

**Figure 17.** (A) *Escherichia coli*, (B) enterococci, and (C) fecal coliform concentrations in water samples collected during high and low flow from streams in the Birmingham area, Alabama, 2000–01.

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

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

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

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

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

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

<sup>a</sup> Actual standard of the U.S. Environmental Protection Agency (2001) is that no more than one sample per month (sampled daily) may be positive for total coliforms, of which fecal coliform and *E. coli* are a subgroup.

<sup>b</sup> Bacterial concentration is the geometric mean of not less than five samples taken over a 30-day period (Alabama Department of Environmental Management, 2000d).

<sup>c</sup> U.S. Environmental Protection Agency, 1986.

<sup>d</sup> Alabama Water Quality Criteria (Alabama Department of Environmental Management, 2000d).

<sup>e</sup> Maximum bacterial concentration not to be exceeded in any sample.

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

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

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

<sup>a</sup> U.S. Environmental Protection Agency (1986).

<sup>b</sup> Alabama Department of Environmental Management (2000d).

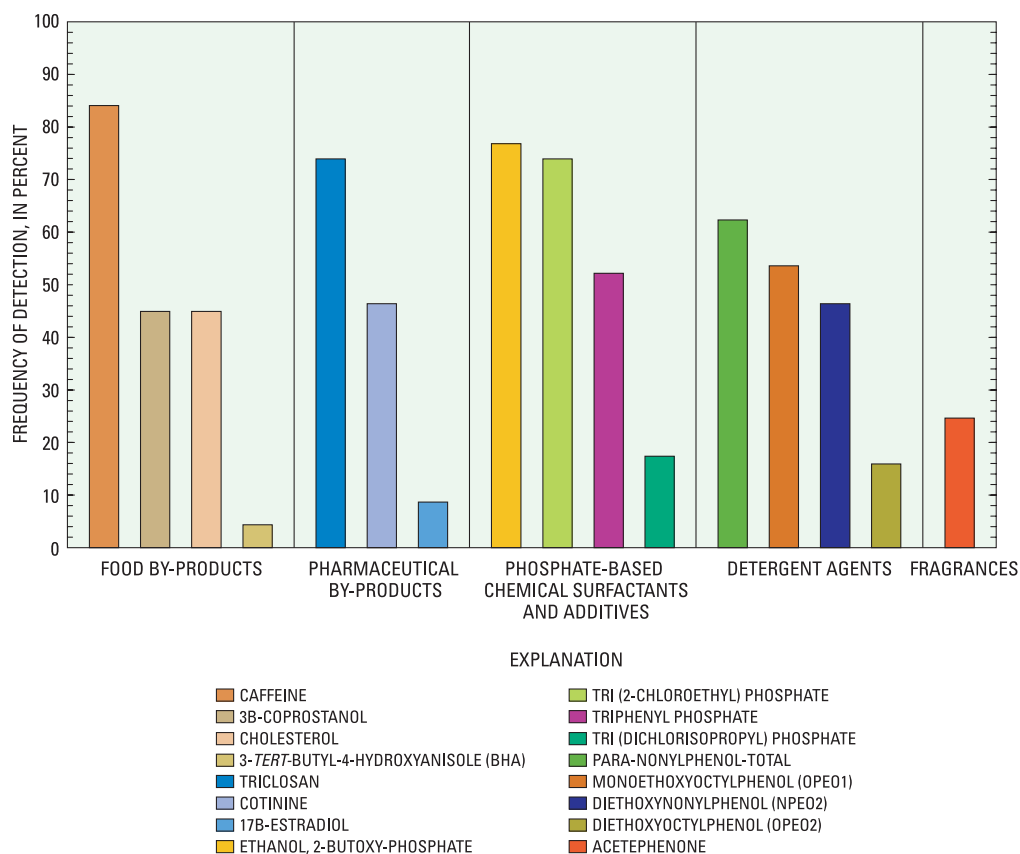
samples were collected at VAL-1. The high-flow sample collected when the discharge was greatest (120 ft<sup>3</sup>/s) contained levels of bacteria that were approximately an order of magnitude less than the high-flow samples collected when the discharge was lower (33–37 ft<sup>3</sup>/s), illustrating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

### Wastewater Indicators

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

been established by the ADEM or the USEPA for these constituents.

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



**Figure 18.** Frequencies of detection for selected wastewater indicators in water samples from streams in the Birmingham area, Alabama, 2000–01.

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

### Trace and Major Elements

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

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

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

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

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

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

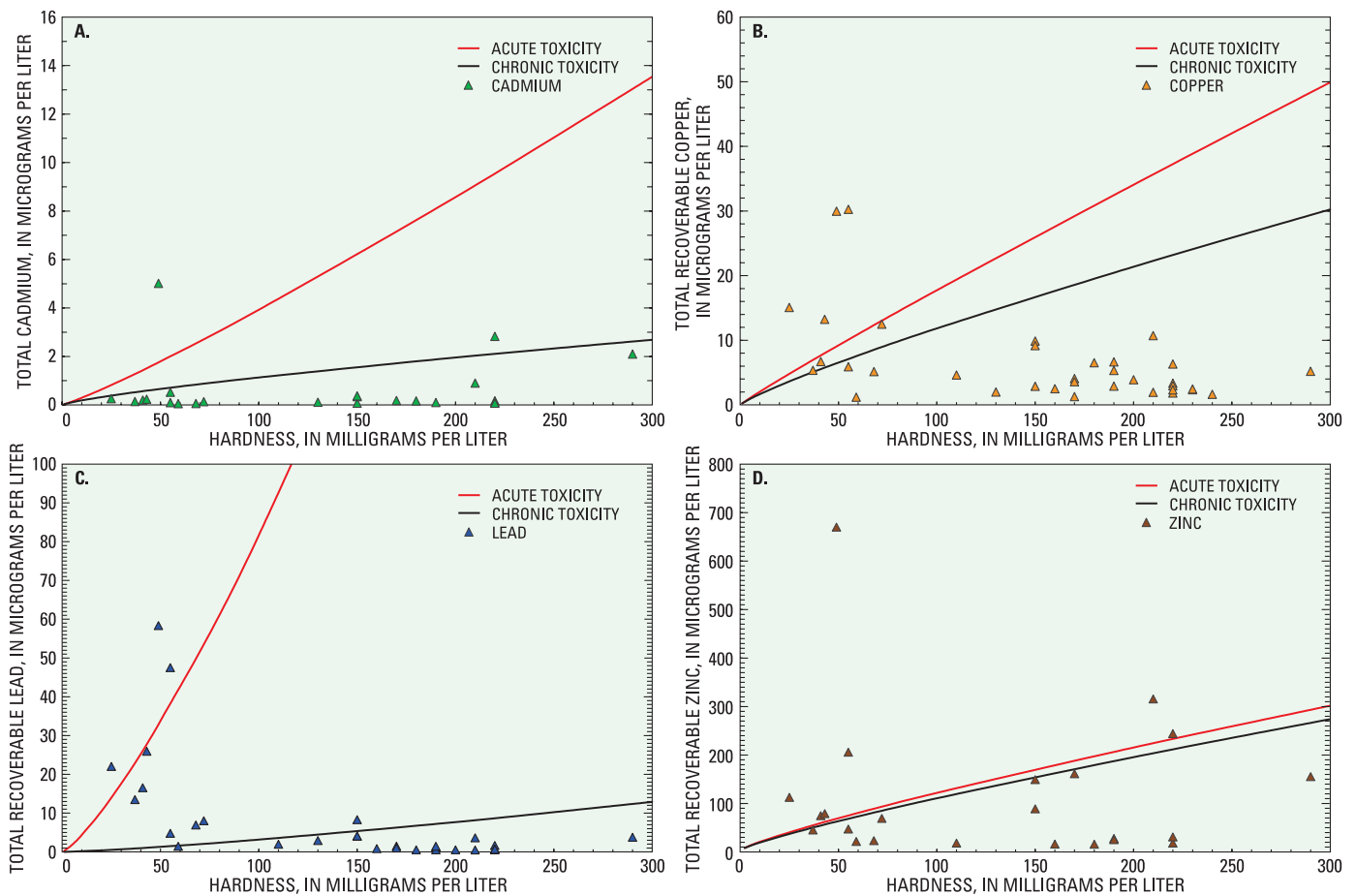
| Trace element        | Primary Drinking Water Standard       | Secondary Drinking Water Standard                    | ADEM acute aquatic life criterion <sup>a</sup> | ADEM chronic aquatic life criterion <sup>a</sup> |
|----------------------|---------------------------------------|--|--|--|
| Arsenic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

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

<sup>b</sup> U.S. Environmental Protection Agency (2000b, 2001).

<sup>c</sup> Alabama Primary Drinking Water Standards (Alabama Department of Environmental Management, 2000b).

<sup>d</sup> Alabama Secondary Drinking Water Standards (Alabama Department of Environmental Management, 2000c).



**Figure 19.** Relations of (A) total cadmium, (B) total recoverable copper, (C) total recoverable lead, and (D) total recoverable zinc in water-quality samples to hardness and acute and chronic toxicity at streams in the Birmingham area, Alabama, 2000–01.

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

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

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

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

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

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

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

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

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

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

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

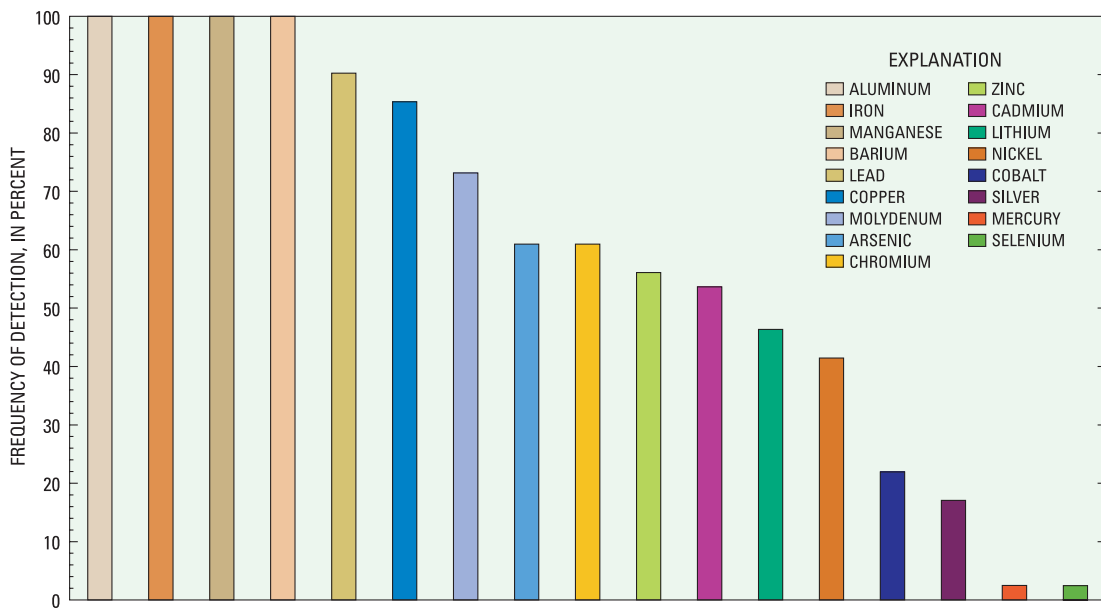
**Table 15.** Summary of trace and major elements detected in water samples and applicable aquatic life criteria at sites in the Birmingham area, Alabama, 2000–01—Continued

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

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

<sup>a</sup> Alabama Water Quality Criteria (Alabama Department of Environmental Management, 2000d).





**Figure 20.** Frequencies of detection for trace and major elements in water samples from streams in the Birmingham area, Alabama, 2000–01.

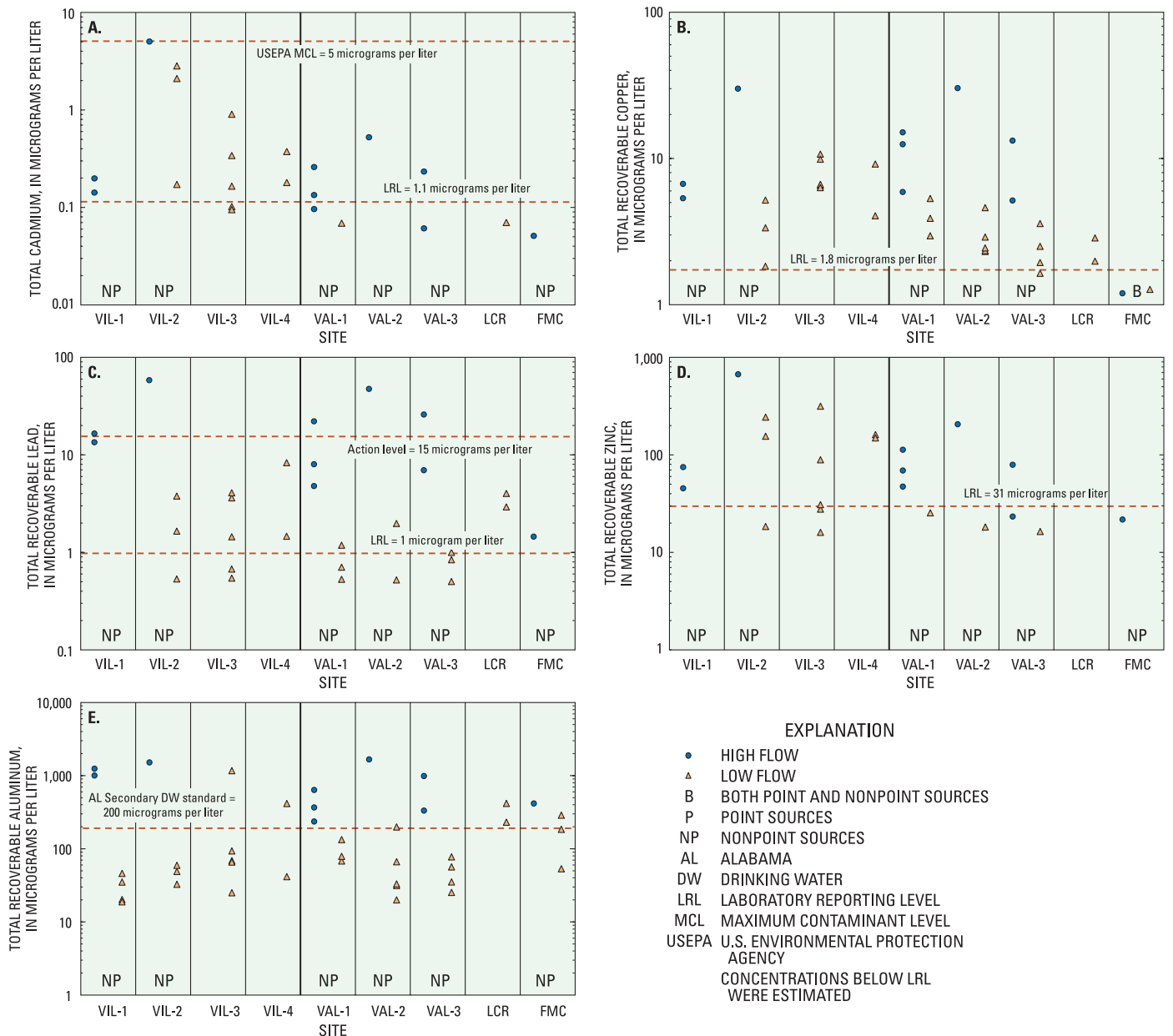
VIL-1 (table 6). Cadmium concentrations were greatest during high flow rather than low flow, indicating the presence of nonpoint sources (fig. 21A). Two of the cadmium concentrations detected at VIL-2 during low flow were higher than concentrations detected at other sites (during low or high flow), indicating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

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

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

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

Molybdenum occurs naturally in streams in trace amounts. Fossil-fuel combustion is a probable source where higher molybdenum concentrations are detected. No water-quality standards or criteria have been set for molybdenum, which was detected in 73 percent of the samples (fig. 20). The maximum molybdenum concentration was 55.7 µg/L at VIL-2 during low flow (table 15). The highest concentrations occurred during low flow at VIL-2, VAL-1, VAL-2, and VAL-3, indicating possible point sources (table 15). Statistically significant differences among sites were identified. Molybdenum concentrations at VIL-2, VIL-3, and VAL-2 were significantly greater than the concentrations at FMC; molybdenum concentrations at VIL-2 and VIL-3 were



**Figure 21.** (A) Total cadmium, (B) total recoverable copper, (C) total recoverable lead, (D) total recoverable zinc, and (E) total recoverable aluminum concentrations detected in water samples collected during high and low flow from streams in the Birmingham area, Alabama, 2000–01.

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

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

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

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

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

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

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

Aluminum is the third most abundant element in the Earth's outer crust, but it is rarely found in solution in surface water in high concentrations (Hem, 1985). The

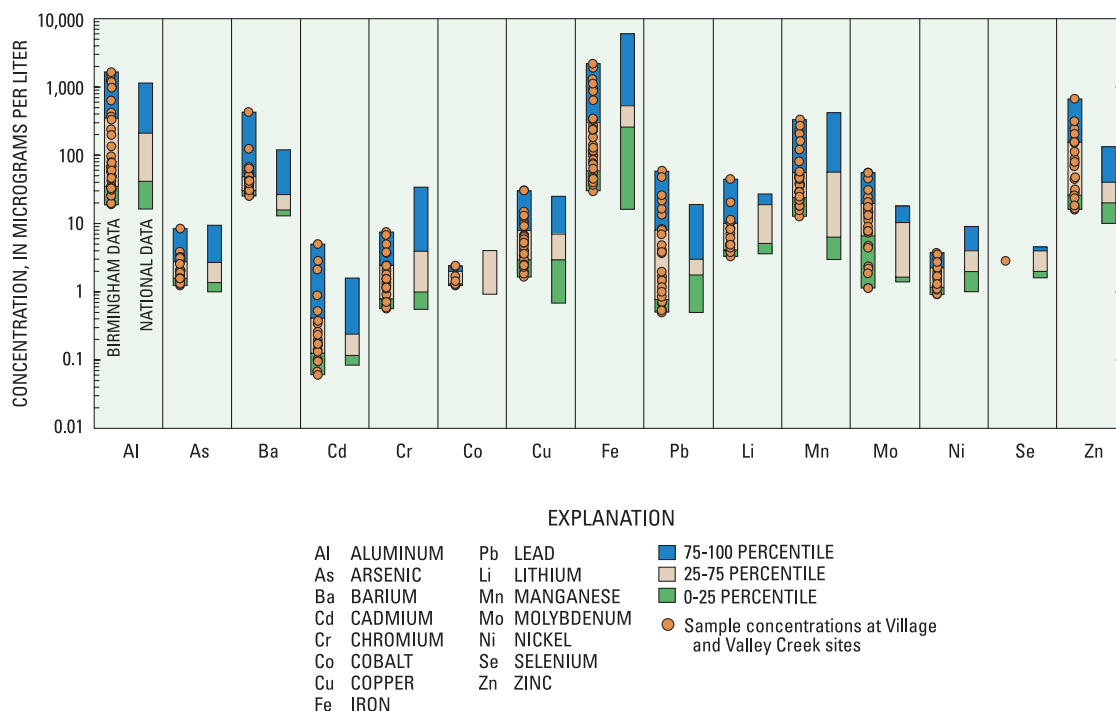
secondary drinking-water standard set by ADEM for aluminum in public water supplies is 200  $\mu\text{g/L}$  (table 14). Concentrations of aluminum ranged from 18.8 to 1,660  $\mu\text{g/L}$  (table 15). Aluminum concentrations exceeded the secondary drinking-water standard in 15 of 41 samples (37 percent)—10 of these exceedances occurred during high flow, indicating possible nonpoint sources (fig. 21E). No statistically significant differences among sites were identified (table 6).

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

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



USGS personnel examining the contents of the seine while collecting fish samples (photograph taken by A.K. McPherson).



**Figure 22.** Comparison of trace and major elements in water samples from urban sites in the Birmingham area, Alabama, to urban sites nationwide.

### Pesticides

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

Comparison of detection frequencies of pesticides can be misleading because of the different laboratory reporting levels associated with each of the pesticides. To reduce this type of bias when comparing detection frequencies of pesticides, concentrations were adjusted by

censoring to a common threshold of 0.01 µg/L. These adjusted data were used when comparing detection frequencies between NAWQA samples and Birmingham samples. Figure 23 illustrates the effect of censoring the data on the frequency of detection for samples from the Birmingham study sites.

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

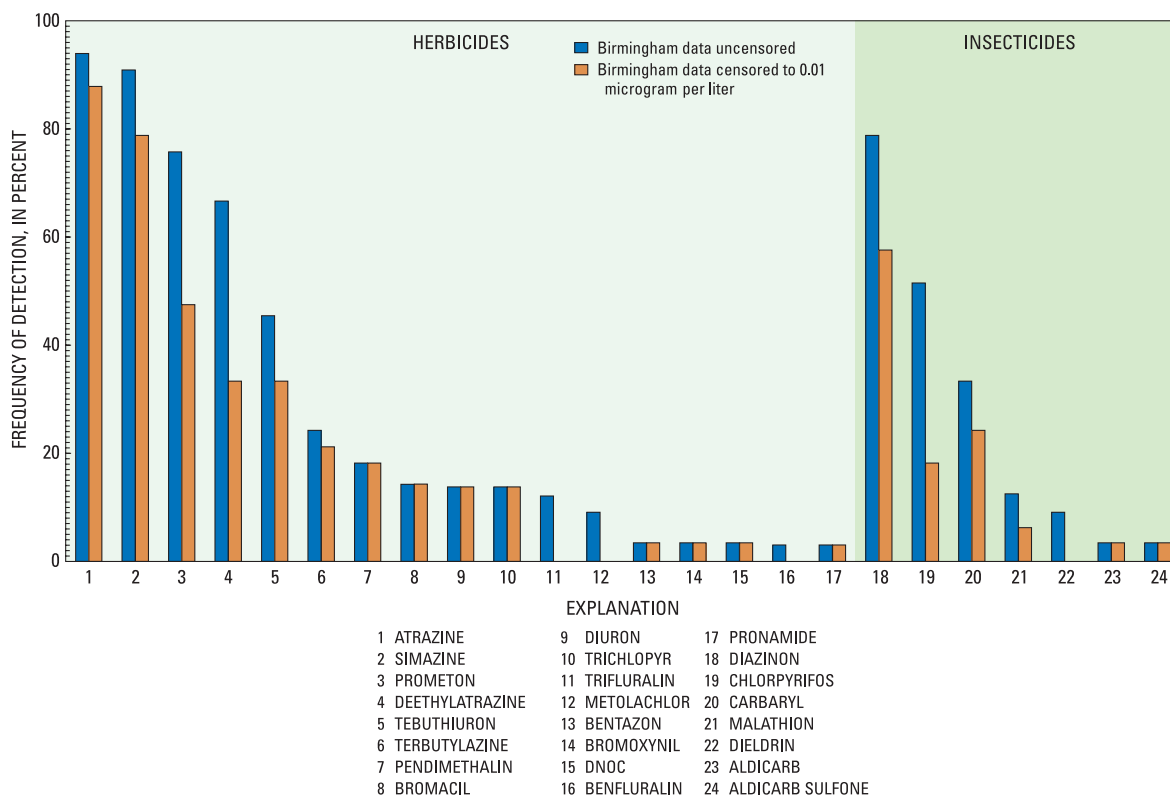
Simazine is an herbicide commonly used in orchards, vineyards, and along rights-of-way. It is frequently used in urban areas for weed control along roadways and railways, along fences, and in other public areas (Hoffman and others, 2000). Concentrations of simazine were detected in 30 of 33 samples (91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

**Table 16.** Pesticides and pesticide degradation products, laboratory reporting levels, and minimum reporting levels  
 [Pesticides that were detected are shown in bold; µg/L, micrograms per liter; H, herbicide; I, insecticide; DP, degradation product]

| Pesticide name   | Pesticide type | Laboratory reporting level <sup>a</sup> (µg/L) | Pesticide name  | Pesticide type | Laboratory reporting level <sup>a</sup> (µg/L) |
|--|----------------|--|---|----------------|--|
| <b>Dissolved pesticides analyzed by gas chromatography/mass spectrometry (GC/MS)</b> |                |  | <b>Dissolved pesticides analyzed by high-performance liquid chromatography (HPLC)</b> |                |  |
| Acetochlor   | H              | 0.0041   | 2,4,5-T   | H              | 0.040  |
| Alachlor   | H              | .0024  | 2,4-D   | H              | .11  |
| <b>Atrazine</b>  | H              | .007   | 2,4-DB  | H              | .10  |
| Azinphos-methyl  | I              | .05  | 2-(2,4,5-Trichlorophenoxy) propionic acid   | H              | .025   |
| <b>Benfluralin</b>   | H              | .010   | 3-Hydroxycarbofuran   | DP             | .11  |
| Butylate   | H              | .002 <sup>b</sup>                              | <b>4,6-Dinitro-2-methylphenol (DNOC)</b>  | H              | .25  |
| <b>Carbaryl</b>  | I              | .041   | Acifluorfen   | H              | .05  |
| Carbofuran   | I              | .020   | <b>Aldicarb</b>   | I              | .21  |
| <b>Chlorpyrifos</b>  | I              | .005   | <b>Aldicarb sulfone</b>   | DP             | .20  |
| Cyanazine  | H              | .018   | Aldicarb sulfoxide  | DP             | .021 <sup>b</sup>                              |
| DCPA (Dacthal)   | H              | .0030  | <b>Bentazon</b>   | H              | .035   |
| <i>p,p'</i> -DDE   | I              | .0025  | <b>Bromacil</b>   | H              | .09  |
| <b>Deethylatrazine</b>   | DP             | .006   | <b>Bromoxynil</b>   | H              | .07  |
| <b>Diazinon</b>  | I              | .005   | <b>Carbaryl</b>   | I              | .024   |
| <b>Dieldrin</b>  | I              | .0048  | Carbofuran  | I              | .29  |
| 2,6-Diethylaniline   | H              | .0017  | Chloramben, methyl ester  | H              | .14  |
| Disulfoton   | I              | .021   | Chlorothalonil  | I              | .13  |
| EPTC   | H              | .0020  | Clopyralid  | H              | .42  |
| Ethalfuralin   | H              | .009   | Dacthal monoacid  | H              | .07  |
| Ethoprophos  | I              | .005   | Dicamba   | H              | .043   |
| Fonofos  | I              | .0027  | Dichlobenil   | H              | .049   |
| Lindane  | I              | .0040  | Dichlorprop   | H              | .050   |
| Linuron  | H              | .035   | Dinoseb   | H              | .09  |
| <b>Malathion</b>   | I              | .027   | <b>Diuron</b>   | H              | .056   |
| <b>Metolachlor</b>   | H              | .013   | Fenuron   | H              | .07  |
| Metribuzin   | H              | .006   | Fluometuron   | H              | .06  |
| Molinate   | H              | .0016  | Linuron   | H              | .021   |
| Napropamide  | H              | .007   | MCPA  | H              | .08  |
| Parathion  | I              | .007   | MCPB  | H              | .13  |
| Parathion-methyl   | I              | .006   | Methiocarb  | I              | .07  |
| Pebulate   | H              | .0016  | Methomyl  | I              | .017 <sup>b</sup>                              |
| <b>Pendimethalin</b>   | H              | .010   | Neburon   | H              | .017   |
| <i>cis</i> -Permethrin   | I              | .006   | Norflurazon   | H              | .042   |
| Phorate  | I              | .011   | Oryzalin  | H              | .28  |
| <b>Prometon</b>  | H              | .015   | Oxamyl  | I              | .018 <sup>b</sup>                              |
| Propachlor   | H              | .010   | Picloram  | H              | .09  |
| Propanil   | H              | .011   | Propham   | H              | .09  |
| Propargite   | I              | .023   | Propoxur  | I              | .12  |
| <b>Pronamide</b>   | H              | .0041  | <b>Triclopyr</b>  | H              | .07  |
| <b>Simazine</b>  | H              | .011   |   |                |  |
| <b>Tebuthiuron</b>   | H              | .016   |   |                |  |
| Terbacil   | H              | .034   |   |                |  |
| Terbufos   | I              | .017   |   |                |  |
| <b>Terbutylazine</b>   | H              | .1 <sup>b</sup>                                |   |                |  |
| Thiobencarb  | H              | .0048  |   |                |  |
| Triallate  | H              | .0023  |   |                |  |
| <b>Trifluralin</b>   | H              | .009   |   |                |  |

<sup>a</sup> Laboratory reporting levels and minimum reporting levels effective October 1, 2000.

<sup>b</sup> Minimum reporting levels.



**Figure 23.** Frequencies of detection for pesticides in water samples from streams in the Birmingham area, Alabama, 2000–01.

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

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

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

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