power of a regression equation. The nonparametric coefficient of efficiency is

Table 5. Theoretical conductance at infinite dilution, regression equation coefficients (equations 4 and 5), the standard error of the estimate, nonparametric coefficients of efficiency, and the median milliequivalent ratio to chloride for major ions in solution measured at highway sites in Massachusetts, 2005–07.[Cl, Chloride; cm, centimeter; MEQ, milliequivalent; L, liter; μ S microsiemens; mg/L, milligrams per liter; CC, calculated specific conductance (equation 1)]

Major ion	Theoretical conductance at infinite dilution (μ S L/cm MEQ)	Median milliequivalent ratio to chloride (MEQ/MEQ)	Intercept of the regression equation, unitless (retransformed)	Slope of the regression equation	Standard error of the estimate (percent)	Nonparametric coefficient of efficiency for ion ratios, unitless	Nonparametric coefficient of efficiency for constituent concentrations, unitless
Chloride	76.31	1	0.0038	1.081	1.26	0.943	Predicting Cl, in mg/L 0.967
Sodium ¹	50.08	1.07	1.394	-0.055	0.35	0.448	Ion (mg/L) 0.94
Sodium ²			0.954	-0.007			
Calcium	59.47	0.23	1.962	-0.449	23	0.305	0.300
Potassium	73.48	0.03	0.270	-0.487	18	0.274	0.556
Magnesium	53.00	0.06	0.198	-0.240	14	0.301	0.409
Sulfate	80.00	0.12	0.661	-0.350	18	0.253	0.529
Bicarbonate	44.5	0.22	14.02	-0.870	10	0.359	0.449

¹Sodium-ratio estimates for specific conductance values less than 3,056 μ S/cm.²Sodium-ratio estimates for specific conductance values greater than or equal to 3,056 μ S/cm.

$$E = 1 - \frac{\sum_{i=1}^N |X_i - Y_i|}{\sum_{i=1}^N |X_i - Y_{median}|}, \quad (3)$$

where X_i is the i^{th} measured value, Y_i is the predicted value, N is the number of measured values, and X_{median} is the median of the measured values. The nonparametric coefficient of efficiency E (Legates and McCabe, 1999) for the CM to CC regression equation is 0.95, indicating that differences between regression estimates and estimates calculated from measured values are about 5 percent of the variability in CC estimates from measured values.

The specific conductance estimated by superposition (CC) from equation 1 may be used with estimates of the predominant ratios among major ions in solution and the theoretical conductance at equivalent dilution to estimate the concentration of Cl and other ions in solution. The concentrations of constituents in highway runoff should asymptotically converge toward the ratio of constituents in deicing materials as conductance increases because the deicing materials become the dominant source of these ions in solution (Granato, 1996). In eastern Massachusetts, ratios among major ions in highway runoff at low conductances also may approximate ratios of ions present in deicing materials because precipitation in the region is affected by coastal storms that are affected by entrainment of salt spray from the ocean by the storm system (Gay and Melching, 1995). For example for Na and Cl , maps with isopleths from the National Atmospheric Deposition Program (2008) indicate a substantial effect from coastal storms on precipitation quality for most of Massachusetts (excluding northwestern Massachusetts). Therefore, nonparametric regression techniques were used to develop equations to predict the ratio of each major ion to Cl (X/Cl) as a function of the specific conductance estimated by superposition (CC). These equations are in the form

$$\log\left(\frac{X}{Cl}\right) = b + m \times \log(CC), \quad (4)$$

where b is the intercept and m is the slope in logarithmic space, and

$$\frac{X}{Cl} = 10^b \times CC^m, \quad (5)$$

when retransformed. Regression coefficients for the equations used to calculate the ratio of Ca , magnesium (Mg), potassium (K), Na , bicarbonate (HCO_3), and SO_4 to Cl from the specific conductance estimated by superposition (CC) are listed in table 5 with the standard error of the estimate calculated for all the ratios using equation 2 and the coefficients of efficiency calculated using equation 3.

The concentrations of Na , Ca , SO_4 , and Cl are of particular interest for analysis of highway-runoff quality because they are the predominant constituents in highway deicing compounds. The regression equations developed to estimate the

milliequivalent ratio of each constituent to Cl can be used to estimate the concentration of these major ions in solution. The equations used to derive EMC values for Na , Ca , SO_4 , and Cl are as follows:

$$Na = Rna \times Cl, \quad (6)$$

$$Ca = Rca \times Cl, \quad (7)$$

$$SO_4 = Rso \times Cl, \quad (8)$$

and

$$Cl = CC \div ((Rna \times Cna) + (Rca \times Cca) + (Rso \times Cso) + (Rk \times Ck) + (Rmg \times Cmg) + (Ralk \times Calk) + (1 \times Ccl)), \quad (9)$$

where

CC	is specific conductance calculated by superposition, in microsiemens per centimeter;
Ca	is the milliequivalent concentration of calcium;
Na	is the milliequivalent concentration of sodium;
Cl	is the milliequivalent concentration of chloride;
SO_4	is the milliequivalent concentration of sulfate;
Rna	is the milliequivalent ratio of sodium to chloride;
Rca	is the milliequivalent ratio of calcium to chloride;
Rso	is the milliequivalent ratio of sulfate to chloride;
Rk	is the milliequivalent ratio of potassium to chloride;
Rmg	is the milliequivalent ratio of magnesium to chloride;
$Ralk$	is the milliequivalent ratio of carbonate to chloride;
Cna	is the equivalent theoretical conductance at infinite dilution of sodium (table 5);
Cca	is the equivalent theoretical conductance at infinite dilution of calcium (table 5);
Cso	is the equivalent theoretical conductance at infinite dilution of sulfate (table 5);
Ck	is the equivalent theoretical conductance at infinite dilution of potassium (table 5);
Cmg	is the equivalent theoretical conductance at infinite dilution of magnesium (table 5);
$Calk$	is the equivalent theoretical conductance at infinite dilution for carbonate (table 5); and
Ccl	is the equivalent theoretical conductance at infinite dilution of chloride (table 5).

These equations provide reasonable estimates of the concentration of Na, Ca, SO_4 , and Cl from flow-weighted event-mean conductance measurements. The coefficient of efficiency of the modified superposition estimates for Na, Ca, SO_4 , and Cl are about 0.94, 0.30, 0.53, and 0.97, respectively. These results indicate that the concentrations predicted using adjusted superposition are slightly better than the results of regression equations between measured conductance and constituent concentrations (table 6).

Data Quality

The accuracy and precision of the data collected in this study were ensured by making quality-control measurements at each of the monitoring stations, operating redundant sensors, collecting various types of quality-control samples, and conducting quality-assurance experiments. Quality-control samples include source-solution blanks, field blanks, replicate samples, field-matrix spike samples, and replicate field-matrix spike samples. Quality-control experiments were performed to assess the collection and processing of water samples containing coarse particles greater than 0.250 mm in diameter. The identification of random error and systematic bias can be achieved through the collection and analysis of quality-control data. These analyses provided the basis for the interpretation of continuous measurements of specific conductance and rainfall, and sediment and chemical data collected in this study.

Continuous Measurements

Comparative measurements of water level, water temperature, air temperature, and specific conductance were routinely made manually during sampling preparation, sample collection, and routine site visits to ensure the accuracy of the measurements and collection of highway-runoff composite samples. Rain gages also were checked periodically for debris buildup that could plug the device. Manual measurements of water levels were made by measuring the distance between the water surface near the site's sensor and some common reference point. Differences resulting from sensor drift were immediately corrected. The accuracy of water-temperature and

air-temperature data was determined by comparing measurements made by the monitoring system with those made by an independent probe calibrated against a National Institute of Standards and Technology traceable thermometer. The accuracy of specific conductance data was obtained by ensuring that the sensor was clean and free from debris, by documenting the performance of the sensor before and after sensor maintenance, and by noting the response of the clean sensor after placing it in several standard solutions. In addition, a redundant rain gage and a redundant specific conductance sensor were installed at the test station on Interstate 190 to determine the potential variability in measurements of rainfall totals and calculated event-mean specific conductance values, respectively.

A comparison of measurements made during site visits at each of the highway-monitoring stations indicated that the continuous measurements were generally accurate and precise. The difference between comparative measurements of water level was often less than about 0.02 ft, which was within the combined uncertainty of the measurements of the sensor and the manual comparative measurements. The median errors for raw measurements of specific conductance, which were the combined errors of fouling and drift measurements, ranged from about 5 to 21 percent prior to any improvements made on the basis of field calibration values. Non-winter rainfall totals measured concurrently by the primary and redundant tipping-bucket gages at the monitoring station on Interstate 190 also were precise. About 80 percent of the redundant rainfall totals were within 0.01 in. of the primary measurements, and about 95 percent of the redundant rainfall totals were within 0.04 in. of the primary measurements. The maximum difference between measurements from the two rain gages was 0.10 in. Larger differences between the amounts of rain measured by each gage could be the result of the physical mounting location of each gage and the direction and speed of wind during the storms.

Event-mean values of specific conductance for each runoff event were calculated on the basis of available continuous records of flow greater than 0.009 ft^3/s and records of in situ specific conductance; results were compared to the respective event-mean specific conductance of flow-weighted composite samples. These comparisons were done, in part, to determine whether the frequency of sample collection within storms was sufficient to accurately characterize the variability of dissolved

Table 6. Regression equation coefficients and nonparametric coefficients of efficiency for measured specific conductance to concentrations for sodium, calcium, chloride, and sulfate measured in composite samples of highway runoff for 12 sites in Massachusetts, 2005–07.

Major ion	Intercept of the regression equation, unitless (retransformed)	Slope of the regression equation	Nonparametric coefficient of efficiency for constituent concentrations, unitless
Chloride	0.111	1.117	0.939
Sodium	0.100	1.071	0.959
Calcium	0.144	0.677	0.263
Sulfate	0.138	0.772	0.509

solids and other constituents in runoff. This also was done to determine whether flows calculated from the stage-discharge relation for each monitoring station were reasonable.

Event-mean values for specific conductance also were calculated using data from the redundant sensor at the monitoring station on Interstate 190. The median difference between estimated event-mean values of specific conductance calculated independently from primary and redundant sensor data at the monitoring station on Interstate 190 is about 6 percent. The interquartile range for the respective differences is about 18 percent; differences vary from 2 to 20 percent. Larger differences between data from the primary and redundant sensors generally are the result of the redundant sensor not being adequately submersed because it was mounted slightly higher than the primary sensor.

The agreement between event-mean specific conductance, which was estimated from continuous records of flow and in situ measurements of specific conductance, and specific conductance measured in composite samples tended to have a low bias but generally was reasonable (fig. 13A) despite the sometimes large dissimilarity in runoff coefficients for storms during which the samples of highway runoff were collected. The median difference between estimated event-mean values of specific conductance and respective manual measurements of specific conductance in the same flow-weighted composite samples of highway runoff was about 10 percent for values less than 1,000 $\mu\text{S}/\text{cm}$ (fig. 13B). For values of specific conductance greater than 1,000 $\mu\text{S}/\text{cm}$ (fig. 13B), the respective difference was about 24 percent. The accuracy of most values of estimated event-mean specific conductance was within the precision of the comparative field measurements (5 to 21 percent) and the precision of the estimates made by the redundant sensor at the monitoring station on Interstate 190 (median difference of 6 percent). However, the accuracy of estimated values of event-mean specific conductance greater than 1,000 $\mu\text{S}/\text{cm}$ was often less, in part, because the sensors were typically calibrated to a 1,000 $\mu\text{S}/\text{cm}$ standard, and as a result, the sensor generally was less accurate at values substantially greater than this value.

Chemical Quality of Water Samples

Quality-control samples of spiked sample water and blank water were collected to identify potential bias in sampling and processing methods and to identify contamination resulting from the sampling equipment and from the sample-collection, sample-processing, and sample-analysis methods. Other quality-control samples were collected in the field and laboratory to estimate analyte degradation, evaluate method recovery and performance, and determine the presence of interfering agents.

Field Quality-Control Samples

Quality-control samples collected in the Massachusetts Water Science Center laboratory and in the field include source-solution blanks, field blanks, replicate samples, field-matrix spike samples, and replicate field-matrix spike samples.

Field-Blank Samples

A field blank is used to test for positive bias that can result from contamination at any stage of sample collection, processing, or analysis, as well as from the sampling equipment itself. Source-solution blanks were prepared from deionized water produced by a laboratory-grade water-purification system that uses ion-exchange packs and reverse osmosis. The source-solution water was stored in Teflon-lined bottles until it was used as blank water for the collection of field blanks. The source-solution water was submitted for analysis of all constituents measured in this study at the time of bottling. Field blanks were collected throughout the study period and at every monitoring station. Field blanks were collected by the automatic sampler during preparation for storm sampling. These samples were collected by pumping blank water through the automatic sampler tubing and into the collection bottle, then processing it in a manner consistent with the collection of environmental samples of stormwater. The number of field blanks collected at each site was proportionate with the total number of samples collected at the site.

Over the course of the study period, 18 field blanks were collected and submitted for chemical and sediment analysis. A single bottle to be analyzed for PAHs and phthalates unfortunately was destroyed during shipment to the NWQL, and therefore, only 17 samples were analyzed for most of these analytes. Three field blanks also were collected and analyzed for concentrations of other less frequently measured anthropogenic and natural organic compounds. These samples provided replicate measurements for concentrations of several PAH and phthalate compounds. Measurable concentrations of each constituent in field-blank samples were compared to the long-term method detection limit (LTMDL). The LTMDL is the lowest detectable concentration of an analyte that can be measured and reported with 99 percent confidence that the concentration is greater than zero. The chance of falsely reporting a concentration at or greater than the LTMDL for a sample that does not contain the analyte is predicted to be less than or equal to 1 percent (Childress and others, 1999). For analytes not detected in samples, a concentration equal to twice the LTMDL value (laboratory reporting limit) is reported with a "less than" (<) remark code in all data tables in this report.

A nonparametric statistical method, which focuses on the ranks of concentrations as opposed to the concentrations themselves, was used to determine whether the potential contamination observed in field-blank samples affected the utility of the data. This statistical technique is described in detail by Mueller (1998). In this study, the confidence level for the one-sided upper contamination limit was estimated

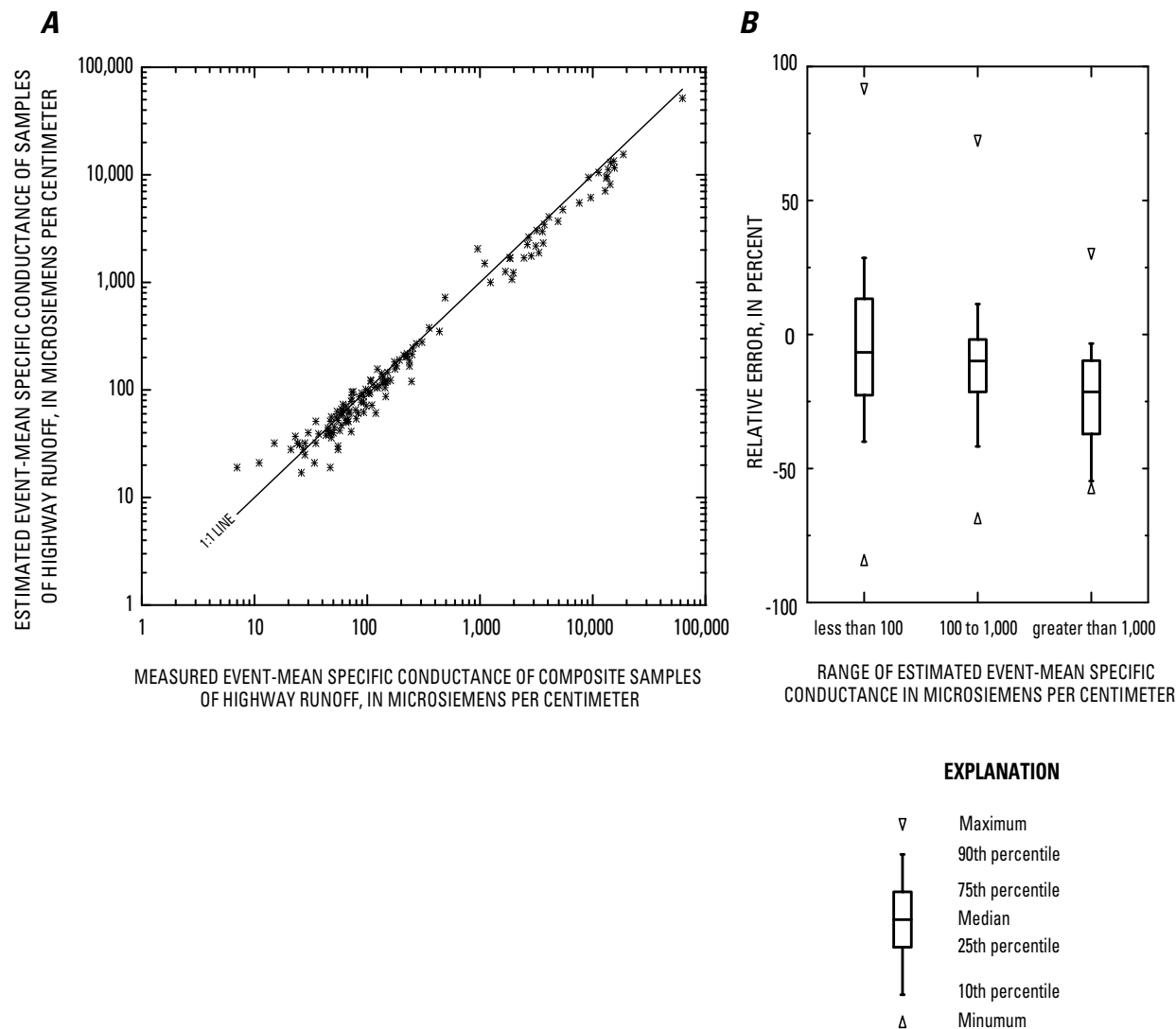


Figure 13. Relation of (A) flow-weighted specific conductance values estimated from continuous records of flow and specific conductance to measured event-mean specific conductance of composite samples of highway runoff collected at 12 monitoring stations on 8 highways for paired events, and (B) relative error between event-mean specific conductance and estimated values of event-mean specific conductance in three ranges.

for the 90th percentile of highway-runoff concentration data on the basis of the number of field-blank samples and the measured concentration of each constituent in field blank samples in the highest rank. The maximum potential contamination bias for at least 90 percent of all samples was estimated (at various levels of confidence; table 7) to be less than the LTMDL for most of the constituents, except for Ca, total N, P, total-recoverable iron (Fe) and manganese (Mn), anthracene, benzo[*a*]pyrene, bis(2-ethylhexyl) phthalate, diethyl phthalate, di-*n*-butyl phthalate, indeno[1,2,3-*cd*]pyrene, naphthalene, and suspended sediment. The detection of a constituent at a concentration greater than or equal to the LTMDL was rare, limited to three or fewer observations, and the concentrations were often small in comparison to those measured in composite samples of highway runoff.

Low levels of contamination may be acceptable if the level of contamination is within the measurement error of the analytical method or is well below the concentrations of the constituent in the environmental samples. For example, the maximum concentration for Ca in the field blanks was an order of magnitude lower than the minimum concentration measured in composite samples of highway runoff. However, for other constituents, such as N, P, Fe, Mn, anthracene, benzo[*a*]pyrene, bis(2-ethylhexyl) phthalate, diethyl phthalate, di-*n*-butyl phthalate, indeno[1,2,3-*cd*]pyrene, naphthalene, and suspended sediment, concentrations in several samples of highway runoff were at or near the LTMDL and similar to the maximum observed concentrations in the field blanks. These cases were generally rare and 90 percent or more of the concentrations of N, Fe, Mn, and suspended sediment in samples of highway runoff were at least one order of magnitude greater than the maximum concentration measured in field blanks. Concentrations of Mn and suspended sediment also were detected in the source water in comparable concentrations, indicating that the water source, analytical containers, or laboratory processes during analysis could have been the source of contaminants. Concentrations of P, anthracene, benzo[*a*]pyrene, bis(2-ethylhexyl) phthalate, diethyl phthalate, di-*n*-butyl phthalate, indeno[1,2,3-*cd*]pyrene, and naphthalene in samples of highway runoff, on the other hand, were generally low, and therefore, the contamination bias is potentially greater. The median P concentration for all samples of highway runoff in this study was 0.10 mg/L. The precision of the analytical method is about ± 0.004 mg/L at this concentration, and the method precision decreases to ± 0.03 mg/L for higher concentrations (Patton and Kryskalla, 2003). Anthracene and naphthalene were detected in a single blank and exceeded only the lower LTMDL for the secondary analytical method. Benzo[*a*]pyrene, bis(2-ethylhexyl) phthalate, diethyl phthalate, di-*n*-butyl phthalate, and indeno[1,2,3-*cd*]pyrene also were infrequently detected in field blanks (table 7); however, the maximum potential contamination estimated for 90 percent of the field data is similar in magnitude to the median concentrations of individual constituents in all composite samples of highway runoff (0.14 to 5.02 $\mu\text{g/L}$). Furthermore, most of the higher concentrations of these constituents, defined by the 95th

percentile (0.9 to 18 $\mu\text{g/L}$), is less than one order of magnitude greater than the respective median concentration in the highway samples. Thus, the maximum contamination level for 90 percent of these data can potentially account for a substantial amount of the concentration in most samples. Therefore, data for benzo[*a*]pyrene, bis(2-ethylhexyl) phthalate, diethyl phthalate, di-*n*-butyl phthalate, and indeno[1,2,3-*cd*]pyrene are to be viewed with caution because the magnitude of potential contamination measured in field blank samples, although rare, is similar to the concentration of each constituent measured in samples of highway runoff.

Contamination bias appeared to be random for all constituents except for naphthalene. Concentrations of naphthalene in field blanks often were equivalent to the concentrations measured in samples of highway runoff. Naphthalene was not detected in the four samples of source water used for field-blank samples; however, these analyses were performed at the time the water was bottled. Analysis of the field-blank concentrations with respect to the holding time of the source water indicates an increasing exponential trend with increased age of the source water. Naphthalene was detected in field blanks where the source water was at least 5 months old, and the concentrations of naphthalene increased with the age of the source water. One possible explanation for the detection of naphthalene in the field blank is that sodium naphthalene is used in the manufacturing of some Teflon products (Benderly, 1962). Because the source water was stored in a bottle lined with a Teflon bag, it is possible that the naphthalene leached from the bag over time. Considering this, it is unlikely that there is any measurable contamination bias for naphthalene in samples of highway runoff.

Replicate Samples

Replicate samples are samples that are thought to be identical in composition to the environmental samples. Replicate samples provide a measure of bias and variability in the method of sample collection, sample processing (splitting, filtering, and preservation), and laboratory analysis, and in sample changes, such as analyte degradation, that can occur prior to laboratory analysis.

In this study, replicate samples generally were not collected, but analyses were conducted for seven SVOCs using different analytical methods on sample splits of flow-weighted composite samples of highway runoff that provide the same kind of information provided by replicate quality-control samples. Replicate samples were split sequentially from 14 composite samples of highway runoff and analyzed for concentrations of anthracene, benzo[*a*]pyrene, bis(2-ethylhexyl) phthalate, fluoranthene, phenanthrene, pyrene, and naphthalene by two different analytical methods. Most of the data on constituents were determined by an analytical method using methylene chloride extraction and gas chromatograph/mass spectrometry analysis (Fishman, 1993). The secondary method, which provided measurements for 69 anthropogenic and natural organic compounds, including the seven

Table 7. Summary for contamination bias expected in 10 percent of samples of highway runoff collected in Massachusetts, 2005–07.

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, concentration is less than value shown; ND, not detected; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; LTMDL, long-term method detection level; values in parentheses were determined by solid-phase extraction and capillary-column gas chromatography/mass spectrometry]

Constituent	Number of field blanks	LTMDL	Maximum concentration detected in field blanks	Number of detects greater than or equal to the LTMDL reporting limit	Maximum concentration measured in blank water	Confidence that the maximum concentration is the upper limit for the 90 percentile of contamination
Calcium, filtered, mg/L	18	0.01	E0.02	3	E0.005	85
Magnesium, filtered, mg/L	18	0.007	ND	0	ND	85
Potassium, filtered, mg/L	18	0.08	ND	0	ND	85
Sodium, filtered, mg/L	18	0.1	ND	0	ND	85
Alkalinity, filtered, laboratory, mg/L as calcium carbonate	18	5	ND	0	ND	85
Chloride, filtered, mg/L	18	0.1	ND	0	ND	85
Sulfate, filtered, mg/L	18	0.09	ND	0	ND	85
Total nitrogen (nitrate + nitrite + ammonia + organic-N), unfiltered, mg/L	18	0.03	E0.04	3	ND	85
Phosphorus, unfiltered, mg/L	18	0.01	E0.01	1	ND	85
Cadmium, unfiltered, µg/L	18	0.02	ND	0	ND	85
Chromium, unfiltered, µg/L	18	0.3	0.2	0	ND	85
Copper, unfiltered, µg/L	18	0.6	E0.38	0	ND	85
Iron, unfiltered, µg/L	18	3	E4	1	ND	85
Lead, unfiltered, µg/L	18	0.03	ND	0	E0.04	85
Manganese, unfiltered, µg/L	18	0.3	E0.2	0	E0.2	85
Nickel, unfiltered, µg/L	18	0.08	ND	0	E0.09	85
Zinc, unfiltered, µg/L	18	1	ND	0	ND	85
1-Methylnaphthalene, unfiltered, µg/L	3	0.03	E0.0066	0	ND	27
2,6-Dimethylnaphthalene, unfiltered, µg/L	3	0.05	ND	0	ND	27
2-Methylnaphthalene, unfiltered, µg/L	3	0.03	E0.0103	0	ND	27
3,4-Dichlorophenyl isocyanate, unfiltered, µg/L	3	0.06	ND	0	ND	27
3beta-Coprostanol, unfiltered, µg/L	2	0.38	ND	0	ND	19
3-Methyl-1H-indole, unfiltered, µg/L	3	0.07	ND	0	ND	27
3-tert-Butyl-4-hydroxyanisole, unfiltered, µg/L	3	0.16	ND	0	ND	27
4-Cumylphenol, unfiltered, µg/L	3	0.13	ND	0	ND	27

Table 7. Summary for contamination bias expected in 10 percent of samples of highway runoff collected in Massachusetts, 2005–07.—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, concentration is less than value shown; ND, not detected; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; LTMDL, long-term method detection level; values in parentheses were determined by solid-phase extraction and capillary-column gas chromatography/mass spectrometry]

Constituent	Number of field blanks	LTMDL	Maximum concentration detected in field blanks	Number of detects greater than or equal to the LTMDL reporting limit	Maximum concentration measured in blank water	Confidence that the maximum concentration is the upper limit for the 90 percentile of contamination
4- <i>n</i> -Octylphenol, unfiltered, µg/L	3	0.11	ND	0	ND	27
4-Nonylphenol, unfiltered, µg/L	3	1.2	ND	0	ND	27
4- <i>tert</i> -Octylphenol, unfiltered, µg/L	3	0.11	ND	0	ND	27
5-Methyl-1H-benzotriazole, unfiltered, µg/L	3	0.35	ND	0	ND	27
9H-Fluorene, unfiltered, µg/L	17	0.17	ND	0	ND	83
Acenaphthene, unfiltered, µg/L	17	0.14	ND	0	ND	83
Acenaphthylene, unfiltered, µg/L	17	0.15	ND	0	ND	83
Acetophenone, unfiltered, µg/L	3	0.07	ND	0	ND	27
Acetyl hexamethyl tetrahydro naphthalene, unfiltered, µg/L	3	0.11	ND	0	ND	27
Anthracene, unfiltered, µg/L	20	0.19 (0.08)	E0.009	(1)	ND	88
9,10-Anthraquinone, unfiltered, µg/L	3	0.08	ND	0	ND	27
Atrazine, unfiltered, µg/L	3	0.08	ND	0	ND	27
BDE congener 47, unfiltered, µg/L	1	0.1	ND	0	ND	10
Benzo[<i>a</i>]anthracene, unfiltered, µg/L	17	0.13	E0.02	0	ND	83
Benzo[<i>a</i>]pyrene, unfiltered, µg/L	20	0.16 (0.06)	E0.196	1	ND	88
Benzo[<i>b</i>]fluoranthene, unfiltered, µg/L	17	0.9	ND	0	ND	83
Benzo[<i>ghi</i>]perylene, unfiltered, µg/L	17	0.32	E0.127	0	ND	83
Benzo[<i>k</i>]fluoranthene, unfiltered, µg/L	17	0.23	E0.117	0	ND	83
Benzophenone, unfiltered, µg/L	3	0.1	E0.0544	0	ND	27
Benzo[<i>n</i>]butyl phthalate, unfiltered, µg/L (butylbenzyl phthalate)	17	0.63	ND	0	ND	83
<i>beta</i> -Sitosterol, unfiltered, µg/L	2	0.11	ND	0	ND	19
<i>beta</i> -Stigmasterol, unfiltered, µg/L	2	0.22	ND	0	ND	19
Bis(2-ethylhexyl) phthalate, unfiltered, µg/L	20	0.53 (0.85)	E4.12	3	ND	88
Bisphenol A, unfiltered, µg/L	3	0.22	ND	0	ND	27
Bromacil, unfiltered, µg/L	3	0.1	ND	0	ND	27

Table 7. Summary for contamination bias expected in 10 percent of samples of highway runoff collected in Massachusetts, 2005–07.—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, concentration is less than value shown; ND, not detected; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; LTMDL, long-term method detection level; values in parentheses were determined by solid-phase extraction and capillary-column gas chromatography/mass spectrometry]

Constituent	Number of field blanks	LTMDL	Maximum concentration detected in field blanks	Number of detects greater than or equal to the LTMDL reporting limit	Maximum concentration measured in blank water	Confidence that the maximum concentration is the upper limit for the 90 percentile of contamination
Caffeine, unfiltered, µg/L	3	0.06	E0.0438	0	ND	27
Camphor, unfiltered, µg/L	3	0.09	ND	0	ND	27
Carbaryl, unfiltered, µg/L	3	0.13	ND	0	ND	27
Carbazole, unfiltered, µg/L	3	0.12	ND	0	ND	27
Chlorpyrifos, unfiltered, µg/L	3	0.12	ND	0	ND	27
Cholesterol, unfiltered, µg/L	2	0.3	ND	0	ND	19
Chrysene, unfiltered, µg/L	17	0.16	E0.03	0	ND	83
Cotinine, unfiltered, µg/L	3	0.29	ND	0	ND	27
N,N-diethyl-meta-tolamide (DEET), unfiltered, µg/L	3	0.12	ND	0	ND	27
Diazinon, unfiltered, µg/L	3	0.11	ND	0	ND	27
Dibenzo[<i>a,h</i>]anthracene, unfiltered, µg/L	17	0.35	E0.214	0	ND	83
Dichlorvos, unfiltered, µg/L	3	0.11	ND	0	ND	27
Diethoxynonylphenol (all isomers), unfiltered, µg/L (4-Nonylphenol diethoxylates)	3	1.2	ND	0	ND	27
Diethoxyoctylphenol, filtered, µg/L (4- <i>tert</i> -Octylphenol diethoxylate, aka OP2EO)	3	0.05	ND	0	ND	27
Diethyl phthalate, unfiltered, µg/L	20	0.31 (0.1)	E0.453	1	ND	88
Dimethyl phthalate, unfiltered, µg/L	17	0.3	ND	0	ND	83
Di-n-butyl phthalate, unfiltered, µg/L	17	0.44	ND	2	ND	83
Di-n-octyl phthalate, unfiltered, µg/L	17	0.93	ND	0	ND	83
<i>d</i> -Limonene, unfiltered, µg/L	3	0.02	ND	0	ND	27
Fluoranthene, unfiltered, µg/L	20	0.15 (0.08)	E0.05	0	ND	88
Hexahydrohexamethyl cyclopentabenzopyran (HHCB), unfiltered, µg/L	3	<2	ND	0	ND	27
Indeno[1,2,3- <i>cd</i>]pyrene, unfiltered, µg/L	17	0.11	E0.164	1	ND	83
Indole, unfiltered, µg/L	3	0.08	ND	0	ND	27
Isoborneol, unfiltered, µg/L	2	0.05	ND	0	ND	19
Isophorone, unfiltered, µg/L	3	0.08	ND	0	ND	27

Table 7. Summary for contamination bias expected in 10 percent of samples of highway runoff collected in Massachusetts, 2005–07.—Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; <, concentration is less than value shown; ND, not detected; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; LTMDL, long-term method detection level; values in parentheses were determined by solid-phase extraction and capillary-column gas chromatography/mass spectrometry]

Constituent	Number of field blanks	LTMDL	Maximum concentration detected in field blanks	Number of detects greater than or equal to the LTMDL reporting limit	Maximum concentration measured in blank water	Confidence that the maximum concentration is the upper limit for the 90 percentile of contamination
Isoquinoline, unfiltered, µg/L	3	0.09	ND	0	ND	27
Menthol, unfiltered, µg/L	2	0.05	ND	0	ND	19
Metaxyl, unfiltered, µg/L	3	0.13	ND	0	ND	27
Methyl salicylate, unfiltered, µg/L	3	0.07	ND	0	ND	27
Metolachlor, unfiltered, µg/L	3	0.12	ND	0	ND	27
Monoethoxynonylphenol (all isomers), unfiltered, µg/L	3	1.35	ND	0	ND	27
Monoethoxyoctylphenol, filtered, µg/L (4-tert-Octylphenol monoethoxylate, aka OP1EO)	3	0.5	ND	0	ND	27
Nitrobenzene, unfiltered, µg/L	17	0.11	ND	0	ND	83
p-Cresol, unfiltered, µg/L	3	0.08	ND	0	ND	27
Pentachlorophenol, unfiltered, µg/L	3	0.33	ND	0	ND	27
Phenanthrene, unfiltered, µg/L	20	0.16 (0.07)	E0.02	0	ND	88
Phenol, unfiltered, µg/L	3	0.07	ND	0	ND	27
Prometon, unfiltered, µg/L	3	0.08	ND	0	ND	27
Pyrene, unfiltered, µg/L	20	0.18 (0.08)	E0.04	0	ND	88
Tributyl phosphate, unfiltered, µg/L	3	0.11	ND	0	ND	27
Triclosan, unfiltered, µg/L	3	0.09	ND	0	ND	27
Triethyl citrate, unfiltered, µg/L	3	0.07	ND	0	ND	27
Triphenyl phosphate, unfiltered, µg/L	3	0.1	ND	0	ND	27
Tris(2-butoxyethyl) phosphate, unfiltered, µg/L	3	0.05	ND	0	ND	27
Tris(2-chloroethyl) phosphate, unfiltered, µg/L	3	0.08	E0.0411	0	ND	27
Tris(dichloroisopropyl) phosphate, unfiltered, µg/L	3	0.05	ND	0	ND	27
1,4-Dichlorobenzene, unfiltered, µg/L	3	0.03	ND	0	ND	27
Isopropylbenzene, unfiltered, µg/L	3	0.02	ND	0	ND	27
Naphthalene, unfiltered, µg/L	20	0.16 (0.03)	E0.06	(1)	ND	88
Tetrachloroethene, unfiltered, µg/L	3	0.22	ND	0	ND	27
Tribromomethane, unfiltered, µg/L (Bromoform)	3	0.03	ND	0	ND	27
Perylene, unfiltered, µg/L	17	0.2	ND	0	ND	83
Suspended sediment concentration, mg/L	18	1	1	1	1	85

compounds listed immediately above, used continuous liquid-liquid extraction and capillary-column gas chromatography/mass spectrometry analysis (Zaugg and others, 2006a). Replicate sample sets were evaluated by comparing the relative percent differences (RPDs) of the results for each pair of samples where the same analyte was detected in both samples. The average absolute RPD ranged from 12 to 16 percent for five of the seven compounds (table 8). The average RPDs for anthracene and bis(2-ethylhexyl) phthalate were 30 and 35 percent (table 8), respectively. The standard deviation for the RPDs indicates the most precise values were determined for benzo[*a*]pyrene (standard deviation of about 5 percent) and the standard deviation for the other compounds (table 8) ranged from about 11 to 29 percent. The relative concentrations of the target analytes in the water samples did not seem to affect the variability of analyte recovery between samples processed using the different analytical methods.

Field-Spiked and Replicate Field-Spiked Samples

Field-spiked samples are quality-control samples in which known amounts of target compounds are added to environmental replicate-split samples, which are then measured. The degree of recovery for each target analyte added to the environmental sample is used to determine the bias and variability attributed to the amount of degradation of target analytes during holding and shipment to the laboratory, the analytical method, and interferences contained in the environmental sample that mask or enhance determinations of the target analytes, or matrix effects. Replicate field-spiked samples also were submitted to the NWQL for analysis. Similarly, known amounts of target compounds were added to replicate field-spiked samples. These samples were processed in the same manner as the field-spiked samples, such that the samples were expected to be essentially identical in composition. Comparing the recovery for an analyte in a replicate field-spiked sample to the recovery for an analyte in the paired field-spiked sample provides a measure of the variability

attributed to the aforementioned processes that can affect the concentration of each analyte.

Field-spiked samples and replicate field-spiked samples were split sequentially from composites of water collected at most monitoring stations throughout the study period, so comparisons of different matrices and concentrations reveal storm-to-storm and seasonal variations in water chemistry. For two samples, the analytical detection level was raised for bis(2-ethylhexyl) phthalate by the NWQL to a value greater than the fortification amount, and as a result, recoveries for field-spiked samples could not be calculated. The analytical detection level also was raised for benzyl *n*-butyl phthalate, and a recovery for the field-spiked sample could not be calculated. The average recovery of each compound and the precision of the recoveries, determined on the basis of spiked replicate data, are presented table 9.

A single field-spiked sample and a single replicate field-spiked sample also were collected and analyzed for the other anthropogenic and natural compounds that were sampled for less frequently. These data are presented in table 10. The average RPD between analyte recoveries in the field-spiked sample and analyte recoveries in the replicate field-spiked sample for all analytes was about 27 percent. Because only a single field-spiked sample was collected, broad generalizations for the recovery of concentrations of organic compounds measured in the other 14 samples of highway runoff cannot be made with reasonable certainty.

Laboratory Quality Assurance and Quality-Control Samples

In addition to the quality-control samples collected during this project, the NWQL routinely analyzes various quality-control samples, including laboratory reagent blanks, interference check solutions, laboratory-control samples, standard-reference materials, laboratory-reagent spiked samples, laboratory-preparation spiked samples, and

Table 8. Replicate sample statistics for seven organic compounds determined by methylene chloride extraction and gas chromatograph/mass spectrometry analysis and by continuous liquid-liquid extraction and capillary-column gas chromatography/mass spectrometry analysis for 14 samples of highway runoff collected in Massachusetts, 2005–07.

Analyte	Relative percent difference			
	Mean	Standard deviation	Minimum	Maximum
Anthracene	30	29	3	94
Benzo[<i>a</i>]pyrene	12	5	5	22
Bis(2-ethylhexyl) phthalate	35	25	3	75
Fluoranthene	16	11	1	41
Phenanthrene	15	14	1	53
Pyrene	15	13	1	38
Naphthalene	14	14	1	34

Table 9. Recovery statistics for total-recoverable metals, polyaromatic hydrocarbons, and phthalate esters in laboratory-spiked preparation samples, field-spiked samples, and field-replicate-spiked samples and *p* values for Mann-Whitney tests between laboratory spiked preparation samples and field spiked samples for the study in Massachusetts, 2005–07.

[NWQL, National Water Quality Laboratory; N, number of samples; CI, confidence interval; RPD, relative percent difference; %, percent; --, no data; NWQL preparation spike recoveries for organic compounds were provided in a written communication by the NWQL in 2007; NWQL preparation spike recoveries for inorganic constituents were obtained from the NWQL quality control data system in 2008 (<http://nwqlqc.cr.usgs.gov/>)]

Analyte	NWQL preparation spike recoveries (percent)			Field spike recoveries (percent)				Mann-Whitney test (95% CI)		Spike replicate recovery (percent)	
	Average	Standard deviation	N	Average	Standard deviation	Maximum	Minimum	<i>p</i> -value	Average RPD	Standard deviation for RPD	N
Cadmium	98	2	152	--	--	--	--	--	--	--	--
Chromium	94	5	127	--	--	--	--	--	--	--	--
Copper	93	4	74	--	--	--	--	--	--	--	--
Iron	91	6	143	--	--	--	--	--	--	--	--
Lead	97	2	154	--	--	--	--	--	--	--	--
Manganese	96	3	153	--	--	--	--	--	--	--	--
Nickel	94	3	72	--	--	--	--	--	--	--	--
Zinc	93	4	79	--	--	--	--	--	--	--	--
Acenaphthene	77	15	64	80	16	101	52	0.661	12	14	7
Acenaphthylene	76	15	64	75	17	98	53	0.740	11	13	7
Anthracene	74	15	64	70	14	91	53	0.395	9	10	7
Benz[<i>a</i>]anthracene	78	14	64	73	11	85	58	0.490	9	8	7
Benzo[<i>a</i>]pyrene	70	15	64	65	13	83	48	0.375	8	8	7
Benzo[<i>b</i>]fluoranthene	77	15	64	80	26	122	43	0.661	12	10	7
Benzo[<i>ghi</i>]perylene	59	17	64	41	10	56	31	0.005	10	5	7
Benzo[<i>k</i>]fluoranthene	76	16	64	80	15	103	62	0.635	9	9	7
bis(2-Ethylhexyl) phthalate (DEHP)	100	89	61	38	55	111	0	0.064	36	30	5
Benzyl n-butyl phthalate (butylbenzyl phthalate)	102	23	64	118	28	163	93	0.140	16	17	6
Chrysene	78	14	64	74	18	103	48	0.525	10	7	7
Dibenz[<i>a,h</i>]anthracene	56	16	64	51	14	68	33	0.356	8	4	7

Table 9. Recovery statistics for total-recoverable metals, polyaromatic hydrocarbons, and phthalate esters in laboratory-spiked preparation samples, field-spiked samples, and field-replicate-spiked samples and *p* values for Mann-Whitney tests between laboratory spiked preparation samples and field spiked samples for the study in Massachusetts, 2005–07.—Continued

[NWQL, National Water Quality Laboratory; N, number of samples; CI, confidence interval; RPD, relative percent difference; %, percent; --, no data; NWQL preparation spike recoveries for organic compounds were provided in a written communication by the NWQL in 2007; NWQL preparation spike recoveries for inorganic constituents were obtained from the NWQL quality control data system in 2008 (<http://nwqlqc.cr.usgs.gov/>)]

Analyte	NWQL preparation spike recoveries (percent)			Field spike recoveries (percent)				Mann-Whitney test (95% CI)	Spike replicate recovery (percent)		
	Average	Standard deviation	N	Average	Standard deviation	Maximum	Minimum		N	Average RPD	Standard deviation for RPD
Diethyl phthalate (DEP)	99	21	64	90	31	126	30	0.687	17	13	7
Dimethyl phthalate	90	18	64	94	22	114	46	0.375	19	18	7
Di-n-butyl phthalate	98	19	64	75	26	108	38	0.015	9	10	7
Di-n-octyl phthalate	64	28	64	58	36	109	0	0.622	25	18	7
Fluoranthene	86	15	64	80	32	143	44	0.200	11	7	7
Fluorene	85	15	64	81	16	103	58	0.436	12	15	7
Indeno[1,2,3- <i>cd</i>]pyrene	61	15	64	47	13	64	35	0.031	9	5	7
Naphthalene	79	14	64	82	17	102	51	0.573	12	16	7
Nitrobenzene	87	15	64	92	18	110	55	0.200	15	16	7
Phenanthrene	79	14	64	82	26	136	50	0.837	10	11	7
Pyrene	85	16	64	77	28	132	44	0.160	9	7	
Perylene	69	19	64	71	23	124	53	0.837	13	13	7

Table 10. Recovery statistics for selected natural and anthropogenic organic compounds in laboratory-spiked preparation samples, a single field-spiked sample, and a single replicate field-spiked sample for the study in Massachusetts, 2005–07.

[NWQL, National Water Quality Laboratory; RPD, relative percent difference; NWQL preparation spike recoveries for inorganic compounds were obtained from the NWQL QC Data system in 2008]

Analyte	NWQL preparation spike recoveries (percent)		Field spike recovery (percent)	Spike replicate RPD (percent)
	Average	Standard deviation		
1-Methylnaphthalene	66	17	72	24
2,6-Dimethylnaphthalene	63	17	68	19
2-Methylnaphthalene	64	17	71	22
3,4-Dichlorophenyl isocyanate	124	119	105	10
3 β -Coprostanol	74	24	208	6
3-Methyl-1(H)-indole (Skatole)	77	18	44	19
3- <i>tert</i> -Butyl-4-hydroxy anisole (BHA)	45	30	8	44
4-Cumylphenol	78	18	80	26
4- <i>n</i> -Octylphenol	74	18	69	14
4-Nonylphenol diethoxylate, (sum of all isomers) aka NP2EO	80	18	579	12
4- <i>tert</i> -Octylphenol	88	20	87	30
5-Methyl-1H-benzotriazole	74	21	464	13
Acetophenone	84	19	108	22
Acetyl hexamethyl tetrahydronaphthalene (AHTN)	79	17	64	13
Anthracene	73	16	63	16
Anthraquinone	79	17	82	26
Atrazine	81	20	45	36
Benzo[<i>a</i>]pyrene	69	17	47	24
Benzophenone	84	20	96	22
β -Sitosterol	64	27	102	11
β -Stigmastanol	61	27	156	11
bis(2-Ethylhexyl) phthalate	161	331	1	206
Bisphenol A	83	19	70	39
Bromacil	79	17	331	18
Caffeine	76	16	75	37
Camphor	77	17	86	34
Carbaryl	73	20	98	28
Carbazole	77	17	78	28
Chlorpyrifos	74	17	61	13
Cholesterol	69	22	163	16
Cotinine	48	17	185	42
N,N-diethyl-meta-toluamide (DEET)	88	20	108	26
Diazinon	77	20	48	30
Dichlorvos	77	19	101	26
para-Nonylphenol (total) (branched)	83	20	1,020	7

Table 10. Recovery statistics for selected natural and anthropogenic organic compounds in laboratory-spiked preparation samples, a single field-spiked sample, and a single replicate field-spiked sample for the study in Massachusetts, 2005–07.—Continued

[NWQL, National Water Quality Laboratory; RPD, relative percent difference; NWQL preparation spike recoveries for inorganic compounds were obtained from the NWQL QC Data system in 2008]

Analyte	NWQL preparation spike recoveries (percent)		Field spike recovery (percent)	Spike replicate RPD (percent)
	Average	Standard deviation		
4- <i>tert</i> -Octylphenol diethoxylate, aka OP2EO	117	117	76	14
Diethyl phthalate	90	21	102	26
<i>d</i> -Limonene	29	15	61	22
Fluoranthene	78	17	60	22
Hexahydrohexamethyl cyclopentabenzopyran (HHCB)	80	17	58	11
Indole	78	18	26	16
Isoborneol	77	22	87	25
Isophorone	78	18	97	27
Isoquinoline	76	18	88	48
Menthol	85	29	84	34
Metalaxyl	83	18	89	35
Methyl salicylate	83	19	69	24
Metolachlor	80	16	80	21
4-Nonylphenol monoethoxylate, (sum of all isomers) aka NP1EO	83	18	557	18
4- <i>tert</i> -Octylphenol monoethoxylate, aka OP1EO	85	19	143	17
<i>p</i> -Cresol	78	18	77	45
Pentachlorophenol	65	25	330	38
Phenanthrene	74	16	65	23
Phenol	77	19	63	61
Prometon	79	18	86	33
Pyrene	74	19	61	24
Tributyl phosphate	89	23	84	7
Triclosan	83	18	102	25
Triethyl citrate (ethyl citrate)	82	20	97	30
Triphenyl phosphate	76	16	64	13
Tris(2-butoxyethyl)phosphate	82	23	95	18
Tris(2-chloroethyl)phosphate	79	17	80	26
Tris(dichlorisopropyl)phosphate	78	17	71	20
1,4-Dichlorobenzene	51	20	73	24
Isopropylbenzene	36	18	66	25
Naphthalene	69	18	81	23
Tetrachloroethylene	24	12	49	28
Bromoform	62	15	74	23

laboratory-duplicate samples to test and track method performance (Garbarino and others, 2006). The NWQL also adds surrogate compounds to all samples for determinations of SVOCs. Surrogate compounds, such as 2-fluorobiphenyl and p-terphenyl-d14, are expected to perform similarly to the compounds being analyzed for in the laboratory. Because these compounds are not normally found in the environment, the recovery of the surrogate compounds can be used to qualify the performance of the analysis.

Laboratory Spiked Samples

Laboratory-preparation spiked samples provide a measure of method performance because they are processed and analyzed in the same manner as environmental samples. Laboratory-preparation spiked samples are prepared by adding known concentrations of target analytes to blank water. Average field spike recoveries for PAH compounds were similar to the average laboratory-preparation spike recoveries (table 9), except for benzo[ghi]perylene and indeno[1,2,3-cd]pyrene, which were lower for field-spiked samples. Average spike recoveries for the study period for phthalate compounds also were similar to the average laboratory-preparation spike recoveries for the respective compounds, except for bis(2-ethylhexyl) phthalate and di-n-butyl phthalate (table 9), which were notably lower.

The Mann-Whitney test, also referred to as the rank-sum test, was used to determine whether the independent populations of field-spike values were statistically different than laboratory-preparation spike values to comprehend whether or not the sample collection and field processing potentially affected the concentration of the PAH and phthalates in the composite samples of highway runoff. The Mann-Whitney test is a nonparametric method that makes no assumptions about the distribution of data and is used to determine whether groups of data come from the same population or, alternatively, whether the median values are different (Helsel and Hirsch, 2002). Resultant *p* values are listed in table 9. These data indicate the populations of field-spike recoveries for benzo[ghi]perylene, indeno[1,2,3-cd]pyrene, and di-n-butyl phthalate are significantly different (*p* value less than 0.05) than the populations of laboratory-preparation spike recoveries for the respective compounds. The result for bis(2-ethylhexyl) phthalate is significant at a slightly higher confidence interval (table 9). Because the variability of field-spike recoveries for these compounds was similar to the variability of laboratory-preparation spike recoveries, and because the replicate field-spike recoveries for these compounds indicate that the measurements are relatively precise, such differences are likely attributable to the degradation of the compounds prior to laboratory processing or potential matrix effects that masked the compounds. As a result, these data indicate that concentrations of benzo[ghi]perylene, indeno[1,2,3-cd]pyrene, and di-n-butyl phthalate are likely underestimated in samples of highway runoff collected in this study. The recoveries for other analytes that were fortified in samples of highway runoff

were similar to the recoveries of the same analytes in laboratory-preparation spike samples, which were prepared from organic-free blank water.

For the less frequently measured natural and anthropogenic compounds (table 4), about 57 and about 84 percent of the spike recoveries in the single composite sample of highway runoff were within one and three standard deviations, respectively, of the average recoveries for the same analytes in laboratory-preparation spiked samples analyzed during the sampling period. Field-spike recoveries of 3beta-coprostanol, 4-nonylphenol diethoxylate, beta-stigmastanol, bromacil, cholesterol, cotinine, para-nonylphenol, 4-nonylphenol monoethoxylate, 4-tert-octylphenol monoethoxylate, and pentachlorophenol, which were greater than three standard deviations from the average recoveries for the same analytes in laboratory-preparation spiked samples, ranged from 142 to 1,020 percent. Except for the aforementioned compounds, the field and laboratory spike recoveries are similar for this sample of highway runoff (table 10).

Field-spiked samples for major ions and total-recoverable metals were not collected during this study because these constituents do not readily degrade during the short holding periods prior to shipment to the laboratory. However, laboratory-preparation spike recoveries were routinely performed for total-recoverable metals to monitor potential losses during sample digestion. These data indicate that the average recovery for fortified concentrations of total-recoverable metals in laboratory-preparation spiked samples was relatively accurate and precise. Average recoveries for total-recoverable metals processed by the in-bottle digestion method (Garbarino and Hoffman, 1999) ranged from 91 to 98 percent during this study (table 9).

Surrogate-Compound Recovery

Surrogate-compound recoveries provide a measure of method performance for each individual sample. The recoveries of all surrogate compounds are used to evaluate process control of the analytical method. Thus, if the recovery of only one surrogate is outside of acceptable control limits, the sample measurements typically are considered valid. When surrogate recoveries are outside acceptable control limits (usually low) as a result of an identified process failure, the results for the associated analytes are usually flagged by the NWQL as estimated values; if the recovery of the surrogate compounds is poor, the results are deleted. Reporting levels are adjusted upward under some circumstances.

The surrogate compounds 2-fluorobiphenyl and p-terphenyl-d14 were routinely added to samples during the sample preparation at the NWQL for the analysis PAHs and phthalates. The median recovery of these surrogate compounds for all composite samples of highway runoff was about 71 and 52 percent, respectively. Surrogate recoveries of 2-fluorobiphenyl and p-terphenyl-d14 for about 19 percent and about 12 percent of the samples, respectively, were outside of laboratory control limits of 38 to 90 percent and 27 to

102 percent, respectively (Duane Wydoski, written commun. 2008). For nine composite samples of highway runoff (about 7 percent of all composite samples analyzed using the primary method), the recovery of both surrogate compounds was outside of control limits. The surrogate compounds caffeine-13C, fluoranthene-d10, bisphenol A-d3, and decafluorobiphenyl were added to samples during the sample preparation at the NWQL for the analysis of other natural and anthropogenic organic compounds. With the exception of a recovery for bisphenol A-d3 in a single sample of highway runoff, recoveries for all surrogate compounds in samples of highway runoff were within acceptable laboratory control limits.

Laboratory-Blind Samples

The USGS Office of Water Quality Branch of Quality Systems also submits various quality-control samples to ensure that data produced by USGS laboratories, including sediment laboratories, are of a known quality and are sufficient to provide long-term comparability and consistency on a national basis (U.S. Geological Survey, 2008a). Two single-blind sediment-laboratory quality assurance tests were conducted during each year of this study. Single-blind samples were samples of known concentrations and particle-size distribution values that were submitted to the sediment laboratory for analysis and identified as quality-control samples. Laboratory results were compared to the known values to measure the bias and variance of suspended-sediment data.

Analyses of laboratory blind samples indicate that the measurements of concentrations of suspended sediment in water samples collected during this study are accurate and precise. The median absolute difference between known concentrations of sediment in laboratory blind samples and concentrations of suspended sediment reported by the Kentucky Water-Science Center Sediment Laboratory was less than 1 percent for the study period (U.S. Geological Survey, 2008b). Concentrations of suspended sediment in laboratory blind samples ranged from 134 to 10,333 mg/L in these samples. The absolute median differences for concentrations of suspended sediment less than 0.063 mm in diameter and greater than or equal to 0.063 mm in diameter were within about 2.8 and 7.7 percent, respectively (U.S. Geological Survey, 2008c, 2008d). Concentrations of sediment greater than or equal to 0.063 mm in diameter had higher variability than the concentrations of the total sediment mass and the fine sediment fraction. This is likely because finer material (composed of silts and clays) has a tendency to conglomerate. As a result, the determination of fines is generally biased low, whereas determinations of sands are biased high as a result of the conglomeration of fines. The percent error decreases for samples with high concentrations because the percent errors are exaggerated for analyses of samples with low-concentrations. Loss or reduction in diameter of a few grains of sand-size material during sample processing also can cause errors. About 5 to 15 percent of the sample sediment mass in the laboratory-blind samples was composed of sand-size material, and error may,

to some degree, be exaggerated for determinations of these low quantities.

Sampling Methods, Chemical Quality, and Particle Size for Suspended Sediment and Soil Samples

Effectiveness of Sampling Methods for Suspended Sediment

Three quality-control experiments were performed to assess the accuracy and bias of automatic-sample collection and manual-processing methods that could affect the distribution of sediment particle size in water samples. The concentration and size distribution of sediment can vary widely in samples of highway runoff. Most of the coarse-grained material in samples of bottom material collected from oil-grit separators on Interstate 93 that receive flow from catch basins (Smith, 2002) ranged from fine sand to gravel less than about 6 mm in diameter. Quality-assurance data from recent studies indicate that samples of water containing clay- and silt-size particles can be collected with automatic samplers and processed with standard splitting techniques with reasonable precision (Breault and others, 2005; Smith, 2002); however, it is more difficult to collect and split representative samples of water containing large concentrations of sand-size particles (Selbig and others, 2007).

Automated Collection of Samples of Suspended Sediment, Controlled Experiment

Automatic sampling is a convenient, cost-effective, and systematic method for collecting samples of water that represent the mean quality of stormwater, which would be impractical if performed manually. Nevertheless, all sampling, as well as sample-processing techniques, are subject to bias. The automatic samplers used in this study were basically heavy-duty battery-powered peristaltic pumps under the control of the datalogger. Like most modern automatic samplers, these devices are capable of purging and rinsing the sample lines and dispensing relatively precise amounts of water to the sample-collection bottle (generally within about 5 percent of the programmed volume during calibration tests in the field). The sampler pumps operate at a fixed speed producing a constant intake velocity of about 2 ft/s and, therefore, are not capable of collecting isokinetic samples (a sample collected with the velocity of water at the intake of the collection device being the same as the velocity of water flowing past the device) under all circumstances. As a result, the distribution of the particle size in sediment in water samples collected by such devices can be affected by the hydraulic characteristics at the point within the pipe where the intake is located. For small diameter pipes, the sampler intakes are often mounted near the floor of the pipe to maximize the allowable range for

the collection of samples. Consequently, this increases the risk of oversampling coarse particles because vertical gradients of sediment can form with the largest particles concentrating near the floor of the pipe (Bent and others, 2001). In contrast, under environmental conditions where the water velocity is greater than that of the intake velocity of the sampler, the momentum of coarse particles may preclude them from being entrapped by the currents at the sample intake (Edwards and Glysson, 1999). To overcome such shortcomings, a static mixer was developed prior to the field study to reduce the bias associated with the collection of water samples by a pump with a fixed intake velocity over the expected range of field conditions. The static mixer (fig. 12) is a carefully designed baffle, which was mounted in a pipe, produced a hydraulic environment with reduced sediment-transport velocities and provided turbulence that enabled the collection of coarse-grained sediments over a wide range of flows. The design of the static mixer and the relative placement of the sampler intake were modified on a trial and error basis as a result of observations of the behavior of coarse-grain sediments over a range of flows in the test pipe (fig. 14) where the static mixer was mounted and by collection of samples of sediment-laden water. During this time, other tests were conducted with the automatic sampler, but without the static mixer. With the sampler intake oriented downstream and without a static mixer installed, the successful collection of samples of water by the automatic sampler decreased as velocity increased, and visual inspections of the contents of sample collected under high water-velocity conditions indicated that few coarse-grain particles were collected at higher velocities. Mixed results also were noted in tests where the static mixer was not used and the sampler intake was oriented upstream. Occasionally during these tests, the sampler intake was plugged by coarse sand- and small gravel-size particles, and the sampler could not successfully purge and dislodge the particles under high water-velocity conditions.

Previous studies indicate that fine-grained particles are evenly distributed throughout the water column (Smith, 2002; Butler and others, 1996). Therefore, the focus of the experiments in this study was to define the potential limitations of collecting representative samples of water containing a distribution of sediment particles ranging from about 0.250 mm to about 6 mm in diameter. During the first experiment, a test structure was designed to simulate flow and sampling conditions in a typical highway drainage pipe (fig. 14). Artificial flows containing low concentrations of suspended sediment (about 3–6 mg/L) were metered into one end of a test pipe, which was 12 in. in diameter by 20 ft in length. Flow in the test pipe was generated by as many as three 9,600-gal/h centrifugal pumps. Flow from each pump was measured by an industrial flow sensor. A dry mixture of sand and gravel with particle diameters as large as about 6 mm was metered by gravity into the flow stream about 4 ft downstream from the point where the flow entered the pipe. The sampler intake, which was fixed 0.1 ft upstream from the static mixer, was mounted about 4 ft from the outlet of the test pipe. Two sets of paired samples were collected at five different flow rates

ranging from about 0.10 to 0.85 ft³/s. One 850-mL sample of water was collected by the automatic sampler while a paired sample of sediment was collected concurrently during the forward-pumping cycle of the automatic sampler with a plankton net at the end of the pipe (fig. 14). The plankton net captured the entire mass of sediment greater than 0.250 mm in diameter during the sampling period of the automatic sampler. The distribution of particle sizes in samples of suspended sediment collected by the automatic sampler and samples of sediment collected from the plankton net were determined by wet-sieving methods.

Particle-size analysis of samples of water collected by an automatic sampler in conjunction with a static mixer indicate that samples of suspended sediment with particle sizes ranging from 0.250 mm to more than 4.0 mm can be consistently collected using this method over a range of flows (fig. 15). Results of the experiment indicate that fine-grain sands (0.250 to 0.500 mm) were consistently undersampled by the automatic sampler. This systemic bias could have resulted from water-surface tension that prevented the powdered sediment, which was metered by gravity through the top of the pipe, from thoroughly mixing with the flowing water in the pipe. As a result, the difference in distributions of the coarser particles also appeared to be systemic. Because these data are expressed as a percentage of the total distribution, the bias in the larger size particles is likely the result of the forward propagation of the systemic bias observed in the 0.250- to 0.500-mm diameter range. Furthermore, although the samples of suspended sediment were collected concurrently with samples from the autosampler and with the plankton net, the physical segments of water that were sampled were not necessarily identical in concentration because the sampling locations were different; therefore, the concentrations of sediment for each particle-size fraction cannot be compared without error.

Automated Collection of Samples of Suspended Sediment, Field Experiment

The second experiment was conducted in the field at the primary station on Interstate 495. For this experiment, samples of stormwater for the evaluation of concentrations of suspended sediment were collected by an automatic sampler and static-mixer assembly concurrently with samples of total sediment greater than 0.250 mm in diameter collected by a plankton net fastened to the outlet of the drainage pipe (fig. 16). The automatic sampler was triggered to collect samples of highway runoff on a flow proportional basis consistent with the protocols used throughout the study; therefore, only a small fraction of water was collected compared to the amount that flowed through the plankton net. The concentration of suspended sediment greater than 0.250 mm in diameter in the water samples was determined by dividing the dry mass of sediment by the mass of the water (ASTM, 2002). In most cases, the water samples were not split for other analyses, and the entire sample was processed. Similarly, the concentration of suspended sediment greater than 0.250 mm in diameter collected



Figure 14. Test pipe and sampling equipment (top) where the static mixer assembly was tested; (lower left) looking upstream; and (lower right) turbulence created by the static mixer at the sampler intake location. The plankton net, which was used to collect the total mass of sediment at the end of the test pipe during the experiment, is draped over the end of the pipe in the photograph.

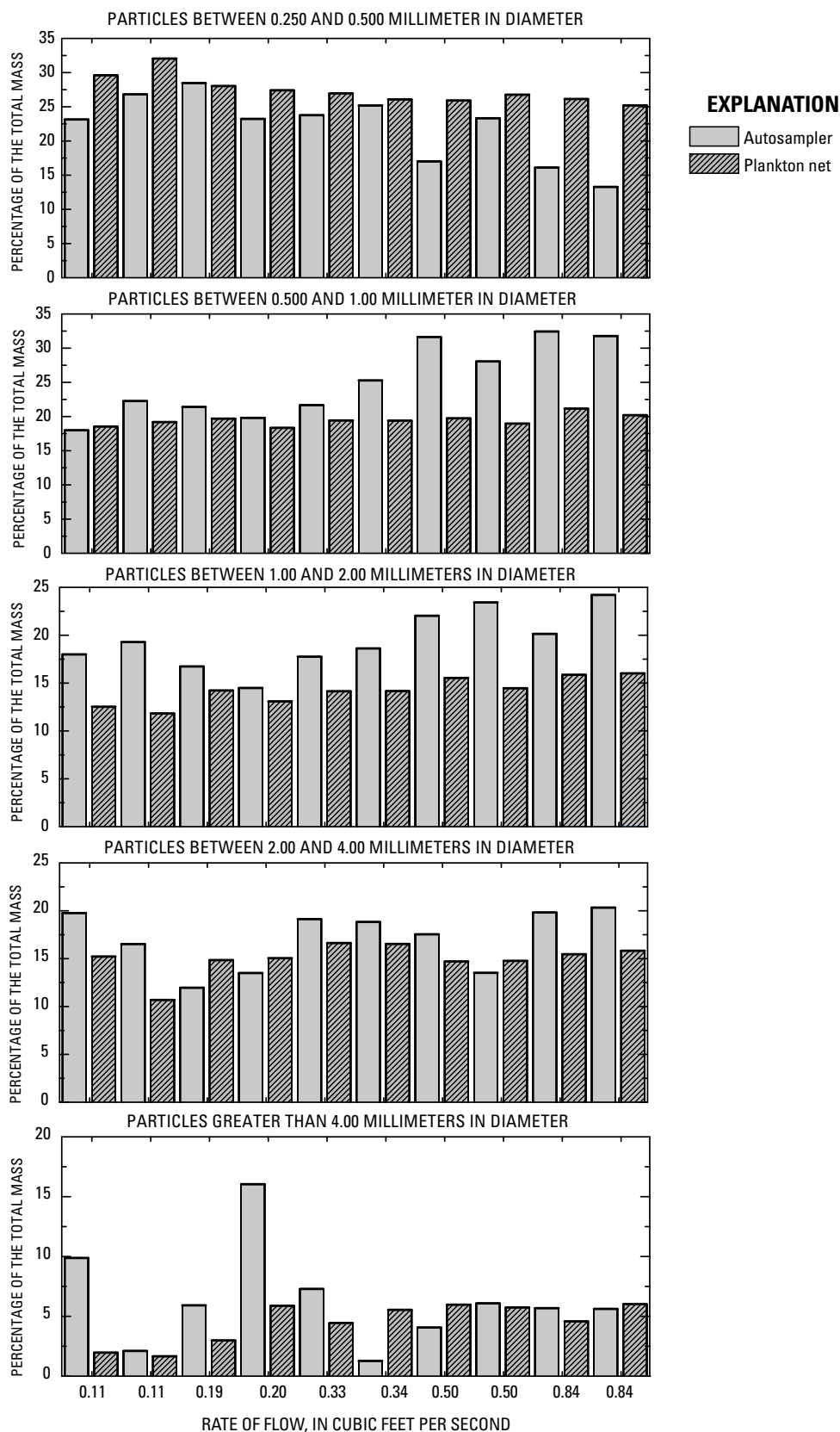


Figure 15. Sediment particles greater than 0.250 millimeters in diameter collected by an automatic sampler with the intake mounted to a static mixer over a range of artificial flows in relation to the percentage of the total mass of sediment particles greater than 0.250 millimeters in diameter collected at the end of the test pipe.



Figure 16. Plankton net attached to the outfall of the primary highway-runoff monitoring site on Interstate 495, Boxborough, Massachusetts.

by the plankton net was determined by dividing the dry mass of sediment less than 6.0 mm by the volume of the water calculated for the entire storm. This experiment was conducted for 10 storms from January 2007 through October 2007.

Information from this test indicates that the concentrations of suspended sediment greater than 0.250 mm in diameter in flow-proportional composite samples of highway runoff were higher than the concentrations estimated for samples collected by a plankton net fixed to the end of the pipe (table 11). The average and relative standard deviation for the differences between paired samples were 187 and 56 percent, respectively. Considering that the amount of water collected by the automatic sampler for each storm was about 0.03 percent of the entire storm volume, the variability in the differences between the concentrations in the paired samples is not unreasonable. However, for samples of highway runoff collected by the automatic sampler, these data potentially indicate that there is a positive bias for the concentration of sediment particles greater than 0.250 mm in diameter. In contrast, the average TOC content in nine samples of material retained by the plankton net was about 20 percent and ranged as high as 43 percent (table 12). The high TOC content in these samples is attributed to large amounts of natural organic material (grass and leave particles). Because these materials are less dense than mineral sediments, it also is possible that the automatic samplers collected these materials disproportionately. The lack of precision in sampling coarse sediments has only marginal effects on the concentrations of many constituents affiliated with suspended sediment because most metals and hydrophobic organic compounds tend to be concentrated on the particles less than 0.063 mm in diameter (Smith, 2005; Breault and

others, 2005). Similarly, if the positive bias for the concentration of coarse sediment particles is explained by the disproportionate collection of natural organic particles, the effect on the concentrations of many constituents in the water samples may not be large; P is the exception because it is generally present in high concentrations in vegetation matter compared to the concentrations in soil and sediments. The difference between concentrations of suspended sediment greater than 0.250 mm in diameter collected by the automatic sampler and that collected by the plankton net can be explained by the previously stated reasons. Nevertheless, the quality-assurance data indicate that potentially there is a positive bias for concentrations of sediment particles greater than 0.250 mm in diameter, and there could be a bias for concentrations of P in some samples of highway runoff. Because water samples were collected in a nearly identical manner at all monitoring stations, it also is likely that this same bias may affect the concentrations of coarse sediments and P in water samples collected from other monitoring stations in this study as well.

Sample Splitting

One of the most often overlooked sources of bias in concentrations of sediment particles, as well as in concentrations of constituents affiliated with such sediments, results from splitting the water sample in the field or in the laboratory prior to analysis (Selbig and others, 2007). The analysis for concentrations of suspended sediment used in this study (ASTM, 2002) did not require that the water sample be split in the laboratory, in contrast to the total suspended solid method (American Public Health Association, American Water

Table 11. Results of field tests of paired samples of suspended sediment greater than 0.250 millimeters in diameter in highway runoff collected by a plankton net and an automatic sampler used in conjunction with a static mixer for the total flow-weighted mass of sediment collected at the end of a pipe at the primary station on Interstate 495, in Boxborough, Massachusetts, 2005–07.

[mm/dd/yyyy, month/day/year; in., inches; mm, millimeter; mg/L, milligrams per liter]

Storm	Date (mm/dd/yyyy)	Storm total (in.)	Concentration of suspended sediment greater than 0.250 mm in diameter		Water sample difference (percent)
			Estimated plankton net sample (mg/L)	Flow-weighted composite sample (mg/L)	
1	01/08/2008	0.88	0.9	2.8	301
2	05/02/2007	0.14	3.8	12	313
3	05/18/2007	1.56	5.3	1.4	26
4	07/11/2007	0.19	8.2	14	169
5	07/18/2007	0.23	1.9	2.1	113
6	08/06/2007	0.23	15	22	144
7	08/08/2007	0.51	18	19	105
8	09/10/2007	0.37	31	40	129
9	10/12/2007	0.74	5.6	20	351
10	10/20/2007	1.19	40	88	222

Table 12. Concentrations of constituents measured in samples of solids with diameters ranging from 0.250 millimeter to 6.0 millimeters collected from a plankton net at the outfall of the primary station on Interstate 495 in Massachusetts, 2005–07.

[mm/dd/yyyy, month/day/year; <, less than value shown; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Storm date (mm/dd/yyyy)	Silver (ppm)	Aluminum %	Arsenic (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)	Calcium %	Cadmium (ppm)	Cobalt (ppm)	Chromium (ppm)	Copper (ppm)	Iron %
1/8/2007	<0.2	0.62	7	320	<0.5	<5	0.71	1	6	361	184	2.9
3/2/2007	<0.2	0.37	8	155	<0.5	<5	0.68	<1	4	123	78.9	1.74
4/27/2007	<0.2	0.64	12	183	<0.5	<5	0.91	<1	5	136	69.2	2.49
5/2/2007	<0.2	0.64	7	212	<0.5	<5	0.98	<1	6	1,110	106	2.88
5/18/2007	<0.2	0.54	7	288	<0.5	<5	0.72	<1	6	214	111	1.79
7/11/2007	<0.2	0.43	7	291	<0.5	<5	0.94	<1	6	171	156	2.03
7/18/2007	0.4	0.36	3	291	<0.5	<5	0.87	2	5	439	179	1.53
8/6/2007	<0.2	0.55	6	313	<0.5	<5	1.02	4	9	120	182	2.37
8/8/2007	<0.2	0.52	6	340	<0.5	<5	0.9	<1	15	123	142	2.84

Storm date (mm/dd/yyyy)	Potassium %	Lanthanum (ppm)	Lithium (ppm)	Magnesium %	Manganese (ppm)	Molybdenum (ppm)	Sodium %	Nickel (ppm)	Phosphorus %	Lead (ppm)	Antimony (ppm)	Scandium (ppm)
1/8/2007	0.12	8.2	12	0.3	290	12	0.07	33	0.06	53	7	0.9
3/2/2007	0.09	6.5	9	0.24	188	6	0.05	17	0.02	32	<5	0.7
4/27/2007	0.13	8.6	13	0.41	260	6	0.05	22	0.04	24	<5	1.2
5/2/2007	0.16	11.5	11	0.36	318	12	0.09	32	0.06	24	<5	1.2
5/18/2007	0.13	6.5	10	0.3	211	10	0.05	23	0.04	44	<5	1
7/11/2007	0.11	8.6	15	0.25	255	30	0.07	31	0.11	75	<5	0.6
7/18/2007	0.09	4.3	27	0.19	236	16	0.08	34	0.25	42	<5	<0.5
8/6/2007	0.13	7.4	14	0.31	291	17	0.08	46	0.1	53	<5	1
8/8/2007	0.12	7.9	11	0.28	279	15	0.06	92	0.07	54	<5	0.9

Storm date (mm/dd/yyyy)	Tin (ppm)	Strontium (ppm)	Thallium %	Vanadium (ppm)	Tungsten (ppm)	Yttrium (ppm)	Zinc (ppm)	Zirconium (ppm)	TOC %
1/8/2007	10	45.4	0.03	42	<10	3.9	1,310	3.2	19
3/2/2007	<10	38.9	0.03	23	<10	2.8	365	2.8	8.74
4/27/2007	<10	32.3	0.04	27	<10	4.2	386	4.7	9.53
5/2/2007	10	40.1	0.04	32	<10	4.2	488	3.4	13.2
5/18/2007	<10	33.2	0.03	25	<10	3.4	568	4.5	15.6
7/11/2007	10	48.8	0.02	23	<10	3	1370	2.4	32.8
7/18/2007	10	47.4	<0.01	20	<10	2.5	1370	1.7	43.2
8/6/2007	<10	45.7	0.03	24	<10	3.5	1700	3.5	20.7
8/8/2007	<10	41.3	0.03	22	<10	3.2	1520	5.8	19.9

Works Association, and Water Pollution Control Federation, 1995). Furthermore, an in-bottle digestion method (Garbarino and Hoffman, 1999) was used to partially digest unfiltered samples of water prior to analysis for total-recoverable metals at the NWQL. These methods eliminate any potential bias associated with splitting samples containing large amounts of coarse materials in the laboratory. However, when samples of stormwater are analyzed for a wide range of constituents, it is often necessary to split samples of water in the field into representative aliquots to satisfy different analytical methods. In this study, samples of highway runoff were split directly from the Teflon-lined bottle as described earlier. This method eliminated contact of the sample with additional processing equipment and reduced the potential for contamination. To determine the limitations of this method, a mixture of sediment containing five particle-size ranges of known mass was added to 12 L of deionized water and poured into a typical 20-L Teflon-lined bottle. Samples of the sediment/water mixture of near equal volume were dispensed into 1-L bottles, and the concentration of each particle-size range was determined.

The method used in this study for splitting samples of water containing different size fractions of solids from the automatic sampler bottle into representative aliquots was evaluated under controlled conditions. Using the methods described earlier, 14 sequential replicate samples were collected from a 20-L bottle with an inner Teflon bag containing 12 L of water and a sediment concentration of 1,424 mg/L. The total concentration of suspended sediment and the concentrations for five particle-size ranges were determined for each sample. The mean and relative standard deviation for each particle-size range calculated from these data are presented in table 13. Concentrations of suspended-sediment particles less than 0.063 mm in diameter in samples split from the sediment/water mixture were both accurate and precise. However, the variability in suspended-sediment concentrations in samples of the sediment/water mixture increased for each size class as the diameter of the sediment particles increased. In part, this

decrease in precision is a function of fewer particles being split into a limited number of bottles. These results are not uncommon among splitting devices. Results of experimental tests conducted by the USGS (Capel and Larson, 1996; Capel and nacionales, 1995; Selbig and others, 2007) indicate that concentrations of coarse sediments collected from a churn splitter can deviate from the true concentration by as much as 65 percent, and the relative standard deviation for samples split by a cone splitter range from about 21 to 45 percent. Although the reported results indicate that samples containing coarse sediment may be more precisely collected with a cone splitter, the large and sometimes unpredictable volumes of water collected during storms would require multiple passes through the cone splitter and, because the error is additive, the device may be less effective than the sample splitting method used in this study. Fortunately, the lack of precision in splitting coarse sediments has only marginal effects on the concentrations of many constituents affiliated with suspended sediment because most metals and SVOCs tend to be more concentrated on the particles less than 0.063 mm in diameter.

Chemical Quality and Particle Size of Suspended Sediment, Soil Samples, and Other Miscellaneous Samples

Standard reference samples were submitted to laboratories to identify potential contamination bias and to assess analytical method performance. Replicate samples of background soils, highway-berm soils, suspended sediment, and other miscellaneous samples were collected to determine the precision of the data.

Reference Samples

Five blind samples of standard reference soil (National Institute of Standards and Technology, 2003) from the National Institute of Standards and Technology (NIST)

Table 13. Means and relative standard deviations for 14 sequential replicate samples analyzed for concentrations of suspended sediment in an experiment to assess the precision of field-splitting methods used in this highway-runoff study in Massachusetts, 2005–07.

[mm, millimeter; mg/L, milligrams per liter; <, less than]

Sediment-size description	Range of particle diameters (mm)	True concentration of sediment-water mixture (mg/L)	Mean concentration of sediment in subsamples (mg/L)	Relative standard deviation for concentrations of sediment in subsamples (percent)
Clay and silt	< 0.063 mm	158	158	2.4
Very fine to fine sand	0.063 < 0.250 mm	308	316	32.9
Median to coarse sand	0.250 < 1.0 mm	503	523	61.6
Very coarse sand	1.0 < 2.0 mm	456	475	77.6
Very-fine sand to coarse sand	0.063 < 2.0 mm	1,267	1,314	58.8

containing high levels of trace elements were submitted simultaneously with samples of background soils, highway-berm soils, highway runoff sediment, and other miscellaneous samples for analysis of elements. Standard reference soil was analyzed to determine both total concentrations and total-recoverable concentrations of 32 elements. Concentrations that are certified by the NIST are based on measurements obtained by two or more independent analytical techniques used by multiple laboratories. Concentrations of total metals, which are measured in samples completely digested by hydrofluoric acid, are certified by the NIST and provide the best estimate of the true concentration. For some elements, noncertified concentration data are provided by the NIST for informational purposes only. Leachable concentrations of the elements also are available for reference material. Concentrations of total-recoverable metals determined under mild leaching conditions that only partially digest the solids are not certified by the NIST but do provide quality-control data for the USEPA digestion method 3050B used predominantly in this study. Results of total-recoverable digestion procedures are generally considered by the USEPA to be an indication of bioavailability of trace elements (U.S. Environmental Protection Agency, 1986).

For about 40 percent of the measured elements for which there were certified concentration values in the standard reference soil, median total concentrations in blind samples were within the certified concentration ranges (table 14). For those elements that were outside the certified concentration ranges, the median total concentrations (except for antimony (Sb)) were within 15 percent of the lower certified concentration ranges. Median concentrations of total aluminum (Al), copper (Cu), K, Mn, nickel (Ni), and vanadium (V) fall within about 4 percent of the certified concentrations ranges; median concentrations for lead (Pb), Sb, titanium (Ti), and zinc (Zn) fall within about 6 to 15 percent from the certified concentration ranges. The relative standard deviations for concentrations in the blind samples range from 1 to 7 percent, indicating that the measurements are relatively precise (table 14). The median concentrations in blind samples with the measured elements for which there are noncertified values generally were less than, but within 20 percent of, the noncertified values. Median concentrations of total cobalt (Co), chromium (Cr), lanthanum (La), tungsten (W), and yttrium (Y) in blind samples were about 14 to 20 percent less than the noncertified total values for the NIST reference material (table 14). The median concentrations of total molybdenum (Mo), scandium (Sc), and strontium (Sr) in blind samples are within 5 percent of the noncertified total values for the NIST reference material (table 14). The relatively close agreement between known values and analytical results from blind samples demonstrates that the analytical methods generally were accurate.

Concentrations for total-recoverable elements in NIST reference material also are presented in table 14 with the associated NIST recovery (or leach) range for each element. Because total-recoverable concentrations are determined using partial digestion methods, the total-recoverable concentration

generally is lower than the total concentration; however, the entire concentration can sometimes be recovered even using the weaker digestion method if the element is completely labile. As a result, many of the concentrations of elements that were determined using different digestion methods are similar. The median total-recoverable concentrations for all elements with available reference criteria were within the NIST reported recovery ranges, except for the median total-recoverable concentrations of arsenic (As), K, and P. The median total-recoverable concentrations for As and K were about 3 and 8 percent higher than the upper recovery range for the reference material, respectively. However, the variability in recovery of these elements was within the respective recovery range. The median total-recoverable concentration for P was about 15 percent lower than the lower recovery range for the reference material. These data indicate that the total-recoverable concentrations for this element may exhibit a negative bias.

Inorganic blank water was spiked with known amounts of the NIST reference material to test for differences among total-recoverable concentrations digested using the USEPA method 3050B, the whole-water-in-bottle digestion method (Garbarino and Hoffman, 1999), and the alkaline persulfate digestion method (Patton and Kryskalla, 2003). The latter two methods were used predominantly to determine total-recoverable concentrations for metals and total P, respectively, in samples of highway runoff. Concentrations in parts per million of total-recoverable elements in samples of the sediment/water mixture were calculated on the basis of the mass of blank water and reference material, and the reported concentration for each element in milligrams per liter. Total-recoverable concentrations of Cu and Pb in the samples of the sediment/water mixture were similar to the respective measurements made using USEPA method 3050B; however, the total-recoverable concentrations of the other elements in the samples of the sediment/water mixture were lower than the respective measurements made using USEPA method 3050B (table 14). Total-recoverable concentrations of Cr, Fe, Ni, P, and Zn in the samples of the sediment/water mixture were lower than the lower recovery range for the reference material. These data do not indicate a process failure in the analytical method because partial digestion methods often provide dissimilar results. The in-bottle digestion method described by Garbarino and Hoffman (1999) partially digests whole-water samples with nitric acid, whereas USEPA method 3050B digests samples with repeated additions of nitric acid and hydrogen peroxide, followed by additions of hydrochloric acid and sample refluxing. Coincidentally, USEPA method 3050B is the method by which the ranges of leachable concentrations are determined for the reference material (National Institute of Standards and Technology, 2003). Although the results obtained by nitric-acid digestion often are slightly lower than results obtained by the USEPA method, the precision of the in-bottle digestion method is greater because hydrochloric acid can cause spectral inference in the latter method (Garbarino and Hoffman, 1999). The difference between concentrations of P for each method also can be explained by the different digestion procedures

Table 14. Median values and relative standard deviations for selected concentrations of total and total-recoverable metals in quality-control samples consisting of National Institute of Standards and Technology standard reference soil.

[NIST, National Institute of Standards and Technology; RSD, relative standard deviation; ppm, parts per million; --, no data available; >, greater than; ±, plus or minus; total-recoverable concentrations are comparable to NIST-reported leachable concentrations. Blind sample analytical results are for five samples of the standard reference soil and two artificial water samples consisting of a mixture of inorganic blank water and the standard reference soil submitted separately to laboratories during this study]

Element	NIST standard reference soil reported concentrations		Standard reference soil blind sample analytical results					
	Certified total value (ppm)	Leach range concentrations (ppm)	Total concentration		Total-recoverable concentration		Total-recoverable concentration for reference soil in deionized water	
			Median concentration (ppm)	RSD	Median concentration (ppm)	RSD	Average concentration (ppm)	RSD
Aluminum	64,400 ± 800	12,000–26,000	63,100	4	20,800	8	--	--
Arsenic	626 ± 38	490–600	635	5	616	2	--	--
Barium	707 ± 51	300–400	701	1	328	7	--	--
Calcium	12,500 ± 300	3,800–4,800	12,200	2	4,000	9	--	--
Cadmium	21.8 ± 0.2	13–26	22	4	21	1	16.4	1
Cobalt	10 ¹	6.3–12	8	7	8	6	--	--
Chromium	38 ¹	15–23	31	1	23	15	9	2
Copper	2,950 ± 130	2,400–3,400	2,700	2	2,820	3	2,774	1
Iron	33,800 ± 1,000	22,000–32,000	33,400	2	26,600	9	19,176	1
Lanthanum	34 ¹	--	27.9	3	19.5	6	--	--
Potassium	21,100 ± 1,100	3,700–5,000	19,300	2	5,400	11	--	--
Magnesium	8,530 ± 420	4,300–6,000	8,300	2	5,400	7	--	--
Manganese	10,100 ± 400	6,200–9,000	9,320	4	8,160	6	7,499	1
Molybdenum	19 ¹	13–27	18	5	17	5	--	--
Sodium	11,400 ± 600	490–620	11,000	5	600	23	--	--
Nickel	14.3 ± 1.0	8.8–15	13	7	13	8	6.91	1
Phosphorus	1,060 ± 150	1,060–1,100	1,000	0	900	6	860	2
Lead	5,532 ± 80	4,300–7,000	5,000	3	5,140	4	5,127	2
Antimony	38.4 ± 3	--	44	5	--	--	--	--
Scandium	8.7 ¹	--	8.5	3	4.4	23	--	--
Silver	35.3 ± 1.5	24–30	>10	--	>10	--	--	--
Strontium	330 ¹	94–110	321	3	102	6	--	--
Titanium	2,830 ± 100	920–1,100	2,400	3	1,100	8	--	--
Tungsten	93 ¹	--	80	0	60	8	--	--
Vanadium	76.6 ± 2.3	37–50	73	3	49	7	--	--
Yttrium	23 ¹	--	19	3	13.3	6	--	--
Zinc	6,952 ± 91	5,200–6,900	5,820	4	5,870	5	4,919	2

¹Noncertified value.

used in the various methods. The alkaline persulfate digestion method (Patton and Kryskalla, 2003), which provides results statistically similar to those for samples digested by Kjeldahl method, is a weaker digestion method. These data indicate that whole-water concentrations of Cr, Fe, Ni, P, and Zn that are estimated from sediment data will exhibit a positive bias when compared to the whole-water concentrations determined by the in-bottle digestion method, assuming that dissolved concentrations of the elements are ignored.

Replicate Samples

Replicate samples of background soils, highway-berm soils, suspended sediment, and other miscellaneous materials, including samples of highway-maintenance sand, roadside grass, and solids discharged from the outlet pipe at the primary monitoring station on Interstate 495 were collected to determine the precision of the data. General statistics for the RPDs for 17 pairs of samples are presented in table 15. The average RPD was less than 10 percent for all elements except As, Na, Pb, Sc, and Ti. For these elements, the average RPD between replicate pairs ranged from about 11 to 16 percent. The maximum RPDs between replicate pairs for all elements, except for As, Co, Mo, Pb, Sc, and Ti, were less than 20 percent. The precision of the measurements of environmental samples (table 15) was less than the precision of the measurements of the reference materials (table 14). However, the environmental samples of soil and sediments were not milled prior to laboratory analysis, unlike the NIST reference material, so that comparisons could be made later between concentrations of metals in soils and sediment and concentrations in whole water samples. Because the environmental samples were not milled, greater variability between replicate pairs of samples was expected.

Particle Size

The variability in the distribution of particles sizes associated with replicate split samples of berm material and some soil samples also was assessed because small changes in the overall content of silt- and clay-size particles that contain disproportional amounts of many elements can affect the elemental concentration in the aggregate. The median RPDs for the amounts of material in particle-size classes less than 0.063 mm in diameter, from 0.063 mm to 0.250 mm in diameter, and greater than 0.250 mm in diameter for 16 replicate pairs were 7, 8, and 4 percent, respectively. The RPDs between the amounts of material in the particle-size class less than 0.063 mm in diameter were less than 20 percent for about 90 percent of the replicate pairs. The maximum RPDs between the amounts of material in particle-size classes less than 0.063 mm in diameter, from 0.063 mm to 0.250 mm in diameter, and greater than 0.250 mm in diameter were 36, 19, and 26 percent. Although these data indicate that the distribution of particle sizes in split samples was generally precise, some of the variability observed in the concentrations of elements

in replicate pairs could, in part, result from differences in the distribution of particle sizes in the samples.

Quality of Highway Runoff

Physical characteristics and concentrations of 6 dissolved major ions, total N, total P, 8 total-recoverable metals, 24 SVOCs (including priority PAHs and phthalate compounds), and suspended sediment in highway runoff samples are presented in table 16 (in the back of the report). Concentrations of 73 organic compounds, including an additional 62 organic compounds, which were measured in fewer samples and include selected organic compounds generally found in urban and industrial wastewater discharges, are presented in table 17 (in the back of the report). These data document the chemistry of runoff from Massachusetts highways during 2005–07, as sampled at the four primary monitoring stations, four secondary monitoring stations, and the four monitoring stations on the test highways. The data also are provided in digital form in the HRBD (appendix A) that was developed by USGS, in cooperation with the Federal Highway Administration (Granato and Cazenias, 2009). Various summary statistics for the highway-runoff data presented in tables 16 and 17 can be generated by use of the database, as described by Granato and Cazenias (2009).

Several types of analyses were conducted with the data to evaluate their suitability for the development of planning-level estimates and other applications. Concentrations of highway-runoff constituents from primary, secondary, and test stations were compared to determine whether significant differences exist among the stations, or whether data from the multiple stations can be aggregated. Relations of constituent concentrations to traffic volume were investigated. The effects of seasonality on concentrations also were examined. The frequent measurements of specific conductance during storms and relations developed between specific conductance and element concentrations allowed for a detailed characterization of the components of road salt in the highway runoff at the monitoring stations. A probability distribution for concentrations and loads of Cl in highway runoff and descriptive statistics for the major constituents in road salt were computed on the basis of available continuous records of flow and specific conductance for the entire monitoring period. Potential contributions of highway constituents were estimated on the basis of the chemistry of available soil, berm materials, and highway-maintenance material data, and published source reference data. Finally, the relation of concentrations of selected constituents to suspended sediment was evaluated. In some of the analyses, concentrations of constituents in suspended sediment, constituents in soil samples collected near highways, and other solid-phase matrices were used in the interpretation of the highway runoff data. Constituent concentrations in samples of sieved suspended sediments, soils, and highway berms are presented in tables 18 through 21.

Table 15. Relative percent differences between 17 replicate pairs for samples of background soils, highway-berm soils, suspended sediment, and other miscellaneous samples collected from and near highways in Massachusetts, 2005–07.

Element	Relative percent difference between replicate pairs				Relative standard deviation (percent)
	Minimum (percent)	Average (percent)	Median (percent)	Maximum (percent)	
Aluminum	0.0	5.6	8.2	9.9	66
Arsenic	0.0	14.7	22.2	22.2	67
Barium	1.6	7.1	9.5	9.5	43
Beryllium	0.0	7.7	7.7	15.4	141
Calcium	0.0	1.5	0.0	10.5	216
Cobalt	0.0	2.9	0.0	30.8	293
Chromium	0.8	3.9	3.3	12.2	73
Copper	0.6	5.2	6.0	10.0	46
Iron	0.6	4.6	6.2	8.0	53
Potassium	0.0	5.6	8.0	9.5	63
Lanthanum	1.3	4.8	5.6	5.9	32
Lithium	0.0	6.8	9.5	9.5	60
Magnesium	0.0	1.3	0.0	10.5	217
Manganese	0.0	6.9	10.1	10.1	56
Molybdenum	0.0	2.9	0.0	22.2	217
Sodium	0.0	11.0	18.2	18.2	80
Nickel	0.0	0.7	0.0	11.5	412
Phosphorus	0.0	0.6	0.0	9.5	412
Lead	0.0	16.1	28.6	28.6	85
Scandium	0.0	12.2	12.8	46.2	82
Strontium	0.8	3.9	3.8	8.5	42
Titanium	0.0	13.3	15.4	40.0	75
Vanadium	0.0	4.7	6.1	6.1	43
Yttrium	0.0	7.8	11.1	11.4	56
Zinc	0.7	3.8	3.0	15.6	94
Zirconium	3.5	9.9	10.1	14.6	28

Intrasite Evaluation of Constituents in Samples of Runoff from the Principal Highways

The primary and secondary monitoring stations were located along principal highways (table 1). Paired primary and secondary sites were located within a few miles of each other on a section of highway with limited access to ensure comparable levels of traffic volume and density. Although the design and operation of the primary and secondary monitoring stations were similar, the monitoring period and number of samples of highway runoff collected at the primary stations were greater than at the secondary stations. Populations of concentration data for constituents in samples routinely collected at the secondary monitoring stations on each of the principal highways were compared to the populations of concentration data for associated primary monitoring stations to determine whether the variability between the data was significantly different or whether the data could be aggregated. The nonparametric Mann-Whitney test was used to determine whether the independent populations were statistically different (p value less than 0.05). For constituents whose concentrations either were not detected or were estimated to be less than the LTMDL (censored data), concentrations were set equal to a value less than the respective LTMDL. This approach is appropriate for rank-based nonparametric methods for singly censored data (Helsel, 2005). Analyses for many PAH and phthalate compounds were not performed because they either were not detected in the samples or all of the concentrations were estimated to be less than the LTMDL.

With a few exceptions, results of tests of paired populations of individual constituent concentrations, where sufficient data were available, generally indicate that the populations were not significantly different at a 95-percent confidence interval for each pair of sites on the principal highways. The resultant p values for each of the principal highways are listed in table 22. Results of tests between paired populations of concentrations of all constituents in samples collected at the monitoring stations on Route 119, except suspended sediment less than 0.063 mm in diameter, indicate no significant difference (table 22). The difference between the median concentrations of suspended sediment less than 0.063 mm in diameter for each site is about 19 mg/L or about 22 percent. The lack of significance observed in the test between paired populations of concentrations of suspended sediment with particles less than 0.063 mm in diameter may be the result of runoff patterns associated with the secondary monitoring station that differed from those at the primary monitoring station. For example, a pair of parallel ruts in each travel lane on the road surface in the drainage area of the secondary monitoring station (fig. 17) often caused smaller flows to bypass the catch basin; furthermore, frost heaves in the roadway within the drainage area of the secondary monitoring station also diverted water away from the catch basin during the winter when runoff concentrations of suspended sediment are generally high as a result of winter sanding. It is plausible that these factors affected the flow patterns sufficiently to introduce bias into the sample

population of sediment concentrations less than 0.063 mm in diameter at the secondary monitoring station on Route 119. Tests between paired populations of concentrations for all constituents in runoff collected at the monitoring station on Route 2, except for concentrations of total-recoverable Zn, also determined no significant difference (table 22). For this highway, the median concentration of total-recoverable Zn in composite samples of highway runoff at the primary station (308 mg/L) was about twice as high as the median concentration measured in composite samples at the adjacent secondary station (152 mg/L). The significant difference resulting from the test between paired populations of total-recoverable Zn is not fully explainable with available data. Tests between paired populations of constituent concentrations from the monitoring stations on Interstate 495, except for concentrations of suspended sediment less than 0.063 mm in diameter, also determined no significant difference (table 22). The difference between the median concentrations of suspended sediment less than 0.063 mm in diameter for each set of paired sites was about 34 mg/L or about 41 percent. The significant difference between the paired populations of concentrations of suspended sediment is likely attributable to berm material that eroded onto the roadway surface in the drainage area of the primary monitoring station because the height of the berm along the highway at the secondary monitoring station was lower than the berm at the primary monitoring station and showed little evidence of erosion. Results for all tests between paired populations of constituent concentrations in samples from the monitoring site on Interstate 95 (table 22) indicate that the populations are not significantly different from each other. A greater number of constituents were tested for this highway than for other highways because the frequency of detection for most PAH and phthalate compounds was greater here than at other highways.

In summary, there were few significant differences between constituent concentrations in samples collected at primary and secondary sites on the principal highways. Consequently, in subsequent analyses, data from the primary and secondary monitoring stations were combined to characterize the quality of runoff from the principal highways. For those tests between populations of suspended sediment less than 0.063 mm in diameter, it was unusual that the concentrations of fine sediment were significantly different between the paired stations on Route 119 and Interstate 495. Yet, concentrations of no other constituents were significantly different between the paired sites for each highway because the concentrations of many elements generally are greater on the fine sediment fraction than on the coarser sand fractions (table 18 in the back of the report). Alternatively, the effects of the distributions of sediment particle size, concentration, and associated sediment chemistry may be small if the dissolved fraction of the total-recoverable metals was high in samples of runoff. Other studies that included analyses for concentrations of filtered composite samples have shown that the concentrations of some dissolved trace elements can account for about 10 to 65 percent of the total concentration (Smith, 2002;

Table 22. Resultant *p* values for Mann-Whitney tests for paired populations of constituent concentrations for highway runoff collected from the primary and secondary stations on four principal highways in Massachusetts, 2005–07.

[<, Less than value shown; --, insufficient detections to perform test; mm, millimeters in diameter; shaded areas indicate values that are significant at a 95-percent confidence interval]

Constituent	Route 119	Route 2	Interstate 495	Interstate 95
Chloride	0.467	0.429	0.672	0.710
Sodium	0.445	0.401	0.672	0.204
Calcium	0.813	0.303	0.410	1.000
Magnesium	0.580	0.565	0.963	0.108
Potassium	0.772	0.848	1.000	0.108
Sulfate	0.564	0.905	0.869	0.281
Nitrogen, total	0.407	0.867	0.742	0.632
Phosphorus, total	0.920	0.737	0.258	0.701
Cadmium	0.520	0.061	0.888	0.314
Chromium	0.340	0.810	0.796	0.886
Copper	0.514	0.867	0.347	0.517
Iron	0.564	0.867	0.204	1.000
Lead	0.900	0.774	0.397	0.270
Manganese	0.900	0.829	0.452	0.649
Nickel	0.633	0.829	0.605	0.581
Zinc	0.861	0.010	0.452	0.719
Fluorene	--	--	--	--
Acenaphthene	--	--	--	1.000
Acenaphthylene	--	--	--	--
Anthracene	--	--	--	0.423
Benzo[<i>a</i>]anthracene	1.000	0.744	0.234	0.734
Benzo[<i>a</i>]pyrene	0.568	0.293	0.125	0.827
Benzo[<i>b</i>]fluoranthene	0.949	0.623	0.165	0.905
Benzo[<i>ghi</i>]perylene	0.775	0.971	0.223	0.595
Benzo[<i>k</i>]fluoranthene	--	0.437	0.570	0.829
Benzyl n-butyl phthalate	--	--	0.970	0.282
Bis(2-ethylhexyl) phthalate	0.153	0.848	0.772	0.290
Chrysene	0.736	0.585	0.126	0.848
Dibenzo[<i>a,h</i>]anthracene	--	--	--	--
Diethyl phthalate	--	--	--	0.598
Dimethyl phthalate	--	--	--	--
Di-n-butyl phthalate	--	0.163	0.107	0.975
Di-n-octyl phthalate	0.784	0.692	0.484	0.103
Fluoranthene	0.687	0.449	0.126	0.649
Indeno[1,2,3- <i>cd</i>]pyrene	--	0.423	0.532	0.632
Nitrobenzene	--	--	--	--
Phenanthrene	0.840	0.482	0.100	0.360
Pyrene	0.949	0.566	0.066	0.684
Naphthalene	--	--	--	--
Perylene	--	--	0.324	0.294
Suspended sediment	0.230	0.821	0.034	0.737
Suspended sediment < 0.063 mm	0.003	0.688	0.001	0.157



Figure 17. Ruts on the roadway surface running parallel with the road that often caused small flows to bypass the catch basin at the secondary highway-monitoring station on Route 119 in Ashburnham, Massachusetts.

Breault and Granato, 2000). The partitioning of metals from the dissolved, colloidal, and solid states is poorly understood. Various factors, including pH, ionic strength, temperature, hardness, concentration of anions and suspended sediment, oxidation reduction potential, and in some cases, the presence of other trace elements (Bricker, 1999) can affect the partitioning process in runoff. The duration that the sample remains in the sample bottle prior to processing also can affect the partitioning process as well. Unfortunately, characterization of the dissolved phase of constituents was outside of the scope of this study.

Inter-Site Evaluation of Constituents in Runoff from Test Highways and Principal Highways

Populations of all concentration data for runoff collected from the test highways were compared to populations of concentration data from the principal highways of similar AADT volumes to determine whether the data were transferable from highway to highway on the basis of AADT volume. Statistically similar sample populations for the primary and secondary stations on the principal highways were combined into one data set. Results of Mann-Whitney tests were used to determine whether the independent populations from the paired highways were statistically different (p value less than 0.05). As previously indicated, censored concentrations of any constituent were set equal to a value less than the LTMDL.

Mann-Whitney tests were performed between populations of constituent concentrations in samples from the monitoring stations on three principal highways and four test highways—Route 119 and Route 8 (low AADT volume), Route 2 and Interstate 190 (moderate AADT volume), Route 2 and Interstate 195 (moderate AADT volume), and Interstate 95 and Interstate 93 (very high AADT volume). The resulting p values for each of the tests are listed in table 23. Where sufficient concentration data were available for testing, the results showed no significant difference between populations of constituent concentrations collected from the sites on Route 119 and Route 8, and only populations of total-recoverable Zn were significantly different in test results for Route 2 and Interstate 190. Consequently, the significant difference may be attributable to the high total-recoverable Zn concentrations observed at the primary monitoring station on Route 2. The test results for populations of total-recoverable Zn concentrations in samples only from the secondary station on Route 2 and the test station on Interstate 190 indicate that populations were not significantly different (p value = 0.213). Results for most tests between populations of constituent concentrations in samples collected from the stations on Route 2 and Interstate 195, and for stations on Interstate 95 and Interstate 93, indicate that the populations of several constituents were significantly different. Results of tests between populations of concentrations of dissolved Ca and K, total P, and total-recoverable Cd, Cr, Cu, Mn, and Zn in samples from the stations on Route 2 and on Interstate 195 indicate that populations were

significantly different. Test results between populations of concentrations of total N; dissolved Mg, Na, Cl, SO_4 ; total-recoverable Cu, Fe, Pb, and Ni; suspended sediment; and PAH and phthalate compounds, where sufficient data were available, indicate populations or concentrations were not significantly different. Because the concentrations of total-recoverable Zn at the primary monitoring station on Route 2 were significantly higher than at the test monitoring stations, another test was performed between the populations of total-recoverable Zn concentrations collected from the secondary station on Route 2 and the station on Interstate 195. However, results from this test also indicated that the two populations were significantly different (p value = 0.017). Because winter-maintenance sanding generally is not practiced on Interstate 195 in the vicinity of the monitoring location (Roy Fierro, Massachusetts Department of Transportation, written commun., 2006), Mann-Whitney tests also were performed on a subset of concentrations of total P and total-recoverable Cd, Cr, Cu, Mn, and Zn that excluded concentrations in samples collected during winter storms at the Route 2 monitoring locations. These test results indicate that populations of total-recoverable Cr, Mn, and Zn collected from the stations on Route 2 and on Interstate 195 remain significantly different at a 95-percent confidence interval.

The monitoring station on Interstate 195 is located near Cape Cod and USEPA level III ecoregion 84 where the soil and vegetation are different than at the monitoring station on Route 2. Background soils can be deposited on the highway by hydraulic erosion of the roadway berm, or directly deposited on the road by automobiles. As a result of these processes, local soils can be a large part of the suspended sediment in highway runoff (Gupta and others, 1981) and may provide a base concentration for total P and many metals. Analysis of samples of soil collected along both highways indicate that concentrations of elements were lower near the Interstate 195 station than concentrations near the stations on Route 2 (fig. 18). In fact, concentrations of total P and total-recoverable Cr, Cu, Fe, Ni, Mn, Pb, and Zn in samples of soil collected along Interstate 195 were consistently lower than the concentrations of the same constituents collected along six of the other highways (fig. 18) located in Massachusetts. Because concentrations of suspended sediment were not significantly different between the two highways, it is reasonable to conclude that highways with similar anthropogenic-enrichment rates may produce runoff of dissimilar quality, depending on the base quality of the local soils.

These findings indicate that it may be unwise to use descriptive statistics generated by data sets of similar AADT volumes to estimate constituent loads for highways located in the southeastern coastal areas of Massachusetts and USEPA level III ecoregion 84 because the use of the descriptive statistics may result in grossly overestimated loads.

Concentrations of most total-recoverable metals in composite samples of highway runoff collected on Interstate 93 were considerably higher than the concentrations in composite samples from Interstate 95. Results for Mann-Whitney tests

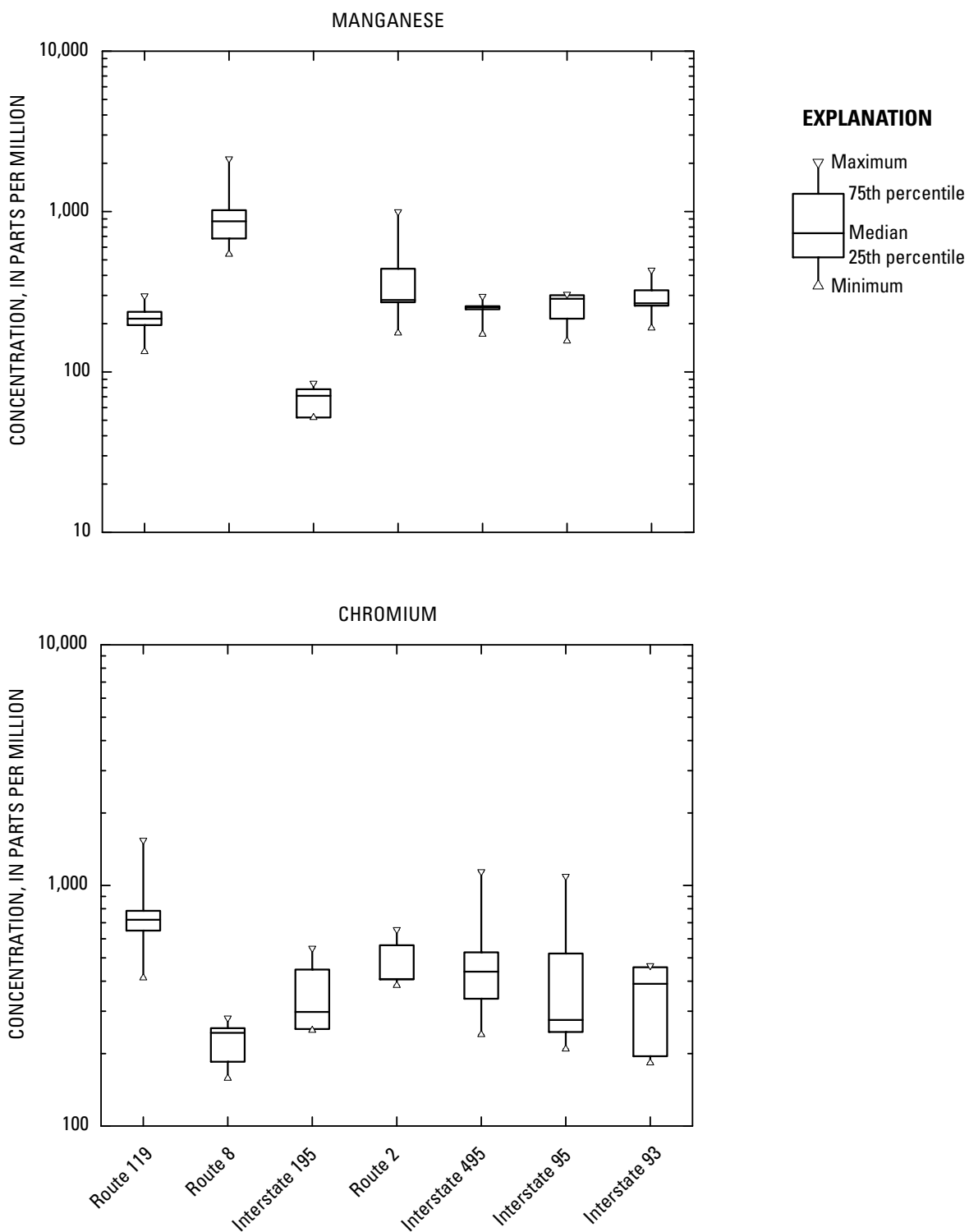


Figure 18. Distribution of concentrations of selected constituents in samples of soil collected in the vicinity of seven highway-runoff monitoring sites in Massachusetts, 2005–07.

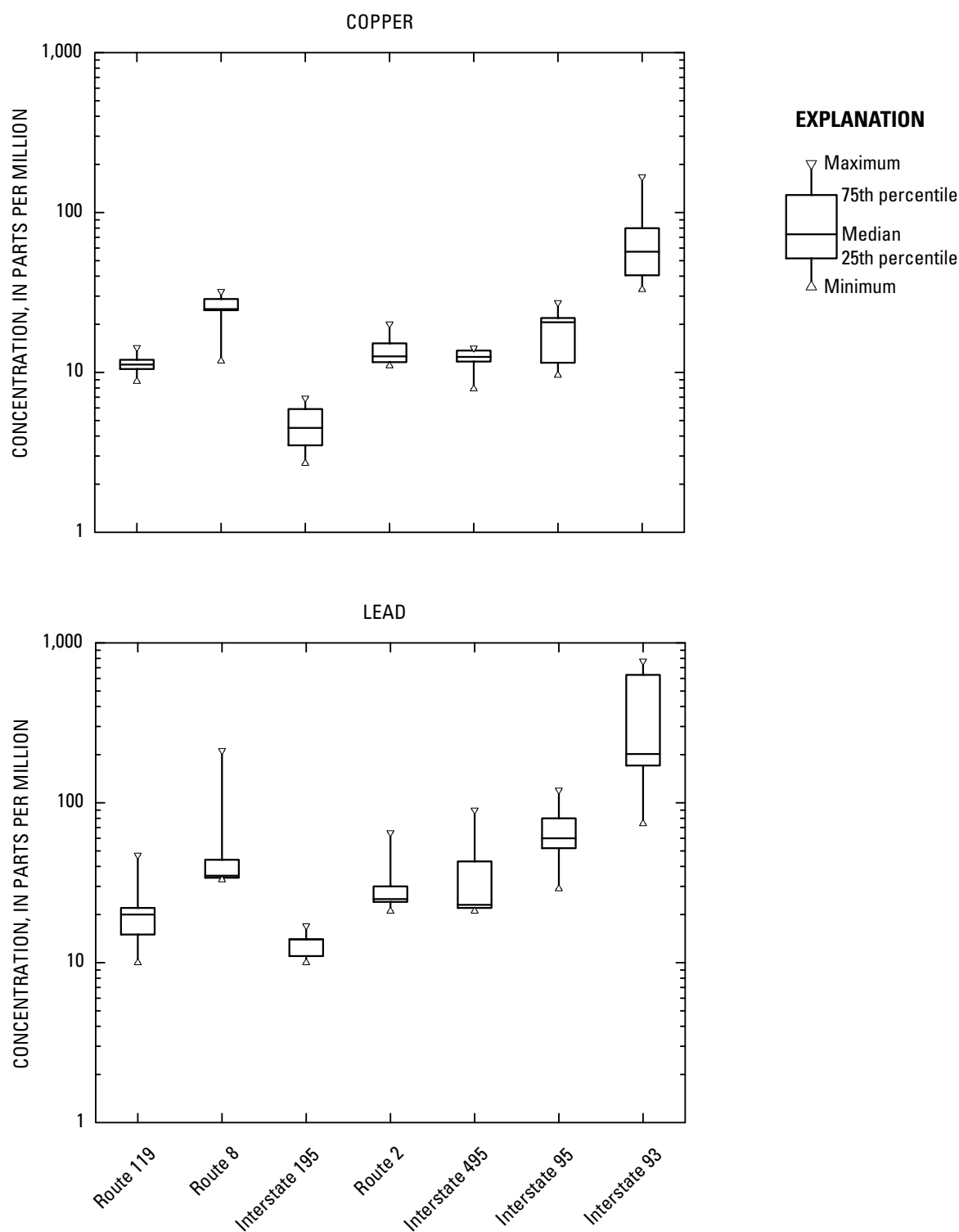


Figure 18. Distribution of concentrations of selected constituents in samples of soil collected in the vicinity of seven highway-runoff monitoring sites in Massachusetts, 2005–07.—Continued

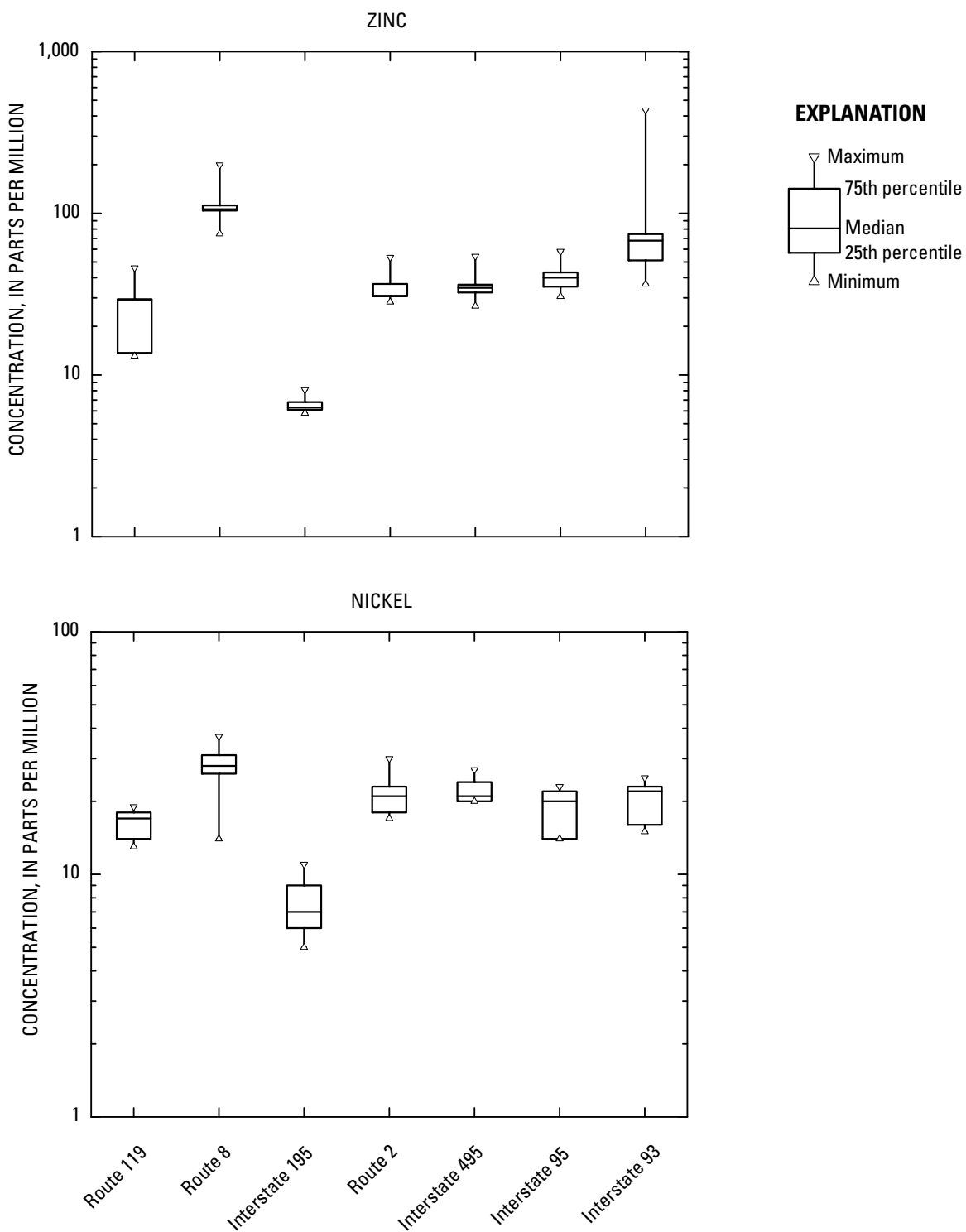


Figure 18. Distribution of concentrations of selected constituents in samples of soil collected in the vicinity of seven highway-runoff monitoring sites in Massachusetts, 2005–07.—Continued

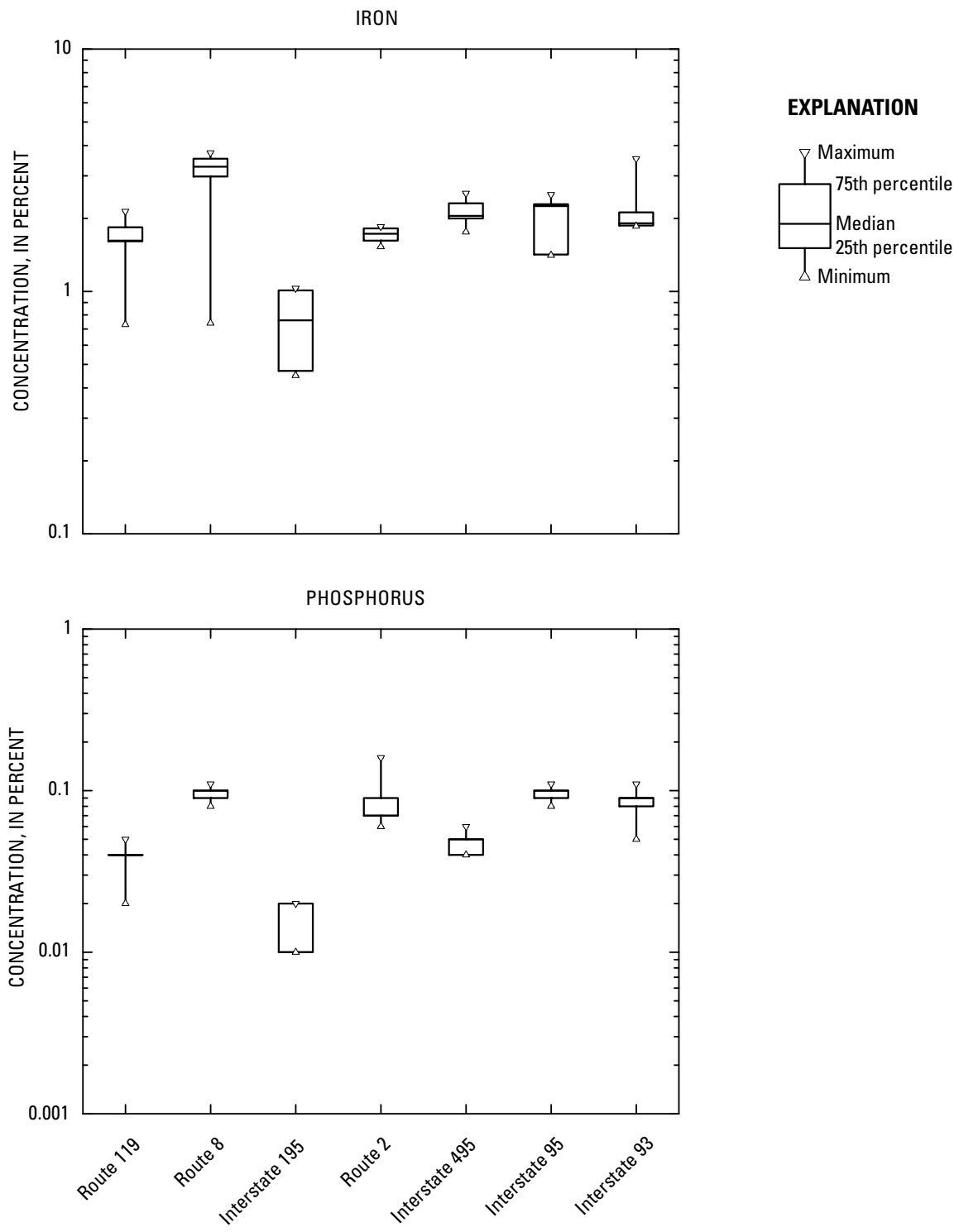


Figure 18. Distribution of concentrations of selected constituents in samples of soil collected in the vicinity of seven highway-runoff monitoring sites in Massachusetts, 2005–07.—Continued

Table 23. Resultant *p* values for Mann-Whitney tests for paired populations of constituent concentrations in highway runoff collected from three stations on principal highways and four stations on the test highways in Massachusetts, 2005–07.

[<, Less than value shown; --, insufficient detections to perform test; mm, millimeters in diameter; shaded areas indicate values that are significant at a 95-percent confidence interval]

Constituent	Route 119 and Route 8	Route 2 and Interstate 190	Route 2 and Interstate 195	Interstate 95 and Interstate 93
Chloride	0.177	0.067	0.598	0.298
Sodium	0.248	0.082	0.633	0.407
Calcium	0.091	0.542	0.045	0.951
Magnesium	0.271	0.429	0.103	0.821
Potassium	0.554	0.288	0.008	0.744
Sulfate	0.959	0.946	0.303	0.821
Nitrogen, total	0.119	0.701	0.167	0.451
Phosphorus, total	0.362	0.560	0.039	0.092
Cadmium	0.096	0.342	0.044	0.108
Chromium	0.194	0.603	0.013	0.040
Copper	0.119	0.378	0.280	0.011
Iron	0.917	0.821	0.126	0.026
Lead	0.119	0.343	0.498	0.021
Manganese	0.568	0.769	0.014	0.033
Nickel	0.568	0.946	0.259	0.060
Zinc	0.697	0.040	0.001	0.022
Fluorene	--	--	--	0.412
Acenaphthene	--	--	--	--
Acenaphthylene	--	--	--	0.690
Anthracene	--	--	--	0.084
Benzo[<i>a</i>]anthracene	0.810	0.431	0.255	0.090
Benzo[<i>a</i>]pyrene	0.701	--	0.168	0.403
Benzo[<i>b</i>]fluoranthene	0.872	--	0.266	0.114
Benzo[<i>ghi</i>]perylene	--	--	--	0.522
Benzo[<i>k</i>]fluoranthene	--	--	--	0.114
Benzyl n-butyl phthalate	--	--	0.527	0.360
Bis(2-ethylhexyl) phthalate	0.162	--	0.711	0.019
Chrysene	0.789	--	0.184	0.145
Dibenzo[<i>a,h</i>]anthracene	--	--	--	--
Diethyl phthalate	--	--	0.174	0.159
Dimethyl phthalate	--	--	--	--
Di-n-butyl phthalate	--	--	0.681	0.806
Di-n-octyl phthalate	0.091	--	0.820	0.031
Fluoranthene	0.900	0.752	0.496	0.139
Indeno[1,2,3- <i>cd</i>]pyrene	--	--	--	0.472
Nitrobenzene	--	--	--	--
Phenanthrene	0.091	--	0.583	0.175
Pyrene	0.900	0.846	0.451	0.103
Naphthalene	--	--	--	0.174
Perylene	--	--	--	0.679
Suspended sediment	0.258	0.363	0.065	0.020
Suspended sediment < 0.063 mm	0.615	0.073	0.194	0.238

between populations of concentrations of total-recoverable metals, except for Cd and Ni, and suspended sediment collected from the stations on Interstate 95 and Interstate 93 were significantly different at a 95-percent confidence interval. No significant differences were found between populations of concentrations of total nutrients, major ions, and SVOCs. Concentrations of total-recoverable Cu, Pb, and Zn in local soils near the monitoring station on Interstate 93 were greater than the concentrations present in soil samples collected near the monitoring stations on Interstate 95, as well as the other six highways (table 19 in the back of the report and fig. 18). Albeit these soil samples were collected at a distance of about 30 ft from the edge of the highways and samples from other highways were collected at a distance of about 100 ft from the edge of the highways, the concentrations of many metals in soils adjacent to highways have been shown to decay exponentially (Jaradat and Momani, 1999); thus even at about 30 ft from the highway edge, for many metals, concentrations in the soil may approach background concentrations. In part, the higher concentrations of Cu, Pb, and Zn in local soils near the monitoring station on Interstate 93 may explain some of the differences between the two populations for these constituents; however, concentrations of the other metals in samples of soil collected near the monitoring station on Interstate 93 were similar to concentrations present in soil samples collected near the monitoring stations on other highways. The concentrations of suspended sediment present in composite samples of highway runoff from the station on Interstate 93 were higher than in composite samples of highway runoff collected at stations on Interstate 95. This is likely the main factor in the significant difference between populations of metals. The median concentration of suspended sediment for the station on Interstate 93 (714 mg/L) is nearly an order of magnitude higher than the median concentration for the station on Interstate 95 (87 mg/L).

Although the median concentration of suspended sediment for the monitoring station on Interstate 93 is based on only five measurements, data collected with nearly identical methods at three locations on Interstate 93 in 1999 and 2000 (Smith, 2002) support the high concentrations of suspended sediment observed in this study. In fact, the median concentrations of most constituents in composite samples from the station on Interstate 93 in this study are within the interquartile range of the previous study (table 24); the exceptions are dissolved Ca, Cl, and Na; total-recoverable Cd, Cu, and Fe; and a few PAHs. Concentrations of dissolved Ca, Cl, and Na were lower than in the previous study likely because, in this study, fewer samples were collected during the winter when deicing compounds are applied than during the prior study when 50 percent of the samples were collected in the months of January and March. Concentrations of PAHs also tend to be higher during the colder months, so a similar bias is applicable. Concentrations of total-recoverable Cu and Fe were within about 3 percent of the upper quartile range. Results for Mann-Whitney tests for the respective data sets indicate the populations from the two studies are not statistically different

at a 95-percent confidence interval, except for populations of acenaphthylene concentrations (table 24). Acenaphthylene concentrations were significantly different between the two populations at a slightly higher confidence interval.

The higher concentrations of suspended sediment in samples collected from Interstate 93 may be an artifact of the urban environment. Higher concentrations of airborne sediment build up near highway curbing, guardrails, and other barriers in highly urbanized areas that lack natural vegetation barriers that trap dust fall. Dry-deposition rates are reported to increase substantially from rural areas, which generally have low deposition rates, to urban areas, which have high deposition rates (Colman and others, 2001). In this study, impervious surface area (roofs, paved areas, concrete surfaces) is used in place of generalized land-use indexes to quantify urbanization. Concentration data for stations on highways in this study indicate that the amount of suspended sediment in samples of highway runoff increases with the amount of impervious area surrounding the sampling station on the highway (fig. 19). The amount of impervious area surrounding the Interstate 93 station is about twice that of the areas surrounding the Interstate 95 stations, despite the fact that a substantial amount of land to the east of Interstate 93 consists of park land, river, and embayment. These data indicate that the quantity, as well as the quality, of sediment in highway runoff can be affected by the proximity to highly urbanized areas containing large amounts of impervious area. Thus, information on loads for Interstate 93 within the urbanized area may more accurately be determined from descriptive statistics generated by data collected specifically from Interstate 93 during this study and the previous study (Smith, 2002) than from data sets for other highways with similar AADT volumes.

Intersite Evaluation of Constituents in Samples of Runoff from the Principal Highways

Populations of all concentration data (table 16) collected from each principal highway (primary and secondary sites) were compared to populations from each of the other principal highways to determine whether the populations were significantly different from highway to highway. Results of the Mann-Whitney tests were used to determine whether the independent populations from each of the principal highways were statistically different (p value less than 0.05). As previously indicated, censored data values were set equal to a value less than the LTMDL for each constituent. For several PAH and phthalate compounds, analysis was limited by the lack of detections in samples of highway runoff. The resultant p values for each of the constituents are listed in table 25.

Results indicate that, in general, concentrations of most constituents in composite samples collected at the monitoring stations on Route 119, were significantly different from those from the other three principal highways (table 25). Results of paired tests between populations of concentration data from Route 119 and each of the other principal highways show that

Table 24. Median and interquartile values and resultant *p* values for Mann-Whitney tests at a 95-percent confidence interval for paired populations of constituent concentrations in highway runoff collected from Interstate 93 in Massachusetts in 1999 through 2000 and 2006 through 2007.

[mg/L, milligrams per liter; µg/L, micrograms per liter; mm, millimeters in diameter; shaded area indicates values that are significant at a 95-percent confidence interval]

Constituent	Interstate 93 (1999–2000) 25th percentile	Interstate 93 (1999–2000) median	Interstate 93 (1999–2000) 75th percentile	Interstate 93 (2006–07) median	<i>p</i> -value
Calcium, filtered, mg/L	7.65	11	11	7.2	0.33
Magnesium, filtered, mg/L	0.60	0.70	0.80	0.75	0.86
Potassium, filtered, mg/L	1.3	1.5	1.8	1.38	0.79
Sodium, filtered, mg/L	31	54	155	25	0.79
Chloride, filtered, mg/L	46.5	76	245	31.2	0.93
Sulfate, filtered, mg/L	9.6	13	76	10.2	0.73
Total nitrogen, unfiltered, mg/L	1.87	2.54	3.12	2.09	0.28
Phosphorus, unfiltered, mg/L	0.29	0.44	0.62	0.34	0.59
Cadmium, unfiltered, µg/L	2	2	3	0.78	0.12
Chromium, unfiltered, µg/L	24.75	36	42	40	0.54
Copper, unfiltered, µg/L	107.5	140	172.5	178	0.71
Iron, unfiltered, µg/L	9,300	11,000	12,000	12,100	0.84
Lead, unfiltered, µg/L	74	95	112.5	75.6	0.62
Manganese, unfiltered, µg/L	210	230	280	220	0.71
Nickel, unfiltered, µg/L	15	17.5	20.5	18.2	0.97
Zinc, unfiltered, µg/L	477.5	575	935	613	0.90
Fluorene, unfiltered, µg/L	0.10	0.10	0.20	0.12	0.51
Acenaphthene, unfiltered, µg/L	0.10	0.10	0.10	0.07	0.05
Acenaphthylene, unfiltered, µg/L	0.10	0.10	0.20	0.06	0.00
Anthracene, unfiltered, µg/L	0.10	0.20	0.30	0.21	0.76
Benzo[<i>a</i>]pyrene, unfiltered, µg/L	0.50	0.60	0.90	0.73	0.69
Benzo[<i>b</i>]fluoranthene, unfiltered, µg/L	0.70	1.0	1.3	1.6	0.11
Benzo[<i>ghi</i>]perylene, unfiltered, µg/L	0.30	0.80	1.0	0.49	0.59
Benzo[<i>k</i>]fluoranthene, unfiltered, µg/L	0.40	0.50	0.90	0.63	1.00
Chrysene, unfiltered, µg/L	0.60	1.2	1.6	1.2	0.92
Fluoranthene, unfiltered, µg/L	1.1	1.6	2.3	2.0	0.69
Indeno[1,2,3- <i>cd</i>]pyrene, unfiltered, µg/L	0.30	0.60	0.90	0.43	0.62
Phenanthrene, unfiltered, µg/L	0.50	0.80	1.3	0.91	0.69
Pyrene, unfiltered, µg/L	1.0	1.4	2.2	1.6	0.84
Naphthalene, unfiltered, µg/L	0.14	0.20	0.20	0.07	0.31
Suspended sediment, mg/L	276	426	665	714	0.74
Suspended sediment < 0.063 mm, percent	43	71.6	86	21	0.27

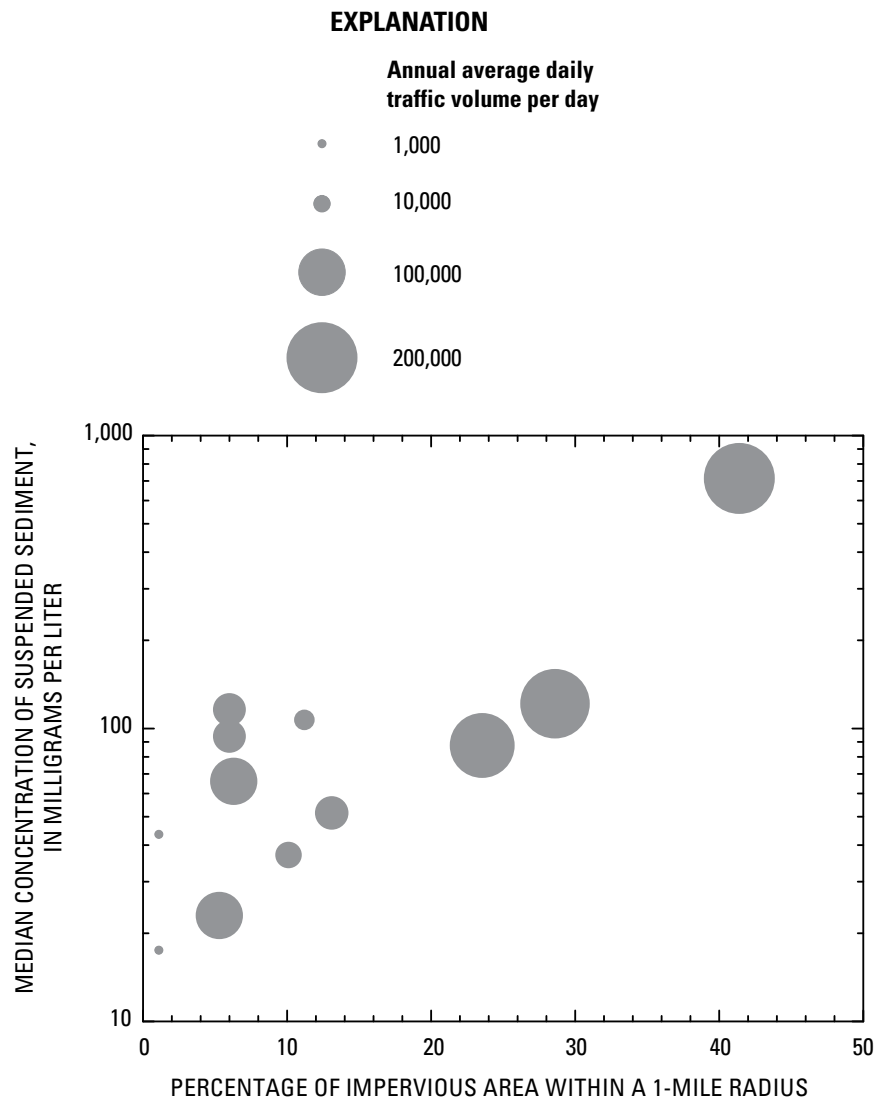


Figure 19. Relation of the percentage of impervious area within a 1-mile radius around each of the 12 highway-runoff monitoring sites in Massachusetts to the median concentration of suspended sediment and annual average traffic volumes.

Table 25. Resultant *p* values for Mann-Whitney tests for paired populations of concentrations of highway-runoff constituents collected from the primary and secondary stations on the four principal highways in Massachusetts, 2005–07.

[<, Less than value shown; --, insufficient detections to perform test; mm, millimeters in diameter; shaded areas indicate values that are significant at a 95-percent confidence interval]

Constituent	Route 119 and Route 2	Route 119 and Interstate 495	Route 119 and Interstate 95	Route 2 and Interstate 495	Route 2 and Interstate 95	Interstate 495 and Interstate 95
Chloride	0.705	0.847	0.424	0.838	0.825	0.676
Sodium	0.829	0.986	0.411	0.812	0.572	0.466
Calcium	0.382	0.236	0.003	0.974	<0.001	0.001
Magnesium	0.610	0.749	0.345	0.330	0.291	0.110
Potassium	0.068	0.544	0.007	0.138	0.143	0.003
Sulfate	0.263	0.285	0.023	0.863	0.008	0.019
Nitrogen, total	0.000	0.001	<0.001	0.896	0.015	0.013
Phosphorus, total	0.051	0.082	0.006	0.844	0.844	0.408
Cadmium	<0.001	<0.001	<0.001	0.600	0.658	0.980
Chromium	<0.001	<0.001	<0.001	0.670	0.436	0.325
Copper	<0.001	<0.001	<0.001	0.363	0.041	0.310
Iron	0.091	0.009	0.061	0.577	0.737	0.572
Lead	0.004	0.001	<0.001	0.617	0.064	0.310
Manganese	0.065	0.024	0.010	0.774	0.306	0.476
Nickel	0.040	0.007	0.003	0.572	0.210	0.346
Zinc	<0.001	<0.001	<0.001	0.053	0.075	0.774
Fluorene	--	--	--	--	--	0.954
Acenaphthene	--	--	--	--	--	0.975
Acenaphthylene	--	--	--	--	--	--
Anthracene	--	--	--	--	--	0.626
Benzo[<i>a</i>]anthracene	0.003	0.002	0.030	0.612	0.395	0.766
Benzo[<i>a</i>]pyrene	<0.001	<0.001	<0.001	0.808	0.162	0.295
Benzo[<i>b</i>]fluoranthene	0.005	0.006	<0.001	0.878	0.185	0.121
Benzo[<i>ghi</i>]perylene	0.283	0.097	0.002	0.385	0.017	0.149
Benzo[<i>k</i>]fluoranthene	0.011	0.007	<0.001	0.658	0.064	0.157
Benzyl n-butyl phthalate	0.841	0.834	0.144	0.920	0.193	0.280
Bis(2-ethylhexyl) phthalate	0.003	<0.001	<0.001	0.468	0.231	0.550
Chrysene	0.008	0.018	0.000	0.786	0.144	0.131
Dibenzo[<i>a,h</i>]anthracene	--	--	--	--	--	--
Diethyl phthalate	<0.001	<0.001	0.228	0.556	<0.001	<0.001
Dimethyl phthalate	--	--	--	--	--	--
Di-n-butyl phthalate	0.893	0.876	0.316	0.911	0.239	0.340
Di-n-octyl phthalate	0.001	0.003	0.001	0.365	0.532	0.142
Fluoranthene	0.002	0.002	<0.001	0.967	0.148	0.244
Indeno[1,2,3- <i>cd</i>]pyrene	0.044	0.007	0.001	0.362	0.029	0.210
Nitrobenzene	--	--	--	--	--	--
Phenanthrene	0.095	0.060	0.005	0.685	0.159	0.367
Pyrene	0.008	0.004	<0.001	0.771	0.066	0.184
Naphthalene	--	--	--	--	--	0.520
Perylene	--	--	--	0.093	<0.001	0.172
Suspended sediment	0.031	0.034	0.020	0.749	0.820	0.629
Suspended sediment < 0.063 mm	0.002	0.550	0.079	0.049	0.183	0.403

total N; total-recoverable Cd, Cr, Cu, Pb, Ni, and Zn; most PAH and phthalates compounds; and suspended sediment were significantly different at a 95-percent confidence interval.

Paired tests between populations of concentration data from Route 119 and Interstate 95 show that populations of concentrations of dissolved Ca, K, and SO_4 ; total P; benzo[ghi]perylene; and phenanthrene also were significantly different at a 95-percent confidence interval. Results of paired tests between populations of concentration data from Route 2 and Interstate 495 indicate that these constituents were not significantly different at the respective confidence intervals. Results of paired tests between populations of Fe concentrations indicate that concentrations were significantly different only for Route 119 and Interstate 495, and results of paired tests between populations of Mn concentrations indicate concentrations were significantly different for Route 119 and Interstate 495, and for Route 119 and Interstate 95. Results of paired tests between populations of concentration data from Route 119 and each of the other principal highways indicate that dissolved Cl, Na, and Mg; benzyl n-butyl phthalate; and di-n-butyl phthalate were not significantly different at the respective confidence intervals. Although results of paired tests of concentrations of suspended sediment indicate a significant difference only for Route 119 (highway with the lowest AADT volume), results of tests were significant for concentrations of suspended sediment less than 0.063 mm in diameter in samples from Route 119 and Route 2. The significant difference between populations of concentrations of suspended sediment from Route 119 and the other principal highways may, in part, explain the significant difference between the populations of concentrations of sediment-associated constituents from the other principal highways. No significant difference was found for tests between populations of concentration data for Route 2 and Interstate 495, except for concentrations of sediment less than 0.063 mm in diameter. However, results of paired tests for populations of dissolved Ca and SO_4 , total N, total-recoverable Cu, benzo[ghi]perylene, diethyl phthalate, indeno[1,2,3-cd]pyrene, and perylene concentrations between Route 2 and Interstate 95 indicate concentrations were significantly different a 95-percent confidence interval. Results of paired tests between populations of concentration data from Interstate 495 and Interstate 95 indicate concentrations were significantly different at a 95-percent confidence interval only for dissolved Ca, K, and SO_4 ; total N; and diethyl phthalate. Concentrations of dissolved Ca were significantly different for all paired tests on data from Interstate 95. The highway-monitoring stations on Interstate 95 are located in a section of highway designated as a low-salt area because of the proximity to a major drinking-water source area; thus, the significant difference in concentrations of Ca for Interstate 95 are likely a function of more wide-spread use of liquid calcium chloride on that highway during the winter than on the other highways.

Relation of Constituents to Annual Average Daily Traffic

Because the principal highways share many similarities in construction, surrounding land use, and local soil composition, and because the samples of highway runoff were collected during similar storm and antecedent conditions, traffic volume was the most prominent factor distinguishing each highway and likely explains much of the observed difference in the data. The significant differences determined between populations of concentrations of data from Route 119, the highway with the lowest traffic volume, and populations of concentrations of data from the other principal highways are similar to findings from previous studies (Driscoll and others, 1990b) where an AADT volume of 30,000 vehicles was a noted breaking point for low and high concentrations of several constituents. Despite the similarities in highway design and land use among the four principal highways, few results of the Mann-Whitney tests between data sets for highways with AADT volumes greater than 30,000 vehicles per day (Route 2, Interstate 495, and Interstate 95) were significantly different at the 95-percent confidence interval.

The lack of test significance between populations of data for the principal highways with moderate or higher volumes of traffic (Route 2 and Interstates 495 and 95) could be a function of the finite capacity of a highway surface to entrain fine particulates as a result of roadway dispersion by vehicle turbulence. In controlled highway turbulence tests, more than 70 percent of marked particles 12 μm in diameter were removed from the highway surface within four passes of a passenger vehicle at 40 mi/h (Nicholson and Branson, 1990), and the percentage of particles removed from the highway surface increased with vehicle speed. The actual distance from the highway where resuspended particles deposit is largely a function of particle size; Gupta and others (1981) report that particles from 5 to 50 μm in diameter rapidly deposit near the highway right of way, and smaller particles deposit in places remote from the highway system. Most of the mass of particulate matter emitted in gasoline and diesel exhausts, and created from brake and tire wear, are reported to be less than 20 μm in diameter. For example, in two different standardized automotive tests, Cadle and others (2001) found that about 97 and 95 percent of the mass of particles emitted in exhaust from gasoline engines were less than 12.2 μm in diameter, and about 92 and 84 percent of the mass of particles were less than 1.2 μm in diameter. Councell and others (2004) report that mean tire-wear particles were between 10 and 20 μm in diameter, and Garg and others (2000) report that from 63 to 86 percent of airborne particles from brake wear were less than 10 μm in diameter. These distributions of source-particle size indicate that a large quantity of the particles potentially are lost entirely from the highway system as a result of vehicle disturbance.

These factors may explain why populations of suspended-sediment concentrations were not significantly different (table 25) among the larger highways. In part, these factors

also may explain some subtle similarities between concentration data from the principal highways. For example, the median and interquartile concentrations of several constituents (fig. 20) measured in composite samples of stormwater collected at the monitoring stations on Route 2 and Interstate 495 were similar. Although the traffic density at the monitoring stations on Route 2 (about 9,920 vehicles per day per travel lane) was less than the traffic density at the monitoring stations on Interstate 495 (about 13,650 vehicles per day per travel lane), the posted speed limits were similar (55 and 65 mi/h, respectively), and traffic at both sites generally was free flowing. Consequently, the constant vehicle turbulence on the highways at these stations may have prevented a significantly dissimilar buildup of anthropogenic particles. In contrast, the differences between concentrations of the same constituents for Route 2 and Interstate 95, and Interstate 495 and Interstate 95, were greater than those between Route 2 and Interstate 495. Although the posted speed limit for Interstate 95 (55 mi/h) was similar to the posted speed limits for the Route 2 and Interstate 495, the traffic density per lane mile was about 94 and 41 percent higher than the traffic density for Route 2 and Interstate 495, respectively. Consequently, Interstate 95 was generally more congested, and traffic movement often was slower, particularly during poor weather.

Although the populations of concentrations of most constituents were not significantly different among the three highways with higher AADT volumes, the median concentrations and upper interquartile ranges for many metals increased with increasing AADT volume (fig. 20), indicating a positive correlation between the two variables. The frequency of detection for various organic compounds also increased with the traffic volume on the principal highways (table 26). To further investigate the relation between concentration data and traffic volume, Kendall's tau correlation coefficient and Spearman rank correlation coefficient tests (SAS Institute, 1998) were performed to evaluate monotonic correlations between the median concentrations of selected constituents that were routinely detected at greater than the LTMDL and the AADT volume for each of the eight highways. Both tests are based on the ranks of the data and, therefore, are resistant to effects caused by outliers and are appropriate for use with censored values (Helsel and Hirsch, 2002). Each method provides results ranging from -1 (negative relation) through 0 (no relation) to +1 (positive relation) (SAS Institute, 1998). Although the results for each test are similar, the test methods differ from each other. For example, differences between data values ranked farther apart are treated the same for Kendall tau test but receive more weight for the Spearman rank correlation coefficient test (Helsel and Hirsch, 2002).

The resultant test statistics and the respective *p* values for the Kendall's Tau correlation coefficient and Spearman rank correlation coefficient tests are presented in table 27. Test results for one or both methods indicate that correlations of the median concentrations of total N, total P; all total-recoverable metals; benzo[*a*]anthracene, benzo[*b*]fluoranthene, fluoranthene, and pyrene with AADT volumes are significantly

different at a 95-percent confidence interval. Spearman rank correlation coefficient test results for benzo[*a*]anthracene and benzo[*b*]fluoranthene were not significantly different at a 95-percent confidence interval; however, correlations between the median concentrations of these constituents and the respective AADT volumes were significantly different at slightly lower confidence intervals. Test results for concentrations of dissolved Cl, Na, Ca, Mg, K, and SO₄; benzo[*a*]pyrene; bis(2-ethylhexyl) phthalate; chrysene; di-*n*-octyl phthalate; and suspended sediment were not significantly different at confidence intervals greater than 89 percent for either test; therefore, AADT volumes may be a poor predictor of concentrations of these constituents in the absence of additional data.

Estimated Concentrations of Major Constituents in Road Salt

Concentrations of Ca, Cl, Na, and SO₄, which constitute the major constituents of road salt, were estimated on the basis of the superpositioning method and the event-mean values for specific conductance for all available data collected at 11 highway-monitoring stations. Unfortunately, population statistics for the estimated concentrations of these major ions were not computed for runoff events at Route 8 because available data for non-winter storms were insufficient to model the transition from low-ionic strength runoff to runoff dominated by deicing compounds. Although the general statistics for the population of flow-weighted specific-conductance values were similar to that of the other highways sites, estimates for major ions could not accurately be made for 60 to 70 percent of the available data because of the disparity between ratios of Cl to the other major ions at the Route 8 station. Runoff quality in this area of the state may be different because the chemistry of precipitation in this area is different (National Atmospheric Deposition Program, 2008), and the composition of soils in this area is affected by weathering of limestone bedrock. Data for the other 11 monitoring stations were estimated for 1,381 runoff events that include periods of measurable snowmelt (periods of runoff during the winter months with air temperatures greater than the freezing point and no records of measurable precipitation). These estimated concentration data provide an order of magnitude increase in data density over available water-sample data. Statistics for populations of estimated event-mean concentrations of selected constituents at all highways are listed in table 28. The median estimated concentrations of Cl ranged from about 10 to 40 mg/L for all highway sites, except for the site on Interstate 93 where the median estimated concentration was 79 mg/L. The median estimated concentrations of Cl were lowest for the monitoring stations on Route 119. Estimated concentrations of Ca, Na, and SO₄, which were derived from estimated concentrations of Cl, followed the same pattern. Estimated average concentrations for each constituent were substantially greater than the median estimated concentrations for each highway (table 28). This is a function of high right skew in the data populations caused by a

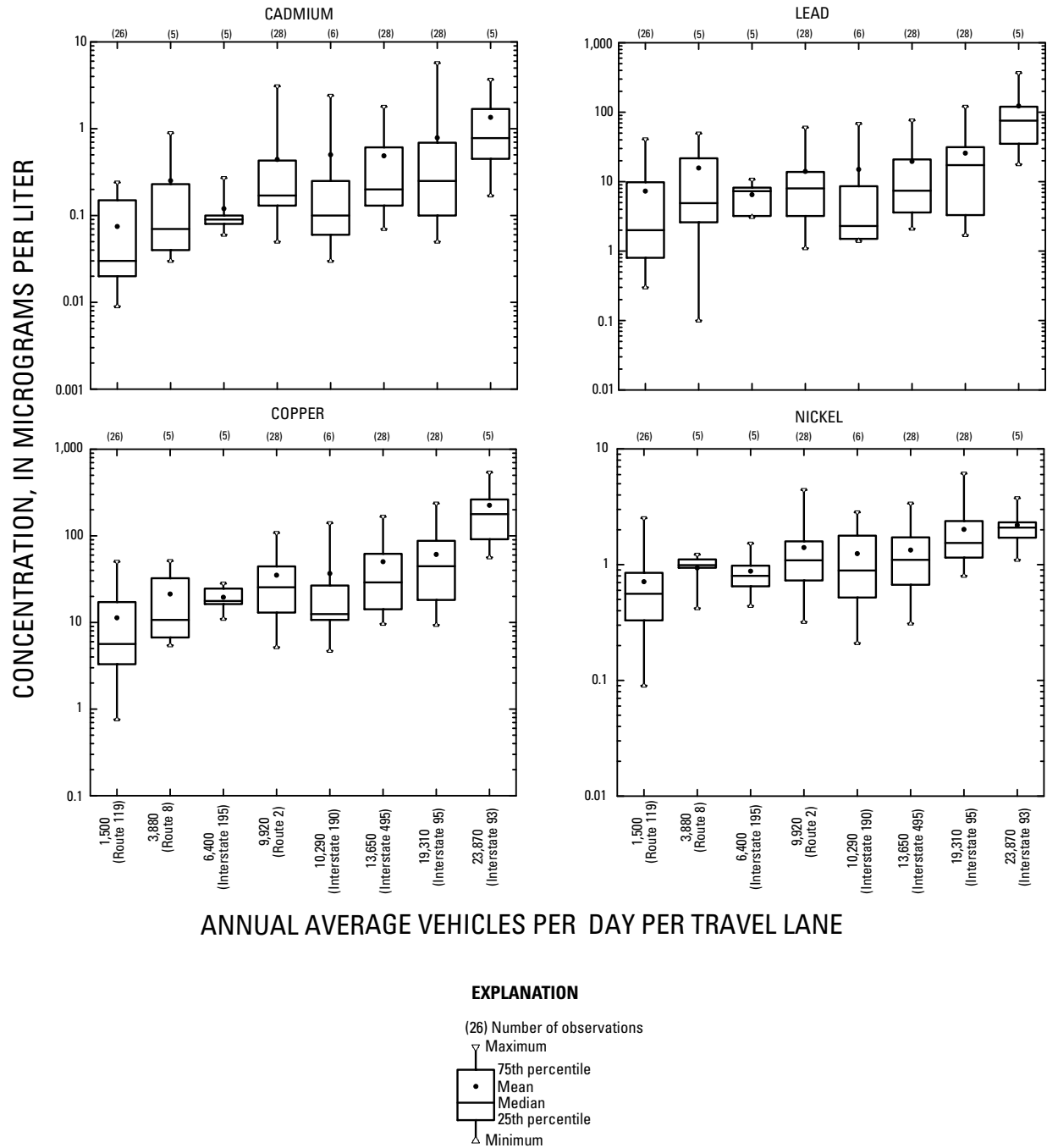


Figure 20. Concentrations of selected constituents in samples of highway runoff collected at eight highway-monitoring stations in Massachusetts in relation to the annual average daily vehicles per travel lane.

Table 26. Frequency of detection for selected polyaromatic hydrocarbons and phthalate compounds in composite samples of highway runoff collected from the four principal highways at eight sites in Massachusetts, 2005–07.

[LTMDL, long-term method detection level; ≥, greater than or equal to LTMDL]

Compound	Frequency of detection (percent)				Frequency of detection (percent ≥ LTMDL)			
	Route 119	Route 2	Interstate 495	Interstate 95	Route 119	Route 2	Interstate 495	Interstate 95
Fluorene	38	67	68	46	0	0	7	7
Acenaphthene	27	44	50	43	0	0	11	11
Acenaphthylene	31	48	50	46	0	0	4	0
Anthracene	35	59	86	86	0	0	11	21
Benzo[<i>a</i>]anthracene	38	85	96	96	12	52	54	71
Benzo[<i>a</i>]pyrene	62	89	93	100	23	56	50	68
Benzo[<i>b</i>]fluoranthene	69	96	100	100	31	70	68	82
Benzo[<i>ghi</i>]perylene	77	85	89	93	8	19	29	43
Benzo[<i>k</i>]fluoranthene	50	89	96	100	4	30	32	46
Benzyl n-butyl phthalate	8	19	18	32	8	11	14	25
Bis(2-ethylhexyl) phthalate (DEHP)	50	85	79	82	50	85	79	82
Chrysene	62	85	100	100	27	59	61	75
Dibenzo[<i>a,h</i>]anthracene	4	22	32	36	0	0	0	4
Diethyl phthalate (DEP)	19	19	7	21	4	4	4	14
Dimethyl phthalate	12	22	18	25	0	0	0	0
Di-n-butyl phthalate	27	41	39	36	15	15	21	29
Di-n-octyl phthalate	54	93	75	86	19	74	61	75
Fluoranthene	88	100	100	100	38	81	82	86
Indeno[1,2,3- <i>cd</i>]pyrene	69	93	89	93	4	22	32	43
Nitrobenzene	4	7	14	0	0	0	0	0
Phenanthrene	85	96	100	96	23	52	46	61
Pyrene	88	100	100	100	31	70	71	82
Naphthalene	19	44	39	54	0	0	7	4
Perylene	12	67	64	68	0	0	18	35

Table 27. Resultant test and p values for Kendall Tau and Spearman Rank correlation tests performed on median values of populations of constituent concentrations in highway runoff and annual average daily traffic volumes for the principal highways in Massachusetts, 2005–07.

[Shaded areas indicate values that are significant at a 95-percent confidence interval]

Constituent	Kendall Tau value	Kendall Tau p value	Spearman Rho value	Spearman Rho p value
Chloride	0.357	0.216	0.405	0.284
Sodium	0.429	0.138	0.429	0.257
Calcium	0.286	0.322	0.238	0.529
Magnesium	0.429	0.138	0.310	0.413
Potassium	0.429	0.138	0.595	0.115
Sulfate	0.500	0.083	0.595	0.115
Nitrogen, total	0.857	0.003	0.952	0.012
Phosphorus, total	0.714	0.013	0.857	0.023
Cadmium	0.929	0.001	0.976	0.010
Chromium	0.714	0.013	0.881	0.020
Copper	0.929	0.001	0.976	0.010
Iron	0.786	0.007	0.857	0.023
Lead	0.786	0.007	0.881	0.020
Manganese	0.679	0.019	0.804	0.034
Nickel	0.786	0.007	0.905	0.017
Zinc	0.786	0.007	0.857	0.023
Benzo[<i>a</i>]anthracene	1.000	0.042	1.000	0.083
Benzo[<i>a</i>]pyrene	0.667	0.174	0.800	0.166
Benzo[<i>b</i>]fluoranthene	0.800	0.050	0.900	0.072
Bis(2-ethylhexyl) phthalate	0.333	0.348	0.486	0.277
Chrysene	0.667	0.174	0.800	0.166
Di-n-octyl phthalate	0.429	0.177	0.643	0.115
Fluoranthene	0.867	0.015	0.943	0.035
Pyrene	0.867	0.015	0.943	0.035
Suspended sediment	0.357	0.216	0.476	0.208

Table 28. Selected statistics for populations of concentrations of chloride, sodium, calcium, and sulfate estimated from event-mean values of specific conductance calculated from continuous measurements of flow and specific conductance for the period of record for 11 highway monitoring stations in Massachusetts, 2005–07.

[USGS, U.S. Geological Survey]

USGS station number	Highway	Number of events	Statistic	Chloride	Sodium	Calcium	Sulfate
424209071545201	Route 119	149	Maximum	4,500	2,600	65	140
			Median	18	13	2.7	3.4
			Average	285	168	7.8	14
			Standard deviation	818	473	13	28
			Skew	3.76	3.76	2.86	3.10
			Minimum	1.1	0.87	0.44	0.45
424155071543201	Route 119	105	Maximum	3,100	1,800	53	110
			Median	10	7.6	1.9	2.3
			Average	96	58	4.2	6.6
			Standard deviation	359	208	7.3	14
			Skew	6.72	6.72	4.29	4.99
			Minimum	1.1	0.91	0.45	0.46
423027071291301	Route 2	148	Maximum	11,000	6,100	100	240
			Median	36	25	4.0	5.4
			Average	542	315	11	21
			Standard deviation	1,510	860	19	41
			Skew	3.98	3.87	2.67	2.96
			Minimum	1.8	1.4	0.62	0.65
423027071291302	Route 2	72	Maximum	25,000	14,000	170	420
			Median	32	22	3.8	5.0
			Average	1,070	612	14	28
			Standard deviation	4,040	2,276	31	74
			Skew	4.69	4.65	3.80	4.05
			Minimum	3.2	2.5	0.90	0.99
422821071332001	Interstate 495	178	Maximum	20,000	11,000	150	360
			Median	29	20	3.6	4.7
			Average	543	315	11	20
			Standard deviation	2,000	1,130	20	44
			Skew	7.08	6.86	3.91	4.56
			Minimum	1.6	1.3	0.57	0.59
422716071343901	Interstate 495	115	Maximum	14,000	7,800	120	280
			Median	37	25	4.1	5.5
			Average	834	478	14	27
			Standard deviation	2,400	1,350	25	56
			Skew	3.83	3.76	2.73	2.98
			Minimum	0.58	0.48	0.29	0.28

Table 28. Selected statistics for populations of concentrations of chloride, sodium, calcium, and sulfate estimated from event-mean values of specific conductance calculated from continuous measurements of flow and specific conductance for the period of record for 11 highway monitoring stations in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey]

USGS station number	Highway	Number of events	Statistic	Chloride	Sodium	Calcium	Sulfate
422620071153301	Interstate 95	126	Maximum	10,000	5,800	100	230
			Median	40	27	4.3	5.9
			Average	441	258	11	19
			Standard deviation	1,320	761	17	36
			Skew	5.07	5.09	3.14	3.62
			Minimum	0.48	0.40	0.25	0.24
422420071153302	Interstate 95	103	Maximum	12,000	6,900	110	260
			Median	26	18	3.3	4.3
			Average	526	306	11	20
			Standard deviation	1,630	935	19	42
			Skew	4.69	4.69	3.03	3.40
			Minimum	0.58	0.48	0.29	0.28
423016071431501	Interstate 190	138	Maximum	22,000	13,000	160	390
			Median	24	17	3.1	4.1
			Average	1,340	778	18	37
			Standard deviation	3,710	2,150	32	76
			Skew	3.57	3.60	2.59	2.85
			Minimum	1.2	0.99	0.48	0.49
414339070462201	Interstate 195	125	Maximum	8,500	4,900	92	210
			Median	22	15	3.0	3.8
			Average	478	278	11	20
			Standard deviation	1,280	732	18	37
			Skew	3.85	3.87	2.55	2.86
			Minimum	1.6	1.2	0.57	0.59
421647071024703	Interstate 93	122	Maximum	21,000	12,000	150	380
			Median	79	52	6.4	9.3
			Average	897	521	16	31
			Standard deviation	2,510	1,430	24	55
			Skew	5.43	5.40	2.86	3.46
			Minimum	7.4	5.5	1.5	1.8
All sites	--	1381	Maximum	25,000	14,000	170	420
			Median	29	20	3.5	4.7
			Average	627	364	12	22
			Standard deviation	2,160	1,240	21	49
			Skew	6.06	6.02	3.50	4.05
			Minimum	0.5	0.4	0.3	0.2

relatively small number of high estimated concentrations. For example, the percentage for all estimated concentrations of Cl greater than 10,000 mg/L was less than 2 percent (fig. 21), and the percentage for all estimated concentrations of Cl greater than 230 mg/L (the USEPA national recommended freshwater-quality criteria; U.S. Environmental Protection Agency, 2009) was about 20 percent (fig. 21). The highest EMCs of deicing compounds were typically measured for mixed precipitation storms, which usually generate only small flows, for small rain storms that occur subsequent to applications of deicing compounds, and for relatively small amounts of snowmelt water. Thus, Cl yields per lane mile may be more useful for estimating the potential effects on receiving water quality. The frequency at which a given yield of Cl per lane mile was equaled or exceeded is illustrated in figure 22. If the average background in-storm concentration of Cl and volume of flow corresponding to the runoff event for the receiving water body are known, and the area of highway draining directly to the water body can be calculated, the data illustrated in figure 22 can be used to determine the potential risk for exceeding some threshold concentration of Cl in the receiving water body during the runoff event.

Evaluation of Constituents in Seasonal Samples of Runoff from the Principal Highways

The concentrations of constituents in samples of highway runoff varied considerably from storm to storm, as well as from station to station. However, concentrations of nearly all constituents measured in composite samples of highway runoff collected after the first snowfall in January 2006 through April 2006, and March 2007 through April 2007, increased substantially during the winter months. The average concentrations of total P, total-recoverable metals, and suspended sediment in samples of highway runoff collected during the winter were about 3 to 11 times the average concentrations observed in samples of non-winter runoff (table 29). Concentrations of suspended sediment and majors ions are expected to increase during the winter season in Massachusetts as a result of the application of deicing compounds and maintenance sands to the highway surface; however, virtually all populations of winter and non-winter concentrations of metals, PAH compounds, and phthalates also increased substantially. Changes in ambient temperature, differences in driving methods, snow-removal operations, and the presence of snow embankments along the highways also affect the winter concentrations of metals and

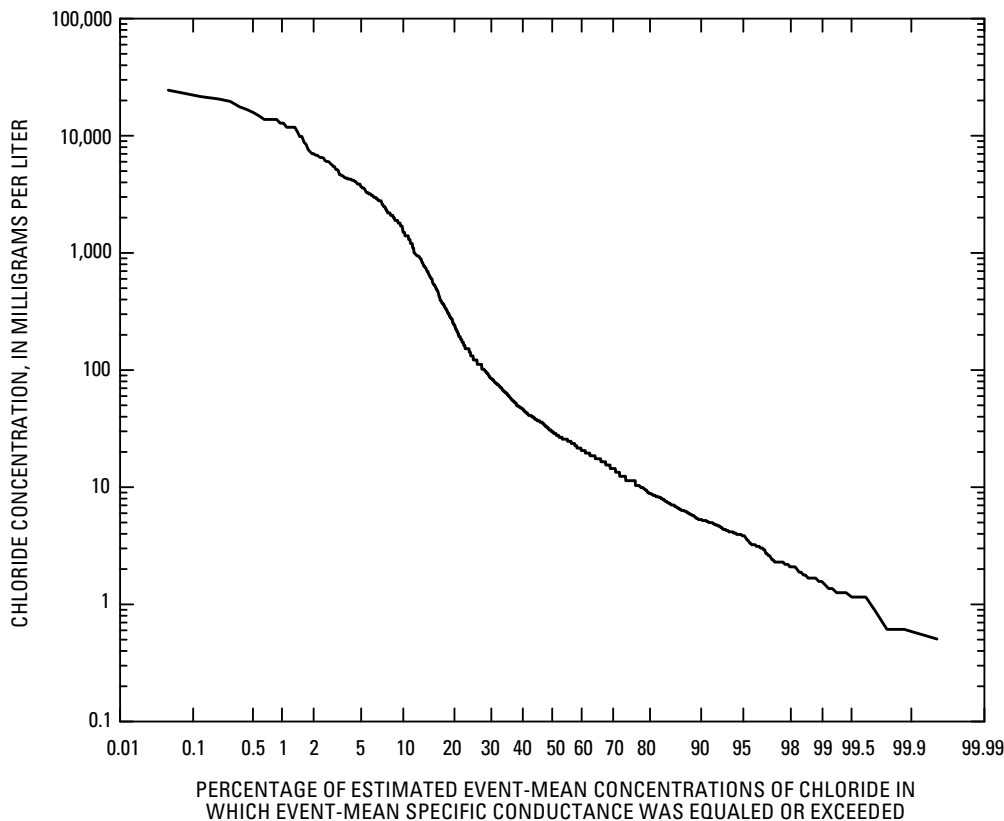


Figure 21. Percentage of event-mean concentrations of chloride estimated from continuous records of specific conductance for 1,381 runoff events from 11 highway-monitoring stations on 7 highways in Massachusetts to measured concentrations of chloride in composite samples of highway runoff.

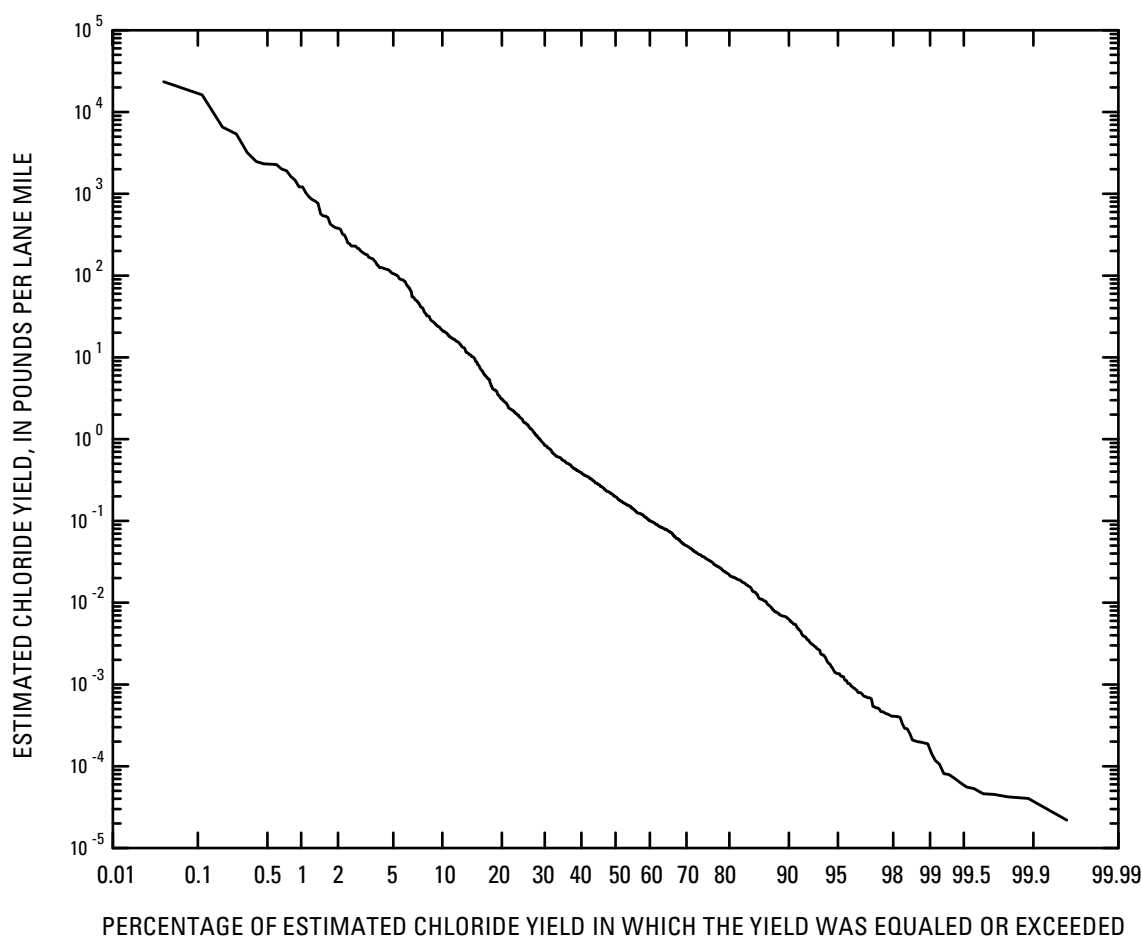


Figure 22. Probability distribution for loads of chloride estimated from continuous records of specific conductance for 1,381 runoff events from 11 highway-monitoring stations on 7 highways in Massachusetts.

Table 29. The ratio of mean concentrations of total nutrients, total-recoverable metals, and suspended sediment in composite samples of highway runoff collected during winter storms to mean concentrations of the respective constituents in samples collected during non-winter storms for the primary and secondary stations on four principal highways in Massachusetts, 2005–07.

Highway	Nitrogen	Phosphorus	Cadmium	Chromium	Copper	Iron
Route 119	1.5	3.9	5.0	5.8	4.4	14.4
Route 2	1.1	2.4	6.6	2.9	3.1	6.8
Interstate 495	1.4	3.7	6.3	4.0	4.0	8.2
Interstate 95	1.6	2.4	11.4	3.5	3.3	6.9

Highway	Lead	Manganese	Nickel	Zinc	Suspended sediment
Route 119	11.4	6.6	6.9	6.0	11.6
Route 2	5.5	4.9	7.1	3.8	3.1
Interstate 495	7.9	6.4	6.1	4.3	9.1
Interstate 95	4.2	6.0	5.4	4.3	5.8

organic compounds measured in this study. Results of single-tail Mann-Whitney tests indicate that the concentrations of nearly all constituents measured in samples of highway runoff collected during the winter and after the first snowfall from each principal highway were significantly greater at a 99-percent confidence interval (p value less than 0.01; table 30).

Deicing compounds are not entirely pure and thus contain trace amounts of elements typically associated with highway runoff; however, the trace amounts of total N and total-recoverable metals in highway deicing compounds do not fully explain the significant differences in concentrations observed during winter. Ratios for concentrations of nitrate and total-recoverable Cr, Cu, Fe, Pb, and Ni to concentrations of Cl in samples of Massachusetts road salt reported by Granato (1996) and in a sample of liquid calcium chloride (table 31) collected at the Lexington, Massachusetts, DOT maintenance depot ranged from 10^{-5} to 10^{-6} . At a ratio of 10^{-5} for nitrate and Fe to Cl, the estimated increase in the EMC for these constituents, resulting from the addition of deicing compounds at a Cl concentration of 10,000 mg/L (which occurred in less than 2 percent of all of the runoff events during the 2.5-year monitoring period; fig. 21), is about 0.1 mg/L. In contrast, the difference between the mean non-winter and mean winter concentrations of nitrate and Fe in composite samples of runoff was many times larger. For example, the differences between the mean non-winter and winter concentrations for total N and total-recoverable Fe in composites of highway runoff collected at the monitoring stations on Interstate 495 are about 0.45 and 14.4 mg/L, respectively. For the same EMC of Cl and using a ratio of 10^{-6} for total-recoverable Cr, Cu, and Pb to Cl, the estimated increase in the EMC, resulting from the addition of deicing compounds, is about 10 μ g/L. In contrast, the differences between the mean non-winter and winter concentrations for these same constituents in composite samples of runoff collected at the monitoring stations on Interstate 495 are about 27.8, 85.4, and 49.4 μ g/L, respectively. At more typical Cl concentrations of about 1,000 mg/L (which occurred in less than 12 percent of all of the storms during the 2.5-year monitoring period; fig. 21), the concentrations of nitrate and the total-recoverable metals would decrease by an order of magnitude. These levels represent less than 4 percent of the mean increase in EMCs for the respective constituents measured in composite samples of highway runoff collected during the winter at the monitoring stations on Interstate 495. Although the ratios of winter to non-winter concentrations of total-recoverable Cr, Cu, and Pb are somewhat similar from highway to highway (table 29), road salt could account, in part, for the larger increases in concentrations of the respective elements during winter for smaller highways, such as Route 119, because the non-winter concentrations of the metals are lower than the non-winter concentrations for the other principal highways. For example, the differences between the mean non-winter and winter concentrations of total-recoverable Cr, Cu, and Pb at the monitoring stations on Route 119 are about 11.9, 18, and 17 μ g/L, respectively. At Cl concentrations of about 1,000 mg/L, the concentration of

the three total-recoverable metals associated with the deicing compounds represent about 8 to 6 percent, respectively, of the mean increase in the EMC for the respective constituents measured in composite samples of highway runoff collected at the Route 119 monitoring stations.

The increase in concentrations of total P and total-recoverable metals during winter also are associated with the application of maintenance sand. Highway maintenance sand is a hard material, free of organic material, with no melting capabilities. Winter maintenance sands are applied to the highway to increase tire traction on the pavement. Maintenance sand, like soils, contains trace amounts of total P and total-recoverable metals. Although the concentrations of these constituents in the sand are small, the amount of sand applied to the highways during the winter can increase the concentration of suspended sediment by as much as an order of magnitude. For example, the ratios of mean non-winter EMCs of suspended sediment to mean winter EMCs in samples collected at the monitoring stations on the principal highways ranged from 3.1 to 11.6 (table 29). An approximate contribution of total P and total-recoverable metals from the application of maintenance sand was estimated on the basis of the average change in the concentration of suspended sediment during winter storms and on the basis of the mean concentrations of the associated constituents in samples of highway maintenance sand (table 18 in the back of the report). For example, the average increase in the EMC of suspended sediment in composite samples of runoff collected during winter storms at the monitoring stations on Interstate 495 was about 637 mg/L. Assuming that the increase in the concentration of suspended sediment is exclusively accounted for by the addition of maintenance sand, the estimated concentrations for total P, and total-recoverable Cu, Fe, Mn, Ni, Pb, and Zn associated with the sand are about 0.24 mg/L and 5.7, 7, 640, 134, 5.3, 4.3, and 10.1 μ g/L, respectively. After further adjusting the estimated concentrations of P, Fe, Ni, and Zn on the basis of the performance of the different analytical digestion methods discussed earlier, highway maintenance sand would account for about 94, 7, 38, 53, 15, 9, and 2 percent of the increase in winter EMCs for P, Cu, Fe, Mn, Ni, Pb, and Zn, respectively. As noted earlier, the differences between winter and non-winter EMCs for P, Cu, Fe, Mn, Ni, Pb, and Zn are greater for smaller highways because those highways have lower non-winter EMCs for these constituents (table 29).

The Mass DOT typically uses salt alone, but also applies maintenance sand to the highway as a 1-to-1 sand-to-salt premix at low temperatures and on roadway sections with steep grades, ramp sections, sharp curves, and at intersections (Massachusetts Department of Transportation, 2006). Routine application of maintenance sand is limited to reduced salt zones, such as Interstate 95 in this study (Massachusetts Department of Transportation, 2008). However, Mass DOT records indicate that maintenance sand was applied to a greater extent on Massachusetts highways during this study (Paul Brown, Massachusetts Department of Transportation, written commun., 2010). As a result, concentrations for

Table 30. Resultant *p* values for single-tail Mann-Whitney tests between paired populations of winter and non-winter concentrations of constituents in highway runoff collected from the primary and secondary stations on the four principal highways in Massachusetts, 2005–07.

[<, Less than value shown; --, insufficient detections to perform test; mm, millimeters in diameter; shaded areas indicate values that are significant at a 99-percent confidence interval]

Constituent	Route 119	Route 2	Interstate 495	Interstate 95
Chloride	<0.001	<0.001	<0.001	<0.001
Sodium	<0.001	<0.001	<0.001	<0.001
Calcium	<0.001	<0.001	<0.001	<0.001
Magnesium	<0.001	<0.001	<0.001	<0.001
Potassium	<0.001	<0.001	<0.001	<0.001
Sulfate	<0.001	<0.001	<0.001	<0.001
Nitrogen, total	0.011	0.084	0.017	0.013
Phosphorus, total	<0.001	0.001	<0.001	0.001
Cadmium	<0.001	<0.001	0.014	<0.001
Chromium	<0.001	<0.001	<0.001	<0.001
Copper	<0.001	<0.001	<0.001	<0.001
Iron	<0.001	<0.001	<0.001	<0.001
Lead	<0.001	<0.001	<0.001	<0.001
Manganese	<0.001	<0.001	<0.001	<0.001
Nickel	<0.001	<0.001	<0.001	<0.001
Zinc	<0.001	<0.001	<0.001	<0.001
Fluorene	--	--	--	--
Acenaphthene	--	--	--	--
Acenaphthylene	--	--	--	--
Anthracene	--	--	--	--
Benzo[<i>a</i>]anthracene	--	<0.001	<0.001	<0.001
Benzo[<i>a</i>]pyrene	--	<0.001	<0.001	<0.001
Benzo[<i>b</i>]fluoranthene	<0.001	<0.001	<0.001	<0.001
Benzo[<i>ghi</i>]perylene	--	0.002	0.001	<0.001
Benzo[<i>k</i>]fluoranthene	--	<0.001	<0.001	<0.001
Benzyl n-butyl phthalate	--	--	0.003	0.003
Bis(2-ethylhexyl) phthalate	0.002	<0.001	<0.001	<0.001
Chrysene	<0.001	<0.001	<0.001	<0.001
Dibenzo[<i>a,h</i>]anthracene	--	--	--	--
Diethyl phthalate	--	--	--	0.162
Dimethyl phthalate	--	--	--	--
Di-n-butyl phthalate	0.203	--	--	0.008
Di-n-octyl phthalate	<0.001	<0.001	<0.001	0.005
Fluoranthene	--	<0.001	<0.001	<0.001
Indeno[1,2,3- <i>cd</i>]pyrene	--	<0.001	<0.001	<0.001
Nitrobenzene	--	<0.001	--	--
Phenanthrene	<0.001	<0.001	<0.001	<0.001
Pyrene	<0.001	<0.001	<0.001	<0.001
Naphthalene	--	--	--	--
Perylene	--	--	<0.001	<0.001
Suspended sediment	<0.001	0.001	<0.001	<0.001
Suspended sediment < 0.063 mm	0.384	<0.001	0.017	0.003

Table 31. Concentrations of selected constituents measured in a sample of liquid calcium chloride collected at the highway-service depot near Interstate 95, Lexington, Massachusetts and diluted to 3.5 percent by mass and the ratio of the concentration of each constituent to the concentration of chloride.

[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration is less than value shown; E, the concentration reported is less than laboratory reporting level and is qualified as estimated; --, no information]

Constituent	Concentration or measurement	Ratio of constituent concentration to chloride concentration
pH in standard units	10.0	--
Specific conductance in $\mu\text{S}/\text{cm}$	19,600	--
Calcium, filtered, mg/L	3,640	4.98×10^{-1}
Magnesium, filtered, mg/L	0.26	3.56×10^{-5}
Potassium, filtered, mg/L	150	2.05×10^{-2}
Sodium, filtered, mg/L	85.9	1.18×10^{-2}
Alkalinity, filtered, laboratory, mg/L as calcium carbonate	28	--
Chloride, filtered, mg/L	7,310	1.00
Sulfate, filtered, mg/L	<4.5	$<6.16 \times 10^{-4}$
Total nitrogen (nitrate + nitrite + ammonia + organic-N), unfiltered, mg/L	0.17	2.33×10^{-5}
Phosphorus, unfiltered, mg/L	<.02	$<2.74 \times 10^{-6}$
Arsenic, unfiltered, mg/L	E2.5	3.42×10^{-4}
Barium, unfiltered, $\mu\text{g}/\text{L}$	210	2.78×10^{-2}
Cadmium, unfiltered, $\mu\text{g}/\text{L}$	E0.11	1.50×10^{-5}
Chromium, unfiltered, $\mu\text{g}/\text{L}$	<3.2	$<4.38 \times 10^{-4}$
Copper, unfiltered, $\mu\text{g}/\text{L}$	<9.6	$<1.31 \times 10^{-3}$
Iron, unfiltered, $\mu\text{g}/\text{L}$	E84	1.15×10^{-2}
Lead, unfiltered, $\mu\text{g}/\text{L}$	0.3	4.10×10^{-5}
Manganese, unfiltered, $\mu\text{g}/\text{L}$	<6.4	$<8.76 \times 10^{-4}$
Nickel, unfiltered, $\mu\text{g}/\text{L}$	0.96	1.31×10^{-4}
Selenium, unfiltered, $\mu\text{g}/\text{L}$	<0.6	$<8.21 \times 10^{-5}$
Zinc, unfiltered, $\mu\text{g}/\text{L}$	16	2.19×10^{-3}
Total organic carbon, mg/L	<0.4	$<5.47 \times 10^{-5}$

suspended sediment and other constituents associated with highway maintenance sands in composite samples collected during winter storms in this study (except for samples collected at the primary and secondary stations of Interstate 95 and the test station on Interstate 195) may represent higher values in regard to the 2008 sanding policy.

Changes in ambient temperature affect the rate of emissions for both gasoline and diesel engines. In controlled tests, Westerholm and Egeback (1994) reported that the mean emission rates for particulate matter and oxides of nitrogen for five gasoline-powered vehicles increased by a factor of two between tests conducted at 22 and -10°C, and total PAHs increased by about a factor of five. In a larger scale test, Cadle and others (2001) noted that particulate matter increased by a factor of 2.5 between tests conducted at mean temperatures of 15.5 and 3.3°C. Increases in the rate of emissions from diesel vehicles during winter operation also have been reported (Kuusimäki, 2003). The rate of vehicle emission, as well as brake and tire wear, can increase during poor winter driving conditions when vehicle speeds are slower and less constant. Inconsistent regulation of the engine speed results in temporary fuel enrichment that potentially increases emission rates. Colder winter temperatures also affect the rate of volatilization and bacterial degradation for PAHs and phthalates (Lopes and Dionne, 1998). These factors also contribute to the increase in concentrations of total N, total-recoverable metals (except for Mn, which may have a greater association with sanding or road wear), PAHs, and phthalates observed in samples collected during winter.

One final factor that could explain, in part, the increase in concentrations of total P, total-recoverable metals, PAH, and phthalates between winter and non-winter samples is the effect of snow removal from the roadway. Snow is generally removed from the highway with heavy trucks equipped with plows, and in some cases, tire chains. This results in contact wear of both the equipment and the roadway surface. Snowplows and tire chains are constructed predominantly from Fe or Fe alloys. In contrast, Mn and Zn are the dominant metals found in asphalt with lesser amounts of Cr, Fe, Pb, and Ni (Breault and others, 2005). Asphalt also contains several PAH compounds, such as benzo[*b*]fluoranthene, chrysene, and phenanthrene. Increases in concentrations of Fe, Mn, Zn, and the above PAHs during winter could result, in part, from the wear of these contact surfaces. Another effect of snow plowing is the tendency for snow to pack into the openings of highway guardrails. Such snow packs effectively form large curbs that can be as high as or higher than the guardrails (fig. 23). In such cases, not only do solids build up near the base of the pack, but the snow pack itself absorbs large amounts of particulates that subsequently are deposited on or near the highway shoulder after the snow melts. Glenn and Sansalone (2002) found that various highway-related constituents accumulated in fresh snow banks quickly during the first 12 hours after plowing, and Reinosdotter and others (2006) report that in snow surveys done perpendicular to highways, most of the highway-related metals were present in the first few horizontal

feet of highway snow banks. Because most of the monitoring stations in the study have guardrails within the highway-drainage areas, deposition of particulates near or on the highway shoulder from melting snow packs also is an important factor that may explain some of the significant differences in concentrations of the constituents measured in this study between non-winter and winter storms.

Comparison of Historical and Concurrent Data Sets

Highway managers and other data analysts need current data to accurately estimate loads of various constituents discharged from highways and to determine the effects of these loads on receiving water bodies. The accuracy of information on constituent loads is ensured, in part, by periodically collecting new data. Comparisons of the data collected in this study with other subsequent data can provide useful information for identifying compositional differences and trends in highway runoff. Such differences can result over time from changes in anthropogenic sources, sampling methods, and laboratory analytical methods. Differences in the composition of highway runoff also are affected by local materials that are deposited on the highways in different geographic areas. Populations of constituent concentrations, separated by either time or space, that are similar can be combined to form a robust data set. In contrast, it is inappropriate to combine populations of constituents that exhibit large but potentially explainable differences, and at best, the data sets are periodically updated to monitor trends in the concentrations so that future analyses will be accurate.

From 1985 to 2009, automobile technology, tire and brake-pad formulations, fuel additives, construction materials, and highway maintenance practices have changed. Methods used for sample collection, handling, and analysis of environmental samples have improved since the early 1980s. As a result, the laboratory analytical techniques have improved the accuracy and precision of analysis and the detection of contaminants in stormwater runoff (Van Loon, 1985; Thompson and Walsh, 1989; Garbarino and Struzeski, 1998). To determine the potential effect of these changes, the median concentrations of dissolved Cl, total N and P, and total-recoverable Cd, Cr, Cu, Fe, Pb, and Zn in all data sets collected for Interstate 190, Interstate 195, Interstate 495, and Route 2 were compared to the median concentrations recorded in historical highway-runoff data sets (Driscoll and others, 1990a) collected by eight other states from 1976 to 1984 at highway sites with similar AADT volumes of 30,000 to 85,000 vehicles per day (table 32). The 90-percent confidence interval was computed for the median value of each constituent using the methods described by McGill and others (1978). With the exception of dissolved Cl, the median concentrations of the nutrients and metals in this study were less than the median concentrations in the historical data. Furthermore, the median



Figure 23. A snow bank along the guard rail near the highway-monitoring station on Route 119, in Ashburnham, Massachusetts.

Table 32. Median of event-mean concentrations and 90-percent confidence interval for selected constituents in samples of highway runoff collected during this study, historical highway studies, and other recent studies for highways with annual average daily traffic volumes of 30,000 to 85,000 vehicles.

[CI, 90-percent confidence interval for median; mg/L, milligrams per liter; µg/L, micrograms per liter; AR, Arizona; CA, California; MA, Massachusetts; MN, Minnesota; NC, North Carolina; PA, Pennsylvania; TN, Tennessee; TX, Texas; WA, Washington; WI, Wisconsin; --, no data]

State where data were collected	Data collection period (years)	Statistic	Constituent				
			Chloride (mg/L)	Total nitrogen (mg/L)	Total Phosphorus (mg/L)	Total recoverable cadmium (µg/L)	Total recoverable chromium (µg/L)
MA	2005–07	Median	17.6	1.09	0.11	0.175	11
		CI	10.8	0.21	0.03	0.07	2.4
		Samples	67	67	67	67	67
		Sites	4	4	4	4	4
AR, CA, MN, NC, PA, TN, WA, WI	1976–84	Median	17.5	2.64	0.37	20	20
		CI	8.37	0.63	0.06	5.06	6.8
		Samples	270	56	262	116	115
		Sites	10	4	10	6	5
CA	1999–2003	Median	490	--	0.22	0.45	5.5
		CI	55	--	0.03	0.07	0.74
		Samples	17	--	242	225	225
		Sites	1	--	14	13	14
WA	1994–97	Median	--	--	0.11	0.46	--
		CI	--	--	0.03	0.23	--
		Samples	--	--	57	31	--
		Sites	--	--	4	4	--
TX	1994–97	Median	--	--	0.22	--	--
		CI	--	--	0.03	--	--
		Samples	--	--	102	--	--
		Sites	--	--	3	--	--

Table 32. Median of event-mean concentrations and 90-percent confidence interval for selected constituents in samples of highway runoff collected during this study, historical highway studies, and other recent studies for highways with annual average daily traffic volumes of 30,000 to 85,000 vehicles.—Continued

[CI, 90-percent confidence interval for median; mg/L, milligrams per liter; µg/L, micrograms per liter; AR, Arizona; CA, California; MA; Massachusetts; MN, Minnesota; NC, North Carolina; PA, Pennsylvania; TN, Tennessee; TX, Texas; WA, Washington; WI, Wisconsin; --, no data]

State where data were collected	Statistic	Constituent				Data source
		Total recoverable copper (µg/L)	Total recoverable iron (µg/L)	Total recoverable lead (µg/L)	Total recoverable Zinc (µg/L)	
MA	Median	25.5	1,690	8	166	This study
	CI	8.5	677	2.4	53.5	
	Samples	67	67	67	67	
	Sites	4	4	4	4	
AR, CA, MN, NC, PA, TN, WA, WI	Median	55	5,800	400	300	Driscoll and others, 1990a
	CI	8.3	848	67.1	32.25	
	Samples	289	154	319	210	
	Sites	10	6	11	9	
CA	Median	22	2,930	6.05	105.5	California Department of Transportation Office of Environmental Engineering, 2000, 2002, 2003a, 2003b, 2003c, 2003d, 2004
	CI	2.57	2,525	1.72	15.0	
	Samples	242	39	242	242	
	Sites	14	3	14	14	
WA	Median	20	--	10	120	Taylor Associates, Inc., 2002a, 2002b; Tetra Tech, Inc. and Envirovision Corporation, 2002; Tetra Tech, Inc. 2003, 2004; Washington State Department of Transportation, Environmental Services Office, 2001, 2002, 2003, 2004
	CI	5.53	--	2.93	30.05	
	Samples	57	--	31	57	
	Sites	4	--	4	30.05	
TX	Median	11	1,500	49	101	Barrett and others, 1995, 1996; Walsh and others, 1997
	CI	4.81	448	18.24	31.17	
	Samples	84	87	82	94	
	Sites	3	3	3	3	

historical concentrations for these constituents were outside the 90-percent confidence interval determined for this study, indicating there is a significant difference between data sets. Although the median concentrations for dissolved Cl were quite similar between the study and historical data sets, the differences for other constituents were often substantial. For example, the median concentrations for total-recoverable Cd and Pb for this study were 114 and 50 times lower, respectively, than the historical median concentrations. These data indicate that concentrations of nutrients and metals in highway runoff, particularly Cd and Pb, are substantially lower in this study than in the 1970s and 1980s, despite the fact that total vehicle miles have increased (Colman and others, 2001; Breault and Granato, 2000). These differences are likely attributable, at least in part, to improvements in fuel formulations, emission control systems, and tire life.

As discussed earlier, large differences in the composition of wash-on materials (adjacent soils and berm materials) and differences in the amount of impervious area surrounding the highway can potentially cause significant differences between the data populations. However, it is not logistically or economically feasible to collect data for every storm and on every highway. As a result, population statistics are limited by the number of samples, and data are often extrapolated to highways that do not necessarily share all of the characteristics of the highway where the data were originally collected. With this in mind, it is often beneficial to systematically combine smaller data sets to form more robust data populations. The median concentrations of dissolved Cl, total P, and total-recoverable Cd, Cr, Cu, Fe, Pb, and Zn from all data collected from Interstate 190, Interstate 195, Interstate 495, and Route 2 were compared to available median concentrations of the respective constituents for highway with AADT volumes of 30,000 to 85,000 vehicles per day to determine whether data collected in other recent studies are similar to the data presented in this study (table 32). The previous studies were conducted between 1994 and 2003 in California, Texas, and Washington. Concentration data for Cl was available for only one station near Lake Tahoe in California, and most of the samples were collected during the winter months (California Department of Transportation, Office of Environmental Engineering, 2003a-d), thus explaining the larger median concentration of Cl compared to the median concentration in this study. The median concentration of 0.11 mg/L for total P in this study is identical to the median concentration reported for the state of Washington but is about half of the median concentration for the California and Texas studies (table 32). The median concentration of Cr for this study is higher than the median concentration for the California data set, and the 90-percent confidence intervals do not overlap. Median concentrations for Cu and Pb for this study are similar to the median concentrations in the California and Washington studies, but the 90-percent confidence intervals for this study and the Texas data set do not overlap. The 90-percent confidence intervals for the median concentrations of Fe and Zn overlap for all four studies. The similarities in many of these populations selected

on the basis of AADT volumes indicate that some recent data collected in states other than Massachusetts could supplement the data collected in this study.

Sources of Highway-Runoff Constituents

Highway runoff is a complex mix of contaminants from multiple sources that include automobile and highway residuals, atmospheric deposition, local soils, highway-berm soil, highway-maintenance materials, and other sources. Antecedent conditions, traffic volume, climate, storm characteristics, and other factors also can affect the quality of highway runoff. Identification of individual sources of specific constituents is difficult because many highway-related constituents are found in a wide variety of natural and anthropogenic materials deposited on highways. For example, Zn is found in soil (table 19 in the back of the report), berm materials (table 20 in the back of the report), highway guardrails, automobile components, automobile emissions, tire particles, brake dust, automobile lubricants, and atmospheric deposition. Accurate assessments of yields of specific constituents are further complicated by differences in exhaust emissions rates, and brake and tire wear rates, which are a function of road conditions and traffic density.

Common Highway Constituents

Principal component analysis was used for dimensional reduction of the data. In general, principal component techniques are used to identify underlying data structures by establishing linear combinations of the p original variables, which form new sets of variables or axes that are uncorrelated with one another (Helsel and Hirsch, 2002). Results of principal component analysis of all data and data subsets for total-recoverable metals and for SVOCs from the principal highways indicate that 80 to 95 percent of the variance is explained by a single variable. This likely stems from the high degree of correlation between most of the constituents. For example, the average Pearson correlation coefficient for total-recoverable metals and SVOCs in samples of runoff collected from the principal highway, Interstate 95, was about 0.83 (table 33). The Pearson product moment correlation coefficient measures the degree of linear relation between two variables. The correlation coefficient ranges from -1 to +1. A negative coefficient indicates that one variable tends to increase as the other decreases, and a positive coefficient indicates that the two variables tend to increase together. Unfortunately, the high degree of correlation between most of the constituents makes it difficult to identify individual source patterns.

Further research indicates that the use of ratios between certain PAH compounds, and ratios of the dominant particulate-associated PAHs to P and to selected metals, may provide

Table 33. Pearson correlation coefficients for total nutrients, total-recoverable metals, and polycyclic aromatic hydrocarbons in samples of highway runoff collected from Interstate 95 in Lexington and Waltham, Massachusetts, 2005–07.

[<, less than value shown; mm, millimeters]

Constituent	Nitrogen	Phosphorus	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Zinc	Anthracene	Benzo[a]anthracene	Benzo[a]pyrene	Benzo[b]fluoranthene	Benzo[ghi]perylene	Benzo[k]fluoranthene	Chrysene	Fluoranthene	Indeno[1,2,3-cd]pyrene	Phenanthrene	Pyrene	Perylene
Phosphorus	0.762																					
Cadmium	0.742	0.726																				
Chromium	0.676	0.751	0.738																			
Copper	0.776	0.804	0.866	0.925																		
Iron	0.645	0.854	0.872	0.904	0.925																	
Lead	0.646	0.760	0.827	0.870	0.924	0.929																
Manganese	0.754	0.777	0.925	0.895	0.949	0.938	0.909															
Nickel	0.673	0.825	0.877	0.886	0.916	0.955	0.851	0.930														
Zinc	0.749	0.799	0.870	0.951	0.960	0.960	0.925	0.958	0.943													
Anthracene	0.428	0.743	0.742	0.561	0.658	0.799	0.642	0.649	0.786	0.696												
Benzo[a]anthracene	0.565	0.809	0.822	0.707	0.799	0.898	0.814	0.771	0.826	0.825	0.928											
Benzo[a]pyrene	0.647	0.828	0.848	0.751	0.864	0.912	0.873	0.833	0.842	0.850	0.807	0.941										
Benzo[b]fluoranthene	0.603	0.803	0.827	0.743	0.861	0.910	0.871	0.825	0.840	0.848	0.821	0.948	0.993									
Benzo[ghi]perylene	0.718	0.765	0.886	0.684	0.846	0.846	0.831	0.819	0.782	0.803	0.696	0.859	0.960	0.932								
Benzo[k]fluoranthene	0.543	0.808	0.740	0.743	0.819	0.895	0.839	0.788	0.835	0.835	0.840	0.936	0.939	0.963	0.813							
Chrysene	0.611	0.827	0.879	0.761	0.849	0.934	0.841	0.833	0.881	0.869	0.914	0.988	0.943	0.942	0.884	0.915						
Fluoranthene	0.540	0.777	0.838	0.662	0.758	0.869	0.754	0.742	0.819	0.789	0.949	0.983	0.898	0.897	0.834	0.873	0.984					
Indeno[1,2,3-cd]pyrene	0.698	0.801	0.895	0.718	0.874	0.889	0.857	0.841	0.830	0.836	0.766	0.910	0.983	0.965	0.991	0.871	0.931	0.885				
Phenanthrene	0.445	0.738	0.762	0.596	0.656	0.809	0.642	0.655	0.789	0.712	0.973	0.927	0.791	0.792	0.703	0.793	0.929	0.970	0.767			
Pyrene	0.613	0.816	0.887	0.721	0.820	0.911	0.814	0.807	0.857	0.838	0.912	0.978	0.941	0.930	0.905	0.879	0.992	0.987	0.942	0.935		
Perylene	0.702	0.871	0.827	0.697	0.832	0.886	0.790	0.800	0.857	0.815	0.853	0.935	0.970	0.972	0.886	0.962	0.928	0.889	0.929	0.806	0.917	
Suspended sediment	0.318	0.552	0.497	0.599	0.643	0.702	0.731	0.610	0.606	0.678	0.626	0.761	0.745	0.802	0.573	0.887	0.698	0.648	0.636	0.547	0.632	0.728
Suspended sediment <0.063 mm in diameter	0.661	0.862	0.882	0.903	0.925	0.994	0.907	0.937	0.963	0.952	0.798	0.893	0.905	0.899	0.845	0.880	0.937	0.875	0.888	0.821	0.916	0.880

qualitative estimates of the proportion of most highway-runoff constituents attributable to likely sources. Comparisons of ratios of PAH compounds in environmental samples to PAH ratios from known sources are commonly used to determine potential sources (Breault and others, 2005; Lima and others, 2005; Yunker and others, 2002; Dickhut and others, 2000). Ratios are derived for PAH compounds of the same molecular mass to avoid differences in volatility, water solubility, and absorption (Yunker and others, 2002).

For this study, ratios for anthracene to anthracene plus phenanthrene ($An/(An+Phe)$), fluoranthene to fluoranthene plus pyrene ($Fl/(Fl+Py)$), benzo[a]anthracene to benzo[a]anthracene plus chrysene ($Ba/(Ba+Chr)$), and indeno[1,2,3-*cd*]pyrene to indeno[1,2,3-*cd*]pyrene plus benzo[ghi]perylene ($Ip/(Ip+Bghi)$) were computed from sample pairs for each highway. The median ratios for these PAH compounds in composite samples of highway runoff for each highway in this study are listed with ratios related to potential sources of highway PAHs reported in the literature in table 34. Ratios for $An/(An+Phe)$ greater than 0.1 generally indicate combustion sources, and ratios less than 0.1 indicate petroleum sources (Yunker and others 2002). The median ratios for $An/(An+Phe)$ in this study ranged from about 0.13 to 0.24, and most of these ratios are within the range of ratios for gasoline-engine exhaust emissions (table 34). The median ratios for $An/(An+Phe)$ in composite samples of highway runoff during, or shortly after, winter plowing operations (runoff events in January, February, March, and April 2006, and March and April 2007) on the principal highways were closer to 0.08. This lower ratio indicates that the dominant source of individual PAHs could shift from gasoline-engine exhaust emissions to asphalt wear during the winter, possibly as the result of contact wear of the asphalt surface during snow plowing. Transition breaks between sources of combustion and petroleum are less certain for ratios for $Fl/(Fl+Py)$ (Yunker and others, 2002). The median ratios for $Fl/(Fl+Py)$ in this study ranged from about 0.53 to 0.57 (table 34), which were slightly higher than ratios for $Fl/(Fl+Py)$ in automobile exhaust generated from gasoline engines (Cadle and others, 2001) but within the rather large range of ratios for diesel-exhaust emissions (Westerholm and Egeback, 1994; Strandell and others, 1994; Rogge and others, 1993). However, it is unlikely that these ratios result from diesel-exhaust emissions because of the low inter-highway variability and the dissimilar heavy truck traffic on the different highways. Furthermore, the range of ratios for $Fl/(Fl+Py)$ calculated by Miguel and others (1998) is more precise for diesel-exhaust emissions than for gasoline-exhaust emissions, and the ratios are lower than those calculated for exhaust from gasoline engines. The median environmental PAH ratios for the highways in this study also might be higher than those in the literature as a result of further improvements in engine technology and fuel formulations since the test data were reported. Differences in the age of engines, emission controls, vehicle speed, fuel formulations, and engine operational procedures affect the assemblage of PAHs, thus, potentially affecting the final ratios (Lima and others, 2005).

For example, ratios for $Fl/(Fl+Py)$ derived from emission samples from older catalyst-equipped automobiles (Rogge and others, 1993) are lower than ratios from tests conducted with newer model vehicles (Cadle and others, 2001), and although the research by Marr and others (1999) indicated that fuel was not the only source of the PAHs in exhaust, they reported that particle-phase emission factors correlated well for most PAH compounds in gasoline. The median ratios for $Ba/(Ba+Chr)$ in composites of highway runoff in this study ranged from about 0.30 to 0.46 (table 34), which are within the range of ratios for automobile exhaust generated by gasoline engines (Cadle and others, 2001). The higher ratios for $Ba/(Ba+Chr)$ for some of the highways may have been affected by larger amounts of diesel-exhaust emissions from heavy trucks. The presence of benzo[a]anthracene and the absence of chrysene in diesel exhaust results in an increased $Ba/(Ba+Chr)$ ratio. The median ratios for $Ip/(Ip+Bghi)$ in composite samples of highway runoff in this study ranged from about 0.44 to 0.48 (table 34); this range is greater than the range of ratios for gasoline and diesel exhaust emissions. These ratios likely reflect a blend of different potential sources that include gasoline and diesel exhaust emissions, and asphalt and tire wear. Ratios for $Fl/(Fl+Py)$, $Ba/(Ba+Chr)$, and $Ip/(Ip+Bghi)$, calculated on the basis of available concentration data for samples of suspended sediment (table 21 in the back of the report), are similar to the median ratios calculated from the concentration data for the composite samples of highway runoff. Ratios for $An/(An+Phe)$, $Fl/(Fl+Py)$, and $Ip/(Ip+Bghi)$ also are similar to ratios for precipitation calculated on the basis of the mean concentration of the above PAHs reported for precipitation in Narragansett Bay, Rhode Island (Latimer, 1997). However, these similarities more likely indicate that automobile emissions are the source of the PAHs in the atmosphere rather than wet deposition is the source of PAHs in highway runoff.

In this study, the median concentrations of total P and most metals measured in samples of highway runoff from each principal highway were compared to the concentrations expected from automobile emissions. Average emission rates for Cr, Cu, Ni, and Pb in oxygenated fuel, using different standardized-test procedures and different automobiles, are similar to the emission rates for major particulate-associated PAHs (chrysene and indeno[1,2,3-*cd*]pyrene), but the emission rates for P, Fe, and Zn are reported to be about 6 to 38 times greater than the emission rates for the respective PAHs (Cadle and others, 2001). Concentrations of each element in automobile exhaust were estimated on the basis of the average ratio for the emission rate of the individual element to the emission rates for chrysene and indeno[1,2,3-*cd*]pyrene in exhaust, which were obtained from the literature (Cadle and others, 2001). Assuming the dispersion for both metals and PAHs associated with exhaust particles is similar, exhaust emissions account for only a small fraction of metals measured in samples of highway runoff. For example, ratios for median concentrations of total P and total-recoverable Cu and Fe to the concentration of the respective elements estimated from the median concentrations of chrysene and indeno[1,2,3-*cd*]pyrene in samples of

Table 34. Median ratios between selected polycyclic aromatic hydrocarbons in composites of highway runoff for eight highways in Massachusetts, 2005–07, and ratios for common sources of polycyclic aromatic hydrocarbons found in highway runoff.

[PAHs, polycyclic aromatic hydrocarbons; An, anthracene; Phe, phenanthrene; Fl, fluoranthene; Py, pyrene; Ba, benz[a]anthracene; Chr, chrysene; Ip, indeno[1,2,3-*cd*]pyrene; Bghi, benzo[ghi]perylene; *, median value based on three samples or less; --, insufficient data to compute ratio; PAH ratios estimated from the average of the range values]

Highway-runoff monitoring station or potential source of PAHs	Median ratio for selected PAHs in composite samples of highway runoff or range of ratios for selected PAHs as sources reported in literature			
	An/(An+Phe)	Fl/(Fl+Py)	Ba/(Ba+Chr)	Ip/(Ip+Bghi)
	Highway-runoff monitoring station			
Route 119	0.14	0.56	0.34	0.47
Route 8	0.24	0.53*	0.46*	0.47*
Interstate 195	0.23*	0.55	0.39	0.45
Route 2	0.13	0.57	0.35	0.44
Interstate 190	0.23	0.54	0.33	0.47
Interstate 495	0.17	0.54	0.39	0.45
Interstate 95	0.15	0.55	0.30	0.48
Interstate 93	0.16	0.56	0.32	0.47
	Potential sources of PAHs			
Asphalt	0.08 ^{1,2}	0.33 ¹ and 0.44 ²	0.16 ¹ and 0.50 ³	0.52 to 0.54 ³
Brake dust	--	0.30 ⁴	0.47 ⁴	--
Gasoline exhaust emissions	0.13 to 0.17 ⁵	0.47 to 0.52 ⁵	0.29 to 0.48 ⁵	--
Diesel exhaust emissions	0.12 ⁴ , 0.10 ⁶ , and 0.08 ⁷	0.37 ⁴ , 0.61 ⁶ , and 0.55 ⁷	0.35 ⁷	--
Highway tunnel, diesel exhaust emissions	--	0.41 to 0.43 ⁸	0.56 to 0.68 ⁸	--
Highway tunnel, gasoline exhaust emissions	--	0.43 to 0.47 ⁸	0.41 to 0.51 ⁸	0.27 to 0.33 ⁸
Precipitation	0.14 ⁹	0.49 ⁹	0.18 ⁹	0.43 ⁹
Road dust	0.18 ³	.42 ³	0.13 ³	0.51 ³
Road-side vegetation	--	0.56	0.54 to 0.61	--
Tire particles	0.04 ¹	0.11 ¹ , 0.17 ⁴ , 0.17–.29 ¹⁰ , and 0.20 ¹¹	--	0.91 ¹
Used oil (gasoline engine)	0.22 ³	0.511, 0.303 ^{3,11}	0.50 ³	0.33 ¹ and 0.183

¹Braut and others, 2005; ²Brandt and De Groot (2001); ³Mean values from Yunker and others (2002); ⁴Rogge and others (1993); ⁵Cadle and others (2001); ⁶Westerholm and Egeback (1994); ⁷Strandell (1994); ⁸Miguel and others (1998); ⁹Latimer (1997); ¹⁰Gadd and Kennedy (2003); ¹¹King County and SPU (2004).

highway runoff collected at the principal highways indicate that less than 3 percent of the constituents are accounted for by exhaust emissions from gasoline engines, whereas ratios for median concentrations for total-recoverable Cr, Mn, Ni, Pb, and Zn to the concentration of the respective elements estimated from the median concentrations of chrysene and indeno[1,2,3-*cd*]pyrene indicate that from about 4 to 13 percent of the of the constituents are accounted for by exhaust emissions from gasoline engines.

Atmospheric deposition also can affect the quality of highway runoff. Atmospheric deposition of constituents measured in samples of highway runoff occurs in the form of dry and wet deposition. Dry deposition includes settleable particulates, aerosols, gases, and vapors. The deposition of these particles is dependent on the size, surface area, and mass of the particle (Legge, 1990). Larger airborne particles, greater than a few micrometers in diameter, result from natural sources of mechanical abrasion and wind erosion, and are subject to gravitational settling, whereas smaller particles are removed from the atmosphere by precipitation scavenging (Colman and others, 2001). Available data for dry deposition rates are sparse, and particle chemistry and deposition rates are subject to local conditions. However, concentration data on ammonia, nitrate, and most major ions, which are available from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), are more common. Concentrations of total P were unavailable; however, concentrations of P in precipitation generally are too low to be measured accurately (Colman and others, 2001). Concentrations of major ions in precipitation do not constitute a large fraction of the major ions in samples of highway runoff, except for Mg and SO_4 . Comparisons of annual precipitation weighted-mean concentrations (concentration for each storm is weighted by the respective volume) of major ions other than Mg and SO_4 in 2005 and 2006 for NADP/NTN site MA13 in Lexington, Massachusetts (NADP/NTN, 2008), to mean concentrations for the same constituents in composite samples of highway runoff from non-winter storms (where the effect of addition of deicing compounds is eliminated) for the principal highway Interstate 95 in parts of Lexington and Waltham, Massachusetts, indicate that less than about 4 percent of the concentrations of the respective major ions is explained by atmospheric deposition in the non-winter months. In contrast, weighted-mean concentrations of Mg and SO_4 in precipitation may account for about 10 and 21 percent, respectively, of the mean concentrations in non-winter highway runoff. Weighted-mean concentrations of NH_4 and NO_3 in precipitation may account for about 55 percent of the mean concentrations of total N in all samples (winter and non-winter) collected at Interstate 95 in this study. Concentrations of total N in precipitation likely constitute a greater percentage of total N in highway runoff at the other principal highways because the concentrations of total N in samples of highway runoff at those sites were significantly different (table 22). Data on concentrations of metals in precipitation in the Massachusetts area could not be located; however, concentrations of metals measured in wet

precipitation in Michigan, Illinois, and Indiana (Coleman and others, 2001) are low and likely represent only a small fraction of the metal content measured in samples of highway runoff in Massachusetts.

Local soils and highway-berm soil can represent much of the suspended sediment entrained in highway runoff (Gupta and others, 1981). As a result, background soil adjacent to each highway can affect the composition and concentrations of many constituents in highway runoff. Soils often are washed onto the roadway surface during stormflows or are directly deposited on the road by automobiles (for example, vehicles that have come into contact with adjacent unpaved shoulders).

Soil is natural material occupying the portion of the earth mainly composed of mineral and organic materials and develops from surficial material that unless otherwise specified can include any unconsolidated deposits down to bedrock. Geologic processes, such as weathering and erosion, break bedrock down into small particles of sediment. Sediments such as clay, silt, sand, gravel, and other loose deposits that lie on top of bedrock are grouped together in the general category of surficial materials. These materials are not soils, but are the deeper earth materials that lie between the soil zone and the underlying bedrock. Soils commonly develop by weathering of the uppermost part of these materials. Differences in weathering as a function of climate, presence of salt, and topography also can affect the development of soils (Ritter and others, 1995). This may explain in part the difference between the composition of soil in samples collected in southeastern Massachusetts, USEPA level III ecoregion 84 on and near Cape Cod, and samples collected elsewhere in Massachusetts in areas with similar surficial materials (table 19 in the back of the report).

The extent to which background soils contribute to the concentrations of P, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in highway runoff was estimated on the basis of the median concentrations of suspended sediment in composite samples of highway runoff (table 16 in the back of the report) and the median concentrations of each of these constituents in background samples of soils from each of the principal highways (table 19 in the back of the report). The median concentrations for P, Cr, Fe, Mn, Ni, and Zn in soil were adjusted on the basis of quality-control data to account for differences between the digestion techniques used in the analytical methods for the soil and whole-water samples. These initial estimates indicate that background soils account for on average about 37 percent of the median P concentration, 100 percent of the median Cr concentration, 4 percent of the median Cu concentration, 53 percent of the median Fe concentration, 54 percent of the median Mn concentration, 15 percent of the median Ni concentration, 44 percent of the median Pb concentration, and 2 percent of the median Zn concentration in samples of highway runoff from the principal highways. Except for Cr, these values are likely conservative because the values were estimated without regard to the distribution of the particle sizes for the two media—soil and sediment. The distribution of particle sizes in samples of soil or sediment can have great

effects on the concentrations of many constituents. The disproportionate differences in concentrations of inorganic constituents relative to grain size are well documented (table 18 in the back of the report; fig. 24; Breault and others, 2005; Smith, 2002, 2005; Horowitz, 1991; Horowitz and Elrick, 1987; Forstner and Wittmann, 1981; Salomons and Forstner, 1984). In general, surface area and trace-element concentrations tend to increase with a decrease in particle-grain size. Furthermore, the silt- and clay-sized particle group contains more clay minerals, which typically have higher sorptive capacities, than other groups. In contrast, concentrations of Cr typically are greater in the coarse fractions of sediment (table 18 in the back of the report; fig. 24; Breault and others, 2005; Smith, 2002, 2005); therefore, the contribution of Cr from local soils, which contain a higher proportion of coarse particles than highway sediments, results in an overestimation of Cr in highway sediments.

Highway-berm soils often are composed of soil excavated from nearby locations during highway construction. The concentrations of many metals in berm soils become enriched over time through the deposition of small particulates emitted from automobiles and pavement wear. Winter sanding of pavement surfaces also contributes to the buildup of berm soils near the highway shoulder. As a result, the median concentrations and upper ranges of concentrations of most constituents, except P, in samples of highway-berm soils increase with the AADT volume of the highways (fig. 25). Moreover, the chemical composition of these berm soils often is comparable to the chemical composition of samples of suspended sediment in highway runoff. This is further illustrated by normalizing data collected in this study on the basis of the particle-size distribution to reduce the disproportionate differences between concentrations of constituents that are affiliated with sediment relative to grain size. Specifically, concentrations of Cu, Cr, Fe, Mn, Ni, P, Pb, and Zn in suspended sediment for each principal highway (fig. 25) were estimated on the basis of the concentrations of the respective constituents affiliated with the three particle-size fractions in sieved samples of suspended sediment to reflect the particle-size distribution of the five respective berm samples (table 20 in the back of the report) for each principal highway. The distributions of concentrations of the selected elements in highway berm and the distributions of normalized concentrations measured in suspended sediment were most similar for P and Zn, with few exceptions. In several cases, the ranges of concentrations of Cu, Fe, Pb, Mn, and Ni in samples of highway berm soil overlapped the ranges of the estimated concentrations in suspended sediment. These data indicate that erosion or mechanical transport of highway-berm soils onto the paved surface is potentially a large source for P and other metals. Furthermore, although the concentrations of most constituents (except for Cr and P) in winter-maintenance sand were relatively low compared to concentrations measured in samples of highway berm (fig. 25), high concentrations of maintenance sand, which contain Cu, Cr, Fe, Pb, Mn, and Ni, and Zn in samples of winter runoff can cause

large increases in concentrations of these constituents and, as discussed earlier, may account for most of the P concentration.

Thus far, much of the concentrations of PAHs, major ions, and metals can be accounted for by exhaust emissions, road wear, atmospheric deposition, local and berm soils, and highway maintenance materials. However, these potential sources do not fully account for concentrations of Cu, Zn, and phthalates measured in samples of highway runoff. Sources reported to contribute substantial amounts of Cu and Zn in highway and urban runoff are brake and tire wear (Hjortenkrans and others, 2007; Hulskotte and others, 2006; Councell and others, 2004; Gadd and Kennedy, 2000). The composition of individual brake pads can vary widely from manufacturer to manufacturer, and the composition also can vary between front and rear brakes (Hjortenkrans and others, 2007). Garg and others (2000) report that 19 different elements were found in the analysis of 7 different brake pads, and the analysis of most brakes indicated that Fe, Cu, Ba, and S were the major elements associated with particle matter emitted during brake wear. As discussed earlier, the size of the emission particle can have a large effect on where the particles are deposited. Laboratory brake-wear tests indicated that 3 to 30 percent of the brake debris falls on the road surface, 16 to 22 percent is retained on the wheel, and 8 to 25 percent is retained on the vehicle steering and suspension equipment (Sanders and others, 2003). The latter two depositional areas are likely subject to wash-off during rainstorms. Emission rates for brake wear depend strongly on traffic conditions and brake temperature, but Garg and others (2000) report that emission rates for Fe and Cu in brake wear are 2.21 and 0.70 mg/mi, respectively, which are more than an order of magnitude greater than emission rates reported for exhaust emissions from gasoline engines. Given these emission rates, brake wear as a source of Cu can easily account for the mass closure in concentrations measured in samples of highway runoff. Similarly, phthalate esters, including bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, di-n-octyl phthalate, and diethyl phthalate, are reported to be used in brake-pad construction (King County and SPU, 2004); this may explain much of the observed concentrations in composite samples of highway runoff.

In contrast, anthropogenic sources of Zn have largely been linked to tire emissions. Zn is used to facilitate vulcanization of the rubber in the manufacturing process for tires (Councell and others, 2004), and as a result, Zn can account for about 1 percent of the mass of the tread particles (Hjortenkrans and others, 2007; Breault and others, 2005; Councell and others, 2004). To determine the relative magnitude of Zn loading to the highway surface as a function of tire wear, the load of Zn for a single day was estimated for each of the principal highways on the basis of an average tire-tread wear rate of about 0.08 g/mi/tire (Councell and others, 2004), a tread-wear composition consisting of 1-percent Zn, the AADT volumes (assuming four wheels per vehicle) for each principal highway (table 1), and an average linear distance of about 300 ft for the sites on the principal highways. These simple estimates indicate that for a 0.5-in. rainstorm, the estimated

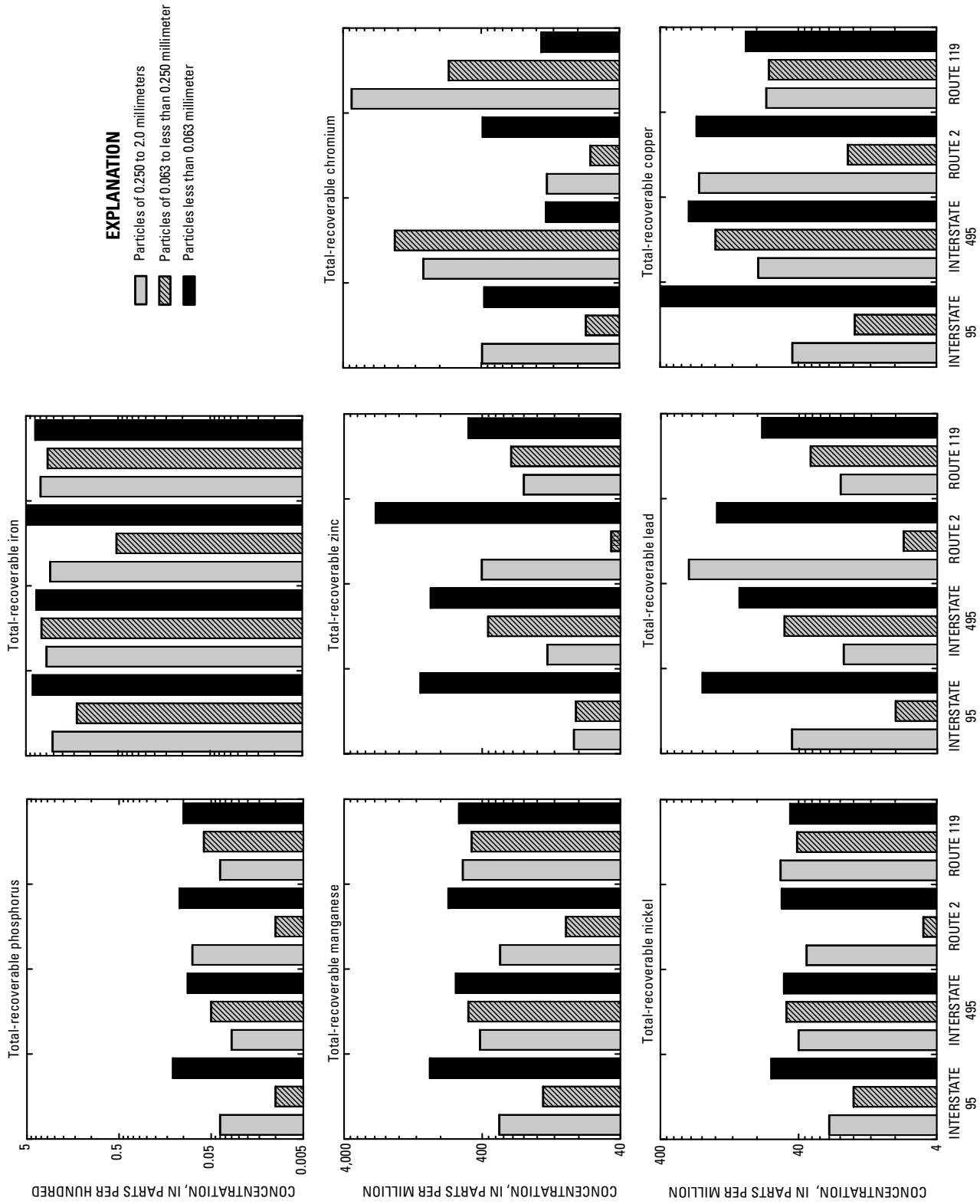


Figure 24. Concentrations of total-recoverable metals in three particle-size ranges of suspended sediment in samples of highway runoff collected by automatic samplers at the principal highways in Massachusetts, 2005–07.

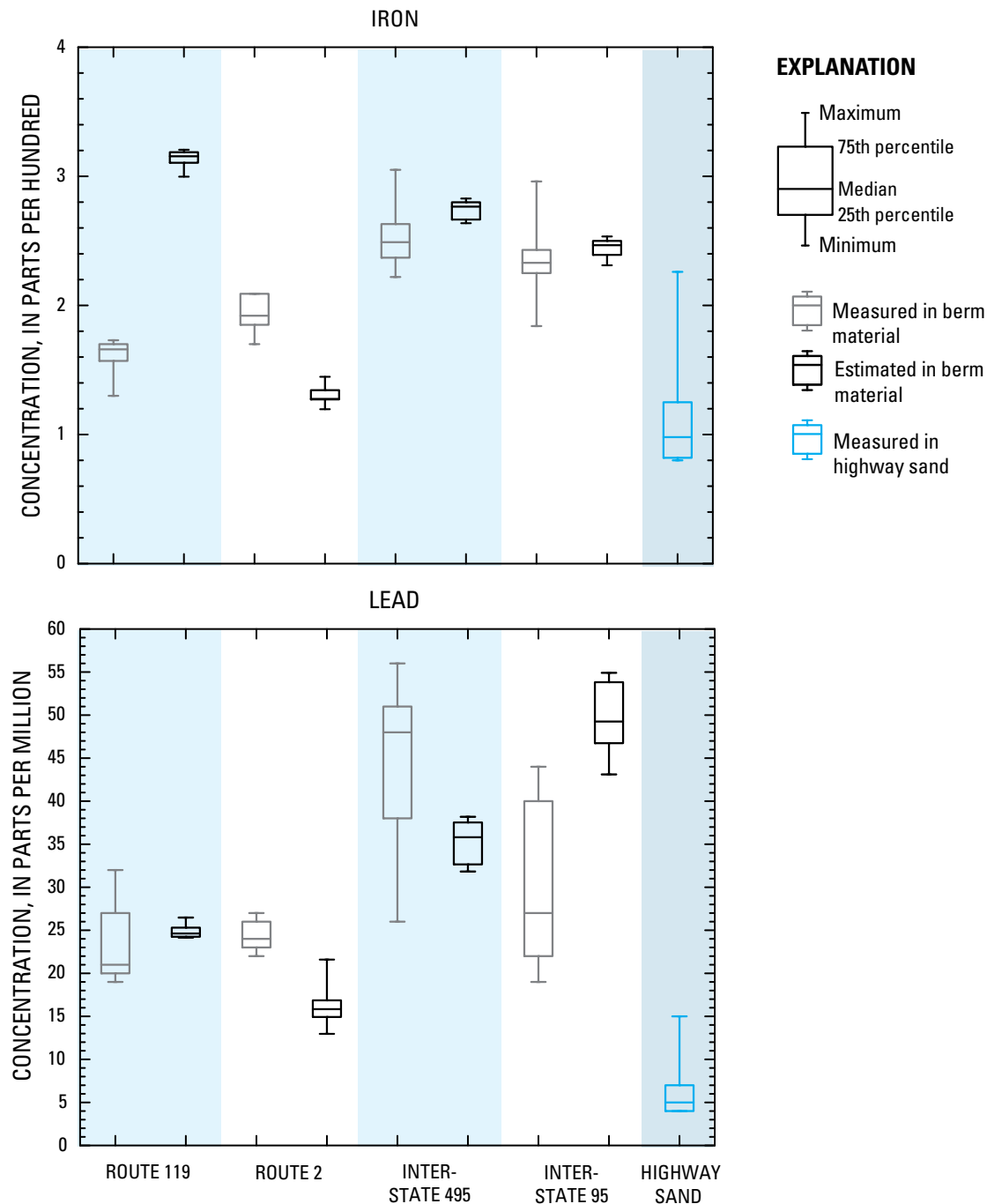


Figure 25. Distribution of concentrations of selected constituents measured in samples of berm material from four principal highways and in samples of highway-maintenance sand, and estimated concentrations of berm material derived from samples of suspended-sediment quality and particle size in Massachusetts, 2005–07. Five samples of highway-berm material were collected within 1 foot of the edge of the pavement in the vicinity of each of eight highway-monitoring stations. Eight samples of highway-maintenance sand were collected.

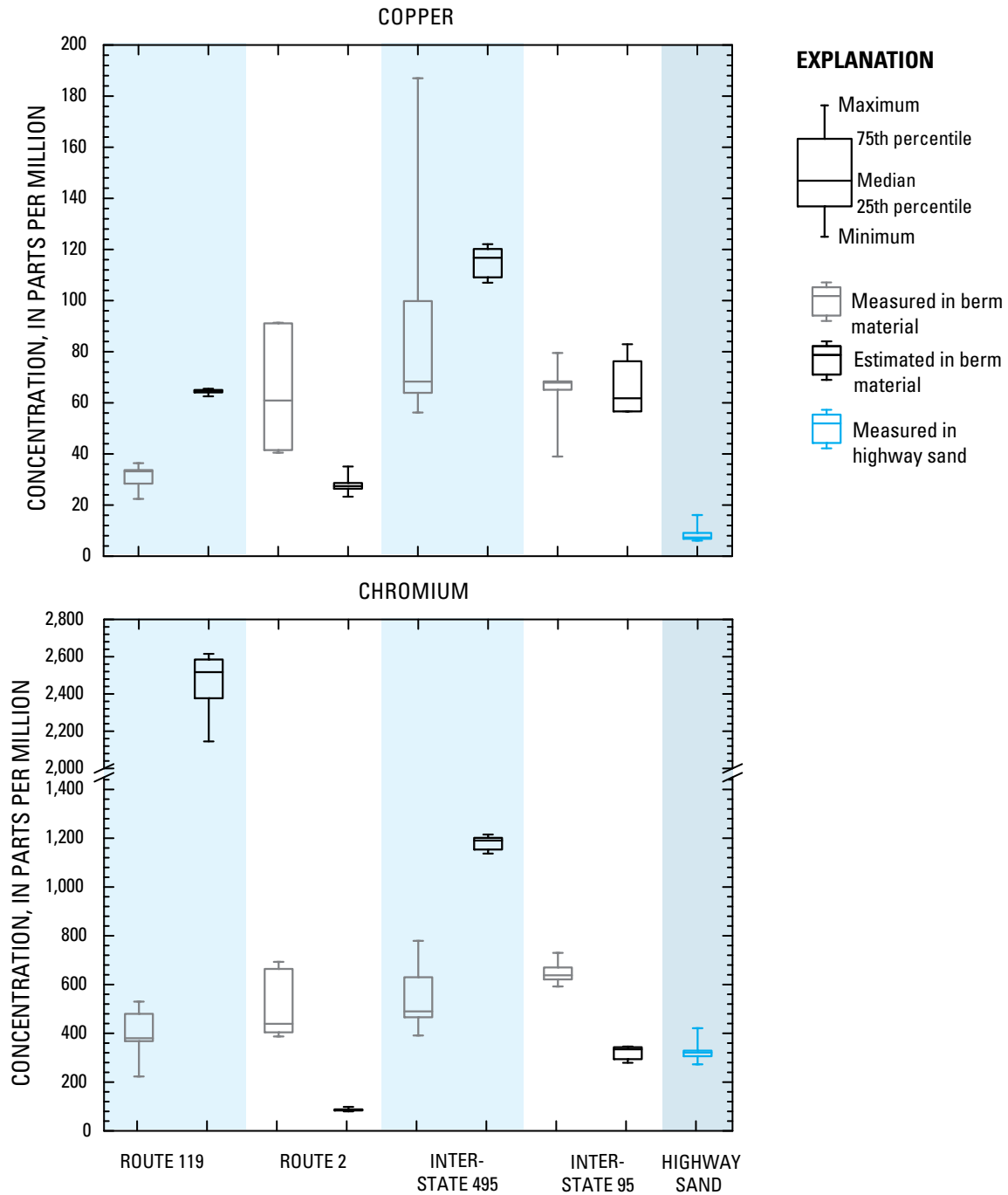


Figure 25. Distribution of concentrations of selected constituents measured in samples of berm material from four principal highways and in samples of highway-maintenance sand, and estimated concentrations of berm material derived from samples of suspended-sediment quality and particle size in Massachusetts, 2005–07. Five samples of highway-berm material were collected within 1 foot of the edge of the pavement in the vicinity of each of eight highway-monitoring stations. Eight samples of highway-maintenance sand were collected.—Continued

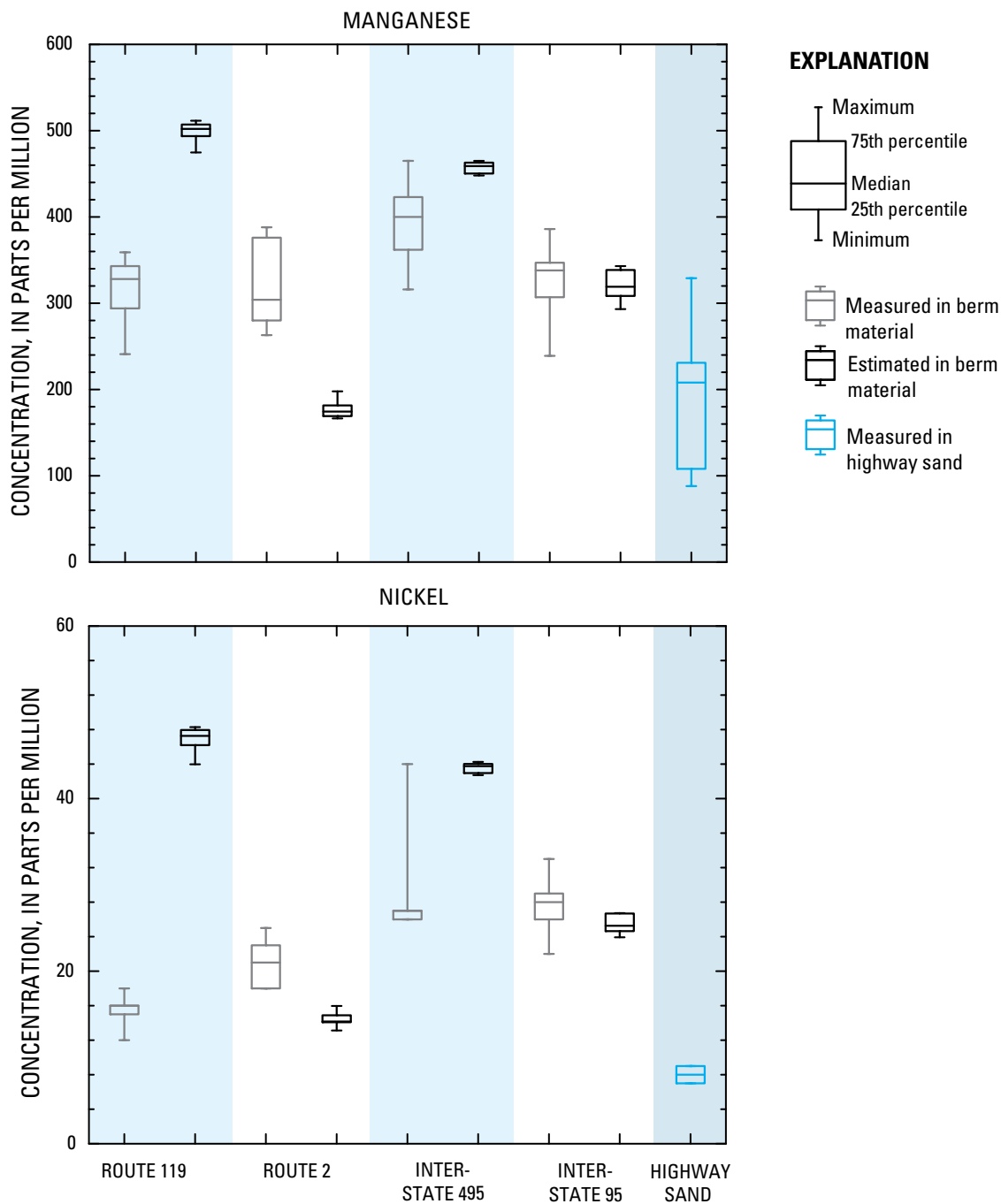


Figure 25. Distribution of concentrations of selected constituents measured in samples of berm material from four principal highways and in samples of highway-maintenance sand, and estimated concentrations of berm material derived from samples of suspended-sediment quality and particle size in Massachusetts, 2005–07. Five samples of highway-berm material were collected within 1 foot of the edge of the pavement in the vicinity of each of eight highway-monitoring stations. Eight samples of highway-maintenance sand were collected.—Continued

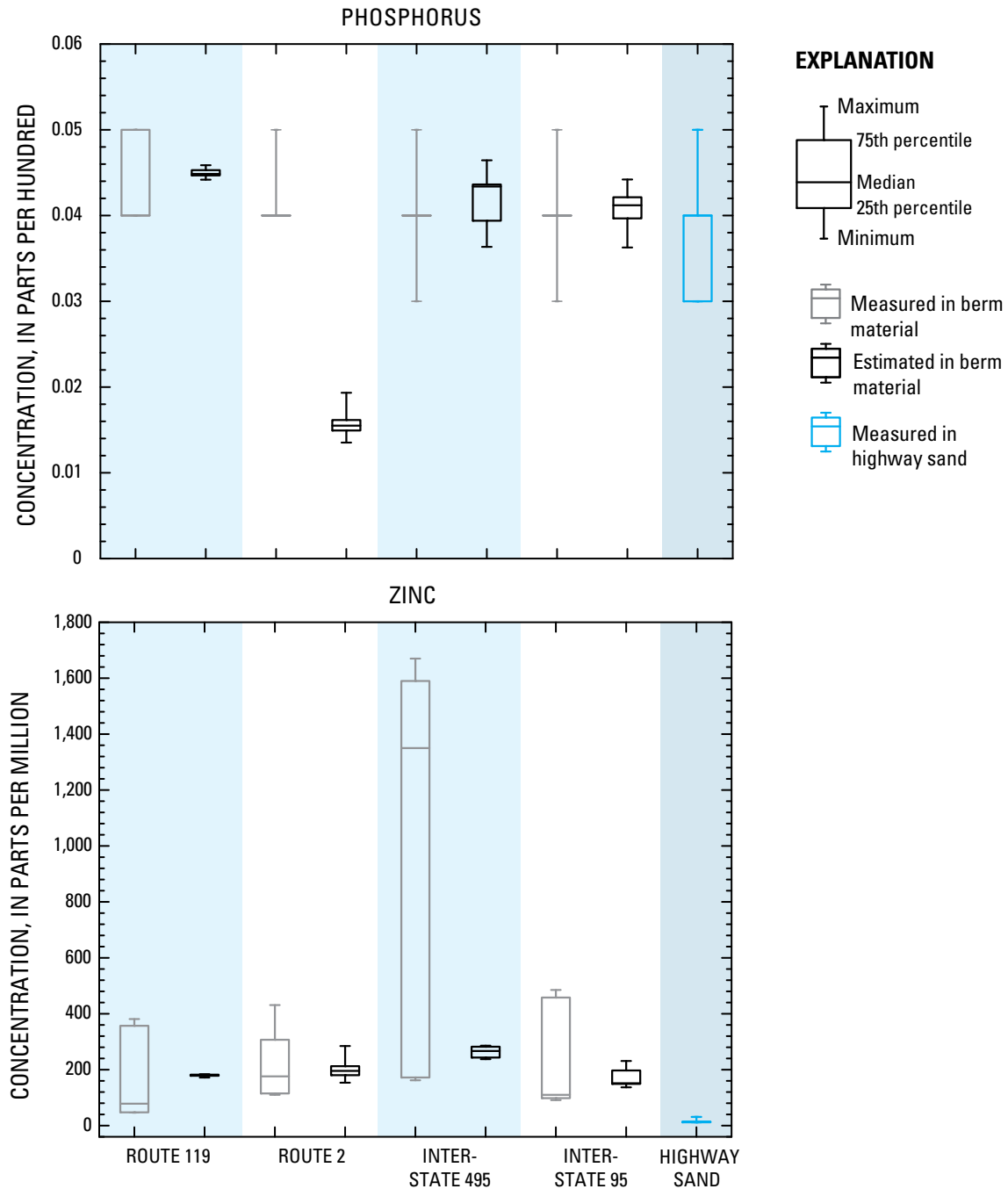


Figure 25. Distribution of concentrations of selected constituents measured in samples of berm material from four principal highways and in samples of highway-maintenance sand, and estimated concentrations of berm material derived from samples of suspended-sediment quality and particle size in Massachusetts, 2005–07. Five samples of highway-berm material were collected within 1 foot of the edge of the pavement in the vicinity of each of eight highway-monitoring stations. Eight samples of highway-maintenance sand were collected.—Continued

concentration of Zn emitted from tire wear was about 1.5 to 6 times greater than the median non-winter concentrations of Zn for the principal highways. For the estimates, it was assumed that all of the tire particles are retained on the highway, which is highly unlikely given the small diameter of the tire particles. In one study (Rogge and others, 1993), 30 percent of the mass of tire-wear particles measured near the street surface was found in air-quality samples at more than 200 ft above the street. Accurate load estimates for Zn as a function of tire wear are difficult to make because tire-emission rates vary widely depending on tire construction, vehicle weight, and pavement and driving conditions. Although Councell and others (2004) suggest that about 0.08 g/mi/tire is a reasonable rate for average driving conditions, they also report emission rates ranging from about 0.002 to about 40 g/mi/tire. Nevertheless, the evidence indicates that tire-wear is a substantial source for Zn in highway runoff, and other material testing indicates that some tires also may be a source of bis(2-ethylhexyl)phthalate (King County and SPU, 2004).

Other Anthropogenic and Natural Organic Compounds

The vast majority of highway-runoff data documents the concentrations of major ions, nutrients, metals, PAHs, and suspended sediments; however, few data sets document the concentration or detection for some of the lesser-known anthropogenic and natural organic compounds that have recently been detected in surface water and groundwater throughout the Nation (Zaugg, and others, 2006a). In this study, a subset of samples of highway runoff were collected at the primary sites on the principal highways and on Interstate 93 and analyzed for an additional 62 organic compounds (table 17 in the back of the report). These analyses include many compounds that typically are associated with industrial and household wastewater (Paxéus and others, 1992), such as nonionic surfactants, caffeine, indicators of plant sterols, indicators of fecal bacteria, flame retardants, wood preservatives, gasoline and diesel compounds, antioxidants, and personal care products.

In 15 samples of highway runoff, 45 of the 62 compounds were detected at least once, and 23 compounds were detected at concentrations greater than the LTMDL (table 35). Anthraquinone, bisphenol A, camphor, and cholesterol were the most frequently detected compounds. Although some compounds were detected less frequently in samples of highway runoff collected on Route 119, the frequency of detection for most compounds generally was similar among the other highways. About one-third of the compounds that were detected are likely attributable to vehicle fuels, lubricants, antifreeze, windshield fluids, chemical treatments of the engine compartments, finish-paint coats, automotive panels, and other vehicle components. *Beta*-sitosterol and cholesterol can originate from plant sources; *3beta*-coprostanol and *beta*-stimastanol are indicators of fecal bacteria (Zaugg, and others, 2006a). The sources for many of the remaining compounds may be

leachates from highway litter. These compounds consist of caffeine, cotinine, and various flavor enhancers used in beverages, cigarettes, and ointments commonly found in food wrappers, containers, and other litter along the edge of the highway.

Relations of Concentrations of Selected Elements and Organic Compounds to Suspended Sediment

Suspended sediment in runoff often can cause degradation in the receiving waters by affecting the clarity of the water and through large-scale depositions. Many trace elements and hydrophobic-organic compounds are associated with sediments (Breault and others, 2005; Smith, 2002, 2005; Lopes and Dionne, 1998; Horowitz, 1991; Gupta and others, 1981). Suspended sediment can represent a major transport mechanism for many constituents in highway runoff. Results of laboratory analysis for sieved samples of suspended sediment collected in highway runoff for this study indicate that highway suspended sediment contains high concentrations of P, trace elements, PAHs, and phthalates (tables 18 and 21). Results also indicate that in many cases, the fine fraction of sediment less than 0.063 mm in diameter was more enriched compared to the coarser sediment fractions (figs. 24 and 26).

Concentrations of suspended sediment measured in samples of highway runoff were examined as a potential surrogate for concentrations of sediment-affiliated constituents. Results of statistical tests between concentrations of suspended sediment and concentrations of total P, total-recoverable metals, and PAH compounds in samples collected at Interstate 95 indicate a positive relation between the test pairs (table 33). Furthermore, correlations are stronger between concentrations of suspended sediment less than 0.063 mm in diameter and concentrations of total P, total-recoverable metals, and PAH compounds (table 33) than for concentrations of total suspended sediment. Pearson correlation coefficients for total P, total-recoverable metals, and PAH compounds are 0.86, 0.88 to 0.99, and 0.80 to 0.94, respectively (calculated from data presented in table 33). These data further demonstrate that the distribution of grain size in suspended sediment may have an effect on the concentration of the various constituents in samples of highway runoff. Regression techniques may provide reasonable estimates for many of these constituents on the basis of concentrations of suspended sediment; however, such methods may not be transferable to other locations without additional measurements of highway runoff, which often require substantial capital and time. Instead, planning-level estimates of concentrations of many total-recoverable elements can be made directly from the respective constituent concentrations in samples of sieved suspended sediment and from the concentrations of specific particle classes of suspended sediment in samples of highway runoff. To demonstrate the applicability of this method, EMCs of Cu were

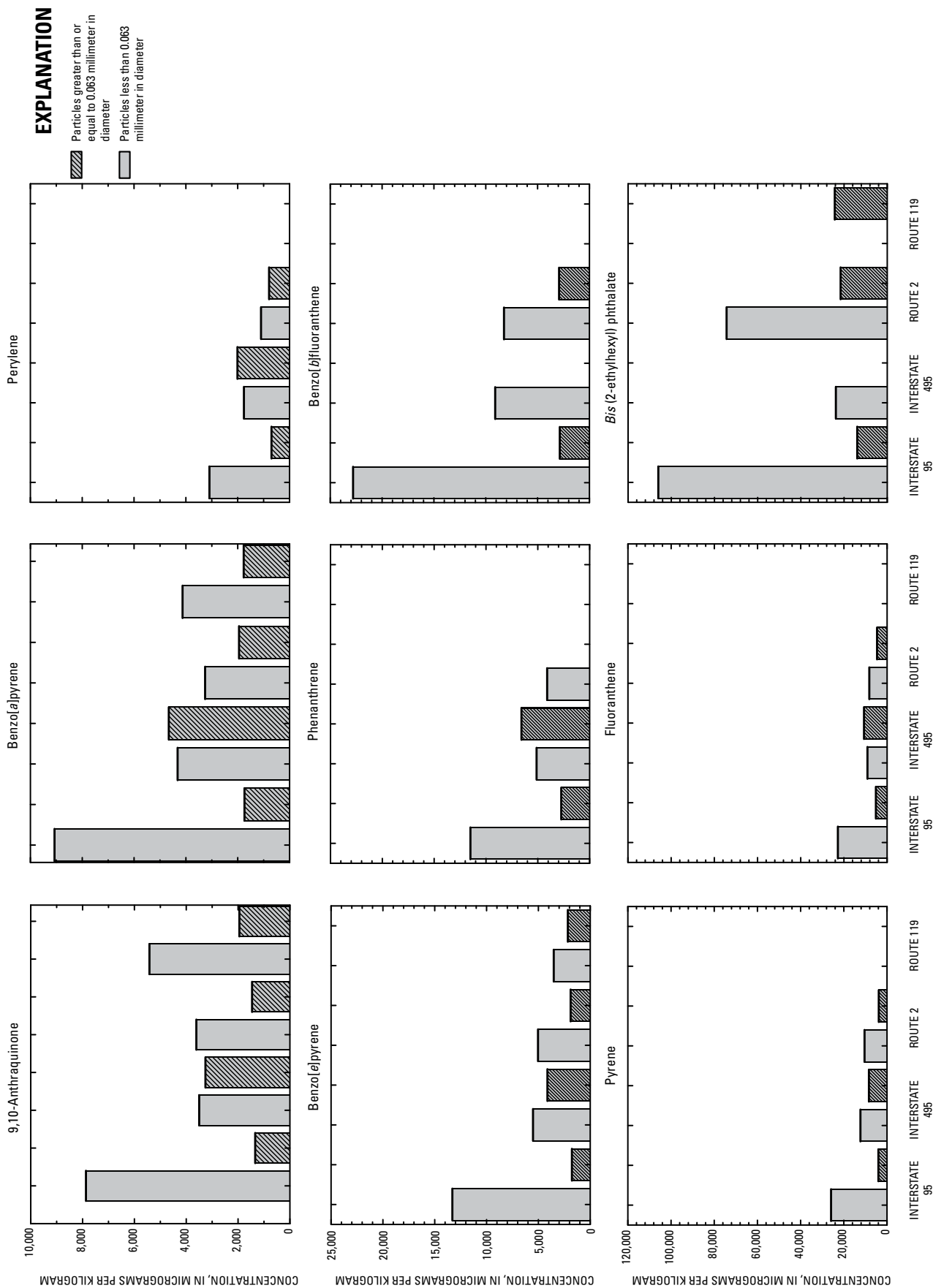


Figure 26. Distribution of concentrations for selected polycyclic aromatic hydrocarbons in two particle-size ranges for suspended sediment in samples of highway runoff collected by automatic samplers at the principal highways in Massachusetts, 2005–07.

Table 35. Frequency of detection, frequency of detection greater than or equal to the long-term method detection level, and possible sources of selected anthropogenic and natural organic compounds in 15 composite samples of highway runoff collected at 5 sites in Massachusetts, 2006–07.

[LTMDL, long-term method detection level; %, percent; possible compound sources from Zaugg and others, 2006a; U.S. Environmental Protection Agency, 2002; Agency for Toxic Substances and Disease Registry, 2005]

Compound name	Frequency of detection	Frequency of detection above LTMDL	Concentration at LTMDL	Possible compound uses or sources
1-Methylnaphthalene	60	20	0.03	2–5% of gasoline, diesel fuel, or crude oil
2,6-Dimethylnaphthalene	27	7	0.05	Diesel/kerosene (trace in gasoline)
2-Methylnaphthalene	73	33	0.03	2–5% of gasoline, diesel fuel, or crude oil
3,4-Dichlorophenyl isocyanate	14	0	0.06	Degradate of diuron, a noncrop herbicide
3 β -Coprostanol	33	33	0.38	Carnivore fecal indicator
3-Methyl-1H-indole (skatol)	7	0	0.07	Fragrance, stench in feces, indicator of decaying animal tissue, and coal tar
4-Cumylphenol	7	0	0.13	Nonionic detergent or metabolite
4-Nonylphenol (total, NP)	40	13	1.2	Nonionic detergent or metabolite
4- <i>tert</i> -Octylphenol	60	53	0.11	Nonionic detergent or metabolite
5-Methyl-1H-benzotriazole	40	40	0.35	Antioxidant in antifreeze and deicers
Acetophenone	60	60	0.07	Fragrance in detergent and tobacco, flavor in beverages
Anthraquinone	93	86	0.08	Manufacture dye/textiles, seed treatment, bird repellent
Benzophenone	13	13	0.1	Fixative for perfumes and soaps
β -Sitosterol	87	87	0.11	Plant sterol
β -Stigmastanol	7	7	0.22	Herbivore fecal indicator (digestion of sitosterol)
Bisphenol A	93	73	0.22	Manufacture polycarbonate resins, antioxidant
Caffeine	80	80	0.06	Beverages
Camphor	93	53	0.09	Flavor, odorant, ointments
Carbazole	80	30	0.12	Manufacture dyes, explosives, and lubricants
Cholesterol	93	93	0.3	Often a fecal indicator, also a plant sterol
Cotinine	20	13	0.29	Primary nicotine metabolite
N,N-diethyl-meta-tolamide (DEET)	53	27	0.12	Urban uses, mosquito repellent
Dichlorvos	7	0	0.11	Insecticide in pet collars; naled or trichlofon degradate
Diethoxynonylphenol (4-Nonylphenol diethoxylate; NP2EO)	33	20	1.2	Nonionic detergent
Diethoxyoctylphenol (4- <i>tert</i> -Octylphenol diethoxylate; OP2EO)	20	20	0.05	Nonionic detergent

Table 35. Frequency of detection, frequency of detection greater than or equal to the long-term method detection level, and possible sources of selected anthropogenic and natural organic compounds in 15 composite samples of highway runoff collected at 5 sites in Massachusetts, 2006–07.—Continued

[LTMDL, long-term method detection level; %, percent; possible compound sources from Zaugg and others, 2006a; U.S. Environmental Protection Agency, 2002; Agency for Toxic Substances and Disease Registry, 2005]

Compound name	Frequency of detection	Frequency of detection above LTMDL	Concentration at LTMDL	Possible compound uses or sources
<i>d</i> -Limonene	33	33	0.02	Antimicrobial, antiviral, fragrance in aerosols, major constituent in several citrus oils
Indole	7	0	0.08	Pesticide inert ingredient, fragrance in coffee
Isophorone	67	13	0.08	Solvent for lacquer, plastic, oil, silicon, resin
Menthol	50	50	0.05	Cigarettes, cough drops, liniment, mouthwash
Methyl salicylate	40	7	0.07	Liniment, food, beverage, wintergreen scent, ultraviolet absorbing lotion
Monoethoxynonylphenol (4-Nonylphenol monoethoxylate; NP1EO)	27	0	1.35	Nonionic detergent
<i>p</i> -Cresol	73	47	0.08	Wood preservative
Pentachlorophenol	53	20	0.33	Wood preservative, termite control
Phenol	73	73	0.07	Disinfectant, Manufacture several products, leachate
Tributyl phosphate	20	7	0.11	Antifoaming agent, flame retardant
Triphenyl phosphate	60	13	0.1	Plasticizer, resin, wax, finish, roofing paper
Tri(2-butoxyethyl) phosphate	53	53	0.05	Flame retardant
Tri(2-chloroethyl) phosphate	67	27	0.08	Plasticizer, flame retardant
Tri(dichloroisopropyl) phosphate	73	73	0.05	Flame retardant
1,4-Dichlorobenzene	7	0	0.03	Moth repellent, fumigant, deodorant
Tribromomethane (Bromoform)	13	0	0.03	Previously used in fire-extinguisher fluids, spray can propellants, and refrigerator fluid

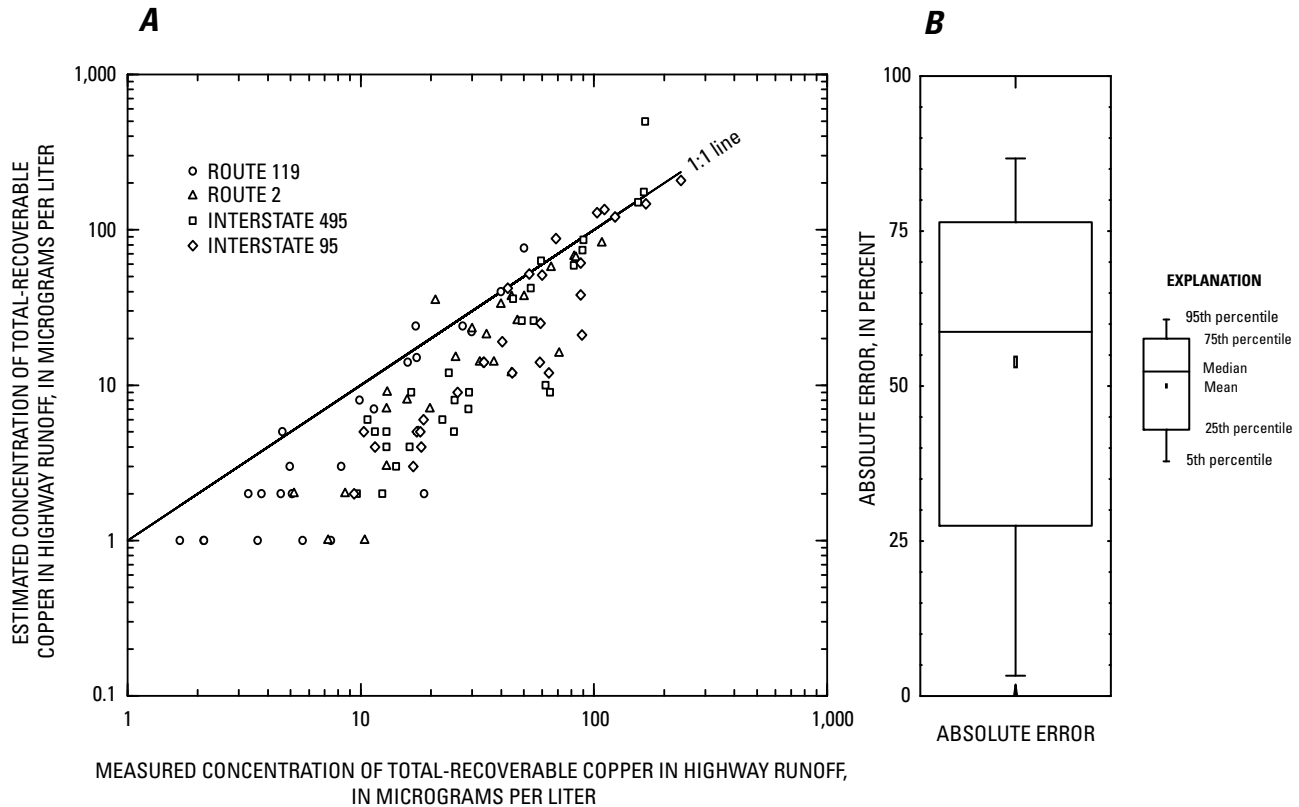


Figure 27. (A) Concentrations of total-recoverable copper in samples of highway runoff collected from eight stations on four highways in Massachusetts in relation to concentrations of total-recoverable copper estimated on the basis of the concentration of total-recoverable copper associated with three particle-size ranges in sediment collected from composite samples of highway runoff and the concentration and particle-size distribution of suspended sediment in the respective samples of highway runoff, and (B) distribution of absolute error between estimated concentrations of total-recoverable copper and measured concentrations of total-recoverable copper in samples of highway runoff, Massachusetts, 2005–07.

estimated for each principal highway (fig. 27) on the basis of the EMCs for the three respective particle-size classes of suspended sediment in the composite samples (table 16) and the concentration of Cu for the respective particle-size classes in samples of sieved suspended sediment for each highway (table 18 in the back of the report). The absolute difference between measured concentrations of Cu and estimated concentrations of Cu for about 95 percent of the samples were within 87 percent of the measured total-recoverable Cu values (fig. 27). In general, estimated concentrations of Cu less than about 90 µg/L tended to be underestimated, particularly for highways other than Route 119. This bias is predictable because the whole-water concentrations of Cu estimated from the concentrations of Cu in samples of sieved suspended sediment do not account for the dissolved fraction of Cu in the whole-water samples. In contrast, the difference between the estimated concentration of Cu and the measured concentration of Cu in composite samples decreases as the concentration of suspended sediment increases. This indicates that most of the Cu is partitioned to the solid phase in composite samples with high concentrations of suspended sediment. Similar results were found for P and most of the total-recoverable metals, except for Cr (table 36). These data also indicate that the vast majority of sediment-associated concentrations of P and metals are associated with sediment particles less than 0.063 mm in diameter. Such information is important for choosing appropriate BMPs.

Reasonable planning-level estimates for many constituents can be derived from known concentrations of specific constituents affiliated with sediments and from the average gradated concentrations of suspended sediment in the composite samples collected in this study. For many applications, the average gradated concentrations of suspended sediment measured in composite samples of highway runoff in this study can be used in the absence of site-specific concentration data for suspended sediment because most results of statistical tests between populations of concentrations of suspended sediment among the highways and results for median concentrations of suspended sediment with AADT volume were not significantly different (p value > 0.05). If the concentrations of sediment-affiliated constituents presented in this study (tables 18 and 21) are used to estimate planning-level EMCs or loads of constituents, the appropriate step is to select data with regard to the AADT volume of the principal highways and degree of urbanization. Ideally, site-specific samples of suspended sediment would be collected and analyzed for the constituents of interest. In theory, gradated samples of road dust, street sweepings, catch-basin-sump sediments, and highway sediments from other structural features could be practical substitutes for highway suspended sediment, although such testing was outside the scope of this study. Use of this method may have broad application and provide useful information for stormwater-monitoring applications.

Highway-Runoff Database and Runoff Model Overview

The data from this study were entered into the HRDB (appendix A) that was developed by the USGS, in cooperation with the Federal Highway Administration (FHWA) (Granato and Cazenias, 2009). The HRDB was designed to serve as a data warehouse for current and future highway-runoff data sets. The HRDB application also was developed to serve as a data preprocessor for the SELDM (Granato, 2007). SELDM is a water-quality model designed to facilitate the estimation of runoff flows, and constituent concentrations and loads in highway runoff and in receiving waters at unmonitored sites, using site characteristics as a basis for the estimates. Runoff coefficients and EMC statistics are used with SELDM to generate random populations of runoff volumes, and constituent concentrations and loads, from regional precipitation statistics and site characteristics by use of Monte Carlo simulation methods. This information can be used to estimate runoff quantity and quality based on site characteristics, and to predict potential effects of highway runoff on receiving waters. Proper application of such a model, however, requires technically sound statistical estimates of the quality and quantity of runoff and receiving waters upstream from the highway outfall. Such statistical estimates require technically sound and well-documented data and statistically valid estimation methods appropriate for the data. As SELDM was developed, it was realized that use of the model, as well as other analyses and applications of highway-runoff data, would be greatly facilitated by a database for complete and comprehensive storage, retrieval, and analysis of these data in a consistent format. Thus, the HRDB warehouse was created to document data and information from available highway-runoff monitoring studies. The HRDB application, which is the graphical user interface and associated computer code, can be used to facilitate estimation of statistical properties of runoff coefficients, runoff-quality statistics, and relations between water-quality variables in highway runoff from the available data.

Entering data into version 1.0.0a of the HRDB database is an important step in meeting the State and national data needs. The need for available, consistent, and technically sound runoff-monitoring data was highlighted by the findings of the FHWA National Highway Runoff Data and Methodology Synthesis (NDAMS) (Granato and others, 1998; Granato, 2009). Results of the NDAMS study indicate that knowledge of the details of highway-runoff studies is not persistent or pervasive and that detailed data and documentation for studies more than 5 years old often are unobtainable because of changes in personnel and computer systems (Granato, 2009). Similarly, a recent study by the National Cooperative Highway Research Program (NCHRP) concluded that a national highway-runoff database, available in the public domain, was needed to document the results of monitoring efforts to characterize the quality of runoff from operating highways (Venner and others, 2004). Data from the current study, an earlier

Table 36. Statistics for concentrations of selected constituents estimated on the basis of the concentration of suspended sediment for three particle-size ranges in 105 samples of highway runoff and for concentrations of the constituents measured in samples of suspended sediment for equivalent particle sizes collected from the principal highways in Massachusetts, and the differences between the estimated concentrations and the measured concentrations in composite samples of highway runoff.

[<, less than the value shown; >, greater than the value shown; mm, millimeters in diameter]

Constituent	Statistic	Percent associated with particles of diameter < 0.063 mm	Percent associated with particles of diameter between 0.063 and 0.250 mm	Percent associated with particles of diameter > 0.250 mm	Difference between estimated constituent concentrations and measured concentrations in composite samples of highway runoff (percent)
Phosphorus	25th percentile	77.6	1.3	1.8	-66
	Median	89.3	4.4	5.4	-43
	75th percentile	94.7	10.0	9.3	-2
	Average	83.7	7.0	9.3	-28
Chromium	25th percentile	20.0	5.0	10.3	-51
	Median	52.6	10.5	22.3	-2
	75th percentile	82.9	24.9	48.2	104
	Average	50.8	18.5	30.7	104
Copper	25th percentile	78.4	1.0	1.6	-76
	Median	91.1	4.0	4.0	-57
	75th percentile	95.8	10.6	9.1	-20
	Average	84.8	7.3	7.9	-45
Iron	25th percentile	65.8	3.1	3.9	-30
	Median	81.2	6.1	11.2	-15
	75th percentile	91.1	12.9	20.5	4
	Average	75.0	9.0	15.9	-8
Lead	25th percentile	82.5	0.8	1.2	-44
	Median	92.4	2.5	3.4	-21
	75th percentile	96.6	7.7	6.6	-6
	Average	87.6	5.7	6.8	-20
Manganese	25th percentile	68.0	2.4	3.0	-60
	Median	83.8	6.6	8.6	-32
	75th percentile	92.0	12.0	18.0	3
	Average	77.6	8.8	13.6	-23
Nickel	25th percentile	63.6	2.9	3.6	-77
	Median	80.6	6.3	10.5	-58
	75th percentile	90.7	13.2	21.0	-41
	Average	75.3	9.3	15.4	-53
Zinc	25th percentile	86.6	1.0	0.9	-81
	Median	94.3	2.8	2.1	-69
	75th percentile	97.5	6.7	5.4	-46
	Average	89.5	5.4	5.1	-60

Massachusetts highway-runoff study (Smith, 2002), and other highway-runoff studies (for example, Hardee and others, 1978; Harned, 1988; Waschbusch, 2003) are available from the USGS National Water Information System Web (NWIS Web). The NWIS Web format, however, does not facilitate use of the data with the SELDM model, and the NWIS Web database does not include data collected by organizations other than the USGS. As such, Version 1.0.0a of the HRDB database will be archived with this report at the USGS Publications Warehouse (available on the web at: <http://pubs.usgs.gov>) to document currently available highway-runoff data in a format that facilitates use of the data with SELDM. A copy of the HRDB documentation, the data dictionary, and the database design plate (Granato and Cazenias, 2009) are on the CD-ROM accompanying this report to facilitate use of the HRDB.

The summary in figure 28 provides an overview of the complete HRDB version 1.0.0a data set that is currently available for analysis of highway-runoff quality. Currently, the database includes data from 9 highway-runoff data sets with 117 stations, 4,186 storms, and 54,383 individual stormwater-quality measurements. Data from the 1990 FHWA runoff-quality model “working database,” which represents a compilation of previous studies (Driscoll and others, 1990a; b), are included to supplement and to provide a basis for comparison with newer data sets. The California data set (CA 2003) currently is one of the largest highway-runoff data sets collected, processed, analyzed, and recorded in a robust and consistent data-quality system (California Department of Transportation, Office of Environmental Engineering, 2000, 2002, 2003a, 2003b, 2003c, 2003d, 2004). Highway-runoff data from Massachusetts represent results from this investigation (MA 2009) and the BMP characterization study (MA 2002). The Michigan Department of Transportation data (MI 1998) are results from a highway stormwater-runoff characterization study (CH2M-Hill, Inc., 1998). The Ohio data (OH 1997) are results from a small highway stormwater-runoff characterization study in Cincinnati, Ohio (Sansalone and Buchberger, 1997; Sansalone and others, 1997). The Texas data set represents results from a characterization study (Barrett and others, 1995, 1996) and a BMP study (Walsh and others, 1997). The Washington State data sets include highway runoff characterization data for NPDES permits (Tetra Tech, Inc., 2002, 2003, 2004; Washington State Department of Transportation, Environmental Services Office, 2001, 2002, 2003, 2004) and BMP monitoring data (Taylor Associates, Inc., 2002a, 2002b). The Wisconsin study (Waschbusch, 2003) documents highway-runoff quality with and without street sweeping. The current data set (MA 2009) represents about 11 percent of the sites, 36 percent of the storm events, and about 27 percent of the EMC values in version 1.0.0a of the HRDB (fig 28). Combined, the two Massachusetts studies (MA 2002 and MA 2009) represent about 14 percent of the sites, 43 percent of the storm events, and 29 percent of the EMC values in the database. The storm events in the highway-runoff database span a period of more than three decades from 1975 to 2007 (fig. 29). The two Mas-

sachusetts studies (MA 2002 and MA 2009) represent current conditions in Massachusetts.

Summary and Conclusions

The USGS, in cooperation with FHWA and the Massachusetts DOT, began a study in September 2004 to characterize the quality of highway runoff for a wide range of constituents for selected highways in Massachusetts with AADT volumes ranging from about 3,000 to more than 190,000 vehicles per day. Highway-monitoring stations were installed at 12 locations on 8 highways throughout the State of Massachusetts. The highway-monitoring stations were selected on the basis of published AADT volumes; proximity to each other; similarities in surficial geology, soils, vegetation, and land use as a function of USEPA level III ecoregions; highway and drainage construction; site accessibility and safety; and suitability for hydrologic and meteorologic monitoring and collection of stormwater samples. The 12 stations were subdivided into four primary, four secondary, and four test stations. Paired primary and secondary stations were located within a few miles of each other on a limited-access section of the same highway to ensure comparable levels of traffic volume and density. Although both the design and operation of the primary and secondary monitoring stations were similar, the monitoring period and number of samples of highway runoff collected at the primary station were greater than at the secondary stations. Most of the stormwater samples were collected at the primary and secondary stations, which were located on four principal highways in the eastern region of the State. Samples of stormwater collected at the test stations were used to assess the transferability of the data collected from the principal highways to other highways with characteristics that differ in construction, land use, and geography from the principal highways.

Methods

Automatic-monitoring techniques were used extensively to collect continuous measurements of water level, water temperature, specific conductance, air temperature, and rainfall, and to collect composite samples of highway runoff. Runoff coefficients were computed on the basis of the drainage areas, and flow and rainfall records for each storm for which data were available. Event-mean specific conductance values were calculated for each highway site on the basis of calculated values of discharge greater than 0.009 ft³/s and corresponding measurements of specific conductance to supplement and expand the number of event-mean values of specific conductance. Additionally, EMCs for dissolved Ca, Cl, Na, and SO₄ were estimated on the basis of the event-mean specific conductance values with the adjusted superpositioning technique for most monitoring stations.

A Count of sites, storm events, and event-mean concentration values

Highway-Runoff Data Set	Count of		
	Sites	Storms	EMC
Federal:			
FHWA 1990	24	937	8,428
State:			
CA 2003	52	981	26,104
MA 2002	4	285	1,236
MA 2009	13	1,523	14,563
MI 1998	3	9	198
OH 1997	1	13	169
TX 1997	6	187	1,925
WA 2005	12	155	1,486
WI 2000	2	96	725
Sum	117	4,186	54,384

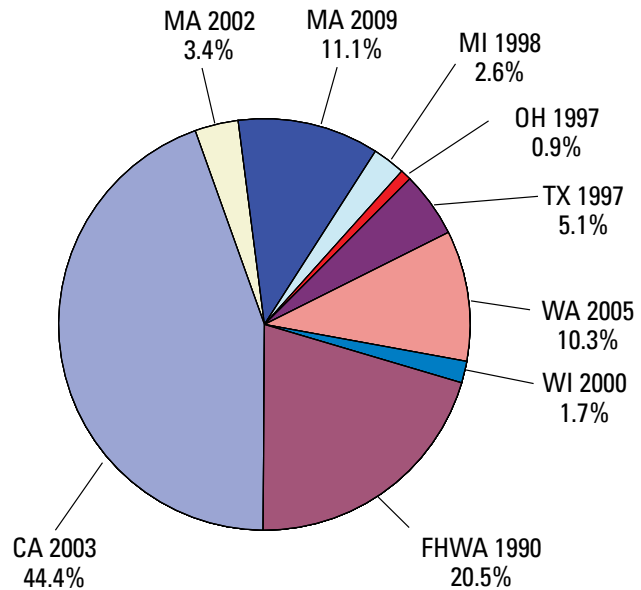
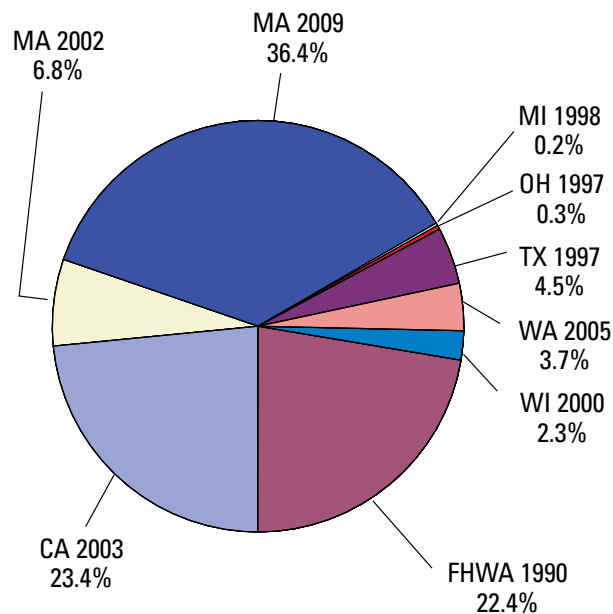
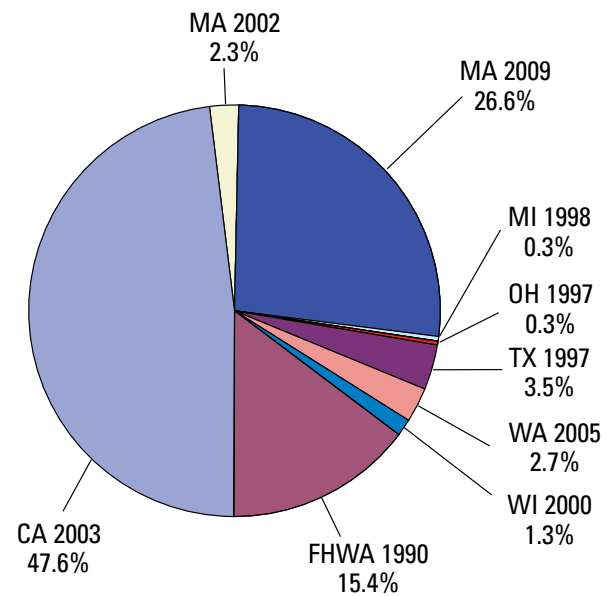
B Percentage of sites in each data set**C** Percentage of storm events in each data set**D** Percentage of event-mean concentration values in each data set

Figure 28. Summary of the highway-runoff data including (A) a count of sites, storms, and event-mean concentration values in the database, and the percentage of (B) sites, (C) storm events, and (D) event-mean concentration values in each highway-runoff data set. (FHWA, Federal Highway Administration)

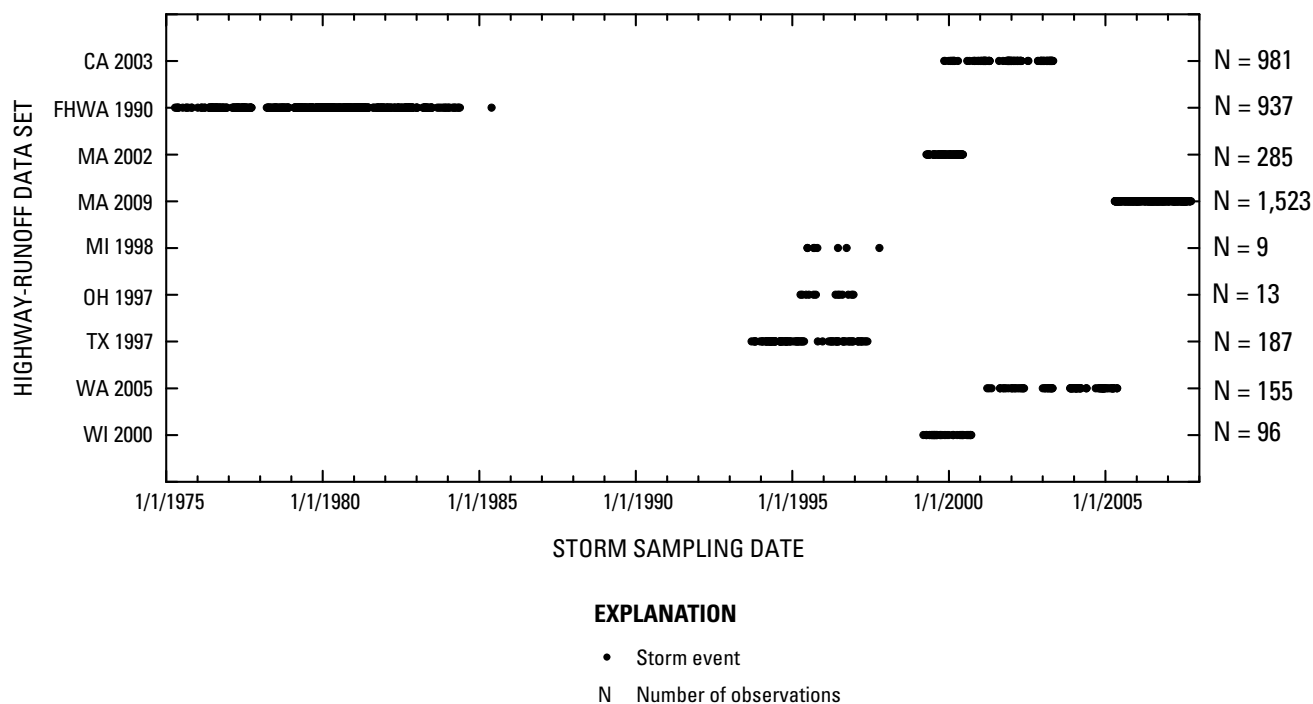


Figure 29. Temporal distribution of storm sampling dates for each data set in the highway-runoff database.

Approximately 140 flow-weighted samples were collected automatically during rain and mixed precipitation storms at the 12 monitoring stations from September 2005 through September 2007 and analyzed for concentrations of selected dissolved major ions, total N and P, selected total-recoverable metals, suspended sediment, and SVOCs. Samples of highway runoff were collected year-round during storms with various antecedent dry periods throughout the 2-year sampling period. The distribution of the duration of dry antecedent periods, as well as the distribution of event-mean specific conductance values, for storms during which samples were collected at each of the principal highways was similar to the distribution of both of these conditions during the monitoring period. Precipitation totals ranged from about 0.1 to 5.1 in. for storms that were sampled at the principal highways and most precipitation totals for sampled storms were within the interquartile range of precipitation totals greater than 0.10 in. recorded from 1967 through 2007 by the National Climatic Data Center near Worcester, Massachusetts.

In addition to the collection of samples of highway runoff, samples of other media were collected to supplement the data set and support data analysis. These media include sieved highway-runoff sediment from the principal highways, and background soils, berm materials, maintenance sands, deicing compounds, and vegetation matter collected near or on the highway. Most of these samples were analyzed for 32 elements. Samples of sieved highway-runoff sediment and vegetation matter also were analyzed for selected PAHs and TOC.

Data Quality

The accuracy and precision of the data collected in this study were ensured by making quality-control measurements at each of the monitoring stations, operating redundant sensors, conducting quality-assurance experiments, and collecting various types of quality-control samples. Quality-control samples of artificial and blank water were collected to identify potential bias in sampling and processing methods and contamination resulting from the sampling equipment and from the sample collection, processing, and analysis. Other quality-control samples were collected in the field and laboratory to estimate analyte degradation, analytical-method recovery and performance, and presence of interfering agents.

Comparative measurements made during site visits at each of the highway-monitoring stations indicate that the continuous measurements of water level, water temperature, and specific conductance recorded by the monitoring stations were generally accurate and precise. Despite the sometimes large variability in runoff coefficients, the agreement between values of event-mean specific conductance estimated from continuous records of flow and specific conductance, and the measured specific conductance of flow-weighted water samples indicate that flows calculated from a stage-discharge relation for each monitoring station were reasonable. This also indicates that the frequency of sample collection within storms was sufficient to accurately characterize the variability of the quality of runoff during the storms. Experimental results indicate that concentrations of suspended sediment with diameters ranging from 0.250 mm to about 6.0 mm in water samples

collected by an automatic sampler in conjunction with the static-mixer assembly reasonably represent the distribution of particle sizes in an artificial flow stream over a range of flows. However, a comparison of measurements of suspended sediment greater than 0.250 mm in diameter collected at the end of the highway discharge pipe and in flow-weighted composite samples of runoff from one of the primary monitoring stations indicates that there is a potential positive bias associated with concentrations of coarse particles in samples of water collected using automatic-sampling methods in this study. The bias observed for the environmental samples could, in part, result from the automatic sampler disproportionately collecting natural organic materials, which are less dense than mineral sediments and relatively abundant. Considering that the concentration of P in natural organic matter is high compared to the concentration of metals, the concentrations for P also may be elevated in samples of highway runoff, particularly during the growing season.

Results of analyses of sample volumes reduced through splitting indicate that concentrations of suspended-sediment particles less than 0.063 mm in diameter in the subsamples of the sediment/water mixture were both accurate and precise. Analysis of field-blank data indicates that the cleaning and preparation of sampling equipment, sample processing, and respective analytical methods were not a source of contamination bias for most constituents. With the exception of naphthalene, contamination bias appeared to be random for all constituents. Low-level measurements for naphthalene in field blanks are believed to be from contaminated source water.

Analysis of replicate samples for selected PAH and phthalate compounds and spike recoveries in fortified environmental samples analyzed for PAH, phthalate, and other anthropogenic organic and natural organic compounds indicate that the measured concentrations for most of these constituents are reasonably precise and that field and laboratory processing, analytical method performance, and sample matrix effects for the constituents are not a large source of bias for most constituents. The average spike recoveries for both PAH and phthalate compounds were similar to the average laboratory-preparation spike recoveries for the respective compounds for the study period, except for benzo[ghi]perylene, indeno[1,2,3-cd]pyrene, bis(2-ethylhexyl) phthalate, and di-n-butyl phthalate, which were notably lower. Because the variability of field-spike recoveries for these compounds was similar to the variability of the respective laboratory preparation-spike recoveries and because the replicate field-spike recoveries for these compounds were relatively precise, such differences are likely attributable to degradation of the compounds prior to laboratory processing or matrix effects that mask the respective compounds. As a result, these data indicate that concentrations of these four compounds are likely underestimated for samples of highway runoff collected in this study.

Standard-reference samples were submitted to laboratories to identify potential contamination bias and to assess analytical method performance. Samples were analyzed

for both total and total-recoverable concentrations, in part, because reference materials are certified only for total concentrations. Concentrations of P and selected metals also were determined in reference-material water mixtures. Median total concentrations in blind samples for about 40 percent of the measured elements, for which there were certified concentration values for standard reference soil, were within the certified concentration ranges. The median concentrations for blind samples of the measured elements, for which there were noncertified values, were generally less than, but within 20 percent of, the noncertified values. The median total-recoverable concentrations of elements in NIST reference material samples were within the reported range of recovery, except those for As, La, and P. Total-recoverable concentrations of selected elements, except Cu and Pb, measured in artificial samples of water were lower than the respective measurements made by the USEPA method 3050B in samples of solid media. Concentrations of total-recoverable Cr, Fe, Ni, P, and Zn in the artificial water samples were lower than the lower recovery limit of the reference material. These quality-control data were used as a basis to adjust the concentrations of constituents in solid media when comparisons were made with whole-water concentration data.

Replicate samples of background soils, highway-berm soils, suspended sediment, and other miscellaneous samples were collected to determine the precision of the data. The average absolute RPD was less than 10 percent for all elements, except for As, Na, Pb, Sc, and Ti. For these elements, the average absolute RPD between replicate pairs ranged from about 11 to 16 percent. The variability observed in the concentrations of elements in replicate pairs could be, in part, a result of differences in the distribution of particle sizes in the samples. The median RPD between the amount of material in particle-size classes less than 0.063 mm in diameter, between 0.063 mm and 0.250 mm in diameter, and greater than 0.250 mm in diameter for 16 replicate pairs was 7, 8, and 4 percent, respectively.

Quality of Highway Runoff

The data presented in this report represents the quality of stormwater runoff from highways with AADT volumes ranging from about 3,000 to more than 190,000 vehicles per day at 12 locations on 8 highways throughout the State of Massachusetts. These data were analyzed to determine the appropriate aggregation for individual data sets to estimate planning-level highway contributions for the constituents presented in this study for other highways in Massachusetts.

Evaluation of Highway Runoff

Highway-runoff data, including populations of concentrations of selected dissolved major ions, total nutrients, total-recoverable metals, PAHs, phthalates, and suspended sediments (including particle size) were evaluated using the

nonparametric Mann-Whitney test. Mann-Whitney tests were used to determine significant differences between sample populations collected from the same highways, but at different locations, and to determine significant differences between sample populations collected from different highways, but with similar AADT volumes. Similar statistical methods also were used to test for differences between the populations of sample concentrations among the four principal highways that differed mainly by traffic volume. Sample concentrations that were not detected or were estimated to be below the LTMDL were set equal to a value less than the LTMDL for each constituent evaluated. Analyses for many PAH and phthalate compounds were not performed because these compounds were consistently undetected in samples or because all of the concentrations were estimated to be below the LTMDL.

With a few exceptions, test results between paired populations (that is, data from the primary and secondary stations on each principal highway) show that concentration data generally are not statistically different at a 95-percent confidence interval, indicating similarities between populations. Results of tests between populations of concentrations of suspended sediment and (or) concentrations of suspended sediment less than 0.063 mm in diameter show that populations of concentrations are significantly different for the stations on Route 119 and Interstate 495. These differences are believed to be the result of runoff patterns and berm conditions associated with the secondary monitoring station that differed from the primary monitoring station for each highway. Also, results of tests between populations of concentrations of total-recoverable Zn for the stations on Route 2 show that populations of concentrations are significantly different (p value less than 0.05). Unfortunately, this difference is not fully explainable with available data.

Concentration data collected from the test highways were compared to concentration data collected from the principal highways of similar AADT volumes to determine whether the data were transferable from highway to highway on the basis of AADT volume. Where sufficient concentration data were available for testing, no significant differences were found between populations of concentrations of selected dissolved major ions, total nutrients, total-recoverable metals, PAHs, phthalates, and suspended sediments (including particle size) in composite samples of highway runoff collected from the stations on Route 119 and Route 8 (highways with the lowest AADT volumes), and the only significant difference observed in test results between populations of constituent concentrations for the stations on Route 2 and Interstate 190 (highways with moderate AADT volumes) was for total-recoverable Zn. As previously discussed, the significant difference between the populations of total-recoverable Zn concentrations may be attributable to the high concentrations (median value of 308 $\mu\text{g/L}$) determined for the primary monitoring station on Route 2. In contrast, results of many tests between populations of constituent concentrations collected from the sites on Route 2 and Interstate 195 (highways with moderate AADT volumes) were significant at a 95-percent confidence interval.

Test results between populations of dissolved concentrations of Ca and K; concentrations of total P; and total-recoverable concentrations of Cd, Cr, Cu, Mn, and Zn from Route 2 and Interstate 195 were significant at a 95-percent confidence interval. Test results between populations of concentrations of total N; dissolved Mg, Na, Cl, and SO_4 ; total-recoverable Cu, Fe, Pb, and Ni; suspended sediment; and PAH and phthalate compounds, where sufficient data were available, were not significant at a 95-percent confidence interval. Results of many tests between populations of constituent concentrations in composite samples of highway runoff collected from stations on Interstate 95 and Interstate 93 (highways with very high AADT volumes) also were significant. Concentrations of most total-recoverable metals in samples of highway runoff collected from Interstate 93 were considerably higher than the respective concentrations measured in samples from Interstate 95. Results for Mann-Whitney tests between populations of concentrations of total-recoverable metals, except for Cd and Ni, and suspended sediment collected from the stations on Interstate 95 and on Interstate 93 were significant at the 95-percent confidence interval. No significant differences were found between populations of concentrations of total nutrients, major ions, and PAH and phthalate compounds.

The significant differences between many of the populations of metal concentrations for Route 2 and Interstate 195, and for Interstate 95 and Interstate 93, in part, could be due to the effect of local soil deposition on the highway surfaces. The concentrations of many metals in samples of soil collected near Interstate 195 were substantially lower than the concentrations of those metals in samples of soil collected near Route 2. Likewise, the concentrations of many metals in samples of soil collected near Interstate 93 were substantially higher than the concentrations of the same constituents collected in samples of soil near Interstate 95. The differences in the test results are, in part, a function of the local soil chemistry near each of the highways, given the dissimilar enrichment of metal concentrations measured in the samples of soil. However, though this may help to explain the higher concentrations of Cu, Pb, and Zn in samples of highway runoff collected from Interstate 93, concentrations of other metals in soil samples collected near Interstate 93 were similar to the concentrations in soil samples collected near the other highways. The nearly order-of-magnitude higher concentration of suspended sediment measured in samples of highway runoff collected at Interstate 93 is likely the main factor in the difference between the populations of concentration data for many of the total-recoverable metals for the two highways. High rates of dry deposition, which are commonly reported for urbanized areas containing large impervious areas, also could explain the significant difference between concentrations of suspended sediment measured for Interstate 93. These data indicate that the quantity, as well as the quality, of sediment in highway runoff can be affected by the proximity of the site to highly urbanized areas containing large amounts of impervious area.

Populations of concentration data collected for each principal highway were compared to the populations of

concentration data collected for each of the other principal highways to determine whether the populations are significantly different from highway to highway. Most of the Mann-Whitney test results indicate that the data collected for the principal highway on Route 119, which had the lowest AADT volume, are significantly different at a 95-percent confidence interval from data collected for the other three principal highways. Results for paired tests between populations of concentrations of dissolved Cl, Na, and Mg; benzyl n-butyl phthalate; and di-n-butyl phthalate for Route 119 and each of the other principal highways are not significant at the respective confidence interval. Results for paired tests for concentrations of suspended sediment were not significant for any of the principal highways other than Route 119. Only a handful of test results indicate a significant difference between populations of constituent concentrations among the three larger highways. Concentrations of dissolved Ca were significantly different for all paired tests of data from Interstate 95. The highway-monitoring stations on Interstate 95 were located in a section of highway designated as a low-salt area because of its proximity to a major drinking-water-source area; thus, the significant difference between concentrations of Ca for Interstate 95 and the other highways is likely a function of the more widespread use of liquid calcium chloride for winter highway maintenance on Interstate 95.

Relation of Constituents to Annual Average Daily Traffic Volume

Although the populations of concentrations of most constituents were not significantly different among the three larger highways, the median concentrations and upper inter-quartile ranges for many total-recoverable metals collected from the 12 monitoring stations increased with increasing AADT volumes, indicating a positive correlation between the two variables. The frequency of detection for various organic compounds also increased with traffic volume for the four principal highways. Results for Kendal's Tau correlation coefficient and Spearman rank correlation coefficient tests for all highways indicate that correlations between the median concentrations of total N, total P, all total-recoverable metals, benzo[a]anthracene, benzo[b]fluoranthene, fluoranthene, and pyrene and AADT volumes are significantly different at a 95-percent confidence interval. Spearman rank correlation coefficient test results for benzo[a]anthracene and benzo[b]fluoranthene are not significant at a 95-percent confidence interval; however, correlations between the median concentrations of these constituents and the AADT volumes are significantly different at slightly lower confidence intervals. Test results for concentrations of dissolved Cl, Na, Ca, Mg, K, and SO_4 ; benzo[a]pyrene; Bis(2-ethylhexyl) phthalate; chrysene; di-n-octyl phthalate; and suspended sediment are not significant at confidence intervals greater than 89 percent for either test; therefore, AADT volumes may be a poor pre-

dictor for concentrations of these constituents in the absence of additional data.

Highway Winter Maintenance Materials and Data Seasonality

Concentrations of Ca, Cl, Na, and SO_4 , which are the major constituents of road salt, were estimated using the adjusted superposition technique over the full range of flow-weighted measurements of specific conductance for all available data, including snowmelt events, collected at 11 highway-monitoring stations. These 1,381 estimated concentrations provide a nearly order of magnitude increase in data density over water-sample data collected during this study. The estimated data from this study indicate that less than about 2 percent of the event-mean concentrations of Cl exceed 10,000 mg/L, and about 20 percent of the event-mean concentrations exceed 230 mg/L (the USEPA freshwater aquatic life criteria).

Concentrations of nearly all constituents measured in samples of highway runoff in this study increased substantially in composite samples collected during the winter months compared to the concentrations in non-winter composite samples. Average concentrations of total P, total-recoverable metals, and suspended sediment in samples of highway runoff collected from the principal highways during the winter were about 3 to 11 times greater than the average concentrations in samples of non-winter runoff. Changes in ambient temperature, differences in driving methods, snow removal operations, and the presence of snow embankments along the highways potentially affect winter concentrations of metals and organic compounds measured in this study. Results of the single-tail Mann-Whitney test indicate that the concentrations of nearly all constituents measured in composite samples collected during the winter were significantly higher at a 99-percent confidence interval than the concentrations of constituents measured in composite samples collected during the non-winter months. The use of deicing compounds, which contain trace amounts of N and total-recoverable metals, does not fully explain the significant differences observed between winter and non-winter concentrations of each of the constituents. Ratios for nitrate and total-recoverable metals associated with road salt and calcium chloride to Cl are estimated to account for only a small fraction of the increase in overall concentrations from non-winter levels. However, many of the same constituents were measured in samples of winter maintenance sands, and although the concentrations of these constituents in the sand were small, the amount of sand applied to the highways during the winter increased the concentrations of suspended sediment by as much as an order of magnitude. The contribution of P and total-recoverable metals from the application of maintenance sand was estimated on the basis of the average increase in the concentration of suspended sediment during winter storms and on the basis of the average concentrations of P and total-recoverable metals in samples of

highway-maintenance sand. Data on concentrations of several elements estimated on the basis of stormwater EMCs in samples collected on Interstate 495 and highway-maintenance sand indicate that highway-maintenance sand accounts for about 94, 7, 38, 53, 15, 9, and 2 percent of the increase in the winter concentrations of P, Cu, Fe, Mn, Ni, Pb, and Zn, respectively. The increase in the difference between winter and non-winter concentrations of these constituents is likely greater for smaller highways, such as Route 119, because such highways have similar levels of winter maintenance and lower non-winter stormwater concentrations of the same constituents. Other winter conditions have the potential to increase concentrations of many constituents in runoff. Low ambient temperatures can affect volatilization rates for SVOCs and increase engine emission rates. Poor winter driving conditions affect vehicle operations and can increase the rate of wear for vehicle components as well as the highway surface, and snow banks can entrain large amounts of highway-related particles near the shoulder that subsequently can wash onto the highway surface.

Comparison of Historical Data and Concurrent Data Sets

Comparisons of data collected during this study with data in other published data sets can provide useful information for identifying compositional differences and trends in concentrations of highway-related constituents in highway runoff. In this study, the median concentrations of dissolved Cl, total N, and total-recoverable P, Cd, Cr, Cu, Fe, Pb, and Zn in samples collected from highway sites with AADT volumes of 30,000 to 85,000 vehicles (Interstate 190, Interstate 195, Interstate 495, and Route 2) were compared to median concentrations in other published data sets containing data collected from highways of similar AADT volume. With the exception of dissolved Cl, the median concentrations of nutrients and total-recoverable metals in this study were much lower than the respective median concentrations in the historical data collected by the FHWA from 1976 to 1984. These data indicate that concentrations of total P and many total-recoverable metals in highway runoff, particularly Cd and Pb, are substantially lower than the historical concentrations from the 1970s and 1980s, despite the fact that total vehicle miles have increased. Favorable comparisons with more recent studies indicate that some concentration data collected in other states could be used to supplement the data collected in this study.

Sources of Highway-Runoff Constituents

Identification of individual sources of specific constituents is difficult because many highway-related constituents coexist in a wide variety of both natural and anthropogenic materials deposited on highways. The proportions of most highway constituents attributable to likely sources were estimated from ratios of certain PAH compounds and from

ratios of the dominant particulate-associated PAHs to selected elements. For example, the median ratios for all concentrations of An/(An+Phe) in composites of runoff from each highway in this study are synonymous with the ratios reported for gasoline-engine emissions. In contrast, the median ratios for winter concentrations of An/(An+Phe) in composites of highway runoff during, or shortly after, winter plowing operations of the principal highways decreased, likely indicating that the dominant source of the PAHs shifted from gasoline-engine emissions to asphalt wear. The median ratios for concentrations of Fl/(Fl+Py) and Ba/(Ba+Chr) in composites of highway runoff in this study also were similar to ratios for emissions from gasoline and diesel engines.

The median concentrations of total P and most trace elements measured in composite samples of highway runoff from each principal highway were compared to estimated concentrations expected from automobile emissions. Concentrations of the above constituents in exhaust were estimated on the basis of the average ratio of the reported emission rates for each constituent to the emission rates for chrysene and indeno[1,2,3-*cd*]pyrene. Assuming the dispersion of both trace metals and PAHs associated with exhaust particles is similar, exhaust emissions account for only a small fraction of metals measured in samples of highway runoff. Ratios of median EMCs of P and total-recoverable Cu, and Fe to average metal concentrations associated with concentrations of chrysene and indeno[1,2,3-*cd*]pyrene indicate that less than 3 percent of the constituents are accounted for by exhaust emissions from gasoline engines. Similar ratios for median concentrations for total-recoverable Cr, Mn, Ni, Pb, and Zn indicate that about 4 to 13 percent of the respective constituents are accounted for by exhaust emissions from gasoline engines.

Atmospheric deposition also can affect the quality of highway runoff. Concentrations of major ions in precipitation do not constitute a large fraction of the major ions in samples of highway runoff in Massachusetts, except for Mg and SO₄. Concentrations of Mg and SO₄ in precipitation account for about 10 and 21 percent, respectively, of the mean concentrations in non-winter highway runoff for Interstate 95, and concentrations of NH₄ and NO₃ in precipitation account for about 55 percent of the mean concentrations of total N in all samples collected on Interstate 95 in this study. Concentrations of total N in precipitation potentially constitute a greater percentage of the concentrations in highway runoff from the other principal highways because the concentrations of total N in samples of highway runoff from those sites were lower.

Local soils and highway-berm soil can contribute much of the suspended sediment entrained in highway runoff. As discussed earlier, adjacent soils deposited on the surface of the highway can affect the composition of, and concentrations of many elements in, highway runoff. Contributions of many of the total-recoverable metals in background soils were estimated on the basis of the median concentration of suspended sediment in composite samples of highway runoff from the principal highways along with median concentrations of the same total-recoverable metals in samples of local

soil collected near the primary highway-monitoring stations. These estimates indicate that background soils account for on average about 37 percent of the median P concentration, 100 percent of the median Cr concentration, 4 percent of the median Cu concentration, 53 percent of the median Fe concentration, 54 percent of the median Mn concentration, 15 percent of the median Ni concentration, 44 percent of the median Pb concentration, and 2 percent of the median Zn concentration in samples of runoff from the principal highways. The contributions of the elements to concentrations in whole water samples are likely conservative, excluding Cr which is overestimated, because the values were estimated without regard to the distribution of the particle sizes for background soils and total concentrations of suspended sediment. The concentrations of many elements in berm materials composed of native soils, winter maintenance materials, and other anthropogenic particles also can affect the quality of highway runoff. Data from this study indicate that the distributions for concentrations of Cu, Fe, Mn, Ni, P, Pb, and Zn in highway-berm soils and for normalized concentrations of these constituents in suspended sediment often overlap. These data indicate that erosion or mechanical transport of highway-berm soils onto the paved surface could be a large source of P and several total-recoverable metals in samples of highway runoff.

The mass of Cu, Zn, and phthalate compounds measured in samples of highway runoff is only partially, if at all, accounted for by the application of deicing compounds, exhaust emissions, soils, and berm materials. Tire and brake wear appears to be the dominant source of these constituents on the basis of the composition and wear rates for these items reported elsewhere in the literature.

For 15 samples of highway runoff collected from the principal highways and from Interstate 93, an additional 62 organic compounds that include nonionic surfactants, caffeine, plant sterols, flame retardants, trace compounds associated with fecal bacteria, wood preservatives, gasoline and diesel fuels, antioxidants, and personal care products were included in the sample analysis. For these 15 samples, 45 of the 62 compounds were detected at least once, and 23 compounds were detected at concentrations greater than the laboratory LTMDL. Anthraquinone, bisphenol A, camphor, and cholesterol were the most frequently detected compounds. Although most compounds were detected less frequently in samples of highway runoff collected on Route 119 (the most rural highway with the lowest AADT volume) than in other samples, the frequency of detection generally was similar among highways. About one-third of the compounds that were detected are likely attributable to fuels, lubricants, antifreeze, windshield fluids, chemical treatments of the engine compartments, finish coats, panels, and other vehicle components. Other compounds detected in samples of highway runoff indicate the presence of plant materials, fecal bacteria, and potential leachates from highway litter.

Suspended Sediment as a Surrogate for Highway-Runoff Constituents

Suspended sediment can be a major transport mechanism for many constituents in highway runoff. Data collected in this study indicate that highway suspended sediment contains relatively high concentrations of P, trace elements, PAHs, and phthalates. These analyses also indicate that, in many cases, the fine fraction of sediment less than 0.063 mm in diameter often is more enriched in these constituents than the coarser sediment fractions. Concentrations of suspended sediment for three particle-size ranges were examined as potential surrogates for concentrations of sediment-affiliated constituents measured in samples of highway runoff.

Planning-level estimates for concentrations of total P and total-recoverable metals were made directly from the constituent concentrations in samples of sieved suspended sediment and from the concentrations of the three particle-size grades of suspended sediment in samples of highway runoff. Comparisons of these estimated P and total-recoverable metal concentrations with concentrations in whole-water samples indicate that it is possible to estimate reasonable planning-level loads for many constituents discharged from highways. For many applications, the average concentration for gradated concentrations of suspended sediment measured in composite samples of highway runoff in this study may be used in the absence of site-specific data because tests between most populations of concentrations of suspended sediment among the highways in this study, and tests between median concentrations of suspended sediment with AADT volume were not significantly different. Use of this method could have broad application and may provide useful information for the selection of BMP and for stormwater-monitoring applications.

Highway-Runoff Database

Data from this study are stored in Version 1.0.0a of the HRDB database, which is presented in the appendix of this report. The HRDB warehouse was created to document data and information from available highway-runoff monitoring studies. Version 1.0.0a of the HRDB database also contains data from an earlier Massachusetts highway-runoff study, and other highway-runoff studies conducted across the Nation since 1978. The HRDB application, which is the graphical user interface and associated computer code, can be used to facilitate estimation of statistical properties of runoff coefficients, runoff-quality statistics, and relations between water-quality variables in highway runoff from the available data. Thus, the HRDB application can serve as a data preprocessor for the Stochastic Empirical Loading and Dilution Model, which is designed to facilitate the estimation of runoff flows, concentrations of constituents, and loads of constituents from highways and in receiving waters at unmonitored sites on the basis of site characteristics.

Data Application

In general, concentrations of many total-recoverable metals, PAHs, and phthalate compounds increase with increasing AADT volume and amount of urbanization or surrounding impervious area. Concentrations of all constituents measured in samples of highway runoff in this study increased significantly during the winter months. Increases in concentrations of total P and many total-recoverable metals in this study were specifically attributed to maintenance sands applied to the highways. Therefore, information on use and application rate for maintenance sands may be important to include in future studies of the quality of highway runoff. The geographic location of a given highway under study is important because the level of highway maintenance during the winter is different across Massachusetts because the climate away from the coast generally is cooler, and the highway grades tend to be steeper. Ancillary data, collected as part of this study, also indicate that soil chemistry can affect the base concentration of total P and many total-recoverable metals in samples of highway runoff. As a result, the quality of highway runoff can differ within the natural features of the State. Mobilization of these soils, either from vehicles that track materials onto the road surface or from erosion of adjacent highway shoulders, can cause large increases in constituent concentrations. The data presented in this report represent the typical quality of highway runoff discharged through catch basins for eight Massachusetts highways over a large range of AADT volumes. Concentrations in highway runoff for the constituents reported in this study may be different for other highways within the State that have different levels of winter maintenance activity, or additional BMPs within the drainage system, or that have site characteristics that were previously identified to affect runoff quality.

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Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour:minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Begin time (hr:mn)	End date (mm/dd/yyyy)	End time (hr:mn)	Total precipitation (inches)	Total storm volume (cubic feet)	Runoff coefficient (percent)
Route 119 -P	424209071545201	09/15/2005	0602	09/15/2005	1659	0.11	286	120
Route 119 -P	424209071545201	09/29/2005	1357	09/29/2005	1532	1.94	3,760	89
Route 119 -P	424209071545201	10/22/2005	2107	10/23/2005	0111	0.96	6,520	314
Route 119 -P	424209071545201	10/24/2005	2007	10/25/2005	1028	1.95	2,060	49
Route 119 -P	424209071545201	01/11/2006	2040	01/11/2006	2344	0.55	3,340	280
Route 119 -P	424209071545201	01/18/2006	0752	01/18/2006	1500	1.16	1,890	75
Route 119 -P	424209071545201	03/13/2006	2118	03/13/2006	2250	0.19	1,390	338
Route 119 -P	424209071545201	05/09/2006	1705	05/10/2006	0617	0.52	436	39
Route 119 -P	424209071545201	06/01/2006	2219	06/02/2006	0715	0.35	2,100	277
Route 119 -P	424209071545201	09/14/2006	1518	09/14/2006	2035	0.35	1,660	219
Route 119 -P	424209071545201	09/19/2006	1930	09/20/2006	0122	0.27	1,040	178
Route 119 -P	424209071545201	10/20/2006	0333	10/20/2006	1356	0.7	3,700	244
Route 119 -P	424209071545201	11/08/2006	0450	11/08/2006	2153	2.35	11,400	224
Route 119 -P	424209071545201	11/12/2006	1509	11/12/2006	1727	0.46	1,810	182
Route 119 -P	424209071545201	01/08/2007	0059	01/08/2007	1432	1.02	2,660	120
Route 119 -P	424209071545201	04/01/2007	2252	04/02/2007	0601	0.34	822	112
Route 119 -P	424209071545201	04/14/2007	1331	04/16/2007	0134	2.03	3,590	82
Route 119 -P	424209071545201	06/03/2007	1546	06/04/2007	2126	0.93	3,560	177
Route 119 -P	424209071545201	07/11/2007	2108	07/11/2007	2355	0.61	4,220	319
Route 119 -S	424155071543201	09/29/2005	1359	09/29/2005	1422	0.51	289	49
Route 119 -S	424155071543201	10/24/2005	2207	10/25/2005	0356	1.94	209	9
Route 119 -S	424155071543201	01/11/2006	2046	01/11/2006	2335	0.55	132	21
Route 119 -S	424155071543201	01/18/2006	1058	01/18/2006	1458	1.16	116	9
Route 119 -S	424155071543201	03/13/2006	2150	03/14/2006	0913	0.53	75	12
Route 119 -S	424155071543201	08/20/2006	0313	08/20/2006	0506	1.02	188	16
Route 119 -S	424155071543201	11/08/2006	1341	11/08/2006	2312	2.35	342	13
Route 119 -S	424155071543201	04/27/2007	0636	04/27/2007	0659	0.52	47	8
Route 119 -S	424155071543201	06/03/2007	1550	06/04/2007	1444	0.93	160	15
Route 119 -S	424155071543201	07/11/2007	2206	07/11/2007	2331	0.61	254	36
Route 119 -S	424155071543201	08/03/2007	1935	08/03/2007	1958	0.31	144	40
Route 8 -T	424019073062601	04/22/2006	1949	04/23/2006	1538	1.22	1,630	68
Route 8 -T	424019073062601	06/23/2006	2100	06/24/2006	0839	0.56	453	41
Route 8 -T	424019073062601	09/23/2006	0810	09/24/2006	1356	0.22	398	92
Route 8 -T	424019073062601	12/01/2006	1329	12/01/2006	1926	1.59	1,850	59
Route 8 -T	424019073062601	03/02/2007	1042	03/02/2007	1525	0.5	553	56

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Begin time (hrmn)	End date (mm/dd/yyyy)	End time (hrmn)	Total precipitation (inches)	Total storm volume (cubic feet)	Runoff coefficient (percent)
Interstate 190 -T	423016071431501	08/14/2005	1736	08/15/2005	0757	0.92	960	50
Interstate 190 -T	423016071431501	09/29/2005	1416	09/29/2005	1459	0.36	196	26
Interstate 190 -T	423016071431501	10/07/2005	2345	10/08/2005	1142	5.09	3,320	31
Interstate 190 -T	423016071431501	10/22/2005	1831	10/23/2005	0004	1.33	784	28
Interstate 190 -T	423016071431501	10/24/2005	2148	10/25/2005	0620	2.73	1,900	33
Interstate 190 -T	423016071431501	03/13/2006	1237	03/13/2006	2340	0.49	249	24
Route 2 -P	423027071291301	09/15/2005	1007	09/15/2005	1315	0.25	172	72
Route 2 -P	423027071291301	09/29/2005	1449	09/29/2005	1613	0.43	292	71
Route 2 -P	423027071291301	10/22/2005	1927	10/23/2005	0038	0.57	1,530	280
Route 2 -P	423027071291301	10/24/2005	2222	10/25/2005	0545	1.08	4,170	404
Route 2 -P	423027071291301	01/11/2006	2045	01/12/2006	0333	0.48	375	82
Route 2 -P	423027071291301	01/18/2006	0910	01/18/2006	1843	0.81	554	72
Route 2 -P	423027071291301	03/13/2006	2245	03/14/2006	0214	0.63	1,340	222
Route 2 -P	423027071291301	05/09/2006	1530	05/10/2006	1250	0.93	1,220	137
Route 2 -P	423027071291301	06/02/2006	2021	06/04/2006	0152	2.86	4,290	157
Route 2 -P	423027071291301	06/23/2006	1617	06/23/2006	1914	1.03	656	67
Route 2 -P	423027071291301	08/20/2006	0331	08/20/2006	0824	1.00	954	100
Route 2 -P	423027071291301	08/27/2006	1450	08/28/2006	0413	0.84	512	64
Route 2 -P	423027071291301	09/19/2006	2100	09/19/2006	2351	0.67	778	121
Route 2 -P	423027071291301	11/07/2006	2203	11/08/2006	1450	1.57	4,930	328
Route 2 -P	423027071291301	01/08/2007	0455	01/08/2007	1645	0.88	1,170	139
Route 2 -P	423027071291301	03/02/2007	0413	03/02/2007	0711	--	4,200	--
Route 2 -P	423027071291301	04/12/2007	1424	04/12/2007	1811	1.15	1,240	113
Route 2 -P	423027071291301	08/06/2007	1515	08/06/2007	1532	0.19	96	53
Route 2 -P	423027071291301	08/08/2007	0629	08/08/2007	0747	0.51	498	102
Route 2 -P	423027071291301	09/10/2007	2308	09/11/2007	0107	0.31	346	117
Route 2 -S	423027071291302	08/20/2006	0328	08/20/2006	0820	1	177	16
Route 2 -S	423027071291302	08/27/2006	1527	08/27/2006	2219	0.84	283	30
Route 2 -S	423027071291302	09/19/2006	2059	09/19/2006	2355	0.67	599	79
Route 2 -S	423027071291302	12/01/2006	1618	12/01/2006	2127	0.5	456	81
Route 2 -S	423027071291302	01/08/2007	0501	01/08/2007	1319	0.88	24	2
Route 2 -S	423027071291302	03/17/2007	1312	03/18/2007	0228	0.31	847	241
Route 2 -S	423027071291302	04/12/2007	1346	04/12/2007	1906	1.15	1,180	90
Route 2 -S	423027071291302	05/16/2007	1515	05/16/2007	2312	0.32	533	147
Route 2 -S	423027071291302	08/08/2007	0629	08/08/2007	0829	0.51	619	107

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Begin time (hrmn)	End date (mm/dd/yyyy)	End time (hrmn)	Total precipitation (inches)	Total storm volume (cubic feet)	Runoff coefficient (percent)
Route 2 -S	423027071291302	08/06/2007	1514	08/06/2007	1544	0.31	196	56
Interstate 195 -T	414339070462201	04/23/2006	1904	04/23/2006	2350	0.82	1,040	123
Interstate 195 -T	414339070462201	06/24/2006	0215	06/24/2006	0730	2.55	2,130	81
Interstate 195 -T	414339070462201	09/29/2006	0121	09/29/2006	1318	0.67	250	36
Interstate 195 -T	414339070462201	12/01/2006	0907	12/01/2006	1742	0.39	106	26
Interstate 195 -T	414339070462201	02/14/2007	1208	02/14/2007	1419	0.63	769	118
Interstate 495 -P	422821071332001	09/15/2005	0951	09/15/2005	1559	0.29	569	142
Interstate 495 -P	422821071332001	09/29/2005	1439	09/29/2005	1613	0.46	1,040	164
Interstate 495 -P	422821071332001	10/22/2005	1940	10/23/2005	0720	1.28	2,990	169
Interstate 495 -P	422821071332001	10/24/2005	2200	10/25/2005	0953	2.99	6,440	156
Interstate 495 -P	422821071332001	01/11/2006	2021	01/12/2006	0039	0.5	2,530	366
Interstate 495 -P	422821071332001	03/13/2006	1309	03/14/2006	1040	0.53	2,090	285
Interstate 495 -P	422821071332001	05/09/2006	1458	05/10/2006	0800	0.86	1,980	167
Interstate 495 -P	422821071332001	06/02/2006	0554	06/03/2006	1705	2.57	8,380	236
Interstate 495 -P	422821071332001	08/20/2006	0314	08/20/2006	0940	1.36	3,660	195
Interstate 495 -P	422821071332001	08/27/2006	1429	08/28/2006	0417	0.85	1,730	147
Interstate 495 -P	422821071332001	09/19/2006	2048	09/19/2006	2357	0.64	1,080	122
Interstate 495 -P	422821071332001	11/12/2006	1206	11/12/2006	1650	1.83	1,340	53
Interstate 495 -P	422821071332001	01/08/2007	0456	01/08/2007	1450	0.88	1,470	121
Interstate 495 -P	422821071332001	03/02/2007	0335	03/02/2007	0930	1.95	8,500	316
Interstate 495 -P	422821071332001	04/12/2007	1233	04/12/2007	1857	1.06	1,060	72
Interstate 495 -P	422821071332001	08/06/2007	1502	08/06/2007	1521	0.23	200	63
Interstate 495 -P	422821071332001	08/08/2007	0612	08/08/2007	0739	0.51	614	87
Interstate 495 -P	422821071332001	09/10/2007	2252	09/10/2007	2312	0.37	364	71
Interstate 495 -S	422716071343901	09/15/2005	0958	09/15/2005	1255	0.29	207	1
Interstate 495 -S	422716071343901	09/29/2005	1441	09/29/2005	1626	0.46	460	1
Interstate 495 -S	422716071343901	10/22/2005	1856	10/23/2005	0105	1.29	2,210	1
Interstate 495 -S	422716071343901	10/24/2005	2156	10/26/2005	0518	2.99	4,830	1
Interstate 495 -S	422716071343901	01/11/2006	2024	01/12/2006	0114	0.5	920	2
Interstate 495 -S	422716071343901	01/18/2006	0259	01/18/2006	1801	1.14	1,700	1
Interstate 495 -S	422716071343901	03/13/2006	2246	03/14/2006	0548	0.53	1,390	2
Interstate 495 -S	422716071343901	05/09/2006	1506	05/10/2006	0535	0.86	986	1
Interstate 495 -S	422716071343901	06/02/2006	2058	06/04/2006	0032	2.57	2,440	1
Interstate 495 -S	422716071343901	08/20/2006	0315	08/20/2006	2052	1.36	1,390	1
Interstate 495 -S	422716071343901	09/19/2006	2048	09/19/2006	2345	0.64	1,110	1

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Begin time (hrmn)	End date (mm/dd/yyyy)	End time (hrmn)	Total precipitation (inches)	Total storm volume (cubic feet)	Runoff coefficient (percent)
Interstate 95 -P	422620071153301	09/15/2005	1007	09/15/2005	1620	0.96	1,760	70
Interstate 95 -P	422620071153301	09/29/2005	1518	09/29/2005	1630	0.39	548	54
Interstate 95 -P	422620071153301	10/22/2005	2356	10/23/2005	0045	0.99	842	32
Interstate 95 -P	422620071153301	11/16/2005	2056	11/17/2005	0221	0.6	713	45
Interstate 95 -P	422620071153301	01/12/2006	0026	01/12/2006	0106	0.28	230	31
Interstate 95 -P	422620071153301	01/18/2006	1311	01/18/2006	1535	0.72	1,150	61
Interstate 95 -P	422620071153301	03/13/2006	2311	03/13/2006	2343	0.52	625	46
Interstate 95 -P	422620071153301	05/09/2006	1456	05/09/2006	2010	1.12	1,540	52
Interstate 95 -P	422620071153301	06/02/2006	0356	06/03/2006	1517	0.18	9,880	149
Interstate 95 -P	422620071153301	08/20/2006	0429	08/20/2006	0652	0.49	2,590	97
Interstate 95 -P	422620071153301	08/27/2006	1636	08/27/2006	2300	0.72	2,230	118
Interstate 95 -P	422620071153301	09/19/2006	2136	09/20/2006	0000	0.71	3,330	179
Interstate 95 -P	422620071153301	10/20/2006	1601	10/20/2006	1812	0.59	837	54
Interstate 95 -P	422620071153301	10/28/2006	0551	10/28/2006	1440	1.92	2,700	54
Interstate 95 -P	422620071153301	11/07/2006	2306	11/08/2006	2331	1.54	2,350	58
Interstate 95 -P	422620071153301	03/11/2007	0320	03/11/2007	0508	0.23	195	32
Interstate 95 -P	422620071153301	03/17/2007	0311	03/17/2007	1017	1.86	235	5
Interstate 95 -P	422620071153301	04/12/2007	1403	04/12/2007	1726	1.06	1,060	38
Interstate 95 -P	422620071153301	08/06/2007	1538	08/06/2007	1605	E0.28	35	--
Interstate 95 -P	422620071153301	08/08/2007	0722	08/08/2007	0859	E0.19	113	--
Interstate 95 -S	422420071153302	08/20/2006	0334	08/20/2006	0654	0.81	654	76
Interstate 95 -S	422420071153302	08/27/2006	1556	08/28/2006	0133	0.72	443	58
Interstate 95 -S	422420071153302	09/19/2006	2028	09/20/2006	0005	0.71	542	72
Interstate 95 -S	422420071153302	11/07/2006	2138	11/09/2006	0104	1.28	856	63
Interstate 95 -S	422420071153302	03/02/2007	0257	03/02/2007	1019	1.81	1,840	96
Interstate 95 -S	422420071153302	03/17/2007	0226	03/17/2007	0900	2.25	731	31
Interstate 95 -S	422420071153302	04/12/2007	1353	04/12/2007	1817	1.03	553	51
Interstate 95 -S	422420071153302	05/16/2007	1532	05/16/2007	1831	1.41	811	54
Interstate 95 -S	422420071153302	08/06/2007	1541	08/06/2007	1601	0.28	91	31
Interstate 95 -S	422420071153302	08/08/2007	0726	08/08/2007	0753	0.19	60	30
Interstate 93 -T	421647071024703	04/23/2006	1444	04/24/2006	0423	0.64	2,320	67
Interstate 93 -T	421647071024703	06/23/2006	1427	06/23/2006	1847	1.6	6,100	71
Interstate 93 -T	421647071024703	09/19/2006	2235	09/20/2006	0321	0.61	2,600	79
Interstate 93 -T	421647071024703	12/01/2006	1634	12/01/2006	2217	0.26	829	59
Interstate 93 -T	421647071024703	02/14/2007	1108	02/14/2007	1436	2	8,690	94

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Antecedent dry period between periods of flow (days)	Storm duration (hours)	Sampled duration	Turbidity (NTRU)	pH, total, field (standard units)
Route 119 -P	424209071545201	09/15/2005	14.3	41.1	11.0	16	5.9
Route 119 -P	424209071545201	09/29/2005	2.6	2.0	1.6	13	5.5
Route 119 -P	424209071545201	10/22/2005	7.1	10.8	4.1	6.8	6.5
Route 119 -P	424209071545201	10/24/2005	1.6	19.5	14.3	2.2	6.2
Route 119 -P	424209071545201	01/11/2006	12.8	4.7	3.1	260	6.8
Route 119 -P	424209071545201	01/18/2006	3.5	8.6	7.1	150	7.1
Route 119 -P	424209071545201	03/13/2006	24.0	10.3	1.5	400	7
Route 119 -P	424209071545201	05/09/2006	0.3	18.3	13.2	13	6.8
Route 119 -P	424209071545201	06/01/2006	11.2	9.3	8.9	48	6.6
Route 119 -P	424209071545201	09/14/2006	8.8	5.9	5.3	12	6.3
Route 119 -P	424209071545201	09/19/2006	4.9	5.9	5.9	9.1	6
Route 119 -P	424209071545201	10/20/2006	1.8	15.9	10.4	5.5	6.5
Route 119 -P	424209071545201	11/08/2006	5.8	25.7	17.1	6.2	6.3
Route 119 -P	424209071545201	11/12/2006	3.3	6.1	2.3	2.5	6.1
Route 119 -P	424209071545201	01/08/2007	1.1	14.9	13.5	17	6.2
Route 119 -P	424209071545201	04/01/2007	5.8	7.2	7.2	35	7.2
Route 119 -P	424209071545201	04/14/2007	2.8	77.7	36.0	65	7.2
Route 119 -P	424209071545201	06/03/2007	1.6	30.9	29.7	6.7	6.8
Route 119 -P	424209071545201	07/11/2007	1.6	10.4	2.8	5.7	6.2
Route 119 -S	424155071543201	09/29/2005	2.6	0.5	0.4	2	5.7
Route 119 -S	424155071543201	10/24/2005	1.6	8.0	5.8	1.9	6.1
Route 119 -S	424155071543201	01/11/2006	12.8	3.0	2.8	240	6.5
Route 119 -S	424155071543201	01/18/2006	3.5	4.1	4.0	130	7.1
Route 119 -S	424155071543201	03/13/2006	24.0	11.4	11.4	230	6.9
Route 119 -S	424155071543201	08/20/2006	4.9	6.1	1.9	5	6.5
Route 119 -S	424155071543201	11/08/2006	3.3	10.5	9.5	2.5	6.3
Route 119 -S	424155071543201	04/27/2007	1.2	1.0	0.4	27	7.3
Route 119 -S	424155071543201	06/03/2007	1.6	22.9	22.9	8.2	6.5
Route 119 -S	424155071543201	07/11/2007	1.6	1.5	1.4	5.3	6.3
Route 119 -S	424155071543201	08/03/2007	4.0	0.4	0.4	5	6.7
Route 8 -T	424019073062601	04/22/2006	7.4	26	19.8	15	7.3
Route 8 -T	424019073062601	06/23/2006	3.1	7	11.7	16	7
Route 8 -T	424019073062601	09/23/2006	1.1	30	29.8	20	7.2
Route 8 -T	424019073062601	12/01/2006	7.9	6	6.0	56	7.6
Route 8 -T	424019073062601	03/02/2007	3.1	5	4.7	570	7.7

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour:minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Antecedent dry period between periods of flow (days)	Storm duration (hours)	Sampled duration	Turbidity (NTRU)	pH, total, field (standard units)
Interstate 190 -T	423016071431501	08/14/2005	12.2	16	14.3	33	6
Interstate 190 -T	423016071431501	09/29/2005	2.8	1	0.7	38	6.3
Interstate 190 -T	423016071431501	10/07/2005	8.4	30	12.0	12	6
Interstate 190 -T	423016071431501	10/22/2005	7.1	11	5.6	13	6.2
Interstate 190 -T	423016071431501	10/24/2005	1.6	24	8.5	3.2	6.2
Interstate 190 -T	423016071431501	03/13/2006	16.0	7	11.1	500	6.8
Route 2 -P	423027071291301	09/15/2005	14.3	6.3	3.1	37	6.6
Route 2 -P	423027071291301	09/29/2005	2.7	1.5	1.4	31	5.9
Route 2 -P	423027071291301	10/22/2005	7	11.1	5.2	12	6.2
Route 2 -P	423027071291301	10/24/2005	1.5	30.6	7.4	3.9	6.2
Route 2 -P	423027071291301	01/11/2006	3.1	4.4	6.8	400	7
Route 2 -P	423027071291301	01/18/2006	2.5	11.6	9.6	190	6.8
Route 2 -P	423027071291301	03/13/2006	15.7	13.2	3.5	290	7.1
Route 2 -P	423027071291301	05/09/2006	5.6	21.9	21.3	1.4	7
Route 2 -P	423027071291301	06/02/2006	7	29.9	29.5	23	6.8
Route 2 -P	423027071291301	06/23/2006	8.4	16.8	3.0	84	6.6
Route 2 -P	423027071291301	08/20/2006	4.7	5.2	4.9	6.9	6.5
Route 2 -P	423027071291301	08/27/2006	1.9	6.8	13.4	4.8	6.6
Route 2 -P	423027071291301	09/19/2006	5	3	2.9	7.6	6.5
Route 2 -P	423027071291301	11/07/2006	5.5	30.6	16.8	7.2	6.6
Route 2 -P	423027071291301	01/08/2007	2.2	9.8	11.8	27	6.6
Route 2 -P	423027071291301	03/02/2007	3.4	10.7	3.0	440	7.5
Route 2 -P	423027071291301	04/12/2007	7.1	4.4	3.8	210	6.9
Route 2 -P	423027071291301	08/06/2007	7.4	0.3	0.3	27	6.7
Route 2 -P	423027071291301	08/08/2007	1.6	1.3	1.3	29	6.6
Route 2 -P	423027071291301	09/10/2007	23.9	1.1	2.0	18	6.8
Route 2 -S	423027071291302	08/20/2006	0.5	0.7	4.9	3.8	6.5
Route 2 -S	423027071291302	08/27/2006	2.3	6.7	6.9	4.9	6.4
Route 2 -S	423027071291302	09/19/2006	5.0	2.9	2.9	12	6.2
Route 2 -S	423027071291302	12/01/2006	7.6	5.0	5.2	24	6.6
Route 2 -S	423027071291302	01/08/2007	2.2	0.8	8.3	20	6.8
Route 2 -S	423027071291302	03/17/2007	0.1	13.2	13.3	80	7
Route 2 -S	423027071291302	04/12/2007	6.9	7.0	5.3	120	6.8
Route 2 -S	423027071291302	05/16/2007	0.6	8.0	8.0	27	6.2
Route 2 -S	423027071291302	08/08/2007	7.3	0.6	2.0	24	6.3

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Antecedent dry period between periods of flow (days)	Storm duration (hours)	Sampled duration	Turbidity (NTRU)	pH, total, field (standard units)
Route 2 -S	423027071291302	08/06/2007	1.6	1.9	0.5	27	6.4
Interstate 195 -T	414339070462201	04/23/2006	8.8	6	4.8	24	6.8
Interstate 195 -T	414339070462201	06/24/2006	3.8	33	5.3	8.3	6
Interstate 195 -T	414339070462201	09/29/2006	8.9	3	12.0	9.7	5.9
Interstate 195 -T	414339070462201	12/01/2006	7.1	9	8.6	17	6.5
Interstate 195 -T	414339070462201	02/14/2007	11.4	6	2.2	45	6.2
Interstate 495 -P	422821071332001	09/15/2005	14.3	6.0	6.1	49	6.1
Interstate 495 -P	422821071332001	09/29/2005	2.7	2.0	1.6	33	5.7
Interstate 495 -P	422821071332001	10/22/2005	7.1	12.0	11.7	12	6
Interstate 495 -P	422821071332001	10/24/2005	1.6	32.0	11.9	9	5.7
Interstate 495 -P	422821071332001	01/11/2006	3.3	8.0	4.3	670	7.7
Interstate 495 -P	422821071332001	03/13/2006	17.8	23.0	21.5	400	6.9
Interstate 495 -P	422821071332001	05/09/2006	6.9	27.0	17.0	32	6.7
Interstate 495 -P	422821071332001	06/02/2006	6.4	38.0	35.2	23	6.6
Interstate 495 -P	422821071332001	08/20/2006	4.7	7.0	6.4	9.3	6.6
Interstate 495 -P	422821071332001	08/27/2006	1.9	11.0	13.8	12	6.6
Interstate 495 -P	422821071332001	09/19/2006	5	3.0	3.1	17	6
Interstate 495 -P	422821071332001	11/12/2006	3.4	5.0	4.7	15	6.2
Interstate 495 -P	422821071332001	01/08/2007	1.8	10.0	9.9	28	6.7
Interstate 495 -P	422821071332001	03/02/2007	3.7	12.0	5.9	470	8
Interstate 495 -P	422821071332001	04/12/2007	6.9	8.0	6.4	200	7
Interstate 495 -P	422821071332001	08/06/2007	7.1	1.0	0.3	37	6.5
Interstate 495 -P	422821071332001	08/08/2007	1.6	2.0	1.5	39	6.4
Interstate 495 -P	422821071332001	09/10/2007	1.7	1.0	0.3	20	7.1
Interstate 495 -S	422716071343901	09/15/2005	14.3	6.0	3.0	40	6.1
Interstate 495 -S	422716071343901	09/29/2005	2.7	1.7	1.7	20	5.8
Interstate 495 -S	422716071343901	10/22/2005	7.1	13.3	6.1	14	6.2
Interstate 495 -S	422716071343901	10/24/2005	1.6	31.5	31.4	9.4	6.2
Interstate 495 -S	422716071343901	01/11/2006	3.3	5.2	4.8	540	7.3
Interstate 495 -S	422716071343901	01/18/2006	2.6	15.7	15.0	230	7
Interstate 495 -S	422716071343901	03/13/2006	15.7	22.0	7.0	280	7
Interstate 495 -S	422716071343901	05/09/2006	6.9	8.6	14.5	31	6.6
Interstate 495 -S	422716071343901	06/02/2006	7.1	22.5	27.6	15	7
Interstate 495 -S	422716071343901	08/20/2006	4.7	7.1	17.6	13	6.4
Interstate 495 -S	422716071343901	09/19/2006	5.0	3.4	3.0	16	6.2

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Antecedent dry period between periods of flow (days)	Storm duration (hours)	Sampled duration	Turbidity (NTRU)	pH, total, field (standard units)
Interstate 95 -P	422620071153301	09/15/2005	14.3	9	6.2	34	6.8
Interstate 95 -P	422620071153301	09/29/2005	2.6	2	1.2	16	6.2
Interstate 95 -P	422620071153301	10/22/2005	7.2	7	0.8	7.1	6.6
Interstate 95 -P	422620071153301	11/16/2005	4.9	14	5.4	16	6.4
Interstate 95 -P	422620071153301	01/12/2006	16.3	1	0.7	730	6.8
Interstate 95 -P	422620071153301	01/18/2006	3.5	3	2.4	290	6.9
Interstate 95 -P	422620071153301	03/13/2006	36.7	9	0.5	670	6.6
Interstate 95 -P	422620071153301	05/09/2006	6.6	5	5.2	55	6.7
Interstate 95 -P	422620071153301	06/02/2006	14	29	35.3	22	6.9
Interstate 95 -P	422620071153301	08/20/2006	4.6	7	2.4	6.4	6.6
Interstate 95 -P	422620071153301	08/27/2006	2	10	6.4	9.6	6.9
Interstate 95 -P	422620071153301	09/19/2006	5	5	2.4	11	6.4
Interstate 95 -P	422620071153301	10/20/2006	8.5	3	2.2	28	6.9
Interstate 95 -P	422620071153301	10/28/2006	7.4	11	8.8	15	6.6
Interstate 95 -P	422620071153301	11/07/2006	10.3	27	24.4	26	6.7
Interstate 95 -P	422620071153301	03/11/2007	8.5	2	1.8	180	7
Interstate 95 -P	422620071153301	03/17/2007	5.9	4	7.1	310	7.1
Interstate 95 -P	422620071153301	04/12/2007	7.4	4	3.4	150	6.8
Interstate 95 -P	422620071153301	08/06/2007	7	<1	0.4	24	6.6
Interstate 95 -P	422620071153301	08/08/2007	1.6	1	1.6	33	6.6
Interstate 95 -S	422420071153302	08/20/2006	4.7	3.0	3.3	7.2	6.4
Interstate 95 -S	422420071153302	08/27/2006	2.0	10.0	9.6	10	6.6
Interstate 95 -S	422420071153302	09/19/2006	5.0	5.0	3.6	15	6.2
Interstate 95 -S	422420071153302	11/07/2006	5.5	28.0	27.4	15	6.6
Interstate 95 -S	422420071153302	03/02/2007	3.6	11.0	7.4	420	7
Interstate 95 -S	422420071153302	03/17/2007	0.6	6.0	6.6	260	7.1
Interstate 95 -S	422420071153302	04/12/2007	7.1	4.0	4.4	100	6.9
Interstate 95 -S	422420071153302	05/16/2007	0.7	7.0	3.0	46	6.1
Interstate 95 -S	422420071153302	08/06/2007	7.0	<1	0.3	34	6.4
Interstate 95 -S	422420071153302	08/08/2007	1.6	1.0	0.5	47	6.6
Interstate 93 -T	421647071024703	04/23/2006	15.3	14	13.6	91	7.1
Interstate 93 -T	421647071024703	06/23/2006	2.7	5	4.3	78	6.6
Interstate 93 -T	421647071024703	09/19/2006	5.1	5	4.8	28	6.8
Interstate 93 -T	421647071024703	12/01/2006	3.1	6	5.7	96	6.9
Interstate 93 -T	421647071024703	02/14/2007	11	8	3	540	7

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	pH, total, laboratory (standard units)	Specific conductance, laboratory (µS/cm)	Specific conductance, field (µS/cm)	Hardness (mg/L as calcium carbonate)	Calcium, dissolved (mg/L)
Route 119 -P	424209071545201	09/15/2005	6.6	346	354	29	8.31
Route 119 -P	424209071545201	09/29/2005	7	29	30	2	0.74
Route 119 -P	424209071545201	10/22/2005	--	--	37	--	--
Route 119 -P	424209071545201	10/24/2005	8.5	8	7	1	0.36
Route 119 -P	424209071545201	01/11/2006	7.5	4,940	5,430	130	15.9
Route 119 -P	424209071545201	01/18/2006	7.5	3,540	3,580	120	36.2
Route 119 -P	424209071545201	03/13/2006	7.5	494	490	31	4.95
Route 119 -P	424209071545201	05/09/2006	6.5	308	306	17	4.29
Route 119 -P	424209071545201	06/01/2006	7.1	254	254	15	3.73
Route 119 -P	424209071545201	09/14/2006	7.2	74	73	5	1.49
Route 119 -P	424209071545201	09/19/2006	6.6	151	150	12	3.33
Route 119 -P	424209071545201	10/20/2006	7.8	53	50	--	--
Route 119 -P	424209071545201	11/08/2006	7.4	32	28	3	0.85
Route 119 -P	424209071545201	11/12/2006	--	--	24	--	--
Route 119 -P	424209071545201	01/08/2007	7.1	102	103	3	0.64
Route 119 -P	424209071545201	04/01/2007	7.6	1,820	1,850	15	3.34
Route 119 -P	424209071545201	04/14/2007	7.9	9,200	9,160	260	15.5
Route 119 -P	424209071545201	06/03/2007	7.6	69	65	4	1.04
Route 119 -P	424209071545201	07/11/2007	7.4	50	47	4	0.96
Route 119 -S	424155071543201	09/29/2005	7	20	21	2	0.55
Route 119 -S	424155071543201	10/24/2005	6.1	10	8	1	0.3
Route 119 -S	424155071543201	01/11/2006	7.5	2,960	3,130	83	14.2
Route 119 -S	424155071543201	01/18/2006	7.5	2,810	2,850	91	26.8
Route 119 -S	424155071543201	03/13/2006	7	1,090	1,100	42	8.63
Route 119 -S	424155071543201	08/20/2006	7.9	44	43	5	1.56
Route 119 -S	424155071543201	11/08/2006	7.9	16	11	2	0.55
Route 119 -S	424155071543201	04/27/2007	7.1	2,750	2,710	95	22.9
Route 119 -S	424155071543201	06/03/2007	7.8	90	89	--	--
Route 119 -S	424155071543201	07/11/2007	8.2	28	25	2	0.52
Route 119 -S	424155071543201	08/03/2007	6.7	136	134	13	3.72
Route 8 -T	424019073062601	04/22/2006	7.3	48	48	11	4.24
Route 8 -T	424019073062601	06/23/2006	7	65	65	22	8.27
Route 8 -T	424019073062601	09/23/2006	7.2	71	68	27	10.2
Route 8 -T	424019073062601	12/01/2006	8.2	48	48	16	5.93
Route 8 -T	424019073062601	03/02/2007	7.8	E14,400	14,400	77	29.7

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	pH, total, laboratory (standard units)	Specific conductance, laboratory (µS/cm)	Specific conductance, field (µS/cm)	Hardness (mg/L as calcium carbonate)	Calcium, dissolved (mg/L)
Interstate 190 -T	423016071431501	08/14/2005	6.8	89	97	17	6.03
Interstate 190 -T	423016071431501	09/29/2005	6.8	71	75	12	4.16
Interstate 190 -T	423016071431501	10/07/2005	7.5	35	35	7	2.54
Interstate 190 -T	423016071431501	10/22/2005	7.2	70	72	14	4.96
Interstate 190 -T	423016071431501	10/24/2005	7.9	15	15	4	1.25
Interstate 190 -T	423016071431501	03/13/2006	7.2	E11,300	11,300	600	125
Route 2 -P	423027071291301	09/15/2005	7.1	268	273	21	6.62
Route 2 -P	423027071291301	09/29/2005	6.9	79	85	7	2.34
Route 2 -P	423027071291301	10/22/2005	7.2	90	93	9	2.79
Route 2 -P	423027071291301	10/24/2005	8.2	35	34	4	1.3
Route 2 -P	423027071291301	01/11/2006	7.5	2,870	3,190	97	21.9
Route 2 -P	423027071291301	01/18/2006	7.5	1,870	1,920	57	12.5
Route 2 -P	423027071291301	03/13/2006	7.2	1,820	1,840	59	13.8
Route 2 -P	423027071291301	05/09/2006	7.2	261	237	15	4.28
Route 2 -P	423027071291301	06/02/2006	7.9	49	45	4	1.38
Route 2 -P	423027071291301	06/23/2006	--	--	226	--	--
Route 2 -P	423027071291301	08/20/2006	7.4	61	60	5	1.74
Route 2 -P	423027071291301	08/27/2006	7.2	69	69	7	2.28
Route 2 -P	423027071291301	09/19/2006	7	76	72	7	2.29
Route 2 -P	423027071291301	11/07/2006	7.1	92	88	10	3.06
Route 2 -P	423027071291301	01/08/2007	6.5	151	152	8	1.98
Route 2 -P	423027071291301	03/02/2007	7.5	E29,900	29,900	840	108
Route 2 -P	423027071291301	04/12/2007	7.2	3,390	3,330	100	8.72
Route 2 -P	423027071291301	08/06/2007	6.8	229	226	--	--
Route 2 -P	423027071291301	08/08/2007	6.8	108	104	9	2.92
Route 2 -P	423027071291301	09/10/2007	7.9	126	123	10	3.24
Route 2 -S	423027071291302	08/20/2006	--	--	73	7	2.1
Route 2 -S	423027071291302	08/27/2006	6.3	58	57	6	1.9
Route 2 -S	423027071291302	09/19/2006	7	63	59	7	2.1
Route 2 -S	423027071291302	12/01/2006	7.7	45	46	5	1.66
Route 2 -S	423027071291302	01/08/2007	8	138	138	7	1.57
Route 2 -S	423027071291302	03/17/2007	7.6	E60,500	62,500	650	88
Route 2 -S	423027071291302	04/12/2007	7.3	2,500	2,460	76	7.09
Route 2 -S	423027071291302	05/16/2007	6.6	64	61	5	1.43
Route 2 -S	423027071291302	08/08/2007	6.3	94	89	9	2.93

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	pH, total, laboratory (standard units)	Specific conductance, laboratory (µS/cm)	Specific conductance, field (µS/cm)	Hardness (mg/L as calcium carbonate)	Calcium, dissolved (mg/L)
Route 2 -S	423027071291302	08/06/2007	6.5	199	193	17	5.06
Interstate 195 -T	414339070462201	04/23/2006	7.1	118	116	5	1.31
Interstate 195 -T	414339070462201	06/24/2006	6.3	36	35	4	1.13
Interstate 195 -T	414339070462201	09/29/2006	6.1	55	53	5	1.37
Interstate 195 -T	414339070462201	12/01/2006	7.4	85	93	8	2.48
Interstate 195 -T	414339070462201	02/14/2007	7.9	3,790	3,720	9	2.92
Interstate 495 -P	422821071332001	09/15/2005	7	228	247	17	5.52
Interstate 495 -P	422821071332001	09/29/2005	6.9	66	65	5	1.58
Interstate 495 -P	422821071332001	10/22/2005	7.5	28	28	3	1.06
Interstate 495 -P	422821071332001	10/24/2005	8.1	27	27	3	1.01
Interstate 495 -P	422821071332001	01/11/2006	7.6	1,890	1,980	43	13.6
Interstate 495 -P	422821071332001	03/13/2006	7	1,670	1,680	100	25.6
Interstate 495 -P	422821071332001	05/09/2006	6.9	224	220	14	3.99
Interstate 495 -P	422821071332001	06/02/2006	6.9	145	144	9	2.77
Interstate 495 -P	422821071332001	08/20/2006	7.3	60	59	6	1.9
Interstate 495 -P	422821071332001	08/27/2006	7.3	56	54	5	1.75
Interstate 495 -P	422821071332001	09/19/2006	6.5	65	62	7	2.18
Interstate 495 -P	422821071332001	11/12/2006	7.3	27	23	3	1.01
Interstate 495 -P	422821071332001	01/08/2007	7.9	189	190	12	2.4
Interstate 495 -P	422821071332001	03/02/2007	7.7	15,300	15,400	430	38.1
Interstate 495 -P	422821071332001	04/12/2007	7.2	9,820	9,600	110	16.4
Interstate 495 -P	422821071332001	08/06/2007	6.7	178	176		
Interstate 495 -P	422821071332001	08/08/2007	6.4	109	106	10	3.32
Interstate 495 -P	422821071332001	09/10/2007	6.7	125	119	10	3.04
Interstate 495 -S	422716071343901	09/15/2005	7	237	250	21	6.9
Interstate 495 -S	422716071343901	09/29/2005	7	73	79	7	2.21
Interstate 495 -S	422716071343901	10/22/2005	8	107	110	10	3.35
Interstate 495 -S	422716071343901	10/24/2005	8	26	26	3	1.14
Interstate 495 -S	422716071343901	01/11/2006	7.4	7,120	7,600	120	35.3
Interstate 495 -S	422716071343901	01/18/2006	7.5	4,820	4,930	200	75.1
Interstate 495 -S	422716071343901	03/13/2006	7.6	2,640	2,630	140	37.8
Interstate 495 -S	422716071343901	05/09/2006	7.4	242	237	15	4.38
Interstate 495 -S	422716071343901	06/02/2006	7.8	53	48	4	1.44
Interstate 495 -S	422716071343901	08/20/2006	7.7	67	67	6	1.92
Interstate 495 -S	422716071343901	09/19/2006	6.7	71	69	7	2.4

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	pH, total, laboratory (standard units)	Specific conductance, laboratory (µS/cm)	Specific conductance, field (µS/cm)	Hardness (mg/L as calcium carbonate)	Calcium, dissolved (mg/L)
Interstate 95 -P	422620071153301	09/15/2005	7.1	117	128	18	6.09
Interstate 95 -P	422620071153301	09/29/2005	6.7	130	141	20	6.89
Interstate 95 -P	422620071153301	10/22/2005	7.4	54	55	9	3.1
Interstate 95 -P	422620071153301	11/16/2005	7.8	140	146	13	4.46
Interstate 95 -P	422620071153301	01/12/2006	7.1	E12,900	13,700	560	191
Interstate 95 -P	422620071153301	01/18/2006	7.1	4,000	4,080	200	77.1
Interstate 95 -P	422620071153301	03/13/2006	6.5	E18,500	18,700	960	270
Interstate 95 -P	422620071153301	05/09/2006	6.8	442	437	21	6.44
Interstate 95 -P	422620071153301	06/02/2006	7.1	124	123	9	2.95
Interstate 95 -P	422620071153301	08/20/2006	7.3	98	98	13	4.21
Interstate 95 -P	422620071153301	08/27/2006	6.7	95	93	12	3.89
Interstate 95 -P	422620071153301	09/19/2006	6.9	83	80	12	3.8
Interstate 95 -P	422620071153301	10/20/2006	7.5	82	83	--	--
Interstate 95 -P	422620071153301	10/28/2006	7.4	50	47	--	--
Interstate 95 -P	422620071153301	11/07/2006	7.2	60	55	10	3.41
Interstate 95 -P	422620071153301	03/11/2007	6.8	E13,300	13,400	740	215
Interstate 95 -P	422620071153301	03/17/2007	7.4	E13,800	14,300	720	194
Interstate 95 -P	422620071153301	04/12/2007	6.9	3,700	3,640	160	47.4
Interstate 95 -P	422620071153301	08/06/2007	6.6	214	211	22	7.38
Interstate 95 -P	422620071153301	08/08/2007	6.5	179	174	10	6.16
Interstate 95 -S	422420071153302	08/20/2006	7.2	53	51	14	5.23
Interstate 95 -S	422420071153302	08/27/2006	7.1	60	59	11	4.1
Interstate 95 -S	422420071153302	09/19/2006	7	58	55	12	4.11
Interstate 95 -S	422420071153302	11/07/2006	7.2	49	45	9	3.32
Interstate 95 -S	422420071153302	03/02/2007	7.1	E13,000	12,900	1,300	502
Interstate 95 -S	422420071153302	03/17/2007	7.7	E15,100	15,600	590	167
Interstate 95 -S	422420071153302	04/12/2007	7	971	954	51	18.8
Interstate 95 -S	422420071153302	05/16/2007	6.1	112	107	11	3.75
Interstate 95 -S	422420071153302	08/06/2007	6.7	154	145	24	8.46
Interstate 95 -S	422420071153302	08/08/2007	6.2	163	161	21	7.55
Interstate 93 -T	421647071024703	04/23/2006	7	1,260	1,240	37	9.74
Interstate 93 -T	421647071024703	06/23/2006	6.7	136	137	12	4.16
Interstate 93 -T	421647071024703	09/19/2006	7.1	112	108	9	3.15
Interstate 93 -T	421647071024703	12/01/2006	7.4	172	183	21	7.17
Interstate 93 -T	421647071024703	02/14/2007	8	E12,900	13,200	400	48

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Magnesium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity, dissolved, laboratory (mg/L as calcium carbonate)	Chloride, dissolved (mg/L)
Route 119 -P	424209071545201	09/15/2005	2	1.36	54.3	8	89.5
Route 119 -P	424209071545201	09/29/2005	0.159	0.22	4.46	<5	6.37
Route 119 -P	424209071545201	10/22/2005	--	--	--	--	--
Route 119 -P	424209071545201	10/24/2005	0.062	<0.16	0.84	<5	0.99
Route 119 -P	424209071545201	01/11/2006	22.6	7.32	970	12	1,620
Route 119 -P	424209071545201	01/18/2006	8.26	4.37	619	9	1,100
Route 119 -P	424209071545201	03/13/2006	4.61	1.3	73.8	14	121
Route 119 -P	424209071545201	05/09/2006	1.57	0.98	49.5	13	78.6
Route 119 -P	424209071545201	06/01/2006	1.5	0.76	38.8	9	63.5
Route 119 -P	424209071545201	09/14/2006	0.368	0.33	10.9	6	15.1
Route 119 -P	424209071545201	09/19/2006	0.945	0.7	21.2	6	32.8
Route 119 -P	424209071545201	10/20/2006	--	--	--	6	8.82
Route 119 -P	424209071545201	11/08/2006	0.153	0.14	4.08	5	5.62
Route 119 -P	424209071545201	11/12/2006	--	--	--	--	--
Route 119 -P	424209071545201	01/08/2007	0.317	0.19	17.9	6	26
Route 119 -P	424209071545201	04/01/2007	1.51	0.92	338	15	562
Route 119 -P	424209071545201	04/14/2007	53.8	14	1,750	14	2,880
Route 119 -P	424209071545201	06/03/2007	0.329	0.26	9.79	7	12.8
Route 119 -P	424209071545201	07/11/2007	0.272	0.19	7.58	<5	9.92
Route 119 -S	424155071543201	09/29/2005	0.1	0.17	2.99	<5	4.08
Route 119 -S	424155071543201	10/24/2005	0.075	<0.16	1.18	<5	1.25
Route 119 -S	424155071543201	01/11/2006	11.6	3.7	548	17	921
Route 119 -S	424155071543201	01/18/2006	5.85	3.09	471	10	864
Route 119 -S	424155071543201	03/13/2006	4.86	1.64	185	18	302
Route 119 -S	424155071543201	08/20/2006	0.237	0.27	5.93	8	7.62
Route 119 -S	424155071543201	11/08/2006	0.094	0.08	1.34	<5	1.69
Route 119 -S	424155071543201	04/27/2007	9.29	3.13	466	37	808
Route 119 -S	424155071543201	06/03/2007	--	--	--	--	--
Route 119 -S	424155071543201	07/11/2007	0.137	0.17	3.9	<5	4.92
Route 119 -S	424155071543201	08/03/2007	1.02	1.04	18.1	8	28.2
Route 8 -T	424019073062601	04/22/2006	0.134	E0.14	4.85	15	5.35
Route 8 -T	424019073062601	06/23/2006	0.282	0.31	3.01	22	2.4
Route 8 -T	424019073062601	09/23/2006	0.508	0.61	2.71	20	2.64
Route 8 -T	424019073062601	12/01/2006	0.171	0.23	1.82	16	2.02
Route 8 -T	424019073062601	03/02/2007	0.723	3.07	2,890	38	4,930

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Magnesium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity, dissolved, laboratory (mg/L as calcium carbonate)	Chloride, dissolved (mg/L)
Interstate 190 -T	423016071431501	08/14/2005	0.474	0.58	9.49	7	12.5
Interstate 190 -T	423016071431501	09/29/2005	0.384	0.78	8.83	9	12
Interstate 190 -T	423016071431501	10/07/2005	0.218	0.37	3.31	8	4.03
Interstate 190 -T	423016071431501	10/22/2005	0.507	0.89	6.84	11	9.35
Interstate 190 -T	423016071431501	10/24/2005	0.115	0.2	1.08	6	1.54
Interstate 190 -T	423016071431501	03/13/2006	70.6	17.9	2050	19	3710
Route 2 -P	423027071291301	09/15/2005	1	1.8	42	12	62.6
Route 2 -P	423027071291301	09/29/2005	0.346	1.54	11.9	8	16.9
Route 2 -P	423027071291301	10/22/2005	0.435	1.38	12.2	9	18.6
Route 2 -P	423027071291301	10/24/2005	0.182	0.46	4.44	6	6.05
Route 2 -P	423027071291301	01/11/2006	10.4	4.39	561	18	915
Route 2 -P	423027071291301	01/18/2006	6.32	2.58	328	16	558
Route 2 -P	423027071291301	03/13/2006	5.84	2.43	321	13	538
Route 2 -P	423027071291301	05/09/2006	1	0.75	38.1	15	56.7
Route 2 -P	423027071291301	06/02/2006	0.241	0.32	6.04	7	7.58
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	0.279	0.53	9.88	7	13.2
Route 2 -P	423027071291301	08/27/2006	0.35	0.36	8.74	8	11.8
Route 2 -P	423027071291301	09/19/2006	0.385	0.84	9.4	6	13.2
Route 2 -P	423027071291301	11/07/2006	0.464	0.65	11.2	11	15.2
Route 2 -P	423027071291301	01/08/2007	0.793	0.39	23.5	9	37.2
Route 2 -P	423027071291301	03/02/2007	138	37	6,240	24	10,700
Route 2 -P	423027071291301	04/12/2007	19.2	5.59	588	14	1,010
Route 2 -P	423027071291301	08/06/2007	--	--	--	--	--
Route 2 -P	423027071291301	08/08/2007	0.528	0.86	13.9	8	17.6
Route 2 -P	423027071291301	09/10/2007	0.448	2.36	17.4	12	24.6
Route 2 -S	423027071291302	08/20/2006	0.331	0.99	10	6	14.1
Route 2 -S	423027071291302	08/27/2006	0.303	0.66	6.67	6	9.54
Route 2 -S	423027071291302	09/19/2006	0.346	1.27	7.01	6	9.55
Route 2 -S	423027071291302	12/01/2006	0.252	0.42	5.68	6	7.69
Route 2 -S	423027071291302	01/08/2007	0.709	0.41	21.8	7	33.8
Route 2 -S	423027071291302	03/17/2007	103	36.7	13,900	27	22,600
Route 2 -S	423027071291302	04/12/2007	14.2	4.74	425	12	727
Route 2 -S	423027071291302	05/16/2007	0.332	0.39	8.82	5	11.1
Route 2 -S	423027071291302	08/08/2007	0.498	1.02	11.1	7	15.5

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Magnesium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity, dissolved, laboratory (mg/L as calcium carbonate)	Chloride, dissolved (mg/L)
Route 2 -S	423027071291302	08/06/2007	0.94	1.63	27.8	9	40.4
Interstate 195 -T	414339070462201	04/23/2006	0.3	0.29	19.8	6	28.2
Interstate 195 -T	414339070462201	06/24/2006	0.169	E0.15	3.86	<5	5.5
Interstate 195 -T	414339070462201	09/29/2006	0.272	0.29	6.84	<5	10.4
Interstate 195 -T	414339070462201	12/01/2006	0.533	0.5	12.5	8	16
Interstate 195 -T	414339070462201	02/14/2007	0.465	0.66	718	7	1,210
Interstate 495 -P	422821071332001	09/15/2005	0.819	1.62	36.4	9	52.6
Interstate 495 -P	422821071332001	09/29/2005	0.213	0.66	9.25	6	12.6
Interstate 495 -P	422821071332001	10/22/2005	0.12	0.19	3.52	5	5.24
Interstate 495 -P	422821071332001	10/24/2005	0.118	0.17	3.41	5	4.84
Interstate 495 -P	422821071332001	01/11/2006	2.09	1.77	354	15	577
Interstate 495 -P	422821071332001	03/13/2006	9.44	3.34	265	15	457
Interstate 495 -P	422821071332001	05/09/2006	0.881	0.83	35.3	11	52.5
Interstate 495 -P	422821071332001	06/02/2006	0.564	0.56	21.8	8	32.5
Interstate 495 -P	422821071332001	08/20/2006	0.24	0.35	8.02	6	11.1
Interstate 495 -P	422821071332001	08/27/2006	0.225	0.27	6.78	7	9.51
Interstate 495 -P	422821071332001	09/19/2006	0.329	0.93	7.58	5	10.3
Interstate 495 -P	422821071332001	11/12/2006	0.107	0.15	2.3	<5	2.95
Interstate 495 -P	422821071332001	01/08/2007	1.34	0.64	29.4	9	47.3
Interstate 495 -P	422821071332001	03/02/2007	81.1	21.1	2,990	20	5,190
Interstate 495 -P	422821071332001	04/12/2007	16.6	5.17	1,940	14	3,110
Interstate 495 -P	422821071332001	08/06/2007	--	--	--	--	--
Interstate 495 -P	422821071332001	08/08/2007	0.465	0.61	14	7	18.6
Interstate 495 -P	422821071332001	09/10/2007	0.534	0.8	17.4	6	26.5
Interstate 495 -S	422716071343901	09/15/2005	0.845	1.28	37.1	10	53.3
Interstate 495 -S	422716071343901	09/29/2005	0.259	0.47	11.7	6	16.1
Interstate 495 -S	422716071343901	10/22/2005	0.375	0.46	15.6	8	23.2
Interstate 495 -S	422716071343901	10/24/2005	0.113	0.17	2.98	6	4.25
Interstate 495 -S	422716071343901	01/11/2006	7.29	5.33	1,430	17	2,380
Interstate 495 -S	422716071343901	01/18/2006	3.12	3.58	850	14	1,540
Interstate 495 -S	422716071343901	03/13/2006	12.1	3.53	441	14	761
Interstate 495 -S	422716071343901	05/09/2006	0.873	0.74	37	9	53.8
Interstate 495 -S	422716071343901	06/02/2006	0.215	0.22	6.34	6	8.89
Interstate 495 -S	422716071343901	08/20/2006	0.272	0.27	9.34	5	13.5
Interstate 495 -S	422716071343901	09/19/2006	0.308	0.74	8.71	6	11.7

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Magnesium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity, dissolved, laboratory (mg/L as calcium carbonate)	Chloride, dissolved (mg/L)
Interstate 95 -P	422620071153301	09/15/2005	0.73	1.5	14.8	14	17.7
Interstate 95 -P	422620071153301	09/29/2005	0.763	1.65	16.1	15	22.8
Interstate 95 -P	422620071153301	10/22/2005	0.4	0.67	5.2	--	--
Interstate 95 -P	422620071153301	11/16/2005	0.536	1.06	21.1	--	--
Interstate 95 -P	422620071153301	01/12/2006	20.9	14	2,600	19	4,500
Interstate 95 -P	422620071153301	01/18/2006	2.98	3.83	686	12	1,260
Interstate 95 -P	422620071153301	03/13/2006	68.1	23.4	3,600	23	6,200
Interstate 95 -P	422620071153301	05/09/2006	1.26	1.61	73.5	15	114
Interstate 95 -P	422620071153301	06/02/2006	0.425	0.81	18.5	13	23.5
Interstate 95 -P	422620071153301	08/20/2006	0.609	0.98	12.4	9	16.6
Interstate 95 -P	422620071153301	08/27/2006	0.545	0.96	11.1	14	13.2
Interstate 95 -P	422620071153301	09/19/2006	0.55	0.93	8.74	8	10.7
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	14	9.15
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	9	5.42
Interstate 95 -P	422620071153301	11/07/2006	0.398	0.79	5.12	13	5.21
Interstate 95 -P	422620071153301	03/11/2007	50	16.1	2,490	19	4,400
Interstate 95 -P	422620071153301	03/17/2007	57.6	17	2,630	19	4,570
Interstate 95 -P	422620071153301	04/12/2007	9.2	4.49	622	14	1,130
Interstate 95 -P	422620071153301	08/06/2007	0.792	2	31.3	16	39.7
Interstate 95 -P	422620071153301	08/08/2007	0.628	1.68	24.3	13	30
Interstate 95 -S	422420071153302	08/20/2006	0.228	0.76	2.9	8	6.42
Interstate 95 -S	422420071153302	08/27/2006	0.243	0.7	4.32	9	7.97
Interstate 95 -S	422420071153302	09/19/2006	0.301	0.63	3.79	6	5.57
Interstate 95 -S	422420071153302	11/07/2006	0.275	0.7	3.37	10	4.26
Interstate 95 -S	422420071153302	03/02/2007	14.9	15.8	1,980	18	4,430
Interstate 95 -S	422420071153302	03/17/2007	41.3	13.2	3,020	16	5,070
Interstate 95 -S	422420071153302	04/12/2007	1.04	1.01	159	11	276
Interstate 95 -S	422420071153302	05/16/2007	0.369	0.77	14.5	7	22
Interstate 95 -S	422420071153302	08/06/2007	0.647	1.63	16.6	13	22.6
Interstate 95 -S	422420071153302	08/08/2007	0.641	1.54	18.7	11	25.5
Interstate 93 -T	421647071024703	04/23/2006	3.15	2.64	219	21	342
Interstate 93 -T	421647071024703	06/23/2006	0.417	0.84	19.9	12	26.7
Interstate 93 -T	421647071024703	09/19/2006	0.315	0.95	15.1	14	17.7
Interstate 93 -T	421647071024703	12/01/2006	0.748	1.38	24.7	20	31.2
Interstate 93 -T	421647071024703	02/14/2007	68	21	2,500	21	4,380

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Sulfate, dissolved (mg/L)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), total (mg/L)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	8.07	2.52	0.1	0.11	3.3
Route 119 -P	424209071545201	09/29/2005	1	0.4	0.04	E0.02	3.3
Route 119 -P	424209071545201	10/22/2005	--	0.33	<0.02	E0.02	1.2
Route 119 -P	424209071545201	10/24/2005	0.34	0.09	<0.02	<0.04	1
Route 119 -P	424209071545201	01/11/2006	82.1	0.85	0.2	0.21	17
Route 119 -P	424209071545201	01/18/2006	32.7	0.61	0.19	0.15	14
Route 119 -P	424209071545201	03/13/2006	22.5	2.07	0.51	0.24	34
Route 119 -P	424209071545201	05/09/2006	6.66	0.86	0.05	E0.04	3.5
Route 119 -P	424209071545201	06/01/2006	6.09	1.49	0.24	0.08	7.9
Route 119 -P	424209071545201	09/14/2006	1.49	0.56	0.03	<0.04	4.1
Route 119 -P	424209071545201	09/19/2006	5.91	1.5	0.06	E0.03	2.9
Route 119 -P	424209071545201	10/20/2006	2.39	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	0.63	0.24	E0.02	E0.009	2.1
Route 119 -P	424209071545201	11/12/2006	--	--	--	--	--
Route 119 -P	424209071545201	01/08/2007	2.17	0.21	0.03	E0.01	2.7
Route 119 -P	424209071545201	04/01/2007	11.9	0.59	0.05	0.03	3.7
Route 119 -P	424209071545201	04/14/2007	187	0.64	0.08	0.08	7.5
Route 119 -P	424209071545201	06/03/2007	2.2	0.43	E0.02	E0.01	2.4
Route 119 -P	424209071545201	07/11/2007	1.22	0.41	0.04	0.03	2.1
Route 119 -S	424155071543201	09/29/2005	0.57	0.43	0.06	E0.03	2.4
Route 119 -S	424155071543201	10/24/2005	0.47	0.1	<0.02	<0.04	0.4
Route 119 -S	424155071543201	01/11/2006	46.7	0.85	0.19	0.2	15
Route 119 -S	424155071543201	01/18/2006	27.2	0.59	0.15	0.17	9.9
Route 119 -S	424155071543201	03/13/2006	21.1	1.55	0.33	0.19	23
Route 119 -S	424155071543201	08/20/2006	0.97	0.33	0.04	<0.04	0.7
Route 119 -S	424155071543201	11/08/2006	0.25	0.1	0.03	E0.01	0.9
Route 119 -S	424155071543201	04/27/2007	42.1	0.52	0.08	0.21	4.7
Route 119 -S	424155071543201	06/03/2007	--	0.65	0.03	0.03	1.4
Route 119 -S	424155071543201	07/11/2007	0.71	0.32	0.03	0.03	2
Route 119 -S	424155071543201	08/03/2007	6.33	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	1.08	0.42	0.03	E0.03	5
Route 8 -T	424019073062601	06/23/2006	3.36	1.11	0.07	0.07	3.4
Route 8 -T	424019073062601	09/23/2006	5.71	0.99	0.06	E0.04	2.9
Route 8 -T	424019073062601	12/01/2006	1.91	0.94	0.18	0.23	7.8
Route 8 -T	424019073062601	03/02/2007	55.6	1.22	0.21	0.89	34

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Sulfate, dissolved (mg/L)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), total (mg/L)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	10	1.78	0.16	0.25	13
Interstate 190 -T	423016071431501	09/29/2005	4.51	0.89	0.14	0.17	14
Interstate 190 -T	423016071431501	10/07/2005	2.02	0.52	0.05	0.06	7.3
Interstate 190 -T	423016071431501	10/22/2005	5.2	1.24	0.04	0.1	6.7
Interstate 190 -T	423016071431501	10/24/2005	1.04	0.21	E0.01	E0.03	2.3
Interstate 190 -T	423016071431501	03/13/2006	306	2.83	0.4	2.4	58
Route 2 -P	423027071291301	09/15/2005	7.91	4.42	0.15	0.43	13
Route 2 -P	423027071291301	09/29/2005	3.33	1.07	0.16	0.49	17
Route 2 -P	423027071291301	10/22/2005	3.17	1.09	0.05	0.14	7.8
Route 2 -P	423027071291301	10/24/2005	1.23	0.32	0.02	0.08	2
Route 2 -P	423027071291301	01/11/2006	79.6	1.38	0.2	0.66	24
Route 2 -P	423027071291301	01/18/2006	36.7	0.84	0.16	0.47	20
Route 2 -P	423027071291301	03/13/2006	33.2	1.59	0.29	0.88	31
Route 2 -P	423027071291301	05/09/2006	5.65	1.09	0.06	0.24	13
Route 2 -P	423027071291301	06/02/2006	1.7	0.66	0.12	0.19	8.9
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	1.98	0.57	0.05	0.12	3
Route 2 -P	423027071291301	08/27/2006	3.18	0.69	E0.009	0.13	9.3
Route 2 -P	423027071291301	09/19/2006	3.52	0.97	0.06	0.17	6.3
Route 2 -P	423027071291301	11/07/2006	3.23	1.16	0.04	0.14	5.1
Route 2 -P	423027071291301	01/08/2007	4.14	0.68	0.05	0.17	13
Route 2 -P	423027071291301	03/02/2007	528	2.65	0.34	2.34	50
Route 2 -P	423027071291301	04/12/2007	72.8	1.51	0.32	0.76	47
Route 2 -P	423027071291301	08/06/2007	--	2.34	0.11	0.32	12
Route 2 -P	423027071291301	08/08/2007	5.8	2.56	0.13	0.3	22
Route 2 -P	423027071291301	09/10/2007	3.76	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	2.25	1.08	0.08	0.08	4.8
Route 2 -S	423027071291302	08/27/2006	3.4	0.73	0.02	0.05	7.9
Route 2 -S	423027071291302	09/19/2006	3.21	1.16	0.13	0.1	11
Route 2 -S	423027071291302	12/01/2006	2.35	0.74	0.15	0.16	14
Route 2 -S	423027071291302	01/08/2007	3.91	0.57	0.05	0.07	6.3
Route 2 -S	423027071291302	03/17/2007	402	1.74	0.11	3.08	16
Route 2 -S	423027071291302	04/12/2007	55.9	1.04	0.17	0.35	26
Route 2 -S	423027071291302	05/16/2007	3.2	1.36	0.14	0.13	17
Route 2 -S	423027071291302	08/08/2007	5.39	2.44	0.16	0.16	16

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Sulfate, dissolved (mg/L)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), total (mg/L)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	8.21	2.9	0.23	0.19	12
Interstate 195 -T	414339070462201	04/23/2006	2.46	0.65	0.04	0.06	7.6
Interstate 195 -T	414339070462201	06/24/2006	2.46	0.98	0.04	0.09	2.6
Interstate 195 -T	414339070462201	09/29/2006	2.26	0.8	0.04	0.08	2.8
Interstate 195 -T	414339070462201	12/01/2006	4.35	1.52	0.06	0.1	4.8
Interstate 195 -T	414339070462201	02/14/2007	5.85	0.44	0.06	0.27	9.3
Interstate 495 -P	422821071332001	09/15/2005	8.71	3.07	0.19	0.41	11
Interstate 495 -P	422821071332001	09/29/2005	2.85	0.99	0.17	0.35	19
Interstate 495 -P	422821071332001	10/22/2005	1.17	0.39	0.02	0.08	3.4
Interstate 495 -P	422821071332001	10/24/2005	1.21	0.31	0.02	0.07	4.4
Interstate 495 -P	422821071332001	01/11/2006	38.3	1.58	0.39	1.07	47
Interstate 495 -P	422821071332001	03/13/2006	74.2	2.36	0.68	1.15	42
Interstate 495 -P	422821071332001	05/09/2006	5.66	1.12	0.1	0.2	8.7
Interstate 495 -P	422821071332001	06/02/2006	4.83	1.41	0.21	0.61	13
Interstate 495 -P	422821071332001	08/20/2006	2.38	0.97	0.1	0.11	4.2
Interstate 495 -P	422821071332001	08/27/2006	2.53	0.67	E0.01	0.08	8.1
Interstate 495 -P	422821071332001	09/19/2006	3.81	1.2	0.14	0.17	6.7
Interstate 495 -P	422821071332001	11/12/2006	1.87	0.48	0.08	0.13	9.1
Interstate 495 -P	422821071332001	01/08/2007	6.22	0.67	0.04	0.14	6.5
Interstate 495 -P	422821071332001	03/02/2007	296	1.77	0.42	1.72	53
Interstate 495 -P	422821071332001	04/12/2007	75.6	1.24	0.25	1.79	35
Interstate 495 -P	422821071332001	08/06/2007	--	2.84	0.2	0.34	16
Interstate 495 -P	422821071332001	08/08/2007	6.43	2.25	0.13	0.31	12
Interstate 495 -P	422821071332001	09/10/2007	4.3	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	9.96	3.37	0.18	0.38	18
Interstate 495 -S	422716071343901	09/29/2005	3.83	0.98	0.08	0.18	12
Interstate 495 -S	422716071343901	10/22/2005	4.3	1.2	0.03	0.16	7.7
Interstate 495 -S	422716071343901	10/24/2005	1.61	0.39	E0.02	0.08	4.3
Interstate 495 -S	422716071343901	01/11/2006	83.7	1.72	0.24	1.43	32
Interstate 495 -S	422716071343901	01/18/2006	31.8	1.09	0.16	1.17	21
Interstate 495 -S	422716071343901	03/13/2006	94.3	1.95	0.23	0.93	29
Interstate 495 -S	422716071343901	05/09/2006	5.48	1.1	0.06	0.2	8.2
Interstate 495 -S	422716071343901	06/02/2006	2.01	0.53	0.03	0.1	8.5
Interstate 495 -S	422716071343901	08/20/2006	2.62	0.77	0.04	0.13	5.6
Interstate 495 -S	422716071343901	09/19/2006	3.77	0.98	0.05	0.15	6.9

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Sulfate, dissolved (mg/L)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), total (mg/L)	Phosphorus, total (mg/L)	Cadmium, total (µg/L)	Chromium, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	8.62	1.54	0.13	0.25	24
Interstate 95 -P	422620071153301	09/29/2005	10.8	1.37	0.12	0.26	15
Interstate 95 -P	422620071153301	10/22/2005	--	1.46	0.03	0.06	4.7
Interstate 95 -P	422620071153301	11/16/2005	--	1.19	0.05	0.08	4.9
Interstate 95 -P	422620071153301	01/12/2006	125	3.74	0.31	2.4	89
Interstate 95 -P	422620071153301	01/18/2006	19.8	1.58	0.23	1.03	39
Interstate 95 -P	422620071153301	03/13/2006	468	6.12	0.54	5.7	73
Interstate 95 -P	422620071153301	05/09/2006	9.18	1.52	0.13	0.16	21
Interstate 95 -P	422620071153301	06/02/2006	5.12	0.95	0.09	0.09	9
Interstate 95 -P	422620071153301	08/20/2006	6.02	0.8	0.04	0.06	4
Interstate 95 -P	422620071153301	08/27/2006	6.16	0.89	0.03	0.05	7.2
Interstate 95 -P	422620071153301	09/19/2006	6.87	1.12	0.07	0.11	9.9
Interstate 95 -P	422620071153301	10/20/2006	6.28	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	3.25	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	3.8	1.25	0.1	0.37	9.7
Interstate 95 -P	422620071153301	03/11/2007	364	3.32	0.15	2.63	16
Interstate 95 -P	422620071153301	03/17/2007	214	1.75	0.38	1.31	47
Interstate 95 -P	422620071153301	04/12/2007	43.6	2.05	0.2	0.69	29
Interstate 95 -P	422620071153301	08/06/2007	12.4	2.32	0.21	0.08	11
Interstate 95 -P	422620071153301	08/08/2007	13.1	2.38	0.16	0.1	8.3
Interstate 95 -S	422420071153302	08/20/2006	3.39	1.02	0.05	0.17	3.1
Interstate 95 -S	422420071153302	08/27/2006	4	1.04	E0.01	0.15	11
Interstate 95 -S	422420071153302	09/19/2006	6.24	1.65	0.06	0.23	6.1
Interstate 95 -S	422420071153302	11/07/2006	3.33	1.15	0.06	0.11	5.9
Interstate 95 -S	422420071153302	03/02/2007	76.9	2.62	0.36	3.05	40
Interstate 95 -S	422420071153302	03/17/2007	154	1.54	0.27	1.34	28
Interstate 95 -S	422420071153302	04/12/2007	8.85	1.3	0.2	0.42	27
Interstate 95 -S	422420071153302	05/16/2007	4.35	2.8	0.33	0.3	27
Interstate 95 -S	422420071153302	08/06/2007	9.82	4.07	0.41	0.53	16
Interstate 95 -S	422420071153302	08/08/2007	10.9	3.89	0.15	0.28	39
Interstate 93 -T	421647071024703	04/23/2006	17.4	1.71	0.13	0.45	26
Interstate 93 -T	421647071024703	06/23/2006	5.13	2.09	0.71	1.69	100
Interstate 93 -T	421647071024703	09/19/2006	4.84	1.1	0.11	0.17	13
Interstate 93 -T	421647071024703	12/01/2006	10.2	2.32	0.34	0.78	40
Interstate 93 -T	421647071024703	02/14/2007	257	4	1	4	110

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Copper, total, recoverable (µg/L)	Iron, total, recoverable (µg/L)	Lead, total, recoverable (µg/L)	Manganese, total, recoverable (µg/L)	Nickel, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	18.7	467	2	83.5	5.69
Route 119 -P	424209071545201	09/29/2005	4.97	824	2.1	17.7	1.25
Route 119 -P	424209071545201	10/22/2005	2.13	186	0.6	13.7	0.55
Route 119 -P	424209071545201	10/24/2005	1.1	112	0.3	6.1	0.25
Route 119 -P	424209071545201	01/11/2006	27.4	9,750	20.2	171	12.5
Route 119 -P	424209071545201	01/18/2006	17.2	7,330	19.3	129	8.31
Route 119 -P	424209071545201	03/13/2006	50.2	23,900	40.7	312	22.7
Route 119 -P	424209071545201	05/09/2006	7.46	441	1.3	22.8	1.64
Route 119 -P	424209071545201	06/01/2006	17.4	3,780	9.8	82.4	6.24
Route 119 -P	424209071545201	09/14/2006	5.64	367	1.1	11.6	1.11
Route 119 -P	424209071545201	09/19/2006	6.68	186	0.7	25.9	1.66
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	1.68	100	0.4	4.5	0.34
Route 119 -P	424209071545201	11/12/2006	--	--	--	--	--
Route 119 -P	424209071545201	01/08/2007	5.08	810	2.4	14.3	1.18
Route 119 -P	424209071545201	04/01/2007	8.26	1,350	3.6	27.8	4.45
Route 119 -P	424209071545201	04/14/2007	11.4	3,610	6.9	74.1	4.59
Route 119 -P	424209071545201	06/03/2007	3.62	294	0.8	9.9	0.83
Route 119 -P	424209071545201	07/11/2007	3.75	654	1.4	16.7	1.16
Route 119 -S	424155071543201	09/29/2005	4.62	1,030	2.6	19.8	1.29
Route 119 -S	424155071543201	10/24/2005	0.76	94	0.3	7.5	0.2
Route 119 -S	424155071543201	01/11/2006	29.9	10,400	22.4	179	12.4
Route 119 -S	424155071543201	01/18/2006	15.9	5,630	16	104	6.59
Route 119 -S	424155071543201	03/13/2006	39.9	16,900	32.5	224	15.9
Route 119 -S	424155071543201	08/20/2006	2.12	629	0.9	20.3	0.64
Route 119 -S	424155071543201	11/08/2006	1.68	319	0.6	8.2	0.38
Route 119 -S	424155071543201	04/27/2007	9.89	2,780	6.4	80.5	3.31
Route 119 -S	424155071543201	06/03/2007	4.54	456	1	16.2	0.95
Route 119 -S	424155071543201	07/11/2007	3.3	606	1.2	12.8	0.76
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	5.45	546	2.6	21.3	1.12
Route 8 -T	424019073062601	06/23/2006	10.7	842	4.9	39.6	2.08
Route 8 -T	424019073062601	09/23/2006	6.71	9	0.1	0.9	1.02
Route 8 -T	424019073062601	12/01/2006	32.4	3,580	21.7	115	4.48
Route 8 -T	424019073062601	03/02/2007	51.2	9,760	49.3	234	18.9

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Copper, total, recoverable (µg/L)	Iron, total, recoverable (µg/L)	Lead, total, recoverable (µg/L)	Manganese, total, recoverable (µg/L)	Nickel, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	25.9	2,360	8.3	70.8	6.21
Interstate 190 -T	423016071431501	09/29/2005	26.7	2,950	8.6	62.6	5.23
Interstate 190 -T	423016071431501	10/07/2005	10.7	681	2.3	21.4	1.84
Interstate 190 -T	423016071431501	10/22/2005	12.5	606	1.4	88.2	2.45
Interstate 190 -T	423016071431501	10/24/2005	4.7	415	1.5	14.7	0.88
Interstate 190 -T	423016071431501	03/13/2006	140	21,800	67.9	390	33.5
Route 2 -P	423027071291301	09/15/2005	44.3	1,360	8	64	6.03
Route 2 -P	423027071291301	09/29/2005	34.6	2,930	12.7	64.6	4.59
Route 2 -P	423027071291301	10/22/2005	12.9	725	3	33.9	1.66
Route 2 -P	423027071291301	10/24/2005	5.18	298	1.5	15.8	0.74
Route 2 -P	423027071291301	01/11/2006	65.6	9,990	39.1	213	15.6
Route 2 -P	423027071291301	01/18/2006	39.9	7,060	30.3	121	8.54
Route 2 -P	423027071291301	03/13/2006	82.2	13,200	47.4	205	16.6
Route 2 -P	423027071291301	05/09/2006	20.9	1,080	4.8	33.3	2.52
Route 2 -P	423027071291301	06/02/2006	23	2,220	6.6	35.3	2.82
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	15.8	1,090	3.2	18.8	1.52
Route 2 -P	423027071291301	08/27/2006	7.24	187	1.1	12.8	0.9
Route 2 -P	423027071291301	09/19/2006	13	841	3.1	27.4	1.95
Route 2 -P	423027071291301	11/07/2006	10.4	258	1.6	20.3	1
Route 2 -P	423027071291301	01/08/2007	19.8	1,320	6.3	25.4	2.12
Route 2 -P	423027071291301	03/02/2007	108	16,600	60	325	37.9
Route 2 -P	423027071291301	04/12/2007	83.7	12,100	43.6	185	15.7
Route 2 -P	423027071291301	08/06/2007	37.2	1,970	9.8	69.2	5.01
Route 2 -P	423027071291301	08/08/2007	32.4	2,110	10.2	56.6	4.53
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	12.9	665	3.5	22.6	1.67
Route 2 -S	423027071291302	08/27/2006	8.57	307	1.6	16.6	0.95
Route 2 -S	423027071291302	09/19/2006	20.9	1,860	6.1	38.1	2.93
Route 2 -S	423027071291302	12/01/2006	44.4	3,520	16	65.9	4.44
Route 2 -S	423027071291302	01/08/2007	17.6	955	5.1	20.7	1.65
Route 2 -S	423027071291302	03/17/2007	70.9	4,110	13.1	217	50
Route 2 -S	423027071291302	04/12/2007	50.2	7,050	21.1	100	8
Route 2 -S	423027071291302	05/16/2007	25.5	2,170	9.4	42.6	3.42
Route 2 -S	423027071291302	08/08/2007	46.9	2,360	10.9	64.7	6.81

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Copper, total, recoverable (µg/L)	Iron, total, recoverable (µg/L)	Lead, total, recoverable (µg/L)	Manganese, total, recoverable (µg/L)	Nickel, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	30	2,730	13.8	86.5	7.02
Interstate 195 -T	414339070462201	04/23/2006	16.3	1,380	8.2	18.6	2.5
Interstate 195 -T	414339070462201	06/24/2006	11	527	3.2	13.6	1.62
Interstate 195 -T	414339070462201	09/29/2006	28.1	542	3.1	13.1	1.5
Interstate 195 -T	414339070462201	12/01/2006	17.7	947	7.3	22.6	2.35
Interstate 195 -T	414339070462201	02/14/2007	24.6	1,690	10.7	30.3	5.38
Interstate 495 -P	422821071332001	09/15/2005	64.9	1,740	8.7	71.5	7.65
Interstate 495 -P	422821071332001	09/29/2005	59.3	7,640	20.9	92.8	7.24
Interstate 495 -P	422821071332001	10/22/2005	10.7	868	3.2	18.3	1.47
Interstate 495 -P	422821071332001	10/24/2005	11.5	840	3	18	1.44
Interstate 495 -P	422821071332001	01/11/2006	164	28,000	76.2	459	29.9
Interstate 495 -P	422821071332001	03/13/2006	155	20,200	69.7	303	24.2
Interstate 495 -P	422821071332001	05/09/2006	29	1,530	5.9	39.4	2.98
Interstate 495 -P	422821071332001	06/02/2006	45.1	7,240	10.6	114	6.83
Interstate 495 -P	422821071332001	08/20/2006	16.5	1,110	3.6	23	1.84
Interstate 495 -P	422821071332001	08/27/2006	12.4	561	2.1	16.5	1.31
Interstate 495 -P	422821071332001	09/19/2006	29.2	1,670	7	42	3.03
Interstate 495 -P	422821071332001	11/12/2006	23.9	1,720	7.4	29.4	2.39
Interstate 495 -P	422821071332001	01/08/2007	22.4	1,370	5.8	28.9	2.24
Interstate 495 -P	422821071332001	03/02/2007	166	21,600	75.5	328	34.6
Interstate 495 -P	422821071332001	04/12/2007	89.4	11,500	53.5	184	15.6
Interstate 495 -P	422821071332001	08/06/2007	55.2	3,680	14.3	85.7	7
Interstate 495 -P	422821071332001	08/08/2007	49	3,310	12.6	77	6.46
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	62	1,870	12.1	75.6	8.85
Interstate 495 -S	422716071343901	09/29/2005	25.3	1,460	8.8	34.2	3.23
Interstate 495 -S	422716071343901	10/22/2005	14.2	591	2.9	23.2	1.9
Interstate 495 -S	422716071343901	10/24/2005	9.64	627	2.5	14.6	1.12
Interstate 495 -S	422716071343901	01/11/2006	90.3	13,800	47.5	299	21.4
Interstate 495 -S	422716071343901	01/18/2006	53.6	8,660	32.2	175	12.3
Interstate 495 -S	422716071343901	03/13/2006	82	10,900	41.6	198	15.7
Interstate 495 -S	422716071343901	05/09/2006	25.1	1,420	6.9	40.2	2.9
Interstate 495 -S	422716071343901	06/02/2006	12.9	1,090	4.5	20.5	1.71
Interstate 495 -S	422716071343901	08/20/2006	12.9	688	5.5	19	1.78
Interstate 495 -S	422716071343901	09/19/2006	16.2	727	2.7	24.2	1.99

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Copper, total, recoverable (µg/L)	Iron, total, recoverable (µg/L)	Lead, total, recoverable (µg/L)	Manganese, total, recoverable (µg/L)	Nickel, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	58.7	1,440	18.2	62.7	4.7
Interstate 95 -P	422620071153301	09/29/2005	40.4	3,620	31.4	65	4.78
Interstate 95 -P	422620071153301	10/22/2005	9.37	451	2.4	19.9	1.08
Interstate 95 -P	422620071153301	11/16/2005	18	536	3.8	27.5	1.88
Interstate 95 -P	422620071153301	01/12/2006	167	15,100	85.5	493	28.4
Interstate 95 -P	422620071153301	01/18/2006	111	10,100	67.9	231	16
Interstate 95 -P	422620071153301	03/13/2006	236	20,600	120	594	36.4
Interstate 95 -P	422620071153301	05/09/2006	59	2,450	14.9	59.1	4.38
Interstate 95 -P	422620071153301	06/02/2006	33.6	1,230	8.4	35.2	2.58
Interstate 95 -P	422620071153301	08/20/2006	18.2	389	3.2	29.7	1.66
Interstate 95 -P	422620071153301	08/27/2006	16.8	328	2.2	21.5	1.3
Interstate 95 -P	422620071153301	09/19/2006	26	1,280	13.2	43.1	2.39
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	33.8	1,690	46.2	34.1	3.28
Interstate 95 -P	422620071153301	03/11/2007	87.6	3,810	21.9	288	16.2
Interstate 95 -P	422620071153301	03/17/2007	123	11,800	54	263	27.3
Interstate 95 -P	422620071153301	04/12/2007	87.6	6,470	36.1	152	10.5
Interstate 95 -P	422620071153301	08/06/2007	44.6	1,160	14.4	53.6	4.26
Interstate 95 -P	422620071153301	08/08/2007	64.1	1,200	17.3	58.9	3.72
Interstate 95 -S	422420071153302	08/20/2006	10.3	414	2.3	17.1	2.85
Interstate 95 -S	422420071153302	08/27/2006	11.5	386	1.7	13.6	1.99
Interstate 95 -S	422420071153302	09/19/2006	18.6	593	2.8	25.6	4.36
Interstate 95 -S	422420071153302	11/07/2006	17.4	702	3.3	29	2.14
Interstate 95 -S	422420071153302	03/02/2007	103	12,600	46.2	254	25
Interstate 95 -S	422420071153302	03/17/2007	68.8	8,920	30.1	179	23.4
Interstate 95 -S	422420071153302	04/12/2007	52.8	5,320	19.5	81.1	9.2
Interstate 95 -S	422420071153302	05/16/2007	60	4,870	21.4	95.3	8
Interstate 95 -S	422420071153302	08/06/2007	42.7	4,230	19.3	120	7.81
Interstate 95 -S	422420071153302	08/08/2007	88.9	1,910	13.7	76.3	12.5
Interstate 93 -T	421647071024703	04/23/2006	91.4	4,060	35.1	84.5	6.84
Interstate 93 -T	421647071024703	06/23/2006	263	38,500	120	819	35.3
Interstate 93 -T	421647071024703	09/19/2006	56.4	3,380	17.8	81.2	4.49
Interstate 93 -T	421647071024703	12/01/2006	178	12,100	75.6	220	18.2
Interstate 93 -T	421647071024703	02/14/2007	538	27,200	366	535	48

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Zinc, total, recoverable (µg/L)	Fluorene, total, recoverable (µg/L)	Acenaphthene, total, recoverable (µg/L)	Acenaphthylene, total, recoverable (µg/L)	Anthracene, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	82.5	<2	<2	<2	<2
Route 119 -P	424209071545201	09/29/2005	25.4	<2	<2	<2	E0.02
Route 119 -P	424209071545201	10/22/2005	16.1	--	--	--	--
Route 119 -P	424209071545201	10/24/2005	8	--	--	--	--
Route 119 -P	424209071545201	01/11/2006	188	E0.06	E0.02	E0.04	E0.07
Route 119 -P	424209071545201	01/18/2006	145	E0.04	E0.02	E0.04	E0.05
Route 119 -P	424209071545201	03/13/2006	293	<80	<72	<96	<80
Route 119 -P	424209071545201	05/09/2006	25.6	<0.33	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	06/01/2006	107	<0.33	<0.28	E0.0240	E0.0316
Route 119 -P	424209071545201	09/14/2006	17.8	<0.33	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	09/19/2006	29.7	<0.33	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	9.4	E0.0057	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	11/12/2006	--	E0.0057	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	01/08/2007	23.6	E0.0073	E0.0027	E0.0096	E0.0116
Route 119 -P	424209071545201	04/01/2007	58.5	E0.0205	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	04/14/2007	72.4	E0.0128	E0.0052	E0.0104	E0.0199
Route 119 -P	424209071545201	06/03/2007	14.7	<0.33	<0.28	<0.30	<0.39
Route 119 -P	424209071545201	07/11/2007	19.8	<0.33	<0.28	<0.30	<0.39
Route 119 -S	424155071543201	09/29/2005	26.7	<2	<2	<2	<2
Route 119 -S	424155071543201	10/24/2005	8	<2	<2	<2	<2
Route 119 -S	424155071543201	01/11/2006	249	E0.05	E0.03	E0.05	E0.09
Route 119 -S	424155071543201	01/18/2006	91.4	E0.03	E0.01	E0.03	E0.05
Route 119 -S	424155071543201	03/13/2006	202	<80	<72	<96	<80
Route 119 -S	424155071543201	08/20/2006	21.2	<0.33	<0.28	<0.30	<0.39
Route 119 -S	424155071543201	11/08/2006	14.6	<0.33	<0.28	<0.30	<0.39
Route 119 -S	424155071543201	04/27/2007	187	E0.0131	E0.0043	E0.0195	E0.0200
Route 119 -S	424155071543201	06/03/2007	25.4	<0.33	<0.28	<0.30	<0.39
Route 119 -S	424155071543201	07/11/2007	17.1	<0.33	<0.28	<0.30	<0.39
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	21.5	E0.0100	<0.28	<0.30	E0.0131
Route 8 -T	424019073062601	06/23/2006	30.5	<0.33	<0.28	<0.30	<0.39
Route 8 -T	424019073062601	09/23/2006	9.2	E0.0100	<0.28	E0.0173	E0.0125
Route 8 -T	424019073062601	12/01/2006	107	E0.0176	E0.0083	E0.0290	E0.0518
Route 8 -T	424019073062601	03/02/2007	301	E0.0317	<0.28	E0.0419	E0.0444

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Zinc, total, recoverable (µg/L)	Fluorene, total, recoverable (µg/L)	Acenaphthene, total, recoverable (µg/L)	Acenaphthylene, total, recoverable (µg/L)	Anthracene, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	171	<2	<2	<2	<2
Interstate 190 -T	423016071431501	09/29/2005	103	E0.02	<2	<2	E0.04
Interstate 190 -T	423016071431501	10/07/2005	37.7	<2	<2	<2	E0.01
Interstate 190 -T	423016071431501	10/22/2005	59.2				
Interstate 190 -T	423016071431501	10/24/2005	23.6	E0.01	<2	<2	E0.01
Interstate 190 -T	423016071431501	03/13/2006	630	<40	E0.1	<48	E0.2
Route 2 -P	423027071291301	09/15/2005	402	<2	<2	<2	<2
Route 2 -P	423027071291301	09/29/2005	420	E0.03	<2	<2	E0.06
Route 2 -P	423027071291301	10/22/2005	182	E0.02	<2	<2	<2
Route 2 -P	423027071291301	10/24/2005	119	E0.01	<2	E0.01	<2
Route 2 -P	423027071291301	01/11/2006	1,100	E0.09	E0.04	E0.07	E0.09
Route 2 -P	423027071291301	01/18/2006	647	E0.06	E0.03	E0.04	E0.08
Route 2 -P	423027071291301	03/13/2006	926	E0.04	E0.02	E0.02	E0.05
Route 2 -P	423027071291301	05/09/2006	266	<0.33	<0.28	<0.30	<0.39
Route 2 -P	423027071291301	06/02/2006	195	<0.33	E0.0069	E0.0156	E0.0222
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	128	E0.0091	<0.28	E0.0090	E0.0125
Route 2 -P	423027071291301	08/27/2006	131	--	--	--	--
Route 2 -P	423027071291301	09/19/2006	166	E0.0144	<0.28	<0.30	E0.0182
Route 2 -P	423027071291301	11/07/2006	194	E0.0105	<0.28	<0.30	<0.39
Route 2 -P	423027071291301	01/08/2007	237	E0.0166	E0.0068	<0.30	E0.0203
Route 2 -P	423027071291301	03/02/2007	1,130	E0.142	E0.0555	E0.0634	E0.144
Route 2 -P	423027071291301	04/12/2007	833	E0.0908	E0.0466	E0.0533	E0.127
Route 2 -P	423027071291301	08/06/2007	382	<0.33	<0.28	E0.0371	<0.39
Route 2 -P	423027071291301	08/08/2007	350	<0.33	<0.28	<0.30	E0.0504
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	76	<0.33	<0.28	E0.0138	<0.39
Route 2 -S	423027071291302	08/27/2006	55	<0.33	<0.28	<0.30	<0.39
Route 2 -S	423027071291302	09/19/2006	128	E0.0133	<0.28	<0.30	E0.0242
Route 2 -S	423027071291302	12/01/2006	165	E0.0721	E0.0415	E0.0268	E0.147
Route 2 -S	423027071291302	01/08/2007	72	E0.0114	E0.0052	<0.30	E0.0284
Route 2 -S	423027071291302	03/17/2007	371	E0.0508	E0.0244	<0.30	<0.39
Route 2 -S	423027071291302	04/12/2007	228	E0.0688	E0.0258	E0.0251	E0.0855
Route 2 -S	423027071291302	05/16/2007	139	E0.0263	E0.0111	E0.0145	E0.0351
Route 2 -S	423027071291302	08/08/2007	207	<0.33	<0.28	<0.30	<0.39

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Zinc, total, recoverable (µg/L)	Fluorene, total, recoverable (µg/L)	Acenaphthene, total, recoverable (µg/L)	Acenaphthylene, total, recoverable (µg/L)	Anthracene, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	167	<0.33	<0.28	<0.30	<0.39
Interstate 195 -T	414339070462201	04/23/2006	52.8	E0.0190	<0.28	E0.0127	<0.39
Interstate 195 -T	414339070462201	06/24/2006	55.6	<33	<0.28	<0.30	<0.39
Interstate 195 -T	414339070462201	09/29/2006	52.9	E0.0183	<0.28	<0.30	E0.0135
Interstate 195 -T	414339070462201	12/01/2006	68.5	E0.0445	E0.0270	E0.0138	E0.104
Interstate 195 -T	414339070462201	02/14/2007	82.1	E0.0655	E0.0170	E0.0316	E0.0730
Interstate 495 -P	422821071332001	09/15/2005	211	<2	<2	<2	<2
Interstate 495 -P	422821071332001	09/29/2005	213	E0.05	E0.03	<2	E0.10
Interstate 495 -P	422821071332001	10/22/2005	51.9	E0.02	<2	E0.02	E0.02
Interstate 495 -P	422821071332001	10/24/2005	42.6	<2	<2	<2	E0.02
Interstate 495 -P	422821071332001	01/11/2006	687	E0.5	E0.3	E0.2	E0.8
Interstate 495 -P	422821071332001	03/13/2006	580	<80	E0.2	<96	E0.5
Interstate 495 -P	422821071332001	05/09/2006	90	E0.0143	E0.0078	<0.30	E0.0316
Interstate 495 -P	422821071332001	06/02/2006	131	E0.0318	E0.0214	E0.0243	E0.0775
Interstate 495 -P	422821071332001	08/20/2006	69	E0.0055	<0.28	E0.0178	E0.0110
Interstate 495 -P	422821071332001	08/27/2006	44.6	<0.33	<0.28	<0.30	E0.0099
Interstate 495 -P	422821071332001	09/19/2006	175	E0.0183	E0.0094	E0.0219	E0.0416
Interstate 495 -P	422821071332001	11/12/2006	96.7	E0.0306	E0.0114	E0.0160	E0.0504
Interstate 495 -P	422821071332001	01/08/2007	78.2	E0.0254	E0.0170	<0.30	E0.0633
Interstate 495 -P	422821071332001	03/02/2007	758	E0.300	E0.208	E0.0972	E0.526
Interstate 495 -P	422821071332001	04/12/2007	339	E0.100	E0.0622	E0.0304	E0.182
Interstate 495 -P	422821071332001	08/06/2007	293	<0.33	<0.28	E0.0507	E0.0584
Interstate 495 -P	422821071332001	08/08/2007	242	E0.0380	<0.28	E0.0352	E0.0999
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	238	<2	<2	<2	<2
Interstate 495 -S	422716071343901	09/29/2005	102	<2	<2	<2	E0.02
Interstate 495 -S	422716071343901	10/22/2005	73.1	<2	<2	<2	E0.02
Interstate 495 -S	422716071343901	10/24/2005	38.5	E0.02	<2	<2	<2
Interstate 495 -S	422716071343901	01/11/2006	537	E0.1	E0.05	E0.1	E0.1
Interstate 495 -S	422716071343901	01/18/2006	276	E0.07	E0.03	E0.05	E0.1
Interstate 495 -S	422716071343901	03/13/2006	413	<40	<36	<48	<40
Interstate 495 -S	422716071343901	05/09/2006	89.9	E0.0130	E0.0051	<0.30	E0.0127
Interstate 495 -S	422716071343901	06/02/2006	51.3	E0.0121	E0.0076	E0.0201	E0.0144
Interstate 495 -S	422716071343901	08/20/2006	64.6	E0.0072	<0.28	E0.0133	E0.0100
Interstate 495 -S	422716071343901	09/19/2006	84.3	E0.0153	<0.28	<0.30	E0.0169

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Zinc, total, recoverable (µg/L)	Fluorene, total, recoverable (µg/L)	Acenaphthene, total, recoverable (µg/L)	Acenaphthylene, total, recoverable (µg/L)	Anthracene, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	110	<2	<2	<2	E0.07
Interstate 95 -P	422620071153301	09/29/2005	228	E0.05	E0.03	E0.1	E0.1
Interstate 95 -P	422620071153301	10/22/2005	37.5	<2	<2	<2	E0.02
Interstate 95 -P	422620071153301	11/16/2005	51	<2	<2	<2	<2
Interstate 95 -P	422620071153301	01/12/2006	847	E0.08	E0.04	E0.08	E0.1
Interstate 95 -P	422620071153301	01/18/2006	509	E0.1	E0.08	E0.09	E0.3
Interstate 95 -P	422620071153301	03/13/2006	963	<80	E0.2	<96	E0.4
Interstate 95 -P	422620071153301	05/09/2006	122	E0.0206	<0.28	E0.0461	E0.0786
Interstate 95 -P	422620071153301	06/02/2006	79.4	<0.33	<0.28	E0.0170	E0.0315
Interstate 95 -P	422620071153301	08/20/2006	41	<0.33	<0.28	E0.0128	E0.0088
Interstate 95 -P	422620071153301	08/27/2006	35	<0.33	<0.28	<0.30	E0.0210
Interstate 95 -P	422620071153301	09/19/2006	83.3	<0.33	<0.28	E0.0363	E0.0385
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	108	E0.0249	E0.0129	E0.0194	E0.0428
Interstate 95 -P	422620071153301	03/11/2007	312	E0.0391	<0.28	<0.30	E0.151
Interstate 95 -P	422620071153301	03/17/2007	462	E0.116	E0.0751	<0.30	E0.205
Interstate 95 -P	422620071153301	04/12/2007	339	E0.0682	E0.0372	E0.0330	E0.118
Interstate 95 -P	422620071153301	08/06/2007	114	<0.33	<0.28	<0.30	<0.39
Interstate 95 -P	422620071153301	08/08/2007	101	<0.33	<0.28	E0.0480	<0.39
Interstate 95 -S	422420071153302	08/20/2006	68.3	<0.33	<0.28	<0.30	E0.0083
Interstate 95 -S	422420071153302	08/27/2006	48.5	<0.33	<0.28	<0.30	<0.39
Interstate 95 -S	422420071153302	09/19/2006	115	<0.33	<0.28	<0.30	E0.0205
Interstate 95 -S	422420071153302	11/07/2006	69.3	E0.0519	E0.0310	<0.30	E0.0750
Interstate 95 -S	422420071153302	03/02/2007	553	0.448	E0.270	E0.127	0.519
Interstate 95 -S	422420071153302	03/17/2007	336	E0.297	E0.211	<0.30	E0.343
Interstate 95 -S	422420071153302	04/12/2007	218	E0.146	E0.0964	<0.30	E0.192
Interstate 95 -S	422420071153302	05/16/2007	238	E0.0970	E0.0594	<0.30	E0.150
Interstate 95 -S	422420071153302	08/06/2007	208	<0.33	<0.28	E0.108	E0.100
Interstate 95 -S	422420071153302	08/08/2007	371	<0.33	<0.28	E0.0868	E0.0453
Interstate 93 -T	421647071024703	04/23/2006	301	E0.0566	E0.0217	E0.0497	E0.0983
Interstate 93 -T	421647071024703	06/23/2006	1,380	E0.139	E0.0954	E0.0869	E0.266
Interstate 93 -T	421647071024703	09/19/2006	180	E0.0212	E0.0146	E0.0263	E0.0617
Interstate 93 -T	421647071024703	12/01/2006	613	E0.115	E0.0668	E0.0666	E0.205
Interstate 93 -T	421647071024703	02/14/2007	1,870	E0.300	E0.184	<0.30	1

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzo[a]-anthracene, total, recoverable (µg/L)	Benzo[a]-pyrene, total, recoverable (µg/L)	Benzo[b]fluoranthene, total, recoverable (µg/L)	Benzo[ghi]perylene, total, recoverable (µg/L)	Benzo[k]-fluoranthene, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	<2	<1	<2	E0.03	<2
Route 119 -P	424209071545201	09/29/2005	E0.04	E0.07	E0.1	E0.05	<2
Route 119 -P	424209071545201	10/22/2005	--	--	--	--	--
Route 119 -P	424209071545201	10/24/2005	--	--	--	--	--
Route 119 -P	424209071545201	01/11/2006	E0.2	E0.3	E0.7	E0.2	E0.2
Route 119 -P	424209071545201	01/18/2006	E0.2	E0.3	E0.6	E0.1	E0.2
Route 119 -P	424209071545201	03/13/2006	<96	E0.5	E0.6	E0.4	E0.2
Route 119 -P	424209071545201	05/09/2006	<0.26	<0.33	<0.40	E0.0209	<0.45
Route 119 -P	424209071545201	06/01/2006	E0.0911	E0.147	E0.255	E0.141	E0.0931
Route 119 -P	424209071545201	09/14/2006	<0.26	<0.33	<0.40	<0.64	<0.45
Route 119 -P	424209071545201	09/19/2006	<0.26	E0.0294	E0.0408	E0.0287	E0.0176
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	<0.26	<0.33	<0.40	<0.64	<0.45
Route 119 -P	424209071545201	11/12/2006	<0.26	E0.0380	E0.0600	E0.0387	<0.45
Route 119 -P	424209071545201	01/08/2007	E0.0336	E0.0417	E0.0764	E0.0461	E0.0246
Route 119 -P	424209071545201	04/01/2007	<0.26	E0.0695	E0.149	E0.0899	E0.0597
Route 119 -P	424209071545201	04/14/2007	E0.0606	E0.0970	E0.218	E0.0705	E0.0782
Route 119 -P	424209071545201	06/03/2007	<0.26	<0.33	<0.40	<0.64	<0.45
Route 119 -P	424209071545201	07/11/2007	<0.26	<0.33	E0.0440	E0.0256	<0.45
Route 119 -S	424155071543201	09/29/2005	E0.05	E0.08	E0.1	E0.06	<2
Route 119 -S	424155071543201	10/24/2005	<2	<1	<2	<3	<2
Route 119 -S	424155071543201	01/11/2006	E0.3	E0.4	E0.9	E0.2	E0.3
Route 119 -S	424155071543201	01/18/2006	E0.1	E0.2	E0.4	E0.1	E0.1
Route 119 -S	424155071543201	03/13/2006	<96	E0.4	E0.6	E0.4	E0.2
Route 119 -S	424155071543201	08/20/2006	<0.26	<0.33	<0.40	<0.64	<0.45
Route 119 -S	424155071543201	11/08/2006	<0.26	E0.0214	E0.0316	E0.0175	<0.45
Route 119 -S	424155071543201	04/27/2007	E0.0440	E0.0800	E0.160	E0.0410	E0.0517
Route 119 -S	424155071543201	06/03/2007	<0.26	<0.33	<0.40	<0.64	<0.45
Route 119 -S	424155071543201	07/11/2007	<0.26	<0.33	E0.0433	E0.0302	E0.0142
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	<0.26	E0.0366	E0.0564	E0.0329	E0.0223
Route 8 -T	424019073062601	06/23/2006	<0.26	<0.33	<0.40	E0.0572	<0.45
Route 8 -T	424019073062601	09/23/2006	E0.0406	E0.0770	E0.114	E0.0682	E0.0461
Route 8 -T	424019073062601	12/01/2006	E0.160	E0.218	E0.356	E0.125	E0.144
Route 8 -T	424019073062601	03/02/2007	<0.26	E0.176	E0.586	E0.163	<0.45

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzo[<i>a</i>]-anthracene, total, recoverable (µg/L)	Benzo[<i>a</i>]-pyrene, total, recoverable (µg/L)	Benzo[<i>b</i>]fluoranthene, total, recoverable (µg/L)	Benzo[<i>ghi</i>]-perylene, total, recoverable (µg/L)	Benzo[<i>k</i>]-fluoranthene, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	<2	<1	<2	E0.1	<2
Interstate 190 -T	423016071431501	09/29/2005	E0.1	E0.2	E0.4	E0.1	E0.1
Interstate 190 -T	423016071431501	10/07/2005	E0.03	E0.06	E0.1	E0.05	E0.05
Interstate 190 -T	423016071431501	10/22/2005	--	--	--	--	--
Interstate 190 -T	423016071431501	10/24/2005	E0.04	E0.04	E0.09	<3	<2
Interstate 190 -T	423016071431501	03/13/2006	E0.9	E1	E2	E1	E0.7
Route 2 -P	423027071291301	09/15/2005	E0.05	<1	E0.1	E0.08	E0.05
Route 2 -P	423027071291301	09/29/2005	E0.2	E0.2	E0.5	E0.2	E0.1
Route 2 -P	423027071291301	10/22/2005	E0.06	E0.08	E0.2	E0.07	E0.06
Route 2 -P	423027071291301	10/24/2005	<2	<1	E0.08	<3	E0.04
Route 2 -P	423027071291301	01/11/2006	E0.5	E0.6	E2	E0.4	E0.4
Route 2 -P	423027071291301	01/18/2006	E0.4	E0.5	E1	E0.3	E0.4
Route 2 -P	423027071291301	03/13/2006	E0.2	E0.3	E0.6	E0.2	E0.2
Route 2 -P	423027071291301	05/09/2006	E0.0659	E0.105	E0.201	E0.104	E0.0724
Route 2 -P	423027071291301	06/02/2006	E0.103	E0.144	E0.261	E0.197	E0.104
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	E0.0666	E0.0946	E0.172	E0.0831	E0.0567
Route 2 -P	423027071291301	08/27/2006	--	--	--	--	--
Route 2 -P	423027071291301	09/19/2006	E0.0868	E0.149	E0.261	E0.150	E0.0805
Route 2 -P	423027071291301	11/07/2006	<0.26	<0.33	<0.40	<0.64	<0.45
Route 2 -P	423027071291301	01/08/2007	E0.0804	E0.103	E0.192	E0.124	E0.0657
Route 2 -P	423027071291301	03/02/2007	E0.564	0.411	E1.11	E0.326	E0.328
Route 2 -P	423027071291301	04/12/2007	0.645	0.854	2.02	E0.518	E0.722
Route 2 -P	423027071291301	08/06/2007	E0.157	E0.260	0.508	E0.238	E0.199
Route 2 -P	423027071291301	08/08/2007	E0.254	E0.269	E0.562	<0.64	E0.184
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	<0.26	E0.0310	E0.0506	E0.0384	<0.45
Route 2 -S	423027071291302	08/27/2006	<0.26	E0.0344	E0.0655	<0.64	<0.45
Route 2 -S	423027071291302	09/19/2006	E0.118	E0.193	E0.324	E0.162	E0.130
Route 2 -S	423027071291302	12/01/2006	0.519	0.638	1.03	E0.367	E0.396
Route 2 -S	423027071291302	01/08/2007	E0.0702	E0.107	E0.187	E0.117	E0.0598
Route 2 -S	423027071291302	03/17/2007	0.351	0.467	1.1	E0.280	E0.400
Route 2 -S	423027071291302	04/12/2007	0.486	0.596	1.5	E0.352	E0.609
Route 2 -S	423027071291302	05/16/2007	E0.198	E0.266	0.566	E0.133	E0.222
Route 2 -S	423027071291302	08/08/2007	E0.179	E0.302	E0.495	E0.198	E0.181

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzo[a]-anthracene, total, recoverable (µg/L)	Benzo[a]-pyrene, total, recoverable (µg/L)	Benzo[b]fluoranthene, total, recoverable (µg/L)	Benzo[ghi]perylene, total, recoverable (µg/L)	Benzo[k]-fluoranthene, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	E0.238	0.417	0.66	E0.301	E0.343
Interstate 195 -T	414339070462201	04/23/2006	E0.0705	E0.121	E0.285	E0.0892	E0.104
Interstate 195 -T	414339070462201	06/24/2006	<0.26	E0.0876	E0.122	E0.0843	E0.0656
Interstate 195 -T	414339070462201	09/29/2006	<0.26	E0.0851	E0.154	E0.0684	E0.0497
Interstate 195 -T	414339070462201	12/01/2006	E0.169	E0.273	E0.394	E0.144	E0.141
Interstate 195 -T	414339070462201	02/14/2007	E0.138	E0.110	E0.318	E0.123	E0.188
Interstate 495 -P	422821071332001	09/15/2005	E0.07	E0.10	E0.2	E0.1	E0.07
Interstate 495 -P	422821071332001	09/29/2005	E0.4	E0.5	E1	E0.4	E0.4
Interstate 495 -P	422821071332001	10/22/2005	E0.09	E0.1	E0.2	E0.08	E0.10
Interstate 495 -P	422821071332001	10/24/2005	E0.05	<1	E0.1	<3	<2
Interstate 495 -P	422821071332001	01/11/2006	E2	E2	E4	E1.0	E1
Interstate 495 -P	422821071332001	03/13/2006	E2	E3	E4	E2	E2
Interstate 495 -P	422821071332001	05/09/2006	E0.0970	E0.149	E0.254	E0.123	E0.0933
Interstate 495 -P	422821071332001	06/02/2006	0.281	E0.327	0.616	E0.270	E0.178
Interstate 495 -P	422821071332001	08/20/2006	E0.0513	E0.0828	E0.150	E0.0820	E0.0516
Interstate 495 -P	422821071332001	08/27/2006	E0.0319	E0.0438	E0.0757	E0.0357	E0.0337
Interstate 495 -P	422821071332001	09/19/2006	E0.172	E0.239	E0.391	E0.161	E0.139
Interstate 495 -P	422821071332001	11/12/2006	E0.197	E0.240	0.406	E0.167	E0.149
Interstate 495 -P	422821071332001	01/08/2007	E0.166	E0.188	E0.305	E0.186	E0.0966
Interstate 495 -P	422821071332001	03/02/2007	E1.33	E0.760	E1.55	E0.464	E0.477
Interstate 495 -P	422821071332001	04/12/2007	0.699	0.815	1.68	E0.424	E0.652
Interstate 495 -P	422821071332001	08/06/2007	0.29	0.471	0.79	E0.388	E0.292
Interstate 495 -P	422821071332001	08/08/2007	0.27	0.365	E0.564	E0.264	E0.190
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	E0.2	<1	E0.3	E0.1	E0.09
Interstate 495 -S	422716071343901	09/29/2005	E0.07	E0.1	E0.2	E0.10	E0.09
Interstate 495 -S	422716071343901	10/22/2005	<2	E0.08	E0.1	<3	E0.06
Interstate 495 -S	422716071343901	10/24/2005	E0.04	E0.06	E0.09	<3	E0.04
Interstate 495 -S	422716071343901	01/11/2006	E0.6	E0.7	E2	E0.4	E0.6
Interstate 495 -S	422716071343901	01/18/2006	E0.5	E0.6	E1	E0.3	E0.4
Interstate 495 -S	422716071343901	03/13/2006	E0.5	E0.5	E1	E0.7	E0.4
Interstate 495 -S	422716071343901	05/09/2006	E0.0465	E0.0826	E0.151	E0.0802	E0.0547
Interstate 495 -S	422716071343901	06/02/2006	E0.0722	E0.111	E0.183	E0.0874	E0.0662
Interstate 495 -S	422716071343901	08/20/2006	E0.0427	E0.0584	E0.111	E0.0721	E0.0364
Interstate 495 -S	422716071343901	09/19/2006	E0.0508	E0.0980	E0.166	E0.0911	E0.0547

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzo[a]-anthracene, total, recoverable (µg/L)	Benzo[a]-pyrene, total, recoverable (µg/L)	Benzo[b]fluoranthene, total, recoverable (µg/L)	Benzo[ghi]perylene, total, recoverable (µg/L)	Benzo[k]-fluoranthene, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	E0.2	E0.3	E0.5	E0.2	E0.2
Interstate 95 -P	422620071153301	09/29/2005	E0.3	E0.3	E0.6	E0.2	E0.2
Interstate 95 -P	422620071153301	10/22/2005	E0.04	E0.06	E0.10	<3	E0.03
Interstate 95 -P	422620071153301	11/16/2005	E0.09	E0.1	E0.2	E0.06	E0.08
Interstate 95 -P	422620071153301	01/12/2006	E0.8	E1	E2	E0.7	E0.8
Interstate 95 -P	422620071153301	01/18/2006	E2	E2	E5	E1	2
Interstate 95 -P	422620071153301	03/13/2006	E3	E4	E8	E4	E2
Interstate 95 -P	422620071153301	05/09/2006	0.424	0.533	1.05	E0.364	E0.358
Interstate 95 -P	422620071153301	06/02/2006	E0.162	E0.230	0.476	E0.249	E0.165
Interstate 95 -P	422620071153301	08/20/2006	E0.0324	E0.0422	E0.0820	E0.0425	E0.0283
Interstate 95 -P	422620071153301	08/27/2006	E0.0619	E0.0734	E0.109	E0.0353	E0.0481
Interstate 95 -P	422620071153301	09/19/2006	E0.160	E0.228	0.404	E0.162	E0.140
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	E0.197	E0.286	0.444	E0.160	E0.187
Interstate 95 -P	422620071153301	03/11/2007	E0.291	0.433	E1.10	E0.420	E0.403
Interstate 95 -P	422620071153301	03/17/2007	1.11	E1.42	E3.14	E0.827	E1.15
Interstate 95 -P	422620071153301	04/12/2007	0.684	0.812	1.98	E0.582	E0.661
Interstate 95 -P	422620071153301	08/06/2007	<0.26	E0.147	E0.277	E0.127	E0.104
Interstate 95 -P	422620071153301	08/08/2007	E0.130	E0.184	E0.473	<0.64	E0.169
Interstate 95 -S	422420071153302	08/20/2006	E0.0473	E0.0676	E0.117	E0.0834	E0.0428
Interstate 95 -S	422420071153302	08/27/2006	E0.0295	E0.0417	E0.0814	E0.0372	E0.0347
Interstate 95 -S	422420071153302	09/19/2006	E0.0958	E0.158	E0.261	E0.143	E0.0994
Interstate 95 -S	422420071153302	11/07/2006	E0.148	E0.155	E0.248	E0.0971	E0.0970
Interstate 95 -S	422420071153302	03/02/2007	E2.49	1.5	E3.18	E1.02	E1.18
Interstate 95 -S	422420071153302	03/17/2007	1.07	E1.31	E2.78	E0.894	E0.993
Interstate 95 -S	422420071153302	04/12/2007	0.905	1.07	2.13	E0.600	E0.746
Interstate 95 -S	422420071153302	05/16/2007	0.732	0.881	1.76	E0.457	E0.543
Interstate 95 -S	422420071153302	08/06/2007	0.576	0.796	1.3	E0.551	0.748
Interstate 95 -S	422420071153302	08/08/2007	E0.235	E0.310	E0.584	E0.241	E0.293
Interstate 93 -T	421647071024703	04/23/2006	0.427	0.542	1.26	E0.343	E0.408
Interstate 93 -T	421647071024703	06/23/2006	E1.15	E1.36	E2.56	E0.662	E0.918
Interstate 93 -T	421647071024703	09/19/2006	0.28	0.364	0.679	E0.267	E0.298
Interstate 93 -T	421647071024703	12/01/2006	0.763	0.926	1.58	E0.490	0.626
Interstate 93 -T	421647071024703	02/14/2007	1	<1.89	E4.14	E1.00	E1.50

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzyl n-butyl phthalate, total, recoverable (µg/L)	Bis(2-ethylhexyl) phthalate, total, recoverable (µg/L)	Chrysene, total, recoverable (µg/L)	Dibenzo[a,h] anthracene, total, recoverable (µg/L)	Diethyl phthalate, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	<1.26	<1.85	<3	<3	<0.61
Route 119 -P	424209071545201	09/29/2005	<1.26	<2.01	E0.08	<3	<0.61
Route 119 -P	424209071545201	10/22/2005	--	--	--	--	--
Route 119 -P	424209071545201	10/24/2005	--	--	--	--	--
Route 119 -P	424209071545201	01/11/2006	<1.26	E6.35	E0.6	<3	<0.61
Route 119 -P	424209071545201	01/18/2006	E14.6	E4.95	E0.3	<3	<0.61
Route 119 -P	424209071545201	03/13/2006	<50.4	<42	E0.4	<140	<24.4
Route 119 -P	424209071545201	05/09/2006	<1.26	<1.23	E0.0201	<0.70	<0.61
Route 119 -P	424209071545201	06/01/2006	<1.26	<1.57	E0.175	E0.0352	<0.61
Route 119 -P	424209071545201	09/14/2006	<1.26	E4.83	<0.33	<0.70	E0.176
Route 119 -P	424209071545201	09/19/2006	<1.26	E1.18	<0.33	<0.70	<0.61
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	<1.26	E1.73	<0.33	<0.70	<0.61
Route 119 -P	424209071545201	11/12/2006	<1.26	E3.54	<0.33	<0.70	<0.61
Route 119 -P	424209071545201	01/08/2007	<1.26	E1.31	E0.0627	<0.70	<0.61
Route 119 -P	424209071545201	04/01/2007	<1.26	E2.05	E0.127	<0.70	E0.166
Route 119 -P	424209071545201	04/14/2007	<1.26	E2.45	E0.112	<0.70	E0.128
Route 119 -P	424209071545201	06/03/2007	<1.26	<1.16	<0.33	<0.70	<0.61
Route 119 -P	424209071545201	07/11/2007	<1.26	<1.05	E0.0229	<0.70	<0.61
Route 119 -S	424155071543201	09/29/2005	<1.26	<1.71	E0.09	<3	<0.61
Route 119 -S	424155071543201	10/24/2005	<1.26	<1.05	<3	<3	<0.61
Route 119 -S	424155071543201	01/11/2006	<1.26	E4.79	E0.6	<3	<0.61
Route 119 -S	424155071543201	01/18/2006	E1.67	E4.14	E0.2	<3	<0.61
Route 119 -S	424155071543201	03/13/2006	<50.4	<42	E0.5	<140	<24.4
Route 119 -S	424155071543201	08/20/2006	<1.26	E0.652	<0.33	<0.70	E0.262
Route 119 -S	424155071543201	11/08/2006	<1.26	E0.866	<0.33	<0.70	<0.61
Route 119 -S	424155071543201	04/27/2007	<1.26	<1.67	E0.104	<0.70	<0.61
Route 119 -S	424155071543201	06/03/2007	<1.26	<1.05	<0.33	<0.70	<0.61
Route 119 -S	424155071543201	07/11/2007	<1.26	<1.05	E0.0305	<0.70	E0.466
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	<1.26	<1.44	E0.0320	<0.70	<0.61
Route 8 -T	424019073062601	06/23/2006	<1.26	<1.36	<0.33	<0.70	<0.61
Route 8 -T	424019073062601	09/23/2006	<1.26	E7.67	E0.0542	<0.70	<0.61
Route 8 -T	424019073062601	12/01/2006	E0.367	E4.89	E0.164	<0.70	E0.200
Route 8 -T	424019073062601	03/02/2007	<1.26	E12.6	E0.333	<0.70	<0.61

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzyl n-butyl phthalate, total, recoverable (µg/L)	Bis(2-ethylhexyl) phthalate, total, recoverable (µg/L)	Chrysene, total, recoverable (µg/L)	Dibenzo[a,h] anthracene, total, recoverable (µg/L)	Diethyl phthalate, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	<1.26	<5.30	<3	<3	<0.61
Interstate 190 -T	423016071431501	09/29/2005	<1.26	E5.09	E0.2	<3	<0.61
Interstate 190 -T	423016071431501	10/07/2005	<1.26	E4.45	E0.06	<3	<0.61
Interstate 190 -T	423016071431501	10/22/2005	--	--	--	--	--
Interstate 190 -T	423016071431501	10/24/2005	<1.26	<1.52	E0.05	<3	<0.61
Interstate 190 -T	423016071431501	03/13/2006	<25.2	<21	E2	<68	<12.2
Route 2 -P	423027071291301	09/15/2005	<1.26	E5.60	E0.08	<3	<0.61
Route 2 -P	423027071291301	09/29/2005	<1.26	E5.35	E0.3	<3	<0.61
Route 2 -P	423027071291301	10/22/2005	<1.26	E3.50	E0.1	<3	<0.61
Route 2 -P	423027071291301	10/24/2005	<1.26	<1.70	<3	<3	<0.61
Route 2 -P	423027071291301	01/11/2006	<1.26	E9.15	E1	<3	<0.61
Route 2 -P	423027071291301	01/18/2006	E1.39	E13.8	E0.8	<3	<0.61
Route 2 -P	423027071291301	03/13/2006	<1.26	E3.91	E0.5	E0.06	<0.61
Route 2 -P	423027071291301	05/09/2006	<1.26	<2.67	E0.102	E0.0266	<0.61
Route 2 -P	423027071291301	06/02/2006	<1.26	<2.98	E0.201	E0.0512	<0.61
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	<1.26	1.37	E0.122	<0.70	E0.385
Route 2 -P	423027071291301	08/27/2006	--	E1.71	--	--	--
Route 2 -P	423027071291301	09/19/2006	<1.26	E2.58	E0.115	E0.0329	<0.61
Route 2 -P	423027071291301	11/07/2006	<1.26	E1.89	<0.33	<0.70	E0.192
Route 2 -P	423027071291301	01/08/2007	<1.26	E3.79	E0.119	<0.70	<0.61
Route 2 -P	423027071291301	03/02/2007	E1.14	E26.1	E1.49	<0.70	<0.61
Route 2 -P	423027071291301	04/12/2007	E0.759	E15.6	1.48	<0.70	<0.61
Route 2 -P	423027071291301	08/06/2007	<1.26	E5.60	0.375	<0.70	<0.61
Route 2 -P	423027071291301	08/08/2007	<1.26	E6.75	0.438	<0.70	<0.61
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	<1.26	E0.721	<0.33	<0.70	E0.210
Route 2 -S	423027071291302	08/27/2006	<1.26	E2.12	<0.33	<0.70	<0.61
Route 2 -S	423027071291302	09/19/2006	<1.26	E2.99	E0.197	E0.0512	<0.61
Route 2 -S	423027071291302	12/01/2006	E0.459	E7.00	0.786	E0.0983	E0.198
Route 2 -S	423027071291302	01/08/2007	<1.26	E2.87	E0.107	<0.70	<0.61
Route 2 -S	423027071291302	03/17/2007	<1.26	E6.97	0.801	<0.70	<0.61
Route 2 -S	423027071291302	04/12/2007	E0.593	E10.6	1.02	<0.70	E0.139
Route 2 -S	423027071291302	05/16/2007	<1.26	<10.2	0.368	<0.70	<0.61
Route 2 -S	423027071291302	08/08/2007	<1.26	E3.76	0.416	<0.70	<0.61

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzyl n-butyl phthalate, total, recoverable (µg/L)	Bis(2-ethylhexyl) phthalate, total, recoverable (µg/L)	Chrysene, total, recoverable (µg/L)	Dibenzo[a,h] anthracene, total, recoverable (µg/L)	Diethyl phthalate, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	<1.26	E5.09	0.569	<0.70	<0.61
Interstate 195 -T	414339070462201	04/23/2006	<1.26	<4.99	E0.109	E0.0273	<0.61
Interstate 195 -T	414339070462201	06/24/2006	<1.26	<1.13	<0.33	<0.70	<0.61
Interstate 195 -T	414339070462201	09/29/2006	E1.49	E231	<0.33	<0.70	1.32
Interstate 195 -T	414339070462201	12/01/2006	<1.26	E5.41	E0.271	<0.70	<0.61
Interstate 195 -T	414339070462201	02/14/2007	<1.26	E3.82	E0.209	E0.0388	<0.61
Interstate 495 -P	422821071332001	09/15/2005	<1.26	E5.41	E0.2	<3	<0.61
Interstate 495 -P	422821071332001	09/29/2005	<1.26	E8.50	E0.7	<3	<0.61
Interstate 495 -P	422821071332001	10/22/2005	E1.39	E3.09	E0.1	<3	<0.61
Interstate 495 -P	422821071332001	10/24/2005	<1.26	E4.95	E0.07	<3	<0.61
Interstate 495 -P	422821071332001	01/11/2006	<1.26	E13.5	3	E0.3	<0.61
Interstate 495 -P	422821071332001	03/13/2006	<50.4	<42	E4	<140	<24.4
Interstate 495 -P	422821071332001	05/09/2006	<1.26	<2.61	E0.180	E0.0307	<0.61
Interstate 495 -P	422821071332001	06/02/2006	<1.26	<4.71	0.414	E0.0482	<0.61
Interstate 495 -P	422821071332001	08/20/2006	<1.26	E1.94	E0.105	<0.70	<0.61
Interstate 495 -P	422821071332001	08/27/2006	<1.26	E3.28	E0.0409	<0.70	<0.61
Interstate 495 -P	422821071332001	09/19/2006	<1.26	E2.97	E0.194	E0.0455	<0.61
Interstate 495 -P	422821071332001	11/12/2006	E0.436	E4.12	E0.222	E0.0398	1.52
Interstate 495 -P	422821071332001	01/08/2007	<1.26	E3.95	E0.231	E0.0434	<0.61
Interstate 495 -P	422821071332001	03/02/2007	E1.14	E17.1	E2.06	<0.70	<0.61
Interstate 495 -P	422821071332001	04/12/2007	E0.718	E9.88	1.23	E0.137	<0.61
Interstate 495 -P	422821071332001	08/06/2007	<1.26	E6.82	0.45	<0.70	<0.61
Interstate 495 -P	422821071332001	08/08/2007	<1.26	E5.20	0.434	<0.70	<0.61
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	<1.26	E9.30	E0.2	E0.06	<0.61
Interstate 495 -S	422716071343901	09/29/2005	<1.26	E5.80	E0.1	<3	<0.61
Interstate 495 -S	422716071343901	10/22/2005	<1.26	5.16	E0.1	<3	<0.61
Interstate 495 -S	422716071343901	10/24/2005	<1.26	E4.06	E0.06	<3	<0.61
Interstate 495 -S	422716071343901	01/11/2006	<1.26	E9.81	E1	<3	<0.61
Interstate 495 -S	422716071343901	01/18/2006	E1.53	E10.5	E1.0	<3	<0.61
Interstate 495 -S	422716071343901	03/13/2006	<25.2	<21	E0.8	<68	<12.2
Interstate 495 -S	422716071343901	05/09/2006	<1.26	<2.25	E0.0806	E0.0187	<0.61
Interstate 495 -S	422716071343901	06/02/2006	<1.26	<3.15	E0.121	<0.7	<0.61
Interstate 495 -S	422716071343901	08/20/2006	<1.26	2.06	E0.0594	<0.70	E0.235
Interstate 495 -S	422716071343901	09/19/2006	<1.26	E4.02	E0.0763	<0.70	<0.61

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Benzyl n-butyl phthalate, total, recoverable (µg/L)	Bis(2-ethylhexyl) phthalate, total, recoverable (µg/L)	Chrysene, total, recoverable (µg/L)	Dibenzo[a,h] anthracene, total, recoverable (µg/L)	Diethyl phthalate, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	<1.26	E5.84	E0.4	E0.05	<0.61
Interstate 95 -P	422620071153301	09/29/2005	<1.26	E5.73	E0.4	<3	<0.61
Interstate 95 -P	422620071153301	10/22/2005	<1.26	<2.09	E0.06	<3	<0.61
Interstate 95 -P	422620071153301	11/16/2005	<1.26	E2.79	E0.1	<3	<0.61
Interstate 95 -P	422620071153301	01/12/2006	<1.26	E6.18	E2	E0.2	<0.61
Interstate 95 -P	422620071153301	01/18/2006	E1.81	E21.9	3	E0.4	<0.61
Interstate 95 -P	422620071153301	03/13/2006	<50.4	<52.1	E6	<140	<24.4
Interstate 95 -P	422620071153301	05/09/2006	<1.26	<3.46	0.802	E0.104	<0.61
Interstate 95 -P	422620071153301	06/02/2006	<1.26	<4.78	E0.256	E0.0347	<0.61
Interstate 95 -P	422620071153301	08/20/2006	<1.26	E0.898	E0.0459	<0.70	<0.61
Interstate 95 -P	422620071153301	08/27/2006	<1.26	E1.50	E0.0722	<0.70	<0.61
Interstate 95 -P	422620071153301	09/19/2006	<1.26	E3.66	E0.251	E0.0525	<0.61
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	<1.26	E5.87	E0.246	E0.0388	E0.315
Interstate 95 -P	422620071153301	03/11/2007	E0.504	E7.34	E0.814	<0.70	E0.468
Interstate 95 -P	422620071153301	03/17/2007	E0.750	E14.8	2.47	<0.70	<0.61
Interstate 95 -P	422620071153301	04/12/2007	E0.778	E14.0	1.5	E0.143	E0.209
Interstate 95 -P	422620071153301	08/06/2007	<1.26	E3.96	E0.197	<0.70	<0.61
Interstate 95 -P	422620071153301	08/08/2007	<1.26	E5.61	E0.304	<0.70	<0.61
Interstate 95 -S	422420071153302	08/20/2006	<1.26	1.83	E0.0957	<0.70	<0.61
Interstate 95 -S	422420071153302	08/27/2006	<1.26	E3.22	E0.0502	<0.70	<0.61
Interstate 95 -S	422420071153302	09/19/2006	E0.968	E3.73	E0.133	<0.70	<0.61
Interstate 95 -S	422420071153302	11/07/2006	E0.464	E4.95	E0.160	<0.70	E0.406
Interstate 95 -S	422420071153302	03/02/2007	E1.71	E24.2	E4.80	E0.274	<0.61
Interstate 95 -S	422420071153302	03/17/2007	E0.691	E11.9	2	<0.70	E0.330
Interstate 95 -S	422420071153302	04/12/2007	E0.722	E11.2	1.52	E0.163	E0.231
Interstate 95 -S	422420071153302	05/16/2007	<0.00	<17.0	1.13	<0.70	<0.61
Interstate 95 -S	422420071153302	08/06/2007	<1.26	E9.81	1.06	<0.70	<0.61
Interstate 95 -S	422420071153302	08/08/2007	<1.26	E8.12	0.462	<0.70	<0.61
Interstate 93 -T	421647071024703	04/23/2006	<1.24	E5.98	0.827	E0.0908	<0.61
Interstate 93 -T	421647071024703	06/23/2006	<1.26	E20.4	E1.91	E0.207	<0.61
Interstate 93 -T	421647071024703	09/19/2006	<1.26	E12.8	0.462	<0.70	<0.61
Interstate 93 -T	421647071024703	12/01/2006	E1.46	E14.3	1.23	<0.70	E0.357
Interstate 93 -T	421647071024703	02/14/2007	E3.76	E18.1	E2.22	<0.70	E0.491

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour:minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Dimethyl phthalate, total, recoverable (µg/L)	Di-n-butyl phthalate, total, recoverable (µg/L)	Di-n-octyl phthalate, total, recoverable, (µg/L)	Fluoranthene, total, recoverable (µg/L)	Indeno[1,2,3- <i>cd</i>]-pyrene, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	<0.59	<0.87	E0.798	<2	<3
Route 119 -P	424209071545201	09/29/2005	<0.59	E0.792	<1.86	E0.1	E0.04
Route 119 -P	424209071545201	10/22/2005	--	--	--	--	--
Route 119 -P	424209071545201	10/24/2005	--	--	--	--	--
Route 119 -P	424209071545201	01/11/2006	<0.59	<0.87	E1.97	E1	E0.2
Route 119 -P	424209071545201	01/18/2006	<0.59	E0.443	E2.46	E0.7	E0.1
Route 119 -P	424209071545201	03/13/2006	<23.6	<34.8	<74.4	E0.9	E0.2
Route 119 -P	424209071545201	05/09/2006	<0.59	<0.87	<1.86	E0.0465	E0.0206
Route 119 -P	424209071545201	06/01/2006	<0.59	<0.87	<1.86	0.322	E0.122
Route 119 -P	424209071545201	09/14/2006	<0.59	<0.87	E0.911	E0.0844	<0.56
Route 119 -P	424209071545201	09/19/2006	E0.0590	<0.87	E0.405	E0.0418	<0.56
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	<0.59	E0.174	<1.86	E0.0389	<0.56
Route 119 -P	424209071545201	11/12/2006	<0.59	<0.87	E0.503	E0.0784	E0.0279
Route 119 -P	424209071545201	01/08/2007	<0.59	<0.87	E0.327	E0.131	E0.0361
Route 119 -P	424209071545201	04/01/2007	<0.59	<0.87	<1.86	E0.225	E0.0785
Route 119 -P	424209071545201	04/14/2007	<0.59	E0.192	E1.16	E0.263	E0.0527
Route 119 -P	424209071545201	06/03/2007	<0.59	<0.87	E0.357	<0.30	<0.56
Route 119 -P	424209071545201	07/11/2007	E0.0293	<0.87	E0.0860	E0.0616	E0.0243
Route 119 -S	424155071543201	09/29/2005	<0.59	E0.415	<1.86	E0.1	E0.05
Route 119 -S	424155071543201	10/24/2005	<0.59	E0.480	<1.86	E0.03	<3
Route 119 -S	424155071543201	01/11/2006	<0.59	<0.87	E1.93	E1	E0.2
Route 119 -S	424155071543201	01/18/2006	<0.59	E0.534	E1.74	E0.5	E0.09
Route 119 -S	424155071543201	03/13/2006	<23.6	<34.8	<74.4	E0.9	E0.3
Route 119 -S	424155071543201	08/20/2006	<0.59	<0.87	<1.86	E0.0317	<0.56
Route 119 -S	424155071543201	11/08/2006	<0.59	<0.87	<1.86	E0.0698	E0.0159
Route 119 -S	424155071543201	04/27/2007	<0.59	<0.87	<1.86	E0.178	E0.0393
Route 119 -S	424155071543201	06/03/2007	<0.59	<0.87	E0.162	<0.30	<0.56
Route 119 -S	424155071543201	07/11/2007	E0.0497	<0.87	E0.0739	E0.0488	E0.0224
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	E0.0359	<0.87	E0.827	E0.0782	E0.0290
Route 8 -T	424019073062601	06/23/2006	<0.59	<0.87	<1.86	E0.114	<0.56
Route 8 -T	424019073062601	09/23/2006	<0.59	<0.87	E1.16	E0.101	<0.56
Route 8 -T	424019073062601	12/01/2006	<0.59	E0.351	E1.87	0.385	E0.107
Route 8 -T	424019073062601	03/02/2007	<0.59	<0.87	E3.47	0.825	E0.167

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Dimethyl phthalate, total, recoverable (µg/L)	Di-n-butyl phthalate, total, recoverable (µg/L)	Di-n-octyl phthalate, total, recoverable, (µg/L)	Fluoranthene, total, recoverable (µg/L)	Indeno[1,2,3- <i>cd</i>]-pyrene, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	<0.59	<0.87	E2.06	E0.5	E0.1
Interstate 190 -T	423016071431501	09/29/2005	<0.59	<0.87	E1.29	E0.3	E0.10
Interstate 190 -T	423016071431501	10/07/2005	<0.59	<0.87	E2.66	E0.09	E0.04
Interstate 190 -T	423016071431501	10/22/2005	--	--	--	--	--
Interstate 190 -T	423016071431501	10/24/2005	<0.59	E0.575	<1.86	E0.07	<3
Interstate 190 -T	423016071431501	03/13/2006	<11.8	<17.4	<37.2	E4	E0.7
Route 2 -P	423027071291301	09/15/2005	<0.59	<0.87	E1.85	E0.1	E0.06
Route 2 -P	423027071291301	09/29/2005	<0.59	E0.784	E1.44	E0.4	E0.1
Route 2 -P	423027071291301	10/22/2005	<0.59	E0.458	E1.14	E0.2	E0.05
Route 2 -P	423027071291301	10/24/2005	<0.59	E0.484	<1.86	E0.09	<3
Route 2 -P	423027071291301	01/11/2006	<0.59	E0.437	E3.08	E2	E0.3
Route 2 -P	423027071291301	01/18/2006	<0.59	E0.577	E6.92	E1	E0.2
Route 2 -P	423027071291301	03/13/2006	<0.59	<0.87	E1.39	E0.9	E0.2
Route 2 -P	423027071291301	05/09/2006	<0.59	<0.87	E1.81	E0.236	E0.0823
Route 2 -P	423027071291301	06/02/2006	<0.59	<0.87	<1.86	0.336	E0.153
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	<0.59	<0.87	E0.232	E0.209	E0.0622
Route 2 -P	423027071291301	08/27/2006	--	--	E0.547	E0.0315	--
Route 2 -P	423027071291301	09/19/2006	E0.0563	<0.87	E0.842	E0.255	E0.114
Route 2 -P	423027071291301	11/07/2006	<0.59	E0.294	E0.529	E0.0522	<0.56
Route 2 -P	423027071291301	01/08/2007	E0.0339	E0.300	E1.21	E0.262	E0.0888
Route 2 -P	423027071291301	03/02/2007	<0.59	<0.87	E7.64	2.45	E0.323
Route 2 -P	423027071291301	04/12/2007	<0.59	E0.348	E6.66	2.43	E0.464
Route 2 -P	423027071291301	08/06/2007	<0.59	<0.87	E1.76	0.421	E0.217
Route 2 -P	423027071291301	08/08/2007	<0.59	<0.87	E2.40	0.735	E0.176
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	<0.59	<0.87	E0.287	E0.0591	E0.0267
Route 2 -S	423027071291302	08/27/2006	E0.0314	<0.87	E0.912	E0.0708	E0.0215
Route 2 -S	423027071291302	09/19/2006	E0.0572	<0.87	E1.33	0.361	E0.142
Route 2 -S	423027071291302	12/01/2006	E0.0480	<0.87	E2.46	1.61	E0.326
Route 2 -S	423027071291302	01/08/2007	<0.59	E0.311	E1.12	E0.268	E0.0888
Route 2 -S	423027071291302	03/17/2007	<0.59	<0.87	2.33	1.39	E0.310
Route 2 -S	423027071291302	04/12/2007	<0.59	E0.338	E5.12	1.84	E0.366
Route 2 -S	423027071291302	05/16/2007	<0.59	E0.285	E3.19	0.642	E0.141
Route 2 -S	423027071291302	08/08/2007	E0.0592	<0.87	E1.34	0.525	E0.154

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Dimethyl phthalate, total, recoverable (µg/L)	Di-n-butyl phthalate, total, recoverable (µg/L)	Di-n-octyl phthalate, total, recoverable, (µg/L)	Fluoranthene, total, recoverable (µg/L)	Indeno[1,2,3- <i>cd</i>]-pyrene, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	<0.59	<0.87	E1.67	0.741	E0.279
Interstate 195 -T	414339070462201	04/23/2006	E0.0337	<0.87	E1.95	E0.282	E0.0858
Interstate 195 -T	414339070462201	06/24/2006	<0.59	<0.87	<1.86	E0.157	E0.0690
Interstate 195 -T	414339070462201	09/29/2006	E0.0595	E0.882	E1.30	E0.148	E0.0519
Interstate 195 -T	414339070462201	12/01/2006	<0.59	<0.87	E1.70	0.489	E0.120
Interstate 195 -T	414339070462201	02/14/2007	E0.113	<0.87	E1.53	0.498	E0.113
Interstate 495 -P	422821071332001	09/15/2005	<0.59	<0.87	E1.30	E0.2	E0.07
Interstate 495 -P	422821071332001	09/29/2005	<0.59	E0.554	E1.97	E1	E0.3
Interstate 495 -P	422821071332001	10/22/2005	<0.59	E0.501	E0.841	E0.2	E0.05
Interstate 495 -P	422821071332001	10/24/2005	<0.59	E0.415	E0.901	E0.2	<3
Interstate 495 -P	422821071332001	01/11/2006	<0.59	E0.437	E3.88	6	E0.9
Interstate 495 -P	422821071332001	03/13/2006	<23.6	<34.8	<74.4	E7	E2
Interstate 495 -P	422821071332001	05/09/2006	<0.59	<0.87	<1.86	E0.293	E0.105
Interstate 495 -P	422821071332001	06/02/2006	<0.59	<0.87	<1.86	0.714	E0.239
Interstate 495 -P	422821071332001	08/20/2006	<0.59	<0.87	E0.423	E0.139	E0.0591
Interstate 495 -P	422821071332001	08/27/2006	<0.59	<0.87	E1.26	E0.0861	E0.0284
Interstate 495 -P	422821071332001	09/19/2006	E0.0754	<0.87	E1.11	0.434	E0.140
Interstate 495 -P	422821071332001	11/12/2006	<0.59	E0.312	<1.86	0.598	E0.139
Interstate 495 -P	422821071332001	01/08/2007	E0.0390	E0.386	E0.946	0.494	E0.144
Interstate 495 -P	422821071332001	03/02/2007	E0.179	<0.87	E2.74	E3.87	E0.482
Interstate 495 -P	422821071332001	04/12/2007	<0.59	<0.87	E3.40	2.33	E0.407
Interstate 495 -P	422821071332001	08/06/2007	<0.59	<0.87	E1.62	0.7	E0.313
Interstate 495 -P	422821071332001	08/08/2007	<0.59	<0.87	E1.37	0.717	E0.194
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	<0.59	<0.87	E2.13	E0.3	E0.1
Interstate 495 -S	422716071343901	09/29/2005	<0.59	E0.453	E1.61	E0.2	E0.06
Interstate 495 -S	422716071343901	10/22/2005	<0.59	E0.541	E1.41	E0.1	<3
Interstate 495 -S	422716071343901	10/24/2005	<0.59	E0.670	E1.20	E0.1	<3
Interstate 495 -S	422716071343901	01/11/2006	<0.59	E0.407	E3.40	E2	E0.3
Interstate 495 -S	422716071343901	01/18/2006	<0.59	E0.637	E4.34	E2	E0.3
Interstate 495 -S	422716071343901	03/13/2006	<11.8	<17.4	<37.2	E2	E0.5
Interstate 495 -S	422716071343901	05/09/2006	<0.59	<0.87	<1.86	E0.179	E0.0660
Interstate 495 -S	422716071343901	06/02/2006	E0.0403	<0.87	<1.86	E0.205	E0.0785
Interstate 495 -S	422716071343901	08/20/2006	<0.59	<0.87	E0.429	E0.122	E0.0512
Interstate 495 -S	422716071343901	09/19/2006	E0.0699	<0.87	E1.57	E0.158	E0.0711

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Dimethyl phthalate, total, recoverable (µg/L)	Di-n-butyl phthalate, total, recoverable (µg/L)	Di-n-octyl phthalate, total, recoverable, (µg/L)	Fluoranthene, total, recoverable (µg/L)	Indeno[1,2,3- <i>cd</i>]-pyrene, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	<0.59	<0.87	E1.66	E0.5	E0.2
Interstate 95 -P	422620071153301	09/29/2005	<0.59	E0.464	E1.38	E0.7	E0.2
Interstate 95 -P	422620071153301	10/22/2005	<0.59	<0.87	E0.819	E0.1	<3
Interstate 95 -P	422620071153301	11/16/2005	<0.59	E0.451	<1.86	E0.2	E0.07
Interstate 95 -P	422620071153301	01/12/2006	<0.59	<0.87	E1.33	E2	E0.6
Interstate 95 -P	422620071153301	01/18/2006	<0.59	E0.750	E11.9	5	E1
Interstate 95 -P	422620071153301	03/13/2006	<23.6	<34.8	<74.4	E10	E3
Interstate 95 -P	422620071153301	05/09/2006	<0.59	<0.87	E2.81	1.15	E0.331
Interstate 95 -P	422620071153301	06/02/2006	<0.59	<0.87	<1.86	0.507	E0.197
Interstate 95 -P	422620071153301	08/20/2006	<0.59	E0.599	<1.86	E0.0877	E0.0312
Interstate 95 -P	422620071153301	08/27/2006	<0.59	<0.87	E0.511	E0.170	E0.0348
Interstate 95 -P	422620071153301	09/19/2006	E0.0554	<0.87	E1.55	0.41	E0.146
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	E0.106	<0.87	E1.95	0.554	E0.151
Interstate 95 -P	422620071153301	03/11/2007	<0.59	<0.87	E1.35	1.31	E0.422
Interstate 95 -P	422620071153301	03/17/2007	<0.59	E0.454	E3.32	3.68	E0.899
Interstate 95 -P	422620071153301	04/12/2007	E0.0675	E0.402	E5.01	2.42	E0.547
Interstate 95 -P	422620071153301	08/06/2007	<0.59	<0.87	E1.16	E0.237	E0.128
Interstate 95 -P	422620071153301	08/08/2007	<0.59	<0.87	E2.32	0.348	<0.56
Interstate 95 -S	422420071153302	08/20/2006	<0.59	<0.87	E0.359	E0.137	E0.0520
Interstate 95 -S	422420071153302	08/27/2006	E0.0372	<0.87	E1.32	E0.0994	E0.0281
Interstate 95 -S	422420071153302	09/19/2006	E0.0752	<0.87	E1.68	E0.253	E0.114
Interstate 95 -S	422420071153302	11/07/2006	E0.110	E0.364	E1.96	0.458	E0.0846
Interstate 95 -S	422420071153302	03/02/2007	<0.59	E1.60	E4.04	E9.95	E1.04
Interstate 95 -S	422420071153302	03/17/2007	<0.59	E0.467	E3.27	3.76	E0.762
Interstate 95 -S	422420071153302	04/12/2007	E0.0652	E0.442	E5.44	3.02	0.584
Interstate 95 -S	422420071153302	05/16/2007	<0.59	<0.426	E5.99	2.13	E0.425
Interstate 95 -S	422420071153302	08/06/2007	<0.59	<0.87	E3.24	1.6	E0.433
Interstate 95 -S	422420071153302	08/08/2007	<0.59	<0.87	E2.93	0.642	E0.211
Interstate 93 -T	421647071024703	04/23/2006	E0.131	E0.756	E5.19	1.41	E0.327
Interstate 93 -T	421647071024703	06/23/2006	E0.164	<0.87	E6.78	E2.96	E0.594
Interstate 93 -T	421647071024703	09/19/2006	<0.59	<0.87	E2.52	0.697	E0.230
Interstate 93 -T	421647071024703	12/01/2006	E0.123	E0.343	E5.33	1.96	E0.428
Interstate 93 -T	421647071024703	02/14/2007	<0.59	E2.01	<12.8	7	E1.08

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Nitrobenzene, total, recoverable (µg/L)	Phenanthrene, total, recoverable (µg/L)	Pyrene, total, recoverable (µg/L)	Naphthalene, total, recoverable (µg/L)	Perylene, total, recoverable (µg/L)
Route 119 -P	424209071545201	09/15/2005	<2	E0.02	<2	<2	<1
Route 119 -P	424209071545201	09/29/2005	<2	E0.06	E0.1	<2	<1
Route 119 -P	424209071545201	10/22/2005	--	--	--	--	--
Route 119 -P	424209071545201	10/24/2005	--	--	--	--	--
Route 119 -P	424209071545201	01/11/2006	<2	E0.7	E0.8	E0.05	E0.07
Route 119 -P	424209071545201	01/18/2006	<2	E0.4	E0.5	E0.03	<1
Route 119 -P	424209071545201	03/13/2006	<80	E0.6	E0.7	<72	<40
Route 119 -P	424209071545201	05/09/2006	<0.21	E0.0228	E0.0367	<0.32	<1
Route 119 -P	424209071545201	06/01/2006	<0.21	E0.158	E0.246	<0.32	E0.04
Route 119 -P	424209071545201	09/14/2006	<0.21	<0.32	E0.0778	<0.32	<1
Route 119 -P	424209071545201	09/19/2006	<0.21	E0.0198	E0.0364	<0.32	<1
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	<0.21	E0.0198	E0.0273	<0.32	<1
Route 119 -P	424209071545201	11/12/2006	<0.21	E0.0368	E0.0702	<0.32	<1
Route 119 -P	424209071545201	01/08/2007	<0.21	E0.0614	E0.101	<0.32	E0.01
Route 119 -P	424209071545201	04/01/2007	<0.21	E0.116	E0.151	<0.32	<1
Route 119 -P	424209071545201	04/14/2007	<0.21	E0.146	E0.181	<0.32	<1
Route 119 -P	424209071545201	06/03/2007	<0.21	<0.32	<0.35	<0.32	<1
Route 119 -P	424209071545201	07/11/2007	<0.21	E0.0317	E0.0460	<0.32	<1
Route 119 -S	424155071543201	09/29/2005	<2	E0.06	E0.1	<2	<1
Route 119 -S	424155071543201	10/24/2005	<2	E0.03	E0.03	<2	<1
Route 119 -S	424155071543201	01/11/2006	<2	E0.6	E0.9	E0.04	<1
Route 119 -S	424155071543201	01/18/2006	<2	E0.3	E0.4	E0.03	<1
Route 119 -S	424155071543201	03/13/2006	<80	E0.5	E0.6	<72	<40
Route 119 -S	424155071543201	08/20/2006	E0.0287	E0.0163	E0.0277	<0.32	<1
Route 119 -S	424155071543201	11/08/2006	<0.21	E0.0303	E0.0556	E0.0345	<1
Route 119 -S	424155071543201	04/27/2007	<0.21	E0.0921	E0.126	<0.32	<1
Route 119 -S	424155071543201	06/03/2007	<0.21	<0.32	<0.35	<0.32	<1
Route 119 -S	424155071543201	07/11/2007	<0.21	<0.32	E0.0455	<0.32	<1
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	<0.21	E0.0363	E0.0676	E0.0186	<1
Route 8 -T	424019073062601	06/23/2006	<0.21	E0.0549	E0.101	<0.32	E0.03
Route 8 -T	424019073062601	09/23/2006	<0.21	E0.0406	E0.0984	<0.32	<1
Route 8 -T	424019073062601	12/01/2006	<0.21	E0.155	0.355	E0.0290	E0.04
Route 8 -T	424019073062601	03/02/2007	<0.21	0.602	0.606	<0.32	<1

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Nitrobenzene, total, recoverable (µg/L)	Phenanthrene, total, recoverable (µg/L)	Pyrene, total, recoverable (µg/L)	Naphthalene, total, recoverable (µg/L)	Perylene, total, recoverable (µg/L)
Interstate 190 -T	423016071431501	08/14/2005	<2	<2	E0.4	<2	E0.05
Interstate 190 -T	423016071431501	09/29/2005	<2	E0.1	E0.3	E0.02	E0.03
Interstate 190 -T	423016071431501	10/07/2005	<2	E0.03	E0.08	<2	<1
Interstate 190 -T	423016071431501	10/22/2005	--	--	--	--	--
Interstate 190 -T	423016071431501	10/24/2005	<2	E0.04	E0.06	<2	<1
Interstate 190 -T	423016071431501	03/13/2006	<40	E2	E3	<36	E0.3
Route 2 -P	423027071291301	09/15/2005	<2	<2	E0.1	<2	<1
Route 2 -P	423027071291301	09/29/2005	<2	E0.2	E0.4	E0.06	E0.06
Route 2 -P	423027071291301	10/22/2005	<2	E0.07	E0.1	<2	<1
Route 2 -P	423027071291301	10/24/2005	<2	E0.05	E0.08	<2	<1
Route 2 -P	423027071291301	01/11/2006	<2	E1	E1	E0.09	E0.1
Route 2 -P	423027071291301	01/18/2006	<2	E0.8	E1	E0.04	E0.1
Route 2 -P	423027071291301	03/13/2006	E0.02	E0.5	E0.6	E0.04	E0.07
Route 2 -P	423027071291301	05/09/2006	<0.21	E0.0934	E0.169	E0.0349	E0.02
Route 2 -P	423027071291301	06/02/2006	<0.21	E0.134	E0.262	<0.32	E0.04
Route 2 -P	423027071291301	06/23/2006	--	--	--	--	--
Route 2 -P	423027071291301	08/20/2006	<0.21	E0.0896	E0.166	<0.32	E0.02
Route 2 -P	423027071291301	08/27/2006	--	E0.0141	E0.0242	--	--
Route 2 -P	423027071291301	09/19/2006	<0.21	E0.101	E0.207	<0.32	E0.03
Route 2 -P	423027071291301	11/07/2006	E0.0585	E0.0305	E0.0509	E0.0231	<1
Route 2 -P	423027071291301	01/08/2007	<0.21	E0.121	E0.215	<0.32	E0.02
Route 2 -P	423027071291301	03/02/2007	<0.21	1.6	1.71	E0.112	E0.1
Route 2 -P	423027071291301	04/12/2007	<0.21	1.22	1.75	E0.0721	E0.2
Route 2 -P	423027071291301	08/06/2007	<0.21	E0.184	E0.372	<0.32	<1
Route 2 -P	423027071291301	08/08/2007	<0.21	E0.274	E0.547	<0.32	<1
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	<0.21	E0.0235	E0.0480	<0.32	<1
Route 2 -S	423027071291302	08/27/2006	<0.21	E0.0295	E0.0495	<0.32	<1
Route 2 -S	423027071291302	09/19/2006	<0.21	E0.138	E0.277	<0.32	E0.03
Route 2 -S	423027071291302	12/01/2006	<0.21	0.787	1.21	E0.0369	E0.1
Route 2 -S	423027071291302	01/08/2007	<0.21	E0.127	E0.203	<0.32	E0.02
Route 2 -S	423027071291302	03/17/2007	<0.21	0.848	0.945	E0.0444	<1
Route 2 -S	423027071291302	04/12/2007	<0.21	0.964	1.2	E0.0475	E0.1
Route 2 -S	423027071291302	05/16/2007	<0.21	E0.296	0.468	E0.0396	E0.06
Route 2 -S	423027071291302	08/08/2007	<0.21	E0.228	E0.417	<0.32	E0.1

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Nitrobenzene, total, recoverable (µg/L)	Phenanthrene, total, recoverable (µg/L)	Pyrene, total, recoverable (µg/L)	Naphthalene, total, recoverable (µg/L)	Perylene, total, recoverable (µg/L)
Route 2 -S	423027071291302	08/06/2007	<0.21	0.329	E0.598	<0.32	E0.1
Interstate 195 -T	414339070462201	04/23/2006	<0.21	E0.107	E0.203	E0.0191	E0.02
Interstate 195 -T	414339070462201	06/24/2006	<0.21	E0.0546	E0.135	<0.32	E0.03
Interstate 195 -T	414339070462201	09/29/2006	<0.21	E0.0702	E0.114	<0.32	E0.02
Interstate 195 -T	414339070462201	12/01/2006	<0.21	0.341	0.394	E0.0454	E0.06
Interstate 195 -T	414339070462201	02/14/2007	<0.21	E0.230	0.402	<0.32	<1
Interstate 495 -P	422821071332001	09/15/2005	<2	E0.09	E0.2	<2	<1
Interstate 495 -P	422821071332001	09/29/2005	<2	E0.5	E1.0	E0.05	E0.1
Interstate 495 -P	422821071332001	10/22/2005	<2	E0.1	E0.2	<2	<1
Interstate 495 -P	422821071332001	10/24/2005	<2	E0.08	E0.2	<2	<1
Interstate 495 -P	422821071332001	01/11/2006	<2	5	E4	E0.4	E0.5
Interstate 495 -P	422821071332001	03/13/2006	<80	E4	E5	<72	E0.6
Interstate 495 -P	422821071332001	05/09/2006	E0.0277	E0.124	E0.216	E0.0220	E0.04
Interstate 495 -P	422821071332001	06/02/2006	<0.21	E0.292	0.596	<0.32	E0.09
Interstate 495 -P	422821071332001	08/20/2006	<0.21	E0.0458	E0.129	<0.32	E0.03
Interstate 495 -P	422821071332001	08/27/2006	<0.21	E0.0297	E0.0724	<0.32	<1
Interstate 495 -P	422821071332001	09/19/2006	<0.21	E0.158	0.373	<0.32	E0.05
Interstate 495 -P	422821071332001	11/12/2006	<0.21	E0.246	0.478	E0.0581	E0.05
Interstate 495 -P	422821071332001	01/08/2007	<0.21	E0.280	0.396	<0.32	E0.05
Interstate 495 -P	422821071332001	03/02/2007	<0.21	E3.14	E2.68	E0.349	E0.2
Interstate 495 -P	422821071332001	04/12/2007	<0.21	1.33	1.68	E0.0841	E0.2
Interstate 495 -P	422821071332001	08/06/2007	<0.21	E0.309	E0.586	<0.32	E0.1
Interstate 495 -P	422821071332001	08/08/2007	<0.21	0.431	E0.591	<0.32	E0.1
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	<2	E0.09	E0.3	E0.02	<1
Interstate 495 -S	422716071343901	09/29/2005	<2	E0.08	E0.2	<2	<1
Interstate 495 -S	422716071343901	10/22/2005	<2	E0.07	E0.1	<2	<1
Interstate 495 -S	422716071343901	10/24/2005	<2	E0.06	E0.10	<2	<1
Interstate 495 -S	422716071343901	01/11/2006	<2	E1	E2	E0.09	E0.2
Interstate 495 -S	422716071343901	01/18/2006	<2	E0.9	E1	E0.06	E0.1
Interstate 495 -S	422716071343901	03/13/2006	<40	E0.8	E1	<36	E0.1
Interstate 495 -S	422716071343901	05/09/2006	E0.0529	E0.0850	E0.140	E0.0266	<1
Interstate 495 -S	422716071343901	06/02/2006	<0.21	E0.0796	E0.168	E0.0237	E0.02
Interstate 495 -S	422716071343901	08/20/2006	E0.0442	E0.0462	E0.108	<0.32	<1
Interstate 495 -S	422716071343901	09/19/2006	E0.0564	E0.0548	E0.151	<0.32	E0.02

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	Nitrobenzene, total, recoverable (µg/L)	Phenanthrene, total, recoverable (µg/L)	Pyrene, total, recoverable (µg/L)	Naphthalene, total, recoverable (µg/L)	Perylene, total, recoverable (µg/L)
Interstate 95 -P	422620071153301	09/15/2005	<2	E0.2	E0.4	E0.03	E0.05
Interstate 95 -P	422620071153301	09/29/2005	<2	E0.3	E0.6	E0.03	E0.07
Interstate 95 -P	422620071153301	10/22/2005	<2	E0.04	E0.09	<2	<1
Interstate 95 -P	422620071153301	11/16/2005	<2	E0.06	E0.2	E0.02	<1
Interstate 95 -P	422620071153301	01/12/2006	<2	E1	E2	E0.08	E0.2
Interstate 95 -P	422620071153301	01/18/2006	<2	2	E3	E0.08	E0.5
Interstate 95 -P	422620071153301	03/13/2006	<80	E4	E8	<72	E0.8
Interstate 95 -P	422620071153301	05/09/2006	<0.21	0.442	0.858	E0.0467	E0.1
Interstate 95 -P	422620071153301	06/02/2006	<0.21	E0.138	0.422	<0.32	E0.05
Interstate 95 -P	422620071153301	08/20/2006	<0.21	E0.0230	E0.0769	<0.32	
Interstate 95 -P	422620071153301	08/27/2006	<0.21	E0.0823	E0.119	<0.32	E0.02
Interstate 95 -P	422620071153301	09/19/2006	<0.21	E0.138	E0.333	<0.32	E0.04
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	<0.21	E0.182	0.485	E0.0281	E0.05
Interstate 95 -P	422620071153301	03/11/2007	<0.21	0.645	0.945	E0.0853	<1
Interstate 95 -P	422620071153301	03/17/2007	<0.21	1.83	2.79	E0.132	E0.4
Interstate 95 -P	422620071153301	04/12/2007	<0.21	1.03	1.77	E0.0860	
Interstate 95 -P	422620071153301	08/06/2007	<0.21	<0.32	E0.198	<0.32	<1
Interstate 95 -P	422620071153301	08/08/2007	<0.21	E0.136	E0.283	<0.32	<1
Interstate 95 -S	422420071153302	08/20/2006	<0.21	E0.0528	E0.111	<0.32	E0.02
Interstate 95 -S	422420071153302	08/27/2006	<0.21	E0.0402	E0.0812	<0.32	<1
Interstate 95 -S	422420071153302	09/19/2006	<0.21	E0.0966	E0.220	<0.32	E0.03
Interstate 95 -S	422420071153302	11/07/2006	<0.21	E0.258	0.408	E0.0533	E0.03
Interstate 95 -S	422420071153302	03/02/2007	<0.21	5.82	6.07	E0.152	E0.4
Interstate 95 -S	422420071153302	03/17/2007	<0.21	2.75	2.68	E0.226	E0.4
Interstate 95 -S	422420071153302	04/12/2007	<0.21	1.77	2.14	E0.0913	E0.3
Interstate 95 -S	422420071153302	05/16/2007	<0.21	1.12	1.55	E0.0672	E0.2
Interstate 95 -S	422420071153302	08/06/2007	<0.21	0.62	E1.24	<0.32	E0.3
Interstate 95 -S	422420071153302	08/08/2007	<0.21	E0.252	E0.513	<0.32	<1
Interstate 93 -T	421647071024703	04/23/2006	<0.21	0.529	1.08	E0.0596	E0.1
Interstate 93 -T	421647071024703	06/23/2006	<0.21	E1.40	E2.22	E0.0573	E0.4
Interstate 93 -T	421647071024703	09/19/2006	<0.21	E0.234	0.603	<0.32	--
Interstate 93 -T	421647071024703	12/01/2006	<0.21	0.914	1.59	E0.0743	E0.2
Interstate 93 -T	421647071024703	02/14/2007	<0.21	3	6	E0.273	<1

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	2-Fluoro-biphenyl, surrogate (percent recovery)	p-Terphenyl-d14 (percent recovery)	Suspended sediment (percent < 0.063 mm)	Suspended sediment (percent < 0.25 mm)	Suspended sediment concentration (mg/L)
Route 119 -P	424209071545201	09/15/2005	93.9	41.2	84	89	17
Route 119 -P	424209071545201	09/29/2005	97.7	E111	61	86	38
Route 119 -P	424209071545201	10/22/2005	--	--	75	85	6
Route 119 -P	424209071545201	10/24/2005	--	--	83	90	3
Route 119 -P	424209071545201	01/11/2006	64.3	48.7	89	97	263
Route 119 -P	424209071545201	01/18/2006	76.4	85.8	63	80	278
Route 119 -P	424209071545201	03/13/2006	20.7	18.3	68	83	879
Route 119 -P	424209071545201	05/09/2006	59.5	41.3	82	91	12
Route 119 -P	424209071545201	06/01/2006	55.8	43.6	90	99	157
Route 119 -P	424209071545201	09/14/2006	93.8	92.5	94	97	8
Route 119 -P	424209071545201	09/19/2006	72.8	58.8	90	95	5
Route 119 -P	424209071545201	10/20/2006	--	--	--	--	--
Route 119 -P	424209071545201	11/08/2006	75.9	82.4	80	88	3
Route 119 -P	424209071545201	11/12/2006	79.6	95.3	69	87	12
Route 119 -P	424209071545201	01/08/2007	52.1	38.0	91	98	18
Route 119 -P	424209071545201	04/01/2007	85.2	42.9	80	88	33
Route 119 -P	424209071545201	04/14/2007	83.5	68.0	94	98	76
Route 119 -P	424209071545201	06/03/2007	59.2	32.3	94	97	7
Route 119 -P	424209071545201	07/11/2007	71.7	45.9	56	82	22
Route 119 -S	424155071543201	09/29/2005	97.3	E91.6	44	77	57
Route 119 -S	424155071543201	10/24/2005	97.5	112.0	67	97	4
Route 119 -S	424155071543201	01/11/2006	71.8	62.2	64	95	263
Route 119 -S	424155071543201	01/18/2006	78.4	107.0	79	94	160
Route 119 -S	424155071543201	03/13/2006	63.8	49.6	85	98	439
Route 119 -S	424155071543201	08/20/2006	89.1	73.1	52	66	17
Route 119 -S	424155071543201	11/08/2006	79.9	80.1	28	44	19
Route 119 -S	424155071543201	04/27/2007	67.6	65.9	59	82	95
Route 119 -S	424155071543201	06/03/2007	69.2	47.0	54	87	30
Route 119 -S	424155071543201	07/11/2007	71.6	76.0	64	93	18
Route 119 -S	424155071543201	08/03/2007	--	--	--	--	--
Route 8 -T	424019073062601	04/22/2006	60.0	43.1	96	--	13
Route 8 -T	424019073062601	06/23/2006	65.0	31.8	27	44	107
Route 8 -T	424019073062601	09/23/2006	70.7	38.2	91	94	20
Route 8 -T	424019073062601	12/01/2006	74.4	55.6	25	34	400
Route 8 -T	424019073062601	03/02/2007	55.0	E56.6	99	100	242

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

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Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	2-Fluoro-biphenyl, surrogate (percent recovery)	p-Terphenyl-d14 (percent recovery)	Suspended sediment (percent < 0.063 mm)	Suspended sediment (percent < 0.25 mm)	Suspended sediment concentration (mg/L)
Interstate 190 -T	423016071431501	08/14/2005	94.6	56.7	59	88	86
Interstate 190 -T	423016071431501	09/29/2005	92.9	E73.5	56	88	112
Interstate 190 -T	423016071431501	10/07/2005	94.8	55.6	74	94	17
Interstate 190 -T	423016071431501	10/22/2005	--	--	63	78	11
Interstate 190 -T	423016071431501	10/24/2005	102.4	88.8	87	97	8
Interstate 190 -T	423016071431501	03/13/2006	41.3	31.7	86	96	528
Route 2 -P	423027071291301	09/15/2005	88.6	51.1	50	56	57
Route 2 -P	423027071291301	09/29/2005	88.5	E52.1	46	68	121
Route 2 -P	423027071291301	10/22/2005	94.9	77.4	31	66	51
Route 2 -P	423027071291301	10/24/2005	107.9	128.0	37	60	13
Route 2 -P	423027071291301	01/11/2006	62.8	39.1	98	99	266
Route 2 -P	423027071291301	01/18/2006	69.9	80.5	97	99	153
Route 2 -P	423027071291301	03/13/2006	14.5	9.3	87	94	327
Route 2 -P	423027071291301	05/09/2006	62.3	29.5	--	--	--
Route 2 -P	423027071291301	06/02/2006	57.7	40.2	--	--	--
Route 2 -P	423027071291301	06/23/2006	--	--	35	69	124
Route 2 -P	423027071291301	08/20/2006	63.2	55.6	29	57	49
Route 2 -P	423027071291301	08/27/2006	17.1	19.6	59	79	6
Route 2 -P	423027071291301	09/19/2006	79.7	59.1	34	59	56
Route 2 -P	423027071291301	11/07/2006	76.5	38.8	47	71	6
Route 2 -P	423027071291301	01/08/2007	57.9	29.1	60	73	39
Route 2 -P	423027071291301	03/02/2007	59.7	E60.7	77	84	406
Route 2 -P	423027071291301	04/12/2007	84.9	63.8	84	94	336
Route 2 -P	423027071291301	08/06/2007	74.4	51.2	18	66	114
Route 2 -P	423027071291301	08/08/2007	73.9	69.9	57	90	94
Route 2 -P	423027071291301	09/10/2007	--	--	--	--	--
Route 2 -S	423027071291302	08/20/2006	60.2	43.9	54	77	19
Route 2 -S	423027071291302	08/27/2006	60.0	48.0	42	61	14
Route 2 -S	423027071291302	09/19/2006	74.1	51.1	11	28	198
Route 2 -S	423027071291302	12/01/2006	71.1	63.1	25	63	268
Route 2 -S	423027071291302	01/08/2007	53.6	34.6	74	83	26
Route 2 -S	423027071291302	03/17/2007	86.1	50.5	85	92	80
Route 2 -S	423027071291302	04/12/2007	86.3	55.4	63	71	187
Route 2 -S	423027071291302	05/16/2007	84.2	93.3	66	91	87
Route 2 -S	423027071291302	08/08/2007	68.9	72.3	33	58	157

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hrmm, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	2-Fluoro-biphenyl, surrogate (percent recovery)	p-Terphenyl-d14 (percent recovery)	Suspended sediment (percent < 0.063 mm)	Suspended sediment (percent < 0.25 mm)	Suspended sediment concentration (mg/L)
Route 2 -S	423027071291302	08/06/2007	69.3	45.4	47	75	145
Interstate 195 -T	414339070462201	04/23/2006	79.3	64.8	86	91	37
Interstate 195 -T	414339070462201	06/24/2006	69.7	61.5	52	80	39
Interstate 195 -T	414339070462201	09/29/2006	69.2	75.7	59	77	28
Interstate 195 -T	414339070462201	12/01/2006	71.2	77.8	70	90	31
Interstate 195 -T	414339070462201	02/14/2007	59.8	50.1	63	70	48
Interstate 495 -P	422821071332001	09/15/2005	82.9	41.2	74	82	41
Interstate 495 -P	422821071332001	09/29/2005	96.8	E79.2	13	25	572
Interstate 495 -P	422821071332001	10/22/2005	98.9	79.2	45	71	33
Interstate 495 -P	422821071332001	10/24/2005	98.7	87.9	29	40	38
Interstate 495 -P	422821071332001	01/11/2006	43.6	39.4	58	66	958
Interstate 495 -P	422821071332001	03/13/2006	63.0	67.9	48	62	877
Interstate 495 -P	422821071332001	05/09/2006	40.7	21.4	91	97	28
Interstate 495 -P	422821071332001	06/02/2006	74.2	53.4	18	39	284
Interstate 495 -P	422821071332001	08/20/2006	60.5	46.5	28	65	59
Interstate 495 -P	422821071332001	08/27/2006	58.7	43.1	65	86	12
Interstate 495 -P	422821071332001	09/19/2006	74.0	60.3	46	76	52
Interstate 495 -P	422821071332001	11/12/2006	78.2	76.4	51	81	66
Interstate 495 -P	422821071332001	01/08/2007	58.3	40.2	81	89	25
Interstate 495 -P	422821071332001	03/02/2007	44.4	E38.8	95	98	2,060
Interstate 495 -P	422821071332001	04/12/2007	60.7	35.1	72	89	347
Interstate 495 -P	422821071332001	08/06/2007	66.0	52.1	48	84	136
Interstate 495 -P	422821071332001	08/08/2007	54.2	48.2	51	86	134
Interstate 495 -P	422821071332001	09/10/2007	--	--	--	--	--
Interstate 495 -S	422716071343901	09/15/2005	93.7	58.2	89	92	41
Interstate 495 -S	422716071343901	09/29/2005	75.9	E55.1	88	98	33
Interstate 495 -S	422716071343901	10/22/2005	101.0	89.6	85	93	11
Interstate 495 -S	422716071343901	10/24/2005	98.3	109.0	79	93	8
Interstate 495 -S	422716071343901	01/11/2006	51.4	42.1	98	99	351
Interstate 495 -S	422716071343901	01/18/2006	77.0	93.3	98	99	173
Interstate 495 -S	422716071343901	03/13/2006	41.2	38.5	98	99	242
Interstate 495 -S	422716071343901	05/09/2006	62.7	28.8	79	94	22
Interstate 495 -S	422716071343901	06/02/2006	68.4	53.8	85	96	23
Interstate 495 -S	422716071343901	08/20/2006	62.4	46.0	82	99	19
Interstate 495 -S	422716071343901	09/19/2006	77.2	75.9	81	88	16

Table 16. Physical properties and concentrations of dissolved major ions, total nutrients, total-recoverable metals, polyaromatic hydrocarbons, phthalate esters, and suspended sediment in stormwater composite samples of highway runoff collected from 12 stations on 8 highways in Massachusetts, 2005–07.—Continued

[USGS, U.S. Geological Survey; -P, primary monitoring station; -S, secondary monitoring station; -T, monitoring station on test highway; mm/dd/yyyy, month, day, year; hr:mn, hour minute; NTRU, nephelometric turbidity ratio units; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mm, millimeter; <, concentration is less than the laboratory reporting limit; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; blue-shaded values are associated with the secondary monitoring sites for each principal highway; gray-shaded values are associated with the monitoring sites for each test highway]

Highway and designation	USGS station number	Begin date (mm/dd/yyyy)	2-Fluoro-biphenyl, surrogate (percent recovery)	p-Terphenyl-d14 (percent recovery)	Suspended sediment (percent < 0.063 mm)	Suspended sediment (percent < 0.25 mm)	Suspended sediment concentration (mg/L)
Interstate 95 -P	422620071153301	09/15/2005	77.9	25.0	36	63	87
Interstate 95 -P	422620071153301	09/29/2005	93.5	E78.9	9	15	254
Interstate 95 -P	422620071153301	10/22/2005	65.0	46.1	53	86	11
Interstate 95 -P	422620071153301	11/16/2005	99.2	62.6	60	73	19
Interstate 95 -P	422620071153301	01/12/2006	29.4	20.9	97	98	387
Interstate 95 -P	422620071153301	01/18/2006	75.6	104.0	16	18	1,360
Interstate 95 -P	422620071153301	03/13/2006	52.4	55.4	79	79	655
Interstate 95 -P	422620071153301	05/09/2006	61.9	37.2	70	77	88
Interstate 95 -P	422620071153301	06/02/2006	44.1	22.2	39	46	78
Interstate 95 -P	422620071153301	08/20/2006	53.6	19.8	32	46	26
Interstate 95 -P	422620071153301	08/27/2006	24.5	27.5	56	71	12
Interstate 95 -P	422620071153301	09/19/2006	80.8	64.2	18	36	91
Interstate 95 -P	422620071153301	10/20/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	10/28/2006	--	--	--	--	--
Interstate 95 -P	422620071153301	11/07/2006	84.7	57.1	51	63	66
Interstate 95 -P	422620071153301	03/11/2007	53.1	E34.2	85	88	112
Interstate 95 -P	422620071153301	03/17/2007	77.2	45.1	74	84	406
Interstate 95 -P	422620071153301	04/12/2007	69.1	39.0	88	93	174
Interstate 95 -P	422620071153301	08/06/2007	61.4	40.3	51	85	58
Interstate 95 -P	422620071153301	08/08/2007	69.5	49.1	88	95	35
Interstate 95 -S	422420071153302	08/20/2006	64.0	30.3	56	82	20
Interstate 95 -S	422420071153302	08/27/2006	50.5	19.7	82	95	12
Interstate 95 -S	422420071153302	09/19/2006	68.5	35.9	65	86	22
Interstate 95 -S	422420071153302	11/07/2006	86.1	55.0	84	95	16
Interstate 95 -S	422420071153302	03/02/2007	66.2	E75.5	95	99	347
Interstate 95 -S	422420071153302	03/17/2007	89.6	67.5	87	94	255
Interstate 95 -S	422420071153302	04/12/2007	71.0	32.9	77	88	169
Interstate 95 -S	422420071153302	05/16/2007	85.3	97.1	49	75	248
Interstate 95 -S	422420071153302	08/06/2007	60.0	55.9	54	86	188
Interstate 95 -S	422420071153302	08/08/2007	58.4	47.4	70	83	74
Interstate 93 -T	421647071024703	04/23/2006	72.4	27.5	96	99	90
Interstate 93 -T	421647071024703	06/23/2006	23.7	18.6	4	13	4,050
Interstate 93 -T	421647071024703	09/19/2006	83.3	46.1	17	32	207
Interstate 93 -T	421647071024703	12/01/2006	74.1	45.5	21	39	714
Interstate 93 -T	421647071024703	02/14/2007	60.9	56.4	62	81	718

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hr:mn, hour:minute]

Highway	USGS station number	Begin date (mm/dd/yyyy)	Begin time (hr:mn)	End date (mm/dd/yyyy)	End time (hr:mn)	Total precipitation (inches)	Total storm volume (cubic feet)	Runoff coefficient (percent)	Antecedent dry period between periods of flow (days)
Interstate 93	421647071024703	9/19/2006	2236	9/20/2006	0321	0.61	2,600	79	5.1
Interstate 93	421647071024703	12/1/2006	1635	12/1/2006	2217	0.26	829	59	3.1
Interstate 93	421647071024703	2/14/2007	1109	2/14/2007	1436	1.72	8,690	94	11.4
Interstate 95	422620071153301	8/20/2006	0430	8/20/2006	0652	0.49	2,590	97	4.6
Interstate 95	422620071153301	3/11/2007	0321	3/11/2007	0508	0.23	195	32	8.5
Interstate 95	422620071153301	4/12/2007	1404	4/12/2007	1726	1.06	1,060	38	7.4
Interstate 495	422821071332001	8/20/2006	0315	8/20/2006	0940	1.36	3,660	195	4.7
Interstate 495	422821071332001	1/8/2007	0457	1/8/2007	1450	0.88	1,470	121	1.8
Interstate 495	422821071332001	4/12/2007	1234	4/12/2007	1857	1.06	1,060	72	6.9
Route 2	423027071291301	8/27/2006	1451	8/28/2006	0413	0.84	512	64	1.9
Route 2	423027071291301	1/8/2007	0456	1/8/2007	1645	0.88	1,170	140	2.2
Route 2	423027071291301	9/10/2007	2309	9/11/2007	0107	0.31	346	117	23.9
Route 119	424209071545201	9/14/2006	1519	9/14/2006	2035	0.35	1,660	219	8.8
Route 119	424209071545201	1/8/2007	0100	1/8/2007	1432	1.02	2,660	120	1.1
Route 119	424209071545201	4/14/2007	1332	4/16/2007	0134	2.03	3,590	82	2.8

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hr:mn, hour minute]

Highway	Storm duration (hours)	Turbidity (NTRU)	pH, field (standard units)	Specific conductance ($\mu\text{S}/\text{cm}$)	1-Methyl-naphthalene ($\mu\text{g}/\text{L}$)	2,6-Dimethyl-naphthalene ($\mu\text{g}/\text{L}$)	2-Methyl-naphthalene ($\mu\text{g}/\text{L}$)	3,4-Dichloro-phenyl isocyanate ($\mu\text{g}/\text{L}$)
Interstate 93	5	28	6.8	108	E0.0129	E0.0089	E0.0164	<0.2
Interstate 93	6	96	6.9	183	E0.0246	<0.2	E0.0381	<2
Interstate 93	8	540	7.1	13,200	E0.118	E0.117	E0.197	<2
Interstate 95	7	6.4	6.6	98	<0.2	<0.2	<0.2	<2
Interstate 95	2	180	7	13,400	E0.0148	E0.0270	E0.0311	<2
Interstate 95	4	150	6.8	3,640	E0.0308	<0.2	E0.0549	<2
Interstate 495	7.0	9.3	6.6	59	<0.2	<0.2	<0.2	<2
Interstate 495	10.0	28	6.7	190	E0.0103	<0.2	E0.0161	E0.0583
Interstate 495	8.0	200	7	9,600	E0.0314	<0.2	E0.0490	<2
Route 2	6.8	4.8	6.6	69	<0.2	<0.2	<0.2	
Route 2	9.8	27	6.6	152	E0.0082	<0.2	E0.0150	E0.0268
Route 2	1.1	18	6.8	123	E0.0204	<0.2	E0.0238	<2
Route 119	5.9	12	6.3	73	<0.2	<0.2	E0.0051	<2
Route 119	14.9	17	6.2	103	<0.2	E0.0053	E0.0097	<2
Route 119	77.7	65	7.2	9,160	<0.2	<0.2	<0.2	<2

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hr:mn, hour:minute]

Highway	3 β - Coprostanol ($\mu\text{g}/\text{L}$)	3-Methyl- 1H-indole ($\mu\text{g}/\text{L}$)	3- <i>tert</i> -Butyl-4- hydroxyanisole ($\mu\text{g}/\text{L}$)	4-Cumylphenol ($\mu\text{g}/\text{L}$)	4-n-Octylphenol ($\mu\text{g}/\text{L}$)	4-Nonylphenol ($\mu\text{g}/\text{L}$)	4- <i>tert</i> -Octylphenol ($\mu\text{g}/\text{L}$)
Interstate 93	<3.20	<0.2	<0.2	<0.2	<0.2	E0.573	E0.193
Interstate 93	E1.52	E0.0483	<0.2	<0.2	<0.2	E1.36	0.374
Interstate 93	<0.8	<0.2	<0.2	<0.2	<0.2	<4.33	E0.626
Interstate 95	<0.8	<0.2	<0.2	<0.2	<0.2	<1.6	<0.2
Interstate 95	<0.8	<0.2		<0.2	<0.2	E0.576	<0.2
Interstate 95	<0.8	<0.2		<0.2	<0.2	E1.35	0.351
Interstate 495	E0.435	<0.2	<0.2	<0.2	<0.2	<1.6	<0.2
Interstate 495	E0.574	<0.2	<0.2	<0.2	<0.2	<1.6	E0.154
Interstate 495	<0.8	<0.2		<0.2	<0.2	<1.6	E0.209
Route 2	<0.8	<0.2	<0.2	<0.2	<0.2	<1.6	E0.0959
Route 2	<0.8	<0.2	<0.2	E0.0210	<0.2	E0.403	0.222
Route 2	<0.8	<0.2	<0.2	<0.2	<0.2	E0.397	<0.2
Route 119	E0.784	<0.2	<0.2	<0.2	<0.2	<1.6	E0.146
Route 119	<0.8	<0.2	<0.2	<0.2	<0.2	<1.6	<0.2
Route 119	1.14	<0.2		<0.2	<0.2	<1.6	<0.2

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

Highway	5-Methyl- 1H-benzotriazole ($\mu\text{g}/\text{L}$)	Acetophenone ($\mu\text{g}/\text{L}$)	Acetyl hexamethyl tetrahydro naphthalene ($\mu\text{g}/\text{L}$)	Anthracene ($\mu\text{g}/\text{L}$)	9,10-Anthraquinone ($\mu\text{g}/\text{L}$)	Atrazine ($\mu\text{g}/\text{L}$)	BDE congener 47 ($\mu\text{g}/\text{L}$)
Interstate 93	E1.50	0.431	<0.2	E0.0897	0.301	<0.2	<0.2
Interstate 93	E1.57	0.304	<0.2	E0.166	0.556	<0.2	--
Interstate 93	<1.6	1.04	<0.2	.384	1.64	<0.2	<0.2
Interstate 95	E0.585	0.296	<0.2	<0.2	E0.105	<0.2	<0.2
Interstate 95	<1.6	1	<0.2	E0.0545	0.386	<0.2	<0.2
Interstate 95	<1.6	E0.755	<0.2	E0.128	0.706	<0.2	<0.2
Interstate 495	E0.405	E0.178	<0.2	E0.0098	E0.103	<0.2	<0.2
Interstate 495	<1.6	<0.2	<0.2	E0.0454	0.255	<0.2	<0.2
Interstate 495	<1.6	<0.468	<0.2	E0.177	E0.446	<0.2	<0.2
Route 2	<1.6	E0.162	<0.2	<0.2	E0.0592	<0.2	<0.2
Route 2	<1.6	<0.2	<0.2	<0.2	E0.195	<0.2	<0.2
Route 2	E0.492	<0.326	<0.2	E0.0359	E0.150	<0.2	<0.2
Route 119	E0.599	E0.158	<0.2	<0.2	E0.0671	<0.2	<0.2
Route 119	<1.6	<0.2	<0.2	<0.2	E0.116	<0.2	<0.2
Route 119	<1.6	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

Highway	Benz[a]pyrene ($\mu\text{g}/\text{L}$)	Benzophenone ($\mu\text{g}/\text{L}$)	<i>beta</i> -Sitosterol ($\mu\text{g}/\text{L}$)	<i>beta</i> -Stigmasterol ($\mu\text{g}/\text{L}$)	<i>beta</i> -Stigmasterol ($\mu\text{g}/\text{L}$)	# P62816 Bisphenol A ($\mu\text{g}/\text{L}$)	Bisphenol A-d3, surrogate (percent recovery)
Interstate 93	0.332	E0.0738	E2.58	<3.20	5.85	1.15	97.6
Interstate 93	0.973	<0.2	E7.68	--	17.7	0.916	101
Interstate 93	<1.29	<0.349	E5.04	<2.97	E17.6	1.24	91.2
Interstate 95	E0.0471	<0.2	<0.8	<0.8	<2	E0.242	72.6
Interstate 95	0.348	<0.2	E0.840	<0.8	5.56	E0.260	50.8
Interstate 95	0.861	<0.2	E2.29	<0.8	<12.0	0.446	93.8
Interstate 495	E0.0708	<0.2	E1.07	<0.8	<2	E0.255	98
Interstate 495	E0.175	<0.2	E1.14	<0.8	E3.03	E0.293	85.9
Interstate 495	E0.677	<0.2	E1.23	<0.8	<7.00	E0.486	53.2
Route 2	<0.2	<0.2	<1.60	<1.60	2.97	E0.309	109
Route 2	E0.0906	<0.2	E0.754	<0.8	E4.34	E0.313	97.3
Route 2	E0.194	E0.0507	E2.18	E0.766	E2.91	E0.179	98.7
Route 119	E0.0460	<0.2	E1.72	<0.8	2.53	E0.200	154
Route 119	E0.0472	<0.2	E0.402	<0.8	E1.20	E0.0607	96.2
Route 119	<0.2	<0.2	E0.971	<0.8	E1.38	<0.4	86.8

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

Highway	Bromacil ($\mu\text{g}/\text{L}$)	Caffeine ($\mu\text{g}/\text{L}$)	Caffeine-13C, surrogate (percent recovery)	Camphor ($\mu\text{g}/\text{L}$)	Carbaryl ($\mu\text{g}/\text{L}$)	Carbazole ($\mu\text{g}/\text{L}$)	Chlorpyrifos ($\mu\text{g}/\text{L}$)	Cholesterol ($\mu\text{g}/\text{L}$)	Cotinine ($\mu\text{g}/\text{L}$)	Decafluoro- biphenyl, surrogate (percent recovery)
Interstate 93	<0.2	0.618	81.6	E0.0474	<0.2	E0.0803	<0.2	2.17	E0.310	57.1
Interstate 93	<0.2	1.13	90	E0.130	<0.2	0.254	<0.2	E5.17	E0.410	66.6
Interstate 93	<0.747	E1.47	110	E0.194	<0.2	0.68	<0.2	<3.40	<0.8	71.6
Interstate 95	<0.2	E0.190	74.2	E0.0302	<0.2	E0.0251	<0.2	0.824	<0.8	57
Interstate 95	<0.2	0.392	56.2	E0.0856	<0.2	E0.144	<0.2	E0.576	<0.8	64.7
Interstate 95	<0.2	0.528	97.7	E0.0635	<0.2	0.293	<0.2	E1.27	<0.216	68.6
Interstate 495	<0.2	E0.162	67.5	E0.0781	<0.2	E0.0228	<0.2	1.61	<0.8	47
Interstate 495	<0.2	0.306	78.7	E0.0913	<0.2	E0.0800	<0.2	E1.26	<0.8	45
Interstate 495	<0.2	<0.2	45.9	E0.0512	<0.2	E0.235	<0.2	E1.25	<0.8	47.2
Route 2	<0.2	E0.0634	81.2	E0.120	<0.2	<0.2	<0.2	E0.492	<0.8	74.5
Route 2	<0.2	E0.114	81.2	E0.0985	<0.2	E0.0569	<0.2	E0.488	<0.8	56.6
Route 2	<0.2	E0.113	91.8	0.319	<0.2	E0.0567	<0.2	E1.69	E0.167	76
Route 119	<0.2	E0.124	111	<0.2	<0.2	E0.0146	<0.2	E2.68	<0.8	80.2
Route 119	<0.2	<0.2	79.3	E0.0924	<0.2	<0.2	<0.2	E0.414	<0.8	59.1
Route 119	<0.2	<0.2	97.5	E0.155	<0.2	<0.2	<0.2	E1.51	<0.8	80.4

Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

Highway	N,N-diethyl- meta-tolamide (DEET) ($\mu\text{g}/\text{L}$)	Diazinon ($\mu\text{g}/\text{L}$)	Dichlorvos ($\mu\text{g}/\text{L}$)	Diethoxynonylphenol (Nonylphenol monoethoxylate; NP1EO) (sum of all isomers) ($\mu\text{g}/\text{L}$)	Diethoxy octylphenol (4-tert-Octylphenol diethoxylate; OP2EO) ($\mu\text{g}/\text{L}$)	Diethyl phthalate ($\mu\text{g}/\text{L}$)	D-Limonene ($\mu\text{g}/\text{L}$)	Fluoranthene ($\mu\text{g}/\text{L}$)
Interstate 93	0.318	<0.2	<0.2	E1.61	<0.32	E0.180	E0.104	0.733
Interstate 93	0.287	<0.2	<0.2	E4.43	<0.32	0.262	<0.2	2.49
Interstate 93	<0.2	<0.2	<0.2	<3.2	<0.644	0.276	E0.175	E8.14
Interstate 95	E0.119	<0.2	<0.2	<3.2	<0.32	<0.2	<0.2	E0.0763
Interstate 95	E0.0277	<0.2	<0.2	<3.2	<0.32	E0.161	E0.0363	1.04
Interstate 95	<0.2	<0.2	<0.2	<3.2	<0.32	0.236	<0.2	2.39
Interstate 495	0.264	<0.2	<0.2	E1.53	E0.129	<0.2	E0.0209	E0.121
Interstate 495	<0.2	<0.2	<0.2	<3.2	<0.32	<0.2	<0.2	0.39
Interstate 495	<0.2	<0.2	<0.2	<3.2	E0.256	<0.2	<0.2	E1.90
Route 2	E0.142	<0.2	<0.400	<3.2	<0.32	<0.2	<0.2	E0.0406
Route 2	<0.2	<0.2	<0.2	<3.2	<0.32	<0.2	<0.2	0.236
Route 2	E0.0956	<0.2	E0.0416	E0.826	<0.32	<0.2	<0.2	0.344
Route 119	E0.0972	<0.2	<0.2	E1.14	E0.110	E0.115	<0.2	E0.0555
Route 119	<0.2	<0.2	<0.2	<3.2	<0.32	<0.2	E0.0428	E0.143
Route 119	<0.2	<0.2	<0.2	<3.2	<0.32	<0.2	<0.2	E0.266

[USGS, U.S. Geological Survey, NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; $<$, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

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Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07.—Continued

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

Highway	Monoethoxynonyl-phenol (4-Nonylphenol monoethoxylate; NP1EO) ($\mu\text{g}/\text{L}$) (sum of all isomers)	Monoethoxyoctyl-phenol (4-tert-Octylphenol monoethoxylate; OP1EO) ($\mu\text{g}/\text{L}$)	p-Cresol ($\mu\text{g}/\text{L}$)	Pentachlorophenol ($\mu\text{g}/\text{L}$)	Phenanthrene ($\mu\text{g}/\text{L}$)	Phenol ($\mu\text{g}/\text{L}$)	Prometon ($\mu\text{g}/\text{L}$)
Interstate 93	<2	<1	E0.0749	E1.10	0.236	E0.148	<0.2
Interstate 93	E1.61	<1	E0.141	E0.483	1.15	E0.174	<0.2
Interstate 93	<2	<0.574	<1.37	<0.8	3.21	E1.81	<0.2
Interstate 95	<2	<1	E0.0560	E0.325	E0.0263	<0.2	<0.2
Interstate 95	<2	<1	0.237	E0.207	0.575	0.36	<0.2
Interstate 95	<2	<1	<0.424	<0.8	1.08	0.483	<0.2
Interstate 495	E0.328	<1	E0.0644	E0.283	E0.0514	<0.2	<0.2
Interstate 495	E0.556	<1	E0.0919	E0.291	0.217	0.204	<0.2
Interstate 495	<2	<1	<0.403	<0.8	E1.17	E0.814	<0.2
Route 2	<2	<1	<0.400	<8.00	E0.0242	<0.400	<0.2
Route 2	E0.346	<1	0.319	E0.186	E0.117	0.582	<0.2
Route 2	<2	<1	E0.197	E0.834	E0.160	0.494	<0.2
Route 119	<2	<1	E0.0420	<1.60	E0.0309	<0.2	<0.2
Route 119	<2	<1	E0.125	<0.8	E0.0694	0.278	<0.2
Route 119	<2	<1	0.246	<0.8	<0.2	0.645	<0.2

[USGS, U.S. Geological Survey, NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; $<$, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hr:mn, hour minute]

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Table 17. Physical properties and concentrations of anthropogenic and natural organic compounds in unfiltered composite samples of highway runoff collected during three storms from five highways in Massachusetts, 2006–07—Continued.

[USGS, U.S. Geological Survey; NTRU, nephelometric turbidity ratio units; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; <, concentration shown is less than the laboratory reporting limit; E, the recovery or variation in recovery of the analyte is outside the acceptable range or the concentration reported is less than laboratory reporting level and is qualified as estimated; mm/dd/yyyy, month/day/year; hrmm, hour minute]

Highway	Isopropyl- benzene, ($\mu\text{g}/\text{L}$)	Naphthalene, ($\mu\text{g}/\text{L}$)	Tetrachloro- ethene ($\mu\text{g}/\text{L}$)	Tribromo- methane ($\mu\text{g}/\text{L}$)
Interstate 93	<0.2	E0.0300	<0.4	<0.2
Interstate 93	<0.2	E0.0739	<0.4	<0.2
Interstate 93	<0.2	E0.286	<0.4	<0.2
Interstate 95	<0.2	<0.2	<0.4	<0.2
Interstate 95	<0.2	E0.0605	<0.4	<0.2
Interstate 95	<0.2	E0.0925	<0.4	<0.2
Interstate 495	<0.2	<0.2	<0.4	<0.2
Interstate 495	<0.2	E0.0310	<0.4	<0.2
Interstate 495	<0.2	E0.0661	<0.4	<0.2
Route 2	<0.2	<0.2	<0.4	<0.2
Route 2	<0.2	<0.2	<0.4	E0.0049
Route 2	<0.2	<0.2	<0.4	<0.2
Route 119	<0.2	<0.2	<0.4	<0.2
Route 119	<0.2	<0.2	<0.4	E0.0090
Route 119	<0.2	<0.2	<0.4	<0.2

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.

[<, Less than the value shown; ≥, greater than or equal to the value shown; ≤, less than or equal to the value shown; mm, millimeters in diameter; W, whole sample; --, no data; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Highway	Sample type	Particle-size fraction	Antimony (ppm)	Aluminum (%)	Arsenic (ppm)	Barium (ppm)	Beryllium (ppm)
Route 119	Suspended sediment	< 0.063 mm	<5	1.91	39	79	0.8
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	<5	1.59	19	87	0.5
Route 119	Suspended sediment	≥ 0.250 mm	<5	0.89	22	55	<0.5
Route 2	Suspended sediment	< 0.063 mm	9	2.81	29	157	1.1
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	<5	0.15	3	19	<0.5
Route 2	Suspended sediment	≥ 0.250 mm	<5	0.27	3	27	<0.5
Interstate 495	Suspended sediment	< 0.063 mm	7	2.32	21	615	0.9
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	<5	1.36	17	314	0.6
Interstate 495	Suspended sediment	≥ 0.250 mm	<5	0.77	13	101	<0.5
Interstate 95	Suspended sediment	< 0.063 mm	10	2.03	20	268	0.9
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	<5	0.99	9	109	<0.5
Interstate 95	Suspended sediment	≥ 0.250 mm	<5	0.75	6	47	<0.5
Route 119	Maintenance sand	W	<5	0.74	5	46	<0.5
Route 119	Maintenance sand	W	<5	0.82	5	50	<0.5
Route 2	Maintenance sand	W	<5	0.49	<3	30	<0.5
Route 2	Maintenance sand	W	<5	0.63	<3	38	<0.5
Interstate 495	Maintenance sand	W	<5	0.57	<3	37	<0.5
Interstate 495	Maintenance sand	W	<5	0.54	<3	33	<0.5
Interstate 95	Maintenance sand	W	<5	0.3	11	19	<0.5
Interstate 95	Maintenance sand	W	<5	0.27	15	15	<0.5
Interstate 95	Road salt (sodium chloride)	W	<5	0.02	<3	3	<0.5
Interstate 495	Roadside grasses	W	<5	0.2	4	33	<0.5
Interstate 495	Roadside grasses	W	<5	0.18	<3	31	<0.5
Route 119	Pine needles	W	<5	0.05	<3	26	<0.5

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

[<, Less than the value shown; ≥, greater than or equal to the value shown; ≤, less than or equal to the value shown; mm, millimeters in diameter; W, whole sample; --, no data; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Highway	Sample type	Particle-size fraction	Bismuth (ppm)	Calcium (%)	Cadmium (ppm)	Cobalt (ppm)	Chromium (ppm)
Route 119	Suspended sediment	< 0.063 mm	<5	0.25	<1	19	147
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	<5	0.27	<1	13	687
Route 119	Suspended sediment	≥ 0.250 mm	<5	0.33	<1	11	3,470
Route 2	Suspended sediment	< 0.063 mm	<5	0.35	1	15	391
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	<5	0.1	<1	<1	65
Route 2	Suspended sediment	≥ 0.250 mm	<5	0.22	<1	2	70
Interstate 495	Suspended sediment	< 0.063 mm	<5	0.34	1	14	136
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	<5	0.39	<1	10	1,690
Interstate 495	Suspended sediment	≥ 0.250 mm	<5	0.3	<1	6	1,050
Interstate 95	Suspended sediment	< 0.063 mm	<5	0.51	2	15	381
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	<5	0.62	<1	7	134
Interstate 95	Suspended sediment	≥ 0.250 mm	<5	0.5	<1	5	395
Route 119	Maintenance sand	W	<5	0.11	<1	3	325
Route 119	Maintenance sand	W	<5	0.12	<1	3	361
Route 2	Maintenance sand	W	<5	0.07	<1	1	273
Route 2	Maintenance sand	W	<5	0.08	<1	2	308
Interstate 495	Maintenance sand	W	<5	0.12	<1	2	306
Interstate 495	Maintenance sand	W	<5	0.13	<1	2	321
Interstate 95	Maintenance sand	W	<5	0.04	<1	2	421
Interstate 95	Maintenance sand	W	<5	0.03	<1	2	329
Interstate 95	Road salt (sodium chloride)	W	<5	0.26	<1	<1	12
Interstate 495	Roadside grasses	W	<5	0.33	<1	2	483
Interstate 495	Roadside grasses	W	<5	0.25	<1	1	227
Route 119	Pine needles	W	<5	0.47	<1	<1	34

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

[<, Less than the value shown; ≥, greater than or equal to the value shown; ≤, less than or equal to the value shown; mm, millimeters in diameter; W, whole sample; --, no data; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Highway	Sample type	Particle-size fraction	Copper (ppm)	Iron (%)	Lanthanum (ppm)	Lead (ppm)	Lithium (ppm)
Route 119	Suspended sediment	< 0.063 mm	95.8	3.96	28.1	74	50
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	65.2	2.91	15.6	33	32
Route 119	Suspended sediment	≥ 0.250 mm	68.2	3.47	9.7	20	14
Route 2	Suspended sediment	< 0.063 mm	218	4.89	32.6	157	69
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	17.5	0.52	5.6	7	2
Route 2	Suspended sediment	≥ 0.250 mm	15.6	1.4	5.8	8	4
Interstate 495	Suspended sediment	< 0.063 mm	248	3.85	24.8	108	67
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	159	3.39	14.6	51	27
Interstate 495	Suspended sediment	≥ 0.250 mm	78	2.99	8.9	19	13
Interstate 95	Suspended sediment	< 0.063 mm	391	4.22	23.7	200	47
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	209	2.73	11.7	251	14
Interstate 95	Suspended sediment	≥ 0.250 mm	44.2	2.57	15.4	45	14
Route 119	Maintenance sand	W	16.1	1.21	19.8	15	10
Route 119	Maintenance sand	W	10.3	1.25	20.7	8	10
Route 2	Maintenance sand	W	8.9	0.82	12	5	6
Route 2	Maintenance sand	W	9.1	0.98	15.1	5	6
Interstate 495	Maintenance sand	W	6.8	0.8	16.8	4	6
Interstate 495	Maintenance sand	W	7.1	0.85	16.6	4	6
Interstate 95	Maintenance sand	W	7.3	1.69	10.6	7	2
Interstate 95	Maintenance sand	W	6.1	2.26	10.5	7	1
Interstate 95	Road salt (sodium chloride)	W	1.1	0.05	0.7	<2	<1
Interstate 495	Roadside grasses	W	23.7	0.65	3.2	12	3
Interstate 495	Roadside grasses	W	18	0.43	2	11	3
Route 119	Pine needles	W	2.1	0.04	<0.5	7	<1

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

[<, Less than the value shown; ≥, greater than or equal to the value shown; ≤, less than or equal to the value shown; mm, millimeters in diameter; W, whole sample; --, no data; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Highway	Sample type	Particle-size fraction	Magnesium (%)	Manganese (ppm)	Molybdenum (ppm)	Nickel (ppm)	Phosphorus (%)
Route 119	Suspended sediment	< 0.063 mm	1.24	589	5	46	0.1
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	0.72	477	7	41	0.06
Route 119	Suspended sediment	≥ 0.250 mm	0.29	553	12	54	0.04
Route 2	Suspended sediment	< 0.063 mm	1.92	703	11	53	0.11
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	0.06	99	1	5	0.01
Route 2	Suspended sediment	≥ 0.250 mm	0.13	145	2	16	0.01
Interstate 495	Suspended sediment	< 0.063 mm	1.88	621	11	51	0.09
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	0.67	504	13	49	0.05
Interstate 495	Suspended sediment	≥ 0.250 mm	0.3	415	11	40	0.03
Interstate 95	Suspended sediment	< 0.063 mm	1.14	957	17	63	0.13
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	0.46	297	7	35	0.08
Interstate 95	Suspended sediment	≥ 0.250 mm	0.35	301	6	24	0.04
Route 119	Maintenance sand	W	0.21	304	6	9	0.04
Route 119	Maintenance sand	W	0.2	329	6	9	0.04
Route 2	Maintenance sand	W	0.1	198	2	8	0.03
Route 2	Maintenance sand	W	0.14	220	2	7	0.03
Interstate 495	Maintenance sand	W	0.12	208	5	7	0.04
Interstate 495	Maintenance sand	W	0.12	231	13	8	0.04
Interstate 95	Maintenance sand	W	0.06	108	2	9	0.03
Interstate 95	Maintenance sand	W	0.07	88	3	9	0.05
Interstate 95	Road salt (sodium chloride)	W	1.56	15	<1	<1	<0.01
Interstate 495	Roadside grasses	W	0.27	265	4	14	0.27
Interstate 495	Roadside grasses	W	0.23	246	2	7	0.22
Route 119	Pine needles	W	0.05	1,150	<1	2	0.04

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

[<, Less than the value shown; ≥, greater than or equal to the value shown; ≤, less than or equal to the value shown; mm, millimeters in diameter; W, whole sample; --, no data; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Highway	Sample type	Particle-size fraction	Potassium (%)	Scandium (ppm)	Silver (ppm)	Sodium (%)	Tin (ppm)
Route 119	Suspended sediment	< 0.063 mm	0.36	4.2	<0.2	0.13	<10
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	0.46	3.8	<0.2	0.11	<10
Route 119	Suspended sediment	≥ 0.250 mm	0.3	1.6	<0.2	0.16	<10
Route 2	Suspended sediment	< 0.063 mm	0.54	6	<0.2	0.15	10
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	0.04	<0.5	<0.2	0.02	<10
Route 2	Suspended sediment	≥ 0.250 mm	0.07	0.6	<0.2	0.03	<10
Interstate 495	Suspended sediment	< 0.063 mm	0.4	5	<0.2	0.07	10
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	0.33	3.6	<0.2	0.11	<10
Interstate 495	Suspended sediment	≥ 0.250 mm	0.21	1.7	<0.2	0.07	<10
Interstate 95	Suspended sediment	< 0.063 mm	0.39	4.3	0.3	0.19	20
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	0.17	1.8	<0.2	0.07	<10
Interstate 95	Suspended sediment	≥ 0.250 mm	0.28	2.1	<0.2	0.06	<10
Route 119	Maintenance sand	W	0.33	2.1	<0.2	0.05	<10
Route 119	Maintenance sand	W	0.36	2.2	<0.2	0.05	<10
Route 2	Maintenance sand	W	0.2	1.3	<0.2	0.04	<10
Route 2	Maintenance sand	W	0.25	1.5	<0.2	0.05	<10
Interstate 495	Maintenance sand	W	0.24	1.4	<0.2	0.05	<10
Interstate 495	Maintenance sand	W	0.22	1.5	<0.2	0.06	<10
Interstate 95	Maintenance sand	W	0.14	0.7	<0.2	0.07	<10
Interstate 95	Maintenance sand	W	0.14	0.8	<0.2	0.27	<10
Interstate 95	Road salt (sodium chloride)	W	0.37	<0.5	<0.2	>15	<10
Interstate 495	Roadside grasses	W	0.97	<0.5	<0.2	0.21	<10
Interstate 495	Roadside grasses	W	0.59	<0.5	<0.2	0.14	<10
Route 119	Pine needles	W	0.12	<0.5	<0.2	0.01	<10

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

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Highway	Sample type	Particle-size fraction	Strontium (ppm)	Thallium (%)	Vanadium (ppm)	Tungsten (ppm)	Yttrium (ppm)
Route 119	Suspended sediment	< 0.063 mm	23.8	0.07	68	40	10.8
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	21.3	0.09	60	20	6.6
Route 119	Suspended sediment	≥ 0.250 mm	28	0.04	35	<10	4.5
Route 2	Suspended sediment	< 0.063 mm	39.2	0.09	93	<10	13.6
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	4.6	0.02	5	<10	2.3
Route 2	Suspended sediment	≥ 0.250 mm	9.1	0.02	8	<10	2.4
Interstate 495	Suspended sediment	< 0.063 mm	29.8	0.09	88	<10	12
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	27.3	0.09	63	<10	7.8
Interstate 495	Suspended sediment	≥ 0.250 mm	18.2	0.03	24	<10	4.8
Interstate 95	Suspended sediment	< 0.063 mm	40.5	0.12	125	<10	11.8
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	34.5	0.07	48	<10	6.2
Interstate 95	Suspended sediment	≥ 0.250 mm	35.8	0.08	27	<10	7.4
Route 119	Maintenance sand	W	8.8	0.06	16	<10	6.5
Route 119	Maintenance sand	W	10.4	0.06	16	<10	6.8
Route 2	Maintenance sand	W	8	0.03	9	<10	4.5
Route 2	Maintenance sand	W	10.1	0.04	12	<10	5.5
Interstate 495	Maintenance sand	W	9.5	0.05	10	<10	5.7
Interstate 495	Maintenance sand	W	8	0.05	11	<10	6
Interstate 95	Maintenance sand	W	7.9	0.02	32	<10	4.6
Interstate 95	Maintenance sand	W	6.8	0.02	47	<10	4.5
Interstate 95	Road salt (sodium chloride)	W	120	<0.01	<2	<10	<0.5
Interstate 495	Roadside grasses	W	27	0.01	6	<10	1.2
Interstate 495	Roadside grasses	W	22	<0.01	5	<10	1
Route 119	Pine needles	W	25.3	<0.01	<2	<10	<0.5

Table 18. Concentrations of 32 elements and total organic carbon in samples of sieved suspended sediment, highway maintenance sand, road salt, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

[<, Less than the value shown; ≥, greater than or equal to the value shown; ≤, less than or equal to the value shown; mm, millimeters in diameter; W, whole sample; --, no data; ppm, parts per million; %, parts per hundred; TOC, total organic carbon]

Highway	Sample type	Particle-size fraction	Zinc (ppm)	Zirconium (ppm)	TOC (%)
Route 119	Suspended sediment	< 0.063 mm	503	10.4	7.86
Route 119	Suspended sediment	0.063 ≤ 0.250 mm	247	6.8	7.56
Route 119	Suspended sediment	≥ 0.250 mm	200	5.3	10.2
Route 2	Suspended sediment	< 0.063 mm	2,360	15.2	11.7
Route 2	Suspended sediment	0.063 ≤ 0.250 mm	46.6	1.8	12.3
Route 2	Suspended sediment	≥ 0.250 mm	83.9	3.4	12.2
Interstate 495	Suspended sediment	< 0.063 mm	945	12.6	11.7
Interstate 495	Suspended sediment	0.063 ≤ 0.250 mm	363	8.2	7.69
Interstate 495	Suspended sediment	≥ 0.250 mm	135	6.7	2.78
Interstate 95	Suspended sediment	< 0.063 mm	1,120	16.6	17.5
Interstate 95	Suspended sediment	0.063 ≤ 0.250 mm	403	6.1	17.1
Interstate 95	Suspended sediment	≥ 0.250 mm	86.8	11.3	1.08
Route 119	Maintenance sand	W	31.2	4.5	--
Route 119	Maintenance sand	W	20.1	4.7	--
Route 2	Maintenance sand	W	11.7	4.1	--
Route 2	Maintenance sand	W	14.4	4.7	--
Interstate 495	Maintenance sand	W	12.3	4.8	--
Interstate 495	Maintenance sand	W	12.9	4.5	--
Interstate 95	Maintenance sand	W	12.5	6.9	--
Interstate 95	Maintenance sand	W	11.8	6.7	--
Interstate 95	Road salt (sodium chloride)	W	5.2	<0.5	--
Interstate 495	Roadside grasses	W	76.6	0.5	--
Interstate 495	Roadside grasses	W	67.7	<0.5	--
Route 119	Pine needles	W	29.3	<0.5	--

Table 19. Distribution of particle sizes and concentrations of 32 elements measured in samples of soil collected near seven highways in Massachusetts, 2005–07.

[Latitude and longitude: in degrees, minutes, and seconds; <, actual value is less than the value shown; mm, millimeters; ppm, parts per million; %, parts per hundred; -- no data]

Highway	Sample number	Latitude	Longitude	Particles < 0.063 mm in diameter (%)	Particles < 0.25 mm in diameter (%)	Silver (ppm)	Aluminum (%)	Arsenic (ppm)
Route 119	1	42 41 51.8	71 54 16.8	16	53	<0.2	1.36	19
Route 119	2	42 41 49.6	71 54 18.2	20	52	<0.2	0.6	11
Route 119	3	42 41 55.9	71 54 32.6	22	49	<0.2	0.36	4
Route 119	4	42 42 34.6	71 54 31.9	27	60	<0.2	1.86	8
Route 119	5	42 42 41.3	71 54 39.3	18	52	<0.2	1.54	6
Route 2	1	42 30 53.7	71 29 39.3	26	76	<0.2	1.53	10
Route 2	2	42 30 46.8	71 29 39.3	19	58	<0.2	1.36	11
Route 2	3	42 30 15.2	71 29 01.7	35	80	<0.2	2.09	6
Route 2	4	42 30 14.8	71 29 49.4	24	65	<0.2	1.74	8
Route 2	5	42 30 29.6	71 29 15.3	40	74	<0.2	1.73	9
Interstate 495	1	42 27 11.6	71 34 35.8	42	71	<0.2	2.18	14
Interstate 495	2	42 27 32.4	71 34 13.1	45	77	<0.2	2.03	10
Interstate 495	3	42 27 56.1	71 34 47.4	35	68	<0.2	1.61	12
Interstate 495	4	42 28 10.7	71 33 37.8	50	81	<0.2	2.61	11
Interstate 495	5	42 27 16.3	71 34 40.6	35	62	<0.2	2.16	20
Interstate 95	1	42 24 09.6	71 15 37.3	32	64	<0.2	1.9	6
Interstate 95	2	42 24 17.4	71 15 35.9	36	69	<0.2	2.06	6
Interstate 95	3	42 26 13.3	71 15 37.5	44	78	<0.2	1.72	8
Interstate 95	4	42 26 14.6	71 15 37.1	43	76	<0.2	1.64	8
Interstate 95	5	42 25 17.8	71 16 22.4	29	63	<0.2	1.29	9
Route 8	1	42 40 47.9	73 06 25.1	--	--	<0.2	1.51	9
Route 8	2	42 40 46.6	73 06 25.6	--	--	<0.2	1.97	10
Route 8	3	42 40 32.1	73 06 28.9	--	--	1	0.5	4
Route 8	4	42 40 30.4	73 06 29.5	--	--	<0.2	2.15	10
Route 8	5	42 40 26.9	73 06 29.4	--	--	<0.2	1.94	6
Interstate 93	1	42 16 01.5	71 02 48.4	--	--	<0.2	1.11	6
Interstate 93	2	42 16 05.8	71 02 50.8	--	--	<0.2	1.29	4
Interstate 93	3	42 16 48.6	71 02 46.6	--	--	<0.2	1.11	4
Interstate 93	4	42 16 52.0	71 02 48.0	--	--	<0.2	1.17	10
Interstate 93	5	42 16 03.0	71 02 53.2	--	--	<0.2	1.05	6
Interstate 195	1	41 43 57.3	70 46 13.3	--	--	<0.2	0.57	<3
Interstate 195	2	41 43 46.7	70 46 19.2	--	--	<0.2	0.64	3
Interstate 195	3	41 43 41.8	70 46 23.0	--	--	<0.2	0.26	3
Interstate 195	4	41 44 17.8	70 45 56.3	--	--	<0.2	0.46	<3
Interstate 195	5	41 44 23.5	70 45 23.5	--	--	<0.2	0.69	<3

Table 19. Distribution of particle sizes and concentrations of 32 elements measured in samples of soil collected near seven highways in Massachusetts, 2005–07.—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred; -- no data]

Highway	Sample number	Silver (ppm)	Aluminum (%)	Arsenic (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)	Calcium (%)	Cadmium (ppm)
Route 119	1	<0.2	1.36	19	43	0.6	<5	0.05	<1
Route 119	2	<0.2	0.6	11	28	<0.5	<5	0.03	<1
Route 119	3	<0.2	0.36	4	26	<0.5	<5	0.02	<1
Route 119	4	<0.2	1.86	8	46	0.8	<5	0.06	<1
Route 119	5	<0.2	1.54	6	41	<0.5	<5	0.05	<1
Route 2	1	<0.2	1.53	10	45	0.5	<5	0.11	<1
Route 2	2	<0.2	1.36	11	55	<0.5	<5	0.26	<1
Route 2	3	<0.2	2.09	6	92	1.3	<5	0.22	<1
Route 2	4	<0.2	1.74	8	45	0.6	<5	0.12	<1
Route 2	5	<0.2	1.73	9	42	0.7	<5	0.11	<1
Interstate 495	1	<0.2	2.18	14	48	0.6	<5	0.14	<1
Interstate 495	2	<0.2	2.03	10	40	0.5	<5	0.16	<1
Interstate 495	3	<0.2	1.61	12	40	<0.5	<5	0.14	<1
Interstate 495	4	<0.2	2.61	11	36	0.6	<5	0.1	<1
Interstate 495	5	<0.2	2.16	20	53	0.7	<5	0.1	<1
Interstate 95	1	<0.2	1.9	6	42	0.5	<5	0.54	<1
Interstate 95	2	<0.2	2.06	6	41	0.9	<5	0.3	<1
Interstate 95	3	<0.2	1.72	8	38	0.6	<5	0.12	<1
Interstate 95	4	<0.2	1.64	8	27	<0.5	<5	0.1	<1
Interstate 95	5	<0.2	1.29	9	31	<0.5	<5	0.21	<1
Route 8	1	<0.2	1.51	9	125	<0.5	<5	0.25	<1
Route 8	2	<0.2	1.97	10	80	0.6	<5	0.37	<1
Route 8	3	1	0.5	4	37	<0.5	<5	>15	<1
Route 8	4	<0.2	2.15	10	74	<0.5	<5	0.4	<1
Route 8	5	<0.2	1.94	6	126	<0.5	<5	0.5	<1
Interstate 93	1	<0.2	1.11	6	48	<0.5	<5	0.24	<1
Interstate 93	2	<0.2	1.29	4	37	<0.5	<5	0.25	<1
Interstate 93	3	<0.2	1.11	4	42	<0.5	<5	0.26	<1
Interstate 93	4	<0.2	1.17	10	203	0.6	<5	0.31	1
Interstate 93	5	<0.2	1.05	6	45	<0.5	<5	0.15	<1
Interstate 195	1	<0.2	0.57	<3	14	<0.5	<5	0.02	<1
Interstate 195	2	<0.2	0.64	3	14	<0.5	<5	0.04	<1
Interstate 195	3	<0.2	0.26	3	12	<0.5	<5	0.03	<1
Interstate 195	4	<0.2	0.46	<3	13	<0.5	<5	0.03	<1
Interstate 195	5	<0.2	0.69	<3	13	<0.5	<5	0.08	<1

Table 19. Distribution of particle sizes and concentrations of 32 elements measured in samples of soil collected near seven highways in Massachusetts, 2005-07.—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred; -- no data]

Highway	Sample number	Cobalt (ppm)	Chromium (ppm)	Copper (ppm)	Iron (%)	Potassium (%)	Lanthanum (ppm)
Route 119	1	2	413	11.2	1.62	0.22	20.4
Route 119	2	3	1540	14.3	1.61	0.16	19.7
Route 119	3	1	784	12	0.73	0.11	15.3
Route 119	4	3	649	10.5	1.84	0.19	26.1
Route 119	5	2	720	8.8	2.14	0.17	26.1
Route 2	1	4	384	11	1.53	0.17	22.4
Route 2	2	8	655	15.2	1.82	0.31	22.4
Route 2	3	6	408	20.1	1.85	0.15	29.7
Route 2	4	4	407	12.6	1.62	0.16	22.1
Route 2	5	4	564	11.6	1.73	0.14	24
Interstate 495	1	6	338	13.7	2	0.21	27.8
Interstate 495	2	4	1140	14.2	2.54	0.16	20.3
Interstate 495	3	4	438	12.5	1.76	0.18	15.9
Interstate 495	4	5	240	7.9	2.05	0.16	25.7
Interstate 495	5	4	527	11.7	2.31	0.22	25.5
Interstate 95	1	10	209	27.3	2.51	0.17	18.9
Interstate 95	2	7	521	20.6	2.25	0.13	26
Interstate 95	3	4	276	9.6	1.41	0.11	23.9
Interstate 95	4	3	246	11.5	1.42	0.1	20.9
Interstate 95	5	5	1090	21.9	2.29	0.11	12.6
Route 8	1	12	158	32.1	2.98	0.18	30.7
Route 8	2	14	185	24.5	3.27	0.25	34
Route 8	3	3	244	11.8	0.74	0.15	7.7
Route 8	4	14	255	28.8	3.73	0.28	18.3
Route 8	5	13	281	24.9	3.53	0.23	18.3
Interstate 93	1	5	464	56.9	2.12	0.2	17.2
Interstate 93	2	4	457	33	1.86	0.24	22.9
Interstate 93	3	5	195	40.5	1.87	0.16	17.8
Interstate 93	4	8	390	167	3.53	0.2	18
Interstate 93	5	4	183	79.8	1.91	0.15	20.9
Interstate 195	1	1	298	4.5	1.01	0.06	9.3
Interstate 195	2	1	447	5.9	1.03	0.07	13.4
Interstate 195	3	1	548	6.9	0.76	0.05	11.8
Interstate 195	4	<1	250	3.5	0.47	0.05	7.6
Interstate 195	5	1	253	2.7	0.45	0.06	10.5

Table 19. Distribution of particle sizes and concentrations of 32 elements measured in samples of soil collected near seven highways in Massachusetts, 2005-07.—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred; -- no data]

Highway	Sample number	Lithium (ppm)	Magnesium (%)	Manganese (ppm)	Molybdenum (ppm)	Sodium (%)	Nickel (ppm)
Route 119	1	23	0.11	196	4	0.03	13
Route 119	2	8	0.03	215	5	0.02	19
Route 119	3	3	0.01	134	5	0.01	17
Route 119	4	14	0.12	298	4	0.04	14
Route 119	5	9	0.06	237	6	0.03	18
Route 2	1	13	0.26	272	2	0.03	17
Route 2	2	14	0.39	440	5	0.06	30
Route 2	3	16	0.38	997	2	0.04	23
Route 2	4	15	0.25	175	3	0.04	21
Route 2	5	14	0.24	281	3	0.04	18
Interstate 495	1	18	0.36	296	3	0.04	24
Interstate 495	2	17	0.22	257	4	0.05	27
Interstate 495	3	16	0.24	246	4	0.04	21
Interstate 495	4	20	0.34	172	2	0.03	20
Interstate 495	5	25	0.32	253	3	0.04	20
Interstate 95	1	13	0.54	286	2	0.07	22
Interstate 95	2	13	0.36	301	4	0.05	20
Interstate 95	3	12	0.21	215	3	0.04	14
Interstate 95	4	12	0.21	156	3	0.03	14
Interstate 95	5	8	0.22	305	4	0.05	23
Route 8	1	24	0.42	870	2	0.03	26
Route 8	2	29	0.52	1020	2	0.03	31
Route 8	3	6	0.27	542	3	0.02	14
Route 8	4	39	0.7	679	3	0.03	37
Route 8	5	34	0.61	2130	2	0.03	28
Interstate 93	1	11	0.29	268	5	0.09	22
Interstate 93	2	27	0.3	259	4	0.11	15
Interstate 93	3	12	0.3	323	2	0.04	16
Interstate 93	4	15	0.28	431	4	0.07	25
Interstate 93	5	14	0.27	188	4	0.03	23
Interstate 195	1	2	0.03	52	2	0.01	6
Interstate 195	2	3	0.03	78	3	0.02	11
Interstate 195	3	<1	0.02	85	3	0.02	9
Interstate 195	4	2	0.03	52	2	0.02	7
Interstate 195	5	4	0.05	71	1	0.01	5

Table 19. Distribution of particle sizes and concentrations of 32 elements measured in samples of soil collected near seven highways in Massachusetts, 2005-07—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred; -- no data]

Highway	Sample number	Phosphorus (%)	Lead (ppm)	Antimony (ppm)	Scandium (ppm)	Tin (ppm)	Strontium (ppm)
Route 119	1	0.05	47	<5	1.5	<10	5.8
Route 119	2	0.04	22	<5	0.7	<10	4.1
Route 119	3	0.02	10	<5	<0.5	<10	4.5
Route 119	4	0.04	15	<5	2.6	<10	8.1
Route 119	5	0.04	20	<5	1.8	<10	7
Route 2	1	0.07	25	<5	1.9	<10	10.2
Route 2	2	0.07	21	<5	2.8	<10	19.4
Route 2	3	0.16	30	<5	1.6	<10	14
Route 2	4	0.06	65	<5	1.8	<10	10.1
Route 2	5	0.09	24	<5	1.8	<10	9.1
Interstate 495	1	0.06	23	<5	2.5	<10	11.2
Interstate 495	2	0.04	43	<5	1.9	<10	13.6
Interstate 495	3	0.05	90	<5	1.8	<10	11.9
Interstate 495	4	0.04	22	<5	2.9	<10	8.4
Interstate 495	5	0.05	21	<5	2.4	<10	10.6
Interstate 95	1	0.11	120	<5	3.9	<10	25.3
Interstate 95	2	0.1	29	<5	2.7	<10	15.8
Interstate 95	3	0.08	52	<5	2.3	<10	8.2
Interstate 95	4	0.1	80	<5	1.9	<10	7.2
Interstate 95	5	0.09	60	<5	1.5	<10	16.4
Route 8	1	0.08	212	<5	2.5	<10	10.1
Route 8	2	0.09	33	<5	3.1	<10	10.9
Route 8	3	0.09	35	<5	0.8	<10	151
Route 8	4	0.09	44	<5	2.4	<10	12.3
Route 8	5	0.11	34	<5	2.2	<10	13.7
Interstate 93	1	0.08	171	<5	2.7	<10	29.8
Interstate 93	2	0.05	74	<5	2.9	<10	25.9
Interstate 93	3	0.09	202	<5	2.5	<10	27.2
Interstate 93	4	0.11	631	<5	2.6	230	35.1
Interstate 93	5	0.09	770	<5	2	<10	16.8
Interstate 195	1	0.02	14	<5	<0.5	<10	5.4
Interstate 195	2	0.02	17	<5	0.5	<10	6.7
Interstate 195	3	0.01	14	<5	<0.5	<10	5.4
Interstate 195	4	0.01	11	<5	<0.5	<10	6.1
Interstate 195	5	0.01	10	<5	1	<10	13.3

Table 19. Distribution of particle sizes and concentrations of 32 elements measured in samples of soil collected near seven highways in Massachusetts, 2005-07—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred; -- no data]

Highway	Sample number	Thallium (%)	Vanadium (ppm)	Tungsten (ppm)	Yttrium (ppm)	Zinc (ppm)	Zirconium (ppm)
Route 119	1	0.05	26	<10	5.2	29.3	1.7
Route 119	2	0.03	20	<10	3.8	13.1	1.6
Route 119	3	0.02	7	<10	3.1	13.7	1.3
Route 119	4	0.08	25	<10	6.8	46	1.8
Route 119	5	0.07	31	<10	5.7	29.4	3.1
Route 2	1	0.08	25	<10	6.7	30.7	1.7
Route 2	2	0.11	30	<10	9.4	36.6	3.6
Route 2	3	0.1	29	<10	10.1	53.4	1.7
Route 2	4	0.1	33	<10	7.6	30.9	2
Route 2	5	0.09	27	<10	7.9	28.3	1.9
Interstate 495	1	0.11	34	<10	8.6	36.2	2.2
Interstate 495	2	0.13	41	<10	6.8	26.7	4.3
Interstate 495	3	0.1	34	<10	4.7	54.2	2.5
Interstate 495	4	0.13	38	<10	7.2	32.4	4.2
Interstate 495	5	0.09	33	<10	7.6	34.6	2.6
Interstate 95	1	0.21	81	<10	13.9	58.2	5.1
Interstate 95	2	0.14	51	<10	18.4	40	2.8
Interstate 95	3	0.09	27	<10	9.8	35.2	1.8
Interstate 95	4	0.08	34	<10	7.2	30.6	1.5
Interstate 95	5	0.1	48	<10	5.9	43.1	2.2
Route 8	1	0.02	19	<10	13.7	199	3.3
Route 8	2	0.03	25	<10	15.3	104	3.2
Route 8	3	0.01	14	<10	5.2	74.7	0.8
Route 8	4	0.03	33	<10	8.4	112	3.1
Route 8	5	0.03	29	<10	6.9	106	2.8
Interstate 93	1	0.09	42	<10	9	51.2	3.6
Interstate 93	2	0.1	36	<10	10.1	36.5	3.4
Interstate 93	3	0.1	36	<10	9.2	74.4	4.8
Interstate 93	4	0.08	40	<10	9.4	435	5.4
Interstate 93	5	0.07	60	<10	9.9	67.8	4.4
Interstate 195	1	0.03	16	<10	2.4	6.8	1.6
Interstate 195	2	0.04	17	<10	2.8	6.3	4.5
Interstate 195	3	0.04	12	<10	2.1	5.8	1.3
Interstate 195	4	0.04	8	<10	2.4	8.1	2.3
Interstate 195	5	0.05	14	<10	3.6	6.1	0.9

Table 20. Distribution of particle sizes and concentrations of 32 elements measured in samples of berm material collected at the edge of the pavement for four highways in Massachusetts, 2005–07.

[Latitude and longitude: in degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred]

Highway	Sample number	Latitude	Longitude	Particles <0.063 mm in diameter (percent)	Particles <0.25 mm in diameter (percent)	Silver (ppm)	Aluminum (%)	Arsenic (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)	Calcium (%)	Cadmium (ppm)
Route 119	1	42 41 52.7	71 54 27.5	5.2	29.5	<0.2	0.64	13	31	<0.5	<5	0.19	<1
Route 119	2	42 41 55.9	71 54 32.6	8.9	35.4	<0.2	0.75	22	37	<0.5	<5	0.19	<1
Route 119	3	42 42 09.2	71 54 52.4	12.7	42.0	<0.2	0.8	21	34	<0.5	<5	0.17	<1
Route 119	4	42 42 08.7	71 54 52.8	6.8	27.7	<0.2	0.74	19	38	<0.5	<5	0.17	<1
Route 119	5	42 42 07.7	71 54 51.1	7.5	30.9	<0.2	0.78	20	38	<0.5	<5	0.18	<1
Route 2	1	42 30 59.0	71 29 56.6	6.2	37.0	<0.2	0.67	10	44	<0.5	<5	0.25	<1
Route 2	2	42 30 26.9	71 29 13.4	5.5	41.4	<0.2	0.74	9	54	<0.5	<5	0.39	<1
Route 2	3	42 30 16.6	71 28 59.2	3.5	32.1	<0.2	0.54	6	39	<0.5	<5	0.29	<1
Route 2	4	42 30 14.2	71 29 51.1	9.3	41.0	<0.2	0.61	9	42	<0.5	<5	0.23	<1
Route 2	5	42 30 27.3	71 29 12.8	4.9	47.7	<0.2	0.72	10	54	<0.5	<5	0.34	<1
Interstate 495	1	42 27 12.6	71 34 38.9	6.3	31.5	<0.2	0.67	9	87	<0.5	<5	0.5	<1
Interstate 495	2	42 27 57.4	71 33 47.1	6.3	28.9	<0.2	0.74	11	105	<0.5	<5	0.54	<1
Interstate 495	3	42 28 21.0	71 34 20.4	8.1	45.5	<0.2	0.83	19	150	<0.5	<5	0.54	<1
Interstate 495	4	42 28 19.9	71 33 21.6	8.5	42.7	<0.2	0.79	15	162	<0.5	<5	0.49	<1
Interstate 495	5	42 27 15.9	71 34 39.0	6.9	40.3	<0.2	0.71	11	70	<0.5	<5	0.4	<1
Interstate 95	1	42 27 06.6	71 15 36.1	6.1	36.9	<0.2	0.65	9	78	<0.5	<5	0.5	<1
Interstate 95	2	42 24 12.2	71 15 35.1	14.1	49.1	<0.2	0.95	12	59	<0.5	<5	0.44	<1
Interstate 95	3	42 26 11.0	71 15 37.2	6.3	21.2	<0.2	0.82	9	61	<0.5	<5	0.5	<1
Interstate 95	4	42 26 22.1	71 15 37.5	10.7	29.0	<0.2	0.96	9	60	<0.5	<5	0.63	<1
Interstate 95	5	42 26 25.3	71 15 31.4	4.9	20.6	<0.2	0.52	6	49	<0.5	<5	0.35	<1

Table 20. Distribution of particle sizes and concentrations of 32 elements measured in samples of berm material collected at the edge of the pavement for four highways in Massachusetts, 2005–07.—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred]

Highway	Sample number	Cobalt (ppm)	Chromium (ppm)	Copper (ppm)	Iron (%)	Potassium (%)	Lanthanum (ppm)	Lithium (ppm)	Magnesium (%)	Manganese (ppm)	Molybdenum (ppm)	Sodium (%)	Nickel (ppm)
Route 119	1	3	223	22.4	1.3	0.2	15.3	9	0.21	241	3	0.04	12
Route 119	2	5	380	33.7	1.66	0.25	21.8	12	0.28	294	3	0.05	15
Route 119	3	4	480	36.4	1.7	0.21	22.2	11	0.23	343	9	0.05	16
Route 119	4	4	368	28.4	1.57	0.25	20.3	12	0.26	328	3	0.05	16
Route 119	5	5	530	33.2	1.73	0.26	21	12	0.28	359	10	0.05	18
Route 2	1	4	404	40.5	1.85	0.21	15.3	11	0.26	304	3	0.11	18
Route 2	2	4	664	91.3	2.09	0.22	16.5	12	0.3	388	12	0.07	23
Route 2	3	3	387	41.5	1.7	0.17	13.3	9	0.21	263	4	0.05	18
Route 2	4	4	439	60.9	1.92	0.17	15.2	10	0.23	280	8	0.22	21
Route 2	5	5	693	91.1	2.09	0.22	15.4	11	0.27	376	5	0.07	25
Interstate 495	1	5	391	63.9	2.22	0.17	14.1	12	0.34	316	9	0.04	26
Interstate 495	2	5	490	68.3	2.49	0.21	13.4	13	0.33	362	6	0.1	27
Interstate 495	3	6	779	187	3.05	0.22	18.2	13	0.36	465	15	0.07	44
Interstate 495	4	6	466	99.8	2.63	0.21	17	12	0.36	423	6	0.05	27
Interstate 495	5	5	630	56.2	2.37	0.2	15.9	11	0.28	400	12	0.07	26
Interstate 95	1	5	638	79.5	2.25	0.18	11.9	10	0.25	307	7	0.07	26
Interstate 95	2	6	670	67.9	2.43	0.23	20.1	13	0.3	347	13	0.09	29
Interstate 95	3	6	621	65.1	2.33	0.3	14.7	14	0.37	338	6	0.06	28
Interstate 95	4	8	730	68.4	2.96	0.31	17	15	0.49	386	15	0.07	33
Interstate 95	5	3	592	39	1.84	0.18	11.5	9	0.21	239	4	0.05	22

Table 20. Distribution of particle sizes and concentrations of 32 elements measured in samples of berm material collected at the edge of the pavement for four highways in Massachusetts, 2005–07.—Continued

[Latitude and longitude: In degrees, minutes, and seconds; <, actual value is less than shown; mm, millimeters; ppm, parts per million; %, parts per hundred]

Highway	Sample number	Phosphorus (%)	Lead (ppm)	Antimony (ppm)	Scandium (ppm)	Tin (ppm)	Strontium (ppm)	Thallium (%)	Vanadium (ppm)	Tungsten (ppm)	Yttrium (ppm)	Zinc (ppm)	Zirconium (ppm)
Route 119	1	0.04	21	<5	1.7	<10	11.8	0.04	14	<10	5.6	47.5	4
Route 119	2	0.05	20	<5	2.2	<10	13.8	0.06	19	30	7.9	78.3	6.4
Route 119	3	0.05	19	<5	2.3	<10	12	0.06	18	<10	8	46.5	3.6
Route 119	4	0.04	27	<5	2.3	<10	13.9	0.06	18	<10	8.3	381	7.8
Route 119	5	0.04	32	<5	2.5	<10	14.4	0.06	20	<10	8.6	357	8.7
Route 2	1	0.04	23	<5	1.8	<10	16.9	0.05	17	<10	6.4	110	6.1
Route 2	2	0.04	24	<5	1.8	<10	24.4	0.06	18	<10	6.6	431	7.1
Route 2	3	0.04	22	<5	1.4	<10	16.2	0.04	15	<10	5.3	176	4.4
Route 2	4	0.04	27	<5	1.5	<10	15.4	0.05	17	<10	5.9	115	4.4
Route 2	5	0.05	26	<5	1.9	<10	25.8	0.06	21	<10	6.9	307	6.1
Interstate 495	1	0.04	38	<5	1.8	<10	18.8	0.05	24	<10	6.3	1670	5.4
Interstate 495	2	0.03	26	<5	1.8	<10	31.1	0.05	23	<10	6.3	172	7.6
Interstate 495	3	0.05	56	<5	2.4	<10	22.7	0.07	28	<10	8.7	1350	7.5
Interstate 495	4	0.04	48	<5	2.2	<10	22.6	0.07	27	<10	8	1590	6.6
Interstate 495	5	0.04	51	<5	1.9	<10	21	0.06	20	<10	6.8	162	6.5
Interstate 95	1	0.04	44	<5	2.1	<10	66.3	0.06	27	<10	6.4	458	7.2
Interstate 95	2	0.04	40	<5	2.8	<10	205	0.1	33	<10	9.7	91.1	8.4
Interstate 95	3	0.04	27	<5	2.2	<10	35	0.09	34	<10	7.3	485	8.5
Interstate 95	4	0.05	22	<5	3.1	<10	43.2	0.12	42	<10	8.8	110	11
Interstate 95	5	0.03	19	<5	1.3	<10	39.1	0.05	22	<10	5.3	98.1	8

Table 21. Concentrations of selected polyaromatic hydrocarbons and phthalate compounds in samples of suspended sediment, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.

[Values are in micrograms per kilogram ; <, less than the value shown; ≥, greater than or equal to the value shown; mm, millimeters in diameter; W, whole sample; -R, replicate sample; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range, or concentration reported is less than laboratory reporting level and is qualified as estimated]

Highway	Sample type	Particle-size fraction	124-Trichloro-benzene	12-Dimethyl-naphthalene	16-Dimethyl-naphthalene	1-Methyl-9H-fluorene
Route 119	Suspended sediment	< 0.063 mm	<2,850	<2,850	<2,850	<2,850
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	<1,840	<1,840	<1,840	<1,840
Route 2	Suspended sediment	≥ 0.063 mm	<2,010	<2,010	<2,010	<2,010
Interstate 495	Suspended sediment	< 0.063 mm	<2,580	<2,580	<2,580	<2,580
Interstate 495	Suspended sediment	≥ 0.063 mm	<5,020	<5,020	<5,020	<5,020
Interstate 95	Suspended sediment	< 0.063 mm	<3,460	<3,460	<3,460	<3,460
Interstate 95	Suspended sediment	≥ 0.063 mm	<1,540	<1,540	<1,540	<1,540
Interstate 495	Roadside grasses	W	--	<200	<200	<200
Interstate 495	Roadside grasses -R	W	--	<200	<200	<200
Route 119	Pine needles	W	--	<250	<250	<250
Route 119	Pine needles -R	W	--	<250	<250	<250

Highway	Sample type	Particle-size fraction	1-Methyl-phenanthrene	1-Methylpyrene	236-Trimethyl-naphthalene	26-Dimethyl-naphthalene
Route 119	Suspended sediment	< 0.063 mm	<2,850	<2,850	<2,850	610
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	<1,840	<1,840	813	<1,840
Route 2	Suspended sediment	≥ 0.063 mm	<2,010	<2,010	<2,010	<2,010
Interstate 495	Suspended sediment	< 0.063 mm	<2,580	1,340	<2,580	<2,580
Interstate 495	Suspended sediment	≥ 0.063 mm	<5,020	<5,020	<5,020	<5,020
Interstate 95	Suspended sediment	< 0.063 mm	1,820	<3,460	<3,460	<3,460
Interstate 95	Suspended sediment	≥ 0.063 mm	<1,540	<1,540	<1,540	<1,540
Interstate 495	Roadside grasses	W	<200	<200	<200	E63.4
Interstate 495	Roadside grasses -R	W	<200	<200	<200	E55.1
Route 119	Pine needles	W	<250	<250	<250	<250
Route 119	Pine needles -R	W	<250	<250	<250	<250

Table 21. Concentrations of selected polyaromatic hydrocarbons and phthalate compounds in samples of suspended sediment, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005-07.—Continued

[Values are in micrograms per kilogram ; <, Less than the value shown; ≥, greater than or equal to the value shown; mm, millimeters in diameter; W, whole sample; -R, replicate sample; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or concentration reported is less than laboratory reporting level and is qualified as estimated]

Highway	Sample type	Particle-size fraction	2-Ethyl-naphthalene	2-Fluorobiphenyl, surrogate (percent recovery)	2-Methyl-anthracene	4H-Cyclopenta[def]phenanthrene
Route 119	Suspended sediment	< 0.063 mm	<2,850	79	<2,850	<2,850
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	76.6	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	<1,840	104	<1,840	<1,840
Route 2	Suspended sediment	≥ 0.063 mm	<2,010	91.3	<2,010	<2,010
Interstate 495	Suspended sediment	< 0.063 mm	<2,580	55.5	<2,580	<2,580
Interstate 495	Suspended sediment	≥ 0.063 mm	<5,020	86.1	<5,020	<5,020
Interstate 95	Suspended sediment	< 0.063 mm	<3,460	53.8	<3,460	<3,460
Interstate 95	Suspended sediment	≥ 0.063 mm	<1,540	83.5	<1,540	<1,540
Interstate 495	Roadside grasses	W	<200	120.9	<200	--
Interstate 495	Roadside grasses -R	W	<200	118.2	<200	--
Route 119	Pine needles	W	<250	105	<250	--
Route 119	Pine needles -R	W	<250	102.9	<250	--

Highway	Sample type	Particle-size fraction	910-Anthra-quinone	Fluorene	Acenaphthene	Acenaphthylene
Route 119	Suspended sediment	< 0.063 mm	1950	<2,850	<2,850	<2,850
Route 119	Suspended sediment	≥ 0.063 mm	5,420	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	3,610	<1,840	<1,840	719
Route 2	Suspended sediment	≥ 0.063 mm	1,460	<2,010	<2,010	<2,010
Interstate 495	Suspended sediment	< 0.063 mm	3,500	<2,580	<2,580	<2,580
Interstate 495	Suspended sediment	≥ 0.063 mm	3,260	<5,020	<5,020	<5,020
Interstate 95	Suspended sediment	< 0.063 mm	7,870	<3,460	<3,460	<3,460
Interstate 95	Suspended sediment	≥ 0.063 mm	1,340	<1,540	<1,540	<1,540
Interstate 495	Roadside grasses	W	--	<200	<200	913
Interstate 495	Roadside grasses -R	W	--	<200	<200	864
Route 119	Pine needles	W	--	<250	<250	<657
Route 119	Pine needles -R	W	--	<250	<250	<852

Table 21. Concentrations of selected polycyclic aromatic hydrocarbons and phthalate compounds in samples of suspended sediment, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005–07.—Continued

[Values are in micrograms per kilogram ; <, Less than the value shown; ≥, greater than or equal to the value shown; mm, millimeters in diameter; W, whole sample; -R, replicate sample; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or concentration reported is less than laboratory reporting level and is qualified as estimated]

Highway	Sample type	Particle-size fraction	Anthracene	Benzo[a]-anthracene	Benzo[a]pyrene	Benzo[b]-fluoranthene
Route 119	Suspended sediment	< 0.063 mm	<2,850	<2,850	1770	<2,900
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	<10,200	4,130	<10,200
Route 2	Suspended sediment	< 0.063 mm	<1,840	2,850	3,260	8,240
Route 2	Suspended sediment	≥ 0.063 mm	<2,010	<2,010	1,950	2,930
Interstate 495	Suspended sediment	< 0.063 mm	<2,580	4,340	4,320	9,090
Interstate 495	Suspended sediment	≥ 0.063 mm	<5,020	<5,020	4,660	<6,420
Interstate 95	Suspended sediment	< 0.063 mm	<3,460	8,090	9,070	22,800
Interstate 95	Suspended sediment	≥ 0.063 mm	<1,540	<1,540	1,740	2,860
Interstate 495	Roadside grasses	W	<200	E68.2	<200	<200
Interstate 495	Roadside grasses -R	W	<200	E88.6	<200	<200
Route 119	Pine needles	W	<250	<250	<250	<250
Route 119	Pine needles -R	W	<250	<250	<250	<250

Highway	Sample type	Particle-size fraction	Benzo[e]pyrene	Benzo[ghi]-perylene	Benzo[k]-fluoranthene	Bis(2-ethyl-hexyl) phthalate
Route 119	Suspended sediment	< 0.063 mm	2,160	<2,850	<2,850	24,300
Route 119	Suspended sediment	≥ 0.063 mm	3,520	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	5,040	3,880	3,040	74,400
Route 2	Suspended sediment	≥ 0.063 mm	1,890	<2,010	<2,010	21,600
Interstate 495	Suspended sediment	< 0.063 mm	5,520	4,020	3,370	23,800
Interstate 495	Suspended sediment	≥ 0.063 mm	4,130	<5,020	<5,020	<17,900
Interstate 95	Suspended sediment	< 0.063 mm	13,300	8,950	8,560	106,000
Interstate 95	Suspended sediment	≥ 0.063 mm	1,770	<1,540	<1,540	13,900
Interstate 495	Roadside grasses	W	<200	<200	<200	--
Interstate 495	Roadside grasses -R	W	<200	<200	<200	--
Route 119	Pine needles	W	<250	<250	<250	--
Route 119	Pine needles -R	W	<250	<250	<250	--

Table 21. Concentrations of selected polyaromatic hydrocarbons and phthalate compounds in samples of suspended sediment, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005-07.—Continued

[Values are in micrograms per kilogram ; <, Less than the value shown; ≥, greater than or equal to the value shown; mm, millimeters in diameter; W, whole sample; -R, replicate sample; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or concentration reported is less than laboratory reporting level and is qualified as estimated]

Highway	Sample type	Particle-size fraction	Chrysene	Dibenzo[<i>ah</i>]-anthracene	Dibenzo-thiophene	Diethyl phthalate
Route 119	Suspended sediment	< 0.063 mm	<2,850	<2,850	<2,850	<2,850
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	7,530	<1,840	<1,840	<1,840
Route 2	Suspended sediment	≥ 0.063 mm	<2,560	<2,010	<2,010	<2,430
Interstate 495	Suspended sediment	< 0.063 mm	7,890	<2,580	<2,580	<2,580
Interstate 495	Suspended sediment	≥ 0.063 mm	<5,430	<5,020	<5,020	<5,020
Interstate 95	Suspended sediment	< 0.063 mm	18,300	<3,460	<3,460	<3,460
Interstate 95	Suspended sediment	≥ 0.063 mm	2,540	<1,540	<1,540	<1,540
Interstate 495	Roadside grasses	W	E44.2	<200	--	--
Interstate 495	Roadside grasses -R	W	E75.9	<200	--	--
Route 119	Pine needles	W	<250	<382	--	--
Route 119	Pine needles -R	W	<250	<378	--	--

Highway	Sample type	Particle-size fraction	Fluoranthene	Hexachloro-benzene	Indeno[123- <i>cd</i>]-pyrene	Naphthalene
Route 119	Suspended sediment	< 0.063 mm	<3,260	<2,850	<2,850	<2,850
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	13,700	<1,840	3,530	<1,840
Route 2	Suspended sediment	≥ 0.063 mm	4,660	<2,010	1,440	<2,010
Interstate 495	Suspended sediment	< 0.063 mm	14,900	<2,580	3,740	<2,580
Interstate 495	Suspended sediment	≥ 0.063 mm	10,700	<5,020	<5,020	<5,020
Interstate 95	Suspended sediment	< 0.063 mm	34,700	<3,460	8,930	<3,460
Interstate 95	Suspended sediment	≥ 0.063 mm	5,190	<1,540	1,240	<1,540
Interstate 495	Roadside grasses	W	E109	--	<200	E39.0
Interstate 495	Roadside grasses -R	W	E147	--	<200	E13.9
Route 119	Pine needles	W	<250	--	<250	<250
Route 119	Pine needles -R	W	<250	--	<250	<250

Table 21. Concentrations of selected polyaromatic hydrocarbons and phthalate compounds in samples of suspended sediment, roadside grasses, and dry pine needles collected from four highways in Massachusetts, 2005-07.—Continued

[Values are in micrograms per kilogram ; <, Less than the value shown; ≥, greater than or equal to the value shown; mm, millimeters in diameter; W, whole sample; -R, replicate sample; --, no data; E, the recovery or variation in recovery of the analyte was outside the acceptable range or concentration reported is less than laboratory reporting level and is qualified as estimated]

Highway	Sample type	Particle-size fraction	Nitrobenzene-d5, surrogate (percent recovery)	Pentachloro-anisol	Pentachloro-nitrobenzene	Perylene
Route 119	Suspended sediment	< 0.063 mm	52.9	<2,850	<2,850	<2,850
Route 119	Suspended sediment	≥ 0.063 mm	61.3	<10,200	<10,200	<10,200
Route 2	Suspended sediment	< 0.063 mm	44.9	<1,840	<1,840	1,100
Route 2	Suspended sediment	≥ 0.063 mm	80.3	<2,010	<2,010	789
Interstate 495	Suspended sediment	< 0.063 mm	33.9	<2,580	<2,580	1,760
Interstate 495	Suspended sediment	≥ 0.063 mm	70.4	<5,020	<5,020	2,010
Interstate 95	Suspended sediment	< 0.063 mm	34.6	<3,460	<3,460	3,090
Interstate 95	Suspended sediment	≥ 0.063 mm	68.8	<1,540	<1,540	696
Interstate 495	Roadside grasses	W	78.6	--	--	<200
Interstate 495	Roadside grasses -R	W	80.4	--	--	<200
Route 119	Pine needles	W	81.6	--	--	<250
Route 119	Pine needles -R	W	61.3	--	--	<250

Highway	Sample type	Particle-size fraction	Phenanthrene	Phenanthridine	P-terphenyl-d14 surrogate (percent recovery)	Pyrene
Route 119	Suspended sediment	< 0.063 mm	<2,850	<2,850	119	<2,920
Route 119	Suspended sediment	≥ 0.063 mm	<10,200	<10,200	90.7	<10,200
Route 2	Suspended sediment	< 0.063 mm	4,100	766	136	10,400
Route 2	Suspended sediment	≥ 0.063 mm	<2,620	<2,010	120	3,820
Interstate 495	Suspended sediment	< 0.063 mm	5,120	<2,580	101	12,300
Interstate 495	Suspended sediment	≥ 0.063 mm	6,580	<5,020	124	8,380
Interstate 95	Suspended sediment	< 0.063 mm	11,500	<3,460	117	25,900
Interstate 95	Suspended sediment	≥ 0.063 mm	2,740	<1,540	124	3,990
Interstate 495	Roadside grasses	W	<200	--	108	E86.0
Interstate 495	Roadside grasses -R	W	<200	--	115	E117
Route 119	Pine needles	W	<250	--	98.4	<250
Route 119	Pine needles -R	W	<250	--	99.7	<250

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