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

Identifying sources of nitrogen from chemical analyses is difficult because nitrogen is readily converted from one form to another. However, large quantities of nitrogen compounds in surface waters usually indicate point and nonpoint source contamination. Excessive amounts of ammonia and organic nitrogen may result from treated water discharges or surface runoff. If streams are well oxygenated and uncontaminated, then ammonia concentrations generally are negligible. Nitrite usually is unstable in aerated water, but is considered to be a good indicator of poor water quality when detected. When most of the nitrogen is in the nitrate form, the water is considered to have stabilized; high levels generally indicate prior contamination rather than recent contamination (Krenkel and Novotny, 1980).

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

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

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

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

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

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

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

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

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

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

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

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

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

USGS personnel collecting a water-quality sample (photograph taken by J.B. Atkins, USGS).

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

Nitrogen Concentrations and Distribution

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

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

Statistically significant differences ($p \leq 0.05$) in nitrogen concentrations were found (table 6). Total nitrogen concentrations at VIL-3, VAL-1, and VAL-2 were significantly greater than concentrations at the reference site (FMC). Ammonia and nitrite concentrations at VIL-2, VIL-3, VAL-1, and VAL-2 were significantly greater than concentrations at FMC. In Village Creek, concentrations of nitrite were significantly

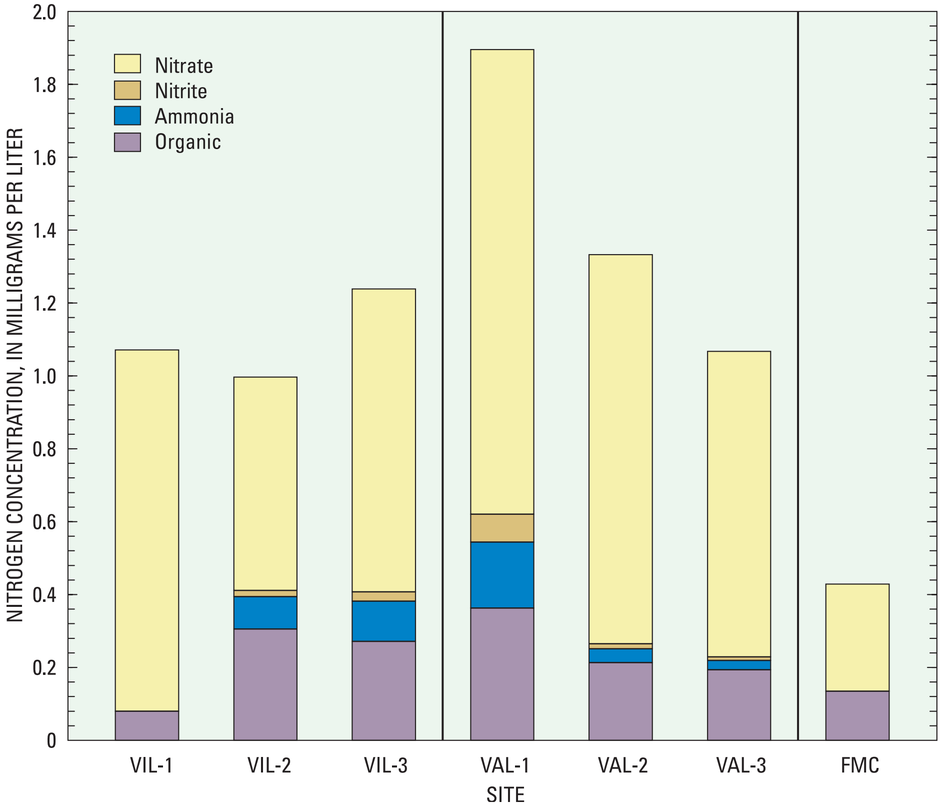

Figure 11. Median concentrations of measured forms of dissolved nitrogen in water samples from streams in the Birmingham area, Alabama, 2000–01.

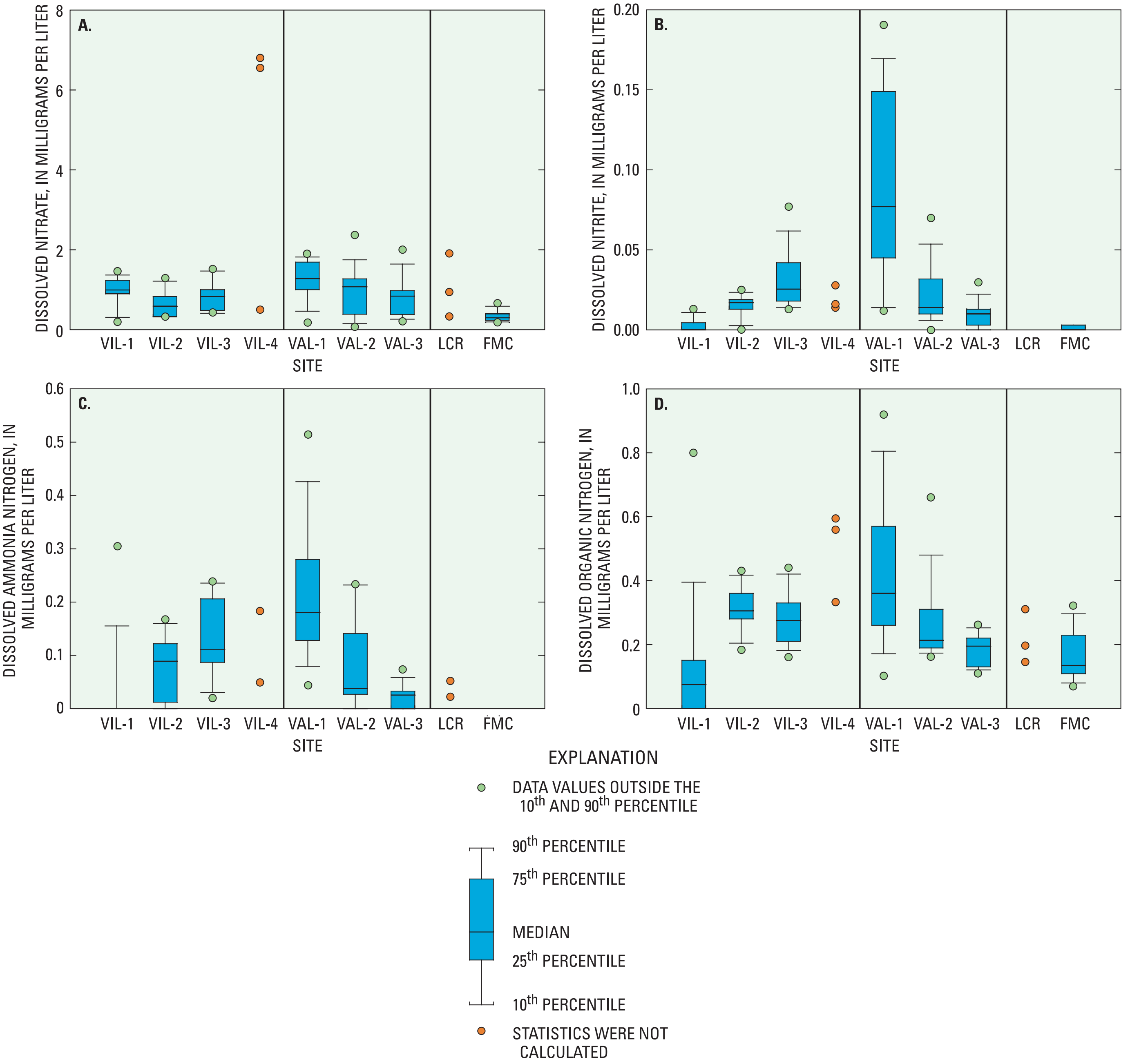

Figure 12. Box plots of dissolved (A) nitrate, (B) nitrite, (C) ammonia, and (D) organic nitrogen concentrations in water samples from streams in the Birmingham area, Alabama, 2000–01.

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

In December 2000, the USEPA published recommendations for ambient water-quality criteria for surface water in Nutrient Ecoregion XI (U.S. Environmental Protection Agency, 2000a). Nutrient Ecoregion XI is composed mostly of the unglaciated, forested low mountains and upland plateaus in more than 14 states of the central and eastern United States and is subdivided into 8 Level III Ecoregions. Birmingham is located in the Ridge and Valley Level III Ecoregion. For

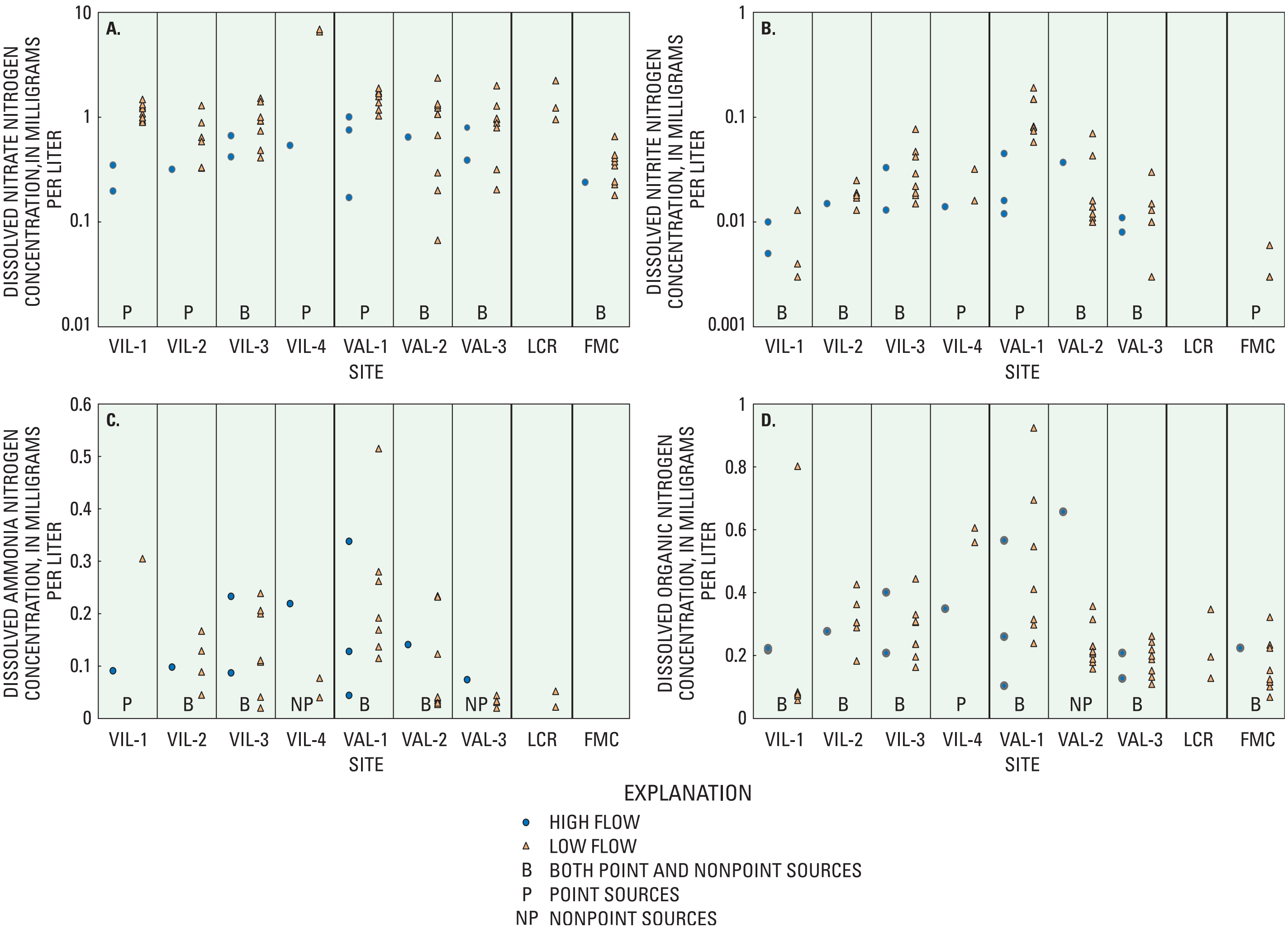

Figure 13. Dissolved (A) nitrate, (B) nitrite, (C) ammonia, and (D) organic nitrogen concentrations in water samples collected during high and low flow from streams in the Birmingham area, Alabama, 2000–01.

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

Phosphorus Concentrations and Distribution

Median concentrations of dissolved phosphorus varied considerably among all sites during this study (fig. 14). The highest median concentrations of phosphorus were detected at VAL-1 and the lowest median concentrations were detected at FMC. At Village Creek, median concentrations of suspended phosphorus and non-orthophosphorus were highest at VIL-2 followed by those at VIL-3 and VIL-1. Of the Village Creek sites, median concentrations of orthophosphate were highest at VIL-2. In Valley Creek, median concentrations of suspended phosphorus, orthophosphate, and non-orthophosphorus were highest at VAL-1 and decreased in a downstream direction. The range and distribution of suspended phosphorus, orthophosphate, and non-orthophosphorus at each of the sampling sites are shown in figure 15. Maximum concentrations of suspended phosphorus were detected during high flow at all sites on Village and Valley Creeks. Concentrations of orthophosphate at VIL-4 and VAL-1 were an order of magnitude greater during low flow than during high flow, indicating that the high concentrations may be due to the presence of point sources.

Significant differences ($p \leq 0.05$) in phosphorus concentrations were identified among sites (table 6). Total phosphorus concentrations at VIL-2, VAL-1, and VAL-2 were significantly higher than at FMC. Dissolved orthophosphate concentrations were significantly higher at VIL-2, VAL-1, VAL-2, and VAL-3 than at FMC.

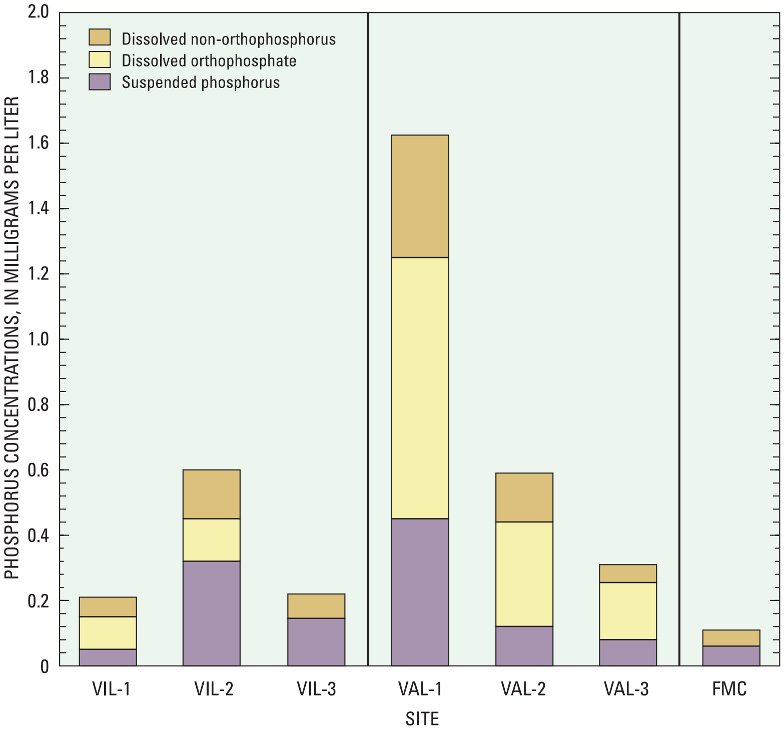

Figure 14. Median concentrations of measured forms of dissolved phosphorus in water samples from streams in the Birmingham area, Alabama, 2000–01.

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

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

Programming data-collection platform for satellite telemetry of hydrologic data (photograph taken by J.B. Atkins, USGS).

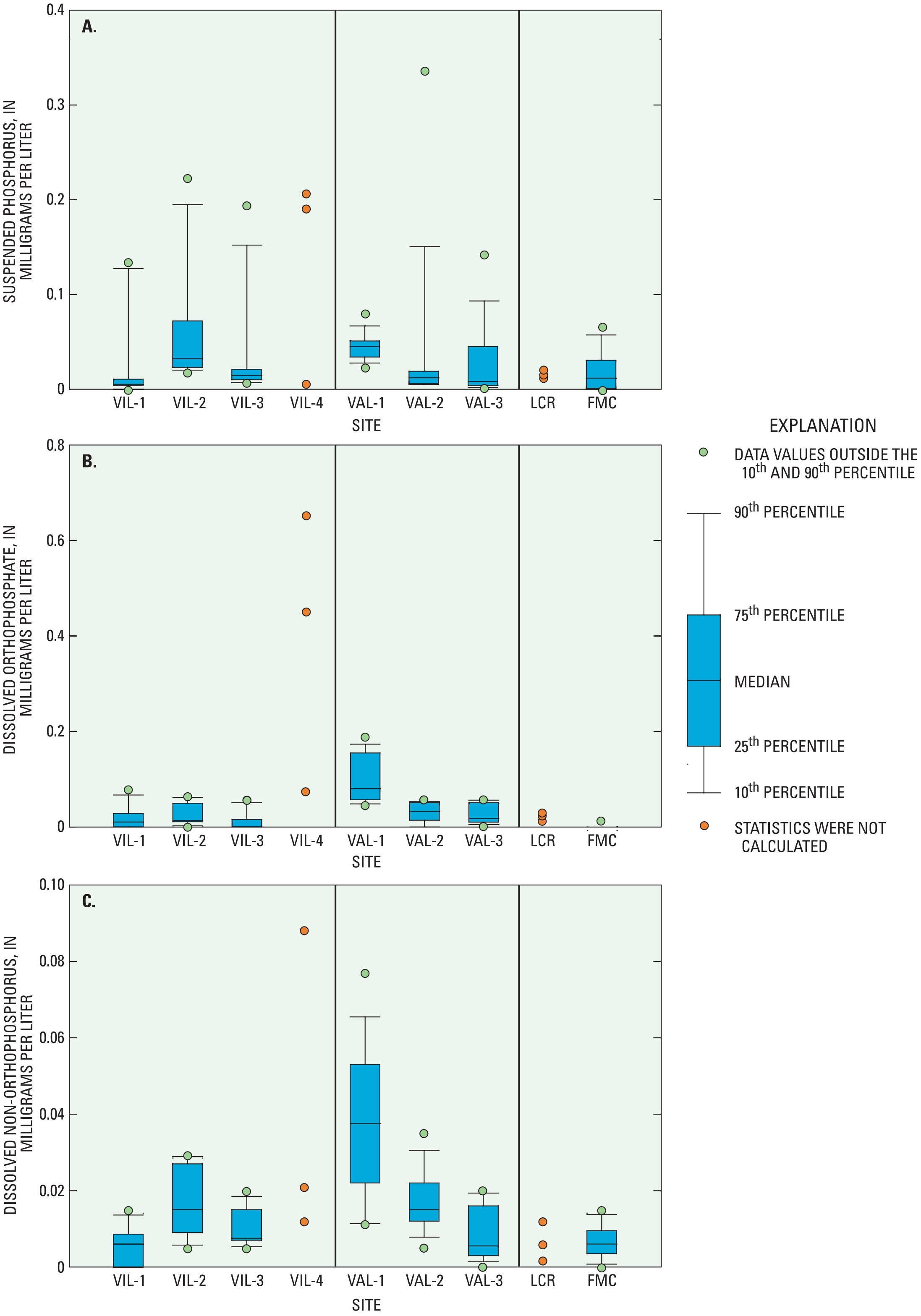

Figure 15. Box plots of (A) suspended phosphorus, (B) dissolved orthophosphate, and (C) dissolved non-orthophosphorus concentrations in water samples from streams in the Birmingham area, Alabama, 2000–01.

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

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

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

Nutrient data from Village and Valley Creeks were compared to nutrient data collected from urban sites throughout the Nation in the NAWQA Program (U.S. Geological Survey, 2001). More than 2,800 nutrient samples were collected from urban NAWQA sites between 1991 and 2001. Nutrient concentrations from Village and Valley Creeks were plotted over a bar graph illustrating ranges, which included the lowest 25 percent, the middle 50 percent, and the highest 25 percent of the Birmingham data (fig. 16). To the right of each bar graph in figure 16 is another bar graph illustrating the same ranges for data collected at urban NAWQA sites nationwide. The statistical quartiles of both data sets were computed by using detected values in order to better illustrate the spread of the data. The nutrient concentrations detected in this study fell within a narrower range than the concentrations reported nationally.

Instantaneous Nutrient Loads and Yields

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

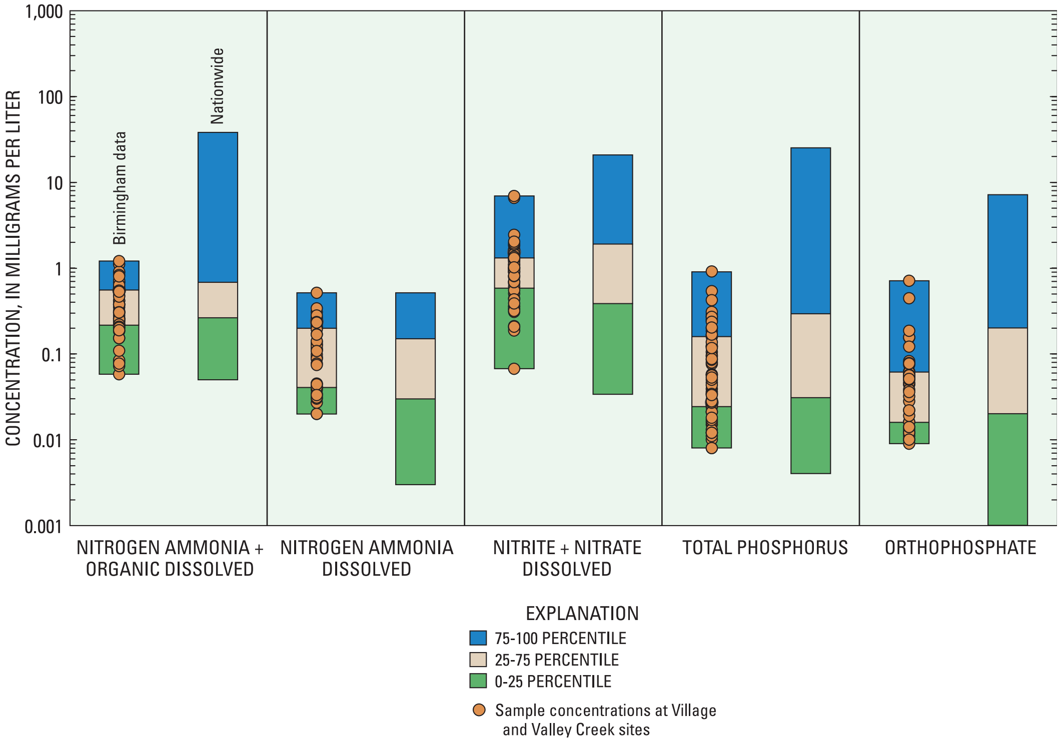

Figure 16. Comparison of nutrients in water samples from urban sites in the Birmingham area, Alabama, to urban sites nationwide.

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

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

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

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

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

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

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

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

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

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

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

Biochemical Oxygen Demand and Total Organic Carbon

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

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

Fecal Indicator Bacteria

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

Concentrations of fecal indicator bacteria often depend on hydrologic conditions prior to and during sampling. For example, higher concentrations occur during high flow as a result of nonpoint sources, such as overland runoff that carries high concentrations of bacteria from many different sources, including domestic pets and wildlife. Combined sewer overflows or sanitary sewer overflows also can contribute high levels of bacteria during storm events. Leaking sanitary sewer lines or connections to sewer lines are likely the source of high levels of bacteria during low flow. When point-source discharges contribute fecal indicator bacteria, high concentrations may be present during low flow (leaking sanitary sewer lines or failing septic systems) as well as high flow (combined sewer overflows; Gregory and Frick, 2000).

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

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

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

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

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

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

Site label (fig. 1)	*Escherichia coli* (col/100 mL)			Enterococci (col/100 mL)			Fecal coliform (col/100 mL)		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
VIL-1	250	780	31,000	330	1,500	69,000	270	1,300	28,000
VIL-2	440	3,000	9,200	900	5,700	18,000	350	2,300	13,000
VIL-3	34	280	17,000	17	315	25,000	23	400	19,000
VIL-4	200	—	44,000	3,000	—	>4,000	180	—	>3,000
VAL-1	770	13,600	78,000	600	4,300	70,000	2,100	13,950	85,000
VAL-2	51	800	25,000	59	360	22,000	41	680	16,000
VAL-3	5	225	11,000	12	110	52,000	10	98	16,000
LCR	270	—	1,800	72	—	290	62	—	490
FMC	3	175	3,000	62	810	14,000	9	70	3,000