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

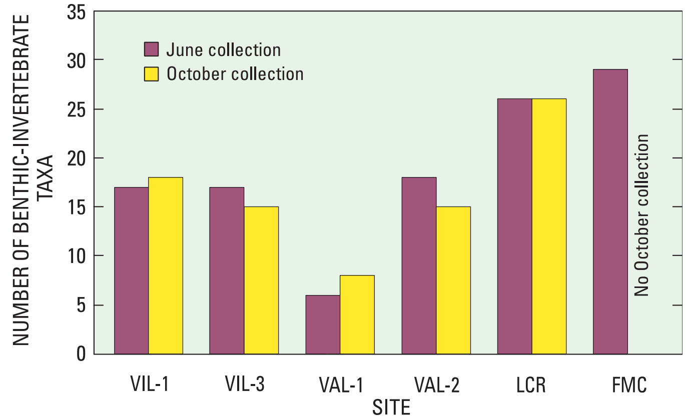

Figure 35. Benthic-invertebrate community richness in streams in the Birmingham area, Alabama, 2000.

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

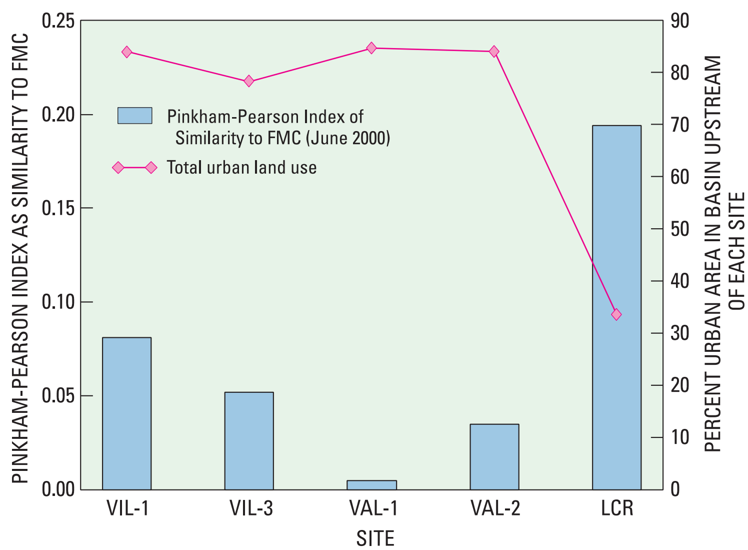

Figure 36. Similarity of the benthic-invertebrate community at five sites in the Birmingham area, Alabama, to that of a reference site—FMC—(June 2000), compared with the percentage of urban land use in the drainage basin.

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).

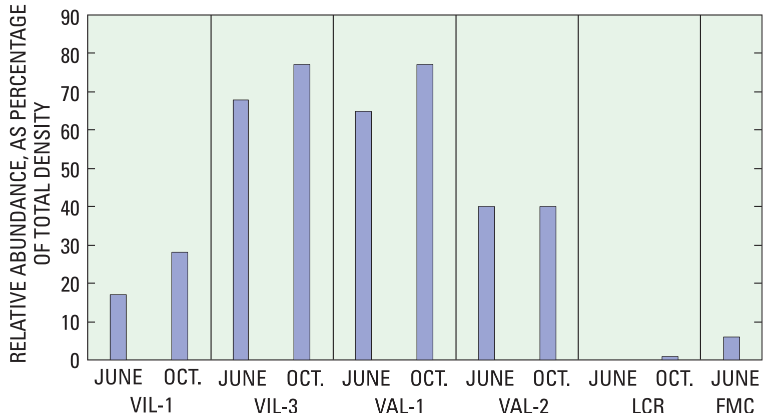

Figure 38. The relative abundance of midges (Chironomidae) in selected streams in the Birmingham area, Alabama, June and October 2000.

Benthic-invertebrate density decreased in a downstream direction in both Village and Valley Creeks in 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.

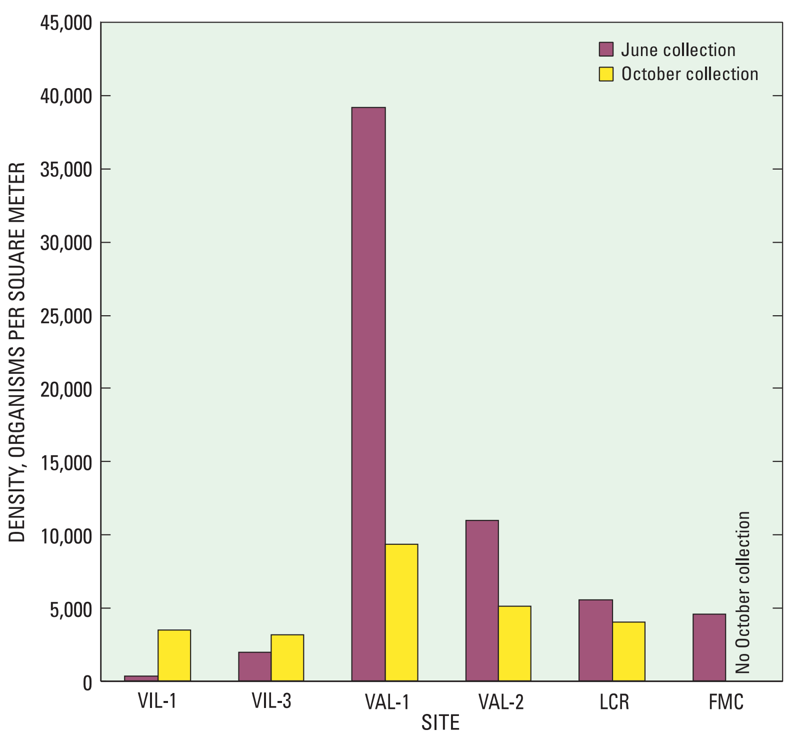

Figure 37. Density of benthic-invertebrate taxa in selected streams in the Birmingham area, Alabama, June and October 2000.

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

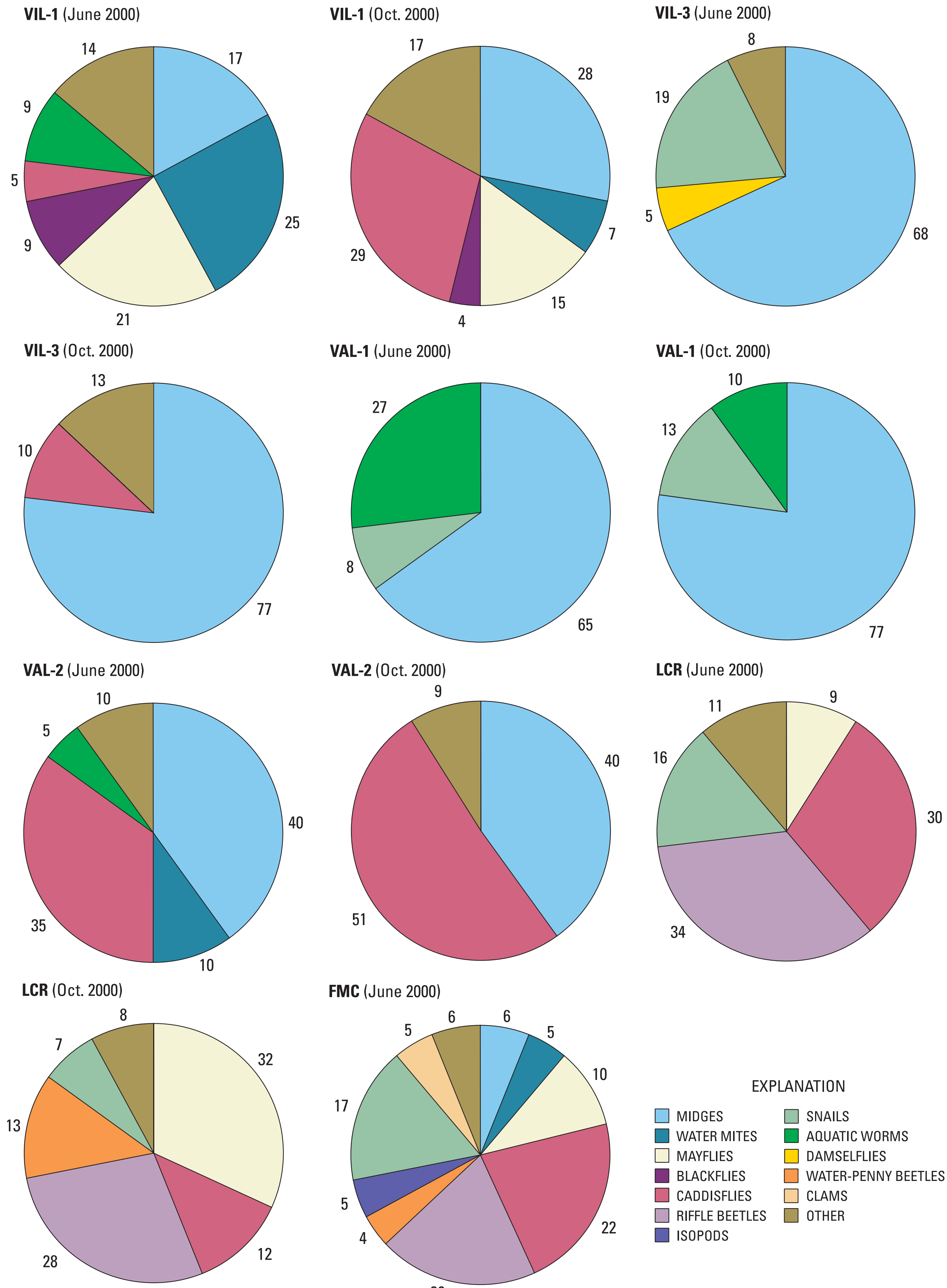

Figure 39. Comparison of the relative abundances of the dominant benthic-invertebrate taxa collected from streams in the Birmingham area, Alabama, 2000. (Numbers beside each pie section are percentages of the total sample.)

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.

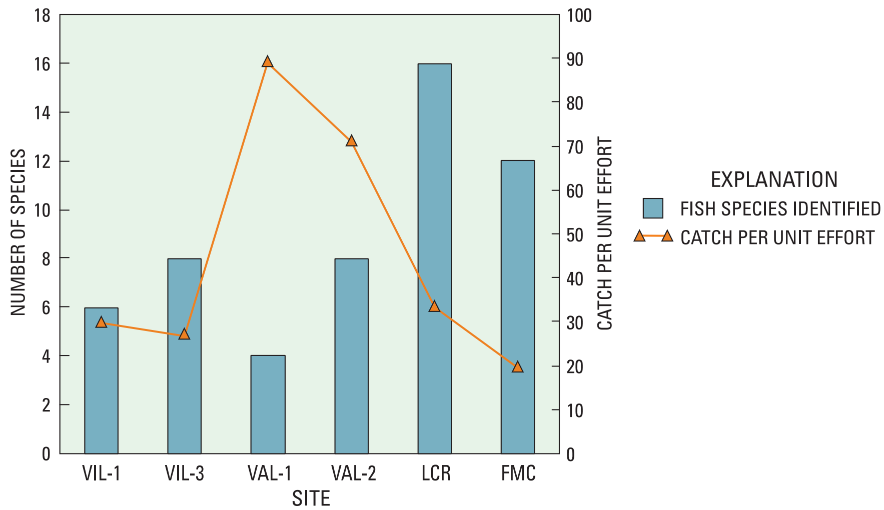

Figure 40. Fish-community richness and catch per unit effort in streams in the Birmingham area, Alabama, 2001.

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 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,

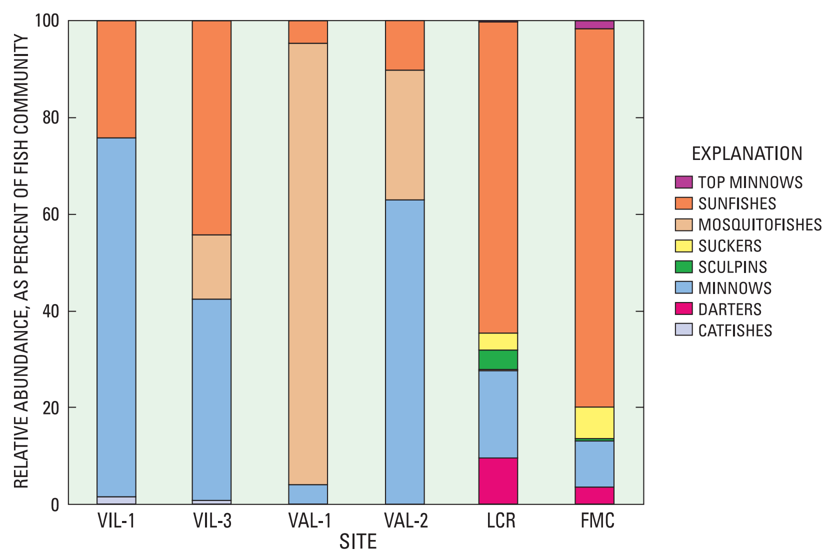

Figure 41. Relative abundance of fish families in streams in the Birmingham area, Alabama, 2001.

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-Dimethylnaphthalene	0.829	6	None		
			Pyrene	.829	6	1-Methylphenanthrene	.886	6			
			Acridine	.928	6	1-Methylpyrene	.943	6			
						2,6-Dimethylnaphthalene	.829	6			
						4H-Cyclopentaphenanthrene	.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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