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.

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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

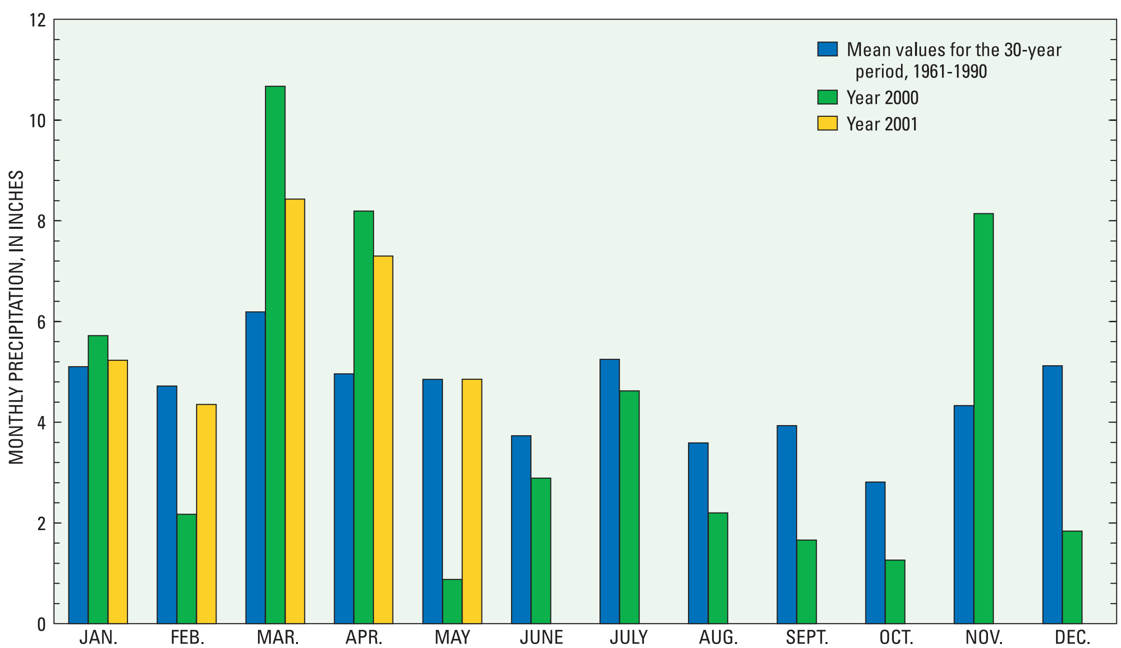

Figure 2. Mean monthly precipitation for the 30-year period (1961–1990) and monthly precipitation (January 2000–May 2001) at the Birmingham International Airport, National Weather Service, Birmingham, Alabama (National Oceanic and Atmospheric Administration, 2001a, 2001b).

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

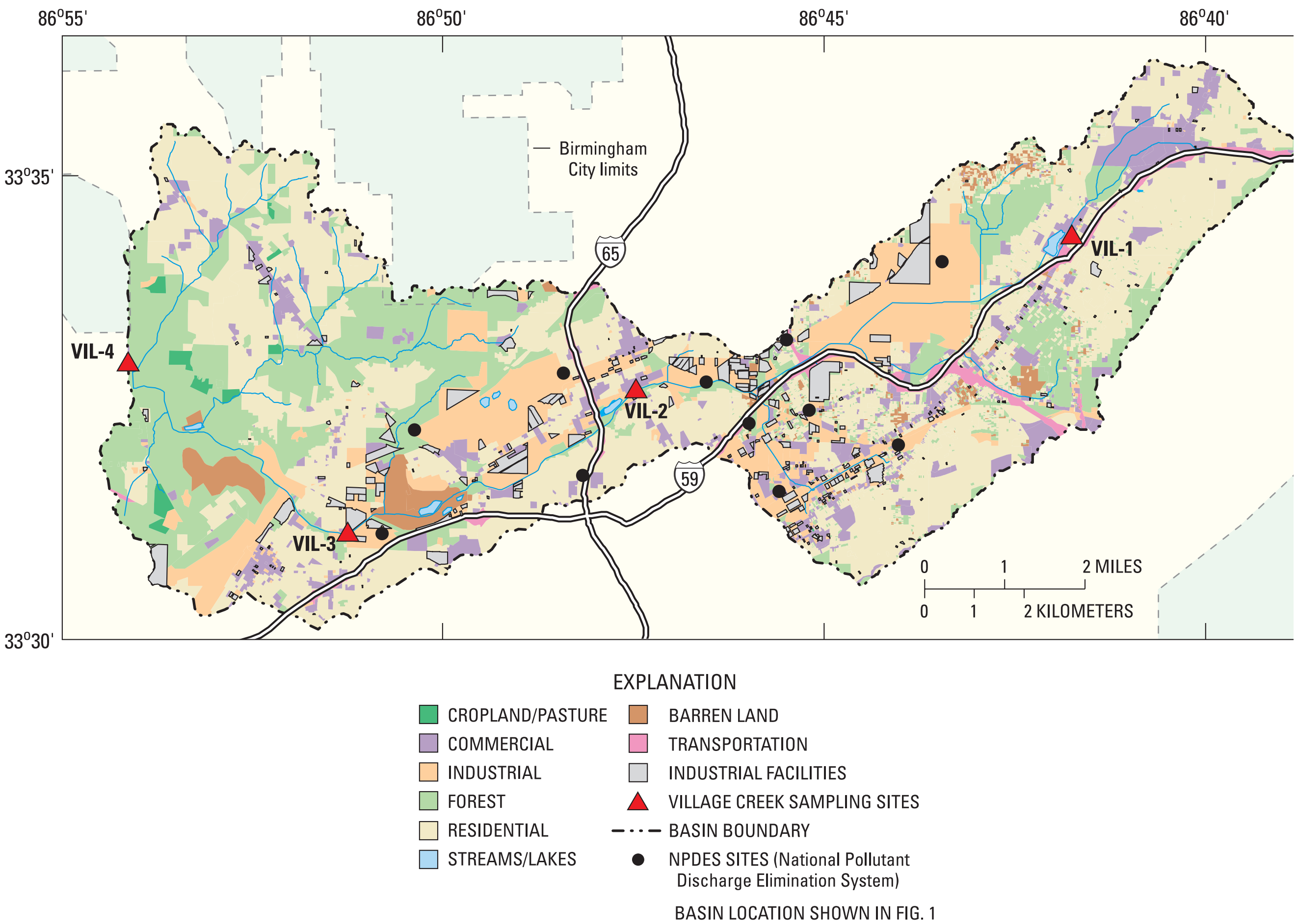

Figure 3. 1992 Multi-resolution land characteristics in the Village Creek watershed, Birmingham, Alabama.

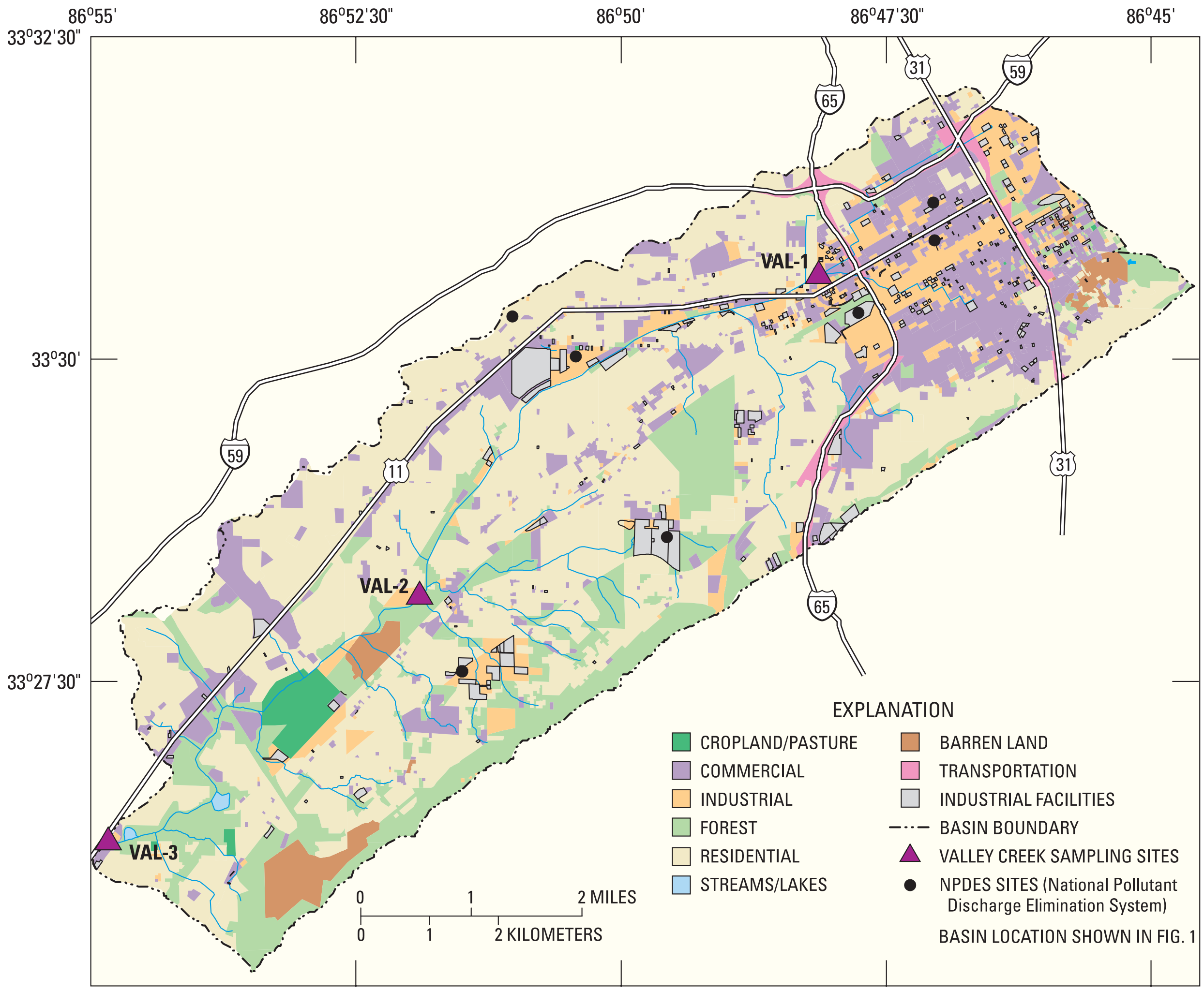

Figure 4. 1992 Multi-resolution land characteristics in the Valley Creek watershed, Birmingham, Alabama.

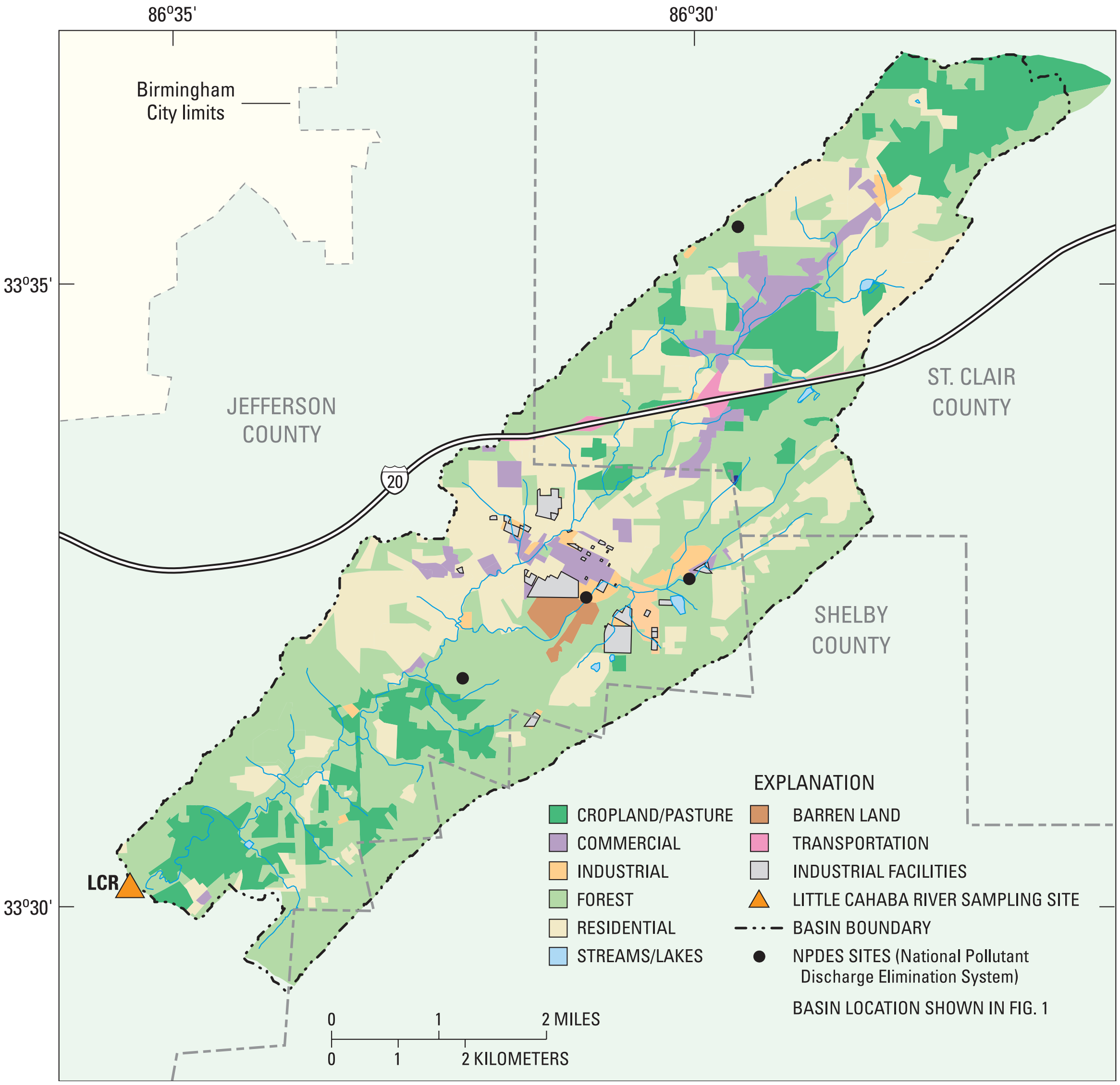

Figure 5. 1992 Multi-resolution land characteristics in the Little Cahaba River watershed, Jefferson County, Alabama.

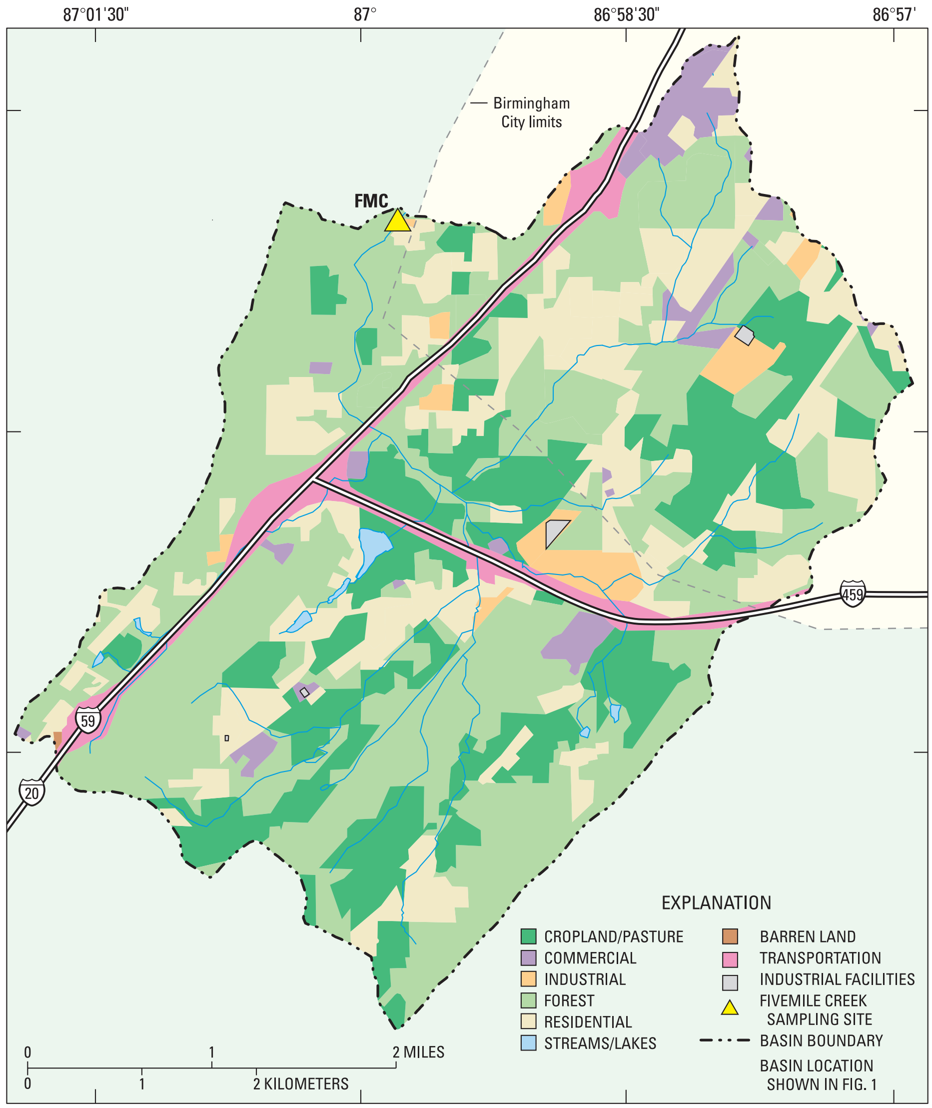

Figure 6. 1992 Multi-resolution land characteristics in the Fivemile Creek watershed, Jefferson County, Alabama.

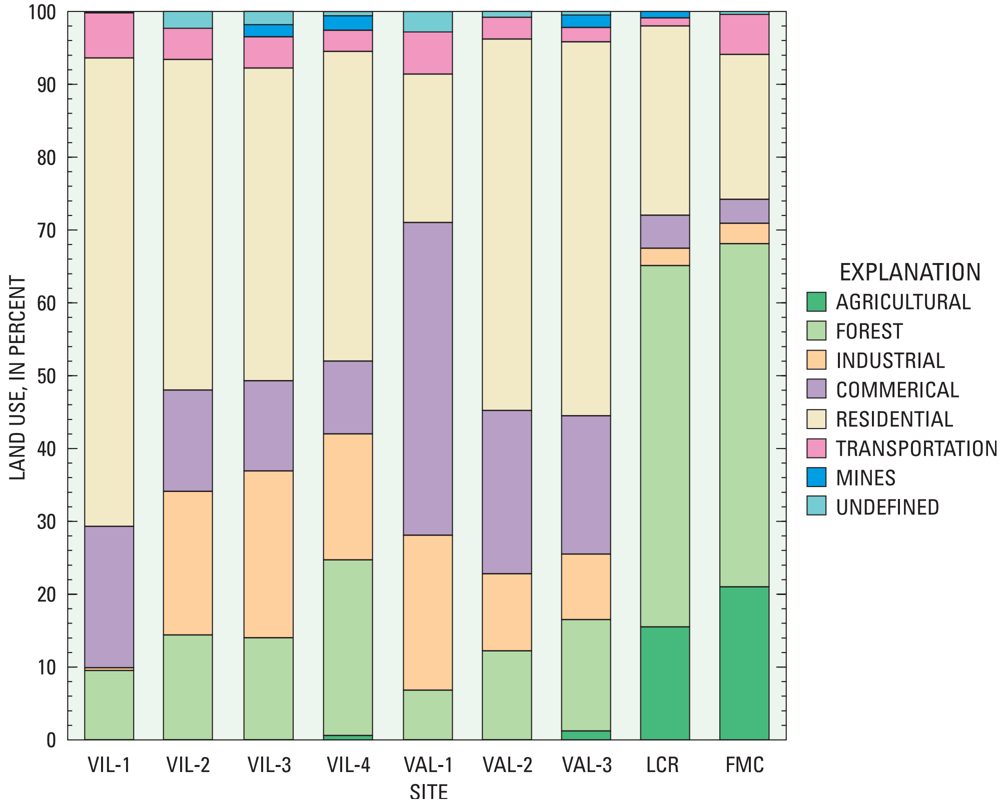

Figure 7. Land use in the watersheds of sampling sites in the Birmingham area, Alabama (U.S. Environmental Protection Agency, 1992a).

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

[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 ft^3/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)

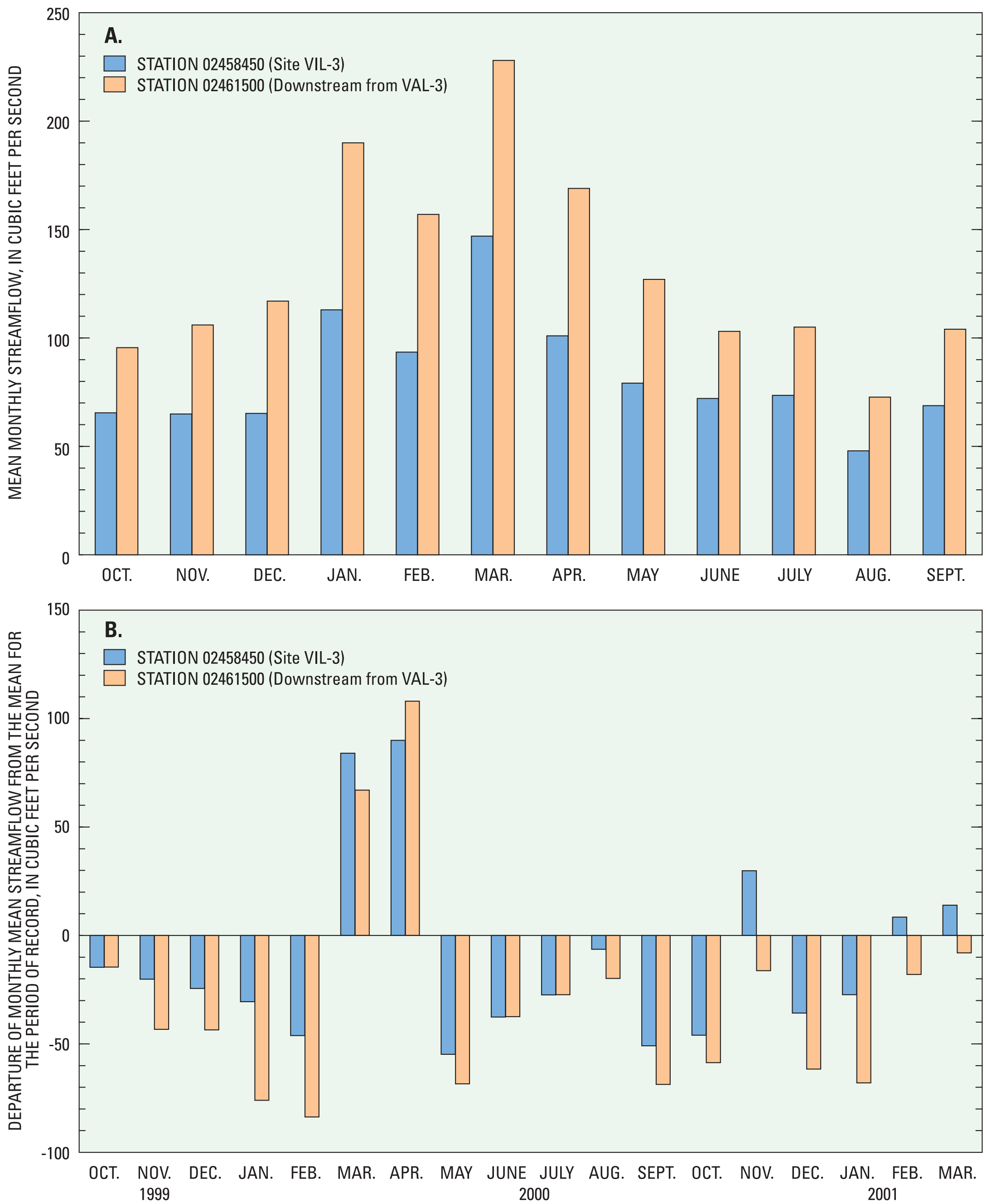

Figure 8. (A) Mean monthly streamflow and (B) departure of monthly mean streamflow from the mean for the period of record (1975–79 and 1988–2000) at U.S. Geological Survey streamgaging stations 02458450 (VIL-3) and 02461500 (downstream from VAL-3) in Birmingham, Alabama.