U.S. Department of the Interior
U.S. Geological Survey

Priority-Pollutant Trace Elements in Streambed Sediments of the Cook Inlet Basin, Alaska, 1998–2000

Water-Resources Investigations Report 02-4163

Prepared as part of the
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

USGS
science for a changing world

Cover photograph: Costello Creek at the mouth of Camp Creek, Denali National Park and Preserve, Alaska. (Photograph by Timothy P. Brabets, U.S. Geological Survey.)

U.S. Department of the Interior
U.S. Geological Survey

Priority-Pollutant Trace Elements in Streambed Sediments of the Cook Inlet Basin, Alaska, 1998–2000

By STEVEN A. FRENZEL

Water-Resources Investigations Report 02–4163

Prepared as part of the
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Anchorage, Alaska
2002

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

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

For additional information:

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

Copies of this report may be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

Internet URLs:
Alaska Water Resources: **http://ak.water.usgs.gov**
Cook Inlet Basin NAWQA: **http://ak.water.usgs.gov/Projects/Nawqa/**
National NAWQA: **http://water.usgs.gov/nawqa/nawqa_home.html**

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. 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.

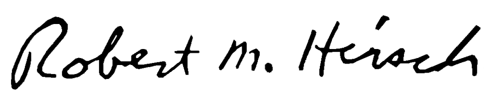
The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, Tribal, State, and local agencies, the NAWQA 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. NAWQA results can contribute to informed decisions that result in practical and effective water-resource 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. 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, multi-scale 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.

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-resource 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, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

This page intentionally blank

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in)
kilometer (km)	0.6214	mile
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

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.

Concentrations of trace elements in sediment are given in micrograms per gram (mg/g), which is equivalent to parts per million.

MAPPING SOURCES:

Base map modified from U.S. Geological Survey 1:250,000 State base maps.

U.S. Geological Survey Digital Line Graphs published at 1:2,000,000.

Publication projection is Albers Conical Equal Area.

Standard parallels are 55°00′ and 65°00′, central meridian –154°00′, latitude of project origin 50°00′.

Priority-Pollutant Trace Elements in Streambed Sediments of the Cook Inlet Basin, Alaska, 1998–2000

By Steven A. Frenzel

Abstract

Trace element concentrations in 48 streambed sediment samples collected at 47 sites in the Cook Inlet Basin, Alaska, were compared to concentrations from studies in the conterminous United States using identical methods and to Probable Effect Concentrations. Concentrations of arsenic, chromium, mercury, and nickel in the 0.063-mm size fraction of streambed sediments from the Cook Inlet Basin were elevated relative to reference sites in the conterminous United States. Concentrations of cadmium, lead, and zinc were highest at the most urbanized site in Anchorage and at two sites downstream from an ore body in Lake Clark National Park and Preserve. At least 35 percent of the 48 samples collected in the Cook Inlet Basin exceeded the Probable Effect Concentration for arsenic, chromium, or nickel. More than 50 percent of the samples were considered to have low potential toxicity for cadmium, lead, mercury, nickel, selenium, and zinc. A Probable Effect Concentration quotient that reflects the combined toxicity of arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc was exceeded in 44 percent of the samples from the Cook Inlet Basin. The potential toxicity was high in the Denali and Lake Clark National Parks and Preserves where organic carbon concentrations in streambed sediments were low. However, potential toxicity results should be considered in context with the very small amounts of fine-grained sediment present in the streambed sediments of the Cook Inlet Basin.

INTRODUCTION

The U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program began full-scale implementation in 1991; in the first decade of the program, studies were conducted that included parts of all 50 states. The Cook Inlet Basin Study Unit investigation began in 1997. The basin includes numerous drainages into Cook Inlet in south-central Alaska, (fig.1). Analysis of streambed sediments for trace element concentrations is one aspect of the integrated assessment of water quality in the NAWQA program (Gurtz, 1994). The Cook Inlet Basin Study Unit sampling network was designed to assess the occurrence of trace elements in the Cook Inlet Basin and to define their distribution in the parts of Denali and Lake Clark National Parks and Preserves within the basin. Sites also were sampled in Anchorage, the largest city in the basin (population about 256,000 in 2000), as part of a study of water quality along an urban gradient. This report describes the analysis of priority-pollutant trace element concentrations in streambed sediment samples collected in the Cook Inlet Basin during 1998 to 2000.

The environmental setting of the 101,800 square kilometer Cook Inlet Basin Study Unit has been described in detail by Brabets and others (1999). Typically, lowlands in the basin are underlain predominantly by alluvial or glacial deposits, whereas uplands are more commonly underlain by metamorphic or igneous rock. Sites sampled for streambed sediments and discussed in this report were most often located in lowland settings. Many of the drainages, however, include upland areas and glaciers. Mining and processing of ore have a large potential for introducing trace elements to nearby water bodies.

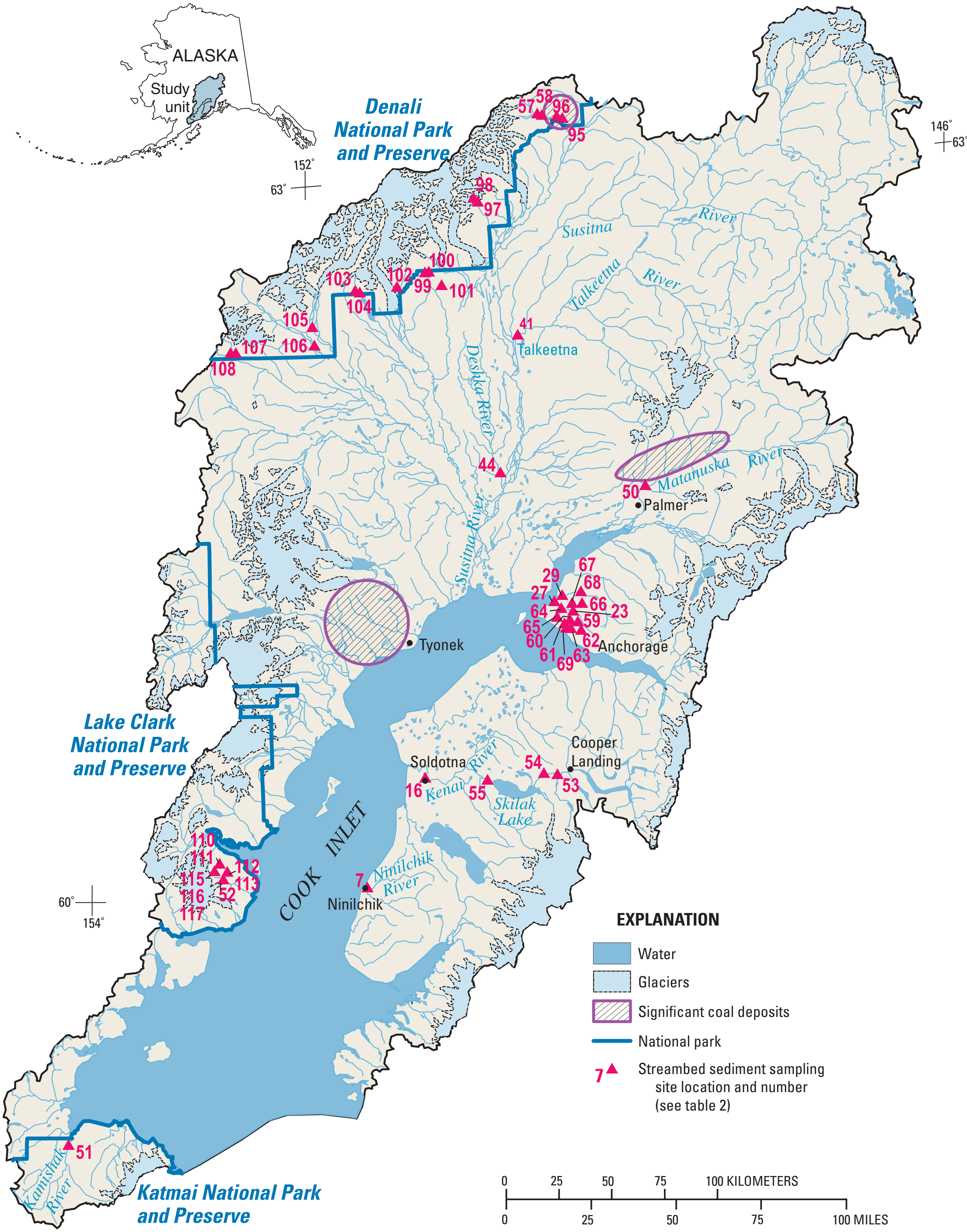


Figure 1. Cook Inlet Basin, Alaska, and location of streambed sediment sampling sites. (Refer to http://ak.water.usgs.gov/Projects/Nawqa/water-sites.htm for the location and names of all Cook Inlet Basin National Water-Quality Assessment (NAWQA) surface-water sites.)

Precious metals have been mined at small scales throughout the basin. Large-scale mining does not currently exist in the Cook Inlet Basin, although exploratory gold mining exists in the Johnson River Basin in Lake Clark National Park and Preserve on the west side of Cook Inlet. The ore (gold, lead, and zinc) body in the Johnson River Basin is drained by East Fork Ore Creek, a tributary to Ore Creek. Coal deposits are more economically important in the Cook Inlet Basin than are precious metals. Coal has been mined at a relatively small scale from an area now contained in Denali National Park and Preserve (hereinafter called the Denali area). From 1940 to 1954, 64,000 tons of coal were produced from Dunkle Mine in the Costello Creek Basin. An estimated 8 million tons of coal remain in the upper Costello and Colorado Creek Basins (National Park Service, 1983). Coal mining has been proposed for the area drained by Moose Creek near Palmer. On the west side of Cook Inlet, industry sources have identified more than 750 million tons of economically extractable coal (Nelson, 1985).

METHODS

Sample Collection and Analysis

Streambed sediment samples were collected from depositional areas accessible by wading in the selected stream reaches. Typically, these depositional areas were along channel margins or bar formations. The surficial 2 cm of sediment was collected from several areas and composited to form a large sample volume from which material was removed and sieved using a 0.063-mm nylon mesh (Shelton and Capel, 1994). Sediments were digested in strong acid prior to analysis by the USGS National Water-Quality Laboratory in Lakewood, Colorado. Concentration data were reported on a dry-weight basis.

Streambed sediments were collected at sites in Anchorage for determination of particle-size distribution in conjunction with a study of benthic invertebrates and fish communities. Three samples were collected from riffles at each of 12 sites by lowering a 15-cm diameter enclosure to the streambed and excavating the sample within the enclosure. This technique eliminated currents that would carry away fine-grained sediments. Streambed sediments were dried at 70°C, sieved, and weighed by size class. A geometric mean of the three samples was determined and presented for five size classes, including the less than 0.063-mm size fraction.

Data Analysis

Although concentrations of 44 elements were determined for the streambed sediment samples, only the results for 9 trace elements are discussed here. Those trace elements, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc, are listed as priority pollutants (U.S. Environmental Protection Agency, 1994). Trace element concentrations from the Cook Inlet Basin Study Unit were not normalized for organic carbon content in the streambed sediments for comparisons with data from other NAWQA study units and the determination of background concentrations. Analysis of 541 streambed sediment samples collected during previous NAWQA studies showed that sieving the samples removed most of the background differences in the samples, making further "normalization" unnecessary (Rice, 1999). However, for comparing data from the Cook Inlet Basin Study Unit to toxicity guidelines, data were normalized for organic carbon concentrations (dry weight) to equate to the sediment quality guidelines (SQGs) described by MacDonald and others (2000). Organic carbon in the streambed sediments likely affects the bioavailability of trace elements such that sediments containing relatively high concentrations of organic carbon will have a lower potential toxicity than sediments with lower organic carbon concentrations and identical trace element concentrations.

Cook Inlet Basin Study Unit samples were compared with samples collected by identical methods in 46 other NAWQA study units throughout the United States between 1992 and 2000. Those comparisons were made after stratification of the NAWQA sites into the following land use groups: (1) reference (relatively undisturbed basins) and forest, (2) mining, and (3) urban, residential, and commercial. Land use categories used in this study differ from those used by Rice (1999) in a study of trace element concentrations from streambed sediment samples collected for the NAWQA program from 1992 to 1996. Our urban category also included sites classified as residential and commercial, whereas Rice's urban category did not. Comparisons between Cook Inlet Basin Study Unit samples and national NAWQA samples in the three land use categories were done using boxplots and a Wilcoxon rank-sum test. Computed p-values less than 0.05 indicated a significant difference in a given comparison.

Cumulative-frequency plots were used to determine background concentrations by locating a sharp upward break in the cumulative-frequency distribution, which would indicate an anthropogenic affect within the Cook Inlet Basin Study Unit (Velz, 1984). For purposes of plotting, concentrations less than the minimum reporting limits for the analytical method were assigned a value of one-half the reporting limit. A smoothing function was applied to reduce noise in the data.

Concentrations of trace elements, excluding selenium, were compared to consensus-based SQGs (MacDonald and others, 2000). Those guidelines were developed from studies that typically use bulk sediment samples rather than the fine-grained fraction sampled by the NAWQA program. The SQGs identify a Threshold Effect Concentration (TEC) below which sediment-dwelling organisms are unlikely to be adversely affected and a Probable Effect Concentration (PEC) above which toxicity is likely (MacDonald and others, 2000). These values were determined by matching sediment chemistry and toxicity data from field studies. MacDonald and others (2000) did not determine a PEC for selenium. For that element, Van Derveer and Canton (1997) suggested a no effect level of 2.5 μg/g (10^{th} percentile of effects) and a toxicity level of 4 μg/g (100^{th} percentile of effects).

Guideline concentrations from MacDonald and others (2000) and Van Derveer and Canton (1997) used in this report are shown in table 1. Additionally, the toxicity of the combined trace element concentrations was assessed by the method of MacDonald and others (2000). They found that when the sum of normalized concentrations was divided by the number of constituents used in the calculation, a resulting value of 0.5 was a threshold that defined toxicity. Sediments with mean PEC quotients of less than 0.5 accurately predicted the absence of toxicity in 83 percent of the samples they examined. Mean PEC quotients greater than 0.5 accurately predicted toxicity in 85 percent of the samples. However, their mean PEC quotients included organic contaminants as well as trace elements. Our calculation of mean PEC quotient was done for the priority-pollutant trace elements, excluding selenium.

Table 1. Guidelines for trace element concentrations, in micrograms per gram, dry weight

Element	Low potential for toxicity	High potential for toxicity
Arsenic (As)	9.79 [a]	33 [b]
Cadmium (Cd)	.99 [a]	4.98 [b]
Chromium (Cr)	43.4 [a]	111 [b]
Copper (Cu)	31.6 [a]	149 [b]
Lead (Pb)	35.8 [a]	128 [b]
Mercury (Hg)	.18 [a]	1.06 [b]
Nickel (Ni)	22.7 [a]	48.6 [b]
Selenium (Se)	2.50 [c]	4.00 [d]
Zinc (Zn)	121 [a]	459 [b]

[a] Threshold Effect Level (TEC: MacDonald and others, 2000).
[b] Probable Effect Level (PEC: MacDonald and others, 2000).
[c] 10th percentile of effects (Van Derveer and Canton, 1997).
[d] 100th percentile of effects (Van Derveer and Canton, 1997).

RESULTS

Relatively high trace element concentrations occurred at highly urbanized sites, in the Denali area, and at sites downstream of an ore body in Lake Clark National Park and Preserve (table 2). Low concentrations were found in Hidden Creek, in the Talkeetna and Kamishak Rivers, and at sites in Anchorage with low population density.

Cook Inlet Basin Study Unit concentration data were compared to concentrations in samples collected during other NAWQA studies at sites in specific land use categories with varying results (fig. 2, table 3). Mercury and nickel concentrations were statistically similar to those in other NAWQA samples from sites downstream from urban and mining areas. Arsenic concentrations were statistically similar to concentrations from sites in areas with a mining-dominated land use, whereas chromium concentrations were similar to those at sites in urban areas. Zinc concentrations were statistically similar to concentration at sites representing reference, or background conditions. Samples from Cook Inlet Basin Study Unit sites were similar to those in other NAWQA studies for all land use categories with respect to selenium concentrations and were statistically different with respect to cadmium, copper, and lead concentrations.

Table 2. Concentrations, in micrograms per gram dry weight, of priority-pollutant trace elements in streambed sediments finer than 0.063 millimeters in the Cook Inlet Basin, Alaska, 1998 to 2000

[Site no. refers to site number in figure 1; latitude/longitude are given in °, degrees; ’, minutes; ”, seconds; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Se, selenium; Zn, zinc; organic carbon in percent; **values in bold** are concentrations that when normalized to 1 percent organic carbon, exceed Probable Effect Concentration (PEC), or, for the mean PEC quotient, indicate toxicity for the sum of trace elements, excluding selenium (MacDonald and others, 2000); St., Street; Dr., Drive; Hwy., Highway; Pkwy., Parkway; <, less than; refer to http://ak.water.usgs.gov/Projects/Nawqa/ water-sites.htm for the location and names of all Cook Inlet Basin National Water-Quality Assessment (NAWQA) surface-water sites]

Site no.	Site name	Latitude	Longitude	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Zn	Organic carbon	Mean PEC quotient
	Municipality of Anchorage													
23	South Fork Campbell Creek near Anchorage	61°10’02”	149°46’14”	10	.2	100	50	11	.81	44	2.2	100	6.32	.07
27	Chester Creek at Arctic Blvd. (1998) at Anchorage	61°12’19”	149°53’43”	23	1.2	120	60	90	.18	64	.8	600	6.96	.11
27	Chester Creek at Arctic Blvd. (1999) at Anchorage	61°12’19”	149°53’43”	26	1.0	120	64	110	.17	50	1.1	590	6.04	.12
29	Ship Creek below power plant at Elmendorf Air Force Base	61°13’29”	149°50’39”	11	.2	110	61	15	.16	46	.8	120	2.90	.14
59	Rabbit Creek at Hillside Dr. near Anchorage	61°05’51”	149°43’52”	7.7	.2	72	47	10	.34	32	2.1	110	7.26	.04
60	Rabbit Creek at East 140th Ave. near Anchorage	61°05’41”	149°47’14”	7.9	.2	85	43	10	.29	35	1.5	110	5.07	.07
61	Rabbit Creek at Porcupine Trail Rd. near Anchorage	61°05’15”	149°49’06”	7.6	.2	91	45	11	.36	36	1.5	120	5.71	.06
62	Little Rabbit Creek at Nickleen St. near Anchorage	61°04’21”	149°43’26”	6.2	0.2	62	44	10	0.21	28	2.1	110	5.51	0.05
63	Little Rabbit Creek at Goldenview Dr. near Anchorage	61°04’54”	149°46’20”	8.8	.3	63	41	10	.25	30	2.1	140	6.74	.04
64	Campbell Creek at New Seward Hwy. near Anchorage	61°10’33”	149°51’23”	9.6	.2	99	40	11	.61	40	1.4	92	4.99	.08
65	Campbell Creek at C St. near Anchorage	61°08’55”	149°53’03”	9.1	.3	110	49	17	.33	62	1.1	180	4.63	.10
66	South Branch of South Fork Chester Creek at Tank Trail near Anchorage	61°11’25”	149°42’13”	15	.2	81	38	10	.16	29	5.8	82	16.00	.02
67	South Branch of South Fork Chester Creek at Boniface Pkwy. near Anchorage	61°11’23”	149°46’33”	15	.7	110	53	61	.17	47	1.4	420	6.93	.08
68	Ship Creek at Glenn Hwy. near Anchorage	61°14’20”	149°41’32”	10	.2	95	48	11	.18	43	.9	100	3.16	.11
69	Little Rabbit Creek (at Old Seward Hwy.) near Anchorage	61°04’42”	149°48’36”	7.6	.2	64	37	10	.22	31	1.6	160	4.30	.07
	Denali National Park and Preserve area													
57	Colorado Creek near Colorado	63°16’29”	149°35’20”	**44**	.5	**220**	59	15	.18	**130**	.7	150	.52	**1.71**
58	Costello Creek near Colorado (Site no. 6310181493237)	63°16’18”	149°32’37”	**23**	.3	**170**	64	16	.23	**98**	.7	140	.46	**1.46**
95	Camp Creek at mouth near Colorado	63°16’12”	149°31’33”	**49**	.5	**110**	35	27	.24	**42**	.5	140	1.00	**.55**
96	Costello Creek below Camp Creek near Colorado	63°16’09”	149°31’34”	**25**	.3	**140**	55	18	.16	**70**	.6	130	.47	**1.19**
97	Crystal Creek at mouth near Talkeetna	62°50’12”	150°18’27”	10	.2	24	16	20	.02	11	.6	68	.80	.19
98	Coffee River above Crystal Creek near Talkeetna	62°50’14”	150°18’32”	**9.1**	.2	**10**	10	22	<.02	**6**	.1	56	.08	**1.39**
99	Bear Creek near Talkeetna	62°38’34”	150°54’33”	**42**	.5	**140**	59	17	.03	**81**	.9	150	1.20	**.54**
100	Wildhorse Creek near Talkeetna	62°39’20”	150°54’03”	56	1.9	120	48	17	.08	56	5.2	170	6.90	.09
101	Long Creek near Talkeetna	62°35’10”	150°45’04”	46	.2	79	26	10	.04	32	1.7	80	7.10	.06
102	Hidden Creek near Talkeetna	62°35’30”	151°11’29”	**3.3**	<.1	3	3	25	<.02	<2	<.1	16	.09	**.53**
103	Snowslide Creek at mouth near Talkeetna	62°33’24”	151°32’16”	1.7	.4	**10**	11	76	<.02	**6**	.1	92	.07	**2.17**
104	Cripple Creek above Snowslide Creek near Talkeetna	62°33’25”	151°32’18”	8.7	.3	**68**	26	20	<.02	**37**	.3	80	.53	**.52**
105	Cascade Creek at mouth near Talkeetna	62°25’22”	151°59’22”	**88**	.2	**87**	48	13	<.02	**49**	.6	95	.36	**1.78**

Table 2. Concentrations, in micrograms per gram dry weight, of priority-pollutant trace elements in streambed sediments finer than 0.063 millimeters in the Cook Inlet Basin, Alaska, 1998 to 2000—Continued

[Site no. refers to site number in figure 1; latitude/longitude are given in °, degrees; ’, minutes; ”, seconds; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Se, selenium; Zn, zinc; organic carbon in percent; **values in bold** are concentrations that when normalized to 1 percent organic carbon, exceed Probable Effect Concentration (PEC), or, for the mean PEC quotient, indicate toxicity for the sum of trace elements, excluding selenium (MacDonald and others, 2000); St., Street; Dr., Drive; Hwy., Highway; Pkwy., Parkway; <, less than; refer to http://ak.water.usgs.gov/Projects/Nawqa/ water-sites.htm for the location and names of all Cook Inlet Basin National Water-Quality Assessment (NAWQA) surface-water sites]

Site no.	Site name	Latitude	Longitude	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Zn	Organic carbon	Mean PEC quotient
	Denali National Park and Preserve area—Continued													
106	Fourth of July Creek at mouth near Talkeetna	62°19’36”	151°58’27”	**26**	0.3	**150**	49	16	0.02	**80**	0.8	130	0.57	**1.01**
107	Morris Creek at mouth near Talkeetna	62°17’59”	152°41’05”	**30**	.2	**150**	47	14	.07	**94**	1.2	150	.49	**1.29**
108	Kichatna River above Morris Creek near Talkeetna	62°18’00”	152°41’06”	**16**	<.1	**29**	13	**33**	.02	**17**	.2	**63**	.11	**1.82**
	Johnson River Basin—Lake Clark National Park and Preserve													
52	Johnson River above Lateral Glacier near Tuxedni Bay	60°05’41”	152°54’38”	**16**	.2	**66**	**75**	4	**.13**	**17**	.3	**130**	.05	**6.02**
110	Kona Creek 3 miles above mouth above Lateral Glacier near Tuxedni Bay	60°08’26”	152°55’44”	**19**	<.1	**38**	**56**	6	**.75**	11	.6	**120**	.25	**1.27**
111	Kona Creek 2.5 miles above Lateral Glacier near Tuxedni Bay	60°08’03”	152°55’24”	**18**	.1	**42**	**57**	5	.16	11	.6	**140**	.26	**.98**
112	Kona Creek tributary above Lateral Glacier near Tuxedni Bay	60°06’35”	152°55’09”	18	<.1	77	47	4	.10	25	.2	85	1.30	.23
113	Kona Creek 0.8 miles above mouth above Lateral Glacier near Tuxedni Bay	60°06’36”	152°55’14”	**16**	.4	48	63	17	.28	14	.7	150	.49	**.62**
115	East Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	60°07’15”	152°57’28”	**34**	<.1	**41**	**54**	<1	**.53**	**15**	.2	**120**	.16	**2.21**
116	North Fork Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	60°07’13”	152°57’40”	**64**	**4.3**	14	76	**230**	.93	4	2.6	**1,000**	1.00	**.72**
117	Ore Creek near mouth near Johnson Glacier near Tuxedni Bay	60°06’58”	152°58’14”	**44**	**4.6**	23	**92**	**180**	**.28**	8	1.2	**1,800**	.24	**4.60**
	Miscellaneous basins													
7	Ninilchik River at Ninilchik	60°02’54”	151°39’54”	30	.2	50	14	8	.05	20	.4	74	3.57	.08
16	Kenai River at Soldotna	60°28’39”	151°04’46”	23	.3	84	36	15	.03	42	.3	85	.91	.41
41	Talkeetna River near Talkeetna	62°20’49”	150°01’01”	**5.2**	<.1	**38**	**27**	7	.04	**18**	.1	53	.16	**.99**
44	Deshka River near Willow	61°46’05”	150°20’13”	50	.3	67	26	12	.05	29	.5	100	2.87	.14
50	Moose Creek near Palmer	61°41’00”	149°02’36”	23	.3	84	74	16	.20	40	.5	120	1.52	.28
51	Kamishak River near Kamishak	58°57’50”	154°10’11”	8.9	.1	**78**	38	7	.04	**29**	.4	93	.58	.46
53	Kenai River below Russian River near Cooper Landing	60°29’07”	150°00’35”	17	.3	110	46	16	.07	52	.3	110	1.51	.28
54	Kenai River at Jim's Landing near Cooper Landing	60°28’55”	150°06’36”	11	.3	110	45	17	.09	54	.7	110	2.61	.16
55	Kenai River below Skilak Lake outlet near Sterling	60°28’00”	150°35’56”	9.3	.2	**82**	41	13	.07	**42**	.2	80	.72	.44
	Percentage of sites with low potential toxicity			40	83	48	46	75	73	50	94	54		56
	Percentage of sites with high potential toxicity			40	6	40	15	12	6	35	4	19		44

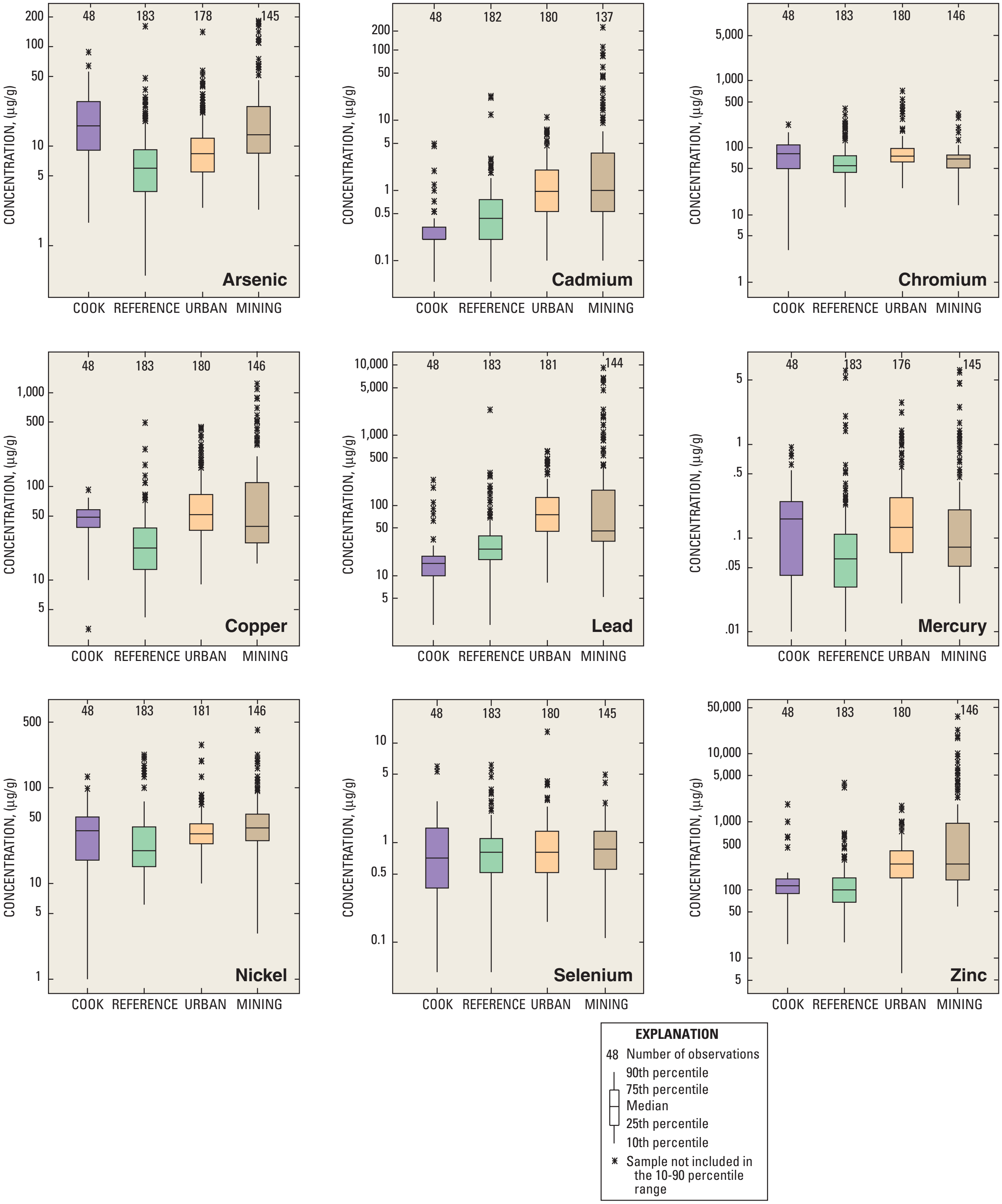


Figure 2. Concentrations of priority-pollutant trace elements in streambed sediment samples from the U.S. Geological Survey's (USGS) Cook Inlet Basin (COOK) National Water-Quality Assessment (NAWQA) Study Unit and from reference streams and streams in urban and mining areas sampled nationally for the USGS NAWQA program, 1992. (µg/g, micrograms per gram)

Table 3. Statistical significance of comparisons of trace element concentrations from the U.S. Geological Survey's Cook Inlet Basin (COOK) National Water-Quality Assessment (NAWQA) Study Unit and national NAWQA samples, grouped by dominant land use

[vs., versus; p, probability; <, less than; =, equals; Wilcoxon rank-sum test; COOK, n=48; Reference, n=183; Urban, n=178; Mining, n=145]

Element	COOK vs. Reference	COOK vs. Urban	COOK vs. Mining
Arsenic	$p < 0.001$	$p < 0.001$	$p = 0.430$
Cadmium	$p = 0.004$	$p < 0.001$	$p < 0.001$
Chromium	$p = 0.007$	$p = 0.890$	$p = 0.010$
Copper	$p < 0.001$	$p < 0.001$	$p < 0.001$
Lead	$p < 0.001$	$p < 0.001$	$p < 0.001$
Mercury	$p = 0.002$	$p = 0.347$	$p = 0.566$
Nickel	$p = 0.020$	$p = 0.938$	$p = 0.185$
Selenium	$p = 0.678$	$p = 0.318$	$p = 0.182$
Zinc	$p = 0.092$	$p < 0.001$	$p < 0.001$

Background levels could be determined from cumulative-frequency plots for cadmium (0.40 µg/g), lead (21 µg/g), and zinc (190 µg/g; fig. 3). Arsenic (range 1.7–88 µg/g), chromium (range 3–220 µg/g), copper (range 3–92 µg/g), nickel (range < 2–130 µg/g), and selenium (range < 0.1–5.8 µg/g) concentrations did not have a distinct break point indicative of an anthropogenic effect (fig. 3). Cadmium (range < 0.1–4.6 µg/g), lead (range < 1–230 µg/g), and zinc (range 16–1,800 µg/g) concentrations were higher than the background level for the Cook Inlet Basin Study Unit at sites in the most urbanized basin (fig. 1, table 2, sites 27 and 67), downstream from an ore body (sites 116 and 117), or downstream from an old coal mine (site 95).

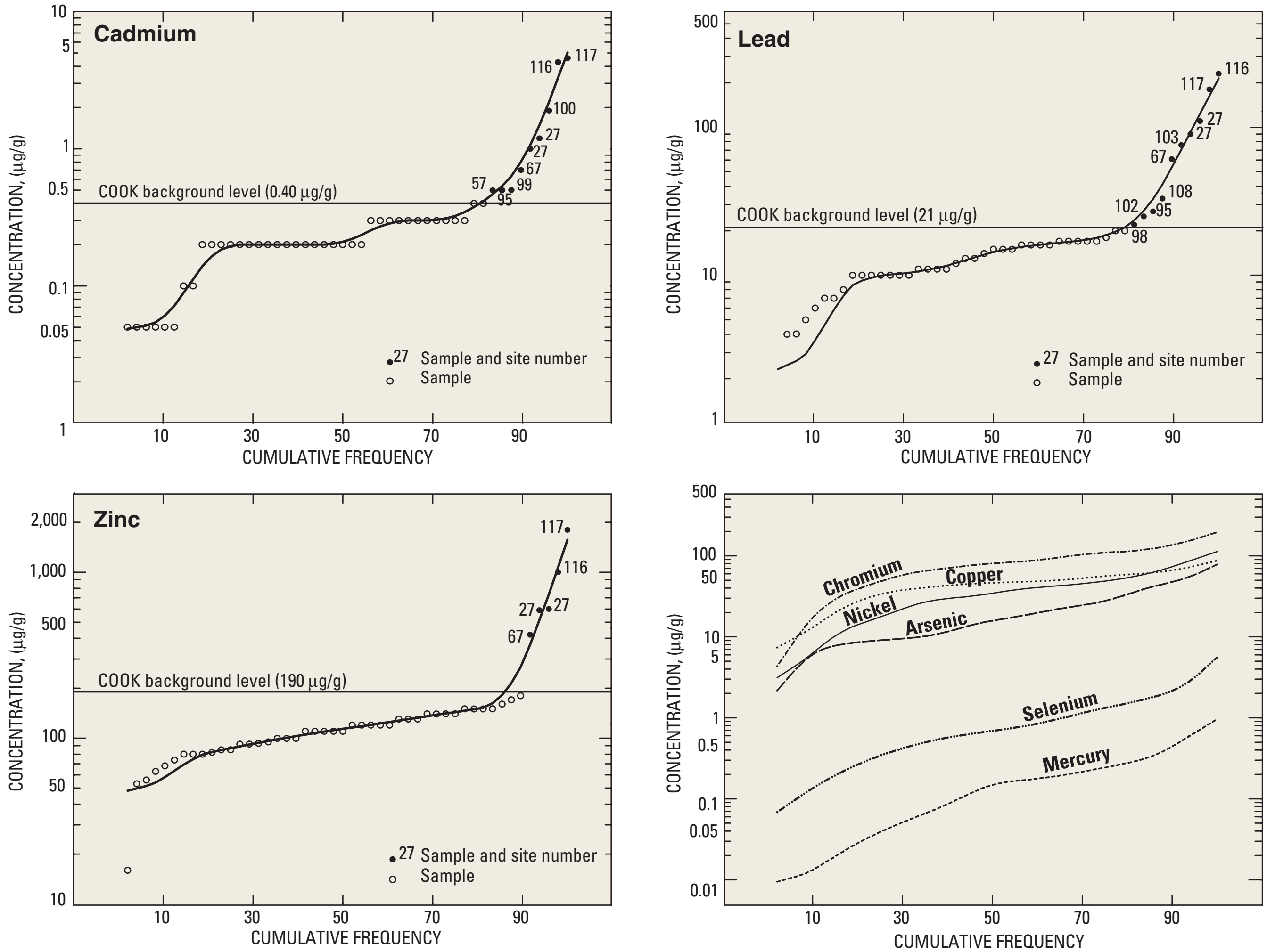


Figure 3. Cumulative frequency plots for priority-pollutant trace elements in streambed sediments from the U.S. Geological Survey's Cook Inlet Basin (COOK) National Water-Quality Assessment Study Unit. (µg/g, micrograms per gram; refer to figure 1 and table 2 for site information)

The potential toxicity of individual priority-pollutant trace elements from the less than 0.063-mm size fraction of streambed sediments was low in at least 50 percent of the samples for cadmium, lead, mercury, nickel, selenium, and zinc (table 2). High potential toxicity was determined in at least 35 percent of the samples for arsenic, chromium, and nickel. Cadmium, lead, and selenium had high potential toxicity in a very low percentage of samples. The mean PEC quotient, which reflects the combined toxicity of trace elements in the streambed sediment (excluding selenium) indicated that 56 percent of the samples would be classified as not toxic, and 44 percent of the samples would be classified as toxic.

Particle-size analysis of streambed sediment samples collected from riffles at sites in Anchorage, except for Ship Creek (sites 29 and 68), showed that the less than 0.063-mm size fraction composed less than 0.01 to only 16 percent of the material by weight for all samples (not shown); the geometric mean of samples collected at individual sites was typically less than 0.01 percent (table 4). Although particle-size analyses were done for only a few sites, the relative magnitude of the percent of fine-grained sediment in riffles at other sites can be inferred from these data.

Table 4. Mean percentage of streambed sediment in selected size classes from sites in Anchorage, Alaska

[For site no. information refer to table 2 and figure 1; mm, millimeter; values are geometric means of three samples from riffles at each site; <, less than]

Site no.	64 mm	64 mm	2 mm	0.5 mm	0.063 mm
23	55.26	12.42	2.48	.32	< .01
59	66.75	17.44	4.59	.60	< .01
60	57.74	15.82	3.77	.49	< .01
61	64.36	16.79	3.65	.56	.01
62	64.80	22.24	8.03	2.13	0.03
63	57.36	16.62	4.81	.85	.01
64	69.72	17.75	3.88	.50	< .01
65	53.28	13.71	3.25	.33	< .01
66	51.12	13.95	3.41	.37	< .01
67	45.99	11.54	3.15	.37	< .01
69	65.24	15.05	4.11	.60	< .01

DISCUSSION

Priority-Pollutant Trace Element Concentrations

Trace element concentrations can be elevated in streambed sediments as a result of anthropogenic activities, such as mining or industrial/urban development, or as a result of natural geologic factors. Data from previous NAWQA studies have shown that median concentrations of chromium, copper, lead, nickel, and zinc were higher at sites downstream of urban areas than at nonurban sites (Rice, 1999). However, Rice (1999) combined many land use categories into a nonurban group. Our comparison of urban and mining sites sampled in the NAWQA program showed that chromium, copper, lead, mercury, and zinc had higher median concentrations at urban sites. A gradient of urbanization in Anchorage (sites 23, 27, 29, 59–69) sampled during this study included basins with population density less than 100 persons/km^2 (sites 23, 59, 62–63, 66) as well as basins with over 500 persons/km^2 (sites 27, 65, 67). Concentrations of cadmium, lead, and zinc increased markedly at the most highly urbanized sites (sites 27 and 67).

Two samples collected at Chester Creek at Arctic Boulevard (site 27) had two of the three highest concentrations from sites sampled in Anchorage for seven of the nine priority-pollutant trace elements. Additionally, antimony, iron, manganese, silver, and tin were higher at Chester Creek at Arctic Boulevard than at other sites in Anchorage (U.S. Geological Survey, 2000). Sites in Anchorage had low arsenic concentrations relative to other parts of the Cook Inlet Basin. However, the arsenic concentration was 23 and 26 µg/g in 1998 and 1999, respectively, at Chester Creek at Arctic Boulevard (site 27). That site was the most urbanized site, in terms of population and road densities, sampled in Anchorage. The second most urbanized site, South Branch of South Fork Chester Creek at Boniface Parkway (site 67), had an arsenic concentration of 15 µg/g. All other sites in Anchorage had arsenic concentrations of 10 µg/g or less. Cadmium, lead, and zinc concentrations at the two downstream Chester Creek sites were much greater than at other Anchorage sites, but were lower than concentrations at two sites near an ore body in the Johnson River Basin (sites 116 and 117).

The elevated lead and zinc concentrations in the Chester Creek Basin were consistent with results from similar locations sampled in the 1980s (Brabets, 1987). Lead and zinc often are associated with urbanized areas and were elevated at many urban sites sampled in the NAWQA program (Callender and Rice, 2000; Kroening and others, 2000).

Although large-scale precious metal mining does not exist presently in the Cook Inlet Basin, small exploratory claims are abundant. Most claims are for gold mines, but a variety of mineral deposits are present, and arsenopyrite occurs widely. Arsenic concentrations in Cook Inlet Basin Study Unit streambed sediments tended to be higher than for the areas sampled for the NAWQA program in the conterminous United States. However, naturally high concentrations are not unprecedented. In the Upper Colorado River Basin NAWQA Study Unit, unmined sites had arsenic concentrations as high as 62 μg/g, whereas mined sites had arsenic concentrations as high as 180 μg/g (Deacon and Driver, 1999). Basins sampled in the Denali area contain bedrock formations of basalt, argillite, and chert that contain numerous metal deposits (National Park Service, 1983). Many abandoned exploratory mines exist in the southern part of the Denali area, and arsenopyrite is commonly associated with those mines.

Cadmium, copper, lead, and zinc concentrations were elevated at two sites (sites 116 and 117) downstream of an ore body and at two urban sites (sites 27 and 67). Those trace elements often are elevated in mining areas (Heiny and Tate, 1997; Deacon and Driver, 1999) and in urban runoff (Rice, 1999; Callender and Rice, 2000). Although most sites sampled in the Cook Inlet Basin are in essentially undeveloped areas, mercury and nickel concentrations were statistically similar to those in samples from urban and mining-dominated basins in other NAWQA study units. Additionally, arsenic concentrations from the basin were similar to those from mining-dominated sites in other NAWQA studies, and chromium concentrations were similar to those at urban-dominated NAWQA sites. However, arsenic, chromium, mercury, and nickel concentrations from the Cook Inlet Basin did not show a break in the cumulative frequency plots that would indicate an anthropogenic effect. Mercury concentrations in Anchorage generally were larger than those measured in a study of mercury associated with mining activities in the Sacramento River Basin that used methods similar to those used in this study (Domagalski, 1998). Sources of mercury in the Anchorage area are unknown, but may be a combination of natural geologic and atmospheric sources.

Chromium and nickel concentrations in the Cook Inlet Basin were highest from sites in the Denali area and from the most urbanized site (site 27) in Anchorage. Chromium and nickel concentrations in streambed sediments in the Denali area may be indicative of the metamorphic and igneous bedrock in that area (Silberling and others, 1994). In contrast, relatively low concentrations of chromium and nickel in the Johnson River Basin likely are indicative of the sample location's proximity to the Alaska–Aleutian Range Batholith, which contains little chromium and nickel (Waythomas and others, 2000).

Potential Toxicity

Given that NAWQA methods specify a 0.063-mm size fraction and strong acid digestion, any implied toxicity concerns from these data should be considered in that context: Larger-grained sediments likely contain lower trace element concentrations than the 0.063-mm fraction (Horowitz, 1991), whereas strong acid digestion may result in an overestimation of bioavailability. However, a direct comparison to the PEC guidelines developed by MacDonald and others (2000) showed an exceedance of the PEC in at least 35 percent of the samples from the Cook Inlet Basin with respect to arsenic, chromium, and nickel. Low toxicity, as indicated by the TEC guidelines, was exceeded by more than 50 percent of the samples from the basin for arsenic, chromium, copper, and zinc. The success of the SQGs in predicting toxicity was tested by MacDonald and others (2000). They found that except for mercury, the TEC and PEC concentrations were successful in differentiating between low and high occurrences of toxicity. Mercury showed incidences of toxicity in nearly 66 percent of samples with concentrations below the TEC, 70 percent of samples with concentrations between the TEC and PEC, and 100 percent of samples with concentrations higher than the PEC (MacDonald and others, 2000).

Potential toxicity for sediment-dwelling organisms exists in some areas of the Cook Inlet Basin study, particularly in the areas of Denali and Lake Clark National Parks and Preserves. The relatively low amounts of organic carbon in the streambed sediments from those areas increased the potential toxicity. For example, concentrations of all of the priority-pollutant trace elements were relatively low at Snowslide Creek (site 103) in the Denali area, yet the toxicity potential at that site was considered high for chromium, copper, lead, nickel, and zinc because the organic carbon concentrations was just 0.07 percent. In Anchorage, Chester Creek at Arctic Boulevard (site 27) had concentrations of cadmium, lead, and zinc that were elevated above a background level for the Cook Inlet Basin Study Unit and were higher than most sites in the Denali and Lake Clark areas, yet because the organic carbon concentration was about 6 percent the toxicity potential was low.

Streambed sediment data collected in the Cook Inlet Basin during 1998 and included in this report (sites 7, 16, 23, 27, 41, 44, 50–55, and 57–58) were also discussed by Frenzel (2000). In that report, the trace element concentrations were compared to guidelines for bulk sediment (Canadian Council of Ministers of the Environment, 1999) and were not normalized for organic carbon. Frenzel (2000) found that the Canadian guidelines were exceeded in 57 percent of the streambed sediment samples for arsenic, 43 percent of the samples for chromium, and 7 percent of the samples for zinc. None of the samples exceeded the Canadian guidelines for the other six priority-pollutant trace elements.

The mean PEC quotient was effective in defining overall sediment toxicity in more than 170 samples examined by MacDonald and others (2000). When applied to streambed sediments in the Cook Inlet Basin Study Unit, 44 percent of the samples would be classified as toxic. Therefore, concerns of potential toxicity to salmonid eggs and fry could exist where fine-grained sediments are abundant and trace element concentrations exceed PECs. Erosional areas of the streambed, such as riffles, where salmonid eggs typically are deposited and incubated, contained little of the finest-grained sediments—less than 0.01 percent of the sediment matrix was finer than 0.063 mm. However, fine-grained sediments are more abundant in depositional areas such as pools and sloughs, which are preferred rearing habitat for many salmonid fry.

Because of the minute amount of fine-grained sediments in riffles, toxicity of trace elements in streambed sediments likely is low for salmonid eggs, despite concentrations that may exceed the PEC. However, since finer-grained sediments are more abundant in pools and sloughs, they may present greater toxicity for salmonid fry rearing in those areas. No concomitant biological data were collected to verify whether toxicity actually exists where a high potential toxicity is indicated.

SUMMARY

Concentrations of arsenic, chromium, mercury, and nickel in streambed sediments of the Cook Inlet Basin National Water-Quality Assessment (NAWQA) Study Unit were greater than concentrations in samples from reference areas sampled for the U.S. Geological Survey's NAWQA program in the conterminous United States. Chromium and nickel concentrations were highest in the Denali area, while mercury concentrations were highest in the Lake Clark National Park and Preserve and in the Municipality of Anchorage. Arsenic concentrations were high in both Denali area and Lake Clark National Park Preserve. Concentrations of cadmium, lead, and zinc were highest at the most urbanized site in Anchorage and at two sites downstream from an ore body in Lake Clark National Park and Preserve.

At least 35 percent of the 48 samples collected in the Cook Inlet Basin Study Unit had high potential toxicity for arsenic, chromium, or nickel. The potential toxicity was high in the Denali area and Lake Clark National Park and Preserve, where organic carbon concentrations in streambed sediments were low. Potential toxicity results should be considered in context with the very small amounts of fine-grained sediment present in the streambed sediments of the Cook Inlet Basin. To more accurately assess the toxicity of trace elements in the streambed sediments, measures of the aquatic communities are needed.

REFERENCES CITED

Brabets, T.P., 1987, Quantity and quality of urban runoff from the Chester Creek Basin, Anchorage, Alaska: U.S. Geological Survey Water-Resources Investigations Report 86–4312, 58 p.

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.

Callender, E., and Rice, K.C., 2000, The urban environmental gradient—Anthropogenic influences on the spatial and temporal distributions of lead and zinc in sediments: Environmental Science and Technology, v. 34, no. 2, p. 232–238.

Canadian Council of Ministers of the Environment, 1999, Canadian sediment quality guidelines for the protection of aquatic life: Winnipeg, Ottawa, Canada.

Deacon, J.R., and Driver, N.E., 1999, Distribution of trace elements in streambed sediment associated with mining activities in the Upper Colorado River Basin, Colorado, 1995–96: Archives of Environmental Contamination and Toxicology, v. 37, p. 7–18.

Domagalski, J., 1998, Occurrence and transport of total mercury and methyl mercury in the Sacramento River Basin, California: Journal of Geochemical Exploration, v. 64, p. 277–291.

Frenzel, S.A., 2000, Selected organic compounds and trace elements in streambed sediments and fish tissues, Cook Inlet Basin, Alaska:. U.S. Geological Survey Water-Resources Investigations Report 00–4004, 39 p.

Gurtz, M.E., 1994, Design of biological components of the National Water-Quality Assessment (NAWQA) program *in* Loeb, S.L., and Spacie, A., eds., Biological monitoring of aquatic ecosystems: Lewis Publishers, Boca Raton, Florida, p. 323–354.

Heiny, J.S., and Tate, C.M., 1997, Concentration, distribution, and comparison of selected trace elements in bed sediment and fish tissue in the South Platte River Basin, 1992–93: Archives of Environmental Contamination and Toxicology, v. 32, p. 246–259.

Horowitz, A.J., 1991, A primer on sediment-trace element chemistry: Lewis Publishers, Boca Raton, Florida, 136 p.

Kroening, S.E., Fallon, J.D., and Lee, K.E., 2000, Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin—Trace elements in streambed sediment and fish livers 1995–96: U.S. Geological Survey Water-Resources Investigations Report 00–4031, 26 p.

MacDonald, D.D., Ingersoll, C.G., and Berger, T.A., 2000, Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems: Archives of Environmental Contamination and Toxicology, v. 39, p. 20–31.

National Park Service, 1983, Denali National Park and Preserve—Kantishna Hills/Dunkle Mine, Alaska: Draft environmental impact statement, 215 p.

Nelson, G.L., 1985, Results of test drilling and hydrogeology of Capps coal field, Alaska: U.S. Geological Survey Water-Resources Investigations Report 85–4114, 23 p.

Rice, K.C., 1999, Trace-element concentrations in streambed sediments across the conterminous United States: Environmental Science and Technology, v. 33 no. 15, p. 2499–2504

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.

Silberling, N.L., Jones, D.L., Monger, J.W.H., Coney, P.J., Berg, H.C., and Plafker, G., 1994, Lithotectonic terrane map of Alaska and adjacent parts of Canada, *in* Plafker, G., and Berg, H.C., eds., The geology of Alaska, Volume G-1, *in* The Geology of North America: The Geological Society of America, plate 3, 1 sheet, scale 1:7,500,000.

U.S. Environmental Protection Agency, 1994, Water quality standards handbook (2d ed.): U.S. Environmental Protection Agency, EPA–823-B-94-005-B, appendix P.

U.S. Geological Survey, 2000, Water resources data—Alaska—Water year 1999: U.S. Geological Survey Water-Data Report AK–99, 508 p.

Van Derveer, W.D., and Canton, S., 1997, Selenium sediment toxicity thresholds and derivation of water-quality criteria for freshwater biota of western streams: Environmental Toxicology and Chemistry, v. 16, p. 1260–1268.

Velz, C.J., 1984, Applied stream sanitation (2d ed.): John Wiley & Sons, New York, 619 p.

Waythomas, C.F., Miller, T.P., and Begét, J.E., 2000, Record of late Holocene debris avalanches and lahars at Iliamna Volcano, Alaska: Journal of Volcanology and Geothermal Research, v. 104, p. 97–130.

Frenzel —**Priority-Pollutant Trace Elements in Streambed Sediments of the Cook Inlet Basin, Alaska, 1998–2000** — Water-Resources Investigations Report 02-4163

USGS

Printed on recycled paper