Investigation of Water Quality and Aquatic-Community Structure in Village and Valley Creeks, City of Birmingham, Jefferson County, Alabama, 2000–01

By Ann K. McPherson, Thomas A. Abrahamsen, and C.A. Journey

Cover photographs— *Top:* Stream reach upstream from USGS streamgaging station 02458450 (site VIL-3). *Right:* USGS personnel collecting invertebrate samples. *Bottom left:* USGS personnel using a seine to collect fish at USGS streamgaging station 02458450 (site VIL-3). *Bottom middle:* USGS personnel sampling for fish at USGS streamgaging station 02458450 (VIL-3) using a backpack electrofisher *(photographs taken by A.K. McPherson, USGS).*

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CONVERSION FACTORS, TEMPERATURE, ABBREVIATIONS, AND ACRONYMS

Multiply	by	To obtain
Length		
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
Mass		
pound, avoirdupois (lb)	0.4536	kilogram
Volume		
gallon (gal)	3.785	liter
acre-foot (acre-ft)	1,233	cubic meter
Flow		
inch per year (in/yr)	25.4	millimeter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature: Temperature is given in degrees Fahrenheit (°F), which can be converted to degree Celsius (°C) as follows:

$$°C = 5/9 \ (°F - 32)$$

Abbreviations and Acronyms:

α	probability of a Type I error
col/100 mL	colonies per 100 milliliters
g	gram
g/kg	grams per kilogram
kg/d	kilograms per day
(kg/ha)/yr	kilograms per hectare per year
m^2	square meter
m^3	cubic meter
µg/kg	micrograms per kilogram
µg/g	micrograms per gram
µg/L	micrograms per liter

Abbreviations and Acronyms (Continued):

μm	micron
μS/cm	microsiemens per centimeter at 25 °C as measure of specific conducance
meq/L	milliequivalents per liter
mg/L	milligrams per liter
mL	milliliter
n	sample size
ADEM	Alabama Department of Environmental Management
ANOVA	analysis of variance
BHA	3-*tert*-butyl-4-hydroxyanisole
BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
DC	direct current
DDD	degradation product of DDT
DDE	degradation product of DDT
DDT	dichlorodiphenyltrichloroethane
DNOC	4,6-dinitro-2-methylphenol
DO	dissolved oxygen
DP	degradation product
E	concentration is estimated
E. coli	*Escherichia coli*
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FDA	Food and Drug Administration
GC/MS	gas chromatography/mass spectrometry
GIS	geographic information system
H	herbicide
HPLC	high-performance liquid chromatography
I	insecticide
IDAS	Invertebrate Data Analysis System
K	counts greater than or less than ideal
LN	natural log
LRL	laboratory reporting level
LT-MDL	long-term method detection limit
MCL	Maximum Contaminant Level
MRL	minimum reporting level
MRLC	multi-resolution land characteristics
NAS/NAE	National Academy of Science/National Academy of Engineering
NAWQA	National Water-Quality Assessment
NPDES	National Pollutant Discharge Elimination System
NPEO2	diethoxynonylphenol
NTU	nephelometric turbidity units
NWQL	National Water Quality Laboratory
OPEO1	monoethoxyoctylphenol
OPEO2	diethoxyoctylphenol
OT	other, exposed rock
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyl
PEL	probable effect level
RW	right-of-way
SC	specific conductance
SW	shrubs or woodland
TEPP	trace-element priority pollutants
TOC	total organic carbon
UI	urban industrial
UR	urban residential
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WY	water year (Water year is the period October 1 through September 30 and is identified by the year in which it ends.)

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ABSTRACT

The U.S. Geological Survey conducted a 16-month investigation of water quality, aquatic-community structure, bed sediment, and fish tissue in Village and Valley Creeks, two urban streams that drain areas of highly intensive residential, commercial, and industrial land use in Birmingham, Alabama. Water-quality data were collected between February 2000 and March 2001 at four sites on Village Creek, three sites on Valley Creek, and at two reference sites near Birmingham—Fivemile Creek and Little Cahaba River, both of which drain less-urbanized areas. Stream samples were analyzed for major ions, nutrients, fecal bacteria, trace and major elements, pesticides, and selected organic constituents. Bed-sediment and fish-tissue samples were analyzed for trace and major elements, pesticides, polychlorinated biphenyls, and additional organic compounds. Aquatic-community structure was evaluated by conducting one survey of the fish community and in-stream habitat and two surveys of the benthic-invertebrate community. Bed-sediment and fish-tissue samples, benthic-invertebrates, and habitat data were collected between June 2000 and October 2000 at six of the nine water-quality sites; fish communities were evaluated in April and May 2001 at the six sites where habitat and benthic-invertebrate data were collected. The occurrence and distribution of chemical constituents in the water column and bed sediment provided an initial assessment of water quality in the streams. The structure of the aquatic communities, the physical condition of the fish, and the chemical analyses of fish tissue provided an indication of the cumulative effects of water quality on the aquatic biota.

Water chemistry was similar at all sites, characterized by strong calcium-bicarbonate component and magnesium components. Median concentrations of total nitrogen and total phosphorus were highest at the headwaters of Valley Creek and lowest at the reference site on Fivemile Creek. In Village Creek, median concentrations of nitrite and ammonia increased in a downstream direction. In Valley Creek, median concentrations of nitrate, nitrite, ammonia, organic nitrogen, suspended phosphorus, and orthophosphate decreased in a downstream direction. Median concentrations of *Escherichia coli* and fecal coliform bacteria were highest at the most upstream site of Valley Creek and lowest at the reference site on Fivemile Creek. Concentrations of enterococci exceeded the U.S. Environmental Protection Agency criterion in 80 percent of the samples; concentrations of *Escherichia coli* exceeded the criterion in 56 percent of the samples. Concentrations of bacteria at the downstream sites on Village and Valley Creeks were elevated during high flow rather than low flow, indicating the presence of nonpoint sources. Surface-water samples were analyzed for chemical compounds that are commonly found in wastewater and urban runoff. The median number of wastewater indicators was highest at the most upstream site on Valley Creek and lowest at the reference site on Fivemile Creek. Concentrations of total recoverable cadmium, copper, lead, and zinc in surface water exceeded acute and chronic aquatic life criteria in up to 24 percent of the samples that were analyzed for trace and major elements. High concentrations of trace and major elements in the water column were detected most frequently during high flow, indicating the presence of nonpoint sources. Of

the 24 pesticides detected in surface water, 17 were herbicides and 7 were insecticides. Atrazine, simazine, and prometon were the most commonly detected herbicides; diazinon, chlorpyrifos, and carbaryl were the most commonly detected insecticides. Concentrations of atrazine, carbaryl, chlorpyrifos, diazinon, and malathion periodically exceeded criteria for the protection of aquatic life.

Trace-element priority pollutants, pesticides, and other organic compounds were detected in higher concentrations in bed sediment at the Village and Valley Creek sites than at the reference site on Fivemile Creek. Bed-sediment concentrations of chromium, copper, lead, mercury, and silver were highest at the most upstream site on Valley Creek; and concentrations of cadmium, nickel, selenium, and zinc were highest at the second downstream site on Village Creek. Bed-sediment concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc from the Village and Valley Creek sites exceeded median concentrations observed nationwide. Concentrations of cadmium, selenium, and zinc were highest in fish-liver tissue samples collected from the second downstream site on Village Creek—concentrations of copper and mercury in fish-liver samples were highest at the most downstream site on Village Creek.

The highest total concentration of organic compounds detected in bed-sediment samples occurred at the most upstream site on Valley Creek and the lowest total concentration occurred at Fivemile Creek. In Village Creek, concentrations of 75 percent of the detected organic compounds increased in a down-stream direction; in Valley Creek, concentrations of about 70 percent of the detected organic compounds decreased in a downstream direction. Concentrations of 10 organic compounds in bed-sediment samples, including chlordane and *p,p*'-DDE, exceeded levels considered harmful to aquatic organisms at sites on Village and Valley Creeks. Concentrations of dieldrin, chlordane, and polychlorinated biphenyls in fish-tissue samples exceeded National Academy of Science/ National Academy of Engineering guidelines for the protection of fish-eating wildlife.

Fish and benthic-invertebrate community structure differed between Village and Valley Creeks and the reference streams. Multiple lines of evidence, including the richness and density of benthic invertebrates as well as fish-community structure, indicate that the aquatic community in Village Creek is similar to that of Valley Creek, but that the integrity of the aquatic communities in both creeks is poor in comparison to that observed at the two reference sites.

The abundance of mayflies and the number of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa (two well-known indicators of good water quality) were negatively correlated with industrial land use. The abundance of midges (an indicator of poor water quality) was positively correlated with industrial land use—and midge density was positively correlated with commercial land use, providing additional evidence that these streams have been negatively affected by urbanization in the basins. The percentage of mosquitofishes (a tolerant species) was positively correlated with commercial land use. In contrast, the numbers of fish species, fish families, and the percentage of sunfishes (intolerant species) were positively correlated with forested land use, indicating that the more diverse fish communities were found in basins with a higher percentage of forested land. The concentrations of 12 water-quality constituents (including several nitrogen species, chloride, copper, and molybdenum, and the detection frequency of wastewater indicators) and 18 organic compounds detected in bed sediment were positively correlated with industrial land use. Mercury and molybdenum concentrations detected in fish-liver tissue also were positively correlated with industrial land use. Bed-sediment and water-quality constituents that were found to have significant correlations with land use often were found to be correlated with many biological indicators, further supporting the link between increased urbanization and changes in aquatic-community structure.

The water quality and aquatic-community structure in Village and Valley Creeks are degraded in comparison to streams flowing through less-urbanized areas. Low community richness and increased density of certain species within the fish and benthic-invertebrate communities indicate that degradation has occurred during an extended period of time. Decreased diversity in the aquatic communities and elevated concentrations of trace elements and organic contaminants in the water column, bed sediment, and fish tissues at Village and Valley Creeks are indicative of the effects of urbanization. The degree of degradation may be related to point and nonpoint sources of contamination originating within the basins. Industrial land use, in particular, was significantly correlated to elevated contaminant levels in the water

column, in bed sediment, in fish tissue, and to the declining health of the benthic-invertebrate communities. The results of the 16-month study have long-range watershed management implications, demonstrating the association of urban development and stream degradation. These data can serve as a baseline from which to determine the effectiveness of stream-restoration programs.

INTRODUCTION

Birmingham, the most populated city in Alabama, is located in Jefferson County in the north-central part of the State (fig. 1). Covering more than 163 square miles (mi^2), the city had a population of nearly 243,000 in 2000 (U.S. Census Bureau, 2001). Once the South's foremost industrial center, supporting iron and steel production, Birmingham has developed diverse commercial and industrial enterprises including chemical, manufacturing, and medical businesses. As a result, this intensely urbanized area now contains numerous industrial and municipal point and nonpoint sources of contamination that influence the water quality in several stream basins draining the city, including Village Creek and Valley Creek.

The Alabama Department of Environmental Management (ADEM) has classified some creeks that
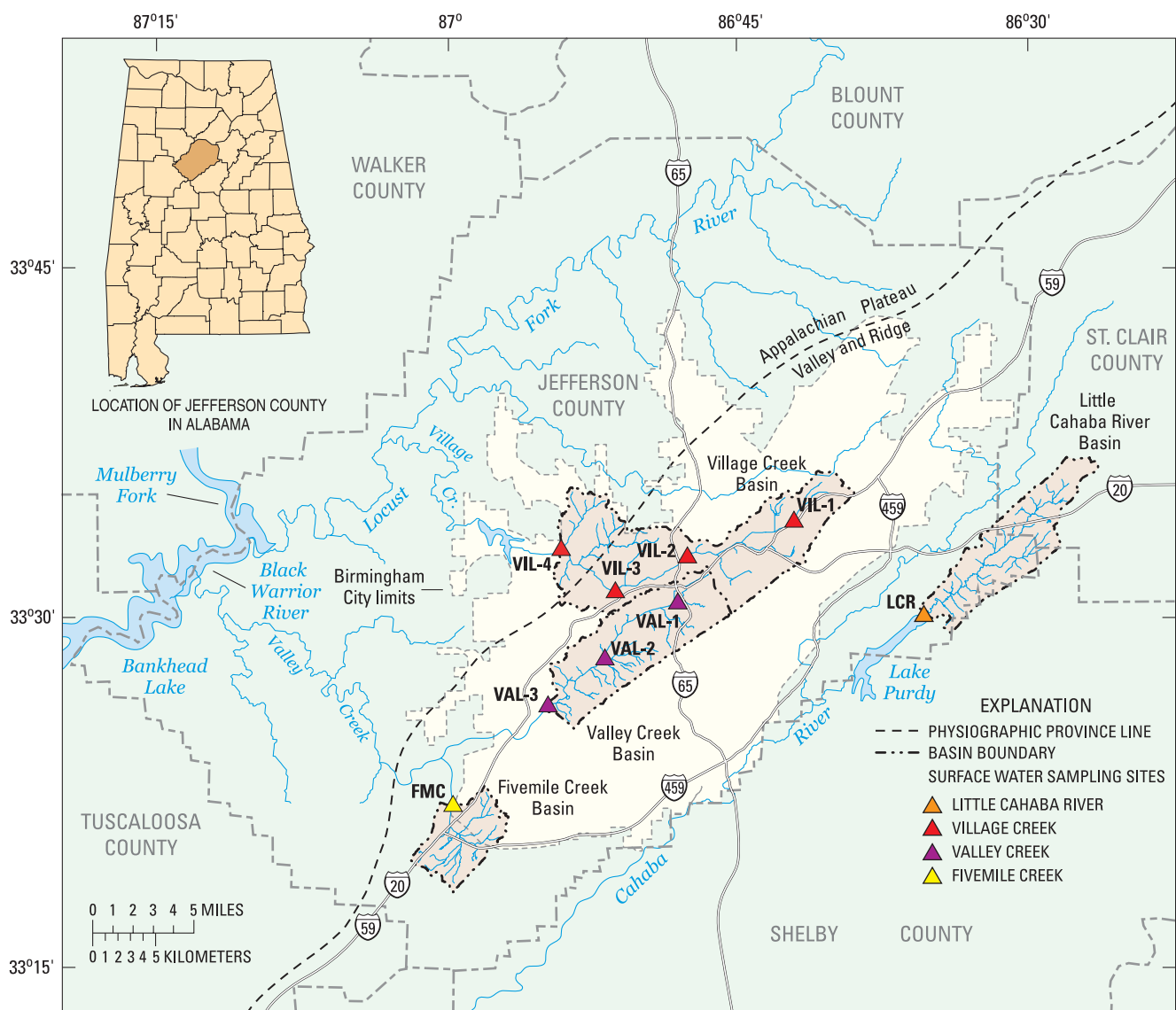
Figure 1. Locations of sampling sites and physiographic provinces in the Birmingham area, Jefferson County, Alabama.

drain portions of the Village Creek and Valley Creek watersheds as impaired due to poor water-quality conditions (Alabama Department of Environmental Management, 1998). Removal of riparian vegetation and the channelization of streams have altered aquatic habitat availability by changing the natural flows and temperatures in these streams. Point-source discharges, surface runoff, and sewer overflows (combined storm and sanitary) have been reported by ADEM as sources of contamination that degrade water quality, habitat, and biological communities in Village and Valley Creeks by contributing metals, nutrients, pathogens, silt, organic compounds, and oxygen-demanding compounds. In-place contaminants (that is, persistent contaminants in bed sediment that continually leach to the environment) and periodic chemical spills also have been attributed to the overall impairment of water quality in these two urban streams.

In an effort to address water-quality problems and flooding in these stream basins, the U.S. Army Corps of Engineers (USACE), in cooperation with the City of Birmingham, is conducting a feasibility study of the restoration of stream watersheds in Birmingham, called the Birmingham Watersheds Project. The project objective is to implement stream management zones in the floodplains of Village and Valley Creeks, as well as other strategies to reduce flood damage, improve water quality, and restore the urban ecosystems in these watersheds.

Before the effectiveness of these proposed management strategies and restoration efforts can be assessed, however, sufficient water-quality, aquatic-habitat, and biological community data are needed to define current conditions in the two urban watersheds. In response to this need, the U.S. Geological Survey (USGS), in cooperation with the USACE, initiated a 16-month multidisciplinary study to assess spatial information on the chemical, biological, and physical properties characterizing baseline water-quality and aquatic-ecosystem conditions in Village and Valley Creeks.

Assessing water quality at varying temporal and spatial scales and understanding the effects of urbanization on stream ecosystems reflects one of the priorities of the USGS National Water-Quality Assessment (NAWQA) Program. NAWQA is designed to evaluate water-quality conditions and factors affecting water quality on a national and regional basis. The results of this study when combined with other NAWQA studies from across the Nation will provide resource managers and interested partners with a better understanding of how ecosystems respond to land-use changes associated with urbanization, and how these responses vary across a range of environmental settings.

Purpose and Scope

The purpose of this report is to present the results of a 16-month study that assessed water-quality conditions, aquatic-community structure, habitat, and bed-sediment and fish-tissue data collected from Village and Valley Creeks, two urban streams draining parts of Birmingham, Alabama. The natural and anthropogenic characteristics of each watershed are described, including the major land-use types present in each watershed. Water quality is described over a range of flow conditions, and the extent to which point and nonpoint sources influence water quality based on low-flow/high-flow conditions, respectively, is presented for nutrients, bacteria, and trace elements. The structure of the fish and benthic-invertebrate communities is compared among sites sampled in the watersheds.

During this investigation, water-quality and ecological data were examined in an upstream-downstream order to identify spatial differences in water quality. Data from urban stream sites were compared to data from less-urbanized reference sites to evaluate the effects of urbanization on water quality. Statistical and graphical analyses of selected land-use, chemical, sediment, and biological data were used to provide a general assessment of current (2000–01) conditions at the selected stream sites.

Data used to characterize water quality and aquatic biota were collected during the period from February 2000 through May 2001. Specifically, stream water-quality data—including major ions, nutrients, trace elements, pesticides, selected organic constituents, and fecal bacteria—were collected from February 2000 through February 2001, with one additional sample collected in March 2001. Aquatic-community structure was evaluated by conducting one survey of fish communities and in-stream habitats, and two surveys of the invertebrate communities. Bed-sediment, fish-tissue, benthic-invertebrate, and habitat data were collected between June and October 2000. Fish communities were evaluated in April and May 2001. Data from this investigation will provide information for planners and resource managers to use in selecting appropriate restoration options, and provide a baseline from which to determine the effectiveness of future stream restoration programs.

Study Sites

During the initial phase of the study (December 1999 through February 2000), field reconnaissance was conducted to select representative sampling sites in the watersheds (fig. 1; table 1). Sites were selected based on land-use characteristics in the drainage area of each watershed (table 2). Seven sampling sites, draining areas of highly intensive residential, commercial, and industrial land use, were identified on Village and Valley Creeks (VIL-1, VIL-2, VIL-3, VIL-4, and VAL-1, VAL-2, VAL-3, respectively). For comparison with the urban sites, two reference sites (FMC and LCR) were identified on nearby creeks (Fivemile Creek and Little Cahaba River, respectively) where commercial, industrial, and residential activities are limited. These reference sites were selected because both drain less-urbanized areas, thereby minimizing urbanization effects on water quality, and yet the natural physical features characterizing the reference sites (such as climate, geology, and hydrology) are similar to the urban sites in the study area. In this report, study area refers to those portions of each watershed upstream from the most downstream sampling site. For example in Valley Creek, the study area is defined as the area upstream from VAL-3, the most downstream sampling site (fig. 1).

The sampling network on Village Creek and the reference site on Little Cahaba River were adjusted after initial sampling and data review. Water-quality data were collected from urban site VIL-4 on Village Creek and reference site LCR on Little Cahaba River between March and July 2000. Urban site VIL-2 on Village Creek and reference site FMC on Fivemile Creek were added to the sampling network in August 2000, and were sampled throughout the remainder of the study period.

Reference site FMC replaced site LCR and site VIL-2 replaced site VIL-4. Site FMC was selected to replace site LCR as the reference site because of the absence of municipal discharges and reduced influence from urbanization at FMC. Although site FMC had similar characteristics to site LCR with respect to basin size and geology, the degree of urbanization was less. Site VIL-4 was replaced in the study by site VIL-2 for the following reasons: (1) VIL-4 was located directly downstream from a large wastewater-treatment plant, (2) the site was located outside the area of consideration for stream restoration efforts, (3) VIL-4 was geologically different from the other urban sites in Village Creek, and (4) the habitat at site VIL-4 differed substantially from other sites for biological sampling. Site VIL-2 was selected to replace VIL-4 because VIL-2 was situated in

Table 1. Description of surface-water sites selected for water-quality and biological sampling in the Birmingham area, Alabama, 2000–01

[USGS, U.S. Geological Survey; mi^2, square mile; —, none]

Site label (fig. 1)	USGS station number[a]	Station name	Site location		Drainage area (mi^2)	Period of continuous record	
			Latitude	Longitude		Streamflow	Water quality
VIL-1	02458150	Village Creek at Eastlake Park in Birmingham	33°34'06"	86°43'31"	4.89	1998–2001[b]	2000–2001[b]
VIL-2	02458300	Village Creek at 24th Street at Birmingham	33°32'33"	86°49'03"	26.0	1988–2001	—
VIL-3	02458450	Village Creek at Avenue W at Ensley	33°31'03"	86°52'45"	33.5	1975–1979 1988–2001	1991–2001
VIL-4	02458600	Village Creek near Docena	33°32'53"	86°55'53"	52.2	1996–2001	1996–2001
VAL-1	02461120	Valley Creek at 5th Avenue and 7th Street in Birmingham	33°26'07"	86°56'15"	4.94	—	—
VAL-2	02461200	Valley Creek at Cleburn Avenue near Powderly	33°28'08"	86°53'18"	20.1	—	—
VAL-3	02461300	Valley Creek at U.S. Highway 11 at Birmingham	33°26'07"	86°56'15"	30.0	—	2000–2001
LCR	02423400	Little Cahaba River near Jefferson Park	33°29'59"	86°36'51"	24.4	1986–2000	—
FMC	02461670	Fivemile Creek at Freeman Avenue near McCalla	33°21'49"	87°01'09"	13.0	—	—

[a] USGS station number is based on geographic location and the downstream order of streamflow.

[b] Continuous record monitored upstream from site VIL-1 at station 02458148.

Table 2. Land-use characteristics in the watersheds of sampling sites in the Birmingham area, Alabama

[Data from the 1992 Multi-Resolution Land Characteristics coverage (U.S. Environmental Protection Agency, 1992a)]

Site label (fig. 1)	Land use, in percentage of basin								
	Agriculture	Forest	Urban land-use categories				Total urban (computed)	Mines and quarries	Undefined or transitional
			Commercial	Industrial	Residential	Transportation			
VIL-1	0	9.5	19.4	0.4	64.3	6.2	90.3	0.1	0.1
VIL-2	0	14.4	13.9	19.7	45.4	4.3	83.3	0	2.3
VIL-3	0	14.0	12.4	22.9	42.9	4.3	82.5	1.7	1.8
VIL-4	.6	24.1	10.0	17.3	42.5	2.9	72.7	2.0	.6
VAL-1	0	6.8	42.9	21.3	20.4	5.8	90.4	0	2.8
VAL-2	0	12.2	22.4	10.6	51.0	3.0	87.0	0	.8
VAL-3	1.2	15.3	19.0	9.0	51.3	2.0	81.3	1.7	.5
LCR	15.5	49.6	4.5	2.4	26.0	1.1	34.0	.9	0
FMC	21.0	47.1	3.3	2.8	19.9	5.5	31.5	0	.4

an area considered for stream restoration, and because the site is geologically similar to sites VIL-1 and VIL-3.

Sites VIL-1, VAL-2, and FMC also are part of the national NAWQA Land-Use Gradient Study, currently (2000–01) being conducted in Alabama. The Land-Use Gradient Study is part of a national focus by the USGS to investigate the effects of urbanization on water quality and stream biota across the Nation.

Previous Investigations

Little information has been published on the water quality of Village and Valley Creeks. Every other year, the ADEM provides to Congress a 305(b) report on the water quality of rivers, streams, lakes, and ground water in Alabama. In the most recent reports, ADEM indicated that Village Creek was nonsupportive of its agricultural and industrial water-supply classification because of elevated concentrations of metals, nonpriority organics, and ammonia (Alabama Department of Environmental Management, 1998, 2000a). Organic enrichment, high dissolved-oxygen concentrations, high pH, and siltation problems also were listed as impairments to water quality in Village Creek (Alabama Department of Environmental Management, 1998, 2000a). Various sources for these contaminants have been identified by ADEM, including industrial and municipal discharges, urban runoff and storm sewers, and abandoned mining operations.

A number of scientific studies have been conducted to investigate the environmental factors influencing the watersheds of Village and Valley Creeks and other streams in Jefferson County. Several reports have been published that describe the geologic structure, stratigraphy, and lithology of the Jefferson County area

(Newton and Hyde, 1971; Thomas, 1972; Kidd and Shannon, 1977, 1978; Kidd, 1979; Geological Survey of Alabama, 1981). Descriptions of ground-water resources in the Jefferson County area are provided in reports by Knight, 1976; Moffet and Moser, 1978; Planert and Pritchett, 1989; and Hunter and Moser, 1990. The travel time of solutes in Village Creek was investigated in a report published by the Geological Survey of Alabama (Tucker, 1979).

In 1991, Congress appropriated funds for the USGS to begin the NAWQA Program, which is an ongoing assessment of water-quality conditions in the Nation's surface-water and ground-water resources and the effects of land use on these resources. One component of the NAWQA Program is to determine the effects of urbanization on stream water quality and ecosystem health. Results of NAWQA studies for selected river basins throughout the United States have been summarized in national synthesis reports, including descriptions of the occurrence of pesticides (Larson and others, 1998; Gilliom and others, 1999; Hoffman and others, 2000; Hopkins and others, 2000) and nutrients in surface- and ground-water resources (Puckett, 1994; Mueller and others, 1995; Mueller and Helsel, 1996; Fuhrer and others, 1999; Clark and others, 2000), and the presence of organic compounds and trace elements in bed sediment and fish tissue (Wong and others, 2000). Strong correlations have been identified between the degree of urbanization in a watershed and the extent of biological impairment (McMahon and Cuffney, 2000). The following section briefly summarizes the complex relation between urbanization and aquatic-community structure.

Effects of Urbanization on Aquatic Communities

The distribution of benthic invertebrates and fish in surface water is influenced by natural and human factors that affect water quality and habitat. Activities related to urbanization can modify watershed characteristics and influence patterns of runoff into streams. Several recent studies have contributed to the documentation of disruptive effects of urbanization on stream hydrology and ecology (Booth, 1990; Richards and Host, 1994; Finkenbine and others, 2000; Wang and others, 2000). Aquatic biota can be used as indicators of water quality. Walsh and others (2001) determined that the composition of benthic-invertebrate communities is a sensitive indicator of urban effects, and that urban density appears to be a key factor in the degradation of benthic-invertebrate communities.

Urbanization can promote increased loadings of nutrients, pesticides, heavy metals, and other contaminants to streamwater and bed sediment. Such contaminants can have significant detrimental effects on invertebrate and fish communities (Wang and others, 2000). Walsh and others (2001) studied urban streams with severely degraded benthic-invertebrate communities and speculated that the efficient transport of contaminants into receiving streams by storm-water drainage was a causative factor. External anomalies on fishes—including sores, lesions, and tumors—also can result from increased loadings of contaminants.

Detrimental effects of contaminants include lethal and sublethal toxicity. Lethal effects include those that kill organisms quickly (acute toxicity) and those that kill over a longer period of time (chronic toxicity). Sublethal effects also can be devastating to individual organisms and species. A behavioral deviation caused by damage to the nervous system—for example, damage caused by exposure to methyl mercury—can prevent an organism from mating or from locating food. Lethal and sublethal toxicity may result in a decrease in richness, which can be followed by an increase in the density of one or more tolerant species. Other effects of urbanization can be more indirect, such as the reduction of a nutrient source or the death of a food organism.

An increase in the amount of impervious area in an urban environment may cause frequent changes in flow and rapid fluctuations of water levels, which can lead to a reduction in biodiversity. For example, greater stream velocity during peak flow can remove established habitat that normally provides resources and shelter for fish and other organisms (Finkenbine and others, 2000). Likewise, more frequent and intense flooding can interfere with the life-cycle activities of aquatic organisms (Booth, 1990). Low base flow also can be detrimental to aquatic communities. As urbanization increases, the amount of area available for ground-water recharge decreases, resulting in low base flow at certain times of the year (Finkenbine and others, 2000), which can interfere with breeding cycles by stranding fishes and exposing eggs of aquatic insects to desiccation.

Construction activities and removal of riparian vegetation have been found to adversely affect stream biota by increasing the sediment load in streams (Waters, 1995). As sediment in the water column settles to the bottom, it fills interstitial spaces and may prevent the attachment of primary producers, such as intolerant algal taxa, leading to a reduction in species richness. The negative effects of sediment on stream biota can persist for years (Richards and Host, 1994). Alternatively, removal of riparian plants can lead to an increase in the amount of sunlight that reaches a stream, improving conditions for the growth of algae and aquatic plants.

WATERSHED CHARACTERISTICS

Causes of water-quality and aquatic-community degradation in urban watersheds can be difficult to identify because of the diversity of potential contamination sources and land-use activities. This complicated relation among land-use activities, water quality, and aquatic biota in a watershed requires an integrated approach designed to identify those factors that negatively affect a stream ecosystem. Natural environmental factors in a watershed influence water quality, aquatic habitat, community structure, and flow regime. These natural factors include climate, geology, latitude, longitude, altitude, and basin morphology. Anthropogenic factors, however, can have greater influence on the ecosystem of a stream than natural conditions. Industrial or municipal discharges, combined sewer overflows, runoff from parking lots, removal of riparian cover, and channel or flow modifications can

alter stream hydrology, affect water quality, and influence the aquatic-community structure.

Birmingham has a temperate climate. Summers are characterized by warm, humid weather with frequent thunderstorms. Monthly mean temperatures range from 41.5 degrees Fahrenheit (°F) in January to 79.8 °F in July (National Oceanic and Atmospheric Administration, 1999, 2000). Annual rainfall averages about 55 inches per year (in/yr) and is fairly well distributed throughout the year (National Oceanic and Atmospheric Administration, 2001a). Most of the rainfall during the summer is from scattered afternoon and early evening thunderstorms, but rainfall during the winter and spring tends to be of longer duration and is usually associated with frontal systems. October generally is the driest month of the year with less than half the mean precipitation typically observed in March (fig. 2). During this study, precipitation amounts recorded in Birmingham from May through October 2000 were the lowest on record. Year-end precipitation amounts were 4.5 inches below normal.

The Village Creek and Valley Creek watersheds are located in two physiographic provinces—the Appalachian Plateau and the Valley and Ridge (fig. 1; Sapp and Emplaincourt, 1975). Fivemile Creek, Little Cahaba River, and the upper watersheds of Village and Valley Creeks are located in the Valley and Ridge Physiographic Province. Therefore, to ensure consistent geologic and topographic features between reference sites

and urbanized sites, the focus of this study was on sites located only within the Valley and Ridge Physiographic Province.

The Valley and Ridge Province consists of a series of parallel, northeast-trending ridges and valleys formed by faulted, folded, and eroded rocks. Resistant sandstone units form the ridges, and more easily eroded carbonate or shale units form the valleys through which the streams flow (Kidd and Shannon, 1977). These sandstone, carbonate, and shale units consist of Paleozoic rocks that range in age from early Cambrian to early Pennsylvanian. The areally extensive geologic units that crop out in the watershed are carbonates of Cambrian to Ordovician age (Kidd and Shannon, 1977). Stream drainage in the study area is aligned in a northeast-southwest trend and exhibits a rectangular pattern, demonstrating the strong influence of geologic structure on hydrology in the Valley and Ridge Province (fig. 1).

Altitudes in the Village and Valley Creek watersheds range from 397 feet (ft) above sea level (121 meters [m]) in the valleys to 1,250 ft above sea level (381 m) on the ridges (U.S. Geological Survey, 1993). Relief is greatest in Village Creek watershed, ranging from about 600 ft (183 m) in the headwaters to a little more than 800 ft (244 m) at the physiographic boundary. Valley Creek watershed has relief that ranges from about
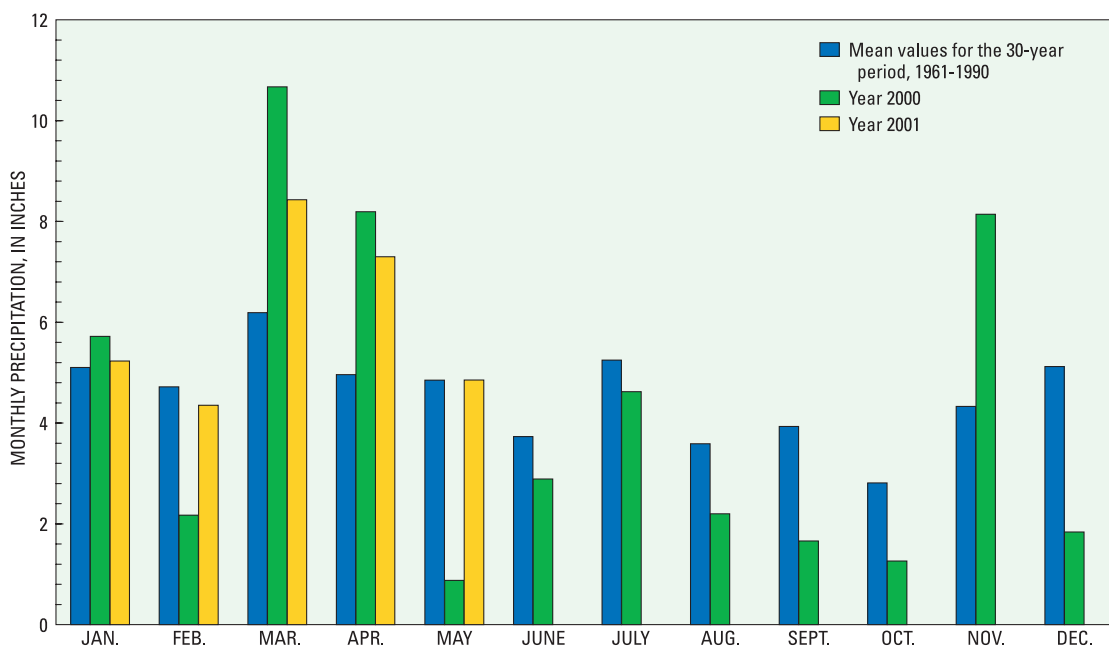
Figure 2. Mean monthly precipitation for the 30-year period (1961–1990) and monthly precipitation (January 2000–May 2001) at the Birmingham International Airport, National Weather Service, Birmingham, Alabama (National Oceanic and Atmospheric Administration, 2001a, 2001b).

470 ft (143 m) in the headwaters to about 630 ft (192 m) at the physiographic boundary. The watersheds of the less-urbanized sites (FMC and LCR) have relief of about 300 and 690 ft (91 and 210 m), respectively.

Major soil associations were surveyed in Jefferson County by the U.S. Department of Agriculture, Natural Resource Conservation Service; and a county map of the major soil associations was published based on the survey (Spivey, 1982). The Nauvoo fine sandy loam and the Montevallo-Nauvoo association are the most predominant soil associations in the watersheds of Village and Valley Creeks. The Nauvoo fine sandy loam is the predominant soil association in the Little Cahaba River watershed. The Townley-Nauvoo complex and the Sullivan-State complex are the most predominant soil associations in the Fivemile Creek watershed.

Birmingham is situated in the Southwestern Appalachian Ecoregion, classified by Omernik (1987) as an oak (*Quercus*), hickory (*Carya*), and pine (*Pinus*) mesophytic forest with an associated grouping of maples (*Acer*), tulip trees (*Liriodendron*), and lindens (*Tilia*). Ecoregions are areas in which the effects of human activities, environmental resources, and conditions can be recognized initially by their distinctive vegetation patterns, which are a reflection of soil type, climate, rainfall, and human activities. The principal land uses in the Southwestern Appalachian Ecoregion are forest, woodland, cropland, and pasture.

Land Use in the Watershed

Land use in the study area is characterized by extensive areas of urbanization that include industrial, commercial, municipal, and residential activities (table 2). These land uses can be sources of both point and(or) nonpoint pollution, which affect water quality in the streams. Fertilizers and pesticides applied in residential and commercial areas can run off into streams during storm events or migrate through the soil into ground water, which ultimately discharges to nearby streams. Exhaust from vehicles and storm runoff from parking lots and roadways can contribute trace elements and organic compounds present in diesel fuel, gasoline, motor oils, and hydraulic fluid. Heavily commercialized or industrialized areas can contribute trace metals, motor oils, polycyclic aromatic hydrocarbons (PAH), solvents, bacteria, and nutrients either by direct discharge into the stream (point source) or by storm runoff (nonpoint source). Elevated levels of bacteria, ammonia, detergents, and by-products of human waste can enter a stream by combined sewer overflows during storm events and by leaking sewer lines during dry periods. Municipal

discharges of treated wastewater also can be the sources of high levels of bacteria, nutrients, and biochemical oxygen demand (BOD).

The 1992 Multi-Resolution Land Characteristics (MRLC) map was used to quantify land-use characteristics in the selected watersheds of Village and Valley Creeks and in the watersheds of the reference sites, FMC and LCR. The MRLC is a digital coverage (30-m resolution) of LANDSAT satellite imagery of major land use and land cover (U.S. Environmental Protection Agency, 1992a). The total urban land use within a watershed was considered to be the sum of the industrial, commercial, high- and low-intensity residential, and transportation land-use categories within the MRLC coverage (table 2). Forested land use includes the sum of the deciduous, evergreen, and mixed-forest categories in the MRLC; agriculture is the sum of row crops, pastures, and hay categories.

Urbanization accounts for about 73 and 81 percent of the land use in the Village Creek watershed at VIL-4 and in the Valley Creek watershed at VAL-3, respectively (figs. 3, 4; table 2). Residential land use represents about half of the urbanization in both watersheds—about 43 percent at VIL-4 and 51 percent at VAL-3. The Village Creek watershed is more heavily industrial than the Valley Creek watershed, and the Valley Creek watershed has the greatest percentage of commercial activities. Forested land covers only about 24 and 15 percent of the Village Creek and Valley Creek watersheds, respectively; agricultural land covers about 1 percent of each watershed (table 2).

The reference sites on the Little Cahaba River and Fivemile Creek were selected because they were located in less-urbanized areas than the sites along Village and Valley Creeks. The watersheds of the reference sites are predominantly forested—about 50 percent of LCR and 47 percent of FMC, respectively (table 2; figs. 5, 6). However, these reference sites are not considered pristine, because they are influenced by human activities. Agricultural land use covers about 16 and 21 percent of the LCR and FMC watersheds, respectively. Urban land use constitutes about 34 and 32 percent of the LCR and FMC watersheds, respectively; of these urban totals, industrial and commercial activities combined represent less than 10 percent (table 2).

The headwaters of Village Creek to VIL-1 are influenced by a greater percentage of residential and commercial land use than the more downstream sites of VIL-2 and VIL-3 (table 2; figs. 3, 7). The percentage of industrial land use increases downstream from VIL-1 to VIL-3. The headwaters of Valley Creek to VAL-1 are influenced by a greater percentage of industrial and
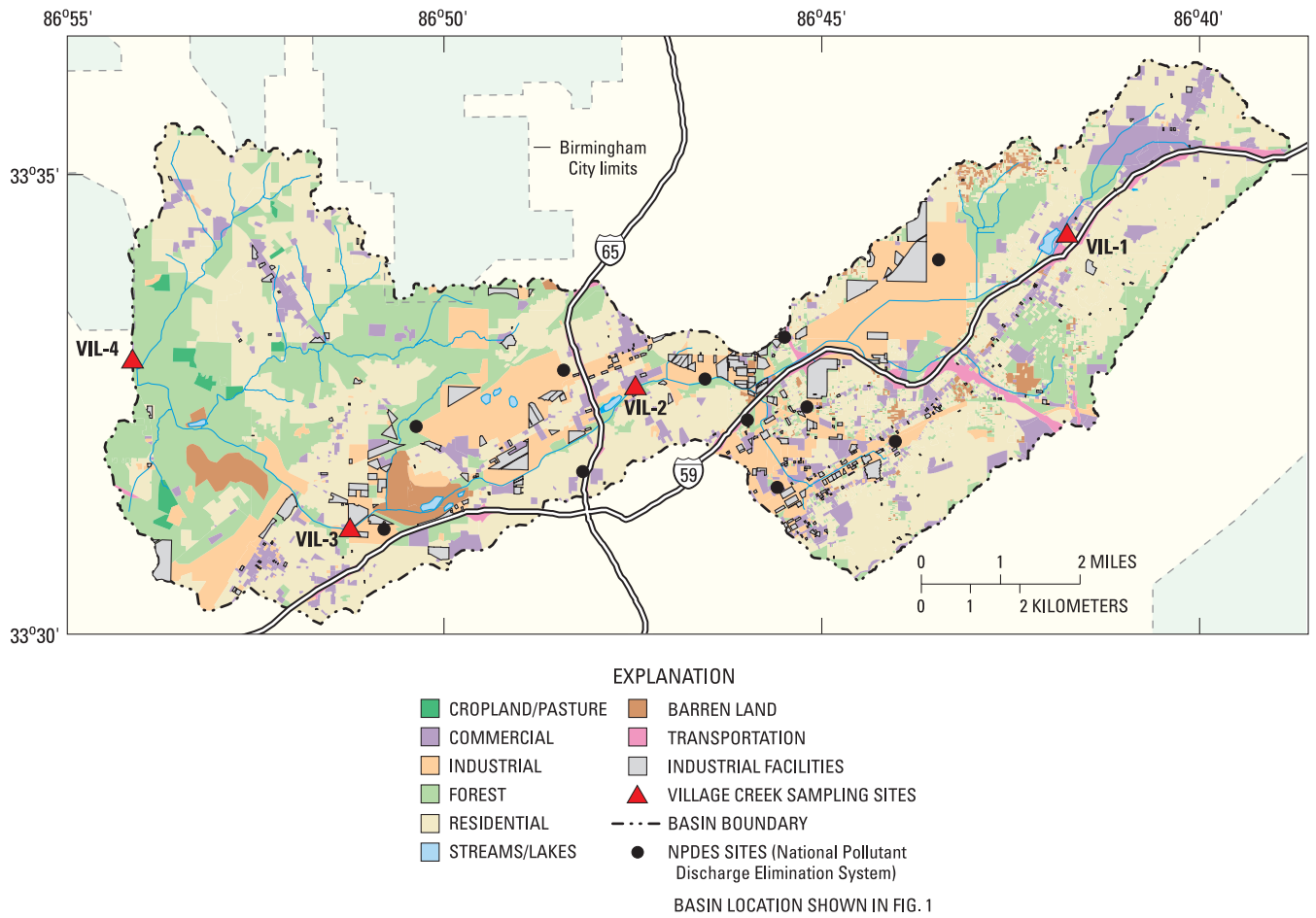
Figure 3. 1992 Multi-resolution land characteristics in the Village Creek watershed, Birmingham, Alabama.
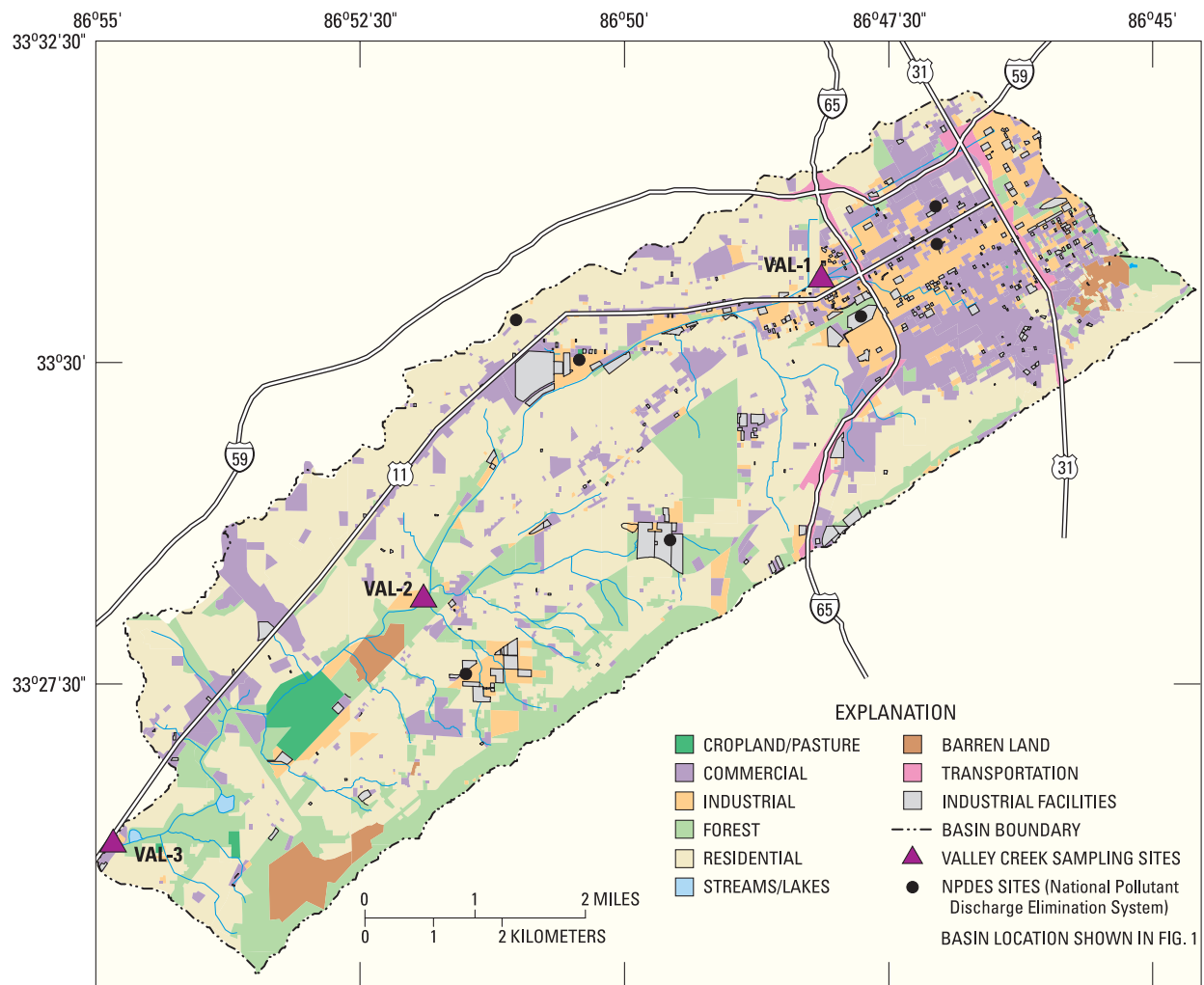
Figure 4. 1992 Multi-resolution land characteristics in the Valley Creek watershed, Birmingham, Alabama.
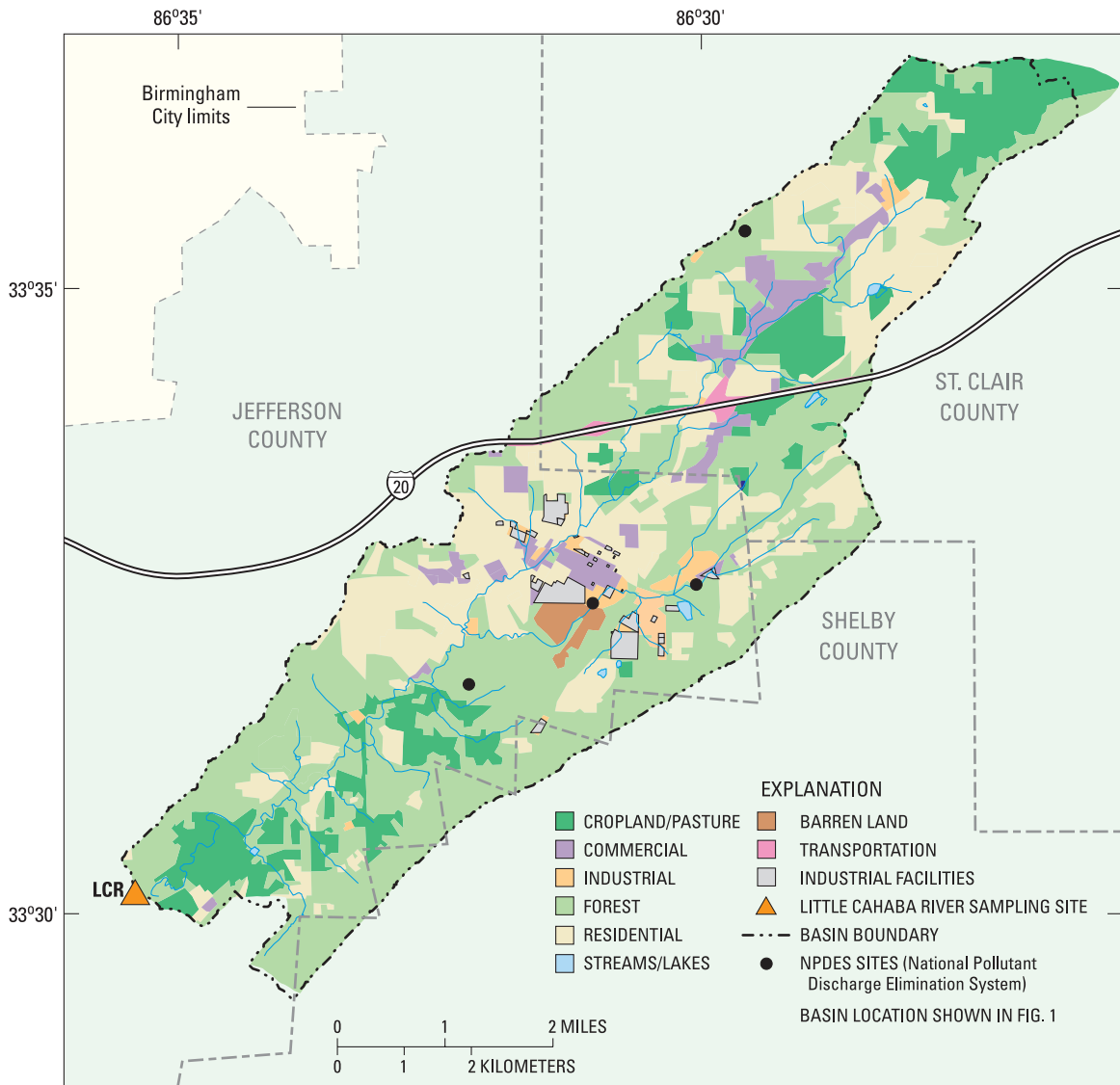
Figure 5. 1992 Multi-resolution land characteristics in the Little Cahaba River watershed, Jefferson County, Alabama.
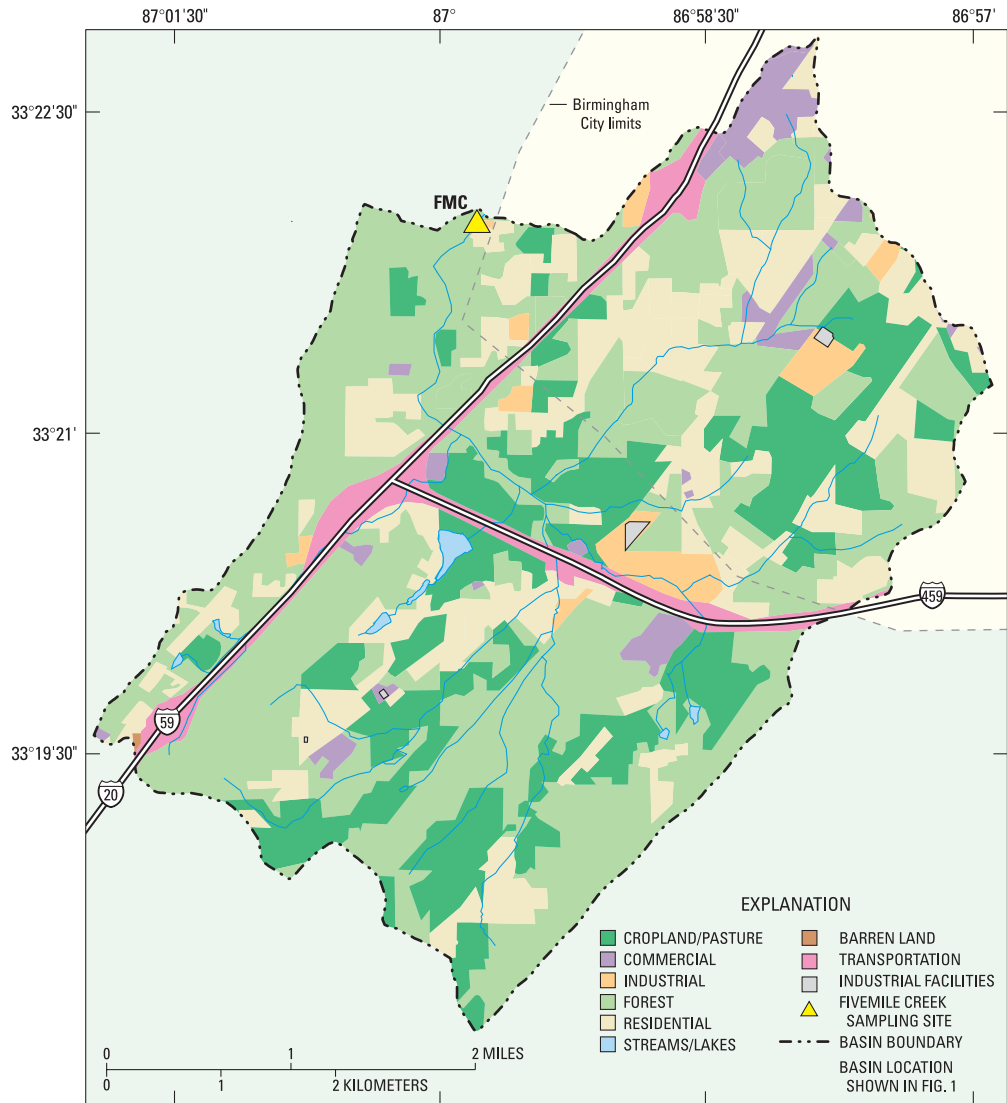
Figure 6. 1992 Multi-resolution land characteristics in the Fivemile Creek watershed, Jefferson County, Alabama.
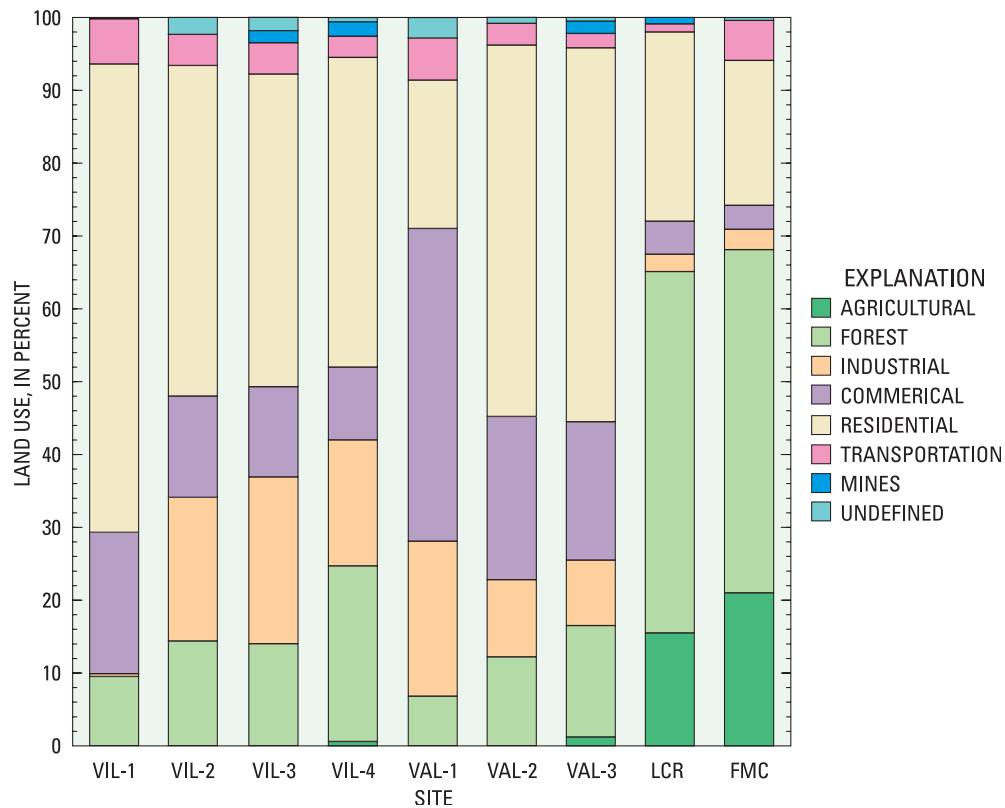
Figure 7. Land use in the watersheds of sampling sites in the Birmingham area, Alabama (U.S. Environmental Protection Agency, 1992a).

commercial land use than the more downstream sites of VAL-2 and VAL-3 (table 2; figs. 4, 7). The percentage of residential land use increases downstream from VAL-1 to VAL-3. The percentage of commercial land use decreases downstream in both watersheds. The Valley Creek watershed at VAL-1 is influenced by a greater percentage of commercial and industrial land-use activities (about 64 percent) compared to the Village Creek watershed at VIL-1 (about 20 percent; table 2).

Population density is considered to be a good indicator of urbanization within a watershed. Digital coverages of population data for Jefferson County for 1970–90 were used to compute the population density in the watersheds of the sampling sites (table 3) (U.S. Census Bureau, 2001). The reference sites (LCR and FMC) had a much lower population density throughout the 20-year period than the more urbanized sites (table 3). Of the two urbanized watersheds (Valley and Village), subbasins on Valley Creek had nearly twice the

Table 3. Population changes (1970–90) in the watersheds of sampling sites in the Birmingham area, Alabama

[Data from the U.S. Census Bureau digital coverage (2001); mi^2, square mile]

Site label (fig. 1)	Drainage area (mi^2)	Population			Population density, per square mile		
		1970	1980	1990	1970	1980	1990
VIL-1	4.89	7,868	8,199	11,462	1,609	1,677	2,344
VIL-2	26.0	68,615	71,474	66,752	2,639	2,749	2,567
VIL-3	33.5	86,284	89,877	80,622	2,583	2,691	2,414
VIL-4	52.2	108,940	113,481	109,401	2,087	2,174	2,096
VAL-1	4.94	25,185	26,242	20,905	5,098	5,312	4,232
VAL-2	20.1	84,585	88,107	91,822	4,208	4,383	4,568
VAL-3	30.0	121,265	126,319	120,152	4,042	4,211	4,005
LCR	24.4	8,148	8,485	13,557	334	348	556
FMC	13.0	7,178	8,019	4,162	552	617	320

population density of the sites on Village Creek. From 1980 to 1990, population density decreased at most sites, with the exception of LCR, VIL-1, and VAL-2, which showed small increases.

Mining has played a key role in the history and development of Birmingham. The three basic raw materials necessary to produce steel are iron ore, coal, and limestone. All three of these materials occur in close proximity to Birmingham. Approximately 63 percent of the land surface in Jefferson County is underlain by coal (Geological Survey of Alabama, 1981). Iron ore was mined until 1974 from the Red Mountain Formation, which contains several seams of hematite iron ore. Limestone and dolomite are quarried at several different locations in the valley. Specifically, mines and quarries cover about 2 percent of the watersheds of Village and Valley Creeks at each of the most downstream sites (VIL-4 and VAL-3) in the study area (table 2). Coal mining activity accounts for only a percentage of the overall mines and quarries. However, exposure of coal and iron ore at the surface can contribute trace elements and acidity to streams during weathering, and movement of oxidized water through surface and subsurface mines can leach trace elements from coal into the ground water (Knight and Newton, 1977).

Hydrology

Urbanization influences the hydrology of streams in several ways. As the amount of impervious surface area in a watershed increases, the amount and velocity of runoff to streams increases (Dunne and Leopold, 1978), causing rapid increases in water level and velocity in streams during storm events. Urbanization often results in channel modification, causing higher flows during storms and frequent flooding. Long-term continuous streamflow monitoring provides hydrologic data that can be used to determine the effects of urbanization on the hydrology of streams over time.

Daily streamflow data have been collected at some USGS streamgaging stations in Village and Valley Creeks since 1975 (table 4). Two of the long-term record stations, Village Creek at Avenue W (VIL-3) and Valley Creek near Bessemer (downstream from VAL-3), had mean annual streamflow for the period of record (1975–79, 1988–2000) of 82.4 and 131 cubic feet per second (ft^3/s), respectively (Pearman and others, 2001). The region was experiencing drought conditions when samples were collected for this study. The effects of the drought were evident in the mean annual streamflow for water years[1] 1999 and 2000 at the long-term record stations on Village and Valley Creeks (table 4). At the VIL-3 gaging station, the mean annual streamflow for the 2000 water year was 14 percent lower than the mean annual streamflow for the period of record. The lowest daily mean streamflow (9.4 ft^3/s) at this site for the period of record was recorded in September 2000. At the Valley Creek near Bessemer station, located downstream from VAL-3, mean annual streamflow was 19 percent lower than the mean annual streamflow for the period of record (1975–79, 1988–2000). The lowest daily mean streamflow at this site for the 2000 water year was 25 ft^3/s, recorded in September 2000, which was almost equal to the lowest

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[1] A water year is defined as the period October 1–September 30, and is identified by the year in which it ends.

Table 4. Mean annual streamflow at selected continuous-record stations on Village and Valley Creeks, Birmingham, Alabama

[mi^2, square mile; WY, water year is defined as the period from October 1 to September 30 and is identified by the year in which it ends; ft^3/s, cubic feet per second; data from Pearman and others, 2001]

Location relative to surface-water sampling site (fig. 1)	Station number	Station name	Drainage area (mi^2)	Period of record (WY)	Mean annual streamflow (ft^3/s)		
					Period of record	1999 WY	2000 WY
Upstream from VIL-1	02458148	Village Creek at 86th Street North at Roebuck	4.1	1998–2000	7.32	7.86	6.79
VIL-2	02458300	Village Creek at 24th Street at Birmingham	26	1988–2000	52.9	52	48.3
VIL-3	02458450	Village Creek at Avenue W at Ensley	33.5	1975–79; 1988–2000	82.4	73.3	71.2
VIL-4	02458600	Village Creek near Docena	52.2	1996–2000	161	152	155
Downstream from VAL-3	02461500	Valley Creek near Bessemer	52.5	1975–79; 1988–2000	131	111	106

daily mean for the period of record (23 ft³/s), recorded in August 1988 (Pearman and others, 2001).

The mean monthly streamflow at the long-term stations, VIL-3, and the station downstream from VAL-3, was computed for the period of record (1975–79, 1988–2000; fig. 8A). Monthly mean streamflow is the arithmetic mean of the individual daily mean discharges during a month. The monthly mean streamflow for specific months during the sampling period for this study was compared to the mean monthly streamflow computed for the period of record at these two sites. For most months during the sampling period, the monthly mean streamflow was less than the mean monthly streamflow as represented by the negative departures (differences)
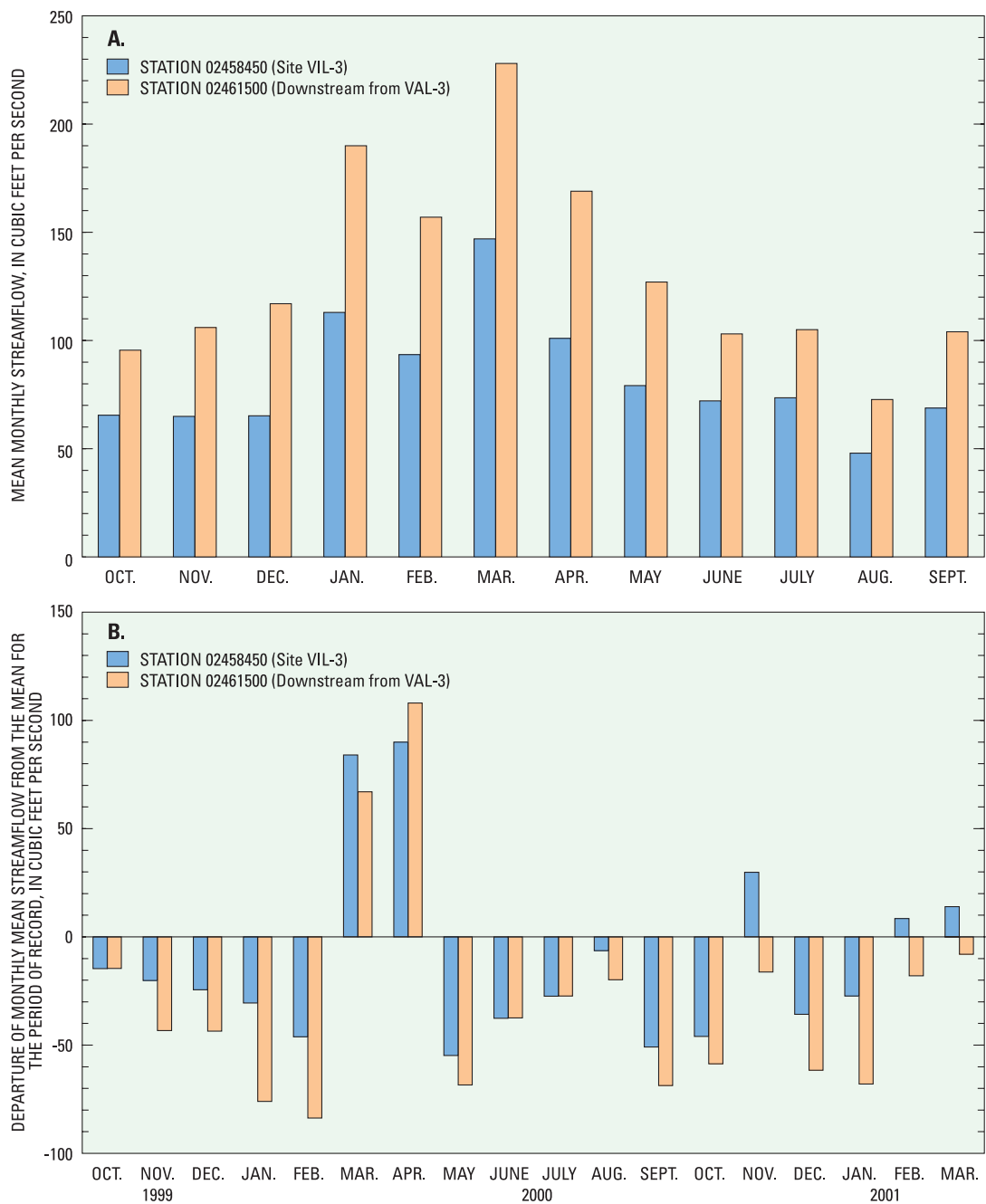
Figure 8. (A) Mean monthly streamflow and (B) departure of monthly mean streamflow from the mean for the period of record (1975–79 and 1988–2000) at U.S. Geological Survey streamgaging stations 02458450 (VIL-3) and 02461500 (downstream from VAL-3) in Birmingham, Alabama.

shown in figure 8B. The exceptions were March and April 2000.

APPROACH

An integrated approach is needed to assess the effects of land use on water quality. Bed sediment, fish-tissue, aquatic-community structure, and water chemistry are environmental indicators that represent stream conditions at differing time scales. Water samples represent water quality at the time of sample collection. Benthic invertebrates can integrate water-quality conditions over a span of many weeks to year(s) and the fish-community structure can indicate stream conditions over many years (Wynn and others, 2001). Because of these varying time scales, it is important to interpret the sampling results for these water-quality indicators within the context of spatial and temporal scales of condition and response.

Authors of previous studies have concluded that both bed-sediment and fish-tissue samples are required for a complete assessment of the occurrence and distribution of trace elements (Wynn and others, 2001). Many constituents, such as trace elements and organic compounds, may be present in water but commonly are at concentrations that are difficult to quantify. These constituents are more likely to be detectable or even elevated in other sample media such as bed sediment, due to the tendency of some contaminants to adsorb onto small particles or bioaccumulate in the tissues of aquatic organisms.

Another important aspect is the condition of the hydrologic system at the time of sampling. Surface-water samples were collected over a wide range of flow conditions, including low flow and high flow, in an attempt to characterize the water quality during varying hydrological conditions. High flow was defined to include samples collected during an actual storm (rising limb and[or] peak of the hydrograph), as well as samples collected directly after a storm (on the falling limb of the hydrograph). If the sample was collected after the stream returned to pre-storm levels, then the sample was not considered to be a high-flow sample. Of the 14 high-flow samples, 2 were collected on the rising limb, 5 were collected at the peak of the hydrograph, and 7 were collected on the falling limb. Concentrations of contaminants from nonpoint sources typically increase during a storm as a result of overland runoff, but concentrations of contaminants from point sources may decrease during a storm as a result of dilution. By understanding the hydrologic condition at the time of sampling and reviewing the data in this context, the

influence of point and nonpoint source contributions of contaminants on water quality can be examined.

This study was designed to assess the current conditions of Village and Valley Creeks by using three specific approaches: (1) water-quality, bed-sediment, fish-tissue, and aquatic-community structure data were collected from sites on Village and Valley Creeks and compared with data from two less-urbanized sites (LCR and FMC) to evaluate the effects of urban land use on water quality; (2) sites along Village and Valley Creeks were evaluated in an upstream-downstream order to assess which sites were most affected by specific constituents; and (3) water-quality data collected during low and high flow at each site were examined to assess the potential source(s) of contaminants.

Data-Collection Methods

The data-collection methods used during this study for water quality, bed sediment, fish tissue, aquatic communities, and stream habitat are described in this section. Field methods and laboratory methods are discussed.

Water-Quality Samples

Surface-water samples were collected during the period February 28, 2000, through February 14, 2001. Additional samples were collected at VIL-1, VAL-2, and FMC in May 2000 and at FMC in March 2001 as part of the USGS NAWQA Program. The frequency of sampling varied at different sites (table 5), primarily due to the modification of site selection in August 2000. Samples were not collected at FMC in October 2000 because the stream was dry. Each surface-water sample was analyzed for nutrients, major ions, total organic carbon (TOC), wastewater indicators, and fecal bacteria. Sampling for other constituents, such as trace elements, pesticides, PAHs, 5-day biochemical oxygen demand (BOD_5), and chlorophyll a and b was less frequent. Samples for BOD_5 and chlorophyll a and b analysis were shipped to the USGS Ocala Water Quality and Research Laboratory in Ocala, Florida. All other water samples were shipped to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for analysis.

Continuous water-quality monitors, installed at two sites on Village Creek (VIL-3 and VIL-4) before this study was initiated, provided a continuous record of water temperature, specific conductivity, and dissolved oxygen for the period between March 2000 and March 2001. In conjunction with this study, additional monitors were installed upstream from VIL-1 and at VAL-3, and

Table 5. Sampling type and frequency of water-quality and biological constituents at sites in the Birmingham area, Alabama, 2000–01

[NAWQA, National Water-Quality Assessment Program; BOD$_5$, 5-day biochemical oxygen demand; GC/MS, gas chromatography/mass spectrometry; HPLC, high-performance liquid chromatography; PCBs, polychlorinated biphenyls]

Site label (fig. 1)	NAWQA land-use gradient site	Field properties[a], nutrients[b], major ions[c]	BOD$_5$[a]	Chlorophyll a and b[a]	Enterococci[a]	Escherichia coli[a]	Fecal coliform[a]	Wastewater indicators[d]	Total organic carbon[a]	Trace and major elements[e]	Pesticides (GC/MS)[f]	Pesticides (HPLC)[f]	Polycyclic aromatic hydrocarbons[g]
								Type and frequency of water-quality sampling					
VIL-1	yes	12	5	6	9	12	11	10	10	6	6	6	4
VIL-2	no	7	6	7	7	7	7	7	7	4	3	3	3
VIL-3	no	10	7	7	8	9	9	10	10	5	3	4	3
VIL-4	no	3	0	0	2	3	3	3	3	2	1	1	1
VAL-1	no	10	6	6	8	10	10	10	10	6	5	5	6
VAL-2	yes	11	6	7	9	11	10	10	10	6	4	4	5
VAL-3	no	10	6	6	9	10	10	10	10	6	4	4	4
LCR	no	3	0	0	2	3	3	3	3	2	2	2	2
FMC	yes	8	7	7	6	8	7	6	5	4[h]	5	5	2

Site label (fig. 1)	NAWQA land-use gradient site	Bed sediment trace and major elements[i]	Bed sediment pesticides and other organic compounds[j]	Fish (liver tissue) trace and major elements[k]	Fish (whole body) pesticides and PCBs[l]	Habitat survey[m]	Benthic invertebrate community survey[n]	Fish community survey[o]
		Type and frequency of biological sampling						
VIL-1	yes	1	1	1	1	1	2	1
VIL-2	no	1	1	1	1	0	0	0
VIL-3	no	1	1	1	1	1	2	1
VIL-4	no	0	0	0	0	0	0	0
VAL-1	no	1	1	1	1	1	2	1
VAL-2	yes	1	1	1	1	1	2	1
VAL-3	no	0	0	0	0	0	0	0
LCR	no	0	0	0	0	1	2	1
FMC	yes	1	1	1	1	1	1	1

[a] See appendix table 2-2.
[b] See table 8.
[c] See appendix table 2-1.
[d] See appendix table 2-3.
[e] See table 15.
[f] See table 16 and appendix table 2-4.
[g] See appendix table 2-5.
[h] For mercury only, the sample size was 3.
[i] See appendix table 3-1.
[j] See table 22
[l] See table 24.
[m] See table 25.
[n] See appendix tables 3-2 and 3-3.
[o] See appendix table 3-4.

turbidity probes were added to the monitors at VIL-1, VIL-3, and VAL-3. All four measurements were recorded at VIL-1 and VIL-3 between April 2000 and February 2001; all four measurements were recorded at VAL-3 between June 2000 and February 2001.

Data-collection procedures, which conformed to standard USGS protocols (Wilde and others, 1999), included equal-width increment sampling (Shelton, 1994). Equal-width increment sampling produces a composite sample that is representative of flow in a cross section. Most water samples were collected by using a DH-81 sampler (Edwards and Glysson, 1999). Storm samples were not flow-weighted composite samples taken at specific intervals, as described in a U.S. Environmental Protection Agency (USEPA) sampling guide (U.S. Environmental Protection Agency, 1992b); instead, the storm samples were discrete. Field measurements of stream discharge, air temperature, water temperature, pH, dissolved oxygen, and specific conductance were made at the time of sampling.

A Teflon cone splitter and bottles were used to composite and split the water samples into separate sample bottles for various analyses. After splitting, water samples for dissolved nutrients and major ions were filtered by using a 0.45-micron (μm) pore size filter that was pre-rinsed with deionized water and native streamwater. Samples for dissolved pesticide analyses were filtered by using a 0.7-μm pore size glass-fiber filter. Wastewater indicator samples and PAH samples were collected as grab samples directly from the stream in 1-liter (L) glass bottles. Samples were preserved and chilled immediately after filtration and shipped overnight to the USGS laboratories in Denver and Ocala. Pesticide samples were analyzed by using gas chromatography/ mass spectrometry (Zaugg and others, 1995) or high-performance liquid chromatography (Werner and others, 1996). All equipment that was used to collect and process samples was cleaned with a 0.2-percent nonphosphate detergent and rinsed with tap water and deionized water. Equipment was rinsed with a solution of 5-percent hydrochloric acid followed by deionized water if metals were sampled. A rinse of pesticide-grade methanol was added if organic compounds were sampled.

Water samples for analysis of fecal-indicator bacteria were processed in the field by USGS personnel for fecal coliform, *Escherichia coli* (*E. coli*), and enterococci (U.S. Environmental Protection Agency, 1997). Samples were collected by using an autoclaved 1-L polyethylene bottle with the DH-81 sampler. Samples were treated with a solution of 10-percent sodium thiosulfate to counteract the effects of residual chlorine in the water and processed within 6 hours of collection by membrane filtration techniques, as described in the USGS National Field Manual (Myers and Wilde, 1999). Results were reported as colonies per 100 milliliters (col/100 mL).

Bed-Sediment Samples

Bed-sediment samples were collected in October 2000 at VIL-1, VIL-2, VIL-3, VAL-1, VAL-2, and FMC to determine the concentration of trace and major elements. Sediment samples were collected from the upper 3 centimeters (cm) of fine sediment in depositional areas of each stream reach following the protocols described in Shelton and Capel (1994). Several samples were collected from each of five depositional areas, composited, and homogenized by mixing. The composited material was processed through a 0.063-millimeter (mm) mesh nylon screen. Samples were sent to the NWQL for analyses of trace and major elements.

The NWQL analytical procedure for trace and major elements in bed sediment uses multi-acid digestion and inductively coupled plasma-mass spectrometry techniques. Results are reported in micrograms of analyte per gram dry weight of sediment, or as a percentage of dry weight (Briggs and Meier, 1999). This method provides a total extractable metals concentration that includes mineral-bound metals. Nine major elements—including aluminum, calcium, iron, magnesium, phosphorus, potassium, sodium, sulfur, and titanium—were reported as a percentage of dry weight. Concentrations of total carbon, organic carbon, inorganic carbon, and 36 trace elements were reported in concentrations as microgram(s) per gram (μg/g) of bed sediment (dry weight). Trace elements are defined as elements that usually occur in concentrations less than 1,000 μg/g (Forstner and Wittmann, 1979). Ten trace elements—arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc—are classified as priority pollutants (Code of Federal Regulations, 1996) because in low concentrations they are toxic to aquatic organisms; however, some of these trace elements are necessary for metabolic processes in aquatic organisms.

A subsample of the composited bed-sediment material, collected before the remainder was processed through the screen, was analyzed for particle-size composition at the USGS Cascades Volcano Observatory Laboratory in Vancouver, Washington, by using a sand-only procedure (Guy, 1969). The sand-only analysis was used to determine the percentage of bed-sediment material that was less than 0.063 mm in diameter. Particulate size is important in understanding the concentration and distribution of trace element in the

environment because trace elements tend to adsorb onto the fine particulates of bed sediment (Horowitz, 1991).

Sediment samples from six sites were analyzed for the presence of organochlorine pesticides, chlorpyrifos, six other organophosphate pesticides, and other organic compounds. Initial sample collection for the analysis of pesticides and other organic compounds was the same as for the trace elements. However, aliquots of the homogenized mixture were processed through a 2-mm mesh stainless steel sieve, placed in a methanol-washed glass container, and preserved on dry ice for transport to the NWQL. The NWQL analytical procedure for organics in bed sediment includes dual capillary-column gas chromatography with electron-capture detection. Results are reported in microgram(s) of analyte per kilogram of the wet weight of the sediment (Foreman and others, 1995).

Fish-Tissue Samples

Fishes were collected in October 2000 at six sites coincident with bed-sediment sample collections. The fishes were collected by use of a backpack mounted, DC-powered electrofishing unit following NAWQA protocols (Meador and others, 1993). The targeted fish species was the longear sunfish (*Lepomis megalotis*) because of its reported abundance and feeding habits. However, fish collections at the FMC site failed to yield enough longear sunfish to provide adequate liver tissue. Therefore, bluegill sunfish (*Lepomis macrochirus*) also were collected. The longear sunfish was not captured at VIL-1, so the bluegill sunfish was used for tissue assessment at that site. Fish-tissue samples were taken from the targeted species and processed in accordance with NAWQA protocols (Crawford and Luoma, 1993).

Fishes were processed on site for two types of tissues, liver and whole-body tissue minus the livers. Tissue samples from the two species of fishes collected from FMC were composited and submitted to NWQL as a single sample. For analysis of trace-element concentrations, the livers of at least five individuals from each site were removed by use of a ceramic knife and Teflon forceps, weighed, placed in acid-cleaned glass containers, preserved with dry ice, and shipped overnight to the NWQL. In the laboratory, tissue samples were processed by nitric acid and hydrogen peroxide digestion. Acid-processed samples were dried, reconstituted with a 5-percent nitric acid solution, and filtered. The filtrate was diluted to a specific volume. The analysis of fish-liver tissue for concentrations of trace elements was conducted by using inductively coupled plasma/mass spectrometry or inductively coupled plasma/atomic emission spectroscopy for all trace elements except

mercury. Procedures for mercury analysis incorporate cold vapor atomic absorption spectrophotometry (Olson and DeWild, 1999). All results were reported as dry weight, total recoverable concentrations in microgram(s) of analyte per gram of tissue, as detailed by Hoffman (1996).

For the analyses of organochlorine pesticides and polychlorinated biphenyls (PCBs), the remainder of each fish (whole body minus the liver) was wrapped in aluminum foil and preserved with dry ice. The fish tissues were shipped overnight to the NWQL and analyzed for organochlorine pesticides by capillary-column gas chromatography with electron-capture detection (Leiker and others, 1995). Successful detection of organic compounds and the levels of detection can vary from site to site because of the inherent variability of biological tissues. Results are reported as microgram(s) of analyte per kilogram of tissue (μg/kg), wet weight. Values reported with a "less than" symbol (<) are considered to be nondetections. Values reported with an "E" are considered to be estimates because definitive quantification was not possible. Estimated values are considered to approximate actual values for the purpose of comparative evaluations and statistical analysis.

Aquatic-Community Samples

Benthic invertebrates and fishes were collected following procedures outlined in Cuffney and others (1993) and Meador and others (1993), respectively. The health of these organisms is often directly related to changes in water quality and habitat. Changes in the composition of an aquatic community and functional changes in the ecosystem can result from exposure to contaminants, changes in the riparian zone, or changes in the hydrology of the aquatic system. For example, changes in the numbers and types of algae and aquatic plants due to exposure to herbicides or nutrients, may result in changes in the numbers and types of aquatic organisms that use them for shelter and resources. Benthic invertebrates occupy diverse functional niches in aquatic ecosystems. They recycle organic matter, consume smaller organisms, and are important components in the diet of fishes. Benthic invertebrates are commonly used to assess the health of aquatic communities because they are easy to collect and identify, usually abundant, and relatively sessile (Merritt and Cummins, 1996).

Benthic-invertebrate samples were collected at VIL-1, VIL-3, VAL-1, VAL-2, FMC, and LCR. One collection was made at each of six sites in June 2001. A second collection was made at the same sites in October 2000, except at FMC, where the stream was dry. All samples of benthic invertebrates were sent to the NWQL

for taxonomic evaluation and determination of benthic-invertebrate density, as described in Moulton and others (2000).

Quantitative samples of benthic invertebrates were collected from five riffle habitats at each site by using a 0.25 square meter (m^2) Slack sampler with a 425-μm mesh net (Cuffney and others, 1993) and then composited into one sample (1.25 m^2 total area). The quantitative collection provided an estimate of aquatic invertebrate richness and density in the targeted habitat. Qualitative samples were collected from all accessible habitat types at each site by using a D-frame net (210-μm mesh) and by hand-picking invertebrates from rocks and other substrates. The qualitative collection further characterizes the invertebrate taxa present throughout the sampling reach.

Fishes were collected in April and May 2001 at the same six sites. The primary fish-collection device was a backpack-mounted, DC-powered electrofishing unit. Two passes were made along the stream reach. Stunned fishes were netted and placed in a collection bucket. At the completion of the first pass, the collected fishes were identified, weighed, measured (standard length and total length), and evaluated for anomalies such as lesions, tumors, parasites, and eroded fins (Meador and others, 1993). Once processing was completed, the fishes were placed in a holding container to prevent them from returning upstream and being recaptured during the second pass. The second pass was made along the length of the reach and the fishes were processed in a like manner. Additional collections of fishes were made with a seine at VIL-1, VIL-3, VAL-2, and LCR to capture species that might have eluded the shocking effort. Fishes captured by seining were processed in the same manner as those captured by electrofishing. Seine collections at VAL-1 were impractical because of shallow depth and obstructions.

Fishes that could not be readily identified at each site were preserved in 10-percent buffered formalin and were sent to the USGS laboratory at the Florida Caribbean Science Center in Gainesville, Florida, for identification. All remaining fishes were released unharmed to the stream when processing was completed.

Stream-Habitat Characterization

Measures of habitat conditions and structure are important components of any ecological study. Several measures of biological condition are related to stream habitat (Fitzpatrick and others, 1998). For example, removal of trees from the riparian zone during construction may cause increased amounts of solar radiation to reach a stream's surface. Increased sunlight may lead to an increase in the number of photosynthetic organisms, such as algae and plants, which can influence the density of organisms that use them for food and shelter. The amount of infrared radiation that reaches a stream's surface can have a direct influence on the invertebrate community. Invertebrate emergence periods are often regulated by water temperature, and the effects of temperature influence the distribution patterns of aquatic insects (Ward, 1992).

Aquatic insects are closely associated with the bed material of the stream in which they live, at least for a portion of their lives. Bed substrate provides food, shelter, and habitat space. Therefore, the type of substrate in a stream influences the abundance and distribution of aquatic insects (Minshall, 1984). The size of substrate particles, the amount of organic material in and on the substrate, and the stability and texture of the substrate have been found to be of ecological importance (Ward, 1992; Allen, 1995).

Habitat assessments were made at six sites (VIL-1, VIL-3, VAL-1, VAL-2, LCR, and FMC) following the protocols described in Fitzpatrick and others (1998). Stream reaches ranging in length from 150 to 349 m were sampled. Within each reach, habitat characteristics were measured at 11 transects. A transect is an imaginary line across the stream, oriented perpendicular to stream flow. The first and last transect defined the start and end, respectively, of the stream reach. Transects were established at approximately equidistant intervals along each reach, and the habitat characteristics of at least seven points along each transect were evaluated. The points included the left and right edges of the water, three or more sites in the stream that corresponded to the thalweg (the deepest part of the channel) and one location on each side of the thalweg, and one or more points on each bank.

Three collection points in the wetted channel were made along each of the 11 transects resulting in a total of 33 collection points. Observations and measurements within the reaches and along the transects included many physical characteristics of the stream channel, quantitative evaluation of riparian-zone shading, and the amount and type of geomorphic channel units (runs, pools, riffles) in each stream reach (Fitzpatrick and others, 1998).

Data Analysis and Review

This section includes data analysis and review for water quality, bed sediment, fish tissue, aquatic communities, and stream habitat in the study area. Specific methods used to interpret data, including graphical and statistical presentation, are discussed.

Water-Quality Data

Methods used to interpret water-quality results in this report include various graphical tools and statistical methods. Graphical tools include the use of bar charts, which illustrate the speciation of certain nutrients (nitrogen and phosphorus) and the frequency of detection for other constituents (trace and major elements, wastewater indicators, pesticides). Box plots are used to display the variability in nutrient concentrations, and high-flow/low-flow figures are used to illustrate the concentrations of different constituents, as well as the hydrologic condition at the time of sampling. Only detected values (including estimated concentrations) are shown on the high-flow/low-flow figures—non-detections are not shown. If the concentrations detected during low flow were consistently higher than those during high flow, a "P" was placed on the graph, indicating point sources. If the concentrations detected during high flow were consistently higher than those during low flow, an "NP" was placed on the graph, indicating nonpoint sources. If the results were mixed, a "B" was placed on the graph, indicating that both point and nonpoint sources may be contributing. No symbols were placed on sites if this designation could not be made from the available data, such as at LCR, where high-flow samples were not collected. Data also were examined in terms of maximum concentrations and(or) ranges of concentrations, with respect to flow. Statistical methods could not be applied to evaluate the relation between discharge and concentration because the samples were collected over such a limited range of discharge (either high flow or low flow). This interpretation of the data, using high-flow/low-flow figures, can be useful in defining the influence of point and nonpoint source contributions of contaminants on water quality; however, the interpretation is limited because of the small sample size, and results should be viewed as preliminary or exploratory rather than conclusive.

The USGS NWQL has implemented new procedures for interpreting and reporting low-concentration data in water-quality samples (Childress and others, 1999). Concentrations of analytes that either were not detected or were not identified are reported as "less than" the laboratory reporting level (<LRL) and are considered to be nondetections. Analytes that were detectable at concentrations between the LRL and the long-term method detection level (LT-MDL), which is usually one-half the LRL, and that pass identification criteria were estimated. Estimated concentrations are noted with the remark code "E". The uncertainty associated with the magnitude of estimated concentrations is greater than that associated with values that were not estimated (Martin and others, 1999). The sample matrix and the instrument condition sometimes limit the reliable measurement of an analyte in the laboratory. The minimum reporting level (MRL) and(or) LRL for organic compounds have been calculated by the NWQL. The NWQL collects quality-control data on a continuing basis to determine the MRLs, LT-MDLs, and LRLs. These values are re-evaluated each year and, consequently, may change from year to year. Values listed in this report were those in effect on October 1, 2000.

Sensitive analytical methods used in this study resulted in low detection limits and higher frequencies for many pesticides. Comparison of detection frequencies among pesticides can be misleading because of the different LRLs associated with each of the pesticides. For example, atrazine has an LRL of 0.007 micrograms per liter (μg/L) and may have been detected more often than prometon, which has an LRL of 0.015 μg/L, even though prometon may have been present at significantly higher concentrations than atrazine. To reduce this type of bias when calculating detection frequencies, pesticide data were adjusted by censoring to a common threshold of 0.01 μg/L so that values less than 0.01 μg/L were not considered detections. These adjusted procedures were used when comparing the pesticide detection frequency between national data from the NAWQA Program and data from this investigation as part of the Birmingham Watersheds Project. Non-adjusted data were used when evaluating the frequency of detection for pesticides in the Birmingham area.

Median concentrations of constituents were used when comparing constituent levels between sites along the urban streams. Median concentrations represent the 50th percentile of the concentration data and are less affected than mean concentrations by the value of extremely high or low concentrations. Median concentrations were not computed at two sites (LCR and VIL-4) because of the limited number of samples (three) at each site and the brief time that the samples were collected (February 28–July 1, 2000).

Nonparametric hypothesis tests were used to evaluate relations between water-quality parameters and land-use characteristics. The Spearman-rho rank sum correlation test was used to assess the strength of these relations (SAS Institute Inc., 1989). In this non-parametric test, data are represented by ranks rather than actual values. Median values of selected water-quality constituents were calculated and then compared to land-use characteristics. Logarithmic probability regression was used to predict the values of data below the detection limit prior to calculating median values. In many instances, median values at particular sites could not be

calculated due to either the large number of non-detections, multiple-detection levels, or the limited sample size. Correlation coefficients were calculated only for those parameters with high detection rates (greater than 50 percent). Correlation coefficients were examined only when median values could be determined at a minimum of five sites. Although statistically significant differences were found, the significance of the results and the power of the tests used are limited because of the small sample size. The results should be viewed as preliminary or exploratory rather than conclusive.

Correlation tests calculate a probability statistic (p) and a correlation coefficient (rho). The probability statistic relates to the confidence level. A probability statistic of 0.05, as used in this report, means that there is a 95-percent probability that the correlation is statistically significant. The correlation coefficient can range from -1 to +1 and describes the strength of the correlation and how the correlated parameters vary. The correlation coefficient, rho, is positive when one variable increases with the other and negative when one variable increases as the other decreases. For this report, significant correlation was determined by an absolute rho value of 0.7 or greater, provided that the p value was less than or equal to 0.05. All data sets with rho and p values within the designated ranges were verified by scatter plots to determine the distribution of the data. Plots that indicated poor distribution by showing grouped data points or outliers were not considered in the correlation analysis. The determination that a correlation existed meant that the data sets varied with each other in a constant pattern, but did not necessarily indicate a cause and effect relation (Helsel and Hirsch, 1995).

The Kruskal-Wallis test and the Tukey multiple-comparison test were used to test whether water-quality constituent concentrations at one site were significantly different from constituent concentrations at other sites (SAS Institute Inc., 1989). The Kruskal-Wallis test is a one-way nonparametric analysis of variance (ANOVA) that was used to determine whether significant differences existed between independent data groups—sites on Village Creek, sites on Valley Creek, and the combined sites (VIL-1, VIL-2, VIL-3, VAL-1, VAL-2, VAL-3, and FMC). The Tukey multiple-comparison test was then used to compare the differences in concentrations in an upstream-downstream order on each stream and to compare the concentrations of selected constituents in Village and Valley Creeks to concentrations at FMC. The simplest procedures for performing nonparametric multiple comparisons are rank transformation tests (Helsel and Hirsch, 1995). Ranks were substituted for the original data and the Tukey multiple-comparison test was performed on the ranks. Data were censored to the highest detection level whenever multiple detection levels were present. Statistical tests were not performed on parameters if censoring resulted in a severe (near 50 percent or more) loss of data (Helsel and Hirsch, 1995). As stated earlier, the significance of the results and the power of the tests used are limited because of the small sample size and the inherent limitations of statistical tests performed on small data sets. The results should be viewed as preliminary or exploratory rather than conclusive.

The USEPA has water-quality standards and guidelines for certain chemicals that can have adverse effects on human health, aquatic organisms, and wildlife. Although the Maximum Contaminant Levels (MCL) established by the USEPA pertain to finished drinking water supplied by a community water supply, they provide values with which the sampled concentrations can be compared (U.S. Environmental Protection Agency, 2001). Aquatic life criteria established by the USEPA and ADEM provide for the protection of aquatic organisms for short-term (acute) and long-term (chronic) exposures. In some instances, Canadian guidelines were used for comparisons when other criteria were not available. Fecal-bacteria concentrations were compared to established State and Federal standards and criteria. The USEPA defines criteria for single sample densities for *E. coli* and enterococci based on the designated use of the water (U.S. Environmental Protection Agency, 1986). The ADEM defines criteria for fecal coliform based on water-use classification, single sample density, and the geometric mean of at least five samples taken over a 30-day period (Alabama Department of Environmental Management, 2000d). Exceedance frequencies were calculated by summing the number of exceedances and dividing by the total number of samples collected for each type of bacteria.

Concentrations of total nitrogen, total phosphorus, and chlorophyll *a* in the study basins were compared to recommended criteria developed for Nutrient Ecoregion XI (U.S. Environmental Protection Agency, 2000a). The USEPA has identified quantified endpoints for these variables to provide for the protection and propagation of aquatic life and recreation, and to provide sufficient protection of uses (and to maintain downstream uses) on rivers and streams. Instantaneous loads, in kilograms per day, were calculated for total nitrogen and total phosphorus and were computed as the product of discharge and concentration at the time of sampling. Instantaneous yields, in kilograms per hectare per year, were computed as the product of the instantaneous load and the numbers of days in the year divided by the

drainage area in hectares. Accurate estimates of daily or annual loads could not be computed from the limited amount of data available.

The following equation was used to calculate instantaneous load:

$$L_i = Q_i \times C_i \times K \ . \tag{1}$$

The following equation was used to calculate instantaneous yield:

$$Y_i = \frac{L_i \times T}{(J \times DA)} , \tag{2}$$

where:

L_i = Instantaneous load in kilograms per day (kg/d) based on the discharge and concentration at the time of sampling;

Y_i = Instantaneous yield in kilograms per hectare per year (kg/ha)/yr;

Q_i = Instantaneous discharge in ft^3/s;

K = 2.447, correction factor for unit conversion from (ft^3–mg)/(sec–L) to kg/d;

C_i = Instantaneous concentration in milligrams per liter (mg/L);

T = 365.25, the number of days per year;

DA = Drainage area, mi^2; and

J = 259, correction factor for unit conversion from square miles to hectare.

Quality-Control Methods and Results

Quality-assurance and quality-control measures were practiced throughout the study according to established USGS guidelines (Mueller and others, 1997). Laboratory and field blank samples were processed using water certified to contain undetectable concentrations of constituents to be analyzed. Data from blank samples were used to determine the extent of contamination potentially introduced during sampling, sample processing, shipping, or laboratory analysis. Blank water used for the inorganic constituent sample was distilled, deionized water obtained from the Ocala Water Quality Research Laboratory in Ocala, Florida. Blank water used for the organic constituent sample was either pesticide-grade or volatile-organic-compound-grade blank water obtained from the NWQL.

Four blank samples were analyzed for nutrients, major ions, organic carbon, and trace metals. No constituents were detected at levels greater than the LRL. Constituents that were detected in field blanks at levels

below the LRL include dissolved nitrogen (ammonia + organic), total organic carbon, dissolved phosphorus, silica, copper, and chloride (appendix table 1-1). Constituents that were detected in the equipment blank at levels below the LRL include calcium, magnesium, and silica—zinc was detected at a level exceeding the low-level MRL for the equipment blank (appendix table 1-1). Six out of 75 environmental samples had nutrient concentrations at or near the levels found in the field blanks. One out of 41 environmental samples had copper concentrations at or near the level found in the field blanks. The concentrations of silica, chloride, calcium, magnesium, zinc, and total organic carbon found in the field and equipment blanks were substantially lower than concentrations found in stream samples. Three additional blank samples were analyzed for PAHs and pesticides—no constituents were detected in these blanks. These low-level detections indicate little potential for contamination of streamwater samples.

The method designed by the NWQL for wastewater indicators was considered experimental during this sampling period. Data were censored according to the detection level of constituents found in laboratory and field blanks. If a constituent were found in either a laboratory blank or a field blank and also detected in a stream sample during that same sampling trip at the same magnitude, then the detection was not included. The NWQL analyzed 18 laboratory blanks on batches including samples from this study. Eight of the 16 constituents that were examined in detail for this report were detected in laboratory blanks (appendix table 1-1). Seven field blanks were sent to the NWQL. Triclosan was the only one of the 16 constituents to be detected in a field blank (appendix table 1-1); triclosan was also detected in the laboratory blank for that particular batch of samples.

Sample replicates were collected to quantify the reproducibility of the results. Data from replicate samples were used to assess variability due to sample processing and laboratory analysis. The relative percentage difference (relative percentage difference = |A – B| / [(A + B)/2]) between the environmental samples and the corresponding replicate samples ranged from 0 to 54.6 percent with a median of 2.8 percent. Replicate results from nutrients, major ions, and metals indicated good reproducibility of data (less than 10-percent difference) in 95 percent of the detections (appendix table 1-2). Replicate results from pesticides indicated good reproducibility of data in 73 percent of the detections. For some pesticides, such as diazinon and simazine, the relative percentage difference (9.3–13.6 percent) was consistently higher than other pesticides, such as atrazine or prometon (2.0–4.0 percent;

appendix table 1-2). Replicate results from wastewater indicators showed good reproducibility of the data in 50 percent of the detections (appendix table 1-2).

The effectiveness of sterilization and processing procedures for bacterial analyses was checked by processing a sterile water blank at each site. Additional procedures included the regular analysis of procedure blanks as well as the frequent analysis of replicate samples.

Bed-Sediment Data

Sediment samples with particles larger in size than 0.063 mm have lower concentrations of trace elements because there is less surface area available for adsorption. A grain size ≤0.063 mm was selected for analysis for trace elements in bed sediment because of the underlying assumption that most, if not all, of the trace elements would be contained within that fraction (Horowitz, 1991). Concentrations of trace elements detected in the ≤0.063-mm fraction of the bed sediment may not be biologically available because of the strong attraction of the elements to particulates of this size. Therefore, particulate-bound concentrations of trace elements that exceed a known toxic limit may not present a toxic hazard. Changes in water chemistry (such as a decrease in pH), however, can facilitate the release of sediment-bound trace elements. Biological activity, such as the methylation of metallic mercury by microorganisms, also can remove elements from bed-sediment particulates and make them biologically available. Resuspension in the water column and transport of sediment-bound elements during storms and floods to locations downstream also may occur. Reservoirs, small impoundments, and backwaters can become sinks for trace elements, which can increase in concentration and toxicity as sediment is accumulated.

To determine whether a trace-element concentration may have an adverse effect on aquatic biota, it is useful to compare the concentration with a known toxic-effect level. Sediment-quality guidelines for the protection of aquatic life commonly are used for determining the potential toxicity of bed-sediment trace elements to aquatic organisms (Canadian Council of Ministers of the Environment, 1995). The probable effect level (PEL) is the concentration of an element or compound that is likely to cause an adverse effect on aquatic biota. The concentrations of trace elements in bed sediments were compared with the PELs and also with median concentrations determined from bed-sediment samples collected at sites across the Nation as part of the NAWQA Program (Rice, 1999).

Fish-Tissue Data

Aquatic organisms can accumulate trace elements and organic compounds in their bodies. This bioaccumulation can provide useful evidence about the occurrence and distribution of these substances. Concentrations of organic compounds and trace elements in fish tissue can be biomagnified to concentrations that are higher than those in the surrounding water or bed sediment (Laws, 1993; Brigham and others, 1998). It is important to quantify the concentration of specific substances in fish tissue because, while they may be detected in very low levels in the environment and thus be considered harmless, biomagnification can yield concentrations that may result in detrimental effects not only to biota that contain them but to organisms that consume them. Many trace elements are deposited in the liver, which is the primary detoxifying organ of the body. Organochlorine pesticides, such as DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane), are lipophilic and are stored in fat tissue.

In general, standards and guidelines aimed at the protection of human health apply to contaminant concentrations in the edible portion of the fish. The only national guidelines that apply to whole fish tissue are the preliminary recommendations made by National Academy of Science/National Academy of Engineering (NAS/NAE) in 1972, and these are aimed at the protection of fish-eating wildlife (National Academy of Science/National Academy of Engineering, 1973). Most standards and guidelines for pesticides in fish tissue apply to edible portions of fish rather than whole fish—and contaminant-residue data in whole fish cannot be compared directly with them—except as a screening procedure to determine whether additional sampling is warranted (Nowell and Resek, 1994). NAS/NAE and Canadian standards for trace-element concentrations in fish-liver tissue do not exist. The concentrations of trace elements, organochlorine pesticides, and PCBs detected in fish tissue were compared among sites and to the available standards and guidelines.

Aquatic-Community Data

Benthic-invertebrate community data were processed by using the Invertebrate Data Analysis System (IDAS), a computer program developed for evaluating invertebrate communities for the NAWQA Program (T.F. Cuffney, U.S. Geological Survey, written commun., October 2001). The output of the program includes diversity and similarity indices that allow comparisons of community attributes. For this study, two analyses were conducted. The first was based on the results of the

quantitative data collected in each stream, and provided information on invertebrate density and community composition. The second analysis included the combined results of the quantitative and qualitative invertebrate data and, using IDAS, provided species-richness information and calculated an index of similarity. The invertebrate collections were divided into three groups: (1) insects without midges (Chironomidae), (2) midges, and (3) non-insect invertebrates. Results of the community assessments were used to evaluate possible relations with bed sediment, habitat, and land use for each sample site.

Community metrics based on benthic-invertebrate structure may be indicative of water quality. For streams in the Birmingham area, the metrics were chosen from a subset of rapid bioassessment protocols used by the USEPA (Plafkin and others, 1989). These metrics include:

Community richness – This metric is a measure of the number of taxa present in the community. In general, the number of taxa decreases as the water quality decreases. The fewer taxa, the more likely the community has been degraded.

Diversity – The Shannon index of diversity (sometimes called the Shannon-Wiener index) was used to evaluate the diversity of the benthic-invertebrate community at the study sites. This index is based on the proportional abundance of species and accounts for both species richness and evenness (Magurran, 1988).

Density – This measurement refers to the total number of individual organisms within a specified area, such as a square meter. Density can be calculated for the entire community or for individual species or trophic levels. The density of the benthic-invertebrate community may be indicative of changes in habitat or water quality in a stream. Under stressful conditions, sensitive organisms disappear and tolerant organisms increase in numbers. Communities with only a few dominant species generally are considered to be stressed.

Similarity – Similarity is a measure of how alike two communities are. The use of similarity indices is based on the assumption that communities become more dissimilar as stress increases (Rosenberg and Resh, 1993). The measure is a comparison of the taxonomic structure of a representative sample of the community at a selected site and time with that of an index site. The higher the value of the similarity index, the more similar the two communities. A Pinkham-Pearson similarity index was calculated for the benthic-invertebrate communities sampled in streams in the Birmingham area, comparing the benthic-invertebrate community in each site to that in FMC. This index measures the degree of similarity in

communities between sites, incorporating presence/absence data, abundance, and the types of taxa present.

The Ephemeroptera, Plecoptera, Trichoptera (EPT) index – This index refers to the number of mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) taxa in a sample. Total EPT richness is an important indicator of water quality because these insects are known to be relatively sensitive to contamination. The EPT index has been empirically shown to track other indicators of ecological degradation (Wallace and others, 1996).

The ratio of EPT abundance to chironomid abundance – This ratio can be indicative of changing water quality. As the ratio decreases in magnitude, the proportion of EPT taxa decreases. A disproportionate number of chironomids relative to the EPT taxa may be indicative of environmental stress.

Relative abundance – The relative abundance of a taxon is the proportional abundance of that taxon within the sample or community; that is, the percentage of the total number of individuals in the community that is represented by that taxon. Relative abundance can indicate whether one or more taxa comprise an unusually large percentage of the community. If there is an equitable distribution of individuals within all of the taxa, the community appears to be well balanced with no taxon being unusually dominant. In general, when the number of individuals in a few taxa or a single taxon is disproportionately greater than that of any other taxon of the same type, it is likely there has been an environmental perturbation.

Community metrics (measures of community structure and function) have been developed to evaluate the relative health of fish communities and can be used as an indicator of environmental stress (Plafkin and others, 1989). Metrics used in this study include: (1) total number of fish species, (2) community diversity, (3) similarity of fish communities among sample sites, (4) the number and identification of darter and sculpin species, (5) the relative abundance and identity of sunfish species, (6) the number and identity of minnow or sucker species, (7) the relative abundance of green sunfishes, (8) the number of intolerant taxa, and (9) the relative abundance of anomalies among the fishes.

The sampling time for each reach differed, depending on the length and width of the reach and the complexity of habitat. To reduce the bias associated with different sampling times, the total electrofishing time (application of power to the water) was converted to units of effort. A unit of effort was defined as 300 seconds (5 minutes) of power application. Total numbers of fishes captured at each site were divided by the units of effort to

provide a more equitable comparison of fish capture among sites.

The Sorenson similarity index was calculated to determine how similar the fish communities were between the reference site (FMC) and the other sampling sites. This is a widely used index based on species presence and absence, and is designed to equal 1 in the case of complete similarity (Magurran, 1988):

$$S = \frac{2c}{(a + b)},\qquad(3)$$

where

S = Index of similarity,
a = the number of species occurring in the first site,
b = the number of species occurring in the second site, and
c = the number of species common to both sites.

Benthic-invertebrate data and fish-community data also were compared among the streams, with land-use and habitat characteristics, and with chemical and physical characteristics of the bed sediment by using the Spearman-rho rank correlation test (SAS Institute Inc., 1989).

Stream-Habitat Data

The habitat data evaluated in this report represent major components of habitat along each transect and in each stream reach. The habitat features evaluated include the physical characteristics of the stream channel, the water depth and wetted channel width, the amount of shading by riparian vegetation, the amount of ground cover along the banks, and the percentage of each type of geomorphic channel units (pools, runs, riffles) in the reaches. Habitat characteristics were compared among the streams and with benthic-invertebrate and fish-community data, land-use data, and with chemical and physical characteristics of the bed sediment by using the Spearman-rho rank correlation test (SAS Institute Inc., 1989).

RESULTS AND DISCUSSION

This section includes the analytical results and discussion related to water chemistry, bed-sediment and fish-tissue samples, and an evaluation of the benthic-invertebrate and fish communities in the study area.

Water Quality

This section includes the results and discussion of water-quality data evaluated for this study. Topics discussed include analytical results related to basic water chemistry, major ions, field and continuous measurements of water properties, nutrients, fecal indicator bacteria, wastewater indicators, trace elements, pesticides, and PAHs.

Basic Water Chemistry

The chemistry of surface water is the result of interactions between rain, ground water, rocks, and soils near the Earth's surface. Dissolved and particulate constituents enter a stream by surface runoff, precipitation, or ground-water discharge. The major dissolved constituents that give water its characteristic chemistry are cations and anions. Cations are positively charged and include calcium, magnesium, sodium, and potassium. Anions are negatively charged and include chloride, nitrate, sulfate, bicarbonate, and carbonate. The concentrations of these dissolved ions generally are reported in parts per million (milligrams per liter).

Streamwater chemistry varies with flow conditions because flow pathways change in the watershed. Under low-flow conditions, streamwater is predominantly ground-water discharge. The nature and concentration of dissolved constituents are dependent on the composition of the aquifers through which the ground water flows. During and immediately after a storm event, streamwater is a mixture of rainwater and surface runoff, shallow subsurface flow through the soil zone, and ground-water discharge. Precipitation produces an overall dilution of the major ion composition. Human activity also can alter water chemistry by contributing additional ions, such as sodium and chloride, from leaking or overflowing sewer systems, industrial discharge, or urban runoff. Although basic ions are not considered contaminants, elevated levels (above natural background levels) may indicate potential sources of contaminants (nutrients, trace elements, synthetic organic compounds).

Major Ions

Major ions constitute the greatest part of the dissolved solids in water. A summary of major ion concentrations, expressed in milliequivalents per liter (meq/L), during low, median, and high flow is presented in appendix table 2-1. Concentrations were summarized for all sites except VIL-4 and LCR (due to the small sample sizes). All sites exhibited similar water quality, characterized by a strong calcium-bicarbonate

component, which was most pronounced during low flow, due to ground-water discharge from the underlying carbonate rocks in the stream valleys. The bicarbonate component was most pronounced at VIL-1. The water chemistry at VIL-1 and FMC exhibited the lowest median concentrations of sodium, potassium, chloride, and sulfate. The similarity of the basic water chemistry at VIL-1 and FMC indicates that VIL-1 is the least impacted (of the Village and Valley Creek sites) from urbanization. The highest level of chloride was detected at VIL-2 during low flow. Median levels of chloride were highest at VIL-3, VAL-1, and VAL-2. Median levels of sodium were highest at VAL-1 and VAL-2, indicating that water chemistry at these sites may be more strongly influenced by anthropogenic factors. All sites exhibited the effects of dilution during storm events.

The Kruskal-Wallis test and the Tukey multiple-comparison test were applied to the major ion data at seven sites to determine if the variations in water chemistry among sites were statistically significant (table 6). Although statistically significant differences were found for several of the major ions, the significance of the results and the power of the tests used are limited because of the small sample sizes. Potassium and sulfate concentrations at VIL-2, VIL-3, VAL-1, VAL-2, and VAL-3 were significantly greater than concentrations at FMC. Chloride concentrations at VIL-2, VIL-3, VAL-1, and VAL-2 were significantly greater than concentrations at FMC. Sodium concentrations at VAL-1 and VAL-2 were significantly greater than concentrations at FMC. Concentrations of sodium, potassium, chloride, and sulfate at VIL-2 and VIL-3 were significantly greater than concentrations at VIL-1; concentrations of potassium at VAL-3 were significantly greater than at VAL-2.

Field and Continuous Measurements of Water Properties

Field measurements of physical properties of water, such as pH, temperature, specific conductance, and dissolved oxygen, can be used to compare chemical conditions in the streams at the time of sampling. Water quality, however, continually changes over time, and repeated measurements are necessary to characterize variations in quality. Continuous water-quality monitors have sensors and recording systems that measure water-quality properties at discrete time intervals and provide a continuous record of these properties over time.

The ADEM established criteria for pH, water temperature, dissolved oxygen, and turbidity based on water-use classification. Water-quality properties, including field measurements and continuous water-quality monitoring data, are summarized with applicable criteria in table 7. More detailed information obtained

from continuous water-quality monitors in Village and Valley Creeks is summarized in the most recent USGS Annual Data Reports for Alabama (Pearman and others, 2001, 2002).

Long-term continuous water-quality data are available for two sites on Village Creek—VIL-3 since 1991 and VIL-4 since 1996 (table 1). In conjunction with this study, additional monitors were installed upstream from VIL-1 and at VAL-3 and turbidity probes were added to the monitors at VIL-1, VIL-3, and VAL-3. Continuous measurements of all four water-quality properties at VIL-1 and VIL-3 were recorded between April 2000 and February 2001; continuous measurements of all four properties at VAL-3 were recorded between August 2000 and February 2001 (table 7; Pearman and others, 2001, 2002).

The pH of surface water generally ranges from 6 to 9. When the pH falls below 4 or 5, possibly as a result of commercial or industrial discharges, urban runoff, acid mine drainage, or acid rain, the structure of the aquatic community may be affected. The ADEM established a pH range of 6 to 8.5 to reduce the effects of highly acidic or highly basic water on fish and wildlife (Alabama Department of Environmental Management, 2000d). Field measurements of pH were made at all sites at the time of sampling (appendix table 2-2). Continuous monitors, however, were not equipped to measure pH. In Valley Creek, pH ranged from 7.3 at VAL-1 to 8.5 at VAL-2; in Village Creek pH ranged from 6.9 at VIL-1 to 8.5 at VIL-3 (table 7). The pH values at all sites sampled were within the criteria established for agricultural and industrial water supply as well as fish and wildlife (Alabama Department of Environmental Management, 2000d). The higher pH measurements found at VIL-3, VAL-2, and VAL-3 are indicative of the carbonate-based geology in the area. The lowest pH measurements in both streams were recorded during storm events.

Specific conductance (SC) is an indicator of the ability of water to conduct an electric current and is proportional to the dissolved-solids concentration in water. Many factors affect the SC of streams, including flow conditions, bedrock geology, and contributions of dissolved solids from point and nonpoint sources. Standards or criteria for SC have not been established by the ADEM or the USEPA. SC was measured at the time of sample collection and by continuous water-quality monitors at four sites (table 7). In Valley Creek, field measurements of SC ranged from 57.5 to 599 microsiemens per centimeter at 25 degrees Celsius (µS/cm) at VAL-1. Continuous SC measurements ranged from 68 to 621 µS/cm at VAL-3. In Village Creek, field measurements of SC ranged from 76.3 µS/cm at VIL-1 to

Table 6. Results of the Kruskal-Wallis test and the Tukey multiple-comparison test illustrating statistically significant ($p \leq 0.05$) differences for selected water-quality constituents at sites in the Birmingham area, Alabama

[BOD, biochemical oxygen demand; °C, degree Celsius; *E. coli, Escherichia coli*]

Site label (fig. 1)	Water temperature	Discharge	pH	Specific conductance	Dissolved oxygen	Alkalinity	Total organic carbon	BOD	Hardness	Calcium
VIL1 to VIL2		X				X	X			
VIL2 to VIL3					X					
VIL1 to VIL3		X				X				
VAL1 to VAL2										
VAL2 to VAL3										
VAL1 to VAL3		X			X					
VIL1 to FMC										
VIL2 to FMC										
VIL3 to FMC										
VAL1 to FMC										
VAL2 to FMC				X						
VAL3 to FMC										

Site label (fig. 1)	Magnesium	Sodium	Potassium	Chloride	Sulfate	Fluoride	Silica	Solids, residue at 180 °C	Solids, sum of constituents, dissolved	Total nitrogen
VIL1 to VIL2		X	X	X	X	X				
VIL2 to VIL3										
VIL1 to VIL3	X	X	X	X	X	X				
VAL1 to VAL2										
VAL2 to VAL3		X								
VAL1 to VAL3						X				X
VIL1 to FMC	X									
VIL2 to FMC			X	X	X	X				
VIL3 to FMC			X	X	X	X				X
VAL1 to FMC		X	X	X	X	X				X
VAL2 to FMC		X	X	X	X	X		X	X	X
VAL3 to FMC			X		X	X				

Site label (fig. 1)	Dissolved nitrogen organic	Total nitrogen organic + ammonia	Dissolved nitrogen organic + ammonita	Dissolved nitrogen ammonia	Dissolved nitrite	Dissolved nitrate	Dissolved nitrite + nitrate	Total phosphorus	Dissolved phosphorus	Dissolved ortho phosphate
VIL1 to VIL2	X	X	X		X			X		
VIL2 to VIL3					X					
VIL1 to VIL3	X		X	X	X					
VAL1 to VAL2		X	X	X	X			X	X	X
VAL2 to VAL3										
VAL1 to VAL3	X	X	X	X	X			X	X	X
VIL1 to FMC						X	X			
VIL2 to FMC			X	X	X			X	X	X
VIL3 to FMC			X	X	X					
VAL1 to FMC	X	X	X	X	X	X	X	X	X	X
VAL2 to FMC			X	X				X	X	X
VAL3 to FMC									X	X

☐ (shaded) $p > 0.05$ No statistically significant differences between sites as determined by the Kruskal-Wallis test.

☒ $p \leq 0.05$ Statistically significant differences between sites as determined by the Tukey multiple-comparison test (nonparametric).

☐ $p > 0.05$ No statistically significant differences between sites as determined by the Tukey multiple-comparison test (nonparametric).

Table 6. Results of the Kruskal-Wallis test and the Tukey multiple-comparison test illustrating statistically significant ($p \leq 0.05$) differences for selected water-quality constituents at sites in the Birmingham area, Alabama—Continued

[BOD, biochemical oxygen demand; °C, degree Celsius; *E. coli, Escherichia coli*]

Site label (fig. 1)	Suspended phosphorus	Dissolved nonortho-phosphorus	Nitrogen load	Nitrogen yield	Phosphorus load	Phosphorus yield	Fecal coliform	*E. coli*	Enterococci	Aluminum
VIL1 to VIL2	X	X			X					
VIL2 to VIL3										
VIL1 to VIL3			X		X					
VAL1 to VAL2	X	X					X	X		
VAL2 to VAL3										
VAL1 to VAL3	X	X					X	X		
VIL1 to FMC										
VIL2 to FMC										
VIL3 to FMC										
VAL1 to FMC	X	X					X	X		
VAL2 to FMC		X								
VAL3 to FMC										

Site label (fig. 1)	Barium	Cadmium	Copper	Iron	Lead	Manganese	Molybdenum	Zinc	Simazine	Prometon
VIL1 to VIL2	X	X					X			
VIL2 to VIL3										
VIL1 to VIL3	X						X			
VAL1 to VAL2	X									
VAL2 to VAL3										
VAL1 to VAL3										
VIL1 to FMC										
VIL2 to FMC	X	X					X			
VIL3 to FMC	X		X				X			
VAL1 to FMC			X							
VAL2 to FMC							X			X
VAL3 to FMC										

Site label (fig. 1)	Diazinon	Atrazine	Number of pesticide detections	Food by-products	Pharma-ceuticals	Phosphates	Detergents	Fragrance	Total concen-tration	Number of detections
				Wastewater indicators						
VIL1 to VIL2						X				X
VIL2 to VIL3										
VIL1 to VIL3						X		X		X
VAL1 to VAL2				X						X
VAL2 to VAL3										
VAL1 to VAL3				X	X	X		X		X
VIL1 to FMC										
VIL2 to FMC						X	X		X	X
VIL3 to FMC						X	X		X	X
VAL1 to FMC				X	X	X	X		X	X
VAL2 to FMC						X	X		X	X
VAL3 to FMC										

⬜ (shaded) $p > 0.05$ No statistically significant differences between sites as determined by the Kruskal-Wallis test.

X $p \leq 0.05$ Statistically significant differences between sites as determined by the Tukey multiple-comparison test (nonparametric).

⬜ $p > 0.05$ No statistically significant differences between sites as determined by the Tukey multiple-comparison test (nonparametric).

Table 7. Water-quality properties of streams in the Birmingham area, Alabama, 2000–01

[Values shown in **bold** exceeded the criteria. μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degree Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity unit; —, no criteria established; ≤, equal to or less than; ≥, equal to or greater than; ND, no data were collected]

Site label (fig. 1)	pH	Specific conductivity (μS/cm)	Water temperature (°C)	Dissolved oxygen (mg/L)	Specific conductivity (μS/cm)	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)
Water-quality criteria for agricultural and industrial water supply[a]								
	6.0–8.5	—	≤ 32.2	≥3.0	—	≤ 32.2	≥3.0	≤ 50[b]
Water-quality criteria for fish and wildlife[a]								
	6.0–8.5	—	≤ 32.2	≥ 5.0[c]	—	≤ 32.2	≥ 5.0[c]	≤ 50[b]
Field measurements					**Continuous water-quality data**			
VIL-1	6.9–8.1	76.3–393	11.3–24.0	7.0–9.2	54–403[d]	7.4–29.7[d]	**2.8**–15.8[d]	0.5–870[d]
VIL-2	7.0–8.1	114–760	10.3–26.2	5.4–10.5	ND	ND	ND	ND
VIL-3	7.2–8.5	184–467	9.9–29.2	5.9–11.8	77–614	1.7–**33.5**	**1.7**–17.7	1.0–1,900[e]
VIL-4	7.2–7.4	144–510	15–25.8	**0.0**–8.6	81–587	8.1–30.7	**2.7**–12.7	ND
VAL-1	7.3–8.0	57.5–599	10.9–25.1	**3.3**–10.4	ND	ND	ND	ND
VAL-2	7.5–8.5	126–539	5.5–30.0	**4.3**–13.1	ND	ND	ND	ND
VAL-3	7.6–8.4	103–489	7.0–27.9	6.5–13.9	68–621	1.9–31.3	**3.8**–19.6	0.1–100
LCR	7.5–8.0	296–403	14.6–23.3	6.6–9.9	ND	ND	ND	ND
FMC	7.4–8.2	128–364	8.5–24.4	6.6–12.2	ND	ND	ND	ND

[a] Criteria established by the Alabama Department of Environmental Management (2000d).

[b] Turbidity will not exceed 50 NTU above background (Alabama Department of Environmental Management, 2000d).

[c] Criteria for dissolved oxygen under extreme conditions is 4.0–5.0 mg/L (Alabama Department of Environmental Management, 2000d).

[d] Continuous water-quality monitor located upstream from site VIL-1 at station 02458148.

[e] Instrument range from 0 to 1,000 NTU.

760 μS/cm at VIL-2. Continuous SC measurements ranged from 54 μS/cm at VIL-1 to 614 μS/cm at VIL-3. The lowest specific conductance measurements in both streams were made during storm events and are a result of dilution by rainwater.

Dissolved-oxygen (DO) concentration is widely used for evaluating the biochemistry of streams and lakes. DO concentrations may be depleted by processes that consume organic matter. Actively photosynthesizing algae and aquatic plants can increase concentrations of DO (Hem, 1985). The ADEM established criteria for DO concentrations in streams based on water-use classification (Alabama Department of Environmental Management, 2000d). For diversified warm-water biota, daily DO should not fall below 5 mg/L. Under extreme conditions resulting from natural causes, DO may range from 4.0 to 5.0 mg/L provided that the water quality is favorable in all other properties (Alabama Department of Environmental Management, 2000d). In streams classified for agricultural and industrial use, daily DO should not fall below 3.0 mg/L (Alabama Department of Environmental Management, 2000d). Low concentrations are commonly found in waters that are warm and not

well mixed. DO concentrations typically vary in a diurnal fashion, and differences between high and low values can exceed 10 mg/L within a 24-hour period (Pearman and others, 2001). An example of the diurnal fluctuation of DO at VIL-3 is illustrated in figure 9. During low-flow conditions (August 27–31, 2000) peak DO concentrations (11.9–13.3 mg/L) were recorded between 4 and 6 p.m. (1600 and 1800 hours, fig. 9) each day, and minimum DO concentrations (3.6–5.4 mg/L) were recorded between 5 and 6 a.m. (0500 and 0600 hours, fig. 9) each day.

During this study, DO did not always remain within levels established by the ADEM. In Valley Creek, DO remained above the criterion established for agricultural and industrial water supply, but was less than the criterion established for fish and wildlife (table 7). In Valley Creek, field measurements of DO ranged from 3.3 mg/L at VAL-1 to 13.9 mg/L at VAL-3. Continuous measurements of DO ranged from 3.8 to 19.6 mg/L at VAL-3. Concentrations between 4.0 and 5.0 mg/L were measured in the field twice at VAL-1 and twice at VAL-2. Daily minimum concentrations between 4.0 and 5.0 mg/L were recorded by the continuous water-quality monitor at
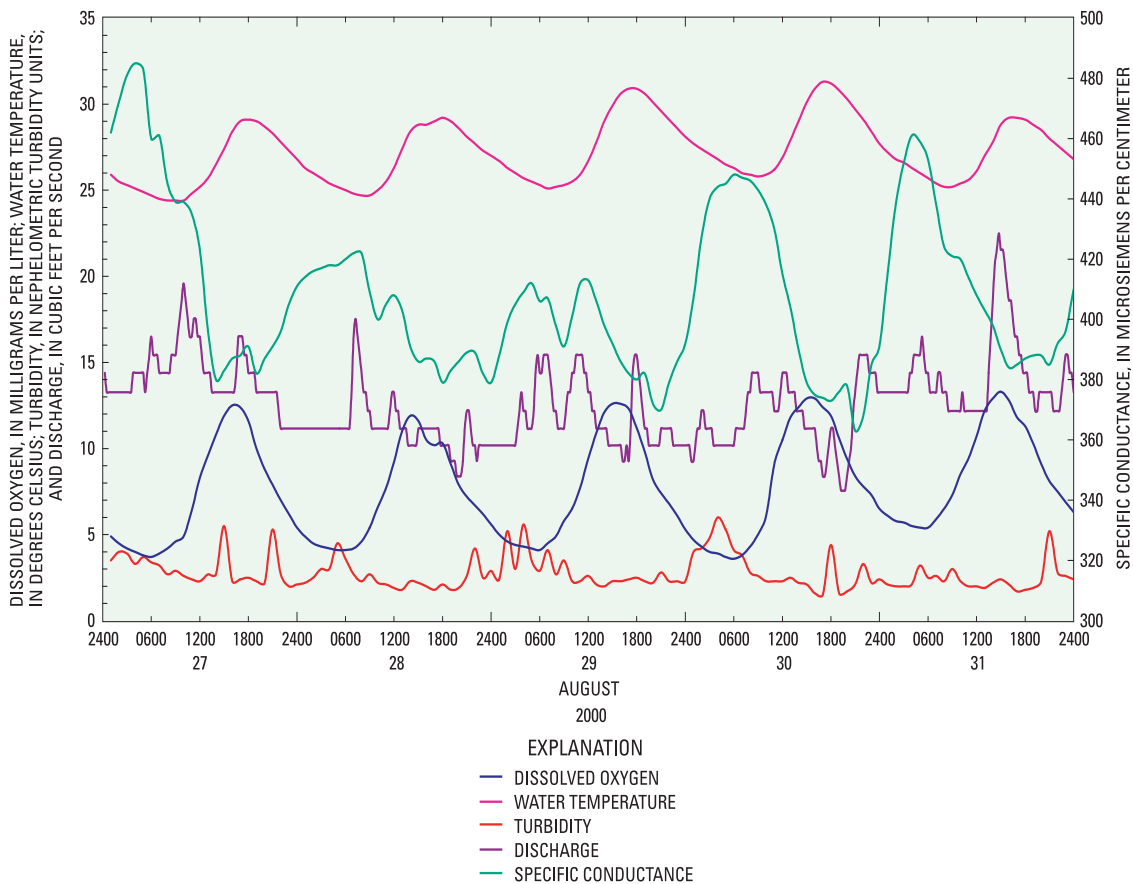
Figure 9. Dissolved oxygen, water temperature, turbidity, discharge, and specific conductivity at U.S. Geological Survey streamgaging station 02458450 (VIL-3) during low-flow conditions, August 27–31, 2000.

VAL-3 on 39 separate days between June 15, 2000, and February 22, 2001; concentrations less than 4.0 mg/L were recorded on 1 day during this time period.

In Village Creek, DO levels were recorded that were less than the minimum criteria established for both agricultural and industrial water supply and for fish and wildlife (table 7). Field measurements of DO ranged from 0.0 mg/L at VIL-4 to 11.8 mg/L at VIL-3. Continuous DO measurements ranged from 1.7 to 17.7 mg/L at VIL-3. At VIL-1, daily minimum DO concentrations ranged between 4.0 and 5.0 mg/L on 2 separate days between April 26, 2000, and February 21, 2001; concentrations were less than 4.0 mg/L on 8 days and less than 3.0 mg/L on 4 days. At VIL-3, daily minimum DO concentrations ranged between 4.0 and 5.0 mg/L on 53 separate days between April 1, 2000, and March 31, 2001; concentrations were less than 4.0 mg/L on 35 days and less than 3.0 mg/L on 7 days. At VIL-4, daily minimum DO concentrations ranged between 4.0 and 5.0 mg/L on 53 separate days between April 1, 2000, and March 31, 2001; concentrations were less than 4.0 mg/L on 17 days and less than 3.0 mg/L on 2 days. On occasion,

continuous DO data collection was interrupted because of technical difficulties in the field.

Turbidity, a measure of water clarity, is determined by measuring the degree that particles suspended in water decrease the passage of light through the water. Particles may come from soil, sediment, algae, plankton, natural organic matter, or manmade compounds. High turbidities are commonly measured during storms when overland runoff erodes soil and carries it to the stream, and increased flow resuspends sediment in the streambed. However, high turbidities can also be measured during low flow when certain materials or compounds are discharged from industrial and commercial facilities. The ADEM criterion requires that turbidity not exceed 50 nephelometric turbidity units (NTU) above background except due to natural origin (Alabama Department of Environmental Management, 2000d). Background levels have not been defined by the ADEM for Village and Valley Creeks; consequently, turbidity values were not compared to this criterion.

Continuous measurements of turbidity in Village and Valley Creeks varied with streamflow (Pearman and

others, 2001, 2002). At VAL-3, turbidity ranged from 0.1 to 100 NTU. At VIL-1, turbidity ranged from 0.5 to 870 NTU. At VIL-3, turbidity ranged from 1.0 to 1,900 NTU (table 7). High turbidities were observed at both streams and in many cases, likely were the result of natural runoff, but in some instances, particularly at Village Creek, these high turbidities may be attributed to anthropogenic causes. At Valley Creek, high turbidity was consistently measured during high flow. At Village Creek, high turbidity was measured during low flow as well as high flow, which may indicate the presence of point or other anthropogenic sources.

Turbidity also can be used to examine whether high-flow samples were collected during the first flush, when many contaminants may be at a maximum level. Continuous water-quality data were recorded over a 4-day period at VIL-3 (August 1–4, 2000) during which two storms occurred (fig. 10). During the first storm (August 2, 2000), turbidity peaked (915.2 NTU) at 3 p.m. (1500 hours, fig. 10)—while discharge peaked (1,829 ft^3/s) at 4:30 p.m. (1630 hours, fig. 10). The first

flush most likely occurred around 3 p.m. (1500 hours, fig. 10), when turbidity values were highest. During the second storm (August 4, 2000), turbidity peaked (681.2 NTU) at 5 p.m. (1700 hours, fig. 10), and discharge peaked (1,003 ft^3/s) at 4:45 p.m. (1645 hours, fig. 10), illustrating the likelihood that there was no first flush associated with this storm, perhaps due to the preceding storm 2 days earlier. Turbidity values were recorded on an hourly basis at VIL-1, VIL-3, and VAL-3. Discharge was recorded every 15 minutes at VIL-1 and VIL-3.

Nutrients

In natural waters, nitrogen is a combination of different chemical forms, depending on the source and environmental conditions. Common forms include organic nitrogen, which can be in dissolved or particulate form, and the inorganic ions, ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-), which are typically in dissolved form. The nitrogen cycle is a series of
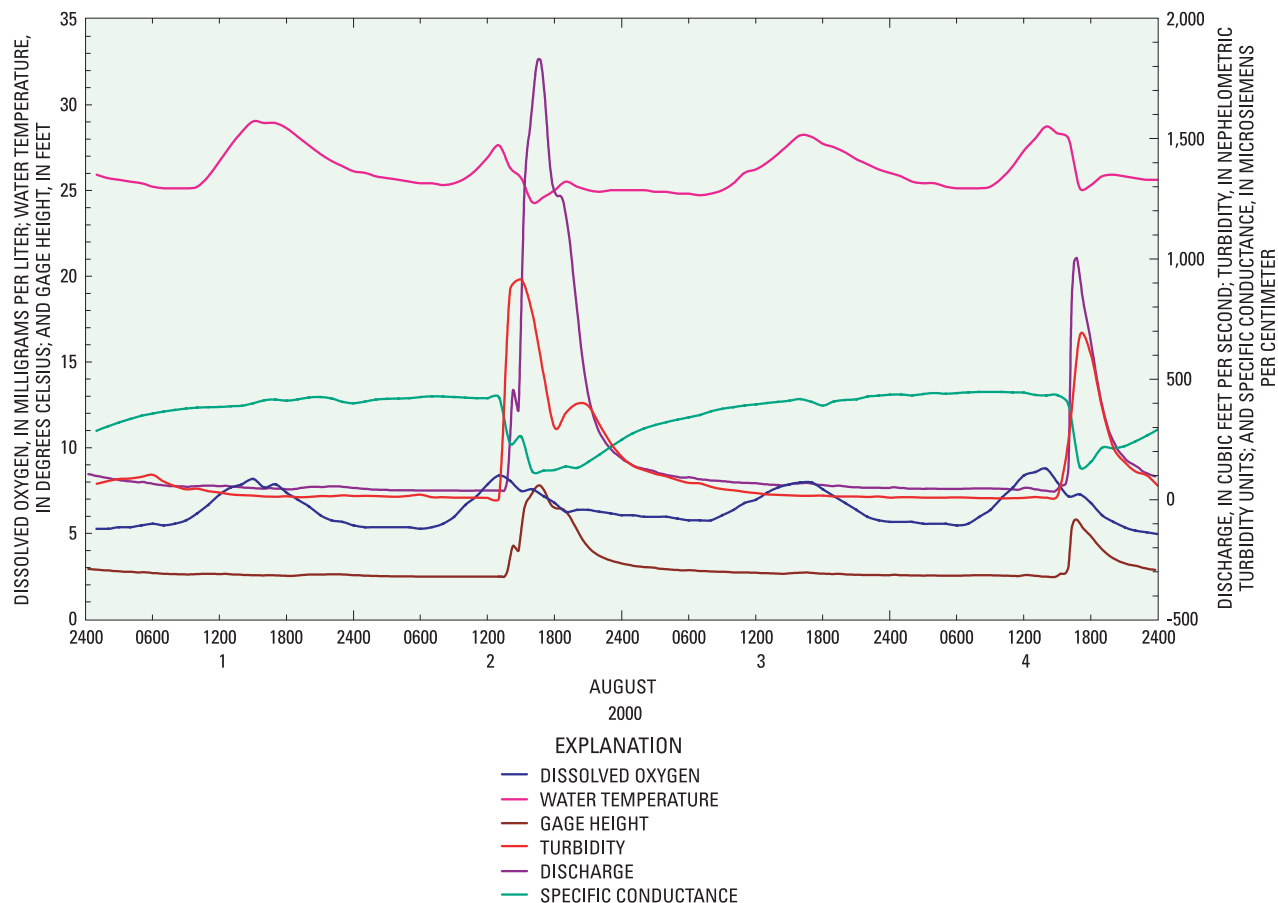
Figure 10. Dissolved oxygen, water temperature, gage height, discharge, turbidity, and specific conductivity at U.S. Geological Survey streamgaging station 02458450 (VIL-3) during two storms, August 1–4, 2000.

biologically catalyzed, geochemical reactions in which one form of nitrogen is transformed into another (Belval and others, 1995). Bacteria and blue-green algae can transform atmospheric nitrogen into ammonium through nitrogen fixation. Other bacteria catalyze the oxidation of ammonia to nitrite, then to nitrate by nitrification, which can occur rapidly in the oxygen-rich environment of many streams. Nitrogen species can be taken up by organisms and incorporated into organic materials, which in turn decay and release nitrogen in the form of ammonia.

Identifying sources of nitrogen from chemical analyses is difficult because nitrogen is readily converted from one form to another. However, large quantities of nitrogen compounds in surface waters usually indicate point and nonpoint source contamination. Excessive amounts of ammonia and organic nitrogen may result from treated water discharges or surface runoff. If streams are well oxygenated and uncontaminated, then ammonia concentrations generally are negligible. Nitrite usually is unstable in aerated water, but is considered to be a good indicator of poor water quality when detected. When most of the nitrogen is in the nitrate form, the water is considered to have stabilized; high levels generally

indicate prior contamination rather than recent contamination (Krenkel and Novotny, 1980).

Several species of nitrogen were measured for this study, including dissolved nitrite, dissolved nitrite plus nitrate, dissolved ammonia, and total and dissolved ammonia plus organic nitrogen (table 8). Total concentrations of nutrients represent both dissolved and particulate forms and are measured from unfiltered samples. For the purpose of this study, total nitrogen was computed as the sum of the total organic and ammonia nitrogen and the dissolved nitrite plus nitrate nitrogen. Total organic nitrogen was computed by subtracting dissolved ammonia nitrogen from the total ammonia plus organic nitrogen. Because inorganic species of nitrogen (nitrite, nitrate, and ammonia) mainly occur in the dissolved form, these computed total values are considered relatively accurate estimates. Dissolved organic nitrogen concentrations were computed by subtracting dissolved ammonia nitrogen from the dissolved ammonia and organic nitrogen. If the concentration of one of the nitrogen forms used in the computation was a censored value (below the reporting

Table 8. Summary of selected nutrients at sampling sites in the Birmingham area, Alabama, 2000–01

[mg/L, milligrams per liter; N, nitrogen; <, less than; P, phosphorus; —, value not calculated. Site locations are shown in figure 1]

Nutrients	Sample size	Minimum (mg/L)	25% (mg/L)	Median 50% (mg/L)	75% (mg/L)	Maximum (mg/L)
VIL-1						
Nitrogen, ammonia, dissolved (mg/L as N)	12	< 0.020	< 0.020	< 0.020	< 0.041	0.305
Nitrogen, nitrite, dissolved (mg/L as N)	12	< .010	< .010	< .010	.004	.013
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	12	< .100	< .100	.072	.084	1.107
Nitrogen, ammonia plus organic, total (mg/L as N)	12	.053	.079	.095	.613	1.128
Nitrite plus nitrate, dissolved (mg/L as N)	12	.202	.898	.992	1.247	1.48
Phosphorus, total (mg/L as P)	12	.008	.01	.013	.083	.199
Phosphorus, dissolved (mg/L as P)	12	< .006	.007	.008	.011	.092
Phosphorus, orthophosphate, dissolved (mg/L as P)	12	< .010	< .010	.01	.012	.077
VIL-2						
Nitrogen, ammonia, dissolved (mg/L as N)	7	< 0.020	< 0.041	0.089	0.129	0.167
Nitrogen, nitrite, dissolved (mg/L as N)	7	< .010	.013	.017	.019	.025
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	7	.183	.305	.375	.53	.555
Nitrogen, ammonia plus organic, total (mg/L as N)	7	.276	.451	.541	.905	1.346
Nitrite plus nitrate, dissolved (mg/L as N)	7	.331	.333	.604	.906	1.305
Phosphorus, total (mg/L as P)	7	.039	.046	.076	.121	.286
Phosphorus, dissolved (mg/L as P)	7	.015	.021	.036	.063	.089
Phosphorus, orthophosphate, dissolved (mg/L as P)	7	< .010	.011	.013	.058	.062
VIL-3						
Nitrogen, ammonia, dissolved (mg/L as N)	10	0.02	0.075	0.111	0.213	0.239
Nitrogen, nitrite, dissolved (mg/L as N)	10	.013	.017	.025	.043	.077
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	10	.256	.291	.393	.549	.634
Nitrogen, ammonia plus organic, total (mg/L as N)	10	.312	.389	.493	.755	1.192
Nitrite plus nitrate, dissolved (mg/L as N)	10	.431	.489	.875	1.12	1.535
Phosphorus, total (mg/L as P)	10	.012	.02	.027	.069	.269
Phosphorus, dissolved (mg/L as P)	10	.005	.007	.012	.031	.075
Phosphorus, orthophosphate, dissolved (mg/L as P)	10	< .010	< .010	< .018	.016	.055

Table 8. Summary of selected nutrients at sampling sites in the Birmingham area, Alabama, 2000–01—Continued

[mg/L, milligrams per liter; N, nitrogen; <, less than; P, phosphorus; —, value not calculated. Site locations are shown in figure 1]

Nutrients	Sample size	Minimum (mg/L)	25% (mg/L)	Median 50% (mg/L)	75% (mg/L)	Maximum (mg/L)
VIL-4						
Nitrogen, ammonia, dissolved (mg/L as N)	3	0.04	—	—	—	0.219
Nitrogen, nitrite, dissolved (mg/L as N)	3	.014	—	—	—	.032
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	3	.568	—	—	—	.683
Nitrogen, ammonia plus organic, total (mg/L as N)	3	.573	—	—	—	1.268
Nitrite plus nitrate, dissolved (mg/L as N)	3	.551	—	—	—	6.914
Phosphorus, total (mg/L as P)	3	.307	—	—	—	.912
Phosphorus, dissolved (mg/L as P)	3	.095	—	—	—	.721
Phosphorus, orthophosphate, dissolved (mg/L as P)	3	.074	—	—	—	.712
VAL-1						
Nitrogen, ammonia, dissolved (mg/L as N)	10	0.044	0.125	0.181	0.294	0.515
Nitrogen, nitrite, dissolved (mg/L as N)	10	.012	.038	.077	.149	.181
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	10	.232	.358	.694	.891	1.204
Nitrogen, ammonia plus organic, total (mg/L as N)	10	.422	.567	.818	1.003	1.467
Nitrite plus nitrate, dissolved (mg/L as N)	10	.187	.962	1.387	1.838	1.946
Phosphorus, total (mg/L as P)	10	.096	.133	.164	.246	.289
Phosphorus, dissolved (mg/L as P)	10	.056	.072	.119	.208	.223
Phosphorus, orthophosphate, dissolved (mg/L as P)	10	.044	.056	.08	.155	.185
VAL-2						
Nitrogen, ammonia, dissolved (mg/L as N)	11	< 0.020	0.027	0.038	0.141	0.234
Nitrogen, nitrite, dissolved (mg/L as N)	11	< .010	.01	.014	.037	.07
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	11	.19	.21	.25	.48	.8
Nitrogen, ammonia plus organic, total (mg/L as N)	11	.25	.27	.33	.53	2.2
Nitrite plus nitrate, dissolved (mg/L as N)	11	.057	.309	1.08	1.3	2.44
Phosphorus, total (mg/L as P)	11	.033	.034	.057	.085	.421
Phosphorus, dissolved (mg/L as P)	11	.005	.029	.044	.07	.085
Phosphorus, orthophosphate, dissolved (mg/L as P)	11	< .010	.014	.032	.051	.053
VAL-3						
Nitrogen, ammonia, dissolved (mg/L as N)	10	< 0.020	< 0.041	0.02	0.033	0.074
Nitrogen, nitrite, dissolved (mg/L as N)	10	< .010	.003	.01	.013	.03
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	10	.109	.152	.204	.245	.306
Nitrogen, ammonia plus organic, total (mg/L as N)	10	.156	.194	.264	.37	.819
Nitrite plus nitrate, dissolved (mg/L as N)	10	.207	.37	.85	1.063	2.027
Phosphorus, total (mg/L as P)	10	.018	.021	.027	.094	.203
Phosphorus, dissolved (mg/L as P)	10	.011	.016	.019	.064	.074
Phosphorus, orthophosphate, dissolved (mg/L as P)	10	< .010	.01	.016	.061	.058
LCR						
Nitrogen, ammonia, dissolved (mg/L as N)	3	< 0.020	—	—	—	0.052
Nitrogen, nitrite, dissolved (mg/L as N)	3	< .010	—	—	—	< .010
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	3	.15	—	—	—	.399
Nitrogen, ammonia plus organic, total (mg/L as N)	3	.2	—	—	—	.727
Nitrite plus nitrate, dissolved (mg/L as N)	3	.951	—	—	—	2.235
Phosphorus, total (mg/L as P)	3	.03	—	—	—	.058
Phosphorus, dissolved (mg/L as P)	3	.019	—	—	—	.041
Phosphorus, orthophosphate, dissolved (mg/L as P)	3	.02	—	—	—	.029
FMC						
Nitrogen, ammonia, dissolved (mg/L as N)	8	< 0.020	< 0.020	< 0.041	< 0.041	< 0.041
Nitrogen, nitrite, dissolved (mg/L as N)	8	< .006	< .006	< .010	.003	.003
Nitrogen, ammonia plus organic, dissolved (mg/L as N)	8	.068	.105	.134	.231	.322
Nitrogen, ammonia plus organic, total (mg/L as N)	8	.109	.139	.215	.357	.675
Nitrite plus nitrate, dissolved (mg/L as N)	8	.18	.231	.296	.402	.656
Phosphorus, total (mg/L as P)	8	< .004	.005	.009	.03	.089
Phosphorus, dissolved (mg/L as P)	8	< .006	.003	.005	.008	.023
Phosphorus, orthophosphate, dissolved (mg/L as P)	8	< .010	< .010	< .18	< .018	.012

limit), the censored concentration was assumed to be negligible and substituted with zero.

Phosphorus is present in natural waters in several forms—orthophosphate, which includes species of PO_4^{-3} ion; polyphosphates and metaphosphates; and organic phosphorus. Orthophosphate is the most stable and biochemically available form of phosphorus and is readily available for uptake by aquatic plants. In many natural waters, much of the phosphorus present is organically bound. Phosphorus tends to adsorb strongly onto particles in soils, suspended solids, and streambed sediment. The most common point source of phosphorus is municipal wastewater discharge, which contains phosphorus as orthophosphate and organic phosphorus. Common nonpoint sources of phosphorus include weathering of natural soils and rocks, and runoff from agricultural land. Phosphate from fertilizers binds to soils and may add considerable amounts of suspended phosphate to streams by erosion during storm events (Hem, 1985).

Three different forms of phosphorus were measured during this study—dissolved phosphorus, orthophosphate, and total phosphorus (table 8). Dissolved phosphorus includes the orthophosphate form and other forms. Dissolved non-orthophosphorus was computed by subtracting the orthophosphate from the dissolved phosphorus. Suspended phosphorus (particulate form, computed as total minus dissolved) includes phosphorus that is attached to or part of suspended sediment and phosphorus that is incorporated into algal cells (Tornes and others, 1997).

Nutrient enrichment in a stream can produce excessive growth of algae. In flowing waters, however, the occurrence of increased algal growth is not limited by only nutrient concentrations. Channel geomorphology, habitat, and flow characteristics of the stream also are considered to be important variables. Algae in streams can occur as periphyton (attached to substrate at the bottom of the stream) or phytoplankton (suspended in the water column). Phytoplankton tend to be less useful for indicating and integrating water-quality changes relative to a fixed sampling location, particularly in wadeable streams and rivers, because the plankton suspended in the water column of many streams consists of benthic algal species that have been dislodged from periphyton microhabitats as a result of physical disturbance, such as scouring. During low- or base-flow conditions, however, phytoplankton growth can be predominant in a nutrient-enriched stream. In this study, the algal response to nutrient loading was estimated by measuring the photosynthetic pigments, chlorophyll a and chlorophyll b in the water column of the streams. Chlorophyll a is present in most algal families, but chlorophyll b is present only in green algae.

The following sections present an overview of selected constituent concentrations at sampling sites on Valley Creek (VAL-1, VAL-2, VAL-3) and Village Creek (VIL-1, VIL-2, VIL-3, VIL-4), and at reference sites FMC and LCR. Statistical summaries of selected nutrients are reported in table 8. Bar charts are used to show the speciation of nitrogen and phosphorus based on median concentrations. Box plots or scatter plots, which differentiate between high-flow and low-flow samples,

USGS personnel processing a water-quality sample using a Teflon cone splitter (photograph taken by J.B. Atkins, USGS).
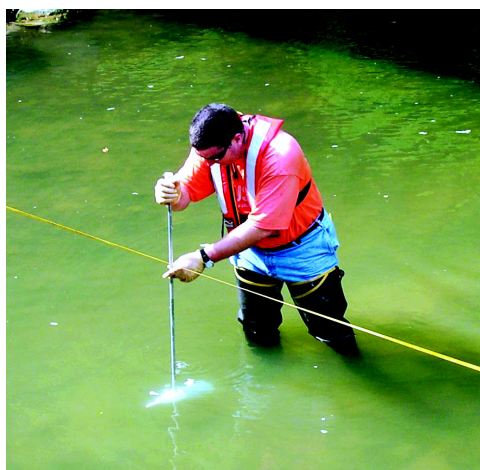
USGS personnel collecting a water-quality sample (photograph taken by J.B. Atkins, USGS).

are used to display the variability in nutrient concentrations. Median nutrient concentrations were not computed for LCR or VIL-4 because of the limited number of samples (3) at each site.

Nitrogen Concentrations and Distribution

Median concentrations of nitrate, nitrite, ammonia, and organic nitrogen at seven of the nine sites are shown in figure 11. The sum of each of the components of the bar chart approximates the median total nitrogen concentration. The highest median concentrations of dissolved nitrogen were detected at VAL-1 and the lowest median concentrations were detected at FMC. In Village Creek, median concentrations of nitrite and ammonia increased in a downstream direction. Median concentrations of organic nitrogen in Village Creek were highest at VIL-2; median concentrations of nitrate were highest at VIL-1. In Valley Creek, median concentrations of nitrate, nitrite, ammonia, and organic nitrogen decreased in a downstream direction. The highest concentration of nitrite plus nitrate (6.914 mg/L) was measured at VIL-4 (table 8). The range and distribution of nitrate, nitrite, ammonia, and organic nitrogen concentrations at each of the sampling sites are shown in figure 12.

Maximum concentrations of nitrate and nitrite were detected during low flow at all sites; maximum concentrations of ammonia were detected during low flow at all sites except VIL-4, VAL-3, and FMC; maximum concentrations of organic nitrogen were detected during low flow at all sites except VAL-2 (fig. 13). The high concentrations of nitrate, nitrite, ammonia, and organic nitrogen during low flow at the majority of the sites indicate that the nutrient concentrations may be point-source related (or present in the ground water). However, high levels of many nutrients were seen during both high and low flow, indicating both point and nonpoint sources (fig. 13). The relation between nutrient concentrations and point and nonpoint sources is complex, and the power of the tests used to analyze these data is limited due to the sample size as well as the range of hydrologic factors affecting the samples.

Statistically significant differences ($p \leq 0.05$) in nitrogen concentrations were found (table 6). Total nitrogen concentrations at VIL-3, VAL-1, and VAL-2 were significantly greater than concentrations at the reference site (FMC). Ammonia and nitrite concentrations at VIL-2, VIL-3, VAL-1, and VAL-2 were significantly greater than concentrations at FMC. In Village Creek, concentrations of nitrite were significantly
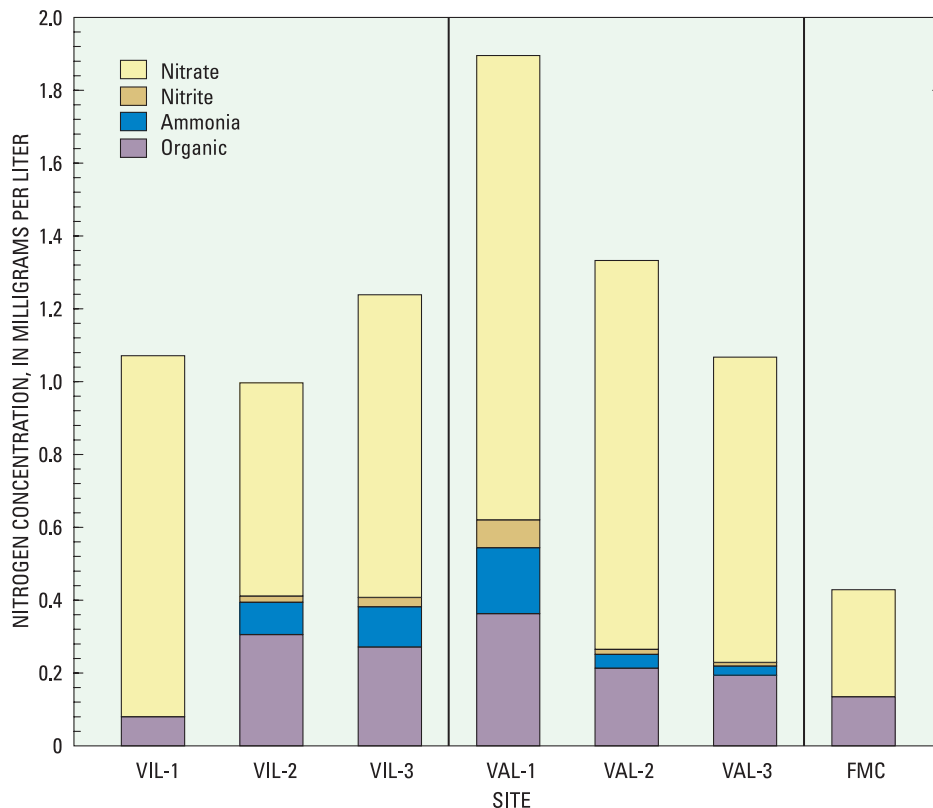
Figure 11. Median concentrations of measured forms of dissolved nitrogen in water samples from streams in the Birmingham area, Alabama, 2000–01.
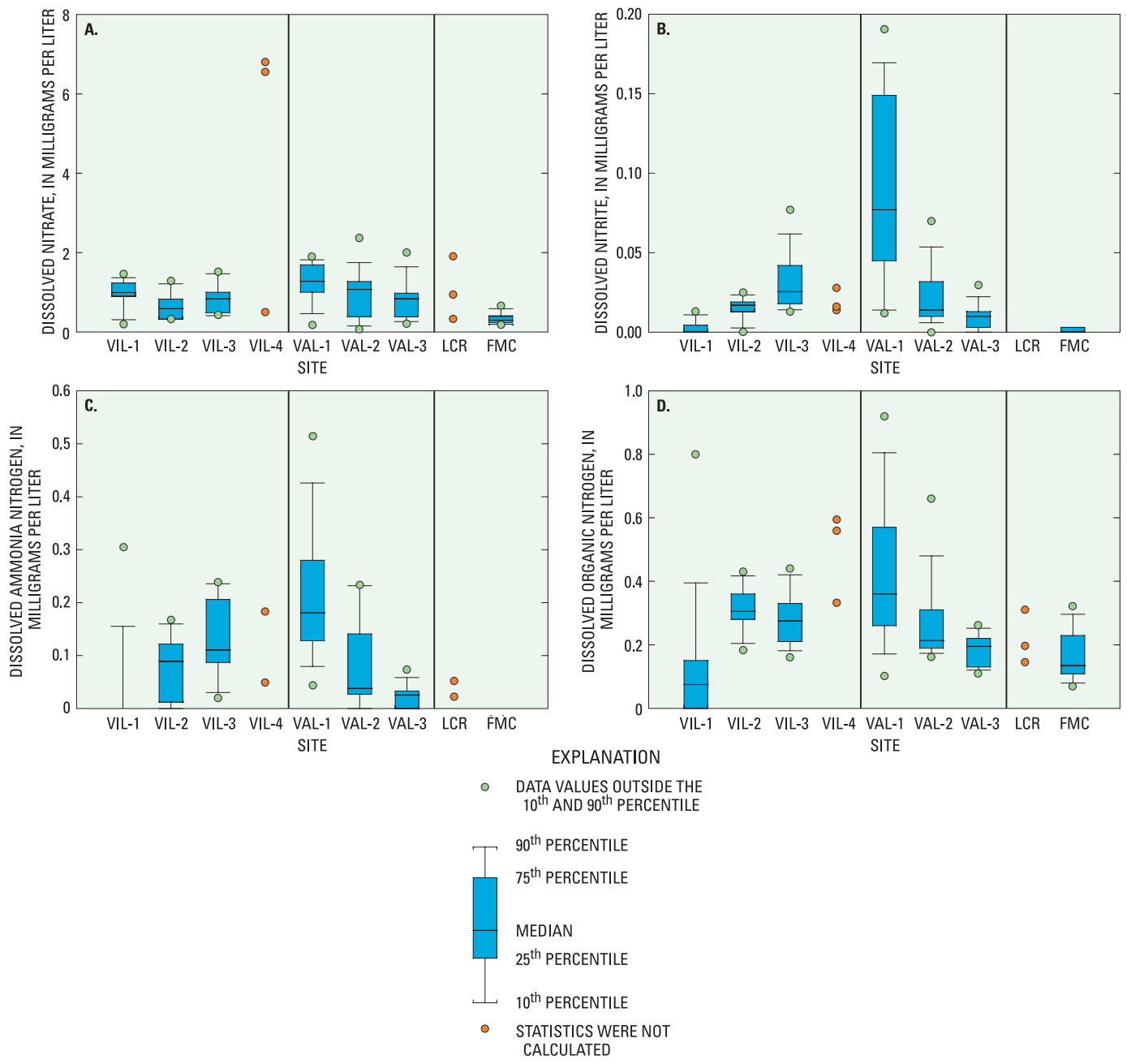
Figure 12. Box plots of dissolved (A) nitrate, (B) nitrite, (C) ammonia, and (D) organic nitrogen concentrations in water samples from streams in the Birmingham area, Alabama, 2000–01.

elevated at VIL-2 compared to VIL-1, and at VIL-3 compared to VIL-1 or VIL-2; concentrations of ammonia were significantly elevated at VIL-3 compared to ammonia concentrations at VIL-1 (table 6). In Valley Creek, concentrations of nitrite and ammonia were significantly elevated at VAL-1 compared to concentrations at VAL-2 or VAL-3; concentrations of total nitrogen were significantly elevated at VAL-1 compared to those concentrations at VAL-3 (table 6).

In December 2000, the USEPA published recommendations for ambient water-quality criteria for surface water in Nutrient Ecoregion XI (U.S. Environmental Protection Agency, 2000a). Nutrient Ecoregion XI is composed mostly of the unglaciated, forested low mountains and upland plateaus in more than 14 states of the central and eastern United States and is subdivided into 8 Level III Ecoregions. Birmingham is located in the Ridge and Valley Level III Ecoregion. For
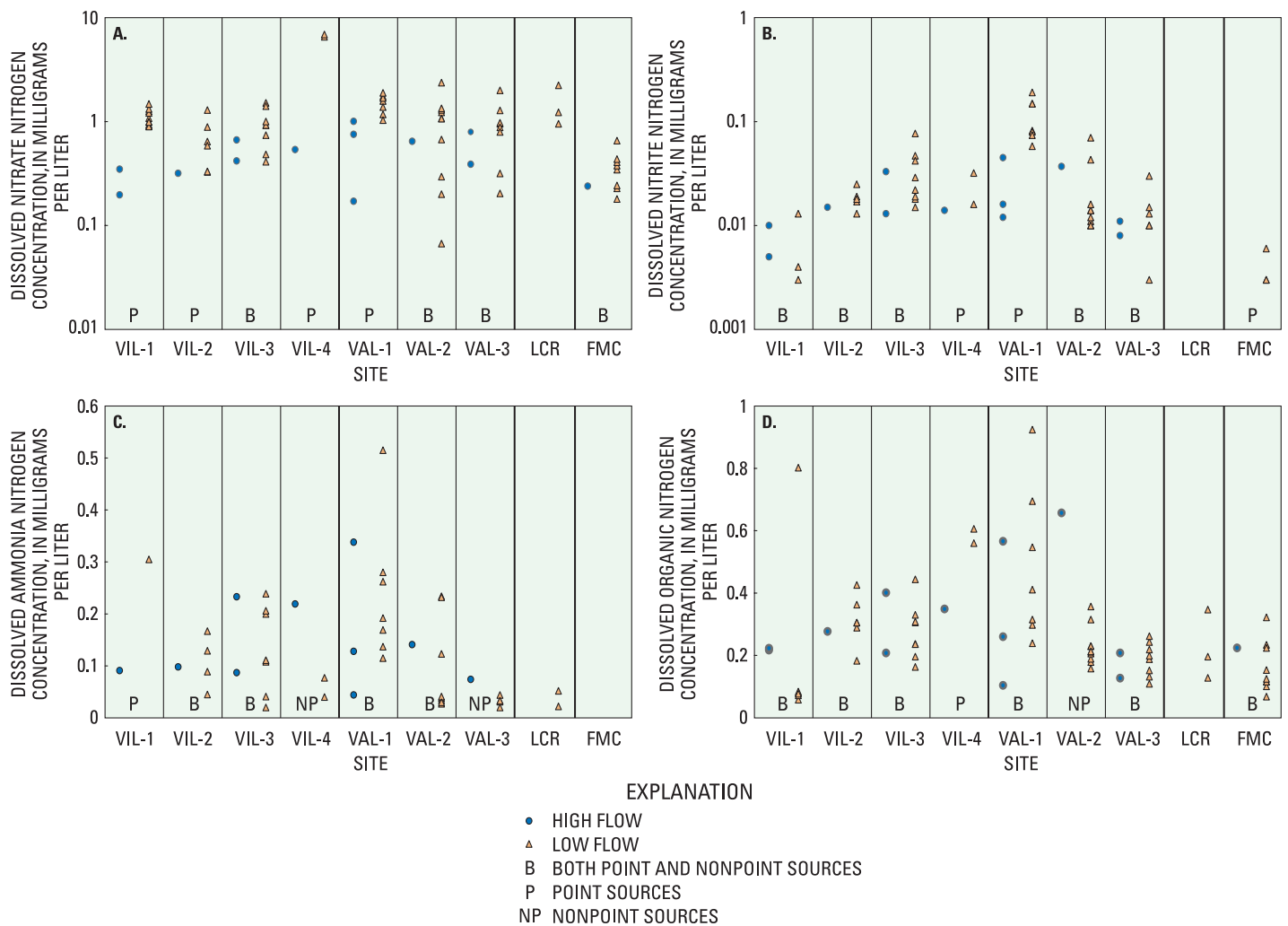
Figure 13. Dissolved (A) nitrate, (B) nitrite, (C) ammonia, and (D) organic nitrogen concentrations in water samples collected during high and low flow from streams in the Birmingham area, Alabama, 2000–01.

each Nutrient Ecoregion, the USEPA developed a set of recommendations for two causal variables (total nitrogen and total phosphorus) and two early indicator response variables (chlorophyll *a* and some measure of turbidity). For the Ridge and Valley Level III Ecoregion, the USEPA recommended that total nitrogen not exceed 0.214 mg/L for rivers and streams. During this study, concentrations of total nitrogen exceeded this recommendation in all samples, including reference sites.

Phosphorus Concentrations and Distribution

Median concentrations of dissolved phosphorus varied considerably among all sites during this study (fig. 14). The highest median concentrations of phosphorus were detected at VAL-1 and the lowest median concentrations were detected at FMC. At Village Creek, median concentrations of suspended phosphorus and non-orthophosphorus were highest at VIL-2 followed by those at VIL-3 and VIL-1. Of the Village Creek sites,

median concentrations of orthophosphate were highest at VIL-2. In Valley Creek, median concentrations of suspended phosphorus, orthophosphate, and non-orthophosphorus were highest at VAL-1 and decreased in a downstream direction. The range and distribution of suspended phosphorus, orthophosphate, and non-orthophosphorus at each of the sampling sites are shown in figure 15. Maximum concentrations of suspended phosphorus were detected during high flow at all sites on Village and Valley Creeks. Concentrations of orthophosphate at VIL-4 and VAL-1 were an order of magnitude greater during low flow than during high flow, indicating that the high concentrations may be due to the presence of point sources.

Significant differences ($p \leq 0.05$) in phosphorus concentrations were identified among sites (table 6). Total phosphorus concentrations at VIL-2, VAL-1, and VAL-2 were significantly higher than at FMC. Dissolved orthophosphate concentrations were significantly higher at VIL-2, VAL-1, VAL-2, and VAL-3 than at FMC.
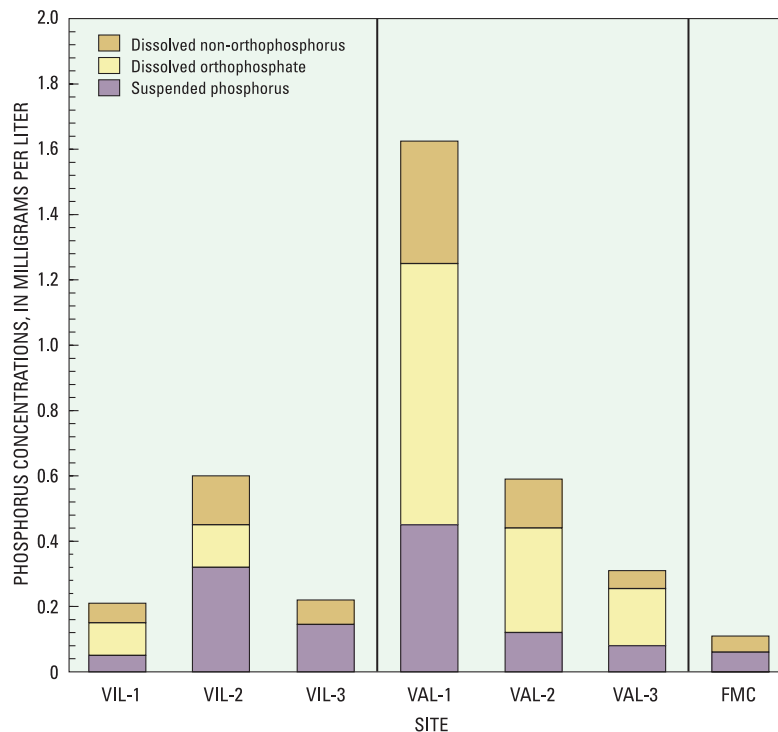
Figure 14. Median concentrations of measured forms of dissolved phosphorus in water samples from streams in the Birmingham area, Alabama, 2000–01.

Suspended phosphorus concentrations were significantly higher at VAL-1 than at FMC. At Village Creek, total phosphorus, suspended phosphorus, and dissolved non-orthophosphorus concentrations were significantly higher at VIL-2 than at VIL-1 (table 6). At Valley Creek, total phosphorus, suspended phosphorus, dissolved non-ortho-phosphorus, and dissolved orthophosphate concentrations were significantly higher at VAL-1 than at VAL-2 or VAL-3 (table 6).

For the Ridge and Valley Level III Ecoregion, the USEPA recommended that total phosphorus not exceed 10 µg/L for rivers and streams (U.S. Environmental Protection Agency, 2000a). During this study, concentrations of total phosphorus exceeded this recommendation at sites on Village and Valley Creeks in 60 of 63 samples (95.2 percent). At the reference sites, concentrations of total phosphorus exceeded this recommendation in 7 of 11 samples (63.6 percent).

Programming data-collection platform for satellite telemetry of hydrologic data (photograph taken by J.B. Atkins, USGS).
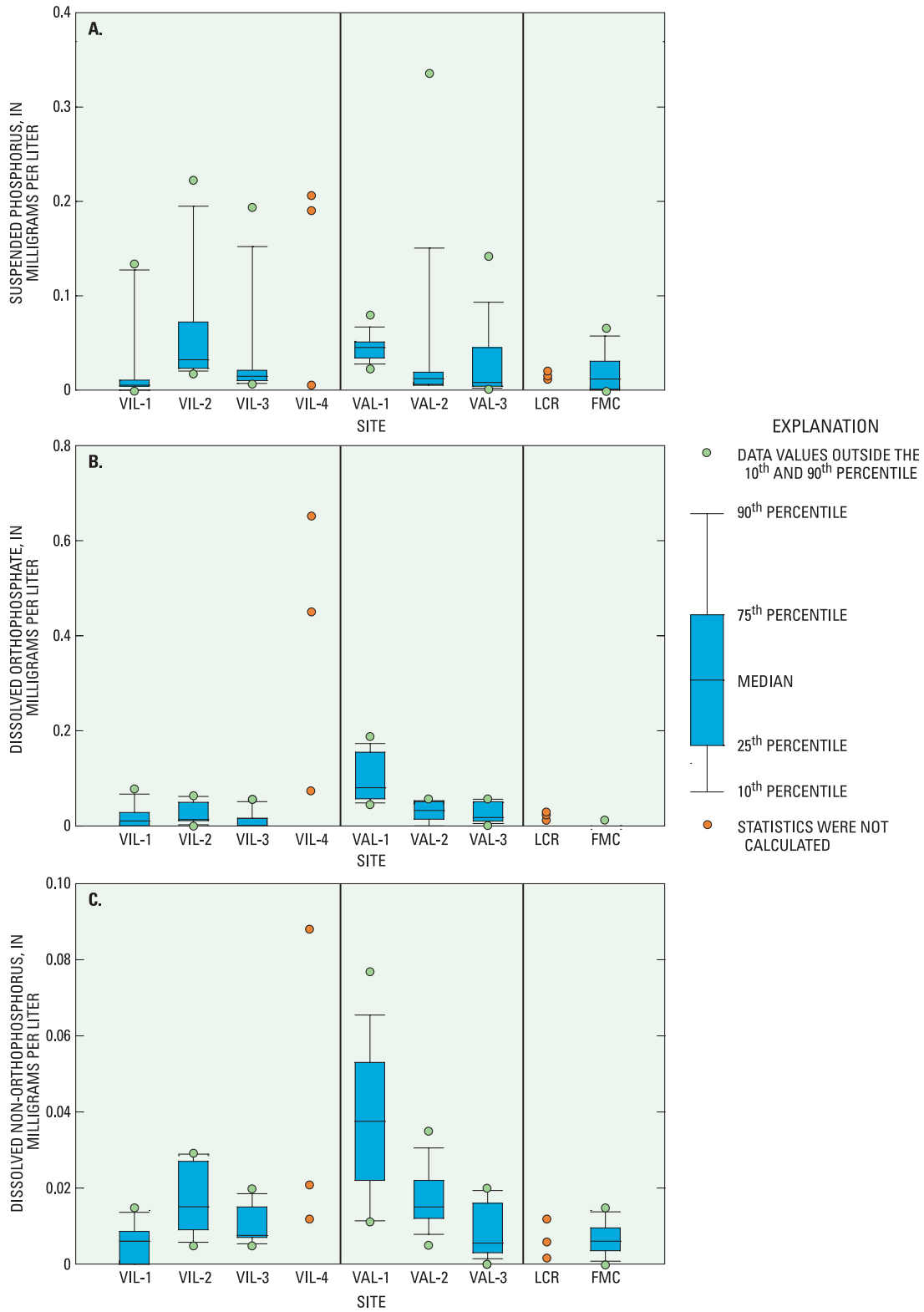
Figure 15. Box plots of (A) suspended phosphorus, (B) dissolved orthophosphate, and (C) dissolved non-orthophosphorus concentrations in water samples from streams in the Birmingham area, Alabama, 2000–01.

Chlorophyll *a* and Chlorophyll *b* Concentrations and Distribution

Chlorophyll *a* was detected in 5 of 46 samples at four sites (VIL-2, VIL-3, VAL-2, and VAL-3). Concentrations of chlorophyll *a* ranged from 6 to 31 µg/L (appendix table 2-2). Chlorophyll *a* was detected at VAL-2 and VIL-3 during low flow and ranged from 6 to 9.1 µg/L; it was detected at VIL-2, VAL-2, and VAL-3 during high flow and ranged from 10 to 31 µg/L. For the Ridge and Valley Level III Ecoregion, the USEPA recommended that chlorophyll *a* not exceed 1.063 µg/L for rivers and streams. During this study, chlorophyll *a* exceeded this recommendation at sites on Village and Valley Creeks in 5 of 46 samples (11 percent). Chlorophyll *b* was not detected in any sample.

Comparison of Nutrient Data from Urban Sites in Birmingham to Urban Sites Nationwide

Nutrient data from Village and Valley Creeks were compared to nutrient data collected from urban sites throughout the Nation in the NAWQA Program (U.S. Geological Survey, 2001). More than 2,800 nutrient samples were collected from urban NAWQA sites between 1991 and 2001. Nutrient concentrations from Village and Valley Creeks were plotted over a bar graph

illustrating ranges, which included the lowest 25 percent, the middle 50 percent, and the highest 25 percent of the Birmingham data (fig. 16). To the right of each bar graph in figure 16 is another bar graph illustrating the same ranges for data collected at urban NAWQA sites nationwide. The statistical quartiles of both data sets were computed by using detected values in order to better illustrate the spread of the data. The nutrient concentrations detected in this study fell within a narrower range than the concentrations reported nationally.

Instantaneous Nutrient Loads and Yields

This section presents instantaneous nutrient loads and yields calculated at all the sampling sites (table 9). Median instantaneous loads of total nitrogen and total phosphorus were calculated in units of kilograms per day (kg/d) at sites on Village, Valley, and Fivemile Creeks—excluding LCR and VIL-4 (table 9). In Village Creek, median nitrogen loads ranged from 11.2 to 77.7 kg/d and median phosphorus loads ranged from 0.093 to 3.83 kg/d. In Valley Creek, median nitrogen loads ranged from 12.2 to 90 kg/d, and median phosphorus loads ranged from 1.06 to 2.09 kg/d. The
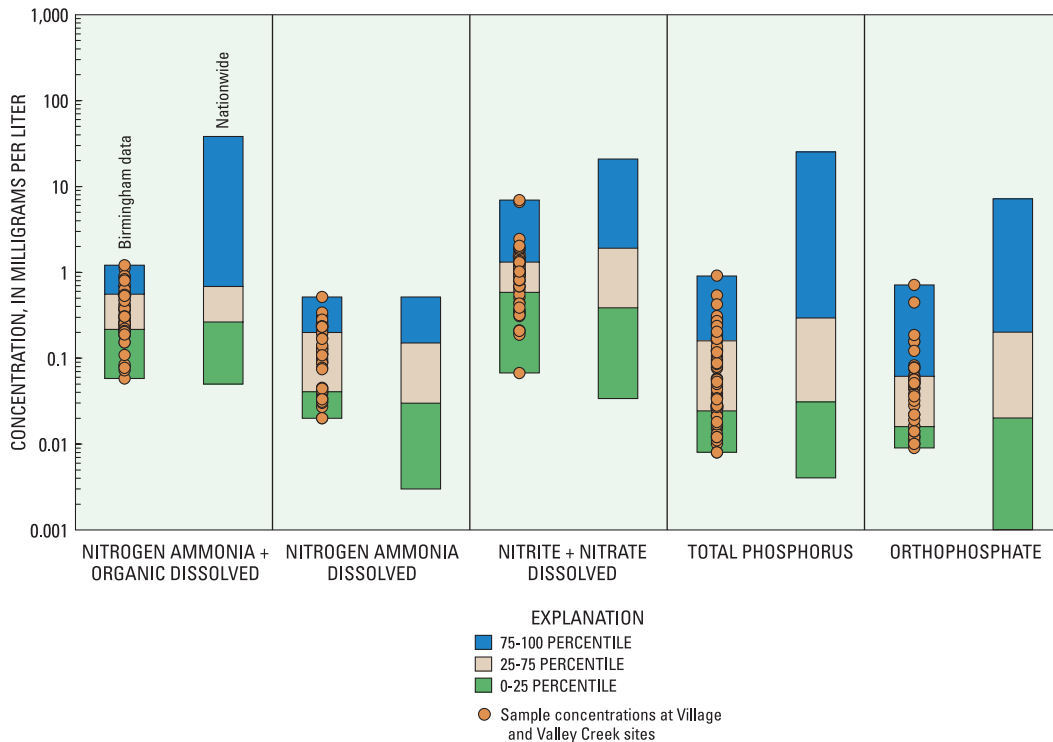
Figure 16. Comparison of nutrients in water samples from urban sites in the Birmingham area, Alabama, to urban sites nationwide.

Table 9. Instantaneous loads of total nitrogen and total phosphorus at sites in the Birmingham area, Alabama, 2000–01

[kg/d, kilograms per day; —, median values were not calculated because of limited sample size]

Site label (fig. 1)	Instantaneous loads of total nitrogen (kg/d)			Instantaneous loads of total phosphorus (kg/d)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
VIL-1	2.90	11.2	338	0.035	0.093	61.3
VIL-2	11.1	56.6	3,743	.713	3.83	638
VIL-3	28.7	77.7	1,627	.407	1.39	272
VIL-4	1,520	—	10,847	115	—	1,831
VAL-1	6.11	12.2	227	.430	1.06	39.9
VAL-2	7.29	43.1	2,626	.502	1.82	385
VAL-3	12.4	90.0	2,835	.602	2.09	477
LCR	49.6	—	109	.955	—	3.99
FMC	.493	17.1	335	.012	.129	29.1

highest loads of nitrogen and phosphorus were found at VIL-4, but median values were not calculated because of the limited sample size (3). The highest loads of both nitrogen and phosphorus were calculated during periods of high flow. Statistically significant differences ($p \leq 0.05$) in nutrient loads were identified among sites (table 6). Nitrogen loads at VIL-3 were significantly greater than nitrogen loads at VIL-1; phosphorus loads at VIL-2 and VIL-3 were significantly greater than phosphorus loads at VIL-1 (table 6).

Although loads are useful in understanding the total contribution of nutrients, loads are heavily weighted by streamflow, which is dependent on the size of the watershed and runoff. Yields, however, indicate how much material is contributed per unit area of the watershed and can be used to determine relative sources of nutrients. Instantaneous yields were calculated, in units of kilograms per hectare per year ([kg/ha]/yr) for all the sampling sites (table 10). In Village Creek, median nitrogen yields were highest at VIL-3 followed by those at VIL-2 and VIL-1; median phosphorus yields were highest at VIL-2 followed by those at VIL-3 and VIL-1. In Valley Creek, median nitrogen yields were highest at VAL-3 followed by those at VAL-1 and VAL-2; median

Table 10. Nutrient yields at sites in the Birmingham area, Alabama, and at sites nationwide

[(kg/ha)/yr, kilograms per hectare per year; —, median values were not calculated because of limited sample size]

Site label (fig. 1)	Total nitrogen yield ([kg/ha]/yr)			Total phosphorus yield ([kg/ha]/yr)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
VIL-1	0.76	2.93	88.2	0.01	0.02	16.0
VIL-2	.67	3.40	225	.04	.23	38.3
VIL-3	1.30	3.51	73.5	.02	.06	12.3
VIL-4	52.7	—	376	3.98	—	63.4
VAL-1	1.46	2.93	54.3	.10	.25	9.55
VAL-2	.49	2.91	177	.03	.12	26.0
VAL-3	.57	4.12	130	.03	.10	21.8
LCR	2.92	—	6.39	.06	—	.23
FMC	.05	1.85	36.3	.00	.01	3.15
Urban[a]	1.48	5.5	38.5	0.19	1.10	6.23
Forest[a]	1.38	2.46	6.26	.02	.21	.83

[a] National data summarized from Reckhow and others (1980).

phosphorus yields were highest at VAL-1 followed by those at VAL-2 and VAL-3. No statistically significant differences ($p \leq 0.05$) were identified between nitrogen or phosphorus yields among sites (table 6).

Different land-use practices affect the amount of nutrients that are contributed to surface water by nonpoint sources. Values of nutrient export from a variety of nonpoint sources were summarized in a study by Reckhow and others (1980). The ranges in nutrient yields are a result of differences in climate, soils, and land-management practices for each category. Instantaneous yields for total nitrogen and total phosphorus for sites in Birmingham were compared to the yields from urban sites in 20 watersheds from across the country (table 10). For a watershed draining urban land use, the median nitrogen yield from nonpoint sources was 5.5 (kg/ha)/yr. Median yields for urban sites in Birmingham were less than those at the national sites. Maximum nitrogen yields at urban sites in Birmingham exceeded the maximum nitrogen yields measured in other urban environments across the country (table 10). The median phosphorus yield from nonpoint sources at urban sites across the country was 1.1 (kg/ha)/yr. The median phosphorus yields for urban sites in the Birmingham area were approximately an order of magnitude less than those at urban sites across the country (table 10). Maximum phosphorus yields in Birmingham exceeded maximum phosphorus yields in other urban environments across the country (table 10).

Biochemical Oxygen Demand and Total Organic Carbon

Biochemical oxygen demand (BOD_5) is the amount of dissolved oxygen used by microorganisms to break down organic matter in water at 20 degrees Celsius (°C) during a 5-day period. The standard BOD_5 value is commonly used to define the strength of municipal wastewaters, to evaluate the efficiency of treatment by measuring oxygen demand remaining in the effluent, and to determine the amount of organic pollution in surface waters (Viessman and Hammer, 1993). Most moderately contaminated streams have BOD_5 values ranging between 1 and 8 mg/L (Nemerow, 1974). Typical domestic wastewater can have BOD_5 values ranging between 50 and 200 mg/L (Camp and Meserve, 1974; McGhee, 1991). In Village Creek, BOD_5 ranged from 0.3 (VIL-1) to 8.7 mg/L (VIL-2); in Valley Creek, BOD_5 ranged from 0.3 (VAL-3) to 8.6 mg/L (VAL-3); at FMC, BOD_5 ranged from 0.3 to 8.6 mg/L (appendix table 2-2).

The total organic carbon (TOC) represents the amount of carbon present in organic molecules. The average TOC concentration in rivers is about 7 mg/L (Thurman, 1985). TOC concentrations can be elevated due to natural conditions, such as in marshland or boggy areas, where average concentrations may range from 17 to 33 mg/L (Thurman, 1985). In contaminated rivers, TOC concentrations can be even higher (30–58 mg/L; Dojlido and Best, 1993). In Village Creek, TOC ranged from 0.534 (VIL-1) to 23.4 mg/L (VIL-2); in Valley Creek, TOC ranged from 1.93 (VAL-3) to 29.2 mg/L (VAL-2); at FMC, TOC ranged from 1.57 to 8.14 mg/L (appendix table 2-2). Higher TOC concentrations were detected during high flow. TOC concentrations at VIL-2 were significantly higher than TOC concentrations at VIL-1 (table 6).

Fecal Indicator Bacteria

Fecal indicator bacteria are useful in assessing water quality because they are commonly associated with the presence of other waterborne pathogens (Myers and Wilde, 1999). The presence or absence of indicator organisms is used to evaluate the microbiological quality of water because current techniques to analyze for pathogens are either quantitatively unreliable or difficult to perform. The most common fecal indicator bacteria include fecal coliform, *E. coli*, and enterococci. Although most species of fecal coliform bacteria can be detected in the feces of humans and other warm-blooded animals, some species can occur naturally in soils. The USEPA has recommended that *E. coli* or enterococci be used instead of fecal coliform bacteria as an indicator of fecal contamination in waters used for recreation (U.S. Environmental Protection Agency, 1986). This recommendation was based on studies that showed a strong correlation between the number of gastrointestinal illnesses associated with water-contact recreational activities and the concentrations of *E. coli* or enterococci bacteria.

Concentrations of fecal indicator bacteria often depend on hydrologic conditions prior to and during sampling. For example, higher concentrations occur during high flow as a result of nonpoint sources, such as overland runoff that carries high concentrations of bacteria from many different sources, including domestic pets and wildlife. Combined sewer overflows or sanitary sewer overflows also can contribute high levels of bacteria during storm events. Leaking sanitary sewer lines or connections to sewer lines are likely the source of high levels of bacteria during low flow. When point-source discharges contribute fecal indicator bacteria, high concentrations may be present during low flow (leaking sanitary sewer lines or failing septic systems) as well as

high flow (combined sewer overflows; Gregory and Frick, 2000).

Concentrations of *E. coli*, enterococci, and fecal coliform bacteria in water samples collected from the Birmingham study sites are summarized in table 11—and are described in detail in appendix table 2-2. Scatter plots, which differentiate between high-flow and low-flow samples, were used to display the variability in concentrations of *E. coli*, enterococci, and fecal coliform bacteria (fig. 17). The USEPA has defined criteria for single sample densities for *E. coli* and enterococci based on body contact and frequency of use (U.S. Environmental Protection Agency, 2001). For infrequent, full-body recreational contact, *E. coli* and enterococci samples should not exceed 576 and 151 col/100 mL, respectively (table 12). The ADEM has defined criteria for fecal coliform bacteria based on water-use classification (Alabama Department of Environmental Management, 2000d). For agricultural and industrial use, the geometric mean of at least five samples taken over a 30-day period shall not exceed 2,000 col/100 mL; nor shall any one sample exceed a maximum of 4,000 col/100 mL (table 12).

E. coli concentrations ranged from 3 to 78,000 col/100 mL (table 11). Median concentrations of *E. coli* were highest at VAL-1 and lowest at FMC (table 11). In Village Creek, the highest concentration (44,000 col/100 mL) was detected at VIL-4 during low flow in July 2000 (fig. 17A; appendix table 2-2). Median concentrations of *E. coli* in Village Creek were highest at VIL-2, followed by VIL-1 and VIL-3, respectively (table 11). In Valley Creek, the highest concentration (78,000 col/100 mL) was detected at VAL-1 during low flow in August 2000 (fig. 17A; appendix table 2-2).

Median concentrations of *E. coli* in Valley Creek were highest at VAL-1 and decreased in a downstream direction (table 11).

Similar patterns were observed for concentrations of enterococci and fecal coliform bacteria (table 11; fig. 17). Enterococci concentrations ranged from 12 to 70,000 col/100 mL; fecal coliform concentrations ranged from 9 to 85,000 col/100 mL. Median concentrations of enterococci were highest at VIL-2 and lowest at VAL-3; median concentrations of fecal coliform were highest at VAL-1 and lowest at FMC (table 11). Along Village Creek, the highest concentrations of enterococci (69,000 col/100 mL) and fecal coliform (28,000 col/100 mL) were detected at VIL-1 during high flow in November 2000 (fig. 17B,C; appendix table 2-2). In Village Creek, median concentrations were highest at VIL-2, followed by VIL-1 and VIL-3, respectively (table 11). In Valley Creek, the highest concentrations of enterococci (70,000 col/100 mL) and fecal coliform (85,000 col/100 mL) were detected at VAL-1 during high flow after a storm in November 2000 (fig. 17B,C; appendix table 2-2). Median concentrations for enterococci and fecal coliform were highest at VAL-1 and decreased in a downstream direction (table 11).

Enterococci and *E. coli* concentrations in the study area were compared to USEPA criteria (single sample maximum for infrequent full-body contact), and exceedance frequencies were calculated (table 13). Fecal coliform concentrations were compared to ADEM single-sample criterion for streams classified for industrial and agricultural use. Concentrations of enterococcal bacteria at sites in the Birmingham area exceeded the USEPA criterion (151 col/100 mL) in 80 percent of the samples; *E. coli* concentrations exceeded the USEPA criterion

Table 11. Statistical summary of *Escherichia coli*, enterococci, and fecal coliform concentrations at sites in the Birmingham area, Alabama, 2000–01

[col/100 mL, colonies per 100 milliliters; —, median values were not calculated because of limited sample size; >, greater than]

Site label (fig. 1)	*Escherichia coli* (col/100 mL)			Enterococci (col/100 mL)			Fecal coliform (col/100 mL)		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
VIL-1	250	780	31,000	330	1,500	69,000	270	1,300	28,000
VIL-2	440	3,000	9,200	900	5,700	18,000	350	2,300	13,000
VIL-3	34	280	17,000	17	315	25,000	23	400	19,000
VIL-4	200	—	44,000	3,000	—	>4,000	180	—	>3,000
VAL-1	770	13,600	78,000	600	4,300	70,000	2,100	13,950	85,000
VAL-2	51	800	25,000	59	360	22,000	41	680	16,000
VAL-3	5	225	11,000	12	110	52,000	10	98	16,000
LCR	270	—	1,800	72	—	290	62	—	490
FMC	3	175	3,000	62	810	14,000	9	70	3,000
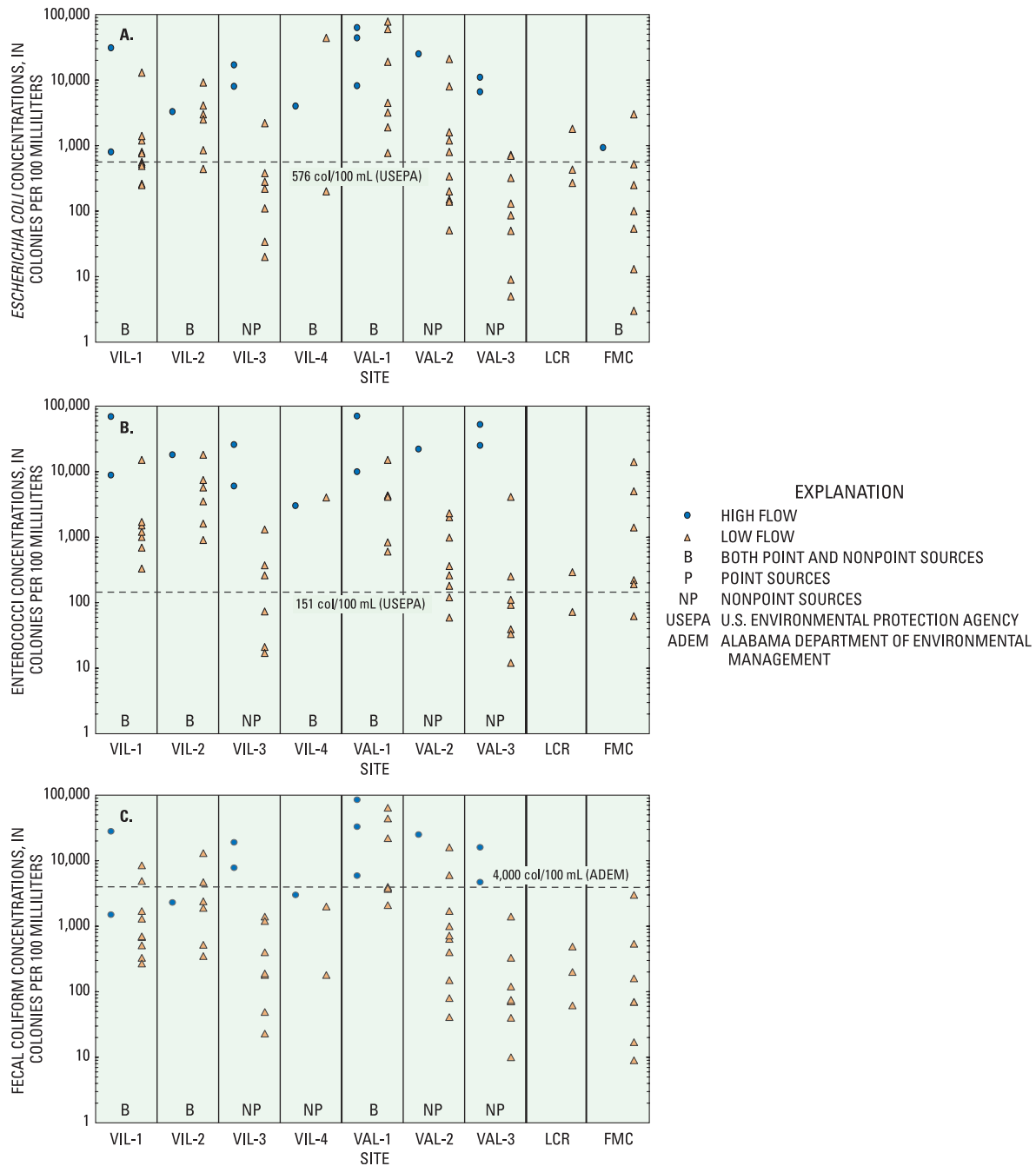
Figure 17. (A) *Escherichia coli*, (B) enterococci, and (C) fecal coliform concentrations in water samples collected during high and low flow from streams in the Birmingham area, Alabama, 2000–01.

(576 col/100 mL) in 56 percent of the samples; fecal coliform concentrations exceeded the ADEM criterion (4,000 col/100 mL) in 26 percent of the samples (table 13). Statistically significant differences ($p \leq 0.05$) in bacteria concentrations were identified among sites (table 6). *E. coli* and fecal coliform concentrations at VAL-1 were significantly higher than concentrations at FMC. Along Valley Creek, *E. coli* concentrations at

VAL-1 were significantly higher than concentrations at VAL-2 or VAL-3.

Concentrations of bacteria at VIL-3, VAL-2, and VAL-3 were elevated during high flow rather than low flow, indicating the presence of nonpoint sources (fig. 17). Concentrations of bacteria at VIL-1, VIL-2, VIL-4, and VAL-1 were elevated during low and high flow, indicating both point and nonpoint sources (fig. 17). Three high-flow

Table 12. State and Federal standards and criteria for bacteria in surface water

[USEPA, U.S. Environmental Protection Agency; col/100 mL, colonies per 100 milliliters; ADEM, Alabama Department of Environmental Management]

Fecal indicator bacteria	USEPA Primary Drinking Water Standard[a] (col/100 mL)	ADEM swimming and other whole-body water contact sports[b] criterion (col/100 mL)	USEPA single sample infrequent full-body contact[c] criterion (col/100 mL)	ADEM agricultural and industrial water supply[d] criterion (col/100 mL)
Fecal coliform	0[a]	200[b]	none	2,000[b] 4,000[e]
Escherichia coli (E. coli)	0[a]	none	576[e]	none
Enterococci	0[a]	none	151[e]	none

[a] Actual standard of the U.S. Environmental Protection Agency (2001) is that no more than one sample per month (sampled daily) may be positive for total coliforms, of which fecal coliform and *E. coli* are a subgroup.
[b] Bacterial concentration is the geometric mean of not less than five samples taken over a 30-day period (Alabama Department of Environmental Management, 2000d).
[c] U.S. Environmental Protection Agency, 1986.
[d] Alabama Water Quality Criteria (Alabama Department of Environmental Management, 2000d).
[e] Maximum bacterial concentration not to be exceeded in any sample.

Table 13. Exceedance frequencies for fecal indicator bacteria detected at sites in the Birmingham area, Alabama, 2000–01

[USEPA, U.S. Environmental Protection Agency; col/100 mL, colonies per 100 milliliters; ADEM, Alabama Department of Environmental Management]

Site label (fig. 1)	Enterococci			*Escherichia coli*			Fecal coliform		
	Total number of samples	Samples exceeding USEPA criterion[a] (151 col/100 mL)	Exceedance frequency (percent)	Total number of samples	Samples exceeding USEPA criterion[a] (576 col/100 mL)	Exceedance frequency (percent)	Total number of samples	Samples exceeding ADEM criterion[b] (4,000 col/100 mL)	Exceedance frequency (percent)
VIL-1	9	9	100	12	7	58	11	3	27
VIL-2	7	7	100	7	6	86	7	2	29
VIL-3	8	5	63	9	3	33	9	2	22
VIL-4	2	2	100	3	2	67	3	0	0
VAL-1	8	8	100	10	10	100	10	6	60
VAL-2	9	7	78	11	6	55	10	3	30
VAL-3	9	4	44	10	4	40	10	2	20
LCR	2	1	50	3	1	33	3	0	0
FMC	6	5	83	8	2	25	7	0	0
TOTALS	60	48	80	73	41	56	70	18	26

[a] U.S. Environmental Protection Agency (1986).
[b] Alabama Department of Environmental Management (2000d).

samples were collected at VAL-1. The high-flow sample collected when the discharge was greatest (120 ft^3/s) contained levels of bacteria that were approximately an order of magnitude less than the high-flow samples collected when the discharge was lower (33–37 ft^3/s), illustrating the diminishing influence of point source(s) as streamflow increased (appendix table 2-2).

Wastewater Indicators

Wastewater indicators are chemical compounds commonly found in wastewater and urban runoff that can be indicative of contamination associated with a human source. Sixteen constituents that are good indicators of the presence of human wastewater were selected for analysis in the stream samples collected at the Birmingham study sites (appendix table 2-3). These constituents were classified into five different categories: (1) food by-products, (2) pharmaceutical by-products, (3) phosphate-based chemical surfactants and additives, (4) detergent agents, and (5) fragrances. Standards or criteria have not been established by the ADEM or the USEPA for these constituents.

Of the 16 constituents analyzed in stream samples from the study sites, 7 wastewater indicators were detected in more than 50 percent of the samples (fig. 18). The median number of wastewater indicators detected in individual samples ranged from 1 (FMC) to 10 (VAL-1). In Village Creek, the median number of detections was highest at VIL-3 (9), followed by VIL-2 and VIL-1 (8 and 3.5, respectively), and in Valley Creek, the median number of detections was highest at VAL-1 (10), followed by VAL-2 and VAL-3 (8.5 and 6.5, respectively). Statistically significant differences in concentrations and number of detections of wastewater indicators among sites were identified (table 6). The number of detections, the total concentration of wastewater indicators, the total concentration of the phosphate-based chemical surfactants, and the total concentration of the detergent agents at VIL-2, VIL-3, VAL-1, and VAL-2 were significantly greater than at FMC (table 6). The total concentrations of the food by-products and pharmaceutical by-products at VAL-1 were significantly
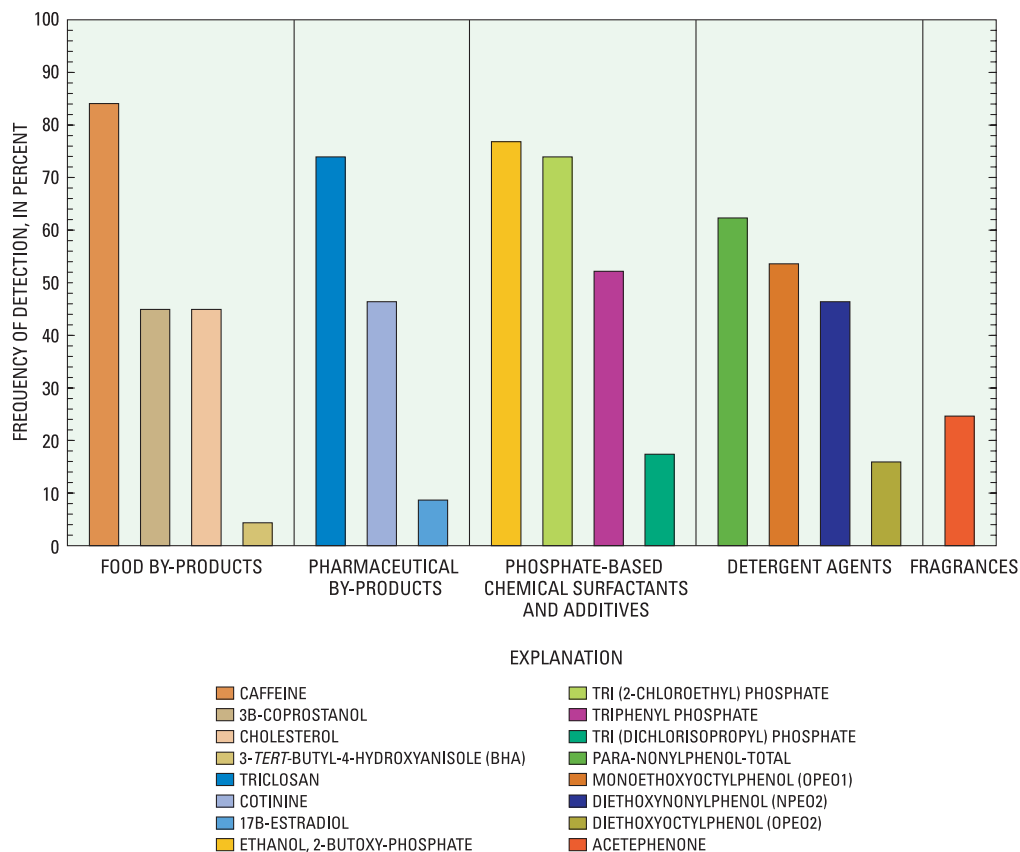
Figure 18. Frequencies of detection for selected wastewater indicators in water samples from streams in the Birmingham area, Alabama, 2000–01.

greater than at FMC (table 6). At Village Creek, the number of detections and the total concentration of phosphate-based chemical surfactants at VIL-1 were significantly lower than at VIL-2 or VIL-3; the total concentration of fragrances was significantly lower at VIL-1 than at VIL-3 (table 6). At Valley Creek, the number of detections and the total concentration of food by-products were significantly greater at VAL-1 than at VAL-2 or VAL-3; the total concentrations of the pharmaceutical by-products, phosphate-based surfactants, and fragrances were significantly greater at VAL-1 than at VAL-3 (table 6).

Trace and Major Elements

Trace and major elements commonly are found in surface water and may occur naturally due to geochemical weathering of rocks and soil. Trace elements, such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc generally are present in water in concentrations less than 25 µg/L (Hem, 1985). Abundant metals such as iron, manganese, and aluminum commonly are found in greater concentrations and are frequently detected in the water column. High frequencies

of detection do not necessarily imply anthropogenic sources. However, industrial and municipal discharges, as well as urban land-use activities, often account for elevated concentrations above natural background levels.

Standards and criteria applicable to the trace and major elements are sometimes computed by equations based on the hardness of the water (table 14). Trace elements are more lethal to fish and invertebrates in soft water than in hard water (Alabama Department of Environmental Management, 2000d). Concentrations of cadmium, copper, lead, and zinc detected in stream samples from the study sites were plotted to illustrate their relation to hardness and toxicity (fig. 19). Values above acute and chronic toxicity lines indicate that the trace-element concentration can be acutely and(or) chronically toxic to fish and other aquatic organisms.

Concentrations of the trace and major elements detected during this study are labeled as total or total recoverable concentrations rather than dissolved concentrations (table 15). Samples at the Birmingham study sites were analyzed for 18 elements—17 were detected in at least one stream sample (fig. 20). Iron,

Table 14. State and Federal standards and criteria for trace and major elements in surface water

[µg/L, micrograms per liter; e, 2.718; LN, natural log]

Trace element	Primary Drinking Water Standard	Secondary Drinking Water Standard	ADEM acute aquatic life criterion[a]	ADEM chronic aquatic life criterion[a]
Arsenic	50 µg/L[b,c]			
Aluminum		200 µg/L[d] 50–200 µg/L[b]		
Barium	2,000 µg/L[b,c]			
Beryllium	4 µg/L[b,c]			
Cadmium	5 µg/L[b,c]		$=e^{((1.128*LN(Hardness))-3.828)}$	$=e^{((0.7852*LN(Hardness))-3.49)}$
Chromium (total)	100 µg/L[b,c]			
Chromium (trivalent)			$=e^{((0.819*LN(Hardness))+3.688)}$	$=e^{((0.819*LN(Hardness))+1.561)}$
Copper	1,300 µg/L[b]	1,000 µg/L[b,d]	$=e^{((0.9422*LN(Hardness))-1.464)}$	$=e^{((0.8545*LN(Hardness))-1.465)}$
Iron		300 µg/L[b,d]		
Lead	15 µg/L[b,c] - Action Level		$=e^{((1.273*LN(Hardness))-1.46)}$	$=e^{((1.273*LN(Hardness))-4.705)}$
Manganese		50 µg/L[b,d]		
Mercury	2 µg/L[b,c]			
Nickel	100 µg/L[c]		$=e^{((0.846*LN(Hardness))+3.3612)}$	$=e^{((0.846*LN(Hardness))+1.1645)}$
Selenium	50 µg/L[b,c]			
Silver		100 µg/L[b,d]	$=e^{((1.72*LN(Hardness))-6.52)}$	None
Zinc		5,000 µg/L[b,d]	$=e^{((0.8473*LN(Hardness))+0.8604)}$	$=e^{((0.8473*LN(Hardness))+0.7614)}$

[a] Alabama Water Quality Criteria (Alabama Department of Environmental Management, 2000d). Toxicity lines for cadmium, copper, lead, and zinc are shown in figure 19.

[b] U.S. Environmental Protection Agency (2000b, 2001).

[c] Alabama Primary Drinking Water Standards (Alabama Department of Environmental Management, 2000b).

[d] Alabama Secondary Drinking Water Standards (Alabama Department of Environmental Management, 2000c).
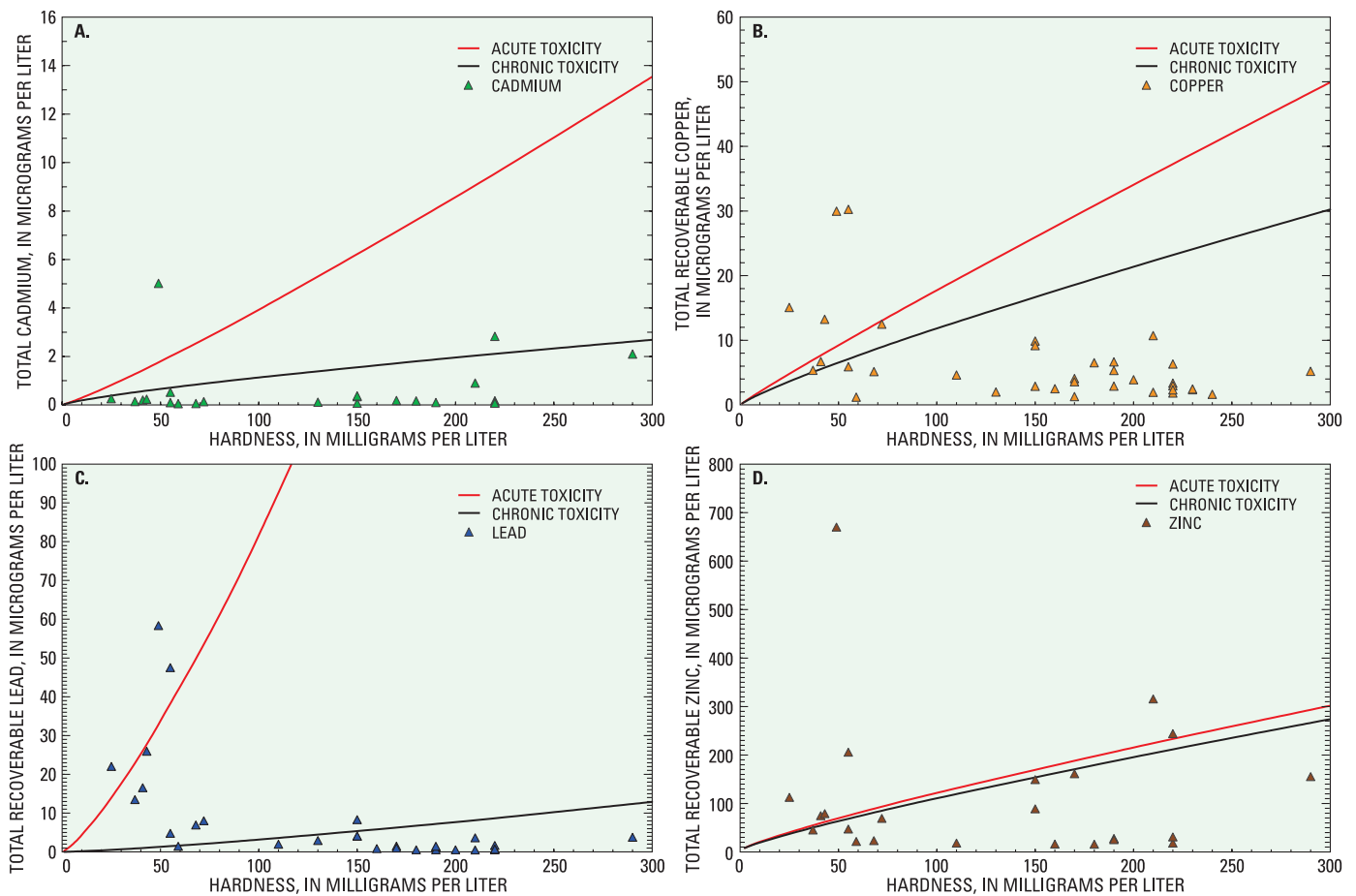
Figure 19. Relations of (A) total cadmium, (B) total recoverable copper, (C) total recoverable lead, and (D) total recoverable zinc in water-quality samples to hardness and acute and chronic toxicity at streams in the Birmingham area, Alabama, 2000–01.

manganese, barium, and aluminum were detected in every sample (fig. 20); beryllium was not detected in any sample; mercury and selenium each were detected once.

Scatter plots, which differentiate between high-flow and low-flow samples, were used to display the variability in concentrations of the different trace and major elements (fig. 21). High-flow samples were not collected at VIL-3, VIL-4, and LCR—generalized statements concerning source (point or nonpoint) cannot be made for these sites. Generally, higher concentrations of most of the trace and major elements were observed during periods of high flow, which may be the result of resuspension of silt, clay, and organic particles that are associated with adsorbed trace elements. Higher concentrations detected consistently during high flow may indicate the presence of nonpoint sources.

Arsenic is a trace element that is toxic in relatively small amounts (Childress and Treece, 1996). Although naturally occurring, it can be produced as a by-product when coal is burned or iron is smelted, and it is commonly

used in pesticides. Arsenic was detected in 61 percent of the Birmingham study samples (fig. 20). The primary drinking-water standard for arsenic is 50 µg/L (table 14). The maximum concentration of arsenic detected during this study was 8.4 µg/L at VIL-2 during low flow (table 15).

Cadmium occurs in some ores and is used extensively in industry. It can become an environmental contaminant through waste-disposal practices or from atmospheric deposition (Childress and Treece, 1996). Cadmium was detected in 53 percent of the samples (fig. 20). The USEPA primary drinking-water standard for cadmium is 5 µg/L (table 14). The maximum concentration of cadmium, 5.02 µg/L, occurred at VIL-2 during high flow (table 15; fig 21A). Concentrations of cadmium exceeded the acute aquatic life criterion in 1 of 41 samples (2.4 percent) and the chronic aquatic life criterion in 2 of 41 samples (4.9 percent) at VIL-2 (fig. 19A; table 15). Concentrations of cadmium at VIL-2 were significantly greater than concentrations at FMC or

Table 15. Summary of trace and major elements detected in water samples and applicable aquatic life criteria at sites in the Birmingham area, Alabama, 2000–01

Samples shaded gray were collected during high flow; ▓ , exceeded secondary drinking water standards; ▓ , exceeded chronic aquatic life criteria; ▓ , exceeded acute aquatic life criteria; μg/L, micrograms per liter; E, estimated; <, less than; —, criteria not calculated; ND, no data were collected]

Site label (fig. 1)	Date	Time	Hardness	Aluminum, total recoverable (μg/L)	Arsenic, total (μg/L)	Barium, total recoverable (μg/L)	Beryllium, total recoverable (μg/L)	Cadmium, total (μg/L)	Cadmium (μg/L)		Chromium, total recoverable (μg/L)	Cobalt, total recoverable (μg/L)
									Acute aquatic life criterion[a]	Chronic aquatic life criterion[a]		
VIL-1	3/1/2000	1625	200	E 20.2	< 2.6	27.1	< 5	< 0.11	—	—	< 1.00	< 1.8
VIL-1	6/30/2000	1020	200	35.1	< 2.6	27.3	< 5	< .11	—	—	< 1.00	< 1.8
VIL-1	8/30/2000	1345	190	E 18.8	E 1.5	27.5	< 5	< .11	—	—	E .749	< 1.8
VIL-1	11/8/2000	2000	37	**1,000**	2.8	29.9	< 2.5	.142	1.28	0.52	2.03	E 1.2
VIL-1	1/24/2001	905	200	46.0	< 1.9	30.0	< 2.5	< .11	—	—	< 1.00	< 2.4
VIL-1	1/29/2001	1900	41	**1,240**	E 1.2	32.2	< 2.5	.198	1.43	.56	3.71	E 1.7
VIL-2	8/30/2000	830	220	49.0	8.4	124	< 5	**2.83**	9.54	2.11	1.80	< 1.8
VIL-2	11/14/2000	820	290	32.7	E 1.6	426	< 2.5	2.10	13.0	2.62	2.39	< 2.4
VIL-2	1/24/2001	1500	220	59.4	< 1.9	42.4	< 2.5	.172	9.54	2.11	E .59	< 2.4
VIL-2	1/29/2001	2100	49	**1,510**	2.1	50.5	< 2.5	**5.02**	1.75	.65	7.52	E 2.3
VIL-3	3/2/2000	1010	210	E 25.1	< 2.6	57.8	< 5	.904	9.06	2.03	< 1.00	< 1.8
VIL-3	6/30/2000	1630	150	65.9	E 2.1	56.3	< 5	.341	6.20	1.56	< 1.00	< 1.8
VIL-3	8/29/2000	830	180	68.9	E 1.7	66.3	< 5	.165	7.61	1.80	E .612	< 1.8
VIL-3	11/14/2000	1430	190	**1,170**	E 1.9	50.4	< 2.5	E .102	8.09	1.88	1.36	E 1.3
VIL-3	1/23/2001	1445	220	93.4	< 1.9	47.6	< 2.5	E .095	9.54	2.11	< 1.00	< 2.4
VIL-4	3/2/2000	1600	170	41.6	E 2.0	27.7	< 5	.180	7.14	1.72	< 1.00	< 1.8
VIL-4	7/1/2000	1415	150	**416**	2.7	49.9	< 5	.374	6.20	1.56	1.20	< 1.8
VAL-1	3/1/2000	945	200	68.1	< 2.6	32.6	< 5	< .11	—	—	< 1.00	< 1.8
VAL-1	6/29/2000	1020	72	**367**	E 2.1	25.6	< 5	.134	2.71	.88	2.45	< 1.8
VAL-1	8/31/2000	850	190	134	< 2.6	30.6	< 5	< .11	—	—	1.55	< 1.8
VAL-1	11/9/2000	840	55	**235**	3.4	25.8	< 2.5	E .096	2.00	.71	1.53	< 2.4
VAL-1	1/23/2001	920	220	78.8	< 1.9	34.7	< 2.5	E .07	9.54	2.11	< 1.00	< 2.4
VAL-1	2/12/2001	1435	25	**636**	E 1.9	32.8	< 2.5	.259	.82	.38	4.93	E 1.3
VAL-2	2/29/2000	1600	220	31.4	E 1.3	39.2	< 5	< .11	—	—	<1.00	< 1.8
VAL-2	6/29/2000	1805	110	199	3.8	30.8	< 5	< .11	—	—	E .659	< 1.8
VAL-2	8/29/2000	1345	190	66.4	E 1.5	40.0	< 5	< .11	—	—	E .563	< 1.8
VAL-2	11/15/2000	950	230	E 20.0	E 1.3	42.6	< 2.5	< .11	—	—	E .911	< 2.4
VAL-2	1/25/2001	920	230	33.1	< 1.9	42.1	< 2.5	< .11	—	—	E .706	< 2.4
VAL-2	2/9/2001	2150	55	**1,660**	3.2	63.4	< 2.5	.524	2.00	.71	6.85	E 2.4
VAL-3	2/29/2000	935	210	E 25.3	< 2.6	39.3	< 5	< .11	—	—	< 1.00	< 1.8
VAL-3	6/28/2000	1035	160	56.4	2.6	39.8	< 5	< .11	—	—	< 1.00	< 1.8
VAL-3	8/31/2000	1425	170	77.5	E 1.6	37.4	< 5	< .11	—	—	1.12	< 1.8
VAL-3	11/9/2000	1135	68	**332**	3.1	25.3	< 2.5	E .061	2.54	.84	1.15	< 2.4
VAL-3	1/25/2001	1530	240	35.2	< 1.9	42.3	< 2.5	< .11	—	—	< 1.00	< 2.4
VAL-3	2/13/2001	1005	43	**985**	2.5	32.1	< 2.5	.233	1.51	.58	3.78	E 1.4
LCR	2/28/2000	1115	130	**418**	< 2.6	39.1	< 5	< .11	—	—	< 1.00	< 1.8
LCR	6/27/2000	1115	150	**231**	< 2.6	58.8	< 5	E .07	6.20	1.56	< 1.00	E 1.0
FMC	8/28/2000	1100	170	53.4	< 2.6	43.0	< 5	< .11	—	—	E .591	E .9
FMC	11/13/2000	1330	160	185	E 1.0	40.7	< 2.5	< .11	—	—	E .854	< 2.4
FMC	1/22/2001	1310	140	**288**	< 1.9	32.7	< 2.5	< .11	—	—	< 1.00	< 2.4
FMC	3/20/2001	1615	59	**415**	E 1.4	20.7	< 2.5	E .051	2.16	.75	E .899	< 2.4

Table 15. Summary of trace and major elements detected in water samples and applicable aquatic life criteria at sites in the Birmingham area, Alabama, 2000–01—Continued

Samples shaded gray were collected during high flow; ▨, exceeded secondary drinking water standards; ▨, exceeded chronic aquatic life criteria; ▨, exceeded acute aquatic life criteria; µg/L, micrograms per liter; E, estimated; <, less than; —, criteria not calculated; ND, no data were collected]

Site label (fig. 1)	Date	Time	Copper, total recover-able (µg/L)	Copper (µg/L) Acute aquatic life criterion[a]	Copper (µg/L) Chronic aquatic life criterion[a]	Iron, total recoverable (µg/L)	Iron, dissolved (µg/L)	Lead, total (µg/L)	Lead (µg/L) Acute aquatic life criterion[a]	Lead (µg/L) Chronic aquatic life criterion[a]	Lithium, total recoverable (µg/L)	Manganese, total recoverable (µg/L)	Manganese, dissolved (µg/L)
VIL-1	3/1/2000	1625	< 1.2	—	—	43.3	10.5	< 1.00	197	7.69	E 4.0	12.7	11.1
VIL-1	6/30/2000	1020	< 1.2	—	—	36.5	< 10.0	< 1.00	197	7.69	< 7.0	18.4	15.5
VIL-1	8/30/2000	1345	< 1.2	—	—	30.0	< 10.0	< 1.00	185	7.20	< 7.0	15.7	12.0
VIL-1	11/8/2000	2000	5.34	6.95	5.10	950	24.6	13.5	23.0	.90	< 7.0	211	6.0
VIL-1	1/24/2001	905	< 1.8	—	—	63.9	21.2	< 1.00	197	7.69	< 7.0	46.1	47.0
VIL-1	1/29/2001	1900	6.70	7.65	5.57	1,300	30.6	16.5	26.2	1.02	< 7.0	236	8.6
VIL-2	8/30/2000	830	3.36	37.3	23.4	230	48.0	1.65	223	8.68	20.3	52.9	47.5
VIL-2	11/14/2000	820	5.19	48.3	29.6	236	28.7	3.78	317	12.3	44.9	57.3	55.7
VIL-2	1/24/2001	1500	1.83	37.3	23.4	233	51.9	E .5	223	8.68	< 7.0	49.0	50.4
VIL-2	1/29/2001	2100	30.0	9.05	6.48	1,940	34.9	58.4	32.9	1.28	E 4.0	332	15.1
VIL-3	3/2/2000	1010	10.7	35.7	22.5	142	33.7	3.62	210	8.18	8.4	47.0	43.9
VIL-3	6/30/2000	1630	9.88	26.0	16.9	125	29.2	4.09	137	5.33	10.5	36.2	30.8
VIL-3	8/29/2000	830	6.52	30.8	19.7	98.7	28.3	E .54	172	6.72	7.1	47.6	33.8
VIL-3	11/14/2000	1430	6.65	32.5	20.6	275	E 8.0	1.45	185	7.20	10.5	205	39.4
VIL-3	1/23/2001	1445	6.31	37.3	23.4	183	E 9.4	E .67	223	8.68	E 4.0	53.2	48.5
VIL-4	3/2/2000	1600	4.06	29.2	18.8	99.4	22.2	1.46	160	6.25	8.2	37.1	34.5
VIL-4	7/1/2000	1415	9.16	26.0	16.9	638	28.7	8.31	137	5.33	11.2	121	37.8
VAL-1	3/1/2000	945	3.89	34.1	21.6	113	49.7	E .53	197	7.69	E 4.9	39.7	36.2
VAL-1	6/29/2000	1020	12.5	13.0	9.01	331	22.7	8.01	53.7	2.09	E 5.0	38.2	20.1
VAL-1	8/31/2000	850	5.32	32.5	20.6	115	31.9	1.19	184	7.20	E 6.2	28.2	13.5
VAL-1	11/9/2000	840	5.89	10.1	7.15	241	27.6	4.78	38.1	1.49	< 7.0	23.3	11.8
VAL-1	1/23/2001	920	2.96	37.3	23.4	85.5	17.7	E .70	223	8.68	E 3.3	36.2	32.5
VAL-1	2/12/2001	1435	15.1	4.80	3.65	867	17.4	22.0	14.0	0.54	< 7.0	80.8	8.3
VAL-2	2/29/2000	1600	2.31	37.3	23.4	47.1	14.8	< 1.00	223	8.68	< 7.0	22.2	19.7
VAL-2	6/29/2000	1805	4.61	19.4	12.9	128	E 7.9	1.98	92.2	3.59	< 7.0	29.1	22.1
VAL-2	8/29/2000	1345	2.90	32.5	20.6	53.7	12.8	E 0.52	184	7.20	E 3.8	29.0	20.3
VAL-2	11/15/2000	950	2.34	38.9	24.3	45.2	14.9	<1.00	236	9.19	E 4.4	28.8	27.8
VAL-2	1/25/2001	920	2.44	38.9	24.3	44.7	14.8	<1.00	236	9.19	< 7.0	24.8	24.3
VAL-2	2/9/2001	2150	30.3	10.1	7.15	2,190	115.7	47.5	38.1	1.49	< 7.0	272	26.2
VAL-3	2/29/2000	935	1.94	35.7	22.5	75.9	20.6	E .50	210	8.18	E 4.9	22.7	20.1
VAL-3	6/28/2000	1035	2.51	27.6	17.8	40.2	E 7.1	E .84	149	5.79	< 7.0	18.3	14.7
VAL-3	8/31/2000	1425	3.58	29.2	18.8	73.5	E 6.9	1.00	160	6.25	< 7.0	20.7	11.5
VAL-3	11/9/2000	1135	5.16	12.3	8.58	342	12.0	6.95	50.0	1.95	< 7.0	44.5	6.4
VAL-3	1/25/2001	1530	E 1.64	40.4	25.2	46.9	10.3	< 1.00	249	9.70	< 7.0	18.3	17.2
VAL-3	2/13/2001	1005	13.2	8.00	5.80	1,110	44.6	25.9	27.9	1.09	< 7.0	162	6.9
LCR	2/28/2000	1115	1.98	22.7	14.9	360	17.2	2.93	114	4.44	E 6.1	19.3	9.3
LCR	6/27/2000	1115	2.86	26.0	16.9	246	< 10.0	4.03	137	5.33	< 7.0	44.2	11.7
FMC	8/28/2000	1100	1.27	29.2	18.8	47.7	< 10.0	< 1.00	160	6.25	< 7.0	8.89	6.0
FMC	11/13/2000	1330	< 1.8	—	—	205	E 5.7	< 1.00	149	5.79	< 7.0	24.8	5.9
FMC	1/22/2001	1310	< 1.8	—	—	185	14.5	< 1.00	125	4.88	< 7.0	8.14	5.4
FMC	3/20/2001	1615	E 1.20	10.8	7.60	333	54.8	1.45	41.7	1.63	< 7.0	35.3	12.9

Table 15. Summary of trace and major elements detected in water samples and applicable aquatic life criteria at sites in the Birmingham area, Alabama, 2000–01—Continued

Samples shaded gray were collected during high flow; ▨, exceeded secondary drinking water standards; ▨, exceeded chronic aquatic life criteria; ▨, exceeded acute aquatic life criteria; µg/L, micrograms per liter; E, estimated; <, less than; —, criteria not calculated; ND, no data were collected]

Site label (fig. 1)	Date	Time	Mercury, total recoverable (µg/L)	Molybdenum, total recoverable (µg/L)	Nickel, total recoverable (µg/L)	Nickel (µg/L) Acute aquatic life criterion[a]	Nickel (µg/L) Chronic aquatic life criterion[a]	Selenium, total (µg/L)	Silver, total recoverable (µg/L)	Silver (µg/L) Acute aquatic life criterion[a]	Zinc, total recoverable (µg/L)	Zinc (µg/L) Acute aquatic life criterion[a]	Zinc (µg/L) Chronic aquatic life criterion[a]
VIL-1	3/1/2000	1625	< 0.3	< 1.0	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VIL-1	6/30/2000	1020	< .3	< 1.0	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VIL-1	8/30/2000	1345	< .3	< 1.0	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VIL-1	11/8/2000	2000	< .14	< 1.5	E 1.2	612	68.0	< 2.6	< .43	—	45.4	50.4	45.6
VIL-1	1/24/2001	905	< .14	< 1.5	< 1.8	—	—	< 2.6	< .43	—	< 31	—	—
VIL-1	1/29/2001	1900	< .14	E 1.1	E 1.2	667	74.2	< 2.6	< .43	—	**74.9**	55.0	49.8
VIL-2	8/30/2000	830	.3	55.7	E .9	2,760	307	2.85	< 1	—	**244**	228	207
VIL-2	11/14/2000	820	< .14	31.1	E 1.3	3,490	388	< 2.6	< .43	—	155	288	261
VIL-2	1/24/2001	1500	< .14	17.5	E 1.1	2,760	307	< 2.6	.58	15.8	E 18.4	228	207
VIL-2	1/29/2001	2100	< .14	2.4	3.7	776	86.2	< 2.6	0.50	1.19	**670**	63.9	57.9
VIL-3	3/2/2000	1010	< .3	16.3	E 1.7	2,660	295	< 2.6	< 1	—	**316**	219	199
VIL-3	6/30/2000	1630	< .3	14.4	< 1.8	—	—	< 2.6	< 1	—	89.1	165	149
VIL-3	8/29/2000	830	< .3	45.7	E .9	2,330	259	< 2.6	< 1	—	E 16.1	193	174
VIL-3	11/14/2000	1430	< .14	19.3	3.0	2,440	271	< 2.6	< .43	—	E 27.8	202	183
VIL-3	1/23/2001	1445	< .14	12.3	1.9	2,760	307	< 2.6	< .43	—	E 30.8	228	207
VIL-4	3/2/2000	1600	< .3	14.5	2.2	2,220	247	< 2.6	< 1	—	161	183	166
VIL-4	7/1/2000	1415	< .3	20.7	2.2	2,000	222	< 2.6	< 1	—	149	165	149
VAL-1	3/1/2000	945	< .3	11.1	3.5	2,550	283	< 2.6	1.97	13.4	< 31	—	—
VAL-1	6/29/2000	1020	< .3	7.3	< 1.8	—	—	< 2.6	1.14	2.31	69.1	88.6	80.2
VAL-1	8/31/2000	850	< .3	54.9	< 1.8	—	—	< 2.6	< 1	—	E 25.4	202	183
VAL-1	11/9/2000	840	< .14	2.2	< 1.8	—	—	< 2.6	E .32	1.45	47.3	70.5	63.9
VAL-1	1/23/2001	920	< .14	14.1	E 1.1	2,760	307	< 2.6	< .43	—	< 31	—	—
VAL-1	2/12/2001	1435	< .14	< 1.5	E 1.5	439	48.8	< 2.6	< .43	—	**113**	36.2	32.7
VAL-2	2/29/2000	1600	< .3	13.2	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VAL-2	6/29/2000	1805	< .3	9.0	< 1.8	—	—	< 2.6	< 1	—	E 18.2	127	115
VAL-2	8/29/2000	1345	< .3	24.5	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VAL-2	11/15/2000	950	< .14	20.7	< 1.8	—	—	< 2.6	< .43	—	< 31	—	—
VAL-2	1/25/2001	920	< .14	7.8	< 1.8	—	—	< 2.6	< .43	—	< 31	—	—
VAL-2	2/9/2001	2150	.144	E 1.1	2.8	855	95.1	< 2.6	.54	1.45	**206**	70.5	63.9
VAL-3	2/29/2000	935	< .3	4.8	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VAL-3	6/28/2000	1035	< .3	7.7	< 1.8	—	—	< 2.6	< 1	—	E 16.4	174	158
VAL-3	8/31/2000	1425	< .3	15.4	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
VAL-3	11/9/2000	1135	< .14	1.9	< 1.8	—	—	< 2.6	< .43	—	E 23.3	84.4	76.4
VAL-3	1/25/2001	1530	< .14	4.4	< 1.8	—	—	< 2.6	< .43	—	< 31	—	—
VAL-3	2/13/2001	1005	< .14	< 1.5	E 1.7	694	77.2	< 2.6	E .21	.95	**79.1**	57.2	51.8
LCR	2/28/2000	1115	< .3	6.1	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
LCR	6/27/2000	1115	< .3	3.5	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
FMC	8/28/2000	1100	< .3	< 1.0	< 1.8	—	—	< 2.6	< 1	—	< 31	—	—
FMC	11/13/2000	1330	< .14	< 1.5	< 1.8	—	—	< 2.6	< .43	—	< 31	—	—
FMC	1/22/2001	1310	< .14	< 1.5	< 1.8	—	—	< 2.6	< .43	—	< 31	—	—
FMC	3/20/2001	1615	ND	< 1.5	< 1.8	—	—	< 2.6	< .43	—	E 21.7	74.8	67.8

[a] Alabama Water Quality Criteria (Alabama Department of Environmental Management, 2000d).
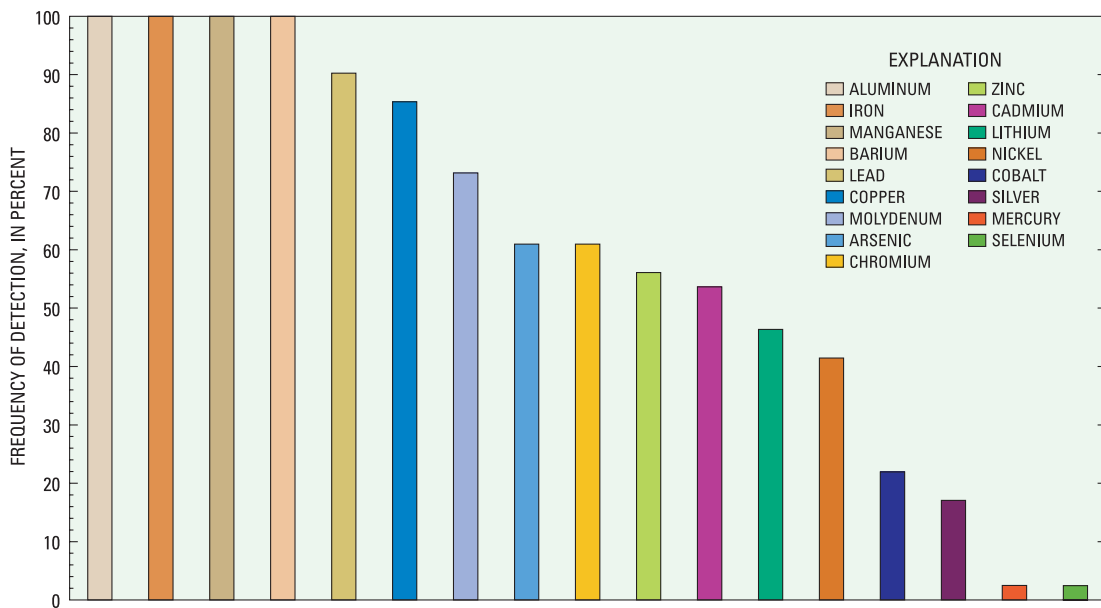
Figure 20. Frequencies of detection for trace and major elements in water samples from streams in the Birmingham area, Alabama, 2000–01.

VIL-1 (table 6). Cadmium concentrations were greatest during high flow rather than low flow, indicating the presence of nonpoint sources (fig. 21A). Two of the cadmium concentrations detected at VIL-2 during low flow were higher than concentrations detected at other sites (during low or high flow), indicating that point sources may exist upstream from this site.

Chromium concentrations in natural waters generally are less than 10 µg/L; however, chromium may be introduced to surface waters by industrial wastes. The USEPA drinking-water standard for chromium is 100 µg/L. The highest concentration of chromium was 7.52 µg/L at VIL-2 during high flow (table 15). Higher chromium concentrations were detected during high flow than low flow, which may indicate nonpoint sources.

Copper commonly is detected in the environment and may originate from natural sources or from industry and agriculture. The USEPA action level is 1,300 µg/L (table 14). Copper was found in 85 percent of the Birmingham study samples (fig. 20). The highest concentration detected was 30.3 µg/L at VAL-2 during high flow (table 15). Concentrations of copper exceeded the acute aquatic life criterion in 4 of 41 samples (10 percent) and the chronic aquatic life criterion in 7 of 41 samples (17 percent; fig. 19B). Concentrations of copper at VIL-3 and VAL-1 were significantly greater than copper concentrations at FMC (table 6). High copper concentrations were detected during high flow, indicating the presence of nonpoint sources (fig. 21B).

Lead concentrations tend to be low in surface water because lead adsorbs readily to inorganic and organic surfaces. Environmental contamination from lead occurs from its use as an additive in gasoline and from industrial sources such as coal burning. The USEPA action level for lead is 15 µg/L (table 14). Lead was detected in 90 percent of the study samples (fig. 20). The maximum concentration of 58.4 µg/L was detected at VIL-2 during high flow (table 15). The action level was exceeded in 5 of 41 samples (12 percent; fig. 21C); the acute aquatic life criterion was exceeded in 3 of 41 samples (7 percent); and the chronic aquatic life criterion was exceeded in 10 of 41 samples (24 percent; fig. 19C). Higher lead concentrations were detected more frequently during high flow than low flow, indicating the presence of nonpoint sources (fig. 21C).

Molybdenum occurs naturally in streams in trace amounts. Fossil-fuel combustion is a probable source where higher molybdenum concentrations are detected. No water-quality standards or criteria have been set for molybdenum, which was detected in 73 percent of the samples (fig. 20). The maximum molybdenum concentration was 55.7 µg/L at VIL-2 during low flow (table 15). The highest concentrations occurred during low flow at VIL-2, VAL-1, VAL-2, and VAL-3, indicating possible point sources (table 15). Statistically significant differences among sites were identified. Molybdenum concentrations at VIL-2, VIL-3, and VAL-2 were significantly greater than the concentrations at FMC; molybdenum concentrations at VIL-2 and VIL-3 were
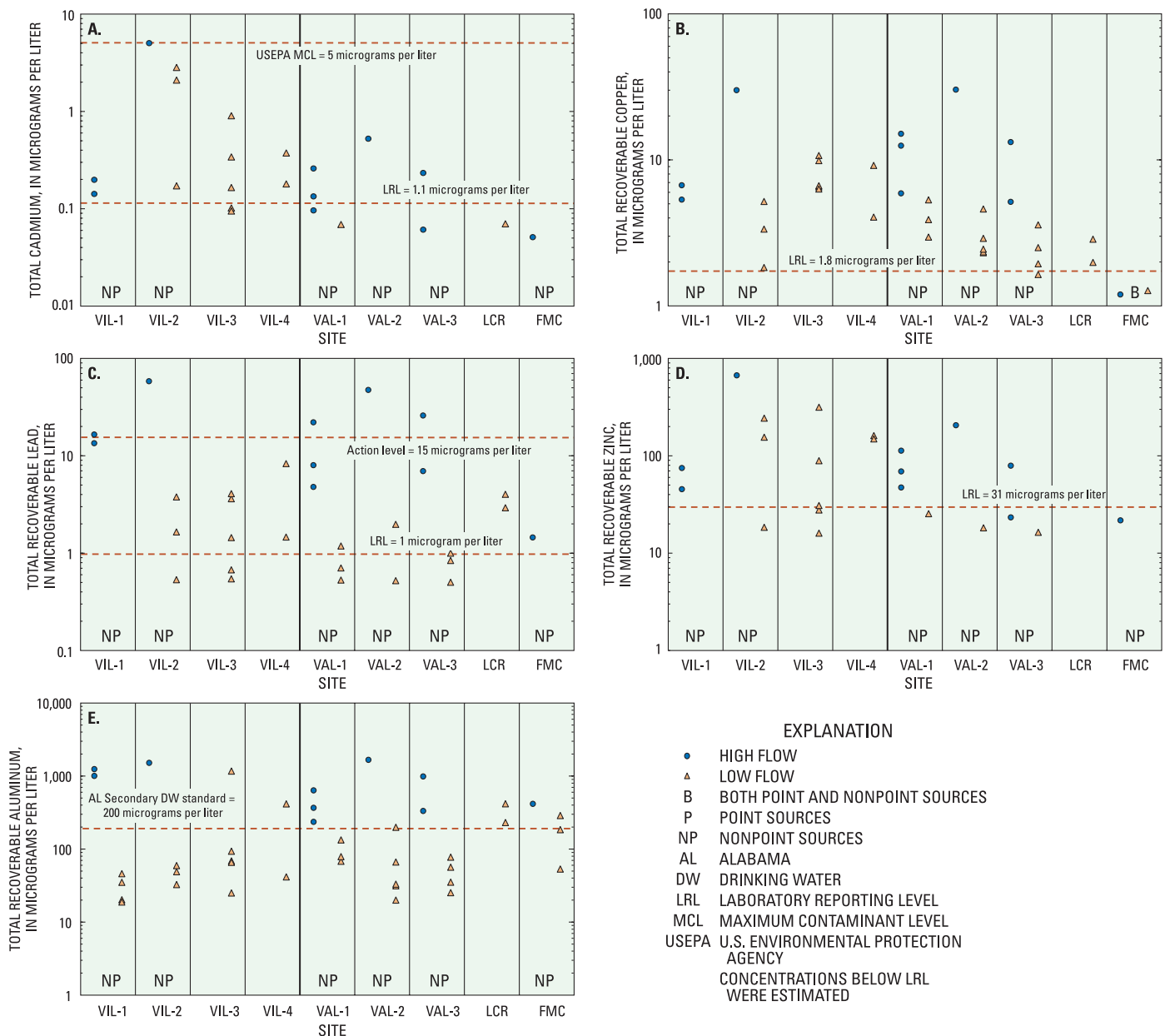
Figure 21. (A) Total cadmium, (B) total recoverable copper, (C) total recoverable lead, (D) total recoverable zinc, and (E) total recoverable aluminum concentrations detected in water samples collected during high and low flow from streams in the Birmingham area, Alabama, 2000–01.

significantly greater than concentrations at VIL-1 (table 6).

Nickel is widely used in industry and is a common environmental contaminant. It is a constituent of stainless steel and other alloys. Nickel was detected in 41 percent of the samples (fig. 20). Acute and chronic criteria were not exceeded at any time during this investigation. The drinking-water standard for nickel is 100 µg/L (Alabama Department of Environmental Management, 2000b). The maximum concentration of nickel detected in this study was 3.7 µg/L at VIL-2.

Silver has numerous anthropogenic sources and was detected in 17 percent of the samples (fig. 20). The greatest concentration of silver detected in this study was 1.97 µg/L at VAL-1 during low flow (table 15). The acute aquatic life criterion for silver was not exceeded (table 15).

Zinc is widely used in combination with other metals, such as galvanizing steel, and is commonly used in paints. The secondary drinking-water standard for zinc is 5,000 µg/L (table 14; Alabama Department of Environmental Management, 2000c). Zinc was detected in 56 percent of the study samples (fig. 20). The

maximum concentration of zinc was 670 µg/L at VIL-2 during high flow (fig. 21D; table 15). Concentrations of zinc exceeded the acute and chronic aquatic life criteria in 7 of 41 samples (17 percent; fig. 19D). High concentrations were detected during high flow, indicating nonpoint sources (fig. 21D). Concentrations were elevated during low flow at VIL-2, VIL-3, and VIL-4—indicating possible point sources along Village Creek (table 15).

Although iron is the second most abundant metal in the Earth's outer crust, concentrations present in surface water generally are small (Hem, 1985). If present in drinking water in excessive amounts, iron tends to form red oxyhydroxide precipitates that may stain laundry and plumbing fixtures. Concentrations of iron at the Birmingham sites ranged from 30.0 to 2,190 µg/L (table 15). Iron concentrations in the study area exceeded the secondary drinking-water standard of 300 µg/L (table 14) in 11 of 41 samples (27 percent)—9 of these exceedances occurred during high flow (table 15). No statistically significant differences among sites were identified (table 6).

Manganese is undesirable in water supplies because it tends to deposit black oxide stains (Hem, 1985). Concentrations in untreated surface water commonly exceed the secondary drinking-water standards because iron and manganese commonly coat clay particles. The secondary drinking-water standard set by ADEM for manganese in public water supplies is 50 µg/L (table 14). Concentrations of manganese ranged from 8.14 to 332 µg/L in the study area and exceeded the secondary drinking-water standard in 10 of 41 samples (24 percent)—6 of these exceedances occurred during high flow (table 15). No statistically significant differences among sites were identified (table 6).

Aluminum is the third most abundant element in the Earth's outer crust, but it is rarely found in solution in surface water in high concentrations (Hem, 1985). The secondary drinking-water standard set by ADEM for aluminum in public water supplies is 200 µg/L (table 14). Concentrations of aluminum ranged from 18.8 to 1,660 µg/L (table 15). Aluminum concentrations exceeded the secondary drinking-water standard in 15 of 41 samples (37 percent)—10 of these exceedances occurred during high flow, indicating possible nonpoint sources (fig. 21E). No statistically significant differences among sites were identified (table 6).

Comparison of Trace and Major Element Data from Urban Sites in Birmingham to Urban Sites Nationwide

Trace and major element data from Village and Valley Creeks were compared to trace and major element data collected from selected urban sites across the Nation in the NAWQA Program (U.S. Geological Survey, 2001). Trace and major elements were not frequently sampled in the NAWQA Program, but data were available from urban sampling sites in Pennsylvania, Connecticut, Colorado, New Mexico, Oregon, Utah, and Washington for 1991 and 1997. Concentrations of trace and major elements from Village and Valley Creeks were plotted over a bar graph illustrating ranges, which included the lowest 25 percent, the middle 50 percent, and the highest 25 percent of the Birmingham data (fig. 22). To the right of each bar graph in figure 22 is another bar graph illustrating the same ranges for data collected from the urban sites sampled in the NAWQA Program. The statistical quartiles of both data sets were computed by using detected values in order to better illustrate the spread of the data. Aluminum, barium, cadmium, copper, lead, lithium, molybdenum, and zinc concentrations in Village and Valley Creeks exceeded the maximum concentrations detected at urban sites sampled in the NAWQA Program.

USGS personnel examining the contents of the seine while collecting fish samples (photograph taken by A.K. McPherson).
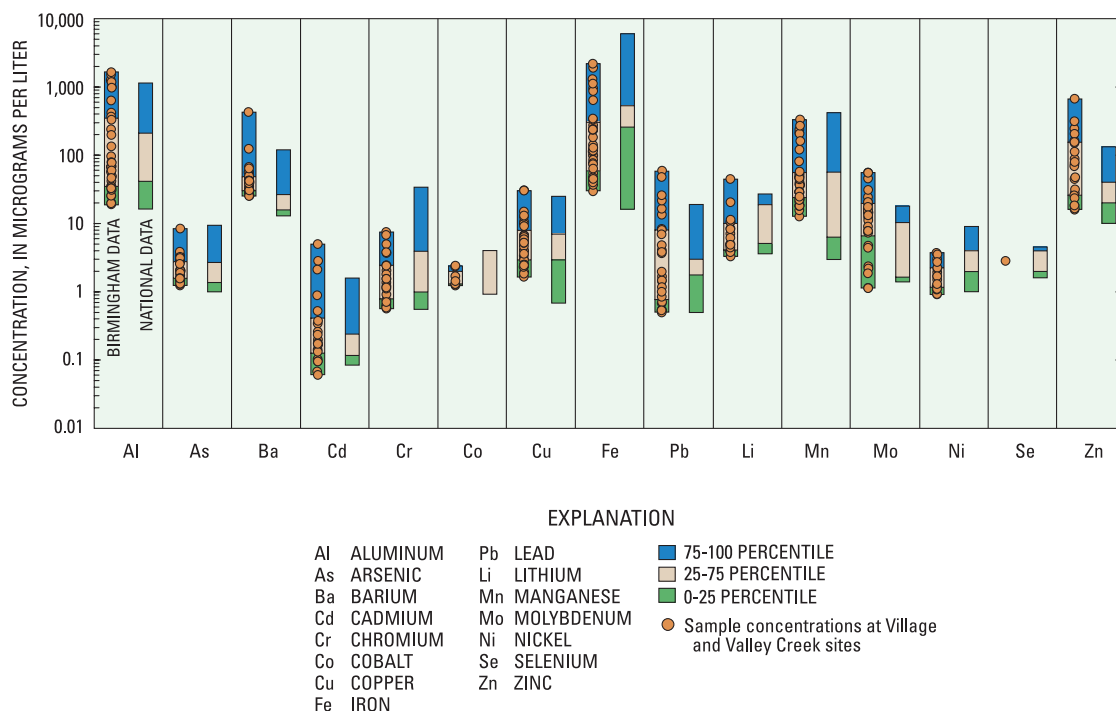
Figure 22. Comparison of trace and major elements in water samples from urban sites in the Birmingham area, Alabama, to urban sites nationwide.

Pesticides

Of the 84 pesticides and degradation products analyzed in samples from the Birmingham study sites, 24 were detected in one or more stream samples (table 16; appendix table 2-4). Of the 24 detected pesticides, 17 were herbicides and 7 were insecticides (fig. 23). Water-quality standards and guidelines have been developed for many pesticides in order to protect human health and aquatic life. Fourteen of the pesticides detected in this study have maximum recommended concentration limits established by the USEPA (2000b), the ADEM (2000b), the International Joint Commission United States and Canada (1978) or the Canadian Council of Ministers of the Environment (2001; table 17). Aquatic life criteria have been established for 13 of the 24 pesticides detected in this study (table 17). These criteria were exceeded by concentrations of the herbicide atrazine and four insecticides—carbaryl, chlorpyrifos, diazinon, and malathion (table 17; appendix table 2-4). Four of the pesticides detected in this study have maximum concentration limits for drinking water. These limits were exceeded by concentrations of the herbicides, atrazine and simazine (table 17).

Comparison of detection frequencies of pesticides can be misleading because of the different laboratory reporting levels associated with each of the pesticides. To reduce this type of bias when comparing detection frequencies of pesticides, concentrations were adjusted by censoring to a common threshold of 0.01 µg/L. These adjusted data were used when comparing detection frequencies between NAWQA samples and Birmingham samples. Figure 23 illustrates the effect of censoring the data on the frequency of detection for samples from the Birmingham study sites.

Atrazine is the most heavily applied organic pesticide in the United States (Majewski and Capel, 1995). Atrazine was detected in 31 of 33 samples (94 percent; fig. 23). The maximum atrazine concentration of 8.88 µg/L was measured at VAL-3 during low flow in February 2000 and exceeded the USEPA drinking-water standard of 3 µg/L (fig. 24A; table 17; appendix table 2-4). Concentrations of 2.58 µg/L and 1.94 µg/L were recorded at VAL-2 and VAL-3, respectively, in February 2001 during high flow and exceeded the Canadian aquatic life guideline of 1.8 µg/L (fig. 24A; table 17; appendix table 2-4).

Simazine is an herbicide commonly used in orchards, vineyards, and along rights-of-way. It is frequently used in urban areas for weed control along roadways and railways, along fences, and in other public areas (Hoffman and others, 2000). Concentrations of simazine were detected in 30 of 33 samples (91 percent; fig. 23). The maximum concentration of 8.6 µg/L occurred at FMC in February 2001 during low flow (fig. 24B; table 17; appendix table 2-4). The USEPA primary drinking-water standard of 4 µg/L was exceeded once during the study (table 17).

Table 16. Pesticides and pesticide degradation products, laboratory reporting levels, and minimum reporting levels

[Pesticides that were detected are shown in bold; μg/L, micrograms per liter; H, herbicide; I, insecticide; DP, degradation product]

Pesticide name	Pesticide type	Laboratory reporting level[a] (μg/L)
Dissolved pesticides analyzed by gas chromatography/mass spectrometry (GC/MS)		
Acetochlor	H	0.0041
Alachlor	H	.0024
Atrazine	H	.007
Azinphos-methyl	I	.05
Benfluralin	H	.010
Butylate	H	.002[b]
Carbaryl	I	.041
Carbofuran	I	.020
Chlorpyrifos	I	.005
Cyanazine	H	.018
DCPA (Dacthal)	H	.0030
p,p'-DDE	I	.0025
Deethylatrazine	DP	.006
Diazinon	I	.005
Dieldrin	I	.0048
2,6-Diethylaniline	H	.0017
Disulfoton	I	.021
EPTC	H	.0020
Ethalfluralin	H	.009
Ethoprophos	I	.005
Fonofos	I	.0027
Lindane	I	.0040
Linuron	H	.035
Malathion	I	.027
Metolachlor	H	.013
Metribuzin	H	.006
Molinate	H	.0016
Napropamide	H	.007
Parathion	I	.007
Parathion-methyl	I	.006
Pebulate	H	.0016
Pendimethalin	H	.010
cis-Permethrin	I	.006
Phorate	I	.011
Prometon	H	.015
Propachlor	H	.010
Propanil	H	.011
Propargite	I	.023
Pronamide	H	.0041
Simazine	H	.011
Tebuthiuron	H	.016
Terbacil	H	.034
Terbufos	I	.017
Terbuthylazine	H	.1[b]
Thiobencarb	H	.0048
Triallate	H	.0023
Trifluralin	H	.009

Pesticide name	Pesticide type	Laboratory reporting level[a] (μg/L)
Dissolved pesticides analyzed by high-performance liquid chromatography (HPLC)		
2,4,5-T	H	0.040
2,4-D	H	.11
2,4-DB	H	.10
2-(2,4,5-Trichlorophenoxy) propionic acid	H	.025
3-Hydroxycarbofuran	DP	.11
4,6-Dinitro-2-methylphenol (DNOC)	H	.25
Acifluorfen	H	.05
Aldicarb	I	.21
Aldicarb sulfone	DP	.20
Aldicarb sulfoxide	DP	.021[b]
Bentazon	H	.035
Bromacil	H	.09
Bromoxynil	H	.07
Carbaryl	I	.024
Carbofuran	I	.29
Chloramben, methyl ester	H	.14
Chlorothalonil	I	.13
Clopyralid	H	.42
Dacthal monoacid	H	.07
Dicamba	H	.043
Dichlobenil	H	.049
Dichlorprop	H	.050
Dinoseb	H	.09
Diuron	H	.056
Fenuron	H	.07
Fluometuron	H	.06
Linuron	H	.021
MCPA	H	.08
MCPB	H	.13
Methiocarb	I	.07
Methomyl	I	.017[b]
Neburon	H	.017
Norflurazon	H	.042
Oryzalin	H	.28
Oxamyl	I	.018[b]
Picloram	H	.09
Propham	H	.09
Propoxur	I	.12
Triclopyr	H	.07

[a] Laboratory reporting levels and minimum reporting levels effective October 1, 2000.

[b] Minimum reporting levels.
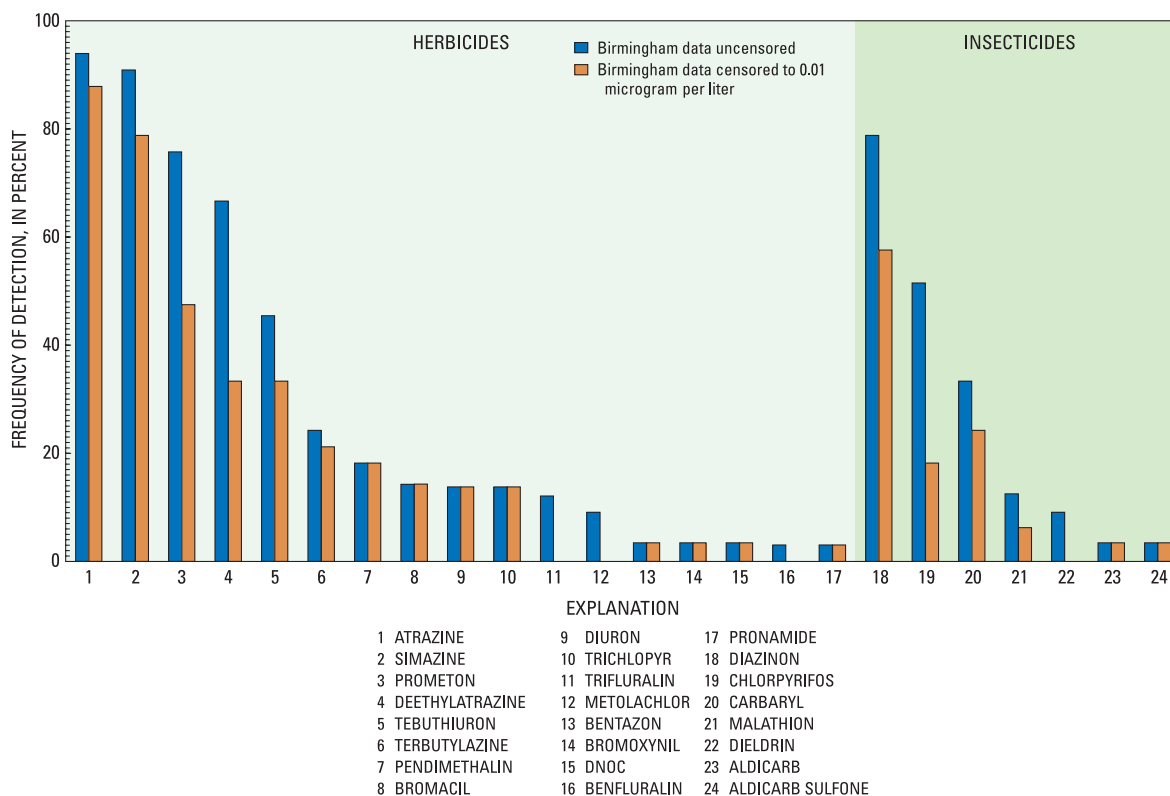
Figure 23. Frequencies of detection for pesticides in water samples from streams in the Birmingham area, Alabama, 2000–01.

EXPLANATION

|			
1 ATRAZINE	9 DIURON	17 PRONAMIDE	
2 SIMAZINE	10 TRICHLOPYR	18 DIAZINON	
3 PROMETON	11 TRIFLURALIN	19 CHLORPYRIFOS	
4 DEETHYLATRAZINE	12 METOLACHLOR	20 CARBARYL	
5 TEBUTHIURON	13 BENTAZON	21 MALATHION	
6 TERBUTYLAZINE	14 BROMOXYNIL	22 DIELDRIN	
7 PENDIMETHALIN	15 DNOC	23 ALDICARB	
8 BROMACIL	16 BENFLURALIN	24 ALDICARB SULFONE	

Chloyrifos is an organophosphate insecticide used in gardens, in residential areas, and on a wide variety of crops to control insects, including the pine beetle. It is also used for termite control in residential and industrial settings and in pet shampoo. Chlorpyrifos is of particular interest because of the Dursban spill in 1997, which occurred approximately 0.8 mile upstream from VIL-2. When the Industrial Distribution Services Warehouse burned on October 2, 1997, approximately 4,000 gallons (gal) of Dursban TC (44 percent pure chlorpyrifos) were released into the environment (The Huntsville Times, 1997). The water used to fight the fire mixed with the insecticide and entered the sewer system. Chlorpyrifos was detected in 17 of 33 samples (52 percent) and was found at all sites except FMC (fig. 24C). Concentrations of chlorpyrifos were detected at VIL-2 and VIL-3 during high flow but not during low flow, indicating nonpoint sources. The maximum concentration of 0.0208 µg/L occurred at VAL-1 and did not exceed the USEPA recommended water-quality criteria for priority toxic pollutants (table 17; U.S. Environmental Protection Agency, 1999). The Canadian aquatic life guideline of 0.0035 µg/L for the protection of aquatic life was exceeded in 15 of 33 samples (45 percent; appendix table 2-4). It was not possible to

statistically evaluate the differences among sites due to the low detection frequency and multiple reporting levels for this compound. Chlorpyrifos is widespread in the watershed, and it was detected in stream samples from Valley Creek as often as those from Village Creek.

Diazinon and carbaryl commonly are used to control insects on lawns and gardens in urban areas. Diazinon was detected in 26 of 33 samples (79 percent) with a maximum concentration of 0.154 µg/L at VIL-4 (table 17; appendix table 2-4). The Great Lakes Water Quality Agreement of 1977 established an aquatic life criterion of 0.08 µg/L for diazinon (table 17). This was exceeded four times at VIL-1, VIL-3, VIL-4, and VAL-2. Carbaryl was detected in 11 of 33 samples (33 percent) with a maximum concentration of 0.426 µg/L at VIL-3. The Canadian Water Quality Guideline of 0.2 µg/L was exceeded twice—at VIL-2 and VIL-3 (appendix table 2-4).

Malathion is an insecticide used in broad-scale aerial applications to control fruit flies and mosquitoes in urban areas. It was detected in 4 of 33 samples (12 percent) in the Birmingham study area. The maximum concentration was 0.156 µg/L at VAL-1, which exceeded

Table 17. Standards, guidelines, and maximum concentrations of pesticides detected in water samples from streams in the Birmingham area, Alabama, 2000–01

[μg/L, micrograms per liter; E, estimated; —, no criteria; DNOC, 4,6-dinitro-2-methylphenol]

Organic chemical	Trade name	Maximum concentration (μg/L)	Drinking-water standard or guideline (μg/L)	Guideline for aquatic life (μg/L)
Herbicides				
Atrazine	Aatrex, Atred, Criazina, Gesaprim	8.88	3[a,b]	1.8[c]
Benfluralin	Balan	E .00619	—	—
Bentazon	Basagran	.196	—	—
Bromacil	Bromax, Hyvar, Urox B, Uragan	1.03	—	5.0[c]
Bromoxynil	Bison, Buctril, Moxy, Brominal	.07	—	5.0[c]
Deethylatrazine		E .522	—	—
Diuron	Direx, Karmex	2.264	—	—
DNOC	Sinox, Trifocide	E .30	—	—
Metolachlor	Dual, Pennant	.00543	—	7.8[c]
Pendimethalin	Prowl, Pre-M, Squaron, Stomp	.0654	—	—
Prometon	Pramitol, Princep	.926	—	—
Pronamide	Kerb	.0127	—	—
Simazine	Princep	8.6	4[a,b]	10[c]
Tebuthiuron	Perflan, Spike, Tebusan	.136	—	1.6[c]
Terbuthylazine		E .401	—	—
Triclopyr	Garlon, Grazon	.384	—	—
Trifluralin	Treflan, Tri-4, Trific, Gowan	E .0065	—	0.20[c]
Insecticides				
Aldicarb	Temik	E 0.064	7[a]	1[c]
Aldicarb sulfone		E .0833	7[a]	—
Carbaryl	Adios, Carbamine, Denapor, Drexel, Sevin	E .426	—	0.2[c]
Chlorpyrifos	Dursban, Brodan, Eradex, Genpest, Lorsban, Profos, Scout	.0208	—	0.0035[c], 0.083[d], 0.041[e]
Diazinon	D.Z.O., Basadin, Diazatol, Knox Out, Sarolex	.154	—	0.08[f]
Dieldrin	Panoram D-31	.00498	—	2.5[g] or 0.0019[h]
Malathion	Cythion, Maltox	.156	—	0.1[e]

[a] Maximum contaminant level (U.S. Environmental Protection Agency, 2000b).

[b] Alabama Primary Drinking Water Standards (Alabama Department of Environmental Management, 2000b).

[c] Canadian Council of Ministers of the Environment, 2001.

[d] Criteria maximum concentration for aquatic life (U.S. Environmental Protection Agency, 1999).

[e] Criterion continuous concentration for aquatic life (U.S. Environmental Protection Agency, 1999).

[f] Great Lakes Water Quality Agreement (International Joint Commission United States and Canada, 1978).

[g] Acute aquatic life criteria (Alabama Department of Environmental Management, 2000d).

[h] Chronic aquatic life criteria (Alabama Department of Environmental Management, 2000d).
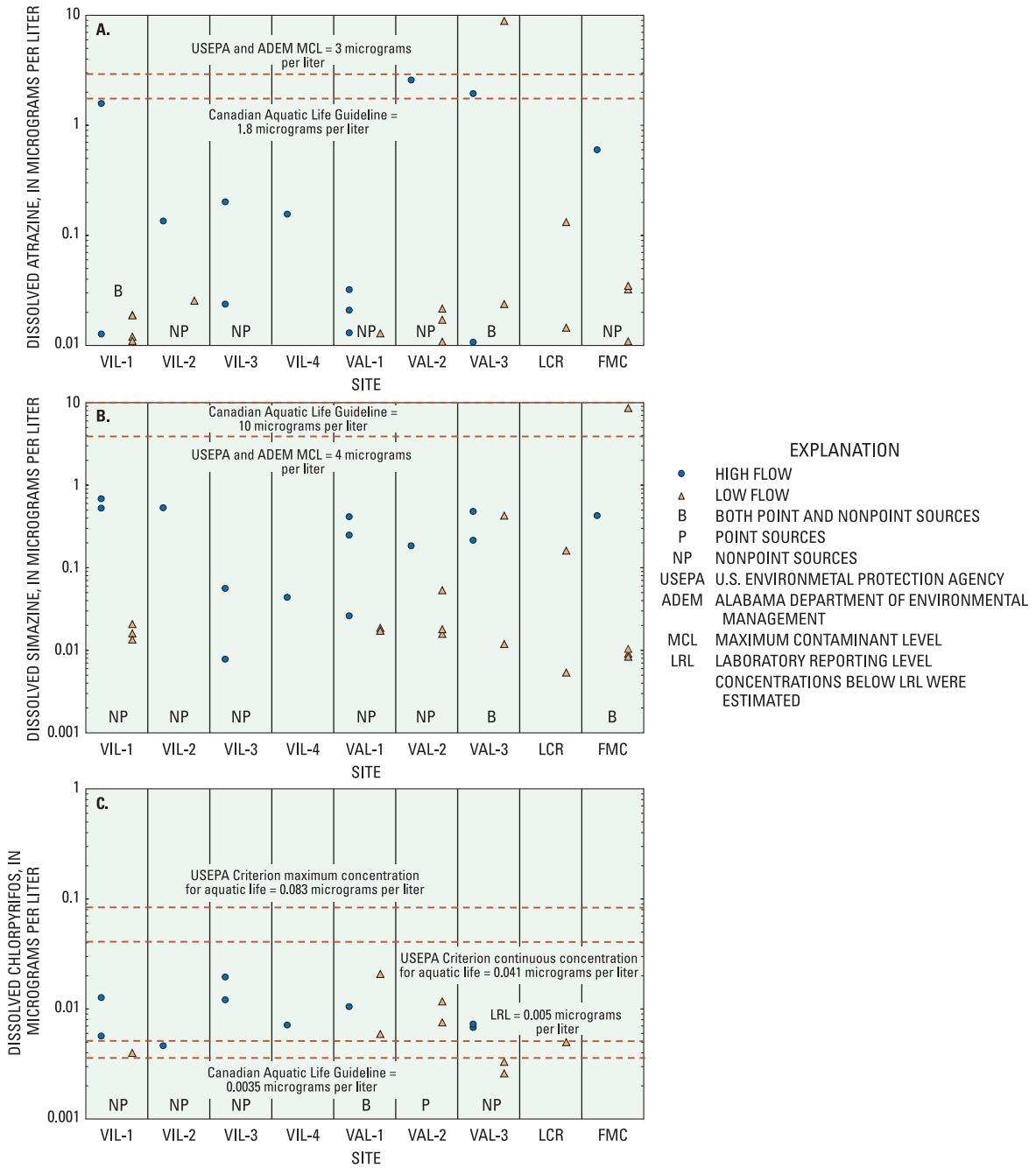
Figure 24. (A) Dissolved atrazine, (B) dissolved simazine, and (C) dissolved chlorpyrifos concentrations detected in water samples during high and low flow at streams in the Birmingham area, Alabama, 2000–01.

the USEPA recommended water-quality criterion for aquatic life of 0.1 µg/L (table 17).

Ninety-four percent of the pesticide samples in this study contained more than one pesticide (appendix table 2-4). Atrazine, chlorpyrifos, diazinon, simazine, and tebuthiuron were detected at every urban site in the Birmingham study area (table 18). Carbaryl and prometon were detected at six of seven urban sites in the Birmingham study area (table 18). The site with the greatest number of pesticides (13) detected was VAL-3; the site with the fewest number of pesticides (8) detected was FMC (table 18). Prometon concentrations at VAL-2 were significantly greater than concentrations at FMC (table 6).

The number of pesticides present in the stream may be important from a toxicological standpoint. Generally, the effects of pesticide mixtures on biota or humans are not included in water-quality criteria, which are most commonly based on single-species, single-chemical toxicity tests conducted under laboratory conditions (Hampson and others, 2000). Some pesticides could be more toxic when combined with other toxic compounds than when present individually. The synergistic effects created from the low concentrations of multiple pesticides have yet to be quantified (Hoffman and others, 2000). The combined ecological effects of the pesticides in the streams are unknown.

Table 18. Pesticide detection frequencies in water samples from streams in the Birmingham area, Alabama, 2000–01

[Numbers shown are number of detections and the number of samples collected at each site. —, compound was not detected at this site; DNOC, 4,6-dinitro-2-methylphenol. Site locations are shown in figure 1]

	VIL-1	VIL-2	VIL-3	VIL-4	VAL-1	VAL-2	VAL-3	LCR	FMC
HERBICIDES									
Atrazine	6 of 6	2 of 3	2 of 3	1 of 1	5 of 5	4 of 4	4 of 4	2 of 2	5 of 5
Benfluralin	1 of 6	—	—	—	—	—	—	—	—
Bentazon	—	—	—	—	1 of 5	—	—	—	—
Bromacil	—	1 of 3	1 of 3	1 of 1	—	—	1 of 4	—	—
Bromoxynil	—	1 of 3	—	—	—	—	—	—	—
Deethylatrazine	5 of 6	—	—	—	2 of 5	4 of 4	4 of 4	2 of 2	5 of 5
Diuron	—	1 of 3	2 of 4	1 of 1	—	—	—	—	—
DNOC	—	—	—		—	—	1 of 4	—	—
Metolachlor	—	—	—	1 of 1	—	—	—	1 of 2	—
Pendimethalin	—	—	1 of 3	1 of 1	1 of 5	2 of 4	1 of 4	—	—
Prometon	4 of 6	—	2 of 3	1 of 1	4 of 5	4 of 4	4 of 4	2 of 2	4 of 5
Pronamide	—	—	—	—	—	—	—	—	1 of 5
Simazine	6 of 6	1 of 3	2 of 3	1 of 1	5 of 5	4 of 4	4 of 4	2 of 2	5 of 5
Tebuthiuron	3 of 6	1 of 3	1 of 3	1 of 1	2 of 5	1 of 4	3 of 4	2 of 2	1 of 5
Trichlopyr	—	2 of 3	—	—	—	—	3 of 4	—	—
Trifluralin	1 of 6	—	2 of 3	—	—	1 of 4	—	—	—
INSECTICIDES									
Aldicarb	—	—	—	—	—	—	—	1 of 2	—
Aldicarb sulfone	—	—	—	—	—	—	—	1 of 2	—
Carbaryl	1 of 6	2 of 3	2 of 3	1 of 1	1 of 5	—	2 of 4	2 of 2	—
Chlorpyrifos	3 of 6	2 of 3	2 of 3	1 of 1	3 of 5	2 of 4	4 of 4	1 of 2	—
Diazinon	4 of 6	2 of 3	2 of 3	1 of 1	5 of 5	4 of 4	4 of 4	2 of 2	2 of 5
Dieldrin	2 of 6	—	—	—	—	—	—	—	1 of 5
Malathion	—	—	—	—	1 of 5	1 of 4	1 of 4	1 of 2	—

Comparison of Pesticide Data from Urban Sites in Birmingham to Urban Sites Nationwide

Pesticide data from Village and Valley Creeks were compared to pesticide data collected from urban sites across the Nation in the NAWQA Program. More than 1,940 pesticide samples were collected from urban sites between 1991 and 2001 (U.S. Geological Survey, 2001). Pesticide concentrations from Village and Valley Creeks were plotted over a bar graph illustrating ranges, which included the lowest 25 percent, the middle 50 percent, and the highest 25 percent of the Birmingham data (fig. 25). To the right of each bar graph in figure 25 is another bar graph illustrating the same ranges for data collected at urban NAWQA sites nationwide. The statistical quartiles of both data sets were computed by using detected values in order to better illustrate the spread of the data. Concentrations of pesticides were adjusted by censoring to a common detection threshold of 0.01 μg/L. The pesticide concentrations detected in this study fell within a narrower range than the concentrations reported nationally.

The most frequently detected herbicide in urban areas in the NAWQA Program was prometon (fig. 26). In the Birmingham study area, prometon was the third most commonly detected herbicide, after atrazine and simazine. All three of these compounds belong to the same category of triazine herbicides. Metolachlor and diuron, also herbicides, were detected more frequently on a national basis than in the Birmingham study area. The most frequently detected insecticide, both locally and nationally, was diazinon (fig. 26). The second and third most frequently detected insecticides were carbaryl and chlorpyrifos, respectively (fig. 26).
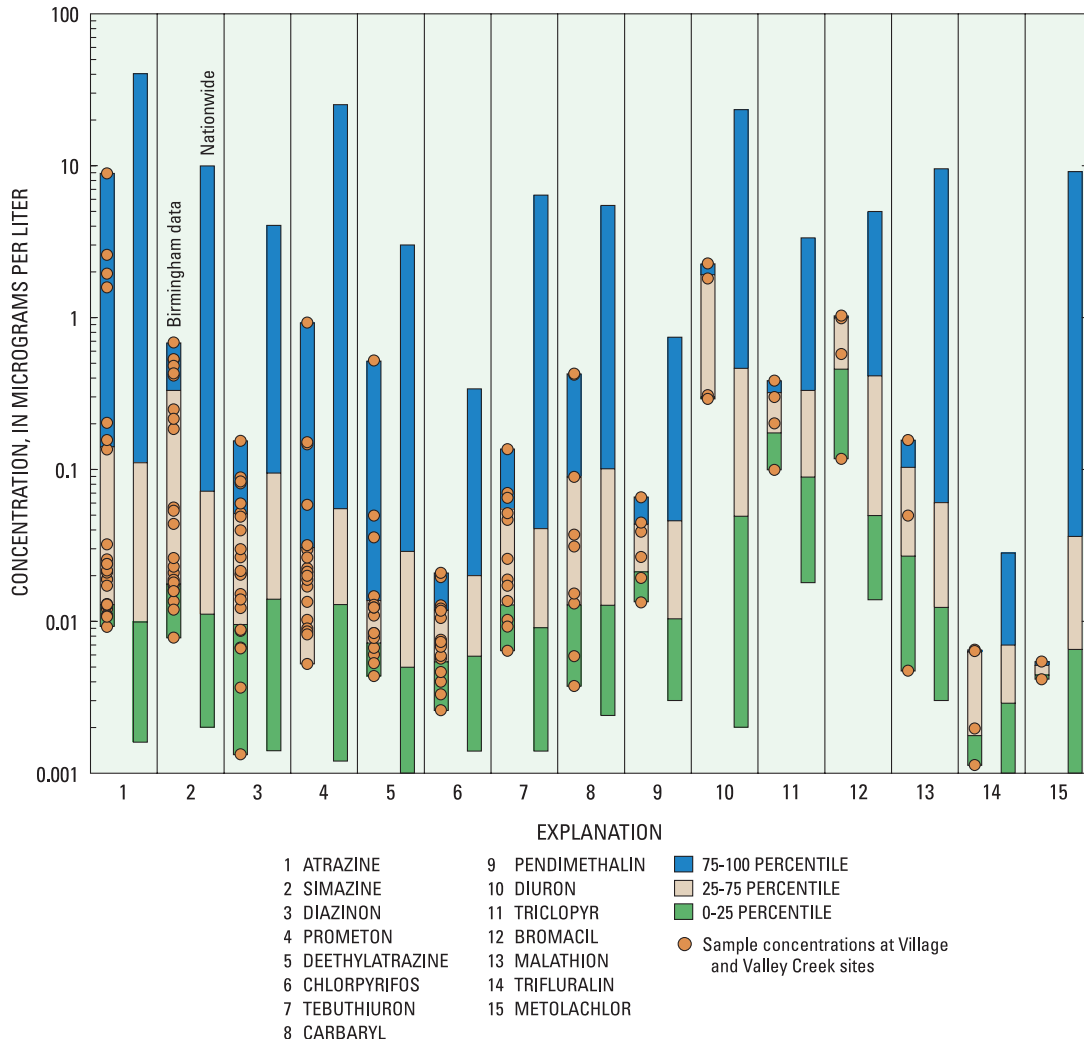
Figure 25. Comparison of pesticides in water samples from urban sites in the Birmingham area, Alabama, to urban sites nationwide.
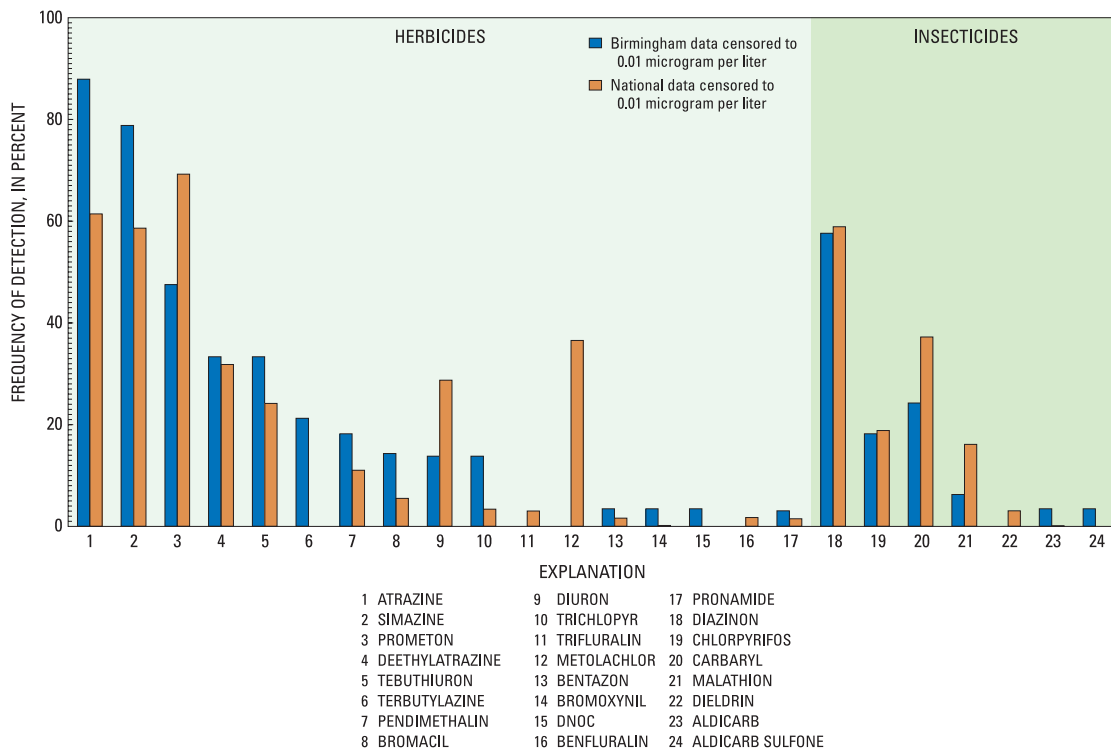
Figure 26. Comparison of frequencies of detection for pesticides in water samples from streams in the Birmingham area, Alabama, to urban sites nationwide.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are formed during combustion processes and may enter surface-water systems in a variety of ways, including atmospheric deposition, surface runoff, and soil leaching (Smith and others, 1988). Several PAHs have been identified as carcinogens or mutagens. Sources of PAHs include domestic sewage, asphalt surfaces, car tires, vehicular exhaust, crude oil, and petroleum (Dojlido and Best, 1993).

Sixteen PAHs were detected in water samples from the Birmingham study sites (appendix table 2-5). PAHs were detected at all sites except LCR (table 19). Fluoranthene and pyrene were the most frequently

detected PAHs (fig. 27). Ninety-nine percent of the detections were estimated values qualified with an "E" and were not compared to criteria because of uncertainty associated with the estimated value (appendix table 2-5). The maximum concentration of fluoranthene was 2.82 µg/L (VAL-2), which exceeded the Canadian guideline of 0.04 µg/L for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2001). The maximum concentration of phenanthrene was 2.27 µg/L (VAL-3), which exceeded the Canadian guideline of 0.4 µg/L for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2001).

Table 19. Polycyclic aromatic hydrocarbon detection frequencies in water samples from streams in the Birmingham area, Alabama, 2000–01

[PAH, polycyclic aromatic hydrocarbon. Numbers shown are number of detections and the number of samples collected at each site. —, compound was not detected at this site. Site locations are shown in figure 1]

PAH	VIL-1	VIL-2	VIL-3	VIL-4	VAL-1	VAL-2	VAL-3	LCR	FMC
Acenaphthene	4 of 4	2 of 3	1 of 3	1 of 1	2 of 6	4 of 5	2 of 4	—	1 of 2
Acenapthylene	2 of 4	3 of 3	1 of 3	—	2 of 6	2 of 5	1 of 4	—	1 of 2
Anthracene	3 of 4	1 of 3	1 of 3	—	4 of 6	3 of 5	2 of 4	—	1 of 2
Benz-a-anthracene	3 of 4	1 of 3	—	—	2 of 6	1 of 5	2 of 4	—	1 of 2
Benzo(a)pyrene	3 of 4	1 of 3	—	—	3 of 6	1 of 5	2 of 4	—	1 of 2
Benzo[b]fluoranthene	3 of 4	1 of 3	—	1 of 1	3 of 6	1 of 5	2 of 4	—	1 of 2
Benzo[ghi]perylene	3 of 4	1 of 3	—	—	3 of 6	1 of 5	2 of 4	—	—
Benzo[k]fluoranthene	3 of 4	1 of 3	—	—	3 of 6	1 of 5	2 of 4	—	1 of 2
Chrysene	3 of 4	1 of 3	—	1 of 1	4 of 6	2 of 5	3 of 4	—	1 of 2
1,2-5,6-dibenzanthracene	3 of 4	1 of 3	—	—	1 of 6	1 of 5	1 of 4	—	—
Fluoranthene	4 of 4	3 of 3	2 of 3	1 of 1	5 of 6	5 of 5	3 of 4	—	2 of 2
Fluorene	4 of 4	2 of 3	2 of 3	1 of 1	3 of 6	4 of 5	2 of 4	—	—
Indeno[1,2,3-cd]pyrene	3 of 4	2 of 3	1 of 3	—	3 of 6	1 of 5	2 of 4	—	—
Naphthalene	3 of 4	3 of 3	2 of 3	—	3 of 6	3 of 5	2 of 4	—	—
Phenanthrene	3 of 4	2 of 3	1 of 3	—	4 of 6	3 of 5	3 of 4	—	1 of 2
Pyrene	4 of 4	3 of 3	2 of 3	1 of 1	5 of 6	5 of 5	3 of 4	—	2 of 2
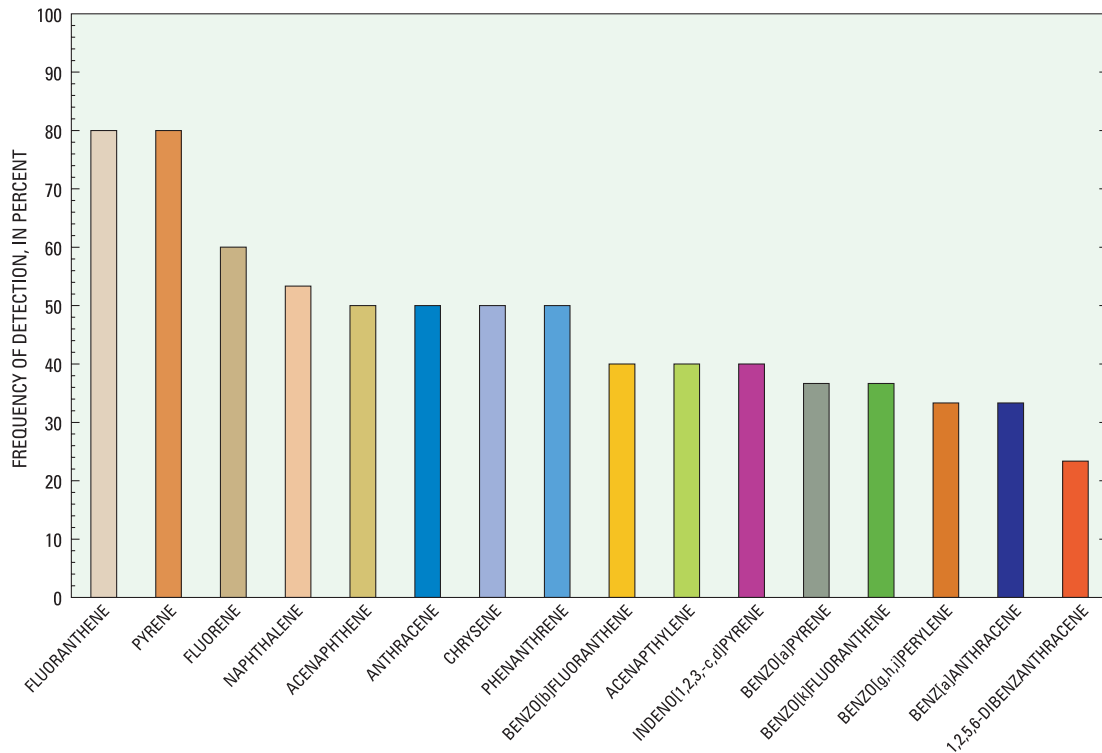
Figure 27. Frequencies of detection for polycyclic aromatic hydrocarbons in water samples from streams in the Birmingham area, Alabama, 2000–01.

Bed Sediment and Fish Tissue

Bed-sediment and fish-tissue samples were collected at VIL-1, VIL-2, VIL-3, VAL-1, VAL-2, and FMC and analyzed for trace and major elements and organic compounds.

Trace and Major Elements in Bed Sediment

Bed-sediment samples from Village and Valley Creeks and FMC were analyzed for 46 trace and major elements, 10 of which are classified by the USEPA (Code of Federal Regulations, 1996) as trace-element priority pollutants (TEPPs) (table 20; appendix table 3-1). Probable-effect levels (PELs) have been established for 8 of the 10 TEPPs, excluding nickel and silver (table 20). A general pattern of increasing concentrations of TEPPs in a downstream direction in Village Creek, especially between VIL-1 and VIL-2, and decreasing concentrations in a downstream direction in Valley Creek was identified. These patterns indicated potential points of origin for the introduction of these contaminants to Village and Valley Creek—upstream from VIL-2 and VAL-1, respectively.

Samples from VAL-1 contained the highest concentrations of chromium, copper, lead (fig. 28A), mercury, and silver among all sites (table 20). Samples from VIL-2 contained the highest concentrations of cadmium (fig. 29), nickel, selenium, and zinc among all sites (table 20). At both sites, the concentrations of arsenic, cadmium, chromium, copper, lead, and zinc (also
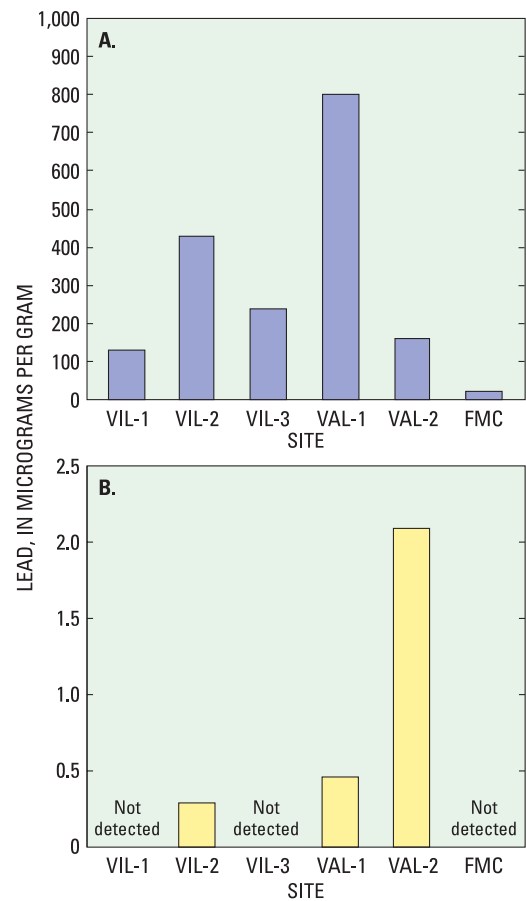
Figure 28. Concentrations of lead detected in (A) bed sediment and (B) fish-liver tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

Table 20. Concentrations of trace-element priority pollutants detected in bed-sediment samples from streams in the Birmingham area, Alabama, 2000

[Values are in micrograms per gram; PEL, probable effect level; LRL, laboratory reporting level; <, less than; na, not available. Shaded values are concentrations that exceeded the PEL. Site locations are shown in figure 1]

Analyte	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	PEL	National median value[a]	LRL
Arsenic	22	20	21	21	14	11	17	6.3	0.01
Cadmium	.60	19	10	4	.82	< .1	3.53	.4	.1
Chromium	83	170	110	180	88	47	90	64	1
Copper	45	210	120	320	54	16	197	27	1
Lead	130	430	240	800	160	23	91.3	27	4
Mercury	.27	.45	.23	1.60	.19	< .02	.49	.06	.02
Nickel	38	57	41	47	21	18	na	27	2
Selenium	.80	1.90	1.20	1.50	.70	.51	4.00	.70	.10
Silver	.20	4.00	1.40	20.00	.90	.44	na	na	.10
Zinc	270	4,000	2,400	1,200	330	120	315	110	4

[a] Rice, 1999.
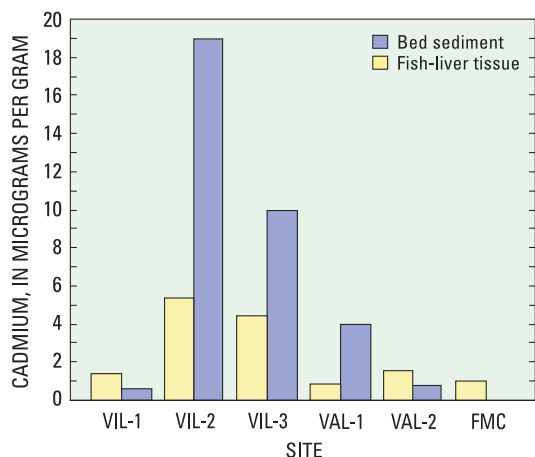
Figure 29. Concentrations of cadmium detected in bed sediment and fish-liver tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

mercury at VAL-1) exceeded PELs that have been found to result in deleterious effects on aquatic biota (Canadian Council of Ministers of the Environment, 1995).

Lead concentrations in bed sediment were elevated above the PEL at all sites in Village and Valley Creeks (table 20). Zinc concentrations were elevated above the PEL at both sites on Valley Creek and at VIL-2 and VIL-3; cadmium and chromium concentrations were elevated above the PELs at VAL-1 and at VIL-2 and VIL-3—the two downstream sites on Village Creek (table 20).

Arsenic concentrations were elevated above the PELs at all sites on Village Creek and the most upstream site on Valley Creek (table 20); however, these values have not been adjusted for natural background levels. A recent survey of stream sediment in northern Alabama, including streams in Jefferson County, reported naturally elevated arsenic concentrations (Goldhaber and others, 2001). In that survey, the sources of arsenic-enriched bed sediments in the carbonate valleys were related to the arsenic-enriched coals from nearby coal fields in Jefferson County. These naturally enriched levels ranged from 7 to 14 µg/g in Jefferson County. Concentrations of arsenic in bed sediment at FMC and VAL-2 were within this naturally enriched range—all other concentrations at sites on Village and Valley Creeks exceeded the naturally enriched range (table 20). Goldhaber and others (2001) did consider the urban area of Birmingham to be a possible source of arsenic from industrial pollution.

With the exception of silver, the concentrations of the TEPPs in the bed-sediment sample from FMC were the lowest in the study, and none exceeded the PELs (table 20). The concentration of silver at VAL-1 (20 µg/g)

was five times greater than that detected at VIL-3 (4 µg/g), and 45 times greater than that detected at FMC (0.44 µg/g). Zinc concentrations in the bed-sediment samples from VIL-2, VIL-3, and VAL-1 were 4 to 12 times greater than those in the samples from VIL-1 and VAL-2. Concen-trations of TEPPs in bed sediment, except for silver, were consistently highest in Village and Valley Creeks and lowest in FMC, indicating possible anthropogenic sources of these TEPPs from the urban land-use activities in the watersheds of Village and Valley Creeks. Potential sources include point sources, such as municipal wastewater, industrial, and commercial discharges, and nonpoint sources, such as runoff from residential, commercial, and industrial areas.

The concentrations of nine TEPPs (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc) in the bed-sediment samples from VIL-1, VIL-2, VIL-3, and VAL-1 exceeded the national median values reported by Rice (1999; table 20). At VAL-2, the concentrations of seven TEPPs (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) exceeded the national median values (table 20). In contrast, only arsenic and zinc concentrations in the bed-sediment sample from FMC exceeded the national median values (table 20).

On a regional level, bed-sediment concentrations of antimony, beryllium, cadmium, chromium, copper, lead, magnesium, mercury, molybdenum, nickel, selenium, silver, and tin at the Village and Valley Creek sites exceeded concentrations at 21 sites in Alabama, Mississippi, and Georgia sampled in 1998 by the USGS as part of the NAWQA Program (Zappia, in press). Concentrations of silver at VAL-1 exceeded concentra-tions from 770 sites sampled nationwide from the 1991 and 1994 USGS NAWQA studies (Zappia, in press).

Concentrations of the TEPPs in each sample were summed to compare bed sediment among the six sites (fig. 30A). The highest summed concentration of the TEPPs (4,912 µg/g) occurred in the bed-sediment sample from VIL-2; the lowest summed concentration of the TEPPs (236 µg/g) occurred at FMC. In Village Creek, concentrations of 8 of the TEPPs (cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc) in bed sediment were highest at VIL-2, followed by VIL-3 and VIL-1—whereas in Valley Creek, however, concentrations of all 10 priority pollutants were highest at VAL-1 and decreased in a downstream direction. Zinc, lead, and copper were the three most abundant TEPPs detected in the bed-sediment samples from Village and Valley Creeks (fig. 30). Zinc accounted for 81 percent of the summed concentrations of the 10 TEPPs detected in the bed-sediment samples from VIL-2 and VIL-3 and
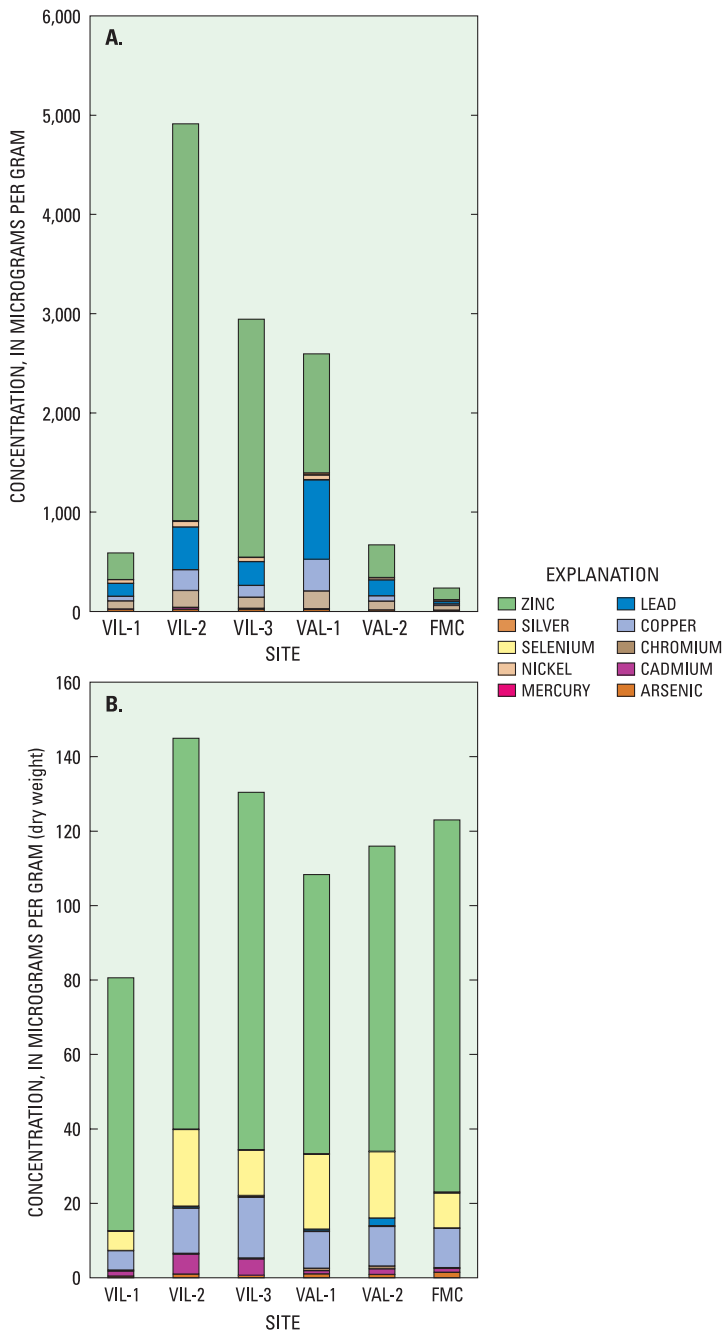
Figure 30. The sum of the concentrations of trace-element priority pollutants detected in (A) bed sediment and (B) fish-liver tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

about 50 percent of the summed TEPP concentrations in bed-sediment samples from each of the other four sites. Lead accounted for the second largest component of the TEPPs from all sites except FMC, where chromium was the second largest component.

Samples from VIL-2 and VAL-1 contained the highest concentrations of the non-TEPP elements. In Valley Creek, there was a general decrease in concentration of the non-TEPPs in a downstream direction (appendix table 3-1). In Village Creek, the summed concentrations of the non-TEPPs were similar among the three sites. With the exception of organic carbon, there was no general pattern of increasing concentration in a downstream direction. Organic carbon concentrations in samples from VIL-2 and VIL-3 were higher than those detected in the sample from VIL-1. The organic carbon in the VIL-2 sample also was higher than that in VIL-3, indicating a source upstream from VIL-2. The bed-sediment sample from FMC generally had the lowest detected concentrations of the 36 non-TEPP elements (appendix table 3-1). Only gold and thallium were not detected at any site.

Trace and Major Elements in Fish-Liver Tissue

Fish-liver tissue samples were analyzed for 22 elements (table 21). Concentrations could not be compared to standards because NAS/NAE and Canadian standards for trace-element concentrations in fish-liver tissue do not exist. No discernible pattern of concentration increase or decrease in a downstream direction among the sites was identified for most of the analytes. The lack of such a pattern may be due to the complexity of fish tissues, the behavior of the fishes, the differences in bioavailability of the elements, and other environmental factors. Four trace elements (antimony, beryllium, silver, and uranium) were not detected in quantifiable amounts in samples from any of the sites.

Cadmium and lead were the most variable of the TEPPs detected in fish-liver samples. The samples from VIL-2 and VIL-3 contained more than twice the concentration of cadmium than samples from any other site (fig. 29) and the sample from VAL-2 contained more than four times the concentration of lead than any other site (fig. 28B). Concentrations of cadmium, selenium, and zinc were highest in fish-liver samples from VIL-2; concentrations of lead and chromium were highest in fish-liver samples from VAL-2; concentrations of copper and mercury were highest at VIL-3; concentrations of arsenic were highest at FMC (table 21). Arsenic is typically not used in metabolic processes of aquatic organisms. The bioavailability of arsenic depends on several factors—including concentration in the bed sediment or water column, the speciation of arsenic present, and other environmental factors such as pH, sulfide, and iron concentrations (Agency for Toxic Substances and Disease

Table 21. Concentrations of trace and major elements detected in fish-liver tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000

[Values are in micrograms per gram, dry weight recoverable; LRL, laboratory reporting level; <, less than; na, not available; E, estimated value. Site locations are shown in figure 1]

Analyte	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	LRL
Aluminum	5.0	7.5	4.0	14.6	66.4	10.6	1.000
Antimony	< .2	< .24	< .22	< .36	< .25	< .52	.100
Arsenic	.41	.99	.66	1.03	.87	1.46	.100
Barium	< .1	.22	.12	.24	.79	.21	.100
Beryllium	< .2	< .24	< .22	< .36	< .25	< .52	.100
Boron	1.2	1.50	1.13	1.49	1.29	2.58	.200
Cadmium	1.4	5.34	4.40	.88	1.54	1.02	.100
Chromium	< .5	< .5	< .5	.61	.75	< .5	.500
Cobalt	1.1	.34	.28	.75	.94	1.68	.100
Copper	5.2	12.1	16.3	9.9	10.6	10.5	.500
Iron	410	283	323	498	568	738	1.000
Lead	< .2	.29	< .22	.46	2.09	< .52	.100
Manganese	3.2	5.6	4.5	6.4	10.4	6.9	.100
Mercury	E .04	.25	.26	.17	.19	.13	na
Molybdenum	.7	1.80	1.55	1.94	1.11	1.01	.100
Nickel	< .2	< .24	.23	< .36	.32	< .52	.100
Selenium	5.2	20.6	12.2	20.1	17.8	9.3	.100
Silver	< .2	< .24	< .22	< .36	< .25	< .52	.100
Strontium	.2	.30	.41	.86	1.46	.42	.100
Uranium	< 2	< .24	< .22	< .36	< .25	< .52	.100
Vanadium	.4	.72	.86	.91	1.35	1.17	.100
Water in tissue (percent)	70	76.7	77.4	77.7	80.1	79.7	na
Zinc	68	105	96	75	82	100	.500

Registry, 2000a). Fish-liver samples from VIL-1 had the lowest concentrations of 12 of the 22 elements (table 21).

The concentrations of the 10 TEPPs detected in fish-liver samples from six sites were summed for comparison among sites (fig. 30B). Those sites with the greatest summed concentrations of TEPPs in fish-liver tissue were VIL-2 and VIL-3. The site with the lowest summed concentrations was VIL-1. Zinc, selenium, and copper were the most abundant TEPPs detected in fish-liver tissue (fig. 30B). On a regional level, concentrations of lead and molybdenum in fish-liver tissue samples at sites in the Birmingham area exceeded concentrations detected at 21 other sites in Alabama, Mississippi, and Georgia sampled in 1998 (Zappia, in press).

Comparison of Trace-Element Priority Pollutants in Bed-Sediment and Fish-Liver Samples

The concentrations of TEPPs in samples of bed sediment and fishes were compared to determine the likelihood of uptake and sequestration of trace elements from the bed sediment to tissue. The mechanism for uptake may be highly variable among aquatic organisms and the sample size was small; therefore, this result should be viewed with caution. Cadmium (rho = 0.976) in fish tissue was the only trace element that showed significant positive correlation to the concentration of TEPP in bed sediment.

Organic Compounds in Bed Sediment

Bed-sediment samples from the Birmingham study sites were analyzed for 89 organic compounds, including organophosphate and organochlorine pesticides, PAHs, and PCBs. Forty-six of those compounds were detected in quantifiable concentrations (table 22).

Chlorpyrifos was the only organophosphate pesticide detected in bed-sediment samples from the Birmingham study sites, and the concentrations were

Table 22. Concentrations of pesticides and other organic compounds detected in bed-sediment samples from streams in the Birmingham area, Alabama, 2000

[Values are in micrograms per kilogram unless otherwise noted; PEL, probable effect level; E, estimated value; <, less than; na, not available; g/kg, grams per kilogram. Shaded values are concentrations that exceeded the PEL. Site locations are shown in figure 1]

Analyte	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	PEL[a] (dry weight)
1,6-dimethylnaphthalene	E 2.7	57.7	81.8	E 27.1	E 27.7	< 50	na
1,2-dimethylnaphthalene	< 50	< 50	E 20.7	< 50	E 2.9	< 50	na
1-methylpyrene	E 14	77.6	109	92.2	68.1	E 4.8	na
1-methylphenanthrene	E 20.6	120	158	96.3	93.1	E 12.5	na
2,3,6-trimethylnaphthalene	< 50	E 47.2	E 41.2	E 22.8	E 19.9	< 50	na
2,6-dimethylnaphthalene	E 3.5	76.2	147	E 30.4	E 33.4	E 3.6	na
2-ethylnaphthalene	< 50	E 11.9	E 12.4	E 17.3	E 3.4	< 50	na
2-methylanthracene	E 9.5	58	83.2	E 47.4	52.6	E 2.7	na
4*H*-cyclopenta-phenanthrene	E 36.7	134	209	203	148	E 7.7	na
9,10-anthraquinone	110	278	286	416	253	E 47.5	na
9h-fluorene	E 12.8	106	170	85.9	67.6	E 9.6	na
Acenaphthene	E 8.6	83.5	**168**	62.5	50.5	E 2.1	88.9
Acenaphthylene	E 7.4	82.2	112	56.7	52.6	E 2.2	128
Acridine	E 29.6	E 42.5	< 50	128	50.4	< 50	na
Anthracene	E 49.7	305	441	302	247	E 19.8	na
Benz(*a*)anthracene	268	**1,020**	**1,150**	**1,110**	**1,170**	69	385
Benzo[*a*]pyrene	274	**929**	**1,120**	**1,180**	**1,050**	80.1	782
Benzo[*b*]fluoranthene	354	1,140	1,550	1,220	1,120	113	na
Benzo[*ghi*]perylene	214	E 305	859	848	E 292	59.3	na
Benzo[*k*]fluoranthene	302	1,000	1,230	732	909	109	na
bis(2-Ethylhexyl) phthalate	114	985	1,150	940	1,070	E 38.5	na
Butylbenzylphthalate	E 10.4	295	134	92	68	< 50	na
Carbazole	51	174	258	273	154	E 14.2	na
Carbon, total (g/kg as carbon)	12	55.45	69.32	33.96	30.03	17.76	na
Chlordane	**34**	**54**	**53**	**46**	**66**	< 3	8.87
Chlorpyrifos	4.15	23.1	9.28	15.7	10.3	.25	na
Chrysene	380	**1,220**	**1,410**	**986**	**1,400**	104	862
DDE, *p,p'*	.4	3.72	**7.1**	.78	.87	< .2	6.75
DDT, *p,p'*	.6	2.7	< 5.2	1.5	1.2	< .5	4.77
Dibenz[*a,h*]anthracene	60	E 103	**273**	**208**	E 112	E 19.5	135
Dibenzothiophene	E 10.1	72.9	86.6	75.2	60.8	E 1.4	na
Diethyl phthalate	< 50	< 50	< 50	E 14.5	< 50	< 50	na
Di-*n*-butyl phthalate	E 11	E 41.7	E 44.8	E 21.7	E 31.1	E 21.7	na
Di-*n*-octylphthalate	< 50	94.2	< 50	1,390	57.3	< 50	na
Fluoranthene	655	1,970	1,710	**2,830**	1,990	202	2,355
Indeno[1,2,3-*cd*]pyrene	258	E 425	1,000	1,040	E 445	88.7	na
Isoquinoline	< 50	< 50	< 50	E 21	< 50	< 50	na
Naphthalene	E 3.1	< 50	258	< 50	< 50	< 50	391
PCB, total	5.7	95	85	28	39	< 5	277
p-CRESOL	E 7.9	262	182	E 47.1	79.9	< 50	na
p-dichlorobenzene	< 50	E 12	< 50	< 50	E 13.6	< 50	na
Phenanthrene	286	**1,210**	**1,490**	**1,320**	**1,000**	104	515
Phenanthridine	E 9.8	E 29.8	< 50	E 39	E 27.6	< 50	na
Phenol	E 6.5	56	63.9	E 38.6	E 14.2	E 7.4	na
Pyrene	504	**1,400**	**1,390**	**2,160**	**1,420**	161	875
Quinoline	< 50	E 1.6	E 12.7	< 50	< 50	< 50	na

Table 22. Concentrations of pesticides and other organic compounds detected in bed-sediment samples from streams in the Birmingham area, Alabama, 2000 — Continued

[Values are in micrograms per kilogram unless otherwise noted; PEL, probable effect level; E, estimated value; <, less than; na, not available; g/kg, grams per kilogram. Shaded values are concentrations that exceeded the PEL. Site locations are shown in figure 1]

Analyte	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	PEL[a] (dry weight)
				Nondetections			
1,2,4-trichlorobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
1-methyl-9h-fluorene	< 50	< 50	< 50	< 50	< 50	< 50	na
2,2'-biquinoline	< 50	< 50	< 50	< 50	< 50	< 50	na
2,4-dinitrotoluene	< 50	< 50	< 50	< 50	< 50	< 50	na
2,6-dinitrotoluene	< 50	< 50	< 50	< 50	< 50	< 50	na
2-chloronaphthalene	< 50	< 50	< 50	< 50	< 50	< 50	na
2-chlorophenol	< 50	< 50	< 50	< 50	< 50	< 50	na
3,5-xylenol (dimethylphenol)	< 50	< 50	< 50	< 50	< 50	< 50	na
4-bromophenyl phenyl ether	< 50	< 50	< 50	< 50	< 50	< 50	na
4-Chloro-*m*-cresol (4-chloro-3-methylphenol)	< 50	< 50	< 50	< 50	< 50	< 50	na
4-Chlorophenyl phenyl ether	< 50	< 50	< 50	< 50	< 50	< 50	na
Aldrin	< .2	< .2	< .2	< .2	< .4	< .2	na
Azobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
Benzo[c]cinnoline	< 50	< 50	< 50	< 50	< 50	< 50	na
bis-2-Chloroethyl ether	< 50	< 50	< 50	< 50	< 50	< 50	na
bis(2-Chloroethoxy)methane	< 50	< 50	< 50	< 50	< 50	< 50	na
C8-alkylphenol	< 50	< 50	< 50	< 50	< 50	< 50	na
Diazinon	< .2	< .2	< .2	< .2	< .2	< .2	na
m-Dichlorobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
o-Dichlorobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
Dieldrin	< .2	< .2	< .2	< .2	< .2	< .2	na
Dimethyl phthalate	< 50	< 50	< 50	< 50	< 50	< 50	na
Endosulfan	< .2	< .2	< .2	< .2	< .2	< .2	na
Endrin	< .2	< .2	< .2	< .2	< .2	< .2	na
Ethion	< .2	< .2	< .2	< .2	< .2	< .2	na
Heptachlor epoxide	< .2	< .2	< .2	< .2	< .2	< .2	na
Heptachlor	< .2	< .2	< .2	< .2	< .2	< .2	na
Hexachlorobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
Isophorone	< 50	< 50	< 50	< 50	< 50	< 50	na
Lindane	< .2	< .2	< .2	< .2	< .2	< .2	na
Malathion	< .2	< .2	< .2	< .2	< .2	< .2	na
Methoxychlor	< 2	< 2.5	< 2.5	< 2.5	< 2.5	< 2.5	na
Methylparathion	< .2	< .2	< .2	< .2	< .2	< .2	na
Mirex	< .2	< .2	< .2	< .2	< .2	< .2	na
Nitrobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
N-nitrosodi-N-propylamine	< 50	< 50	< 50	< 50	< 50	< 50	na
n-Nitrosodiphenylamine	< 50	< 50	< 50	< 50	< 50	< 50	na
p,p'-DDD	< 1.9	< 1.1	< 3	< 2.1	< 2.4	< .5	na
Parathion	< .2	< .2	< .2	< .2	< .2	< .2	na
Pentachloroanisole	< 50	< 50	< 50	< 50	< 50	< 50	na
Pentachloronitrobenzene	< 50	< 50	< 50	< 50	< 50	< 50	na
Toxaphene	< 50	< 50	< 50	< 50	< 50	< 50	na
Trithion	< .2	< .2	< .2	< .2	< .2	< .2	na

[a] Canadian Council of Ministers of the Environment, 1995.

quantifiable in samples from all sites (fig. 31). Concentrations of chlorpyrifos were highest in bed-sediment samples from VIL-2 and lowest in samples from FMC (table 22). The concentrations in bed-sediment samples from VAL-1 and VAL-2 were higher than concentrations from VIL-1 or VIL-3 (table 22). The presence of chlorpyrifos in bed sediment was of particular interest to the city of Birmingham because of the fish kill that resulted from the 1997 spill of Dursban into Village Creek. In addition to a lethal effect on fishes, chlorpyrifos is acutely toxic to some species of aquatic invertebrates at water-column concentrations as low as 0.0035 µg/L, and has been shown to decrease densities of aquatic invertebrates (Odenkirchen and Eisler, 1988). However, since chlorpyrifos has a half-life of about 24 days in a water-column-sediment mixture and about 9 hours in fishes (Odenkirchen and Eisler, 1988), it is unlikely that there was any residual chlorpyrifos in the bed sediment of Village Creek that can be directly attributed to the Dursban spill in 1997. The presence of persistent

Known degradation products, or metabolites, include DDE and DDD, which are also highly persistent. DDE is commonly produced in oxygen-rich environments, such as streams and some soils; DDD is produced only in oxygen-depleted environments, such as ground water (Chapelle, 1993).

The bed-sediment concentrations of DDD, DDE, DDT, and the ratio of DDT/total DDT at the six sites in the Birmingham area are provided in table 23. The p,p'-DDT isomer was detected in the bed-sediment samples at VIL-1, VIL-2, VAL-1, and VAL-2; the p,p'-DDE isomer was detected at every site on Village and Valley Creeks; the p,p'-DDD isomer was not detected at any site (table 23; fig. 32A). The highest concentration of p,p'-DDT (2.7 µg/kg) occurred at VIL-2; the highest concentration of p,p'-DDE (7.10 µg/kg) occurred at VIL-3 and exceeded the PEL of 6.75 µg/kg at that site (fig. 32A; table 22). The highest total DDT concentration, based on only the p,p'-DDE and the p,p'-DDT isomers, occurred at VIL-3 (fig. 32A).

Figure 31. Concentrations of chlorpyrifos detected in bed sediment and fish tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

organochlorine compounds, such as DDT, in the aquatic environment may be related to both past and present land use in the watershed. DDT is relatively immobile and highly persistent in the soil environment, with a reported half-life of between 2 and 15 years (Agency for Toxic Substances and Disease Registry, 2000b). The reported half-life for DDT in the water environment is approximately 56 days in lakes and 28 days in river water (Agency for Toxic Substances and Disease Registry, 2000b). DDT can be degraded in both the soil and aquatic environments; however, degradation occurs much more slowly in soils.

Figure 32. Concentrations of DDT and its degradation products detected in (A) bed sediment and (B) fish tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

Table 23. Concentrations of DDT and its degradation products detected in bed-sediment and fish-tissue samples at selected stream sites in the Birmingham area, Alabama, 2000

[Values are in micrograms per kilogram; NA, no analysis for this isomer; <, less than; ND, not able to be determined because of censored or missing values. Ratios in **bold** indicate recent mobilization and introduction of residual DDT into the hydrologic system at the site]

Site label (fig. 1)	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Total DDT[a]	DDT[b]/ total DDT	DDE, percent of total DDT	DDD, percent of total DDT
				Bed sediment						
VIL-1	NA	< 1.9	NA	0.40	NA	0.6	1.0	ND	40	ND
VIL-2	NA	< 1.1	NA	3.72	NA	2.7	6.4	ND	58	ND
VIL-3	NA	< 3.0	NA	7.10	NA	< 5.2	7.1	ND	100	ND
VAL-1	NA	< 2.1	NA	.78	NA	1.5	2.3	ND	34	ND
VAL-2	NA	< 2.4	NA	.87	NA	1.2	2.1	ND	42	ND
FMC	NA	< .5	NA	< .2	NA	< .5	ND	ND	ND	ND
				Fish tissue						
VIL-1	< 5	7	< 5	20	< 5	4	31	**0.13**	65	23
VIL-2	< 5	< 5	< 5	51	9.7	< 5	61	**.16**	84	ND
VIL-3	< 5	5.1	< 5	16	< 5	< 5	21	ND	76	24
VAL-1	< 5	17	< 5	16	< 5	7.6	41	**.19**	39	42
VAL-2	< 5	20	< 5	25	< 5	7.9	53	**.15**	47	38
FMC	< 5	3.9	< 5	7	< 5	< 5	11	ND	64	36

[a] Total DDT values for bed sediment are estimated from p,p'-isomer data only. Total DDT values for fish tissue are estimated from the p,p'- and o,p'-isomer data.

[b] DDT values for fish tissue are estimated from the p,p'-DDT and o,p'-DDT isomers only.

Studies have indicated that the ratio of DDT[2] / total DDT[3] can be used to determine how long DDT has been in the environment (Nowell and others, 1999). Nowell and others (1999) reported that a ratio exceeding 10 percent (in bed sediment or fish samples) was considered to be indicative of recent movement of DDT (as compared to historical use) into the hydrologic system, for example, by erosion of DDT-contaminated soil. In this study, an accurate estimate of DDT and total DDT for bed-sediment samples could not be made for two reasons: (1) bed-sediment samples were analyzed for the p,p'-isomer of DDT and its metabolites only—o,p'-isomers were not quantified and, (2) p,p'-DDD and p,p'-DDT values were censored at relatively high concentrations.

Chlordane is another persistent organo-chlorine pesticide. Chlordane actually is a mixture of many compounds, the most abundant being *cis*- and *trans*-chlordane (24 and 19 percent, respectively), heptachlor (10 percent), and nonachlor isomers (7 percent). Chlordane was detected in bed-sediment samples from all sites except FMC (fig. 33A). Detections ranged from 34 μg/kg at VIL-1 to 66 μg/kg at VAL-2 (table 22). Chlordane concentra-tions at all sites, except FMC, were

over 3 times the PEL of 8.87 μg/kg; such levels have been linked to physiological changes in aquatic biota (Nowell and others, 1999).

Several PAHs also were detected in measurable quantities at all sites. Among the nonpesticide organic compounds for which bed-sediment samples were analyzed, those accounting for the largest percentage of the summed concentrations (from 10 to 16 percent) at each site were fluoranthene and pyrene (table 22). Concentrations of organic compounds that exceeded PELs are highlighted in table 22—concentrations of eight PAHs (in decreasing order of concentration, fluoroanthene, pyrene, phenanthrene, chrysene, benzo[a]pyrene, benz[a]anthracene, dibenz[ah]anthracene, and acenaphthene) exceeded PELs at sites on Village and Valley Creek (table 22). Concentrations of pyrene, phenanthrene, chrysene, benzo[a]pyrene, and benz(a)anthracene exceeded PELs at all sites except VIL-1 and FMC. PAH concentrations in bed-sediment samples from FMC and VIL-1 did not exceed PELs.

Bed-sediment samples from VAL-1 had the highest summed concentrations and FMC had the lowest summed concentrations of all organic compounds analyzed (table 22). In Village Creek, concentrations of 75 percent of the detected organic compounds were lowest at VIL-1 and increased in a downstream direction from VIL-2 to VIL-3. Concentrations of 25 percent of the detected

[2]DDT refers to the sum of o,p'-DDT and p,p'-DDT.

[3]Total DDT refers to the sum of o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT, and p,p'-DDT.
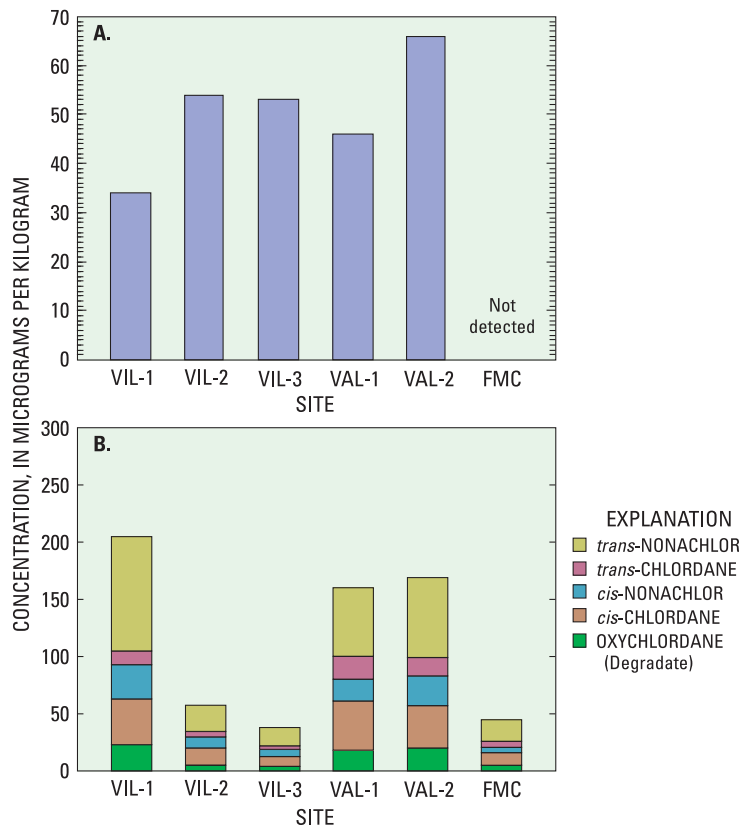
Figure 33. Concentrations of (A) total chlordane detected in bed sediment and (B) components of total chlordane detected in fish tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

organic compounds, including chlorpyrifos, were highest at VIL-2, followed by VIL-3 and VIL-1 (table 22). In contrast, concentrations of about 70 percent of the detected organic compounds in Valley Creek were highest at VAL-1 and decreased in a downstream direction from VAL-1 to VAL-2 (table 22).

Organic Compounds in Fish Tissue

Fish-tissue samples were analyzed for PCBs, 26 organochlorine pesticides, and 19 organophosphate pesticides. Tissue analysis data are presented as reported by the NWQL in table 24. Fourteen organic compounds were quantifiable in the fish-tissue samples. Eight were detected in the samples from all six sites (chlorpyrifos, total DDT, *cis-* and *trans-*nonachlor, *cis-* and *trans-*chlordane, oxychlordane, and total PCBs). Total chlordane refers to the total of the *cis-* and *trans-*chlordane, *cis-*and *trans-*nonachlor, and oxychlordane concen-trations (Nowell and other, 1999). Although the chlordane isomers (*cis-* and *trans-*) are the most abundant components of chlordane, *trans-*nonachlor is the most persistent component. The predominance of *trans-*nonachlor as compared to the other components in fish tissue can be used to indicate a reduction in chlordane

input to the hydrologic system (Nowell and others, 1999).

Total chlordane was detected in the highest concentrations in fish tissue collected at VIL-1, VAL-2, and VAL-1 (table 24). Among the components of total chlordane, *trans-n*onachlor accounted for the largest percentage (38 to 49 percent of the total) among the three streams (fig. 3B). The greatest percentage of the more persistent component of chlordane, *trans-*nonachlor, at all sites indicated long-term residual chlordane in the hydrologic system, not recent input. Total chlordane concentrations in fish-tissue samples from VIL-1, VAL-1, and VAL-2 exceeded guidelines for the protection of fish-eating wildlife (table 24; National Academy of Science/National Academy of Engineering, 1973) and the USEPA screening criterion for edible fish (U.S. Environmental Protection Agency, 1995). A comparison of pesticide concentrations in whole fish samples, as were collected in this study, with standards or guidelines for edible fish is appropriate only as a screening procedure to determine whether additional sampling is warranted (Nowell and Resek, 1994).

Chlorpyrifos was detected in fish-tissue samples from every site. The highest concentrations were found in samples from VAL-1 and VAL-2, respectively, and the lowest concentration from VIL-1 (fig. 31; table 24). Chlorpyrifos also was detected in bed-sediment samples from every site (fig. 31; table 22). The highest concentrations in bed sediment, however, were found in samples from VIL-2 and VAL-1, and the lowest concentration from FMC. In contrast, all fish-tissue samples from Village Creek had lower concentrations of chlorpyrifos than were detected in bed-sediment samples from the same sites—and all fish-tissue samples from Valley Creek had higher concentrations of chlorpyrifos than were detected in bed-sediment samples.

Dieldrin was detected in all of the fish-tissue samples in the Birmingham study (table 24). Dieldrin is both a degradation product of aldrin and a directly applied insecticide. The use of dieldrin began in the 1950's to control pests on cotton and corn, and to kill termites around buildings; however, its use was discontinued by the USEPA in 1987. Dieldrin binds tightly to soil, breaks down very slowly, and is readily washed into streams and waterways by rainfall. Because dieldrin is soluble in lipids, it has a tendency to be stored in fat tissue and leaves the body very slowly. Concentrations of dieldrin were highest in fish-tissue samples from VIL-1, VAL-1, and VAL-2 (table 24). Dieldrin concentrations at these sites

Table 24. Concentrations of pesticides and polychlorinated biphenyls (PCBs) detected in fish tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000

[Values are in micrograms per kilogram; NAS/NAE, National Academy of Sciences/National Academy of Engineering; FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency; <, less than; —, no value; E, estimated; PCB, polychlorinated biphenyl. Shaded values are concentrations that exceeded environmental or human health criteria]

Analyte	Site label (fig. 1)						Environmental criteria	Human health criteria		
	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	NAS/NAE recommended guideline for freshwater whole fish[a]	FDA action level for edible fish[b]	USEPA screening criteria for edible fish[c]	International legal limit for edible fish[d]
Organochlorine pesticides and PCBs										
Dieldrin	**140**	34	23	**170**	**120**	35	100	300	—	300
Aldrin	< 5	< 5	< 5	< 5	< 5	< 5	100	300	—	—
alpha-BHC	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
beta-BHC	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Chlordane, *trans*	12	E 4.7	E 3.1	20	16	5.3	—	—	—	—
Chlordane, *cis*	40	15	8.6	43	37	11	—	—	—	—
Nonachlor, *cis*	30	9.7	6.3	19	26	4.6	—	—	—	—
Nonachlor, *trans*	100	23	16	60	70	19	—	—	—	—
Oxychlordane	23	E 4.9	E 3.9	18	20	5.1	—	—	—	66,100
Total chlordane[e]	**205**	57.3	37.9	**160**	**169**	45	100	300	80	300
Heptachlor epoxide	**39**	E 3.2	< 5	**17**	**20**	E 3.9	100	300	10	300
Heptachlor	< 5	< 5	< 5	< 5	< 5	< 5	100	300	—	—
DCPA	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
DDD, *o,p'*	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
DDD, *p,p'*	7	< 5	5.1	17	20	3.9	—	—	—	5,000
DDE, *o,p'*	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
DDE, *p,p'*	20	51	16	16	25	7	—	—	—	5,000
DDT, *o,p'*	< 5	9.7	< 5	< 5	< 5	< 5	—	—	—	—
DDT, *p,p'*	4	< 5	< 5	7.6	7.9	< 5	—	—	—	5,000
Total DDT[f]	31	61	21	41	53	11	1,000	5,000	300	5,000
delta-BHC	< 5	< 5	< 5	< 5	< 5	< 5	100	—	60,000	—
Endrin	< 5	< 5	< 5	< 5	< 5	< 5	100	300	3,000	300
Hexachlorobenzene	< 5	< 5	< 5	< 5	< 5	< 5	—	—	70	—
Lindane	< 5	< 5	< 5	< 5	< 5	< 5	—	—	80	—
Methoxychlor, *o,p'*	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Methoxychlor, *p,p'*	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Mirex	< 5	< 5	< 5	< 5	< 5	< 5	—	—	2,000	100
PCB total	**170**	**660**	**700**	**320**	**470**	**120**	500	2,000	10	2,000
Pentachloroanisol	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Toxaphene	< 200	< 5	< 5	< 5	< 5	< 5	100	5,000	100	100
Organophosphate pesticides										
Diazinon	< 5	< 5	< 5	E1.52	< 5	< 5	—	—	—	—
Disulfoton	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Ethion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Ethoprop metabolite	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Fenthion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
DEF	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Chlorpyrifos	E1.76	6.52	6.12	44.97	27.19	14	—	—	—	—
Fonofos	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Malathion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Methidathion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Methyl parathion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Parathion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—

[Values are in micrograms per kilogram; NAS/NAE, National Academy of Sciences/National Academy of Engineering; FDA, Food and Drug Administration; USEPA, U.S. Environmental Protection Agency; <, less than; —, no value; E, estimated; PCB, polychlorinated biphenyl. Shaded values are concentrations that exceeded environmental or human health criteria]

| Analyte | Site label (fig. 1) | | | | | | Environmental criteria | Human health criteria | | |
	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	NAS/NAE recommended guideline for freshwater whole fish[a]	FDA action level for edible fish[b]	USEPA screening criteria for edible fish[c]	International legal limit for edible fish[d]
Organophosphate pesticides (Continued)										
Phorate	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Profenofos	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Propetamphos	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Sulfotepp	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Sulprofos	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Terbufos	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—
Trithion	< 5	< 5	< 5	< 5	< 5	< 5	—	—	—	—

[a] National Academy of Sciences/National Academy of Engineering, 1973.

[b] Nowell and Resek, 1994.

[c] U.S. Environmental Protection Agency, 1995.

[d] Nauen, 1983.

[e] Sum of *cis*-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor, and oxychlordane, excluding "<" values.

[f] Sum of *o,p*'-DDD, *p,p*'-DDD, *o,p*'-DDE, *p,p*'-DDE, *o,p*'-DDT, *p,p*'-DDT, excluding "<" values.

exceeded or equaled the criterion for the protection of aquatic life (100 µg/kg; table 24).

The concentrations of total PCBs in fish whole-body tissue were highest at VIL-2 and VIL-3, and exceeded guidelines for the protection of fish and wildlife (500 µg/kg; table 24). The lowest PCB concentration was detected in fish-tissue samples collected at FMC (fig. 34B). The concentrations of PCBs in fishes from all sites greatly exceeded the USEPA screening criterion for the protection of human health (table 24). A similar pattern was seen in the concentrations of total PCBs in bed sediment and fish tissue (fig. 34); however, concentrations in fish tissue were an order of magnitude greater than seen in the bed sediment (table 22).

The relative concentrations of DDT and its degradation products detected in fish tissue are shown in figure 32B. The maximum concentration of total DDT in fish tissue collected from Birmingham area streams was 61 µg/kg at VIL-2 (table 23). Concentrations of total DDT in fish-tissue samples from all sites were lower than any criterion for the protection of aquatic life or human health. Although *p,p'*-DDE was the only degradation product of DDT found in bed sediment (fig. 32A), fish tissue contained *p,p'*-DDD and *p,p'*-DDE (fig. 32B). In Village Creek, *p,p'*-DDE was detected in all fish-tissue samples (fig. 32B) accounting for 65, 84, and 76 percent of the total DDT in fish tissue at VIL-1, VIL-2, and VIL-3, respectively (table 23). In Valley Creek, *p,p'*-DDE and
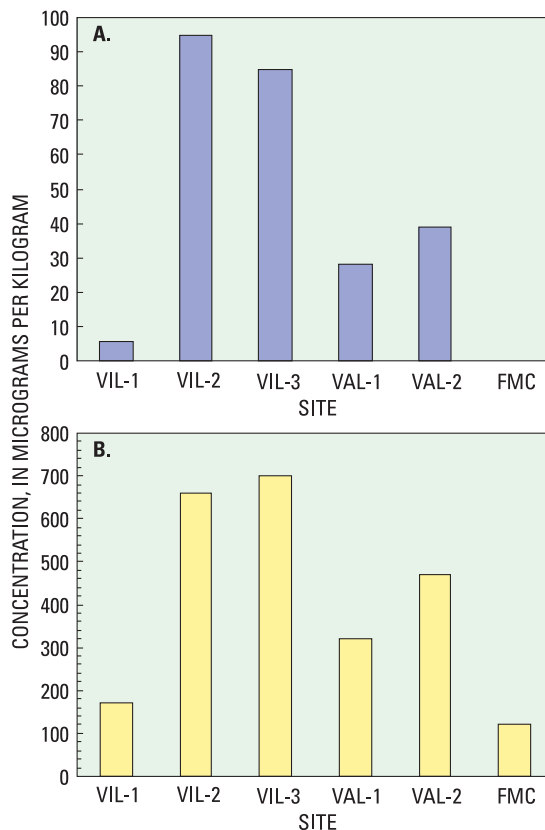
Figure 34. Concentrations of total polychlorinated biphenyls (PCBs) detected in (A) bed sediment and (B) fish tissue (*Lepomis* species) from streams in the Birmingham area, Alabama, 2000.

p,p'-DDD concentrations were relatively equivalent (fig. 32B), accounting for 39 and 42 percent of total DDT, respectively, at VAL-1, and 47 and 38 percent, respectively, at VAL-2 . No *o,p'*-isomers of DDD or DDE were detected at any of the Birmingham sampling sites. The ratios of DDT to total DDT at VIL-1, VIL-2, VAL-1, and VAL-2 were greater than 0.10, indicating recent mobilization of DDT. Although the ratio of DDT to total DDT could not be computed at VIL-3 or FMC because of censored values, the presence of detectable concentrations of the degradation products, DDE and DDD, and the absence of DDT indicated longer-term degradation of residual DDT (table 23).

Habitat

Habitat was evaluated by collecting data on specific physical and geomorphological characteristics of the stream reaches at six of the Birmingham sites, including VIL-1, VIL-3, VAL-1, VAL-2, LCR, and FMC (table 25). No significant correlations were detected between any

habitat characteristic and the aquatic communities in the study sites. The stream reaches, however, differed in several ways (table 25). For example, the length of VIL-3 (349 m) exceeded that of the other stream reaches in order to include two riffle areas for the collection of benthic-invertebrates, whereas two or more riffles were present within a 200-m stream reach at all other sites. The riffles in VIL-3 were located at each end of the reach and were separated by a series of runs and shallow pools. VIL-1 and LCR had no discernable pools, however, pools in the other sites ranged from 6.7 to 18.3 percent of the reach (VAL-1 and VIL-3, respectively). FMC and VIL-1 were totally enclosed by riparian vegetation (zero canopy angle; table 25), whereas the other sites ranged from 37.1 to 99.7 degrees of open canopy angle (VAL-1 and LCR, respectively). Stream gradient differed little from reach to reach. Stream widths in VIL-1, VAL-1, and FMC were similar—with an average wetted channel width of 6.7 m; stream widths at VIL-3, VAL-2, and LCR were twice as large, with an average wetted channel width of 14.7 m.

Table 25. Habitat characteristics in selected streams in the Birmingham area, Alabama, 2000

[m, meter; m^2, square meter; m^3, cubic meter; rth, richest targeted habitat; m/s, meters per second; RW, right-of-way; OT, other—exposed rock; UI, urban industrial; UR, urban residential; SW, shrubs or woodland]

Characteristics	VIL-1	VIL-3	VAL-1	VAL-2	LCR	FMC
Reach length (m)	150	349	150	200	200	180
Reach stream surface area (m^2)	805.2	6,361	1,196	3,022	2,215	1,087
Reach volume (m^3)	147	1,802	844	899	538	119
Reach surface-water gradient	.00220	.00203	.00240	.00253	.00238	.00240
Mean bank height (m)	1.46	3.20	3.27	2.40	1.41	3.55
Mean channel bankfull width (m)	7.45	30.3	22.9	25.8	14.1	10.7
Mean wetted channel width (m)	5.75	18.2	7.97	15.1	11.4	6.04
Mean direction of flow (degrees magnetic)	145	237	235	181	196	38.6
Mean water depth (m) in reach	.182	.3	.1	.3	.246	.08
Mean water depth (m) at rth invertebrate sampling locations	.14	.10	.09	.22	.15	.10
Mean current velocity (m/s) at rth invertebrate sampling locations	.36	.43	.35	.32	.41	.27
Mean percent embeddedness in rth sampling sites	84	83	86	99	65	100
Riffle area in reach (percent)	42.9	13.2	35.3	22.3	16.0	29.0
Frequency of silt in riffle habitats (percent)	73	97	18	100	100	100
Pool area in reach (percent)	0	18.3	6.7	10.6	0	8.06
Run area in reach (percent)	57	68	58	67	84	63
Mean open canopy angle in the reach (degrees)	0	85	37.1	77.4	99.7	0
Mean open canopy angle in riffle habitat (degrees)	90	120	118	139	110	0
Mean bank vegetation cover (percent)	82	40	49	93	94	90
Mean riparian canopy closure in the reach (percent)	100	79.9	48.9	94.9	95.4	95.2
Mean riparian canopy closure in riffle habitat (percent)	100	75	51	97	88	99
Dominant riparian land use	RW/OT	UI	UR	SW	SW	SW

Silt was present in only 18 percent of the riffle habitats at VAL-1 whereas the minimum frequency of occurrence of silt at the other sites was 73 percent (VIL-1; table 25). Silt occurred in 97 percent of the riffle habitats at VIL-3 and was present in 100 percent of the riffle habitats at VAL-2, LCR, and FMC. Channeling by the concrete structures that deliver water to VAL-1 from under the city may facilitate the downstream transport of lighter sediments, resulting in less silt at VAL-1. In addition, less silt may be transported into the system at VAL-1 because of the increased amount of impervious surface in the basin, which has been shown to result in a decrease of silt available in urbanized areas (Doyle and others, 2000).

VAL-1 and VIL-3 had the smallest percentages of riparian canopy closure in riffle habitats and the smallest percentage of bank vegetative cover at all transects (table 25). VAL-1 and VIL-3 also had the highest concentrations of summed organic compounds detected in bed-sediment samples (tables 20, 22). Although, no significant correlation was found between these habitat properties and the concentrations of bed-sediment constituents, these data may indicate the importance of protecting riparian buffer zones that have been found to act as natural filters and reduce the direct runoff of contaminants from modified landscapes to the stream.

Aquatic Community

Benthic-invertebrate and fish communities were evaluated at six of the Birmingham area sites (VIL-1, VIL-3, VAL-1, VAL-2, LCR, and FMC). The primary community metrics investigated were richness and density.

Benthic-Invertebrate Communities

Analysis of qualitative and quantitative samples collected in the Birmingham area streams identified 105 taxa of benthic invertebrates. After censoring, 24 ambiguous taxa were eliminated from the analysis and comparisons were made using the remaining 81 taxa, which represented 5 phyla, 8 classes, and 22 orders of invertebrates (appendix table 3-2).

All sites in Village and Valley Creeks had lower benthic-invertebrate community richness than FMC and LCR (fig. 35). The site with the highest richness was FMC with 29 taxa in the June collection; the site with the lowest richness was VAL-1 with 6 taxa identified in the June collection (appendix table 3-2). Benthic-invertebrate richness was the same at VIL-1 and VIL-3 in June, but
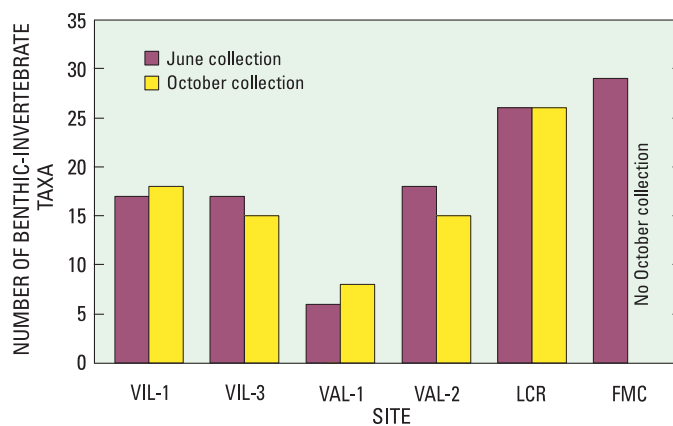
Figure 35. Benthic-invertebrate community richness in streams in the Birmingham area, Alabama, 2000.

richness in Village Creek decreased in a downstream direction from VIL-1 to VIL-3 in October. In contrast, richness increased in a downstream direction from VAL-1 to VAL-2 in both June and October (fig. 35). These downstream patterns were the inverse of those noted previously for the concentrations of organic compounds and trace elements in bed-sediment and water-column samples from these sites.

Benthic-invertebrate community metrics were characterized by using quantitative taxonomic data from samples collected at each site (appendix table 3-3). The highest diversity was seen at FMC (1.12) and LCR (1.06) and the lowest diversity occurred at VAL-1 (0.339). Data from all samples were compared to that collected from the FMC sample using the Pinkham-Pearson similarity index. FMC was selected as the index site because it had the
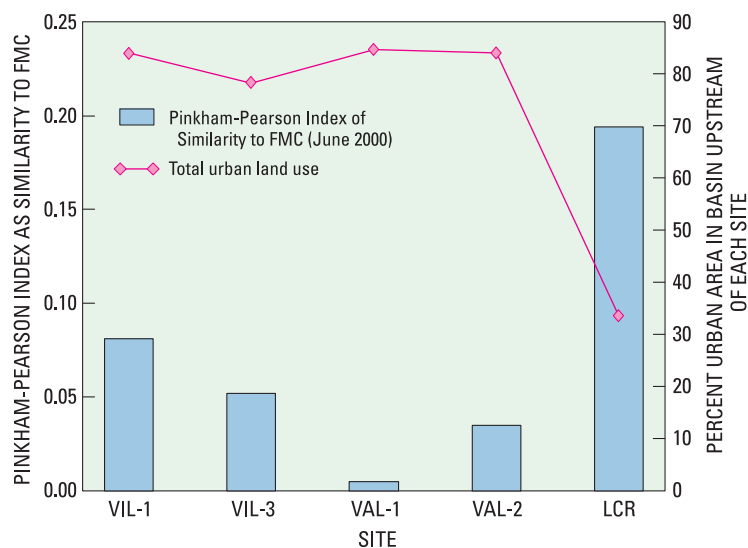
Figure 36. Similarity of the benthic-invertebrate community at five sites in the Birmingham area, Alabama, to that of a reference site—FMC—(June 2000), compared with the percentage of urban land use in the drainage basin.

smallest amount of urban land use upstream from the sampling reach. The site most similar to FMC was LCR (fig. 36), another site with little urban land use. The site most dissimilar to FMC was VAL-1, which had the highest percentage of urban land use of all sites (table 2). This may be related to the presence of highly tolerant organisms such as tubificid worms and chironomids (appendix table 3-2) commonly found at degraded sites with a high percentage of industrial land use.

The greatest density of benthic invertebrates occurred in samples collected during June at VAL-1 (fig. 37). The greatest proportion of that density (65 percent) was contributed by the midges (Chironomidae; figs. 38 and 39; appendix table 3-3), a family of insects whose members commonly are associated with environmental perturbation. The density and the relative abundance of midges decreased in a downstream direction from VAL-1 to VAL-2 and increased in a downstream direction from VIL-1 to VIL-3 (figs. 38 and 39); this pattern was similar for both sampling months. The relative abundance of midges ranged from 17 to 77 percent in Village and Valley Creeks but was less than 2 percent in LCR and less than 7 percent at FMC (appendix table 3-3).

Benthic-invertebrate density decreased in a downstream direction in both Village and Valley Creeks in
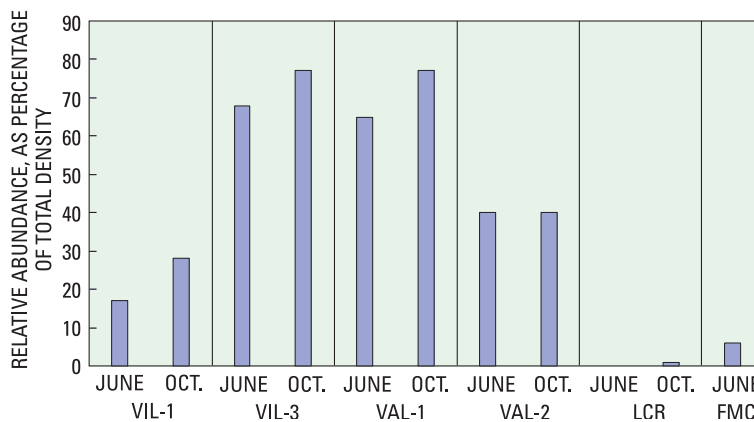
Figure 38. The relative abundance of midges (Chironomidae) in selected streams in the Birmingham area, Alabama, June and October 2000.

June 2000 (appendix table 3-2). In October, benthic-invertebrate density decreased in a downstream direction in Valley Creek, but increased in a downstream direction in Village Creek. The increase at VIL-3 appeared to be due primarily to a greater density of midges (2,415 per m^2) in October compared to June (1,334 per m^2), and to a decrease in the numbers of water mites (Acari) and midges in VIL-1 between June and October (appendix table 3-2). In general, however, these patterns are similar to those observed for the concentrations of bed-sediment organic compounds and trace elements, and are the inverse of the observed patterns of benthic-invertebrate community richness. The patterns seen among multiple environmental indicators in Village and Valley Creeks further strengthen the observation that these aquatic communities reflect anthropogenic effects associated with urbanization.

The number of EPT taxa was higher and the relative abundance of EPT species was greater in samples from the least urbanized sites (FMC and LCR; appendix table 3-3). The difference in EPT richness and abundance likely reflects a difference in water quality between the most and least urbanized sites. The EPT/Chironomid ratios also were highest at LCR and FMC, indicating a richer aquatic community (appendix table 3-3) in comparison to the EPT/Chironomid ratios for samples collected from Village and Valley Creeks. This finding also may indicate that water quality deteriorated downstream in Village Creek. Conversely, water quality appeared to improve in a downstream direction in Valley Creek. In the October sample from VAL-2, the caddisflies (Trichoptera) accounted for a higher proportion
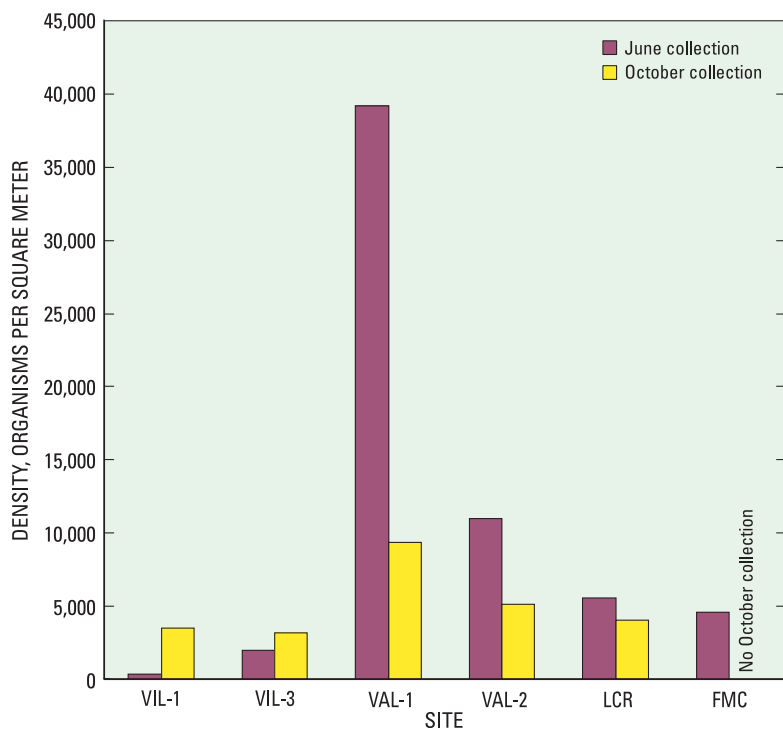
Figure 37. Density of benthic-invertebrate taxa in selected streams in the Birmingham area, Alabama, June and October 2000.
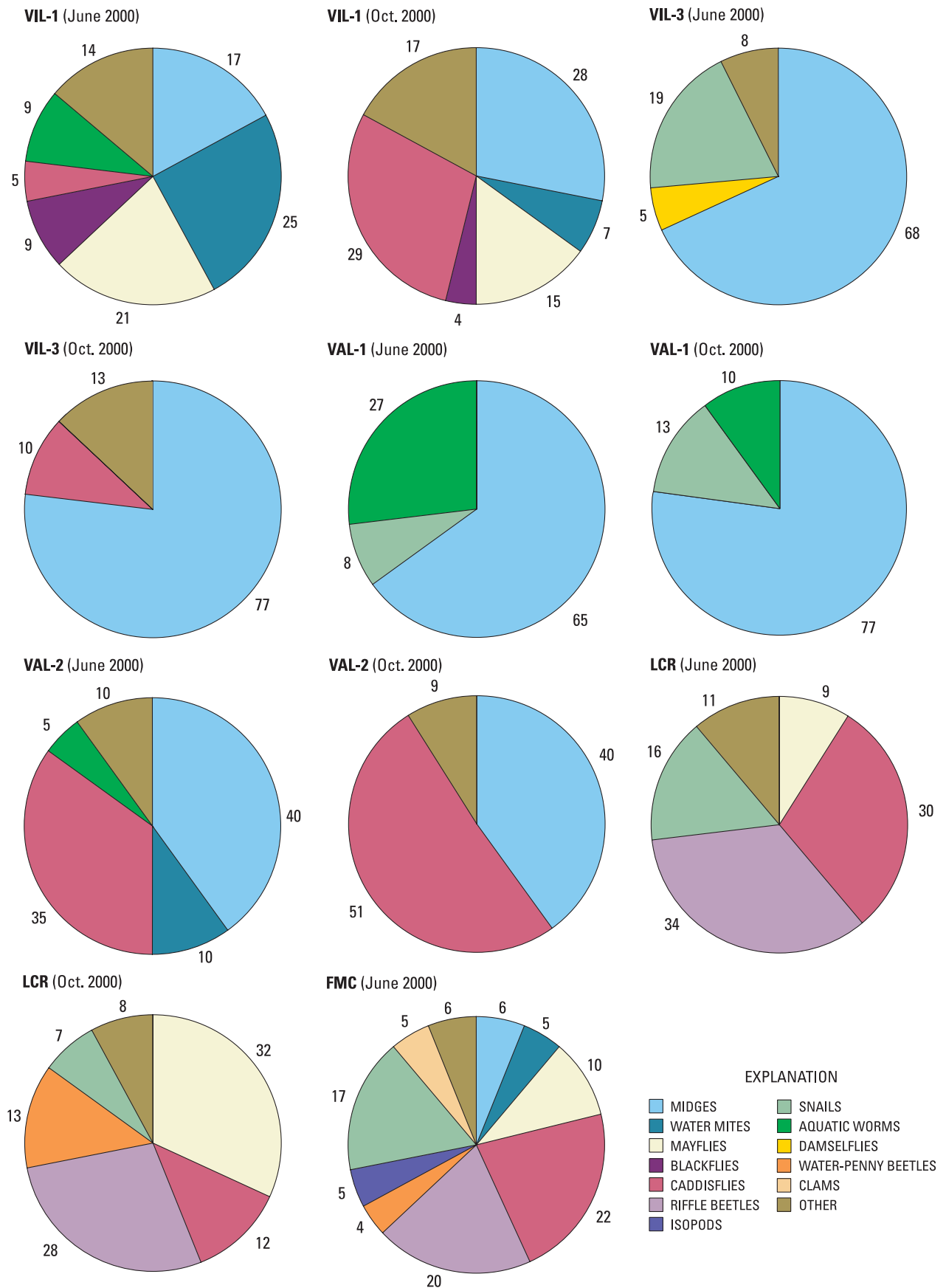
Figure 39. Comparison of the relative abundances of the dominant benthic-invertebrate taxa collected from streams in the Birmingham area, Alabama, 2000. (Numbers beside each pie section are percentages of the total sample.)

of the density than the midges (appendix table 3-3; fig. 39).

The benthic-invertebrate communities at LCR (for both sampling months) and FMC had the highest community richness. Figure 39 shows the relative contributions (as percent relative abundance) of those taxa that contributed to 5 percent or more of the total community abundance. The great abundance and high density of midges at VAL-1 and VIL-3 during both sampling months (appendix table 3-3; fig. 39) may represent changes in community structure at these sites resulting from increasing anthropogenic disturbances in the watersheds.

Fish Communities

Twenty-five fish species and one hybrid, representing 15 genera and 8 families, were collected at VIL-1, VIL-3, VAL-1, VAL-2, LCR, and FMC (appendix table 3-4). Shannon's index of diversity indicated that LCR was the most diverse and VAL-1 was the least diverse of the sites sampled (appendix table 3-4). Diversity at FMC and VIL-3 were highly similar. This finding is not consistent with that found for the invertebrate community, which indicated that FMC was as diverse as LCR. The fish communities' response to environmental perturbations may be related to long-term environmental changes in the watershed.

The fish community at each site was compared to that at FMC by calculating an index of similarity (appendix table 3-4). The fish community at VAL-1 was least similar to that at FMC, which is consistent with results found for the benthic-invertebrate community. However, similarity assessment also indicated that VAL-2 was highly similar to FMC. Although somewhat contradictory, this result may indicate that the fish community is not as sensitive an indicator of anthropogenic perturbation as the benthic-invertebrate community.

The fish communities in Village and Valley Creeks had fewer species than those in LCR and FMC, the two less-urbanized streams. LCR and FMC had 16 and 12 species of fishes, respectively, but only 8 or
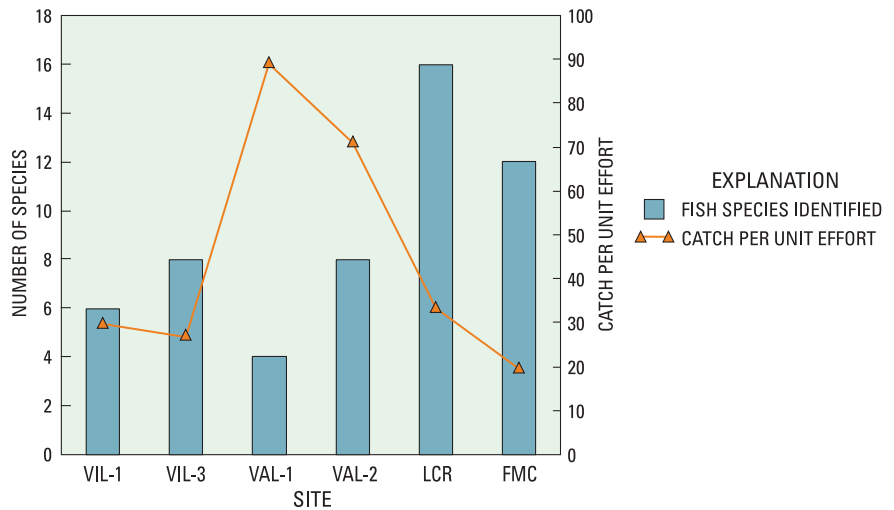
Figure 40. Fish-community richness and catch per unit effort in streams in the Birmingham area, Alabama, 2001.

fewer species were collected at VAL-2, VIL-1, and VIL-3 (fig. 40; appendix table 3-4).

VAL-1 had fewest species (4) and the fish community was dominated by one taxon, the western mosquitofish (*Gambusia affinis*), which accounted for 91 percent of the individuals collected (appendix table 3-4; fig. 41). The dominance of a single species in urbanized streams may be indicative of ecological stress. The mosquitofish is commonly found in degraded waters (Rohde and others, 1994). It has a broad range of temperature tolerance (6 to 35 °C) and can tolerate very low dissolved-oxygen concentrations (Robison and Buchanan, 1984). In addition, this fish is omnivorous,
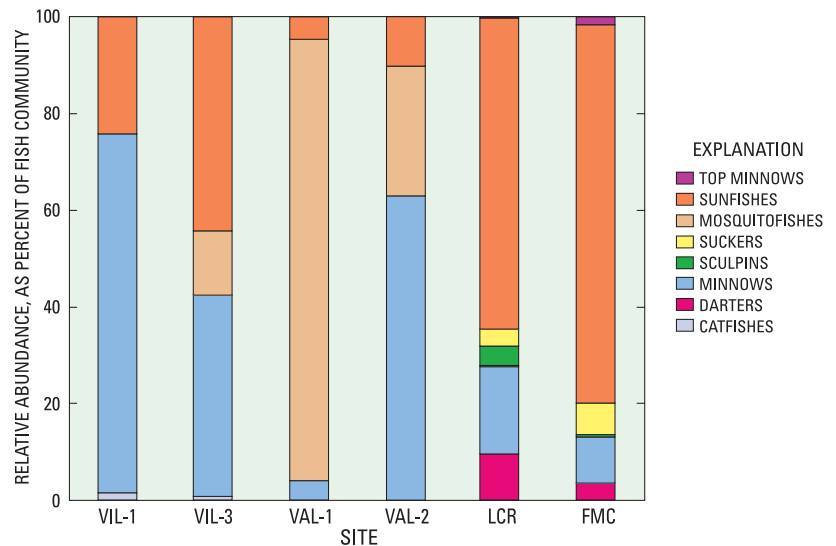
Figure 41. Relative abundance of fish families in streams in the Birmingham area, Alabama, 2001.

consuming mosquito larvae, zooplankton, other fishes, and algae (Lee and others, 1980) and, therefore, is not as resource limited as other species, such as those specializing in one type of food. Because of its dominance and high tolerance to degraded conditions, the mosquitofish is likely a good indicator of the severe environmental stress seen at VAL-1.

The next most abundant species collected at VAL-1 was the longear sunfish (*Lepomis megalotis*), which accounted for only 5 percent of the community abundance (appendix table 3-4; fig. 41). It is considered to be intolerant of contaminants. This fish generally prefers small streams and the upland parts of rivers (Lee and others, 1980) with rocky bottoms, and preys primarily on aquatic insects and small fishes. Its presence at VAL-1 may be related to the presence of an abundant food resource, that is, many small mosquitofishes, and a high density of midges (appendix table 3-3). The presence of the longear sunfish at VAL-1 is somewhat confounding due to its intolerance of environmental degradation; however, it does support the finding that the fish community may not be as sensitive an indicator of recent environmental perturbation as the benthic-invertebrate community.

The most ubiquitously distributed fish was the largescale stoneroller (*Campostoma oligolepis*), a type of minnow, which accounted for more than 60 percent of the abundance at VIL-1 and VAL-2, and for 41 percent of the abundance at VIL-3, and was present in lesser percentages at all other sites (appendix table 3-4; fig. 41). The largescale stoneroller prefers deep, fast riffles, and commonly is found in large to medium streams with clear, cool water, a moderate to swift current, and a gravel bottom (Lee and others, 1980). Its primary food sources are algae and detritus (Robison and Buchanan, 1984). As an algae eater, the stoneroller requires silt-free substrates on which its food resources will grow. The stoneroller is intolerant of siltation (Lee and others, 1980) and its presence at all sites is notable because silt was common (from 73.3 to 100 percent) in the riffle habitats of all sites except VAL-1 (table 25). The presence of the stoneroller may indicate that degradation associated with siltation may not be the primary anthropogenic factor affecting the fish communities at Village and Valley Creeks; however, the amount of siltation in these streams may not be severe enough or persistent enough to directly affect the distribution and abundance of the stoneroller.

The next most common species captured in the study were the green sunfish (*Lepomis cyanellus*) and the bluegill (*Lepomis macrochirus*), which were each collected at all sites except VAL-1 (appendix table 3-4). These two species accounted for 54 percent of the fish

community at LCR, 54 percent at FMC, and 44 percent at VIL-3. The bluegill and green sunfishes accounted for 23 percent of the fishes at VIL-1 and only 0.4 percent at VAL-2 (appendix table 3-4). At VIL-3, VAL-2, and FMC, the percentages of each of these two species were about equal (appendix table 3-4); however, at FMC and VIL-1, the bluegill was considerably more abundant than the green sunfish.

The proportion of individuals as green sunfish may be indicative of degraded surface-water quality (Plafkin and others, 1989). For example, this species is known to tolerate greater turbidity than other sunfishes (Rohde and others, 1994). Green sunfishes were captured at all sites except VAL-1 and were most abundant at LCR and VIL-3. Green sunfishes accounted for 29.7 and 22.9 percent of the total fishes captured at LCR and VIL-3, respectively (appendix table 3-4). The dominance of green sunfish at LCR might be related to an unmeasured perturbation; however, the LCR sampling site is located downstream of a sanitary wastewater-treatment plant and a superfund site. Alternatively, their presence at LCR could be a result of recent migration into the system. At FMC, where a highly diverse invertebrate community is present, the green sunfishes accounted for only 1.78 percent of the total fish abundance. This low abundance may be related to an inadequate food supply, competition for resources, or the green sunfish's affinity for degraded waters.

The number and identification of darter (Percinidae) and sculpin (Cottidae) species are known to be important indicators of water quality. Members of these groups are intolerant of contaminated waters (Klemm and others, 1993) and are commonly associated with good water quality. Darters were collected only at FMC, LCR, and VAL-2 (appendix table 3-4). Two species of darters accounted for 12 percent of the fishes captured at LCR and two additional species accounted for 3.6 percent of the fishes captured at FMC. In contrast, a single darter species, the blackbanded darter (*Percina nigrofasciata*), accounted for about 0.3 percent of those fishes collected at VAL-2 (appendix table 3-4). The blackbanded darter feeds primarily on immature Diptera (such as midge larvae), mayflies, and caddisflies (Lee and others, 1980). Its presence at VAL-2 may be related to the high densities of its primary sources of food (appendix table 3-3).

The banded sculpin (*Cottus carolinae*) was the only sculpin collected in the study and was found only in the predominantly forested sites, LCR and FMC. It accounted for 3.89 percent of the community abundance at LCR and 0.592 percent of the community abundance at FMC. This fish prefers cool, clear streams (Lee and others, 1980) and feeds primarily on crayfish, mayflies, and snails. The

absence of sculpins in Village and Valley Creeks is likely due to poor water quality and hydrologic disturbance (for example, frequent flushing due to runoff from impervious areas) caused by human activities in the basins.

Many minnow species are sensitive to physical and chemical habitat degradation in streams. These fishes make up the largest single family of fishes (Cyprinidae; Moyle, 1993), and the family is well represented in many streams throughout the United States. The shiners are members of this family and many are considered to be intolerant of contamination and habitat perturbation (Klemm and others, 1993); however, few were collected in this study. The blacktail shiner (*Cyprinella venusta*) was collected only at VAL-2 and LCR, but its relative abundance at both sites was low (0.552 and 0.707 percent, respectively). The tricolor shiner (*C. trichroistia*) was collected only at LCR, and represented only 0.4 percent of the fish community. The silverstripe shiner (*Notropis stilbius*) was collected only at FMC and accounted for about 2 percent of the fish community abundance. The absence of the silverstripe shiner from all but the forested site, FMC, may be related to water-quality degradation. Its absence from LCR is likely due to point sources upstream.

The spotted sucker (*Minytrema melanops*) was collected only at LCR. This sucker prefers deep, clear pools with firm bottoms and is intolerant of silty or turbid waters (Rohde and others, 1994). It is moderately common in its range but has disappeared from areas where extensive siltation has occurred (Lee and others, 1980). The spotted sucker's absence from sites in this study that contain silt and its low abundance (0.4 percent) at LCR may be a reflection of that sensitivity. The absence of the spotted sucker from VAL-1, where silt was detected in less that 20 percent of the riffle habitats, however, may be related to the presence of trace elements and organic contaminants, or other anthropogenic influences in the basin.

No anomalies were recorded for fishes collected from VIL-1 or VIL-3. The relatively high percentage of anomalies found at VAL-1 (appendix table 3-4) is consistent with earlier findings that this site has been affected by anthropogenic influences in its watershed.

CORRELATIONS WITH LAND USE

The relations between land use and water quality, bed sediment, fish tissue, and aquatic-community structure in the Birmingham study area were examined by using the Spearman-rho correlation test (SAS Institute, 1989). Table 26 presents the most significant ($p \leq 0.05$) correlations of these factors with residential, commercial,

industrial, and forested land use. Statistically significant correlations between these land uses and water quality and aquatic indicator organisms were determined. However, because of the inherent limitations of statistical tests performed on small data sets, these results should be viewed as preliminary or exploratory rather than conclusive.

As the amount of urbanized area upstream from a site increases, there is an increased probability of elevated concentrations of contaminants in the water column as a result of human activity. Benthic-invertebrate communities are known to be affected by the combined effects of water-column and bed-sediment contaminants (Porcella and Sorensen, 1980; Clements and others, 1988). In a study of streams in New Jersey, Kennen (1999) found that the total area of urban land use in close proximity to a sample site was a good indicator of severely impaired benthic communities. Such communities would be expected to have few species that are intolerant of contamination. Jones and Clark (1987) determined that an increase in tolerant benthic taxa and a decrease in diversity were associated with increasing urbanization, and Garie and McIntosh (1986) found that increasing urbanization had a direct effect on invertebrate richness and density, and was a driving factor in shifting community composition.

Difficulty in measuring specific contamination sources has led investigators to use biological monitoring procedures that rely on the abundance of benthic invertebrates to assess stream degradation (Waters, 1995). Streamwaters of good quality are commonly identified by the greater abundance of pollution-intolerant taxa, such as those in the EPT group. Conversely, streamwaters of poor quality might be identified by the absence of such organisms (especially in areas where they are known to be common) and by the presence of taxa that are more tolerant of contamination and physical perturbation, such as the midges.

Correlation analysis of benthic-invertebrate data with ancillary environmental factors was confined to data collected in June 2000. These data included collections at two reference sites, two sites on Village Creek, and two sites on Valley Creek. Benthic-invertebrate data collected in October 2000 were not used in the correlation analysis due to data limitations; for example, Fivemile Creek was dry and was not sampled during this time period.

The number of EPT taxa is a widely used indicator of stream water quality (for example, Rosenberg and Resh, 1993). Increased numbers of the EPT taxa in streams generally are indicative of favorable water-quality conditions as compared to streams where they are reduced in number or absent. Some Trichopterans, however, are

Table 26. Significant correlations (p ≤0.05) between land use and water quality, bed sediment, fish tissue, and aquatic-community structure at the Birmingham study sites, Alabama, 2000–01

[rho, correlation coefficient; n, sample size]

Residential	rho	n	Commercial	rho	n	Industrial	rho	n	Forested	rho	n
Water quality											
Magnesium	0.821	7	Water temperature	0.964	7	Total organic carbon	0.821	7	Water temperature	-0.857	7
Nitrogen ammonia dissolved	-.900	5	Nitrate dissolved	.964	7	Nitrogen total	.919	7	Fecal coliform	-.786	7
Nitrite dissolved	-.943	6	Nitrite plus nitrate dissolved	.893	7	Nitrogen organic dissolved	.893	7	Nitrate dissolved	-.857	7
						Nitrogen ammonia plus organic total	.893	7	Nitrite plus nitrate dissolved	-.929	7
						Nitrogen ammonia plus organic dissolved	.964	7			
						Nitrogen ammonia dissolved	.900	5			
						Chloride	.857	7			
						Sulfate	.929	7			
						Fluoride	1.000	5			
						Copper	.900	5			
						Molybdenum	.811	7			
						Wastewater indicator detections	.893	7			
Fish community											
Percent minnows	1.000	6	Percent sunfishes	-1.000	6	None			Fish species	0.943	6
Percent herbivores	1.000	6	Percent mosquitofish	.900	6				Fish families	.912	6
Percent insectivores	-1.000	6	Fish diversity	-.886	6				Percent sunfishes	.886	6
Benthic-invertebrate community											
None			Midge density	0.886	6	Mayfly abundance	-0.880	6	None		
			Beetle abundance	-.886	6	Midge abundance	.829	6			
						Number of EPT taxa	-.812	6			
						EPT abundance	-.928	6			
Sediment trace elements											
None			Strontium	0.829	6	None			None		
Sediment organics											
None			Fluoranthene	0.829	6	1,6-Dimethylnaphtha-lene	0.829	6	None		
			Pyrene	.829	6	1-Methylphenanthrene	.886	6			
			Acridine	.928	6	1-Methylpyrene	.943	6			
						2,6-Dimethylnaphtha-lene	.829	6			
						4H-Cyclopentaphe-nanthrene	.886	6			
						9,10-Anthraquinone	.886	6			
						9H-Fluorene	.886	6			
						Acenaphthene	.886	6			
						Acenaphthylene	.886	6			
						Anthracene	.886	6			
						Benzo[*b*]fluoranthene	.943	6			

Table 26. Significant correlations (p ≤0.05) between land use and water quality, bed sediment, fish tissue, and aquatic-community structure at the Birmingham study sites, Alabama, 2000–01—Continued

[rho, correlation coefficient; n, sample size]

Residential	rho	n	Commercial	rho	n	Industrial	rho	n	Forested	rho	n
						Benzo[ghi]perylene	.943	6			
						Carbazole	.886	6			
						Dibenz[ah]anthracene	.886	6			
						Dibenzothiophene	.943	6			
						Indeno[1,2,3-cd] pyrene	.829	6			
						Phenanthrene	.943	6			
						Phenol	.943	6			
Fish-liver tissue trace elements											
Arsenic	-0.829	6	None			Cobalt	-0.886	6	None		
						Mercury	.829	6			
						Molybdenum	.829	6			
Fish-tissue organic compounds											
None			None			None			None		
Habitat											
None			None			None			None		

known to be tolerant of contamination, for example, certain members of the Hydropsychidae family.

Therefore, to prevent biasing the assessment of EPT taxa in this study, the hydropsychid caddisflies were removed from the analysis. In addition, the number of EPT taxa was evaluated at the family level of taxonomy—this was the lowest level common to all taxa (appendix table 3-2). The number of EPT taxa was found to be negatively correlated with industrial land use (rho = - 0.812, p = 0.049) in the Birmingham study area (table 26). This inverse relation indicates that sites downstream from industrial land use are more likely to have fewer EPT taxa and degraded water quality than sites downstream from forested land use.

Mayflies (Ephemeroptera) as a group are intolerant of contaminants. As one of the EPT triad of indicator organisms, their presence and abundance can be used as a measure of the health of a stream (Plafkin and others, 1989). The abundance of mayflies within the study sites varied and was found to be negatively correlated with industrial land use (rho = −0.880, p = 0.021). As the percentage of industrial land use increased, the abundance of mayflies appeared to decrease, indicating that stream health had been negatively affected by industrial urbanization. Stoneflies (Plecoptera), the second leg of the EPT triad, were collected only at LCR and no correlation of their abundance with land use was possible, except that

their absence at all other sites may reflect changes in water quality due to anthropogenic activities in the basins. Caddisflies (Trichoptera), the third leg of the EPT triad, also are intolerant of contaminants (except as noted above). However, the abundance and density of both the non-Hydropsychid and Hydropsychid caddisflies were not found to be significantly correlated with land use.

Midges (Chironomidae) are a family of insects known to be tolerant of contaminants, and they tend to increase in abundance as water quality decreases. The abundance and density of midges was positively correlated with industrial (rho = 0.829, p = 0.042) and commercial (rho = 0.886, p = 0.019) land use, respectively, providing additional evidence that these streams have been negatively affected by urbanization.

Significant correlations were observed between the concentrations of several water-quality constituents and land use (table 26). For example, several nitrogen species, chloride, sulfate, copper, and molybdenum were positively correlated with industrial land use (table 26). As the percentage of industrial land upstream from a sample site increased, the concentrations of these constituents also increased, indicating contamination may be strongly linked to industrial land use. Several of these constituents also were correlated with biological indicators. For example, the number of detections of wastewater indicators and the concentration of total nitrogen in the

water column were negatively correlated with the number of EPT taxa.

Significant correlations also were observed between organic compounds detected in bed sediment and industrial and commercial land use (table 26). Eighteen organic compounds, predominantly PAHs, were positively correlated with industrial land use, and concentrations of acridine, fluoranthene, and pyrene were positively correlated with the percentage of commercial land use in the basins (table 26). Increased concentrations of PAHs are associated with a wide variety of point and nonpoint sources, including domestic sewage, chemical waste, the burning of fossil fuels, automobile exhaust, asphalt, and runoff from roads.

Bed-sediment constituents that had a significant correlation with land use also were found to be correlated with many biological indicators. In general, the number of EPT taxa, mayfly abundance, and mayfly density were negatively correlated with concentrations of PAHs in bed sediment, while the abundance and density of the midges were positively correlated with PAHs. These correlations further support the link between increasing urbanization and changes in aquatic-community structure.

The amount of forested land upstream from a sample site has been found to be a good predictor of unimpaired benthic communities (Kennen, 1999). Although no benthic-invertebrate community metrics were significantly correlated with forested land use during this study, the numbers of fish species, fish families, and the percentage of sunfishes were found to be positively correlated with forested land use (table 26). This relation may indicate that the presence of forested lands in urbanized basins acts as a buffer and may help to maintain fish species diversity. Conversely, the percentage of mosquitofishes, a highly tolerant species, was positively correlated with commercial land use; mosquitofishes were present in greatest numbers (fig. 41) at VAL-1, the site with the highest percentage of commercial land use (table 2). In addition, the percentage of forested land in a basin was inversely related to factors known to be indicative of poor water quality, for example, water temperature, fecal coliform, and dissolved nitrite and nitrate (table 26).

The limited amount of data and the use of a single fish genus make correlations between fish-tissue analytes and land use difficult to discern. Arsenic concentrations detected in fish-liver tissue were negatively correlated with residential land use (table 26). Mercury and molybdenum concentrations detected in fish-liver tissue were positively correlated, and cobalt concentrations detected in fish-liver tissue were negatively correlated with industrial land use (table 26). No correlations were observed between organic compounds detected in fish tissue and land use.

Changes in stream habitat structure can affect the diversity of aquatic communities and these changes are known to be directly and indirectly related to the hydrology of stream systems (Lenat and Crawford, 1994; Richards and others, 1996; Richter and others, 1996). Where frequent and intense flushing occurs (for example, because of increased flow and stronger currents due to impervious area in the drainage basin), habitat complexity decreases as branches and other plant debris are flushed downstream. Instream structures, such as large woody snags or debris dams, increase habitat complexity and living space, reduce the loss of organic material, and provide food resources for aquatic organisms (Ward, 1992; Maser and Sedell, 1994). Evaluating the relations between fish and benthic-invertebrate abundance and habitat structure is important because biota are commonly associated with habitats to which they are best adapted. However, aquatic organisms also are affected by many other environmental conditions that can mask habitat effects. For example, a heated discharge into a shaded stream could increase water temperature in spite of the shade provided by the riparian zone. Increased frequency of flooding, increased water velocities and volume, and increased sedimentation have all been found to be highly related to increased urbanization (Kennen and Ayers, 2002), and all can directly or indirectly affect habitat complexity. Although many habitat characteristics were assessed at the study sites, few correlations between habitat and aquatic-community structure were observed and there were no significant correlations between habitat and land use. This may be due to the limited number of sampling sites evaluated in this study; moreover, it is likely that the high level of variability implicit in habitat assessments prevented appropriate statistical discrimination.

SUMMARY

The U.S. Geological Survey conducted a 16-month investigation of water quality, aquatic-community structure, bed sediment, and fish tissue in Village and Valley Creeks, two urban streams that drain areas of highly intensive residential, commercial, and industrial land use in Birmingham, Alabama. Water-quality data were collected between February 2000 and March 2001 at

four sites on Village Creek, three sites on Valley Creek, and at two reference sites near Birmingham—Fivemile Creek and Little Cahaba River, both of which drain less-urbanized areas. Water-column samples were analyzed for major ions, nutrients, fecal bacteria, trace and major elements, pesticides, and selected organic constituents. Bed-sediment and fish-tissue samples were analyzed for trace and major elements, pesticides, polychlorinated biphenyls, and additional organic compounds. Aquatic-community structure was evaluated by conducting one survey of the fish community and in-stream habitat, and two surveys of the benthic-invertebrate community. Bed-sediment and fish-tissue samples, benthic-invertebrates, and habitat data were collected between June and October 2000 at six of the nine water-quality sites; fish communities were evaluated in April and May 2001 at the six sites where habitat and benthic-invertebrate data were collected. The occurrence and distribution of chemical constituents in the water column and bed sediment provided an initial assessment of water quality in the streams. The structure of the aquatic communities, the physical condition of the fish, and the chemical analyses of fish tissue provided an indication of the cumulative effects of water quality on the aquatic biota.

All sites had similar water chemistry characterized by strong calcium-bicarbonate and magnesium components. Concentrations of total nitrogen exceeded the USEPA recommendation (0.214 mg/L) for streams and rivers in the Ridge and Valley Level III Ecoregion in all samples, including reference sites; concentrations of total phosphorus exceeded the USEPA recommendation (10 µg/L) at sites on Village and Valley Creeks in 60 of 63 samples (95.2 percent), and at references sites in 7 of 11 samples (63.6 percent). Median concentrations of total nitrogen and total phosphorus were highest at the most upstream site on Valley Creek (VAL-1) and lowest at the reference site (FMC). In Village Creek, median concentrations of nitrite and ammonia increased in a downstream direction. In Valley Creek, median concentrations of nitrate, nitrite, ammonia, organic nitrogen, suspended phosphorus, and orthophosphate decreased in a downstream direction. Maximum concentrations of nitrate, nitrite, ammonia, and organic nitrogen were detected during low flow at the majority of the sites, indicating that high levels may be point-source related (or present in the ground water).

Concentrations of enterococci at sites in the Birmingham area exceeded the USEPA criterion (151 col/100 mL) in 80 percent of the samples; *E. coli* concentrations exceeded the USEPA criterion (576 col/100 mL) in 56 percent of the samples; fecal coliform concentrations exceeded the ADEM criterion

(4,000 col/100 mL) in 26 percent of the samples. Median concentrations of *E. coli* and fecal coliform bacteria were highest at VAL-1 and lowest at FMC; median concentrations of enterococci bacteria were highest at VIL-2 and lowest at VAL-3. Concentrations of bacteria at VIL-3, VAL-2, and VAL-3 were elevated during high flow rather than low flow, indicating the presence of nonpoint sources. Concentrations of bacteria at VIL-1, VIL-2, VIL-4, and VAL-1 were elevated during low and high flow, indicating the presence of both point and nonpoint sources.

Water-column samples were analyzed for 16 chemical compounds that are commonly found in wastewater and urban runoff, which can be indicative of contamination attributed to a human source. The median number of wastewater indicators detected in individual samples ranged from 1 (FMC) to 10 (VAL-1). In Village Creek, the median number of detections was lowest in the headwaters and increased in a downstream direction. In Valley Creek, the median number of detections was highest in the headwaters and decreased in a downstream direction.

Concentrations of cadmium, copper, lead, and zinc in the water column exceeded acute and chronic aquatic life criteria in up to 24 percent of the samples that were analyzed for trace and major elements. At Village Creek, median concentrations of cadmium, lead, and zinc were highest at VIL-2, followed by VIL-3 and VIL-1. At Valley Creek, median concentrations of these constituents were highest at VAL-1 and decreased downstream. Concentrations of iron, manganese, and aluminum exceeded secondary drinking-water standards set by ADEM in up to 37 percent of the samples. High concentrations of trace and major elements in the water column were detected most frequently during high flow, indicating the presence of nonpoint sources.

Of the 24 pesticides detected in the water column, 17 were herbicides and 7 were insecticides. Atrazine, simazine, and prometon were the most commonly detected herbicides; diazinon, chlorpyrifos, and carbaryl were the most commonly detected insecticides. Concentrations of atrazine, carbaryl, chlorpyrifos, diazinon, and malathion exceeded criteria for the protection of aquatic life. The highest number of pesticides (13) was detected in samples from VAL-3; the lowest number of pesticides (8) was detected in samples from FMC.

The concentrations of organic compounds and trace-element priority pollutants detected in bed-sediment samples were elevated at all sites in Village and Valley Creeks in comparison to the concentrations detected in samples from FMC. Among all sites, concentrations of

chromium, copper, lead, mercury, and silver were highest at VAL-1—concentrations of cadmium, nickel, selenium, and zinc were highest at VIL-2. The highest total concentration of trace-element priority pollutants detected in bed-sediment samples occurred at VIL-2 and the lowest at FMC. In Village Creek, concentrations of 8 of the TEPPs (cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc) in bed sediment were highest at VIL-2, followed by VIL-3 and VIL-1—whereas in Valley Creek, concentrations of all 10 priority pollutants were highest at VAL-1 and decreased in a downstream direction.

Bed-sediment concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc from the Birmingham area exceeded median concentrations observed nationwide. Concentrations of silver at VAL-1 exceeded concentrations from 770 sites sampled nationwide. On a regional scale, bed-sediment concentrations of antimony, beryllium, cadmium, chromium, copper, lead, magnesium, mercury, molybdenum, nickel, selenium, silver, and tin exceeded concentrations at 21 sites in Alabama, Mississippi, and Georgia sampled in 1998 by the USGS as part of the NAWQA Program.

Fish-liver tissue concentrations of trace elements varied among the streams. Concentrations of cadmium, selenium, and zinc were highest in the sample from VIL-2; copper and mercury were highest in the sample from VIL-3; and lead was highest in the fish-liver tissue sample from VAL-2. On a regional basis, concentrations of lead and molybdenum in fish-liver tissue samples at sites in the Birmingham area exceeded those detected at 21 other sites in Alabama, Mississippi, and Georgia sampled in 1998.

The highest total concentration of organic compounds detected in bed-sediment samples occurred at VAL-1 and the lowest occurred at FMC. At Village Creek, concentrations of the organic compounds increased in a downstream direction from VIL-1 to VIL-3; concentrations of about 25 percent of the detected organic compounds, including chlorpyrifos, were highest at VIL-2, followed by VIL-3 and VIL-1—a pattern similar to that of the trace-element priority pollutants detected in bed sediment in Village Creek. In Valley Creek, concentrations of about 70 percent of the detected organic compounds were highest at VAL-1 and decreased in a downstream direction. Concentrations of PAHs, p,p'-DDE, and chlordane exceeded PELs at sites on Village and Valley Creeks.

Dieldrin was detected in fish-tissue samples from every site and exceeded NAS/NAE guidelines for the protection of fish-eating wildlife at VIL-1, VAL-1, and

VAL-2. Chlorpyrifos was detected in fish-tissue samples from every site, with the highest concentrations at VAL-1, VAL-2, and FMC, respectively. Total PCBs in fish-tissue samples were highest at VIL-3 and VIL-2, and exceeded NAS/NAE guidelines for the protection of fish-eating wildlife at those sites. Total chlordane in fish-tissue samples exceeded NAS/NAE guidelines for the protection of fish-eating wildlife at VIL-1, VAL-1, and VAL-2.

Chlorpyrifos was detected in bed-sediment and fish-tissue samples at every site in the study. Concentrations of chlorpyrifos were highest in bed-sediment samples from VIL-2 and lowest in samples from FMC. Concentrations of chlorpyrifos detected in fish-tissue samples from Valley Creek sites were greater than samples from Village Creek sites or from FMC. The concentration of chlorpyrifos detected in fish-tissue samples from FMC was twice as great as the highest concentration detected in samples from the Village Creek sites. Chlorpyrifos was detected in 51 percent of the water samples at every site in the study, except for FMC. Higher concentrations of chlorpyrifos in the water column were usually detected during high flow, suggesting nonpoint sources. The widespread presence of chlorpyrifos in bed-sediment, fish-tissue, and water samples is indicative of continuing influx of chlorpyrifos at all of the study sites.

The structure of the aquatic communities in Village and Valley Creeks indicated that the water quality was degraded in comparison to the more forested sites, LCR and FMC. The diversity of the benthic-invertebrate and fish communities was greater in LCR and FMC than at any of the sites in Village and Valley Creeks. Benthic-invertebrate diversity in Village Creek decreased in a downstream direction, in a pattern that was generally the inverse of the concentrations of trace elements and organic compounds in the water column, bed sediments, and fish tissues. In Valley Creek, however, benthic-invertebrate diversity increased in a downstream direction, again, in a pattern that generally was the inverse of that seen for the concentrations of trace elements and organic compounds in the water column, bed sediments, and fish tissues. The presence of a few EPT taxa and the high density of midges at VAL-1 and VIL-3 may represent changes in community structure at these sites resulting from increasing anthropogenic disturbances in the watersheds.

The results of the fish community survey indicated that the water quality in Village and Valley Creeks was degraded in comparison to LCR and FMC. Diversity in LCR and FMC was higher than at any site in Village or Valley Creek. Fish-community diversity increased in a downstream direction in both Village and Valley Creeks. For Village Creek, this is contrary to the pattern seen for the benthic-invertebrate community, and may indicate that

the fish community was not as sensitive an indicator of environmental stress within selected stream reaches as the benthic-invertebrate community.

The abundance of mayflies and the number of EPT taxa (well-known indicators of good water quality) were negatively correlated with industrial land use, indicating that the aquatic communities had been negatively affected by industrial activities. The abundance of midges (an indicator of poor water quality) was positively correlated with industrial land use—and midge density was positively correlated with commercial land use, providing additional evidence that these streams have been negatively affected by urbanization in the basins. The percentage of mosquitofishes (a tolerant species) was positively correlated with commercial land use. In contrast, the numbers of fish species, fish families, and the percentage of sunfishes (intolerant species) were positively correlated with forested land use, indicating that the more diverse fish communities were found in basins with a higher percentage of forested land. The concentrations of 12 water-quality constituents (including several nitrogen species, chloride, copper, molybdenum, and the detection frequency of wastewater indicators) and 18 organic compounds detected in bed sediment were positively correlated with industrial land use. Mercury and molybdenum concentrations detected in fish-liver tissue also were positively correlated with industrial land use. Bed-sediment and water-quality constituents that were found to have significant correlations with land use often were found to be correlated with many biological indicators, further supporting the link between increased urbanization and changes in aquatic-community structure.

The water quality and aquatic-community structure in Village and Valley Creeks are degraded in comparison to streams flowing through less-urbanized areas. Low community richness and increased density of certain species within the fish and benthic-invertebrate communities indicate that the degradation has occurred over an extended period of time. Decreased diversity in the aquatic communities and elevated concentrations of trace elements and organic contaminants in the water column, bed sediment, and fish tissues at Village and Valley Creeks, when compared with these same factors at LCR and FMC, are indicative of the effects of urbanization. Of the sites examined, VAL-1 and VIL-3 appear to have been the most stressed, perhaps due to the type and extent of urban land use. The degree of degradation may be related to point and nonpoint sources of contamination originating within the basins. Industrial land use, in particular, was significantly correlated to elevated contaminant levels in the water column, bed sediment, fish tissue, and to the declining health of the benthic-invertebrate communities.

This investigation has provided a detailed survey of water-quality conditions in Village and Valley Creeks for the 16-month period between February 2000 and May 2001. The period of drought that coincided with this study probably affected the results of the aquatic-community investigations and may have influenced constituent concentrations in the water column. A more comprehensive evaluation of the temporal variability of water quality and ecology in Village and Valley Creeks would require more extensive monitoring over a longer period of time, including a greater range of flow and seasonal conditions. The results of this 16-month study have long-range watershed management implications, demonstrating the association between urban development and stream degradation. These data can serve as a baseline from which to determine the effectiveness of stream-restoration programs.

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APPENDIXES

Appendix table 1-1. Concentrations of nutrients, major ions, trace elements, and wastewater indicators detected in blank samples in the Birmingham area, Alabama, 2000–01

[E, estimated; mg/L, milligrams per liter; <, less than; LRL, laboratory reporting level; μg/L, micrograms per liter; MRL, minimum reporting level]

Constituent	Concentration	Reporting level	Reporting level type	Type of blank
Nitrogen, ammonia plus organic, dissolved	E 0.071 mg/L	< 0.1 mg/L	LRL	Field
Total organic carbon	E .344 mg/L	< .6 mg/L	LRL	Field
Phosphorus, dissolved	E .003 mg/L	< .006 mg/L	LRL	Field
Silica	E .0422 mg/L	< .09 mg/L	LRL	Field
Copper	E .976 μg/L	< 1.8 μg/L	LRL	Field
Chloride	E .06 mg/L	< .08 mg/L	LRL	Field
Calcium	.0092 mg/L	< .02 mg/L	LRL	Equipment
Magnesium	.0019 mg/L	< .014 mg/L	LRL	Equipment
Silica	.0826 mg/L	< .09 mg/L	LRL	Equipment
Zinc	3.137 μg/L	< 1.0 μg/L	MRL	Equipment
Acetephenone	E .095 μg/L	< .10 μg/L	MRL	Lab
Caffeine	.063 μg/L	< .08 μg/L	MRL	Lab
3-B Coprostanol	E .310 μg/L	< .60 μg/L	MRL	Lab
Ethanol, 2-butoxy-phosphate	E .122 μg/L	< .070 μg/L	MRL	Lab
NPEO2-Total	E .102 μg/L	< 1.1 μg/L	MRL	Lab
OPEO1-Total	E .073 μg/L	< .10 μg/L	MRL	Lab
OPEO1-Total	E .063 μg/L	< .12 μg/L	MRL	Lab
OPEO1-Total	E .200 μg/L	< 1.0 μg/L	MRL	Lab
OPEO1-Total	E .200 μg/L	< 1.0 μg/L	MRL	Lab
Triclosan	.069 μg/L	< .04 μg/L	MRL	Lab
Triclosan	E .044 μg/L	< .05 μg/L	MRL	Lab
Triclosan	E .034 μg/L	< .05 μg/L	MRL	Field
Tri(dichlorisopropyl)phosphate	.127 μg/L	< .10 μg/L	MRL	Lab

Appendix table 1-2. Concentrations and relative percentage differences for nutrients, major ions, trace elements, pesticides, and wastewater indicators detected in replicate samples in the Birmingham area, Alabama, 2000–01

[mg/L, milligrams per liter; E, estimated; µg/L, micrograms per liter]

Nutrients and major ions (mg/L)	Concentration in replicates	Relative percent difference
Total nitrogen	1.564	2.2
	1.598	
	.289	5.0
	.275	
	3.010	0.7
	2.988	
Dissolved nitrogen	1.214	2.2
	1.241	
	2.989	0.2
	2.994	
Total organic nitrogen	.776	4.5
	.812	
	.336	9.7
	.305	
Dissolved organic nitrogen	.426	6.6
	.455	
	.315	1.3
	.311	
Total ammonia-plus-organic nitrogen	.905	3.8
	.94	
	.109	9.6
	.099	
	.568	5.4
	.538	
Dissolved ammonia-plus-organic nitrogen	.5549	5.0
	.5832	
	E .068	7.8
	E .088	
	.547	0.6
	.544	
Dissolved ammonia nitrogen	.129	0.8
	.128	
	.232	0.4
	.233	
Dissolved nitrite nitrogen	.017	0.0
	.017	
	.07	1.4
	.071	
Dissolved nitrate nitrogen	.642	0.2
	.641	
	2.372	0.3
	2.379	
Dissolved nitrite-plus-nitrate nitrogen	.659	0.2
	.658	
	.18	2.2
	.176	
	2.442	0.3
	2.45	
Total phosphorus	.121	0.8
	.122	
	.007	54.6
	.004	
	.057	0.0
	.057	

Nutrients and major ions (mg/L)	Concentration in replicates	Relative percent difference
Dissolved phosphorus	0.036	0.0
	.036	
	.052	0.0
	.052	
Orthophosphorus	E .013	14.3
	E .015	
	.038	2.6
	.039	
Calcium	89.236	1.1
	90.218	
	51.571	2.0
	50.527	
	67.269	0.6
	66.879	
Magnesium	16.783	3.3
	17.352	
	17.021	4.8
	16.231	
	16.265	0.8
	16.128	
Sodium	15.503	1.4
	15.724	
	3.388	6.2
	3.1856	
	10.113	1.1
	10.001	
Potassium	26.05	1.2
	26.35	
	1.11	0.0
	1.11	
	3.28	2.5
	3.2	
Chloride	91.94	1.1
	92.97	
	4.91	2.9
	4.77	
	10.56	1.6
	10.73	
Sulfate	65.57	0.2
	65.7	
	10.02	0.3
	10.05	
	56.19	0.4
	55.98	
Fluoride	.537	2.8
	.552	
	E .114	19.2
	E .094	
	.236	4.3
	.226	
Silica	13.84	0.3
	13.883	
	5.0611	3.0
	4.9124	
	7.7197	0.9
	7.6538	

Appendix table 1-2. Concentrations and relative percentage differences for nutrients, major ions, trace elements, pesticides, and wastewater indicators detected in replicate samples in the Birmingham area, Alabama, 2000–01—Continued

[mg/L, milligrams per liter; E, estimated; µg/L, micrograms per liter]

Trace elements (mg/L)	Concentration in replicates	Relative percent difference
Aluminum	32.68	4.2
	34.07	
	45.998	3.3
	47.54	
Arsenic	E 1.561	9.2
	E 1.712	
Barium	426.43	1.6
	433.27	
	29.974	0.5
	29.813	
Cadmium	2.1	1.9
	2.141	
Chromium	2.386	3.0
	2.459	
Copper	5.19	0.7
	5.225	
Iron	235.55	5.0
	247.76	
	63.928	5.7
	67.685	
Lead	3.776	2.0
	3.702	
Lithium	44.935	0.7
	45.263	
Manganese	57.326	1.6
	58.263	
	46.121	0.3
	45.979	
Molybdenum	31.082	2.2
	30.408	
Nickel	E 1.304	29.9
	E 1.763	
Zinc	155.32	1.6
	152.79	

Pesticides (µg/L)	Concentration in replicates	Relative percent difference
Atrazine	2.58	4.0
	2.48	
	.0321	2.2
	.0328	
Deethylatrazine	E .0357	3.8
	E .0371	
Diazinon	.0832	12.5
	.0734	
	.0596	11.1
	.0666	
Pendimethalin	.0654	7.4
	.0607	

Pesticides (µg/L) (Continued)	Concentration in replicates	Relative percent difference
Prometon	0.926	3.5
	.894	
	.151	2.0
	.154	
Simazine	.184	9.3
	.202	
	.0261	13.6
	.0299	
Trifluralin	E .00635	5.5
	E .00671	

Wastewater indicators (µg/L)	Concentration in replicates	Relative percent difference
Acetephenone	0.348	27.1
	.265	
Caffeine	.464	1.1
	.469	
	.799	18.1
	.958	
Cholesterol	1.67	12.1
	1.48	
Cotinine	.063	29.7
	.085	
	.066	16.7
	.078	
3B-Coprostanol	.941	16.6
	.797	
Diethoxynonylphenol (NPEO2-total)	3.0	8.7
	2.75	
Ethanol, 2-butoxy-phosphate	1.44	6.4
	1.35	
Monoethoxyoctylphenol (OPEO1)	.693	6.6
	.74	
	.434	10.7
	.39	
Para-nonylphenol-total	.794	34.9
	1.13	
	2.54	6.9
	2.37	
Tri (2-chloro ethyl) phosphate	.128	4.6
	.134	
	.316	7.0
	.339	
Triclosan	.181	37.4
	.124	
	.078	8.0
	.072	
Triphenyl phosphate	.136	2.2
	.133	

Appendix table 2-1. Summary of major ion concentrations during different flow conditions at sites in the Birmingham area, Alabama, 2000–01

[Meq/L, milliequivalents per liter]

Site label (fig. 1)	Hydrologic condition	Date	Calcium (Meq/L)	Magnesium (Meq/L)	Sodium (Meq/L)	Potassium (Meq/L)	Chloride (Meq/L)	Sulfate (Meq/L)	Bicarbonate (Meq/L)
VIL-1	Low flow	8/30/2000	2.19	1.62	0.12	0.02	0.13	0.17	3.87
VIL-1	High flow	1/29/2001	.57	.26	.04	.03	.04	.09	.72
VIL-1	Median		2.30	1.55	.14	.02	.13	.19	3.67
VIL-2	Low flow	8/30/2000	2.88	1.50	.34	.27	1.00	1.09	2.92
VIL-2	High flow	1/29/2001	.72	.25	.06	.06	.10	.18	.82
VIL-2	Median		2.50	1.40	.28	.12	.26	.80	2.88
VIL-3	Low flow	8/29/2000	2.30	1.25	.30	.16	.34	.83	2.75
VIL-3	High flow	3/30/2000	.93	.36	.08	.06	.07	.25	1.10
VIL-3	Median		2.45	1.16	.29	.16	.34	.93	2.58
VAL-1	Low flow	8/31/2000	2.63	1.10	.48	.10	.33	1.01	2.80
VAL-1	High flow	2/12/2001	.41	.08	.04	.02	.03	.11	.43
VAL-1	Median		2.55	1.03	.47	.09	.31	1.01	2.63
VAL-2	Low flow	8/29/2000	2.50	1.26	.46	.08	.35	.86	3.16
VAL-2	High flow	2/9/2001	.86	.24	.10	.03	.09	.30	.75
VAL-2	Median		2.88	1.26	.46	.08	.33	.86	3.38
VAL-3	Low flow	8/31/2000	2.12	1.26	.45	.10	.36	.70	2.74
VAL-3	High flow	2/13/2001	.69	.18	.05	.04	.03	.17	.69
VAL-3	Median		2.25	1.15	.32	.11	.23	.66	2.67
FMC	Low flow	8/28/2000	2.04	1.32	.11	.03	.11	.08	3.36
FMC	High flow	3/20/2001	.80	.37	.06	.02	.07	.13	.95
FMC	Median		1.91	1.03	.11	.03	.11	.19	2.75

Appendix table 2-2. Field water-quality properties, bacteria, and chemical constituents at sites in the Birmingham area, Alabama, 2000–01

[Shaded samples were collected during high flow. ft³/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; col/100 mL, colonies per 100 milliliters; —, no data; >, actual value greater than plate value; <, less than; K, counts greater than or less than ideal; V, estimated due to equipment problems]

Site label (fig. 1)	Date	Discharge (ft³/s)	BOD$_5$ (mg/L)	Chlorophyll a (µg/L)	pH	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Total organic carbon (mg/L)	Fecal coliform (col/100 mL)	E. coli (col/100 mL)	Enterococci (col/100 mL)
VIL-1	3/1/2000	3.7	—	—	7.9	393	8.8	1.32	330	260	—
VIL-1	4/1/2000	10.7	—	—	7.7	381	8.8	3.44	270	> 800	330
VIL-1	5/17/2000	3.86	—	—	7.9	389	8.2	—	680	560	—
VIL-1	6/30/2000	2.7	—	—	7.7	390	7.4	1.62	4,900	K 530	1,000
VIL-1	8/1/2000	2.46	1.5	<0.1	8.1	379	7.1	1.09	1,300	1,200	1,200
VIL-1	8/302000	1.3	1.7	<.1	8.1	389	7.0	.809	510	490	690
VIL-1	10/4/2000	1.2	.3	<.1	8.0	374	8.0	.534	700	760	1,500
VIL-1	11/8/2000	126	—	—	7.4	76	7.9	12.4	K 28,000	K 31,000	K 69,000
VIL-1	12/14/2000	2.17	.6	<.1	8.0	375	8.4	1.32	1,700	1,400	1,700
VIL-1	1/24/2001	6.47	1.6	<.1	8.1	389	8.7	1.96	K 8,500	K 13,000	K 15,000
VIL-1	1/29/2001	101	—	<.1	6.9	86	9.1	18.1	K 1,500	K 800	8,800
VIL-1	3/19/2001	7.02	—	—	7.8	371	9.2	—	—	250	—
VIL-2	8/1/2000	27.9	2.5	<.1	7.8	366	5.4	6.02	2,400	3,000	5,700
VIL-2	8/30/2000	10.5	3.6	<.1	8.0	503	6.2	4.35	K 1,900	K 4,100	K 7,400
VIL-2	10/4/2000	7.47	1.4	<.1	8.0	333	5.5	2.78	K 350	440	1,600
VIL-2	11/14/2000	12.8	8.7	<.1	7.7	760	6.5	23.4	520	850	900
VIL-2	12/14/2000	20.7	7.8	<.1	7.4	227	7.9	7.88	K 13,000	9,200	K 18,000
VIL-2	1/24/2001	29.5	2.5	<.1	8.1	450	10.5	3.34	4,700	2,500	3,500
VIL-2	1/29/2001	911	—	10	7.0	114.	8.6	17.5	K 2,300	3,300	18,000
VIL-3	3/2/2000	23	—	—	8.1	467	11.8	4.05	180	K 280	—
VIL-3	3/30/2000	410	—	—	7.2	184	8.2	9.14	K 7,800	> 8,000	> 6,000
VIL-3	6/30/2000	16.2	—	—	8.5	386	11.1	5.94	K 1,400	K 380	K 260
VIL-3	8/2/2000	413	8.5	<.1	8.1	212	5.9	4.78	19,000	17,000	25,000
VIL-3	8/29/2000	14.6	6.8	9.1	8.1	393	9.9	3.98	400	220	370
VIL-3	10/3/2000	15.6	1.1	<.1	8.3	355	10.6	3.09	190	K 110	73
VIL-3	11/14/2000	18.3	.9	<.1	7.8	420	8.9	4.12	—	—	—
VIL-3	12/12/2000	13.8	1.3	<.1	8.1	445	9.6	3.95	V 49	V 20	V 21
VIL-3	1/23/2001	47.3	1	<.1	8.1	459	9.0	3.72	K 23	K 34	K 17
VIL-3	2/14/2001	108	3	<.1	7.9	409	8.6	5.17	1,200	K 2,200	1,300
VIL-4	3/2/2000	87	—	—	7.2	510	8.6	4.12	K 180	200	—
VIL-4	4/2/2000	2440	—	—	7.2	144	0.0	12.7	>3,000	>4,000	>3,000
VIL-4	7/11/2000	77.5	—	—	7.4	477	0.0	5.65	K 2,000	44,000	K 4,000
VAL-1	3/1/2000	1.83	—	—	7.9	473	8.2	4.12	3,700	4,500	—
VAL-1	3/31/2000	1.77	—	—	7.6	599	7.1	5.35	22,000	60,000	4,300
VAL-1	6/29/2000	33.4	—	—	7.5	205	5.1	16.6	> 33,000	> 44,000	—
VAL-1	8/2/2000	2.25	4.9	<0.1	8.0	408	5.3	27.1	K 64,000	K 78,000	K 15,000
VAL-1	8/31/2000	1.12	4.8	<.1	7.9	416	5.0	3.45	4,000	1,900	K 600
VAL-1	10/3/2000	1.12	1.7	<.1	7.9	386	3.3	3.64	2,100	3,200	830

[Shaded samples were collected during high flow. ft³/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; col/100 mL, colonies per 100 milliliters; —, no data; >, actual value greater than plate value; <, less than; K, counts greater than or less than ideal; V, estimated due to equipment problems]

Site label (fig. 1)	Date	Discharge (ft³/s)	BOD5 (mg/L)	Chlorophyll a (µg/L)	pH	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Total organic carbon (mg/L)	Fecal coliform (col/100 mL)	E. coli (col/100 mL)	Enterococci (col/100 mL)
VAL-1	11/9/2000	37	—	—	7.6	135	8.2	5.88	K 85,000	63,000	70,000
VAL-1	12/12/2000	1.64	4.8	<.1	7.6	407	4.2	7.05	V 44,000	V 19,000	V 4,300
VAL-1	1/23/2001	2.49	2.4	<.1	7.9	480	7.8	4.24	3,800	770	4,100
VAL-1	2/12/2001	120	4.4	<.1	7.3	58	10.4	8.21	5,900	8,200	9,900
VAL-2	2/29/2000	13	—	—	8.5	491	13.1	2.21	K 41	K 150	—
VAL-2	3/31/2000	20.7	—	—	7.5	455	8.0	2.4	1,000	>1,600	980
VAL-2	5/16/2000	9.7	—	—	7.6	498	6.8	—	400	340	—
VAL-2	6/29/2000	22.6	—	—	7.9	265	5.6	6.98	>6,000	>8,000	2,000
VAL-2	8/3/2000	18.2	1.2	<.1	8.2	423	7.8	3.14	1,700	1,200	360
VAL-2	8/29/2000	6.03	2.4	6	8.4	432	4.3	4.55	K 640	800	120
VAL-2	10/5/2000	5.2	.9	<.1	8.0	393	4.7	2.70	150	140	260
VAL-2	11/15/2000	8.73	.9	<.1	8.2	539	9.9	2.89	K 16,000	K 21,000	2,300
VAL-2	12/13/2000	7.84	.8	<.1	8.1	468	11.0	3.39	720	200	180
VAL-2	1/25/2001	14.0	.5	<.1	8.0	492	9.3	2.82	K 80	K 51	59
VAL-2	2/9/2001	374	—	31	7.7	126	6.1	29.2	—	25,000	22,000
VAL-3	2/29/2000	27.3	—	—	7.9	455	10.1	5.18	K 72	K 130	—
VAL-3	3/29/2000	42	—	—	7.7	454	10.4	1.93	120	320	39
VAL-3	6/28/2000	14.7	—	—	7.6	358	7.0	3.31	330	720	250
VAL-3	8/3/2000	32.9	1	<.1	7.9	278	7.2	5.41	1,400	700	4,100
VAL-3	8/31/2000	11.7	8.6	<.1	8.2	386	11.1	2.63	K 71	K 86	K 33
VAL-3	10/2/2000	12.3	.5	<.1	8.1	347	10.2	2.75	K 40	50	92
VAL-3	11/9/2000	240	—	—	7.9	163	6.5	5.45	16,000	11,000	52,000
VAL-3	12/13/2000	13.7	.7	<.1	8.3	452	13.9	2.34	75	K 9	110
VAL-3	1/25/2001	33	.3	<.1	8.4	489	11.1	2.80	K 10	K 5	K 12
VAL-3	2/13/2001	960	8.4	16	7.6	103	10.1	9.64	4,700	6,600	25,000
LCR	2/28/2000	28.1	—	—	8.0	296	9.9	4.45	490	430	—
LCR	3/28/2000	27.3	—	—	7.7	378	9.2	2.15	K 62	1,800	K 72
LCR	6/27/2000	6.85	—	—	7.5	403	6.6	2.50	200	270	290
FMC	5/15/2000	1.84	—	—	8.0	323	7.4	—	K 17	K 13	—
FMC	7/31/2000	12.4	2.5	<0.1	7.8	185	6.6	8.14	3,000	3,000	K 14,000
FMC	8/28/2000	.55	1.1	<.1	8.1	335	8.2	1.57	K 70	K 54	220
FMC	11/13/2000	1.16	.6	<.1	7.9	298	10.0	2.99	160	250	5,000
FMC	12/11/2000	.877	.5	<.1	8.2	364	10.7	1.84	9	K 3	K 62
FMC	1/22/2001	21.7	.3	<.1	7.9	276	12.2	4.49	K 70	100	190
FMC	2/13/2001	31.6	7.4	<.1	7.9	230	9.4	—	540	520	1,400
FMC	3/20/2001	220	8.6	<.1	7.4	128	9.9	—	—	930	—

Appendix table 2-3. Wastewater indicators detected in water samples from streams in the Birmingham area, Alabama, 2000–01

[Shaded samples were collected during high flow; BHA, 3-*tert*-butyl-4-hydroxyanisole; µg/L, micrograms per liter; <, not detected; E, estimated; —, no data; *, censored; OPEO1, monoethoxyoctylphenol; OPEO2, diethoxyoctylphenol; NPEO2, diethoxynonylphenol]

| Site label (fig. 1) | Date | Food by-products | | | | Pharmaceutical by-products | | |
		BHA (µg/L)	Caffeine (µg/L)	3B-Coprostanol (µg/L)	Cholesterol (µg/L)	Triclosan (µg/L)	17B-estradiol (µg/L)	Cotinine (µg/L)
VIL-1	3/1/2000	< 0.120	E 0.056	< 0.600	< 1.500	E 0.038	< 0.500	< 0.040
VIL-1	4/1/2000	< .120	< .080	< .600	E .464	.082	< .500	< .040
VIL-1	6/30/2000	< .120	< .080	< .600	< 1.500	.074	< .500	< .040
VIL-1	8/1/2000	< .120	E .047	< .600	< 1.500	.118	< .500	< .040
VIL-1	8/30/2000	< .120	< .080	< .600	< 1.500	—	< .500	< .040
VIL-1	10/4/2000	< .120	< .080	< .600	< 1.500	< .050	< .500	< .080
VIL-1	11/8/2000	< .120	.219	E .873	E 1.450	.077	< .500	< .080
VIL-1	12/14/2000	< .120	E .061	< .600	< 1.500	< .050	< .500	< .080
VIL-1	1/24/2001	< 5.000	.56	E 4.500	E 5.600	E .130	< 5.000	E .250
VIL-1	1/29/2001	< 5.000	1.1	E 1.500	E 2.400	< 1.000	< 5.000	E .280
VIL-2	8/1/2000	< .120	.217	< .600	< 1.500	.132	< .500	.066
VIL-2	8/30/2000	< .120	.428	< .600	< 1.500	—	< .500	.16
VIL-2	10/4/2000	< .120	.195	< .600	< 1.500	E .039	< .500	< .080
VIL-2	11/14/2000	< .120	.464	< .600	< 1.500	.181	< .500	E .063
VIL-2	12/14/2000	< .120	.799	E .941	E 1.670	.078	< .500	E .066
VIL-2	1/24/2001	< 5.000	.8	E 4.100	E 5.000	E .380	< 5.000	E .230
VIL-2	1/29/2001	< 5.000	E .490	E 2.700	E 3.700	< 1.000	< 5.000	< 1.000
VIL-3	3/2/2000	< .120	1.6	E 1.520	E 1.610	.185	< .500	.126
VIL-3	3/30/2000	E .114	.386	E 1.350	E 1.810	.185	< .500	< .040
VIL-3	6/30/2000	< .120	.379	< .600	< 1.500	.251	< .500	.112
VIL-3	8/2/2000	< .120	3.38	E 1.420	E 2.820	.962	< .500	.212
VIL-3	8/29/2000	< .120	.163	< .600	< 1.500	E .049	< .500	E .065
VIL-3	10/3/2000	< .120	.15	< .600	< 1.500	.062	E .128	E .067
VIL-3	11/14/2000	< .120	.152	< .600	< 1.500	.113	< .500	< .080
VIL-3	12/12/2000	< .120	.314	E .546	< 1.500	.106	E .309	.089
VIL-3	1/23/2001	< 5.000	E .270	E 1.000	E 1.800	E .092	< 5.000	< 1.000
VIL-3	2/14/2001	< 5.000	E .240	E .480	E .790	< 1.000	< 5.000	< 1.000
VIL-4	3/2/2000	< .120	1.5	E 1.170	E 1.410	.252	< .500	.133
VIL-4	4/2/2000	< .120	.466	E 3.100	E 3.870	.338	< .500	.076
VIL-4	7/1/2000	< .120	*	< .600	< 1.500	.161	< .500	.053
VAL-1	3/1/2000	< .120	2.47	E 3.100	E 4.290	.434	< .500	.161
VAL-1	3/31/2000	E .056	5.69	E 5.930	E 7.960	.689	< .500	.23
VAL-1	6/29/2000	< .120	1.01	E 1.030	E .981	.071	< .500	< .040
VAL-1	8/2/2000	< .120	.474	< .600	< 1.500	.126	< .500	.119
VAL-1	8/31/2000	< .120	.442	< .600	E 2.180	—	< .500	.115
VAL-1	10/3/2000	< .120	.971	E 1.670	E 2.290	.328	< .500	.092
VAL-1	11/9/2000	< .120	.469	E 2.230	E 2.730	.192	< .500	< .080
VAL-1	12/12/2000	< .120	2.97	E 2.050	E 2.520	.845	E .188	.222
VAL-1	1/23/2001	< 5.000	4	E 4.500	E 6.500	E .330	< 5.000	< 1.000
VAL-1	2/12/2001	< 5.000	2.6	E 7.600	E 10.000	E .210	< 5.000	< 1.000
VAL-2	2/29/2000	< .120	.502	E 1.030	E 2.220	.11	< .500	.067
VAL-2	3/31/2000	< .120	.772	E .849	E 1.460	.188	< .500	.099
VAL-2	6/29/2000	< .120	.542	< .600	< 1.500	.492	< .500	.086
VAL-2	8/3/2000	< .120	.109	< .600	< 1.500	.062	< .500	.045
VAL-2	8/29/2000	< .120	< .080	< .600	< 1.500	E .041	< .500	< .080
VAL-2	10/5/2000	< .120	< .080	< .600	< 1.500	.065	< .500	< .080
VAL-2	11/15/2000	< .120	.361	E .772	E 1.340	.234	< .500	< .080
VAL-2	12/13/2000	< .120	.705	< .600	< 1.500	.228	< .500	.097
VAL-2	1/25/2001	< 5.000	.68	E .880	E 1.800	< 1.000	< 5.000	E .240
VAL-2	2/9/2001	< 5.000	.82	E 2.700	E 4.100	< 1.000	< 5.000	< 1.000
VAL-3	2/29/2000	< .120	.106	E .415	E 1.100	.128	< .500	.066
VAL-3	3/29/2000	E .127	E .076	< .600	E .761	.096	< .500	< .040
VAL-3	6/28/2000	< .120	E .043	< .600	< 1.500	.05	< .500	< .040
VAL-3	8/3/2000	< .120	.208	E .313	< 1.500	.088	E .357	.058
VAL-3	8/31/2000	< .120	< .080	< .600	< 1.500	—	< .500	E .028
VAL-3	10/2/2000	< .120	< .080	< .600	< 1.500	E .046	E .109	< .080

Appendix table 2-3. Wastewater indicators detected in water samples from streams in the Birmingham area, Alabama, 2000–01—Continued

[Shaded samples were collected during high flow; BHA, 3-*tert*-butyl-4-hydroxyanisole; µg/L, micrograms per liter; <, not detected; E, estimated; —, no data; *, censored; OPEO1, monoethoxyoctylphenol; OPEO2, diethoxyoctylphenol; NPEO2, diethoxynonylphenol]

Site label (fig. 1)	Date	Food by-products				Pharmaceutical by-products		
		BHA (µg/L)	Caffeine (µg/L)	3B-Coprostanol (µg/L)	Cholesterol (µg/L)	Triclosan (µg/L)	17B-estradiol (µg/L)	Cotinine (µg/L)
VAL-3	11/9/2000	< .120	.205	E .541	< 1.500	.074	< .500	< .080
VAL-3	12/13/2000	< .120	.109	< .600	< 1.500	E .033	< .500	< .080
VAL-3	1/25/2001	< 5.000	E .110	< 2.000	< 2.000	< 1.000	< 5.000	< 1.000
VAL-3	2/13/2001	< 5.000	E .160	E 1.400	E 2.300	< 1.000	< 5.000	< 1.000
LCR	2/28/2000	< .120	.188	< .600	< 1.500	.078	< .500	.04
LCR	3/28/2000	< .120	E .044	< .600	< 1.500	< .040	< .500	< .040
LCR	6/27/2000	< .120	E .032	< .600	< 1.500	E .022	< .500	< .040
FMC	7/31/2000	< .120	E .065	< .600	< 1.500	.116	E .339	< .040
FMC	8/28/2000	< .120	< .080	< .600	< 1.500	< .050	< .500	< .080
FMC	11/13/2000	< .120	E .065	< .600	< 1.500	*	< .500	< .080
FMC	12/11/2000	< .120	< .080	< .600	< 1.500	< .050	< .500	< .080
FMC	1/22/2001	< 5.000	E .082	< 2.000	< 2.000	< 1.000	< 5.000	< 1.000
FMC	2/13/2001	< 5.000	E .150	< 2.000	< 2.000	< 1.000	< 5.000	< 1.000

Site label (fig. 1)	Date	Phosphate-based chemical surfactants and additives				Detergent agents				Fragrances
		Tri (2-chloro-ethyl) phosphate (µg/L)	Tri (dichloro-isopropyl) phosphate (µg/L)	Ethanol, 2-butoxy phosphate (µg/L)	Triphenyl phosphate (µg/L)	OPEO1 (µg/L)	OPEO2 (µg/L)	NPEO2-total (µg/L)	Para-nonylphe-nol-total (µg/L)	Acetephe-none (µg/L)
VIL-1	3/1/2000	< 0.040	< 0.100	< 0.070	< 0.100	E 0.092	< 0.200	< 1.100	< 0.500	< 1.0
VIL-1	4/1/2000	< .040	< .100	< .070	E .021	< .100	< .200	< 1.100	E .750	< 1.0
VIL-1	6/30/2000	< .040	< .100	< .070	< .100	< .100	< .200	< 1.100	< .500	< 1.0
VIL-1	8/1/2000	< .040	< .100	< .200	< .100	E .068	< .200	< 1.100	< .500	< .220
VIL-1	8/30/2000	.103	< .100	.249	< .100	*	< .200	< 1.100	E 1.360	< .150
VIL-1	10/4/2000	< .040	< .100	< .200	< .100	< .120	< .200	< 1.100	< .700	< .220
VIL-1	11/8/2000	.05	< .100	.657	E .069	E .234	< .200	E 2.100	E .645	< .220
VIL-1	12/14/2000	< .040	< .100	< .200	< .100	E .090	< .200	< 1.100	E .459	< .220
VIL-1	1/24/2001	< .500	< .500	< .500	E .074	< 1.000	< 1.000	< 5.000	< 5.000	< .500
VIL-1	1/29/2001	E .100	E .099	.75	E .130	< 1.000	< 1.000	E 2.700	< 5.000	< .500
VIL-2	8/1/2000	.38	< .100	.804	1.93	E .348	< .200	E 1.390	< .500	<1.0
VIL-2	8/30/2000	.327	.149	.716	< .100	E .260	< .200	< 1.100	E 1.730	< .150
VIL-2	10/4/2000	.564	< .100	< .200	< .100	E .090	< .200	< 1.100	E .438	< .220
VIL-2	11/14/2000	.128	< .100	< .200	< .100	E .693	< .200	< 1.100	E .794	.23
VIL-2	12/14/2000	.316	< .100	1.44	.136	E .434	E .104	E 3.000	E 2.540	.348
VIL-2	1/24/2001	E .340	E .068	E .380	E .091	< 1.000	< 1.000	E 1.800	< 5.000	< .500
VIL-2	1/29/2001	E .250	E .150	.6	E .180	< 1.000	< 1.000	E 2.000	< 5.000	E .28
VIL-3	3/2/2000	.302	< .100	2.13	< .100	E .712	E .159	E 4.640	E 1.720	1.14
VIL-3	3/30/2000	.3	< .100	1.32	E .052	< .100	< .200	E .584	E 1.770	1.51
VIL-3	6/30/2000	.263	< .100	.612	< .100	E .235	E .132	E 2.850	E .666	< .220
VIL-3	8/2/2000	.085	< .100	E 34.200	E .082	E .183	< .200	E 11.400	E 1.590	< .220
VIL-3	8/29/2000	.045	< .100	.301	< .100	E .189	< .200	< 1.100	E .542	< .220
VIL-3	10/3/2000	.086	< .100	E .159	< .100	E .247	< .200	E 1.430	E .560	< .220
VIL-3	11/14/2000	E .031	< .100	1.75	< .100	E .132	< .200	< 1.100	E .375	< .220
VIL-3	12/12/2000	.072	< .100	.907	< .100	E .347	< .200	< 1.100	E 1.040	.856
VIL-3	1/23/2001	E .230	E .160	E .320	E .093	< 1.000	< 1.000	< 5.000	< 5.000	2.8
VIL-3	2/14/2001	E .270	E .180	E .220	E .083	< 1.000	< 1.000	< 5.000	< 5.000	5.6
VIL-4	3/2/2000	.473	< .100	1.14	E .054	E .362	< .200	< 1.100	E 1.080	.43
VIL-4	4/2/2000	.217	< .100	1.45	E .066	< .100	E .039	E 1.900	E 1.610	.528
VIL-4	7/1/2000	.13	< .100	.223	< .100	E .089	< .200	< 1.100	< .500	< .220
VAL-1	3/1/2000	.119	< .100	2.74	E .066	E .159	< .200	E 6.990	E 1.936	.32
VAL-1	3/31/2000	.087	< .100	3.3	E .087	< .100	E .247	E 7.660	E 2.470	.475
VAL-1	6/29/2000	.056	< .100	.59	E .057	E .092	E .016	E .864	E .638	.202
VAL-1	8/2/2000	.139	< .100	.454	.138	E .324	< .200	E 2.520	E .538	.242
VAL-1	8/31/2000	.141	.356	13.9	E .052	E .177	< .200	E 9.360	E 2.950	< .150
VAL-1	10/3/2000	.056	< .100	17.6	< .100	E .185	< .200	E 9.050	E 1.750	< .220
VAL-1	11/9/2000	.068	< .100	.537	E .084	E .176	< .200	E 2.070	E .633	< .220

[Shaded samples were collected during high flow; BHA, 3-*tert*-butyl-4-hydroxyanisole; μg/L, micrograms per liter; <, not detected; E, estimated; —, no data; *, censored; OPEO1, monoethoxyoctylphenol; OPEO2, diethoxyoctylphenol; NPEO2, diethoxynonylphenol]

Site label (fig. 1)	Date	Phosphate-based chemical surfactants and additives				Detergent agents				Fragrances
		Tri (2-chloroethyl) phosphate (μg/L)	Tri (dichloroisopropyl) phosphate (μg/L)	Ethanol, 2-butoxy phosphate (μg/L)	Triphenyl phosphate (μg/L)	OPEO1 (μg/L)	OPEO2 (μg/L)	NPEO2-total (μg/L)	Para-nonylphenol-total (μg/L)	Acetophenone (μg/L)
VAL-1	12/12/2000	.086	< .100	15.1	E .062	E .542	E .615	E 7.300	E 2.620	< .220
VAL-1	1/23/2001	E .065	< .500	E .440	E .076	< 1.000	< 1.000	E 2.800	E .550	< .500
VAL-1	2/12/2001	E .100	E .110	3.7	E .140	< 1.000	< 1.000	E 3.200	E 1.700	E .35
VAL-2	2/29/2000	.118	< .100	1.72	E .083	E .205	E .083	E 2.270	E .617	< 1.0
VAL-2	3/31/2000	.075	< .100	.998	E .069	E .117	E .150	E 3.040	E 1.020	.13
VAL-2	6/29/2000	.138	< .100	2.83	< .100	E .344	E .135	E 2.540	E .423	< .220
VAL-2	8/3/2000	.061	< .100	1.91	E .056	E .150	< .200	< 1.100	E .490	< .220
VAL-2	8/29/2000	< .040	< .100	E .167	< .100	< .120	< .200	< 1.100	E .206	< .220
VAL-2	10/5/2000	.079	< .100	E .163	< .100	< .120	< .200	< 1.100	E .312	< .220
VAL-2	11/15/2000	< .040	< .100	1.87	< .100	< .120	< .200	E 1.490	E .246	< .220
VAL-2	12/13/2000	.067	< .100	2.56	< .100	E .410	E .208	E 1.580	E .654	< .220
VAL-2	1/25/2001	E .069	< .500	1.5	E .077	< 1.000	< 1.000	E 2.000	< 5.000	< .500
VAL-2	2/9/2001	E .130	E .120	.76	E .200	< 1.000	< 1.000	E 2.500	E .880	E .3
VAL-3	2/29/2000	.222	< .100	.48	E .062	E .233	< .200	< 1.100	E .777	< 1.0
VAL-3	3/29/2000	.12	< .100	.62	E .049	< .100	< .200	< 1.100	E .598	< 1.0
VAL-3	6/28/2000	E .021	< .100	.122	E .009	< .100	< .200	E .145	< .500	< 1.0
VAL-3	8/3/2000	.11	< .100	.77	E .066	E .192	< .200	< 1.100	E .582	< .220
VAL-3	8/31/2000	.124	.149	.234	< .100	E .082	< .200	< 1.100	< .500	< .150
VAL-3	10/2/2000	< .040	< .100	< .200	< .100	E .114	< .200	E .557	E .266	< .220
VAL-3	11/9/2000	.065	< .100	.444	E .062	E .167	< .200	< 1.100	E .406	< .220
VAL-3	12/13/2000	< .040	< .100	.493	< .100	E .086	< .200	< 1.100	E .248	< .220
VAL-3	1/25/2001	E .084	< .500	.53	< .500	< 1.000	< 1.000	< 5.000	< 5.000	< .500
VAL-3	2/13/2001	E .082	E .081	E .440	E .110	< 1.000	< 1.000	< 5.000	< 5.000	< .500
LCR	2/28/2000	.146	< .100	.425	E .054	< .100	< .200	< 1.100	< .500	< 1.0
LCR	3/28/2000	< .040	< .100	< .070	< .100	< .100	< .200	< 1.100	< .500	< 1.0
LCR	6/27/2000	< .040	< .100	< .070	< .100	< .100	< .200	< 1.100	< .500	< 1.0
FMC	7/31/2000	< .040	< .100	E .147	< .100	E .191	< .200	E 1.000	< .500	< .220
FMC	8/28/2000	< .040	< .100	< .200	< .100	< 0.120	< 0.200	< 1.100	< 0.700	< 0.220
FMC	11/13/2000	< .040	< .100	< .200	< .100	< .120	< .200	< 1.100	< .700	< .220
FMC	12/11/2000	< .040	< .100	< .200	< .100	< .120	< .200	< 1.100	< .700	< .220
FMC	1/22/2001	< .500	< .500	< .500	< .500	< 1.000	< 1.000	< 5.000	< 5.000	< .500
FMC	2/13/2001	E .067	E .098	E .290	E .074	< 1.000	< 1.000	< 5.000	< 5.000	< .500

Appendix table 2-4. Pesticides detected in water samples from streams in the Birmingham area, Alabama, 2000–01

[Shaded samples were collected during high flow; μg/L, micrograms per liter; —, no data; <, less than; E, estimated; DNOC, 4,6-dinitro-2-methylphenol]

Site label (fig. 1)	Date	Aldicarb (μg/L)	Aldicarb sulfone (μg/L)	Atrazine (μg/L)	Benfluralin (μg/L)	Bentazon (μg/L)	Bromacil (μg/L)	Bromoxynil (μg/L)	Carbaryl (μg/L)	Chlorpyrifos (μg/L)	Deethyl atrazine (μg/L)	Diazinon (μg/L)	Dieldrin (μg/L)	Diuron (μg/L)
VIL-1	5/17/2000	—	—	0.0189	<0.002	—	—	—	<0.003	<0.004	E 0.0146	E 0.00133	<0.001	—
VIL-1	8/1/2000	<0.54	<0.1	.0188	<.002	<0.035	<0.12	<0.04	<.003	E.00399	E.0128	E.00366	.00469	<0.06
VIL-1	8/30/2000	<.57	<.1	.012	<.002	<.035	<.06	<.04	<.003	<.004	E.0109	<.002	<.001	<.06
VIL-1	11/8/2000	<1.48	<.26	.0127	<.01	<.035	<3.45	<.07	<.041	.00568	<.006	.0884	<.0048	<.056
VIL-1	1/29/2001	<.76	<.2	1.580	E.00619	<.035	<.23	<.07	E.00375	.0127	E.0123	.0264	<.0048	<.21
VIL-1	3/19/2001	—	—	.011	<.01	—	—	—	<.041	<.005	E.00837	<.005	.00498	—
VIL-2	8/1/2000	<.21	<.15	.0255	<.002	<.035	.57	<.04	E.419	<.004	<.01	.0298	<.001	.3075
VIL-2	8/30/2000	<1.5	<.1	<.01	<.002	<.035	<.62	.07	<.003	<.004	<.002	<.002	<.001	<.06
VIL-2	1/29/2001	<.76	<.2	.135	<.01	<.035	<.29	<.07	E.0131	E.00463	<.006	.0205	<.0048	<.049
VIL-3	3/30/2000	<8.1	<.1	.202	<.002	<.035	.99	<.04	E.426	E.0121	<.02	.081	<.001	2.264
VIL-3	8/2/2000	<10.8	<.1	.0237	<.002	<.035	<.32	<.04	E.0371	E.0195	<.01	.0151	<.001	E.291
VIL-3	8/29/2000	<10.9	<1.47	<.04	<.002	<.035	<.22	<.04	<.3	<.04	<.2	<.002	<.001	<.12
VIL-3	2/14/2001	<2.9	<.2	—	—	<.035	—	<.07	—	—	—	—	—	<.056
VIL-4	4/2/2000	<3.49	<.1	.156	<.002	<.035	1.03	<.04	E.0893	E.00714	<.0125	.154	<.005	1.8052
VAL-1	6/29/2000	<3	<.47	.013	<.002	<.035	<3.1	<.04	<.003	.0105	<.007	.0516	<.001	<.27
VAL-1	8/2/2000	<3.9	<1.3	.00918	<.002	.196	<.47	<.04	<.003	.00592	E.00436	.00865	<.001	<.06
VAL-1	8/31/2000	<.21	<.1	.0129	<.002	<.16	<.48	<.04	<.003	.0208	E.00603	.00671	<.001	<.06
VAL-1	11/9/2000	<.49	<.2	.0209	<.01	<.035	<.27	<.07	E.0152	<.005	<.006	.0122	<.0048	<.056
VAL-1	2/12/2001	<.21	<.2	.0321	<.01	<.035	<.5	<.07	<.041	<.005	<.006	.0596	<.0048	<.27
VAL-2	5/16/2000	—	—	.0108	<.002	—	—	—	<.003	<.004	E.00668	.0139	<.001	—
VAL-2	6/29/2000	<.21	<.64	.0216	<.002	<.035	<.53	<.04	<.003	.0117	E.00776	.0397	<.001	<.06
VAL-2	8/29/2000	<2.1	<.1	.0171	<.002	<.035	<.23	<.04	<.003	.00756	E.00836	.0202	<.001	<.06
VAL-2	2/9/2001	<6.87	<3.75	2.58	<.01	<.035	<1.09	<.07	<.041	<.005	E.0357	.0832	<.0048	<.3
VAL-3	2/29/2000	<.53	<.12	8.88	<.002	<.035	<1.85	<.04	E.00588	E.0033	E.522	.00878	<.001	<.06
VAL-3	8/31/2000	<.21	<.1	.0238	<.002	<.035	.12	<.04	<.003	E.0026	E.0123	.00662	<.001	<.06
VAL-3	11/9/2000	<.25	<.2	.0107	<.01	<.035	<3	<.07	E.031	.00678	E.0053	.0489	<.0048	<.1
VAL-3	2/13/2001	<.3	<.2	1.94	<.01	<.035	<.09	<.07	<.041	.0073	E.0497	.0214	<.0048	<.11
LCR	2/28/2000	<.25	<1.81	.132	<.002	<.035	<5.35	<.04	E.00455	.00499	E.0126	.035	<.001	<1.74
LCR	6/27/2000	E.064	E.083	.0145	<.002	<.035	<3.48	<.04	E.0756	<.004	E.00672	.0132	<.001	<.06
FMC	5/15/2000	—	—	.0109	<.002	—	—	—	<.003	<.004	E.00388	<.002	.00403	—
FMC	7/31/2000	<.77	<.58	.0323	<.002	<.035	<.06	<.04	<.01	<.01	E.0106	.0773	<.001	<.06
FMC	8/28/2000	<.42	<.1	.00538	<.002	<.035	<.06	<.04	<.003	<.004	E.00423	<.002	<.001	<.06
FMC	2/13/2001	<.21	<.2	.0348	<.01	<.035	<19.15	<.07	<.041	<.005	E.00619	<.005	<.0048	<.056
FMC	3/20/2001	—	—	.6	<.01	—	—	—	<.041	<.005	E.0242	.00868	<.0048	—

Appendix table 2-4. Pesticides detected in water samples from streams in the Birmingham area, Alabama, 2000–01—Continued

[Shaded samples were collected during high flow; µg/L, micrograms per liter; —, no data; <, less than; E, estimated; DNOC, 4,6-dinitro-2-methylphenol]

Site label (fig. 1)	Date	DNOC (µg/L)	Malathion (µg/L)	Metolachlor (µg/L)	Pendimethalin (µg/L)	Prometon (µg/L)	Pronamide (µg/L)	Simazine (µg/L)	Tebuthiuron (µg/L)	Terbuthylazine (µg/L)	Triclopyr (µg/L)	Trifluralin (µg/L)
VIL-1	5/17/2000	—	<0.005	<0.002	<0.004	E 0.0102	<0.003	0.0208	0.0102	—	—	<0.002
VIL-1	8/1/2000	<0.42	<.005	<0.002	<.004	E.00897	<.003	.016	E.00922	—	<0.25	<.002
VIL-1	8/30/2000	<.42	<.005	<0.002	<.004	E.00523	<.003	.0135	<.01	—	<.25	<.002
VIL-1	11/8/2000	<.25	.027	<.013	<.01	<.015	<.0041	.684	<.016	—	<.24	<.009
VIL-1	1/29/2001	<.25	.027	<.013	<.02	<.015	<.0041	.526	<.016	—	<.07	E.0065
VIL-1	3/19/2001	—	.027	<.013	<.01	E.00858	<.0041	.0229	E.00638	—	—	<.009
VIL-2	8/1/2000	.57	<.005	<0.002	<.004	<.018	<.003	<.005	.136	E 0.0197	E.099	<.002
VIL-2	8/30/2000	<.42	<.005	<0.002	<.004	<.018	<.003	<.02	<.03	—	<.25	<.002
VIL-2	1/29/2001	<.25	.027	<.013	<.01	<.015	<.0041	.532	<.08	—	<.07	<.009
VIL-3	3/30/2000	<.42	.025	<0.002	<.04	.146	<.003	.0561	<.075	—	<.25	E.00113
VIL-3	8/2/2000	<.42	—	<.002	.0265	E.0169	<.003	.00779	E.07	E.0382	<.25	E.00197
VIL-3	8/29/2000	<.42	<.005	<0.002	<.004	<.04	<.003	<.03	<.01	E.0292	<.25	<.002
VIL-3	2/14/2001	<.25	—	—	—	—	—	—	—	—	<.355	—
VIL-4	4/2/2000	<.42	<.015	.00414	.0389	.0583	<.003	.0438	E.0649	—	<.25	<.002
VAL-1	6/29/2000	<.42	.156	<.002	.0193	<.018	<.003	.248	<.01	E.243	<.25	<.002
VAL-1	8/2/2000	<.42	<.005	<.002	<.004	E.0296	<.003	.0187	E.0464	E.145	<.25	<.002
VAL-1	8/31/2000	<.42	<.005	<.002	<.004	.0223	<.003	.0172	<.02	E.00585	<.25	<.002
VAL-1	11/9/2000	<.25	<.027	<.013	<.01	E.00819	<.0041	.415	.0514	—	<.27	<.009
VAL-1	2/12/2001	<.25	<.027	<.013	<.01	.151	<.0041	.0261	<.016	—	<.71	<.009
VAL-2	5/16/2000	—	<.005	<.002	<.004	.021	<.003	.018	<.02	.116	—	<.002
VAL-2	6/29/2000	<.42	.0496	.00543	.0133	.0317	<.003	.0533	<.01	E.401	<.34	<.002
VAL-2	8/29/2000	<.42	<.005	<.005	<.004	.0263	<.003	.0158	.0188	—	<.25	<.002
VAL-2	2/9/2001	<.29	<.027	<.013	.0654	.926	<.0041	.184	<.016	—	<.68	E.00635
VAL-3	2/29/2000	<.42	<.005	<.002	<.004	.0199	<.003	.428	E.0257	—	E.201	<.002
VAL-3	8/31/2000	<.42	<.005	<.002	<.004	.0212	<.003	.0119	.0171	—	<.25	<.002
VAL-3	11/9/2000	<.25	E.00473	<.013	<.01	E.0134	<.0041	.481	E.0136	—	.300	<.009
VAL-3	2/13/2001	E.30	<.027	<.013	.0447	.0187	<.0041	.215	<.016	—	.384	<.009
LCR	2/28/2000	<.42	.0079	.00432	<.004	E.00754	<.003	.161	E.0108	—	<.25	<.002
LCR	6/27/2000	<.42	<.005	<.002	<.004	E.00962	<.003	.00537	E.00762	—	<.25	<.002
FMC	5/15/2000	—	<.005	<.002	<.004	E.00216	<.003	.0104	E.00648	—	—	<.002
FMC	7/31/2000	<.42	<.005	<.002	<.004	.0207	<.003	.00907	<.01	—	<.25	<.002
FMC	8/28/2000	<.42	<.005	<.002	<.004	<.018	<.003	.00833	<.01	—	<.25	<.002
FMC	2/13/2001	<.25	<.027	<.013	<.01	E.00855	<.0041	8.6	<.016	—	<.07	<.009
FMC	3/20/2001	—	<.027	<.013	<.01	E.00425	.0127	.428	<.016	—	—	<.009

Appendix table 2-5. Polycyclic aromatic hydrocarbons detected in water samples from streams in the Birmingham area, Alabama, 2000–01

[Shaded samples were collected during high flow; µg/L, micrograms per liter; E, estimated; <, less than]

Site label (fig. 1)	Date	Acenaphthene (µg/L)	Acenaphthylene (µg/L)	Anthracene (µg/L)	Benz[a]anthracene (µg/L)	Benzo[a]pyrene (µg/L)	Benzo[b]fluoranthene (µg/L)	Benzo[ghi]perylene (µg/L)	Benzo[k]fluoranthene (µg/L)
VIL-1	3/1/2000	E 0.014	<1.93	E 0.052	E 0.528	E 0.813	E 0.903	E 0.796	E 0.679
VIL-1	10/4/2000	E.00946	E.011	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
VIL-1	11/8/2000	E.0297	<1.1	E.102	E.408	E.528	E.959	E.552	E.322
VIL-1	1/29/2001	E.0316	E.0197	E.072	E.491	E.792	E 1.44	E.717	E.475
VIL-2	10/4/2000	<1.1	E.0125	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
VIL-2	11/14/2000	E.14	E.112	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
VIL-2	1/29/2001	E.0543	E.0318	E.0818	E.297	E.421	E.73	E.315	E.234
VIL-3	3/2/2000	<1.85	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
VIL-3	10/3/2000	<1.1	<1.1	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
VIL-3	2/14/2001	E.0567	E.0774	E.0261	<1.6	<2.8	<2.6	<2.5	<2.8
VIL-4	3/2/2000	E.0461	<1.93	<1.97	<2.4	<2.8	E.0404	<3.08	<3.24
VAL-1	3/1/2000	<1.85	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
VAL-1	6/29/2000	<1.85	E.0414	E.0878	E.189	E.215	E.502	E.279	E.385
VAL-1	8/31/2000	<1.85	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
VAL-1	10/3/2000	<1.1	<1.1	E.0127	<1.6	<2.8	<2.6	<2.5	<2.8
VAL-1	11/9/2000	E.0218	<1.1	E.0376	<1.6	E.032	E.0643	E.0452	E.0329
VAL-1	2/12/2001	E.0821	E.0528	E.192	E.714	E.885	E 1.56	E 1.11	E.505
VAL-2	2/29/2000	E.0226	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
VAL-2	6/29/2000	<1.85	E.00856	E.0325	<2.4	<2.8	<3.02	<3.08	<3.24
VAL-2	8/3/2000	E.0237	<1.93	E.0217	<2.4	<2.8	<3.02	<3.08	<3.24
VAL-2	10/5/2000	E.0142	<1.1	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
VAL-2	2/9/2001	E.0722	E.0531	E.168	E.855	E 1.2	E 2.3	E 1.53	E.744
VAL-3	2/29/2000	<1.85	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
VAL-3	10/2/2000	<1.1	<1.1	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
VAL-3	11/9/2000	E.026	<1.1	E.0498	E.0662	E.06	E.105	E.0637	E.0444
VAL-3	2/13/2001	E.0405	E.0272	E.0919	E.417	E.55	E 1.04	E.738	E.355
LCR	2/28/2000	<1.85	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
LCR	6/27/2000	<1.85	<1.93	<1.97	<2.4	<2.8	<3.02	<3.08	<3.24
FMC	12/11/2000	<1.1	<1.1	<1.9	<1.6	<2.8	<2.6	<2.5	<2.8
FMC	2/13/2001	E.00845	E.00522	E.0106	E.0441	E.013	E.0449	<2.5	E.0161

Appendix table 2-5. Polycyclic aromatic hydrocarbons detected in water samples from streams in the Birmingham area, Alabama, 2000–01—Continued

[Shaded samples were collected during high flow; µg/L, micrograms per liter; E, estimated; <, less than]

Site label (fig. 1)	Date	Chrysene (µg/L)	Dibenz[a,h]-anthracene (µg/L)	Fluoranthene (µg/L)	Fluorene (µg/L)	Indeno[1,2,3-cd] pyrene (µg/L)	Naphthalene (µg/L)	Phenanthrene (µg/L)	Pyrene (µg/L)
VIL-1	3/1/2000	E 0.827	E 0.329	E 1.17	E 0.0269	E 1.42	<2.07	E 0.319	E 0.911
VIL-1	10/4/2000	<1.9	<2.7	E .0105	E .0182	<1.9	E .0971	<1.5	E .0224
VIL-1	11/8/2000	E .765	E .172	E 1.51	E .0621	E .514	E .0502	E .673	E 1.04
VIL-1	1/29/2001	E 1.16	E .186	E 2.04	E .0529	E .879	E .262	E 0.894	E 1.47
VIL-2	10/4/2000	<1.9	<2.7	E .211	<1.2	E .0355	E .102	<1.5	E .163
VIL-2	11/14/2000	<1.9	<2.7	E .0783	E .131	<1.9	E .241	E 0.164	E .176
VIL-2	1/29/2001	E .454	E .123	E .904	E .0853	E .416	E .232	E 0.45	E .698
VIL-3	3/2/2000	<2.65	<3.35	E .0537	E .0373	E .103	<2.07	<2.05	E .0446
VIL-3	10/3/2000	<1.9	<2.7	<1.5	<1.2	<1.9	E .034	<1.5	<1.5
VIL-3	2/14/2001	<1.9	<2.7	E .0385	E .0957	<1.9	E .358	E 0.0556	E .0377
VIL-4	3/2/2000	E .0284	<3.35	E .0731	E .0262	<3	<2.07	<2.05	E .0442
VAL-1	3/1/2000	<2.65	<3.35	<2.33	<2.04	<3	<2.07	<2.05	<2.23
VAL-1	6/29/2000	E .416	<3.35	E .525	E .0578	E .246	<2.07	E .187	E .456
VAL-1	8/31/2000	E .0285	<3.35	E .0427	<2.04	<3	<2.07	<2.05	E .0548
VAL-1	10/3/2000	<1.9	<2.7	E .245	<1.2	<1.9	E .0289	E .156	E .186
VAL-1	11/9/2000	E .051	<2.7	E .121	E .03	E .0315	E .0761	E .0973	E .0913
VAL-1	2/12/2001	E 1.2	E .417	E 2.1	E .134	E 1.18	E .222	E 1.35	E 1.64
VAL-2	2/29/2000	E .0265	<3.35	E .049	<2.04	<3	<2.07	<2.05	E .0364
VAL-2	6/29/2000	<2.65	<3.35	E .0456	E .0306	<3	<2.07	E .0243	E .0531
VAL-2	8/3/2000	<2.65	<3.35	E .0485	E .0126	<3	E .0662	E .0285	E .0502
VAL-2	10/5/2000	<1.9	<2.7	E .0161	E .0102	<1.9	E .0315	<1.5	E .016
VAL-2	2/9/2001	E 1.66	E .616	2.82	E .1	E 1.6	E .185	E 1.25	E 2.17
VAL-3	2/29/2000	E .0146	<3.35	E .0379	<2.04	<3	<2.07	<2.05	E .0291
VAL-3	10/2/2000	<1.9	<2.7	<1.5	<1.2	<1.9	<1	2.27	<1.5
VAL-3	11/9/2000	E .072	<2.7	E .145	E .0224	E .0512	E .0423	E .097	E .123
VAL-3	2/13/2001	E .714	E .255	E 1.16	E .0542	E .806	E .0878	E .492	E .917
LCR	2/28/2000	<2.65	<3.35	<2.33	<2.04	<3	<2.07	<2.05	<2.23
LCR	6/27/2000	<2.65	<3.35	<2.33	<2.04	<3	<2.07	<2.05	<2.23
FMC	12/11/2000	<1.9	<2.7	E .0117	<1.2	<1.9	<1	<1.5	E .0106
FMC	2/13/2001	E .0327	<2.7	E .0926	<1.2	<1.9	<1	E .0293	E .07

Appendix table 3-1. Trace and major elements detected in bed-sediment samples from streams in the Birmingham area, Alabama, 2000

[LRL, laboratory reporting level; μg/g, micrograms per gram; <, less than]

Analyte (unit)	VIL-1	VIL-2	VIL-3	VAL-1	VAL-2	FMC	LRL
Aluminum (percent)	6.1	4.3	4.9	4.9	2.5	3.7	0.005
Antimony (μg/g)	1.3	5.1	3.8	6.5	1.4	.5	.1
Arsenic (μg/g)	22	20	21	21	14	11	.01
Barium (μg/g)	260	350	300	470	230	200	1
Beryllium (μg/g)	3.1	1.8	2.3	2.2	2	1.2	1
Bismuth (μg/g)	< 1	2	< 1	1.5	< 1	< 1	10
Cadmium (μg/g)	.6	19	10	3.6	.82	< .1	.1
Calcium (percent)	1.3	3.7	4.2	5	5.3	.3	.005
Carbon, inorganic (μg/g)	.41	1.3	1.6	1.74	1.6	.01	.01
Carbon, organic (μg/g)	2.7	5.35	3.63	6.08	4.05	1.7	.01
Carbon, total (μg/g)	3.1	6.7	5.3	7.82	5.7	1.7	.01
Cerium (μg/g)	110	86	84	91	58	85	4
Chromium (μg/g)	83	170	110	180	88	47	1
Cobalt (μg/g)	19	14	14	14	8.2	8	1
Copper (μg/g)	45	210	120	320	54	16	1
Europium (μg/g)	2	< 1	< 1	1.1	< 1	1	2
Gallium (μg/g)	15	11	13	12	5.9	9	4
Gold (μg/g)	< 1	< 1	< 1	< 1	< 1	< 1	8
Holmium (μg/g)	1.4	< 1	< 1	< 1	< 1	< 1	4
Iron (percent)	4.5	4.5	4	4.8	3.1	2.1	.005
Lanthanum (μg/g)	48	37	38	39	25	37	2
Lead (μg/g)	130	430	240	800	160	23	4
Lithium (μg/g)	44	35	37	37	23	31	2
Magnesium (percent)	.7	1.2	1.3	1.7	1.3	.28	.005
Manganese (μg/g)	1,300	1,300	1,200	1,300	840	430	4
Mercury (μg/g)	.27	.45	.23	1.6	.19	< .02	.02
Molybdenum (μg/g)	1.4	7.1	4.6	6.9	2	.7	2
Neodymium (μg/g)	44	31	31	32	22	29	4
Nickel (μg/g)	38	57	41	47	21	18	2
Niobium (μg/g)	19	17	17	17	6.3	19	4
Phosphorus (percent)	.085	.12	.092	.15	.088	.036	.005
Potassium (percent)	1.2	.66	.92	.92	.44	.58	.05
Scandium (μg/g)	12	9	10	9.9	6.1	7	2
Selenium (μg/g)	.8	1.9	1.2	1.5	.7	.51	.1
Silver (μg/g)	.2	4	1.4	20	.9	.44	.1
Sodium (percent)	.055	.06	.058	.075	.078	.062	.005
Strontium (μg/g)	44	80	74	100	94	30	2
Sulfur (percent)	.08	.28	.24	.51	.16	.05	.06
Tantalum (μg/g)	1	1	1	1.6	< 1	1	40
Thallium (μg/g)	< 1	< 1	< 1	< 1	< 1	< 1	40
Thorium (μg/g)	14	11	11	12	7.2	10	4
Tin (μg/g)	6	33	16	32	6.3	2	10
Titanium (percent)	.41	.36	.36	.38	.18	.42	.005
Uranium (μg/g)	4.1	3.5	3.4	3.6	2.1	3.3	.05
Vanadium (μg/g)	87	72	76	88	53	56	2
Ytterbium (μg/g)	4	3	2	2.7	1.7	2	1
Yttrium (μg/g)	36	23	23	24	17	21	2
Zinc (μg/g)	270	4,000	2,400	1,200	330	120	4

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
VIL1	06/09/2000	Arthropoda	Insecta	Collembola					Collembola	11	0.322
VIL1	06/09/2000	Arthropoda	Insecta	Diptera	Nematocera	Tipulidae	Limoniinae		Antocha sp.	11	.322
VIL1	06/09/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae	Hydroptilinae		Hydroptila sp.	11	.322
VIL1	06/09/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae	Hydropsychinae		Hydropsyche depravata group	11	.322
VIL1	06/09/2000	Nematoda							Nematoda	11	.322
VIL1	06/09/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Stenelmis sp.	12	.345
VIL1	06/09/2000	Platyhelminthes	Turbellaria						Turbellaria	22	.645
VIL1	06/09/2000	Arthropoda	Malacostraca	Isopoda	Asellota	Asellidae			Lirceus sp.	23	.668
VIL1	06/09/2000	Mollusca	Gastropoda						Gastropoda	78	2.256
VIL1	06/09/2000	Annelida	Oligochaeta						Megadrile	101	2.901
VIL1	06/09/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae	Hydropsychinae		Cheumatopsyche sp.	158	4.558
VIL1	06/09/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromiinae	168	4.835
VIL1	06/09/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Naididae			Naididae	314	9.024
VIL1	06/09/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	325	9.347
VIL1	06/09/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	594	17.082
VIL1	06/09/2000	Arthropoda	Insecta	Ephemeroptera	Pisciforma	Baetidae			Baetis sp.	739	21.272
VIL1	06/09/2000	Arthropoda	Arachnida						Acari	885	25.462
									Total density	**3,475**	
VIL1	10/25/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Tubificidae			Tubificidae	1	0.34
VIL1	10/25/2000	Arthropoda	Insecta	Collembola					Collembola	1	.34
VIL1	10/25/2000	Arthropoda	Insecta	Odonata	Zygoptera	Calopterygidae			Hetaerina sp.	1	.34
VIL1	10/25/2000	Arthropoda	Insecta	Odonata	Zygoptera	Coenagrionidae			Argia sp.	1	.34
VIL1	10/25/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae	Hydroptilinae		Hydroptila sp.	1	.34
VIL1	10/25/2000	Nematoda							Nematoda	2	.68
VIL1	10/25/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Stenelmis sp.	3	1.01
VIL1	10/25/2000	Arthropoda	Insecta	Diptera	Nematocera	Ceratopogonidae	Forcipomyiinae		Forcipomyia sp.	4	1.35
VIL1	10/25/2000	Platyhelminthes	Turbellaria						Turbellaria	4	1.35
VIL1	10/25/2000	Mollusca	Gastropoda						Gastropoda	5	1.69
VIL1	10/25/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromia sp.	6	2.03
VIL1	10/25/2000	Annelida	Oligochaeta						Megadrile	8	2.70

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000—Continued

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
VIL1	10/25/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Naididae			Naididae	9	3.04
VIL1	10/25/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	12	4.06
VIL1	10/25/2000	Arthropoda	Arachnida						Acari	22	7.44
VIL1	10/25/2000	Arthropoda	Insecta	Ephemeroptera					Ephemeroptera	45	15.21
VIL1	10/25/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	85	28.39
VIL1	10/25/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	88	29.40
									Total density	**299**	
VIL3	06/15/2000	Arthropoda	Insecta	Megaloptera		Corydalidae	Corydalinae		Corydalus cornutus (Linnaeus)	1	0.04
VIL3	06/15/2000	Arthropoda	Malacostraca	Decapoda	Pleocyemata	Cambaridae			Cambaridae	1	.04
VIL3	06/15/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Naididae			Naididae	7	.34
VIL3	06/15/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Hydrophilidae			Enochrus sp.	7	.34
VIL3	06/15/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Stenelmis sp.	7	.34
VIL3	06/15/2000	Arthropoda	Insecta	Diptera	Nematocera	Ceratopogonidae	Forcipomyiinae		Atrichopogon sp.	7	.34
VIL3	06/15/2000	Arthropoda	Insecta	Diptera	Nematocera	Culicidae			Culicidae	7	.34
VIL3	06/15/2000	Arthropoda	Insecta	Hemiptera	Heteroptera	Gerridae			Gerridae	7	.34
VIL3	06/15/2000	Annelida	Oligochaeta						Megadrile	8	.38
VIL3	06/15/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Hydrophilidae			Berosus sp.	13	.68
VIL3	06/15/2000	Arthropoda	Insecta	Hemiptera	Heteroptera	Veliidae	Microveliinae		Microvelia sp.	13	.68
VIL3	06/15/2000	Arthropoda	Insecta	Collembola					Collembola	20	1.02
VIL3	06/15/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromiinae	20	1.02
VIL3	06/15/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	27	1.36
VIL3	06/15/2000	Arthropoda	Insecta	Odonata	Zygoptera				Zygoptera	108	5.49
VIL3	06/15/2000	Mollusca	Gastropoda						Gastropoda	376	19.08
VIL3	06/15/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	1,344	68.15
									Total density	**1,972**	
VIL3	10/25/2000	Arthropoda	Insecta	Megaloptera		Corydalidae	Corydalinae		Corydalus cornutus (Linnaeus)	1	0.03
VIL3	10/25/2000	Arthropoda	Insecta	Odonata	Zygoptera	Calopterygidae			Hetaerina sp.	1	.03
VIL3	10/25/2000	Arthropoda	Malacostraca	Decapoda	Pleocyemata	Cambaridae			Cambaridae	1	.03
VIL3	10/25/2000	Annelida	Hirudinea	Arhynchobdel-lae		Erpobdellidae			Erpobdellidae	2	.05
VIL3	10/25/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae	Hydroptilinae		Hydroptila sp.	9	.29
VIL3	10/25/2000	Arthropoda	Insecta	Odonata	Anisoptera	Gomphidae			Gomphidae	14	.45

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000—Continued

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
VIL3	10/25/2000	Nematoda							Nematoda	18	0.59
VIL3	10/25/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	28	.88
VIL3	10/25/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromia sp.	28	.88
VIL3	10/25/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Hydrophilidae			Berosus sp.	37	1.18
VIL3	10/25/2000	Mollusca	Gastropoda	Basommatophora		Ancylidae			Hebetancylus excentricus (Morelet)	55	1.76
VIL3	10/25/2000	Mollusca	Gastropoda	Basommatophora		Physidae	Physinae		Physella sp.	74	2.35
VIL3	10/25/2000	Annelida	Oligochaeta						Megadrile	129	4.12
VIL3	10/25/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	323	10.30
VIL3	10/25/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	2,415	77.07
									Total density	**3,133**	
VAL1	06/14/2000	Annelida	Hirudinea	Arhynchobdellae		Erpobdellidae			Erpobdellidae	1	0.00
VAL1	06/14/2000	Annelida	Oligochaeta						Megadrile	1	.00
VAL1	06/14/2000	Mollusca	Gastropoda	Basommatophora		Ancylidae			Hebetancylus excentricus (Morelet)	1	.00
VAL1	06/14/2000	Mollusca	Gastropoda	Basommatophora		Physidae	Physinae		Physella sp.	3,102	7.94
VAL1	06/14/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Naididae			Naididae	10,466	26.78
VAL1	06/14/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	25,519	65.28
									Total density	**39,090**	
VAL1	10/24/2000	Annelida	Oligochaeta						Megadrile	1	0.01
VAL1	10/24/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae	Hydropsychinae		Cheumatopsyche sp.	1	.01
VAL1	10/24/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae	Hydroptilinae		Hydroptila sp.	27	.29
VAL1	10/24/2000	Platyhelminthes	Turbellaria						Turbellaria	54	.58
VAL1	10/24/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Tubificidae			Tubificidae	108	1.16
VAL1	10/24/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Naididae			Naididae	806	8.69
VAL1	10/24/2000	Mollusca	Gastropoda						Gastropoda	1,183	12.76
VAL1	10/24/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	7,096	76.50
									Total density	**9,276**	
VAL2	06/08/2000	Arthropoda	Malacostraca	Decapoda	Pleocyemata	Cambaridae			Cambaridae	1	0.01
VAL2	06/08/2000	Mollusca	Gastropoda	Basommatophora		Physidae	Physinae		Physella sp.	1	.01

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000—Continued

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
VAL2	06/08/2000	Arthropoda	Insecta	Odonata	Anisoptera	Gomphidae			Gomphidae	2	0.01
VAL2	06/08/2000	Mollusca	Bivalvia	Veneroida		Corbiculidae			Corbicula sp.	8	.07
VAL2	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Hydrophilidae			Berosus sp.	35	.32
VAL2	06/08/2000	Nematoda							Nematoda	35	.32
VAL2	06/08/2000	Arthropoda	Insecta	Odonata	Zygoptera	Coenagrionidae			Coenagrionidae	72	.66
VAL2	06/08/2000	Mollusca	Gastropoda	Basommatophora		Ancylidae			Ancylidae	72	.66
VAL2	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Elmidae	106	.96
VAL2	06/08/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Naididae			Naididae	107	.98
VAL2	06/08/2000	Annelida	Oligochaeta						Megadrile	107	.98
VAL2	06/08/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae			Empididae	286	2.61
VAL2	06/08/2000	Platyhelminthes	Turbellaria						Turbellaria	286	2.61
VAL2	06/08/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Tubificidae			Tubificidae	394	3.59
VAL2	06/08/2000	Arthropoda	Arachnida						Acari	1,147	10.46
VAL2	06/08/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae			Hydroptilidae	1,685	15.36
VAL2	06/08/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	2,187	19.94
VAL2	06/08/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	4,440	40.47
									Total density	**10,971**	
VAL2	10/24/2000	Arthropoda	Insecta	Lepidoptera					Lepidoptera	1	0.02
VAL2	10/24/2000	Arthropoda	Insecta	Diptera	Nematocera	Ceratopogonidae			Ceratopogonidae	15	.30
VAL2	10/24/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	15	.30
VAL2	10/24/2000	Arthropoda	Insecta	Odonata	Zygoptera	Coenagrionidae			Argia sp.	16	.32
VAL2	10/24/2000	Annelida	Oligochaeta						Megadrile	17	.33
VAL2	10/24/2000	Arthropoda	Insecta	Odonata	Anisoptera	Gomphidae			Gomphidae	18	.35
VAL2	10/24/2000	Arthropoda	Arachnida						Acari	31	.61
VAL2	10/24/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromia sp.	31	.61
VAL2	10/24/2000	Arthropoda	Insecta	Ephemeroptera	Pisciforma	Baetidae			Baetis sp.	31	.61
VAL2	10/24/2000	Mollusca	Gastropoda	Basommatophora		Ancylidae			Ancylidae	31	.61
VAL2	10/24/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Hydrophilidae			Berosus sp.	108	2.13
VAL2	10/24/2000	Mollusca	Bivalvia	Veneroida		Corbiculidae			Corbicula sp.	140	2.78
VAL2	10/24/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae			Hydroptilidae	276	5.48
VAL2	10/24/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	2,028	40.19
VAL2	10/24/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae	Hydropsychinae		Cheumatopsyche sp.	2,289	45.36
									Total density	**5,045**	

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000—Continued

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
LCR	06/12/2000	Arthropoda	Malacostraca	Decapoda	Pleocyemata	Cambaridae			Cambaridae	2	0.03
LCR	06/12/2000	Annelida	Oligochaeta						Megadrile	2	.04
LCR	06/12/2000	Annelida	Oligochaeta	Tubificida	Tubificina	Tubificidae			Tubificidae	18	.34
LCR	06/12/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae	Orthocladiinae		Parametriocnemus sp.	18	.34
LCR	06/12/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromia sp.	18	.34
LCR	06/12/2000	Arthropoda	Insecta	Trichoptera	Integripalpia	Helicopsychidae			Helicopsyche borealis (Hagen)	18	.34
LCR	06/12/2000	Arthropoda	Malacostraca	Amphipoda					Amphipoda	18	.34
LCR	06/12/2000	Mollusca	Bivalvia	Veneroida		Sphaeriidae	Sphaeriinae		Sphaerium sp.	18	.34
LCR	06/12/2000	Arthropoda	Insecta	Megaloptera		Corydalidae	Corydalinae		Corydalus cornutus (Linnaeus)	20	.36
LCR	06/12/2000	Mollusca	Bivalvia	Veneroida		Corbiculidae			Corbicula sp.	24	.44
LCR	06/12/2000	Arthropoda	Arachnida						Acari	37	.67
LCR	06/12/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	37	.67
LCR	06/12/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Hydroptilidae	Hydroptilinae		Hydroptila sp.	37	.67
LCR	06/12/2000	Arthropoda	Insecta	Diptera	Nematocera	Tipulidae	Limoniinae		Antocha sp.	55	1.01
LCR	06/12/2000	Nematoda							Nematoda	55	1.01
LCR	06/12/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Psephenidae			Psephenus herricki (DeKay)	92	1.68
LCR	06/12/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Microcylloepus sp.	110	2.01
LCR	06/12/2000	Arthropoda	Malacostraca	Isopoda					Isopoda	129	2.35
LCR	06/12/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Glossosomatidae	Protoptilinae		Protoptila sp.	147	2.68
LCR	06/12/2000	Arthropoda	Insecta	Trichoptera	Integripalpia	Brachycentridae			Micrasema sp.	221	4.02
LCR	06/12/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Psychomyiidae	Psychomyiinae		Psychomyia flavida Hagen	314	5.71
LCR	06/12/2000	Arthropoda	Insecta	Ephemeroptera					Ephemeroptera	515	9.38
LCR	06/12/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Stenelmis sp.	811	14.77
LCR	06/12/2000	Mollusca	Gastropoda	Mesogastropoda		Pleuroceridae			Elimia sp.	875	15.94
LCR	06/12/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	921	16.77
LCR	06/12/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Optioservus sp.	977	17.79
									Total density	**5,491**	
LCR	10/26/2000	Arthropoda	Insecta	Odonata	Anisoptera	Gomphidae			Lanthus sp.	1	0.02
LCR	10/26/2000	Mollusca	Bivalvia	Veneroida		Corbiculidae			Corbicula sp.	6	.14
LCR	10/26/2000	Arthropoda	Insecta	Diptera	Nematocera	Tipulidae	Limoniinae		Antocha sp.	12	.29
LCR	10/26/2000	Arthropoda	Insecta	Plecoptera					Plecoptera	12	.29

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000—Continued

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
LCR	10/26/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Philopotamidae	Chimarrinae		Chimarra sp.	12	0.29
LCR	10/26/2000	Arthropoda	Insecta	Trichoptera	Integripalpia	Brachycentridae			Micrasema sp.	12	.29
LCR	10/26/2000	Arthropoda	Insecta	Trichoptera		Glossosomatidae	Agapetinae		Agapetus sp.	12	.29
LCR	10/26/2000	Arthropoda	Malacostraca	Amphipoda					Amphipoda	12	.29
LCR	10/26/2000	Arthropoda	Malacostraca	Isopoda	Asellota	Asellidae			Asellidae	12	.29
LCR	10/26/2000	Platyhelminthes	Turbellaria						Turbellaria	12	.29
LCR	10/26/2000	Annelida	Oligochaeta						Megadrile	12	.30
LCR	10/26/2000	Arthropoda	Arachnida						Acari	23	.57
LCR	10/26/2000	Arthropoda	Insecta	Megaloptera		Corydalidae	Corydalinae		Corydalus cornutus (Linnaeus)	24	.60
LCR	10/26/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Psychomyiidae	Psychomyiinae		Psychomyia flavida Hagen	35	.86
LCR	10/26/2000	Arthropoda	Insecta	Odonata	Zygoptera				Zygoptera	47	1.16
LCR	10/26/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	58	1.43
LCR	10/26/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	92	2.29
LCR	10/26/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Glossosomatidae	Protoptilinae		Protoptila sp.	115	2.86
LCR	10/26/2000	Arthropoda	Insecta	Ephemeroptera		Baetidae			Baetidae	230	5.73
LCR	10/26/2000	Mollusca	Gastropoda	Mesogastropoda		Pleuroceridae			Pleuroceridae	267	6.64
LCR	10/26/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	288	7.16
LCR	10/26/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Stenelmis sp.	427	10.63
LCR	10/26/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Psephenidae			Psephenus herricki (DeKay)	519	12.91
LCR	10/26/2000	Arthropoda	Insecta	Ephemeroptera	Setisura	Heptageniidae			Heptageniidae	519	12.91
LCR	10/26/2000	Arthropoda	Insecta	Ephemeroptera	Setisura	Isonychiidae			Isonychia sp.	553	13.75
LCR	10/26/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Optioservus sp.	714	17.76
									Total density	**4,022**	
FMC	06/08/2000	Arthropoda	Insecta	Odonata	Zygoptera	Coenagrionidae			Argia sp.	1	0.02
FMC	06/08/2000	Arthropoda	Malacostraca	Decapoda	Pleocyemata	Cambaridae	Cambarinae		Orconectes sp.	1	.02
FMC	06/08/2000	Annelida	Oligochaeta						Megadrile	2	.03
FMC	06/08/2000	Arthropoda	Insecta	Diptera	Nematocera	Tipulidae	Tipulinae		Tipula sp.	2	.03
FMC	06/08/2000	Arthropoda	Insecta	Megaloptera		Corydalidae	Corydalinae		Corydalus cornutus (Linnaeus)	2	.03
FMC	06/08/2000	Arthropoda	Insecta	Collembola					Collembola	14	.30
FMC	06/08/2000	Arthropoda	Insecta	Diptera	Nematocera	Tipulidae	Limoniinae		Antocha sp.	14	.30
FMC	06/08/2000	Arthropoda	Insecta	Lepidoptera		Pyralidae	Nymphulinae	Argy-actini	Petrophila sp.	14	.30

Appendix table 3-2. Benthic-invertebrate taxa, density, and relative abundance in streams in the Birmingham area, Alabama, 2000—Continued

[m², square meter]

Site label (fig. 1)	Collection date	Phylum	Class	Order	Suborder	Family	Subfamily	Tribe	Identification	Density (per m²)	Percent of total
FMC	06/08/2000	Arthropoda	Insecta	Odonata	Anisoptera	Aeshnidae			Boyeria vinosa (Say)	14	0.31
FMC	06/08/2000	Mollusca	Bivalvia	Veneroida		Corbiculidae			Corbicula sp.	19	.42
FMC	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Optioservus sp.	27	.59
FMC	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Psephenidae			Ectopria sp.	27	.59
FMC	06/08/2000	Arthropoda	Insecta	Diptera	Brachycera	Empididae	Hemerodromiinae		Hemerodromiinae	27	.59
FMC	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Dubiraphia sp.	40	.87
FMC	06/08/2000	Arthropoda	Insecta	Megaloptera		Corydalidae	Chauliodinae		Nigronia serricornis (Say)	40	.87
FMC	06/08/2000	Arthropoda	Insecta	Trichoptera	Spicipalpia	Glossosomatidae	Protoptilinae		Protoptila sp.	67	1.46
FMC	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Microcylloepus sp.	81	1.76
FMC	06/08/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Philopotamidae	Chimarrinae		Chimarra sp.	107	2.33
FMC	06/08/2000	Arthropoda	Insecta	Diptera	Nematocera	Simuliidae			Simuliidae	121	2.63
FMC	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Psephenidae			Psephenus herricki (DeKay)	134	2.92
FMC	06/08/2000	Mollusca	Bivalvia	Veneroida		Sphaeriidae	Sphaeriinae		Sphaerium sp.	201	4.37
FMC	06/08/2000	Arthropoda	Arachnida						Acari	242	5.25
FMC	06/08/2000	Arthropoda	Malacostraca	Isopoda	Asellota	Asellidae			Lirceus sp.	242	5.25
FMC	06/08/2000	Arthropoda	Insecta	Trichoptera	Integripalpia	Brachycentridae			Micrasema sp.	296	6.43
FMC	06/08/2000	Arthropoda	Insecta	Diptera	Nematocera	Chironomidae			Chironomidae	297	6.45
FMC	06/08/2000	Arthropoda	Insecta	Ephemeroptera					Ephemeroptera	457	9.93
FMC	06/08/2000	Arthropoda	Insecta	Trichoptera	Annulipalpia	Hydropsychidae			Hydropsychidae	551	11.98
FMC	06/08/2000	Mollusca	Gastropoda	Mesogastropoda		Pleuroceridae			Pleuroceridae	770	16.73
FMC	06/08/2000	Arthropoda	Insecta	Coleoptera	Polyphaga	Elmidae			Stenelmis sp.	793	17.23
									Total density	**4,600**	

Appendix table 3-3. Benthic-invertebrate community metrics in streams in the Birmingham area, Alabama, 2000

[EPT, Ephemeroptera, Plecoptera, Trichoptera; na, not applicable; nc, not calculated]

Site	VIL-1 (June)	VIL-3 (June)	VAL-1 (June)	VAL-2 (June)	LCR (June)	FMC (June)	VIL-1 (October)	VIL-3 (October)	VAL-1 (October)	VAL-2 (October)	LCR (October)
METRIC											
RICHNESS and DENSITY											
Community richness (number of distinct taxa)	17	17	6	18	26	29	18	15	8	15	26
EPT Index (number of EPT taxa, without Hydropsychidae)	2	0	0	1	6	4	2	1	1	2	8
Mayfly taxa	1	0	0	0	1	1	1	0	0	1	3
Stonefly taxa	0	0	0	0	0	0	0	0	0	0	1
Caddisfly taxa	3	1	0	2	6	4	2	2	2	2	6
Density (organisms per square meter)	3,475	1,972	39,090	10,971	5,491	4,600	299	3,133	9,276	5,045	4,022
Mayfly density	739	0	0	0	515	457	45.5	0	0	31	1,303
Stonefly density	0	0	0	0	0	0	0	0	0	0	11.5
Caddisfly density	181	26.9	0	3,872	1,658	1,022	88.9	332	27.7	2,565	472
EPT density	750	0	0	1,685	1,252	927	46	9	27	307	1,498
Chironomid density	594	1,344	25,519	4,440	18.4	297	84.9	2,415	7,096	2,028	57.6
Shannon's Index of Diversity	.900	.478	.362	.767	1.04	1.12	.856	.410	.339	.557	1.06
Pinkham-Pearson Index of Similarity[a] to FMC	.081	.052	.005	.035	.194	na	nc	nc	nc	nc	nc
TAXA											
RELATIVE ABUNDANCE OF TAXA (as percent of total abundance)											
EPT taxa (without Hydropsychidae)	21.6	0.0	0.0	15.4	22.8	20.2	15.4	0.29	0.29	6.09	37.2
Mayflies (Ephemeroptera)	21.3	.0	.0	.0	9.4	9.9	15.2	.0	.0	.6	32.4
Stoneflies (Plecoptera)	0	0	0	0	0	0	0	0	0	0	0
Caddisflies (Trichoptera)	5.20	1.36	.00	35.3	30.2	22.2	29.7	10.6	.30	50.8	11.7
Midges (Chironomidae)	17.1	68.1	65.3	40.5	.3	6.5	28.4	77.1	76.5	40.2	1.4

[a] The similarity index was calculated only for the June samples because site FMC was dry during the October collection period.

Appendix table 3-4. Fish species collected from streams in the Birmingham area, Alabama, 2001

[x, not captured at the site; kg, kilogram; na, not applicable; ns, no seine collection. Taxa comprising the largest proportion of the community at each site are shaded]

Family	Scientific name	Common name	Presence and proportional abundance (percentage) of fishes collected by electrofishing					
			VIL-1	VIL-3	VAL-1	VAL-2	LCR	FMC
Suckers (Catostomidae)	*Hypentelium etowanum*	Alabama hog sucker	x	x	x	0.138	3.18	6.51
	Minytrema melanops	spotted sucker	x	x	x	x	.353	x
Sunfishes (Centrarchidae)	*Lepomis* (undetermined species)	sunfish	x	x	x	x	2.12	x
	Lepomis cyanellus	green sunfish	4.55	22.9	x	.138	29.7	1.78
	Lepomis gulosus x Lepomis microlophus	warmouth x redear sunfish	x	x	x	x	.353	x
	Lepomis macrochirus	bluegill	18.2	20.9	x	.276	24.4	52.1
	Lepomis megalotis	longear sunfish	x	x	4.67	9.53	2.12	22.5
	Lepomis microlophus	redear sunfish	.758	x	x	x	4.24	x
	Lepomis miniatus	scarlet sunfish	x	x	x	x	x	1.18
	Micropterus punctulatus	spotted bass	x	x	x	x	1.41	x
	Micropterus salmoides	largemouth bass	x	.290	x	x	x	.592
	Micropterus species	black bass species	.758	x	x	x	x	x
	Pomoxis nigromaculatus	black crappie	x	.290	x	x	x	x
Sculpins (Cottidae)	*Cottus carolinae*	banded sculpin	x	x	x	x	3.89	0.592
Minnows (Cyprinidae)	*Campostoma oligolepis*	largescale stoneroller	74.2	41.4	2.33	62.3	17.0	7.69
	Cyprinella trichroistia	tricolor shiner	x	x	x	x	.353	x
	Cyprinella venusta	blacktail shiner	x	x	x	.552	.707	x
	Notropis stilbius	silverstripe shiner	x	x	x	x	x	1.78
	Semotilus atromaculatus	creek chub	x	x	1.67	x	x	x
Top minnows (Cyprinodontidae)	*Fundulus olivaceus*	blackspotted topminnow	x	x	x	x	0.353	1.78
Catfishes (Ictaluridae)	*Ameiurus natalis*	yellow bullhead	1.52	0.290	x	x	x	x
	Ictaluridae	bullhead catfishes	x	.580	x	x	x	x
Darters (Percidae)	*Etheostoma ramseyi*	Alabama darter	x	x	x	x	x	2.37
	Etheostoma stigmaeum	speckled darter	x	x	x	x	x	1.18
	Percina caprodes	logperch	x	x	x	x	0.353	x
	Percina kathae	Mobile logperch	x	x	x	x	9.19	x
	Percina nigrofasciata	blackbanded darter	x	x	x	0.276	x	x

[x, not captured at the site; kg, kilogram; na, not applicable; ns, no seine collection. Taxa comprising the largest proportion of the community at each site are shaded]

Family	Scientific name	Common name	Presence and proportional abundance (percentage) of fishes collected by electrofishing					
			VIL-1	VIL-3	VAL-1	VAL-2	LCR	FMC
Mosquitofishes (Poecilidae)	*Gambusia affinis*	western mosquitofish	x	x	x	26.8	0.353	x
	Gambusia species		x	13.3	91.3	x	x	x
COLLECTION DATA								
Total individuals by electrofishing			132	345	300	724	283	169
Total species collected by electrofishing			6	7	3	8	15	12
Units of effort expended			4.4	12.9	3.4	10.2	6.7	8.7
Fish collected per unit of effort			30	27	88	71	42	33
Total biomass (kg) collected by electrofishing			1	4.85	0.705	3.72	3.80	2.64
Total species collected by electrofishing and seining			6	8	ns	9	15	13
Total individuals collected by seining			2	62	ns	211	5	5
Biomass (kg) collected by seining			0.202	0.032	na	0.612	0.019	0.011
Additional species collected by seining			0	0	na	*M. salmoides*	0	*G. affinis*
Similarity of fish community to that of site FMC			0.440	0.400	0.250	0.500	0.400	1.00
Shannon's Index of Diversity			1.26	2.02	0.551	1.56	2.87	2.32
FISH-COMMUNITY METRICS								
Total number of minnow taxa			1	1	2	2	3	2
Total number of sunfish taxa (excluding black bass, crappie, and hybrids)			3	2	1	3	5	4
Relative abundance of darters			0	0	0	0.276	9.541	3.550
Relative abundance of sunfish (excluding bass, crappie, green sunfishes, and undetermined species)			18.9	20.9	4.7	9.8	30.7	75.7
Relative abundance of suckers			0	0	0	0.138	3.53	6.51
Relative abundance of anomalies			0	0	12	6	2.2	1.2