Effects of Urbanization on Benthic Macroinvertebrate Communities in Streams, Anchorage, Alaska

Water-Resources Investigations Report 01–4278

Oblique aerial view of downtown Anchorage and Cook Inlet, Alaska (photograph taken in 2001 by author)

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Effects of Urbanization on Benthic Macroinvertebrate Communities in Streams, Anchorage, Alaska

By Robert T. Ourso

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01–4278

Anchorage, Alaska
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

For additional information, contact:

District Chief
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, AK 99508–4664

URL: <http://ak.water.usgs.gov>

FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and facilitates effective management of water, biological, energy, and mineral resources. (URL: <http://www.usgs.gov/>). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) program to support national, regional, and local information needs and decisions related to water-quality management and policy. (URL: <http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resources management and strategies that protect and restore water quality.

Since 1991, the NAWQA program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as study units. (URL: <http://water.usgs.gov/nawqa/nawqamap.html>). Collectively, these study units account for more than 60 percent of the overall water use and population served by public water supply and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multiscale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the study-unit findings. (URL: <http://water.usgs.gov/nawqa/natsyn.html>).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA program recognizes that a national assessment by a single program cannot address all water-resources issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, nongovernment organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Associate Director for Water

CONTENTS

FIGURES

TABLES

APPENDIXES

CONVERSION FACTORS, WATER-QUALITY AND OTHER METRIC UNITS, and VERTICAL DATUM

Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
mile per square mile (mi/mi^2)	0.6212	kilometer per square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

In this report, water temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the equation

$$°F = 1.8\ (°C) + 32$$

and ambient (air) temperature is reported in degrees Fahrenheit(°F), which can be converted to degrees Celsius (°C) by the equation

$$°C = (°F - 32) / 1.8$$

Abbreviated water-quality and other metric units used in this report: Chemical concentration in water, or solute mass per unit volume (liter) of water, is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). (A concentration of 1,000 µg/L is equivalent to a concentration of 1 mg/L. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.) Specific conductance is given in microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Other metric units used are micron (µm), centimeter (cm), and square meter (m^2). The unit used for algal standing crop is milligram per square meter (mg/m^2). Standard units are used for pH.

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Effects of Urbanization on Benthic Macroinvertebrate Communities in Streams, Anchorage, Alaska

By Robert T. Ourso

Abstract

The effect of urbanization on stream macroinvertebrate communities was examined by using data gathered during a 1999 reconnaissance of 14 sites in the Municipality of Anchorage, Alaska. Data collected included macroinvertebrate abundance, water chemistry, and trace elements in bed sediments. Macroinvertebrate relative-abundance data were edited and used in metric and index calculations. Population density was used as a surrogate for urbanization. Cluster analysis (unweighted-paired-grouping method) using arithmetic means of macroinvertebrate presence–absence data showed a well-defined separation between urbanized and nonurbanized sites as well as extracted sites that did not cleanly fall into either category. Water quality in Anchorage generally declined with increasing urbanization (population density). Of 59 variables examined, 31 correlated with urbanization. Local regression analysis extracted 11 variables that showed a significant impairment threshold response and 6 that showed a significant linear response. Significant biological variables for determining the impairment threshold in this study were the Margalef diversity index, Ephemeroptera–Plecoptera–Trichoptera taxa richness, and total taxa richness. Significant thresholds were observed in the water-chemistry variables conductivity, dissolved organic carbon, potassium, and total dissolved solids. Significant thresholds in trace elements in bed sediments included arsenic, iron, manganese, and lead. Results suggest that sites in Anchorage that have ratios of population density to road density greater than 70, storm-drain densities greater than 0.45 miles per square mile, road densities greater than 4 miles per square mile, or population densities greater than 125–150 persons per square mile may require further monitoring to determine if the stream has become impaired. This population density is far less than the 1,000 persons per square mile used by the U.S. Census Bureau to define an urban area.

INTRODUCTION

The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program began studies in the Cook Inlet Basin (COOK) study unit in 1997. The goal of the COOK study is to describe the status and trends in the quality of water in the basin and to relate that to an understanding of the natural and human factors controlling water quality.

Increasing urban populations, and the urban sprawl associated with the increase in population, are known to alter drainage basins and the streams that drain these urbanized catchments. Point sources of pollution in the U.S. and most developed countries have been studied intensely and regulated more closely since the passage of the Clean Water Act. The understanding of point-source pollution and its effects has shown that other factors contribute to the degradation of urban water quality as streams still show impairment. Many prior studies describe the effects of nonpoint-source pollution on water quality, especially in urban areas (Klein, 1979; Milner and Oswood, 1989; Wear and others, 1998; Winter and Duthie, 1998). Nonpoint-source pollution factors that are commonly cited as detrimental to water quality are increases in conductivity due to road deicing, organic pollution from high-density livestock facilities, nutrient enrichment from fertilizers, and petroleum byproducts from the use of vehicles, among many others.

Associated with increases in population is increased impervious area, which leads to elevated runoff and streamflows over short time periods. As water in the catchment exits the system more rapidly owing to increases in impervious cover, low flows tend to decrease, and the overall habitat availability for stream-dwelling organisms correspondingly decreases. Increases in pollutants, which also are attributed to increasing populations and impervious areas, exacerbate the problems associated with lowered discharges: Because less water is available for dilution of pollutants, resident organisms are subjected to increasing stress. Macroinvertebrate-community structures have shifted from greater numbers of specialist feeders in undisturbed areas to greater numbers of generalists in less-diverse disturbed areas (Whiting and Clifford, 1983; Garie and McIntosh, 1986).

Anchorage presents a unique opportunity to study the effects of urbanization on benthic macroinvertebrates. Streams in Anchorage originate in undisturbed catchments and then course through areas having different population densities before emptying into Cook Inlet. This report generally describes the results of site reconnaissance for a study examining the changes in water quality along an urban gradient and specifically examines the response of benthic macroinvertebrates to changes in water quality along a gradient of urbanization in five stream basins within the Municipality of Anchorage, Alaska.

BASIN CHARACTERIZATION

The hydrology of Anchorage is dominated by five stream basins, all having headwaters in the Chugach Mountains, which border the municipality on the east side. Each stream courses through the city on the way to its mouth along the Cook Inlet. Anchorage, the most populated city in the State, is located within the Cook Inlet Basin in south-central Alaska. More than one-third of Alaska's population lives in Anchorage. Estimated population of the municipality as of 1996 was approximately 254,000 (Municipality of Anchorage, 1996). The mean annual precipitation is 20 to 25 in. and average temperature is about 27°F (Brabets and others, 1999).

Streams are affected by ice cover for a significant part of the year. Ice typically forms over the streams in late November to early December and open water reappears around the beginning of April. The time of ice cover varies according to the elevation of a particular segment of the stream.

The geology consists primarily of unconsolidated Quaternary alluvial or glacial deposits in the lower elevations and Mesozoic metamorphic, volcanic, and igneous rock in the Chugach Mountains on the east side (Brabets and others, 1999).

Land cover is dominated by moist herbaceous and shrub tundra. Open and closed spruce forest, low and tall shrub, and alpine tundra and barrens cover smaller areas (Brabets and others, 1999). Within the area under investigation in this study, land use is principally forest (military lands and State parklands) and urban (residential and commercial).

STUDY SITES

The five stream basins within the Municipality of Anchorage (**fig. 1**, **fig. 2**, **table 1**) that were chosen for the study were, from north to south, Ship Creek, Chester Creek, Campbell Creek, Rabbit Creek, and Little Rabbit Creek. During August–September 1999, 14 stream sites (**appendix 1**) were selected to represent these 5 basins—2 sites in the Ship Creek Basin and 3 in each of the other 4 basins. Total basin areas range from 125 mi^2 (Ship Creek) to 6.4 mi^2 (Little Rabbit Creek). Snowmelt from the Chugach Mountains is the primary contributor to surface-water flow within the five basins studied.

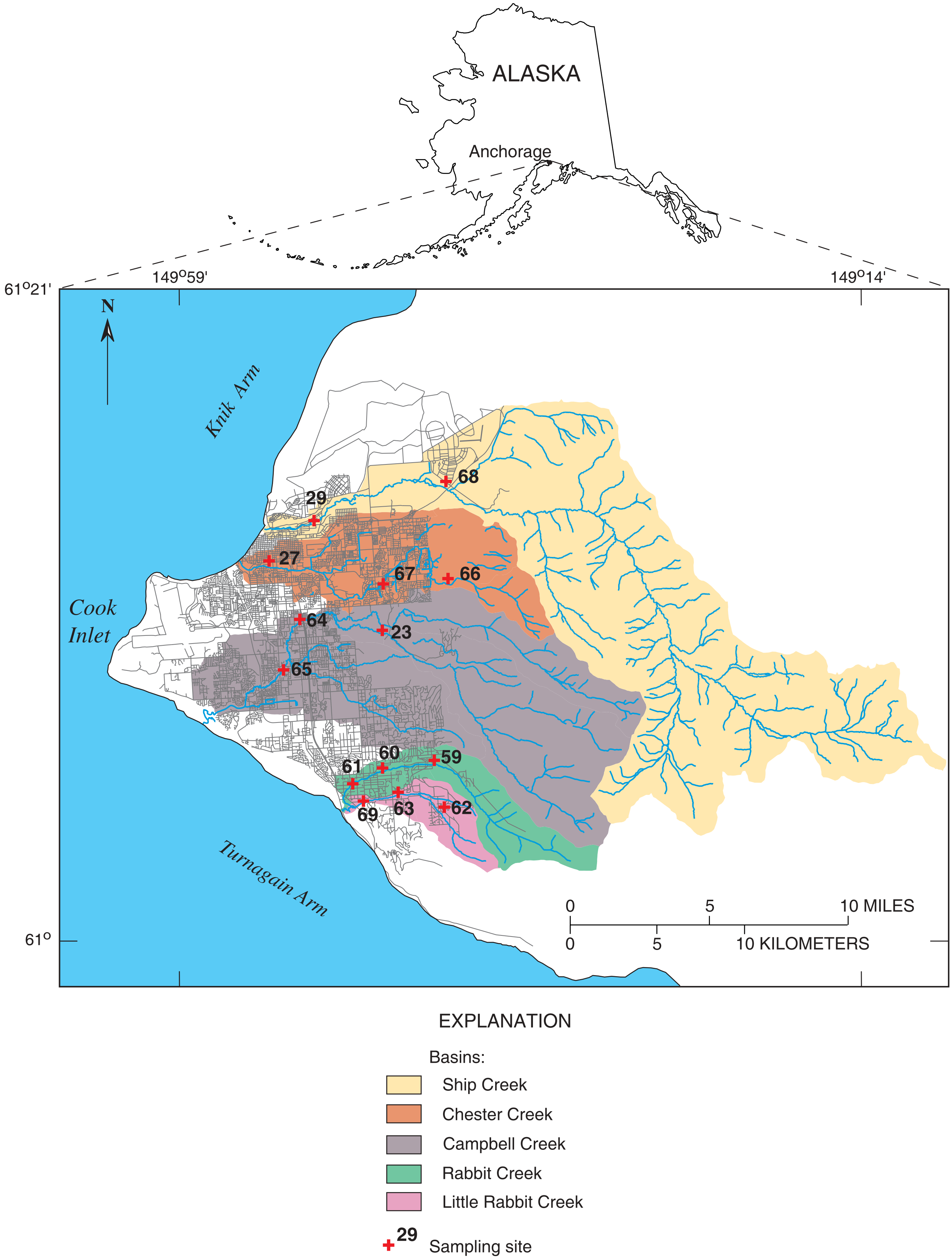

Figure 1. Anchorage area, showing stream basins and sampling sites. Site numbers (appendix 1) correspond to those introduced by Brabets and others (1999) in their National Water-Quality Assessment environmental-setting study.

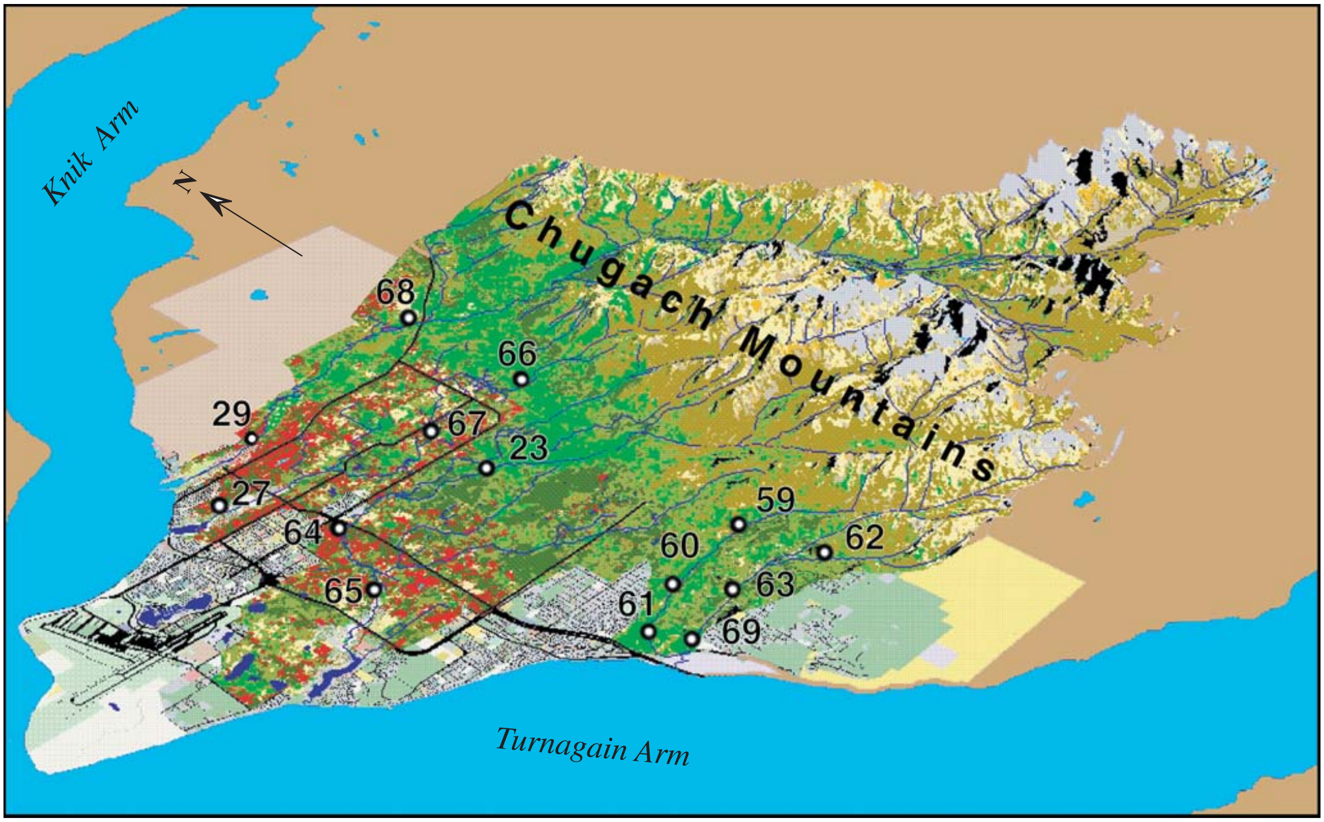

Figure 2. Three-dimensional representation of Anchorage area and sampling sites. (See fig. 1 and appendix 1 regarding sampling sites.)

Sites initially were selected on the basis of their position along a gradient of urbanization as represented by road density (miles of road per square mile of drainage area) upstream from each sample site. The South Fork of Campbell Creek (site 23, fig. 1) and Chester Creek at Arctic Boulevard (site 27) were gaged sites and were planned as upper and lower (respectively) endpoints of the gradient. Upstream sites were chosen on the basis of level of development and access. Upstream sites had road densities that ranged from 0 to 2.1 mi/mi^2 (table 1). Intermediately positioned sites had a greater degree of development (road-density range, 0.9 to 4.2 mi/mi^2). The farthest downstream sites were the most highly developed sites within their respective basins and had road densities ranging from 0.57 to 9.2 mi/mi^2. Ship Creek skewed the road-density calculations at its upstream and downstream sites owing to the overall size of the contributing area of the basin upstream from each site. The most current land-use and population information, used to calculate urbanization metrics, was assembled from land-use maps, satellite images, aerial photography, and geographic information systems databases.

Table 1. Description of sites

[Site no.: Number used in this report (see figs. 1 and 2 for site locations); corresponds to site number assigned by Brabets and others (1999) in earlier National Water-Quality Assessment report. Sites are ordered from least to greatest population density]

Site no.	U.S. Geological Survey station		Elevation (feet above sea level)	Upstream watershed area (square miles)	Discharge (cubic feet per second)	Specific conductance (microsiemens per centimeter at 25°C)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Road density (miles per square mile)	Population density (persons per square mile)	Storm-drain density (miles of storm sewers per square mile)	Ratio of population density to road density
	Station number	Name											
66	15274796	South Branch of South Fork Chester Creek at Tank Trail	358	4.3	3.4	113	8.2	4.5	11.4	0	0	0	0
68	15276200	Ship Creek at Glenn Highway	286	103.4	148	156	7.5	7	11.8	.1	0	.00	0
23	15274000	South Fork Campbell Creek	233	29.2	58	72	7.7	4	12.7	.33	9	0	29.42
29	15276570	Ship Creek below powerplant at Elmendorf Air Force Base	47	113.3	224	169	7.6	9.5	10.7	.6	28	.08	48.28
59	15273020	Rabbit Creek at Hillside Drive	876	9.8	30	86	7.3	3.5	12.2	.98	32	0	32.68
62	15273090	Little Rabbit Creek at Nickleen Street	1,230	2.6	6.2	109	7.7	1	12.6	2.12	60	0	28.36
63	15273097	Little Rabbit Creek at Goldenview Drive	590	5.6	15	128	7.9	2.5	12.8	4.2	125	0	29.86
60	15273030	Rabbit Creek at East 140th Avenue	436	11.3	28	90	7.6	6	12.5	2.97	136	0	45.92
64	15274395	Campbell Creek at New Seward Highway	98	45.9	78	84	7.6	5	11.6	.89	176	.45	198.48
69	15273100	Little Rabbit Creek	92	6.4	15	137	7.9	3	12.4	4.77	182	0	38.39
61	15273040	Rabbit Creek at Porcupine Trail	121	13.3	34	96	7.6	6	12.2	4.04	262	0	64.93
65	15274557	Campbell Creek at C Street	52	65.7	89	92	7.9	8	8.9	3.55	662	1.59	186.52
67	15274830	South Branch of South Fork Chester Creek at Boniface Parkway	197	14.8	12	168	7.7	8	11.7	4.14	1,222	3.22	295.1
27	15275100	Chester Creek at Arctic Boulevard	16	27.3	31	242	8.1	11.5	10.4	9.24	2,736	6.95	296.2

FIELD METHODS

Water-chemistry data (major ions, nutrients, dissolved and suspended organic carbon), field properties (stream discharge, specific conductance, dissolved oxygen, pH, and water temperature), concentrations of trace elements in streambed sediments, macroinvertebrate relative abundances, and chlorophyll-*a* data were collected to assess water quality along the urban gradient. For most sites, data were collected during August 23 to September 23, 1999; for the South Fork of Campbell Creek (site 23), data collected in late July 1999 as part of the NAWQA basic fixed-site sampling regime was used.

Water samples for major ions and nutrients and streambed-sediment samples for trace elements were collected according to NAWQA protocols (Shelton, 1994; Shelton and Capel, 1994) and sent to the USGS National Water-Quality Laboratory (NWQL) for constituent analysis. Major ions and trace elements addressed in this report include calcium, magnesium, sodium, potassium, sulfate, chloride, phosphorus, iron, manganese, aluminum, arsenic, cadmium, cobalt, copper, chromium, lead, mercury, molybdenum, nickel, selenium, silver, sulfur, and zinc.

Epilithic periphyton (algae attached to rocks) was collected using quantitative methods described by Porter and others (1993) and fluorometrically analyzed for chlorophyll-*a* concentrations at the University of Alaska at Fairbanks. Three algae samples comprising five rocks each were collected in each reach. These concentrations were averaged to measure algal standing crop in milligrams per square meter.

Macroinvertebrate samples were collected according to NAWQA protocols (Cuffney and others, 1993). The richest targeted habitat (RTH or semiquantitative) method was designed to provide identification and enumeration of species within a given area. Riffles, which are known to support a taxonomically rich macroinvertebrate community (Hynes, 1970), were targeted for semiquantitative sampling. Five samples, each representing a sampling area of 0.25 m^2, were collected in riffles within each reach by using a 425-µm mesh Slack sampler. Bed sediment within the sample area was disturbed to a depth of approximately 10 cm for approximately one minute. Large rocks were scrubbed to remove any adhering organisms. The five samples then were composited and packaged for shipment. The samples were submitted to the Biological Unit of the NWQL for taxonomic determination. The resulting data was entered into a database for further manipulation (see **appendix 2** for raw data). Macroinvertebrate metrics were calculated and categorized according to richness, composition, tolerance, and feeding measures (**table 2**).

ANALYSIS

Macroinvertebrate identification and presence–absence data were entered into a database and sorted for further analysis. An unweighted-paired-grouping-method (UPGM) cluster analysis using arithmetic means was applied to Bray–Curtis distance matrices and was performed by using lowest identifiable taxa data. Dendrograms were generated to aid in relating clusters of sites. UPGM 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; Ludwig and Reynolds, 1988). The resultant dendrogram grouped the sites on the basis of dissimilarities (**fig. 3**). Groupings that have larger Bray–Curtis dissimilarity values (approaching 1) are more dissimilar.

Table 2. Biological metrics and expected response of macroinvertebrates to perturbation

[Data modified from Kerans and Karr (1994); Barbour and others (1996); and Fore and others (1996). EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera]

Biological metric	Definition and remarks	Expected response to increasing perturbation
Abundance category		
EPT abundance	Number of EPT individuals	Decrease
Composition category		
Margalef diversity index (lowest practical taxonomic level of identification)	Measure of species richness (measured to the lowest practical taxonomic level of identification).	Decrease
Margalef diversity index (family level)	Measure of species richness (measured to the family level of identification).	Decrease
Shannon diversity index	Index that uses richness and evenness to measure general diversity and composition.	Decrease
Percentage Chironomidae	Percentage midge larvae	Increase
Percentage Ephemeroptera	Percentage mayfly nymphs	Decrease
Percentage Plecoptera	Percentage stonefly nymphs	Decrease
Percentage Trichoptera	Percentage caddisfly larvae	Decrease
Percentage Oligochaeta	Percentage aquatic worms	Variable
Ratio of EPT to Chironomidae abundances	Measure of balance between two indicator groups	Decrease
Feeding category		
Percentage filterers	Percentage of macrobenthos that filter from water column or sediment	Variable
Percentage collectors (gatherers)	Percentage of macrobenthos that feed by gathering	Variable
Percentage predators	Percentage of macrobenthos that feed upon other organisms	Variable
Percentage scrapers	Percentage of macrobenthos that scrape or graze on periphyton	Decrease
Percentage shredders	Percentage of macrobenthos that shred leaf material	Decrease
Richness category		
Total taxa richness (lowest practical taxonomic level of identification)	Measure of overall variety of macroinvertebrates at lowest taxa identified	Decrease
Total taxa richness (family level)	Measure of overall variety of macroinvertebrates at family level of identification.	Decrease
EPT taxa richness	Number of EPT taxa represented	Decrease
Tolerance category		
Hilsenhoff family-level biotic index	Index that uses tolerance values to weight family-level identifications to evaluate organic pollution.	Increase
Percentage two dominant taxa	Percentage composition of the two most abundant taxa	Increase
Ratio of Baetidae to Ephemeroptera abundances	Relative abundance of pollution-tolerant mayflies	Increase

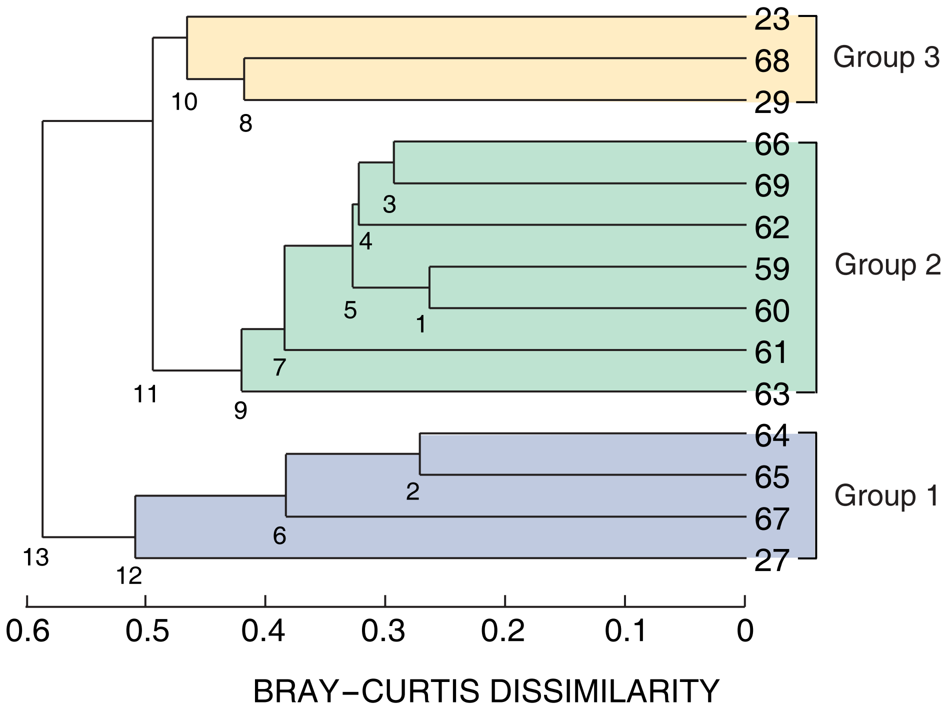

Figure 3. Cluster analysis (unweighted-paired-grouping method) using arithmetic means of macroinvertebrate presence–absence data. Values approaching 1 are more dissimilar. Nodes (13, 11, 10, 12, and others) represent clusters and facilitate assessment of dissimilarity. Group 1 sites are considered “urban impacted”; group 2 sites are “non-impacted”; group 3 sites are considered to be possibly anomalous compared to other two groups. (See fig. 1 and appendix 1 regarding sampling sites.)

Variables for water chemistry (major ions and nutrients) and bed-sediment chemistry (trace elements) that were below detection limits were removed from analysis because of the limited number of sites in the data set. A correlation table of the significant variables ($p < 0.05$, $r > |0.7|$) against population density was generated to determine those variables associated with urbanization for further analysis (**table 3**).

Population, road, and storm-drain densities were calculated by using data provided by the Municipality of Anchorage. Population density was defined as number of persons/mi^2 of basin; road density was defined as linear miles of road per square mile of basin; storm-drain density was defined as miles of storm drains per square mile of basin. The ratio of population density to road density, or PDRD ratio, was calculated as the number of persons per mile of road. Each of these calculations incorporates all basin area upstream from each site.

Local regression analysis, performed by using the statistical package S-Plus 2000 (Mathsoft, Inc., 2000), was used to examine the variables associated with urbanization (measured as population density in this study) for the presence of a threshold response or of a linear response. Threshold responses, visually identified by a breakpoint in or change in slope of a smooth-fit line, suggest a point at which further increases in population density could have a significant effect on stream condition with respect to the particular constituent or metric. Scatterplot smoothing was used to remove noise (that is, extraneous information that reduces our ability to see patterns in the data) from a data set and to produce a more easily interpreted fit. After the threshold had been identified visually on the plot, the breakpoint was tested by determining if the slopes of the two lines converging at the breakpoint differed significantly. A *t*-test (Zar, 1996) was used to check the equality of two population regression coefficients; a linear response indicates that any increase in population density (the independent variable, *x*) relates to an increase or decrease (depending on the variable) in the dependent variable (*y*) in a linear fashion without a significant change in the slope of the line at a breakpoint.

Table 3. Coefficients of correlation between each metric or constituent or field property and population density

[Blue shading indicates that correlation is significant at $p < 0.05$, $n = 14$. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera]

Biological metric or constituent	Coefficient of correlation with population density
Biological variables	
Margalef diversity index (lowest practical taxonomic level of identification)	-0.78
Margalef diversity index (family level)	-.36
Shannon diversity index (lowest practical taxonomic level of identification)	-.81
Total abundance	-.18
EPT abundance	-.33
Hilsenhoff family-level biotic index	.78
Percentage Chironomidae	-.23
Percentage Ephemeroptera	-.38
Percentage Plecoptera	-.43
Percentage Trichoptera	-.36
Percentage Oligochaeta	.71
Percentage filterers	-.34
Percentage collectors	.1
Percentage predators	-.56
Percentage scrapers	-.63
Percentage shredders	-.37
Total taxa richness (lowest practical taxonomic level of identification)	-.73
Total taxa richness (family level)	-.56
Percentage two dominant taxa	.82
Percentage EPT	-.62
EPT taxa richness	-.85
Ratio of EPT to Chironomidae abundances	-.34
Ratio of Baetidae to Ephemeroptera abundances	.65
Chlorophyll-*a*	.35
Water chemistry and field properties	
Silica	.66
Calcium	.61
Chloride	.97
Sodium	.92
Potassium	.95
Magnesium	.84
Sulfate	.27
Total dissolved solids	.76
Organic carbon, dissolved	.74
Discharge	-.15
Specific conductance	.76
pH	-.04
Temperature	.36
Oxygen, dissolved	-.17
Mercury	-.26
Copper	.64
Sulfur	.64
Cobalt	.41
Chromium	.55
Bed-sediment chemistry	
Phosphorus	.15
Sodium	.01
Magnesium	.25
Potassium	-.27
Iron	.85
Calcium	.04
Aluminum	-.15
Selenium	-.27
Arsenic	.86
Cadmium	.97
Silver	.81
Zinc	.98
Lead	.98
Nickel	.5
Molybdenum	.05
Manganese	.84

RESULTS

A UPGM cluster analysis of macroinvertebrate-species abundance data using Bray–Curtis distance matrices is shown in figure 3. The sites separated into three primary groupings based on cluster analysis. These groupings illustrate a delineation between urban-impacted (group 1) and nonimpacted sites (group 2), as well as substantiate the differences between Ship Creek (group 3) and the rest of the basins in the Anchorage Bowl. The South Fork of Campbell Creek site (site 23, group 3) appears anomalous, possibly due to a different sampling time compared to the other sites. The PDRD ratio appears to support the separation of sites in group 1 from those in groups 2 and 3 but does not distinguish group 3 from group 2 (table 1, fig. 3, **fig. 4**). Storm-drain density also supports the separation of group 1 from groups 2 and 3. All group 1 sites had storm-drain densities ≥0.45.

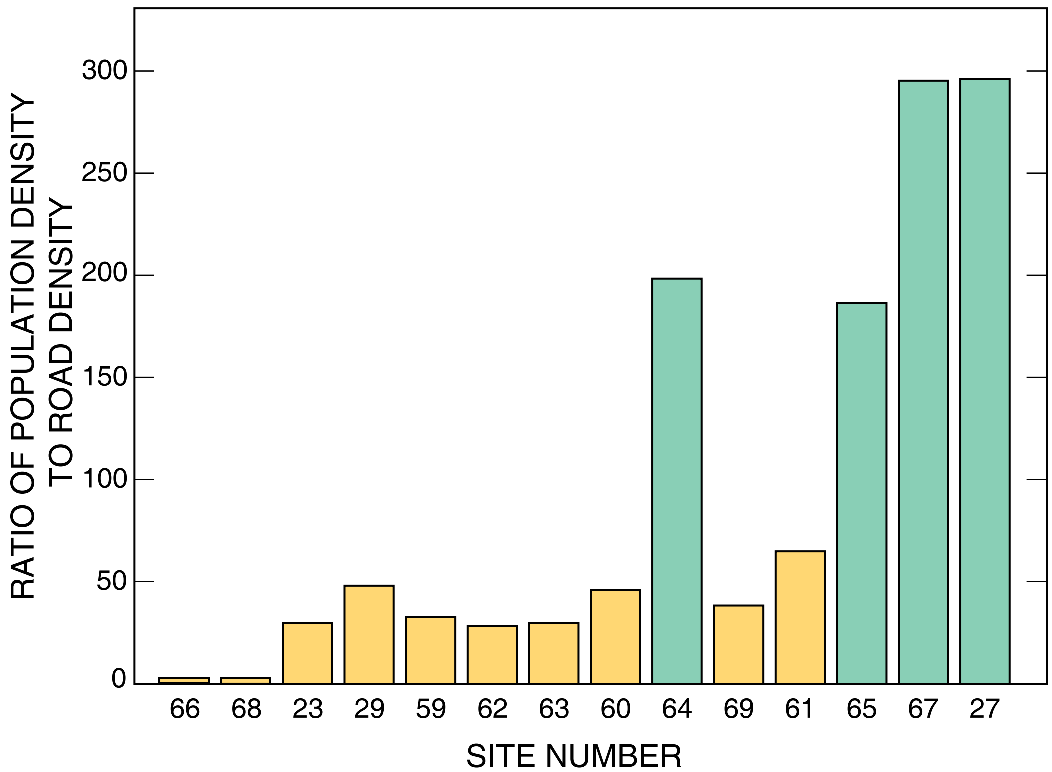

Figure 4. Ratio of population density to road density, comparing group 1 sites (green), which are urban impacted, with groups 2 and 3 sites (yellow), which are nonimpacted and anomalous, respectively. (See fig. 1 and appendix 1 regarding sampling sites.)

Correlation coefficients between chosen metrics or constituents and population density are shown in table 3 ($p < 0.05$, $n = 14$). Of these variables, 12 biological variables (appendix 2 and **appendix 3**), 12 water-chemistry variables (**appendix 4**), and 7 trace-element-in-bed-sediments variables (**appendix 5**) were shown to be significant ($p < 0.05$).

The PDRD ratio was greatest for those sites rated as urban impacted (table 1, fig. 4). The ratios for sites 27, 67, 65, and 64 (members of group 1 in the cluster analysis, fig. 3) were an order of magnitude higher than for all other sites, which had PDRD ratios of less than 70. No difference with respect to the PDRD ratio was evident between UPGM cluster groupings 2 and 3.

Locally weighted regression analysis was performed on 31 macroinvertebrate metrics, water-chemistry variables, field properties, and bed-sediment variables that correlated significantly ($p < 0.05$) with population density (table 3). Of these 31 variables, 11 showed a threshold response of the constituent to population densities when plotted and tested for significance (**fig. 5**, **fig. 6**, **fig. 7**, **table 4**), and 7 exhibited a linear response (no significant breakpoint in the line) (**fig. 8**, table 4).

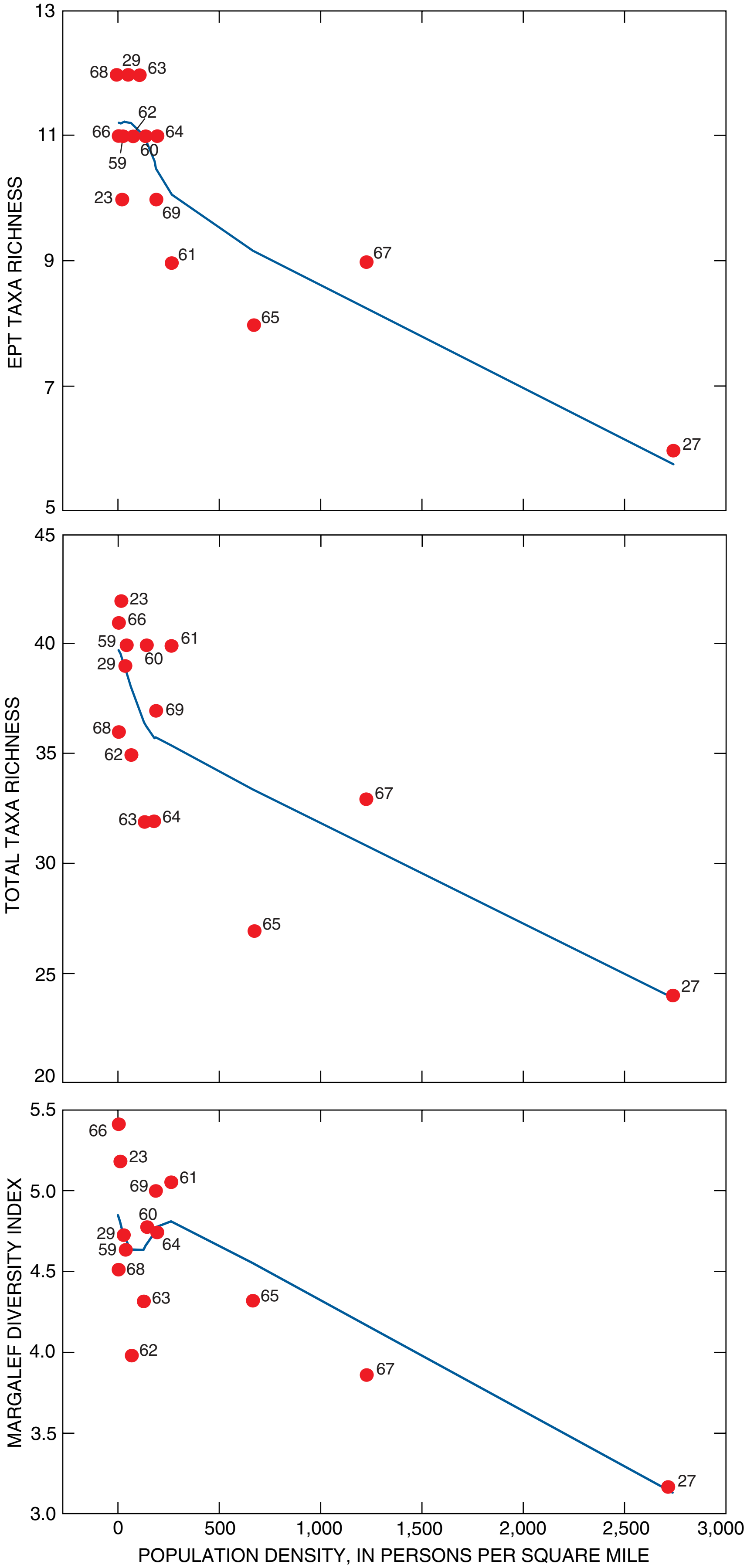

Figure 5. Variable-span bivariate smoothed scatterplot of three significant biological variables ($p < 0.05$, $n = 14$), showing threshold response against population density. Total taxa richness and Margalef diversity index: both at lowest practical taxonomic level of identification. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera. (See fig. 1 and appendix 1 regarding sampling sites.)

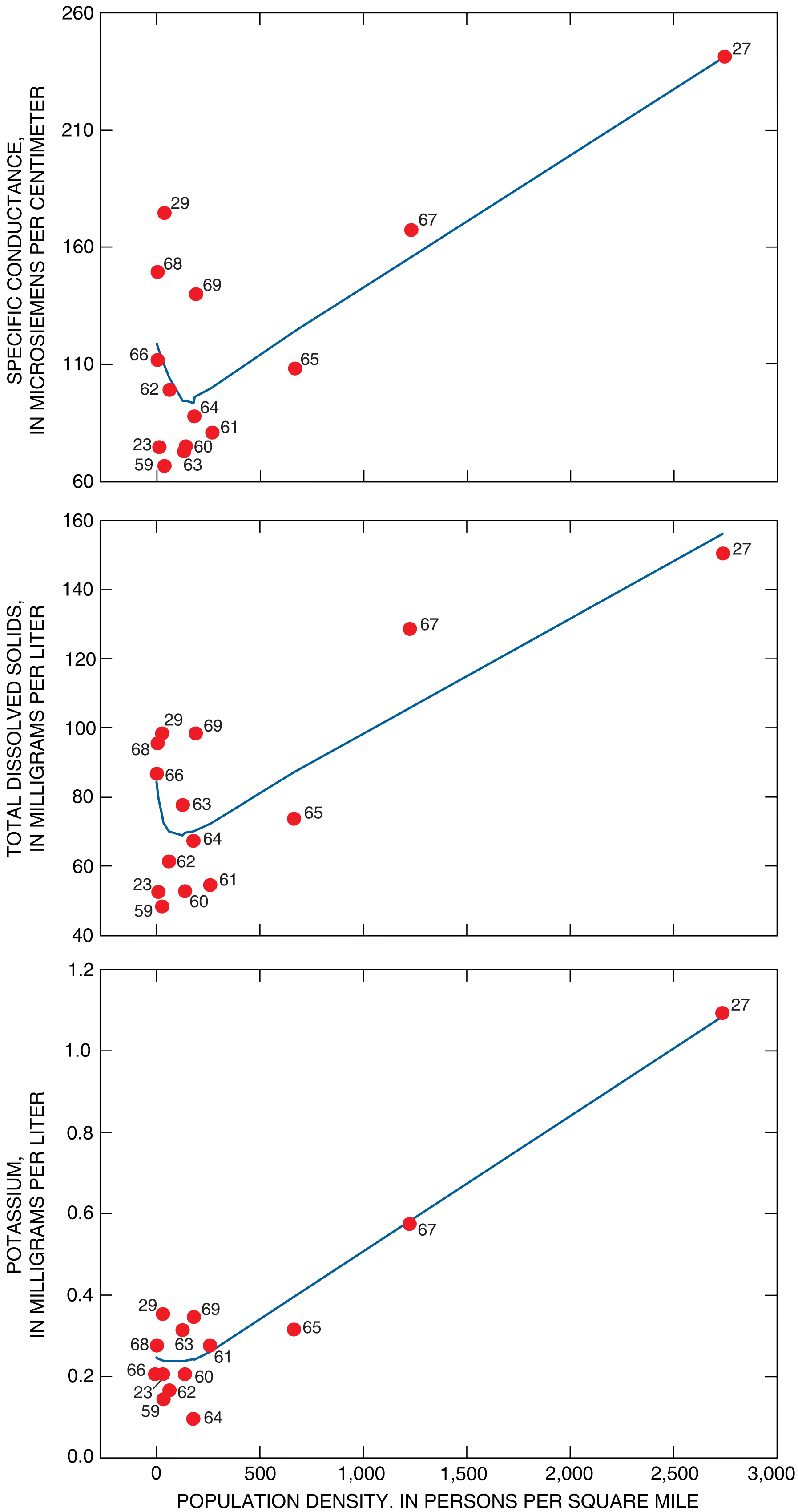

Figure 6. Variable-span bivariate smoothed scatterplot of four significant water-chemistry variables ($p < 0.05$, $n = 14$), showing threshold response against population density. (See fig. 1 and appendix 1 regarding sampling sites.)

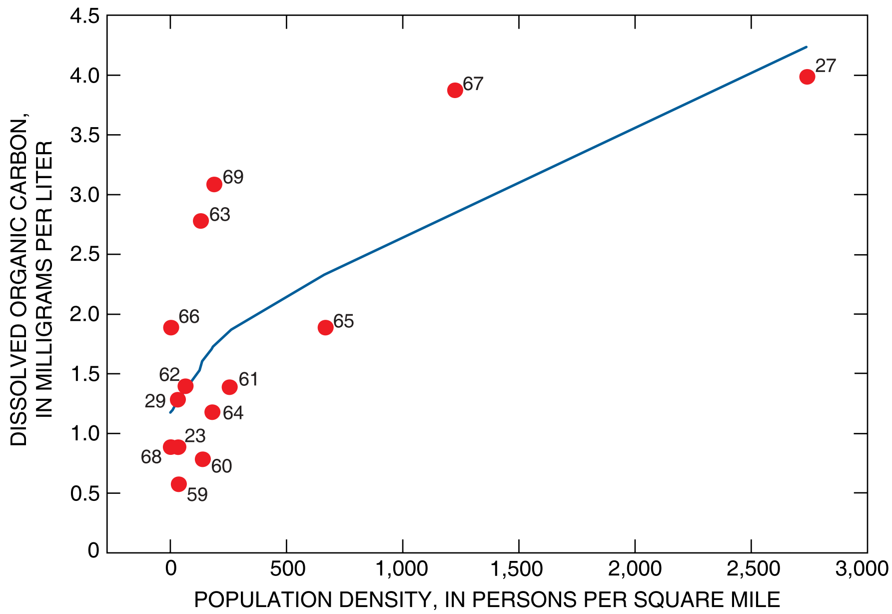

Figure 6.—*Continued*

DISCUSSION

The Bray–Curtis distance measures revealed three distinguishable groupings. Group 1 or the "urban-impacted" group is under the 12th node (dissimilarity index, 0.510). These sites (27, 67, 65, and 64) have the relatively high population densities, road densities, and storm-drain densities (≥0.45). Each of these sites also had PDRD ratios greater than 185. The separation of these sites is due primarily to the presence of oligochaetes (worms) and mayflies of the family Baetidae, both of which commonly are associated with diminished water quality. This is supported further by the metric percentage composition of the two most common taxa (PDT2), higher values of which commonly are associated with impaired water quality (Barbour and others, 1999). Because all the group 1 sites had higher PDT2 values than all other sites, these sites were considered to be urban-impacted sites. At these sites, we observed higher levels of fine sediments in the bed materials, which make better oligochaete habitat (Thorp and Covich, 1991). The two major families, Naididae and Tubificidae, continuously feed on the sediments through which they burrow. Algae and other periphytic materials are the primary food source for most naidids, whereas bacteria are the preferred food source for most tubificids (Brinkhurst and Gelder, 1991). Both these food sources are found in abundance at urban-impacted sites. Epiphytic algal blooms can be related to an increase in nutrients (lawn fertilizers, etc.) entering the stream after a storm event via storm drains, and bacteria in streams are most commonly associated with sewage or other organic pollution (such as from a large population of waterfowl, livestock, etc.). Both of these nutrient sources are common at or near the group 1 sites.

Sites in group 2 or the "nonimpacted" group (63, 61, 60, 59, 62, 69, 66), which is beneath the ninth node (dissimilarity index, 0.421), generally have considerably lower population, road, and storm-drain densities than sites have in the urban-impacted group. Two sites in the group (61 and 69) do have relatively high population densities, but this is offset by the lower PDRD ratio when compared to the urban-impacted sites. The primary macroinvertebrate groups driving this separation in the cluster analysis are those sensitive to perturbation—the mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera).

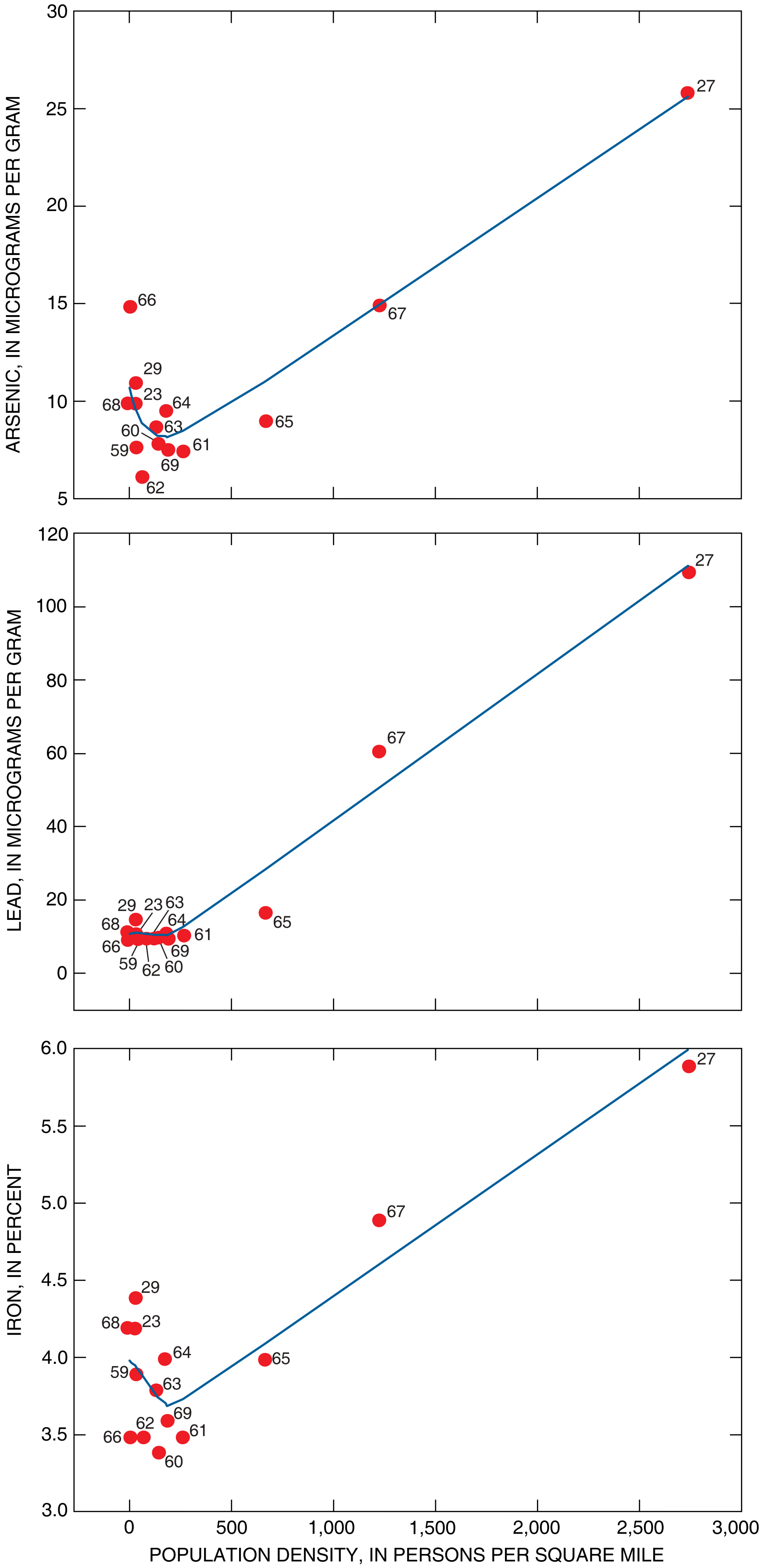

Figure 7. Variable-span bivariate smoothed scatterplot of four significant trace-elements-in-bed-sediments variables ($p < 0.05$, $n = 14$), showing threshold response against population density. (See fig. 1 and appendix 1 regarding sampling sites.)

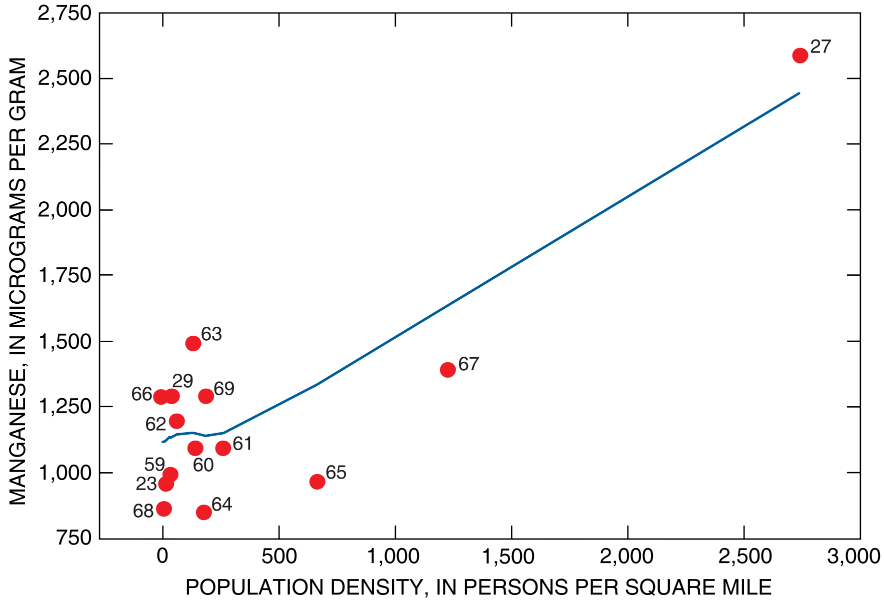

Figure 7.—*Continued*

Table 4. Coefficients of determination (r^2) as calculated by linear and local regression analysis and significance (p)

[Threshold population-density range: Range of values that includes breakpoint. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera. <, less than; —, not applicable]

Biological metric or constituent	Linear-regression model, coefficient of determination, r^2	Significance, p	Local-regression model, coefficient of determination, r^2	Threshold population-density range (persons per square mile)	Type of response
		Biological metrics			
Margalef diversity index[1]	0.62	0.0008	0.78	125–137	Threshold
Hilsenhoff family biotic index	.61	.001	.57	—	Linear
Percentage Oligochaetes	.52	.003	.63	—	Linear
Percentage dominant two taxa	.68	.0002	.27	—	Linear
EPT taxa richness	.72	.001	.8	262–662	Threshold
Total taxa richness[1]	.54	.002	.26	125–137	Threshold
		Water chemistry (major ions)			
Chloride	.94	<.0001	.98	—	Linear
Potassium	.9	<.0001	.91	177–183	Threshold
Magnesium	.7	.002	.79	—	Linear
Sodium	.84	<.0001	.93	—	Linear
Conductivity	.55	.002	.68	125–137	Threshold
Dissolved organic carbon	.55	.002	.66	125–137	Threshold
Total dissolved solids	.58	.001	.6	177–183	Threshold
		Bed-sediment chemistry (trace elements)			
Lead	.96	<.0001	.99	177–183	Threshold
Zinc	.95	<.0001	.99	—	Linear
Arsenic	.75	<.0001	.92	32–60	Threshold
Iron	.73	<.0001	.81	137–177	Threshold
Manganese	.72	.0001	.89	125–137	Threshold

[1]Lowest practical taxonomic identification.

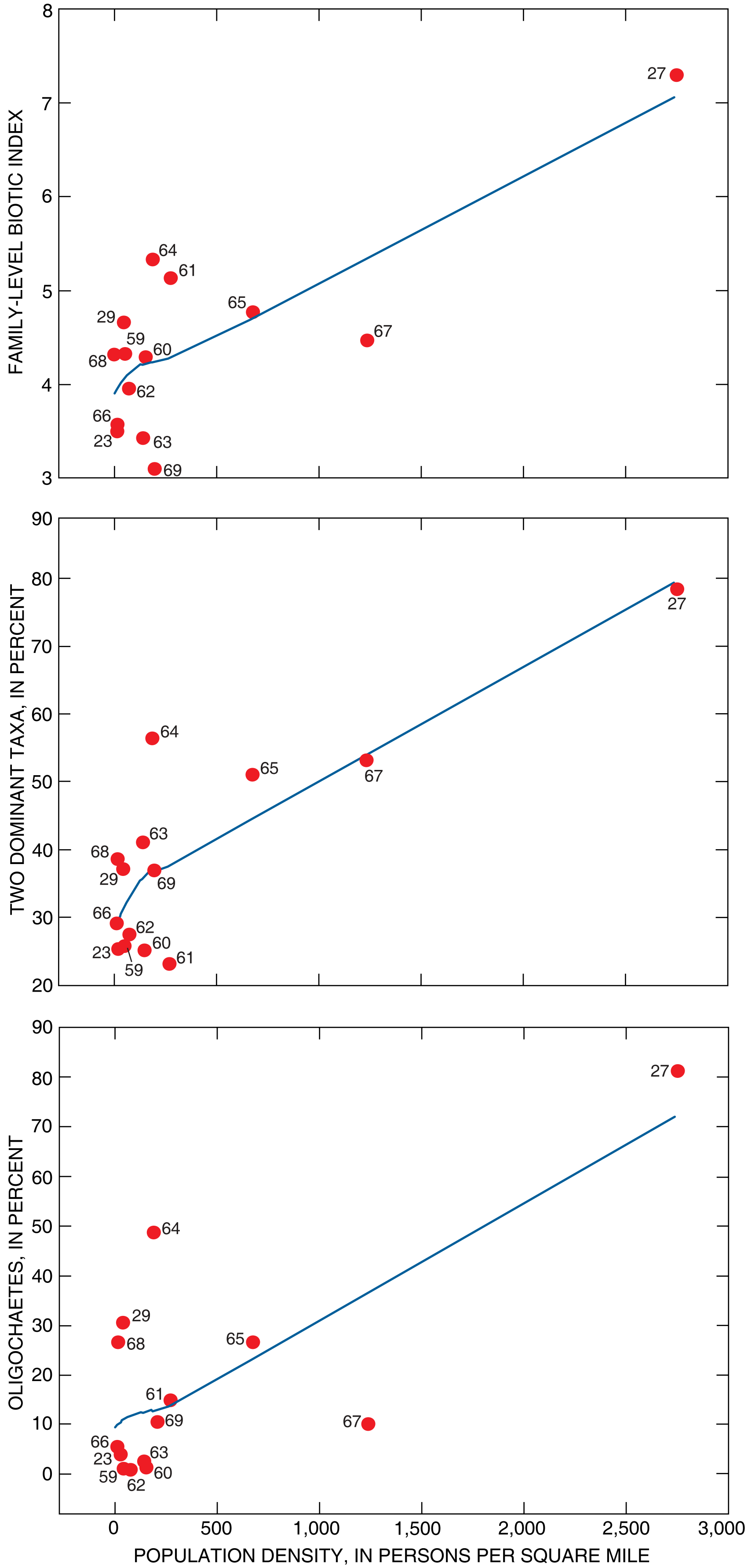

Figure 8. Variable-span bivariate smoothed scatterplot of seven other significant biological and chemical variables ($p < 0.05$, $n = 14$), showing linear response against population density. (See fig. 1 and appendix 1 regarding sampling sites.)

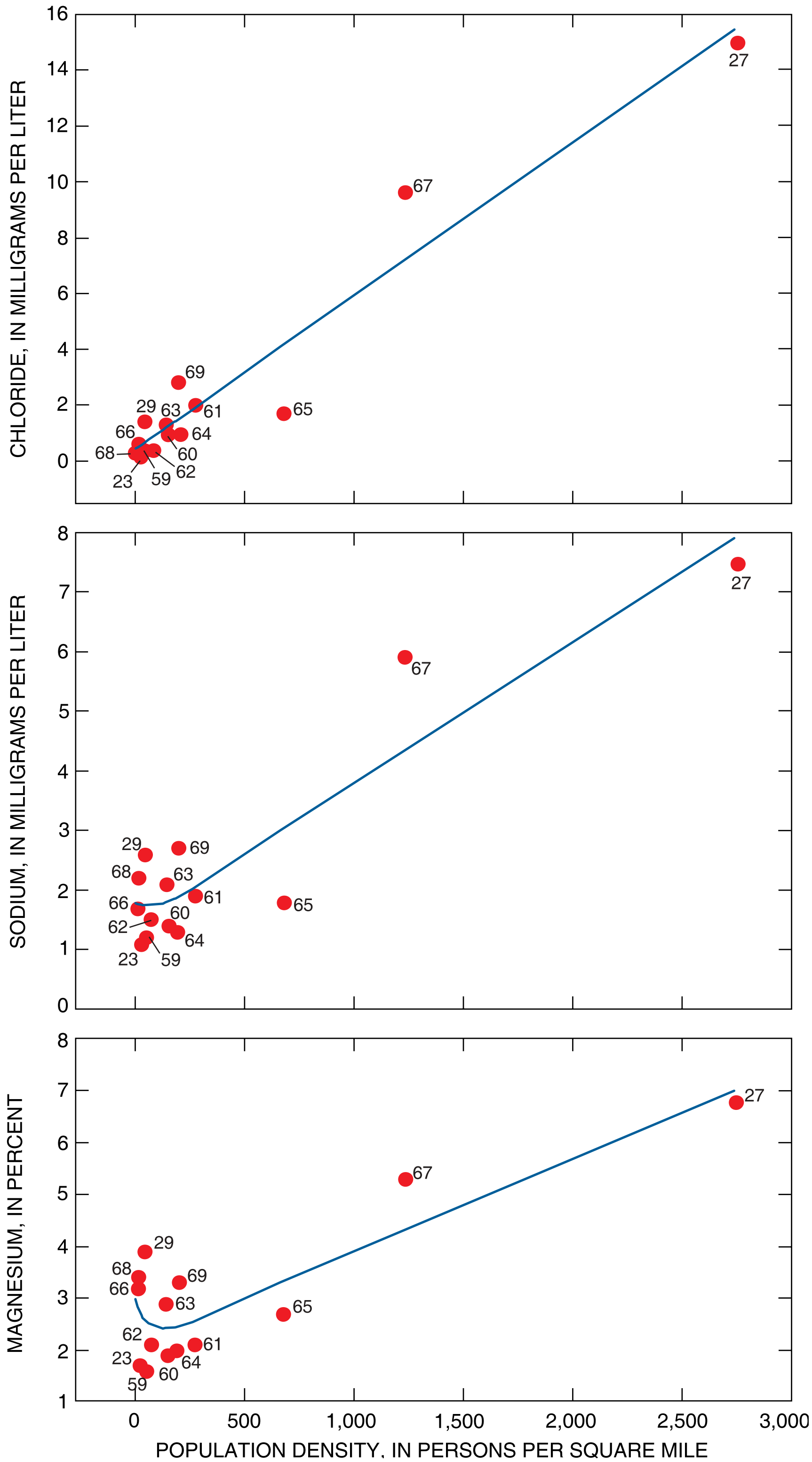

Figure 8.—*Continued*

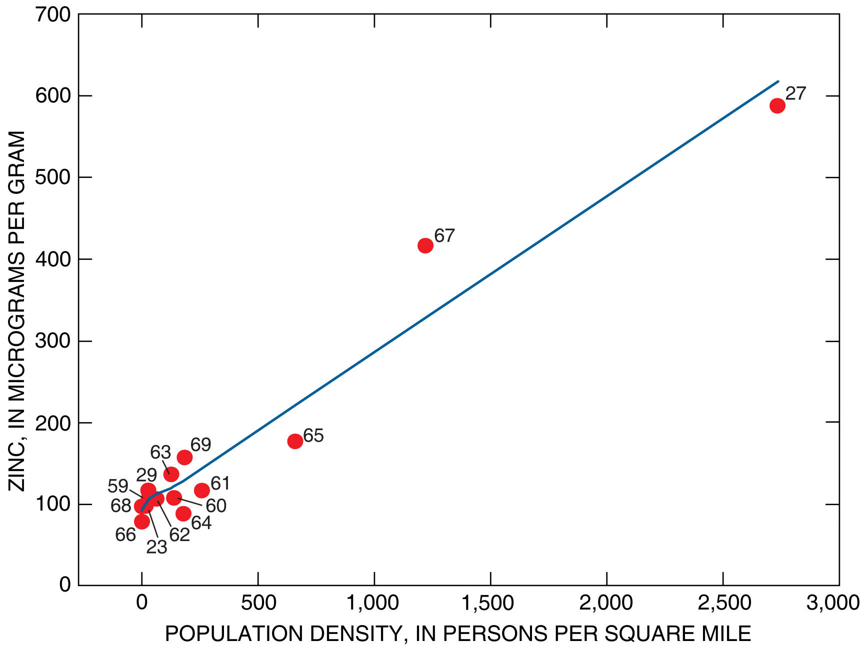

Figure 8.—*Continued*

The last group in the cluster analysis is made up of the two Ship Creek sites (29 and 68) and the reference site for Campbell Creek (site 23). The Ship Creek sites are considered anomalous because of the size of the basin compared to the other basins in the study and the fact that the creek has been regulated through the building of two small dams. Salmon are no longer able to pass to the upper site (68) because of obstructions. Therefore, the replenishment of instream nutrients from salmon carcasses no longer occurs, depriving many macroinvertebrates of an important food source and thereby limiting occurrence and abundance. Another confounding factor relates to the drying of the streambed at the upper site (29) during winter low flows in some years. Discharge for the Ship Creek sites is also considerably greater than the other sites. The South Fork of Campbell Creek site (23) grouped with the Ship Creek sites, probably because of a shift in macroinvertebrate-community structure influenced by the date at which the sample was collected compared to the other sites. Food-type availability could be a driving factor in the separation of this site from group 2. This site was sampled in July and would not have had the abundance of leaf litter found during the later sampling period when all other sites were sampled. That a shift from a feeding regime dominated by grazing (of algae) to one dominated by shredding (of leaf litter) probably had not yet taken place is shown by the relative percentages of scrapers and shredders. We predict that an upstream site having few known urban factors would fit into group 2 if sampled during the same time period.

The PDRD ratio and storm-drain density appear useful for separation of urban-impacted from nonimpacted sites. High PDRD ratios (>70) are associated with areas that have a high percentage impervious cover. As population densities increase, more roads, parking, and housing are required to meet basic needs. Accumulation of pollutants (deicing salts, petroleum products, combustion byproducts, etc.) on road and parking surfaces has been modeled for small watersheds and was shown to have a potentially negative impact on the quality of water in streams when runoff events occur (Novotny and others, 1985). The potentially greater input of pollutants into streams in areas of increased population density and hence high road density may have a significant role in the separation of urban-impacted from nonimpacted areas. Group 1 sites had storm-drain densities ≥0.45. Increased storm-drain density adds to the number of artificial channels that in turn rapidly pass water to the streams, thereby circumventing the natural hydrologic cycle (May and others, 1997). This rapid channeling diminishes infiltration and storage of water in shallow aquifers and hence reduces baseflows during periods of reduced precipitation. Reduced baseflows have the effect of reducing habitat suitable for aquatic species, thereby negatively impacting the "natural state" of the stream.

Regression analysis of the most significant variables, with respect to population density, revealed that the majority exhibited a threshold response to urbanization (table 4, fig. 5, fig. 6, fig. 7). This finding suggests that streams in the Anchorage Bowl are able to accommodate the effects of urbanization only up to a point; beyond that, stream structure and function are impaired.

Three of the six biologically significant variables ($p < 0.05$, $r^2 > 0.5$) showed threshold responses (table 4). Two variables (EPT taxa richness and total taxa richness) are richness measures, and one (Margalef diversity) is an index of the macroinvertebrate community. These biological variables tend to support the separation of urban-impacted from nonimpacted sites revealed by the cluster analysis, especially when related to the PDRD ratio rather than exclusively to population density. Both taxa richness and macroinvertebrate diversity decrease in a downstream direction. In contrast, the percentage oligochaetes, the Hilsenhoff family-level biotic index (FBI) (Hilsenhoff, 1988), and the PDT2 increase downstream; all three exhibit linear responses to population density (fig. 8, table 4). Oligochaetes were generally one of the major components making up the PDT2 at the urban-impacted sites. The FBI, which is a measure of organic pollution and the subsequent response by macroinvertebrates based on tolerance values, also increased downstream. FBI values greater than 5 suggest the probability of organic pollution. Sites that had PDRD ratios greater than 50 had FBI values greater than 5. Urban-impacted sites tended to have fewer species of more-tolerant, generalist organisms, whereas nonimpacted sites had greater numbers of more-sensitive species. Negative impact in general, with respect to the biological variables exhibiting a threshold response, appears to occur near population densities of 140 persons/mi^2. EPT taxa richness shows a break in slope between 262 and 662 persons/mi^2, but this threshold is due in part to the occurrence of the generally perturbation-tolerant Baetid family of mayflies (Ephemeroptera). Removal of this group from the metric calculations increases the sensitivity of the measure and brings it in line with the other two threshold variables.

The major ions (inorganic constituents in water samples) found to be significant with respect to population density include magnesium, sodium, potassium, and chloride (table 4). Magnesium, sodium, and chloride are found in low concentrations in natural streams. The elevated levels found in the urban-impacted sites are probably a result of the application of deicing salts and subsequent runoff and possibly also a result of leakage of domestic wastewater. The linear trends in the fitted curves of the analyses for these three constituents (fig. 8, table 4) suggest that any increase in population density would result in a corresponding increase in the concentration of these constituents in water in Anchorage. Potassium, which showed a threshold response (fig. 6), is an essential element for growth in both plants and animals. Elevated levels in urban areas are generally attributed to nonpoint-source pollution due to the application of fertilizers. The variables conductivity, total dissolved solids, and dissolved organic carbon also showed threshold responses (fig. 6, table 4). The breakpoints for water-chemistry variables reflect the threshold range for the biological metrics (table 4).

Significant trace elements in bed sediments (arsenic, lead, iron, manganese) (fig. 7, table 4), displayed a threshold-response curve with respect to population density (fig. 7). Although Klein (1979) considered the constituents lead and zinc to be good urban-signature constituents with respect to impervious area, zinc exhibited a linear response to population density in this study (fig. 8, table 4). The primary sources for both metals are vehicles, piping, and commercial and industrial nonpoint-source activity. Arsenic, iron, and manganese were more likely from natural sources, but because of organic pollution and the reducing (anaerobic) environment it helps to create in the sediments, they were more readily detected in the highly urbanized areas. The breakpoint for lead, at a population density between 60 and 125 persons/mi^2, suggests that it is a potentially sensitive urbanization variable. Iron and arsenic levels were probably at background levels at upstream sites; changes in concentration were noted at urban-impacted site 65 and increased in a downstream direction. Manganese was in line with the biological metrics; its regression shows a breakpoint at a population density between 125 and 137 persons/mi^2 (fig. 7).

CONCLUSIONS

Site-based reconnaissance data allowed us to visualize the effect of urbanization on stream macroinvertebrates in Anchorage. Population density appears to be a reasonable surrogate of urbanization, but further testing of the PDRD ratio as a rapid urbanization variable is needed. A threshold effect was observed for most of the significant variables. Adversely impacted sites typically had higher human population, road, and storm-drain densities. As trace-element and salt concentrations increased with increasing population, road, and storm-drain densities, macroinvertebrate diversity decreased. PDRD ratios greater than 70, road densities greater than 4.0 mi/mi^2, and(or) population densities of 125–150 persons/mi^2 (a conservative approximation) can be used to warn of the heightened potential of urbanization-induced degradation of streams in Anchorage. Exceptions to this are the Ship Creek sites, which may have skewed the data. Contributing factors may include disproportionate basin size and relative lack of development normally associated with urbanization over much of its area, localized industrialization, impoundments, and cessation of flow during winter months. Incremental areas between sites also should be examined for integration into calculations to determine if a more robust explanation can be generated.

The U.S. Census Bureau (1990) defines urban areas as having minimum population densities of 1,000 persons/mi^2; this criterion is met by only two of the sites in this study, though many of the other sites meet criteria to be designated “urban fringe”. Wear and others (1998) suggested that two main areas along an urban–rural gradient may significantly impact water quality—at the edge of urban expansion and at the most undeveloped parts of the basin. According to results of our study, stream impairment appears to begin within the urban fringe. Areas having population densities of 125–150 persons/mi^2 appear to be the first to start showing signs of stream impairment. We readily could see evidence of changes in the streams and surrounding riparian areas at those sites near or at this threshold. For example, channels had been modified, the riparian zones were altered, manmade litter was observed, and the distance between roads and streams had decreased. The PDRD ratio complemented the results of the cluster analysis, at least with respect to differentiating urban-impacted and nonimpacted sites. Further study of this ratio as a rapid assessment of potential urban impact is warranted.

REFERENCES CITED

Barbour, M.T., Gerritsen, J., Griffith, G.E., Frydenborg, R., McCarron, E., White, J.S., and Bastian, M.L., 1996, A framework for biological criteria for Florida streams using benthic macroinvertbrates: Journal of the North American Benthological Society, v. 15, no. 2, p. 185–211.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers—Periphyton, benthic macroinvertebrates, and fish (2d ed.): U.S. Environmental Protection Agency EPA 841–B–99–002.

Brabets, T.P., Nelson, G.L., Dorava, J.M., and Milner, A.M., 1999, Water-quality assessment of the Cook Inlet Basin, Alaska—Environmental setting: U.S. Geological Survey Water-Resources Investigations Report 99–4025, 65 p.

Brinkhurst, R.O., and Gelder, S.R., 1991, Annelida—Oligochaeta and Branchiobdellida, *in* Thorp, J.H., and Covich, A.P., eds., Ecology and classification of North American freshwater invertebrates: Academic Press, p. 401–435.

Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993, Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment program: U.S. Geological Survey Open-File Report 93–406, 66 p.

Fore, L.S., Karr, J.R., and Wisseman, R.W., 1996, Assessing invertebrate responses to human activities—Evaluating alternative approaches: Journal of the North American Benthological Society, v. 15, no. 2, p. 212–231.

Garie, H.L., and McIntosh, A., 1986, Distribution of benthic macroinvertebrates in a stream exposed to urban runoff: Water Resources Bulletin, v. 22, no. 3, p. 447–451.

Hilsenhoff, W.H., 1988, Rapid field assessment of organic pollution with a family-level biotic index: Journal of the North American Benthological Society, v. 20, no. 1, p. 65–68.

Hynes, H.B.N., 1970, The ecology of running waters: University of Toronto Press, Toronto, 555 p.

Kerans, B.L., and Karr, J.R., 1994, A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley: Ecological Applications, v. 4, p. 768–785.

Klein, R.D., 1979, Urbanization and stream quality impairment: Water Resources Bulletin, v. 15, no. 4, p. 948–963.

Ludwig, J.A., and Reynolds, J.F., 1988, Statistical ecology—A primer on methods and computing: Wiley, 337 p.

Mathsoft, Inc., 2000, S-Plus 2000 Professional—Release 3: Mathsoft, Inc. [CD–ROM].

May, C.W., Welch, E.B., Horner, R.R., Karr, J.R., and Mar, B.W., 1997, Quality indices for urbanization effects in Puget Sound lowland streams: Department of Civil Engineering, University of Washington, Water Resources Series Technical Report no. 154, 229 p.

Milner, A.M., and Oswood, M.W., 1989, Macroinvertebrate distribution and water quality in Anchorage streams: Institute of Arctic Biology, University of Alaska at Fairbanks, 48 p.

Municipality of Anchorage, 1996, Population and housing sampling frame—By census tracts: Municipality of Anchorage Community Planning and Development, 6 p.

Novotny, V., Sung, H.M., Bannerman, R., and Baum, K., 1985, Estimating nonpoint pollution from small urban watersheds: Journal of the Water Pollution Control Federation, v. 57, no. 4, p. 339–348.

Pielou, E.C., 1984, The interpretation of ecological data: Wiley, 263 p.

Porter, S.D., Cuffney, T.F., Gurtz, M.E, and Meador, M.R., 1993, Methods for collecting algal samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93–409, 39 p.

Shelton, L.R., 1994, Field Guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94–455, 42 p.

Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of stream bed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94–458, 20 p.

Thorp, J.H., and Covich, A.P., 1991, Ecology and classification of North American freshwater invertebrates: Academic Press, 911 p.

U.S. Census Bureau, 1990, Population and housing unit counts: 1990 Census of Population and Housing CPH–2–3, 101 p.

Wear, D.N., Turner, M.G., and Naiman, R.J., 1998, Land cover along an urban–rural gradient—Implications for water quality: Ecological Applications, v. 8, no. 3, p. 619–630.

Whiting, E.R., and Clifford, H.F., 1983, Invertebrates and urban runoff in a small northern stream, Edmonton, Alberta, Canada: Hydrobiologia, v. 102, p. 73–80.

Winter, J.G., and Duthie, H.C., 1998, Effects of urbanization on water quality, periphyton and invertebrate communities in a southern Ontario stream: Canadian Water Resources Journal, v. 23, no. 3, p. 245–257.

Zar, J.H., 1996, Biostatistical analysis: Prentice Hall, 662 p.

APPENDIXES

Appendix 1. Cook Inlet Basin National Water-Quality Assessment site-numbering system

[Site numbers used in this report (shown in **bold** and shaded blue; see fig. 1 and fig. 2 for site locations) follow numbering system for stream-gaging stations that was introduced in National Water-Quality Assessment Cook Inlet Basin environmental-setting report (Brabets and others, 1999). Total number of sites listed reflects assignments as of this writing. Sequence of site numbers generally parallels order used in U.S. Geological Survey data-station identification]

Site number	U.S. Geological Survey station	
	Number	Name
1	15238820	Barabara Creek near Seldovia
2	15239500	Fritz Creek near Homer
3	15239000	Bradley River near Homer
4	15239050	Middle Fork Bradley River near Homer
5	15239900	Anchor River near Anchor Point
6	15240000	Anchor River at Anchor Point
7	15241600	Ninilchik River at Ninilchik
8	15242000	Kasilof River near Kasilof
9	15244000	Ptarmigan Creek at Lawing
10	15246000	Grant Creek near Moose Pass
11	15248000	Trail River near Lawing
12	15254000	Crescent Creek near Cooper Landing
13	15258000	Kenai River at Cooper Landing
14	15260000	Cooper Creek near Cooper Landing
15	15264000	Russian River near Cooper Landing
16	15266300	Kenai River at Soldotna
17	15266500	Beaver Creek near Kenai
18	15267900	Resurrection Creek near Hope
19	15271000	Sixmile Creek near Hope
20	15272280	Portage Creek at Portage Lake outlet near Whittier
21	15272550	Glacier Creek at Girdwood
22	15273900	South Fork Campbell Creek at Canyon Mouth near Anchorage
23	**15274000**	**South Fork Campbell Creek near Anchorage**
24	15274300	North Fork Campbell Creek near Anchorage
25	15274600	Campbell Creek near Spenard
26	15275000	Chester Creek at Anchorage
27	**15275100**	**Chester Creek at Arctic Boulevard at Anchorage**
28	15276000	Ship Creek near Anchorage
29	**15276570**	**Ship Creek below powerplant at Elmendorf Air Force Base**
30	15277100	Eagle River at Eagle River
31	15277410	Peters Creek near Birchwood
32	15281000	Knik River near Palmer
33	15282000	Caribou Creek near Sutton
34	15284000	Matanuska River near Palmer
35	15290000	Little Susitna River near Palmer
36	15291000	Susitna River near Denali
37	15291200	Maclaren River near Paxson
38	15291500	Susitna River near Cantwell
39	15292000	Susitna River at Gold Creek
40	15292400	Chulitna River near Talkeetna
41	15292700	Talkeetna River near Talkeetna
42	15294005	Willow Creek near Willow
43	15294010	Deception Creek near Willow
44	15294100	Deshka River near Willow
45	15294300	Skwentna River near Skwentna
46	15294350	Susitna River at Susitna Station
47	15294410	Capps Creek below North Capps Creek near Tyonek
48	15294450	Chuitna River near Tyonek
49	15294500	Chakachatna River near Tyonek
50	15283700	Moose Creek near Palmer
51	585750154101100	Kamishak River near Kamishak
52	15294700	Johnson River above Lateral Glacier near Tuxedni Bay
53	15266010	Kenai River below Russian River near Cooper Landing
54	15266020	Kenai River at Jims Landing near Cooper Landing
55	15266110	Kenai River below Skilak Lake outlet near Sterling
56	15267160	Swanson River near Kenai
57	631629149352000	Colorado Creek near Colorado
58	631018149323700	Costello Creek near Colorado
59	**15273020**	**Rabbit Creek at Hillside Drive near Anchorage**
60	**15273030**	**Rabbit Creek at East 140th Avenue near Anchorage**

Appendix 1. Cook Inlet Basin National Water-Quality Assessment site-numbering system—*Continued*

Site number	U.S. Geological Survey station	
	Number	Name
61	15273040	**Rabbit Creek at Porcupine Trail Road near Anchorage**
62	15273090	**Little Rabbit Creek at Nickleen Street near Anchorage**
63	15273097	**Little Rabbit Creek at Goldenview Drive near Anchorage**
64	15274395	**Campbell Creek at New Seward Highway near Anchorage**
65	15274557	**Campbell Creek at C Street near Anchorage**
66	15274796	**South Branch of South Fork Chester Creek at tank trail near Anchorage**
67	15274830	**South Branch of South Fork Chester Creek at Boniface Parkway near Anchorage**
68	15276200	**Ship Creek at Glenn Highway near Anchorage**
69	15273100	**Little Rabbit Creek near Anchorage**
70	15239070	Bradley River near tidewater near Homer
71	594507151290000	Beaver Creek 2 miles above mouth near Bald Mountain near Homer
72	594734151142900	Anchor River near Bald Mountain near Homer
73	15239840	Anchor River above Twitter Creek near Honmer
74	595126151391000	Chakok River 7.5 miles above mouth near Anchor Point
75	595506152403300	Stariski Creek 2 miles below unnamed tributary near Ninilchik
76	15240300	Stariski Creek near Anchor Point
77	600107151112800	North Fork Deep Creek 4 miles above mouth near Ninilchik
78	600047151383100	Deep Creek 0.4 mile above Clam Creek near Ninilchik
79	600204151401800	Deep Creek 0.6 mile above Sterling Highway near Ninilchik
80	600945151210900	Ninilchik River 1.5 miles below tributary 1 near Ninilchik
81	600321151325000	Ninilchik River below tributary 3 near Ninilchik
82	601100151000000	Nikolai Creek near Kasilof
83	613430150255000	Susitna River above Yentna River near Susitna Station
84	15281500	Camp Creek near Sheep Mountain Lodge
85	15292780	Susitna River at Sunshine
86	622302150083000	Susitna River 5 miles above Talkeetna River near Talkeetna
87	623705150005000	Susitna River at Curry
88	623850147225000	Oshetna River near Cantwell
89	623840147260000	Goose Creek near Cantwell
90	624658147562000	Kosina River near Cantwell
91	624953148151500	Watana Creek near Cantwell
92	625000149223500	Portage Creek near Gold Creek
93	624718149393600	Indian River near Gold Creek
94	15283550	Moose Creek above Wishbone Hill near Sutton
95	15292302	Camp Creek at mouth near Colorado
96	15292304	Costello Creek below Camp Creek near Colorado
97	625012150182700	Crystal Creek at mouth near Talkeetna
98	625014150183200	Coffee River above Crystal Creek near Talkeetna
99	623834150543300	Bear Creek near Talkeetna
100	623920150540300	Wildhorse Creek near Talkeetna
101	623510150450400	Long Creek near Talkeetna
102	623501151112900	Hidden Creek near Talkeeetna
103	623324151321600	Snowslide Creek at mouth near Talkeetna
104	623325151321800	Cripple Creek above Snowslide Creek near Talkeetna
105	622522151592200	Cascade Creek at mouth near Talkeetna
106	621936151582700	Fourth of July Creek at mouth near Talkeetna
107	621759152410500	Morris Creek at mouth near Talkeetna
108	621800152410600	Kichatna River above Morris Creek near Talkeetna
109	15294345	Yentna River near Susitna Station
110	600826152554400	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay
111	600803152552400	Kona Creek 2.5 miles above mouth above Lateral Glacier near Tuxedni Bay
112	600635152550900	Kona Creek tributary above Lateral Glacier near Tuxedni Bay
113	600636152551400	Kona Creek 0.8 mile above mouth above Lateral Glacier near Tuxedni Bay
114	600739152570701	Spring 1 near Johnson Glacier near Tuxedni Bay
115	600715152572800	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay
116	600713152574000	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay
117	600658152581400	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay
118	600609152561100	Johnson River tributary above Lateral Glacier near Tuxedni Bay

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Platyhelminthes														
Turbellaria	84	18	25	25	302	70	20	158	52	12	36	23	0	0
Nematoda	9	0	0	0	14	14	0	11	0	0	14	0	11	0
Cnidaria														
Hydridae														
Hydra sp.	0	0	0	0	0	0	0	0	0	0	0	0	11	0
Mollusca														
Gastropoda														
Hydrobiidae	0	0	0	0	0	0	0	11	0	4	0	0	0	4
Planorbidae	5	0	0	8	0	0	0	0	0	4	0	3	0	0
Valvatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Bivalvia														
Sphaeriidae	0	0	0	0	0	0	0	0	0	0	0	0	137	28
Annelida	0	0	109	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	0	0	0	34	0	0	2	0	2	0	0	1	2	8
Enchytraeidae	0	0	0	67	0	14	4	0	6	16	24	5	21	36
Lumbriculidae	79	84	0	512	58	29	20	53	0	20	0	0	0	0
Naididae	0	534	0	294	0	0	4	0	320	28	240	97	305	904
Tubificidae	5	0	0	34	0	0	0	0	2	76	66	4	63	208
Arthropoda														
Arachnida	14	36	269	76	158	112	24	42	12	72	72	25	126	48
Insecta														
Collembola	0	0	0	0	0	0	4	0	0	24	54	0	11	0
Ephemeroptera	0	0	8L	0	0	0	0	0	0	0	0	0	0	0
Ameletidae														
Ameletus sp.	0	12L	0	0	0	0	0	0	0	0	0	0	0	0
Baetidae	196L	84L	8L	622L	72L 14A	546L	228L	84L	16L	12L	12L	1L	1691L	28L
Acentrella sp.	5L	0	0	0	0	0	0	0	0	0	0	0	0	0
Acentrella turbida	0	0	168L	8L	0	0	0	0	0	0	0	1L	0	0
Baetis bicaudatus	5L	12L	25L	0	30L	14L	0	1L	0	4L	0	0	0	0
Baetis tricaudatus	0	0	0	18L	0	0	0	0	0	0	0	0	0	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Ephemeroptera—*Continued*														
Heptageniidae	140L 5A	186L	17L	8L	101L	392L	92L	168L	6L	8L	42L	0	0	0
Cinygmula sp.	5L	0	202L	0	158L	0	0	189L	0	4L	42L	0	0	0
Epeorus sp.	159L	3L	302L	0	763L	420L	308L	420L	2L	108L	222L	0	0	0
Ephemerellidae														
Drunella doddsi	93L	354L	386L	60L	202L	210L	60L	117L	18L	9L	78L	0	0	0
Ephemerella aurivillii	0	30L	1L	0	0	0	0	0	0	0	0	0	0	0
Plecoptera														
Taeniopterygidae														
Taenionema sp.	0	12L	0	8L	29L	0	12L	105L	32L	0	6L	3L	0	0
Nemouridae														
Zapada sp.	75L	24L	42L	17L	144L	420L	40L	263L	3L	0	48L	0	11L	0
Zapada cinctipes	9L	48L	8L	42L	43L	70L	28L	53L	2L	52L	42L	1L	210L 11A	24L
Leuctridae														
Despaxia augusta	5L	0	0	0	43L	57L	4L	0	0	0	0	0	0	0
Capniidae	5L	6L	0	17L	0	14L	4L	21L	4L	4L	0	3L	63L	0
Eucapnopsis brevicauda	0	18L	0	0	0	0	0	0	0	0	0	0	0	0
Perlodidae	5L	1A	8L	0	14L	0	0	32L	8L	4L	0	1L	53L	4L
Isoperla sp.	0	12L	1L	68L	0	84L	8L	0	0	0	0	0	0	1L
Chloroperlidae	0	102L	25L	34L	72L	84L	17L	42L	38L	0	12L	15L	0	16L
Suwallia sp.	44L	0	25L	0	187L	29L	44L	85L	0	40L	1L	0	0	0
Coleoptera														
Staphylinidae	0	0	0	0	14A	0	0	0	0	0	0	0	0	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Diptera														
Ceratopogonidae														
Ceratopogoninae	5L	6L	0	0	0	0	0	11L	0	0	0	0	0	0
Chironomidae	0	6P	42P 25L	0	14P 130A	0	4A	11L 21P	0	8P 24A	66P 6L	1P 4A	0	0
Tanypodinae														
Macropelopiini														
Macropelopia sp.	0	0	0	0	0	14L	0	0	0	0	0	0	0	0
Pentaneurini	0	0	0	0	0	0	0	0	0	0	0	1L	105L	16L
Diamesinae	0	0	0	8P	0	0	0	0	0	0	0	0	0	0
Diamesini														
Diamesa sp.	0	0	0	25L	0	0	0	0	0	0	0	0	0	0
Pagastia sp.	42L	318L	160L	185L	230L	140L	4L	63L	20L	12L	60L	109L	74L	16L
Potthastia sp.	0	0	0	25L	0	0	0	0	0	20L 12P	0	5L	32L	40L
Prodiamesinae														
Prodiamesa sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	4L
Orthocladiinae	23L 5P	30L	210L 59P	151L 25P	403L 101P	28L	0	85L 53P	2P 2L	0	120L 108P	0	420L	0
Corynoneura sp.	0	0	8L	0	0	0	0	11L	0	0	0	0	0	0
Thienemanniella sp.	0	0	25L	0	0	0	0	0	0	0	0	0	0	0
Brillia sp.	23L	0	0	17L	274L	140L	20L	420L	2L	36L	276L	6L	105L	0
Cricotopus sp.	0	0	0	0	0	0	0	0	0	0	0	0	11L	0
Eukiefferiella sp.	5L	0	50L	17L	130L	504L	4L	32L	0	4L	48L	0	32L	0
Heleniella sp.	9L	0	0	0	0	0	0	0	22L	0	6L	4L	0	0
Orthocladius sp.	0	0	8L	0	14L	14L	0	11L	0	0	6L	0	0	0
Parakiefferiella sp.	0	0	0	0	14L	14L	0	0	0	0	0	0	0	0
Paraphaenocladius sp.	5L	0	25L	0	0	0	0	0	0	0	0	0	0	0
Parorthocladius sp.	0	0	0	0	101L	0	0	0	0	0	12L	0	0	0
Rheocricotopus sp.	5L	6L	0	0	14L	14L	0	11L	0	0	0	0	0	0
Rheosmittia sp.	0	0	0	0	0	0	0	0	2L	0	0	0	0	0
Synorthocladius sp.	0	0	0	0	0	0	0	21L	0	0	0	0	0	0
Tvetenia sp.	5L	6L	17L	25L	72L	0	0	21L	0	24L	0	0	0	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Diptera—*Continued*														
Chironomidae—*Continued*														
Chironominae	0	0	25P	0	0	0	0	0	0	0	0	0	0	0
Chironomini	0	0	0	0	0	0	0	0	0	0	0	0	11L	0
Parachironomus sp.	0	0	0	0	0	0	0	147L	0	0	6L	0	0	0
Polypedilum sp.	0	6L	0	8L	0	0	0	0	0	4L	0	0	0	0
Tanytarsini	0	0	0	0	0	0	0	11L	0	0	0	0	0	0
Micropsectra sp.	65L	0	0	17L	144L	154L	16L	462L	0	60L	192L	0	0	0
Rheotanytarsus sp.	0	0	0	0	0	0	0	0	6L	0	0	11L	84L	0
Stempellina sp.	5L	0	25L	0	0	0	0	0	0	0	0	0	0	0
Psychodidae	5L	0	8L	0	14L	28L	0	0	2L	24L	48L	0	0	4L
Simuliidae	84L 5P	0	101L	0	0	840L	172L	0	2L	4L	6L 6P	0	0	0
Simulium sp.	0	6L	17L 34P	8L	1L	0	0	0	0	0	0	0	0	0
Tipulidae														
Tipula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1L
Dicranota sp.	6L	6L	0	25L	30L	14L	0	11L	6L	4L	0	9L	43L	4L
Hesperoconopa sp.	0	6L	0	0	0	0	0	0	14L	12L	6L	1L	0	0
Pedicia sp.	0	0	0	0	0	0	4L	0	0	0	0	1L	0	0
Empididae	0	0	0	34L	14P	0	0	0	0	0	0	0	0	0
Clinocera sp.	0	0	8L	0	0	28L	0	0	0	24L	6L	0	0	0
Oreogeton sp.	1L	0	0	0	43L	0	0	0	0		6L	0	0	0
Hemerodromiinae	23L	36L	8L	0	72L	14L	0	21L	2L	16L	12L	6L	32L	0
Stratiomyidae	0	0	0	0	0	0	0	0	0	0	6L	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	32L	0

Appendix 2. Abundance and distribution of benthic macroinvertebrates collected at 14 sites in Anchorage in 1999—*Continued*

[Taxon: Phyla are shown in **bold**. Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. L, larvae; P, pupae; A, adults]

Taxon	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Arthropoda—*Continued*														
Insecta—*Continued*														
Trichoptera														
Hydropsychidae														
Ceratopsyche sp.	0	0	0	0	0	0	0	0	0	0	0	0	11L	4L
Rhyacophilidae														
Rhyacophila sp.	23L	0	0	0	15L	280L	24L	43L	0	44L	37L	0	0	0
Glossosomatidae	0	0	0	0	0	0	100L	0	0	0	0	0	0	0
Glossosoma sp.	271L	204L	168L	126L	43L	112L	0	42L	60L	380L	6L	52L 4P	33L 11P	0
Brachycentridae														
Brachycentrus sp.	0	42L	0	0	0	0	0	0	0	0	0	0	63L	0
Brachycentrus americanus	0	1L	8L	314L	0	0	0	0	4L	0	0	0	13L	0
Limnephilidae	23L	36L	0	84L	29L	98L	16L	63L	2L	108L	78L	6L	11L	8L
Apatania sp.	0	0	0	8L	0	0	0	0	0	0	0	0	11L	0
Ecclisomyia sp.	0	15L	9L	3L	45L	0	8L	63L	2L	0	6L	0	0	0
Ecclisocosmoecus scylla	1L	0	0	0	0	17L	4L	11L	0	0	0	0	0	0
Hesperophylax sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1L
Onocosmoecus unicolor	0	0	1L	1L	0	0	0	0	0	0	6P	0	0	0
Psychoglypha subborealis	0	0	1L	0	0	0	0	0	0	0	0	0	0	1P
Lepidoptera														
Pyralidae														
Crambus sp.	9L	0	0	0	0	0	4L	0	0	0	0	0	0	0

Appendix 3. Biological metrics calculated from macroinvertebrate data collected at 14 sites in Anchorage in 1999

[Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. EPT, insect orders Ephemeroptera, Plecoptera, and Trichoptera]

Biological metric	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Margalef diversity index (lowest practical taxonomic level of identification)	5.42	4.52	5.19	4.73	4.65	3.99	4.32	4.78	4.76	5.01	5.06	4.33	3.87	3.17
Margalef's diversity index (family level)	3.12	2.58	2.28	2.87	2.39	2.35	3.07	2.33	3.22	3.2	2.73	2.83	2.54	2.21
Shannon diversity index	2.93	2.59	3.06	2.79	3.18	2.86	2.56	3.10	2.16	2.85	3.16	2.33	2.34	1.46
Hilsenhoff family-level biotic index	3.54	4.33	3.53	4.66	4.32	3.96	3.43	4.30	5.34	3.11	5.14	4.77	4.48	7.30
Percentage Chironomidae	12.0	16.1	25.2	16.4	37.6	20.3	3.7	39.4	8.3	15.4	44.3	35.0	22.6	5.4
Percentage Ephemeroptera	37.9	29.5	41.4	23.4	30.7	31.4	52.8	28.0	6.2	11.0	17.9	.5	43.8	2.0
Percentage Plecoptera	9.5	9.7	4.0	6.1	12.2	15.1	12.0	17.2	12.9	7.6	4.9	5.7	9.0	3.2
Percentage Trichoptera	19.8	12.9	6.9	17.5	3.0	10.1	11.7	6.3	10.1	40.3	6.0	15.4	4.0	1.0
Percentage Oligochaeta	5.2	26.8	4.0	30.8	1.3	.9	2.3	1.5	49.0	10.6	14.9	26.6	10.1	81.6
Percentage filterers	17.5	18.3	31.4	27.0	37.6	37.0	16.9	39.4	9.2	15.7	44.8	35.0	28.4	7.6
Percentage collectors	24.2	24.5	22.1	42.1	8.9	16.4	23.6	7.3	5.9	11.0	9.2	1.7	45.5	17.5
Percentage predators	5.4	5.2	2.5	3.3	7.9	10.0	7.1	6.1	6.8	8.5	3.3	4.0	2.2	1.5
Percentage scrapers	41.4	17.8	26.5	5.2	31.3	19.8	38.4	27.9	17.8	38.8	15.7	19.6	1.1	.0
Percentage shredders	8.0	5.9	2.3	5.6	7.7	13.4	8.0	13.3	4.3	13.3	8.4	4.5	7.4	2.5
Total taxa richness (lowest practical taxonomic level of identification)	41	36	42	39	40	35	32	40	32	37	40	27	33	24
Total taxa richness (family level)	24	21	19	24	21	21	23	20	22	24	22	18	22	17
Percentage two dominant taxa	29.1	38.5	25.5	37.1	25.7	27.5	41.1	25.2	56.5	36.9	23.3	51.1	53.1	78.5
Percentage EPT	67.2	52.1	52.4	47.0	45.9	56.6	76.5	51.5	29.3	58.8	28.9	21.6	56.8	6.1
EPT taxa richness	11	12	10	12	11	11	12	11	11	10	9	8	9	6
Ratio of EPT to Chironomidae abundances	85	76	68	74	55	74	95	57	78	79	39	38	71	53
Ratio of Baetidae to Ephemeroptera abundances	34	14	18	91	9	35	33	9	38	11	3	100	100	100

Appendix 4. Nutrient and major-Ion concentrations in water samples from 14 sites in Anchorage in 1999

[Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. E, estimated value. —, none]

Nutrient, major ion, or physical property	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Water temperature, in degrees Celsius	7.5	7	9.5	9.5	6	8.5	9.5	7.5	11.5	9.5	7.5	9	10	10
Discharge, in cubic feet per second	6.2	148	44	224	18	4.4	6.3	18	71	7	23	99	8.9	31
Specific conductance (laboratory), in microsiemens per centimeter at 25°C	109	156	76	169	68	87	116	60	103	136	86	111	217	242
Oxygen, dissolved, in milligrams per liter	11	11.8	11	10.7	12	11	11.1	12	10.2	11.8	11.6	10.5	10.2	11.3
Field pH, in standard units	7.7	7.5	7.7	7.6	7.4	7.8	7.6	7	7.9	7.9	7.6	7.4	7.3	7.7
Laboratory pH, in standard units	7.8	7.8	7.7	7.8	7.7	7.7	7.9	7.7	7.7	7.9	7.5	7.4	7.3	7.6
Ammonia as nitrogen, in milligrams per liter as N	.002	.003	.009	.004	<.002	.002	.003	.002	.004	<.002	.003	.005	.012	.024
Nitrite as nitrogen, in milligrams per liter as N	.001	<.001	.001	.002	<.001	<.001	.001	<.001	.001	.001	<.001	.001	<.001	.009
Ammonia as nitrogen plus organic nitrogen, in milligrams per liter as N	.14	E .10	<.10	E .10	E .10	.11	.11	E .10	E .10	.17	E .10	<.10	.18	.17
Ammonia plus organic nitrogen, in milligrams per liter as N	.23	E .09	E .07	E .09	E .09	.14	.19	E .09	.1	.15	.16	.14	.26	.22
Nitrite and nitrate, dissolved, in milligrams per liter as N	.412	.106	.064	.356	.282	.194	.437	.287	.098	.505	.318	.228	.462	.629
Total phosphorous, dissolved, in milligrams per liter as P	.022	<.004	<.004	.009	.004	.008	.008	<.004	.008	.009	.014	.012	.026	.022
Phosphorous, dissolved, in milligrams per liter as P	<.004	<.004	<.004	<.004	<.004	<.004	.005	<.004	<.004	<.004	<.004	<.004	.004	.008
Orthophosphorus, in milligrams per liter as P	.004	<.001	.001	<.001	<.001	.002	<.001	<.001	.002	.002	.001	<.001	<.001	.004
Organic carbon, dissolved, in milligrams per liter as C	1.9	.9	.9	1.3	.6	1.4	2.8	.8	1.2	3.1	1.4	1.9	3.9	4
Organic carbon, suspended, in milligrams per liter as C	.2	<.20	.2	<.20	—	—	<.20	<.20	.2	—	.2	<.20	—	.4
Calcium, dissolved, in milligrams per liter as Ca	17	24	13	25	9.6	12	17	11	14	20	12	16	25	29
Magnesium, dissolved, in milligrams per liter as Mg	3.2	3.4	1.7	3.9	1.6	2.1	2.9	1.9	2	3.3	2.1	2.7	5.3	6.8
Sodium, dissolved, in milligrams per liter as Na	1.7	2.2	1.1	2.6	1.2	1.5	2.1	1.4	1.3	2.7	1.9	1.8	5.9	7.5
Potassium, dissolved, in milligrams per liter as K	.21	.28	.21	.36	.15	.17	.32	.21	<.10	.35	.28	.32	.58	1.1
Chloride, dissolved, in milligrams per liter as Cl	.46	.34	.2	1.4	.33	.37	1.3	.96	<.10	2.8	2	1.7	9.6	15
Sulfate, dissolved, in milligrams per liter as SO_4	11	29	13	25	8.9	14	13	7.9	14	16	8.9	14	17	22
Fluoride, dissolved, in milligrams per liter as F	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
Silica, dissolved, in milligrams per liter as SiO_2	10	5.7	6	6.8	7.3	7.3	8.5	7.7	6	8.7	7.8	6.7	11	11
Iron, dissolved, in micrograms per liter as Fe	<10	<10	<10	E 7.5	<10	<10	13	<10	28	12	E 5.8	46	200	160
Manganese, dissolved, in micrograms per liter as Mn	<3.0	<3.0	<3.0	22	<3.0	3.9	3.4	<3.0	5.6	E 2.1	<3.0	16	70	67
Dissolved-solids residue at 180°C, in milligrams per liter	87	96	53	99	49	62	78	53	68	99	55	74	129	151
Specific conductance (field), in microsiemens per centimeter	129	164	87	177	74	96	124	82	101	151	93	120	206	251

Appendix 5. Trace-element concentrations in streambed sediments collected from 14 sites in Anchorage in 1999

[Site number: See fig. 1, fig. 2, and appendix 1 regarding site locations and numbering; sites are ordered from least to greatest population density. <, below detection limit]

Trace element	Site number													
	66	68	23	29	59	62	63	60	64	69	61	65	67	27
Aluminum, in percent	4.6	6.8	6.5	7.1	6.5	6.3	6.1	5.7	6.3	6.4	5.7	6.3	6.3	5.8
Antimony, in micrograms per gram	.6	1.2	1	1.2	1.4	1	1	1.2	.9	.9	1.2	1	1.4	2.4
Arsenic, in micrograms per gram	15	10	10	11	7.7	6.2	8.8	7.9	9.6	7.6	7.6	9.1	15	26
Barium, in micrograms per gram	410	660	720	650	650	670	660	600	610	670	580	610	550	600
Beryllium, in micrograms per gram	1	2	1	2	1	1	1	1	1	1	1	1	1	1
Bismuth, in micrograms per gram	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cadmium, in micrograms per gram	.2	.2	.2	.2	.2	.2	.3	.2	.2	.2	.2	.3	.7	1
Calcium, in percent	2.8	1.7	2.1	1.8	2	1.9	2	1.9	2	1.9	2	2	2.2	2
Cerium, in micrograms per gram	29	49	46	49	41	44	42	44	45	43	45	44	43	32
Cobalt, in micrograms per gram	14	19	21	20	18	15	16	16	17	15	16	18	20	20
Chromium, in micrograms per gram	81	95	110	110	72	62	63	85	99	64	91	110	110	120
Copper, in micrograms per gram	38	48	50	61	47	44	41	43	40	37	45	49	53	64
Europium, in micrograms per gram	<1	1	1	1	1	1	1	1	1	1	1	1	1	1
Gallium, in micrograms per gram	9	16	14	16	13	12	12	12	13	12	13	14	12	13
Gold, in micrograms per gram	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Holmium, in micrograms per gram	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Iron, in percent	3.5	4.2	4.2	4.4	3.9	3.5	3.8	3.4	4	3.6	3.5	4	4.9	5.9
Lanthanum, in micrograms per gram	14	24	22	24	20	22	21	23	21	21	23	22	20	18
Lead, in micrograms per gram	10	11	11	15	10	10	10	10	11	10	11	17	61	110
Lithium, in micrograms per gram	21	40	32	40	31	30	31	28	28	31	28	30	29	27
Magnesium, in percent	.9	1.2	1.2	1.4	1	.94	.96	.98	1.1	.99	1	1.2	1.1	1.2
Manganese, in micrograms per gram	1,300	870	970	1,300	1,000	1,200	1,500	1,100	860	1,300	1,100	970	1,400	2,600
Mercury, in micrograms per gram	.16	.18	.81	.16	.34	.21	.25	.29	.61	.22	.36	.33	.17	.17
Molybdenum, in micrograms per gram	2	1	2	1	1	3	2	1	1	2	1	1	1	2
Neodymium, in micrograms per gram	15	23	21	24	20	21	21	22	20	21	22	21	19	17
Nickel, in micrograms per gram	29	43	44	46	32	28	30	35	40	31	36	62	47	50
Niobium, in micrograms per gram	<4	6	6	7	5	6	6	6	6	6	6	6	5	8
Phosphorus, in percent	.22	.12	.14	.13	.16	.13	.14	.12	.13	.12	.12	.12	.18	.15
Scandium, in micrograms per gram	11	17	17	18	15	14	15	15	16	15	15	17	15	16
Selenium, in micrograms per gram	5.8	.9	2.2	.8	2.1	2.1	2.1	1.5	1.4	1.6	1.5	1.1	1.4	1.1
Silver, in micrograms per gram	.2	.2	.3	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.5
Sodium, in percent	1.2	1.7	1.6	1.8	1.6	1.8	1.7	1.7	1.8	1.8	1.7	1.7	1.8	1.6
Strontium, in micrograms per gram	270	270	240	270	240	270	250	250	250	260	250	240	240	250
Sulfur, in percent	.2	.06	.1	.06	.09	.1	.12	.06	.1	.08	.07	.1	.18	.2
Tantalum, in micrograms per gram	<1	1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Thorium, in micrograms per gram	2	4	4	4	3	3	3	4	4	4	4	4	4	3
Tin, in micrograms per gram	<1	1	1	2	<1	1	<1	<1	1	<1	<1	1	2	4
Titanium, in percent	.33	.43	.52	.47	.47	.48	.4	.36	.49	.41	.41	.4	.37	.39
Uranium, in micrograms per gram	2.4	1.6	2.1	1.6	1.5	1.5	1.5	1.4	1.7	1.4	1.5	1.7	1.4	1.3
Vanadium, in micrograms per gram	100	140	140	150	120	110	110	120	120	110	120	130	120	130
Ytterbium, in micrograms per gram	1	2	2	2	2	2	2	2	2	2	2	2	2	2
Yttrium, in micrograms per gram	15	20	20	22	20	18	19	20	19	19	20	20	18	20
Zinc, in micrograms per gram	82	100	100	120	110	110	140	110	92	160	120	180	420	590
Organic carbon, in percent	16	3.16	6.32	2.9	7.26	5.51	6.74	5.07	4.99	4.3	5.71	4.63	6.93	6.04
Inorganic carbon, in percent	.13	.02	.03	.02	.03	.03	.06	.02	.02	.03	.03	.02	.04	.05
Total, organic plus inorganic carbon, in percent	16.2	3.18	6.35	2.92	7.29	5.54	6.8	5.09	5.01	4.33	5.74	4.65	6.97	6.09