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

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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 downstream 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

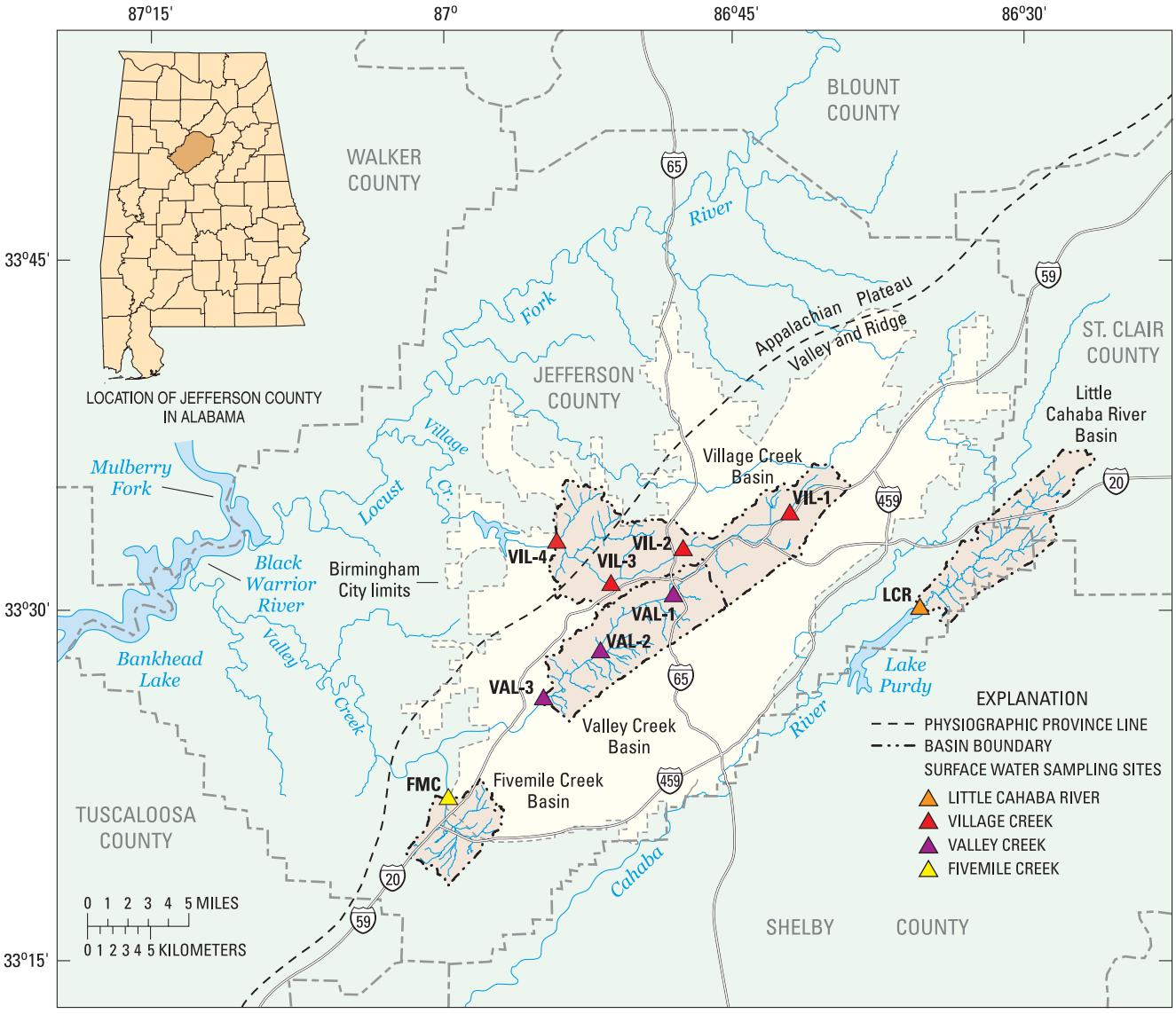

Figure 1. Locations of sampling sites and physiographic provinces in the Birmingham area, Jefferson County, Alabama.

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. Highway11 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.