Characterization and Analysis of Temporal and Spatial Variations in Habitat and Macroinvertebrate Community Structure, Fountain Creek Basin, Colorado Springs and Vicinity, Colorado, 1998–2001

By James F. Bruce

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
foot (ft)	3.048×10^{-1}	meter (m)
foot per second (ft/s)	3.048×10^{-1}	meter per second (m/s)
gallon (gal)	3.785×10^{0}	liter (L)
gallon (gal)	3.785×10^{3}	milliliter (mL)
inch	2.54×10^{0}	centimeter (cm)
inch	2.54×10^{1}	millimeter (mm)
inch	2.54×10^{3}	micrometer (µm)
mile (mi)	1.609×10^{0}	kilometer (km)
square foot (ft^2)	9.29×10^{-2}	square meter (m^2)
square mile (mi^2)	2.590×10^{0}	square kilometer (km^2)

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

°F = 9/5 (°C) + 32

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

°C = 5/9 (°F – 32)

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

Characterization and Analysis of Temporal and Spatial Variations in Habitat and Macroinvertebrate Community Structure, Fountain Creek Basin, Colorado Springs and Vicinity, Colorado, 1998–2001

By James F. Bruce

Abstract

The Fountain Creek Basin in and around Colorado Springs, Colorado, is affected by various land- and water-use activities. Biological, hydrological, water-quality, and land-use data were collected at 10 sites in the Fountain Creek Basin from April 1998 through April 2001 to provide a baseline characterization of macroinvertebrate communities and habitat conditions for comparison in subsequent studies; and to assess variation in macroinvertebrate community structure relative to habitat quality. Analysis of variance results indicated that instream and riparian variables were not affected by season, but significant differences were found among sites. Nine metrics were used to describe and evaluate macroinvertebrate community structure. Statistical analysis indicated that for six of the nine metrics, significant variability occurred between spring and fall seasons for 60 percent of the sites. Cluster analysis (unweighted pair group method average) using macroinvertebrate presence-absence data showed a well-defined separation between spring and fall samples. Six of the nine metrics had significant spatial variation. Cluster analysis using Sorenson's Coefficient of Community values computed from macroinvertebrate density (number of organisms per square meter) data showed that macroinvertebrate community structure was more similar among tributary sites than main-stem sites. Canonical correspondence analysis identified a substrate particle-size gradient from site-specific species-abundance data and environmental correlates that decreased the 10 sites to 5 site clusters and their associated taxa.

INTRODUCTION

Biomonitoring uses living organisms to evaluate the quality of an aquatic environment. Aquatic biological communities integrate acute and(or) chronic changes in the physical, chemical, and biotic components of their environment (Plafkin and others, 1989; Cuffney and others, 1993). Therefore, evaluating the ecological components of an aquatic community is useful in assessing the variation in macroinvertebrate communities and the effects of environmental perturbations on macroinvertebrate community structure. Also, programs that are based on long-term monitoring are useful in identifying trends in biological measurements as well as nonspecific water quality. Fitzpatrick and Giddings (1997) have also suggested that complementary habitat analysis is useful in furthering the understanding of the interactions among chemical, physical, and biological characteristics. When habitat quality among sites is similar, differences in macroinvertebrate communities and measures of these communities can be attributed to water-quality factors. But, when the habitat quality differs, evaluation of the habitat is necessary to determine the magnitude that habitat may be a limiting factor in biological community structure.

Protocols developed for the U.S. Geological Survey (USGS) National Water-Quality Assessment Program (NAWQA) by Meador and others (1993) and Rapid Bioassessment Protocols (RBP) developed by the U.S. Environmental Protection Agency (USEPA) (Plafkin and others, 1989; Barbour and others, 1997) were used to assess instream and riparian habitat conditions. Habitat assessment promotes an understanding of the relations among physical factors that might be limiting to biological communities and provides baseline information necessary to identify future changes in habitat conditions.

Land-use change in the Fountain Creek Basin could result in increased storm runoff over short periods of time and alter baseflow characteristics which might be detrimental to the aquatic community. Changes in erosion, sediment transport, and deposition could affect channel morphology, aquatic habitat, and macroinvertebrate community structure. Little information about the stream-dwelling macroinvertebrates or habitat condition of the Fountain Creek Basin has been compiled, analyzed, or published. To address this concern the USGS, in cooperation with the Colorado Springs City Engineering and Colorado Springs Utilities, began a study in 1998 to assess temporal and spatial variations in habitat and macroinvertebrate community structure at selected sites in the Fountain Creek Basin in the vicinity of Colorado Springs, Colo. The results from this study can be used as baseline information to augment long-term monitoring of water quality, instream and riparian quality and diversity, and biological condition.

Purpose and Scope

This report includes an assessment of temporal and spatial variations in habitat and macroinvertebrate community structure from 10 sites in the Fountain Creek Basin in the vicinity of Colorado Springs, Colo. (fig. 1, table 1). Macroinvertebrate communities and measures of these communities were evaluated, and a baseline characterization of habitat and macroinvertebrate community structure were determined for the sites. Habitat and macroinvertebrate data were collected during spring and fall of 1998 through 2001 at three sites on Fountain Creek (3700, 5500, 5800); one site on Monument Creek, site 3970; four sites in Cottonwood Creek drainage (3977a, 3977b, 3980, 3985, and 3990); and one site on North Rockrimmon Creek (4050). All habitat data collected during 1998–2001 were used in the habitat analysis. Macroinvertebrate data collected during the fall of 2001 were not available at time of report preparation.

Description of Study Area

The study area has a drainage area of about 495 mi^2 (fig. 1). Elevations in the study area range from about 5,460 ft at the southern end of the study area to 14,109 ft at the summit of Pikes Peak. The Front Range of the southern Rocky Mountains and the Colorado Piedmont (Hansen and Crosby, 1982) are the two major landforms in the study area. The Front Range, which comprises the western one-third of the study area, is underlain by granite. The Colorado Piedmont, which comprises the remaining two-thirds of the area from about 3 to 5 mi west of Interstate Highway 25 to the eastern edge of the basin, is underlain by sandstone, shale, and alluvial and windlain deposits. Soils in this area are generally sandy, well drained, with more gentle slopes (Larsen, 1981; von Guerard, 1989) than soils developed in granite. More details of the soils and geology of the study area are contained in von Guerard (1989).

Fountain and Monument Creeks are the two main drainages in the study area. Fountain Creek is a perennial stream that originates near Woodland Park, Colo., and flows southeastward through a deeply incised canyon to Manitou Springs, Colo. The stream channel upstream from Manitou Springs is meandering, has a pool-and-riffle regime, and the bed material ranges from sand and gravel to cobbles and boulders. From Manitou Springs, Fountain Creek flows through alluvial terraces into a wide alluvial valley; the channel meanders less due to channelization, has a pool-and-riffle-and-run regime, and the bed material is predominantly sand, gravel, and cobbles. Downstream from the confluence with Monument Creek, the channel becomes braided, and the streambanks are intermittently lined with concrete. The bed material downstream from the confluence with Monument Creek is variable. Some stream reaches have predominantly cobble beds, some are scoured to bedrock, and others are a mixture of sand, gravel, and cobbles (von Guerard, 1989).

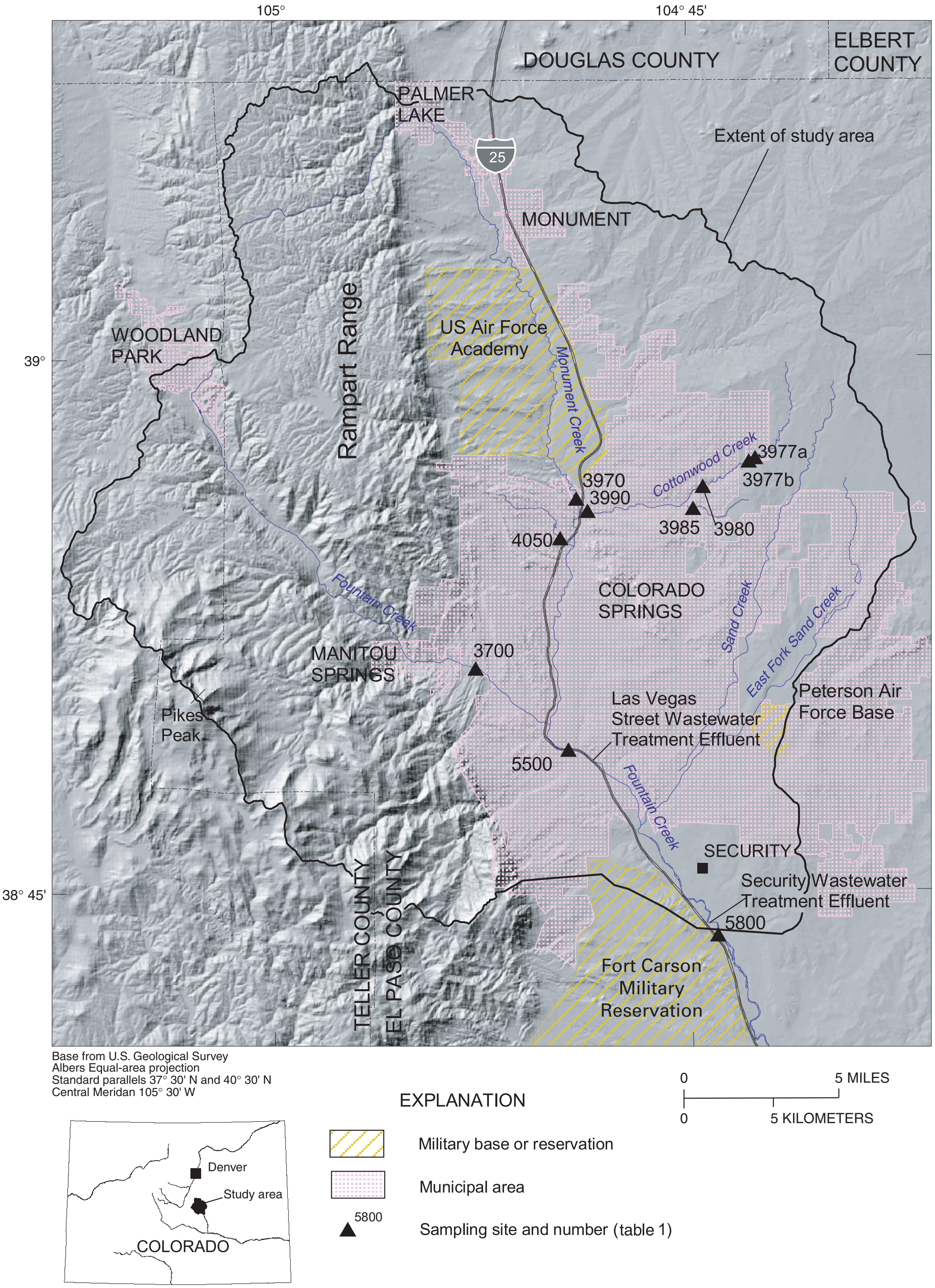

Figure 1. Location of study area and sampling sites in the Fountain Creek Basin.

Table 1. Sampling sites, dates of collection, and types of samples collected in the Fountain Creek Basin, 1998–2001

[FOCR, Fountain Creek; MOCR, Monument Creek; COCR, Cottonwood Creek; NORO, North Rockrimmon Creek; MS4, municipal stormwater permit site; RW, receiving water or main-stem site; B, benthic macroinvertebrate sample; N, National Water-Quality Assessment Program Protocols; R, Rapid Bioassessment Protocols; --, not sampled or measured]

Site number and name[1] (see fig. 1 for location)	Site type	Sample date and types of samples							
		1998		1999		2000		2001	
		Spring B/N/R	Fall B/N/R	Spring B/N/R	Fall B/N/R	Spring B/N/R	Fall B/N/R	Spring B/N/R	Fall B/N/R
3700, FOCR @ 33rd	Main stem, RW	X/X/X	X/--/X	X/X/X	X/--/X	X/X/X	X/--/X	--/--/--	X/X/X
3970, MOCR @ Woodmen	Main stem, RW	X/X/X	X/--/X	X/X/X	X/--/X	X/X/X	X/--/X	--/--/--	X/X/X
3977a, COCR @ Cowpoke	Tributary to Monument Creek, MS4	X/X/--	X/X/--	--/X/--	X/X/--	X/X/--	X/X/--	X/X/--	X/X/X
3977b, COCR @ Cowpoke	Tributary to Monument Creek, MS4	X/X/--	X/X/--	--/X/--	X/X/--	X/X/--	X/X/--	X/X/--	X/X/X
3980, COCR @ Woodmen	Tributary to Monument Creek, MS4	X/X/--	X/X/--	--/X/--	X/X/--	X/X/--	X/X/--	X/X/--	X/X/X
3985, COCR Trib @ Rangewood	Tributary to Cottonwood Creek, MS4	X/X/--	X/X/--	--/X/--	X/X/--	X/X/--	X/X/--	X/X/--	X/X/X
3990, COCR @ Mouth @ Vincent	Tributary to Monument Creek, MS4	X/X/--	X/X/--	--/X/--	X/X/--	X/X/--	X/X/--	X/X/--	X/X/X
4050, NORO @ Delmonico	Tributary to Monument Creek, MS4	X/X/--	X/X/--	--/X/--	X/X/--	X/X/--	X/X/--	X/X/--	X/X/X
5500, FOCR @ Nevada	Main stem, RW	X/X/X	X/--/X	X/X/X	X/--/X	X/X/X	X/--/X	--/--/--	X/X/X
5800, FOCR @ Security	Main stem, RW	X/X/X	X/--/X	X/X/X	X/--/X	X/X/X	X/--/X	--/--/--	X/X/X

[1] Site name used in Colorado Springs Municipal Stormwater Permit.

Monument Creek, the main tributary to Fountain Creek, is a perennial stream that originates in the Rampart Range and flows eastward toward Palmer Lake, then south to Colorado Springs. Upstream from site 3970, Monument Creek is meandering, has a pool-and-riffle-and-run regime, and the streambed consists of sand, gravel, and cobbles. Downstream from site 3970, the channel becomes braided, sand and small gravel compose the streambed, and the banks are intermittently lined with concrete. The braided channel conditions occur intermittently throughout the remaining length of the channel.

Cottonwood Creek (fig. 1) has historically been an ephemeral stream; however, over the past 15 years, flow exists throughout the year. The stream channel is meandering, has a riffle-and-run regime, and the bed material is predominantly sand.

North Rockrimmon Creek originates in the northwest portion of Colorado Springs and flows southeast into Monument Creek near site 4050 (fig. 1). The stream channel is fairly straight, has a pool-and-riffle regime, and the streambed consists of sand, gravel, cobbles, and boulders. The flow is affected by ground-water discharge and runoff from domestic housing, commercial, and industrial developments along its route.

Land Use

Land uses within the study area include urban, military reservations, agriculture, and undeveloped areas. Substantial changes in land use have occurred from increased population. Table 2 shows the total area for various land-use categories for 1998, 1999, and 2000. Estimates of the percentage of impervious and pervious material associated with each land use were applied to estimate the total impervious and pervious area upstream from each sampling site (table 2). Estimates of the percentage of impervious and pervious material associated with each land use were applied using coefficients adapted from Arnold and Gibbons (1996) and the U.S. Environmental Protection Agency (1992). The following estimates of percent impervious material were used: 88 percent of commercial, 75 percent of industrial, 50 percent of residential, 90 percent of streets and easements, 15 percent of airports and military reservations, 15 percent of agricultural, and 15 percent of undeveloped land-use categories. Land-use data for 1998–2000 were provided by the City of Colorado Springs. Between 1998 and 2000, the impervious area upstream from site 3700 (Fountain Creek upstream from Manitou Springs) showed no appreciable change. In Monument Creek, drainage upstream from Cottonwood Creek (site 3970), no appreciable change in impervious area occurred between 1998 and 2000. Overall, the amount of estimated impervious area within the 495-mi^2 study area upstream from site 5800, increased by an estimated 8 percent between 1998 and 2000.

Acknowledgments

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Table 2. Land uses and estimated total impervious and pervious area for the Fountain Creek Basin, 1998–2000

[mi^2, square miles; --, category not reported]

Site (see table 1)	Drainage area[1] (mi^2)	Commercial and industrial (mi^2)	Residential (mi^2)	Streets and easements (mi^2)	Airports and military (mi^2)	Agriculture (mi^2)	Undeveloped (mi^2)	Estimated total impervious area (mi^2)	Estimated total pervious area (mi^2)	Cumulated drainage area[2] (mi^2)
1998										
3700	103	3.91	6.26	2.55	0.00	1.25	88.0	22.2	79.8	102
3970	181	4.72	28.8	7.15	28.9	22.7	87.8	45.8	134	180
3977	5.93	0.06	2.08	--	0.00	0.94	3.03	1.69	4.42	6.11
3985	2.81	0.17	0.58	--	0.00	0.96	1.07	0.73	2.05	2.78
3990	18.7	1.19	6.27	--	0.00	2.44	8.98	5.85	13.0	18.9
5500	392	18.2	55.7	19.1	28.9	32.0	233	105	282	387
5800	495	31.6	82.9	36.8	34.9	59.0	257	154	348	502
1999										
3700	103	4.94	7.62	1.66	0.00	1.24	87.1	22.9	79.7	103
3970	181	5.34	29.0	6.76	28.9	25.5	84.5	46.0	134	180
3977	5.93	0.04	2.26	--	0.00	2.95	.95	1.75	4.45	6.20
3985	2.81	0.17	0.94	--	0.00	0.46	1.25	0.87	1.95	2.82
3990	18.7	0.91	7.97	--	0.00	4.57	5.36	6.26	12.6	18.8
5500	392	20.1	57.5	17.7	28.9	34.5	228	106	281	387
5800	495	33.8	85.8	35.4	34.9	60.5	253	155	348	503
2000										
3700	103	7.10	5.53	1.79	0.00	1.18	86.4	23.8	78.2	102
3970	181	5.71	30.2	7.44	28.9	22.9	85.3	45.0	135	180
3977	5.93	0.56	2.40	--	0.00	2.77	0.46	2.18	4.01	6.19
3985	2.81	0.71	0.66	--	0.00	0.33	1.10	1.16	1.64	2.80
3990	18.7	1.88	7.55	--	0.00	5.07	4.32	6.81	12.0	18.8
5500	392	23.4	57.7	26.0	28.9	30.6	220	114	273	387
5800	495	38.4	86.2	43.8	34.8	55.1	245	166	337	503

[1] Drainage area reported by the U.S. Geological Survey (Crowfoot and others, 2000).

[2] Drainage area computed from accumulating individual land uses provided by the City of Colorado Springs.

METHODS OF INVESTIGATION

Habitat data and benthic macroinvertebrate samples were collected during the spring and fall at selected sites in the Fountain Creek Basin (table 1). Several statistical and ordination approaches were used to assess variability between replicate and composite Hess stream-bottom samples and temporal (seasonal and year) and spatial (between and among sites) variability in habitat and macroinvertebrate community structure.

Riparian and Instream Habitat

Quantitative and qualitative instream and riparian habitat variables were measured following the procedures described by Plafkin and others (1989), Barbour and others (1997), and Meador and others (1993) at four main-stem sites and six tributary sites in Fountain Creek Basin (fig. 1, table 1). Colorado Springs Utilities (CSU) personnel collected habitat data at main-stem sites 3700, 3970, 5500, and 5800. USGS personnel collected habitat data at tributary sites 3977a, 3977b, 3980, 3985, 3990, and 4050. CSU and USGS personnel collaborated on the habitat data collection for the main-stem sites during the fall 2001.

Data Collection

CSU and USGS personnel collected data using the same procedures, and, for the most part, the same habitat variables were measured. Representative reaches were selected on the basis of criteria defined by Meador and others (1993) and equally subdivided into six transects. All sites had at least one transect permanently marked with 4-ft sections of 0.5-inch rebar driven to within about 1 ft of the ground surface. Habitat assessments were conducted in the spring (April or May) and fall (October or November) from 1998 through 2001.

Two categorical habitat assessments were made at each site. The first type (RBP) was a more qualitative assessment of instream and riparian habitat parameters encountered over the entire reach (Plafkin and others, 1989; Barbour and others, 1997). Habitat measurements based on RBP were made during the spring at sites 3700, 3970, 5500, and 5800 from 1998–2000, and at all sites during the fall 2001 (fig. 1, table 1). For each site, the scores for 12 habitat parameters were summed to derive a single numeric value (maximum possible total score = 180, unitless). These habitat parameters were separated into three main categories. The primary parameters (scored 0–20) characterize the instream habitats and have the greatest direct influence on biological community structure. Secondary parameters (scored 0–15) measure the overall channel morphology of the stream reach. Tertiary parameters (scored 0–10) characterize bank structure and riparian areas. These three categories are weighted according to their influence on the biological community, with primary parameters given the most weight and secondary parameters having more weight than tertiary parameters.

The second type of assessment (NAWQA) was a more quantitative study of instream and riparian habitat variables (Meador and others, 1993). Habitat measurements based on the NAWQA protocols were made during the spring for all sites and also in the fall for sites 3977a, 3977b, 3980, 3985, 3990, and 4050 (fig. 1, table 1). These habitat data were collected from the main-stem sites by CSU personnel from 1998 to 2000 and collaboratively by CSU and USGS for the fall 2001. All habitat data collection from the tributary sites was done by USGS personnel. The NAWQA reach characterization included slope, channel, substrate, bank, flow, canopy, and riparian measurements. For each reach, the water surface gradient (dimensionless) was determined by levels, the length of each of the geomorphic channel units (pool, riffle, run) was measured using a 100-m fiberglass tape, and a pebble count (Wolman, 1954) at approximately 100 points was done to characterize stream substrate. Wetted channel, streambed, and bankfull channel width were measured with a fiberglass tape at each transect. If channel bars, shelves, or islands were present, their widths were measured in meters. Canopy angles, in degrees, were measured with a clinometer. Total sun angle was calculated by subtracting the sum of the canopy angles from 180 degrees. Bank angles, in degrees, were measured with a clinometer. Bank substrate was categorized, and erosion was noted as present or absent. Qualitative assessment of the amount and type of bank and riparian vegetation was recorded. Instream habitat features (woody debris, overhanging vegetation, undercut bank, boulder, aquatic macrophytes, manmade structure, or none) were recorded for the left edge of water, two stream points (point 1, point 2), thalweg of the channel, and right edge of water. Stream point measurements of depth, in feet, velocity, in feet per second, dominant bed substrate, embeddedness, and presence or absence of silt were taken in the thalweg and two other stream points (point 1, point 2) that best described the flow regime in the transect. Froude numbers were calculated with depth and velocity point measurements. Froude numbers are dimensionless and generally increase as velocity increases and depth decreases. Froude number (F_r) is calculated by equation 1:

$$F_r = \frac{V}{(gD)} \qquad (1)$$

where

F_r is the Froude number, dimensionless;

V is the velocity of water, in feet per second;

g is the gravitational acceleration, in feet per second squared; and

D is the depth of water, in feet.

A Froude number greater than 1 indicates supercritical flow.

Statistical Analysis of Habitat Data

All habitat variables were tested for normality and homogeneity of variance. Transforming these data using logarithm base 10, logarithm base e, arc sin, square root, or ranks did not improve normality or variance, so raw data were analyzed. Parametric two-way and three-way analysis of variance (ANOVA) were used to determine significant differences among site, season, and year using the site vegetation data collected by USGS personnel. Parametric two-way ANOVA was used to determine significant differences among sites and spring sample dates for most NAWQA variable means and to evaluate seasonal differences in the RBP data collected by CSU personnel at sites 3700, 3970, 5500, and 5800. Due to inconsistencies in the data collection between the USGS and CSU, sites 3700, 3970, 5500, and 5800 were excluded from the two-way ANOVA for the percent grass and percent forbs variables. A one-way ANOVA was used to determine significant differences among all sites for mean streambed width, bank angle, percent riparian vegetation, and RBP score. A $p < 0.05$ was used to reject the null hypothesis for all tests. The Student-Newman-Keuls (SNK) multiple range test was used to identify homogeneous group(s) among all sites. The SNK multiple range test produced a relative ranking of the sites. The site with the greatest mean was listed on the left, and the site with the smallest mean was listed on the right. Basic statistics, ANOVA, and SNK were computed using the computer package SigmaStat 2.0 (SPSS, Inc., 1997).

Macroinvertebrates

Benthic invertebrate samples were collected from 10 sites in the spring and fall from 1998 to 2001 that coincided with the stream reaches used for the habitat characterization (fig. 1, table 1). USGS personnel collected benthic invertebrate samples at sites 3977a, 3977b, 3980, 3985, 3990, and 4050. CSU personnel collected benthic invertebrate samples at sites 3700, 3970, 5500, and 5800. Sites were sampled at approximately the same time each year to allow seasonal, yearly, and multiple-year comparisons within and among sites. Sampling protocols remained constant throughout the study to allow for within-site, among-site, among-year, and seasonal comparisons.

Sample Collection

Benthic invertebrate samples were collected from the richest targeted habitat (RTH) (Cuffney and others, 1993) within a transect that was randomly chosen along the stream reach. The RTH is habitat that is most likely to have the greatest variety and density of organisms, usually riffles, where water flows over completely or partially submerged coarse substrate that produces disruption of the water surface. Transects were often located in runs that have less RTH than riffles and relatively smooth water surfaces. Sample locations within riffles generally had gravel or cobble substrate, the highest velocities, sufficient depth to remain submerged during periods of low flow, and an open canopy. Habitat features associated with samples collected from runs usually had sand or bedrock substrate, manmade debris, and open canopy. No samples were collected from pools.

Abundance data (number of organisms per square meter) were collected using Hess stream-bottom samplers with an area of 0.086 m^2 and 500-μm mesh. One sample at each site consisted of either a composite of three Hess samples or the mean of three

Hess replicate samples. At selected sites, composite and replicate samples were collected to evaluate the appropriateness of composite samples. Whenever possible, composite samples were used in this report for comparisons within and among sites. The Hess sampler was placed over the RTH and pushed firmly into the substrate to reduce the likelihood of escape by benthic invertebrates. Large cobbles were removed from the sampler and inspected for invertebrates. The streambed area within the Hess sampler was then stirred by hand or with rebar to a depth of approximately 10 cm to dislodge invertebrates from smaller substrate and those living in the hyporheic zone. Forceps and water were used to remove organisms clinging to or entwined in the mesh. The Hess sampler was rinsed between sample collections to minimize cross-contamination between samples and sites. Samples were collected from downstream to upstream to prevent habitat disruption. Distances between transects were rarely greater than 5 m.

A D-frame dip net with a 13-inch by 20-inch frame and 500-µm mesh was used to collect kick-sweep samples. These samples provided only qualitative invertebrate data. Kicksweep samples were collected downstream or after the Hess samples had been collected. Organisms in these samples were collected from all available habitat types in the stream reach. Infrequently, the entire stream reach was sampled, but most often all available habitats were found within approximately one-half the reach distance. Kicksweep samples contained a considerable amount of debris that was reduced in the field by elutriating and sieving (500-µm mesh metal sieve) until sample volumes were less than approximately 500 mL. All samples were put in separately labeled 500-mL or 1-L wide-mouth plastic bottles, preserved in the field in 95 percent ethanol, and stored until they could be delivered to the contract laboratory for analysis. Field methods described here were used by USGS personnel and field methods similar or compatible were used by CSU personnel.

Sample Processing and Quality Assurance

Benthic invertebrate processing, taxonomic identification to the lowest possible level, and enumeration were done by Chadwick and Associates in Littleton, Colo., using methods described by Klemm and others (1990) and Britton and Greeson (1987). Chadwick and Associates also prepared a voucher collection of benthic invertebrates collected by the USGS. The USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo., provided independent verification of the voucher collection by a qualified taxonomist as a quality-control check. The NWQL reported 16 misidentifications from the 127 total taxa. Based on these results, the overall taxonomic accuracy of Chadwick and Associates was considered adequate for this study. Seventeen higher taxonomic groups (Order or higher) were identified from the benthic macroinvertebrates collected by the USGS. The Diptera taxa accounted for the largest percentage of the total taxa (37 percent) among the 17 higher taxa. The NWQL listed three misidentifications from the Diptera. Twelve of the 16 misidentifications were from the Order Coleoptera. Chadwick and Associates identified 29 Coleoptera taxa compared to 22 taxa identified by the NWQL. Based on NWQL results, the coleopterans were revised. Twenty-three Coleoptera taxa were used for sites 3977a, 3977b, 3980, 3985, 3990, and 4050. One misidentification was identified by the NWQL from the Heteroptera. In several instances, NWQL revisions involved raising the taxonomic level of immature or nonideal specimens. The revisions made by the NWQL were based on the amount of material available in the voucher collection. If a larger series of specimens had been available for examination, the original identifications might have been endorsed by the NWQL (Brady Richards, National Water-Quality Assessment Program, written commun., 2001).

Benthic macroinvertebrates collected at sites 3700, 3970, 5500, and 5800 by CSU personnel are used in this report and were processed by Chadwick and Associates. The voucher collection prepared from these samples was verified by the laboratory of Boris Kondratieff at Colorado State University in Fort Collins. Additional taxonomic verifications of selected taxa were performed by Len Ferrington, University of Kansas in Lawrence. Internal logic checks of the CSU database were completed by USGS personnel.

Description of Metrics

Metrics are commonly used to characterize the community structure or biological condition of a stream (Plafkin and others, 1989). Two types of data were used to describe the benthic invertebrate communities and measures of these communities.

Qualitative kicksweep samples (collected with a D-frame dip net) were intended to provide a list of taxa present in the stream reach. Semiquantitative samples (collected with a Hess stream-bottom sampler) were intended to provide a measure of relative abundance of each taxon present. These samples, along with corresponding chemical, physical, and land-use data, were used to characterize the aquatic community within the sampling reach, compare reaches among environmental settings, compare changes over time, and couple environmental characteristics with biological characteristics (Cuffney and others, 1993). Overall, metrics related to taxonomic composition and abundance can be indicative of the general condition of the invertebrate community. The nine metrics selected to represent biological attributes of the aquatic communities sampled and their significance are described in the following section. These metrics were not calibrated to a reference or control site, but relative comparisons among the sites were made to provide assessment of the macroinvertebrate communities and measures of these communities. Taxa richness was reported from kicksweep data. All other metrics were computed with semiquantitative data from Hess samples.

Taxa Richness and Total Abundance

Taxa richness (total taxa) can be useful in describing the biological condition of a stream (Resh and Grodhaus, 1983). Taxa richness generally increases with improving water quality and(or) habitat diversity. Total abundance of macroinvertebrates across taxa has been used to assess stream quality (Plafkin and others, 1989). Generally, invertebrate abundances decrease when communities are exposed to stresses such as degraded water quality or habitat alteration that can result from natural or manmade influences or storm runoff.

EPT and Chironomidae

Taxa in the Chironomidae family are generally more tolerant to degraded water quality than Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa (Rosenberg and Resh, 1993). Also, the ratio of EPT abundance to Chironomidae abundance has been used as a stream-water-quality indicator (Resh and Grodhaus, 1983). Thus, higher values for Total Chironomidae and Percent Chironomidae (Chironomidae %) may indicate a degraded stream condition, while higher values for Total EPT, Percent EPT (EPT %), and EPT:Chironomidae Ratio (EPT:C Ratio) may indicate better stream condition. EPT:C Ratio was calculated as E/C = EPT/(EPT + Chironomidae).

Dominant Taxa

Total Dominant taxa and Percent Dominant taxa (% Dominant taxa) are measures of redundancy which assume that a highly redundant community reflects an impaired community (Rosenberg and Resh, 1993). These metrics were calculated as the total or percentage of total abundance represented by the two most abundant taxa. Invertebrate communities under stress are frequently composed of fewer taxa and tend to be dominated by a few tolerant species.

Similarity Measures, Cluster Analysis, and Multivariate Analysis

Similarity measures and dendrograms were used to evaluate the variability between replicate and composite Hess samples and the variation of community structure between seasons and among sites. Sorenson's Coefficient of Community (Beals, 1984) used abundance data to determine the variability between paired replicate and composite Hess samples and to summarize the similarity of invertebrate community structure among sites. The Sorenson value (C) is calculated by equation 2:

$$C = \frac{(2w)}{(a + b) \times 100} \qquad (2)$$

where

C is the Sorenson's Coefficient of Community;

w is the sum of the smaller value between site A and site B;

a is the sum of the frequencies of each taxon at site A; and

b is the sum of the frequencies of each taxon at site B.

The Sorenson value (C) can range from 0 (complete dissimilarity) to 100 (complete similarity). Values above 60 generally indicate agreement between the community structure provided by the two sampling methods.

The Jaccard Coefficient of Community (Jaccard, 1912) provided numerical expression of taxonomic similarity based on presence or absence of taxa. The Jaccard value (J) is calculated by equation 3:

$$J = \frac{a}{a + b + c} \tag{3}$$

where

J is the Jaccard's Coefficient of Community;

a is the number of taxa in common to both samples;

b is the number of taxa present in sample B but not in sample A; and

c is the number of taxa present in sample A but not in sample B.

The Jaccard value can range from 0 (no taxa in common) to 1.0 (all taxa shared) and directly expresses the percentage of taxa shared between two collections. This index is sensitive to variation in taxa occurrence, generally unbiased at small sample sizes, and interpreted unambiguously (Ludwig and Reynolds, 1988).

An unweighted pair group method average (UPGMA) cluster analysis was used to determine if there was seasonal and(or) spatial separation of the samples into discrete groups based on Sorenson and Jaccard values. UPGMA clustering refers to the measurement of the distance between two clusters as measured by the average of all sampling units within each group (Pielou, 1984). This agglomerative process produced a dendrogram by starting with all the samples to be clustered separate, then successively combining the most similar samples and(or) clusters until all were in a single, hierarchical group.

Principal component analysis (PCA) was used to identify environmental variables that accounted for the greatest amount of variance in the data and eliminate redundant variables from subsequent analyses. The multivariate ordination technique Canonical Correspondence Analysis (CCA) was used to identify environmental gradients associated with the distribution of aquatic arthropods (ter Braak, 1986; Palmer, 1993). These analyses were done with the computer program MultiVariate Statistical Package 3.1, MVSP (Kovach, 1999).

Statistical Analysis of Macroinvertebrate Data

The Wilcoxon signed-rank test, paired t-test, and ANOVA were used to examine differences in metrics temporally or spatially. A $p < 0.05$ was used to identify significant differences, and because large variance was often associated with benthic invertebrate data, a $p < 0.10$ was used to identify marginally significant differences. The SNK multiple range test was used to identify homogeneous group(s) among all sites. Data were checked for normality using the Kolmogorov-Smirnov test and in some cases were log or rank transformed before analysis. These tests were from the computer package SigmaStat 2.0 (SPSS, Inc., 1997).

TEMPORAL AND SPATIAL VARIATION IN HABITAT AND MACROINVERTEBRATES

Assessments of temporal and spatial variability in habitat and macroinvertebrate community structure were made for selected sites in the Fountain Creek Basin. The limited amount of data collected from 1998–2001 are not adequate to assess effects from stormwater runoff, but results were used to evaluate the relative differences among selected sites in the basin and provide a baseline characterization of habitat and macroinvertebrates for comparison in future studies. Natural differences in macroinvertebrate communities associated with cold-water (site 3700) and warm-water (sites 3970, 3977a, 3977b, 3980, 3985, 3990, 4050, 5500, 5800) streams complicated the analysis of differences among sites. Instream and riparian habitat variables are presented in Appendix A on CD-ROM in pocket (tables 12–16). Macroinvertebrate data are presented in Appendix B on CD-ROM in pocket (tables 17 and 18).

Habitat

Several generalizations concerning the habitat data are presented. A direct relation was evident between stream discharge (Crowfoot and others, 1999, 2000, 2001) and 3 of the 10 instream habitat variables (wetted channel width, streambed width, and bankfull width). These three variables usually had higher values for sites with the greatest discharge. The exception is site 3990, which ranked higher for these three variables than site 3700. Stream discharge had a less consistent direct relation with bank height and stream velocity. Froude number best demonstrated an indirect relation between stream discharge and any of the instream habitat variables. Froude numbers generally increase as velocity increases and depth decreases. Relatively large Froude numbers indicated that sites 3977a, 3977b, 3980, and 3990 were dominated by fast and shallow flows. The correlation between macroinvertebrate community structure and Froude number is likely important but is complicated by substrate characteristics, water quality, habitat quality, and thresholds of these variables that apply to distinct segments of an insect's life cycle (Resh and Rosenberg, 1984).

Generally sand and fine gravel dominated the streambed substrate within the study-area sites. Site 3990 was dominated by bedrock, site 5800 had moderate amounts of bedrock, and site 3700 had the highest frequencies of substrate with larger particles and lower embeddedness (fig. 2, table 14, Appendix A on CD-ROM in pocket). Also, personal field observations outside the timeframe of this report identified site 3970 as a streambed less dominated by sand and gravel with large abundance of cobbles.

Geomorphic channel units were not balanced well among riffle, run, and pool. Run dominated every site. Pools were identified at sites 3700, 3970, 3977a, 3977b, 3985, 4050, 3990, and 5500, and only site 3985 had pools for each year of the study (1998–2001) (table 16, Appendix A on CD-ROM in pocket).

The most evident impacts to the instream and riparian habitat observed during site visits included downcutting (3970, 3977b, 3980, 3985, 3990, 5800); deposition (3977a, 3985, 4050); urban development (3700, 3970, 3980, 3985); right-of-way construction (3980, 3985, 5500); beaver (*Castor canadensis*) activity (3970, 5500); and manmade litter at all sites.

Prior to rigorous statistical analyses, all habitat variables were tested for normality and homogeneity of variance. All percentage vegetation variables failed the normality test, and all passed the equal variance test except percentage of forbs on bank. Canopy cover and all instream habitat variables failed the tests of normality and equal variance except bank angle, which passed the test of equal variance. Transforming these data using logarithm base 10, logarithm base e, arc sin, square root, or ranks did not improve normality or variance, so raw data were analyzed. The RBP scores were found to be normally distributed with homogeneous variance. Numerous statistical analyses presented in the following sections were performed to evaluate temporal and spatial effects on instream and riparian habitat parameters.

Seasonal Variations

A three-way ANOVA was used to analyze 10 vegetation variables for seasonal differences. These results were from data measured using NAWQA protocols from the six tributary sites (3777a, 3977b, 3980, 3985, 3990, and 4050). Site, season, and year were the factors used in the ANOVA. Nine of the 10 variables had significant differences ($p < 0.05$) among sites. Season and year were significantly different for six and seven of the variables, respectively. Due to the high percentage of significant differences among sites and nondefinitive percentage of significant differences attributed to season, an unambiguous statement regarding seasonal effects on vegetation based on the three-way ANOVA could not be made.

Table 3 summarizes the results, from the preceding data set, of 60 two-way ANOVA's that analyzed the factors season and year for each site separately. Only 16 of the possible 60 ANOVA's (27 percent) indicated a significant seasonal difference, and three of these tests had p-values of 0.049. Differences were proportioned almost equally between bank (7/16) and riparian variables (9/16). Nineteen significant differences for the variables based on factor year were identified. All sites accounted for at least one significant difference due to season or year. Also, results from a two-way ANOVA on RBP scores for main-stem sites on Fountain and Monument Creek (from 1998 to 2001) indicated no significant differences due to season with a p-value of 0.301. The measured habitat variables among the sites in this study did not vary seasonally to the extent that requires measurements each season.

Spatial and Annual Variations

Two-way ANOVA results indicated that all instream and vegetative habitat variables, except bank forbs, had significant differences among sites (table 4). The habitat variables streambed width, bank angle, riparian vegetation, and RBP score were analyzed with a one-way ANOVA because not all these data were collected at each site or were not collected consistently with other sites. Percent grass and percent forbs results were not available for

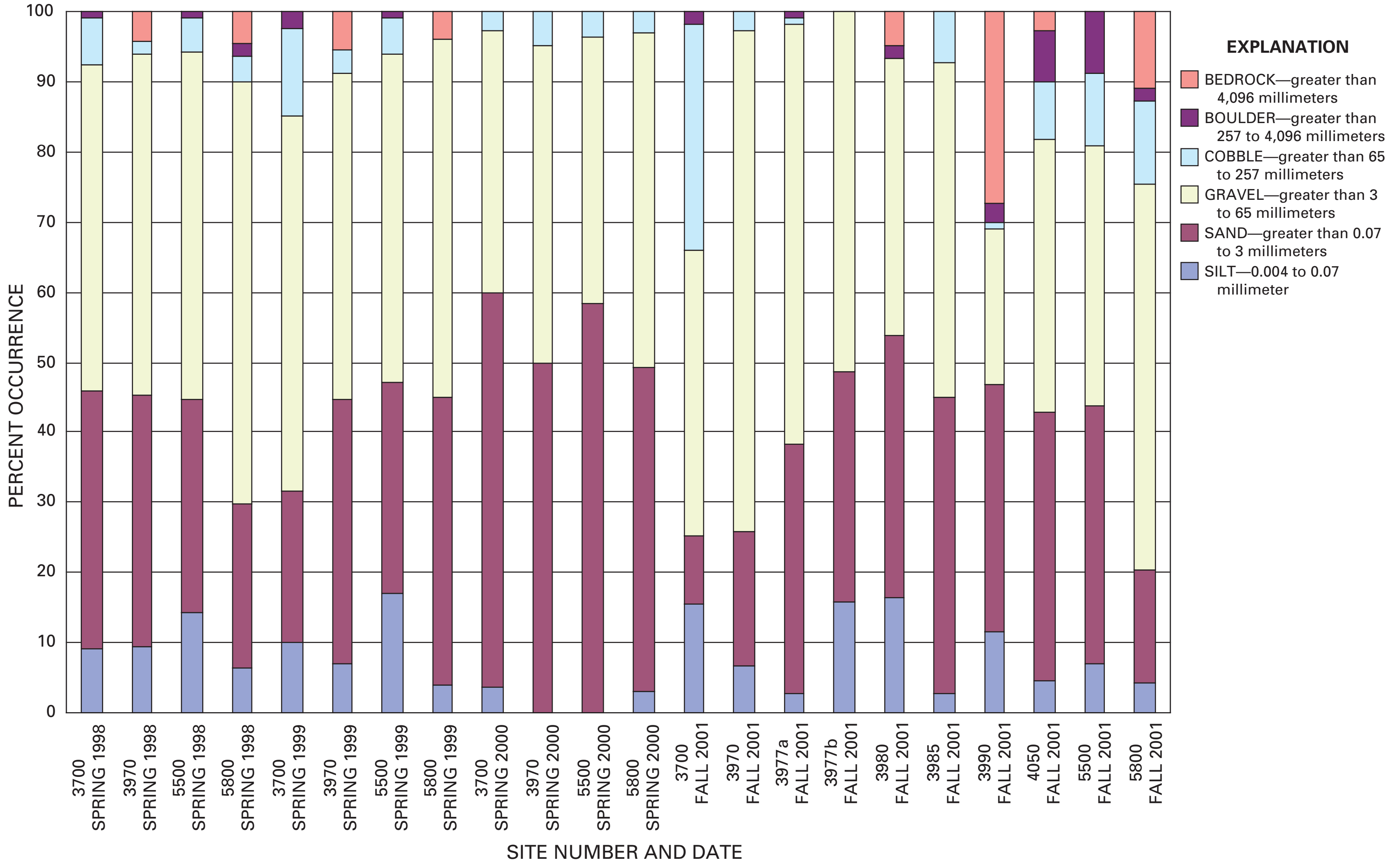


Figure 2. Pebble-count data for selected sites in the Fountain Creek Basin, 1998–2001.

Table 3. Summary of two-way analysis of variance (ANOVA) evaluating seasonal and annual differences of 10 habitat variables measured at selected sites in the Fountain Creek Basin, 1998–2001 (site locations shown in fig. 1)

[S, seasonal p-value; Y, annual p-value; --, not significantly different ($p > 0.05$)]

Site number (fig. 1)	Bank vegetation		Bank grass		Bank forbs		Bank shrubs		Bank trees		Riparian vegetation		Riparian grass		Riparian forbs		Riparian shrubs		Riparian trees	
	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y
3977a	--	0.016	0.009	--	<0.001	--	--	--	--	--	--	--	0.033	--	--	--	<0.001	--	--	--
3977b	--	--	--	0.042	--	--	0.005	--	--	--	0.027	--	--	--	--	<0.001	--	--	--	--
3980	--	--	--	--	--	--	0.026	--	--	--	--	--	0.049	--	0.009	<0.001	--	--	--	--
3985	--	--	--	--	--	0.016	--	--	--	0.041	0.004	<0.001	<0.001	0.010	<0.001	<0.001	0.049	--	--	--
3990	--	--	--	--	--	<0.001	--	--	0.049	--	--	--	--	0.023	--	<0.001	--	0.001	--	0.011
4050	--	--	--	--	--	0.033	0.003	0.044	0.006	0.002	--	<0.001	--	--	--	<0.001	--	--	--	--

Table 4. Results of two-way analysis of variance (ANOVA) and Student-Newman-Keuls (SNK) multiple range tests for spatial variation in 21 instream and riparian habitat variables measured at selected sites in the Fountain Creek Basin, 1998–2000

[Instream habitat variables, 1–10; vegetation habitat variables, 11–20; qualitative habitat variable, 21; RBP, Rapid Bioassessment Protocol; blue shading indicates variable with at least one exclusive group; sites joined by a line were not significantly different; %, percent; no., number; site locations shown in fig. 1; <, less than]

Habitat variable		Unit	SNK multiple range test											ANOVA	
														p-value	Test power
1	Wetted channel width	Meters	Mean	24.4	12.6	10.0	5.8	5.7	3.7	2.5	1.8	1.4	1.1		
			Site no.	5800	5500	3970	3990	3700	3980	3977a	3985	3977b	4050	<0.001	1.000
2[a]	Streambed width	Meters	Mean	27.5	15.3	10.8	7.9	7.6	7.0	3.0	2.9	2.6	2.1		
			Site no.	5800	5500	3970	3990	3700	3980	3977a	4050	3977b	3985	<0.001	1.000
3	Bankfull width	Meters	Mean	30.0	22.0	13.5	11.0	8.8	8.6	6.2	5.3	4.9	4.9		
			Site no.	5800	5500	3970	3990	3700	3980	3977a	3977b	3985	4050	<0.001	1.000
4	Bank height	Meters		6.8	3.7	3.0	1.5	1.2	1.1	0.9	0.8	0.6	0.4		
				5800	3970	5500	3977b	3700	3990	3980	4050	3977a	3985	<0.001	1.000
5[a]	Bank angle	Degrees	Mean	58	49	48	47	46	44	38	35	29	29		
			Site no.	3977b	5500	5800	4050	3990	3980	3970	3985	3977a	3700	<0.001	1.000
6	Total sun angle	Degrees	Mean	154	140	135	121	118	113	100	96	85	41		
			Site no.	3985	3980	3977a	5500	3990	3970	3977b	4050	5800	3700	<0.001	1.000
7	Embeddedness	%	Mean	97	95	88	86	86	79	78	77	72	49		
			Site no.	3985	3977a	3977b	5500	3970	5800	3700	4050	3980	3990	<0.001	1.000
8	Stream depth	Feet	Mean	1.7	1.3	1.3	1.0	0.2	0.2	0.2	0.2	0.2	0.2		
			Site no.	3970	5500	5800	3700	3977b	3990	3985	3980	4050	3977a	<0.001	1.000
9	Stream velocity	Feet per second	Mean	3.2	3.0	2.9	2.9	2.3	2.2	2.0	1.9	1.3	0.9		
			Site no.	5500	3970	5800	3990	3700	3980	3977b	3977a	3985	4050	<0.001	1.000
10	Froude number	None	Mean	1.1	0.9	0.8	0.7	0.5	0.5	0.5	0.4	0.4	0.4		
			Site no.	3990	3980	3977a	3977b	3985	5500	5800	3970	3700	4050	<0.001	1.000
11	Bank vegetation	%	Mean	63	49	46	44	41	39	28	26	24	20		
			Site no.	3985	3970	3977a	5500	3700	4050	3980	3990	5800	3977b	<0.001	1.000
12[b]	Bank grass	%	Mean	88	84	60	49	28	27						
			Site no.	3977a	3985	4050	3980	3977b	3990					0.001	1.000
13[b]	Bank forbs	%	Mean												
			Site no.					not significant						0.052	0.432
14	Bank shrubs	%	Mean	14.2	14.2	13.0	8.3	5.7	4.9	4.7	4.6	2.8	0.6		
			Site no.	3970	5500	3700	4050	3977b	3980	5800	3990	3985	3977a	<0.001	1.000
15	Bank trees	%	Mean	12.8	12.8	6.4	5.3	5.0	3.0	2.8	0.8	0.0	0.0		
			Site no.	5500	3700	4050	5800	3990	3985	3970	3977b	3977a	3980	0.011	0.683
16[a]	Riparian vegetation	%	Mean	75.8	75.7	71.9	67.9	66.7	65.1	59.2	58.8	56.7	27.5		
			Site no.	3700	3977b	3985	4050	3990	3980	5800	3977a	3970	5500	<0.001	1.000
17[b]	Riparian grass	%	Mean	68	66	64	49	48	44						
			Site no.	3985	3977a	3980	4050	3990	3977b					<0.001	1.000
18[b]	Riparian forbs	%	Mean	19	16	15	12	10	8						
			Site no.	3985	3980	3977a	4050	3990	3977b					0.004	0.819
19	Riparian shrubs	%	Mean	30.4	27.5	17.1	15.6	13.9	12.4	10.3	9.7	6.7	2.8		
			Site no.	3977b	4050	3990	3980	3970	3985	3977a	5500	3700	5800	<0.001	1.000
20	Riparian trees	%	Mean	19.0	17.5	13.3	11.9	11.8	10.0	4.3	3.9	0.8	0.0		
			Site no.	3990	3977b	5500	5800	4050	3700	3980	3970	3985	3977a	<0.001	1.000
21[a]	RBP score	None	Mean	114	87	75	67	56	53	50	49	28	22		
			Site no.	3700	4050	3970	3985	3977b	3990	5500	3980	3977a	5800	<0.001	1.000

[a] Results from one-way ANOVA.

[b] Results unavailable for sites 3700, 3970, 5500, and 5800.

sites 3700, 3970, 5500, and 5800 because these data were collected inconsistently with the remaining sites. Measurements for site 3977a were omitted from the spring 1998 and 1999 analysis of bankfull width due to error in data collection or transcription.

Instream habitat variables, which tend to describe channel morphology features, provided the best means of discriminating the differences among sites. The SNK multiple range tests identified 11 habitat variables with at least one exclusive group (table 4, highlighted in blue). An exclusive group includes only one site. Nine of these 11 habitat variables (82 percent) were instream habitat variables. Sites 3970, 5500, and 5800 were found in four exclusive groups, while sites 3977a and 3977b were not isolated into an exclusive group by the SNK method. The sites with the largest drainage area (table 2) had the greatest means for the instream habitat variables wetted channel width, streambed width, and bankfull width. Also, the embeddedness results indicated that site 3990 provided preferred macroinvertebrate habitat with the lowest embeddedness mean, but this measurement was heavily influenced by bedrock (defined as 0 percent embeddedness), which commonly limits the macroinvertebrate community structure. The overall habitat site similarity was greater among the tributary sites compared to the site similarity among main-stem sites.

Two-way ANOVA results indicated that 8 of 13 habitat variables had significant differences due to year, and that during the study, the instream and riparian habitat in the Fountain Creek Basin were not stable. The year 1998 was isolated four times, and 1999 and 2000 were isolated from all other years twice and once, respectively. The year pairs 1998, 1999; 1998, 2000; and 1999, 2000 were found in SNK homogeneous subsets twice, once, and five times, respectively. Although based on a limited amount of data, the observed yearly pattern in habitat variation might be due to the pre- and postconditions of the 1999 flood (Crowfoot and others, 2000). Stogner (2000) found that the high daily-mean streamflows that occurred during the spring 1999 flood remained elevated for a longer period of time than any other event for the entire period of record for six sites in the Fountain Creek Basin. Continued collection of habitat data would be necessary to identify trends in habitat stability at the study sites. This information could be used to evaluate the relation between streamflow patterns and rates of change in measured habitat variables.

Overall, sand and fine gravel dominated the substrate, and runs were the prevalent geomorphic channel unit found at the selected sites in the study area. The range in streamflow among the sites varied greatly, but the prevalent velocity-depth regime was fast and shallow flows. Readily observed deleterious effects to the instream and riparian habitats at the study sites included downcutting, deposition, scour, urban development, right-of-way construction, beaver activity, and manmade litter. Seasonal variation of the habitat variables measured was generally not found. Statistically significant spatial variation in habitat variables was found among the sites, and channel morphology features provided the best discrimination. Habitat similarity was greater within the tributary sites compared to the main-stem sites. Effects on the habitat from the spring 1999 flood might be demonstrated by the yearly grouping pattern that appears to separate pre- and postflood conditions.

Macroinvertebrates

Benthic macroinvertebrate taxa collected from selected sites in the Fountain Creek Basin are listed in Appendix B on CD-ROM in pocket. Hess and kicksweep sampling yielded the identification of 218 macroinvertebrate taxa that were represented by 9 insect orders and 35 noninsect taxa. As a percentage of taxa richness, dipterans accounted for 40 percent of the taxa. Comparisons among the sites showed that site 3700 had consistent and relatively high taxa diversity (number of macroinvertebrate taxa, fig. 3). Taxa diversity was inconsistent at sites 3970, 4050, and 5500. The remaining sites were depauperate in terms of taxa diversity. Total abundance (number per square meter) followed a pattern similar to taxa diversity, with site 3700 having the highest yearly values and sites 3970, 4050, and 5500 having at least 1 year with high total abundance (fig. 4). Only site 3700 had a consistently low relative abundance of chironomids compared to the other sites (fig. 5). Site 3700 was the only site that had the EPT:C ratio skewed in favor of the EPT taxa for each year of the study (fig. 6).

In general, site 3700 was the relatively least impaired stream segment as indicated by the structure of its benthic macroinvertebrate community, described previously by the four metrics, with sites 3970, 4050, and 5500 forming a relatively moderately impaired group. At site 4050, lack of an adequate amount of streamflow could be an important limiting factor of

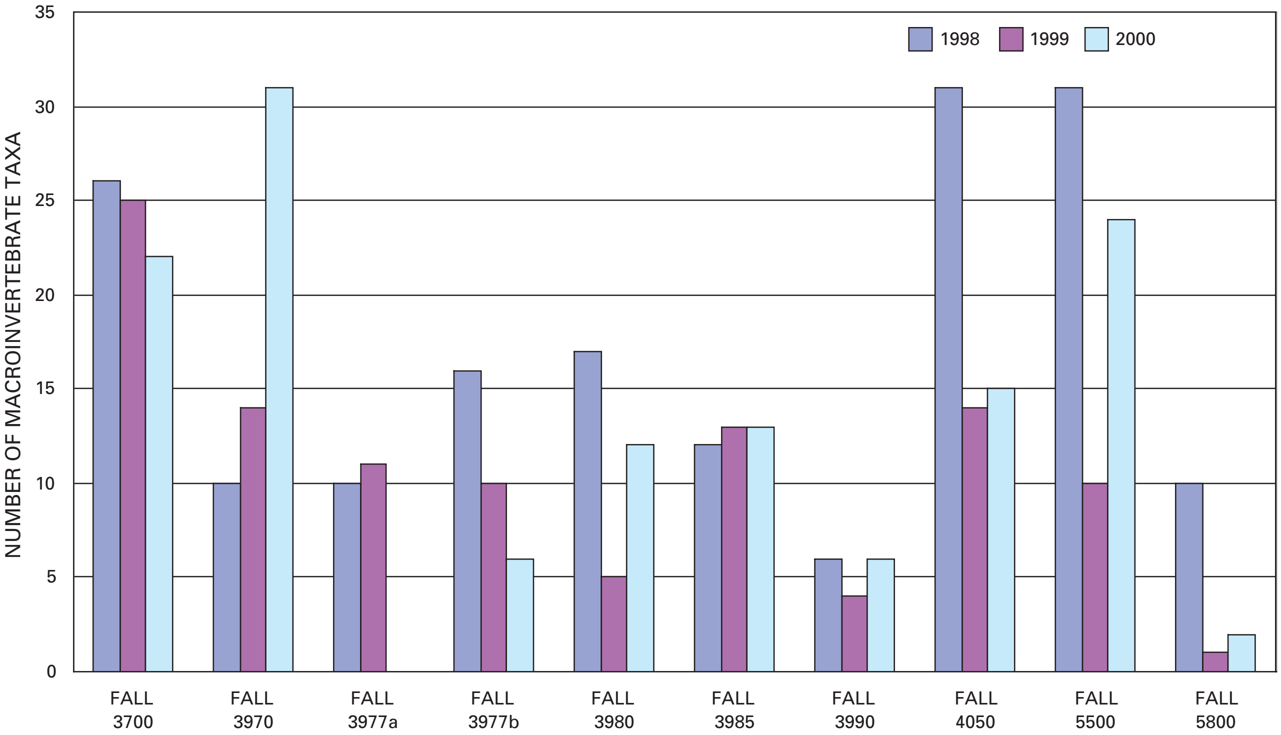


Figure 3. Number of macroinvertebrate taxa collected during the fall at selected sites in the Fountain Creek Basin, 1998–2000.

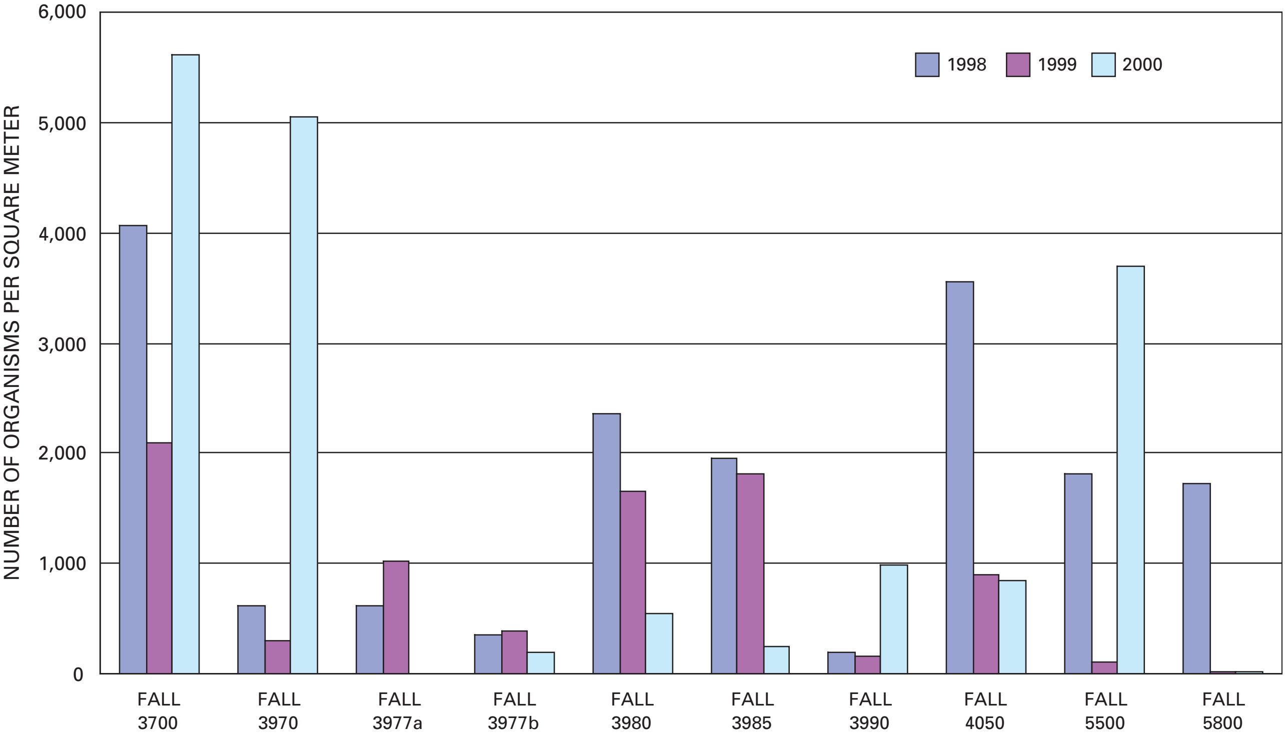


Figure 4. Total abundance of macroinvertebrates collected during the fall at selected sites in the Fountain Creek Basin, 1998–2000.

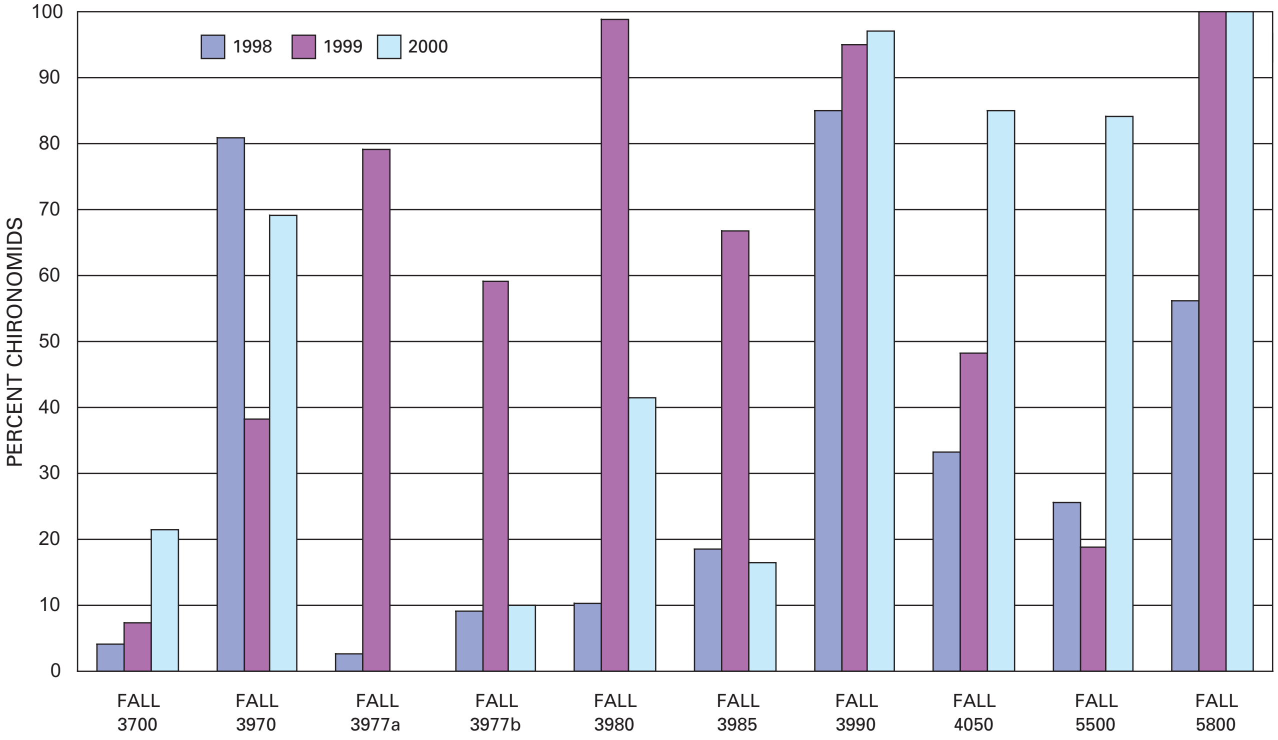


Figure 5. Relative abundance of chironomids collected during the fall at selected sites in the Fountain Creek Basin, 1998–2000.

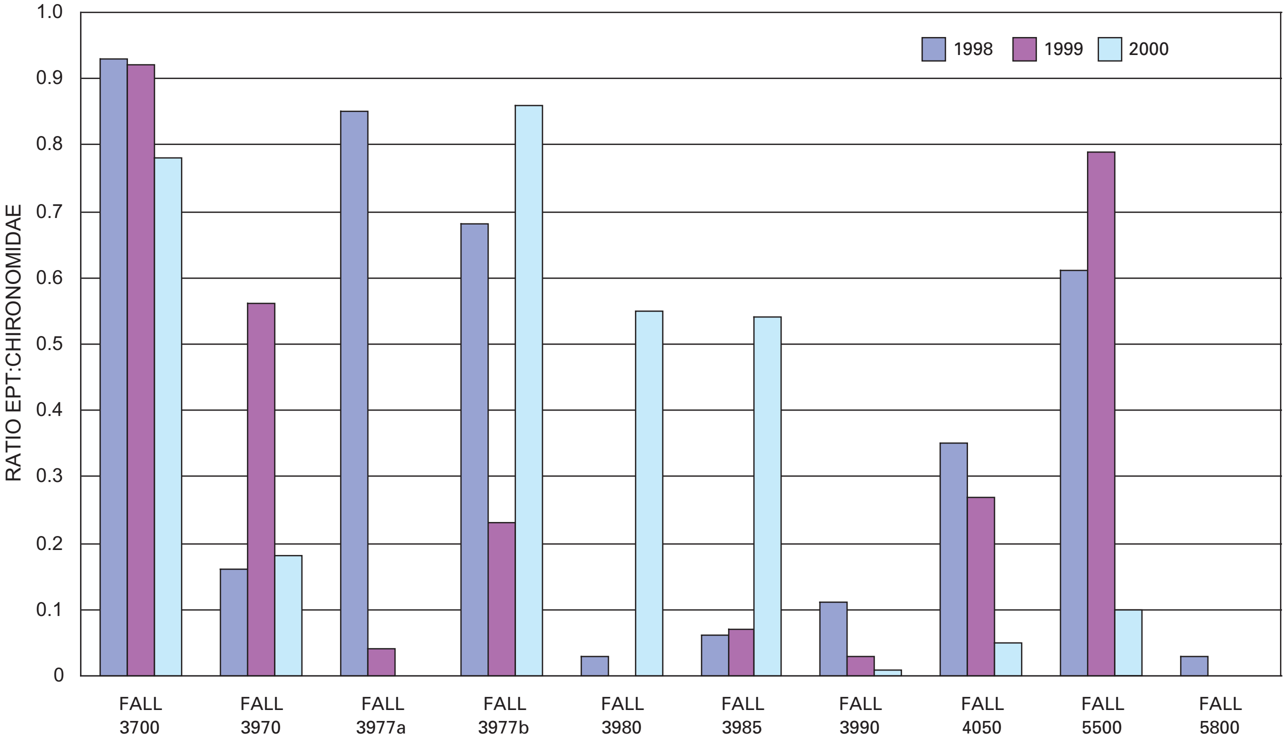


Figure 6. Ratio of EPT abundance to chironomid abundance from fall samples collected at selected sites in the Fountain Creek Basin, 1998–2000.

macroinvertebrate populations. The remaining sites might be termed relatively severely impaired, with inadequate streamflow likely the primary limiting factor of macroinvertebrate populations at sites 3977a and 3977b. Identifying the hydrological, environmental, biological, water-quality, or climatic factors that influenced the macroinvertebrate communities and measures of these communities was not straightforward due to the lack of reference or control sites and qualitative and quantitative differences between and among sites. For example, the difference in base-flow stream discharge (sustained ground-water inflow rather than surface runoff) was up to four orders of magnitude (sites 3977a, 3977b, 4050 < 0.1 ft^3/s; site 5800 > 100 ft^3/s) (Crowfoot and others, 1999, 2000, 2001; field observations, 1998, 1999, 2000), size of drainage basin ranged from 1.8 mi^2 (site 4050) to 495 mi^2 (site 5800) (table 2), land-use types and proportions differed greatly among the sites (table 2), natural differences between cold-water and warm-water stream-dwelling biota, and field observations of the effects of point and nonpoint sources of water-quality degradation were not evenly distributed among the sites. Also, biological data that would best determine possible effects from wastewater-treatment facilities and assess the further relative degradation or recovery of macroinvertebrate communities that inhabit Fountain Creek to its confluence with the Arkansas River were not available.

Comparison of Replicate and Composite Samples

Results from Sorenson's Coefficient of Community (*C*) analysis and from the Wilcoxon signed-rank test are given in table 5. Six of 11 of the signed-rank tests indicated no significant differences ($p > 0.05$) between the replicate and composite samples. Further, 6 of the 11 *C* values from log-transformed data were greater than 60, indicating relatively high similarity between the samples, and only two of these *C* values (site 3970 in fall 1998, and site 3985 in spring 2000) indicated relatively low similarity between the sample types. Differences in results between the tributary and main-stem sites was not apparent, as the nonsignificant signed-rank test-result frequencies are almost equal between stream types, with nonsignificant differences occurring in 50 percent of the tributary sites and 57 percent of the main-stem sites. Table 6 summarizes the Sorenson's Coefficient of Community (*C*) analysis. All mean and median similarity values from log-transformed data were higher than those from raw data, possibly due to the dampening of differences between rare and dominant taxa. Mean similarity values based on log-transformed data were equal between stream types, with the median value for the main-stem sites slightly higher. These results were not definitive but indicated that composite sampling at these sites is an appropriate alternative to replicate sampling and that evaluations among and within sites can be made with data from either sampling method.

Table 5. Results of Wilcoxon signed-rank test and Sorenson's Coefficient of Community[1] for paired replicate and composite invertebrate samples collected from selected sites in the Fountain Creek Basin, 1998–2001

[x, integer]

Site number (fig. 1)	Date	Signed-rank test p-value	Sorenson's Coefficient of Community	Sorenson's Coefficient of Community on log(x+1)
3700	Spring 1999	0.456	72.2	65.9
3700	Spring 2000	0.003	48.0	62.2
3970	Spring 1998	0.001	42.7	62.0
3970	Fall 1998	<0.001	12.7	25.7
3970	Spring 2000	0.216	53.2	62.7
3977b	Fall 1999	0.241	56.4	72.0
3980	Fall 2000	<0.001	15.0	54.0
3985	Spring 2000	<0.001	4.1	18.2
4050	Spring 2001	0.561	63.2	63.2
5500	Fall 1999	0.194	45.0	54.9
5800	Fall 1999	1.000	40.0	55.6

[1] Values above 60 generally indicate agreement between the community structure provided by the two sampling methods.

Table 6. Summary of Sorenson's Coefficient of Community analysis of paired replicate and composite invertebrate samples collected from selected sites in the Fountain Creek Basin, 1998–2001

[x, integer; MS4, municipal stormwater permit or tributary sites are sites 3977a, 3977b, 3980, 3985, 3990, 4050; RW, receiving water or main-stem sites are sites 3700, 3970, 5500, 5800]

Sites (fig. 1; table 1)	Data type	Minimum	Maximum	Mean	Median
All MS4	raw	4.12	63.17	34.70	35.70
	log(x+1)	18.18	71.96	51.80	58.60
All RW	raw	12.74	72.24	44.80	45.00
	log(x+1)	25.68	65.86	51.80	62.00
All sites	raw	4.12	72.24	41.10	45.00
	log(x+1)	18.18	71.96	54.20	62.00

Seasonal Variations

The number of invertebrate species inhabiting the sites ranged from very few to possibly 50 or more from a wide variety of taxonomic orders. Each of these species has evolved unique life history strategies or adaptive traits to minimize competition and predation, exploit seasonally available food sources, avoid unfavorable environmental conditions, and synchronize reproduction with favorable environmental conditions. The sum of all species' life cycles at a given location can potentially cause the community structure to be a continually changing aggregate of populations. Therefore, metrics or indices computed from species assemblages collected in different seasons can reflect natural variation and make comparisons among and within sites more difficult and complicate the assessment of biological condition.

Table 7 lists the seasonal mean for each metric by site and can be used to determine if seasonal differences in metrics occurred at any particular site and compare the behavior of a metric between sites. For example, percent EPT (EPT %) indicated seasonal variation at site 3700 (fall 72 percent, spring 55 percent) but was essentially unchanged at site 3970 (fall 26 percent, spring 25 percent). Preliminary analysis of these data indicated that among all sites, eight out of nine metric values calculated from fall samples were greater than those from spring samples (table 8). These observations coupled with field experience were indications that seasonal differences in community structure existed for at least some of the study sites.

A between-season comparison was performed using a one-way ANOVA on metrics listed in table 7 and, when appropriate, ANOVA on ranks, by combining metric values from like stream types (that is, tests were made on samples collected at tributary sites, $n = 18$; and main-stem sites, $n = 12$). Significant seasonal variation ($p < 0.05$) was identified for all non-percentage metrics from the tributary sites, with the fall values indicating a more robust biological condition. However, results for the main-stem sites did not show significant seasonal differences for any individual metric. The results from the ANOVA test for the main-stem sites might have been complicated by analyzing metric values from a cold-water stream (site 3700) with metrics associated with warm-water streams (sites 3970, 5500, 5800), and further analysis would be necessary to determine if seasonal variation affected the community structure of the main-stem sites. Additional tests also would be necessary to evaluate the components of seasonal and yearly variation at individual sites.

Three cluster analyses (UPGMA), based on Jaccard (J) values, were used to determine if seasonal variation was present at the sites. The first analysis was based on a matrix of J values computed from all kicksweep samples collected from sites 3700, 3970, 5500, and 5800. The results from this analysis demonstrated that site 3700 had higher within-site similarity by forming two-sample fall/spring clusters (nodes) in the dendrogram. Site 3700 was on a cold-water stream dominated by cobbles, whereas the remaining main-stem sites are designated as warm-water streams that were dominated by shifting sand channels. The clustering of site 3700 showed that site differences were more important than seasonal differences to the ordered arrangement of the cold-water site. Eleven of the first 13 clusters were composed of samples from the same season. Differences between the spring and fall samples existed for the warm-water sites, and these seasonal differences override site similarity in the clustering of the warm-water sites.

The second cluster analysis that excluded data from site 3700 was done on the remaining 18 samples. The results of this analysis are reported in a dendrogram (fig. 7) and in table 9. For this data set, the minimum and maximum number of agglomerations to place all samples within a first-order cluster was 9 and 17, respectively. A first-order cluster is one that includes a novel sample. Twelve agglomerations were needed to place each sample within a group. Eleven of

Table 7. Mean metric values for fall and spring samples collected from selected sites in the Fountain Creek Basin, 1998–2001

[F, fall mean; S, spring mean; >, greater than; EPT, Ephemeroptera, Plecoptera, Trichoptera; C, Chironomidae; %, percent]

Metric	Site number (see fig. 1 for locations)																			
	3700		3970		3977a		3977b		3980		3985		3990		4050		5500		5800	
	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S
Total taxa	24	18	18	15	7	2	11	2	11	4	13	5	5	4	20	10	22	9	4	5
Total abundance	3,924	4,741	1,990	1,799	547	12	313	16	1,518	60	1,339	211	442	55	1,764	464	1,868	1,883	582	8,933
Total EPT	2,760	2,959	332	323	42	0	86	3	96	9	56	26	12	8	280	4	387	76	9	7
Total Chironomidae	510	1,257	1,367	1,249	274	7	93	9	701	38	539	34	420	39	776	373	1,193	1,600	330	2,924
EPT %	72	55	26	25	6	0	33	10	17	10	9	43	5	7	13	2	40	7	1	2
Chironomidae %	11	37	63	62	27	42	26	69	50	74	34	8	92	83	55	77	43	80	85	23
EPT:C ratio	0.88	0.6	0.3	0.28	0.3	0	0.59	0.11	0.19	0.12	0.22	0.65	0.05	0.08	0.22	0.03	0.5	0.09	0.01	0.08
Total dominant taxa	2,391	2,620	1,002	1,168	446	9	195	13	1,361	47	974	185	407	39	828	318	1,131	1,563	511	7,837
% Dominant taxa	64	59	61	56	86	83	65	87	89	84	64	90	91	83	53	65	57	78	96	86
Number times F > S	4		8		8		7		8		6		7		7		4		3	
Percentage of times F > S	44		89		89		78		89		67		78		78		44		33	

these 12 (92 percent) first-order clusters placed samples into groups of like season. The 1998 spring sample from site 3970 was placed into an existing cluster of fall samples (node 11). This analysis strongly indicated that seasonal differences occurred among the warm-water main-stem sites. The third cluster analysis of the J values from the kicksweep samples collected at the tributary sites (3977a, 3977b, 3980, 3985, 3990, 4050) also indicated strong seasonal differences with 23 of 25 first-order clusters composing like seasons.

Site-specific seasonality was evaluated using two-way ANOVA (season and year) and the Wilcoxon signed-rank test. Two-way ANOVA's were performed on the nine metrics for each site, which produced a total of 180 test results. The powers of these tests were extremely low and, therefore, the results were not interpreted. For the 90 tests based on season, none had a power greater than or equal to the desired value of 0.80, and 93 percent had powers less than 0.40. Two tests for the season factor had powers greater than or equal to 0.80, but 87 percent had powers less than 0.20.

Results of the Wilcoxon signed-rank test to evaluate seasonal difference between metric values for each site are presented in table 10. Results indicated that significant and marginally significant seasonal variation was found in 67 percent of the tributary sites and 25 percent of the main-stem sites, respectively. Paired t-test results also were not reported or interpreted in this report because the powers of these tests were low (below 0.80).

Table 8. Combined results of all fall and spring metric mean comparisons from 10 sites in the Fountain Creek Basin, 1998–2001

[F, mean fall value; S, mean spring value; >, greater than; EPT, Ephemeroptera, Plecoptera, Trichoptera; C, Chironomidae; %, percent]

Metric	Combined sites
	Percentage of times F > S
Total taxa	90
Total abundance	70
Total EPT	90
Total Chironomidae	70
EPT %	70
Chironomidae %	40
EPT:C ratio	70
Total dominant taxa	60
% Dominant taxa	60

Natural seasonal variation was found in both stream types, with fall samples more robust, as indicated by the one-way ANOVA, cluster analysis, and at specific sites with the signed-rank test. Therefore, the best evaluation of temporal and spatial variation in the aquatic arthropod community structure within and among sites would be achieved by comparing fall samples.

Spatial Variation in Invertebrate Community Structure

A two-way ANOVA was initially used to evaluate annual and spatial variation within and among sites, respectively. In this analysis, metric data from main-stem and tributary sites were analyzed separately. Metric values from fall samples collected between 1998 and 2000 were used to determine if invertebrate community structure varied significantly among years and(or) sites. All metrics were tested for differences in factors, site and year, resulting in 18 tests for each stream type (4 by 9 matrix). The average power of the 36 tests was 0.31, with only three tests having a power greater than 0.80. Test power ranges from 0 to 1.0, and a test power equal to or greater than 0.80 is desired. Results from individual tests that did not meet this criterion were not reported, but a summary of the results was included. Marginally significant ($p < 0.10$) or significant ($p < 0.05$) annual differences were found for two metrics from each of the stream types. The average power of these tests was 0.22, with a range of 0.05–0.72. For the tributary sites, three metrics varied significantly among sites, but the power of these tests was low with a range of 0.05–0.64 and a mean of 0.27. Total EPT, percent EPT, and EPT:Chironomidae ratio (mean power 0.94, range 0.93–0.95) were significantly different ($p < 0.05$) among the main-stem sites. Additionally, marginal or significant differences may have existed for three other metrics among the main-stem sites, but these results had a mean power of 0.45 and a range of 0.35–0.64. Overall, these results tentatively indicated that invertebrate community structure did not vary significantly between years for either main-stem or tributary stream types. In addition, the benthic invertebrate community structure did vary significantly among sites, with the main-stem sites showing more variation.

Because annual variation in the invertebrate community structure appeared negligible, a one-way ANOVA or ANOVA on ranks of the nine metrics from fall samples was used to examine spatial variation in

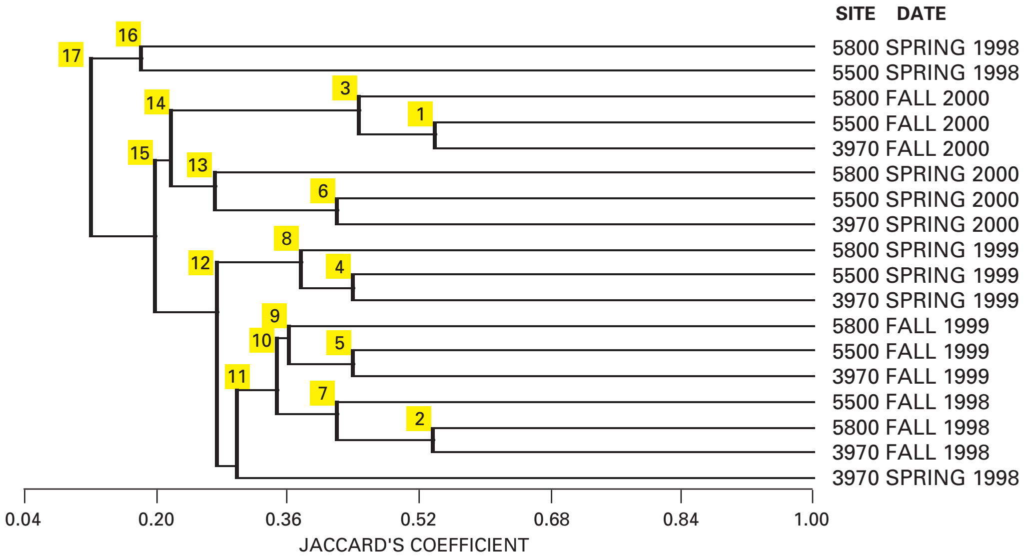


Figure 7. Dendrogram (unweighted pair group method average, UPGMA) based upon Jaccard's Coefficient of Community values summarizing the similarity between selected invertebrate communities collected from the Fountain Creek Basin, 1998–2000. Values approaching 1 are more similar. Nodes on the dendrogram are indicated by highlighted numbers. Site locations shown in figure 1.

Table 9. Seasonal differences in macroinvertebrate samples based upon Jaccard's Coefficient of Community values from selected sites in the Fountain Creek Basin, 1998–2000

[F, fall; S, spring; Sample, site number and date or node; *, not a first-order cluster; site locations shown in fig. 1]

Node (fig. 7)	Sample 1	Sample 2	Samples in group	Seasons in group
1	3970, F 2000	5500, F 2000	2	F-F
2	3970, F 1998	5800, F 1998	2	F-F
3	Node 1	5800, F 2000	3	F-F-F
4	3970, S 1999	5500, S 1999	2	S-S
5	3970, F 1999	5500, F 1999	2	F-F
6	3970, S 2000	5500, S 2000	2	S-S
7	Node 2	5500, F 1998	3	F-F-F
8	Node 4	5800, S 1999	3	S-S-S
9	Node 5	5800, F 1999	3	F-F-F
10	Node 7	Node 9	6	*
11	3970, S 1998	Node 10	7	S-F-F-F-F-F-F
12	Node 11	Node 8	10	*
13	Node 6	5800, S 2000	3	S-S-S
14	Node 13	Node 3	6	*
15	Node 12	Node 14	16	*
16	5500, S 1998	5800, S 1998	2	S-S
17	Node 15	Node 16	18	*

macroinvertebrate community structure among all sites. The test power is an important consideration when interpreting these results. Significant differences among sites were indicated by five metrics, and the results for percent Chironomidae indicated a marginally significant difference (table 11). Results of the SNK multiple range tests showed a fairly consistent pattern for site pairs 3700/5500 and 3990/5800 arranged on opposite ends of the continuum (table 11). Total taxa, Total EPT, percent EPT, and EPT:Chironomidae ratio are positive indicators that tend to increase under improving water quality and(or) habitat conditions. The remaining significant metrics in table 11 are usually considered negative indicators that tend to increase in response to decreasing water quality and(or) habitat conditions. Based on these metrics, the biological condition of site pair 3700/5500 was always better than site pair 3990/5800. The mean metric value ($n = 3$) was presented above each site number in table 11 to demonstrate that substantial differences among the sites were evident, even though the multiple range tests could only accomplish gross separation of statistically significant groups. For example, only two homogeneous groups were identified for the metric Total EPT, but the metric mean values suggested that four exclusive and probably overlapping groups could be formed with sites 3700, 5500/3970/4050, 3980/3977b/3985/3977a, and 3990/5800. The power of all the tests for assessing the variation in invertebrate community structure was adversely affected by sample size and high variance within sites. Sample variance will likely continue to be high, but as more data are collected, the confidence in the test results can improve to an acceptable level.

Table 10. Results of Wilcoxon signed-rank test for paired fall and spring metric values from macroinvertebrate samples collected from selected sites in the Fountain Creek Basin, 1998–2001

[*, marginally significant difference; **, significant difference]

Site number (fig. 1)	p-value
3700	0.164
3970	0.098*
3977a	0.039**
3977b	0.098*
3980	0.039**
3985	0.164
3990	0.027**
4050	0.129
5500	0.426
5800	0.426

The similarity of invertebrate community structure among sites also was examined by cluster analysis because the SNK multiple range tests provided little delineation among sites. This cluster analysis used the mean taxa abundances from fall samples to compute a matrix of Sorenson's Coefficient of Community (*C*) values. Figure 8 is a dendrogram that summarizes and illustrates the similarity of invertebrate community structure provided by the matrix. The clustering of sites in figure 8 does not have statistical significance but furthers the understanding of which sites and clusters are more similar in terms of community composition. Node 1 indicated that the sites with the least spatial separation (sites 3977a and 3977b) had the highest similarity. Node 3 might indicate that community structure is more similar within tributary than main-stem stream types. However, nodes 4, 5, and 6 had sites 3980, 3990, and 5800 forming heterogeneous stream-type clusters, which indicated that site clustering was not completely dependent on stream type. Sites 3700 and 5800 were the last sites to be included in a cluster, and the percent similarity of the nodes that included these sites was small at 23.9 percent and 22.7 percent, respectively. The last observation confirmed results in the multiple range test from the one-way ANOVA of spatial variation that sites 3700 and 5800 were not similar. Beyond node 2, similarity in invertebrate community structure was relatively low between sites.

Environmental Gradient Analysis by Canonical Correspondence Analysis

The statistical analysis of geographic variation in habitat variables and macroinvertebrate community structure identified several patterns and relations among the sites, but consistent separation of the sites into recognizable groups did not occur. Canonical Correspondence Analysis (CCA) was used to determine if distinct species assemblages were associated with specific site(s) or groups of sites. This technique performed a constrained ordination using a matrix of species abundances from each site and an environmental data matrix that corresponded to each site. Seventy-four environmental variables were initially used in the ordination. The type and number of environmental variables used was: stream discharge, 9; water quality, 16; instream habitat, 21; riparian habitat, 6; land use, 22. Taxa that had mean abundances less

Table 11. Results of one-way analysis of variance (ANOVA) and Student-Newman-Keuls (SNK) multiple range tests for spatial variation in invertebrate community structure from selected sites in the Fountain Creek Basin, 1998–2000

[Sites joined by a line were not significantly different; sample size was three (n = 3) for metric means listed above the site numbers; no., number; --, not applicable; site locations shown in fig. 1; <, less than]

Metric		SNK Multiple range test										ANOVA	
												p-value	Test power
Total taxa	Mean	24	22	20	18	13	11	11	7	5	4	0.012	0.752
	Site no.	3700	5500	4050	3970	3985	3980	3977b	3977a	3990	5800		
Total abundance	Mean						not significant					0.119	0.299
	Site no.												
Total EPT	Mean	2760	387	332	280	96	86	56	42	12	9	<0.001	1.000
	Site no.	3700	5500	3970	4050	3980	3977b	3985	3977a	3990	5800		
Total Chironomidae[a]	Mean						not significant					0.576	--
	Site no.												
Percent EPT	Mean	72	40	33	26	17	13	9	6	5	0.5	0.003	0.909
	Site no.	3700	5500	3977b	3970	3980	4050	3985	3977a	3990	5800		
Percent Chironomidae	Mean	92	85	63	55	50	42	34	27	26	11	0.059	0.453
	Site no.	3990	5800	3970	4050	3980	5500	3985	3977a	3977b	3700		
EPT:Chironomidae ratio	Mean	0.88	0.59	0.50	0.30	0.30	0.22	0.22	0.19	0.05	0.01	0.024	0.639
	Site no.	3700	3977b	5500	3970	3977a	4050	3985	3980	3990	5800		
Total dominant taxa	Mean						not significant					0.120	0.332
	Site no.												
Percent dominant taxa	Mean	96	91	89	86	65	64	63	61	57	53	0.006	0.850
	Site no.	5800	3990	3980	3977a	3977b	3700	3985	3970	5500	4050		

[a] Results based upon ANOVA of ranks.

than 5 percent of the average taxa mean were removed from the species matrix to reduce the number of non-differential taxa. The final ordination (fig. 9) contained 59 taxa, 10 sites, and three environmental variables. To limit the noise in the ordination, mean species abundance values from fall samples were used along with means calculated for the environmental variables.

The CCA identified a particle-size gradient (abscissa, CCA 1) that produced a joint plot with five recognizable site clusters and their associated taxa (1, site 3700; 2, sites 3970, 5500; 3, site 3990; 4, sites 3977a, 3977b, 3980, 3985, 4050; and 5, site 5800) (fig. 9). The direction of the solid arrows (vectors) in figure 9 indicates where the largest values for that variable are located, and the length of the solid arrows indicates the relative change in the magnitude of the variables. In figure 9, the vectors for very coarse gravel and sand are highly correlated with the first ordination axis, and their relative lengths indicate large changes in the values for these variables. Therefore, the macroinvertebrate community variation partitioned in figure 9 is strongly correlated with substrate size. The position of site 3990 along CCA 1 was unaffected by the particle-size gradient and can be explained by bedrock dominating the substrate at this site. The positions of site clusters 1 and 4 were most influenced by the particle-size gradient. Cluster 5 is the most downstream site, and its position in the ordination was likely influenced more by stream discharge than by the particle-size gradient. The position of cluster 5 indicated a discontinuity in the geographic distribution of the sites in the network and that environmental gradients other than substrate size are likely important in constraining species assemblages persistent in the Fountain Creek Basin.

Metric values computed from the presence or absence of taxa associated with the clusters indicated disturbance- or pollution-intolerant taxa were associated with cluster 1 (fig. 9). The remaining site clusters were composed primarily of disturbance- or pollution-tolerant taxa and formed a less than strict continuum from the relatively least impaired to most impaired with the site cluster sequence of 2, 4, 3, 5.

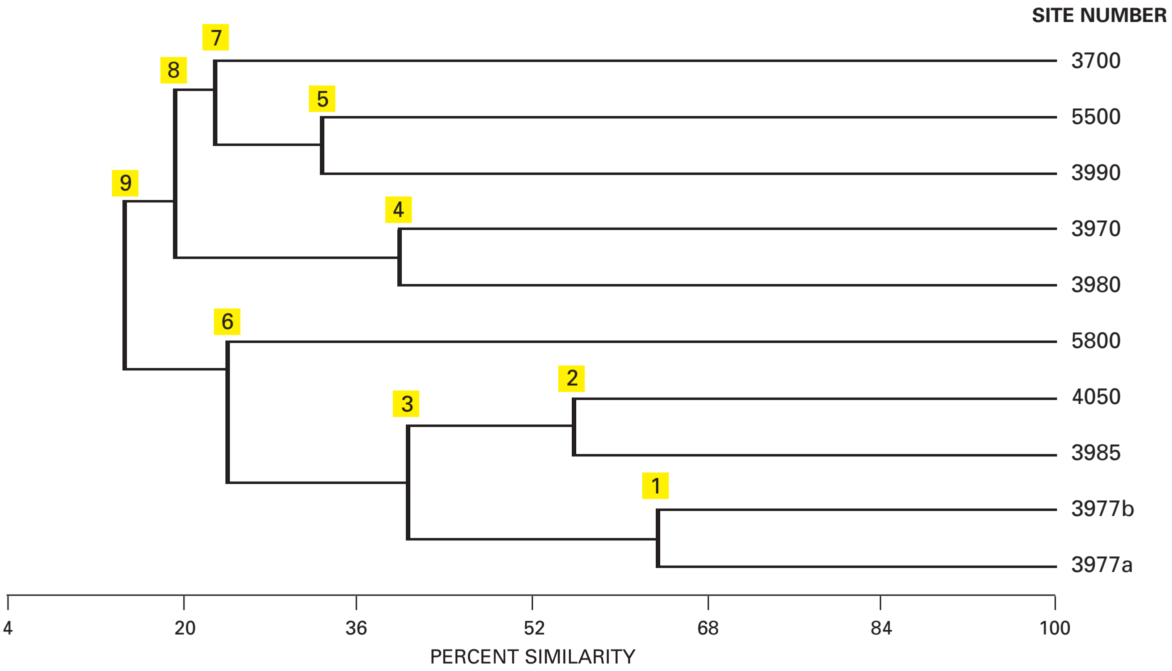
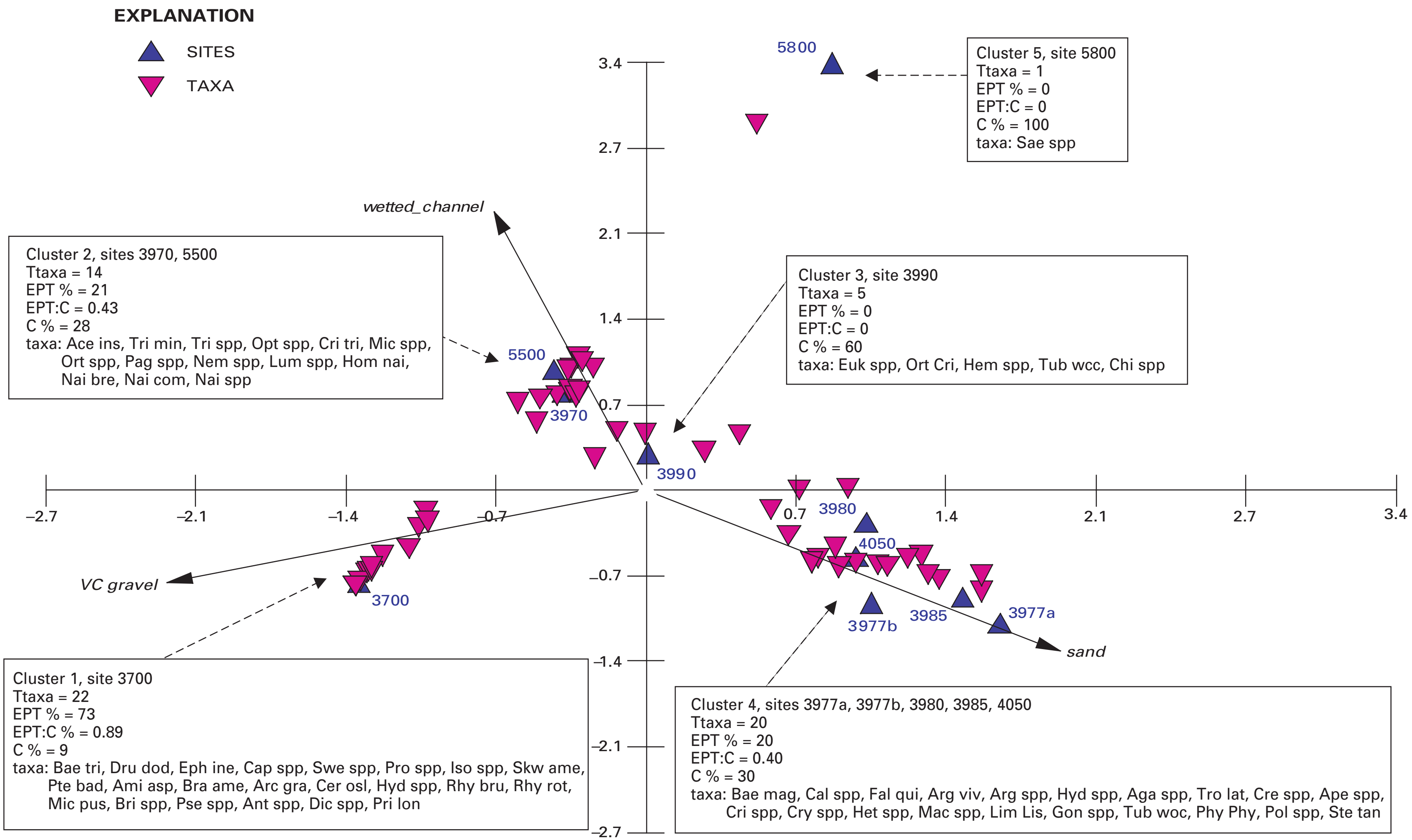


Figure 8. Dendrogram (unweighted pair group method average, UPGMA) based upon Sorenson's Coefficient of Community values summarizing the similarity of invertebrate community structure between selected sites in the Fountain Creek Basin, 1998–2000. Values approaching 100 are more similar. Nodes on the dendrogram are indicated by highlighted numbers. Site locations shown in figure 1.



Cluster 5, site 5800
Ttaxa = 1
EPT % = 0
EPT:C = 0
C % = 100
taxa: Sae spp

Cluster 2, sites 3970, 5500
Ttaxa = 14
EPT % = 21
EPT:C = 0.43
C % = 28
taxa: Ace ins, Tri min, Tri spp, Opt spp, Cri tri, Mic spp, Ort spp, Pag spp, Nem spp, Lum spp, Hom nai, Nai bre, Nai com, Nai spp

Cluster 3, site 3990
Ttaxa = 5
EPT % = 0
EPT:C = 0
C % = 60
taxa: Euk spp, Ort Cri, Hem spp, Tub wcc, Chi spp

Cluster 1, site 3700
Ttaxa = 22
EPT % = 73
EPT:C % = 0.89
C % = 9
taxa: Bae tri, Dru dod, Eph ine, Cap spp, Swe spp, Pro spp, Iso spp, Skw ame, Pte bad, Ami asp, Bra ame, Arc gra, Cer osl, Hyd spp, Rhy bru, Rhy rot, Mic pus, Bri spp, Pse spp, Ant spp, Dic spp, Pri lon

Cluster 4, sites 3977a, 3977b, 3980, 3985, 4050
Ttaxa = 20
EPT % = 20
EPT:C = 0.40
C % = 30
taxa: Bae mag, Cal spp, Fal qui, Arg viv, Arg spp, Hyd spp, Aga spp, Tro lat, Cre spp, Ape spp, Cri spp, Cry spp, Het spp, Mac spp, Lim Lis, Gon spp, Tub woc, Phy Phy, Pol spp, Ste tan

Figure 9. Canonical Correspondence Analysis (CCA) ordination of sampling sites, species, and environmental variables for selected sites in the Fountain Creek Basin, 1998–2000. Site cluster metric values were computed from presence-absence of taxa associated with the clusters. Taxa are indicated by the first three letters of their genus and species name (tables 17 and 18), and environmental variables are represented by solid arrows. Site locations shown in figure 1. The variable very coarse gravel was abbreviated VC gravel, and spp represents species.

SUMMARY

Little information concerning the stream-dwelling macroinvertebrates or habitat condition of the Fountain Creek Basin has been compiled, analyzed, or published. In the spring of 1998, the USGS began a noncomprehensive study to characterize and analyze temporal and spatial variations in habitat and macroinvertebrate community structure by using biological, hydrological, water-quality, and land-use data collected at 10 sites in the Fountain Creek Basin. The results from this study can be used as baseline information to augment long-term monitoring of water quality, instream and riparian habitat quality and diversity, and biological condition.

Generally, sand and fine gravel dominated the substrate, and runs were the prevalent geomorphic channel unit found at the selected sites in the study area. The range in discharge among the sites varied greatly, but the prevalent velocity-depth regime was fast and shallow flows. Site 3700 was a cold-water stream, whereas the remaining sites were designated as warm-water streams. Readily observed deleterious effects to the instream and riparian habitats at the study sites included downcutting, deposition, scour, urban development, right-of-way construction, beaver activity, and manmade litter. Seasonal variation of the habitat variables measured was generally not found. Statistically significant spatial variation in habitat variables was found among the sites, and channel morphology features provided the best discrimination. Habitat similarity was greater within the tributary sites compared to the main-stem sites.

Hess and kicksweep sampling yielded the identification of 218 macroinvertebrate taxa that were represented by 9 insect orders and 35 noninsect taxa. As a percentage of taxa richness, dipterans accounted for 40 percent of the taxa. Site 3700 was the relatively least impaired site based on the metrics used in this study. Lack of adequate streamflow likely had the greatest influence on macroinvertebrate populations at sites 3977a, 3977b, and 4050. Statistical analyses indicated that variability in macroinvertebrate populations between seasons was significant and that fall samples generally had diversity and abundances greater than spring samples. Clustering methods provided strong evidence that seasonal differences in macroinvertebrate populations existed. ANOVA results indicated that annual variation of invertebrate community structure within a given site was negligible and that significant geographic variation for 5 of the 9 metrics existed. Mean metric values indicated substantial biological differences between sites or groups of sites that SNK multiple range tests did not delineate. Because the SNK multiple range tests provided little delineation among the sites, a dendrogram based on the Sorenson's Coefficient of Community was used to examine geographic similarity among the sites. The structure of the dendrogram from this analysis indicated that invertebrate community structure was more similar among tributary sites than main-stem sites. CCA ordination identified a substrate particle-size gradient from site-specific species-abundance data and environmental correlates that reduced the 10 sites to 5 site clusters and their associated taxa. A continuum of the study sites based on metrics computed from the presence or absence of taxa associated with the five CCA clusters from the relatively least impaired to most impaired was 3700, 3970/5500, 3977a/3977b/3980/3985/4050, 3990, 5800.

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Appendix A. Habitat Data (*available in Excel format*)

Table 12. Detailed instream and riparian habitat variables measured at selected sites in the Fountain Creek Basin, 1998–2001

Table 13. Detailed point instream habitat variables measured at selected sites in the Fountain Creek Basin, 1998–2001

Table 14. Pebble-count data for selected sites in the Fountain Creek Basin, 1998–2001

Table 15. Habitat variable scores based upon rapid bioassessment protocols for selected sites in the Fountain Creek Basin, 1998–2001

Table 16. Geomorphic channel unit measurements and water-surface gradient for selected sites in the Fountain Creek Basin, 1998–2001

Tables 12 and 13

Table 14, 15, and 16

Appendix B. Macroinvertebrate Data (*available in Excel format*)

Table 17. Macroinvertebrate taxa collected by kicksweep method at selected sites in the Fountain Creek Basin, 1998–2001

Table 18. Density of macroinvertebrates collected by Hess sampler at selected sites in the Fountain Creek Basin, 1998–2001

Table 17

Table 18