Occurrence and Distribution of Trace Elements in Snow, Streams, and Streambed Sediments, Cape Krusenstern National Monument, Alaska, 2002-2003

By Timothy P. Brabets

Prepared in cooperation with the National Park Service

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Contents

Figures

Tables

Tables—Continued

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton, short (2,000 lb)	0.9072	megagram (Mg)

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

$$°C=(°F-32)/1.8$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations used in this Report

CAKR—Cape Krusenstern National Monument
DENA—Denali National Park and Preserve
LACL—Lake Clark National Park and Preserve
NAWQA—National Water-Quality Assessment Program
Al—Aluminum
As—Arsenic
Ba—Barium
Be—Berylium
Bi—Bismuth
Ca—Calcium
Cd—Cadmium
Ce—Cerium
Co—Cobalt
Cr—Chromium
Cs—Cesium
Cu—Copper
Fe—Iron
Ga—Gallium
K—Potassium
La—Lanthanum
Li—Lithium
Mg—Magnesium
Mn—Manganese
Mo—Molybdenum
Na—Sodium
Nb—Neodymium
Ni—Nickel
P—Phosphorus
Pb—Lead
Rb—Rubidium
Sb—Antimony
Sc—Scandium
Sr—Strontium
Th—Thorium
Tl—Thallium
Ti—Titanium
U—Uranium
V—Vanadium
Y—Yttrium
Zn—Zinc

Mapping Sources

Figures 1, 3 ,4

Base map modified from U.S. Geological Survey 1:63,360 State base maps.

U.S. Geological Survey Digital Line Graphs published at 1:63,360.

Publication projection is Albers Equal Area.

Standard parallels are 55º00´ and 65º00´ , central meridian—154º00´, latitude of projection origin 50º00´.

Occurrence and Distribution of Trace Elements in Snow, Streams, and Streambed Sediments, Cape Krusenstern National Monument, Alaska, 2002-2003

By Timothy P. Brabets

ABSTRACT

Cape Krusenstern National Monument is located in Northwest Alaska. In 1985, an exchange of lands and interests in lands between the Northwest Alaska Native Association and the United States resulted in a 100-year transportation system easement for 19,747 acres in the monument. A road was then constructed along the easement from the Red Dog Mine, a large zinc concentrate producer and located northeast of the monument, through the monument to the coast and a port facility. Each year approximately 1.3 million tonnes of zinc and lead concentrate are transported from the Red Dog Mine via this access road. Concern about the possible deposition of cadmium, lead, zinc and other trace elements in the monument was the basis of a cooperative project with the National Park Service.

Concentrations of dissolved cadmium, dissolved lead, and dissolved zinc from 28 snow samples from a 28 mile by 16 mile grid were below drinking water standards. In the particulate phase, approximately 25 percent of the samples analyzed for these trace elements were higher than the typical range found in Alaska soils. Boxplots of concentrations of these trace elements, both in the dissolved and particulate phase, indicate higher concentrations north of the access road, most likely due to the prevailing southeast wind.

The waters of four streams sampled in Cape Krusenstern National Monument are classified as calcium bicarbonate. Trace-element concentrations from these streams were below drinking water standards. Median concentrations of 39 trace elements from streambed sediments collected from 29 sites are similar to the median concentrations of trace elements from the U.S. Geological Survey's National Water-Quality Assessment database. Statistical differences were noted between trace-element concentrations of cadmium, lead, and zinc at sites along the access road and sites north and south of the access road; concentrations along the access road being higher than north or south of the road. When normalized to 1 percent organic carbon, the concentrations of these trace elements are not expected to be toxic to aquatic life when compared to criteria established by the Canadian government and other recent research.

INTRODUCTION

Cape Krusenstern National Monument (CAKR) is located in Northwest Alaska, approximately 450 miles northwest of Fairbanks and 10 miles northwest of Kotzebue (fig. 1). The monument is bordered by the Chukchi Sea on the west and Kotzebue Sound on the south. To the north and east are the river drainages of the Wulik and Noatak Rivers. CAKR was established in 1978 by presidential proclamation and designated in the 1980 Alaska National Interest Lands and Conservation Act (ANILCA). Section 201 (3) of ANILCA specifies that "The monument shall be managed for the following purposes, among others…to protect habitat for population of birds, other wildlife, and fish resources."

In 1985, an exchange of lands and interests in lands between the Northwest Alaska Native Association (NANA) and the United States resulted in a 100-year transportation system easement for 19,747 acres in the monument. The easement spans approximately 25 miles of the monument. An access road was then constructed along the easement from the Red Dog Mine, located northeast of the monument, through the monument to the coast and a port facility (fig. 1).

Each year approximately 1.3 million tonnes of zinc/lead concentrate are transported from the Red Dog Mine to the port site where it is then shipped to market. Although subsistence activities (the traditional gathering of foods such as berries, birds, mammals, and fish by the local population) are not allowed along the access road corridor, there are still environmental concerns that zinc/lead/cadmium concentrates may be deposited on tundra or in streams and incorporated into the natural food web outside the road corridor. Throughout the operating years of the Red Dog Mine (from 1991 to the present), metal concentrates have been deposited in CAKR either by infrequent truck accidents (fig. 1) or by fugitive dust that blows off the trucks as they travel along the port access road. Improvements made to the trucks, and loading/off loading facilities in 2001 have reduced fugitive dust emissions.

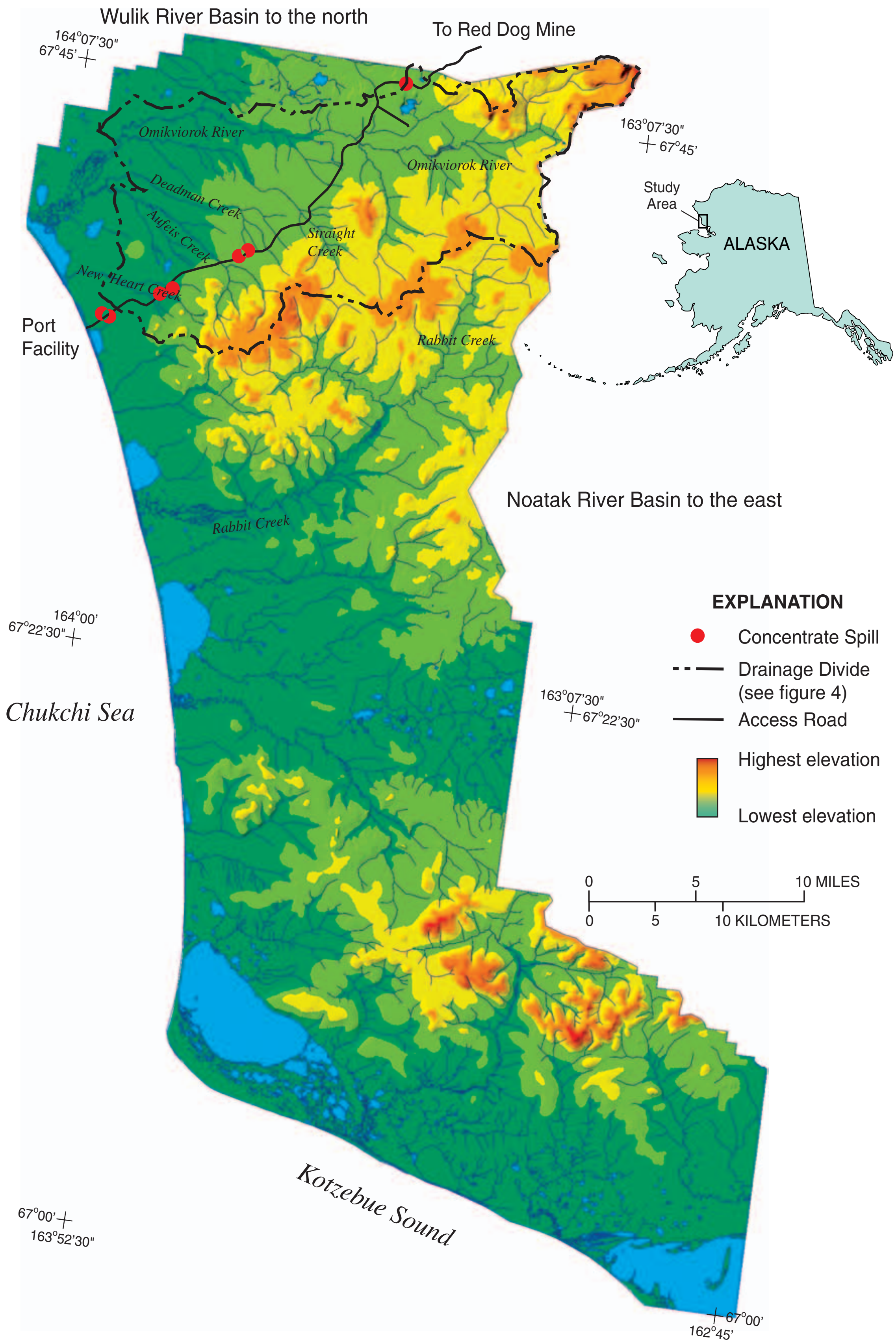
Northwest Alaska is home to about 6,000 people, living in 11 villages, who have traditionally obtained their food supply by hunting and fishing. If water-quality of streams and rivers that are part of the local ecosystem are degraded, it constitutes a potential hazard to residents and wildlife. Collection of water-quality data in CAKR would (1) help determine if the ore concentrate that has been deposited along the road from truck accidents or fugitive dust has affected water quality in nearby streams and (2) establish a baseline of water-quality data from which changes—either anthropogenic or natural—can be measured in future years.

Purpose and Scope

This report summarizes the results of a cooperative study by the National Park Service (NPS) and the U.S. Geological Survey (USGS) to study the water quality of streams located in CAKR near the port access road. The purpose of this study was to: (1) determine if deposition of ore concentrate in CAKR has affected water quality in nearby streams, and (2) establish a water-quality data base for this area of CAKR.

Acknowledgments

The author gratefully acknowledges Teck-Cominco, particularly John Martinisko and Sam Hill, for allowing the USGS to stage its field operations from the Red Dog Mine. Sam Troxel, a volunteer for the NPS, assisted in the collection and processing of the streambed sediment sam-



Fiugre 1. Location of concentrate spill sites within Cape Krusenstern National Monument, Alaska

ples in 2003. The NPS also provided helicopter support for fieldwork in 2003.

DESCRIPTION OF STUDY AREA

CAKR is predominantly a series of moderately sloping hills in the Brooks Hills Ecoregion (Nowacki and others, 2001). Vegetation includes primarily low brush and muskeg, with sparse willows and grasses (fig. 2) (Markon and Wesser, 2000). The area is within the zone of continuous permafrost and is characterized by a semi-arid arctic climate with an average July air temperature of 52 ºF and an average February temperature of –8°F. Mean annual precipitation is 10.1 inches with a mean annual snowfall of 57 inches. The growing season for the area as a whole is generally from mid-May to late August, with initial green-up beginning about mid-May in the southern part to mid-June in the northern part (Markon and others, 1995). Soils consist of loamy, near-level to rolling Histic Pergelic Cryaquepts (cold, wet soils with a thick organic layer and minimal weathering) in low coastal areas along the western and southern coasts to more gravelly Pergelic Cryaquepts or Pergelic Cryorthents (cold wet soils with a thin organic layer and a minimal to small amount of leaching) in the central and northern lowlands and uplands (Rieger and others, 1979).

Bedrock of the study area consists of an east-west-trending fold and thrust belt of Paleozoic and Mesozoic rocks that extends along the entire western and central Brooks Range (Beikman, 1980). Upper Paleozoic sedimentary rocks within this belt host three stratiform massive sulfide and barite mineral deposits and occurrences: the Drenchwater deposit, the Lik deposit, and the Red Dog deposit (Kelly, 1995). The Red Dog deposit is the largest of these deposits. The dominant minerals are sphalerite (zinc sulfide), silver-rich galena (lead sulfide), pyrite (iron sulfide), and marcasite (iron sulfide). Sulfide mineralization at all three deposits is hosted dominantly by black carbonaceous shale and chert of the Mississippian and Pennsylvanian Kuna Formation of the Lisburne Group.

There are several small watersheds and one mid-size watershed within the study area (fig. 1). The largest basin is the Omikviorok River (146 mi^2) and the remaining watersheds range from about 10 mi^2 to 25 mi^2. Since most of northwest Alaska is underlain by continuous permafrost, streams generally approach zero flow during the winter and any flow is derived from springs. Most of the annual runoff from these streams is in June due to snowmelt, with additional high flows in July through September due to rainfall. Runoff from these streams during the summer is characterized by rapid increase and decrease in flow due to the presence of permafrost.

METHODS OF DATA COLLECTION AND ANALYSIS

To accomplish the objectives of the study, data were collected both during the winter season and during the open-water season. In winter, streams located in the study area have little or no flow. It was felt that the water quality of the snow would be similar to the water quality of a stream during snowmelt runoff. In addition, the water quality of the snow samples can indicate the presence or absence of fugitive dust throughout the study area. For the snow sampling, a 16-mile (north/south) by 28-mile (east/west) grid was created with 4 mi^2 grid cells. Snow samples were collected at the center of each of the 28 cells at the time of maximum or near maximum snowpack, April 2002 (fig. 3, table 1).

Figure 2. Camp Krusentern National Monument. Topography is predominantly moderately sloping hills. Vegetation is primarily low brush. Photograph by T.P. Brabets, U.S. Geological Survey.

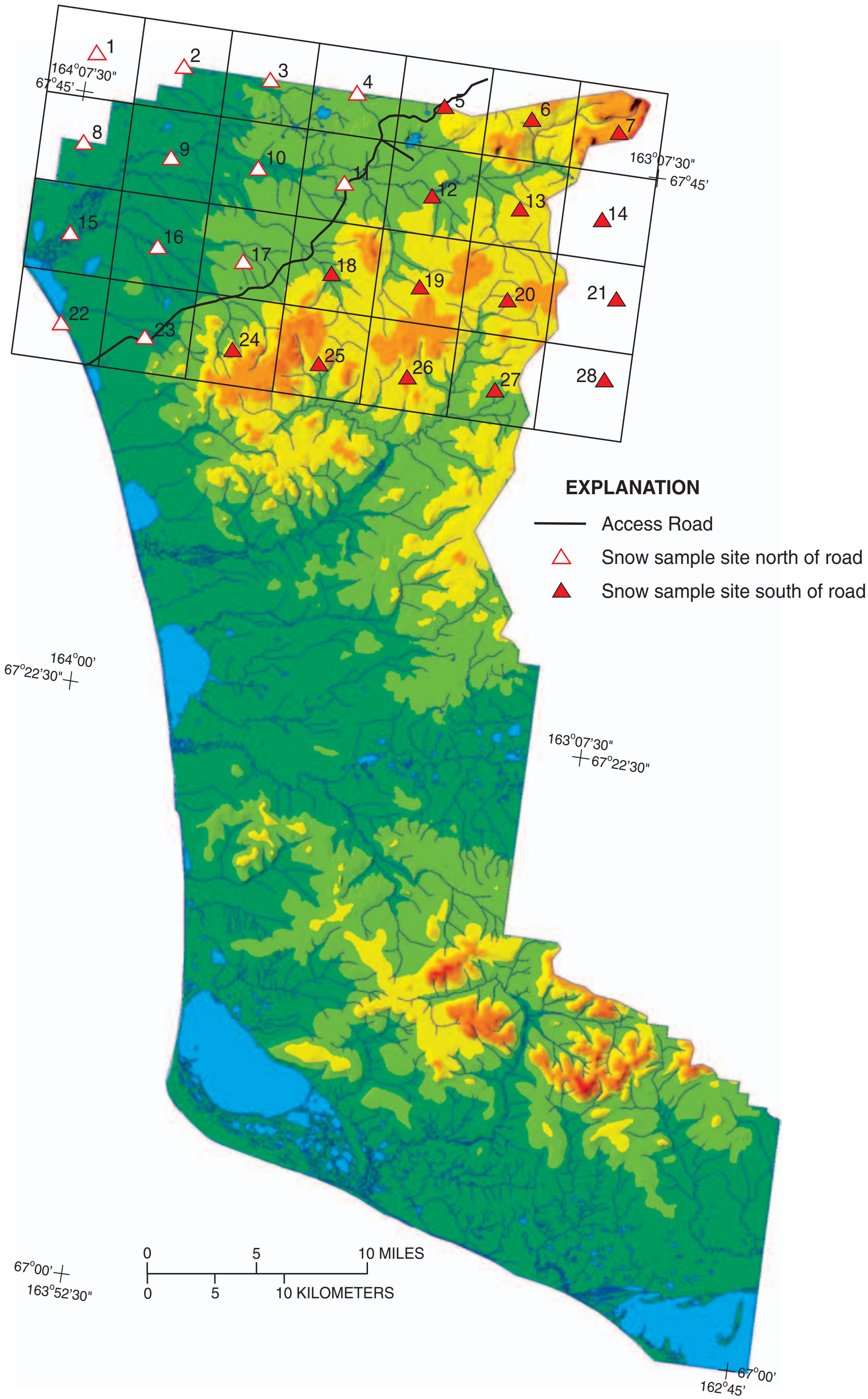


Figure 3. Grid layout and snow sampling sites, Cape Krusenstern National Monument, Alaska

Table 1. Locations of snow sampling sites, Cape Krusenstern National Monument, Alaska

Site number	Latitude/longitude	Watershed
1	67º 46´32″ /164º 06´ 42″	Wulik River
2	67º 46´ 32″ /163º 57´ 37″	Wulik River
3	67º 46´ 32″ /163º 48´ 38″	Wulik River
4	67º 46´ 32″ /163º 39´ 37″	Wulik River
5	67º 46´ 32″ /163º 30´ 31″	Wulik River
6	67º 46´ 32″ /163º 21´ 26″	Omikviorok River
7	67º 46´ 31″ /163º 12´ 25″	Omikviorok River
8	67º 43´ 05″ /164º 06´ 42″	Imikruk Creek
9	67º 43´ 02″ /163º 57´ 36″	Omikviorok River
10	67º 43´ 08″ /163º 48´ 35″	Omikviorok River
11	67º 43´ 05″ /163º 39´ 38″	Omikviorok River
12	67º 43´ 05″ /163º 30´ 32″	Omikviorok River
13	67º 43´ 05″ /163º 21´ 26″	Omikviorok River
14	67º 43´ 08″ /163º 12´ 56″	Noatak River
15	67º 39´ 36″ /164º 06´ 42″	Omikviorok River
16	67º 39´ 36″ /163º 57´ 37″	Aufeis Creek
17	67º 39´ 33″ /163º 48´ 45″	Deadman Creek
18	67º 39´ 36″ /163º 39´ 38″	Straight Creek
19	67º 39´ 36″ /163º 30´ 31″	Omikviorok River
20	67º 39´ 36″ /163º 21´ 26″	Rabbit Creek
21	67º 40´ 14″ /163º 10´ 25″	Noatak River
22	67º 36´ 10″ /164º 06´ 17″	New Heart Creek
23	67º 36´ 08″ /163º 57´ 37″	New Heart Creek
24	67º 36´ 10″ /163º 48´ 34″	Aufeis Creek
25	67º 36´ 08″ /163º 39´ 39″	Rabbit Creek
26	67º 36´ 08″ /163º 30´ 31″	Rabbit Creek
27	67º 36´ 08″ /163º 21´ 28″	Rabbit Creek
28	67º 37´ 12″ /163º 10´ 33″	Noatak River

Snow samples were collected following methods developed by Snyder-Conn and others (1997). At each site, an aluminum shovel was used to dig a trench to expose a vertical snow wall. After the trench was completed, a pre-cleaned rectangular polyethylene scoop was used to trim a 2-4 inch layer away from the trench wall to remove snow that had contacted the aluminum shovel. Snow was then collected from the excavated face of the wall, with the polyethylene scoop, by removing a rectangular vertical core which extended the entire depth of the snowpack. Snow was placed in pre-cleaned, 13 inch x 18 inch Teflon bags. These bags were pre-cleaned at the USGS National-Water Quality Laboratory (NWQL) in Lakewood, Colorado: the inside and outside of each bag was leached with 5 percent nitric acid for 48 hours at 25 °C, thoroughly rinsed with deionized water, air dried, and individually packaged inside two similarly cleaned polyethylene bags. All bags were cleaned and packaged inside a Class-100 clean room equipped with high-efficiency particulate filters. Samples were kept frozen after collection, packed with dry ice in insulated coolers, and then shipped to the NWQL. At the NWQL, the snow was melted in the Class-100 clean room and then filtered through a 45-µm filter. The filtered water and the particulates on the filter were then analyzed for trace elements.

A Perkin-Elmer Model 6000 Inductively Coupled Plasma—Mass Spectrometer (ICP-MS) was used for the determination of major and trace-element concentrations in the samples. The ICP-MS instrument was calibrated using three commercial multi-element aqueous standards, plus two aqueous standards prepared in the NWQL, and one surface-water standard reference material (T-143) prepared and certified by the USGS Water Resources Division. For quality control purposes, the instrument calibration was checked at the beginning and at the end of a single analytical run needed for the entire sample set using two National Institute of Standards and Technology standard reference solutions (NIST 1640 and NIST 1643d).

For the open-water season, efforts were concentrated on six watersheds that are bisected by the access road (fig. 4, table 2). The largest

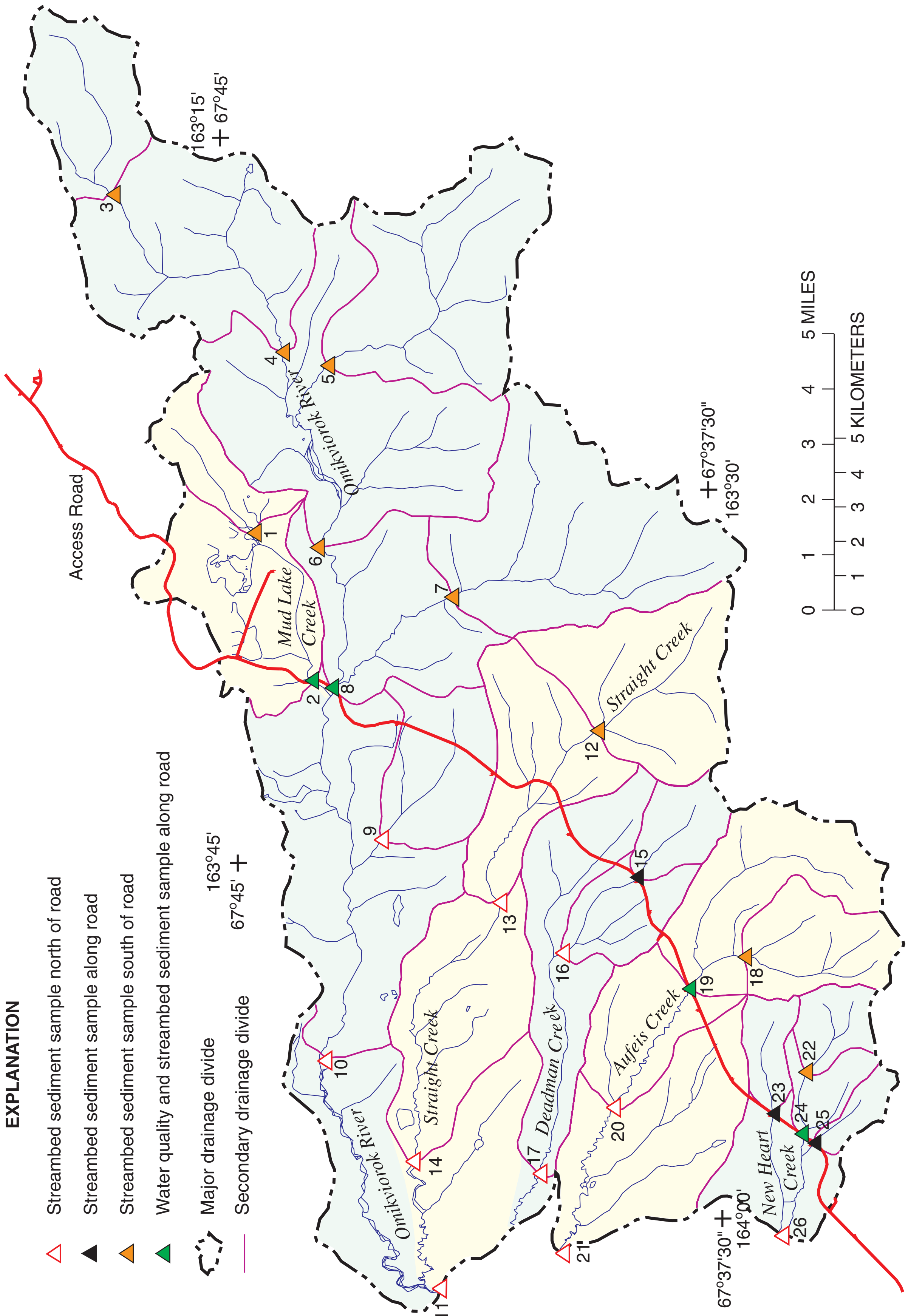


Figure 4. Location of water quality and streambed sediment sampling sites.

Table 2. Locations of water quality and streambed sediment sampling sites, Cape Krusenstern National Monument, Alaska

[area in square miles]

Site number	Latitude/longitude	Station name	Area
1	67º44´37˝/163º31´25˝	Mud Lake Creek 3.4 miles above Port Access Road near Kivalina	2.8
2	67º43´46˝ /163º37´36˝	Mud Lake Creek at Port Access Road near Kivalina	10.4
3	67º46´41˝ /163º17´18˝	North Branch North Fork Omikviorok River 9 miles above Port Access Road near Kivalina	5.4
4	67º44´06˝ /163º23´59˝	North Fork Omikviorok River 6.5 miles above Port Access Road near Kivalina	17.2
5	67º43´24˝ /163º24´35˝	South Branch North Fork Omikviorok River 6.5 miles above Port Access Road near Kivalina	11.5
6	67º43´38˝ /163º32´05˝	North Fork Omikviorok River 2.6 miles above Port Access Road near Kivalina	44.5
7	67º41´33˝ /163º34´15˝	South Fork Omikviorok River 2.5 miles above Port Access Road near Kivalina	13.9
8	67º43´26˝ /163º37´59˝	Omikviorok River at Port Access Road near Kivalina	66.4
9	67º42´44˝ /163º44´11˝	Omikviorok River Tributary 2.3 miles below Port Access Road near Kivalina	5.1
10	67º43´41˝ /163º53´15˝	Omikviorok River 7.0 miles below Port Access Road near Kivalina	82.4
11	67º41´57˝ /164º02´43˝	Omikviorok River 5.5 miles above mouth near Kivalina	146
12	67º39´19˝ 163º39´53˝	Straight Creek 1 mile above Port Access Road near Kivalina	8.4
13	67º40´54˝ /163º46´52˝	Straight Creek 4 miles below Port Access Road near Kivalina	15.2
14	67º42´20˝ /163º57´28˝	Straight Creek 7.7 miles below Port Access Road near Kivalina	23.6
15	67º38´45˝ /163º45´56˝	Deadman Creek at Port Access Road near Kivalina	2.3
16	67º39´56˝ /163º49´00˝	Deadman Creek 2.5 miles below Port Access Road near Kivalina	5.2
17	67º40´21˝ /163º58´03˝	Deadman Creek 6.5 miles below Port Access Road near Kivalina	12.8
18	67º37´05˝ /163º49´18˝	Aufeis Creek 0.8 miles above Port Access Road near Kivalina	4.4
19	67º37´56˝ /163º50´39˝	Aufeis Creek at Port Access Road near Kivalina	11.3
20	67º39´11˝ /163º55´23˝	Aufeis Creek 2.7 miles below Port Access Road near Kivalina	15.5
21	67º40´01˝ /164º01´21˝	Aufeis Creek 5.5 miles below Port Access Road near Kivalina	24.4
22	67º36´10˝ /163º54´04˝	New Heart Creek 0.8 miles above Port Access Road near Kivalina	1.8
23	67º36´41´/163º55´45˝	North Fork New Heart Creek at Port Access Road near Kivalina	1.6
24	67º36´12˝ /163º56´40˝	New Heart Creek at Port Access Road near Kivalina	3.3
25	67º36´03˝ /163º56´59˝	South Fork New Heart Creek at Port Access Road near Kivalina	1
26	67º36´35˝ /164º00´46˝	New Heart Creek 2 miles below Port Access Road near Kivalina	9.7

watershed sampled was the Omikviorok River, which drains 146 mi^2 near its mouth and the smallest watershed was New Heart Creek, which drains 9.7 mi^2 near its mouth. Water samples were collected from four of these streams during the open-water season in 2002 to obtain general background water-quality information. Streambed-sediment samples were collected from seven sites in 2002 and from 19 sites in 2003 and analyzed for 39 trace elements.

Water samples collected from the streams were analyzed for field parameters, major ions and dissolved solids, nutrients, organic carbon, and trace elements. The field-collection and processing equipment used was made from Teflon, glass, or stainless steel to prevent sample contamination and to minimize analyte losses through adsorption. All sampling equipment was cleaned prior to use with a nonphosphate laboratory detergent and then rinsed with deionized water and finally by stream water just prior to sample collection. Depth-integrated water samples were collected across the stream by using the equal-width-increment method (Edwards and Glysson, 1988) and processed in the field using methods and equip¬ment described by Shelton (1994). Samples to be analyzed for dissolved constituents were filtered through 0.45 -um capsule filters. Water samples were sent to the USGS NWQL for analysis using standard USGS analytical methods (Fishman and Friedman, 1989; Patton and Truitt, 1992; Fishman, 1993). A Yellow Springs Instrument meter was used to measure water temperature, dissolved-oxygen concentration, specific conductance, and pH at the time of sampling. Discharge measurements also were made at the time of sampling using methods outlined by Rantz and others (1982).

Because streams in northwest Alaska rapidly rise and fall during rainstorms due to the presence of permafrost, it is difficult to collect water-quality samples during rainfall events. Instead, streambed sediment samples were collected and analyzed for trace-element concentrations. Since these samples were collected from depositional areas, it was felt this sampling approach would provide some indication as to whether ore concentrate—either from ore spills or fugitive dust—had been ‘washed off’ from the access road and deposited in the streambed.

Streambed sediments were sampled from several depositional areas at each site. Sediments were collected from the surface of the streambed using Teflon tubes or Teflon coated spoons and composited in glass bowls (Shelton and Capel, 1994). Because the concentration of trace elements on streambed materials is strongly affected by the particle-size distribution of the sample, only the portion of the sample that was finer than 63-µm was analyzed. Stream water was used for sieving the trace-element sample through a 63-µm mesh. Water included in the trace-element sample was decanted after very fine-grained sediments had settled (about 24 hours). Arbogast (1990) describes laboratory procedures followed for processing streambed samples for trace-element analysis. Trace elements in streambed sediments were analyzed following a total digestion procedure.

The concentrations of various water-quality constituents from the snow, streams, and streambed sediments were evaluated in relation to established water-quality criteria. Boxplots were used to compare data south of the access road, along the access road, and north of the access road. Boxplots serve as a good statistical tool to (1) determine the center of distribution of data (median), (2) measure the variability of the data (the interquartile range), (3) gage the symmetry or skewness of the data (length of the whiskers) and (4) provide a general assessment about the presence of outliers. Kruskal-Wallis tests were used to test for statistically significant differences of data collected north of the access road, along the access road, and south of the access road. The terms “significantly lower than” and “significantly higher than” refer to whether or not the computed probability value is greater than or less than the alpha level of 0.05. Trace-element concentrations in streambed sediments were compared with those collected by the USGS, National Water-Quality Assessment (NAWQA) program, of which one study unit (Cook Inlet Basin) is located in Alaska, and with guidelines established by the Canadian Council of Ministers of the Environment.

TRACE ELEMENTS IN SNOW

Snow sampling took place during April 18-20, 2002. For the 28 sampling sites, snow cover depth ranged from 6 inches to 50 inches, with most depths between 6 and 12 inches. Concentrations in the filtered samples varied between 0.03 and 1.0 µg/L for cadmium, 0.12 µg/L and 8.7 µg/L for lead, and 1.3 and 43.2 µg/L for zinc (table 3). Median concentrations for these elements were 0.12 ug/L, 0.86 µg/L, and 3.9 µg/L respectively (table 4). All concentrations were below the drinking water standards for cadmium (5 µg/L), lead (15 µg/L), and zinc (2,000 µg/L). The highest concentration of dissolved cadmium was found at site 5, just south of the access road (fig. 3). The highest concentration of dissolved lead was found at site 22 and the highest concentration of dissolved zinc was found at site 23, just north of the access road (fig. 3). Boxplots of concentrations of dissolved cadmium, dissolved lead, and dissolved zinc (fig. 5) indicate that concentrations of these trace elements are higher north of the access road, probably reflecting the effects of the prevailing southeast wind.

Concentrations of trace elements in snow samples in the particulate phase varied between 0.39 and 52.4 ppm for cadmium, between 22.9 and 2,480 ppm for lead, and between 91.8 and 4,520 ppm for zinc (table 5). The highest concentration of cadmium was found at site 4 and the highest concentrations for lead and zinc were found at site 7. Median concentrations of these elements were 6.5 ppm, 290 ppm, and 870 ppm, respectively (table 6). Compared with the range of concentrations of trace elements found in soils of Alaska, approximately 25 percent of the lead and zinc values were higher than the range documented by Gough and others (1988) (table 6). Gough and others (1988) did not report values for cadmium. Boxplots of the concentrations of these trace elements in the particulate phase were similar to the dissolved concentrations and showed higher concentrations north of the access road, again reflecting the effects of the prevailing southeast wind (fig. 5).

It should be noted that the replicate snow samples showed considerable variability when compared to the concentrations of the environmental sample. The variability may be due to contamination by sampling and/or differences in the snow that was collected for the environmental sample and the snow collected for the replicate. It also should be noted that based on this snow sampling, concentrations of cadmium, lead, and zinc, both in the dissolved and particulate phase, compared with drinking water standards and Gough's data—appear to be at background levels in the Noatak River Basin and the Rabbit Creek Basin (sites 14, 21, 25-28).

TRACE ELEMENTS IN STREAMS

In the summer of 2002, water samples were collected at streams that crossed the access road (fig. 4). Four streams were sampled: Mud Lake Creek (site 2), Omikviorok River (site 8), Aufeis Creek (site 19), and New Heart Creek (site 24). Samples were collected about 50 feet downstream of the road. Flow at the time of sampling would be characterized as average or below average and ranged from 0.2 ft^3/s to 7.8 ft^3/s. Water samples were collected for analysis of nutrients, organic carbon, and major ions, and the dissolved trace elements cadmium, chromium, copper, lead, and zinc.

Concentrations of all water-quality constituents (table 7) were below drinking-water standards. The water of the four streams was classified as calcium bicarbonate, with New Heart Creek and Aufeis Creek containing slightly more

Table 3. Concentrations of dissolved trace elements in snow samples collected in Cape Krusenstern National Monument, April 2002

[all values in micrograms per liter; * denotes replicate sample; Al, aluminum; Cd, cadmium; Cu, copper; Cr, chromium; Fe, iron; Pb, lead; Zn, zinc]

Site number.	Watershed	Date	Time	Al	Cd	Cu	Cr	Fe	Pb	Zn
1	Wulik River	4/18/2002	1118	2.5	0.16	0.11	0.16	4.0	2.3	3.2
2	Wulik River	4/18/2002	1155	14.1	0.08	0.12	0.39	6.7	1.2	2.0
3	Wulik River	4/18/2002	1230	2.3	0.46	0.32	0.31	4.8	1.4	2.4
3*	Wulik River	4/18/2002	1235	9.8	0.09	0.17	0.05	11.7	1.1	3.0
4	Wulik River	4/20/2003	1653	29.2	0.55	0.28	0.11	36.5	3.2	8.1
5	Wulik River	4/19/2002	1650	6.7	1.0	0.22	1.1	6.7	1.3	5.8
6	Omikviorok River	4/19/2002	940	5.5	0.07	0.56	0.38	4.7	0.49	4.6
7	Omikviorok River	4/19/2002	1016	9.6	0.07	0.28	0.26	10.2	0.99	2.6
8	Imikruk Creek	4/18/2002	1045	1.9	0.10	0.12	0.28	4.1	1.4	2.2
9	Omikviorok River	4/18/2002	1426	13.2	0.16	0.20	0.21	20.7	2.9	4.5
10	Omikviorok River	4/18/2002	1333	4.9	0.09	0.20	0.18	7.2	0.92	3.0
11	Omikviorok River	4/20/2002	1611	45.4	0.48	0.80	0.42	123	0.58	14.6
12	Omikviorok River	4/20/2002	950	5.4	0.14	0.32	0.09	8.1	0.83	5.0
13	Omikviorok River	4/19/2002	1609	5.5	0.06	0.20	0.32	4.5	0.15	2.2
14	Noatak River	4/19/2002	1139	2.9	0.05	0.41	0.46	2.6	0.41	3.9
15	Omikviorok River	4/18/2002	1005	98.9	0.14	0.31	0.17	107	3.8	10.0
16	Aufeis Creek	4/18/2002	1456	11.3	0.10	0.17	0.40	11.1	0.65	5.0
17	Deadman Creek	4/18/2002	1554	18.9	0.22	0.57	0.60	42.2	1.5	14.9
18	Straight Creek	4/20/2002	1525	3.1	0.15	0.26	0.25	3.9	0.59	3.4
18*	Straight Creek	4/20/2002	1530	4.0	0.18	0.28	0.33	5.0	0.81	3.3
19	Omikviorok River	4/20/2002	1021	10.0	0.52	0.35	0.08	11.3	0.71	11.4
20	Rabbit Creek	4/19/2002	1530	20.8	0.05	0.25	0.38	14.8	0.21	2.2
20*	Rabbit Creek	4/19/2002	1535	18.1	0.04	0.26	0.41	13.3	0.39	3.3
21	Noatak River	4/19/2002	1230	1.6	0.04	0.25	0.26	2.6	0.19	1.9
22	New Heart Creek	4/18/2002	850	31.1	0.21	0.29	0.05	43.4	8.7	18.5
23	New Heart Creek	4/18/2002	1720	6.8	0.54	0.52	0.56	35.0	5.4	43.2
23*	New Heart Creek	4/18/2002	1725	24.7	0.34	0.60	0.25	43.5	5.6	28.9
24	Aufeis Creek	4/18/2002	1640	13.3	0.08	0.19	0.05	14.8	0.46	2.1
25	Rabbit Creek	4/20/2002	1446	4.0	0.09	0.33	0.46	8.2	0.90	3.9
26	Rabbit Creek	4/20/2002	1348	3.4	0.19	0.54	0.65	5.3	0.35	4.6
27	Rabbit Creek	4/20/2002	1104	3.9	0.05	0.14	0.26	5.0	0.26	2.1
28	Noatak River	4/19/2002	1411	3.9	0.03	0.37	0.40	4.1	0.12	1.3

Table 4. Summary statistics of concentrations of dissolved trace elements in snow samples collected in Cape Krusenstern National Monument, April 2002

[all values in micrograms per liter]

Constituent	Minimum	Percentile[1]					Maximum
		10	25	50 (median)	75	90	
Aluminum	1.6	2.3	3.7	6.1	13.7	31.1	98.9
Cadmium	0.03	0.05	0.07	0.12	0.22	0.54	1.0
Chromium	0.05	0.08	0.17	0.29	0.41	0.60	1.1
Copper	0.11	0.12	0.20	0.28	0.36	0.56	0.80
Iron	2.6	3.9	4.6	7.6	17.8	43.4	123
Lead	0.12	0.19	0.43	0.86	1.5	3.8	8.7
Zinc	1.3	2.0	2.2	3.9	7.0	14.9	43.2

[1] Percentage of samples (10, 25, 50, 75, 90) equal to or below the indicated concentration for a particular constituent

sulfate than Mud Lake Creek and the Omikviorok River (fig. 6). Nitrogen and phosphorus concentrations were low at all sites as were the dissolved trace elements analyzed. Mud Lake Creek, which drains Mud Lake, contained the highest concentration of dissolved organic carbon. Water was clear at the time of sampling, indicating little or no suspended sediment. Based on the general hydrology of the area, most of the annual runoff or flow is in late May or early June. Most likely, during high flow, there is more material in suspension.

TRACE ELEMENTS IN STREAMBED SEDIMENTS

Streambed sediments at 26 sites were collected and analyzed for 39 trace elements. Seven sites were sampled in 2002 and 19 sites were sampled in 2003 (fig. 4, table 2). These sites were chosen to obtain a good spatial distribution throughout the study area. Sites were chosen south of the access road, along the access road, and north of the access road. Similar to 2002, flow conditions at the time of sampling in 2003 were at average to low flow.

Of the 39 trace elements analyzed (tables 8-9), about one-third were found to be at the same concentration at all sites. Most of the trace elements do not have a corresponding drinking water or aquatic life standard. Thus, to provide a general comparison, the median concentrations of the CAKR data were compared to the median concentrations of the NAWQA program data set, which consists of about 1,000 samples collected throughout the contiguous United States, Alaska, and Hawaii. Of these samples, about 250 samples represent reference or forested areas and about 80 samples represent hard rock mining sites (V. Cory Stephens, U.S. Geological Survey, written commun, 2004). The median concentrations of the CAKR data also were compared to the median concentrations of streambed sediments collected from two other national parks in Alaska for which data are available: Denali National Park and Preserve (DENA) and Lake Clark National Park and Preserve (LACL). These sites were part of the Cook Inlet Basin NAWQA study unit located in southcentral Alaska (Glass and others, 2004). The sites in DENA represent a spatial distribution of

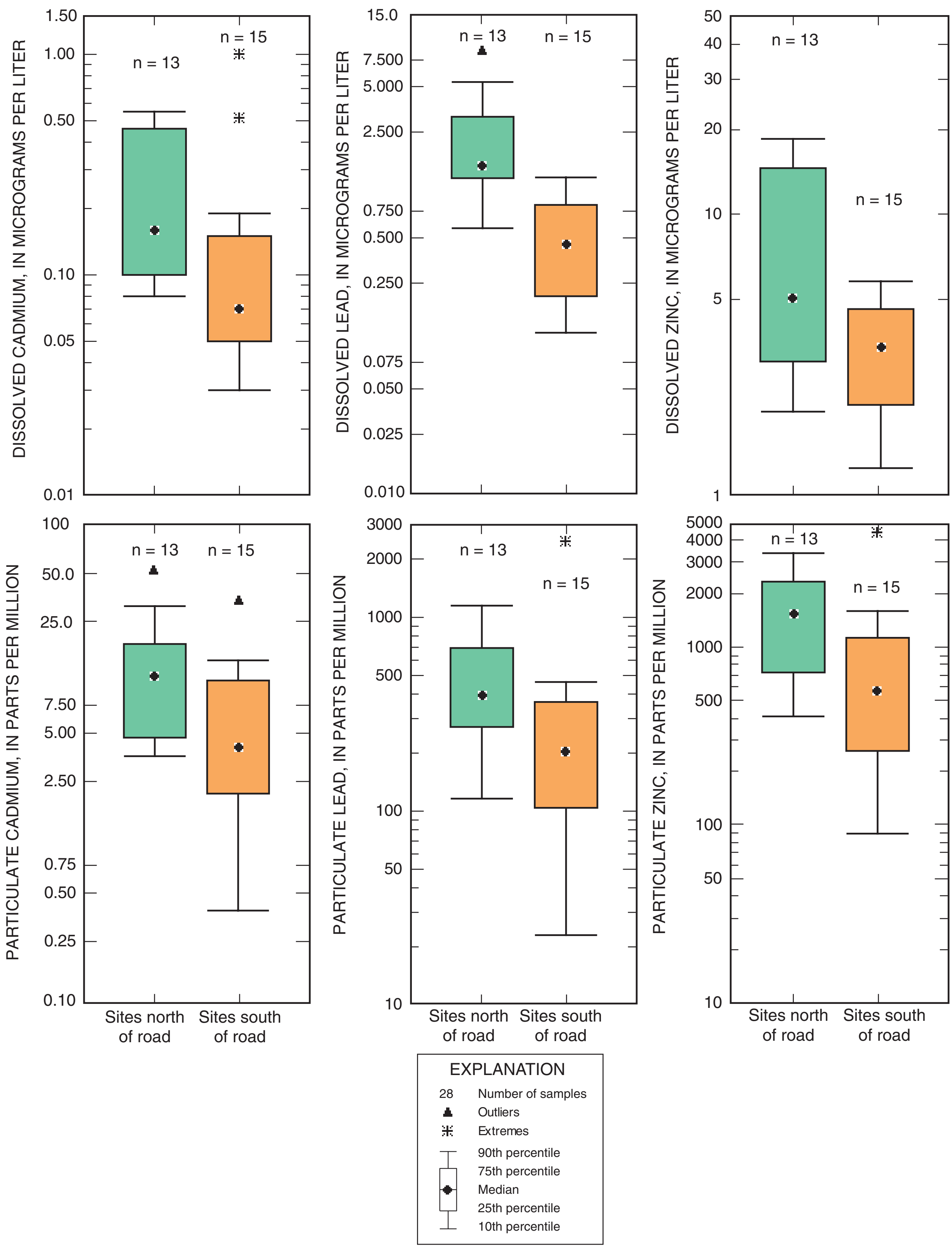


Figure 5. Boxplots of concentrations of dissolved and particulate cadmium, lead, and zinc from 28 snow samples collected in Cape Krusenstern National Monument, April 2002.

Table 5. Concentrations of major ions and trace elements in the particulate phase from snow samples collected in Cape Krusenstern National Monument, April 2002 —Continued

[all values in parts per million; * denotes replicate sample; <, less than; full names of trace elements given on page v]

Site no.	Watershed	Al	As	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr
1	Wulik River	95,300	39.8	2,470	2.0	1.9	1,990	26.0	94.1	23.0	2,400
2	Wulik River	73,200	23.4	1,900	0.52	1.6	< 100	18.1	80.6	16.6	3,180
3	Wulik River	39,300	13.8	1,290	0.22	0.30	1,320	11.3	40.0	10.6	178
3*	Wulik River	52,500	18.1	2,160	0.99	0.55	3,070	26.2	54.8	14.0	1,680
4	Wulik River	47,200	11.4	1,710	1.0	0.28	15,800	52.4	58.0	13.1	121
5	Wulik River	56,900	14.7	1,530	0.73	0.19	12,100	11.5	68.6	14.2	1,980
6	Omikviorok River	70,000	16.3	862	1.9	0.94	3,620	3.6	72.2	13.7	966
7	Omikviorok River	237,000	214	6,120	< 0.03	< 0.06	< 100	33.5	252	46.7	48,600
8	Imikruk Creek	76,600	41.5	2,350	0.90	0.47	1,840	31.2	72.8	21.9	1,890
9	Omikviorok River	5340	5.2	295	< 0.03	< 0.06	771	3.6	6.4	1.7	1,290
10	Omikviorok River	11,200	3.4	628	0.22	< 0.06	2,710	6.1	13.7	3.3	506
11	Omikviorok River	70,800	16.0	1,740	2.9	0.26	7,770	6.2	94.4	20.8	363
12	Omikviorok River	21,700	7.1	542	0.38	0.24	3,520	7.7	19.2	5.0	77.9
13	Omikviorok River	43,200	11.6	517	0.84	0.27	748	4.0	41.8	8.9	1,610
14	Noatak River	60,100	11.9	1,090	< 0.03	0.06	< 100	4.1	55.0	12.1	3,290
15	Omikviorok River	59,000	29.7	1,460	2.0	0.85	5,950	11.8	71.4	13.0	114
16	Aufeis Creek	83,300	19.1	1,090	2.9	0.93	4,780	3.7	89.7	16.8	488
17	Deadman Creek	85,200	15.5	1,420	3.5	0.53	4,660	4.7	95.5	19.1	368
18	Straight Creek	55,700	28.5	1,540	0.85	0.80	< 100	14.3	55.3	13.6	2,790
18*	Straight Creek	60,300	27.9	1,510	0.80	0.64	<100	11.2	64.2	14.6	3,460
19	Omikviorok River	61,600	10.3	1,000	1.4	0.73	< 100	6.7	62.8	13.5	181
20	Rabbit Creek	37,800	8.7	278	1.2	0.45	986	0.39	40.9	6.8	703
20*	Rabbit Creek	8,800	2.1	69	0.3	0.13	555	0.16	8.1	1.6	115
21	Noatak River	21,400	10.1	539	0.55	0.35	< 100	2.1	18.5	6.0	1,720
22	New Heart Creek	5,820	2.1	199	0.11	0.06	353	4.0	6.1	1.5	23.0
23	New Heart Creek	74,400	11.8	1,730	2.9	0.25	5,380	13.0	89.4	18.4	309
23*	New Heart Creek	77,100	12.7	1,680	3.0	0.28	5,130	16.1	91.0	18.8	297
24	Aufeis Creek	43,500	10.8	481	1.7	0.57	582	1.5	47.6	9.3	108
25	Rabbit Creek	70,200	29.4	1,670	1.9	0.80	2,720	10.7	62.7	17.1	1,290
26	Rabbit Creek	2,690	1.1	104	< 0.03	0.16	4,450	1.0	2.6	0.72	153
27	Rabbit Creek	60,500	31.7	1,230	0.60	3.1	5,930	6.8	54.0	16.1	3,200
28	Noatak River	75,600	23.3	1,160	3.2	2.1	3,500	3.1	71.2	16.8	2,210

Site no.	Watershed	Cs	Cu	Fe	Ga	K	La	Li	Mg	Mn	Mo
1	Wulik River	11.1	72.8	60,600	25.1	26,800	49.4	70.6	21,000	561	10.3
2	Wulik River	8.8	40.1	45,400	18.4	21,000	41.2	53.2	17,300	445	6.7
3	Wulik River	4.1	81.7	25,500	10.4	11,200	20.5	33.6	10,100	268	6.3
3*	Wulik River	5.7	44.9	33,300	13.2	14,100	29.2	36.9	12,800	347	4.8
4	Wulik River	5.6	39.8	28,600	11.8	12,800	31.7	38.4	15,700	363	2.6
5	Wulik River	7.8	29.0	31,700	15.5	17,100	41.5	52.4	15,000	352	3.0
6	Omikviorok River	8.4	52.1	39,500	18.7	18,700	36.0	45.3	15,900	523	3.0
7	Omikviorok River	19.5	< 2	175,000	58.6	78,900	121	177	56,800	2,440	34.7
8	Imikruk Creek	9.2	71.1	52,700	21.4	23,200	37.7	53.1	15,800	466	7.0
9	Omikviorok River	0.50	< 2	4,280	1.3	3,650	3.0	4.7	2,070	1,320	1.6
10	Omikviorok River	1.2	7.9	7,460	3.2	4,050	7.1	8.5	3,250	428	0.87
11	Omikviorok River	10.4	41.9	45,600	18.3	21,700	47.5	59.8	11,000	359	1.4
12	Omikviorok River	2.2	19.3	13,300	5.6	5,980	9.6	14.8	5,270	181	1.6
13	Omikviorok River	5.1	24.3	24,700	11.3	12,000	20.7	27.7	10,400	605	2.2
14	Noatak River	6.3	36.2	37,100	15.4	16,900	28.1	35.3	12,800	389	4.6
15	Omikviorok River	7.3	39.8	34,000	15.6	16,200	35.0	43.7	11,800	346	2.3
16	Aufeis Creek	10.9	45.7	44,900	21.7	22,300	45.0	57.3	15,200	464	2.2
17	Deadman Creek	14.5	38.5	47,100	21.2	24,600	49.5	67.0	11,100	316	2.1
18	Straight Creek	6.6	21.4	34,500	14.4	15,500	27.6	37.7	10,700	399	6.3
18*	Straight Creek	7.4	19.5	39,200	16.1	16,900	27.3	42.2	11,900	453	6.1
19	Omikviorok River	6.6	29.2	36,500	16.6	16,700	31.7	43.5	12,600	392	3.0
20	Rabbit Creek	4.9	17.4	21,200	10.4	10,000	20.2	24.0	8,280	250	1.2
20*	Rabbit Creek	1.2	5.0	4,790	2.4	2,370	4.0	5.8	1,860	76	0.3
21	Noatak River	2.2	18.9	15,700	5.5	6,040	9.7	14.4	5,640	211	2.8
22	New Heart Creek	0.69	4.6	3,560	1.5	1,620	3.0	4.2	1,150	32.7	0.30
23	New Heart Creek	10.4	42.2	43,700	19.0	22,400	41.1	56.9	9,010	401	1.2
23*	New Heart Creek	10.6	45.4	46,100	19.4	22,600	44.4	56.7	8,820	445	1.4
24	Aufeis Creek	6.1	19.2	25,500	11.4	12,100	26.0	34.5	7,580	288	1.5
25	Rabbit Creek	8.9	62.2	44,400	18.7	20,300	29.8	49.3	13,900	529	4.2
26	Rabbit Creek	0.25	4.3	1,740	0.72	1,310	1.3	1.2	947	334	0.34
27	Rabbit Creek	8.1	35.4	41,100	19.5	18,000	27.2	36.5	17,500	491	7.7
28	Noatak River	9.0	43.1	45,600	18.6	20,900	35.8	42.0	18,100	515	5.2

Table 5. Concentrations of major ions and trace elements in the particulate phase from snow samples collected in Cape Krusenstern National Monument, April 2002 —Continued

Site No.	Watershed	Na	Nb	Ni	P	Pb	Rb	Sb	Sc	Sr	Th
1	Wulik River	1,0500	50	43.9	1,610	1,150	142	78.4	23.9	135	30.6
2	Wulik River	7,690	44	3.1	1,540	900	115	34.2	18.8	74.2	18.1
3	Wulik River	4,620	22	7.1	744	400	60.1	420	10.3	43.1	6.1
3*	Wulik River	5,800	17	24.6	943	811	76.0	106	12.3	65.9	7.0
4	Wulik River	3,570	14	45.5	924	428	73.5	311	10.5	65.6	5.8
5	Wulik River	2,330	23	19.8	1,550	464	99.4	179	14.4	54.7	10.7
6	Omikviorok River	6,520	20	28.8	890	247	102	314	14.2	90.8	7.8
7	Omikviorok River	11,000	180	< 0.3	16,000	2,480	385	619	157	< 0.8	141
8	Imikruk Creek	8,730	21	46.8	1,080	824	112	37.0	17.6	104	9.4
9	Omikviorok River	185	17	< 0.3	1,130	168	11.0	5.4	4.7	< 0.8	3.0
10	Omikviorok River	1,430	3.6	2.4	750	174	18.6	39.7	2.8	22.5	1.5
11	Omikviorok River	4,020	15	56.0	730	308	135	25.6	16.6	89.6	11.9
12	Omikviorok River	2,410	5.1	11.5	546	156	29.9	449	5.8	28.2	5.8
13	Omikviorok River	3,940	13	< 0.3	1,060	138	60.8	126	11.4	44.6	7.5
14	Noatak River	6,420	120	< 0.3	1,310	366	89.6	297	15.2	42.6	11.2
15	Omikviorok River	5,960	16	36.9	618	424	92.9	216	12.3	92.8	6.8
16	Aufeis Creek	6,550	20	43.4	751	272	129	137	17.1	107	11.2
17	Deadman Creek	3,440	18	60.7	773	325	158	9.9	17.8	88.3	12.2
18	Straight Creek	4,740	13	< 0.3	880	457	89.2	102	13.5	43.1	16.0
18*	Straight Creek	4,620	7	<0.3	890	363	92.2	125	12.0	41.6	10.5
19	Omikviorok River	6,900	12	10.7	579	203	94.0	683	9.8	61.6	5.5
20	Rabbit Creek	3,370	7.8	8.5	369	43.5	54.3	7.9	7.0	48.0	3.6
20*	Rabbit Creek	790	2.1	4.0	126	10.1	13.0	2.7	1.8	11.7	1.2
21	Noatak River	2,060	1.6	< 0.3	575	104	31.1	48.4	5.1	17.0	5.8
22	New Heart Creek	610	1.2	2.1	68.9	116	9.0	48.8	1.1	8.8	0.74
23	New Heart Creek	2,670	14	49.8	603	695	134	11.2	16.8	79.1	10.8
23*	New Heart Creek	2,720	17	50.7	664	735	134	10.4	17.2	84.8	13.0
24	Aufeis Creek	3,710	13	15.5	413	84.0	69.9	119	8.9	46.1	8.0
25	Rabbit Creek	6,810	15	39.2	695	362	105	106	14.8	96.8	8.8
26	Rabbit Creek	256	0.30	0.6	505	22.9	4.4	26.2	0.6	9.6	0.52
27	Rabbit Creek	5,910	5.8	3.2	1,380	265	93.3	48.5	12.3	68.4	5.5
28	Noatak River	7,600	19	14.8	992	195	110	51.3	14.4	93.7	6.4

Site No.	Watershed	Tl	Ti	U	V	Y	Zn
1	Wulik River	3.6	5,650	5.0	180	31.3	3,110
2	Wulik River	2.2	4,380	3.5	101	27.7	2,410
3	Wulik River	0.89	2,470	1.6	82.8	13.1	1,580
3*	Wulik River	1.5	3,250	3.4	89.5	19.4	3,070
4	Wulik River	1.1	2,810	3.3	96.2	23.0	2,190
5	Wulik River	1.1	2,910	4.0	99.6	28.1	1,640
6	Omikviorok River	0.89	3,960	2.1	94.0	23.6	530
7	Omikviorok River	1.2	16,200	2.6	422	87.5	4,520
8	Imikruk Creek	1.7	4,480	4.6	168	25.3	3,470
9	Omikviorok River	0.15	578	0.32	7.5	2.3	419
10	Omikviorok River	0.20	779	0.66	20.7	4.5	740
11	Omikviorok River	1.1	3,820	3.2	142	24.8	1,130
12	Omikviorok River	0.54	1,200	0.87	43.8	6.4	575
13	Omikviorok River	0.54	2,370	1.2	46.9	14.5	268
14	Noatak River	0.62	3,380	1.7	101	17.3	603
15	Omikviorok River	1.1	3,920	2.6	99.3	21.8	1,940
16	Aufeis Creek	1.1	4,620	3.0	127	27.1	676
17	Deadman Creek	1.7	4,250	3.4	161	24.9	920
18	Straight Creek	1.7	3,280	2.2	91.6	17.4	1,460
18*	Straight Creek	0.93	3,150	1.9	101.0	14.6	1,380
19	Omikviorok River	0.74	4,330	2.0	106	17.0	819
20	Rabbit Creek	0.33	2,210	1.1	47.5	13.8	94.1
20*	Rabbit Creek	0.10	488	0.25	11.6	2.8	28.2
21	Noatak River	0.23	1,130	0.79	47.8	7.3	247
22	New Heart Creek	0.14	350	0.29	11.4	2.1	680
23	New Heart Creek	1.4	3,540	3.0	138	21.6	2,400
23*	New Heart Creek	1.5	4,300	3.1	141	23.6	2,830
24	Aufeis Creek	0.77	2,780	1.5	76.5	13.1	292
25	Rabbit Creek	1.2	3,990	3.4	145	20.0	1,160
26	Rabbit Creek	< 0.08	157	0.11	4.7	0.94	91.8
27	Rabbit Creek	0.74	3,520	2.5	110	18.5	980
28	Noatak River	0.75	4,270	2.7	114	24.3	583

Table 6. Summary statistics for trace elements in the particulate phase for snow samples collected in Cape Krusenstern National Monument, April 2002 and ranges of trace elements found in Alaska soils.

[values in parts per million; --, no data available; GM, Geometric Mean; GD, Geometric Deviation; AM, Arithmetic Mean; full names of trace metal given on page v]

Constituent	Minimum	Percentile[1] 10	25	50 (median)	75	90	Maximum	GM[2]	GD[2]	AM[2]	Range[2]
Al	2,690	5,820	38,550	59,550	73,800	85,200	237,000	62,000	13,800	65,000	12,000-100,000
As	1.1	3.4	10.2	14.3	26.0	39.8	214	6.7	2.3	9.6	10-750
Ba	104	278	541	1195	1690	2350	6120	595	1.7	678	39-3,100
Be	0.03	0.03	0.30	0.88	2.0	2.9	3.5	1.5	1.5	1.4	1-7
Bi	0.06	0.06	0.22	0.40	0.82	1.9	3.1	--	--	--	--
Ca	101	101	468	2,350	4,720	7,770	15,800	13,000	26,100	20,000	400-100,000
Cd	0.39	1.5	3.7	6.5	12.4	31.2	52.4	--	--	--	--
Ce	2.6	6.4	40.5	60.4	76.7	94.4	252	28	1.8	33	5-180
Co	0.72	1.7	7.9	13.6	17.0	21.9	46.7	13.0	1.7	14.0	2-55
Cr	23.0	108	180	835	2,095	3,200	48,600	50.0	2.0	64.0	5-390
Cs	0.25	0.69	4.5	7.0	9.1	11.1	19.5	--	--	--	--
Cu	2.0	4.3	19.0	35.8	42.6	71.1	81.7	24.0	1.8	29.0	3-810
Fe	1,740	4,280	22,950	35,500	45,150	52,700	175,000	35,000	15,200	38,000	5,500-100,000
Ga	0.72	1.5	10.4	15.6	18.9	21.7	58.6	15.0	1.4	16.0	4-32
K	1,310	3,650	10,600	16,800	21,350	24,600	78,900	12,000	15,700	13,000	900-40,100
La	1.3	3.0	20.4	30.8	41.2	49.4	121	19.0	1.7	21.0	2-120
Li	1.2	4.7	25.9	40.2	53.2	67.0	177	26.0	1.7	30.0	2-130
Mg	947	2,070	7,930	11,450	15,750	18,100	56,800	9,800	18,400	12,000	1,300-70,400
Mn	32.7	211	325	396	503	605	2,440	510	20,700	670	200-4,000
Mo	0.30	0.87	1.6	2.7	5.8	7.7	34.7	0.9	2.5	1.3	2-15
Na	185	610	2,540	4,320	6,680	8,730	11,000	12,000	17,400	15,000	700-36,000
Nb	0.30	1.6	9.9	15.0	20.5	50.0	180	8.0	1.6	9.0	4-44
Ni	0.30	0.300	1.4	11.1	41.3	49.8	60.7	24.0	2.2	33.0	3-320
P	68.9	413	591	762	1,105	1,550	16,000	780	15,500	860	200-3,400
Pb	22.9	84.0	162	290	443	900	2480	12.0	1.7	14.0	4-310
Rb	4.4	11.0	57.2	93.1	114	142	385	--	--	--	--
Sb	5.4	9.9	35.6	90.2	257	449	683	--	--	--	--
Sc	0.60	2.8	8.0	12.9	16.7	18.8	157	13.0	1.7	14.0	2-39
Sr	8.8	17.0	43.1	67.0	93.3	104	135	159.0	1.9	198.0	21-760
Th	0.52	1.5	5.6	7.7	11.2	18.1	141	6.1	2.0	7.6	1.6-76
Ti	157	578	2,290	3,450	4,260	4,620	16,200	4,800	14,800	5,200	900-15,000
Tl	0.08	0.15	0.54	0.89	1.2	1.7	3.6	--	--	--	--
U	0.11	0.32	1.1	2.3	3.2	4.0	5.0	2.3	1.9	2.8	.22-45
V	4.7	11.4	47.7	99.5	133	168	422	112.0	1.7	129.0	11-490
Y	0.94	2.3	13.1	19.3	24.9	28.1	87.5	14.0	1.6	15.0	4-100
Zn	91.8	247	553	870	1790	3110	4520	70.0	1.6	79.0	20-2,700

[1] Percentage of samples (10, 25, 50, 75, 90) equal to or below the indicated concentration for a particular constitue

[2] from Gough and others, 1988

Table 7. Concentrations of water quality constituents measured in water samples collected from four streams in Cape Krusenstern National Monument, July 2002

[all values in mg/L unless otherwise noted; <, less than; E, estimated; *denotes replicate sample]

Station	Site number	Date	Time	Discharge (ft^3/s)	Dissolved oxygen	pH (units)	Specific conduc-tance	Water temperature (°C)	Calcium
Mud Lake Cr.	2	7/30/2002	1200	0.23	13.6	7.8	153	10.6	28
Omikviorok R.	8	7/28/2002	1015	7.8	11	7.1	177	10.5	28
Aufeis Creek	19	7/28/2002	1430	1.2	11.4	7.5	208	12.4	35
New Heart Cr	24	7/29/2002	1050	0.2	12	7.0	376	10.2	69
New Heart Cr*	24	7/29/2002	1055	0.2	12	7.0	376	10.2	69

Magnesium	Potassium	Sodium	Alkalinity	Bicarbonate	Chloride	Fluoride	Silica	Sulfate	Dissolved solids
3.7	0.16	1.1	78.0	101	1.9	<.1	3	1.2	95
6	0.23	1.6	90.0	117	1.8	<.1	4.7	6.7	108
5.4	0.23	1.2	80.0	104	1.4	<.1	2.8	26	126
9.5	0.32	1.8	160.0	208	2.8	<.1	3.2	45	245
9.5	0.33	1.8	160.0	208	2.7	<.1	3.1	45	248

Ammonia nitro-gen (NH_4)	Nitrogen (NH_4+Org)	Nitrogen (total)	Nitrogen (NO_2+NO_3)	Nitrogen (NO_2)	Phos-phorus dissolved	Phospho-rus ortho	Phospho-rus total	Dissolved organic carbon	Aluminum (µg/L)
<0.015	0.23	0.27	0.101	E0.002	0.005	<0.007	0.013	6.5	<20
<0.015	E0.08	E0.07	0.165	<.002	<0.004	<0.007	E0.003	1.9	<20
<0.015	E0.07	E0.07	0.034	<.002	E0.004	<0.007	0.005	1.8	<20
0.013	0.14	0.13	0.071	<.002	0.002	<0.007	0.002	3.5	<20
0.015	0.13	0.13	0.072	<.002	E0.003	<0.007	E0.003	3.5	<20

Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Manga-nese (ug/L)	Zinc (µg/L)
<0.04	<0.8	1.1	457	<0.08	36	1
E0.03	<0.8	0.6	E8	0.018	E2	2
<0.04	<0.8	0.6	<10	<0.08	E1.6	<1
0.05	<0.8	0.8	E6	E0.05	E2	5
0.05	<0.8	0.8	<10	<0.08	E1.7	5.0

the south side of the park (Brabets and Whitman, 2002) while the sites in LACL represent the upper Johnson River Basin (Brabets and Riehle, 2003).

Most median concentrations of the trace elements collected at CAKR were similar to the medians of the NAWQA reference/forested sites and the NAWQA hard rock mining sites (table 10). Concentrations of barium, chromium, nickel, vanadium, and zinc from the CAKR samples were notably higher than the NAWQA median concentrations from reference/forested sites, while concentrations of strontium were notably lower than the NAWQA median concentrations from reference/forested sites. Compared with the NAWQA

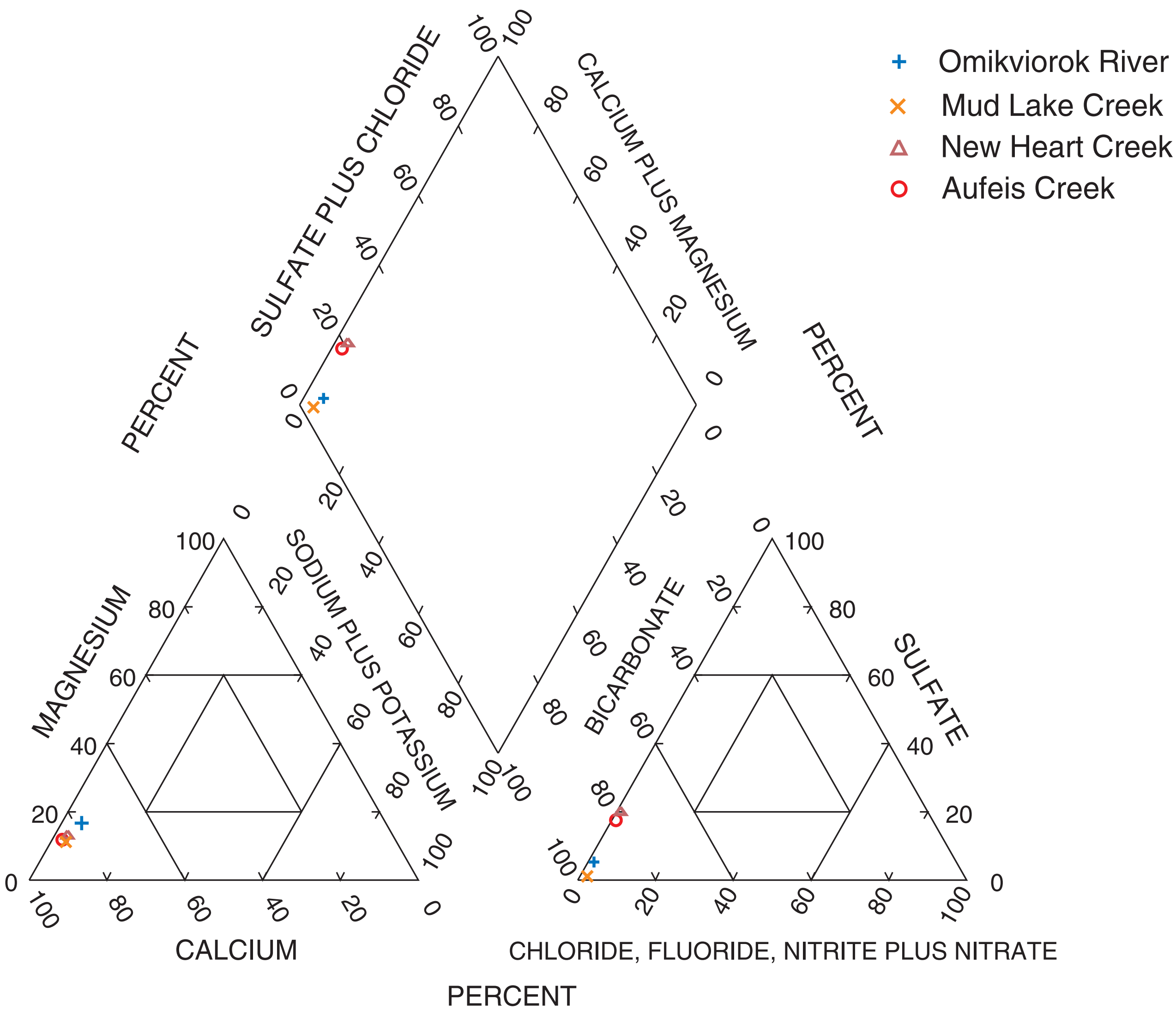


Figure 6. Trilinear diagram of water samples collected from Mud Lake Creek, Omikviorok River, Aufeis Creek, and New Heart Creek, July 2002.

hard rock mining sites, median concentrations of barium, chromium, nickel, and vanadium from CAKR were notably higher than the NAWQA hard rock mining sites, while median concentrations of lead, manganese, strontium, and zinc were notably lower than the NAWQA concentrations for hard rock mining sites.

Comparisons of the median trace-element concentrations between sites in CAKR, DENA, and LACL indicated the highest median concentrations of cadmium, lead, and zinc were from CAKR samples (fig. 7). Ranges in lead concentrations are similar between CAKR and DENA, while ranges in zinc are similar between CAKR and LACL. Other trace-element concentrations of interest were higher median concentrations of arsenic, copper, and strontium found in DENA and LACL than in CAKR.

Boxplots of cadmium, lead, and zinc collected in CAKR show distinct differences between sites

Table 8. Trace-element concentrations and percent carbon measured in streambed sediments collected from sites located in Cape Krusenstern National Monument, July 2002 and July 2003 —Contiuned

[values of carbon in percent; all other values in micrograms per gram; <, less than; * denotes replicate]

Site no.	Site	Date	Time	Carbon (total)	Aluminum	Antimony	Arsenic	Barium	Berylium	Bismuth	Cadmium
1	Mud Lake Cr.	7/26/2003	1530	3.5	7.6	0.9	11	1,200	2.1	1	0.3
2	Mud Lake Cr.	7/30/2002	1200	3.3	4.6	1.1	7.2	1,600	1.6	<1	3.4
3	Mud Lake Cr.	7/26/2003	1625	3.1	6.4	0.7	12	770	1.6	1	0.4
4	NF Omikviorok	7/26/2003	1605	3.5	7.4	0.8	16	1,400	2.4	1	0.9
5	SBNF Omikviorok	7/26/2003	1550	1.8	5.3	0.6	7.2	790	1.6	1	0.3
6	NF Omikviorok	7/26/2003	1515	2.3	5.7	0.8	9	920	1.5	1	0.5
7	SF Omikviorok	7/26/2003	1455	1.6	5.8	0.8	8.7	790	1.6	1	0.3
8	Omikviorok R.	7/28/2002	1100	2.5	5.8	0.8	10	960	1.8	<1	0.9
9	Omikviorok R.	7/26/2003	1330	2.1	5.7	0.7	9.6	990	1.6	1	0.3
10	Omikviorok R.	7/26/2003	1305	2.8	6.4	0.8	11	1,100	1.8	1	0.6
11	Omikviorok R.	7/26/2003	1215	2.3	5.6	0.7	10	900	1.7	1	0.4
11	Omikviorok R*.	7/26/2003	1220	2.4	6.2	0.8	11	1,000	1.8	<1	0.5
12	Straight Creek	7/26/2003	1435	2	5.9	0.7	8.4	730	1.9	1	0.4
13	Straight Creek	7/26/2003	1350	1.5	5.6	0.6	6.3	710	1.7	1	0.4
14	Straight Creek	7/26/2003	1245	2.5	6.3	0.7	9	950	1.8	1	0.7
15	Deadman Creek	7/30/2002	1400	3.4	5.6	0.8	9.4	960	1.9	<1	2
16	Deadman Creek	7/26/2003	1415	3.4	5.2	0.6	8.5	580	1.7	1	1.4
17	Deadman Creek	7/26/2003	1200	3.2	5.9	0.6	11	750	1.7	1	0.6
18	Aufeis Creek	7/26/2003	1000	4	7.4	1	13	1,000	2.3	1	0.3
19	Aufeis Creek	7/29/2002	915	3.5	6.6	0.9	13	1,100	2.4	<1	1.3
20	Aufeis Creek	7/26/2003	1125	2.9	7.2	0.7	13	860	2	1	0.5
21	Aufeis Creek	7/26/2003	1140	2.6	6.3	0.7	12	800	2.1	1	0.4
22	New Heart	7/26/2003	1030	3.4	6.3	0.8	9.8	810	1.9	1	0.3
23	N.F. New Heart	7/29/2002	1415	4.3	6.1	1.1	13	1,100	2.1	<1	2.1
24	New Heart	7/29/2002	1230	3	5.9	0.8	10	1,100	2.1	<1	2
24	New Heart*	7/29/2002	1235	3	5.7	0.8	9.6	1,100	1.7	<1	2.3
25	S.F. New Heart	7/29/2002	1345	4	6	1.1	10	1,100	2.2	<1	3.8
26	New Heart	7/26/2003	1105	3	6.4	0.6	10	860	1.8	1	0.9
26	New Heart*	7/26/2003	1110	2.8	6.5	0.5	13	870	2.1	1	0.7

Site no.	Site	Date	Time	Cerium	Chromium	Cobalt	Copper	Europium	Gallium	Gold	Holmium
1	Mud Lake Cr.	7/26/2003	1530	57	110	17	31	1	18	1	1
2	Mud Lake Cr.	7/30/2002	1200	48	78	23	18	1	11	<1	<1
3	Mud Lake Cr.	7/26/2003	1625	53	100	17	54	1	14	1	1
4	NF Omikviorok	7/26/2003	1605	57	120	29	32	2	18	1	1
5	SBNF Omikviorok	7/26/2003	1550	46	84	14	17	1	11	1	1
6	NF Omikviorok	7/26/2003	1515	45	89	17	21	1	13	1	1
7	SF Omikviorok	7/26/2003	1455	51	87	16	21	1	13	1	1
8	Omikviorok R.	7/28/2002	1100	58	97	17	22	1	14	<1	<1
9	Omikviorok R.	7/26/2003	1330	55	89	20	21	1	13	1	1
10	Omikviorok R.	7/26/2003	1305	51	100	21	34	1	15	1	1
11	Omikviorok R.	7/26/2003	1215	48	94	17	22	1	13	1	1
11	Omikviorok R.*	7/26/2003	1220	53	100	19	26	1.3	14	<1	1
12	Straight Creek	7/26/2003	1435	52	87	15	20	1	13	1	1
13	Straight Creek	7/26/2003	1350	54	82	14	18	1	12	1	1
14	Straight Creek	7/26/2003	1245	55	95	19	23	1	14	1	1
15	Deadman Creek	7/30/2002	1400	41	85	17	18	1	13	<1	<1
16	Deadman Creek	7/26/2003	1415	38	81	17	17	1	12	1	1
17	Deadman Creek	7/26/2003	1200	49	98	17	20	1	13	1	1
18	Aufeis Creek	7/26/2003	1000	57	140	12	54	1	17	1	1
19	Aufeis Creek	7/29/2002	915	49	130	14	29	1	16	<1	<1
20	Aufeis Creek	7/26/2003	1125	49	140	15	25	1	17	1	1
21	Aufeis Creek	7/26/2003	1140	51	110	16	26	1	15	1	1
22	New Heart	7/26/2003	1030	41	140	15	27	1	14	1	1
23	N.F. New Heart	7/29/2002	1415	52	150	14	76	1	15	<1	<1
24	New Heart	7/29/2002	1230	50	100	17	22	1	14	<1	<1
24	New Heart*	7/29/2002	1235	48	98	17	22	1	14	<1	<1
25	S.F. New Heart	7/29/2002	1345	48	120	14	25	1	14	<1	<1
26	New Heart	7/26/2003	1105	45	110	17	21	1	14	1	1
26	New Heart*	7/26/2003	1110	46	110	18	46	1	14	1	1

Site no.	Site	Date	Time	Iron	Lanthanum	Lead	Lithium	Manganese	Mercury	Molybdenum	Neodymium
1	Mud Lake Cr.	7/26/2003	1530	4.7	30	20	49	470	0.05	0.8	29
2	Mud Lake Cr.	7/30/2002	1200	3.9	22	120	31	1,700	0.13	<0.5	22
3	Mud Lake Cr.	7/26/2003	1625	4.2	28	23	48	1,100	0.08	0.8	27
4	NF Omikviorok	7/26/2003	1605	5.3	31	26	61	2,800	0.08	0.9	31
5	SBNF Omikviorok	7/26/2003	1550	3	24	19	38	780	0.04	0.5	25
6	NF Omikviorok	7/26/2003	1515	3.5	24	21	43	1,100	0.05	0.5	25
7	SF Omikviorok	7/26/2003	1455	3.6	27	16	41	710	0.05	0.6	26
8	Omikviorok R.	7/28/2002	1100	3.8	30	34	45	800	0.08	0.5	28
9	Omikviorok R.	7/26/2003	1330	4.2	28	18	37	740	0.04	0.8	28
10	Omikviorok R.	7/26/2003	1305	4.2	25	24	53	1,500	0.1	0.7	26
11	Omikviorok R.	7/26/2003	1215	3.7	25	20	44	960	0.05	0.6	25
11	Omikviorok R.*	7/26/2003	1220	4.1	26	23	48	1,100	0.06	0.7	27
12	Straight Creek	7/26/2003	1435	3.4	27	21	40	560	0.05	0.5	26
13	Straight Creek	7/26/2003	1350	3.1	28	20	39	630	0.04	0.5	28
14	Straight Creek	7/26/2003	1245	4.1	27	26	48	1,100	0.06	0.6	28
15	Deadman Creek	7/30/2002	1400	3.9	20	64	47	1,000	0.1	0.7	21
16	Deadman Creek	7/26/2003	1415	3.4	21	47	45	950	0.09	0.9	21
17	Deadman Creek	7/26/2003	1200	3.6	26	23	56	890	0.06	1	27
18	Aufeis Creek	7/26/2003	1000	3.6	31	20	59	370	0.17	1.2	32
19	Aufeis Creek	7/29/2002	915	3.7	26	50	58	530	0.13	0.8	25

Table 8. Trace-element concentrations and percent carbon measured in streambed sediments collected from sites located in Cape Krusenstern National Monument, July 2002 and July 2003 —Contiuned

Site no.	Site	Date	Time	Iron	Lanthanum	Lead	Lithium	Manganese	Mercury	Molybdenum	Neodymium
20	Aufeis Creek	7/26/2003	1125	3.7	25	21	62	620	0.08	1	25
21	Aufeis Creek	7/26/2003	1140	3.8	28	20	58	880	0.08	0.9	28
22	New Heart	7/26/2003	1030	3.5	23	19	54	1,200	0.13	0.8	23
23	N.F. New Heart	7/29/2002	1415	3.1	30	66	52	580	0.2	1.3	28
24	New Heart	7/29/2002	1230	3.4	30	79	54	720	0.11	0.6	27
24	New Heart*	7/29/2002	1235	3.4	26	87	52	700	0.12	0.6	26
25	S.F. New Heart	7/29/2002	1345	3.6	25	140	52	710	0.21	0.8	25
26	New Heart	7/26/2003	1105	3.7	24	32	58	900	0.08	0.9	25
26	New Heart*	7/26/2003	1110	3.8	24	29	58	1,000	0.06	0.9	24

Site no	Site	Date	Time	Nickel	Niobium	Scandium	Selenium	Silver	Strontium	Tantalum	Thallium
1	Mud Lake Cr.	7/26/2003	1530	57	11	18	0.6	0.2	82	1	1
2	Mud Lake Cr.	7/30/2002	1200	40	8	11	0.3	0.2	76	<1	<1
3	Mud Lake Cr.	7/26/2003	1625	120	8	14	0.8	0.2	72	1	1
4	NF Omikviorok	7/26/2003	1605	85	9	18	1	0.2	85	1	1
5	SBNF Omikviorok	7/26/2003	1550	46	8	12	0.5	0.1	69	1	1
6	NF Omikviorok	7/26/2003	1515	51	8	13	0.5	0.1	70	1	1
7	SF Omikviorok	7/26/2003	1455	47	9	13	0.4	0.1	70	1	1
8	Omikviorok R.	7/28/2002	1100	48	8	14	0.6	0.1	72	<1	<1
9	Omikviorok R.	7/26/2003	1330	46	9	14	0.4	0.2	73	1	1
10	Omikviorok R.	7/26/2003	1305	64	9	16	0.8	0.2	76	1	1
11	Omikviorok R.	7/26/2003	1215	57	8	14	0.6	0.1	74	1	1
11	Omikviorok R.*	7/26/2003	1220	62	8	15	0.4	0.16	76	<1	<1
12	Straight Creek	7/26/2003	1435	48	8	14	0.4	0.1	74	1	1
13	Straight Creek	7/26/2003	1350	42	9	12	0.3	0.1	73	1	1
14	Straight Creek	7/26/2003	1245	61	9	15	0.6	0.1	85	1	1
15	Deadman Creek	7/30/2002	1400	49	8	13	1	0.2	100	<1	<1
16	Deadman Creek	7/26/2003	1415	53	7	11	1	1	130	1	1
17	Deadman Creek	7/26/2003	1200	60	8	13	1.2	0.2	210	1	1
18	Aufeis Creek	7/26/2003	1000	51	10	16	4.3	0.4	180	1	1
19	Aufeis Creek	7/29/2002	915	50	9	15	2.2	0.2	120	<1	<1
20	Aufeis Creek	7/26/2003	1125	61	10	15	1.5	0.2	120	1	1
21	Aufeis Creek	7/26/2003	1140	52	8	15	1.5	0.2	100	1	1
22	New Heart	7/26/2003	1030	55	8	14	1.8	0.3	120	1	1
23	N.F. New Heart	7/29/2002	1415	62	12	14	6	0.8	160	<1	<1
24	New Heart	7/29/2002	1230	61	8	13	1.2	0.3	160	<1	<1
24	New Heart*	7/29/2002	1235	59	8	13	1.1	0.3	160	<1	<1
25	S.F. New Heart	7/29/2002	1345	51	9	14	1.9	0.4	190	<1	<1
26	New Heart	7/26/2003	1105	67	9	13	1.3	0.2	140	1	1
26	New Heart*	7/26/2003	1110	71	9	13	1.3	0.2	150	1	1

Site no.	Site	Date	Time	Thorium	Tin	Titanium	Vanadium	Ytterbium	Yttrium	Zinc	Uranium
1	Mud Lake Cr.	7/26/2003	1530	10	3	0.48	150	2	19	120	2.9
2	Mud Lake Cr.	7/30/2002	1200	7	2	0.27	90	2	16	640	2.3
3	Mud Lake Cr.	7/26/2003	1625	10	3	0.37	120	2	20	160	2.7
4	NF Omikviorok	7/26/2003	1605	11	3	0.39	140	2	23	200	2.8
5	SBNF Omikviorok	7/26/2003	1550	8	2	0.37	86	2	17	110	2.1
6	NF Omikviorok	7/26/2003	1515	8	2	0.36	100	2	16	140	2.2
7	SF Omikviorok	7/26/2003	1455	9	2	0.39	110	2	17	100	2.4
8	Omikviorok R.	7/28/2002	1100	9	2	0.27	110	2	16	200	2.3
9	Omikviorok R.	7/26/2003	1330	8	2	0.42	110	2	18	110	2.2
10	Omikviorok R.	7/26/2003	1305	9	3	0.36	120	2	18	170	2.2
11	Omikviorok R.	7/26/2003	1215	8	2	0.36	110	2	18	140	2.2
11	Omikviorok R.*	7/26/2003	1220	9	2	0.38	120	2	19	150	2.4
12	Straight Creek	7/26/2003	1435	9	2	0.37	100	2	16	120	2.4
13	Straight Creek	7/26/2003	1350	8	2	0.4	97	2	15	120	2.3
14	Straight Creek	7/26/2003	1245	9	2	0.39	120	3	18	180	2.4
15	Deadman Creek	7/30/2002	1400	8	2	0.21	98	2	20	420	2.3
16	Deadman Creek	7/26/2003	1415	8	2	0.28	88	2	22	390	2.2
17	Deadman Creek	7/26/2003	1200	9	2	0.31	110	2	24	220	2.1
18	Aufeis Creek	7/26/2003	1000	12	3	0.38	140	3	23	140	3.7
19	Aufeis Creek	7/29/2002	915	10	3	0.22	130	2	20	330	3.1
20	Aufeis Creek	7/26/2003	1125	10	3	0.39	140	3	23	200	3
21	Aufeis Creek	7/26/2003	1140	10	2	0.33	120	3	23	160	3
22	New Heart	7/26/2003	1030	10	2	0.33	120	2	21	140	2.8
23	N.F. New Heart	7/29/2002	1415	10	3	0.23	130	2	23	740	3.6
24	New Heart	7/29/2002	1230	9	2	0.23	110	2	20	500	2.6
24	New Heart*	7/29/2002	1235	9	2	0.21	110	2	21	540	2.6
25	S.F. New Heart	7/29/2002	1345	9	3	0.24	120	2	21	890	2.6
26	New Heart	7/26/2003	1105	9	2	0.35	120	2	23	320	2.3
26	New Heart*	7/26/2003	1110	9	3	0.37	120	2	23	310	2.4

Table 9. Summary statistics of concentrations of trace elements measured in streambed sediments collected in Cape Krusenstern National Monument, July 2002 and July 2003

[values of aluminum, iron, and titanium in percent; all other values in micrograms per gram]

Constituent	Minimum	Percentile[1]					Maximum
		10	25	50 (median)	75	90	
Aluminum	5	5	6	6	6	7	8
Antimony	1	1	1	1	1	1	1
Arsenic	6	7	9	10	12	13	16
Barium	580	730	790	935	1,100	1,200	1,600
Berylium	2	2	2	2	2	2	2
Bismuth	1	1	1	1	1	1	1
Cadmium	0	0	0	1	1	2	4
Cerium	38	41	48	51	54	57	58
Chromium	78	82	87	99	120	140	150
Cobalt	12	14	15	17	17	21	29
Copper	17	18	20	22	29	54	76
Europium	1	1	1	1	1	1	2
Gallium	11	12	13	14	15	17	18
Gold	1	1	1	1	1	1	1
Holmium	1	1	1	1	1	1	1
Iron	3	3	4	4	4	4	5
Lanthanum	20	22	24	27	28	30	31
Lead	16	19	20	23	47	79	140
Lithium	31	38	43	49	56	59	62
Manganese	370	530	630	840	1,100	1,500	2,800
Mercury	0.04	0.04	0.05	0.08	0.11	0.17	0.21
Molybdenum	1	1	1	1	1	1	1
Neodymium	21	22	25	26	28	29	32
Nickel	40	46	48	53	61	67	120
Niobium	7	8	8	9	9	10	12
Scandium	11	12	13	14	15	16	18
Selenium	0	0	1	1	2	2	6
Silver	0	0	0	0	0	0	1
Strontium	69	70	73	85	130	180	210
Tantalum	1	1	1	1	1	1	1
Thallium	1	1	1	1	1	1	1
Thorium	7	8	8	9	10	10	12
Tin	2	2	2	2	3	3	3
Titanium	0.21	0.23	0.27	0.36	0.39	0.40	0.48
Vanadium	86	90	100	115	120	140	150
Ytterblum	2	2	2	2	2	3	3
Yttrium	15	16	17	20	23	23	24
Zinc	100	110	140	175	330	640	890
Uranium	2	2	2	2	3	3	4

[1] Percentage of samples (10, 25, 50, 75, 90) equal to or below the indicated concentration for a particular constituent

along the access road and sites north and south of the road (fig. 8). A Kruskal-Wallis test of the data indicated statistically significant differences in the median concentrations of these elements along the road. Boxplot comparisons and a Kruskal-Wallis test did not indicate statistically significant differences between concentrations at sites north or south of the road. Further inspection of the data from sites located north of the access road showed the highest concentrations of cadmium, lead, and zinc were found at sites 16 (Deadman Creek) and 26 (New Heart Creek). Possible reasons for these relatively high concentrations may be due to concentrate spills that occurred along the access road near these two streams (fig. 1).

The focus in the literature on criteria for streambed sediments has been limited to nine trace elements: arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. The Canadian Council of Ministers of the Environment (CCME) (1999) has established guidelines for some trace elements in unsieved streambed sediment. These guidelines use two assessment values: a lower value, called the "interim freshwater sediment quality guideline" (ISQG), is the concentration below which adverse effects are expected to occur rarely; the upper value, called the "probable effect level" (PEL), is the concentration above which adverse effects are expected to occur frequently. Because trace-element samples for this study are from sediments finer than 0.063-mm where concentrations tend to be greatest, comparisons with the Canadian guidelines may overestimate the effects on aquatic organisms (Deacon and Stephens, 1998). However, it was felt that the PEL would be useful for comparative purposes when applied to the finer than 0.063-mm size fraction sediment samples analyzed for this study.

MacDonald and others (2000) proposed sediment quality guidelines for eight trace elements and Van Derveer and Canton (1997) proposed guidelines for selenium. These guidelines use the following two concentrations for a given trace element: the threshold effect concentration (TEC) and the probable effect concentration (PEC) and assume a 1 percent organic carbon concentration. The TEC is the concentration below which sediment-dwelling organisms are unlikely to be adversely affected, and the PEC is the concentration above which toxicity is likely. In addition, MacDonald and others (2000) developed a Mean PEC Quotient, which is the toxicity of the combined trace element concentrations. The Mean PEC Quotient is computed by summing the concentrations of all the trace elements analyzed and dividing by the number of elements. MacDonald and others (2000) found that sediments with mean PEC quotients 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.

When compared to the different guidelines, the concentrations of arsenic and chromium of all streambed samples from CAKR exceeded the ISQG guidelines, concentrations of 20 samples exceeded the ISQG guideline for zinc, and concentrations from 13 samples exceeded the ISQG concentration for cadmium (table 11). With the exception of arsenic and cadmium, approximately the same number of samples exceed the TEC. Concentrations of 15 samples exceeded the PEL for chromium. Concentrations of 19 samples exceeded the PEC for nickel and 7 samples exceeded the PEC for chromium. Thus, based on the above guidelines, concentrations of arsenic, chromium, nickel, and zinc of many samples exceeded either the ISQG or TEC guidelines. However, compared with the PEL or PEC guidelines, (shown as PEL/PEC), the number of concentrations that exceed the limits are primarily chromium (15/7 samples), nickel (--/19 samples), and zinc (8/4 samples).

Table 10. Comparison of median concentrations of trace elements measured in streambed sediments from the USGS National Water-Quality Assessment (NAWQA) program, Cape Krusenstern National Monument, Denali National Park and Preserve, and Lake Clark National Park and Preserve

[values for aluminum, iron, and titanium in percent; all other values in micrograms per gram; --, no data]

Trace element	NAWQA Reference Forested Sites (number of samples varies between 241 and 262)	NAWQA Hard Rock Mining Sites (number of samples varies between 65 and 89)	Cape Krusenstern National Monument (26 samples)	Denali National Park and Preserve (16 samples)	Lake Clark National Park and Preserve (8 samples)
Aluminum	6.5	6.8	6.0	6.8	8.6
Antimony	0.7	1.4	0.8	1.2	2.2
Arsenic	7.0	16	10	26	29
Barium	470	645	935	995	255
Berylium	2.0	2.0	1.8	1.9	1
Bismuth	--	--	1.0	1.0	1
Cadmium	0.4	1.3	0.55	0.3	0.15
Cerium	70	79	50	64	27
Chromium	63	53	99	98	42
Cobalt	15	19	17	15	25
Copper	26	64	22	41	60
Europium	1.0	1.0	1.0	1.0	1.0
Gallium	16	16	14	16	16
Gold	--	--	1.0	1.0	1.0
Holmium	--	--	1.0	1.0	1.0
Iron	3.6	3.9	3.7	3.5	7.4
Lanthanum	--	--	26	32	12
Lead	24	110	23	18	6
Lithium	--	--	48	48	14
Manganese	955	1300	840	605	1600
Mercury	0.07	0.09	0.08	0.02	0.28
Molybdenum	1	1.0	0.80	1.1	2.0
Neodymium	--	--	26	29	17
Nickel	26	28	53	46	12
Niobium	--	--	8.5	11	4
Scandium	12	11	14	13	40
Selenium	0.7	0.7	1.0	0.6	0.6
Silver	0.2	0.5	0.2	0.2	0.2
Strontium	140	170	85	145	165
Tantalium	--	--	1.0	1.0	1.0
Thallium	--	--	1.0	1.0	1.0
Thorium	12.0	11.8	9.0	9.5	1.5
Tin	2.5	2.5	2.0	2.0	1.0
Titanium	0.37	0.37	0.36	0.28	0.65
Vanadium	84	82	115	115	260
Ytterbium	--	--	2.0	2.0	4.0
Yettrium	--	--	20	18	35
Uranium	3.9	4.7	2.4	5.6	1.0
Zinc	110	320	175	112	135

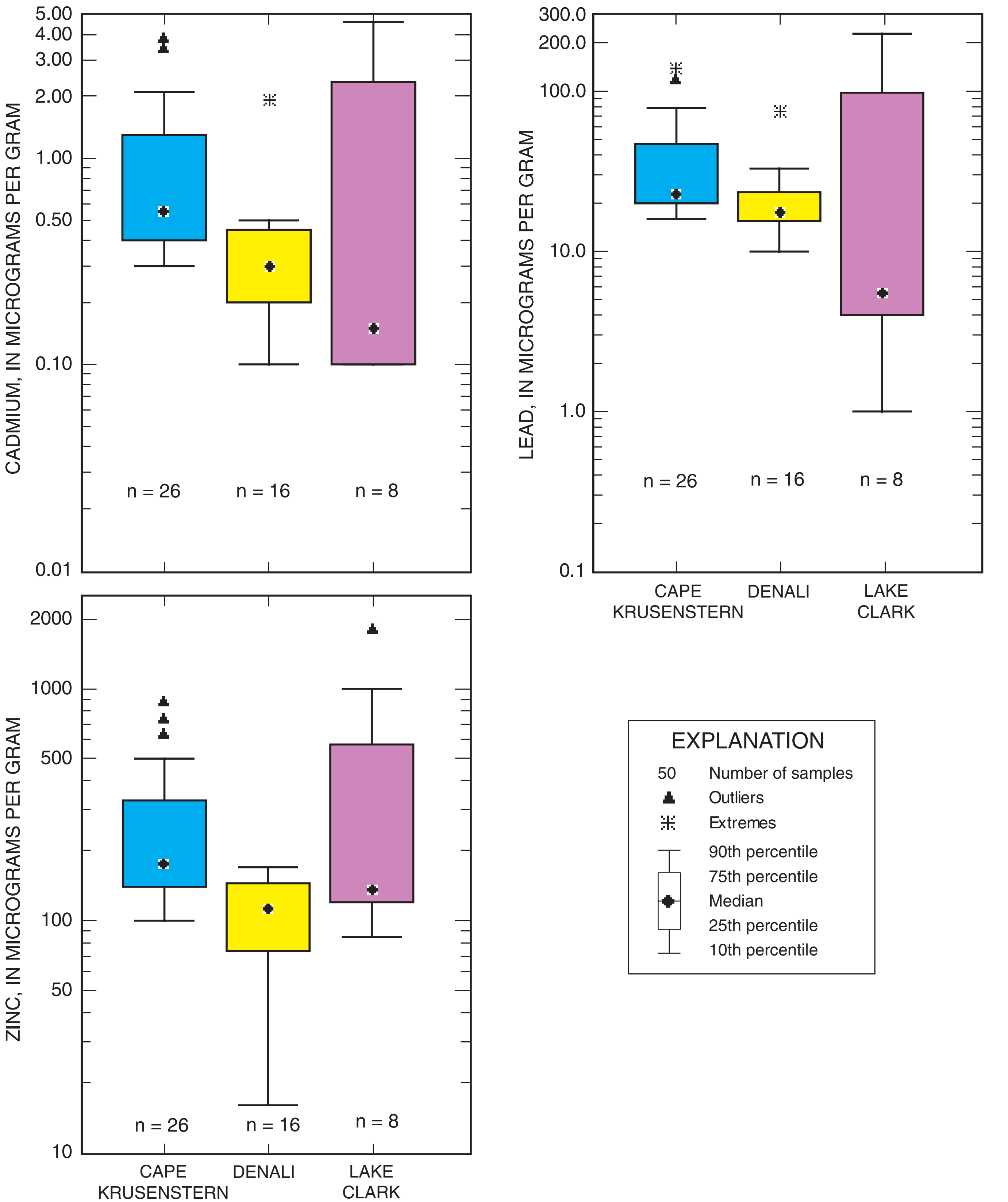


Figure 7. Boxplots of concentrations of cadmium, lead, and zinc. in streambed sediments from sites in Cape Krusenstern National Monument, Denali National Park and Preserve, and Lake Clark National Park and Preserve.

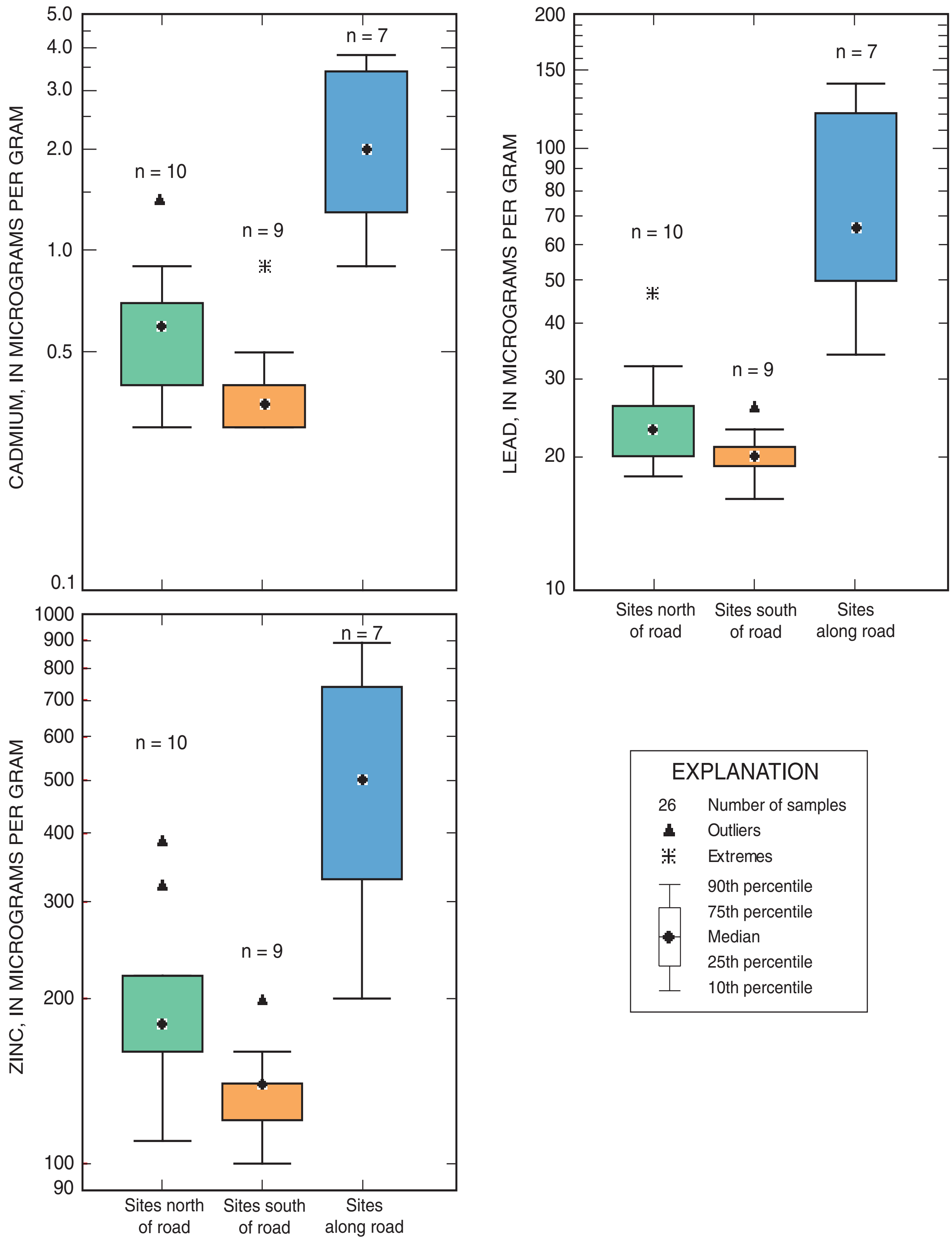


Figure 8. Boxplots of concentrations of cadmium, lead, and zinc in streambed sediments from sites in Cape Krusenstern National Monument located south of the access road, along the access road, and north of the access road.

Table 11. Streambed sediment quality guidelines for selected trace elements and the number of exceedances from samples collected from Cape Krusenstern National Monument

[values in micrograms per gram; --, no guideline established]

Trace Element	Interim Freshwater Sediment Quality Guideline (ISQG)[1]	Number of exceedances	Threshold Effect Concentration (TEC)[2]	Number of exceedances	Probable Effect Level (PEL)[1]	Number of exceedances	Probable Effect Concentration (PEC)[2]	Number of exceedances
Arsenic	5.9	26	9.8	16	17.0	0	33.0	0
Cadmium	0.6	13	0.99	7	3.5	1	5.0	0
Chromium	37.3	26	43.4	26	90	15	111	7
Copper	35.7	3	31.6	5	197	0	149	0
Lead	35.0	7	35.8	7	91.3	2	128	1
Mercury	0.17	3	0.18	1	0.49	0	1.06	0
Nickel	--	--	22.7	26	--	--	48.6	19
Selenium[3]	--	--	2.5	1	--	--	4.0	1
Zinc	123	20	121	20	315	8	459	4

[1] Canadian Council of Ministers of the Environment (1999)

[2] MacDonald and others (2000)

[3] Van Derveer and Canton (1997)

Comparison of the concentrations of the trace elements with the percent organic carbon and Mean PEC Quotient provides some insights about the bioavailability of these trace elements. The concentration of organic carbon in sediment is used to indicate the concentration of organic matter. The ability of organic matter in concentrating some trace elements in stream sediment is well recognized (Gibbs, 1973, Horowitz, 1991) and this ability varies with the type of organic matter. For example, complexation by organic matter, such as humic and fulvic acids, has generally been thought to reduce bioavailability (Spacie and Hamelink, 1985, Newman and Jagoe, 1994). Results of studies by Decho and Luoma (1994) and Winner (1985) suggest that organic carbon compounds may in some cases enhance uptake of certain trace elements. In CAKR, all values of organic carbon for all samples were greater than 1 percent (table 12). Compared to the percent organic carbon found in samples from DENA and LACL, the values of percent organic carbon in CAKR are higher. At all sites in CAKR, the mean PEC quotient was less than 0.50, which would indicate no toxicity. Conversely, at a number of sites in DENA and LACL, percent organic carbon was less than 1 percent and mean PEC quotients were greater than 0.5, which would indicate some level of potential toxicity (table 12). As MacDonald and others (2000) noted, sites containing relatively low concentrations of organic carbon have higher potential toxicity. When normalized to percent organic carbon, concentrations of all the selected trace elements in CAKR, with the exception of one concentration of cadmium, did not exceed the PEC level, whereas concentrations of several samples in DENA and LACL still exceeded PEC levels when normalized to organic carbon.

Table 12. Concentrations of nine trace elements in streambed sediments finer than 0.063 mm in Cape Krusenstern National Monument, Denali National Park and Preserve, and Lake Clark National Park and Preserve—Continued

[Concentrations in micrograms per gram; Organic carbon in percent; As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Hg, mercury; Ni, nickel; Se, selenium; Zn, zinc; values in bold are concentrations that when normalized to one 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)]

Map ID	Site name	Latitude	Longitude	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Zn	Organic carbon	Mean PEC quotient
					Cape Krusenstern									
1	Mud Lake Creek 3.4 miles above Port Access Road	67º 44´37˝	163º 31´25˝	11	0.3	110	31	20	0.05	57	0.6	120	3.50	0.12
2	Mud Lake Creek at Port Access Road	67º 43´46˝	163º 37´36˝	7.2	3.4	78	18	120	0.13	40	0.3	640	2.70	0.23
3	North Branch North Fork Omikviorok River 9 miles above	67º 46´41˝	163º 17´18˝	12	0.4	100	54	23	0.08	120	0.8	160	3.10	0.19
4	North Fork Omikviorok River 6.5 miles above Port Access R	67º 44´06˝	163º 23´59˝	16	0.9	120	32	26	0.08	85	1	200	3.30	0.17
5	South Branch North Fork Omikviorok River 6.5 miles abv	67º 43´24˝	163º 24´35˝	7.2	0.3	84	17	19	0.04	46	0.5	110	1.70	0.19
6	North Fork Omikviorok River 2.6 miles above Port Access R	67º 43´38˝	163º 32´05˝	9	0.5	89	21	21	0.05	51	0.5	140	2.20	0.16
7	South Fork Omikviorok River 2.5 miles above Port Access R	67º 41´33˝	163º 34´15˝	8.7	0.3	87	21	16	0.05	47	0.4	100	1.60	0.20
8	Omikviorok River at Port Access Road	67º 43´26˝	163º 37´59˝	10	0.9	97	22	34	0.08	48	0.6	200	2.50	0.16
9	Omikviorok River Tributary 2.3 miles below Port Access R	67º 43´41˝	163º 44´11˝	9.6	0.3	89	21	18	0.04	46	0.4	110	2.00	0.17
10	Omikviorok River 7.0 miles below Port Access Road	67º 43´41˝	163º 53´15˝	11	0.6	100	34	24	0.1	64	0.8	170	2.70	0.16
11	Omikviorok River 5.5 miles above mouth	67º 41´57˝	164º 02´43˝	10	0.4	94	22	20	0.05	57	0.6	140	2.30	0.17
12	Straight Creek 1 mile above Port Access Road	67º 39´19˝	163º 39´53˝	8.4	0.4	87	20	21	0.05	48	0.4	120	2.00	0.17
13	Straight Creek 4 miles below Port Access Road	67º 40´54˝	163º 46´52˝	6.3	0.4	82	18	20	0.04	42	0.3	120	1.50	0.20
14	Straight Creek 7.7 miles below Port Access Road	67º 42´20˝	163º 57´28˝	9	0.7	95	23	26	0.06	61	0.6	180	2.50	0.17
15	Deadman Creek at Port Access Road	67º 38´45˝	163º 45´56˝	9.4	2.0	85	18	64	0.1	49	1	420	3.00	0.17
16	Deadman Creek 2.5 miles below Port Access Road	67º 39´56˝	163º 49´00˝	8.5	1.4	81	17	47	0.09	53	1	390	2.90	0.16
17	Deadman Creek 6.5 miles below Port Access Road	67º 40´21˝	163º 58´03˝	11	0.6	98	20	23	0.06	60	1.2	220	2.40	0.18
18	Aufeis Creek 0.8 miles above Port Access Road	67º 37´05˝	163º 49´18˝	13	0.3	140	54	20	0.17	51	**4.3**	140	3.90	0.12
19	Aufeis Creek at Port Access Road	67º 37´56˝	163º 50´39˝	13	1.3	130	29	50	0.13	50	2.2	330	3.30	0.16
20	Aufeis Creek 2.7 miles below Port Access Road	67º 39´11˝	163º 55´23˝	13	0.5	140	25	21	0.08	61	1.5	200	2.70	0.18
21	Aufeis Creek 5.5 miles below Port Access Road	67º 40´01˝	164º 01´21˝	12	0.4	110	26	20	0.08	52	1.5	160	2.60	0.16
22	New Heart Creek 0.8 miles above Port Access Road	67º 36´10˝	163º 54´04˝	9.8	0.3	140	27	19	0.13	55	1.8	140	3.30	0.13
23	North Fork New Heart Creek at Port Access Road	67º 36´41˝	163º 55´45˝	13	2.1	150	76	66	0.2	62	6	740	4.00	0.14

Table 12. Concentrations of nine trace elements in streambed sediments finer than 0.063 mm in Cape Krusenstern National Monument, Denali National Park and Preserve, and Lake Clark National Park and Preserve—Continued

Map ID	Site name	Latitude	Longitude	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Zn	Organic carbon	Mean PEC quotient
24	New Heart Creek at Port Access Road	67º 36´12˝	163º 56´40˝	10	2.0	100	22	79	0.11	61	1.2	500	2.30	0.26
25	South Fork New Heart Creek at Port Access Road	67º 36´03˝	163º 56´59˝	10	3.8	120	25	140	0.21	51	1.9	890	3.30	0.24
26	New Heart Creek 2 miles below Port Access Road	67º 36´35˝	164º 00´46˝	10	0.9	110	21	32	0.08	67	1.3	320	2.60	0.19
	Denali National Park and Preserve - south side													
	Colorado Creek	63º 16´29˝	149º 35´20˝	**44**	0.5	**220**	59	15	0.18	**130**	0.7	150	0.52	**1.71**
	Costello Creek	63º 16´18˝	149º 32´37˝	**23**	0.3	**170**	64	16	0.23	**98**	0.7	140	0.46	**1.46**
	Camp Creek at mouth	63º 16´12˝	149º 31´33˝	**49**	0.5	**110**	35	27	0.24	**42**	0.5	140	1.00	**0.55**
	Costello Creek below Camp Creek	63º 16´09˝	149º 31´34˝	**25**	0.3	**140**	55	18	0.16	**70**	0.6	**130**	0.47	**1.19**
	Coffee River above Crystal Creek	62º 50´14˝	150º 18´32˝	**9.1**	0.2	**10**	10	22	<.02	**6**	0.1	56	0.08	**1.39**
	Crystal Creek at mouth	62º 50´12˝	150º 18´27˝	10	0.2	24	16	20	0.02	11	0.6	68	0.80	0.19
	Wildhorse Creek	62º 39´20˝	150º 54´03˝	56	1.9	120	48	17	0.08	56	5.2	170	6.90	0.09
	Bear Creek	62º 38´34˝	150º 54´33˝	**42**	0.5	**140**	59	17	0.03	**81**	0.9	150	1.20	**0.54**
	Hidden Creek	62º 35´30˝	151º 11´29˝	**3.3**	<.1	3	3	**25**	<.02	<2	<.1	16	0.09	**0.53**
	Long Creek	62º 35´10˝	150º 45´04˝	46	0.2	79	26	10	0.04	32	1.7	80	7.10	0.06
	Cripple Creek above Snowslide Creek	62º 33´25˝	151º 32´18˝	8.7	0.3	**68**	26	20	<.02	**37**	0.3	80	0.53	**0.52**
	Snowslide Creek at mouth	62º 33´24˝	151º 32´16˝	1.7	**0.4**	**10**	**11**	**76**	<.02	**6**	0.1	**92**	0.07	
	Cascade Creek at mouth	62º 25´22˝	151º 59´22˝	**88**	0.2	**87**	48	13	<.02	**49**	0.6	95	0.36	**1.78**
	Fourth of July Creek at mouth	62º 19´36˝	151º 58´27˝	**26**	0.3	**150**	49	16	0.02	**80**	0.8	130	0.57	**1.01**
	Kichatna River above Morris Creek	62º 18´00˝	152º 41´06˝	**16**	<.1	**29**	13	**33**	0.02	**17**	0.2	**63**	0.11	**1.82**
	Morris Creek at mouth	62º 17´59˝	152º 41´05˝	**30**	0.2	**150**	47	14	0.07	**94**	1.2	150	0.49	**1.29**
	Lake Clark National Park and Preserve - Johnson River Basin													
	No. Fork Ore Creek near mouth near Johnson Glacier	60º 06´58˝	152º 58´14˝	**34**	<.1	**41**	**54**	<1	**0.53**	**15**	0.2	**120**	0.16	**2.21**
	E. Fork Ore Creek near mouth near Johnson Glacier	60º 07´13˝	152º 57´40˝	**64**	**4.3**	14	76	**230**	0.93	4	2.6	**1000**	1.00	**0.72**
	Ore Creek near mouth near Johnson Glacier	60º 07´15˝	152º 57´28˝	**44**	**4.6**	23	**92**	**180**	**0.28**	8	1.2	**1800**	0.24	**4.60**
	Kona Creek 3 mi above mouth above Lateral Glacier	60º 08´26˝	152º 55´44˝	**19**	<.1	**38**	**56**	6	**0.75**	11	0.6	**120**	0.25	**1.27**
	Kona Creek 2.5 mi above Lateral Glacier	60º 08´03˝	152º 55´24˝	**18**	0.1	**42**	**57**	5	0.16	11	0.6	**140**	0.26	**0.98**
	Kona Creek 0.8 mi above mouth above Lateral Glacier	60º 06´36˝	152º 55´14˝	**16**	0.4	48	63	17	0.28	14	0.7	150	0.49	**0.62**
	Unnamed tributary to Kona Creek above Lateral Glacier	60º 06´35˝	152º 55´09˝	18	<.1	77	47	4	0.1	25	0.2	85	1.30	0.23
	Johnson River above Lateral Glacier	60º 05´41˝	152º 54´38˝	**16**	0.2	**66**	**75**	4	**0.13**	**17**	0.3	**130**	0.05	**6.02**

SUMMARY AND CONCLUSIONS

Cape Krusenstern National Monument encompasses a road and easement from the Red Dog Mine to the coast and a port facility. Concern about the deposition of cadmium, lead, zinc, and other trace elements in the monument and possible environmental effects was the basis of a cooperative project with the NPS. Major findings are:

- Concentrations of dissolved cadmium, dissolved lead, and dissolved zinc from 28 snow samples collected from a 16 mi^2 by 28 mi^2 grid were below standards for drinking water and for aquatic life. Particulate concentrations of these trace elements, compared with the range of concentrations of trace elements found in soils of Alaska, indicated that approximately 25 percent of the lead and zinc values were outside the documented range. Boxplots of the dissolved and particulate concentrations show a general trend of higher concentrations north of the access road, most likely due to the prevailing winds from the southeast.

- Water-quality samples were collected at four streams that cross the port access road and analyzed for general water-quality constituents. Concentrations of all constituents were less than drinking water and aquatic life standards. The water type for all four sites was classified as calcium bicarbonate during low flow.

- Streambed sediments were collected from 26 sites representing streams located south and north of the port access road and along the port access road and analyzed for 39 trace elements. Median concentrations of most trace elements are similar to median concentrations of NAWQA database, which consists of approximately 1,000 samples. Concentrations of cadmium, lead, and zinc at the sites along the port access road were higher than concentrations at sites located north and south of the access road. These concentrations are statistically different from the concentrations of these elements found north and south of the port access road.

- Concentrations of nine trace elements in streambed sediment samples were compared to criteria or guidelines for the protection of aquatic life. Concentrations of chromium and nickel from all samples exceeded the TEC, concentrations of zinc from 20 samples and concentrations of arsenic from 16 samples also exceeded the TEC. Concentrations of nickel from 19 samples and concentrations of chromium from seven samples exceeded the PEC. For all samples, the percent organic carbon was above 1.0 percent and the Mean PEC Quotient for all samples was less than 0.50, indicating no toxicity. When normalized to percent organic carbon, concentrations of the trace elements for all samples do not exceed the PEC.

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