Selected Physical, Chemical, and Biological Data Used to Study Urbanizing Streams in Nine Metropolitan Areas of the United States, 1999–2004

By Elise M.P. Giddings, Amanda H. Bell, Karen M. Beaulieu, Thomas F. Cuffney, James F. Coles, Larry R. Brown, Faith A. Fitzpatrick, James Falcone, Lori A. Sprague, Wade L. Bryant, Marie C. Peppler, Cory Stephens, and Gerard McMahon

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible 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, now 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 condition of our Nation's streams and ground water? How are conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, 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/studyu.html).

Multiple national and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are reassessed. These assessments extend the findings in the Study Units by determining 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 ground water. 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 topics 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. These topical studies are conducted in those Study Units most affected by these issues; they comprise a set of multi-Study-Unit designs for systematic national assessment. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected 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.

Matthew C. Larsen
Associate Director for Water

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
micron (µm)	0.0003937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
liter (L)	61.02	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

SI Prefixes:
milli = 10^{-3}
micro = 10^{-6}
nano = 10^{-9}
pico = 10^{-12}
micron = micrometer

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

$$°F= (1.8 \times °C) + 32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Altitude, as used in this report, refers to distance above the vertical datum.

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

ACFB	Apalachicola-Chattahoochee-Flint River Basin
ADAS	Algal Data Analysis System
AFDM	ash-free dry mass
AhR	aryl hydrocarbon receptor
ALBE	Albemarle-Pamlico Drainage Basin
ATL	Atlanta, Georgia
BIR	Birmingham, Alabama
BOS	Boston, Massachusetts
CA	correspondence analysis
Chl *a*	chlorophyll *a*
D50	mean particle size
DEN	Denver, Colorado
DFW	Dallas-Fort Worth, Texas
DPAC	distribute parents among children
DTH	depositional-targeted habitat
EC_{50}	50-percent effect concentration
EUSE	Effects of Urbanization on Stream Ecosystems
GIS	geographic information system
GRSL	Great Salt Lake Basins
HDAS	Habitat Data Analysis System
IDAS	Invertebrate Data Analysis System
LC_{50}	50-percent lethal concentration
MA-NUII	metropolitan area national urban intensity index
MA-UII	metropolitan area urban intensity index
MDS	multi-dimensional scaling
MGB	Milwaukee-Green Bay, Wisconsin
MOBL	Mobile River Basin
NAWQA	National Water-Quality Assessment
NCDENR	North Carolina Department of Environment and Natural Resources
NECB	New England Coastal Basins
NLCD01	National Land Cover Data 2001
nMDS	nonparametric multi-dimensional scaling
NPDES	National Pollutant Discharge Elimination System
NUII	national urban intensity index
NWQL	National Water Quality Laboratory

PAH	polycyclic aromatic hydrocarbons
PCA	principal components analysis
PCB	polychlorinated biphenyl
POR	Portland, Oregon
PR	period of record
PTI	pesticide toxicity index
QMH	qualitative multi-habitat
QQ	qualitative richness dataset
RAL	Raleigh, North Carolina
RPKC	remove parent keep child
RTH	richest targeted habitat
SD	standard deviation
SLC	Salt Lake City, Utah
SPLT	South Platte River Basin
SPMD	semipermeable membrane device
TIGER	Topologically Integrated Geographic Encoding and Referencing
TRI	Toxic Release Inventory
TRIN	Trinity River Basin
UII	urban intensity index
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UV	ultraviolet
WILL	Willamette River Basin
WMIC	Western Lake Michigan Drainages

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Abstract

This report documents and summarizes physical, chemical, and biological data collected during 1999–2004 in a study titled Effects of Urbanization on Stream Ecosystems, undertaken as part of the U.S. Geological Survey's National Water-Quality Assessment Program. Data-collection methods and data processing are described in this report for streamflow; stream temperature; instream chemistry; instream aquatic habitat; and algal, macroinvertebrate, and fish communities. Data summaries prepared for analytical use are presented in downloadable data tables.

Introduction

This report documents and summarizes physical, chemical, and biological data collected during 1999–2004 in a study titled Effects of Urbanization on Stream Ecosystems (EUSE), undertaken as part of the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program. This study was conducted to examine differences in physical, chemical, and biological characteristics of streams across a gradient of urban-development intensity in each of nine metropolitan study areas that represent distinct environmental settings across the United States: Atlanta, Georgia (abbreviations ATL and ACFB are used in figures and data tables associated with this report); Birmingham, Alabama (BIR, MOBL); Boston, Massachusetts (BOS, NECB); Dallas-Fort Worth, Texas (DFW, TRIN); Denver, Colorado (DEN, SPLT); Milwaukee-Green Bay, Wisconsin (MGB, WMIC); Portland, Oregon (POR, WILL); Raleigh, North Carolina (RAL, ALBE); and Salt Lake City, Utah (SLC, GRSL) (fig. 1). Further information about the study can be obtained at the EUSE Web site.

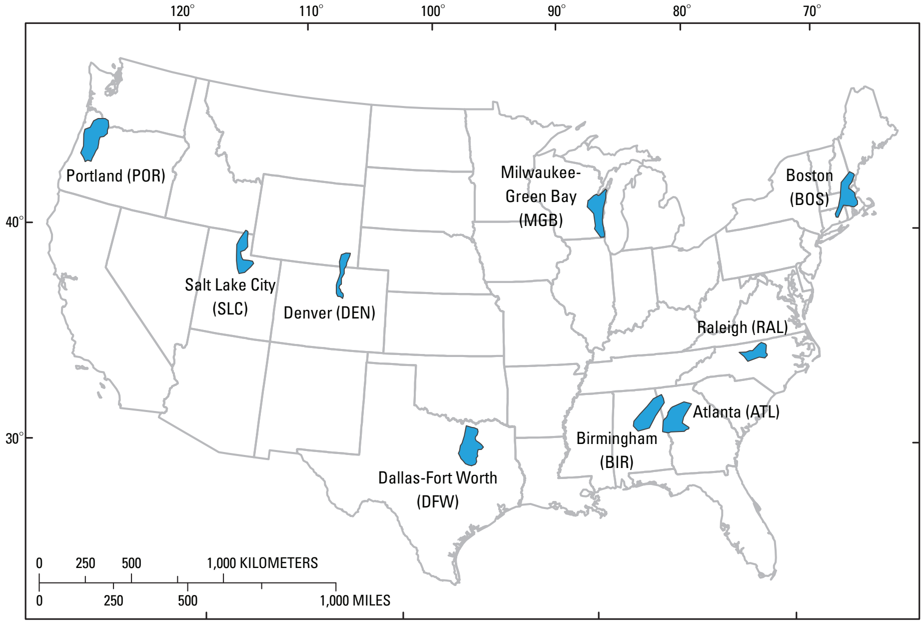

Figure 1. Locations of nine metropolitan study areas for data collection and evaluation of the effects of urbanization on stream ecosystems, 1999–2004. Note: Shaded areas represent the overall boundary of watersheds studied in each metropolitan area.

Purpose and Scope

This report describes the overall EUSE objectives, documents data-collection and processing methods used in the study, and provides summary data tables of watershed characteristics; physical and chemical characteristics, including hydrology, temperature, water chemistry, and habitat; and metrics and other measures of community condition for fish, macroinvertebrate, and algal assemblages. The data tables can be downloaded as Microsoft® Excel files.

Description of Study Objectives

The three primary objectives of the EUSE study are as follows:

- Determine the hydrologic, geomorphic, chemical, habitat, and biological characteristics of streams that respond to land-use changes associated with urbanization in specific environmental settings and among a range of environmental settings.

- Determine the most important landscape features associated with or related to hydrologic, chemical, geomorphic, habitat, and ecological responses to urbanization.

- Determine the physical and chemical characteristics associated with biological responses and compare these characteristics across environmental settings.

In 1999 a series of investigations were initiated in the NAWQA Program to examine differences in biological, chemical, and physical characteristics of streams across a gradient of urban-development intensity. Approximately 30 relatively small watersheds (typically ranging in area from 50 to 250 square kilometers [km^2]) were studied in each of the nine study areas across the United States; a total of 265 watersheds were studied (table 1). These study watersheds correspond to a gradient of urbanization. Urban characteristics, such as land use and density of housing and infrastructure, as well as a composite measure of urban intensity (McMahon and Cuffney, 2000; Tate and others, 2005) range from relatively low intensity to relative high intensity within the study watersheds. Within each of the nine study areas, differences in variability of natural features, such as topography and soil characteristics, were minimized to enhance the likelihood of detecting any effects of urbanization in instream response.

Urbanization, represented by urban land-cover, infrastructure, socioeconomic conditions, and other development characteristics, affects stream ecosystems by a number of intervening processes (fig. 2). The EUSE study was designed to collect information about the processes associated with this complex system and address the objectives described above.

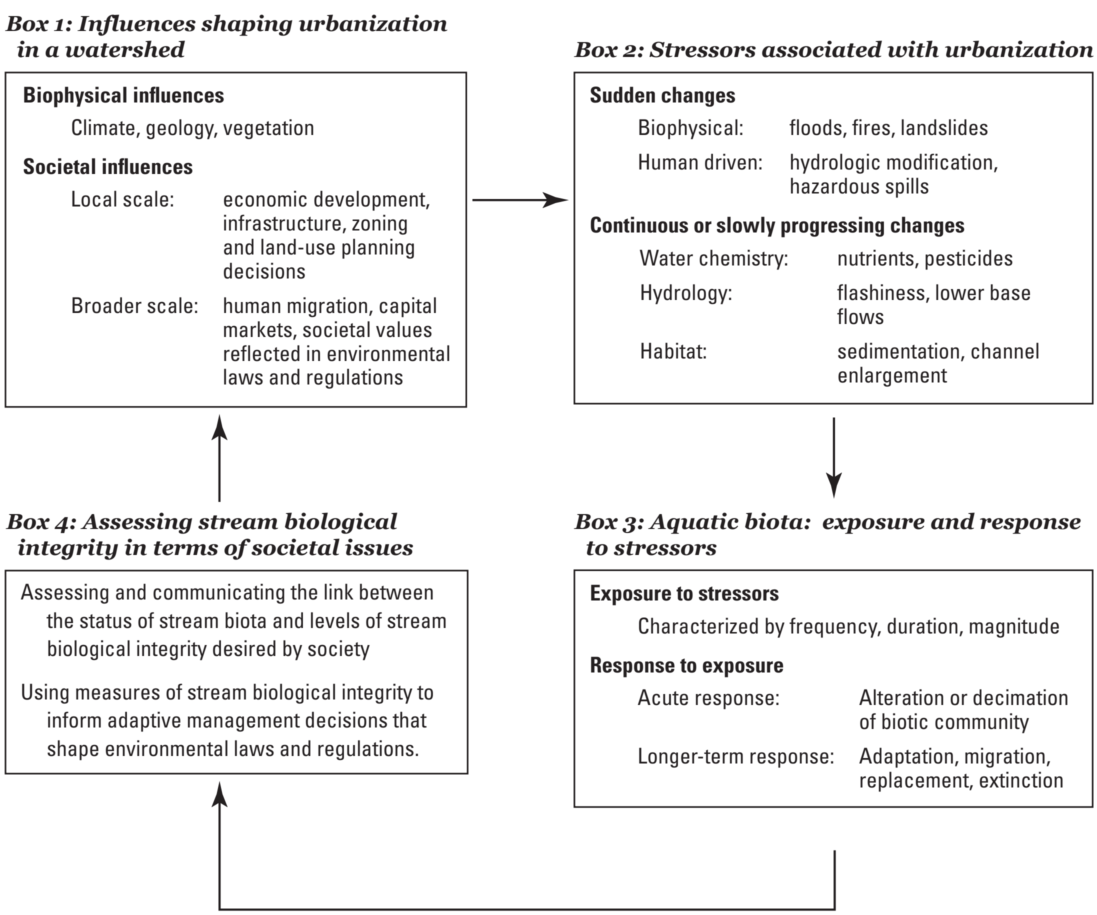

Figure 2. Conceptual framework for studying the effects of urbanization on stream ecosystems, 1999–2004.

Acknowledgments

Jason May of the USGS California Water Science Center and J. Bruce Moring of the USGS Texas Water Science Center provided suggestions that substantially improved the quality of the manuscript. Web formatting and support were provided by Ramona Traynor of the USGS North Carolina Water Science Center.

Data-Collection and Processing Methods

Watershed characteristics were determined by using methods described in greater detail in Falcone and others (2007). Characteristics were determined for each of the study watersheds in the nine EUSE study areas. Continuous stream stage and stream temperature data were collected at or near the biological sampling reach for approximately a 1-year period in coordination with the biological data-collection effort. Streamwater chemistry samples were collected at or near the biological sampling reach two to six times at each stream, with at least one sample representing a period of high base flow and one sample representing a period of low base flow. The exception was the Birmingham study, in which a high base-flow sample could not be obtained because of a drought that occurred during the study. Passive samplers, called semipermeable membrane devices (SPMD), were deployed near the biological sampling reach for several weeks preceding biological data collection to detect hydrophobic organic contaminants. Habitat measures were developed for the stream segments and reaches where the biological sampling occurred. Samples of macroinvertebrate, algal, and fish communities were collected once during low-flow conditions.

Watershed Characteristics

Watershed characteristics associated with the degree of urbanization in each of the study areas were determined for both physical (land cover, infrastructure, hydrologic modifications, soils, topography, and climate) and socioeconomic conditions. Additionally, several composite measures of the intensity of urban development were determined by using a multimetric approach (McMahon and Cuffney, 2000; Cuffney and Falcone, 2009). Watershed characteristics data tables are summarized in table 2.

Land Cover

All land-cover data were based on the National Land Cover Data 2001 (NLCD01) dataset classification scheme and protocols (U.S. Geological Survey, 2005) and were compiled using geographic information system (GIS) software. For this investigation, the data included land cover for the entire watershed (table 2-A), land cover for the entire watershed that is “distance weighted” (land-cover areas close to the sampling site have a higher weighting than areas farther away; weighting is the inverse of the distance of any area in the watershed to the sampling location (table 2-B); and land cover within an approximately 200-meter (m)-wide riparian corridor for all stream segments within each study watershed (table 2-C). Measures of the degree of land-cover fragmentation also were calculated (tables 2-D to 2-K). Information about the derivation of these data is contained in Falcone and others (2007).

Socioeconomic Characteristics

Data from the 2000 U.S. Census (GeoLytics, Inc., 2001) were used to develop socioeconomic characteristics for each of the study watersheds. These characteristics include energy use (table 2-L), ethnicity (table 2-M), housing (tables 2-N and 2-O), income (table 2-P), and population (table 2-Q). Further information about the derivation of these data is contained in Falcone and others (2007).

Infrastructure

Information about roads, point-source dischargers, toxic-release sites, and dams was used to characterize infrastructure in the study watersheds. Road data were obtained from the Census 2000 Topologically Integrated Geographic Encoding and Referencing (TIGER) database (GeoLytics, Inc., 2004). Point-source discharger locations were derived from the U.S. Environmental Protection Agency (USEPA) National Pollutant Discharge Elimination System (NPDES) database (U.S. Environmental Protection Agency, 2005a). Toxic-release locations were derived from the USEPA Toxic Release Inventory (TRI) database (U.S. Environmental Protection Agency, 2005b). Data on dam locations were obtained primarily from the National Inventory of Dams (U.S. Army Corps of Engineers, 1996; table 2-R).

Urban Intensity Index

Three different multimetric indices of urban intensity (UII) were derived for each of the nine urban studies based on a set of census, land-cover, and infrastructure variables that were correlated with population density (Cuffney and Falcone, 2009; table 1). The UII characterizes important types of disturbance associated with urbanization and is assumed to relate to changes in biological assemblages better than any single urban characteristic.

The first set of indices (metropolitan area urban intensity index, MA-UII) was developed uniquely for each study area on the basis of an assessment of factors deemed important in characterizing urbanization in each region. The number of variables included in these indices ranged from as few as 5 to as many as 40. The other two multimetric indices were developed by using a common set of three variables—housing-unit density, percentage of developed land cover, and road density. These variables serve as a proxy for the comprehensive changes associated with urbanization and were selected on the basis of high positive correlations (rho ≥ 0.7) to population density in all of the study areas. One set of index values, representing a gradient of urban intensity, was developed separately for each individual study area (metropolitan-area scaled national urban intensity index, MA-NUII), with values for each study ranging from 0 to 100. A second set of index values was developed to account for differences among the study areas in the rate of change in the MA-NUII relative to changes in population density. This index was scaled to range from 0 to 100 across the nine study areas (nationally scaled urban intensity index, NUII). The range of values for this second index in any of the EUSE study areas can be less than 100, which reflects a limited range of population density in the study area.

Hydrologic Modifications

In-channel structures and other hydrologic modifications can affect the timing, magnitude, duration, and variability of streamflow. Geographic information system analysis was used to identify hydrologic modifications in EUSE study watersheds, which resulted in defining such variables as the number and density of dams, dam storage area, and the percentage of waterbodies associated with canals and other human-developed conveyances (table 2-S).

Soils, Topography, and Climate

Soils, topography, and climate can exert important influences on stream ecosystems at multiple scales. Data on soils and topography (table 2-T) and climate (table 2-U) were prepared using methods described in Falcone and others (2007).

Instream Characteristics

Once the sampling locations were identified, instream characteristics of the streams were determined at or near the sampling locations. These characteristics include stream level (or stage) and temperature conditions, stream chemistry, and instream aquatic habitat. All of these characteristics were measured within a specified time frame that coincided with the biological sampling of the streams. The following sections discuss the collection and characterization of these measurements, and the data are summarized in table 3.

Hydrology

Continuous stream-stage data were collected by using a submersible pressure transducer with an internal data logger and temperature sensor attached (Greenspan Technology Pty Ltd, 2002). Standard USGS streamgaging techniques for collecting streamflow data were not used because of the short data-collection period (equal to or less than (≤) 1 year) and the cost of developing a stage-to-discharge rating at each site. The pressure transducer has a range of 0 to 30 m and an accuracy of plus or minus (±) 0.036 m. This level of accuracy does not meet the USGS standard for accuracy of stage data, which is ± 0.003 m (Sauer, 2002); therefore, the unit values are not published here. A submersible pressure transducer records the pressure of water above the transducer membrane. This value is then converted to water depth from field measurements. The transducer model used in this study recorded changes in stream stage as a result of both water-level changes and atmospheric-pressure changes. As a result, the data were corrected for fluctuations in atmospheric pressure by using barometric pressure data from nearby airports and adjusting for differences in altitude.

Stream-stage values collected at 15-minute intervals were converted subsequently to cross-sectional area in seven of the nine studies (excluded in Birmingham and Boston). A relation between stream stage and cross-sectional area was established by surveying the cross section at the location of the transducer installation.

Stream stage and cross-sectional area values were summarized by using hydrologic-condition metrics (McMahon and others, 2003; table 3-A). An hourly dataset was created by using the data point collected at the beginning of each hour; this dataset was used in further analysis to reduce necessary computing resources. Metrics were calculated to summarize overall hydrologic variability; the rate of change-of-water levels (or flashiness); and the magnitude, frequency, and duration of high and low stage. Calculations generally were based on a 1-year data record that included the biological sampling event. Missing values were not estimated, and the amount of missing data is given as a percentage for each site. The Birmingham area was undergoing drought conditions during much of the study duration.

Stream Temperature

Data loggers were used to record temperature at measurement intervals that ranged from 1 to 60 minutes depending on the equipment, site, and time of year. Equipment malfunctions, floods, droughts, and winter ice led to loss of data and the generation of incomplete annual stage (238 of 265 sites) and temperature (252 of 265 sites) records. Temperature data were processed to produce temperature records and data summaries that could be used to assess the effects of urbanization on water temperature and compare temperature regimes among and across the urban study watersheds and study areas (Cuffney and Brightbill, 2008).

Summary temperature statistics for annual and summer time periods were developed using temperature data collected at each site (table 3-B). Summary statistics consisted of average, minimum, maximum, range, and standard deviation. The rates of change in water temperature (degrees Celsius per hour [°C/h]) also were summarized (average, minimum, maximum, range, standard deviation, and number of observations) for 1-hour intervals. Annual degree-days also were calculated after estimating missing daily average temperature values.

Fluctuations in temperature over the annual and summer periods of record (PR) also were assessed based on the number of hourly rate-of-change values that fall within multiples of the standard deviation (SD) of rates observed over the PR. Rate values were converted to absolute values before calculating the SD over the PR and counting the number of rates that fall within six multiples of the SD for the PR ($0 \leq SD < 1$; $1 \leq SD < 2$; $2 \leq SD < 3$; $3 \leq SD < 4$; $4 \leq SD < 5$; ≥ 5 SD).

Stream Chemistry

Stream chemistry conditions were measured by collecting water samples and deploying SPMDs (Bryant and others, 2007; Sprague and others, 2007). Water samples were collected at equal-width increments across the stream channel and processed on site in accordance with standard USGS protocols (Wilde and others, 1999, 2002). Water samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. SPMDs were placed at each site in six of the study areas for a period of approximately 6 weeks during April and May 2003.

Nutrients and Pesticide Compounds

The NWQL has established two detection-level values for nutrient and pesticide analyses—a lower method detection level, which is set to avoid a false negative reading (not detecting a compound when it actually is present), and a higher reporting level to avoid a false positive reading (detecting a compound when it actually is not present). If a compound is identified at a concentration between these two levels, the result is noted with an "e" to indicate that the concentration was estimated (Childress and others, 1999). The estimated values are greater than zero but are known with less confidence than values above the reporting level. Values also may be noted as estimated when the detected concentration is outside of the calibration range for the instrument, when the average recovery for the analyte in quality-assurance samples is less than 60 percent, or when the analyte is regularly detected in laboratory blank samples. Estimated concentrations must be interpreted with caution. Values reported with a less than (<) symbol were not detected at the lower method detection level and are presented as less than the (higher) reporting limit (Childress and others, 1999).

Two chemistry datasets were created from samples collected during the synoptic water sampling, one for nutrients and other nonpesticide analytes (tables 3-C, 3-D, and 3-E) and the other for pesticide compounds (tables 3-F, 3-G, and 3-H). For each dataset, the data were summarized into three periods—a high-flow period (one sample per site; table 3-C for nutrients and table 3-F for pesticides), a low-flow period (one sample per site; table 3-D for nutrients and table 3-G for pesticides), and a multiple sample period (more than two samples collected per site; table 3-E for nutrients and table 3-H for pesticides). The following censored-data rules were applied in preparing the chemical concentration values reported in the tables. For nonpesticide constituents, half the less-than value was reported. For pesticide constituents, zero was reported for less-than values. For all estimated constituents, the values were reported. The adjusted data for each study site then were recombined into the appropriate flow and constituent spreadsheet (Sprague and others, 2007).

Several summary variables were created for pesticide compounds. The number of detections and total concentrations of different pesticide groups, such as insecticides and herbicides, were compiled. In addition, a pesticide toxicity index (PTI) was determined. The PTI combines information on exposure of aquatic biota to pesticides with toxicity estimates for multiple pesticides in each sample and produces a relative index value for a sample or stream (Munn and Gilliom, 2001). The PTI value was computed for each sample of streamwater by summing the toxicity quotients for all pesticides detected in the sample. The toxicity quotient is the measured concentration of a pesticide in a stream sample divided by the median toxicity concentration from bioassays, such as 50-percent lethal concentration (LC_{50}) or 50-percent effect concentration (EC_{50}). Separate PTI values were computed for fish, cladocerans, and benthic invertebrates by using median toxicity concentrations from Munn and Gilliom (2001) supplemented with updated toxicity data (L.H. Nowell and P.W. Moran, U.S. Geological Survey, written commun., May 13, 2005).

The PTI approach can be a useful tool for examining pesticide mixtures in streams; however, it has several important limitations that must be considered in applications to water-quality data (L.H. Nowell, U.S. Geological Survey, written commun., December 2005). First, the PTI approach assumes that toxicity is additive and combines toxicity-weighted concentrations of pesticides from multiple chemical classes without regard to mode of action. This approach does not account for synergistic or antagonistic effects. Moreover, toxicity values are based on bioassays of acute exposure and do not incorporate the effects of chronic exposure. Environmental factors that can affect bioavailability and toxicity, such as dissolved organic carbon and temperature, are not accounted for. Second, the PTI approach is limited to pesticides measured in the water column—hydrophobic pesticides may be underrepresented in terms of potential toxicity, especially to benthic organisms. Because toxicity values from different sources vary, there is considerable uncertainty in the relative toxicity of pesticides when only a few bioassays are available. The number of bioassays varied among pesticides from 1 to 165 for a given taxonomic group. Finally, not all potentially important local species were included in the bioassays. The PTI does not indicate whether water in a stream sample is toxic; however, the PTI can be used to rank or compare the relative potential toxicity of different samples or different streams.

Hydrophobic Organic Compounds

Semipermeable membrane devices (SPMD) are passive samplers that concentrate trace levels of hydrophobic organic compounds in the water column. The samplers are designed to mimic the bioaccumulation of organic compounds in the tissues of aquatic organisms. To examine concentrations of hydrophobic organic compounds over time, two 6-inch long SPMDs were placed at each site for approximately 6 weeks during the period 4–6 weeks prior to sampling invertebrates, algae, and fish in each stream (Bryant and others, 2007; table 3-I). SPMD data were not collected at the Boston and Salt Lake City study watersheds.

At the end of the 6-week deployment period, compound residues concentrated in the SPMDs were recovered, and three assays were run on the dialysates from each site—an ultraviolet (UV) fluorescence scan (Johnson and others, 2004), a Microtox® bioassay (Johnson, 1998), and a P450RGS test (Bryant and others, 2007). The UV fluorescence scan provided a semiquantitative screen for polycyclic aromatic hydrocarbons (PAH). The Microtox® bioassay measured the light production of photo-luminescent bacteria when exposed to the SPMD residues; the biochemical pathway for light production is lowered by a wide range of compounds sequestered by the SPMDs. The P450RGS test provides a rapid screen for aryl hydrocarbon receptor (AhR) compounds that include polychlorinated biphenyls (PCB), PAHs, dioxins, and furans (Ang and others, 2000). A portion of each SPMD dialysate also was sent to the NWQL for identification and quantification of the target compounds (Tom Leiker, U.S. Geological Survey, written commun., 2005). Results of the bioassays and chemical analyses also were normalized for time of exposure, because the time of exposure directly affects the concentrations in the SPMD. Bioassay values were divided by time of exposure and multiplied by 30 days. Therefore, the values reported have the appropriate units described in the respective analytical methods per 30 days of exposure. This allowed values for all endpoints to be comparable among all sites.

Habitat

Stream habitat characteristics were measured at all EUSE sites during late-summer low flows by using standard NAWQA protocols for wadeable streams (Fitzpatrick and others, 1998). Habitat data consisted of GIS-derived characteristics for stream segments upstream from the sampling location and field-based measurements collected from a sampling reach immediately upstream or downstream from the water-chemistry sampling location. Reach lengths sampled for habitat corresponded to the same reach lengths that were sampled for fish, invertebrates, and algae. Reach lengths optimally were at least 20 times the average wetted stream width and included at least one full meander bend (Leopold and others, 1964). A reach length of at least 150 m and up to 300 m was preferred for wadeable streams. For some studies, reaches were less than 150 m because of the abundance of channel modifications and road crossings in urban areas.

Segment Characteristics

A segment is a length of stream with relatively homogeneous physical, chemical, and biological characteristics (Fitzpatrick and others, 1998). The stream segment length for collecting segment data upstream from the biological sampling location was equal to approximately the log-10 distance of the watershed area (for example, the segment length for a 10-km^2 watershed is 1,000 m; for a 100-km^2 watershed, the segment length is 2,000 m). Segment data include riparian land-cover characteristics, physical characteristics (gradient and sinuosity), and the number of road crossings (table 3-J).

Reach Characteristics

Qualitative and quantitative data on channel geometry and hydraulics, streambed substrate, habitat volume and flow, habitat complexity and cover, and bank and riparian conditions were collected at 11 equally spaced transects along the sampling reach (Fitzpatrick and others, 1998). Reach habitat measurements were summarized for each reach to include minimum, maximum, and mean values, and coefficients of variation for wetted channel width, depth, velocity, and canopy cover. Minimum, maximum, and mean values were calculated for bankfull width, bankfull depth, width-to-depth ratios, bank vegetative cover and shading, and embeddedness. Measurements made at transect points were summarized for bank erosion, substrate size classes, silt covering of substrate, and habitat cover types. To facilitate comparisons of habitat characteristics among sites, average bankfull width, depth, and channel area of geomorphic channel units (riffle, run, and pool) within a reach were standardized by dividing by watershed drainage area. Morphologic indicators were used to estimate bankfull stage and included variations in bank slope and riparian vegetation, undercut banks, and substrate changes associated with point bars (Fitzpatrick and others, 1998). Bankfull data from riffle and run transects only (no pools) were used to calculate reach-averaged dimensions. Transect measurements from pool units can overestimate bankfull dimensions and were, therefore, excluded from the bankfull reach-averaged dimension calculations. Bankfull dimensions then were normalized by drainage area for consistency across the study area. Original drainage areas were smaller for some Salt Lake City streams than in other studies because of issues with a nested design and drainage-network alterations. Drainage areas based on topographic divides were additionally calculated for these streams and used for the drainage-area normalized variables.

Habitat metric and summary data were retrieved from the Habitat Data Analysis System (HDAS, version 4, M.C. Peppler, U.S. Geological Survey, written commun., 2009) for each study area (table 3-K). Several habitat metrics were calculated by HDAS to summarize channel characteristics in the sampling reach. Wetted cross-sectional area, wetted perimeter, and channel shape were calculated at each transect and summarized for the reach by using mean, minimum, and maximum values. Hydraulic conditions were summarized by calculating the mean Froude number, mean Manning's roughness, and a flow-stability index (an indicator of flashiness). Habitat volume measurements included wetted width and depth, reach area and volume, maximum depth, discharge at the time of sampling, and average velocity and coefficient of variation in velocity. Habitat-cover data were not used because many of the streams had water depths of less than 30 centimeters (cm), a limitation of the protocol for small streams selected for the EUSE study.

Raw point and transect-level data were retrieved from internal databases and used to calculate several additional metrics. Point observations of dominant substrate size (categories) were summarized into percentage of transect points with fine (sand-sized or smaller), gravel, cobble, and boulder or bedrock substrate. Other additional substrate characteristics included median particle size (D50) and percentage of embedded particles (to the nearest 10 percent). The definitions tab in the spreadsheet defines the particle-size categories. The percentage of disturbed riparian land cover within a 30-m buffer was calculated on the basis of transect endpoint description of land cover. Disturbed land cover (RipLUDis) included cropland, pasture, farmsteads, residential, commercial, or transportation. Undisturbed land cover included grassland, shrubs and woodland, or wetland. Water-surface slope (ReachSlope) was measured at reaches in eight of the nine study areas.

Additional information was collected on local channel modifications and natural controls that might affect habitat and geomorphic responses to urbanization. Using a combination of remarks on field forms, notes on field-drawn reach diagrams and maps, photographs of the reach taken during the time of sampling, topographic maps and aerial photographs, estimates were made of the percentage of the reach with bank stabilization or channelization, number of grade-control structures (weirs, low-head dams, culverts) within the reach and within a distance of one reach length upstream or downstream, presence or absence of bedrock cropping out in the channel, and presence or absence of depositional features (lateral, mid, or point bars). The degree of confidence in these techniques varied by metropolitan area, depending on the level of details included on field forms and maps and the number of field photographs (Faith Fitzpatrick, U.S. Geological Survey, written commun., 2009). The calculated values represent a minimum for each type of control (table 3-L).

Biological Communities

Biological data were collected from the stream reaches established for characterizing instream habitat. Standard NAWQA sampling protocols were used to collect algae (Porter and others, 1993, for BOS, BIR, and SLC; Moulton and others, 2002, for RAL, ATL, MGB, DEN, DFW, POR); benthic macroinvertebrates (Cuffney and others, 1993, for BOS, BIR, and SLC; Moulton and others, 2002, for RAL, ATL, MGB, DEN, DFW, POR); and fish communities (Moulton and others, 2002). Quantitative samples for the algal and invertebrate communities were composed of five subsamples from riffles with cobble and gravel substrates or woody snags. This sample was called the richest targeted habitat (RTH) sample because, in these streams, riffles were presumed to contain the richest assemblage of algae and macroinvertebrates. In the Atlanta and Dallas-Fort Worth studies, RTH samples were collected from woody debris and snags by cutting pieces of branches and scraping the surfaces into a collection container. The total area of snag samples was determined by considering each branch as a simple cylinder, calculating the area of each cylinder, and summing the areas.

Algae

Richest targeted habitat algal subsamples were collected by scraping the upper surface of cobbles collected from five riffle areas (three to five cobbles from each area) in conjunction with the collection of macroinvertebrate RTH samples. Foil templates were made of the surface areas of rocks from which the algal samples were collected, and these templates later were digitized to determine the areas sampled. For algae, an additional quantitative sample was collected from a composite of five samples from depositional targeted habitats (DTH) in areas of the stream that had little or no streamflow. These areas provide a unique habitat for algal communities that can include motile or sensitive species not found in the main streamflow areas. Depositional targeted habitat samples were collected by inverting a 47-millimeter (mm)-diameter plastic petri dish, gently pressing it into the sediment surface, sliding a spatula under the petri dish to trap the sediment, and removing the petri dish full of sediment.

Invertebrates

Richest targeted habitat macroinvertebrate subsamples consisted of Slack samples (each were 0.25 square meters [m^2]; a 500-micron mesh net was used in RAL, ATL, MGB, DEN, DFW, and POR; a 425-micron mesh was used in BOS, BIR, and SLC) from five separate riffle areas in the sampling reach and combined to form a single composite sample of 1.25-m^2 area. In addition, a qualitative multi-habitat (QMH) sample was collected, which consisted of macroinvertebrates collected from as many habitats in the stream reach as were accessible. The QMH sample was collected by using a dip net (500-micron mesh in RAL, ATL, MGB, DEN, DFW, and POR; 210-micron mesh in BOS, BIR, and SLC) supplemented with hand picking of substrates. Sampling effort (measured as time) was apportioned as equally as possible among accessible habitats in the sampling reach.

Fish

Fish communities at each site were sampled at low-flow conditions by using published protocols (Meador and others, 1993, for BOS, BIR, and SLC; Moulton and others, 2002, for RAL, ATL, MGB, DEN, DFW, POR). Two electrofishing passes were completed in each stream reach, except in SLC, where a single pass was used. Fish were identified to species and counted. Species identifications were made or verified by regional taxonomic specialists. Voucher specimens and specimens that could not be definitely identified in the field were preserved in 10-percent formalin and kept for processing and identification.

Laboratory Analysis

Aliquots of the algal RTH samples were assessed for assemblage composition, biomass as chlorophyll *a* (Chl *a*), and ash-free dry mass (AFDM). For DTH algal samples, only assemblage data were assessed. The assemblage aliquots were preserved in 5-percent buffered formalin and sent to the Academy of Natural Sciences of Philadelphia for identification and enumeration (Charles and others, 2002). The biomass aliquots from the RTH samples were filtered on 45-micron glass-fiber filters, packed in dry ice, and sent to the NWQL for analysis.

Macroinvertebrate samples were preserved in 10-percent buffered formalin and sent to the NWQL for taxa identification and enumeration. Invertebrate samples were processed by using standard NAWQA protocols (Moulton and others, 2000) for RTH (randomized 300-organism count) and QMH (fixed processing time designed to maximize the number of taxa enumerated) samples.

Data Processing

During collection, processing, laboratory analysis, or data analysis, biological samples may have been deemed unusable because of errors in collection, documentation, preservation, or other unforeseen circumstances. These samples were removed for the biological group in question and noted with ND (no data) or NC (not calculated) for the metrics in the biological files. Prior to analysis, biological datasets were examined for errors and corrected for taxonomic ambiguities. All biological data files are organized and listed in tables 4 (algal data, tables 4-A through 4-AC), 5 (macroinvertebrate data, tables 5-A through 5-AE), and 6 (fish data, tables 6-A through 6-C).

Taxonomic ambiguities arise when organisms from a particular sample or group of samples are not identified to the same taxonomic level. For example, an ambiguity occurs in a sample if some organisms are identified to genus (for example, *Hydropsyche* sp.) and some organisms are identified to species within the genus (for example, *H. sparna*, *H. betteni*). In this case, *sparna* and *betteni* are children of the ambiguous parent *Hydropsyche*. The occurrence of taxonomic ambiguities is a problem in determining taxa richness (for example, does the example presented here represent a taxa richness of 1, 2, or 3?) or in comparing the taxonomic composition of one or more samples by using techniques such as ordinations, cluster analysis, similarity indices, or diversity indices.

Ambiguities in the invertebrate data were resolved by using software specifically developed for use in the NAWQA Program—Invertebrate Data Analysis System (IDAS, version 3.9.5; Cuffney, 2003). Ambiguities in the RTH invertebrate samples were resolved by distributing the abundance of ambiguous parents among their children according to the relative abundance of each child (the distribute parents among children (DPAC) method, Cuffney and others, 2007). To create a comprehensive list of taxa present at each site, a qualitative richness dataset (QQ) was created for invertebrates and algae. This dataset consisted of a combination of all taxa found in the RTH and QMH samples for invertebrates and RTH and DTH samples for algae. Ambiguities in the QMH and QQ samples were handled by deleting the ambiguous parents (the remove parent keep child (RPKC) method, Cuffney and others, 2007) since the taxonomic information carried by ambiguous parents already resides in the children. Algal and fish data were identified consistently to species level. Consequently, there was very little ambiguity in these data. A very small number of individual fish were identified to a higher taxonomic level, and these fish were eliminated from the analysis.

Algal Response to Urbanization

Algal response at the study level was characterized in two ways. Ordination of algal data, in a multi-dimensional scaling (MDS) analysis, was used to derive site scores for the first and second axes that characterized overall assemblage structure. Algal metrics were used to characterize attributes of algal structure and function, and included composition, diversity, salinity indicators, trophic status indicators, pollution tolerance, oxygen tolerance, organic nitrogen index, pH preference, saprobity preference, motility of taxa, and biomass. These metrics are described in Porter (2008) as a comprehensive set of indicators for various changes that could occur with urbanization across the study areas. The metrics were calculated by using the Algal Data Analysis System (ADAS, version 2.4.5; T.F. Cuffney, U.S. Geological Survey, written commun., 2009). The ADAS program is a modification of IDAS for use with algae. The calculated metrics and community data for the algal samples can be found in tables 4-A through 4-AC.

Principal components analysis (PCA) was used to characterize environmental index variables associated with habitat, water chemistry, census, and a variety of watershed- and riparian-scale landscape characteristics (tables 7-A through 7-D). Spearman correlation analysis was used to determine the relative associations between algal response variables (the MDS site scores and algal metrics) and the MA-UII and between algal response variables and the environmental factors at both the watershed and the stream-reach scales (Coles and others, 2009).

Invertebrate Response to Urbanization

Calculated metrics and community data for invertebrate RTH, QMH, and QQ samples are summarized in tables 5-A through 5-AE. Several measures of invertebrate response to urbanization were calculated, including metrics and ordination-based site scores. Metrics are individual variables or combinations of variables that emphasize specific characteristics of the assemblage and are used commonly in bioassessments to reduce the complex site-by-species matrix to a few variables that are thought to have significance ecologically and(or) are indicative of water-quality changes (Barbour and others, 1999). Metrics calculated from the invertebrate and algal data were based on measures of abundance, richness, functional groups, tolerance, and indices of diversity. Invertebrate traits used in the calculation of metrics are from Barbour and others (1999) and the North Carolina Department of Environment and Natural Resources (2001).

Assessment of invertebrates responses to urban intensity was based on regressions of nonparametric multi-dimensional scaling (nMDS) ordination scores against urban intensity (MA-NUII and NUII) or correlations (Spearman rank) between urban intensity (MA-NUII) and assemblage metrics (T.F. Cuffney, U.S. Geological Survey, written commun., 2009; tables 8-A through 8-C). The association between environmental variables and invertebrate responses were determined by correlating (Spearman rank) the MDS ordination site scores with environmental variables and urban intensity (tables 8-D through 8-F) using a subset of environmental variables selected for the invertebrate sampling sites. The correspondence between MDS and correspondence analysis (CA) ordination scores were also investigated to support the use of MDS instead of the more commonly used CA (table 8-G).

Fish Response to Urbanization

Fish responses to urban intensity were based on correlations of MDS scores, species richness, and ecological species traits with urban intensity (MA-NUII; Brown and others, 2009). MDS scores were obtained from nonmetric MDS analyses of species abundances. All calculated metrics and community data for fish are summarized in tables 6-A through 6-C. Species richness is the total number of taxa collected at a site. Each of 27 fish traits (Goldstein and Meador, 2004) was scored for each species collected at a sampling site. The traits are divided into six general categories: (1) substrate preference (bedrock, boulder, cobble–rubble, gravel, sand, mud, vegetation, and variable); (2) geomorphic preference (pool, riffle, run, backwater, and variable); (3) trophic ecology (herbivores, detritivores, planktivores, invertivores, and carnivores); (4) locomotion morphology (cruisers, accelerators, maneuverers, benthic high-velocity huggers, benthic low-velocity creepers, and specialists); (5) reproductive strategy (migratory, broadcaster, simple nester, complex nester–guarder, and bearer); and (6) stream-size preference (small streams, small rivers, medium rivers, and large rivers). Each trait then was weighted by the number of individuals with the trait at each site, and the relative abundance was determined for the trait at each site.

Associations between environmental variables, including urban intensity, and fish metrics and traits were examined with Spearman rank correlations. These correlations are arranged by metropolitan study area in tables 9-A through 9-I.

Associations among all urban, hydrology, habitat, stream chemistry, algae, invertebrate, and fish variables also were examined with Spearman rank correlations. These correlations are reported, by metropolitan study area, in table 10.

Data Files

Data files are available to download in Microsoft® Excel. Tables 1–9 are version 2003 files; table 10 is a version 2007 file. Each workbook contains one or more data sheets and a sheet with variable name definitions and notes.

Summary

This report documents and summarizes physical, chemical, and biological data collected during 1999–2004 in a study of the effects of urbanization on stream ecosystems in nine metropolitan areas: Atlanta, Birmingham, Boston, Dallas-Fort Worth, Denver, Milwaukee-Green Bay, Portland, Raleigh, and Salt Lake City. The purpose of this study was to examine differences in biological, chemical, and physical characteristics of streams across a gradient of urban-development intensity. This report describes methods of data collection and processing for streamflow variability, stream temperature, instream chemistry, instream aquatic habitat, and algal, macroinvertebrate, and fish communities. The data summaries prepared for analytical use are presented in downloadable data tables.

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