BENTHIC INVERTEBRATES IN LAKE MARION AND SELECTED TRIBUTARIES IN THE VICINITY OF A HAZARDOUS-WASTE LANDFILL NEAR PINEWOOD, SOUTH CAROLINA, 1988

By Donna L. Belval, Arthur D. Bradfield, David E. Krantz, and Glenn G. Patterson

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ABSTRACT

Benthic macroinvertebrate communities of Lake Marion and three small tributaries near Pinewood, S.C., were studied as part of a 3-year investigation to characterize the geohydrology, streamflow, lake-flow patterns, and water quality near a hazardous-waste landfill. Six sampling stations, located both upstream and downstream of the landfill, were sampled four times during 1988.

The stream and lake sites that were sampled consistently supported benthic invertebrate communities of moderate complexity. The lake site upstream of the landfill supported slightly more taxa (57) than the lake site downstream (44). The stream sites upstream of the landfill supported high and intermediate numbers of taxa (83 and 54), while those downstream supported intermediate and low numbers of taxa (60 and 37). Evidence indicates that operation of the landfill has altered the habitat of the streams below it, and that the major alteration has been sedimentation rather than release of toxic materials into the water.

INTRODUCTION

A hazardous-waste landfill near Pinewood, S.C. is one of two landfills in the southeastern United States permitted to accept hazardous waste. Since 1977, approximately one billion pounds of ignitable, corrosive, acutely hazardous, reactive, and toxic wastes have been buried at the 279-acre site (Environmental Technology Engineering, Inc., 1987). Although much is known about the geohydrology of the immediate site, little is known about the hydrologic effects of the landfill on regional geohydrologic system.

Concerns have been raised about the potential for contamination of ground water and surface water by leakage from the site. The landfill is within 1,200 feet of Lake Marion, South Carolina's largest reservoir. The regional extent of aquifers, the directions of ground-water flow, and interactions among ground water, surface water, water chemistry, and biologicalcommunities are factors that determine the effects of potential contaminants in the vicinity of the landfill. In 1987, the U.S. Geological Survey (USGS), in cooperation with the South Caroina Public Service Authority, undertook a 3-year study to characterize these factors.

Purpose and Scope

The purpose of this report is to describe the benthic invertebrate communities of selected stream and lake sites in an area of approximately 16 mi^2 that surrounds the hazardous-waste landfill near Pinewood. The benthic invertebrate data presented in this report were collected from January through November 1988. The data and interpretations in this report describe natural background conditions of benthic invertebrate communities, compare background conditions with those in areas influenced by runoff from the landfill, and establish a data base with which future data can be compared to evaluate effects of landfill operations on the benthic invertebrate communities.

Study Area

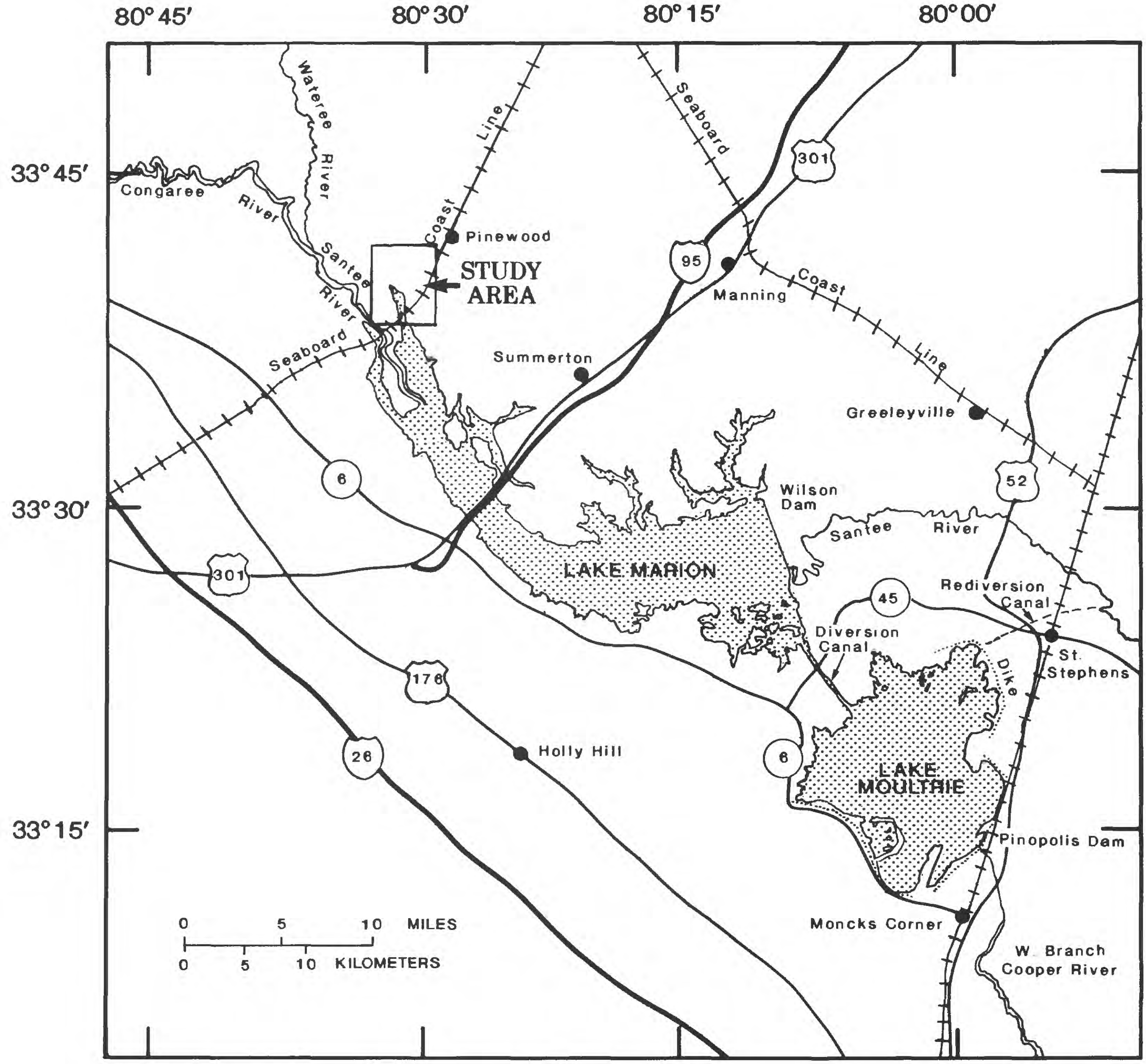
The study area (figs. 1 and 2) is in central South Carolina in Sumter County, about 5 mi southeast of Pinewood, and includes an area of approximately 16 mi^2 that surrounds the landfill. The study area is in the middle Coastal Plain physiographic province, characterized by expansive uplands with subdued relief that separate flat swampy river valleys. The study area includes parts of the Santee River valley and adjacent uplands. The uplands exhibit gently undulating topographic relief of 25 to 50 ft, and contain low-gradient streams; many flat areas contain shallow, swampy, oval depressions as large as 2,000 ft across, known as Carolina Bays. The Santee River valley is separated from the uplands part of the study area by a steep (10- to 20-percent grade) erosional escarpment 70 to 80 feet high. Streams cut the escarpment with gradients of 1 to 5 percent.

Most of the river valley south of the landfill has been flooded to form Lake Marion, the largest reservoir in South Carolina, covering 110,600 acres with an average depth of 12.5 ft. Much of the 6 mi^2 of the upper reaches of the Lake that are in the study area are characterized by dense emergent stands of cypress and tupelo trees. The lake was filled in 1941 with the construction of Wilson Dam, and is owned and managed by the South Carolina Public Service Authority. Lake Marion is used for hydropower generation, flood control, and recreation.

The Santee River valley north and west of the landfill contains riverine wetlands and bottomland forests. The uplands within the study area are approximately 50 percent cleared for agriculture, and 50 percent forested. The landfill covers 279 acres and is predominantly cleared of vegetation.

Previous Investigations

Two investigations of benthic macroinvertebrates have been done in the general vicinity of the study area. One investigation (Smock and Gilinsky, 1982; Smock and others, 1985) included monthly sampling for one year at three sites on Cedar Creek in Congaree Swamp National Monument. Cedar Creek is larger and more biologically diverse than the streams included in this investigation, but its proximity (about 22 mi) to the study area makes it worthy of note.



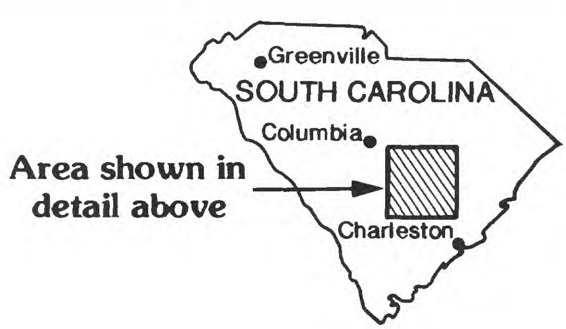


Figure 1.--Location of Study Area.

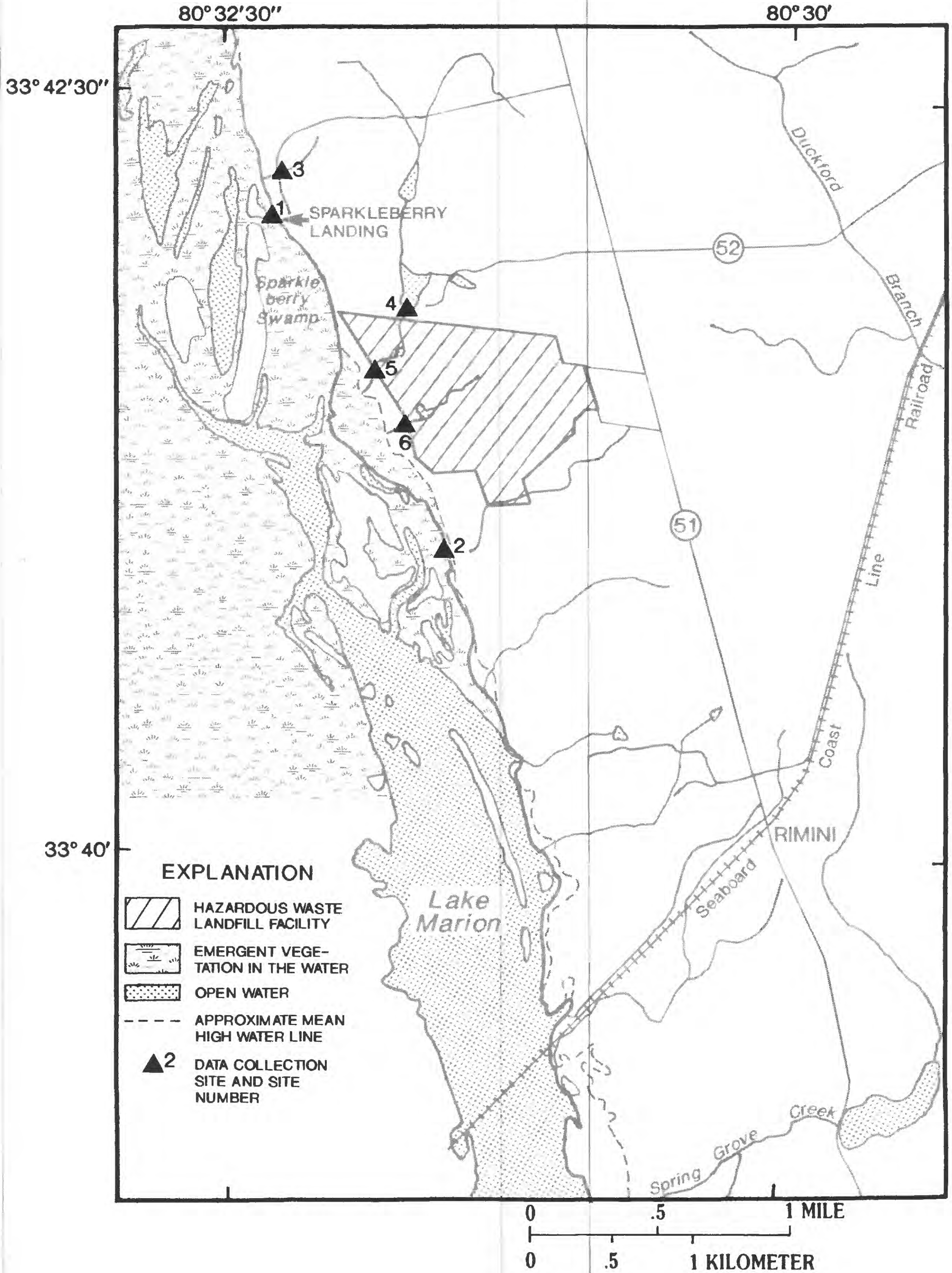


Figure 2.--Study area and locations of data collection stations.

The other investigation (Carlson, 1985) included a single visit to collect samples at six sites on Lake Marion, on small streams, and in a swamp or Carolina Bay in the study area. Four of Carlson's sites are at or near sites where samples were collected in this investigation.

PATTERNS OF SURFACE DRAINAGE AND LAKE FLOW

Patterns of surface-water drainage determine the areas that could potentially be affected by contaminants transported from the landfill by surface water. An understanding of flow patterns in nearby streams and in Lake Marion is necessary for choosing sampling locations to represent both background conditions and conditions influenced by drainage from the landfill.

Surface Drainage

The study area is bisected by a topographic divide that approximately parallels South Carolina Highway 51 (fig. 3). West of the divide, runoff drains directly to Lake Marion by way of several small westward-flowing streams and sloughs. East of the divide, runoff flows to Spring Grove Creek and its tributary, Duckford Branch, Spring Grove Creek discharges to Lake Marion about 2 miles south of the landfill.

Drainage basins of streams in the vicinity of the landfill are delineated in figure 3. Four of the drainage basins, labeled A, D, C, and D, were delineated to correspond to drainage upstream of sampling stations used in this study. Two of the stations are on one stream; therefore, basin D represents drainage upstream of the upper station and basin B represents intervening drainage between the two stations. The unlabeled drainage areas correspond to drainage to Lake Marion from small streams and undefined channels. Drainage areas for the gaged basins ranged from 0.07 to 1.52 mi^2 (fig. 3).

A topographic profile along section A-A' illustrates the steep grade from the upland part of the basin to the river valley (figs 3, 4). The profile shows a mild grade east of the main divide.

The entire landfill site is west of the surface divide. About 65 percent of the landfill property is within drainage basin A, which drains to Lake Marion through a small stream at the western boundary of the landfill (fig. 3). Most of the remaining 35 percent of the landfill is included within drainage basin B, which drains to Lake Marion through another small stream that crosses the northwestern corner of the landfill property.

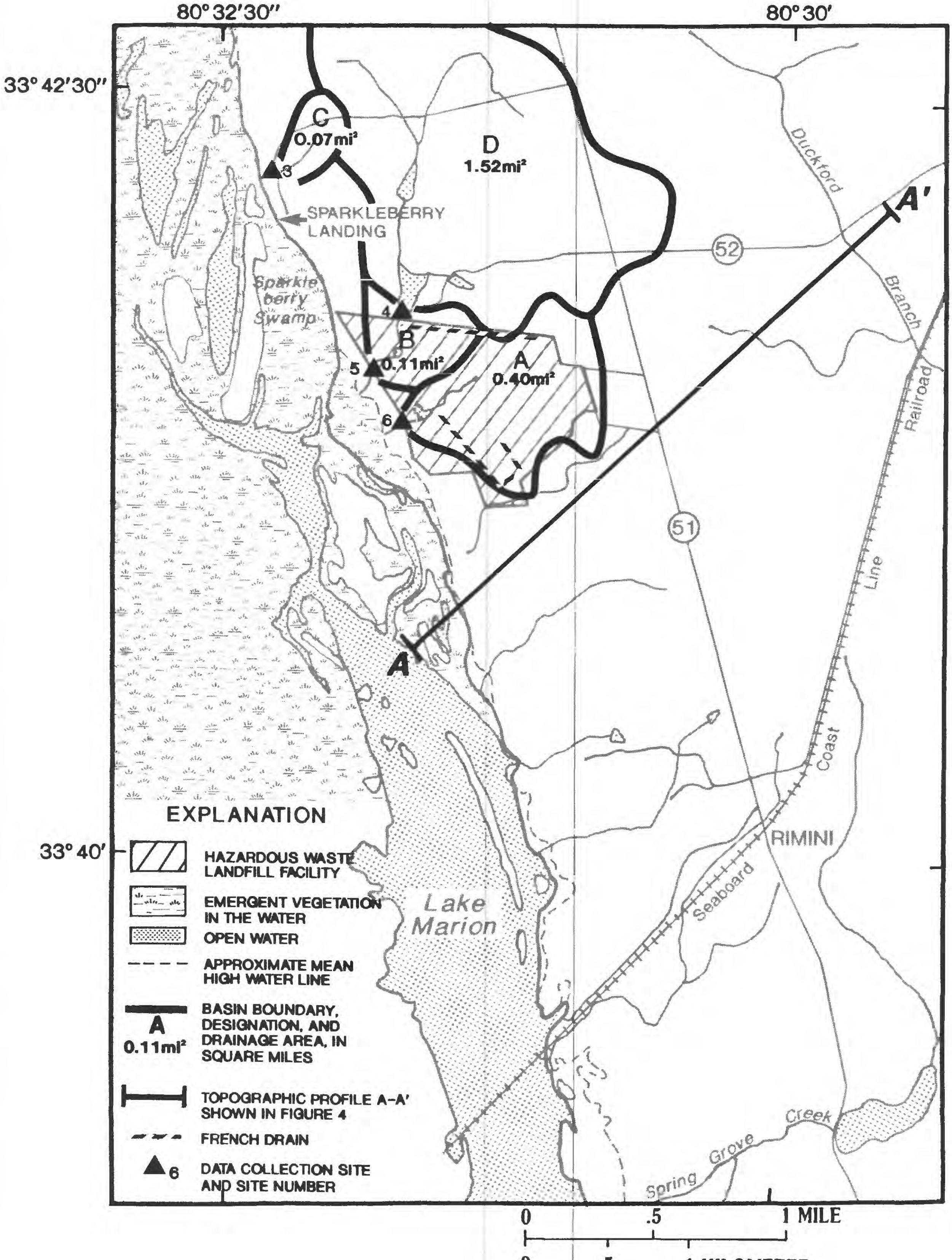


Figure 3.--Drainage areas of streams and location of topographic cross-section A-A'.

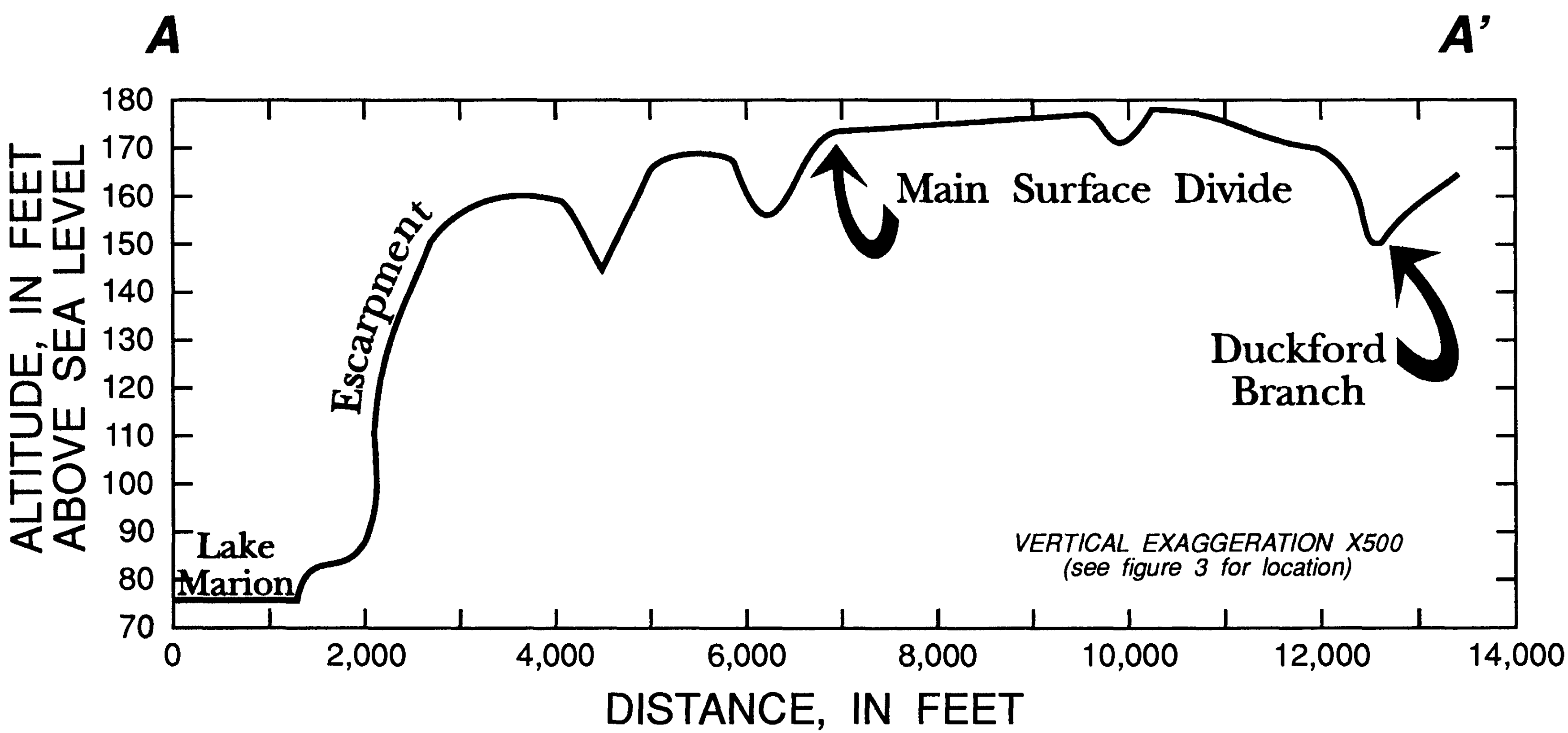


Figure 4--Topographic profile A-A’ across study area.

Lake Flow

The movement of water through the upper reaches of Lake Marion is influenced by the gradient developed between the Santee River, which generally flows within well-defined natural levees, and the lake. The lake flow is also affected by discharges from small streams that enter the lake around its perimeter. Wind generally has a minimal influence on flow in this part of the lake because of the shelter provided by stands of emergent trees. Patterns of flow in the upper 6 mi^2 of Lake Marion, near the landfill site, were delineated using low-flow and high-flow dye-tracer tests. These tracer tests showed that water in the lake adjacent to the landfill tends to flow to the southeast, parallel to shore (Burt and others, 1991).

STATION LOCATIONS AND DESCRIPTIONS

Benthic invertebrate sampling stations were selected to represent lentic (standing water) and lotic (running water) habitats both upstream and downstream of the landfill (fig. 2). Water, sediment and biological samples were collected from stations 1 and 2, located in Lake Marion, and from stations 3, 4, 5, and 6, located on streams. Stream stage, discharge, velocity, depth, and width were also measured at each stream site.

Station 1

Station 1 is in Sparkleberry Swamp, part of the wetlands that make up the upper reaches of Lake Marion, approximately 900 ft south of the mouth of the small stream that drains area C. The water at this station probably is derived from upstream tributaries, located along the eastern banks of the Wateree and Santee Rivers, with some contribution from upstream ground-water discharge directly to the lake. Water in Sparkleberry Swamp flows to the southeast at velocities ranging from barely perceptible during low flow to more than 1 ft/s during high flow. As this station is approximately 4,200 ft upstream of the nearest point of discharge from drainage areas that include parts of the landfill site, it represents background lake conditions unaffected by runoff from the landfill. Although this was not conclusively demonstrated by the dye tracer study (Burt and others, 1991) visual observations of flow in the area of station 1 indicate that station 1 is up-gradient of any stream discharges from the landfill. Water depths ranged from 1 to 3 ft. Bottom material at the site is primarily silt, clay, and organic debris. Station 1 is within 300 ft of Carlson's station 1 (Carlson, 1985).

Station 2

Station 2 is in Lake Marion approximately 3,400 ft south of the mouth of the stream that drains basin A and about 200 ft from shore. Dye tracer studies indicated that this site may be influenced by runoff from the landfill site. Water depths ranged from 3 to 5 ft. Bottom material at the site is primarily silt, clay, and organic debris. Station 2 is within about 1,000 ft of Carlson's station 2.

Station 3

Station 3 is approximately 1 mile northwest of the center of the landfill site on a small unnamed stream in basin C. The stream discharges to Sparkleberry Swamp in upper Lake Marion. The basin is northwest of the landfill and does not include any part of the landfill site. The basin is 90 percent forested with the remaining part cleared for agriculture. A dirt road traverses the basin. This station represents background stream conditions relative to streams that drain parts of the landfill site. Streamflow during October 1987 to January 1989 at station 3 ranged from 0.02 to 6.4 ft^3/s, with a mean of 0.08 ft^3/s. Water depths ranged from 0.1 to 1.4 ft. Widths ranged from 1 to 4 ft. Bottom material at the site is primarily sand and silt. Station 3 is the same as Carlson's station 3.

Station 4

Station 4 is on a small unnamed stream approximately 2,600 ft northwest of the center of the landfill site, and immediately downstream from a 9.2-acre pond in basin D. The stream discharges to Sparkleberry Swamp (Lake Marion) 2,000 ft downstream of the station, and approximately 1 mi southeast of stations 1 and 3. Upstream of station 4 the basin does not include any significant part of the landfill site. The drainage basin is 40 percent forested and the remainder is cleared for agriculture and residential use. Several dirt and paved roads traverse the basin. This station represents background conditions relative to streams that drain the landfill site. Streamflow during October 1987 to January 1989 at station 4 ranged from 0 to 6.3 ft^3/s, with a mean of 0.69 ft^3/s. Water depths ranged from 0.1 to 2.1 ft. Widths ranged from 2 to 6 ft. Bottom material at the site is primarily sand and silt.

Station 5

Station 5 is approximately 1,200 ft downstream from station 4 on the same unnamed stream. The stream discharges to Sparkleberry Swamp (Lake Marion) about 600 ft downstream from station 5. About 90 percent of the drainage area (basin B) between station 4 and station 5 lies in the northwestern corner of the landfill, and the stream flows through a sedimentation pond on the landfill facility. The stream also receives drainage immediately upstream from the sedimentation pond from a French drain (fig. 3) that is in the water-table aquifer along part of the northern boundary of the landfill property. The French drain diverts shallow ground water from parts of drainage basins A and B to the stream. The drainage basin is 20-percent forested with the remainder cleared for agriculture and the landfill operation. This station represents a stream segment that may be influenced by the landfill operation.

Streamflow during the period October 1987 to January 1989 ranged from 0 to about 10 ft^3/s, with a mean of 1.0 ft^3/s. Water depths ranged from 0.1 to 1.4 ft. Widths ranged from 11 to 20 ft. Station 5 is apparently about 300 ft downstream from Carlson's station 6. Bottom material is primarily sand and silt.

Station 6

Station 6 is approximately 1,200 ft west of the center of the landfill on an unnamed stream immediately downstream of a sedimentation pond situated on the landfill site. The stream discharges to Sparkleberry Swamp (Lake Marion) about 500 ft downstream of station 6. The drainage basin of the stream upstream from station 6 (basin A) includes 65 percent of the landfill site area. The stream also receives discharge at the sedimentation pond from a second French drain, located in the water-table aquifer in the southern part of the landfill. The French drain is designed to divert shallow ground water away from one of the waste-burial cells. Station 6 represents a stream influenced by the landfill operation. Except for small stands of trees and brush along stream banks, the basin has been entirely cleared for the landfill. The topography of the landfill site has been changed during the monitoring program by construction and landfilling operations; therefore, the character of the basin has been considerably altered.

Streamflow at station 6 during the period October 1987 to January 1989 ranged from 0 to 9.8 ft^3/s, with a mean of 0.4 ft^3/s. Water depths ranged from 0.1 to 1.3 ft. Widths ranged from 2 to 8 ft. Bottom material at the site is primarily muddy sand and silt.

WATER AND SEDIMENT CHEMISTRY

Water and sediment samples were collected in 1988 from the same six stations sampled for benthic invertebrates. The water and sediment samples were analyzed for physical characteristics, major ions, nutrients, trace elements, and selected priority pollutants (organics). Conditions at the benthic invertebrate sampling stations are summarized in table 1 and are reported in detail in a separate report (Burt and others, 1991).

Water at stations 1-5 was slightly acidic (pH ranged from 4.86 to 6.8) and water at station 6 was slightly alkaline (maximum pH 7.26). Dissolved oxygen concentrations ranged from 1.6 to 11.2 mg/L with the lake stations generally showing lower concentrations than the stream stations.

The stream stations (3 and 4) upstream of the landfill had relatively low concentrations of dissolved solids (36 - 67 mg/L), with no single ion predominating (fig. 5). The downstream stations (5 and 6) had higher concentrations of dissolved solids (52 - 597 mg/L), and sulfate was the dominant ion. Calcium was more abundant at station 6 than at the other stations. It is likely that the relatively high concentrations of dissolved sulfate measured at stations 5 and 6, and the low pH values measured at station 5, are a result of the oxidation of pyrite in spoil piles at the landfill, and leaching of the resultant sulfate and acid to the streams (Burt and others, 1991). Similarly, it is likely that the calcium and alkalinity found at station 6 were derived from dissolution of carbonate shell material in the spoil piles upstream from that station. The lake stations had even distributions of major ions, reflecting little influence from the relatively small streams near the landfill.

Table 1.--Ranges of selected properties and constituent concentrations in water and sediment

[µs/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; mg/kg milligrams per kilogram; µg/kg, micrograms per kilogram; <, less than]

Water									
Site type	Site description	Station identification number	Specific conductance (µs/cm)	Dissolved oxygen (mg/L)	pH (units)	Alkalinity as calcium carbonate (mg/L)	Dissolved solids (mg/L)	Dissolved calcium (mg/L)	Dissolved sulfate (mg/L)
Background sites	Lake	1	72-144	1.6-5.6	6.32-6.62	10-34	58-102	3.6-6.8	5.3-15
	Stream	3	42-48	6.3-10.2	6.21-6.41	5-7	36-46	1.6-2.3	3.2-7.8
	Stream	4	45-118	2.6-11.2	6.26-6.80	5-43	43-67	1.8-6.0	3.4-11
Sites downstream of landfill	Lake	2	106-141	3.1-7.4	6.24-6.68	15-42	67-102	7.0-11	6.8-39
	Stream	5	69-359	7.4-9.8	4.86-6.55	1-6	52-253	4.6-48	16-150
	Stream	6	350-801	6.6-10.2	6.77-7.26	35-83	262-597	54-140	28-350

Sediment									
Site type	Site description	Station identification number	Beryllium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lithium (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Background sites	Lake	1	2-3	8-29	29-41	29-34	25-33	25-45	52-130
	Stream	3	<1	<1	1-2	3	<2	4-5	7-24
	Stream	4	<1	<1-2	4	<2-9	<2-7	7-12	6-18
Sites downstream of landfill	Lake	2	3	7-16	25-50	43-50	29-45	38-39	48-110
	Stream	5	<1-1	2-3	6-10	9-12	9-13	13-23	31-44
	Stream	6	<1	1-3	3-6	5-8	4-10	5-12	18-39

Table 1.--Ranges of selected properties and constituent concentrations in water and sediment--Continued

[µs/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; mg/kg milligrams per kilogram; µg/kg, micrograms per kilogram; <, less than]

Water											
Site type	Site description	Station identification number	Total phosphorus (mg/L)	Total copper (µg/L)	Dissolved iron (µg/L)	Total manganese (µg/L)	Total zinc (µg/L)	Total nickel (µg/L)	Total chromium (µg/L)	Total cadmium (µg/L)
Background sites	Lake	1	0.18-0.20	1-7	600-810	100-640	<10	2-11	<1-1	<1
	Stream	3	.12-.14	1-7	170-360	20-90	<10	<1-5	2-3	<1
	Stream	4	.03-.08	1-2	260-1,800	140-1,300	<10-30	<1-5	<1-1	<1-3
Sites downstream of landfill	Lake	2	.04	2-3	310-670	30-1200	<10	<1-4	<1-1	<1
	Stream	5	.08-1.24	3-8	130-1,800	170-770	<10-120	77	2-36	<1-4
	Stream	6	.15-.83	2-23	30-3,200	430-1,200	<10-100	17-29	1-26	<1-2

Sediment											
Site type	Site description	Station identification number	Vanadium (mg/kg)	Phenol (µg/kg)	DDT[1] (µg/kg)	DDD[2] (µg/kg)	DDE[3] (µg/kg)	PCB[4] (µg/kg)	Chlordane (µg/kg)	Dieldrin (µg/kg)	Toxaphene (µg/kg)
Background sites	Lake	1	93-110	<200	<100	0.4-65	1-54	<1.0-47	<1.0	<0.1	<10
	Stream	3	8-10	<200	<.2	<.1-.2	.5-.7	<1.0	<1.0	<.1	<10
	Stream	4	<2-42	260-7,857	<.2	.6	1.5-2.8	<1.0	<1.0	<.1	<10
Sites downstream of landfill	Lake	2	120-150	<200	<.2	<.1-.2	<.1-.2	<1.0	<1.0	<.1	<10
	Stream	5	58-76	<200	<.2-1.0	<.7-1.5	1.0-1.6	<1.0	<1.0-3	<.1	<10
	Stream	6	24-46	<200	.3- .7	<4	.3-1.4	<1.0	2-13	<.1-0.4	<10-20

[1] 1,1-bis (4-chlorophenyl)-2, 2, 2-trichloroethane
[2] 1,1-Dichloro-2, 2-bis (p-chlorophenyl) ethane
[3] Dichlorodiphenyldichloroethylene
[4] Polychlorinated biphenyls

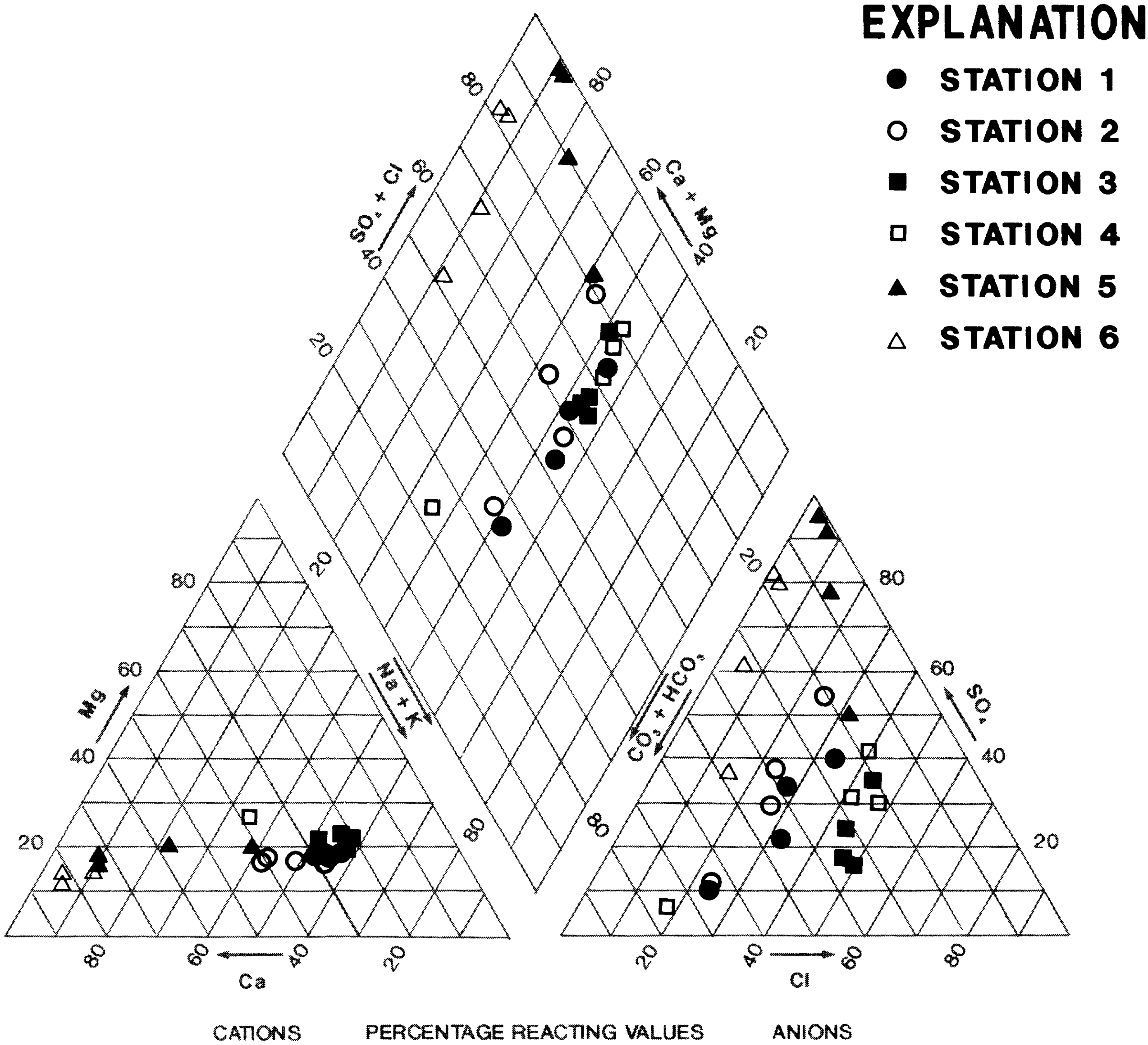


Figure 5.--Chemical analyses of water from stations 1 through 6.

Concentrations of phosphorus were generally moderate to large; one value exceeded 1 mg/L (1.24 mg/L total phosphorus at station 5 in January). Concentrations of ammonia plus organic nitrogen, ammonia plus ammonium nitrogen, and nitrate plus nitrite nitrogen (not listed in table 1) were generally low, ranging from 0.01 to 0.86 mg/L as nitrogen (Burt and others, 1991). Concentrations of trace elements were generally below detection limits. Exceptions included iron, which was moderately abundant at all stations, and copper and manganese, which were consistently detected in small amounts at all stations. Some trace elements were found in higher concentrations in the streams downstream from the landfill, notably zinc (120 ug/L at station 5), nickel (48 ug/L at station 5), and chromium (36 ug/L at station 5). None of the organic compounds for which surface-water samples were tested were detected.

Chemical analyses of bed sediment samples showed that the lakebed sediments generally had slightly higher concentrations of trace elements than the streambed sediments. Streambed sediments downstream from the landfill generally had higher concentrations of trace elements than sediments upstream of the landfill. Several organic compounds were detected in sediment samples collected upstream and downstream from the landfill. One of these was phenol, which was detected in sediment from station 4, but not from station 5, or from surface water at station 4 or 5. Low concentrations of organochlorine compounds such as DDE and DDD were detected in sediment samples from all stations. These low concentrations probably were derived from widespread use of organochlorine pesticides in previous years.

In general, water and sediment chemistry data do not indicate contamination associated with leakage from the landfill. Elevated concentrations of sulfate, hydrogen-ion, calcium, and alkalinity at sites downstream of the landfill probably are related to earth-moving activities at the landfill, which have created spoil piles from which naturally occurring pyrite and shell material can be leached (Burt and others, 1991, p. 91). The earth-moving activities have also resulted in transport of sediment from the landfill to points downstream, as evidenced by alluvial fan-type deposits near station 6.

Comparison of the water-quality data in table 1 with the National Water Quality Criteria for aquatic life (U.S. Environmental Protection Agency, 1986) shows that inorganic constituents in samples from some stations occasionally exceeded recommended limits. The concentration of total copper at station 3 in November 1987 was 7 µg/L compared to the recommended 1-hour average concentration of 2 µg/L copper for the total hardness measured that day. It should be noted that the measured value for copper is for a single point in time. Therefore, comparing this value with time-averaged values should be done with caution. In addition to copper, the concentrations of iron at stations 4, 5, and 6 exceeded the 1 mg/L limit during three sampling periods. Finally, 14 measured values of pH were below the recommended range of 6.5 - 9.0 for freshwater aquatic life. Low pH alone is not critical because the primary effect of low pH is to increase the solubility of other compounds if they are present and, as previously discussed, most other inorganic constituents at these stations were below critical levels.

METHODS USED TO COLLECT SAMPLES

Benthic invertebrate sampling stations were selected to represent both lotic and lentic habitats, upstream and downstream from the area of potential influence from the landfill. Benthic invertebrate sampling stations coincided with stations from which water-quality and streamflow data were obtained.

Benthic invertebrate samples were collected from the six stations during four sampling periods to examine seasonal variability in benthic community structure. The sampling periods were January-February 1988, April 1988, July-August 1988, and November 1988.

Several collection methods were used in this study to maximize the number of species collected. Different combinations of sampling methods were used for lotic and lentic habitats. At the two lake sites, stations 1 and 2, benthic organisms were collected using artificial substrates and a square-foot Ponar grab sampler. The artificial substrate used was the Hester-Dendy "jumbo" modification substrate, with a surface area of 1.4 ft^2. At each station, three substrates were suspended at a depth of approximately 1 ft from a nylon rope strung between trees and left in place for six weeks prior to the collection date to allow for colonization. In addition, three samples were collected from the lake bottom using a Ponar grab sampler.

The sampling methods utilized at each of the stream sites (stations 3, 4, 5, and 6) included artificial substrates, a square-foot Surber sampler, and dip-net sampling for a timed interval. As at the lake sites, three artificial substrates were used per station. Three replicates were collected with the Surber sampler, which utilizes the flow of the stream to carry benthic organisms into a net after the substrate of the stream has been manually disturbed. Finally, the dip-net method was used to sample all available habitats, thereby increasing the chances of collecting rarer species. In this method, a flat-sided net was held downstream, close to the bottom of the stream, while the substrate was disturbed upstream, thereby allowing any dislodged organisms to drift into the dip net. For this study, a 30-minute sampling interval was used. A 210 micrometer size mesh netting was used in both the Surber sampler and the dip net.

The Surber and Ponar samplers collect organisms from a specific known area, and are therefore useful for determining density of organisms per unit area. The dip net was used to collect organisms from larger, undefined areas, thereby ensuring that the collection represents, as nearly as possible, the complete fauna at the station. Some artificial substrates were lost due to stream flooding, while others were left only partially submerged when lake and stream levels dropped. Results from the artificial substrates, therefore, could not be used to quantify density of benthic organisms.

Collection procedures as outlined above are described fully by Britton and others (1988) and Greeson and others (1977). Samples were preserved in 90 percent ethyl alcohol, and rose bengal biological stain was added to aid in identifications. Organisms were counted and identified to the species level when possible by a private contractor.

A number of statistical parameters and population indices were used in the analysis of benthic invertebrate data. These include: 1) species richness, which may be given simply as the number of species in the sample, or as a richness or variation index; 2) diversity, generally defined as a measure of the number of species and their relative abundance in the community, often expressed in terms of a diversity index; 3) biomass, an estimate of the mass of the total biota of a particular habitat or region, expressed as wet weight, including shells, if any, per unit area; and 4) similarity, expressed as a similarity index, in the comparison of two different populations or sites (Lincoln and others, 1982). An analysis of functional feeding groups (Cummins, 1964) was done to determine the extent to which the various feeding opportunities available at a station were utilized by benthic invertebrates.

RESULTS OF BENTHIC INVERTEBRATE SAMPLING

The stream and lake sites sampled consistently supported benthic invertebrate communities of moderate complexity and productivity. Some differences were evident among the stations with regard to numbers of organisms collected, and density, biomass, and diversity of the population, but the differences were not substantial. The data are presented in tables 2 through 7.

Number of Organisms

The number of organisms collected per sample, using the quantitative sampling methods (Surber and Ponar), are compared by station in figure 6 and by month of collection in figure 7. Of the two lake stations, station 1 usually had a larger number of organisms than station 2, primarily because of larger numbers of two Dipteran taxa (tables 2, 3). No organisms were found using the Ponar sampler at station 2 in November, but some were found on artificial substrates suspended above the lake bottom.

The stream stations, with one exception, contained similar numbers of organisms (fig. 6). The exception is station 4, which contained a disproportionately large number of organisms when compared to the other stream sites (stations 3, 5, and 6). Samples from station 4 contained more than 11,000 organisms in January-February; more than 5,000 in April; and more than 20,000 in November. This large number of specimens is mostly from two Dipteran genera, Glyptotendipes and Thienmannimyia (table 5).

The number of organisms varied somewhat from season to season (fig. 7). The sampling period with the lowest number of organisms at most stations was July-August. Dry conditions during the summer of 1988 resulted in zero flow at stations 4, 5, and 6 on several days in May, June, July, or August. Water may still have been present in stagnant pools, but the extent of aquatic habitat and the amount of available food was reduced at all stations during these periods of no flow. Summer is also a time when many aquatic insects have matured to the adult phase and emerged from the water.

Table 2.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 1

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; No., number; m^2, square meters; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass g/m^2	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
INSECTA													
Ephemeroptera (mayflies)	---	---	---	0.0005	---	---	0.120	---	---	0.0038	---	---	---
Caenis sp.	C-G	1	3	---	17	44	---	3	23	---	---	---	---
Diptera (true flies)	---	---	---	.175	---	---	1.64	---	---	1.12	---	---	0.560
Bezzia sp.	P	9	24	---	2	4	---	23	43	---	76	273	---
Chaoborus punctipennis	P	---	---	---	45	162	---	156	839	---	159	570	---
Chironomus sp.	C-G, SH	20	54	---	---	---	---	---	---	---	155	553	---
Cricotopus sp.	SH, C-G	---	---	---	---	---	---	---	---	---	4	14	---
Dicrotendipes sp.	C-G, S	13	35	---	---	---	---	---	---	---	---	---	---
Einfeldia sp.	C-G	---	---	---	---	---	---	---	---	---	69	101	---
Endochironomus sp.	SH	9	24	---	---	---	---	---	---	---	---	---	---
Micropsectra dubia	C-G	---	---	---	4	10	---	11	28	---	---	---	---
Molophilus	SH	1	3	---	---	---	---	---	---	---	---	---	---
Orthocladius sp.	C-G	51	137	---	---	---	---	---	---	---	---	---	---
Parametriocnemus sp.	C-G	17	43	---	---	---	---	---	---	---	---	---	---
Polypedilum sp.	SH, C-G, P	---	---	---	---	---	---	---	---	---	24	86	---
Procladius sp.	P, C-G	12	32	---	---	---	---	---	---	---	48	172	---
Tabanus sp.	P, C-G	1	3	---	---	---	---	---	---	---	---	---	---
Tanypus sp.	P	11	30	---	---	---	---	---	---	---	---	---	---
Tanytarsus sp.	C-G, C-F	6	16	---	---	---	---	---	---	---	5	18	---
Thienemanniella sp.	C-G	---	---	---	2	5	---	---	---	---	---	---	---
Thienemannimyia sp.	P	12	32	---	37	104	---	18	5	---	2	5	---
Tribe *Chironomini*	SH, C-G	---	---	---	804	2,725	---	651	608	---	---	---	---
Tribe Tanypodinae	P	---	---	---	87	313	---	---	---	---	---	---	---

Table 2.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 1--Continued

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; No., number; m^2, square meters; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density ($No./m^2$)	January - February Biomass (g/m^2)	April No.	April Density ($No./m^2$)	April Biomass (g/m^2)	July - August No.	July - August Density ($No./m^2$)	July - August Biomass (g/m^2)	November No.	November Density ($No./m^2$)	November Biomass (g/m^2)
INSECTA													
Coleoptera (beetles)	---	---	---	0.0011	---	---	0.0108	---	---	---	---	---	0.0158
Celina sp.	P	---	---	---	1	3	---	---	---	---	---	---	---
Deronectes griseostriatus	P	---	---	---	1	3	---	---	---	---	---	---	---
Hydroporus sp.	P	1	3	---	---	---	---	---	---	---	---	---	---
Illybius sp.	P	---	---	---	---	---	---	---	---	---	4	14	---
Hemiptera (true bugs)	---	---	---	---	---	---	.0547	---	---	---	---	---	---
Corixidae	SH	---	---	---	4	14	---	---	---	---	---	---	---
Odonata (dragonflies and damselflies)	---	---	---	.3290	---	---	.0136	---	---	0.0049	---	---	.0043
Anomalagrion sp.	P	---	---	---	4	10	---	---	---	---	4	14	---
Argia sp.	P	---	---	---	---	---	---	---	---	---	1	3	---
Cordulegaster sp.	P	---	---	---	---	---	---	1	3	---	---	---	---
Enallagma sp.	P	1	3	---	1	4	---	---	---	---	---	---	---
Erythemis asimplicicollis	P	1	3	---	---	---	---	---	---	---	---	---	---
Gomphidae	P	---	---	---	---	---	---	1	3	---	---	---	---
Tetragoneuria sp.	P	1	3	---	---	---	---	---	---	---	---	---	---
Megaloptera (alderflies and dobsonflies)	---	---	---	---	---	---	---	---	---	.0044	---	---	---
Corydalidae	P	---	---	---	---	---	---	1	3	---	---	---	---
HYDRACARINA (water mites)	---	---	---	.0005	---	---	---	---	---	---	4	14	.0072
Limnesia sp.	P	1	3	---	---	---	---	---	---	---	---	---	---
COLLEMBOLA (springtails)	---	---	---	.0005	---	---	---	---	---	---	---	---	---
Isotomurus palustris	C-G	1	3	---	---	---	---	---	---	---	---	---	---
CRUSTACEA													
Isopoda (sow bugs)	---	---	---	.0826	---	---	---	---	---	---	---	---	---
Asellus intermedius	C-G	35	13	---	---	---	---	---	---	---	---	---	---
Amphipoda (sideswimmers)	---	---	---	.0172	---	---	.0266	---	---	.0056	---	---	.0043
Gammarus lacustris	C-G	1	3	---	---	---	---	---	---	---	---	---	---
Hyalella azteca	C-G	---	---	---	10	26	---	5	13	---	4	14	---

Table 2.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 1--Continued

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; No., number; m^2, square meters; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
CRUSTACEA-cont'd													
Decapoda (crayfish)	---	---	---	0.592	---	---	---	---	---	---	---	---	---
Palaemonetes sp.	SH	2	5	---	---	---	---	---	---	---	---	---	---
MOLLUSCA (snails)	---	---	---	---	---	---	---	---	---	---	---	---	---
Gastropoda	---	---	---	.0145	---	---	.0219	---	---	0.0261	---	---	0.0008
Amnicola limosa	S	14	3	---	1	3	---	---	---	---	---	---	---
Amnicola sp.	S	---	---	---	1	4	---	---	---	---	---	---	---
Ferrissia sp.	S	---	---	---	1	3	---	---	---	---	---	---	---
Helisoma trivolvis	S	---	---	---	---	---	---	4	10	---	---	---	---
Laevapex sp.	S	2	5	---	---	---	---	---	---	---	---	---	---
Menetus dilitatus	S	---	---	---	1	3	---	---	---	---	---	---	---
Physa sp.	S, C-G	---	---	---	---	---	---	---	---	---	1	3	---
Physella heterostropha	S	---	---	---	2	5	---	---	---	---	---	---	---
Pseudosuccinea sp.	S	---	---	---	2	5	---	---	---	---	---	---	---
Succinea ovalis	S	1	3	---	---	---	---	---	---	---	---	---	---
OLIGOCHAETA (worms)	---	---	---	.400	---	---	.294	---	---	.0065	---	---	.0287
Eiseniella tetraedra	C-G	---	---	---	1	4	---	---	---	---	---	---	---
Tubificidae	C-G	266	662	---	298	851	---	374	22	---	53	187	---
HIRUDINEA (LEECHES)	---	---	---	.0086	---	---	.408	---	---	---	---	---	---
Erpobdella punctata	P, C-G	1	3	---	---	---	---	---	---	---	---	---	---
Mooreobdella melanostoma	P	---	---	---	1	4	---	---	---	---	---	---	---
Placobdella sp.	P	2	5	---	---	---	---	---	---	---	---	---	---
TURBELLARIA (flatworms)	---	---	---	.0008	---	---	---	---	---	.0210	---	---	.0014
Dugesia tigrina	P, C-G	1	3	---	---	---	---	---	---	---	4	14	---
Dugesia sp.	C-G	---	---	---	---	---	---	12	31	---	---	---	---
Total organisms	---	494	---	1.62	1,327	---	2.53	1,260	---	1.19	617	---	.623
Total Taxa	57	29	---	---	23	---	---	13	---	---	17	---	---
Shannon Weaver Diversity Index	---	---	2.32	---		1.54	---	---	1.26	---	---	2.79	---

Table 3.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 2

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
INSECTA													
Ephemeroptera (mayflies)	---	---	---	---	---	---	0.0118	---	---	---	---	---	---
Caenis sp.	C-G	---	---	---	1	3	---	---	---	---	---	---	---
Trichoptera (caddisflies)	---	---	---	---	---	---	.0020	---	---	---	---	---	---
Hydroptila sp.	SH, S	---	---	---	1	3	---	---	---	---	---	---	---
Diptera (true flies)	---	---	---	0.581	---	---	2.24	---	---	0.046	---	---	0.0115
Bezzia sp.	P	11	39	---	31	72	---	---	---	---	1	3	---
Chaoborus albatus	P	4	14	---	---	---	---	---	---	---	---	---	---
Chaoborus punctipennis	P	---	---	---	8	29	---	18	65	---	---	---	---
Chironomus sp.	C-G, SH	368	1,321	---	---	---	---	---	---	---	10	26	---
Dicrotendipes sp.	C-G, S	23	83	---	---	---	---	---	---	---	---	---	---
Einfeldia sp.	C-G	---	---	---	---	---	---	---	---	---	4	10	---
Endochironomus sp.	SH	30	! 77	---	---	---	---	---	---	---	11	28	---
Eukiefferiella sp.	C-G, S, P	5	14	---	---	---	---	---	---	---	---	---	---
Glyptotentipes sp.	SH, C-F, C-G	---	---	---	---	---	---	---	---	---	1	3	---
Orthocladius sp.	C-G	64	61	---	---	---	---	---	---	---	---	---	---
Parametriocnemus sp.	C-G	4	10	---	14	25	---	---	---	---	---	---	---
Phaenopsectra sp.	S, C-G	4	14	---	---	---	---	---	---	---	---	---	---
Polypedilum sp.	SH, C-G, P	1	4	---	---	---	---	---	---	---	11	31	---
Procladius sp.	P, C-G	---	---	---	---	---	---	---	---	---	6	15	---
Tabanus sp.	P, C-G	4	14	---	---	---	---	---	---	---	---	---	---
Tanypus sp.	P	136	488	---	---	---	---	---	---	---	---	---	---
Tanytarsus sp.	C-G, C-F	15	43	---	---	---	---	---	---	---	21	54	---
Thienemannimyia sp.	P	---	---	---	---	---	---	23	57	---	---	---	---
Thienemannimyia sp. group	P	82	233	---	54	108	---	---	---	---	---	---	---

Table 3.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 2--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
Diptera-(cont'd)													
Tanypodinae	P	1	3	---	---	---	---	---	---	---	---	---	---
Tribe Tanypodini	P	---	---	---	59	201	---	---	---	---	---	---	---
Tribe Chironomi	SH, C-G	---	---	---	445	1,300	---	157	467	---	---	---	---
Chironomidae pupae	---	---	---	---	8	20	---	---	---	---	1	3	---
Coleoptera (beetles)	---	---	---	0.437	---	---	---	---	---	---	---	---	---
Hydaticus sp.	P, C-G	4	7	---	---	---	---	---	---	---	---	---	---
Odonata (dragonflies and damselflies)	---	---	---	---	---	---	0.789	---	---	---	---	---	0.230
Libellula sp.	P	---	---	---	2	5	---	---	---	---	---	---	---
Pachydiplax longipennis	P	---	---	---	---	---	---	---	---	---	1	3	---
CRUSTACEA		---	---	---	---	---	---	---	---	---	---	---	---
Isopoda (sowbugs)	---	---	---	.238	---	---	.0086	---	---	0.0013	---	---	.0115
Asellus intermedius	C-G	16	36	---	56	143	---	40	140	---	---	---	---
Lirceus sp.	C-G	---	---	---	24	25	---	---	---	---	4	10	---
Amphipoda (sideswimmers or scuds)	---	---	---	.0046	---	---	---	---	---	---	---	---	.0051
Gammarus lacustris	C-G	1	3	---	---	---	---	---	---	---	---	---	---
Hyalella azteca	C-G	---	---	---	---	---	---	---	---	---	1	3	---
MOLLUSCA													
Gastropoda (snails)	---	---	---	.0352	---	---	.1234	---	---	.0015	---	---	.0261
Amnicola limosa	S	---	---	---	9	23	---	---	---	---	---	---	---
Helisoma trivolvis	S	2	4	---	---	---	---	1	3	---	---	---	---
Laevapex sp.	S	1	3	---	---	---	---	---	---	---	---	---	---
Lymnaea sp.	S, C-G	---	---	---	---	---	---	---	---	---	1	3	---
Menetus dilitatus	S	---	---	---	10	26	---	---	---	---	---	---	---
Physella heterostropha	S	1	3	---	10	26	---	---	---	---	---	---	---
Pseudosuccinea sp.	S	---	---	---	3	8	---	---	---	---	---	---	---

Table 3.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 2--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m², square meters; No., number; g/m², grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density (No./m²)	Biomass (g/m²)	No.	Density (No./m²)	Biomass (g/m²)	No.	Density (No./m²)	Biomass (g/m²)	No.	Density (No./m²)	Biomass (g/m²)
MOLLUSCA (cont'd)													
Pelecypoda (clams)	---	---	---	0.550	---	---	0.755	---	---	---	---	---	0.0028
sphaerium sp.	C-F	4	14	---	---	---	---	---	---	---	1	3	---
sphaeriidae	---	---	---	---	3	11	---	---	---	---	---	---	---
OLIGOCHAETA (worms)	---	---	---	.596	---	---	.0639	---	---	0.063	---	---	.0077
Tubificidae	C-G	27	97	---	128	162	---	203	520	---	41	105	---
HIRUDINEA (leeches)	---	---	---	---	---	---	.906	---	---	.306	---	---	---
Helobdella sp.	P, C-G	---	---	---	---	---	---	1	3	---	---	---	---
Mooreobdella melanostoma	P	---	---	---	1	3	---	---	---	---	---	---	---
Placobdella sp.	P	---	---	---	19	49	---	---	---	---	---	---	---
Total organisms	---	808	---	2.44	886	---	4.91	443	---	0.418	115	---	0.295
Total taxa	44	23	---	---	20	---	---	7	---	---	15	---	---
Shannon-weaver diversity index	---	---	2.29	---	---	1.73	---	---	1.47	---	---	2.95	---

Table 4.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 3
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
INSECTA													
Ephemeroptera (mayflies)	---	---	---	0.0003	---	---	---	---	---	---	---	---	0.0007
Baetis tricaudatus	C-G, S	3	12	---	---	---	---	---	---	---	---	---	---
Caenis sp.	C-G	---	---	---	---	---	---	---	---	---	34	4	---
Neuroptera (spongeflies)	---	---	---	.0807	---	---	---	---	---	---	---	---	---
Nigronia sp.	P	1	4	---	---	---	---	---	---	---	---	---	---
Plecoptera (stoneflies)	---	---	---	.0014	---	---	0.0503	---	---	---	---	---	.0001
Amphinemura delora	SH, C-G	267	---	---	9	8	---	---	---	---	---	---	---
Amphinemura sp.	SH, C-G	30	72	---	---	---	---	---	---	---	4	14	---
Trichoptera (caddisflies)	---	---	---	---	---	---	.0287	---	---	0.0004	---	---	.0001
Cheumatopsyche sp.	C-F	20	---	---	5	8	---	---	---	---	---	---	---
Hydropsyche sp.	SH, S	---	---	---	---	---	---	1	4	---	---	---	---
Limnephilidae	SH, C-G, S	---	---	---	---	---	---	---	---	---	1	4	---
Pycnopsyche divergens	SH	8	---	---	---	---	---	---	---	---	---	---	---
Wormaldia sp.	C-F	1	---	---	---	---	---	---	---	---	---	---	---
Lepidoptera (aquatic caterpillers)	---	---	---	---	---	---	---	---	---	---	---	---	.0039
Pyralidae	SH	---	---	---	---	---	---	---	---	---	1	4	---
Diptera (true flies)	---	---	---	1.409	---	---	6.79	---	---	.711	---	---	.338
Anopheles sp.	C-F	1	4	---	---	---	---	---	---	---	---	---	---
Antocha sp.	C-G	1	---	---	---	---	---	---	---	---	---	---	---
Atherix lantha	P	---	---	---	---	---	---	1	4	---	---	---	---
Bezzia sp.	P	100	104	---	84	87	---	15	---	---	213	57	---
Bittacomorpha sp.	C-G	1	---	---	---	---	---	---	---	---	---	---	---
Chaetocladius sp.	C-G	---	---	---	---	---	---	---	---	---	1	4	---
Corynoneura sp.	C-G	526	488	---	---	---	---	---	---	---	---	---	---
Cricotopus sp.	SH, C-G	---	---	---	---	---	---	---	---	---	32	---	---

Table 4.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 3--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
Diptera (cont'd)													
Cryptochironomus sp.	P	69	47	---	---	---	---	---	---	---	4	14	---
Dicranata sp.	P	1	---	---	---	---	---	1	3	---	1	3	---
Dicrotendipes sp.	C-G, S	---	---	---	---	---	---	2	7	---	---	---	---
Dixa sp.	C-G	17	---	---	14	8	---	1	4	---	3	4	---
Dixa punctipennis	C-G	---	---	---	20	---	---	---	---	---	---	---	---
Erioptera sp.	C-G	---	---	---	---	---	---	5	4	---	1	3	---
Glyptotendipes sp.	SH, C-F, C-G	---	---	---	51	13	---	8	25	---	127	50	---
Hexatoma sp.	P	3	7	---	13	10	---	4	---	---	2	4	---
Limnophila sp.	P	39	---	---	2	3	---	---	---	---	---	---	---
Limnophora sp.	P	---	---	---	6	---	---	14	3	---	---	---	---
Micropsectra dubia	C-G	---	---	---	---	---	---	2	---	---	---	---	---
Molophilus sp.	SH	2	---	---	---	---	---	---	---	---	---	---	---
Nanocladius sp.	C-G	---	---	---	---	---	---	---	---	---	32	---	---
Orthocladius sp.	C-G	---	---	---	---	---	---	---	---	---	1	4	---
Parametriocnemus sp.	C-G	274	165	---	348	105	---	5	4	---	---	---	---
Pedicia sp.	P	---	---	---	---	---	---	2	3	---	---	---	---
Phaenopsectra sp.	S, C-G	100	86	---	220	56	---	49	151	---	---	---	---
Pilaria sp.	P	---	---	---	---	---	---	---	---	---	32	---	---
Polypedilum sp.	SH, C-G, P	---	---	---	---	---	---	---	---	---	449	11	---
Procladius sp.	P, C-G	---	---	---	---	---	---	---	---	---	224	---	---
Prosimulium sp.	C-F	6	21	---	---	---	---	---	---	---	99	11	---
Pseudolimnophila sp.	C-G	---	---	---	---	---	---	---	---	---	32	---	---
Psychoda sp.	C-F	---	---	---	---	---	---	---	---	---	1	3	---
Simulium sp.	C-G	56	25	---	9	8	---	5	7	---	---	---	---

Table 4.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 3--Continued

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
Diptera-(cont'd)													
Tanytarsus sp.	C-G, C-F	232	488	---	---	---	---	---	---	---	554	136	---
Thienemanniella sp.	C-G	551	905	---	---	---	---	14	39	---	8	29	---
Thienemanniella sp.	P	117	18	---	248	59	---	23	---	---	16	25	---
Tipula sp.	SH, C-G	91	47	---	46	54	---	10	4	---	183	68	---
Chironomidae pupae	---	16	11	---	39	46	---	2	4	---	3	7	---
Tribe Chironomini	SH, C-G	---	---	---	---	---	---	13	10	---	1	3	---
Empididae	P, C-G	---	---	---	---	---	---	---	---	---	1	4	---
Coleptera (beetles)	---	---	---	0.0004	---	---	---	---	---	0.0004	---	---	0.0001
Optioservus sp.	S, C-G	---	---	---	---	---	---	---	---	---	1	4	---
Psephenus sp.	S	1	---	---	---	---	---	---	---	---	---	---	---
Elmidae	P	2	4	---	---	---	---	1	4	---	---	---	---
Hemiptera (true bugs)	---	---	---	---	---	---	---	---	---	---	---	---	---
Microvelia americana	P	---	---	---	---	---	---	6	---	---	---	---	---
Odonata (dragonflies and damselflies)	---	---	---	---	---	---	2.29	---	---	---	---	---	---
Cordulegaster maculata	P	---	---	---	---	---	---	---	---	---	1	---	---
Cordulegaster marulata	P	---	---	---	---	---	---	6	---	---	---	---	---
Cordulegaster sp.	P	2	---	---	1	3	---	---	---	---	1	4	---
Megaloptera (alderflies and dobsonflies)	---	---	---	---	---	---	---	---	---	.2158	---	---	---
Nigroinia serricornis	P	---	---	---	---	---	---	1	3	---	---	---	---
HYDRACARINA (water mites)	P	---	---	---	1	3	---	---	---	---	---	---	---
COLLEMBOLA (springtails)	---	---	---	---	---	---	.0036	---	---	.0011	---	---	.0043
Hypogastrura denticulata	C-G	---	---	---	---	---	---	---	---	---	195	585	---
Isotomurus palustris	C-G	9	---	---	19	10	---	9	7	---	7	18	---

Table 4.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 3--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)
COLLEMBOLA-(cont'd)													
Proisotoma sp.	C-G	---	---	---	---	---	---	---	---	---	1	3	---
Sminthurides aquaticus	C-G	---	---	---	6	13	---	---	---	---	40	29	---
CRUSTACEA													
Isopoda (sow bugs)	---	---	---	---	---	---	---	---	---	0.0013	---	---	---
Asellus intermedius	C-G	---	---	---	---	---	---	3	3	---	---	---	---
Amphipoda (sideswimmers)	---	---	---	---	---	---	0.0489	---	---	.0092	---	---	0.0113
Hyalella sp.	C-G	24	---	---	---	---	---	---	---	---	---	---	---
Hyalella azteca	C-G	---	---	---	25	5	---	8	3	---	97	3	---
Decapoda (crayfish)	---	---	---	---	---	---	---	---	---	---	---	---	1.6478
Asticidae	C-G	---	---	---	---	---	---	1	---	---	---	---	---
Cambarus sp.	C-G, P	---	---	---	---	---	---	---	---	---	19	11	---
Procambarus sp.	C-G, P	2	---	---	8	---	---	---	---	---	12	---	---
MOLLUSCA													
Gastropoda (snails)	---	---	---	.0062	---	---	.0010	---	---	.0015	---	---	.0010
Ancylidae	S	---	---	---	1	3	---	---	---	---	---	---	---
Ferrissia sp.	S	---	---	---	---	---	---	2	5	---	1	3	---
Laevapex fuscus	S	4	15	---	---	---	---	---	---	---	---	---	---
Pelecypoda (clams)	---	---	---	---	---	---	.0467	---	---	.0046	---	---	.0051
Sphaerium sp.	C-F	30	---	---	9	5	---	6	10	---	2	4	---

Table 4.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 3--Continued

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)
OLIGOCHAETA (worms)	---	---	---	0.0740	---	---	0.0129	---	---	0.0022	---	---	0.2624
Chaetogaster sp.	C-G	---	---	---	---	---	---	---	---	---	1	3	---
Crustipellis tribranchiata	C-G	---	---	---	---	---	---	---	---	---	2	5	---
Eiseniella tetraedra	C-G	4	14	---	---	---	---	1	---	---	7	11	---
Paranais litoralis	C-G	---	---	---	---	---	---	---	---	---	3	8	---
Limnodrilus sp.	C-G	32	93	---	72	5	---	---	---	---	---	---	---
Lumbricidae	C-G	---	---	---	---	---	---	---	---	---	32	---	---
Tubificidae	C-G	243	---	---	32	---	---	110	36	---	356	187	---
HIRUDINEA (leeches)	---	---	---	.0020	---	---	---	---	---	.0735	---	---	---
Helobdella sp.	P, C-G	---	---	---	---	---	---	3	8	---	---	---	---
Placobdella sp.	P	---	---	---	1	3	---	---	---	---	---	---	---
Total organisms	---	2,886	---	1.57	1289	---	9.27	334	---	1.01	2838		2.28
Total taxa	83	38	---	---	26	---	---	33	---	---	46		---
Shannon-weaver diversity index	---	---	2.83	---	---	3.26	---	---	2.51	---	---		2.90

Table 5.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 4
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)
INSECTA													
Ephemeroptera (mayflies)	---	---	---	0.0057	---	---	0.2858	---	---	---	---	---	0.1824
Caenis sp.	C-G	56	4	---	198	138	---	---	---	---	260	445	---
Trichoptera (caddisflies)	---	---	---	.6430	---	---	.0043	---	---	---	---	---	.0416
Cheumatopsyche sp.	C-F	8	29	---	5	16	---	---	---	---	---	---	---
Hydropsyche sp.	SH, S	14	50	---	2	5	---	---	---	---	---	---	---
Oecetis inconspicua	P, SH	---	---	---	---	---	---	---	---	---	32	---	---
Orthotrichia sp.	C-G	2	5	---	---	---	---	---	---	---	4	14	---
Potamyia flava	C-F	---	---	---	---	---	---	---	---	---	4	14	---
Diptera (true flies)	---	---	---	31.9801	---	---	3.8208	---	---	.0126	---	---	17.1789
Alabesmia sp.	P, C-G	---	---	---	---	---	---	3	8	---	---	---	---
Bezzia sp.	P	18	15	---	6	13	---	1	3	---	4	14	---
Chaoborus punctipennis	P	2	4	---	6	5	---	---	---	---	---	---	---
Cryptochironomus sp.	P	20	---	---	---	---	---	---	---	---	---	---	---
Glyptotendipes sp.	SH, C-F, C-G	8,045	5,525	---	3,239	573	---	83	4	---	15,356	5,615	---
Hemerodromia sp.	P, C-G	55	169	---	---	---	---	---	---	---	---	---	---
Limnophila sp.	P	---	---	---	1	---	---	---	---	---	---	---	---
Limophora sp.	P	---	---	---	---	---	---	16	---	---	---	---	---
Ormosia sp.	C-G	---	---	---	---	---	---	1	3	---	---	---	---
Parachironomus sp.	P	---	---	---	---	---	---	2	5	---	---	---	---
Parametriocnemus sp.	C-G	110	122	---	107	135	---	---	---	---	---	---	---
Phaenopsectra sp.	S, C-G	288	143	---	5	13	---	---	---	---	---	---	---
Polypedilum sp.	SH, C-G, P	---	---	---	---	---	---	2	7	---	---	---	---
Simulium sp.	C-F	---	---	---	13	33	---	---	---	---	---	---	---
Tanytarsus sp.	C-G, C-F	60	83	---	596	507	---	---	---	---	---	---	---

Table 5.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 4--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m², square meters; No., number; g/m², grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m²)	January - February Biomass (g/m²)	April No.	April Density (No./m²)	April Biomass (g/m²)	July - August No.	July - August Density (No./m²)	July - August Biomass (g/m²)	November No.	November Density (No./m²)	November Biomass (g/m²)
Thienmannimyia sp.	P	---	---	---	---	---	---	6	5	---	---	---	---
Thienmannimyia sp. group	P	2,567	1,935	---	498	364	---	---	---	---	2,256	2,255	---
Tipula sp.	SH, C-G	---	---	---	---	---	---	4	---	---	---	---	---
Chironomidae pupa	---	34	4	---	55	59	---	---	---	---	44	72	---
Other Chironomini	---	---	---	---	---	---	---	2	5	---	---	---	---
Tanypodinae	---	---	---	---	---	---	---	1	4	---	---	---	---
Coleoptera (beetles)	---	---	---	---	---	---	---	---	---	0.0159	---	---	---
Dytiscidae	P	4	---	---	---	---	---	---	---	---	32	---	---
Hydroporus sp.	P	---	---	---	---	---	---	1	3	---	---	---	---
Hydrophilidae	P	---	---	---	---	---	---	4	---	---	---	---	---
Odonata (dragonflies and damselflies)	---	---	---	0.0904	---	---	0.0739	---	---	.2243	---	---	---
Cordulegaster sp.	P	---	---	---	4	15	---	---	---	---	---	---	---
Enallagma sp.	P	3	8	---	---	---	---	---	---	---	---	---	---
Neurocordulia sp.	P	---	---	---	---	---	---	4	10	---	---	---	---
Megaloptera (alderflies and dobsonflies)	---	---	---	---	---	---	---	---	---	---	---	---	---
Chauliodes Rastricornis	P	---	---	---	---	---	---	4	---	---	---	---	---
HYDRACARINA (water mites)	---	---	---	---	---	---	---	---	---	---	---	---	---
Limnesia sp.	P	---	---	---	4	15	---	---	---	---	---	---	---
COLLEMBOLA (springtails)	---	---	---	---	---	---	---	---	---	.0014	---	---	---
Isotomurus palustris	C-G	---	---	---	2	5	---	---	---	---	---	---	---
Isotomurus viridis	C-G	---	---	---	---	---	---	1	4	---	---	---	---
CRUSTACEA													
Amphipoda (sideswimmers)	---	---	---	.0711	---	---	1.4522	---	---	.0057	---	---	1.3197
Gammarus lacustris	C-G	---	---	---	36	---	---	---	---	---	---	---	---

Table 5.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 4--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)
Hyalella sp.	C-G	91	32	---	---	---	---	---	---	---	---	---	---
Hyalella azteca	C-G	---	---	---	102	5	---	38	14	---	1,348	88	---
Decapoda (crayfish)	---	---	---	---	---	---	---	---	---	---	---	---	---
Cambarus sp.	C-G, P	---	---	---	---	---	---	---	---	---	1	---	---
Procambarus sp.	C-G, P	---	---	---	5	---	---	---	---	---	1	---	---
MOLLUSCA													
Gastropoda (snails)	---	---	---	.1828	---	---	.0345	---	---	.0266	---	---	1.4733
Lymnaea sp.	S, C-G	---	---	---	---	---	---	4	---	---	---	---	---
Physa sp.	S, C-G	39	4	---	78	26	---	7	4	---	288	72	---
Pelecypoda (clams)	---	---	---	.2330	---	---	---	---	---	1.9767	---	---	7.3222
Sphaerium sp.	C-F	37	32	---	---	---	---	50	144	---	512	345	---
OLIGOCHAEATA (worms)	---	---	---	.3859	---	---	.4073	---	---	.0826	---	---	.5543
Eiseniella tetraedra	C-G	---	---	---	---	---	---	40	36	---	32	115	---
Tubificidae	C-G	166	273	---	365	776	---	147	93	---	188	560	---
HIRUDINEA (leeches)	---	---	---	1.5617	---	---	---	---	---	.1224	---	---	3.5541
Batrachobdella sp.	P, C-G	---	---	---	---	---	---	---	---	---	4	10	---
Erpobdella punctata	P, C-G	---	---	---	---	---	---	5	4	---	---	---	---
Erpobdella sp.	P, C-G	11	11	---	1	---	---	---	---	---	104	29	---
Helobdella Stagnalis	P, C-G	---	---	---	---	---	---	---	---	---	216	316	---
Helobdella sp.	P, C-G	---	---	---	---	---	---	112	11	---	---	---	---
Placobdella sp.	P	4	---	---	---	---	---	---	---	---	---	---	---
TURBELLARIA (flat worms)	---	---	---	---	---	---	0.0169	---	---	---	---	---	0.2826
Dugesia sp.	C-G	---	---	---	15	4	---	---	---	---	---	---	---
Dugesia tigrina	P, C-G	---	---	---	---	---	---	---	---	---	68	174	---
Total organisms	---	11,634	---	35.0	5,343	---	6.02	538	---	2.24	20,754	---	31.9
Total taxa	54	22	---	---	23	---	---	24	---	---	20	---	---
Shannon-weaver diversity index	---	---	---	1.48	---	---	2.60	---	---	2.26	---	---	2.17

Table 6.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 5
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)
INSECTA													
Ephemeroptera (mayflies)	---	---	---	0.0003	---	---	0.0591	---	---	---	---	---	---
Caenis sp.	C-G	5	5	---	9	20	---	---	---	---	---	---	---
Trichoptera (caddisflies)	---	---	---	1.1915	---	---	.0180	---	---	0.0271	---	---	---
Cheumatopsyche sp.	C-F	48	97	---	29	65	---	2	5	---	---	---	---
Hydropsyche sp.	SH, S	3	4	---	---	---	---	---	---	---	---	---	---
Potamyia flava	C-F	---	---	---	1	---	---	---	---	---	---	---	---
Limnephilidae	SH, C-G, S	---	---	---	---	---	---	---	---	---	1	4	---
Diptera (true flies)	---	---	---	.3080	---	---	.2321	---	---	.0068	---	---	.0251
Bezzia sp.	P	6	7	---	9	3	---	12	15	---	32	---	---
Chaoborus punctipennis	P	---	---	---	16	14	---	1	---	---	---	---	---
Chaetocladius sp.	C-G	---	---	---	---	---	---	---	---	---	1	4	---
Chironomus sp.	C-G, SH	---	---	---	180	461	---	---	---	---	8	20	---
Corynoneura sp.	C-G	2	5	---	---	---	---	---	---	---	---	---	---
Cryptochironomus sp.	P	88	165	---	8	29	---	---	---	---	---	---	---
Dicrotendipes sp.	C-G, S	---	---	---	---	---	---	85	4	---	---	---	---
Einfeldia sp.	C-G	---	---	---	---	---	---	---	---	---	1	3	---
Endochironomous sp.	SH	---	---	---	---	---	---	---	---	---	6	15	---
Erioptera sp.	C-G	---	---	---	8	---	---	93	4	---	---	---	---
Glyptotendipes sp.	SH, C-F, C-G	67	115	---	427	12	---	3	8	---	16	---	---
Hemerodromia sp.	P, C-G	1	3	---	---	---	---	---	---	---	2	5	---
Limnophila sp.	P	3	7	---	8	---	---	---	---	---	---	---	---
Limnophora sp.	P	---	---	---	---	---	---	5	---	---	---	---	---
Micropsectra sp.	C-G	---	---	---	74	189	---	---	---	---	---	---	---
Parametriocnemus sp.	C-G	5	7	---	154	162	---	4	7	---	---	---	---

Table 6.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 5--Continued

[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)	No.	Density (No./m^2)	Biomass (g/m^2)
Phaenopsectra sp.	S, C-G	1,735	237	---	12	29	---	---	---	---	---	---	---
Polypedilum sp.	SH, C-G	---	---	---	---	---	---	---	---	---	2,200	470	---
Procladius sp.	P, C-G	---	---	---	---	---	---	---	---	---	195	18	---
Prosimulium sp.	C-F	---	---	---	6	22	---	---	---	---	2	7	---
Stratiomys sp.	C-G	---	---	---	---	---	---	1	3	---	---	---	---
Tanytarus sp.	C-G, C-F	1	3	---	---	---	---	---	---	---	17	3	---
Thienemannimyia sp.	P	---	---	---	4	10	---	11	18	---	---	---	---
Thienemannimyia sp. group	P	222	144	---	501	438	---	---	---	---	---	---	---
Tipula sp.	SH, C-G	4	---	---	---	---	---	6	5	---	---	---	---
Chironomidae pupae	---	11	7	---	145	12	---	15	5	---	1	3	---
Dolichopodidae	---	---	---	---	---	---	---	3	---	---	16	---	---
Sciomyzidae	---	---	---	---	---	---	---	---	---	---	16	---	---
Tribe Chironomini	SH, C-G	---	---	---	---	---	---	56	14	---	---	---	---
Coleoptera (beetles)	---	---	---	---	---	---	.0947	---	---	---	---	---	---
Berosus sp.	C-G	---	---	---	14	2	---	1	---	---	---	---	---
Deronectes griscostriatus	P	---	---	---	2	5	---	---	---	---	---	---	---
Dubiraphia sp.	C-G, S	2	3	---	---	---	---	---	---	---	---	---	---
Dytiscidae	---	---	---	---	---	---	---	1	---	---	---	---	---
Odonata (dragonflies and damselflies)	---	---	---	.0079	---	---	---	---	---	---	---	---	---
Calopteryx sp.	P	1	5	---	---	---	---	2	---	---	---	---	---
Calopteryx angustipennis	P	---	---	---	3	---	---	---	---	---	---	---	---
Enallagma sp.	P	---	---	---	1	---	---	---	---	---	---	---	---
Ischnura sp.	P	3	4	---	---	---	---	---	---	---	---	---	---
Omphiogomphus sp.	P	---	---	---	1	---	---	---	---	---	---	---	---

Table 6.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 5--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
Megaloptera (alderflies and dobsonflies)	---	---	---	---	---	---	---	---	---	---	---	---	---
Chauliodes sp.	P	---	---	---	1	---	---	---	---	---	---	---	---
COLLEMBOLA (springtails)	---	---	---	0.0005	---	---	0.0025	---	---	0.0072	---	---	0.0068
Hypogastrura denticulata	C-G	---	---	---	---	---	---	---	---	---	19	68	---
Isotomurus palustris	C-G	6	15	---	4	12	---	9	11	---	1	4	---
Salina sp.	C-G	---	---	---	---	---	---	1	4	---	---	---	---
Sminthurides aquaticus	C-G	---	---	---	---	---	---	---	---	---	7	3	---
CRUSTACEA													
Isopoda (sow bugs)	---	---	---	.0845	---	---	---	---	---	---	---	---	---
Asellus intermedius	C-G	---	---	---	---	---	---	1	3	---	---	---	---
Asellus sp.	C-G	2	5	---	---	---	---	---	---	---	---	---	---
Amphipoda (side swimmers)	---	---	---	.0036	---	---	---	---	---	.0054	---	---	.0004
Gammarus sp.	C-G	1	3	---	---	---	---	---	---	---	---	---	---
Hyalella azteca	C-G	---	---	---	2	5	---	1	4	---	3	11	---
Decapoda (crayfish)	---	---	---	---	---	---	---	---	---	---	---	---	---
Cambaridae	C-G	---	---	---	2	---	---	---	---	---	---	---	---
Cambarus sp.	C-G	---	---	---	---	---	---	---	---	---	32	---	---
MOLLUSCA													
Gastropoda (snails)	---	---	---	1.0798	---	---	.0046	---	---	---	---	---	---
Physa sp.	S, C-G	2	4	---	6	15	---	---	---	---	---	---	---
Pelecypoda (clams)	---	---	---	---	---	---	---	---	---	---	---	---	---
Uniomerus sp.	C-F	---	---	---	---	---	---	1	---	---	---	---	---
OLIGOCHAETA (worms)	---	---	---	.0371	---	---	.0208	---	---	.0162	---	---	.0219
Eiseniella tetraedra	C-G	---	---	---	---	---	---	---	---	---	1	4	---
Lumbricidae	C-G	---	---	---	---	---	---	---	---	---	10	26	---
Naididae	C-G	---	---	---	---	---	---	---	---	---	7	22	---
Tubificidae	C-G	126	144	---	1,041	108	---	51	68	---	437	118	---
HIRUDINEA (leeches)	---	---	---	---	---	---	---	---	---	---	---	---	---
Erpobdella sp.	P, C-G	1	---	---	---	---	---	2	5	---	---	---	---
Total organisms	---	2,345	---	2.72	2,668	---	0.432	367	---	0.0627	3,034	---	0.0542
Total taxa	60	24	---	---	28	---	---	24	---	---	24	---	---
Shannon-weaver diversity index	---	---	---	2.74	---	---	2.34	---	---	2.24	---	---	1.92

Table 7.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 6
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February No.	January - February Density (No./m^2)	January - February Biomass (g/m^2)	April No.	April Density (No./m^2)	April Biomass (g/m^2)	July - August No.	July - August Density (No./m^2)	July - August Biomass (g/m^2)	November No.	November Density (No./m^2)	November Biomass (g/m^2)
INSECTA													
Ephemeroptera (mayflies)	---	---	---	---	---	---	---	---	---	0.0036	---	---	0.0003
Caenis sp.	C-G	---	---	---	---	---	---	3	3	---	1	3	---
Diptera (trueflies)	---	---	---	0.2359	---	---	0.3511	---	---	.0111	---	---	.0969
Bezzia sp.	P	1	4	---	1	---	---	49	47	---	169	7	---
Chaoborus punctipennis	P	---	---	---	---	---	---	1	---	---	---	---	---
Chironomus sp.	C-G, SH	---	---	---	---	---	---	---	---	---	2	7	---
Cricotopus bicintus	SH, C-G	---	---	---	---	---	---	---	---	---	69	39	---
Cricotopus sp.	SH, C-G	---	---	---	---	---	---	2	3	---	22	36	---
Cryptochironomus sp.	P	---	---	---	---	---	---	---	---	---	2	5	---
Einfeldia sp.	C-G	---	---	---	---	---	---	---	---	---	1	3	---
Erioptera sp.	C-G	---	---	---	---	---	---	---	---	---	1	3	---
Glyptotendipes sp.	SH, C-F, C-G	12	32	---	32	90	---	6	3	---	---	---	---
Goeldichironomus holoprasinus	C-G	---	---	---	---	---	---	---	---	---	11	4	---
Molophilus sp.	SH	1	4	---	---	---	---	---	---	---	---	---	---
Parametriocnemus sp.	C-G	7	25	---	931	1,346	---	---	---	---	---	---	---
Phaenopsectra sp.	S, C-G	177	65	---	8	22	---	---	---	---	---	---	---
Polypedilum sp.	SH, C-G, P	---	---	---	---	---	---	7	11	---	3,294	1,278	---
Prosimulium sp.	C-F	---	---	---	---	---	---	---	---	---	1	4	---
Psychoda sp.	C-F	---	---	---	---	---	---	1	4	---	---	---	---
Tanytarsus sp.	C-G, C-F	---	---	---	40	25	---	---	---	---	2	5	---
Tipula sp.	SH, C-G	---	---	---	---	---	---	---	---	---	1	3	---
Thienemannimyia sp.	P	---	---	---	---	---	---	1	3	---	---	---	---
Thienemannimyia sp. group	P	52	47	---	80	136	---	---	---	---	35	11	---

Table 7.--Numbers, density, biomass, and diversity of benthic invertebrates collected at station 6--Continued
[C-G, Collector-gatherer; C-F, Collector-filterer; S, Scraper; SH, Shredder; P, Predator; m^2, square meters; No., number; g/m^2, grams per square meter; ---, no data]

Taxa	Functional group	January - February			April			July - August			November		
		No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)	No.	Density ($No./m^2$)	Biomass (g/m^2)
Diptera-(cont'd)													
Chironomidae pupae	---	2	4	---	7	11	---	1	4	---	8	---	---
Orthocladiinae	C-G, S	---	---	---	---	---	---	---	---	---	8	---	---
Coleoptera (beetles)	---	---	---	0.0008	---	---	---	---	---	---	---	---	---
Dytiscidae	P	2	7	---	---	---	---	---	---	---	---	---	---
Odonata (dragonflies and damselflies)	---	---	---	.1508	---	---	---	---	---	---	---	---	---
Calopteryx sp.	P	1	4	---	---	---	---	---	---	---	---	---	---
Cordulegaster sp.	P	---	---	---	1	---	---	---	---	---	---	---	---
Pachydiplax longipennis	P	---	---	---	---	---	---	---	---	---	8	---	---
Libellulidae	P	---	---	---	---	---	---	---	---	---	1	4	---
HYDRACARINA (water mites)	---	---	---	---	---	---	---	---	---	---	---	---	---
Limnesia sp.	P	---	---	---	---	---	---	---	---	---	8	---	---
COLLEMBOLA (spingtails)	---	---	---	.0004	---	---	0.0007	---	---	---	---	---	0.0071
Hypogastrura denticulata	C-G	---	---	---	---	---	---	---	---	---	55	197	---
Isotomurus palustris	C-G	19	4	---	10	11	---	---	---	---	---	---	---
CRUSTACEA													
Decapoda (crayfish)	---	---	---	---	---	---	---	---	---	---	---	---	---
Cambarus sp.	C-G, P	---	---	---	---	---	---	---	---	---	40	---	---
Procambarus sp.	C-G	---	---	---	2	---	---	---	---	---	---	---	---
MOLLUSCA													
Gastropoda (snails)	---	---	---	.0025	---	---	---	---	---	---	---	---	.0718
Physa sp.	S, C-G	11	4	---	---	---	---	---	---	---	2	7	---
OLIGOCHAETA (worms)	---	---	---	.5295	---	---	---	---	---	1.6026	---	---	.1432
Eiseniella tetraedra	C-G	---	---	---	3	---	---	9	25	---	11	4	---
Limnodrilus sp.	C-G	28	---	---	---	---	---	---	---	---	---	---	---
Lumbriculidae	C-G	---	---	---	---	---	---	1	4	---	---	---	---
Tubificidae	C-G	35	126	---	15	21	---	79	47	---	173	39	---
HIRUDINEA (leeches)	---	---	---	.0129	---	---	---	---	---	---	---	---	---
Erpobdella sp.	P, C-G	1	4	---	---	---	---	---	---	---	---	---	---
Total organisms	---	349	---	0.933	1,130	---	0.352	160	---	1.62	3,925	---	0.318
Total taxa	37	14	---	---	12	---	---	12	---	---	24	---	---
Shannon-weaver diversity index	---	---	---	2.28	---	---	0.98	---	---	2.09	---	---	1.28

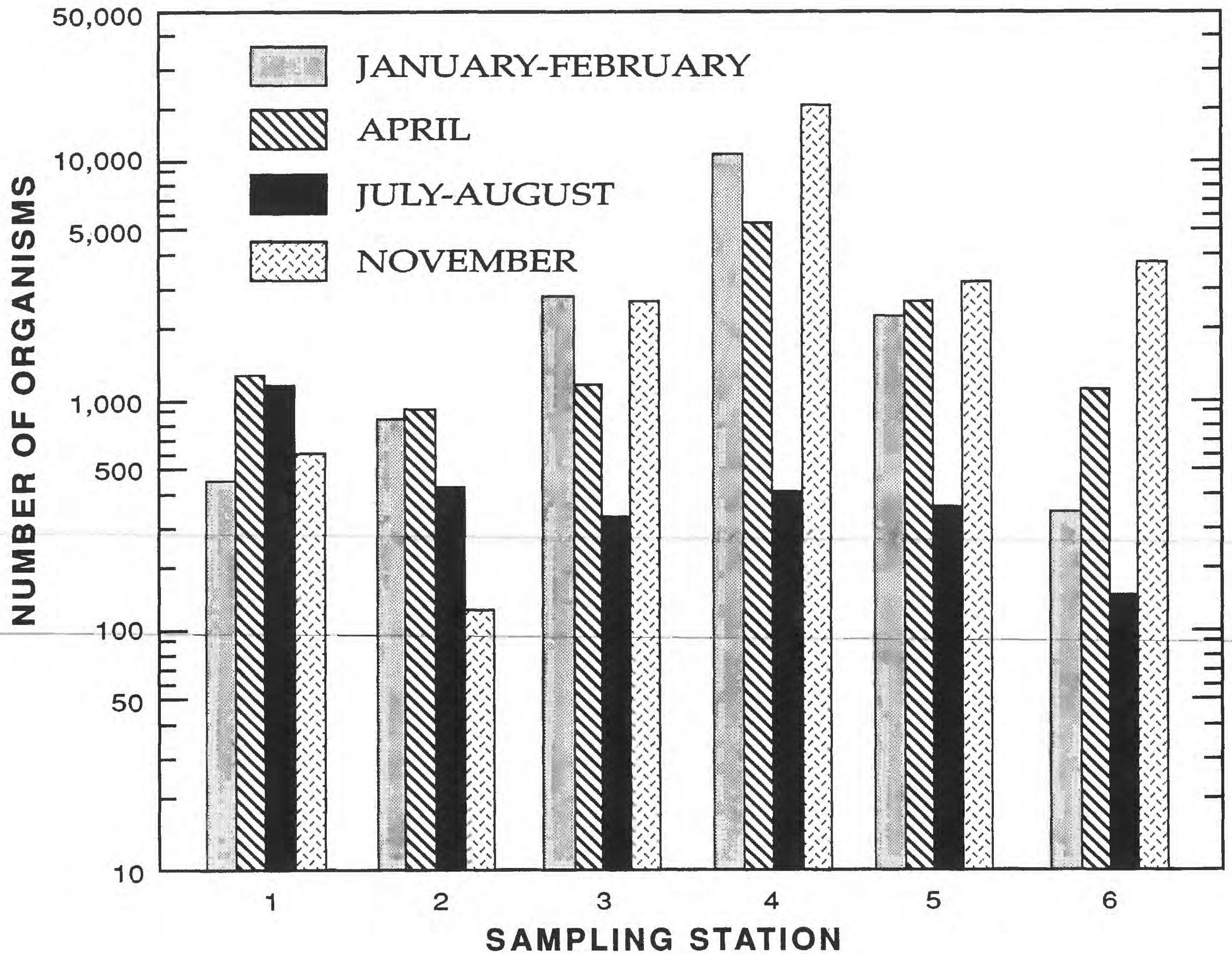


Figure 6.-- Number of benthic invertebrate organisms collected, by station in 1988.

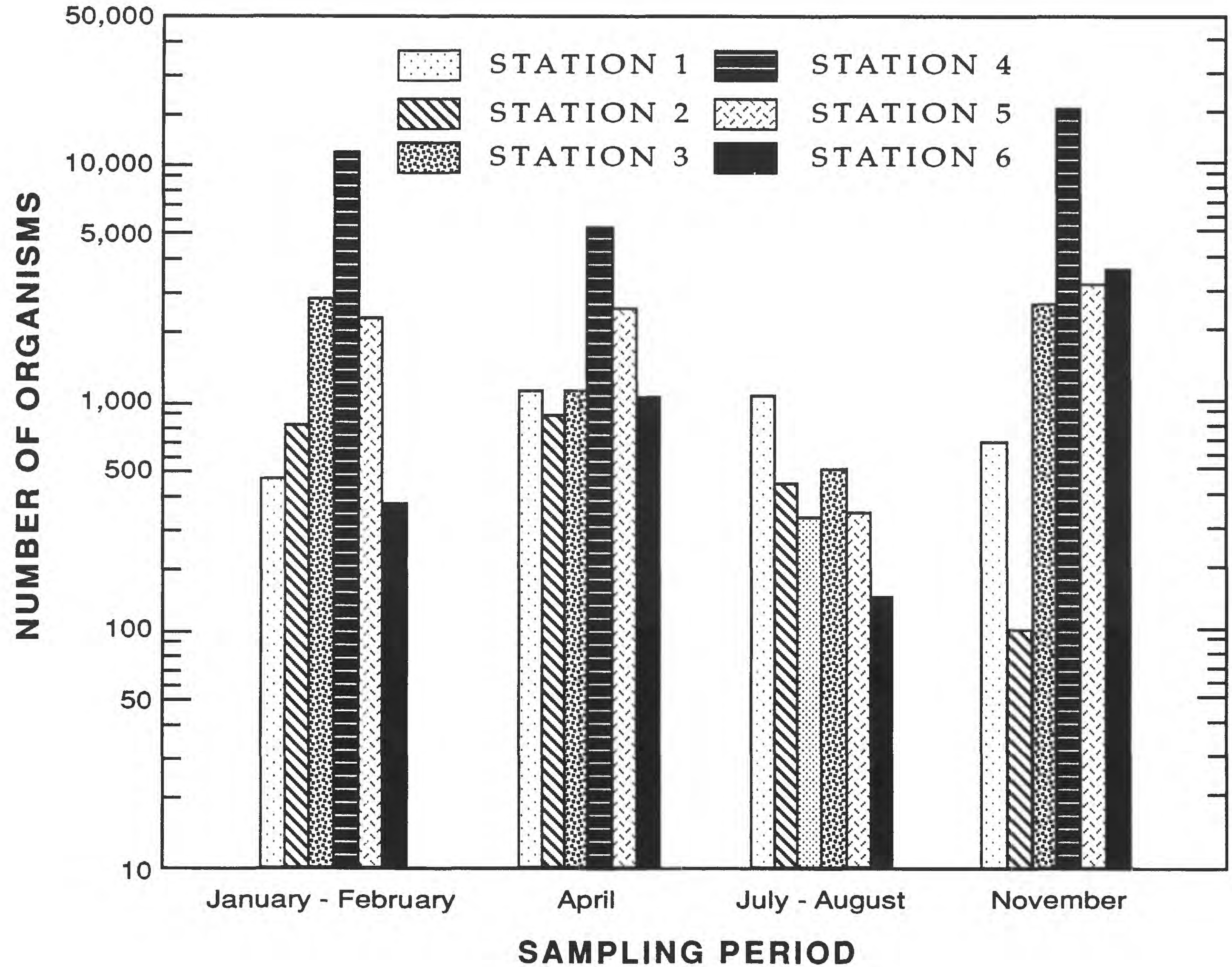


Figure 7.--Number of benthic invertebrate organisms collected, by sampling period in 1988.

Species Richness

Species richness is defined for this study as the number of taxa collected at a station. Generally, the two lake stations were very similar in species richness throughout most of the year, with station 2 showing slightly fewer taxa than station 1 (fig. 8). The total number of taxa found during the year at station 1 was 57, while the number of taxa found at station 2 was 44. The stream stations also supported greater numbers of taxa upstream of the landfill than downstream. The total numbers of taxa found during the year at stations 3 and 4 were 83 and 54, respectively, while the number of taxa found at stations 5 and 6 were 60 and 37, respectively. Of the stream stations, station 3 consistently had the most taxa, including 5 Trichopteran, 2 Plecopteran, and 2 Ephemeropteran taxa. Station 6 usually had the fewest taxa, and stations 4 and 5 had similar intermediate numbers of taxa (fig. 8). Variations in diversity among the Chironomid flies were the primary source of variation in species richness.

Generally, the sampling period with the fewest taxa was July-August (fig. 9). The aquatic habitat at the four stream sites was restricted by low flow during this period. Stations 4, 5, and 6 all had days of zero flow during May, June, July, or August. In addition, summer is a time when many aquatic insects have matured to the adult phase and emerged from the water.

Diversity

The modified Shannon-Weaver diversity index, a measure of the number of species and their relative abundance, is computed from the following formula:

$$H' = -\sum_{i=1}^{s} \frac{n_i}{n} \log_2 \frac{n_i}{n} \qquad (1)$$

where H' = Shannon-Weaver diversity index
s = total number of taxa
n_i = total number of individuals of each single taxon in the sample
n = total number of individuals of all taxa in the sample

The diversity index for most of the samples falls in the range of 1.5 to 3. This is relatively low, considering that the index can range from 1 to 5. The large number of specimens from a relatively small number of Chironomid taxa are primarily responsible for the low values.

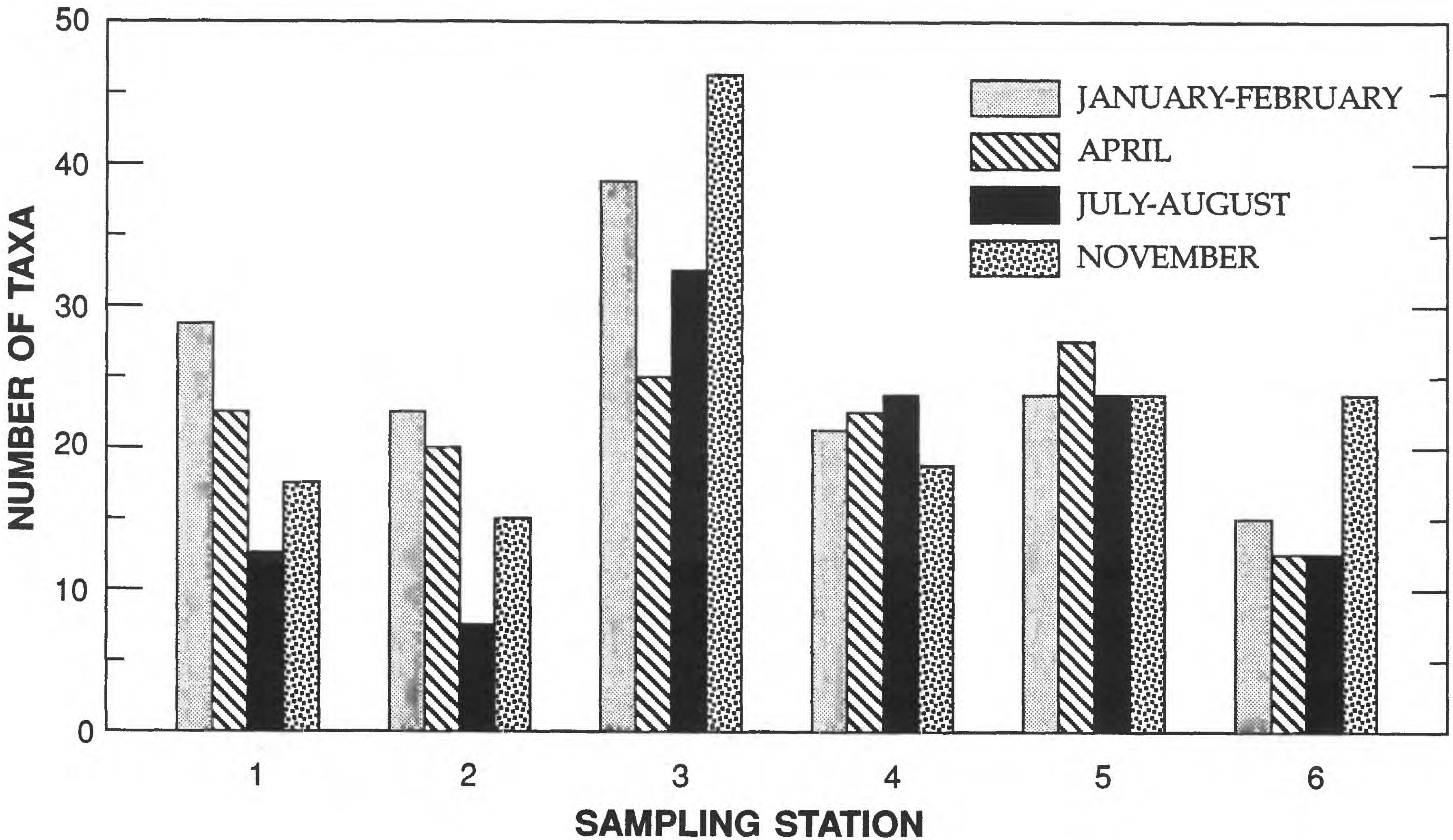


Figure 8.--Species richness, by station.

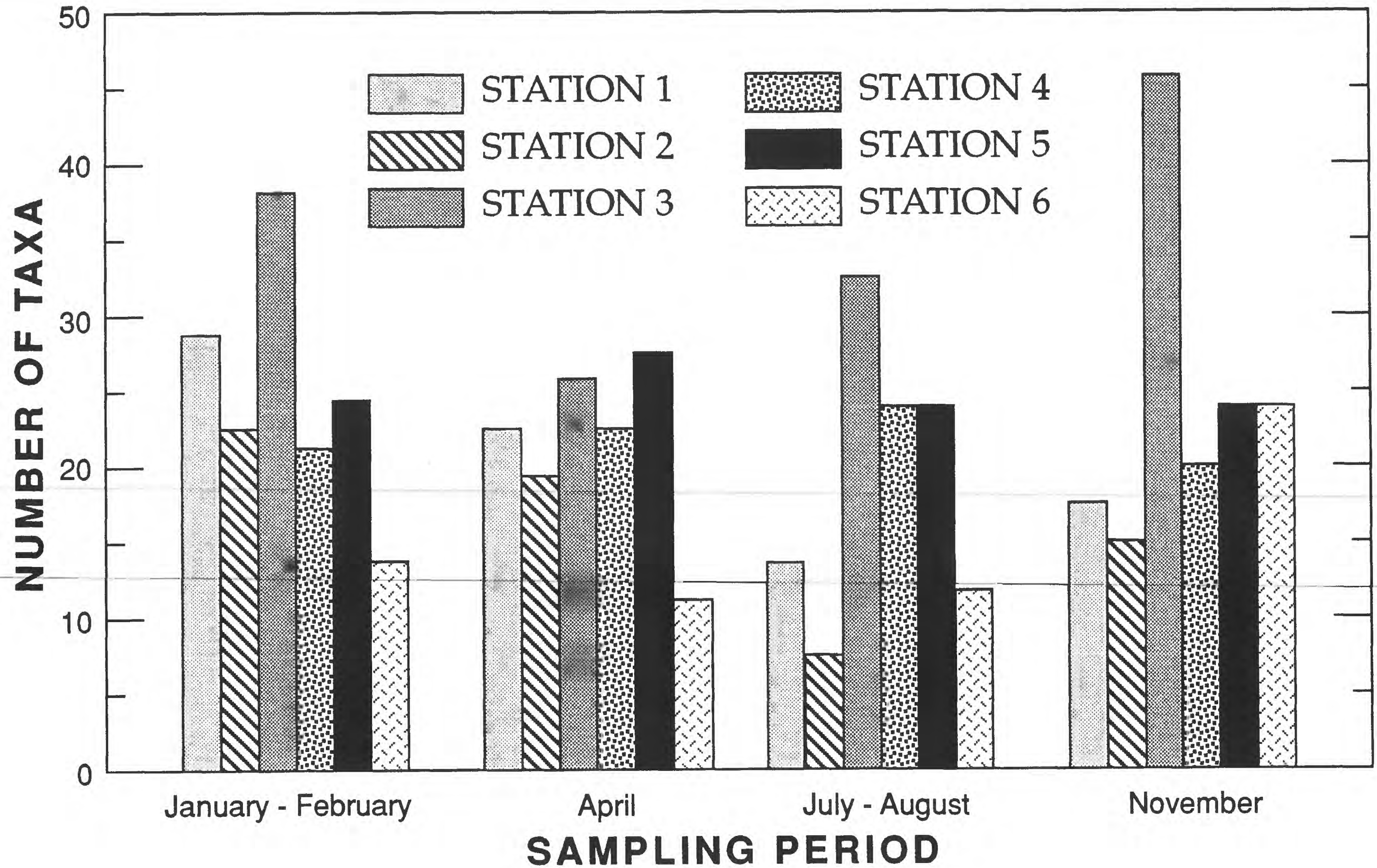


Figure 9.--Species richness, by sampling period.

A comparison of diversity indices for species collected using the Ponar and Surber samplers at the six stations is shown by station in figure 10, and by sampling period in figure 11. The diversity indices for the two lake stations have much the same pattern (fig. 10). Of the stream sites, station 3 consistently shows the greatest diversity; station 6 most often shows the least; and the diversity indices at stations 4 and 5 are intermediate and similar to each other. There does not appear to be a distinct seasonal pattern in the data (fig. 11).

Biomass

The standing crop, or biomass, of benthic invertebrates at a sampling station provides an indicator of the productivity of the benthic community. In this study biomass was computed for each taxonomic order (tables 2-7). Biomass of benthic invertebrates sampled ranged from 0.0542 g/m^2 at station 5 in November to 35.0 g/m^2 at station 4 in January. Mean annual biomass ranged from 0.806 g/m^2 at station 6 to 18.8 g/m^2 at station 4. In general, the biomass at stream stations upstream of the landfill (mean of 11.2 g/m^2) was more than ten times greater than the biomass at stream stations downstream of the landfill (mean of 0.812 g/m^2). Biomass at the lake stations was intermediate, with slightly greater biomass at the downstream lake station (2) than at the upstream lake station (1). Occasionally a high biomass value was due to a few large specimens of crayfish, dragonfly, clam, or snail, but the greatest biomass generally was due to large numbers of small flies and worms.

Biomass varied seasonally at the 6 stations, but there was no consistent pattern. Maximum biomass at stations 1, 2, and 3 occurred in April due primarily to flies, worms, and leeches. Maximum biomass at stations 4 and 5 occurred in January-February due almost entirely to large numbers of Chironomid flies. Maximum biomass at station 6 occurred in July-August due primarily to worms. When data from all stations are averaged, the greatest biomass occurred in January-February and the least in July-August.

Similarity

The Sorensen similarity index, which is used extensively in population studies, gives an indication of how similar the populations at two stations are, based on the taxa at each station. An index value of one indicates that the two stations have exactly the same taxa, and therefore have the greatest degree of similarity. This index does not take into account the relative abundance of organisms in each taxon, so a taxon represented by 1,000 specimens carries the same weight as a taxon represented by a single specimen. This index is computed using the formula:

$$S = 2c / (a + b) \qquad (2)$$

where a and b are the number of taxa occurring only in communities A and B, respectively; and c is the number of taxa common to both populations.

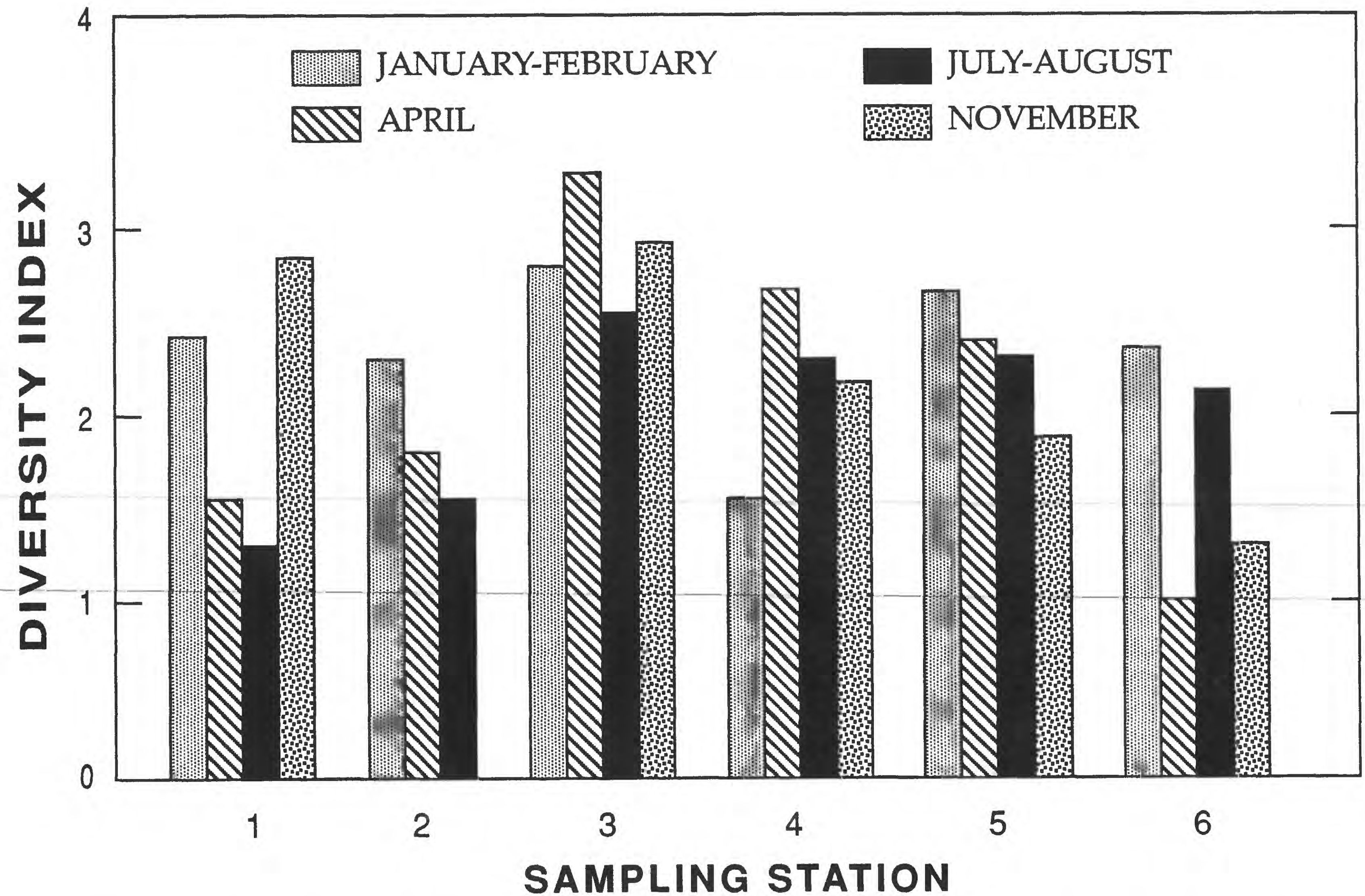


Figure 10.--Diversity index for benthic invertebrate populations sampled using Ponar and Surber samplers, by station.

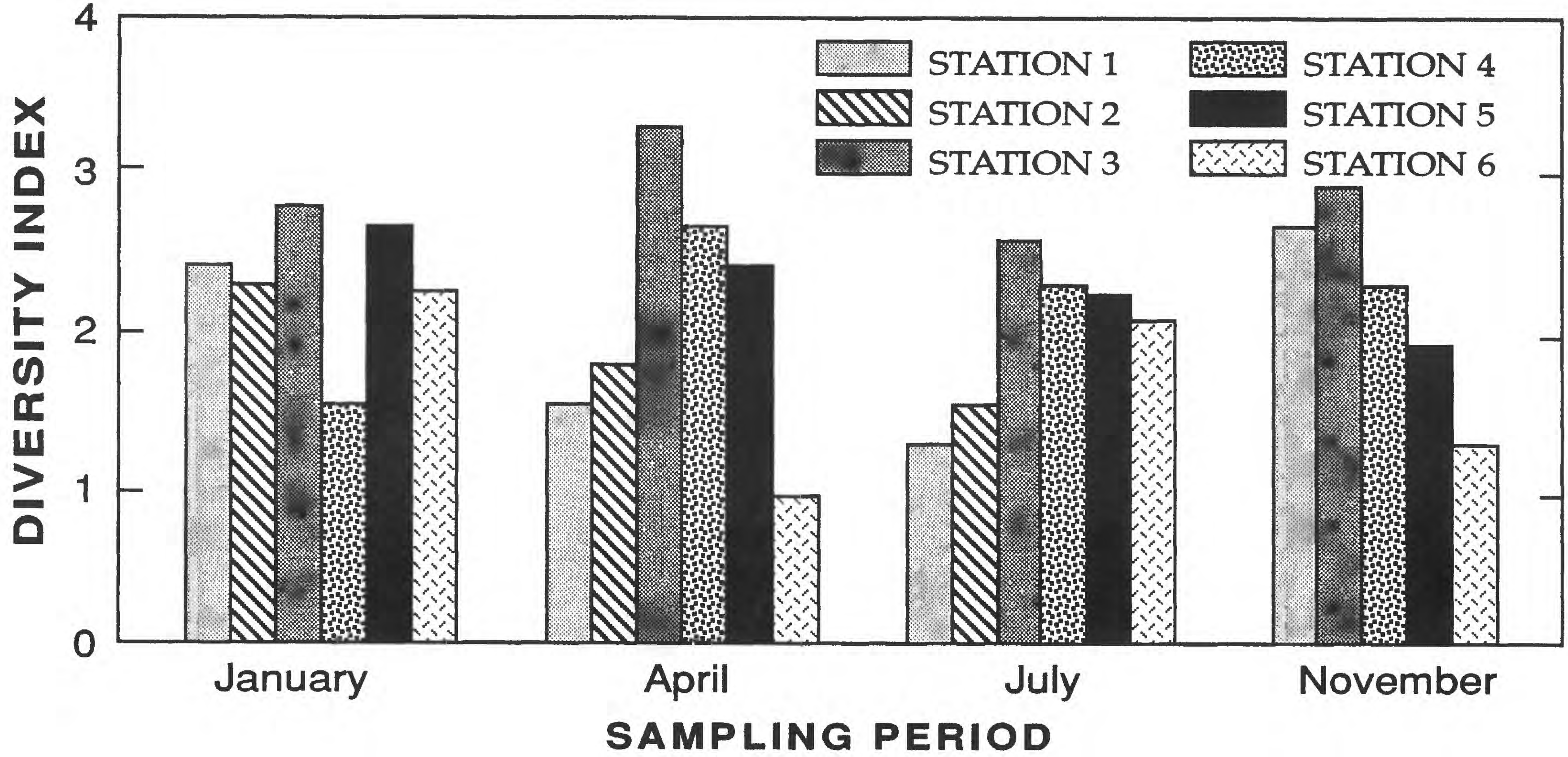


Figure 11.--Diversity index for benthic invertebrate populations sampled using Ponar and Surber samplers, by sampling period.

The similarity index for benthic invertebrates for each of seven pairs of stations is shown in figure 12. The stations that show the highest similarity index are stations 1 and 2. Stations 4 and 5 show a high degree of similarity, as do stations 4 and 6.

Station 3 does not show a high similarity index with any other station. The stream at station 3, unlike the streams at stations 4, 5, and 6, has not been altered substantially from a natural state. The lack of similarity between populations at station 3 and those at other sites may reflect the results of those changes.

The similarity index for the same seven pairs of stations, grouped by sampling period is shown in figure 13. Again there is evidence of seasonality, where the lowest similarity indices are found during November, and the highest in April.

Another approach to the question of similarity is a determination of the number of taxa, of those found at the upstream stations, that were also found at the downstream stations. Of 20 orders of benthic invertebrates found at the 3 upstream stations, 15 were among those found at the 3 downstream stations. Of 116 genera found at the upstream stations, 64 were among those found at the downstream stations. These data indicate that although there is evidence of some limitation of the benthic invertebrate community at the downstream stations relative to the upstream stations, there is still a significant degree of similarity.

Functional Feeding Groups

The benthic invertebrate communities at all six sampling stations contained organisms from all five major functional feeding groups (table 8). Collector-gatherers were dominant, accounting for 35 to 68 percent of the organisms. Shredders, collector-filterers, and predators were moderately abundant. Collector-filterers were scarce at the lake stations however, probably because of the low current velocities. Scrapers were the least abundant group. Proportions of functional feeding groups at the stations upstream of the landfill were similar to those at the downstream stations, except that collector-filterers were less abundant at the downstream stations (5 and 6) than at the upstream stations (3 and 4).

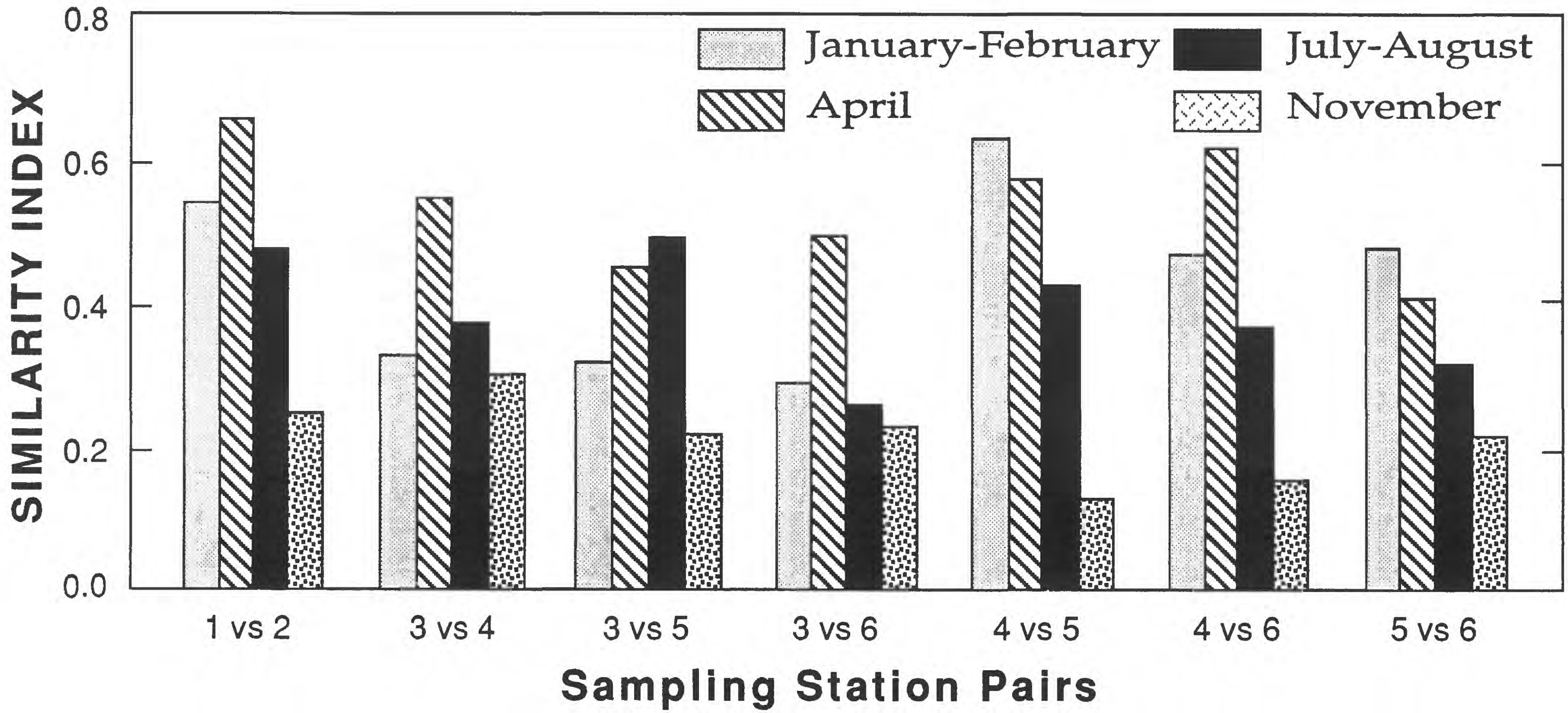


Figure 12.--Similarity index for benthic invertebrate populations sampled using Ponar and Surber samplers, for seven pairs of stations.

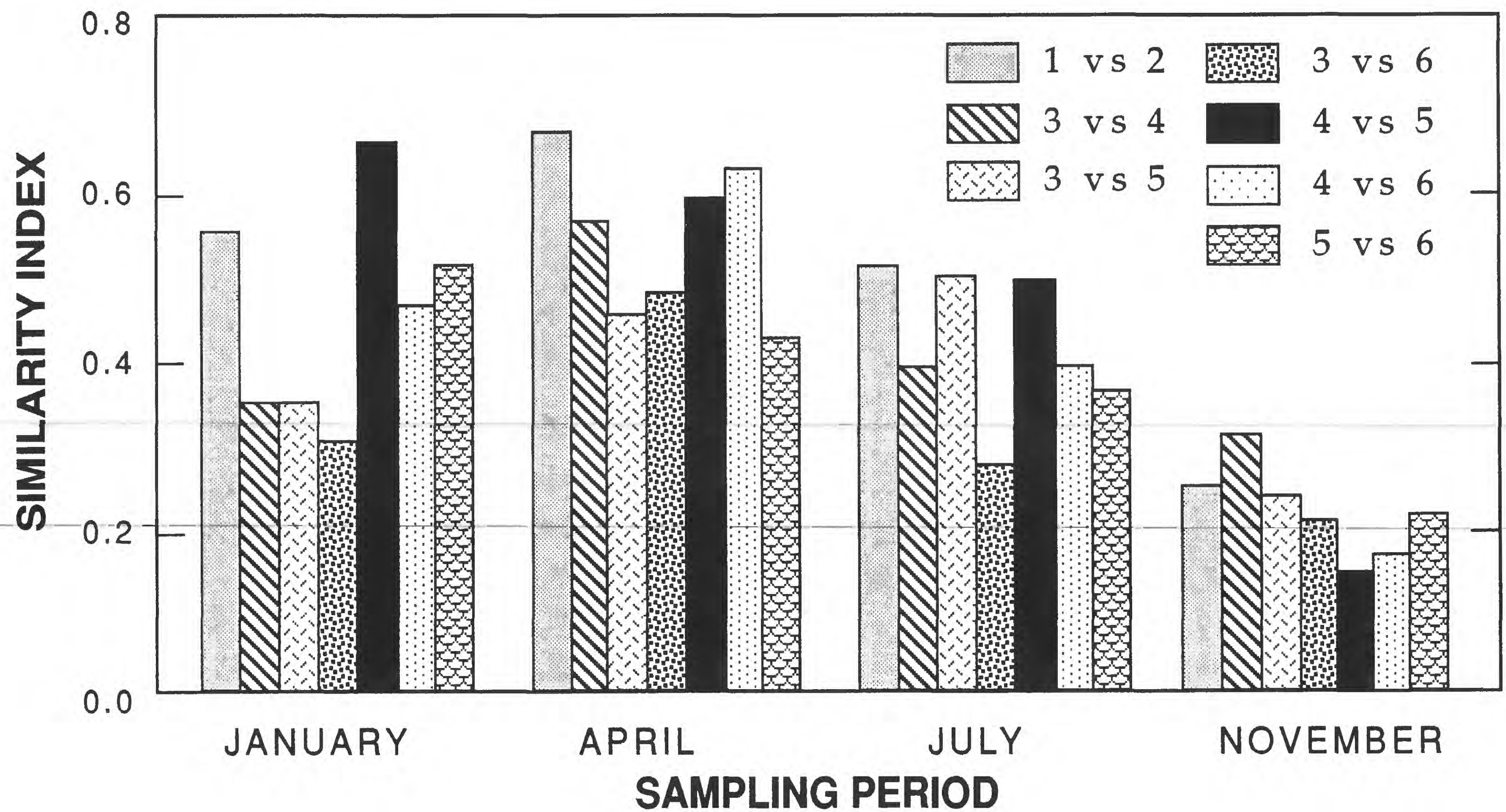


Figure 13.--Similarity index for benthic invertebrate populations at seven pairs of stations sampled using Ponar and Surber samplers, by sampling period.

Table 8--Distribution of functional feeding groups at the six benthic invertebrate sampling stations

Functional feeding group	Number of taxa[1]	Density: Number per square meter	Density: Percent
Station 1			
Collector-gatherer	24	1,180	40
Collector-filterer	1	8	.3
Scraper	11	22	.7
Shredder	8	1,020	35
Predator	25	708	24
Station 2			
Collector-gatherer	22	1,180	48
Collector-filterer	3	29	1
Scraper	11	55	2
Shredder	6	814	33
Predator	18	365	15
Station 3			
Collector-gatherer	49	1,073	68
Collector-filterer	8	196	12
Scraper	10	86	5
Shredder	13	83	5
Predator	26	132	8
Station 4			
Collector-gatherer	30	4,046	35
Collector-filterer	6	3,230	28
Scraper	4	79	1
Shredder	5	2,945	25
Predator	29	1,355	12
Station 5			
Collector-gatherer	37	623	48
Collector-filterer	6	84	6
Scraper	6	68	5
Shredder	8	282	22
Predator	17	225	18
Station 6			
Collector-gatherer	23	883	51
Collector-filterer	4	41	2
Scraper	3	25	1
Shredder	7	376	22
Predator	14	393	23
Mean for all stations			
Collector-gatherer	31	1,498	42
Collector-filterer	5	598	17
Scraper	8	56	2
Shredder	8	920	26
Predator	22	529	15

[1]Total number of taxa in a column may exceed total number of taxa at a station because some taxa fit into more than one functional feeding group.

ANALYSIS OF BENTHIC INVERTEBRATE DATA

Although the parameters and indices described in this report provide a general description of population, some inherent problems in the statistical analysis of biological data should be considered. One of the primary considerations is that most organisms are not randomly distributed within their habitat, and in fact, benthic invertebrates tend to have a clumped distribution. Merritt and Cummins (1984) state that "...the discontinuous (patchy, contagious, negative binomial) distribution pattern of an aquatic insect population is the result of interplay among habitat (for example, sediment-particle size, large wood debris, depth of water), habit (mode of existence), and food availability (Cummins, 1964; Lauff and Cummins, 1964; Anderson and others, 1978)." This distribution makes it difficult to sample a population with much reproducibility. Sampling is further complicated by the fact that habitat, habit and food availability are not constant over time, depending on, for example, the season or extremes in weather.

Another consideration in the analysis of biological data is that each sampling method shows some selectivity; for example, in sampling benthic invertebrates, artificial substrates tend to select for organisms that will live on flat surfaces, while Ponar and Surber samplers are selective for those organisms that can live in the stream or lake bed beneath the water surface, to the exclusion of bank-dwelling, or riparian species. Also, the absence of a species or group of organisms is not necessarily indicative of a problem at that site; the species may have been missed during sampling, or it may not have had the opportunity to inhabit that site, conditions may not have been stable enough for the establishment of the species at that site, or its absence may be a result of species seasonality. All of these variables must all be taken into consideration during the interpretation of the data. Despite the uncertainties, however, there are some general conclusions that can be drawn regarding the six stations sampled in this investigation based on the population parameters and indices, and a knowledge of the localities.

All six stations consistently supported benthic-invertebrate communities of moderate complexity and productivity for the habitats sampled. The ranges of values for density, diversity, and biomass of benthic invertebrates found in this study are generally similar to or greater than those found in other studies in the vicinity (Carlson, 1985; Smock and Gilinsky, 1982; Smock and others, 1985). These coastal-plain habitats have several natural characteristics that tend to limit diversity and productivity of benthic invertebrates. Substrates are primarily sand and silt, which are prone to shift. For many orders such as Ephemeroptera, Plecoptera, and Trichoptera, these substrates are more difficult to colonize than gravel or rocks. The streams are small and prone to dry up, which happened at stations 4, 5, and 6 on several days during the summer. These conditions naturally favor colonization by the opportunistic flies and worms that dominated the samples from these stations. Sedimentation related to earth-moving activities at the landfill apparently decreases the stability of the sandy substrate at the two stream stations downstream of the landfill.

The absence of any specimens in three replicate Ponar samplers at station 2 in November seems highly unusual at first, especially in comparison with station 1. However, the lake is somewhat deeper at station 2 than at station 1, approximately 3 to 5 feet as opposed to 1 to 3 feet, and there is the possibility that the dissolved-oxygen concentration near the bottom of the lake at station 2 may have reached a critical level so that benthic organisms were eliminated from that area. Very low levels of dissolved oxygen are common near the bottom of restricted areas of the lake during the summer and fall (R. Bates, South Carolina Department of Health and Environmental Control, oral commun., 1989); however, no evidence is available to support this hypothesis at station 2. The presence of specimens on the artificial substrates show that shallower depths at station 2 were not affected. Dissolved oxygen at approximately 1 ft below the lake surface at station 2 on November 19, 1987 was 3.5 mg/L (Burt and others, 1991, p. 71).

Of the two lake stations, the one downstream of the landfill (station 2) averaged lower in both species richness and number of organisms. If the calculation of the mean excludes the November sampling, when anoxic conditions may have contributed to a lack of benthic invertebrates at station 2, the difference between the two stations diminishes but does not disappear.

Of the four stream stations, the two stations downstream of the landfill had smaller, less diverse and less productive populations than the two stations upstream of the landfill. Biomass at the upstream stations (stations 3 and 4) was more than ten times greater than at the downstream stations (stations 5 and 6). Station 3 had the most balanced and diverse population. Station 6, downstream of the landfill, had the lowest average species richness and was least similar to station 3. Station 5, also downstream of the landfill, had the lowest average number of organisms.

Among the stream stations, the greatest similarity was between stations 4 and 5, probably because they are on the same stream. Stations 4 and 6 also have a high degree of similarity. All three of these stations are on stream reaches that have undergone some form of disturbance, either damming or landfilling activities. All three also had several days of zero flow during the summer. Station 3, on the other hand, is on a relatively pristine stream, and had sustained flow throughout the study.

Direct comparisons of the data from this study with data from the previous benthic invertebrate study near the landfill (Carlson, 1985) must be made with great caution because of differences in sampling methods, some differences in sampling locations, and the fact that the earlier study was based on a single sampling trip per station. Nevertheless, some comparisons may be informative.

The two studies had four stations (1, 2, 3, and 6) at identical or similar locations, all coincidentally labeled identically. In the 1985 study, stations 1 and 2 were sampled in August and stations 3 and 6 were sampled in November. The comparisons made here apply equally, whether the data from the four 1988 sampling trips are averaged, or whether just the data from the same sampling period as in 1985 are used.

The total number of organisms found at the stations was much greater in 1988 than in 1985. This could be due to differences in sampling methods. Of the four stations in common, shown in following table, the two lake stations (stations 1 and 2) had much lower species richness in the 1988 study than in the 1985 study. One upstream station (station 3) had greater species richness in the 1988 study than in the 1985 study. Species richness at station 6 was similar during the two studies. As in the 1985 study, some relatively intolerant taxa such as mayflies, beetles, caddisflies, and crayfish were found at station 6. These kinds of organisms, usually found in water that has not been heavily contaminated, indicate that the water and habitat conditions at these stations meet certain basic standards required for their survival. The genus of mayfly found at station 6, *Caenis sp.*, is tolerant of a shifting, sandy substrate, unlike most other mayflies. The bulk of the organisms at station 6 were flies and worms, tolerant organisms often associated with disturbed habitats or sandy substrates.

Date	Station 1	Station 2	Station 3	Station 6
	Number of taxa			
1985	26	22	15	23
1988 (1 period)	13	7	46	24
1988 (4 periods)	20	16	36	16
	Number of organisms			
1985	230	288	46	185
1988 (1 period)	1,260	443	2,838	3,925
1988 (4 periods)	924	563	1,837	1,391

Note: 1985 data from Carlson (1985).

Although the biomass of benthic invertebrates at the stream stations downstream of the landfill was about one-tenth that at the stream stations upstream of the landfill in this (1988) study, mean annual biomass at all six stations exceeded the mean annual biomass in stream-channel- bottom sampling sites at three stations on Cedar Creek in Congaree Swamp National Monument that were sampled during October 1980 through September 1981 (Smock and others, 1985). The mean annual biomass in the Cedar Creek samples ranged from 0.15 to 0.25 g/m^2. Cedar Creek is about 20 miles northwest of the landfill and is considered relatively unpolluted (Smock and others, 1985, p. 1492). These results, therefore, indicate that the stream stations downstream of the landfill are less productive than those upstream, but that all six stations are more productive than those on Cedar Creek.

Another indication of the overall condition of the benthic-invertebrate communities near the landfill is the relatively balanced, diverse distribution of the organisms among the five functional feeding groups. The distribution of functional feeding groups found in this study shows greater diversity than the distribution of groups found during 1980-81 at stream-channel-bottom sites in Cedar Creek (Smock and others, 1985). Benthic invertebrate organisms in Cedar Creek included primarily collector-gatherers and collector-filterers. No scrapers or shredders were collected from Cedar Creek.

SUMMARY

As part of a 3-year investigation of surface- and ground-water resources in the vicinity of a hazardous-waste landfill near Pinewood, South Carolina, benthic invertebrates in Lake Marion and three small tributaries near the landfill were studied. Six sampling stations, both upstream and downstream of the landfill, were sampled four times during 1988. The same stations were also sampled for water- and sediment-quality characteristics.

The six stations consistently supported benthic-invertebrate communities of moderate complexity and productivity, comparable to those found in earlier studies in the area. The two lake stations had similar benthic invertebrate communities, but samples from the lake station upstream of the landfill had more organisms and a slightly greater species richness than samples from the lake station downstream of the landfill. The four stream stations, all with moderately complex benthic invertebrate communities, showed a general pattern of decreasing biological diversity and productivity with increasing disturbance of the aquatic habitat. Station 3, on a relatively pristine stream upstream of the landfill, had the greatest species richness and diversity, but it was also the only stream station with no periods of zero flow during this study. The other stream stations, all of which had some disturbance due to damming or landfilling activities, and had several days of zero flow in the summer, had somewhat similar benthic invertebrate communities. Station 4, upstream from the landfill, and station 5, downstream from the landfill on the same stream, had intermediate species richness and diversity. Station 6, downstream from the landfill on a stream originating on the landfill, had the lowest species richness and diversity. The relatively diverse distribution of functional feeding groups at all six stations indicates balanced, complex communities.

Factors other than operation of the landfill may be involved, but evidence indicates that operation of the landfill has resulted in increased sedimentation that has altered the habitat of the streams below it and consequently has reduced the diversity and biomass of the benthic invertebrate communities. Viable benthic invertebrate communities still exist in these streams, however, and no significant contamination has been detected in chemical tests of water and bottom sediment in the streams and in lake Marion. This indicates that the major alteration that has occurred so far is probably due to sedimentation rather than to the release of toxic materials into the water.

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch (in.)	25,400	micrometer
foot (ft)	0.3048	meter
square foot (ft^2)	0.0930	square meter
square meter (m^2)	10.76	square foot
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
yard	0.9144	meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.0282	cubic meter per second
grams per square meter (g/m^2)	0.0002046	pounds per square foot

In keeping with scientific convention, concentrations are reported in milligrams per liter (mg/L), organism density is reported in numbers per square meter, biomass is reported in grams per square meter (g/m^2), and net mesh size is reported in nanometers.

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Degree Fahrenheit (°F) can be converted to degree Celsius (°C) by using the following equation:

$$^{\circ}C = 5/9 \times (^{\circ}F-32)$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.