National Water-Quality Assessment Program

Variability in Stream Chemistry in Relation to Urban Development and Biological Condition in Seven Metropolitan Areas of the United States, 1999–2004

Scientific Investigations Report 2012–5170

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

Cover. Mud Creek at Spencer Road at Appleton, Wisconsin. Photograph by Michelle A. Lutz, U.S. Geological Survey.

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with reliable scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the quality of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991 to 2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studies/study_units.html).

National and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are selectively reassessed. These assessments extend the findings in the Study Units by determining water-quality status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and groundwater. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with many of the Nation's largest community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems. Included are studies on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

William H. Werkheiser
USGS Associate Director for Water

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Conversion Factors and Abbreviations

SI to Inch/Pound

Multiply	By	To obtain
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
milliliter (mL)	0.0338	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

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

Abbreviations

NAWQA	National Water-Quality Assessment
NWQL	National Water-Quality Laboratory
USGS	U.S. Geological Survey

Variability in Stream Chemistry in Relation to Urban Development and Biological Condition in Seven Metropolitan Areas of the United States, 1999–2004

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Abstract

Beginning in 1999, the U.S. Geological Survey National Water Quality Assessment Program investigated the effects of urban development on stream ecosystems in nine metropolitan study areas across the United States. In seven of these study areas, stream-chemistry samples were collected every other month for 1 year at 6 to 10 sites. Within a study area, the sites collectively represented a gradient of urban development from minimally to highly developed watersheds, based on the percentage of urban land cover; depending on study area, the land cover before urban development was either forested or agricultural. The stream-chemistry factors measured in the samples were total nitrogen, total phosphorus, chloride, and pesticide toxicity. These data were used to characterize the stream-chemistry factors in four ways (hereafter referred to as characterizations)—seasonal high-flow value, seasonal low-flow value, the median value (representing a single integrated value of the factor over the year), and the standard deviation of values (representing the variation of the factor over the year). Aquatic macroinvertebrate communities were sampled at each site to infer the biological condition of the stream based on the relative sensitivity of the community to environmental stressors. A Spearman correlation analysis was used to evaluate relations between (1) urban development and each characterization of the stream-chemistry factors and (2) the biological condition of a stream and the different characterizations of chloride and pesticide toxicity.

Overall, the study areas where the land cover before urban development was primarily forested had a greater number of moderate and strong relations compared with the study areas where the land cover before urban development was primarily agriculture; this was true when urban development was correlated with the stream-chemistry factors (except chloride) and when chloride and pesticide toxicity was correlated with the biological condition. Except for primarily phosphorus in two study areas, stream-chemistry factors generally increased with urban development, and among the different characterizations, the median value typically indicated the strongest relations. The variation in stream-chemistry factors throughout the year generally increased with urban development, indicating that water quality became less consistent as watersheds were developed. In study areas with high annual snow fall, the variation in chloride concentrations throughout the year was particularly strongly related to urban development, likely a result of road salt applications during the winter. The relations of the biological condition to chloride and pesticide toxicity were calculated irrespective of urban development, but the overall results indicated that the relations were still stronger in the study areas that had been forested before urban development. The weaker relations in the study areas that had been agricultural before urban development were likely the results of biological communities having been degraded from agricultural practices in the watersheds.

Collectively, these results indicated that, compared with sampling a stream at a single point in time, sampling at regular intervals during a year may provide a more representative measure of water quality, especially in the areas of high urban development where water quality fluctuated more widely between samples. Furthermore, the use of “integrated” values of stream chemistry factors may be more appropriate when assessing relations to the biological condition of a stream because the taxa composition of a biological community typically reflects the water-quality conditions over time.

Introduction

River flow regimes show regional patterns that are, in part, determined by geographic variation in climate, geology, topography, and vegetative cover. Some streams in regions with little seasonal variability in precipitation have relatively stable flows, while in other regions, streamflow can fluctuate greatly throughout the year. As urban development in a watershed increases, changes occur in the magnitude and frequency of high and low streamflows (Poff and others, 1997). These changes are often associated with increases of impervious cover, which reduce infiltration and decrease the time for runoff to reach a stream (Scheuler, 1994). Other effects of urban development include increased loading of nutrients, pesticides, and other contaminants to streams (Paul and Meyer, 2001) and a decline in the biological condition, which is often expressed by a loss of sensitive taxa (Booth and others, 2004).

Variability in stream chemistry occurs throughout the year as streams are subjected to seasonal changes and storm runoff events (Tate and others, 1999). Land-use practices, including seasonal application of nutrients and pesticides during the growing season in agricultural and in suburban areas (U.S. Geological Survey, 1999; Overmyer and others, 2005) and deicing chemicals used in colder regions of the country (Mullaney and others, 2009; Corsi and others, 2010) can elevate the levels of these chemical constituents in streams and groundwater. A further consequence of urban development is that the increases of impervious cover create more direct pathways for stream-chemistry constituents to enter the stream. Such changes in stream chemistry typically degrade biological communities (algae, macroinvertebrates, and fish), but it is often difficult to establish a relation between stream chemistry and the condition of a biological community when stream chemistry is highly variable over time.

In 1999, the U.S. Geological Survey (USGS) began an investigation of the effects of urban development on stream ecosystems as part of the National Water-Quality Assessment Program (NAWQA). Study areas were in nine major metropolitan areas across the United States. In these studies, urban development was defined as the conversion from rural land cover of forest or agricultural land use to urban land cover of residential and commercial land use (Couch and Hamilton, 2002). Within each study area, the selected sites had watershed areas of similar size and were in a region where natural variability was constrained to a single level III ecoregion, as measured by climate, soils, and elevation (Omernik, 1987). Each study area contained 28 to 30 sites that represented a gradient of urban development, from minimally to highly developed, as measured by the percentage of urban land cover in the watershed. Information collected at each site included data from two stream chemistry samples (one during seasonal high-flow conditions and one during seasonal low-flow conditions), a stream habitat survey, and an assessment of the biological communities (algal, macroinvertebrate, and fish). Additional information on study design and study area characteristics has been summarized by the USGS (U.S. Geological Survey, undated).

The investigation of the effects of urban development on stream ecosystems was based on a short-term (1 year) synoptic design that produced high spatial resolution in the information collected at each study area by sampling many sites within the study area. A consequence of this synoptic design, however, is that many sites were sampled over a short time interval at the expense of collecting multiple samples at fewer sites (Gilliom and others, 1995). Because stream chemistry varies seasonally and annually (Tate and others, 1999), the "typical" or midrange water-quality conditions may not be characterized accurately with data from only one or two samples. Furthermore, variations in stream chemistry over the course of 1 year are generally integrated by the aquatic macroinvertebrate community so that the biological condition of a stream may not be characteristic of water-quality conditions at a particular point in time (Barbour and others, 1989). However, the condition of the macroinvertebrate community can provide comprehensive information about the health of a stream that might not be captured with a single stream-chemistry sample.

In seven of the nine study areas (fig. 1), additional stream-chemistry samples were collected generally every other month for 1 year at a subset of 6 to 10 sites. Stream-chemistry factors measured in the samples included total nitrogen, total phosphorus, chloride, and pesticide toxicity. Because values of a factor often vary with time of year a sample is collected, each factor was characterized four separate ways to account for variation throughout the year (hereafter referred to as characterizations)—the seasonal high-flow value, the seasonal low-flow value, the median value (representing an "integrated" value), and the standard deviation of values (representing the variation among values). Additionally, a community tolerance index for macroinvertebrates was used to infer the biological condition for each site.

Purpose and Scope

The purpose of this report is to evaluate how variation in stream chemistry relates to urban development and to the biological condition of streams in seven metropolitan study areas of the United States. This report focuses on four stream-chemistry factors—total nitrogen, total phosphorus, chloride, and pesticide toxicity—and explores how the strength of the relation of these factors to urban development and the aquatic biological condition often depends on how the values of the factors are characterized. The objectives of this report are to (1) describe how relations between urban development and stream-chemistry factors can depend on the time of year or how frequently over the course of 1 year stream-chemistry samples are collected and how the values of the factors are characterized, and (2) identify characterizations of chloride and pesticide toxicity values that have the strongest relations to the biological condition of a stream. Specific questions that are addressed in this report are the following:

- In describing the response of stream-chemistry factors to urban development, are the strongest relations based on factors measured from a seasonal high-flow sample, a seasonal low-flow sample, or the annual integrated value of all samples? (see Relations of Stream-Chemistry Factors to Urban Development section)

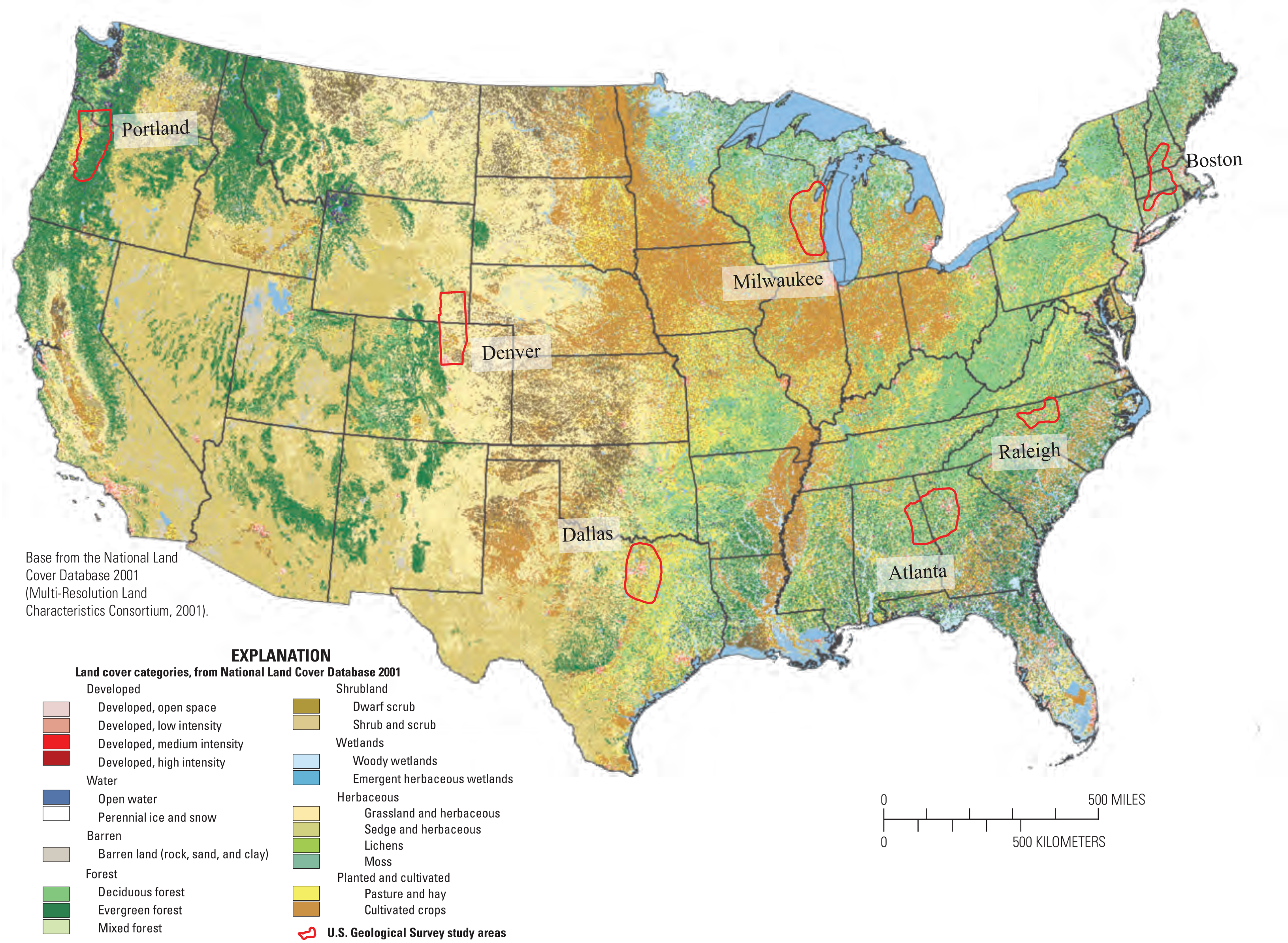

Figure 1. The location of the seven study areas where samples were collected to analyze the chemistry of streams.

- As the percentage of urban development increases in a watershed, do the stream-chemistry factors show greater variance among samples collected throughout the year? (see Variability in Stream-Chemistry Factors section)
- Is the loss of sensitive macroinvertebrate taxa more strongly related to contaminant values measured from a seasonal high-flow sample, a seasonal low-flow sample, or the annual integrated value of all samples? (see Relations of the Biological Condition to Chloride and Pesticide Toxicity section)

Description of the Study Areas

Study areas were located in seven major metropolitan areas across the United States, including Portland, Oregon; Atlanta, Georgia; Raleigh, North Carolina; Boston, Massachusetts; Denver, Colorado; Dallas, Texas; and Milwaukee, Wisconsin. In the Portland, Atlanta, Raleigh, and Boston study areas, the land cover before urban development was primarily forested; in the Denver, Dallas, and Milwaukee study areas, the land cover before urban development was primarily agricultural (table 1). Studies were conducted in the Boston study area during 1999–2000, in the Atlanta, Raleigh, and Denver study areas during 2002–2003, and in the Portland, Dallas, and Milwaukee study areas during 2003–2004. Sixty-one sites were sampled among these seven study areas. Additional information on individual studies can be found for Portland in Waite and others (2008), for Atlanta in Gregory and Calhoun (2007), for Raleigh in Giddings and others (2007), for Boston in Coles and others (2004), for Denver in Sprague and others (2006), for Dallas in Moring (2009), and for Milwaukee in Richards and others (2010).

Data Collection and Characterization Methods

Within a study area, the sites collectively represented a gradient of urban development from minimally to highly developed watersheds, based on the percentage of urban land cover. This gradient of land cover—from forested or agricultural to urban land—represents a “space-for-time substitution” (Pickett, 1989) where the network of sites in essence represents a single watershed as it transitions from low to high urban development over time. For each site, stream-chemistry factors included measured concentrations of total nitrogen, total phosphorus, chloride, and total pesticides, the latter of which was used to calculate the relative pesticide toxicity of the water sample. Macroinvertebrate samples were collected at each site and were used to calculate a community tolerance index for assessing the biological condition of each site.

Watershed Land Cover

Percentages of urban, forest, and agriculture land cover were calculated using the aggregated 2001 National Land Cover Database categories (Multi-Resolution Land Characteristics Consortium, 2001; Falcone and others, 2007). Because urban development occurred with the conversion of land that generally had been forested (Portland, Atlanta, Raleigh, and Boston) or agricultural (Denver, Dallas, and Milwaukee), the study areas are grouped by their land cover before urban development. The 61 sites that were selected among the seven study areas are listed in order of increasing percentage of urban development in their respective study areas in table 1.

Stream-Chemistry Samples

Stream chemistry was sampled at sites usually every other month for a year, but sites in the Boston study area were sampled at least 10 times during the year. Samples were collected and processed using standard USGS protocols (U.S. Geological Survey, variously dated) and were analyzed with the use of standard USGS methods at the USGS National Water-Quality Laboratory (NWQL) in Lakewood, Colo., to measure concentrations of stream-chemistry factors (Fishman and Friedman, 1989; Fishman, 1993; Zaugg and others, 1995). The data from these samples are reported in Giddings and others (2009). Data selected for this report were concentrations of total nitrogen, total phosphorus, chloride, and total pesticides, except that pesticides were not evaluated in samples from the Boston study area. Additionally, total pesticide concentrations were converted to a pesticide toxicity index (described below), which was considered more relevant to the biological condition of streams.

Quantifying pesticide toxicity.—A pesticide toxicity index specific to cladocerans (a type of aquatic invertebrate used in testing contaminant toxicity) was used to calculate the potential total toxicity of all pesticides that were detected in the water samples (Munn and Gilliom, 2001; Munn and others, 2006; Giddings and others, 2009). This index combines information on exposure of aquatic biota to pesticides (measured concentrations of pesticides in water) with toxicity estimates (results from laboratory toxicity studies) to produce a relative pesticide toxicity value for a sample. While the pesticide toxicity index (hereafter referred to as pesticide toxicity) does not indicate whether a water sample is toxic, the index value can be used to rank or compare the relative potential toxicity of different samples and to evaluate the relations between urban development and pesticide toxicity on biological communities, such as the macroinvertebrates. A zero value indicates that pesticides used in the calculation of the pesticide toxicity index were not detected. A value of 1.00 E-1 would indicate relatively high potential toxicity, whereas a value of 1.00 E-4 would be potentially a thousand times less toxic (appendix 1).

Table 1. Site information for sampled streams.

[Includes U.S. Geological Survey (USGS) site identification, site name, and site short name, watershed drainage area, percentage of land cover, and community tolerance index. Study areas are grouped by land cover before urban development (Portland, Atlanta, Raleigh and Boston, under forest and shrubland and Denver, Dallas, and Milwaukee under agriculture) and listed from west to east. Sites within each study area are listed by increasing percentage of urban land. ID, identification number; %, percentage; km2, square kilometers; Oreg., Oregon; Ga., Georgia; N.C. North Carolina; Mass., Massachusetts; Colo., Colorado; Tex., Texas; Wis., Wisconsin]

USGS site ID	USGS site name	Site short code	Watershed drainage area (km^2)	Urban land (%)	Forest and shrubland (%)	Agricul-ture and grassland (%)	Other (%)	Communtiy tolerance index
		Portland, Oreg., study area						
14205400	East Fork Dairy Creek near Meacham Corner, Oreg.	POR_efdar	87.54	0.53	86.92	7.96	4.59	4.20
452231122200000	Deep Creek near Sandy, Oreg.	POR_deep	31.36	4.38	59.76	35.04	0.82	4.19
455122122310600	Rock Creek near Battleground, Wash.	POR_rocwa	26.08	7.51	62.46	19.32	10.71	4.93
454549122295800	Salmon Creek near Battleground, Wash.	POR_salmo	58.84	13.21	70.76	10.73	5.30	4.22
452414122213200	Tickle Creek near Boring, Oreg.	POR_tickl	34.08	19.03	37.36	43.15	0.46	4.83
452337122243500	North Fork Deep Creek at Barton, Oreg.	POR_nfdep	37.01	27.06	13.07	58.47	1.40	5.82
454510122424900	Whipple Creek near Salmon Creek, Wash.	POR_whipp	22.17	37.56	22.77	33.22	6.45	4.98
452526122364400	Kellogg Creek at Milwaukie, Oreg.	POR_kello	34.11	81.00	11.02	6.16	1.82	5.73
445551123015800	Pringle Creek at Salem, Oreg.	POR_pring	24.79	88.71	2.40	8.04	0.85	5.69
450022123012400	Claggett Creek at Keizer, Oreg.	POR_clagg	24.84	97.81	0.10	1.87	0.22	6.66
		Atlanta, Ga., study area						
02338523	Hillabahatchee Creek at Thaxton Road, near Franklin,Ga.	ATL_hil	43.22	2.81	74.77	19.97	2.45	5.08
02337395	Dog River at North Helton Road, near Winston, Ga.	ATL_dog	109.08	13.45	62.18	20.31	4.06	5.67
02344480	Shoal Creek near Griffin, Ga.	ATL_sho	53.40	22.91	49.43	22.01	5.65	6.15
02344737	Whitewater Creek at Willow Pond Road near Fayetteville, Ga.	ATL_whw	110.50	25.08	47.82	18.32	8.78	6.45
02344797	White Oak Creek at Cannon Road, near Raymond, Ga.	ATL_who	112.68	25.73	50.76	15.85	7.66	6.30
02334885	Suwanee Creek at Suwanee, Ga.	ATL_suw	122.10	42.56	39.51	12.10	5.83	6.58
02336968	Noses Creek at Powder Springs Road,Powder Springs, Ga.	ATL_nos	114.79	43.08	41.82	11.39	3.71	6.28
02336635	Nickajack Creek at US 78/278, near Mableton, Ga.	ATL_nic	80.69	66.17	27.80	3.47	2.56	6.32
02335870	Sope Creek near Marietta, Ga.	ATL_sop	79.54	72.51	23.32	2.54	1.63	6.83
		Raleigh, N.C., study area						
02097464	Morgan Creek near White Cross, N.C.	RAL_morgan	21.45	5.19	70.77	23.06	0.98	5.59
0208500600	Cates Creek near Hillsborough, N.C.	RAL_cates	10.88	20.00	64.77	14.76	0.47	5.63
0208726370	Richlands Creek at Schenk Forest near Cary, N.C.	RAL_rschen	11.24	60.14	26.73	12.90	0.23	6.77
02087580	Swift Creek near Apex, N.C.	RAL_swift	54.26	72.19	21.09	4.49	2.23	6.83

Table 1. Site information for sampled streams.—Continued

[Includes U.S. Geological Survey (USGS) site identification, site name, and site short name, watershed drainage area, percentage of land cover, and community tolerance index. Study areas are grouped by land cover before urban development (Portland, Atlanta, Raleigh and Boston, under forest and shrubland and Denver, Dallas, and Milwaukee under agriculture) and listed from west to east. Sites within each study area are listed by increasing percentage of urban land. ID, identification number; %, percentage; km2, square kilometers; Oreg., Oregon; Ga., Georgia; N.C. North Carolina; Mass., Massachusetts; Colo., Colorado; Tex., Texas; Wis., Wisconsin]

USGS site ID	USGS site name	Site short code	Watershed drainage area (km^2)	Urban land (%)	Forest and shrubland (%)	Agriculture and grassland (%)	Other (%)	Communtiy tolerance index
0208726995	Hare Snipe Creek at SR 1822 near Leesville, N.C.	RAL_hare	16.01	76.09	20.03	1.62	2.26	6.79
0208725055	Black Creek at Weston Parkway near Cary, N.C.	RAL_black	8.99	78.96	16.72	4.03	0.29	6.66
0208730725	Beaverdam Creek at Glenwood Aveue at Raleigh, N.C.	RAL_swprng	7.98	94.16	5.19	0.32	0.33	6.68
0208732610	Pigeon House Branch at Crabtree Boulevard at Raleigh, N.C.	RAL_pigeon	11.37	98.41	1.14	0.45	0.00	6.85
	Boston, Mass., study area							
01095220	Stillwater River near Sterling, Mass.	BOS_stil	78.70	3.16	75.83	9.29	11.72	4.24
01109000	Wading River (head of Threemile River) near Norton, Mass.	BOS_wade	113.40	23.49	51.08	6.27	19.16	5.28
01105000	Neponset River at Norwood, Mass.	BOS_nepo	84.90	38.56	41.27	4.93	15.24	5.39
01101500	Ipswich River at South Middleton, Mass.	BOS_ipsw	115.30	43.29	31.05	3.62	22.04	5.55
01102345	Saugus River at Saugus Ironworks at Saugus, Mass.	BOS_saug	60.40	64.45	20.03	1.94	13.58	5.82
01102500	Aberjona River (head of Mystic River) at Winchester, Mass.	BOS_aber	58.20	76.43	16.20	2.05	5.32	6.79
	Denver, Colo., study area							
413659104370001	Bear Creek above Little Bear Cr, near Phillips, Wyo.	DEN_brphil	458.59	1.46	1.96	95.03	1.55	5.48
403308105001601	Boxelder Creek at mouth, near Fort Collins, Colo.	DEN_boxel	558.64	4.42	0.69	89.15	5.74	6.58
403048105042701	Fossil Creek at College Ave, at Fort Collins, Colo.	DEN_fossil	26.68	16.60	1.94	79.52	1.94	6.54
393948105053501	Bear Creek below Estes Road at Lakewood, Colo.	DEN_breste	62.95	38.01	3.83	55.25	2.91	5.89
394919105074601	Ralston Creek above Simms at Arvada Colo.	DEN_ralst	25.46	41.40	4.07	47.10	7.43	6.19
400217105123701	Boulder Creek below 61st Street, near Boulder, Colo.	DEN_bould	87.61	49.38	7.75	38.79	4.08	5.12
06713500	Cherry Creek at Denver, Colo.	DEN_cherry	80.92	79.61	2.14	11.36	6.89	6.75
394409105020501	Lakewood Gulch above Knox Street at Denver, Colo.	DEN_lakew	40.75	89.26	1.90	8.64	0.20	6.36
394921105015701	Little Dry Creek below Lowell Street near Westminster, Colo.	DEN_litdry	18.30	90.37	2.41	6.80	0.42	6.33
	Dallas, Tex., study area							
08063595	South Prong Creek at FM 876 near Waxahachie, Tex.	DFW_sprong	53.41	2.28	25.80	70.90	1.02	6.30
08063565	Mill Creek at Lowell Road near Milford, Tex.	DFW_mill	80.37	2.80	24.52	71.87	0.81	6.05
08063555	S Fk Chambers Creek near CR 102 near Maypearl, Tex.	DFW_sfkcha	291.37	3.34	21.75	73.38	1.53	6.72
08052740	Doe Branch at Fishtrap Road near Prosper, Tex.	DFW_doe	94.53	6.71	9.23	83.20	0.86	7.32
08064695	Tehuacana Creek at Rural Road 27 near Wortham, Tex.	DFW_tehuac	164.70	6.94	32.98	59.71	0.37	6.96

Table 1. Site information for sampled streams.—Continued

[Includes U.S. Geological Survey (USGS) site identification, site name, and site short name, watershed drainage area, percentage of land cover, and community tolerance index. Study areas are grouped by land cover before urban development (Portland, Atlanta, Raleigh and Boston, under forest and shrubland and Denver, Dallas, and Milwaukee under agriculture) and listed from west to east. Sites within each study area are listed by increasing percentage of urban land. ID, identification number; %, percentage; km2, square kilometers; Oreg., Oregon; Ga., Georgia; N.C. North Carolina; Mass., Massachusetts; Colo., Colorado; Tex., Texas; Wis., Wisconsin]

USGS site ID	USGS site name	Site short code	Watershed drainage area (km^2)	Urban land (%)	Forest and shrubland (%)	Agricul-ture and grassland (%)	Other (%)	Communtiy tolerance index
08061780	Buffalo Creek near Trinity Road at Forney, Tex.	DFW_buftri	88.16	15.16	16.78	64.48	3.58	6.93
08057475	Parsons Slough near Davis Road near Crandall, Tex.	DFW_parsn	115.72	21.28	25.04	42.70	10.98	7.28
08057431	Fivemile Creek near Simpson Stuart Road, Dallas, Tex.	DFW_5mile	108.99	61.60	25.29	12.67	0.44	7.05
08057200	White Rock Creek at Greenville Ave, Dallas, Tex.	DFW_white	173.01	83.94	5.66	9.96	0.44	7.08
		Milwaukee, Wis., study area						
040853145	Black Creek at Curran Road near Denmark, Wis.	MGB_blak	56.13	3.23	16.66	73.32	6.79	6.77
04085188	Rio Creek at Pheasant Road near Rio Creek, Wis.	MGB_rioc	55.81	3.53	9.60	78.24	8.63	6.41
040851325	Baird Creek at Superior Road at Green Bay, Wis.	MGB_bair	52.01	5.48	4.58	85.26	4.68	5.93
04081897	Sawyer Creek at Westhaven Road at Oshkosh, Wis.	MGB_sawy	30.60	13.80	2.96	81.34	1.90	6.71
04087258	Pike River at Cth A near Kenosha, Wis.	MGB_pikr	100.29	27.32	5.19	64.74	2.75	5.57
04087030	Menomonee River at Menomonee Falls, Wis.	MGB_meno	87.85	30.39	12.50	45.49	11.62	6.01
04084429	Mud Creek at Spencer Road at Appleton, Wis.	MGB_mudc	33.28	58.83	4.44	35.49	1.24	6.23
04087204	Oak Creek at South Milwaukee, Wis.	MGB_oakc	66.79	62.93	11.17	21.83	4.07	6.43
040869415	Lincoln Creek at 47th Street at Milwaukee, Wis.	MGB_linc	25.96	97.56	2.10	0.10	0.24	6.74
04087118	Honey Creek near Portland Avenue at Wauwatosa, Wis.	MGB_hony	27.74	99.06	0.75	0.00	0.19	7.14

Macroinvertebrate Community Samples

Two types of macroinvertebrate samples were collected along the designated sampling reach for the stream at each site, according to NAWQA methods (Cuffney and others, 1993; Moulton and others, 2002). A quantitative sample was collected from locations in the stream where the maximum taxa richness was likely to occur, generally from rocks in riffle areas or submerged woody snags. A qualitative sample also was collected from multiple locations along the sampling reach, and included areas such as riffles, undercut banks, aquatic vegetation beds, and depositional substrates. Identification of macroinvertebrates in these samples was done at NWQL. Together, these two sample types were used to create a comprehensive list of macroinvertebrate taxa observed at each site, which provided the biological data used in this report.

Characterizing the biological condition.—A community tolerance index for macroinvertebrates was used to characterize the biological condition for each site based on the taxa that occurred in the sampling reach (tables 1 and 2). The community tolerance index represents an average of the pollution-tolerance values for all taxa in the macroinvertebrate community and was calculated with the USGS invertebrate data analysis system (Cuffney, 2003). The values range from 0 (most sensitive) to 10 (most tolerant), and therefore, the index values typically increase when sensitive macroinvertebrate taxa are being lost from the community. The macroinvertebrate community data are available in Giddings and others (2009).

Table 2. Summary of community tolerance indices

[Study areas are grouped based on type of land before urban development. CTI, community tolerance index; XX, not applicable]

Study area	Minimum CTI	Maximum CTI	Range
Forested lands before urban development			
Portland, Oregon	4.19	6.66	2.47
Atlanta, Georgia	5.08	6.83	1.75
Raleigh, North Carolina	5.59	6.85	1.26
Boston, Massachusetts	4.24	6.79	2.55
Average	4.78	6.78	2.01
Overall average	XX	XX	2.66
Agricultural lands before urban development			
Denver, Colorado	5.12	6.75	1.63
Dallas, Texas	6.05	7.32	1.27
Milwaukee, Wisconsin	5.57	7.14	1.57
Average	5.58	7.07	1.49
Overall average	XX	XX	2.20

Data Analysis Methods

For each stream site described in this report (table 1), the stream-chemistry factors and each characterization are reported in appendix 1. Data were analyzed with SYSTAT 12 (SYSTAT Software, Inc., 2007), and the figures were created using TIBCO Software Inc. S–Plus (Insightful Corporation, 2005).

Stream-Chemistry Factors

At each site, each stream-chemistry factor (total nitrogen, total phosphorus, chloride, and pesticide toxicity) was characterized four different ways—the seasonal high-flow value, the seasonal low-flow value, the median value, and the standard deviation of values. Seasonal high-flow values were from the sample collected during the time of year when average climatic conditions reflect frequent precipitation events or snowmelt that results in sustained high flows (typically spring). Seasonal low-flow values were from the sample collected during the time of year when average climatic conditions reflect few precipitation events and sustained low flows are expected (typically summer). The median value of each factor was calculated using all samples collected at a site; it represented an integrated midrange value of what might be expected over the course of 1 year. The standard deviation of values was calculated for each factor using all samples collected at a site; it represented the variation of a factor throughout the year (in other words, the extent that the factor fluctuated over the course of 1 year).

Relating Stream-Chemistry Factors to Urban Development

For this report, data were analyzed separately by study area to evaluate how stream-chemistry factors responded as the percentage of urban development increased. The analyses used Spearman correlations to indicate how strongly each stream-chemistry factor was related to urban development when the factors were characterized by the seasonal high-flow value, the seasonal low-flow value, the median value, and the standard deviation of values. Following the convention for describing results in publications on the effects of urban development on stream ecosystems (Cuffney and others, 2010), the absolute rho values (|rho|) from the Spearman correlations were used to indicate the relative strength of the relations, where 0.70 or greater ($|rho| \geq 0.70$) were considered a strong relation and between 0.5 and 0.70 ($0.50 \leq |rho| < 0.70$) were considered a moderate relation. Correlations were considered statistically significant if the probability of occurrence by chance was less than 5 percent ($p < 0.05$); to indicate that a |rho| value was significant, it was displayed with an asterisk preceding the value (for example, |rho| = *0.72). While all strong correlations were statistically significant, not all moderate correlations were statistically significant, mainly because sample size was smaller for this analysis (6 to 10 sites per study area) compared with the comprehensive investigation of the effects of urban development on stream ecosystems (typically 30 sites per study area).

Relating the Biological Condition to Chloride and Pesticide Toxicity

Data were analyzed by study area to evaluate how the biological condition of a stream would respond to an increase in chloride concentrations and pesticide toxicity. The community tolerance index was compared with chloride concentrations and pesticide toxicity characterized by the seasonal high-flow value, seasonal low-flow value, and median value. The intent of this analysis was to indicate if the loss of sensitive taxa in macroinvertebrate community was more strongly related to a seasonal stream-chemistry value (high- or low-flow) or to an integrated value (median) of chloride concentrations and pesticide toxicity. Additionally, these results were used to indicate if chloride and pesticide toxicity were potential stressors to the macroinvertebrate community in a region. The relative strength of the relations and their significance are based on the Spearman correlations procedures described previously.

Results and Discussion

Results that pertain to the first objective of the study (to describe how variation in the relations between urban development and stream-chemistry factors can depend on when stream-chemistry samples are collected and how their values are characterized) are highlighted in table 3. Results that pertain to the second objective (to identify characterizations of chloride and pesticide toxicity that have the strongest relations to the biological condition of a stream) are highlighted in table 4.

Table 3. Summary of Spearman rho correlation coefficients between characterizations of selected stream-chemistry factors and percentage of urban development.

[Values preceded by asterisk indicate a probability (p) of occurrence by chance was less than 5 percent (p<0.05). Values in **bold** indicate a strong relation. Values in *italic* indicate a moderate relation. Study areas are grouped by primary type of land cover before urban development and listed from west to east. Oreg., Oregon; Ga., Georgia; N.C., North Carolina; Mass., Massachusetts; Colo., Colorado; Tex., Texas; Wis., Wisconsin; ND, no data]

	Forested lands before urban development				Agricultural lands before urban development		
	Portland, Oreg.	Atlanta, Ga.	Raleigh, N.C.	Boston, Mass.	Denver, Colo.	Dallas, Tex.	Milwaukee, Wis.
Total nitrogen							
Seasonal high flow	***0.73**	0.47	0.38	***0.89**	0.07	0.08	0.02
Seasonal low flow	*0.61*	***0.70**	*0.69*	***1.00**	0.05	-0.43	-0.12
Median	*0.62*	**0.67*	0.21	***0.94**	0.05	-0.15	-0.37
Standard deviation	-0.14	0.10	-0.21	***0.83**	0.43	-0.42	-0.13
Total Phosphorus							
Seasonal high flow	*0.58*	0.12	***-0.74**	-0.20	*0.63*	0.25	**-0.68*
Seasonal low flow	***0.75**	0.03	-0.13	***0.94**	0.47	0.27	*-0.50*
Median	**0.66*	-0.07	-0.24	***0.71**	*0.52*	0.22	***-0.70**
Standard deviation	***0.78**	0.37	*-0.62*	0.09	***0.73**	0.30	*-0.62*
Chloride							
Seasonal high flow	***0.76**	***0.83**	0.24	0.49	*0.65*	0.42	***0.94**
Seasonal low flow	0.44	*0.57*	0.38	***0.83**	***0.72**	*0.60*	**0.68*
Median	***0.75**	***0.82**	0.43	***1.00**	***0.90**	0.45	***0.99**
Standard deviation	*0.50*	-0.12	0.31	***0.77**	***0.75**	0.12	***0.96**
Pesticide Toxicity							
Seasonal high flow	*0.56*	*0.63*	0.33	ND	0.25	***0.77**	0.25
Seasonal low flow	**0.68*	0.43	0.43	ND	0.28	*0.50*	-0.18
Median	**0.67*	***0.88**	0.24	ND	***0.73**	*0.63*	**-0.66*
Standard deviation	**0.65*	***0.97**	0.40	ND	***0.77**	0.42	-0.15

Table 4. Summary of Spearman rho correlation coefficients between the community tolerance index and chloride and pesticide toxicity.

[Values preceded by asterisk indicate a probability (p) of occurrence by chance was less than 5 percent (p<0.05). Values in **bold** indicate a strong relation. Values in *italic* indicate a moderate relation. Study areas are grouped by primary type of land cover before urban development and listed from west to east. Oreg., Oregon; Ga., Georgia; N.C., North Carolina; Mass., Massachusetts; Colo., Colorado; Tex., Texas; Wis., Wisconsin; ND, no data]

	Forested lands before urban development				Agricultural lands before urban development		
	Portland, Oreg.	Atlanta, Ga.	Raleigh, N.C.	Boston, Mass.	Denver, Colo.	Dallas, Tex.	Milwaukee, Wis.
Chloride							
Seasonal High Flow	***0.70**	***0.83**	0.38	0.49	***0.73**	0.28	0.36
Seasonal Low Flow	**0.66*	***0.83**	0.33	***0.83**	*0.65*	0.42	0.12
Median	***0.76**	***0.85**	0.10	***1.00**	0.25	0.42	0.24
Pesticide toxicity							
Seasonal High Flow	**0.65*	***0.90**	*0.57*	ND	*0.61*	*0.50*	*0.59*
Seasonal Low Flow	**0.69*	0.17	0.14	ND	0.42	***0.77**	0.45
Median	***0.74**	***0.95**	*0.62*	ND	**0.68*	*0.53*	-0.04

Relations of Stream-Chemistry Factors to Urban Development

Variability in stream chemistry can occur throughout the year as streams are subjected to seasonal changes and storm runoff events (Tate and others, 1999). Stream-chemistry factors depend on conditions in the watershed before collection of the sample, such as road salt applications (chloride inputs) in areas of heavy snowfalls or fertilizer applications (nutrient inputs) for lawn maintenance. If heavy precipitation follows such applications, then these chemical factors can be flushed into the stream; a stream sample collected soon afterwards can result in a spike in value, but subsequent samples often show much lower values. Consequently, the “typical” or midrange water-quality conditions may not be characterized accurately with data from any particular single sample. Thus, the median value for each of the selected stream-chemistry factors is used to represent an integrated value during the course of 1 year at a site.

Total Nitrogen

In study areas where agriculture was the predominant land cover before urban development, there were no moderate or strong relations indicated between total nitrogen and urban development (table 3). In the four study areas where forest was the predominant land cover before urban development, relations between total nitrogen and urban development were either moderate or strong in all four study areas when based on the seasonal low-flow value, in three study areas when based on the median value, and in two study areas when based on the high-flow value. These results indicate that the total nitrogen concentrations increased with urban development in regions where forest was the land cover before urban development, whereas in regions where agricultural was the land cover before urban development, total nitrogen did not change significantly with urban development because total nitrogen concentrations were already relatively high in streams with low percentages of urban land as a result of agricultural practices.

Total Phosphorus

In contrast to the results of total nitrogen (above), moderate or strong relations between total phosphorus and urban development were not limited to study areas where land cover before urban development was forest (table 3). Furthermore, the moderate or strong relations were not associated with a particular characterization of total phosphorus, and some relations were negative, indicating that total phosphorus was decreasing with urban development. The seasonal low-flow value resulted in strong relations in two study areas and a moderate relation in one study area, whereas the seasonal high-flow value resulted in a strong relation in one study area and moderate relations in three study areas. The median values resulted in strong relations in two study areas and moderate relations in two study areas.

In the Milwaukee study area, a negative relation between urban development and total phosphorus was indicated with all three total phosphorus characterizations. The relation was strongest with the median value (rho = *-0.70) and suggests that total phosphorus concentrations decreased significantly in streams as land cover was converted from agricultural to urban. In the Raleigh study area, a negative relation also was indicated between urban development and total phosphorus, but only for the high-flow values of total phosphorus; thus, this apparent decline of total phosphorus concentrations with urban development may have been an artifact of high-flow conditions, such as dilution.

Chloride

The relations between chloride and urban development were notably strongest with the median value (table 3). Strong positive relations were indicated in all but the Dallas and Raleigh study areas. Unlike fertilizers and pesticides, which can be used extensively in both agricultural and urban areas, chloride use is associated primarily with urban development; sources include road salt, wastewater effluent, and industrial processes. The strongest relations (greater than 0.90) were in colder regions of the country and may be related to snowfall and subsequent road salt application.

Pesticide Toxicity

The relations between pesticide toxicity and urban development also were strongest with the median value (table 3). Either moderate or strong positive relations were indicated in all study areas except Raleigh (Boston was excluded because pesticide data were not collected). However, in the Milwaukee study area, the relation between the median pesticide toxicity and urban development was negative (rho = *-0.66). Similar to the negative relation between the median total phosphorus value and urban development in the Milwaukee study area, this response suggests that pesticide toxicity decreased significantly in streams as land cover was converted from agricultural to urban.

Variability in Stream-Chemistry Factors

For each of the selected stream-chemistry factors, the standard deviation of all samples collected in a stream was used to represent the variability throughout the year. Variability is small when a stream-chemistry factor shows little fluctuation among samples collected throughout the year, whereas a relatively large variation results when a stream-chemistry factor shows great fluctuation among samples collected throughout the year. Therefore, an increase in the standard deviation of a stream-chemistry factor that corresponds to an increase in urban development would suggest that, as a watershed is developed, the value of a stream-chemistry factor could be expected to vary more widely among samples collected throughout the year.

Total Nitrogen

Boston was the only study area where the amount of variation throughout the year increased significantly with urban development for total nitrogen (rho=*0.83; table 3). This result suggests that as urban development increases in a watershed, total nitrogen concentrations vary more widely among samples collected throughout the year. In the other study areas, the extent that total nitrogen concentrations fluctuate throughout the year remains relatively constant as urban land cover increases in a watershed.

Total Phosphorus

Total phosphorus showed a different pattern from total nitrogen in how the amount of variation throughout the year was related to urban development. There was no relation indicated in the Boston study area, but moderate or strong relations were indicated in four other study areas (table 3). In the Portland and Denver study areas, the relations were strong, indicating that variation of total phosphorus concentrations throughout the year increased with urban development. Conversely, the Raleigh and Milwaukee study areas had moderate, negative relations (rho = -0.62 for both study areas), which suggests that total phosphorus concentrations in streams varied less as urban development increased. As previously described, this response in the Milwaukee study area might be associated with the agricultural land cover before urban development where fertilizer containing phosphorus is applied to crops only at certain times throughout the year. The reason for the negative response in the Raleigh study area is less clear. Fitzpatrick and Peppler (2010) reported a strong increase in the frequency of high flows related to urban development in the Raleigh study area, and it is possible that otherwise high total phosphorus concentrations in urban streams were diluted by these high flows.

Chloride

The relation between variation throughout the year in chloride concentrations and urban development indicated a pattern that was closely associated with the colder regions of the country (fig. 2; table 3). In the three study areas where road salt is used extensively to maintain travel in the winter (Boston, Denver, and Milwaukee), a strong positive relation was indicated. (Note: The graph for Milwaukee has been charted on a logarithmic scale.) A moderate relation was indicated in the Portland study area where snowfall generally occurs only at the higher elevations, but even then, road salt is typically not used. Because the relation between the median chloride concentration and urban development was also strong in the Boston, Denver, and Milwaukee study areas, the increase in the variation of chloride is consistent with wintertime salt use. Chloride concentrations in colder regions are typically highest during spring snowmelt and lower throughout the rest of the year, and this seasonal fluctuation can account for the greater variability in streams with high percentages of urban land.

Pesticide Toxicity

The relations between variation throughout the year in pesticide toxicity and urban development did not indicate any discernible pattern among the study areas (table 3). The relation was moderate in the Portland study area (rho = *0.65) and strong in the Atlanta (rho = *0.97) and Denver (rho = *0.77) study areas. In these three study areas, there was general agreement among the relations between variation throughout

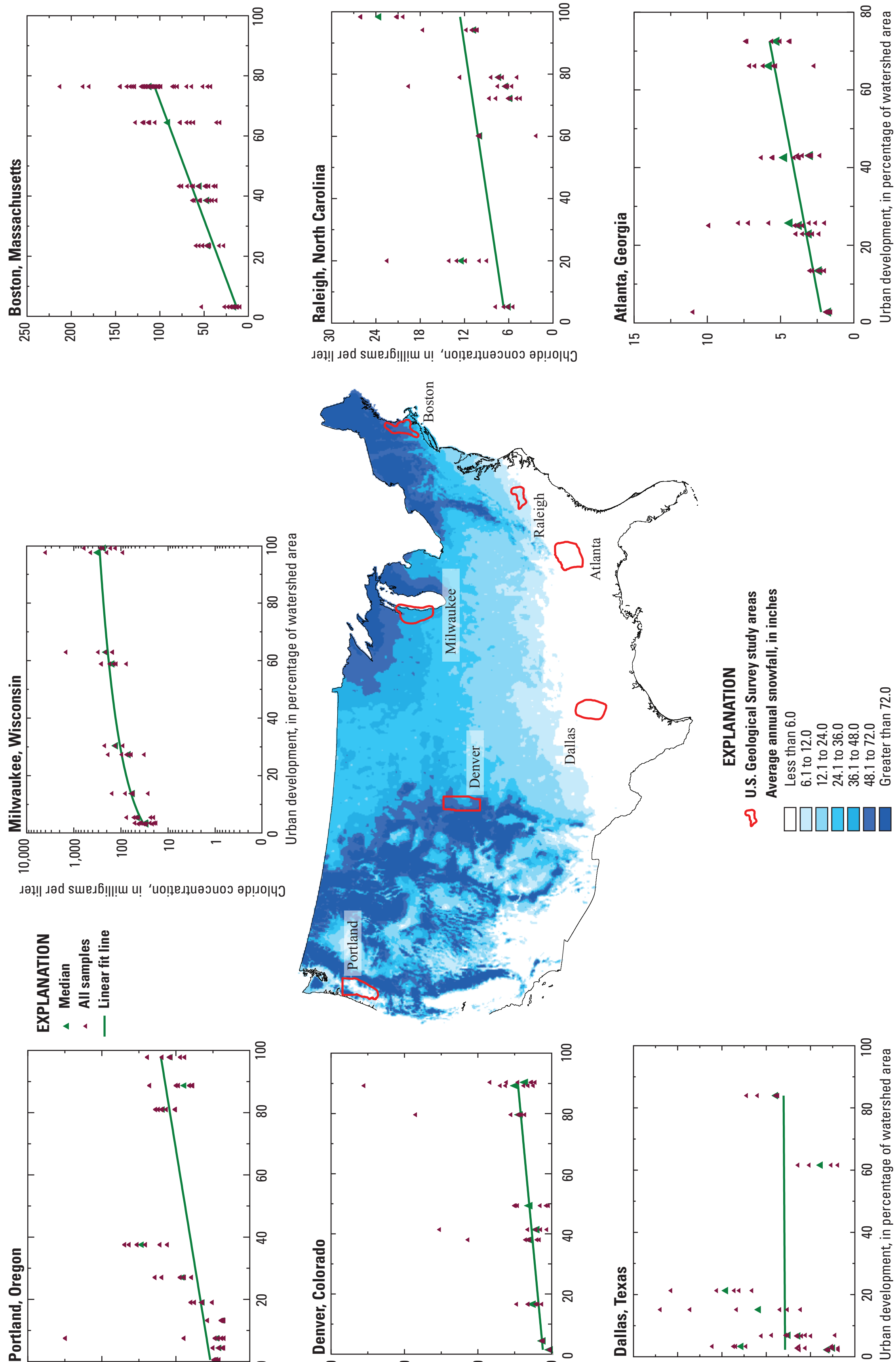

Figure 2. The average annual snowfall for the United States and scatter plots showing the relation of chloride concentrations and urban development for each of the seven study areas sampled.

the year in pesticide toxicity and urban development and the relations between the median pesticide toxicity and urban development. Evaluated together, these results suggest that, while pesticide toxicity increases with urban development in these study areas, levels at sites within these study areas that are more urban are more variable throughout the year. A variance throughout the year such as this could occur when pesticides are applied mainly during warm months, similarly to the variance throughout the year in chloride related to road salt use in winter months.

Relations of the Biological Condition to Chloride and Pesticide Toxicity

Elevated chloride concentrations and pesticide toxicity values in streams are known to be toxic to macroinvertebrate communities (Munn and Gilliom, 2001; Munn and others, 2006; Corsi and others, 2010). Because values of these two stream-chemistry factors can vary among samples collected throughout the year, it is important to determine characterizations of these factors as they relate to biological community condition. The community tolerance index is used to characterize the biological community condition with values ranging from 0 (highly sensitive taxa) to 10 (highly tolerant taxa); therefore, a positive relation of the community tolerance index to a stream-chemistry factor indicates loss of sensitive taxa and a declining stream health.

Comparing the Community Tolerance Index Among Study Areas

Examining the community tolerance index values within each study area provides a better understanding of how the macroinvertebrate community relates to both chloride and pesticide toxicity. The community tolerance index minimum values (table 2) were generally lower in study areas where land cover before urban development was forested (average = 4.78) compared with the study areas where the land cover before urban development was agricultural (average = 5.58). The range of the community tolerance index was calculated by subtracting the minimum value from the maximum value within a study area. The average range of the community tolerance index was greater in study areas where the land cover before urban development was forested (2.66 overall), whereas study areas where land cover before urban development was agricultural had smaller ranges (2.20 overall). The smaller range of community tolerance indices in study areas where the land cover before urban development was agricultural is consistent with less change in the community structure, therefore decreasing the potential response to chloride and pesticide toxicity.

Chloride

All moderate or strong relations between the community tolerance index and chloride were positive, indicating that sensitive taxa were being lost and the biological condition declined as chloride concentrations increased (table 4). In three of the four study areas where the land cover before urban development was forested, the relations with the median value were strong. The exception was the Raleigh study area, where no moderate or strong relations were indicated with any characterization of the chloride concentrations. In study areas where land cover before urban development was agriculture, no moderate or strong relations were indicated except for Denver study area, where the relation was strong with the seasonal high-flow value and moderate with the seasonal low-flow value.

The strongest relation between the community tolerance index and any characterization of chloride was indicated in the Boston study area with the median value (rho=*1.00; fig. 3). This finding supports the premise that the condition of the macroinvertebrate community reflects water-quality conditions integrated over time and is consistent with other studies that identified chloride as an important water-quality factor that can occur at concentrations harmful to aquatic life in the northeastern United States (Mullaney and others, 2009). Furthermore, Kashuba and others (2012) developed a Bayesian model for the northeastern United States that predicted how changes in stream habitat, hydrology, and water quality could degrade macroinvertebrate communities in streams of the region. Using the Bayesian modeling approach of analyzing region-specific data and eliciting information from regional experts, specific conductance (a surrogate for chloride in the region) was identified as the stream-chemistry factor that best predicted the condition of the macroinvertebrate communities.

Pesticide Toxicity

Relations between the community tolerance index and pesticide toxicity indicated moderate to strong positive relations in all study areas with at least one characterization of pesticide toxicity, which suggested that the biological condition declined with an increase in pesticide use (table 4). This finding is supported by the general purpose of pesticides: to eliminate plant and animal species from places such as crops, buildings, and lawns. Thus, when pesticides (especially insecticides) enter a stream, they can affect the macroinvertebrate

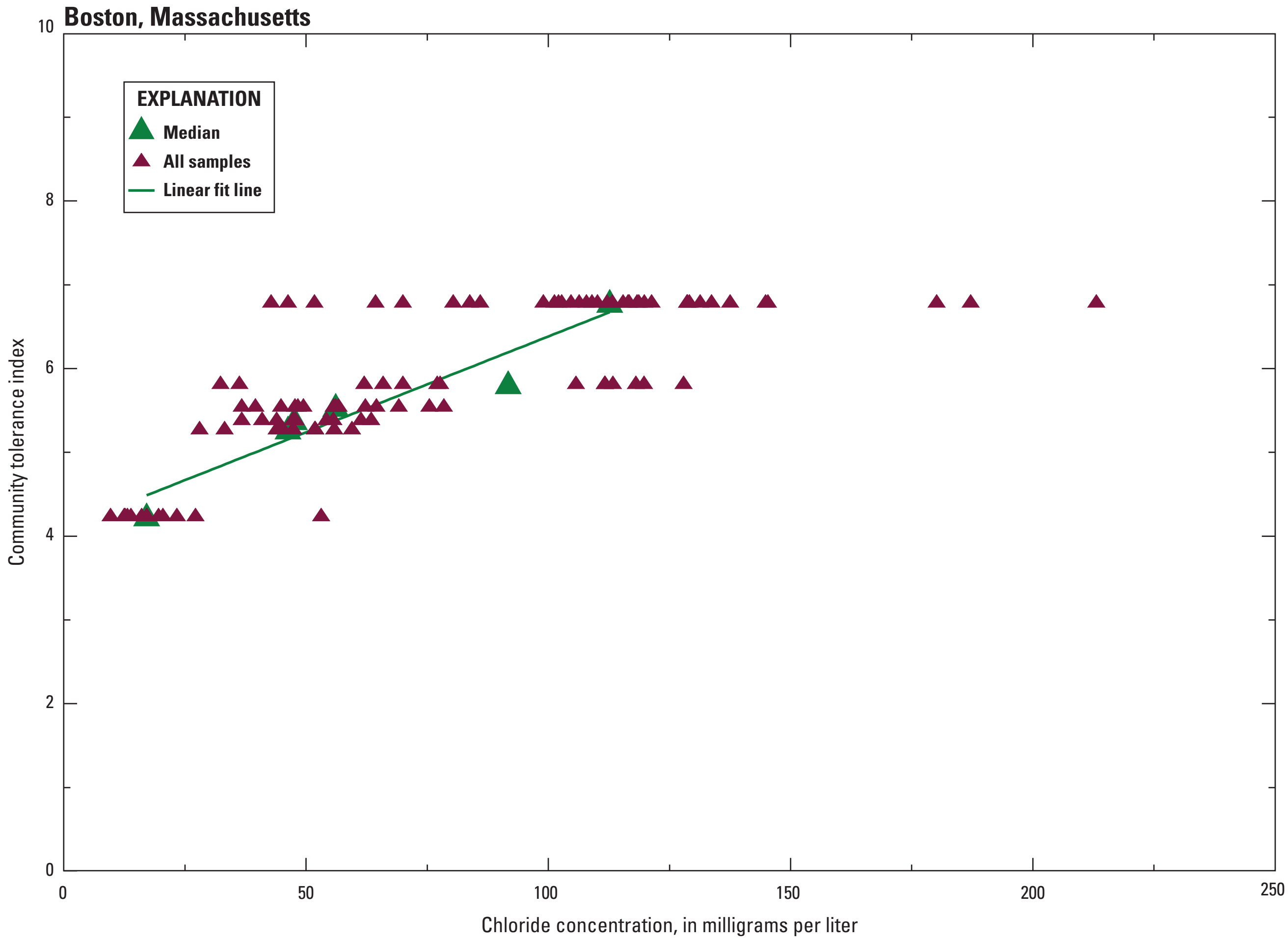

Figure 3. The community tolerance index compared with chloride concentrations in the Boston, Massachusetts, study area.

community. Relations based on the median value were moderate to strong in all study areas except Milwaukee.

The community tolerance index at the least urban site in Milwaukee was 6.77, which, for the seven study areas, is the highest community tolerance index among the least urban sites (table 1). This occurs because streams in watersheds of the Milwaukee study area had agricultural land cover before urban development, which resulted in relatively fewer sensitive macroinvertebrate taxa compared with streams in the other study areas, especially those that had watersheds with forest land cover before urban development; the presence of fewer sensitive taxa in Milwaukee study area may be related, in part, to widespread pesticide application in the watersheds before urban development. Furthermore, the presence of relatively few sensitive taxa in Milwaukee study area may help explain the lack of a relation between the community tolerance index and chloride in that study area (table 4). Even though the relation between the median chloride value and urban development was very strong in the Milwaukee study area (table 3; rho=*0.99), the invertebrate community would not be particularly responsive to an increase in chloride concentrations if the sensitive taxa were already depleted.

These findings are substantiated by the results of Cuffney and others (2010), who reported that watersheds in the Denver, Dallas, and Milwaukee study areas before urban development had relatively few sensitive taxa in their streams because they had been affected by degradation from agricultural practices. Consequently, the expected response of a biological community to urban development and other stressors would be weaker in agricultural areas compared with that in forested areas. Thus, the relatively weak responses in the Denver, Dallas, and Milwaukee study areas does not mean that their aquatic biological communities are more resilient to increases in chloride and pesticides, but more likely that the biological condition was already degraded to some degree before the increases in these stressors.

Results in the Raleigh, North Carolina, study area were not consistent with the study areas where land cover before urban development was forested; the high minimum community tolerance index value (5.59) and the smallest range

(1.26) more closely approximate study areas where land cover before urban development was agricultural (table 2). Although the land cover in Raleigh is being converted from forested to urban, the Raleigh area was farmed in the early 1900s and then allowed to revert to forest (Falcone and others, 2007).

Summary and Conclusions

The U.S. Geological Survey investigated the effects of urban development on stream ecosystems as part of the National Water-Quality Assessment Program beginning in 1999. Water quality was sampled in seven study areas across the United States at 61 stream sites (6 to 10 stream sites in each study area) along a gradient of land cover from forested or agricultural to urban land. Stream-chemistry samples were collected every other month for a year and the aquatic macroinvertebrate community was assessed. The purpose of this report was to evaluate how variation in stream-chemistry factors related to urban development and to the biological condition of these streams.

This report focused on four stream-chemistry factors—total nitrogen, total phosphorus, chloride, and pesticide toxicity—and explored how the strength in their relation to urban development and how the aquatic biological condition often depends on how the stream-chemistry factors are characterized. Because the values of factors can vary with the time of year a sample is collected, each factor was characterized four separate ways to account for variation throughout the year—the seasonal high-flow value, the seasonal low-flow value, the median value (representing an annual “integrated” value), and the standard deviation of values (representing the amount of variation throughout the year among values). Additionally, a community tolerance index for macroinvertebrates was used to infer the biological condition for each site. The objectives of this report were to (1) describe how relations between urban development and stream-chemistry factors depend on when stream-chemistry is sampled and how their values are characterized, and (2) identify characterizations of chloride and pesticide toxicity values that have the strongest relations to the biological condition of a stream. Spearman correlations were used to evaluate these relations.

Stream-chemistry factors generally increased with urban development, with the exception of total phosphorus in Raleigh, North Carolina, and Milwaukee, Wisconsin, study areas and pesticide toxicity in the Milwaukee study area. Among the characterizations of stream-chemistry factors, the median value generally had the greatest number of strong relations with urban development. The variation throughout the year in stream-chemistry factors generally increased with urban development, indicating that the values of stream-chemistry factors (and water-quality in general) became less consistent among samples as watersheds were developed. The study areas where the land cover before urban development was forested generally had a larger number of strong and moderate relations between the stream-chemistry factors and urban development compared to the number of relations in the study areas where the land cover before urban development was agriculture. The relations between chloride and urban development were the strongest of relations with the stream-chemistry factors. The negative relations for total phosphorus and pesticide toxicity in the Milwaukee study area are likely the results of fertilizer and pesticide applications on agricultural crops.

The relations of community tolerance index to chloride and pesticide toxicity were calculated irrespective of the level of urban development. The overall results, however, were similar to results for the stream-chemistry factors and urban development; the forested study areas had a greater number of strong relations compared with the agricultural study areas. This response is likely due to a degraded biological community that resulted from agricultural practices in the watersheds. In general, the median values for chloride and pesticide toxicity provided the strongest relations of the community tolerance index to chloride and pesticide toxicity.

The results of this investigation indicated that, compared with sampling a stream at a single point in time, sampling at regular intervals over the course of 1 year is valuable for determining the overall water quality and for relating water quality to the biological condition of a stream. From these samples, the median value may indicate a more integrated water-quality condition for streams undergoing urban development.

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Appendix 1. Site Summary of Total Nitrogen Concentrations, Total Phosphorus Concentrations, Chloride Concentrations, and the Pesticide Toxicity Index

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Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with "E" and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
		Portland, Oreg., study area				
POR_efdar	14205400	Seasonal high flow	0.41	0.04	2.5	1.04E-7
		Seasonal low flow	0.26	0.05	2.3	0
		Median	0.39	0.03	2.3	5.30E-8
		Standard deviation	0.23	0.01	0.1	6.71E-8
POR_deep	452231122200000	Seasonal high flow	0.38	0.02	1.8	1.68E-7
		Seasonal low flow	0.21	0.03	2.1	0
		Median	0.37	0.02	2.1	3.86E-8
		Standard deviation	0.51	0.01	0.3	9.95E-7
POR_rocwa	455122122310600	Seasonal high flow	0.27	0.05	1.8	3.86E-8
		Seasonal low flow	0.12	0.04	12	0
		Median	0.56	0.03	2.3	1.93E-8
		Standard deviation	0.60	0.01	4.2	1.47E-3
POR_salmo	454549122295800	Seasonal high flow	0.33	0.01	1.8	0
		Seasonal low flow	0.11	0.02	1.9	0
		Median	0.31	0.01	1.9	0
		Standard deviation	0.37	0.00	0.4	9.78E-4
POR_tickl	452414122213200	Seasonal high flow	0.66	0.05	2.6	4.77E-3
		Seasonal low flow	1.1	0.11	4.0	1.17E-2
		Median	1.2	0.05	3.2	5.64E-3
		Standard deviation	0.56	0.03	0.5	5.97E-3
POR_nfdep	452337122243500	Seasonal high flow	1.3	0.06	4.7	2.44E-2
		Seasonal low flow	1.1	0.09	6.0	5.61E-3
		Median	1.4	0.06	4.6	2.45E-2
		Standard deviation	1.3	0.02	1.0	1.70E-2
POR_whipp	454510122424900	Seasonal high flow	0.77	0.16	7.1	2.26E-4
		Seasonal low flow	0.51	0.18	7.6	0
		Median	0.74	0.13	7.4	5.24E-6
		Standard deviation	0.16	0.05	1.1	1.06E-3
POR_kello	452526122364400	Seasonal high flow	2.3	0.10	6.0	4.41E-4
		Seasonal low flow	1.8	0.12	5.0	4.20E-7
		Median	2.1	0.10	5.9	4.76E-6
		Standard deviation	0.24	0.04	0.5	1.23E-3
POR_pring	445551123015800	Seasonal high flow	0.72	0.03	3.9	5.76E-6
		Seasonal low flow	0.60	0.05	4.8	9.45E-6
		Median	0.70	0.03	4.5	4.26E-3
		Standard deviation	0.60	0.01	1.1	1.23E-3

Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with "E" and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
POR_clagg	450022123012400	Seasonal high flow	0.97	0.16	5.4	1.41E-3
		Seasonal low flow	0.84	0.28	6.9	1.41E-2
		Median	0.90	0.14	5.4	1.43E-2
		Standard deviation	0.12	0.06	0.9	8.41E-3
		Atlanta, Ga., study area				
ATL_hil	02338523	Seasonal high flow	0.55	0.01	1.7	0
		Seasonal low flow	0.18	0.01	1.8	0
		Median	0.31	0.01	1.8	0
		Standard deviation	0.78	0.03	3.8	3.53E-4
ATL_dog	02337395	Seasonal high flow	0.34	0.01	2.0	1.70E-5
		Seasonal low flow	0.34	0.01	2.8	1.84E-3
		Median	0.40	0.02	2.4	8.37E-4
		Standard deviation	0.07	0.01	0.4	5.30E-3
ATL_sho	02344480	Seasonal high flow	0.69	0.05	2.8	1.55E-5
		Seasonal low flow	0.34	0.02	4.0	4.94E-6
		Median	0.53	0.03	3.1	1.45E-3
		Standard deviation	0.13	0.02	0.5	4.82E-3
ATL_whw	02344737	Seasonal high flow	0.60	0.23	3.8	1.58E-2
		Seasonal low flow	0.62	0.12	9.9	8.98E-6
		Median	0.62	0.12	3.8	8.53E-3
		Standard deviation	0.13	0.07	2.8	5.82E-3
ATL_who	02344797	Seasonal high flow	1.5	0.08	2.6	4.84E-4
		Seasonal low flow	1.4	0.31	7.2	3.71E-3
		Median	1.2	0.11	4.4	6.56E-3
		Standard deviation	0.33	0.10	2.5	7.55E-3
ATL_suw	02334885	Seasonal high flow	0.96	0.03	3.7	1.17E-2
		Seasonal low flow	0.92	0.03	5.6	7.29E-6
		Median	0.95	0.03	4.8	8.53E-3
		Standard deviation	0.37	0.02	1.1	1.19E-2
ATL_nos	02336968	Seasonal high flow	0.52	0.02	3.1	4.23E-3
		Seasonal low flow	0.38	0.01	3.9	8.40E-4
		Median	0.53	0.02	3.1	5.37E-3
		Standard deviation	0.31	0.06	0.5	1.55E-2
ATL_nic	02336635	Seasonal high flow	0.93	0.01	6.2	5.96E-3
		Seasonal low flow	0.97	0.02	7.1	3.52E-3
		Median	0.95	0.02	5.8	1.24E-2
		Standard deviation	0.12	0.03	1.6	2.43E-2

Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with "E" and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
ATL_sop	02335870	Seasonal high flow	0.87	0.01	5.1	1.08E-2
		Seasonal low flow	0.69	0.01	7.3	7.32E-4
		Median	0.83	0.01	5.3	1.85E-2
		Standard deviation	0.45	0.05	1.4	2.42E-2
		Raleigh, N.C., study area				
RAL_morgan	02097464	Seasonal high flow	0.86	0.07	5.4	2.39E-7
		Seasonal low flow	0.70	0.10	6.2	4.37E-6
		Median	1.0	0.10	6.1	1.64E-7
		Standard deviation	0.83	0.11	0.8	1.72E-6
RAL_cates	0208500600	Seasonal high flow	0.29	0.03	23	7.89E-8
		Seasonal low flow	0.35	0.02	10	1.32E-3
		Median	0.31	0.02	12	2.03E-6
		Standard deviation	0.06	0.01	4.8	1.02E-3
RAL_rschen	0208726370	Seasonal high flow	0.90	0.06	100	1.05E-2
		Seasonal low flow	0.67	0.03	10	1.49E-3
		Median	0.60	0.03	10	4.53E-3
		Standard deviation	0.35	0.24	38	2.82E-2
RAL_swift	02087580	Seasonal high flow	0.75	0.05	8.7	3.82E-2
		Seasonal low flow	0.66	0.05	5.7	5.85E-3
		Median	0.67	0.05	5.9	2.87E-2
		Standard deviation	0.17	0.01	1.6	3.62E-2
RAL_hare	0208726995	Seasonal high flow	0.80	0.05	20	1.07E-2
		Seasonal low flow	1.7	0.03	6.6	1.88E-2
		Median	0.88	0.04	6.5	1.68E-2
		Standard deviation	0.37	0.02	5.4	3.32E-2
RAL_black	0208725055	Seasonal high flow	0.44	0.04	13	3.11E-2
		Seasonal low flow	0.75	0.08	4.9	1.16E-1
		Median	0.24	0.02	7.4	2.55E-3
		Standard deviation	0.24	0.02	2.6	4.61E-2
RAL_swprng	0208730725	Seasonal high flow	0.90	0.01	18	4.12E-5
		Seasonal low flow	0.89	0.03	11	8.32E-3
		Median	0.83	0.02	11	2.23E-3
		Standard deviation	0.11	0.01	2.9	4.01E-3
RAL_pigeon	0208732610	Seasonal high flow	2.2	0.03	36	5.60E-4
		Seasonal low flow	1.6	0.03	21	4.66E-5
		Median	1.8	0.03	24	3.04E-4
		Standard deviation	0.33	0.01	5.9	4.46E-3

Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with "E" and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
		Boston, Mass., study area				
BOS_stil	01095220	Seasonal high flow	0.63	0.15	9.7	ND
		Seasonal low flow	0.48	0.02	20	ND
		Median	0.44	0.02	17	ND
		Standard deviation	0.10	0.04	11	ND
BOS_wade	01109000	Seasonal high flow	0.49	0.01	47	ND
		Seasonal low flow	0.67	0.03	56	ND
		Median	0.63	0.03	46	ND
		Standard deviation	0.15	0.02	9.5	ND
BOS_nepo	01105000	Seasonal high flow	0.66	0.07	47	ND
		Seasonal low flow	0.87	0.04	54	ND
		Median	0.82	0.04	48	ND
		Standard deviation	0.27	0.04	8.6	ND
BOS_ipsw	01101500	Seasonal high flow	0.73	0.02	37	ND
		Seasonal low flow	1.0	0.05	56	ND
		Median	0.81	0.03	56	ND
		Standard deviation	0.16	0.02	12	ND
BOS_saug	01102345	Seasonal high flow	0.66	0.02	32	ND
		Seasonal low flow	1.1	0.05	110	ND
		Median	1.1	0.03	92	ND
		Standard deviation	0.18	0.02	32	ND
BOS_aber	01102500	Seasonal high flow	2.4	0.03	130	ND
		Seasonal low flow	2.9	0.05	120	ND
		Median	2.9	0.04	110	ND
		Standard deviation	0.89	0.04	35	ND
		Denver, Colo., study area				
DEN_brphil	413659104370001	Seasonal high flow	0.25	0.01	6.2	0
		Seasonal low flow	0.20	0.01	6.5	0
		Median	0.49	0.00	6.2	0
		Standard deviation	0.17	0.00	0.8	0
DEN_boxel	403308105001601	Seasonal high flow	4.4	0.02	27	2.09E-6
		Seasonal low flow	4.6	0.03	27	2.15E-6
		Median	5.4	0.03	26	3.47E-6
		Standard deviation	0.59	0.02	2.0	1.94E-6
DEN_fossil	403048105042701	Seasonal high flow	1.6	0.04	38	5.35E-4
		Seasonal low flow	1.5	0.02	42	6.88E-6
		Median	2.0	0.02	53	2.71E-4
		Standard deviation	1.0	0.02	25	1.11E-3

Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with "E" and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
DEN_breste	393948105053501	Seasonal high flow	0.74	0.03	33	1.63E-7
		Seasonal low flow	1.7	0.14	40	3.73E-7
		Median	1.5	0.03	61	1.01E-6
		Standard deviation	0.57	0.05	73	4.94E-4
DEN_ralst	394919105074601	Seasonal high flow	0.60	0.07	13	0
		Seasonal low flow	2.0	0.09	29	4.57E-2
		Median	1.9	0.03	43	5.30E-6
		Standard deviation	0.69	0.04	110	1.86E-2
DEN_bould	400217105123701	Seasonal high flow	0.28	0.02	8.3	9.56E-8
		Seasonal low flow	0.33	0.02	14	4.22E-7
		Median	0.35	0.03	62	6.25E-7
		Standard deviation	0.42	0.07	44	4.89E-4
DEN_cherry	06713500	Seasonal high flow	2.2	0.18	86	7.97E-2
		Seasonal low flow	2.5	0.19	73	1.91E-2
		Median	2.6	0.19	89	2.65E-3
		Standard deviation	1.1	0.04	120	3.13E-2
DEN_lakew	394409105020501	Seasonal high flow	ND	0.06	64	0
		Seasonal low flow	ND	0.06	49	0
		Median	1.1	0.02	100	1.78E-3
		Standard deviation	0.56	0.02	180	9.71E-1
DEN_litdry	394921105015701	Seasonal high flow	0.74	0.04	54	1.10E-2
		Seasonal low flow	0.86	0.05	56	9.06E-3
		Median	2.1	0.03	74	7.23E-3
		Standard deviation	1.3	0.20	48	5.74E-3
Dallas, Tex., study area						
DFW_sprong	08063595	Seasonal high flow	1.3	0.04	13	7.18E-7
		Seasonal low flow	3.4	0.05	13	6.50E-6
		Median	1.4	0.05	13	5.83E-6
		Standard deviation	0.95	0.05	5.9	8.06E-3
DFW_mill	08063565	Seasonal high flow	1.1	0.03	10	2.76E-6
		Seasonal low flow	0.42	0.02	26	1.14E-6
		Median	0.72	0.03	10	3.74E-6
		Standard deviation	0.32	0.02	8.4	7.11E-6
DFW_sfkcha	08063555	Seasonal high flow	0.36	0.04	55	4.43E-5
		Seasonal low flow	4.3	0.10	25	6.81E-4
		Median	0.70	0.10	52	2.08E-4
		Standard deviation	1.7	0.07	21	2.79E-4

Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with “E” and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
DFW_doe	08052740	Seasonal high flow	1.6	0.15	24	5.23E-4
		Seasonal low flow	6.8	0.19	26	8.56E-2
		Median	4.4	0.19	26	1.19E-2
		Standard deviation	2.8	0.13	8.6	3.39E-2
DFW_tehuac	08064695	Seasonal high flow	0.13	0.04	30	1.11E-6
		Seasonal low flow	0.22	0.06	31	4.49E-4
		Median	0.13	0.04	30	1.11E-6
		Standard deviation	0.07	0.05	11	2.27E-4
DFW_buftri	08061780	Seasonal high flow	4.2	0.98	75	4.79E-3
		Seasonal low flow	3.9	1.16	54	8.34E-3
		Median	3.1	0.79	44	1.16E-2
		Standard deviation	1.4	0.84	26	1.06E-2
DFW_parsn	08057475	Seasonal high flow	0.14	0.09	52	1.86E-5
		Seasonal low flow	0.11	0.10	63	7.73E-3
		Median	0.13	0.10	59	2.37E-5
		Standard deviation	0.06	0.07	21	1.01E-2
DFW_5mile	08057431	Seasonal high flow	0.89	0.01	21	1.03E-2
		Seasonal low flow	0.19	0.01	26	1.39E-4
		Median	0.67	0.03	16	2.62E-2
		Standard deviation	0.35	0.03	8.4	4.59E-2
DFW_white	08057200	Seasonal high flow	1.9	0.19	35	2.69E-2
		Seasonal low flow	1.7	0.14	35	9.63E-3
		Median	2.3	0.25	36	1.21E-2
		Standard deviation	0.30	0.09	6.4	7.10E-3
Milwaukee, Wis., study area						
MGB_blak	040853145	Seasonal high flow	2.0	0.19	22	2.25E-2
		Seasonal low flow	2.6	0.31	30	3.86E-1
		Median	2.0	0.14	30	3.19E-2
		Standard deviation	0.29	0.09	7.0	1.45E-1
MGB_rioc	04085188	Seasonal high flow	0.88	0.22	18	3.31E-5
		Seasonal low flow	4.1	0.16	37	1.41E-5
		Median	2.4	0.13	31	1.67E-5
		Standard deviation	1.7	0.07	13	1.07E-5
MGB_bair	040851325	Seasonal high flow	0.43	0.71	20	8.84E-5
		Seasonal low flow	0.09	0.13	24	5.01E-6
		Median	0.26	0.20	46	4.84E-5
		Standard deviation	0.15	0.24	21	1.25E-2

Appendix Table 1-1. Sample characterizations of total nitrogen concentrations, total phosphorus concentrations, chloride concentrations, and pesticide toxicity for each stream.—Continued

[Site information is listed in table 1. The data from these samples are reported in Giddings and others (2009). Values shown as a number followed with "E" and a negative number are the number multiplied by 10 to the power of the second number; thus, 1.04E-7 is 1.04 ×10-7 or 0.000000104. Colo., Colorado; Ga., Georgia; Mass., Massachusetts; N.C., North Carolina; Oreg., Oregon; Tex., Texas; Wis., Wisconsin; ID, identification number; mg/L, milligrams per liter; ND, no data; USGS, U.S. Geological Survey]

Site code	USGS site ID	Sample characterization	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Chloride (mg/L)	Pesticide toxicity[1] (unitless)
MGB_sawy	04081897	Seasonal high flow	8.7	0.07	57	1.06E-2
		Seasonal low flow	0.14	0.15	27	1.47E-3
		Median	5.1	0.09	58	8.00E-4
		Standard deviation	3.5	0.05	45	8.43E-3
MGB_pikr	04087258	Seasonal high flow	9.8	0.12	61	8.18E-3
		Seasonal low flow	0.57	0.12	32	1.61E-5
		Median	4.1	0.10	72	6.60E-5
		Standard deviation	5.1	0.09	54	3.30E-3
MGB_meno	04087030	Seasonal high flow	1.3	0.09	91	1.07E-3
		Seasonal low flow	0.43	0.18	220	8.48E-7
		Median	1.2	0.07	130	2.82E-6
		Standard deviation	1.2	0.07	56	5.35E-4
MGB_mudc	04084429	Seasonal high flow	0.97	0.19	77	1.57E-2
		Seasonal low flow	0.23	0.11	130	9.84E-6
		Median	0.82	0.09	160	4.54E-4
		Standard deviation	0.28	0.05	76	6.33E-3
MGB_oakc	04087204	Seasonal high flow	1.2	0.10	150	1.42E-2
		Seasonal low flow	0.74	0.07	150	3.85E-2
		Median	0.74	0.04	210	9.07E-7
		Standard deviation	0.20	0.03	570	1.68E-2
MGB_linc	040869415	Seasonal high flow	1.0	0.05	200	5.63E-3
		Seasonal low flow	0.32	0.19	93	2.58E-7
		Median	0.79	0.09	320	9.14E-7
		Standard deviation	0.50	0.07	1,900	2.82E-3
MGB_hony	04087118	Seasonal high flow	1.9	0.08	170	1.71E-2
		Seasonal low flow	1.2	0.10	130	1.07E-2
		Median	1.2	0.08	240	6.17E-6
		Standard deviation	0.46	0.03	190	7.95E-3

[1]Pesticide toxicity can be used to rank or compare the relative potential toxicity of different samples and to evaluate the relations between urban development and pesticide toxicity on biological communities, such as the macroinvertebrates (Munn and Gilliom, 2001; Munn and others, 2006; Giddings and others, 2009). A zero value indicates that pesticides used in the calculation of the pesticide toxicity index were not detected. A value of 1.00 E-1 would indicate relatively high potential toxicity, whereas a value of 1.00 E-4 would be potentially a thousand times less toxic.

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Beaulieu and others—**Variability in Stream Chemistry in Seven Metropolitan Areas of the United States, 1999–2004**—Scientific Investigations Report 2012–5170