USGS
science for a changing world

Prepared in cooperation with U.S. Fish and Wildlife Service
and the Bureau of Reclamation

Irrigation Drainage Studies of the Angostura Reclamation Unit and the Belle Fourche Reclamation Project, Western South Dakota: Results of 1994 Sampling and Comparisons with 1988 Data

Water-Resources Investigations Report 01-4103

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

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

Irrigation Drainage Studies of the Angostura Reclamation Unit and the Belle Fourche Reclamation Project, Western South Dakota: Results of 1994 Sampling and Comparisons with 1988 Data

By Steven K. Sando and Joyce E. Williamson, U.S. Geological Survey; Kimberly K. Dickerson, U.S. Fish and Wildlife Service; and Edwin A. Wesolowski, U.S. Geological Survey

Water-Resources Investigations Report 01-4103

Prepared in cooperation with U.S. Fish and Wildlife Service and the
Bureau of Reclamation

U.S. Department of the Interior

GALE A. NORTON, Secretary

U.S. Geological Survey

CHARLES G. GROAT, Director

Rapid City, South Dakota: 2001

For additional information write to:

District Chief
U.S. Geological Survey
1608 Mt. View Road
Rapid City, SD 57702

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

Abbreviations used in this report:

mg/L	milligrams per liter
mm	millimeters
µg/L	micrograms per liter
µg/g	micrograms per gram
µg/g dw	micrograms per gram dry weight
µm	micrometers
mi	mile
ft^3/s	cubic feet per second

Irrigation Drainage Studies of the Angostura Reclamation Unit and the Belle Fourche Reclamation Project, Western South Dakota: Results of 1994 Sampling and Comparisons with 1988 Data

By Steven K. Sando, Joyce E. Williamson, Kimberly K. Dickerson, *and* Edwin A. Wesolowski

ABSTRACT

The U.S. Department of the Interior started the National Irrigation Water Quality Program in 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the western U.S. The Angostura Reclamation Unit (ARU) and Belle Fourche Reclamation Project (BFRP) in western South Dakota were included as part of this program. The ARU and BFRP reconnaissance studies were initiated in 1988, during below-normal streamflow conditions in both study areas. Surface water, bottom sediment, and fish were resampled in 1994 at selected sites in both study areas during generally near-normal streamflow conditions to compare with 1988 study results.

Concentrations of major ions in water for both the ARU and BFRP study areas are high relative to national baseline levels. Major-ion concentrations for both areas generally are lower for 1994 than for 1988, when low-flow conditions prevailed, but ionic proportions are similar between years. For ARU, dissolved-solids concentrations probably increase slightly downstream from Angostura Reservoir; however, the available data sets are insufficient to confidently discern effects of ARU operations on dissolved-solids loading. For BFRP, dissolved-solids concentrations are slightly higher at sites that are affected by irrigation drainage; again, however, the data are inconclusive to determine whether BFRP operations increase dissolved-solids loading.

Most trace-element concentrations in water samples for both study areas are similar between 1988 and 1994, and do not show strong relations with discharge. ARU operations probably are not contributing discernible additional loads of trace elements to the Cheyenne River. For BFRP, concentrations of some trace elements are slightly higher at sites downstream from irrigation operations than at a site upstream from irrigation operations. BFRP operations might contribute to trace-element concentrations in the Belle Fourche River, but available data are insufficient to quantify increases. For both study areas, concentrations of several trace elements occasionally exceed National Irrigation Water Quality Program guidelines. Selenium routinely occurs in concentrations that could be problematic at sites upstream and downstream from both study areas. Elevated selenium concentrations at sites upstream from irrigation operations indicate that naturally occurring selenium concentrations are relatively high in and near the study areas. While ARU operations probably do not contribute discernible additional loads of selenium to the Cheyenne River, BFRP operations might contribute additional selenium loads to the Belle Fourche River.

Concentrations of most trace elements in bottom sediment, except arsenic and selenium, are similar to typical concentrations for western U.S. soils for both study areas. Bottom-sediment arsenic and selenium (1988) concentrations in both study areas can reach levels that might be of concern; however, there is insufficient information to determine whether irrigation operations contribute to these elevated concentrations.

Concentrations of most trace elements in fish in both study areas are less than values known to adversely affect fish or birds, although there are occasional exceedances of established criteria. However, selenium concentrations in fish samples routinely are within the National Irrigation Water Quality Program level of concern, and also commonly exceed the dietary guideline for avian consumers for both study areas. Selenium concentrations in fish samples generally are higher at sites downstream from irrigation operations. For BFRP, arsenic and mercury concentrations are elevated in fish samples from site B-18, which is influenced by mine tailings.

INTRODUCTION

Beginning in the mid-1980's, there has been concern about the quality of irrigation drainage and its potential harmful effects on human health, fish, and wildlife. Concentrations of selenium greater than water-quality criteria for the protection of aquatic life (U.S. Environmental Protection Agency, 1986) have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley in California (Leighton and others, 1992). In 1983, incidences of mortality, birth defects, and reproductive failures in waterfowl were discovered by the U.S. Fish and Wildlife Service (Ohlendorf and others, 1986) at the Kesterson National Wildlife Refuge in the western San Joaquin Valley, where irrigation drainage was impounded. In addition, potentially toxic trace elements and pesticide residues have been detected in other areas in the western U.S. that receive irrigation drainage (Feltz and others, 1991).

Because of concerns expressed by the U.S. Congress, the U.S. Department of the Interior started the National Irrigation Water Quality Program (NIWQP) in 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the western U.S. An interbureau group, the Task Group on Irrigation Drainage, was formed within the U.S. Department of the Interior. This group identified and selected several locations in the western U.S. to conduct reconnaissance-level field investigations to determine if potentially toxic constituents are present in concentrations sufficiently high to possibly cause harmful effects on human health or on fish and wildlife within or immediately downstream from the study units. The Angostura Reclamation Unit (ARU) and Belle Fourche Reclamation Project (BFRP) in western South Dakota were included as part of this program.

The ARU and BFRP reconnaissance studies were initiated in 1988. These 2-year studies were conducted by interbureau teams composed of a scientist from the U.S. Geological Survey (USGS) as team leader, with additional USGS, U.S. Fish and Wildlife Service (USFWS), and Bureau of Reclamation (BOR) scientists representing several different disciplines. The study areas included all of the irrigable land within the irrigation unit and project. Return flows from the irrigable lands in both study areas do not discharge to a wildlife refuge and are not a source of drinking water. Reports that describe the results of the reconnaissance studies were completed for the ARU (Greene and others, 1990) and BFRP (Roddy and others, 1991).

Below-normal streamflows prevailed in both study areas during the sampling phase of the 1988 study. Correlations frequently exist between streamflow magnitude and some constituent concentrations; thus, surface water, bottom sediment, and fish were resampled in 1994 at selected sites in both study areas during generally near-normal streamflow conditions to compare with the 1988 study results.

In the 1988 studies, several criteria were used to evaluate concentrations of various constituents in surface water, bottom sediment, and biota to determine the extent to which these media might be affected by irrigation drainage in the study areas. In 1998, the NIWQP completed the compilation of a document entitled "Guidelines for the Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment" (U.S. Department of the Interior, 1998). This document identifies nine potentially toxic constituents that are commonly encountered in environments affected by irrigation drainage. If present, these constituents might cause harmful effects on human health or fish and wildlife within or immediately downstream from the irrigation areas.

Two primary criteria (the "level of concern" and the "toxicity threshold") have been established by NIWQP as guidelines to evaluate constituent concentrations for adverse environmental impact (U.S. Department of the Interior, 1998). The criteria are based on a study of toxicological benchmarks conducted by Suter and Mabrey (1994). "Level of concern" is defined as "a concentration of a toxic substance above which adverse effects may result from even brief exposure" (U.S. Department of the Interior, 1998). In the NIWQP guidelines, the "level of concern" for a given substance typically is presented as a concentration range. The lower limit of this range represents the lowest concentration that might produce any adverse effects by chronic (that is, long-term and low-level) exposure. The upper limit is equivalent to either the U.S. Environmental Protection Agency ambient water-quality chronic criterion (U.S. Environmental Protection Agency, 1999) or the secondary chronic value defined by Suter and Mabrey (1990); it represents a concentration known to result in more serious adverse effects. The upper limit of the "level of concern" concentration range is equivalent to the NIWQP "toxicity threshold."

The purpose of the 1994 sampling was to determine whether the below-normal streamflows that prevailed during the 1988 reconnaissance studies resulted in concentrations of potentially toxic constituents in the study area that are unrepresentative of typical hydrologic conditions. The objectives were to: (1) resample surface water, bottom sediment, and fish at selected sites in both study areas during near-normal streamflows; (2) assess the effects of streamflow variability on concentrations of potentially toxic constituents by comparing 1988 and 1994 data; and (3) compare results of 1988 and 1994 sampling with current guidelines. This report presents the results of the study.

DESCRIPTION OF THE STUDY AREAS

Angostura Reservoir, formed by the damming of the Cheyenne River, is located 9 mi southeast of Hot Springs, South Dakota (fig. 1). The ARU lands, consisting of 12,200 acres, are located on alluvial terraces and upland soils along both sides of the Cheyenne River from the reservoir downstream for approximately 24 mi. The entire unit lies within Fall River and Custer Counties in the southwestern corner of South Dakota. The study area includes the unit lands and surrounding vicinity. Additional information about the irrigation unit including history, land and water management, fish and wildlife use, climate, geology, soils and agriculture, and hydrologic setting, can be found in Greene and others (1990).

Waterfowl, primarily including blue-winged teal, mallards, widgeons, scaup, and Canada geese, use the area as breeding and wintering grounds and for migratory rest stops. Threatened and endangered species[1] in the area might include piping plover, bald eagle, migrating whooping crane, interior least tern, black-footed ferret, and the American burying beetle. The sturgeon chub, sickle fin chub, black-tailed prairie dog, and swift fox (candidate species), and the mountain plover (a proposed species), also might occur in the area. Other species of special interest that might occur in the area include golden eagle, Swainson's hawk, ferruginous hawk, and long-billed curlew. Additional information concerning wildlife in ARU can be found in Greene and others (1990).

[1]The Endangered Species Act of 1973 (ESA) provided for the conservation of species that are at risk of endangerment or extinction throughout all or a significant part of their range, and the conservation of the ecosystems on which they depend. The law is administered by the USFWS, with primary responsibility for terrestrial and freshwater organisms, and the National Marine Fisheries Service (NMFS), which oversees marine species, such as salmon and whales. Under the terms of the ESA, an at-risk species can be listed as "endangered" or "threatened," and also can be noted as being "proposed" for listing, or a "candidate" for listing (U.S. Fish and Wildlife Service, accessed May 2, 2001). Species determined to be in imminent danger of extinction throughout all or a significant part of their range are listed as "endangered." Species determined likely to become endangered in the foreseeable future are listed as "threatened." Species listed as "endangered" or "threatened" are federally protected. "Proposed" species have undergone preliminary investigation by USFWS and/or NMFS and have been determined to warrant listing. "Proposed" species receive limited legal protection under the ESA. After a species has been proposed for listing, an intensive review process is conducted before a final ruling is made on whether to list the species (Nicholopoulos, accessed May 2, 2001). A "candidate" species is, as its name implies, a candidate for listing; USFWS and/or NMFS are in the process of evaluating information to determine if that species should be proposed for listing. "Candidate" species receive no legal protection under the ESA, but Federal agencies work with State, local, and private groups to implement conservation practices on a voluntary basis.

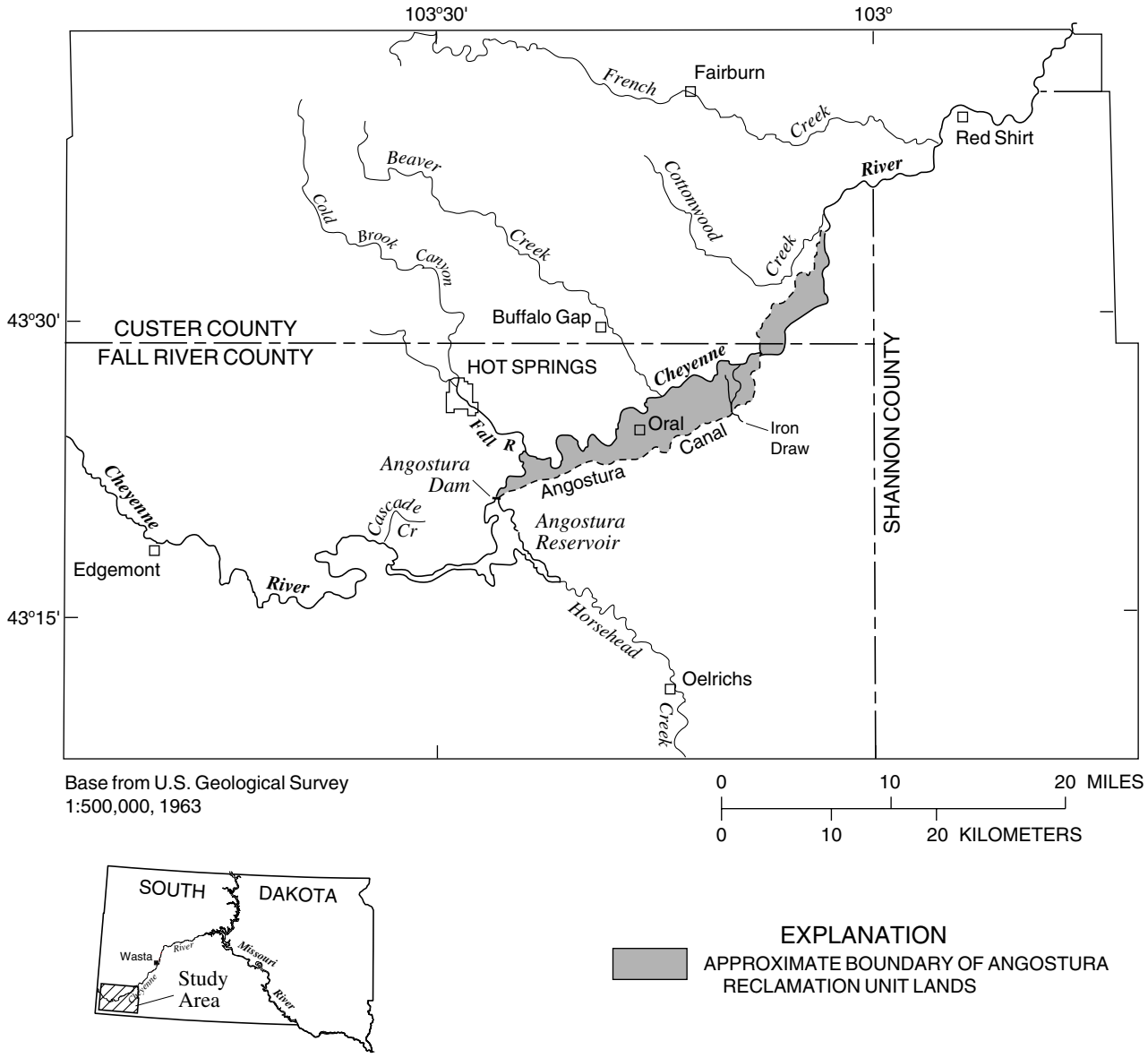


Figure 1. Location of the Angostura Reclamation Unit study area.

The Belle Fourche Reservoir is an offstream storage reservoir formed by water diverted from the Belle Fourche River and is located 6.6 mi northeast of Belle Fourche, South Dakota (fig. 2). The BFRP lands, consisting of 57,100 acres, are located in the Belle Fourche River Basin in the undulating plains of western South Dakota. The project lands extend downstream from the dam and cover an area approximately 25 mi long and 12 mi wide. The project lies almost entirely within Butte County in west-central South Dakota. Extensive irrigation operations also exist upstream from the BFRP along the Belle Fourche River, Redwater River, and Spearfish Creek. Additional information about the irrigation project including history, land and water management, fish and wildlife use, climate, geology, soils and agriculture, and hydrologic setting, can be found in Roddy and others (1991).

Waterfowl use this area for breeding, wintering, and resting during migration. Waterfowl species include those listed above for the ARU. Threatened and endangered species that might occur in the area include black-footed ferret, wintering bald eagle, migrating whooping crane, American burying beetle, interior least tern, and piping plover. Candidate and proposed species include those listed for the ARU. Golden eagle, Swainson's hawk, ferruginous hawk also might occur in the area. Additional information concerning wildlife in BFRP can be found in Roddy and others (1991).

SAMPLING SITES AND METHODS

The scope of the 1994 study was substantially smaller than the 1988 study; as a result, fewer sites, numbers of samples, and types of analyses were included in the 1994 sampling. Results of the 1988 data collection were reviewed in developing the sampling design for the 1994 data collection. In the 1994 sampling, representative index sites, sampling periods, and types of analyses were selected to evaluate effects of streamflow variability between 1988 and 1994 on concentrations of potentially toxic constituents. For the 1994 study, selection of sampling sites generally was based on sites where biota were sampled in the 1988 studies.

In the 1988 studies, 14 sites were sampled in and near the ARU for various media including water, bottom sediment, and biota (Greene and others, 1990). For the 1994 study, four sites were sampled (fig. 3, table 1); these sites are designated as A-1, A-5, A-12, and A-14. Data collected during 1988 at these sites and at sites A-2 and A-8 (fig. 3, table 1) are used for comparisons in following sections of this report. Only site A-14 was sampled for water, bottom sediment, and biota in both 1988 and 1994. Sites A-2 and A-8 were sampled for water and bottom sediment in 1988 and were selected as being reasonably similar to some of the sites sampled in 1994 to allow additional comparison of water-quality and bottom-sediment results between 1988 and 1994.

Table 1. Site information and media samples for selected sampling sites in or near the Angostura Reclamation Unit and the Belle Fourche Reclamation Project

[Media codes: W, surface-water quality; S, bottom sediment; B, biota (fish only in 1994)]

Site number (from 1988 studies)	Station number	Station name	Latitude	Longitude	Media sampled in 1988	Media sampled in 1994
A-1	06395000	Cheyenne River at Edgemont	431820	1034914	B	W, S, B
A-2	06400500	Cheyenne River near Hot Springs	431819	1033343	W, S	
A-5	432121103252600	Cheyenne River 0.75 mile downstream from Angostura Dam	432121	1032526	B	W, S, B
A-8	06402400	Cheyenne River above Buffalo Gap	432505	1031716	W, S	
A-12	433012103042000	Cheyenne River near Custer County bridge 656	433012	1030420	B	W, S, B
A-14	06403700	Cheyenne River at Redshirt[1]	434023	1025336	W, S, B	W, S, B
B-1	06428500	Belle Fourche River at Wyoming-South Dakota State line	444459	1040249	W	W, S, B
B-2		Belle Fourche River above Belle Fourche	444126	1035503	B	
B-12	06436760	Horse Creek above Vale	443908	1032159	W, S, B	W, S, B
B-18	06437000	Belle Fourche River near Sturgis	443047	1030811	W, S, B	W, S, B

[1]Site was called Cheyenne River near Fairburn in 1988.

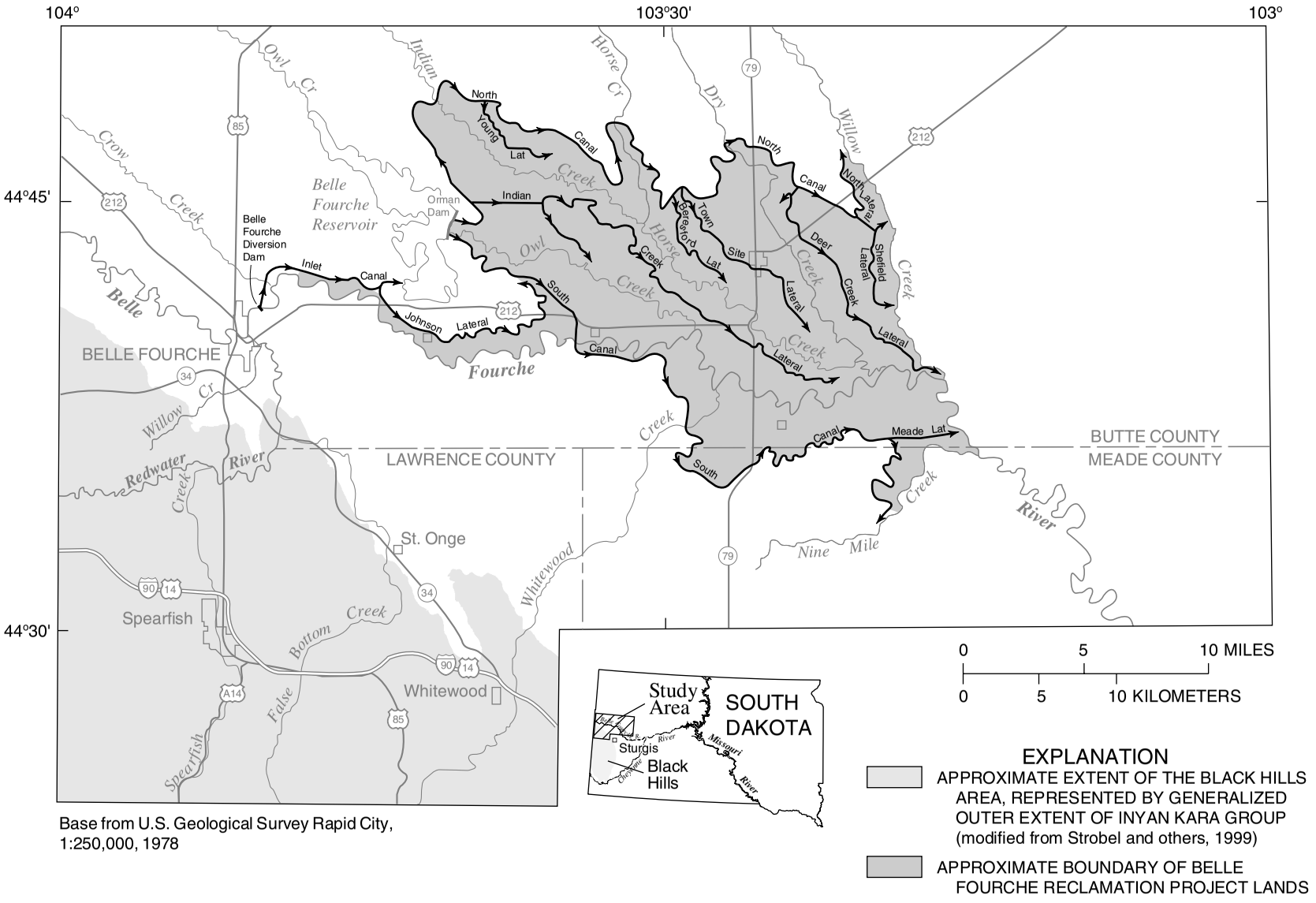
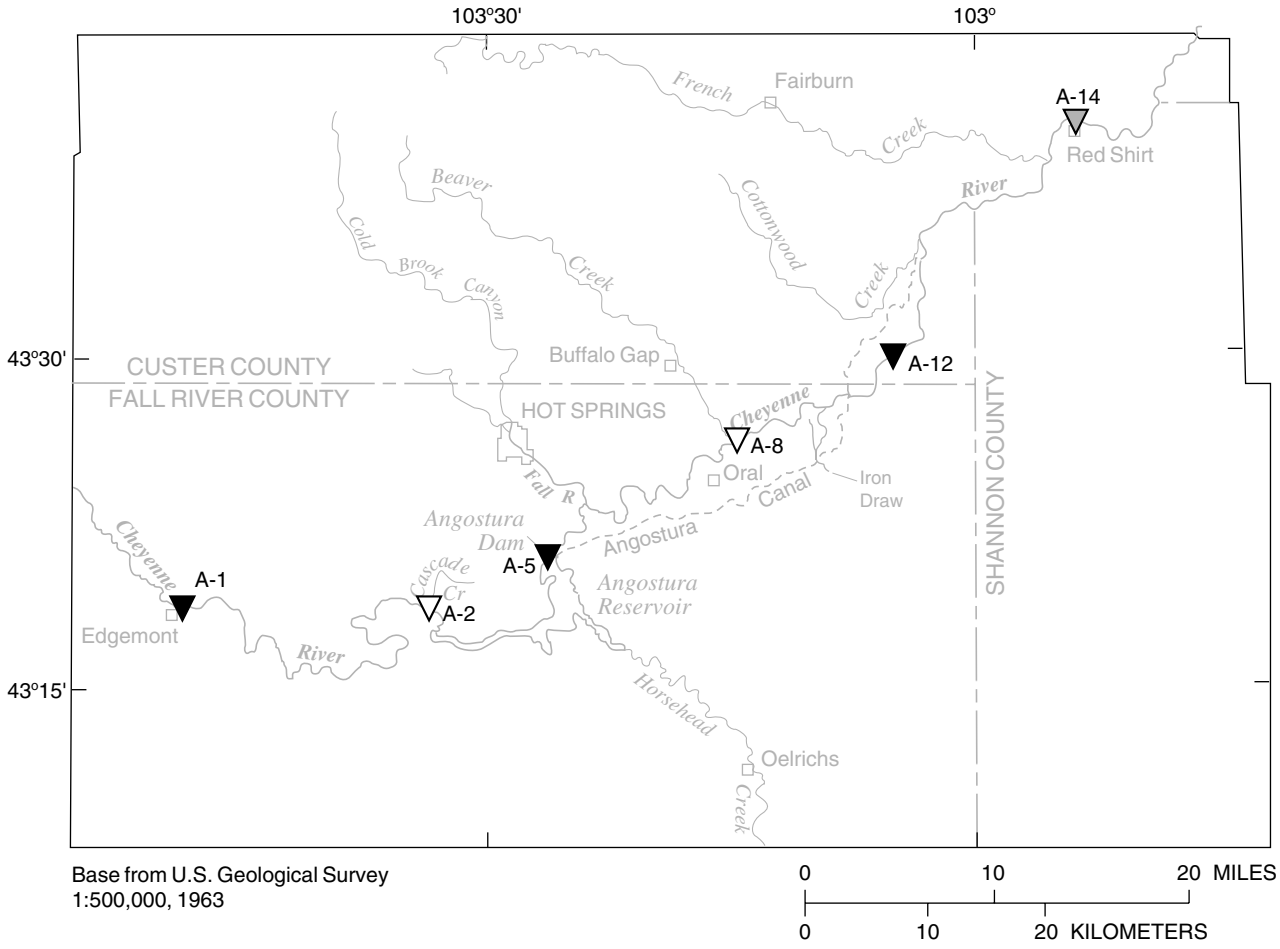


Figure 2. Location of the Belle Fourche Reclamation Project study area.



EXPLANATION

SAMPLING SITE--Number indicates site number

A-1 — Sampled in 1994 for water, bottom sediment, and biota; sampled in 1988 for biota only

A-2 — Sampled in 1988 only for water and bottom sediment

A-14 — Sampled in both 1988 and1994 for water, bottom sediment, and biota

06423500 — STREAMFLOW-GAGING STATION--Number indicates site identification. No water-quality sample collected

Figure 3. Locations of selected sampling sites in the Angostura Reclamation Unit study area.

For the BFRP, 19 sites were sampled in 1988 (Roddy and others, 1991). For the 1994 study, three sites were sampled (B-1, B-12, and B-18; fig. 4, table 1). Data collected during 1988 at sites B-1, B-2, B-12, and B-18 (fig. 4, table 1) are used for comparisons in following sections of this report. No biota samples were collected from site B-1 in 1988; site B-2 was sampled for biota in 1988, and this site was selected as being reasonably similar to site B-1 to allow additional comparison of biota results between 1988 and 1994.

The sampling and analytical methods used in 1994 generally were the same as those used in 1988 (Greene and others, 1990; Roddy and others, 1991). Selected constituents analyzed in the water, bottom sediment, and biota samples for 1994 are presented in table 2. In 1988, a variety of biota (plants, fish, and animals) were sampled; however, only fish-tissue samples were collected in 1994. Sampling and analytical methods are described in detail in those reports, and are summarized below.

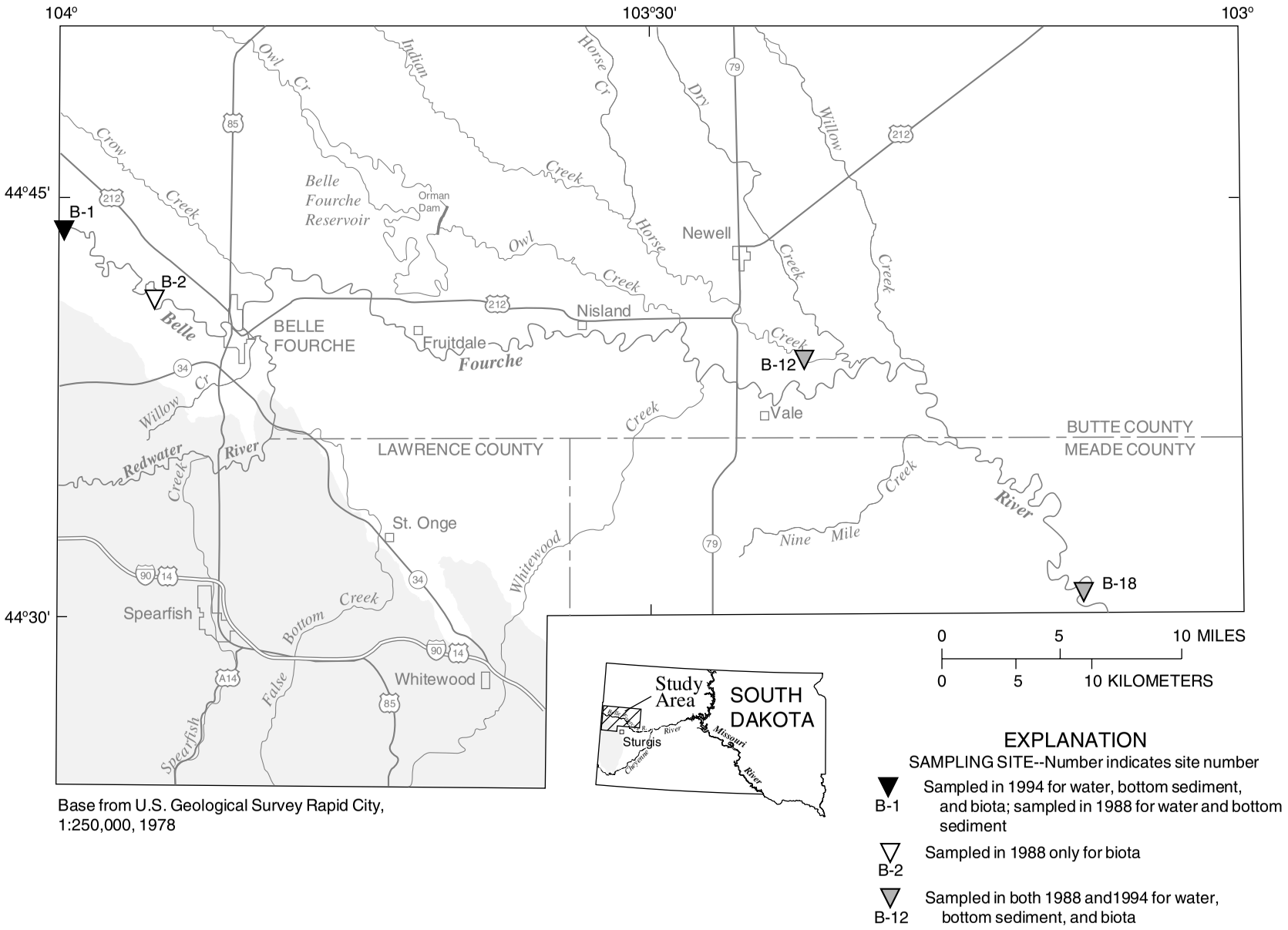
Table 2. Selected constituents and properties analyzed for in water, bottom-sediment, and fish-tissue samples for the Angostura Reclamation Unit and Belle Fourche Reclamation Project in 1994

[µg/L, micrograms per liter]

Surface water (dissolved concentration[1])	Bottom sediment (total recoverable concentration[2])		Fish tissue (total concentration[2])
Constituent or property (milligrams per liter unless noted otherwise)	Trace elements and major ions (micrograms per gram unless noted otherwise)		Trace elements and major ions (micrograms per gram, dry weight)
Calcium	Aluminum (percent)	Mercury	Aluminum
Magnesium	Arsenic	Molybdenum	Arsenic
Potassium	Barium	Neodymium	Boron
Sodium	Beryllium	Nickel	Barium
Alkalinity (as $CaCO_3$)	Bismuth	Niobium	Beryllium
Chloride	Boron	Phosphorus (percent)	Cadmium
Sulfate (as SO_4^{2-})	Cadmium	Potassium (percent)	Chromium
Dissolved solids	Calcium (percent)	Scandium	Copper
Nitrogen species (as nitrogen)	Cerium	Selenium	Iron
Aluminum (µg/L)	Chromium	Silver	Mercury
Arsenic (µg/L)	Cobalt	Sodium (percent)	Magnesium
Boron (µg/L)	Copper	Strontium	Manganese
Cadmium (µg/L)	Europium	Tantalum	Molybdenum
Chromium (µg/L)	Gallium	Thorium	Nickel
Copper (µg/L)	Gold	Tin	Lead
Lead (µg/L)	Holmium	Titanium (percent)	Selenium
Mercury (µg/L)	Iron (percent)	Uranium	Strontium
Molybdenum (µg/L)	Lanthanum	Vanadium	Vanadium
Selenium (µg/L)	Lead	Ytterbium	Zinc
Uranium (µg/L)	Lithium	Yttrium	
Vanadium (µg/L)	Magnesium (percent)	Zinc	
Zinc (µg/L)	Manganese		

[1]"Dissolved" is operationally defined as that part of a water sample that passes through a 0.45-µm pore-size filter.

[2]Distinction should be noted between the "total recoverable" concentrations describing bottom-sediment results and the "total" concentrations describing fish-tissue results. Digestion procedures for bottom-sediment samples typically result in less than 95 percent of the rock/soil material being solubilized; thus, analytical results for bottom-sediment samples are termed "total recoverable" concentrations. Digestion procedures for fish-tissue samples typically result in greater than 95 percent of the tissue material being solubilized; thus, analytical results for fish-tissue samples are termed "total" concentrations.



Base from U.S. Geological Survey Rapid City, 1:250,000, 1978

Figure 4. Locations of selected sampling sites in the Belle Fourche Reclamation Project study area.

In 1994, water and fish samples were collected in April and May, when irrigation return flows constitute the smallest part of streamflows, and in September when irrigation return flows generally constitute the largest part of streamflows. Bottom-sediment samples were collected only in September. In 1988, samples also were collected during similar time periods.

Water-quality samples were collected using standard procedures of the USGS (Edwards and Glysson, 1988). Field parameters, including air temperature, water temperature, pH, alkalinity, specific conductance, dissolved-oxygen concentration, and discharge were determined at each sampling site. Quality-control samples, including blanks, replicates, and split samples, were collected to document the variability in the results and whether contamination was introduced during sampling and processing. Chemical analyses of water samples were performed by the USGS National Water Quality Laboratory, Denver, Colorado.

Generally, quality-control samples indicated that water-quality results were representative of environmental conditions and were not substantially affected by contamination or bias introduced during sampling and analysis processes. Analytical results for field blank samples collected in 1988 were not readily available; however, Greene and others (1990) and Roddy and others (1991) reported that quality-control samples indicated that generally there was no inadvertent gross contamination of water samples from field or laboratory procedures. Some 1988 blank samples had detections of mercury that were comparable to concentrations reported for environmental samples (Roddy and others, 1991); thus, reported concentrations for mercury should be used with caution. Constituent concentrations for field blank samples collected in 1994 were all near or less than minimum reporting limits. Replicate samples for both 1988 and 1994 showed little variability between the replicates and the associated primary samples for most constituents. For a few trace elements that tend to have large potential for contamination (including aluminum, lead, and zinc), some replicate samples for both 1988 and 1994 showed large variability between the replicates and the associated primary samples; thus, reported concentrations for aluminum, lead, and zinc should be used with caution.

Procedures used to collect bottom-sediment samples for both 1988 and 1994 are described in detail in Greene and others (1990) and Roddy and others (1991). Generally, the bottom-sediment sample collection procedures followed guidelines presented in Ward and Harr (1990). Samples of bottom sediments were collected along cross sections at seven sites in both study areas using a stainless-steel, Teflon-coated scoop. At least nine evenly spaced subsamples were collected along each cross section. The subsamples were composited and mixed into a single sample for each site, from which about 300 grams were submitted for analysis to the Branch of Geochemistry Laboratory of the USGS, Geologic Division, Lakewood, Colorado. Prior to analysis, bottom-sediment samples were dried and then processed using a rigorous acid digestion to break down the rock/soil matrix, and desorb and solubilize constituents. However, because some rock/soil material is somewhat resistant to acid activity, not all of the rock/soil material is solubilized. Typically, less than 95 percent of a given bottom-sediment sample is solubilized during analytical processing. Thus, analytical results for bottom-sediment samples are termed "total recoverable" concentrations.

Quality-control replicates for bottom-sediment samples were collected to document variability in the results. Replicate samples for both 1988 and 1994 generally showed little variability between the replicates and the associated primary samples for most constituents. For a few constituents (including barium and manganese), replicates collected in 1988 showed moderate variability between the replicates and the associated primary samples that was larger than the variability for 1994 replicates. However, variability in the replicates for those constituents was not large enough to obscure differences in concentrations between sites or between years.

Fish samples were collected using standard equipment and techniques of USFWS (1985). General information concerning fish sample collection methods used also are described in Greene and others (1990) and Roddy and others (1991). Specific collection procedures varied somewhat between 1988 and 1994. In 1988, numerous samples for several fish species were collected each time a site was sampled; samples consisted of both individual fish as well as composite samples of multiple individuals (from 2 to 19) of a given species. Generally, consistency was maintained

in the species that were collected between different sampling periods for a given site in 1988. In 1994, two fish samples were collected each time a site was sampled; samples consisted of both individual fish as well as composite samples of multiple individuals (from 2 to 29) of a given species. For fish samples collected in 1994, there was substantial variability in the species collected between different sampling periods. Thus, the small number of samples collected and the variability in the species collected complicated the interpretation of 1994 results for fish samples. In 1988, replicate fish samples were collected for quality-control purposes. Generally, replicate fish samples for a given age class and species showed little variability in constituent concentrations.

Fish-tissue samples were analyzed by contract laboratories approved by the USFWS Patuxent Control Facility in Laurel, Maryland. Prior to analysis, fish-tissue samples were freeze dried and then processed using an acid digestion to break down the tissue matrix, and desorb and solubilize constituents. The soft organic material is quite vulnerable to acid activity, and nearly all of the tissue is solubilized. Typically, more than 95 percent of a given fish-tissue sample is solubilized during analytical processing. Thus, analytical results for fish tissues are termed "total" concentrations.

STREAMFLOW CONDITIONS

Streamflow conditions were closer to normal in 1994 than in 1988 (table 3 and fig. 5). Annual discharge for the Cheyenne River at Edgemont was about 99 percent of the long-term median in 1994 and about 19 percent of the long-term median in 1988. Annual discharge for the Belle Fourche River at Sturgis was about 116 percent of the long-term median in 1994 and less than 60 percent of the long-term median in 1988. Discharge measurements made at the times that water and bottom-sediment samples were collected averaged about 40 percent greater for 1994 samples than for 1988 samples, for both ARU and BFRP sites.

Table 3. Comparison of annual discharge for 1988 and 1994 with long-term median annual discharge for selected sites on the Cheyenne and Belle Fourche Rivers

Site number	Station number	Station name	Period of analysis	Annual discharge, in cubic feet per second		Percent of long-term median annual discharge	
				1988	1994	1988	1994
A-1	06395000	Cheyenne River at Edgemont	1903-07, 1928-33, 1947-94	12.0	63.0	18.9	99.2
	06401500	Cheyenne River below Angostura Dam	1946-94	1.53	133	2.4	244.1
	06423500	Cheyenne River near Wasta	1915, 1928-32, 1934-94	132	332	42.2	106.1
B-1	06428500	Belle Fourche River at Wyoming-South Dakota State line	1947-94	52.7	93.9	64.0	114.0
B-12	06436760	Horse Creek above Vale	1981-94	24.3	39.8	67.6	110.9
B-18	06437000	Belle Fourche River near Sturgis	1946-94	133	261	59.3	116.5

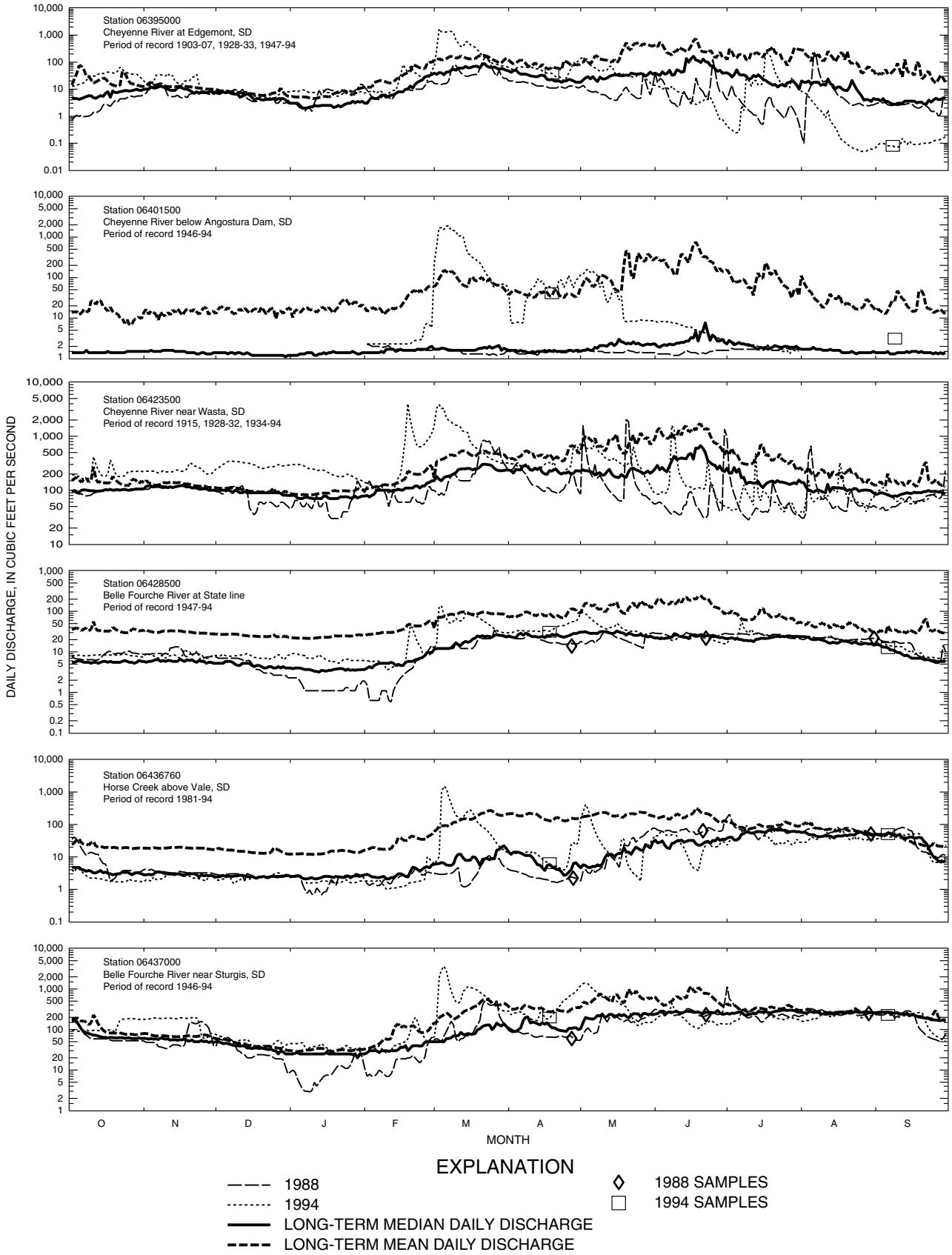


Figure 5. Comparison of daily discharge for 1988 and 1994 with long-term median and mean daily discharge for selected sites on the Cheyenne and Belle Fourche Rivers.

COMPARISON OF RESULTS

Angostura Reclamation Unit

Comparisons are made between data collected in 1988 and 1994 to reach conclusions concerning effects of streamflow variability, and to provide further information about effects of irrigation drainage on aquatic environments. Water-quality, sediment, and fish analytical results are presented for both the ARU and the BFRP.

Water Quality

Analytical results for water samples collected in 1994 are shown in table 10 in the Supplemental Information section at the back of the report. Major-ion and trace-element concentrations for all sites sampled in 1994 are jointly statistically summarized and compared with jointly summarized data from the 1988 representative sites, and with national baseline values (Smith and others, 1987) and various water-quality criteria in table 4. Ranges and medians of concentrations of most major ions for the jointly summarized 1994 data are slightly lower than values for the representative sites sampled in 1988. All major-ion concentrations are high for both 1988 and 1994; minimum concentrations for both 1988 and 1994 generally exceed national baseline values (table 4).

Chemical characteristics of the Cheyenne River and its tributaries in the study area are influenced by a wide variety of geologic conditions that are described in more detail by Greene and others (1990). The majority of the ARU is within outcrops of the Pierre Shale, which is a black marine shale of Cretaceous age. Alluvial and terrace deposits occur along the Cheyenne River and other drainages. Grain-size distributions of these unconsolidated deposits can range from clay to boulders and mineralogic composition also can be extremely variable. Some tributaries of the Cheyenne River in the study area have their headwaters in the Black Hills. Contact with Paleozoic-age limestones in the upper reaches of these streams influences their chemical characteristics.

Stiff diagrams (Stiff, 1951) showing average dissolved-solids concentrations and proportions of major ions in water samples are presented in figure 6 for sites in the study area. The diagrams illustrate differences in water type and ionic proportions at different sites and between 1988 and 1994.

Comparison of ionic proportions and dissolved-solids concentrations between sites and years is difficult because most of the sites did not have water-quality samples collected in both years. Differences in flow conditions could affect comparisons, especially with respect to dissolved-solids concentrations. However, some general patterns might be evident. The ionic composition of the Cheyenne River varies dramatically within the upper part of the study reach. Between sites A-1 and A-2, ionic proportions change and concentrations of dissolved solids substantially decrease, primarily as a result of large decreases in concentrations of sodium and chloride. The dramatic change largely is due to substantial inflow of Cascade Springs water, which has lower dissolved-solids concentration, with calcium and sulfate being dominant ions. Between sites A-2 and A-5, concentrations of dissolved solids decrease further, primarily as a result of decreases in concentrations of calcium and sulfate. Site A-2 is representative of Cheyenne River water flowing into Angostura Reservoir, and site A-5 is representative of water released from Angostura Reservoir. Angostura Reservoir integrates inflows from the Cheyenne River and various upstream tributaries over time. Differences in water quality between sites A-2 and A-5 that are evident in figure 6 might be due to hydrologic differences between 1988 and 1994. The differences might also relate to effects of Angostura Reservoir, which include: (1) mixing of Cheyenne River inflows with inflows of smaller tributaries to Angostura Reservoir; (2) temporal influences related to residence time for water in the reservoir; and (3) geochemical and biological processes occurring within the reservoir. Downstream from Angostura Reservoir during both 1988 and 1994, small increases in concentrations of dissolved solids probably occurred; however, the limited data sets that are available are insufficient to perform a detailed analysis of potential effects of irrigation practices.

Effects of differences in flow conditions between 1988 and 1994 on concentrations of dissolved solids and ionic proportions are best shown by comparing the Stiff diagrams for site A-14 for 1988 and 1994. The mean discharge at the times of sampling was about 40 percent higher in 1994 than in 1988 at this site. Mean dissolved-solids concentrations are smaller for 1994 when flow conditions generally are higher. Proportions of major ions are similar between 1988 and 1994 (fig. 6), even though the concentrations of major ions are somewhat smaller for 1994.

Table 4. Comparison of major-ion and selected trace-element concentrations in surface water for the Angostura Reclamation Unit with selected index values, guidelines, and criteria

[Major-ion concentration, in milligrams per liter; trace-element concentration, in micrograms per liter; <, less than; >, greater than; --, no data; 8 samples per element in 1994, 12 samples per element in 1988]

Constituent	1994			1988			National baseline[1]	National Irrigation Water Quality Program Guidelines level of concern[2]	Surface-water quality criteria		
	Minimum	Maximum	Median	Minimum	Maximum	Median			Aquatic life acute/ chronic[3]	Irrigation[4]	Livestock watering[4]
Major Ions											
Calcium	180	270	240	160	530	265	66.8	--	--	--	--
Magnesium	53	110	79	58	100	86	21.7	--	--	--	--
Sodium	190	1,100	220	100	320	160	68.9	--	--	--	--
Potassium	8.7	20	12	6.8	16	10	--	--	--	--	--
Bicarbonate plus carbonate[5]	168	428	211	80	224	187	161.8	--	--	--	--
Sulfate	790	3,300	1,035	700	1,900	1,200	116.9	--	--	--	--
Chloride	96	540	120	82	170	125	53.3	--	--	--	--
Trace Elements											
Arsenic	<1	2	<1	<1	1	1	3	48–190	360/190	100	200
Boron	160	1,100	270	190	370	265	--	500–10,000 for plants 5,000–25,000 for fish	--	750	5,000
Cadmium	<1	<1	<1	<1	5	<1	< 2	--	[6]40/5.2	10	50
Chromium	<1	<1	<1	<1	4	2	--	--	--	--	--
Copper	<1	1	<1	<1	2	1	--	0.23–12	[6]135/74	200	500
Lead	<1	<1	<1	<5	6	<5	6	--	[6]630/24	5,000	100
Mercury	<0.1	<0.2	<0.1	<0.1	5.3	<0.1	0.3	>30	[7]2.1/0.012	--	10
Molybdenum	4	8	6.5	4	16	8	--	50,000 for plants 20–120 for fish	--	--	--
Selenium	<1	4	2	<1	4	3	1	1–2	20/5	20	50
Uranium	7.6	25	12	6.5	15	9.8	--	--	--	--	--
Zinc	<10	<10	<10	<10	76	10	21	30–110	[6]740/670	2,000	25,000

[1]The National Stream Quality Accounting Network and the National Water Quality Surveillance System have provided information on the Nation's water quality since 1973. Smith and others (1987) used data from these two nationwide sampling networks to provide long-term water-quality trends (national baseline values) of major United States rivers. The national baseline value for each water-quality property or constituent is equal to the 75th station-mean concentration percentile.

[2]U.S. Department of the Interior, 1998; the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

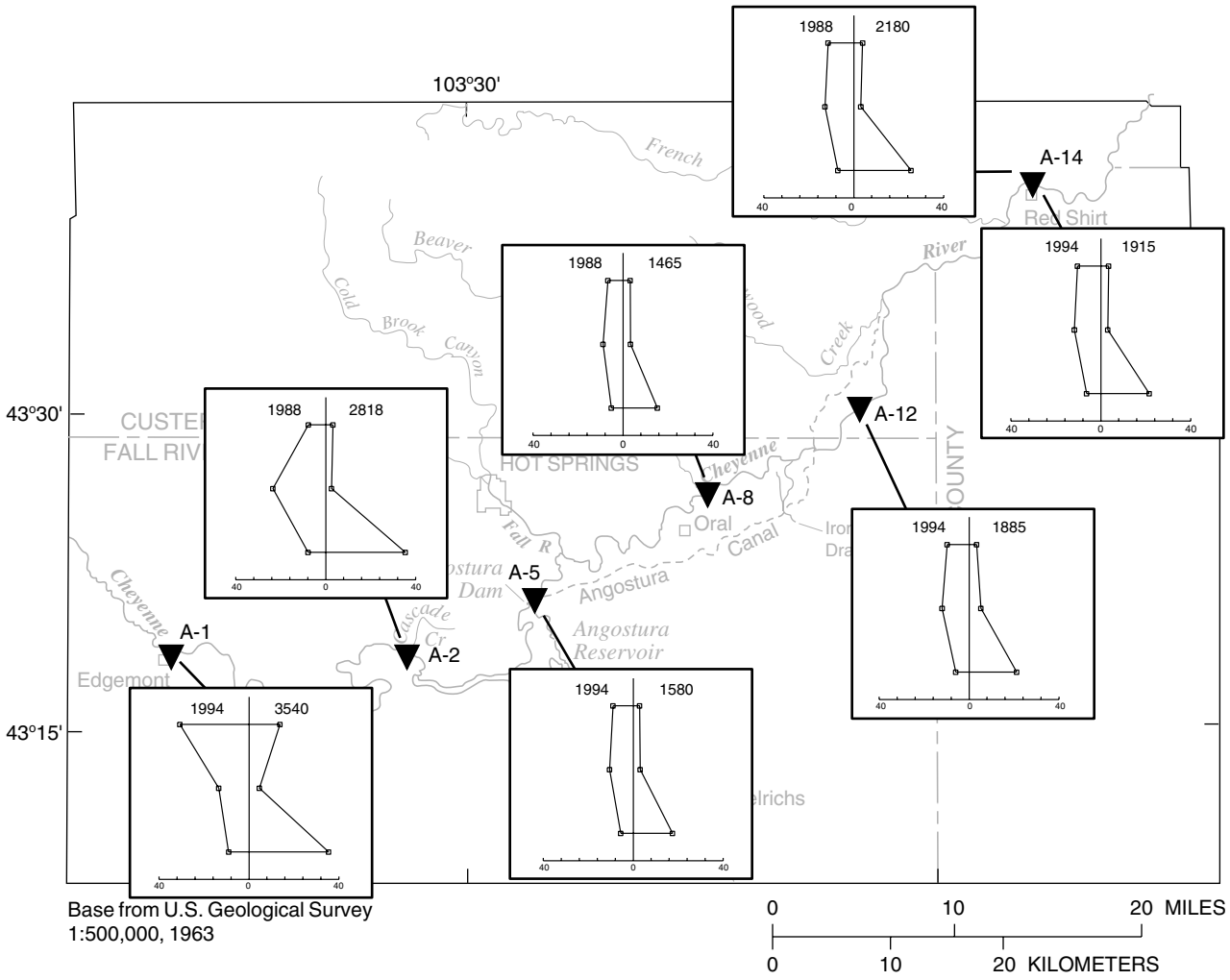
[3]South Dakota Legislative Research Council, accessed May 4, 2001.

[4]National Academy of Sciences – National Academy of Engineering, 1973.

[5]Reported as bicarbonate (HCO_3^-).

[6]Hardness dependent criteria, value shown is based on a hardness of 900 milligrams per liter, a value that is similar to hardness of water in the Angostura Reclamation Unit area.

[7]Based on total recoverable fraction of the metal.



EXPLANATION

▼ A-1 SURFACE-WATER QUALITY SAMPLING SITE--Number indicates site number

STIFF DIAGRAM--Number to the left of y-axis is year sample was collected. Number to the right of y-axis is dissolved-solids concentration in milligrams per liter

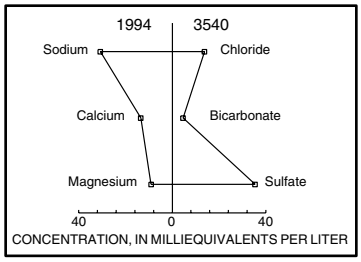


Figure 6. Stiff diagrams showing average dissolved-solids concentrations and proportions of major ions in water samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994.

As is the case for 1988, major-ion concentrations for 1994 at site A-14, at the downstream end of the ARU, are lower than concentrations upstream from Angostura Reservoir at site A-1. Irrigation practices have potential to increase concentrations of dissolved constituents through evaporative concentration and increased contact with geologic materials. However, potential increases in solids concentrations attributable to irrigation operations cannot be quantified from the limited data sets. In addition to the irrigation operations of the ARU, many factors, including other land-use influences and natural variability in dissolved-solids loads from tributaries, contribute to differences between dissolved-solids concentrations upstream and downstream from the ARU. In general, both the 1988 and 1994 data indicate that any increases in dissolved-solids concentrations resulting from irrigation operations are smaller than the overall decreases in dissolved-solids concentrations between sites upstream from Angostura Reservoir and site A-14 at the downstream end of the ARU.

Selected trace-element concentrations in water samples collected from all sites in 1994 and the representative sites for 1988 are shown in figure 7. Concentrations of arsenic, cadmium, copper, lead, and mercury were near or less than the minimum reporting levels (MRL's), and medians and distributions for 1988 and 1994 are similar (table 4, fig. 7). Differences in flow conditions between 1988 and 1994 did not substantially affect concentrations of these constituents, or the effects of the flow variability occurred at concentrations less than the MRL's. Lead and mercury values are not plotted on figure 7 because most of the values are less than the MRL's. Values exceeding the MRL's for lead and mercury might be suspect, primarily due to potential for contamination during sampling and processing.

Concentrations of boron, molybdenum, selenium, and uranium generally are higher than the MRL's, and medians for 1988 and 1994 are similar (table 4, fig. 7) when data for multiple sites in the ARU are summarized jointly. Concentrations of chromium and zinc generally are higher than the MRL's for 1988, but less than the MRL's for 1994.

Effects of flow variability on concentrations of trace elements are best shown by examining relations between trace-element concentrations and discharge at site A-14 for 1988 and 1994 (fig. 8). Concentrations of molybdenum, selenium, and uranium show little correlation with discharge; apparently, in the ARU, these constituents are largely governed by geochemical controls not strongly influenced by discharge. Differences in flow conditions between 1988 and 1994 probably did not substantially affect in-stream concentrations of molybdenum, selenium, and uranium.

Concentrations of chromium and zinc do not show strong correlation with discharge, but tend to be higher for 1988 than for 1994. The higher concentrations for these constituents for 1988 probably are not related to differences in flow conditions.

Concentrations of boron show a strong inverse relation with discharge (fig. 8). Boron is a hydrophilic conservative ion that tends to remain in solution under a wide range of ionic strength (Hem, 1985). During low-flow conditions, base flow derived from groundwater discharge can comprise a larger part of total discharge of the Cheyenne River than during higher flow conditions. Therefore, during low-flow conditions, water in the Cheyenne River could have relatively greater contact with geologic materials and could have higher concentrations of conservative ions. Thus, concentrations of conservative ions, such as boron, were lower in 1994 when discharges generally were greater than in 1988.

As is the case for 1988, 1994 concentrations of trace elements at site A-14, at the downstream end of the ARU, are similar to concentrations upstream from and within the ARU. The 1994 data verify the general conclusion of Greene and others (1990) that irrigation operations of the ARU probably are not contributing discernible additional loads of trace elements to the Cheyenne River.

To determine if trace-element concentrations are high enough to be potentially harmful, they are compared to several standards (table 4, fig. 7). Concentrations of boron, copper, selenium, and zinc for some samples are within or exceed the NIWQP level of concern (U.S. Department of the Interior, 1998), and concentrations of boron, cadmium, lead, and mercury for some samples exceed South Dakota surface-water quality criteria (South Dakota Legislative Research Council, accessed December 20, 1999, appen. B). Concentrations of cadmium, copper, lead (not plotted in fig. 7), mercury (not plotted in fig. 7), and zinc frequently are less than MRL's for both 1988 and 1994 (table 10, fig. 7). Concentrations detected generally are at or very near the MRL where confidence in quantitative results can be low. Although there are some exceedances of criteria for these constituents, concentrations in the ARU area do not routinely occur at levels that are clearly problematic.

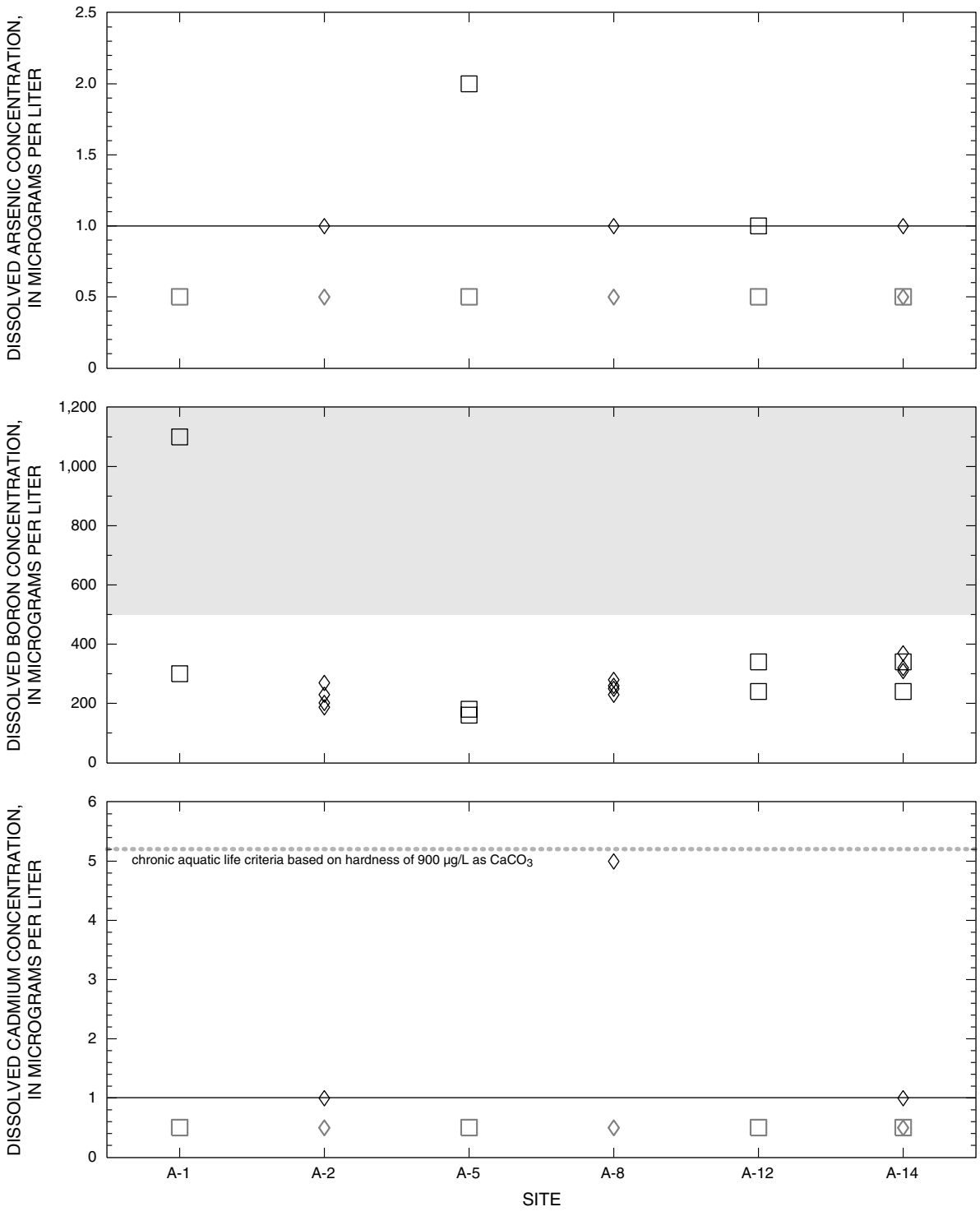


Figure 7. Concentrations of selected trace elements in water samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994.

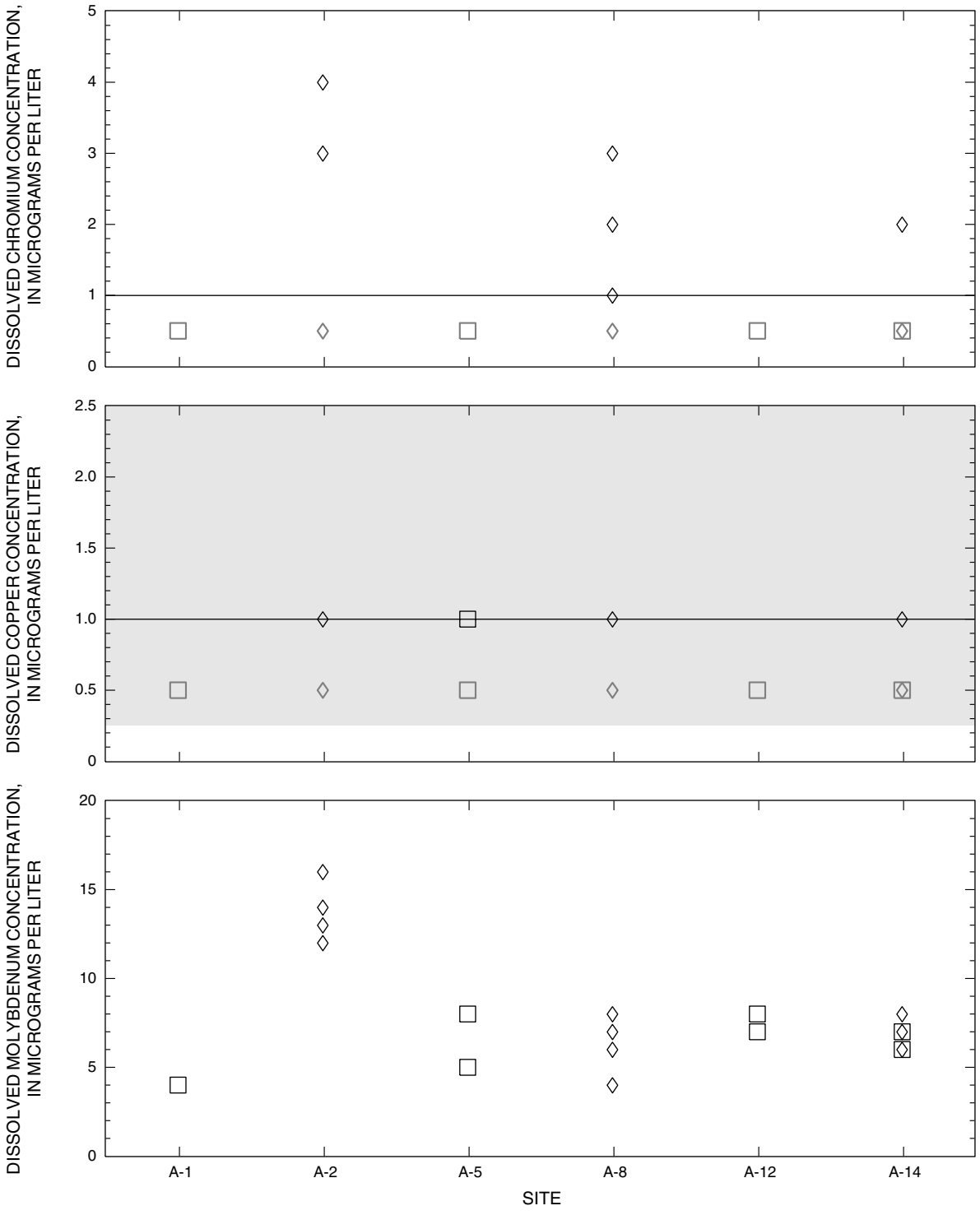


Figure 7. Concentrations of selected trace elements in water samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994. --Continued

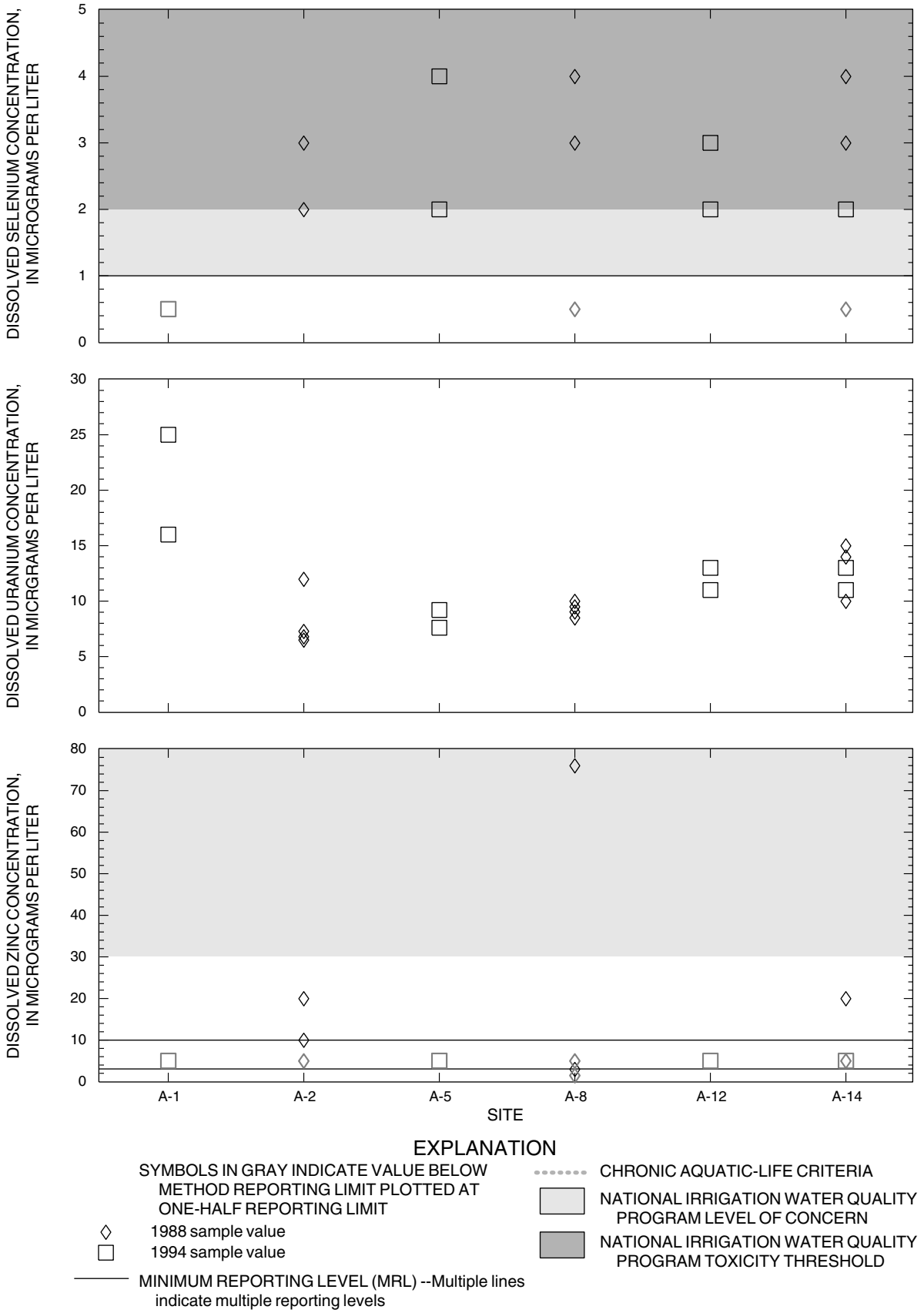


Figure 7. Concentrations of selected trace elements in water samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994. --Continued

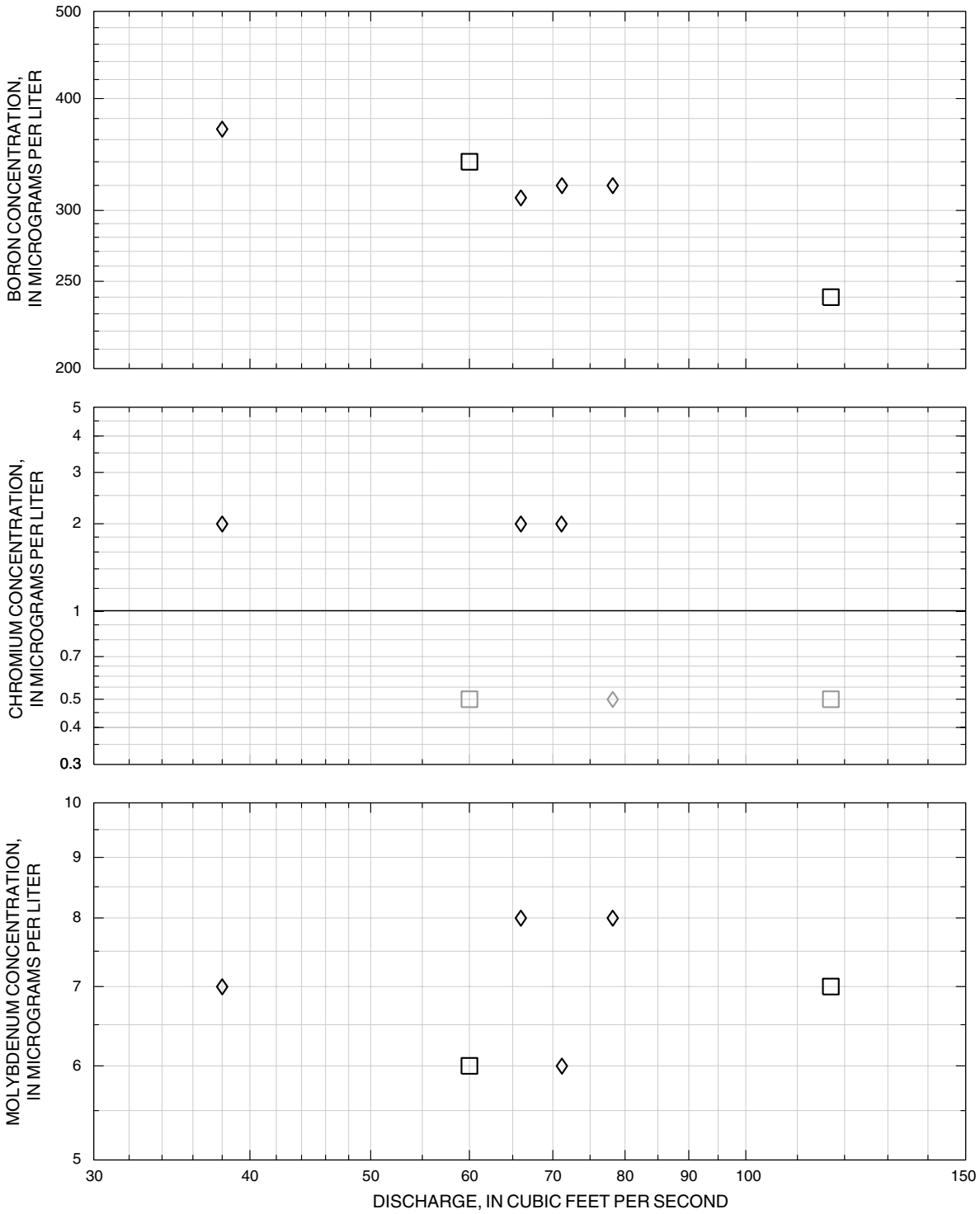


Figure 8. Relations between concentrations of selected constituents and discharge for water samples collected from site A-14 in 1988 and 1994.

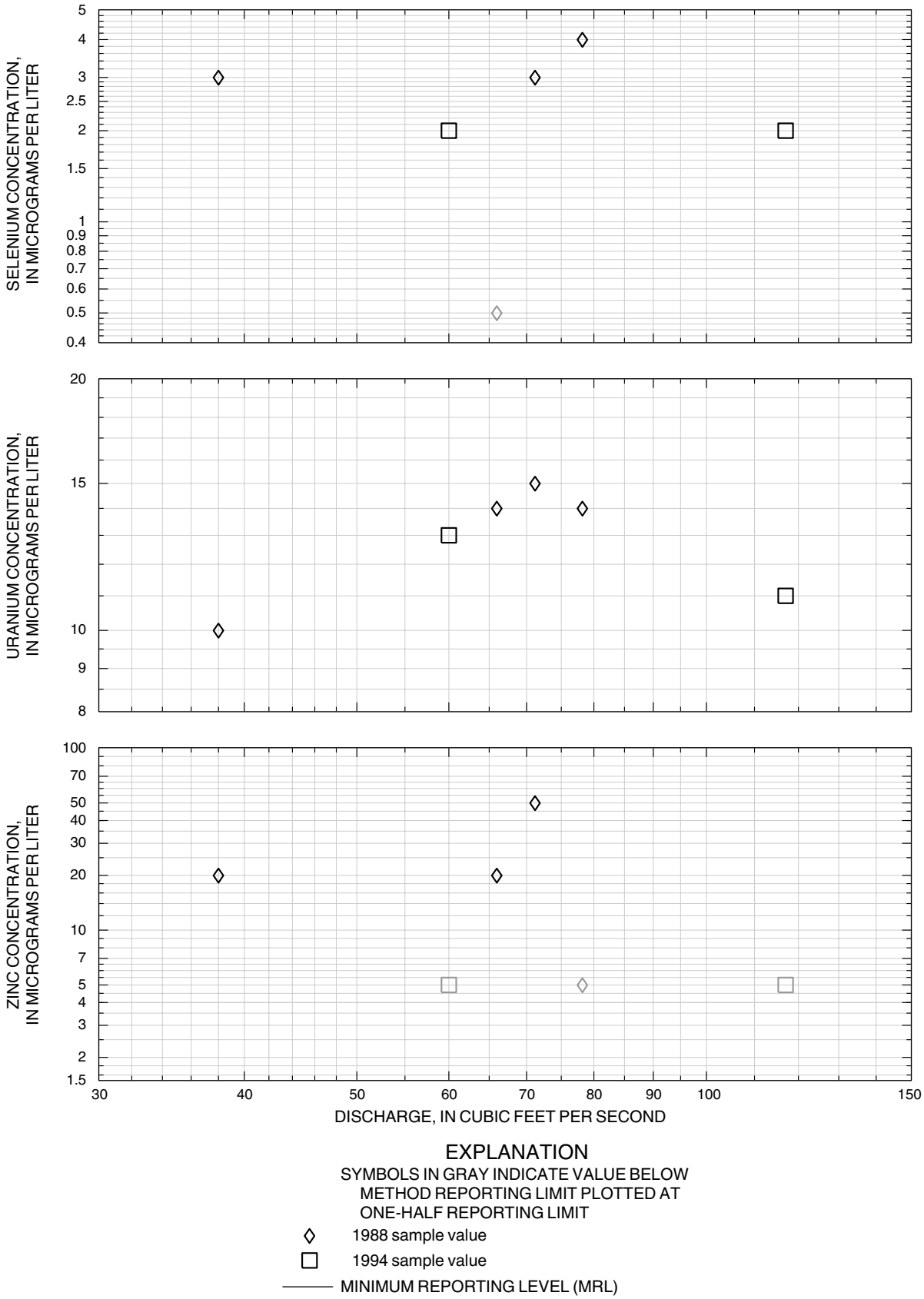


Figure 8. Relations between concentrations of selected constituents and discharge for water samples collected from site A-14 in 1988 and 1994.--Continued

A single water sample collected from site A-1 (upstream from the ARU) for 1994 has a boron concentration (1,100 µg/L) that is within the NIWQP level of concern. This sample was collected during extreme low-flow conditions (0.06 ft^3/s); although this sample is within the NIWQP level of concern and exceeds the National Academy of Sciences - National Academy of Engineering recommended limits for irrigation of 750 µg/L (table 4), the concentration is not typical of general conditions at this site or within the ARU area.

Selenium concentrations for many samples for both 1988 and 1994 are within or exceed the NIWQP level of concern. Concentrations at sites A-2 (1988), A-5 (1994), A-8 (1988), A-12 (1994), and A-14 (1988 and 1994) exceed the NIWQP toxicity threshold. Concentrations within the NIWQP level of concern or exceeding the toxicity threshold occur at sites both upstream and downstream from the ARU. Therefore, elevated selenium concentrations occur naturally in the ARU area, and irrigation operations of the ARU probably do not contribute substantially to selenium concentrations in the Cheyenne River. Concentrations at site A-14 at the downstream end of the ARU are similar to concentrations at sites upstream from and within the ARU (fig. 7). Differences in flow conditions between 1988 and 1994 did not substantially affect selenium concentrations relative to NIWQP guidelines. None of the selenium concentrations in either 1988 or 1994 exceed any South Dakota criteria for surface-water quality.

Sediment

Analytical results for the less-than-62-µm fraction of bottom-sediment samples collected in 1994 are presented in table 11 in the Supplemental Information section. Major-ion and trace-element concentrations for all sites sampled in 1994 are jointly statistically summarized and compared with jointly summarized data from the 1988 representative sites, and with western U.S. soils baseline values and NIWQP bottom-sediment criteria in table 5. The small number of bottom-sediment samples collected from all sites in 1994 and the representative sites for 1988 makes confident determination of changes in constituent concentrations in bottom material difficult. However, some possible general patterns might be evident in the data. Concentrations of arsenic, cadmium (not plotted in fig. 9 because most values were less than the MRL), molybdenum, selenium, vanadium, and zinc, show substantial overlap between samples collected in 1988 and 1994 (table 5, fig. 9), and it is unlikely that there were significant changes in concentrations of these constituents. Chromium and copper concentrations generally were higher in 1988 than in 1994 (table 5, fig. 9). At site A-14, which was the only site with bottom-sediment samples collected in both 1988 and 1994, chromium and copper concentrations in 1988 were more than twice as high as concentrations in 1994. Lead concentrations generally were slightly higher in 1994 than in 1988 (table 5, fig. 9). However, at site A-14, lead concentrations in 1988 and 1994 were the same. Factors that might have contributed to either an increase or decrease in trace-element bottom-sediment concentrations between 1988 and 1994 include: (1) scouring of surficial sediment between 1988 and 1994 to expose underlying sediment of different character; (2) deposition of new surficial sediment of different character; and (3) collection of bottom-sediment samples at different locations between years for a given sampling site, such that the results are not directly comparable. The extent to which any of these factors contributed to differences in bottom-sediment constituent concentrations between 1988 and 1994 is unknown.

Comparison of trace-element concentrations in bottom sediment with index concentrations for western U.S. soils are presented in table 5. In 1994, only the less-than-62-µm grain-size fraction of the bottom-sediment samples were analyzed for constituent concentrations. However, the index concentrations for western U.S. soils, and the NIWQP levels of concern for trace-element concentrations in sediment both are based on bulk-sediment analyses that are not restricted to a particular size fraction. Grain size strongly influences trace-element concentrations in bottom sediment, due to physical factors such as adsorptive surface area and chemical factors such as geochemical composition (that is, certain minerals can occur more frequently in specific grain-size ranges; Horowitz, 1991). Thus, the constituent concentrations in the less-than-62-µm size fraction are not directly comparable to the index and criteria values that are based on bulk-sediment analyses.

Table 5. Comparison of selected trace-element concentrations in bottom sediment[1] for the Angostura Reclamation Unit with selected bulk-sediment index values for soil and bottom sediment

[Total concentration, in micrograms per gram; <, less than; --, no data; 4 samples per element in 1994, 3 samples per element in 1988]

Element	1994			1988			Western U.S. soils[2, 3]		National Irrigation Water Quality Program level of concern[3, 5]
	Minimum	Maximum	Median	Minimum	Maximum	Median	Geometric mean	Baseline range[4]	
Arsenic	<10	19	12	6.5 (9.7)	13 (17)	11 (12)	5.5	1.2–22	8.2–70
Cadmium	<2	<2	<2	<2 (<2)	2 (<2)	<2 (<2)	--	--	--
Chromium	6	30	10	23 (6)	72 (20)	35 (10)	41	8.5–200	--
Copper	3	10	4	8 (3)	28 (10)	16 (7)	21	4.9–90	34–270
Lead	17	28	22	12 (18)	18 (19)	17 (19)	17	5.2–55	--
Molybdenum	<2	<2	<2	<2 (<2)	4 (2)	<2 (<2)	0.85	0.18–4.0	--
Selenium	<1	<1	<1	0.6 (0.2)	4.3 (1.6)	0.9 (0.5)	0.23	0.039–1.4	1–4
Vanadium	14	75	21	38 (13)	200 (56)	67 (24)	70	18–270	--
Zinc	25	64	45.5	49 (23)	120 (51)	58 (31)	55	17–180	150–410

[1]Samples collected from the less-than-62-micrometer fraction of bottom sediment; values in parentheses for 1988 represent samples collected from the less-than-2-millimeter but greater-than-62-micrometer grain-size fraction of bottom sediment. Sites summarized are from figure 9.

[2]Modified from Shacklette and Boerngen, 1984.

[3]Bulk-sediment concentrations.

[4]Range in which 95 percent of sample concentrations are expected to occur.

[5]U.S. Department of the Interior, 1998; the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

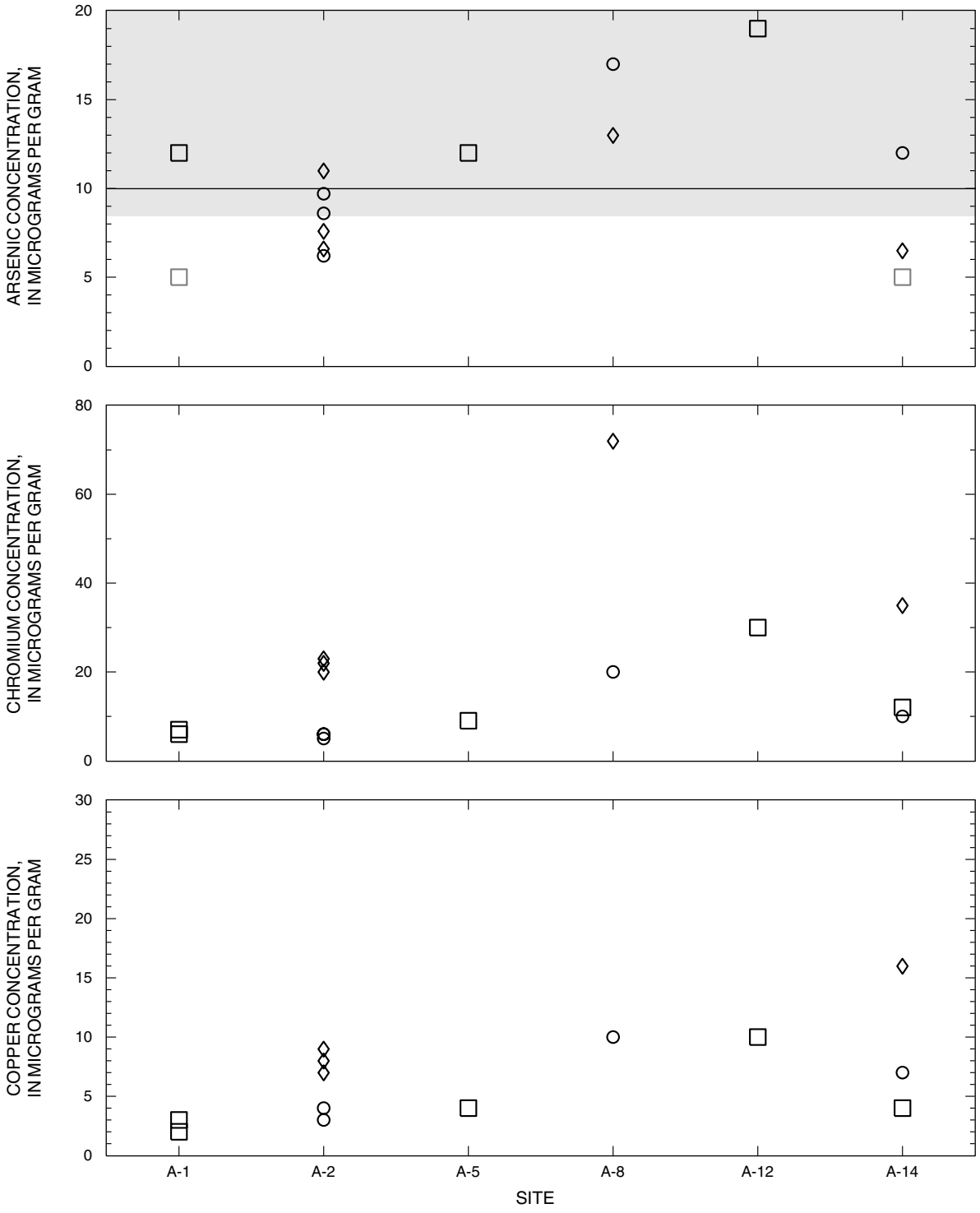


Figure 9. Concentrations of selected trace elements in bottom-sediment samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994.

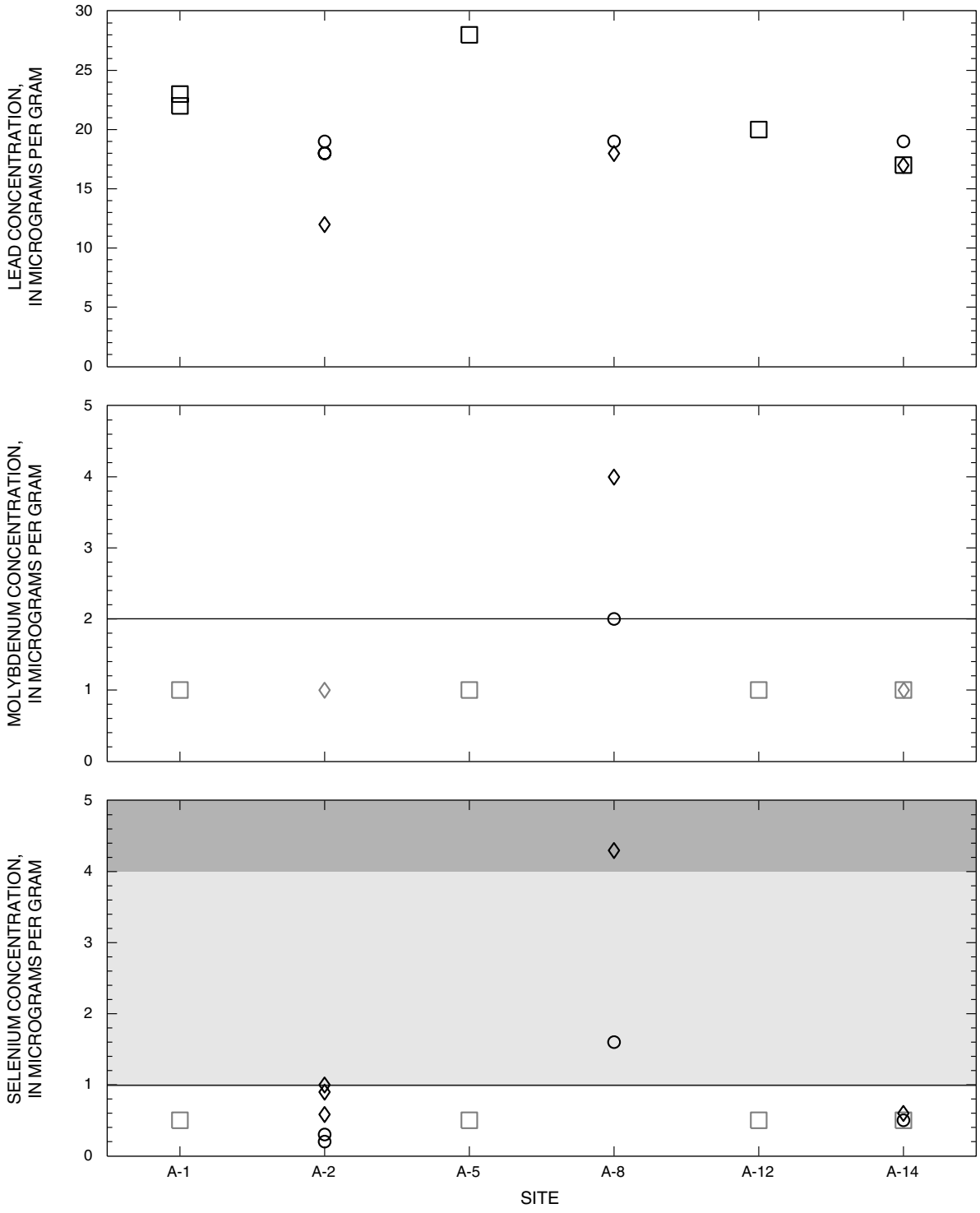
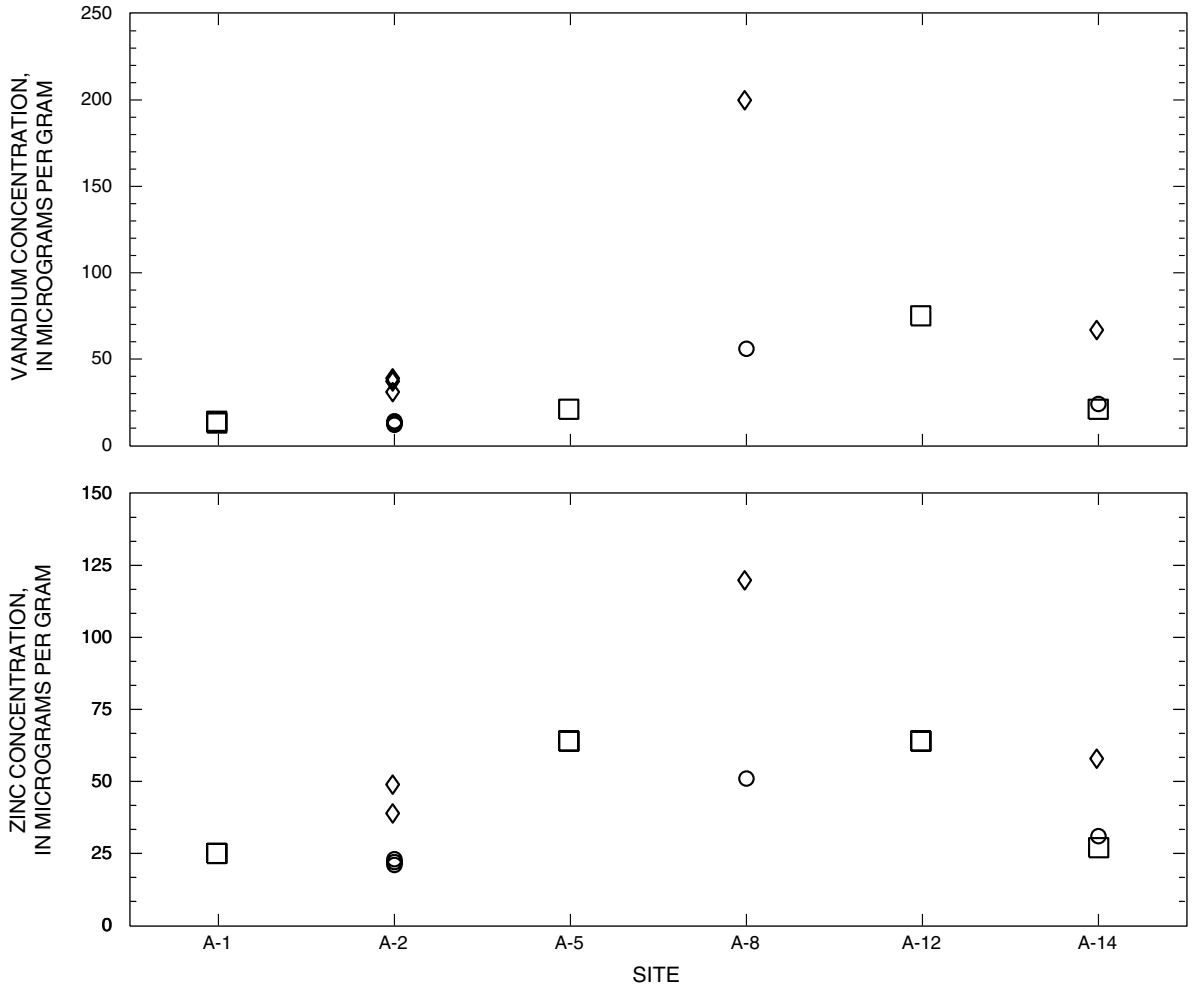


Figure 9. Concentrations of selected trace elements in bottom-sediment samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994. --Continued



EXPLANATION

SYMBOLS IN GRAY INDICATE VALUE BELOW METHOD REPORTING LIMIT PLOTTED AT ONE-HALF REPORTING LIMIT

◊ 1988 sample value(less-than-62-µm grain-size fraction)

○ 1988 sample value (less-than-2-mm but greater-than-62-µm grain-size fraction)

□ 1994 sample value (less-than-62-µm grain-size fraction)

——— METHOD REPORTING LIMIT (1994 ONLY FOR ARSENIC AND SELENIUM)

NATIONAL IRRIGATION WATER QUALITY PROGRAM LEVEL OF CONCERN

NATIONAL IRRIGATION WATER QUALITY PROGRAM TOXICITY THRESHOLD

Figure 9. Concentrations of selected trace elements in bottom-sediment samples collected from sites in or near the Angostura Reclamation Unit in 1988 and 1994. --Continued

In 1988, in addition to the less-than-62-µm grain-size fraction analyses, constituent concentrations also were analyzed for in the less-than-2-mm but greater-than-62-µm size fraction (table 5). Bottom sediment in depositional zones of the Cheyenne River in the ARU area tends to be fine grained, due largely to the predominance of marine shales in the surficial materials of the basin. Although no size-distribution data are available for the bulk bottom-sediment samples that were collected in 1988, most of the bulk sediment collected probably was less than 2 mm in diameter. The less-than-2-mm but greater-than-62-µm size-fraction constituent concentrations also are not directly comparable to the index and criteria values, because they too represent a specific size fraction and not bulk samples. Comparison of constituent concentrations between the two grain-size fractions analyzed in 1988 could provide cursory information on the effect of grain size on constituent concentrations and allow qualitative comparison of both the 1988 and 1994 data with the index and criteria values. For the 1988 data, it could be reasonably assumed that constituent concentrations in the less-than-2-mm but greater-than-62-µm size fraction generally would be lower than concentrations in the bulk samples from which they were derived; conversely, constituent concentrations in the less-than-62-µm size fraction could be reasonably assumed to be generally higher than in the bulk samples from which they were derived. Further, assuming that grain-size distributions in the 1988 samples are similar to the 1994 samples, comparison of constituent concentrations in the 1988 less-than-2-mm but greater-than-62-µm size fraction relative to the 1988 less-than-62-µm size fraction might be used to estimate lower limits for bulk concentrations for 1994 samples.

Concentrations of chromium, copper, lead, molybdenum, vanadium, and zinc for all grain-size fractions for both 1988 and 1994 generally are within baseline soils ranges, and generally are near or less than baseline soils geometric means (table 5). Concentrations of arsenic in all grain-size fractions in both 1988 and 1994 are within baseline soils ranges, but generally exceed the baseline soils geometric mean. Arsenic concentrations in both grain-size fractions in 1988 were similar (generally near or within 10 percent of each other); based on the similarity in arsenic concentrations between grain-size fractions for 1988, bulk sample concentrations for both 1988 and 1994 also can be reasonably assumed to exceed the baseline soils geometric mean. Thus, bottom-sediment arsenic concentrations in the ARU area, both upstream and downstream from irrigation operations, are somewhat higher than typical areas in the western U.S. All concentrations of selenium for 1988 (both grain-size fractions) exceed the baseline soils geometric mean, and one sample (site A-8; both grain-size fractions) exceeds the upper end of the baseline soils range. The 1988 data indicate that selenium concentrations in bottom sediment in the ARU area, both upstream and downstream from irrigation operations, can be higher than typical areas in the western U.S. Bottom-sediment selenium concentrations for 1994 are all less than the 1994 MRL of 1 µg/L. Because the 1994 MRL is higher than the baseline soils geometric mean, comparison of the 1994 data with the baseline data is difficult; however, none of the 1994 concentrations exceed the upper end of the baseline soils range (1.4 µg/g). There is no clear pattern in trace-element concentrations in bottom sediment for sites in the ARU area indicating that irrigation operations either increase or decrease the constituent concentrations.

In 1988, specific guidelines did not exist for assessing the potential toxicity of trace-element concentrations in bottom sediment. However, NIWQP guidelines for four constituents (arsenic, copper, selenium, and zinc) are now available for this purpose and are presented in table 5 and figure 9. Concentrations of copper and zinc in bottom sediment collected at sites in or near the ARU in both 1988 (both grain-size fractions) and 1994 are all less than the NIWQP level of concern. Bottom-sediment arsenic concentrations in both 1988 (both grain-size fractions) and 1994 (less-than-62-µm grain-size fraction) in the ARU area are within the NIWQP level of concern at sites both upstream and downstream from irrigation operations. Arsenic concentrations in both grain-size fractions in 1988 were very similar (generally near or within 10 percent of each other); thus, bulk-sample concentrations for 1994 (although not specifically analyzed for) can be reasonably assumed to also be within the NIWQP level of concern based on results for the less-than-62-µm grain-size fraction. None of the bottom-sediment arsenic concentrations in the ARU area exceed the NIWQP toxicity threshold. Generally, bottom-sediment selenium concentrations in the ARU area are less than the NIWQP level of concern. However, one sample collected at site A-8 in 1988 has a selenium concentration (1.6 µg/g) for the less-than-2-mm but greater-than-62-µm grain-size fraction that is

within the NIWQP level of concern. All bottom-sediment selenium concentrations for 1994 are less than the MRL of 1 µg/g. Bottom-sediment arsenic (and, less frequently, selenium) concentrations in the Angostura area apparently can reach levels of concern; however, there is insufficient information to determine whether the irrigation operations of the ARU contribute to the elevated concentrations.

Fish

Analytical results for fish-tissue samples collected in 1994 are presented in table 12 in the Supplemental Information section. A statistical summary of results for 1988 and 1994 is provided in table 6. For 1988, most trace-element concentrations in fish samples are less than values known to affect growth, reproduction, or survival in either fish or birds (table 6), although some concentrations do exceed established criteria.

Median arsenic concentrations for 1994 and 1988 are identical (0.2 µg/g dw) and are below the NIWQP level of concern for fish (table 6) and below the National Contaminant Biomonitoring Program (NCBP) 85th-percentile baseline value of 0.81 µg/g dw (Schmitt and Brumbaugh, 1990). However, three individual fish-tissue composite samples from 1994 (table 12) have arsenic concentrations (1.3, 2.6, and 1.8 µg/g dw) that are within the level of concern. Several 1988 fish-tissue samples also are within the level of concern (Greene and others, 1990).

Median concentrations for copper are below the NIWQP level of concern (table 6) for 1994 and 1988. The 1994 median (4.1 µg/g dw) is higher than the 1988 median (2.7 µg/g dw) and also is slightly above the NCBP 85th-percentile baseline value for copper of 3.67 µg/g dw (Schmitt and Brumbaugh, 1990). One channel catfish sample in 1988 had a copper concentration of 16.0 µg/g dw (Greene and others, 1990) that exceeds the NIWQP toxicity threshold (table 6). One green sunfish sample in 1994 had a copper concentration of 11 µg/g dw that is within the NIWQP level of concern.

The median mercury concentration for 1988 (0.23 µg/g dw) and for 1994 (0.21 µg/g dw) are below the NIWQP toxicity threshold (table 6) and below the NCBP 85th-percentile baseline value of 0.65 µg/g dw (Schmitt and Brumbaugh, 1990). However, in 1988 several individual fish samples had mercury concentrations that exceed the NCBP 85th-percentile baseline value, and one sauger sample from site A-14 exceeds the NIWQP toxicity threshold (Greene and others, 1990). Additionally, the dietary guideline for the protection of piscivorous birds is 0.4 µg/g dw (U.S. Department of the Interior, 1998). This avian dietary guideline is exceeded in several 1988 individual fish samples (Greene and others, 1990) and two 1994 composite samples of adult goldeyes from sites A-12 and A-14 (mercury concentrations of 0.48 and 0.50 µg/g dw, respectively, table 12).

The median selenium concentration (4.6 µg/g dw) for 1988 is greater than the NCBP 85th-percentile baseline value of 2.8 µg/g dw (Schmitt and Brumbaugh, 1990) and exceeds the NIWQP toxicity threshold (table 6). Most individual fish-tissue samples for 1988 are either within or exceed the NIWQP level of concern (Greene and others, 1990).

The median selenium concentration (3.9 µg/g dw) for 1994 is slightly lower than that of 1988, but is within the NIWQP level of concern (table 6) and is greater than the NCBP 85th-percentile baseline value of 2.8 µg/g dw (Schmitt and Brumbaugh, 1990). Additionally, several individual fish-tissue composite samples for 1994 exceed the NIWQP toxicity threshold (table 6). Recent literature suggests that 4 µg/g dw is the threshold tissue concentration to protect fish from reproductive failure and other health effects (Lemly, 1993). Also, one 1994 composite sample of rock bass from site A-5 has a concentration of 10 µg/g dw. Selenium concentrations between 10 and 20 µg/g dw in whole body fish tissue can cause teratogenesis in fish (U.S. Department of the Interior, 1998).

Most selenium concentrations for 1988 (Greene and others, 1990) and 1994 (table 12) were above the 3.0 µg/g dw recommended dietary threshold for the protection of avian consumers (Lemly, 1993; Heinz, 1996). Dietary selenium concentrations greater than 3.0 µg/g dw can bioaccumulate through the food chain leading to reproductive effects in aquatic birds (Ohlendorf and others, 1986; Lemly and Smith, 1987). According to Lemly (1993), the recommended concentration of 3.0 µg/g dw is the dietary toxicity threshold at which food organisms, although not directly affected, would supply a toxic dose of selenium to consumers. Generally, selenium concentrations are slightly higher at sites downstream from ARU irrigation operations than at site A-1, which is upstream from irrigation operations (table 12). However, different fish species were collected at sites downstream from irrigation operations than were collected at site A-1, which makes interpretation of differences between downstream and upstream concentrations difficult.

Table 6. Comparison of fish-tissue concentrations for the Angostura Reclamation Unit with the National Irrigation Water Quality Program level of concern[1]

[Concentrations in micrograms per gram dry weight; <, less than; --, no data; 16 samples per element in 1994, 126 samples per element in 1988]

Constituent	1994			1988			National Irrigation Water Quality Program level of concern[1] for fish
	Minimum	Maximum	Median	Minimum	Maximum	Median	
Aluminum	11	9,280	120	4.90	6,350	200	--
Arsenic	<0.1	2.6	0.2	0.1	2.3	0.2	1–12
Boron	<0.6	7.6	<2	<2.0	7.8	<3.0	--
Barium	0.84	52.6	3.2	0.6	161	5.4	--
Beryllium	<0.03	0.26	<0.03	0.01	0.2	<0.1	--
Cadmium	0.010	0.41	0.058	0.03	0.6	0.2	--
Chromium	0.24	9.6	0.56	<0.1	8.4	1.6	--
Copper	1.8	11	4.1	0.9	16.0	2.7	9.8–13.3
Iron	78	4,500	158	40	2,730	228	--
Mercury	0.087	0.50	0.21	0.08	1.3	0.23	1.0 (toxicity threshold for coldwater species)
Magnesium	1,280	2,780	1,550	1,080	2,410	1,580	--
Manganese	6.8	1,210	30	4.6	601	34	--
Molybdenum	<0.2	<1	<1	<0.1	4.0	<1	--
Nickel	<0.06	4.6	0.20	0.2	18	1.2	--
Lead	<0.05	2.2	0.09	0.4	5.0	<0.5	--
Selenium	1.9	10	3.9	2.1	13	4.6	3–4 (warmwater species); 2–4 (coldwater species)
Strontium	76	244	172	56	399	194	--
Vanadium	<0.2	15	0.4	0.1	9.7	0.9	--
Zinc	50.1	290	95.2	45	401	97	--

[1]U.S. Department of the Interior, 1998; the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

The 1988 and 1994 median zinc concentrations (97.0 and 95.2 µg/g dw, respectively) are greater than the NCBP 85th-percentile baseline value of 88 µg/g dw (Schmitt and Brumbaugh, 1990). However, toxicity levels for zinc concentrations in animal tissues are not well established and currently there is no established NIWQP level of concern for fish (U.S. Department of the Interior, 1998).

Synopsis of Results for the Angostura Reclamation Unit

Concentrations of major ions in water in the study area are high relative to national baseline levels. Major-ion concentrations generally are lower for 1994 than for 1988, when sampling was conducted during low-flow conditions, but ionic proportions are similar between years. The 1994 results are associated with

more typical hydrologic conditions. Major-ion concentrations and proportions vary substantially in the Cheyenne River upstream from Angostura primarily due to inflows from Cascade Springs. Angostura Reservoir tends to integrate inflows from various tributaries over time, and ionic proportions are fairly constant downstream from the reservoir. Downstream from Angostura Reservoir, a small increase in concentrations of dissolved solids probably occurs; however, the limited data sets available are insufficient to confidently discern effects of ARU operations on dissolved-solids loading.

Concentrations of most trace elements in water are similar between 1988 and 1994, and do not show strong relations with discharge. Concentrations of trace elements at the downstream end of the ARU are similar to concentrations upstream from and within the ARU. Irrigations operations probably are not contributing discernible additional loads of trace elements to the Cheyenne River. Concentrations of several trace elements occasionally exceed NIWQP guidelines, but only selenium routinely occurs at levels that could be problematic. Concentrations within the NIWQP level of concern or exceeding the toxicity threshold occur at sites both upstream and downstream from the ARU. Elevated selenium concentrations at sites upstream from irrigation operations indicate that naturally occurring selenium concentrations are relatively high in the ARU area, and irrigation operations of the ARU probably do not contribute substantially to selenium concentrations in the Cheyenne River.

Concentrations of most trace elements in bottom sediment are similar for 1988 and 1994, and generally are within baseline ranges for western U.S. soils. Concentrations of selenium for 1988, both upstream and downstream from the ARU, routinely exceed typical concentrations for western U.S. soils; however, all selenium concentrations for 1994 were less than 1 µg/g. Bottom-sediment arsenic concentrations in the ARU area commonly are within the NIWQP level of concern, at sites both upstream and downstream from irrigation operations. Bottom-sediment arsenic and selenium concentrations in the ARU area apparently can reach levels that might be of concern; however, there is insufficient information to determine whether the irrigation operations of ARU contribute to elevated concentrations.

Concentrations of most trace elements in fish in the ARU area generally are less than values known to adversely affect fish or birds, although there are occasional exceedances of established criteria. However, selenium concentrations in fish might be problematic. Selenium concentrations in fish samples routinely are within the NIWQP level of concern, and also commonly exceed the dietary guideline for protection of avian consumers. Concentrations generally are slightly higher at sites that are downstream from ARU irrigation operations. However, different fish species are collected at the various sites, which makes direct comparison between downstream and upstream concentrations difficult.

Selenium can occur at concentrations that might have adverse environmental effects in all of the media that were sampled. Also, selenium concentrations in the various media generally are within or exceed NIWQP levels of concern during the varying flow conditions of both 1988 and 1994 (except for selenium concentrations in bottom sediment in 1994 that were all less than the MRL of 1 µg/L). However, the data collected during 1988 and 1994 are insufficient to confidently determine the extent to which ARU operations contribute to elevated selenium concentrations in the various media.

Belle Fourche Reclamation Project

Water Quality

Analytical results for water samples collected in 1994 are shown in table 13 in the Supplemental Information section. Major-ion and trace-element concentrations for all sites sampled in 1994 are jointly statistically summarized and compared with jointly summarized data from 1988, and with national baseline values and various water-quality criteria in table 7. Ranges and medians of concentrations of all major ions for the jointly summarized 1994 data are lower than 1988 values. Major-ion concentrations are high for both 1988 and 1994; minimum concentrations for both 1988 and 1994 generally exceed national baseline values (table 7).

Table 7. Comparison of major-ion and selected trace-element concentrations in surface water for the Belle Fourche Reclamation Project with selected index values, guidelines, and criteria

[Major-ion concentration, in milligrams per liter; trace-element concentration, in micrograms per liter; <, less than; >, greater than; --, no data; 6 samples per element in 1994, 12 samples per element in 1988]

Constituent	1994			1988			National baseline[1]	National Irrigation Water Quality Program Guidelines level of concern[2]	Surface-water quality criteria		
	Minimum	Maximum	Median	Minimum	Maximum	Median			Aquatic life acute/ chronic[3]	Irrigation[4]	Livestock watering[4]
Major Ions											
Calcium	140	210	185	100	360	210	66.8	--	--	--	--
Magnesium	48	150	70	46	300	94	21.7	--	--	--	--
Sodium	56	370	105	69	630	135	68.9	--	--	--	--
Potassium	6.1	10	9.4	734	17	9.6	--	--	--	--	--
Bicarbonate plus carbonate[5]	191	256	209	130	391	190	161.8	--	--	--	--
Sulfate	610	4,100	725	620	2,900	1,100	116.9	--	--	--	--
Chloride	5.9	180	18	4.7	100	21	53.3	--	--	--	--
Trace Elements											
Arsenic	<1	11	1	<1	16	1	3	48–190	360/190	100	200
Boron	160	430	220	180	1,000	275	--	500–10,000 for plants 5,000–25,000 for fish	--	750	5,000
Cadmium	<1	<1	<1	<1	1	<1	< 2	--	[5]40/5.2	10	50
Chromium	<1	<1	<1	<1	2	2	--	--	--	--	--
Copper	1	2	1	<1	4	1	--	0.23–12	[5]135/74	200	500
Lead	<1	<1	<1	<5	<5	<5	6	--	[5]630/24	5,000	100
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	>30	[6]2.1/0.012	--	10
Molybdenum	<1	5	2.5	1	7	3.5	--	50,000 for plants 20–120 for fish	--	--	--
Selenium	<2	4	2	1	11	3	1	1–2	20/5	20	50
Uranium	6.0	17	7.9	5.3	30	9.1	--	--	--	--	--
Zinc	<3	12	8	<3	40	5	21	30–110	[5]740/670	2,000	25,000

[1]The National Stream Quality Accounting Network and the National Water Quality Surveillance System have provided information on the Nation's water quality since 1973. Smith and others (1987) used data from these two nationwide sampling networks to provide long-term water-quality trends (national baseline values) of major United States rivers. The national baseline value for each water-quality property or constituent is equal to the 75th station-mean concentration percentile.

[2]U.S. Department of the Interior, 1998; the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

[3]South Dakota Legislative Research Council, accessed May 4, 2001.

[4]National Academy of Sciences – National Academy of Engineering, 1973.

[5]Reported as bicarbonate (HCO_3^-).

[6]Hardness dependent criteria, value shown is based on a hardness of 900 milligrams per liter, a value that is similar to hardness of waters in the Belle Fourche Reclamation Project area.

[7]Based on total recoverable fraction of the metal.

Chemical characteristics of the Belle Fourche River and its tributaries in the study area are influenced by a wide variety of geologic conditions that are described in more detail by Roddy and others (1991). The majority of the BFRP is within outcrops of the Pierre Shale, which is a black marine shale of Cretaceous age. Alluvial and terrace deposits occur along the Belle Fourche River and other drainages. Grain-size distributions of these unconsolidated deposits can range from clay to boulders and mineralogic composition also can be extremely variable. Some tributaries of the Belle Fourche River in the study area have their headwaters in the Black Hills. Contact with Paleozoic-age limestones in the upper reaches of these streams influences their chemical characteristics.

Stiff diagrams (Stiff, 1951) showing average proportions of major ions in water samples are presented in figure 10 for sites in the BFRP area. Major-ion chemistry of surface water in the BFRP area is influenced primarily by geologic features of the basin. Sodium, calcium, and magnesium are nearly co-dominant among cations, and sulfate is dominant among anions. Mean dissolved-solids concentrations are higher for 1988 than for 1994. Proportions of major ions are similar between 1988 and 1994 (fig. 10), even though the concentrations of major ions are somewhat smaller for 1994.

As in 1988, 1994 concentrations of major ions at sites B-12 and B-18, which are affected by irrigation drainage, are higher than concentrations at site B-1, which is an upstream site relative to the BFRP. In addition to the irrigation operations of BFRP, many factors, including other land-use influences, natural variability in dissolved-solids loads from tributaries due to geologic influences, and historic mining operation influences (site B-18 only), contribute to differences between dissolved-solids concentrations upstream and downstream from the BFRP. Because of these other factors, the degree to which concentrations and loads of dissolved solids are affected by irrigation operations cannot be conclusively determined. However, the 1988 study concluded that irrigation operations increase the amount of surface water that becomes ground-water recharge and expose the irrigation drainage to greater contact with geologic materials (Roddy and others, 1991). The 1988 study further concluded that the greater ground-water recharge probably results in greater discharge of ground water to surface streams during late summer, fall, and winter, thus probably increasing dissolved-solids loads relative to natural conditions (Roddy and others, 1991). With respect to major ions, the 1994 data are too limited to either support or contradict the general conclusions of the 1988 study.

Selected trace-element concentrations in water samples collected from sites B-1, B-12, and B-18 for 1988 and 1994 are shown in figure 11. For most sites, concentrations of arsenic, cadmium, chromium, lead, and mercury generally are near or less than the MRL's, and medians and distributions for 1988 and 1994 are similar (table 7, fig. 11). Differences in flow conditions between 1988 and 1994 probably did not substantially affect concentrations of these constituents, or the effects of the flow variability occurred at concentrations less than the MRL's. Arsenic concentrations at site B-18 are consistently above the MRL for both 1988 and 1994. Elevated arsenic concentrations at this site result from effects of mining in the Whitewood Creek Basin, which enters the Belle Fourche River from the south (Roddy and others, 1991). Elevated concentrations of various other trace elements in mine tailings discharged to Whitewood Creek also have affected water and sediment chemistry in the Belle Fourche River (Goddard, 1989). Arsenic concentrations at site B-18 for 1988 and 1994 are similar.

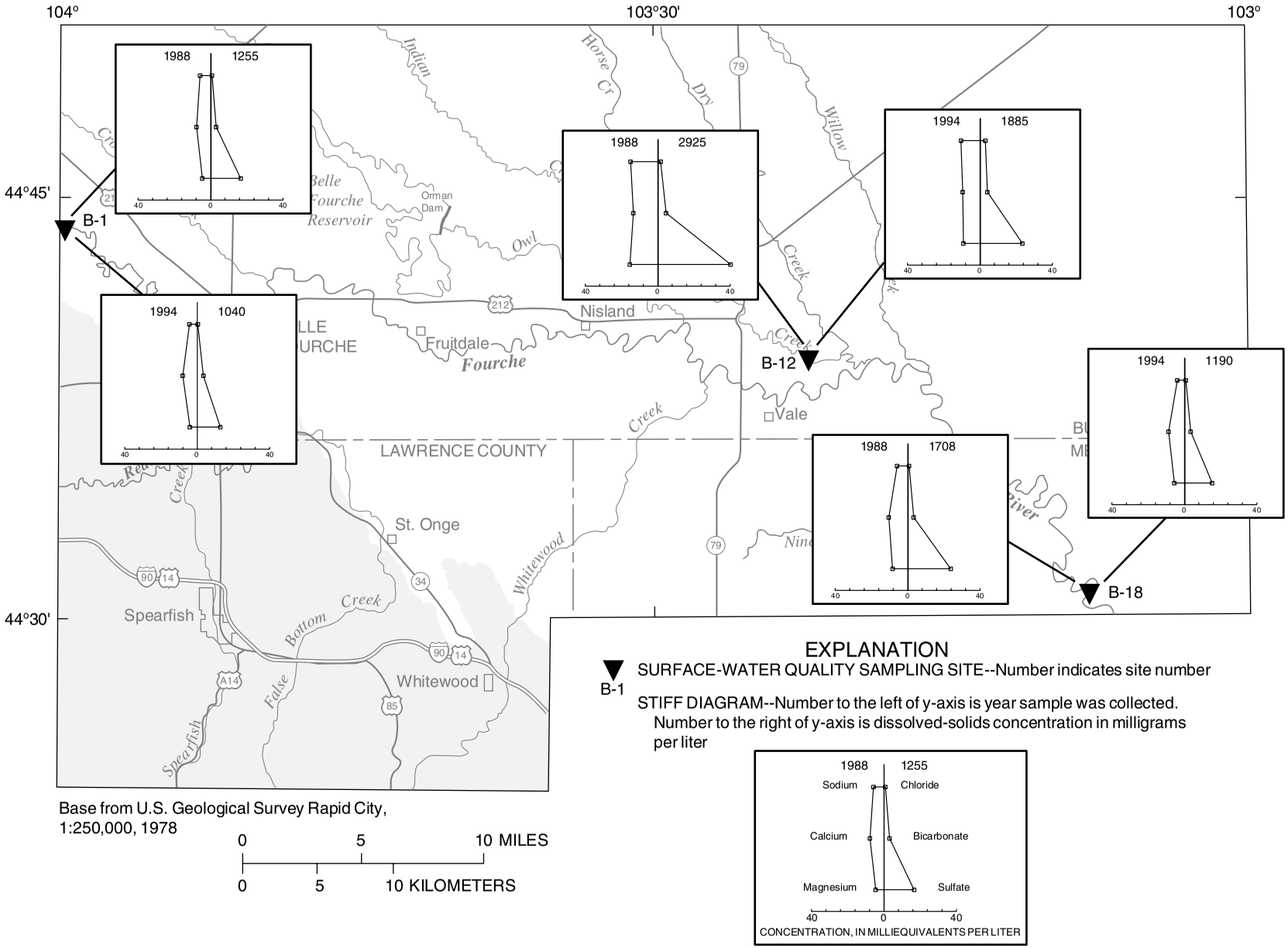


Figure 10. Stiff diagrams showing average dissolved-solids concentrations and proportions of major ions in water samples collected from sites in and near the Belle Fourche Reclamation Project in 1988 and 1994.

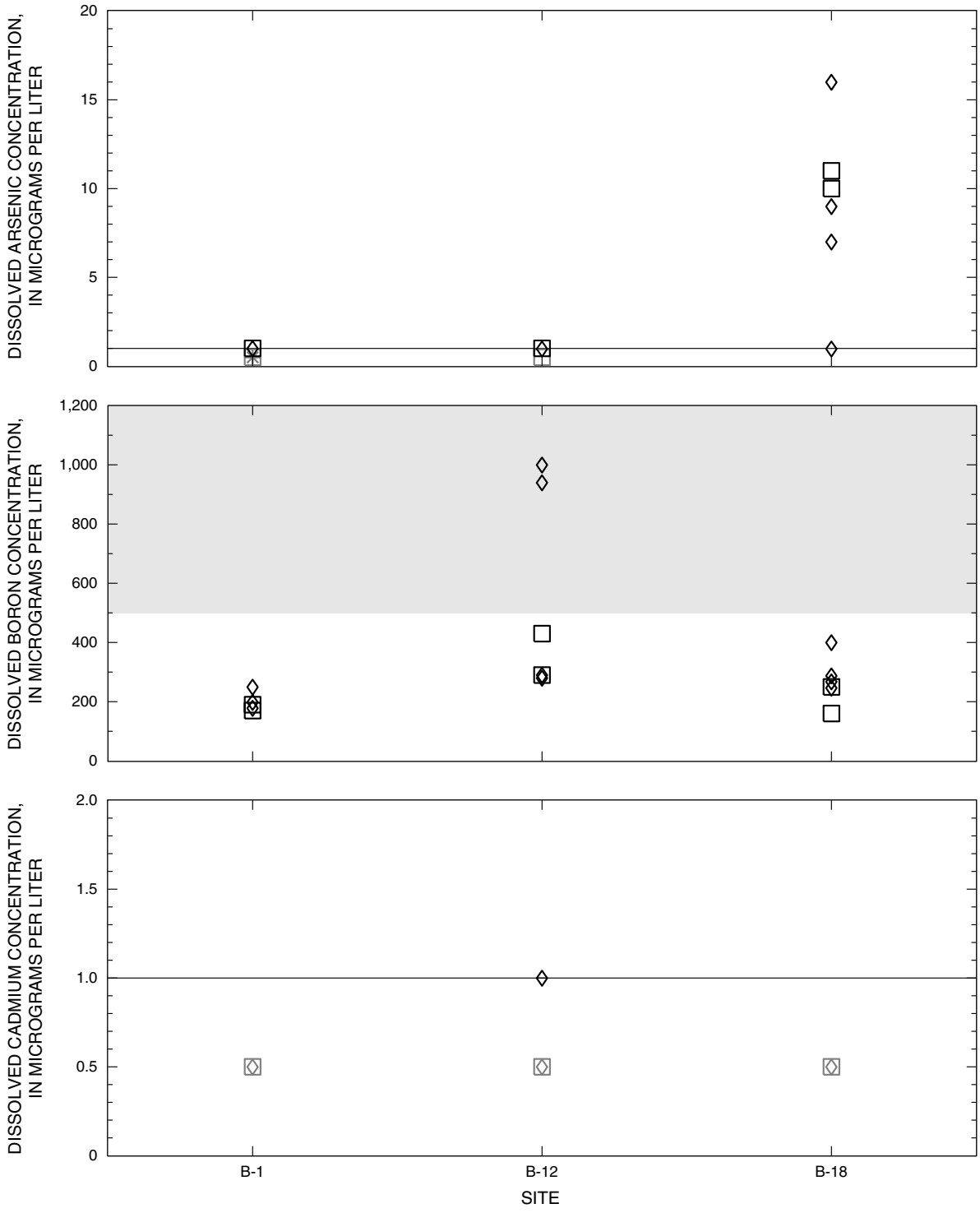


Figure 11. Concentrations of selected trace elements in water samples collected from sites in or near the Belle Fourche Reclamation Project in 1988 and 1994.

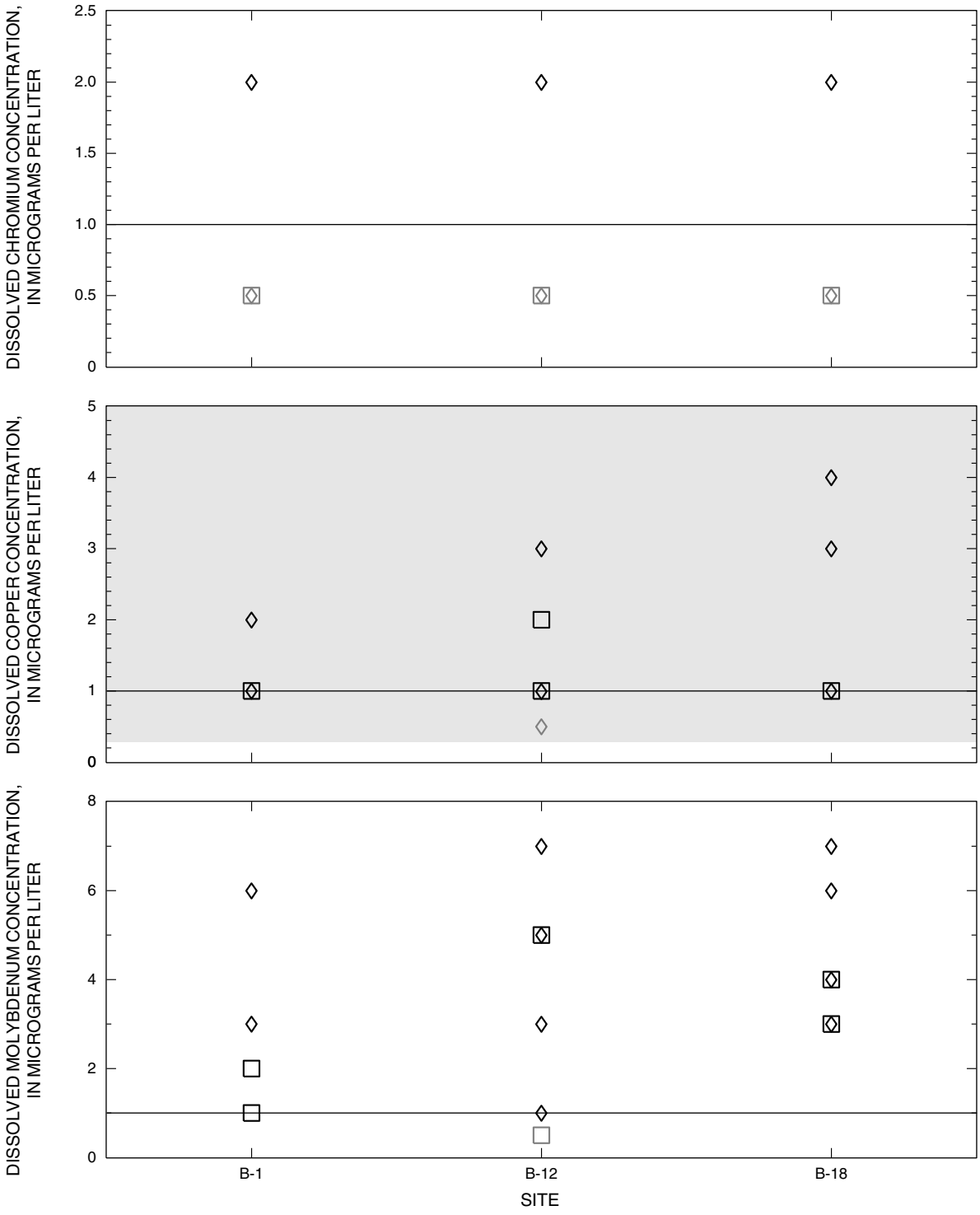


Figure 11. Concentrations of selected trace elements in water samples collected from sites in or near the Belle Fourche Reclamation Project in 1988 and 1994. --Continued

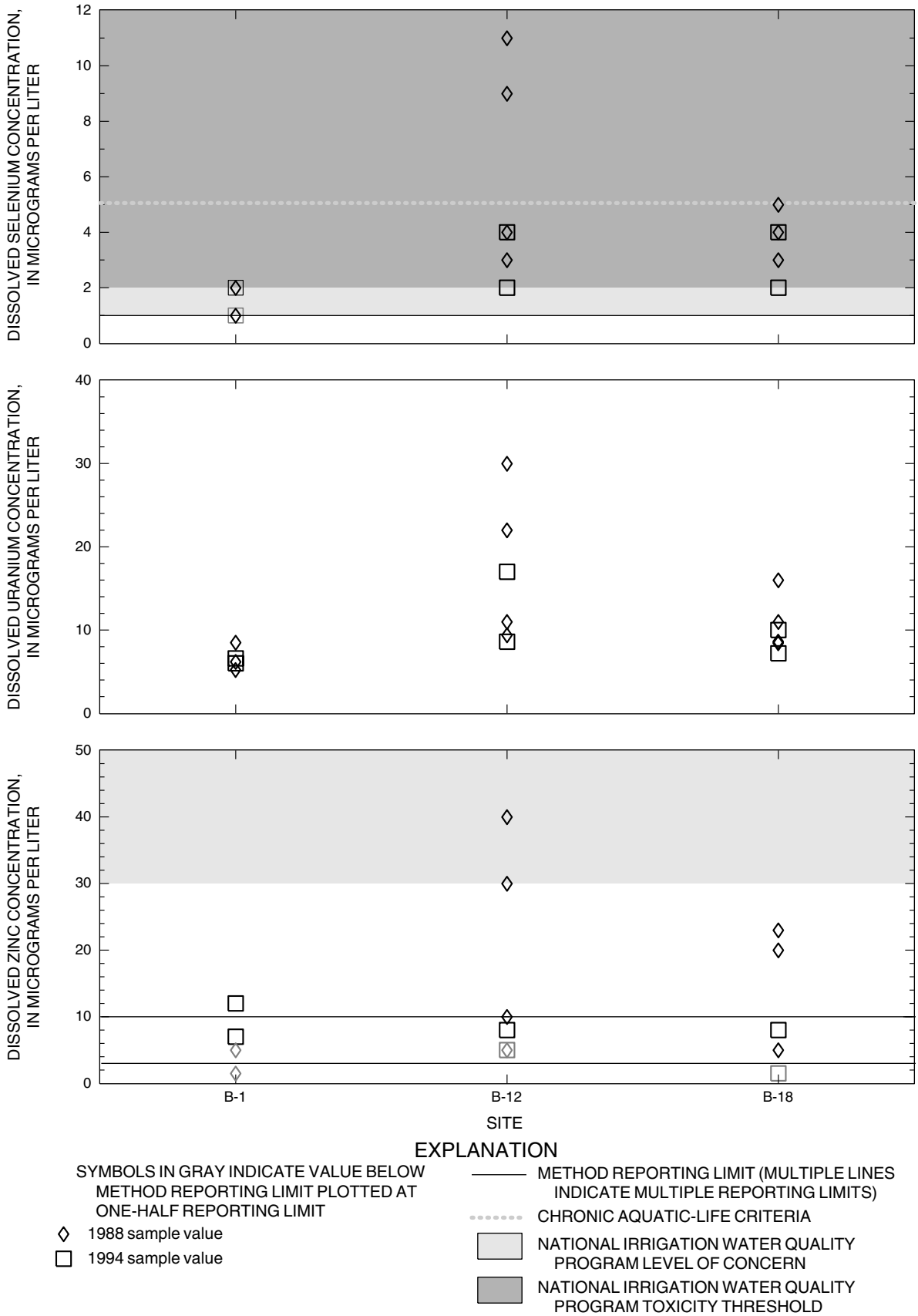


Figure 11. Concentrations of selected trace elements in water samples collected from sites in or near the Belle Fourche Reclamation Project in 1988 and 1994. --Continued

Concentrations of boron, copper, molybdenum, selenium, uranium, and zinc generally are higher than the MRL's at all sites; boron, molybdenum, selenium, and uranium had slightly higher medians and maximums for 1988 than for 1994 (table 7, fig. 11). Effects of flow variability on concentrations of trace elements are best shown by examining relations between trace-element concentrations and discharge at sites B-1, B-12, and B-18 for 1988 and 1994 (fig. 12). Median concentrations of copper and zinc for 1988 and 1994 are similar, and these constituents generally show poor correlations between concentration and discharge (table 7, fig. 12). Median and maximum concentrations of boron and uranium are higher for 1988 than for 1994; concentrations of these constituents show possible weak inverse relations with discharge at all three sites (fig. 12). Slightly higher concentrations of these constituents for 1988 than for 1994 might be due to differences in flow conditions. Average discharges at the time of sampling were about 40 percent less in 1988 than in 1994. Median and maximum concentrations of molybdenum and selenium also are slightly higher for 1988 than for 1994, but these constituents do not show a clear and consistent relation between concentration and discharge (table 7, fig. 12) at all sites. The slightly higher median molybdenum concentration for 1988 might be due to higher concentrations for 1988 than for 1994 at site B-1 (an upstream site; fig. 12); however, the elevated 1988 concentrations at site B-1 probably are not related to differences in flow conditions.

The slightly higher median selenium concentration for 1988 probably reflects the higher concentrations for 1988 than for 1994 at site B-12 (fig. 12). Selenium concentrations at this site appear to have a moderately strong inverse relation between concentration and discharge, and the elevated 1988 concentrations might have been due to differences in flow conditions between years. The relation between selenium concentrations and discharge at this site appears stronger when the 1988 and 1994 data are considered independently (fig. 12). A line defining the selenium concentration/discharge relation for the 1994 data would plot below the 1988 data. This pattern might indicate that selenium present in the geologic materials in the basin upstream from site B-12 is being leached and that the total amount of selenium in rocks and soils is declining with time. However, the data collected during the 1988 and 1994 studies are far too limited to be confident about this interpretation.

Of the BFRP sites sampled in 1994, site B-12 (Horse Creek) is most directly influenced by irrigation drainage; that is, irrigation drainage comprises a larger part of the total annual streamflow at site B-12 than at the other sampling sites. Irrigation operations can contribute to Horse Creek streamflows by (1) direct irrigation surface drainage during the irrigation season, and (2) increasing ground-water recharge, and thus increasing ground-water contribution to streamflow during base-flow conditions. The greater contribution of irrigation drainage to streamflow at site B-12 might contribute to the stronger inverse selenium/discharge relation observed at this site. Higher concentrations of selenium occur during base-flow conditions outside of the irrigation season. BFRP operations could affect the higher base-flow concentrations by increasing contact between water and geologic materials, and also increasing ground-water discharge to Horse Creek during base flow. However, since no data were collected on Horse Creek upstream from irrigation operations, it is impossible to determine whether irrigation operations either increase selenium concentrations in Horse Creek, or increase ground-water discharge to the stream during base flow. Thus, the extent to which BFRP operations increase either selenium loads or concentrations cannot be conclusively determined.

Patterns in spatial variability in trace-element concentrations for 1988 and 1994 are similar. Concentrations of most trace elements (with the exception of arsenic, boron, selenium, and uranium) are not consistently very different between sites B1, B12, and B18. Arsenic concentrations are elevated at site B-18, which can be attributed to effects of mine tailings in Whitewood Creek. The extent to which other constituent concentrations at site B-18 are affected by mine tailings, other human influences, natural geologic factors, or irrigation drainage cannot be determined from the limited data sets. Concentrations of boron, selenium, and uranium generally are higher for site B-12 (Horse Creek) than the other two sites; site B-1 (upstream from the BFRP) had the lowest concentrations of these constituents. Irrigation return flows constitute a large part of the annual flow of Horse Creek, as well as a substantial percentage of the total return flows from the BFRP. Irrigation drainage might increase loading of certain trace elements to the Belle Fourche River. However, data are not available for Horse Creek upstream from the BFRP to quantify any increases in loads.

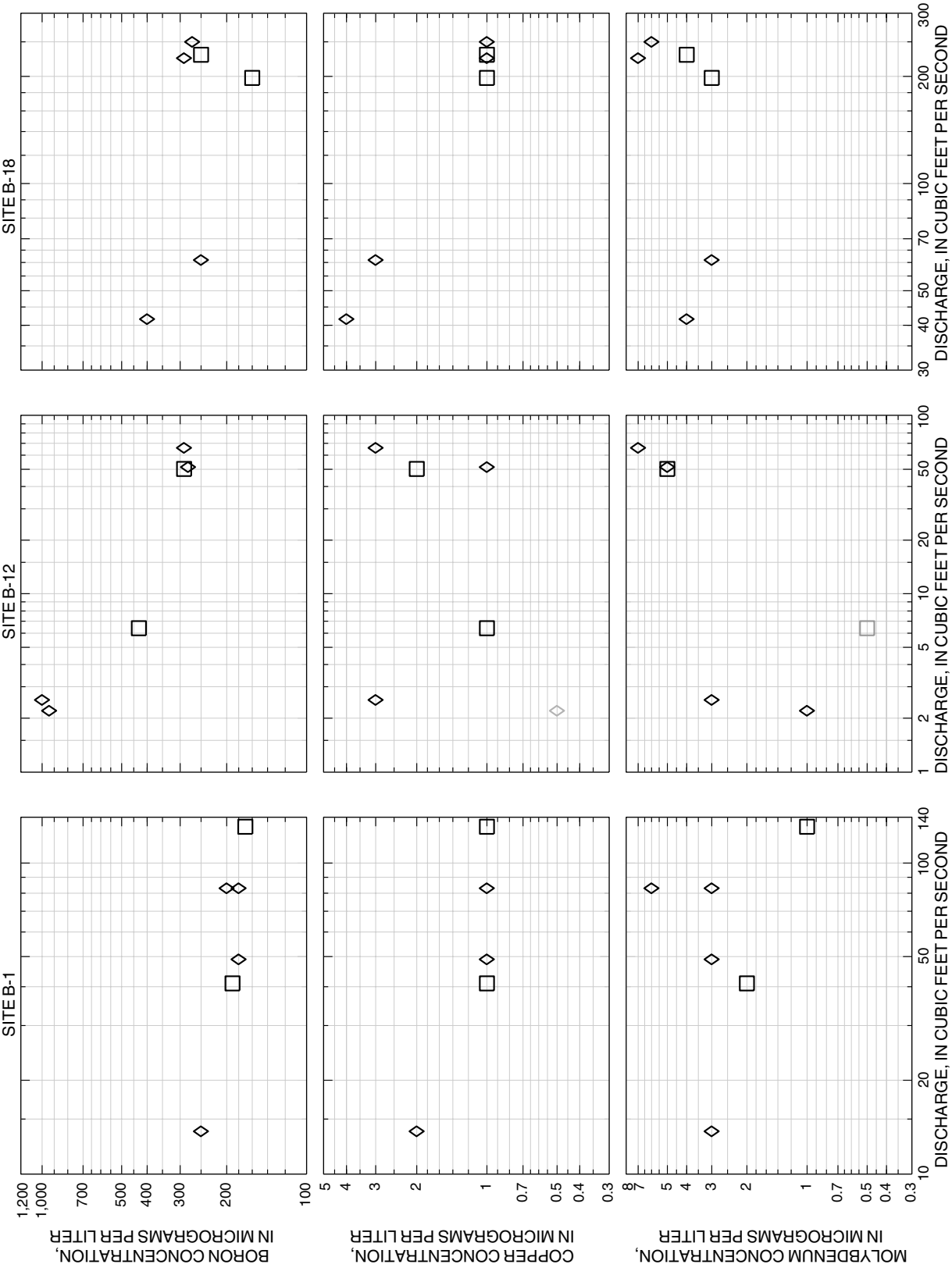


Figure 12. Relation between concentrations of selected trace elements and discharge for water samples collected from sites B-1, B-12, and B-18 in 1988 and 1994.

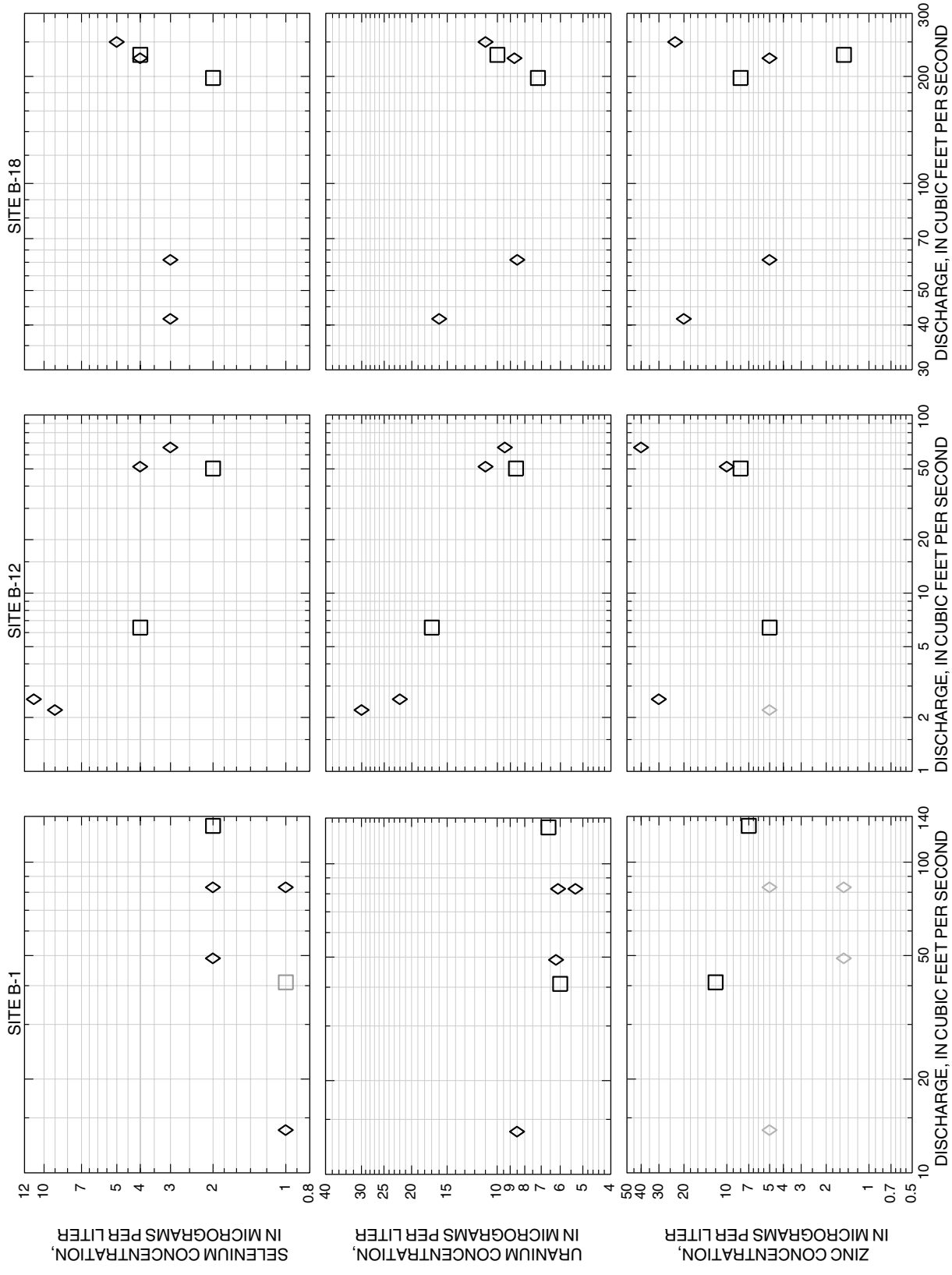


Figure 12. Relation between concentrations of selected trace elements and discharge for water samples collected from sites B-1, B-12, and B-18 in 1988 and 1994.--Continued

To determine if trace-element concentrations are high enough to be potentially harmful, they are compared to several standards (table 7, fig. 11). Concentrations of arsenic, cadmium, lead (not plotted in fig. 11), mercury (not plotted in fig. 11), and molybdenum do not exceed any water-quality criteria for either 1988 or 1994. Concentrations of copper at all sites for both 1988 and 1994 are within the NIWQP level of concern. Concentrations of selenium for most samples equal or exceed the NIWQP toxicity threshold. Boron and zinc concentrations at site B-12 are within the NIWQP level of concern for several 1988 samples; however, none of the 1994 samples are within the level of concern. None of the South Dakota surface-water quality criteria are exceeded for any constituent for 1994; however, for 1988 selenium concentrations in two samples from site B-12 and one sample from site B-18 exceed South Dakota aquatic life chronic criteria (table 7, table 13). Roddy and others (1991) also documented occasional selenium values higher than those considered in this report for sites B-12 and B-18, some of which exceed the South Dakota aquatic life acute criteria of 20 µg/L.

Roddy and others (1991) concluded from the 1988 samples that trace-element concentrations seldom exceed established guidelines. Concentrations of trace elements of concern generally are lower for 1994 samples than for 1988 samples, which were collected under low-flow conditions. The 1994 results are associated with more typical hydrologic conditions in the area of the BFRP. However, applying updated water-quality guidelines affects the previous conclusions somewhat. A few 1988 samples from site B-12 have boron and/or zinc concentrations that equal or exceed various current guidelines. Copper is routinely within the NIWQP level of concern, but none of the samples approach the toxicity threshold of 12 µg/L. The highest copper concentrations, which occurred at site B-18 in 1988, may be influenced by mine tailings in Whitewood Creek.

Selenium is the trace element of greatest concern for the BFRP. Selenium concentrations for all sites routinely are within or exceed the NIWQP level of concern. The fact that most selenium concentrations at site B-1 (which is upstream from the BFRP) are within the NIWQP level of concern indicates that selenium occurs naturally in the area in relatively high concentrations, and/or that some of the selenium is contributed by anthropogenic influences other than BFRP operations. However, selenium concentrations at sites B-12 and B-18, which are affected by BFRP irrigation drainage, are consistently slightly higher than at site B-1 and more frequently exceed various criteria. The extent to which BFRP irrigation operations affect selenium concentrations at site B-18 cannot be determined because of numerous geologic and human influences between sites B-1 and B-18. Selenium concentrations at site B-18 are increased, to some extent, by selenium loads in irrigation return flows that are contributed by Horse Creek. The extent to which selenium concentrations in Horse Creek are affected by irrigation operations cannot be conclusively determined, however, because data are not available for Horse Creek upstream from the BFRP. It can be concluded that selenium concentrations might at times be problematic in the BFRP area. Naturally occurring concentrations are relatively high, and BFRP operations might contribute additional loads. Also, at some sites selenium concentrations increase during low-flow conditions. However, as discussed in Roddy and others (1991), the fact that the BFRP is a flow-through drainage system (that is, the irrigation drainage flows out of the Belle Fourche River Basin, and is not impounded internally such that solutes undergo evaporative concentration) probably tends to diminish the environmental impacts of additional trace-element loading that results from BFRP operations.

Sediment

Analytical results for the less-than-62-µm fraction of bottom-sediment samples collected in 1994 are presented in table 14 in the Supplemental Information section. Major-ion and trace-element concentrations for all sites sampled in 1994 are jointly statistically summarized and compared with jointly summarized data from 1988, and with western U.S. soils baseline values and NIWQP bottom-sediment criteria, in table 8. The small number of bottom-sediment samples collected at sites B-1, B-12, and B-18 in 1988 and 1994 makes confident determination of changes in constituent concentrations in bottom sediment difficult. However, some possible general patterns might be evident in the data. No bottom-sediment samples were collected at site B-1 in 1988, and therefore this site is excluded from discussions of differences in bottom-sediment constituent concentrations between 1988 and 1994. Concentrations of arsenic, cadmium, and zinc in bottom-sediment samples collected at sites B-12 and B-18 showed substantial overlap between 1988 and 1994 (table 8, fig. 13), and it is unlikely that there were significant changes in concentrations of these constituents. Chromium, selenium, and vanadium

Table 8. Comparison of selected trace-element concentrations in bottom sediment[1] for the Belle Fourche Reclamation Project with selected index values for soil and bottom sediment

[Total concentration, in micrograms per gram; <, less than; --, no data; 3 samples per element in 1994, 2 samples per element in 1988]

Element	1994			1988			Western U.S. soils[2, 3]		National Irrigation Water Quality Program level of concern[3, 5]
	Minimum	Maximum	Median	Minimum	Maximum	Median	Geometric mean	Baseline range[4]	
Arsenic	24	170	46	12 (39)	370 (180)	191 (110)	5.5	1.2–22	8.2–70
Cadmium	<2	<2	<2	<2 (<2)	<2 (<2)	<2 (<2)	--	--	--
Chromium	20	37	21	61 (40)	62 (46)	62 (43)	41	8.5–200	--
Copper	11	20	12	19 (19)	31 (21)	25 (20)	21	4.9–90	34–270
Lead	22	35	29	18 (15)	19 (18)	18 (16)	17	5.2–55	--
Molybdenum	2	6	5	<2 (3)	<2 (5)	<2 (4)	0.85	0.18–4.0	--
Selenium	<1	<1	<1	2.2 (1.7)	2.8 (3.5)	2.5 (2.6)	0.23	0.039–1.4	1–4
Vanadium	48	120	58	126 (93)	140 (130)	133 (112)	70	18–270	--
Zinc	64	120	120	104 (120)	112 (89)	108 (104)	55	17–180	150–410

[1]Samples collected from the less-than-62-micrometer grain-size fraction of bottom sediment; values in parentheses for 1988 represent samples collected from the less-than-2-millimeter grain-size fraction. Sites summarized are from figure 13.

[2]Modified from Shacklette and Boerngen, 1984.

[3]Bulk-sediment concentrations.

[4]Range in which 95 percent of sample concentrations are expected to occur.

[5]U.S. Department of the Interior, 1998; the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

concentrations in bottom sediment were higher in 1988 than in 1994 at both sites (table 8, fig. 13). Lead and molybdenum concentrations were lower in 1988 than in 1994 (table 8, fig. 13). Copper concentrations were lower in 1988 than in 1994 at site B-12, but higher in 1988 than in 1994 at site B-18. Factors that might have contributed to either an increase or decrease in trace-element bottom-sediment concentrations between 1988 and 1994 include: (1) scouring of surficial sediment between 1988 and 1994 to expose underlying sediment of different character; (2) deposition of new surficial sediment of different character; and (3) collection of bottom-sediment samples at different locations between years at each of the sampling sites such that the results are not directly comparable. The extent to which any of these factors contributed to differences in bottom-sediment constituent concentrations between 1988 and 1994 is unknown. With the exception of arsenic, consistent trends of increasing or decreasing concentrations throughout the study reach are not apparent. Elevated arsenic concentrations at site B-18 can be attributed to effects of mine tailings in Whitewood Creek, as previously discussed. Data are inadequate to determine the extent to which BFRP operations affect trace-element concentrations in bottom sediment.

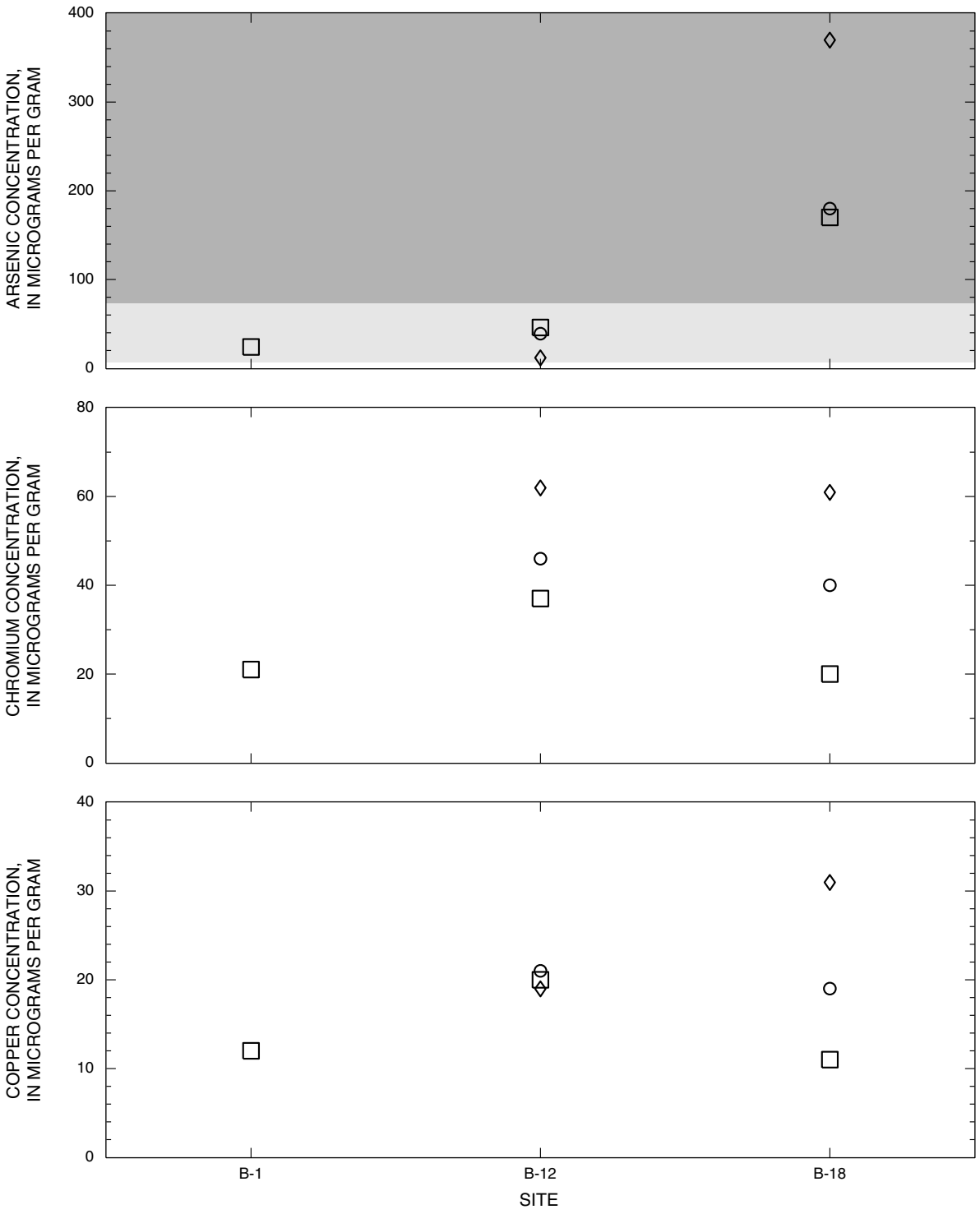


Figure 13. Concentrations of selected trace elements in bottom-sediment samples collected from sites in or near the Belle Fourche Reclamation Project in 1988 and 1994.

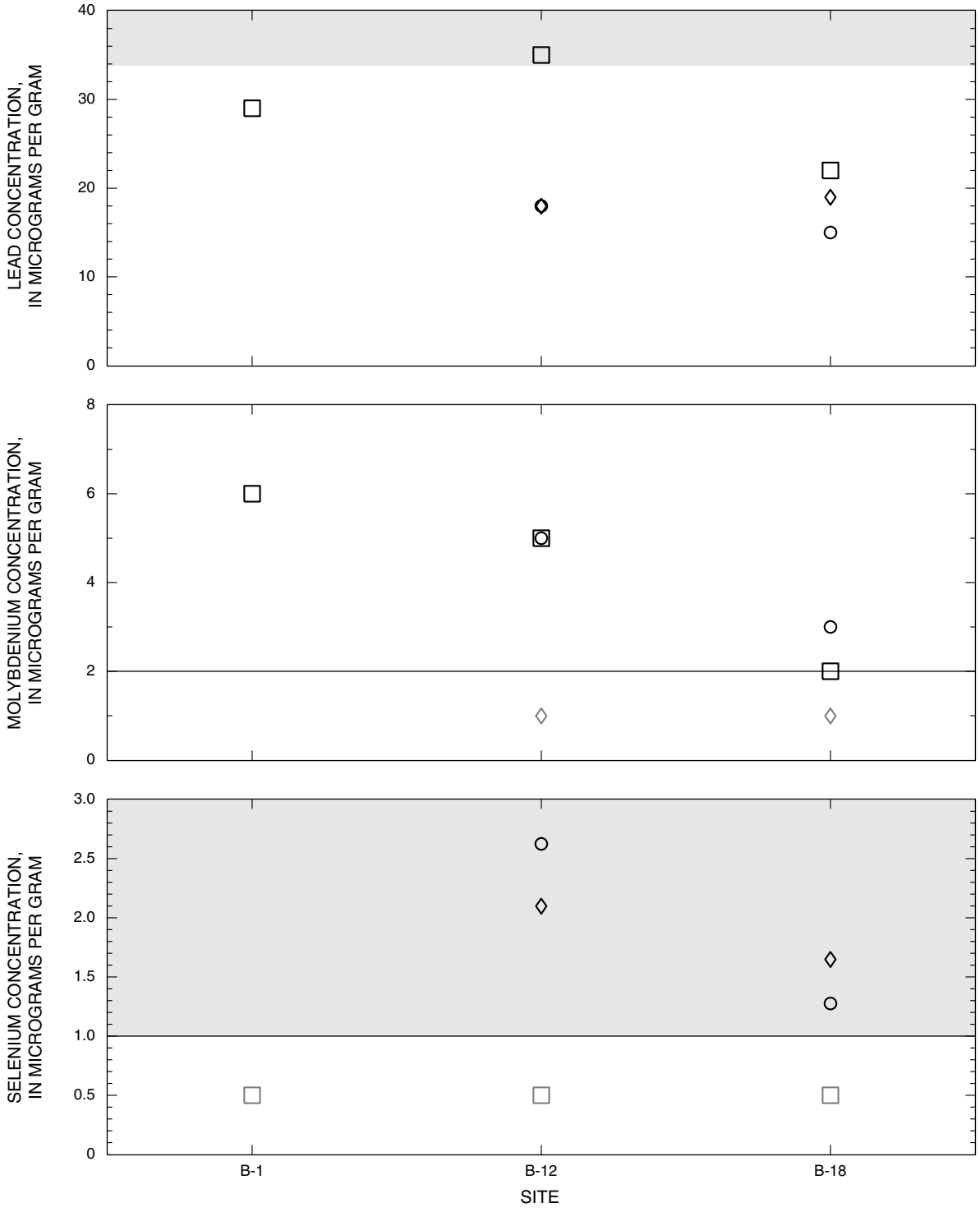


Figure 13. Concentrations of selected trace elements in bottom-sediment samples collected from sites in or near the Belle Fourche Reclamation Project in 1988 and 1994. --Continued

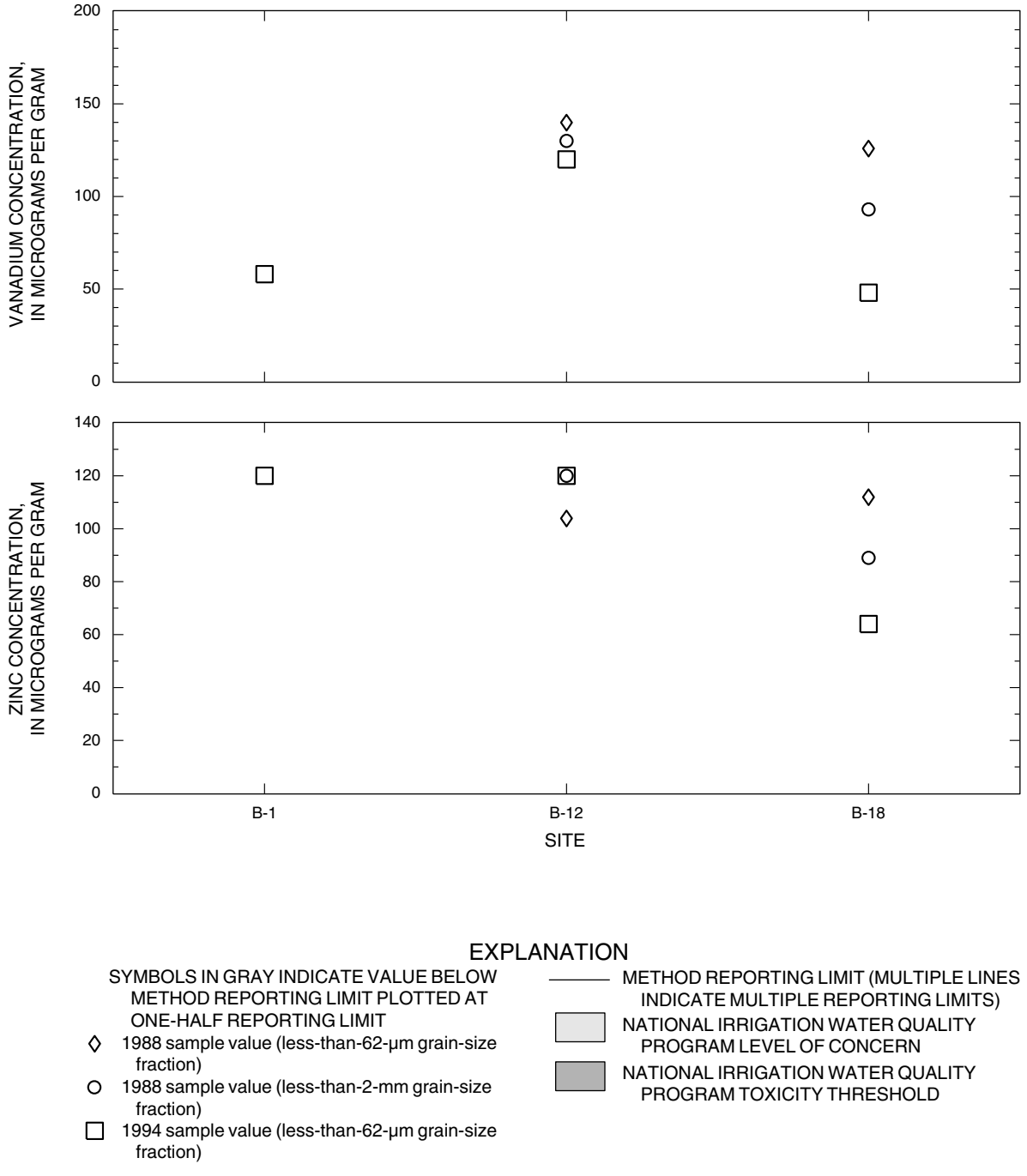


Figure 13. Concentrations of selected trace elements in bottom-sediment samples collected from sites in or near the Belle Fourche Reclamation Project in 1988 and 1994. --Continued

Comparison of trace-element concentrations in bottom sediment with index concentrations for western U.S. soils are presented in table 8. In 1994, only the less-than-62-µm grain-size fraction of the bottom-sediment samples were analyzed for constituent concentrations. However, the index concentrations for western U.S. soils, and the NIWQP levels of concern for trace-element concentrations in sediment both are based on bulk-sediment analyses that are not restricted to a particular-size fraction. Grain size strongly influences trace-element concentrations in bottom sediment, due to physical factors such as adsorptive surface area, and chemical factors such as geochemical composition (that is, certain minerals might occur more frequently in specific grain-size ranges; Horowitz, 1991). Thus, the constituent concentrations in the less-than-62-µm grain-size fraction are not directly comparable to the index and criteria values that are based on bulk-sediment analyses.

In 1988, in addition to the less-than-62-µm grain-size fraction analyses, constituent concentrations also were analyzed for in the less-than-2-mm grain-size fraction (table 8). Bottom sediment in depositional zones of the Belle Fourche River in the BFRP area tends to be fine grained, due largely to the predominance of marine shales in the surficial materials of the basin. Although no size-distribution data are available for the bulk bottom-sediment samples that were collected in 1988, most of the bulk sediment collected probably was less than 2 mm in diameter; therefore, the less-than-2-mm grain-size fraction constituent concentrations probably are comparable to the index and criteria values. Although the less-than-62-µm grain-size fraction data for 1994 are not directly comparable with the index and criteria values, the comparison of constituent concentrations in the 1988 less-than-2-mm grain-size fraction relative to the 1988 less-than-62-µm grain-size fraction might be used to estimate bulk concentrations for 1994 samples for qualitative comparison with index and criteria values.

Arsenic concentrations at all sites exceed typical values for western U.S. soils and are within the NIWQP level of concern. For the 1988 data, the arsenic concentrations in the less-than-2-mm grain-size fraction averaged about one-half of the concentrations in the less-than-62-µm grain-size fraction. For the 1994 data, even if the arsenic concentrations for the less-than-62-µm grain-size fraction are divided by two to allow qualitative comparison with criteria based on bulk samples, all of the concentrations would exceed the geometric mean for western U.S. soils and also would be within the NIWQP level of concern. Thus, bottom-sediment arsenic concentrations in the BFRP area, both upstream and downstream from irrigation operations, probably are higher than typical areas in the western U.S. Very high arsenic concentrations at site B-18 that exceed the NIWQP toxicity threshold result from effects of mining in the Whitewood Creek Basin (Roddy and others, 1991).

All concentrations of chromium, copper, lead, vanadium, and zinc for both 1988 (both grain-size fractions) and 1994 are within baseline soils ranges, although some samples for some of these constituents exceed baseline soils geometric means. Applicable NIWQP guidelines exist for copper and zinc, and no samples exceed the guidelines. Some concentrations of molybdenum in the 1988 less-than-2-mm grain-size fractions exceed the western U.S. soils baseline range. Based on comparison of molybdenum concentrations in the two grain-size fractions for 1988, it is likely that bulk molybdenum concentrations in 1994 samples also would exceed the western U.S. soils baseline range. All selenium concentrations in both grain-size fractions for 1988 exceed the western U.S. soils baseline range and are within the NIWQP level of concern. However, all 1994 samples had selenium concentrations that were lower than the NIWQP level of concern. There is no clear pattern in trace-element concentrations in bottom sediment that indicates BFRP operations either increase or decrease the constituent concentrations.

Fish

Analytical results for fish-tissue samples collected in 1994 are presented in table 15 in the Supplemental Information section. A statistical summary of results for 1988 and 1994 is provided in table 9. For 1988, most trace-element concentrations in biota samples are less than concentrations that might adversely affect fish or birds (table 9), although some concentrations do exceed established criteria.

The median arsenic concentration (0.3 µg/g dw) of fish sampled in 1988 is lower than the NCBP 85th-percentile baseline value of 0.81 µg/g dw (Schmitt and Brumbaugh, 1990) and lower than the NIWQP level of concern (table 9), but several individual fish-tissue samples were within the level of concern (Roddy and others, 1991). In 1994, the median arsenic concentration was lower than the level of concern. However, three individual fish-tissue composite samples from site B-18 are within the level of concern, and a fourth

composite fish sample of adult river carpsuckers from site B-18 had an arsenic concentration of 16 µg/g dw, which exceeds the toxicity threshold (table 15; U.S. Department of the Interior, 1998). The elevated arsenic concentrations in fish at site B-18 probably resulted from effects of mining activities in the Whitewood Creek Basin. Gilderhus (1966) found that an arsenic residue level of 4.68 µg/g dw in juvenile bluegills was associated with poor growth and survival.

The median copper concentration in fish tissue was lower than the NCBP 85th-percentile baseline value for copper of 3.67 µg/g dw (Schmitt and Brumbaugh, 1990) and lower than the NIWQP level of concern for 1994 and 1988 (table 9). All 1988

Table 9. Comparison of fish-tissue concentrations for the Belle Fourche Reclamation Project with the National Irrigation Water Quality Program level of concern[1]

[Concentrations in micrograms per gram dry weight; <, less than; --, no data; 12 samples per element in 1994, 128 samples per element in 1988]

Constituent	1994 (includes data from sites B-1, B-12, and B-18)			1988 (includes data from sites B-2, B-12, and B-18			National Irrigation Water Quality Program level of concern[1] for fish
	Minimum	Maximum	Median	Minimum	Maximum	Median	
Aluminum	51	1,330	352	3	4,100	131	--
Arsenic	<0.3	16	0.55	<0.1	7.6	0.3	1–12
Boron	<0.6	3	<2	<2	17	<2	--
Barium	2.4	35.6	7.1	0.2	84	4.2	--
Beryllium	<0.03	0.05	<0.03	0.01	0.20	<0.10	--
Cadmium	0.048	0.88	0.090	0.02	1.5	0.2	--
Chromium	0.3	1.7	0.7	<0.1	8.4	1.35	--
Copper	2.1	21	3.5	0.7	6.1	2.2	9.8–13.3
Iron	73	1,170	346	43	2,680	180	--
Mercury	0.088	0.418	0.18	0.004	1.1	0.32	1.0 (toxicity threshold for coldwater species)
Magnesium	1,110	2,050	1,395	644	2,510	1,430	--
Manganese	10.9	79.1	24.8	1.8	134	28	--
Molybdenum	<0.2	<1	<1	<0.1	1.0	<1	--
Nickel	<0.06	1.8	0.44	<0.1	5.2	2.0	--
Lead	<0.07	0.57	0.20	<0.4	<5	<0.9	--
Selenium	2.8	6.5	4.5	1.4	5.7	2.8	3–4 (warmwater species); 2–4 (coldwater species)
Strontium	104	263	166	24	2,204	174	--
Vanadium	<0.2	3.5	0.74	<0.1	15	0.6	--
Zinc	70.1	141	93.6	42	601	76	--

[1]U.S. Department of the Interior, 1998; the upper value of the level of concern represents the National Irrigation Water Quality Program toxicity threshold.

individual fish-tissue samples were lower than the level of concern, but one 1994 composite fish sample of adult river carpsuckers from site B-18 had a copper concentration of 21 µg/g dw (table 15), which exceeds the toxicity threshold (table 9). The elevated copper concentrations in fish tissue at site B-18 probably resulted from effects of mining activities in the Whitewood Creek Basin.

Median mercury concentrations in fish tissue decreased from 0.32 µg/g dw in 1988 to 0.18 µg/g dw in 1994, both of which are lower than the toxicity threshold (table 9), the NCBP 85th-percentile baseline value of 0.65 µg/g dw (Schmitt and Brumbaugh, 1990), and the avian dietary guideline of 0.4 µg/g dw. In 1994, only one composite fish-tissue sample (adult sand shiners) from site B-18 (table 15) had a mercury concentration (0.42 µg/g dw) that slightly exceeded the dietary threshold, but in 1988 several fish-tissue samples exceeded this dietary threshold (Roddy and others, 1991); most of those samples also were from site B-18. The elevated mercury concentrations in fish at site B-18 probably resulted from effects of mining activities in the Whitewood Creek Basin.

The median selenium concentration (4.5 µg/g dw) for fish-tissue samples for 1994 is slightly higher than the NIWQP level of concern for either warmwater or coldwater species (table 9) and is higher than the NCBP 85th-percentile baseline value of 2.8 µg/g dw (Schmitt and Brumbaugh, 1990). The 1994 median also is higher than the 1988 median (table 9). Recent literature suggests that 4 µg/g dw is the threshold tissue concentration to protect fish from reproductive failure and other health effects (Lemly, 1993). Additionally, 3 µg/g dw is the recommended threshold in dietary items for the protection of avian consumers (Lemly, 1993; Heinz, 1996). Concentrations in all fish-tissue composite samples from 1994 were higher than 3 µg/g dw with the exception of one subadult orangespotted sunfish sample and one adult channel catfish sample collected at site B-12 (table 15).

The 1994 median zinc concentration (93.6 µg/g dw) is higher than the NCBP 85th percentile baseline value of 88 µg/g dw (Schmitt and Brumbaugh, 1990) and higher than the 1988 median zinc concentration of 76 µg/g dw. Currently, there is not a NIWQP level of concern for fish, and toxicity levels for zinc concentrations in animal tissues are not well established (U.S. Department of the Interior, 1998).

Synopsis of Results for the Belle Fourche Reclamation Project

Concentrations of major ions in water in the study area are high relative to national baseline levels. Major-ion concentrations generally are lower for 1994 than for 1988, when sampling was conducted during generally low-flow conditions, but ionic proportions are similar between years. The 1994 results are associated with more typical hydrologic conditions. Concentrations of major ions at sites B-12 and B-18, which are affected by irrigation drainage (site B-18 also is affected by mining operations), are higher than concentrations at site B-1, which is an upstream site. This pattern might indicate that BFRP operations increase dissolved-solids concentrations in the area, but the data are inadequate to conclusively determine this.

Concentrations of most trace elements in water samples are similar between 1988 and 1994, and do not show strong relations with discharge. However, selenium concentrations at site B-12 are higher for 1988 than for 1994, and show an inverse relation with discharge. Concentrations for 1994 at this site are associated with more typical hydrologic conditions. Concentrations of most trace elements (with the exception of arsenic, boron, selenium, and uranium) are not consistently very different between sites B-1, B-12, and B-18. Arsenic concentrations are elevated at site B-18, which can be attributed to effects of mine tailings in Whitewood Creek. Concentrations of boron, selenium, and uranium are higher for site B-12 (Horse Creek) than the other two sites; site B-1 (upstream from irrigation operations) had the lowest concentrations of these constituents. Site B-12 is most affected by irrigation drainage and BFRP operations probably contribute to trace-element concentrations in the Belle Fourche River, but available data are inadequate to quantify increases. Concentrations of several trace elements occasionally exceed NIWQP guidelines. Copper concentrations routinely are within the NIWQP level of concern, but none of the samples approach the toxicity threshold of 12 µg/L. Concentrations of selenium are within or exceed the NIWQP level of concern, even at site B-1, upstream from Belle Fourche operations. However, selenium concentrations at sites B-12 and B-18, which are affected by BFRP irrigation drainage are consistently slightly higher than at site B-1 and more frequently exceed various criteria. Selenium concentrations might at times be problematic in the BFRP area. Naturally occurring concentrations are relatively

high, and BFRP operations might contribute additional loads. Also, at some sites selenium concentrations increase during low-flow conditions.

Concentrations of most trace elements in bottom sediment are similar for 1988 and 1994, and generally are within baseline ranges for western U.S. soils, with the exception of arsenic and selenium. Concentrations of trace elements do not show either increasing or decreasing trends throughout the study area that could be conclusively attributed to effects of BFRP operations. Arsenic concentrations at all sites exceed typical values for western U.S. soils and are within the NIWQP level of concern. Highest arsenic concentrations in bottom sediment occur at site B-18, which is influenced by mine tailings. Selenium concentrations at sites B-12 and B-18 for 1988 are within the NIWQP level of concern, but all 1994 samples were lower than the NIWQP level of concern.

Concentrations of most trace elements in fish in the BFRP area are lower than values known to adversely affect fish or birds, although there are occasional exceedances of established criteria. Arsenic and mercury concentrations are elevated in fish samples from site B-18, which is influenced by mine tailings. Selenium concentrations in fish might be problematic. Selenium concentrations in fish samples routinely are within the NIWQP level of concern at all sites. Concentrations generally are higher at sites B-12 and B-18, which are influenced by BFRP irrigation drainage.

Selenium can occur at concentrations that might have adverse environmental effects in all of the media that were sampled. However, all bottom-sediment selenium concentrations for 1994 were less than the MRL of 1 µg/g. Selenium concentrations generally exceed NIWQP levels of concern for the various media (with the exception of bottom sediment in 1994) for both 1988 and 1994, during varying flow conditions. Selenium concentrations are larger in all media (with the exception of bottom sediment in 1994) at sites B-12 and B-18, which are influenced by BFRP irrigation drainage. It can be concluded that selenium concentrations might at times be problematic in the BFRP area. Naturally occurring concentrations are relatively high, and BFRP operations might contribute additional loads. Also, at some sites selenium concentrations increase during low-flow conditions.

SUMMARY AND CONCLUSIONS

The U.S. Department of the Interior started the National Irrigation Water Quality Program (NIWQP) in 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the western U.S. The Angostura Reclamation Unit (ARU) and Belle Fourche Reclamation Project (BFRP) in western South Dakota were included as part of this program. The ARU and BFRP reconnaissance studies were initiated in 1988, during below-normal streamflow conditions in both study areas. Surface water, bottom sediment, and fish were resampled in 1994 at selected sites in both study areas during generally near-normal streamflow conditions to compare with the 1988 study results.

Streamflows were closer to normal in 1994 than in 1988. Discharge measurements made at the times that water and bottom-sediment samples were collected averaged about 40 percent greater for 1994 samples than for 1988 samples, for both ARU and BFRP sites.

Concentrations of major ions in water for both the ARU and BFRP study areas are high relative to national baseline levels. Major-ion concentrations for both areas generally are lower for 1994 than for 1988, when sampling was conducted during low-flow conditions, but ionic proportions are similar between years. The 1994 results are associated with more typical hydrologic conditions.

For ARU, major-ion concentrations and proportions vary substantially in the Cheyenne River upstream from Angostura Reservoir, primarily due to inflows from Cascade Springs. Angostura Reservoir integrates inflows from various tributaries over time, and ionic proportions are fairly constant downstream from the reservoir. Downstream from Angostura Reservoir, a small increase in concentrations of dissolved solids probably occurs; however, the limited data sets available are insufficient to confidently discern effects of ARU operations on dissolved-solids loading. For BFRP, concentrations of major ions at sites B-12 and B-18, which are affected by irrigation drainage, are higher than concentrations at site B-1 which is an upstream site. This pattern might indicate that BFRP operations increase dissolved-solids concentrations in the area, but the data are inadequate to conclusively determine this.

Most trace-element concentrations in water samples for both study areas are similar between 1988 and 1994, and do not show strong relations with discharge. Concentrations of trace elements at the

downstream end of the ARU are similar to concentrations upstream from and within ARU. ARU operations probably are not contributing discernible additional loads of trace elements to the Cheyenne River. For BFRP, concentrations of most trace elements (with the exception of arsenic, boron, selenium, and uranium) are not consistently very different between sites B-1, B-12, and B-18. Arsenic concentrations are elevated at site B-18, which can be attributed to effects of mine tailings in Whitewood Creek. Concentrations of boron, selenium, and uranium generally are higher for site B-12 (Horse Creek) than the other two sites; site B-1 (upstream from irrigation operations) had the lowest concentrations of these constituents. BFRP operations probably contribute to trace-element concentrations in the Belle Fourche River, but available data are inadequate to quantify increases. For both study areas, concentrations of several trace elements occasionally exceed NIWQP guidelines. Selenium routinely occurs in concentrations that could be problematic at sites upstream and downstream from both study areas. Elevated selenium concentrations at sites upstream from irrigation operations indicate that naturally occurring selenium concentrations are relatively high in and near the study areas. While ARU operations probably do not contribute discernible additional loads of selenium to the Cheyenne River, BFRP operations might contribute additional loads to the Belle Fourche River.

Concentrations of most trace elements in bottom sediment, except arsenic and selenium, generally are similar to typical concentrations for western U.S. soils for both study areas in both 1988 and 1994. For ARU, some arsenic concentrations at sites both upstream and downstream from irrigation operations are within the NIWQP level of concern, and one selenium sample exceeds the NIWQP toxicity threshold. For BFRP, all arsenic samples at sites both upstream and downstream from BFRP irrigation operations are within or exceed the NIWQP level of concern. Selenium concentrations for 1988 samples are within the NIWQP level of concern, but all concentrations for 1994 samples were lower than the level of concern. Bottom-sediment arsenic and selenium concentrations in both study areas apparently can at times reach levels that might be of concern; however, there is insufficient information to determine whether irrigation operations contribute to elevated concentrations.

Concentrations of most trace elements in fish in both study areas are less than values known to adversely affect fish or birds, although there are occasional exceedances of established criteria. Selenium concentrations in fish might be problematic. Selenium concentrations in fish samples routinely are within the NIWQP level of concern, and also commonly exceed the dietary guideline for protection of avian consumers for both study areas. In both study areas, selenium concentrations in fish samples generally are higher at sites downstream from irrigation operations. For BFRP, arsenic and mercury concentrations are elevated in fish samples from site B-18, which is influenced by mine tailings.

Selenium can occur at concentrations that might have adverse environmental effects in all of the media that were sampled for both study areas. Also, selenium concentrations generally exceed NIWQP levels of concern for the various media (with the exception of bottom sediment in 1994) for both 1988 and 1994, during varying flow conditions. However, the data collected during the 1988 and 1994 studies are insufficient to confidently determine the extent to which irrigation operations contribute to elevated selenium concentrations in the various media.

REFERENCES

Berg, D.J., and Burns, T.A., 1985, The distribution of aluminum in the tissues of three fish species: Journal of Freshwater Ecology, v. 3, no. 1, p. 113-120.

Brumbaugh, W.G., and Kane, D.A., 1985, Variability of aluminum concentrations in organs and whole bodies of smallmouth bass (*Micropterus dolomieui*): Environmental Science and Technology, v. 19, no. 9, p. 828-831.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 240 p.

Eisler, R., 1993, Zinc hazards to fish, wildlife, and invertebrates—A synoptic review: Washington, D.C., U.S. Fish and Wildlife Service Biological Report 10, 106 p.

Feltz, H.R., Sylvester, M.A., and Engberg, R.A., 1991, Reconnaissance investigation of the effects of irrigation drainage on water quality, bottom sediment, and biota in the Western United States, *in* Mallard, G.E., and Aronson, D.A., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Monterey, California, March 11-15, 1991: U.S. Geological Survey Water-Resources Investigations Report 91-4034, p. 319-323.

Gilderhus, P.A., 1966, Some effects of sublethal concentrations of sodium arsenate on bluegills and the aquatic environment: Transactions of the American Fisheries Society, v. 95, no. 3, p. 289-296.

Goddard, K.E., 1989, Composition, distribution, and hydrologic effects of contaminated sediments resulting from the discharge of gold milling wastes to Whitewood Creek at Lead and Deadwood, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 87-4051, 76 p.

Greene, E.A., Sowards, C.L., and Hansmann, E.W., 1990, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Angostura Reclamation Unit, southwestern South Dakota, 1988-1989: U.S. Geological Survey Water-Resources Investigations Report 90-4152, 75 p.

Heinz, G.H, 1996, Selenium in birds, *in* Beyer, W.N., Heinz, G.H., and Redmon-Norwood, A.W., eds., Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations: Boca Raton, Fla., Lewis Publishers, p. 447-458.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Horowitz, A.J., 1991, A primer on sediment-trace element chemistry (2d ed.): Chelsea, Mich., Lewis Publishers, 136 p.

Leighton, D.A., Deverel, S.J., and Macdonald, J.K., 1992, Spatial distribution of selenium and other inorganic constituents in ground water underlying a drained agricultural field, western San Joaquin Valley, California: U.S. Geological Survey Water-Resources Investigations Report 91-4119, 73 p.

Lemly, A.D., 1993, Guidelines for evaluating selenium data from aquatic monitoring and assessment studies: Environmental Monitoring and Assessment, v. 28, p. 83-100.

Lemly, A.D., and Smith G.J., 1987, Aquatic cycling of selenium—implications for fish and wildlife: Washington, D.C., U.S. Fish and Wildlife Service Leaflet 12, 10 p.

National Academy of Sciences – National Academy of Engineering, 1973, Water quality criteria, 1972: Washington, D.C., National Academy of Sciences, 594 p.

Ohlendorf, H.M., Hoffman, D.J., Saiki, M.K., and Aldrich, T.W., 1986, Embryonic mortality and abnormalities of aquatic birds—apparent impacts of selenium from irrigation drainwater: Science of the Total Environment, v. 52, p. 49-63.

Ohlendorf, H.M., Hothem, R.L., Bunck, C.M., Aldrich, T.W., and Moore, J.F., 1986, Relationships between selenium concentration and avian reproduction: North American Wildlife and Natural Resources Conference, 51st, Reno, Nevada, Transactions, 1986, p. 330-442.

Nicholopoulos, Joy, 2001, The endangered species listing program: accessed May 2, 2001, at URL http://endangered.fws.gov/listing/index.html.

Roddy, W.R., Greene, E.A., and Sowards, C.L., 1991, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Belle Fourche Reclamation Project, western South Dakota, 1988-1989: U.S. Geological Survey Water-Resources Investigations Report 90-4192, 113 p.

Schmitt, C.J., and Brumbaugh, W.G., 1990, National contaminant biomonitoring program—Concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976-1984: Archives of Environmental Contamination and Toxicology, v. 19, p. 731-747.

Shacklette, H.T., and Boerngen, J.G., 1984, Element concentrations in soils and other surficial materials of the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.

Smith, R.A., Alexander, R.B., and Wolman, G.M., 1987, Water-quality trends in the Nation's rivers: Science, v. 235, p. 1607-1615.

South Dakota Legislative Research Council, 2001, Administrative Rules Chapter 74:51:01 Surface water quality standards—Appendix B—Toxic pollutant criteria: accessed May 4, 2001, at URL http://legis.state.sd.us/rules/rules/7451.htm.

Stiff, H.A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. 3, no. 10, p. 15-17.

Strobel, M.L, Jarrell, G.J., Sawyer, J.F., Schleicher, J.R., and Fahrenbach, M.D., 1999, Distribution of hydrogeologic units in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-743, 3 sheets, scale 1:100,000.

Suter, G.W., II, and Mabrey, J.B., 1994, Toxicological benchmarks for screening potential contaminants of concern for effects on aquatic biota—1994 revision: Oak Ridge National Laboratory, Oak Ridge, Tennessee ES/ER/TM-96/R, prepared for U.S. Department of Energy, Office of Environmental Restoration and Waste Management.

U.S. Environmental Protection Agency, 1986, Quality criteria for water (updated May 1986), Update No. 2: Washington, D.C., Office of Water Regulations and Standards, EPA 4405/5-86-001.

———1999, National recommended water quality criteria—correction: Office of Water, EPA 822-Z-99-001.

U.S. Fish and Wildlife Service, 1985, Field operations manual for resource contaminant assessment: U.S. Fish and Wildlife Service, Resource Contaminant Assessment Division, Washington, D.C., 331 p.

———2001, ESA basics—over 25 years of protecting endangered species: accessed May 2, 2001, at URL http://endangered.fws.gov/ whatewedo.html.

U.S. Department of the Interior, 1998, Guidelines for the interpretation of the biological effects of selected constituents in biota, water, and sediment: Denver, Colo., National Irrigation Water Quality Program Information Report No. 3., 198 p.

Ward, J.R., and Harr, C.A., eds., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90-140, 71 p.

SUPPLEMENTAL INFORMATION

Table 10. Physical properties, and concentrations of major ions and selected trace elements for water samples collected from sites in or near the Angostura Reclamation Unit in 1994

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius; mm, millimeters; mg/L, milligrams per liter; µg/L, micrograms per liter; inst, instantaneous; TIT, titration; IT, incremental titration; ANC, acid neutralizing capacity; lab, laboratory; <, less than; --, no data available]

Station identification	Site number	Date	Time	Discharge, inst (cubic feet per second) (00061)	Specific conduct-ance (µS/cm) (00095)	pH, unfiltered, lab (stand-ard units) (00400)	Temper-ature, air (deg C) (00020)	Temper-ature, water (deg C) (00010)	Barometric pressure (mm of Hg) (00025)	Oxygen, dissolved (mg/L) (00300)
06395000	A-1	04-19-94	0920	42	4,790	8.4	12.5	15.0	681	9.1
	A-1	09-08-94	1425	.06	7,090	7.7	33.6	24.0	662	7.6
432121103252600	A-5	04-19-94	1220	41	2,000	8.4	23.5	11.1	687	11.8
	A-5	09-09-94	0830	3.1	2,250	8.0	19.2	19.2	668	8.3
433012103042000	A-12	04-20-94	0930	92	2,260	8.2	16.0	14.7	690	9.2
	A-12	09-08-94	1030	54	2,550	8.0	30.0	18.6	677	8.8
06403700	A-14	04-20-94	1145	117	2,320	8.3	21.0	16.5	690	9.6
	A-14	09-08-94	0820	60	2,620	8.2	13.7	17.2	683	8.7

Site number	Date	Oxygen, dissolved (percent saturation) (00301)	Hardness, total (mg/L as $CaCO_3$) (00900)	Alkalinity, filtered, total IT, lab (mg/L as $CaCO_3$) (39086)	ANC, unfiltered, TIT to 4.5, lab (mg/L as $CaCO_3$) (90410)	Calcium, filtered (mg/L as Ca) (00915)	Magne-sium, filtered (mg/L as Mg) (00925)	Sodium, filtered (mg/L as Na) (00930)	Sodium (percent) (00932)	Sodium adsorp-tion ratio (00931)	Potassium, filtered (mg/L as K) (00935)
A-1	04-19-94	103	1,100	246	231	270	110	700	57	9	10
A-1	09-08-94	107	--	332	313	--	--	1,100	--	--	20
A-5	04-19-94	120	670	138	138	180	53	190	38	3	8.7
A-5	09-09-94	104	930	174	174	240	81	210	33	3	12
A-12	04-20-94	101	860	169	351	230	69	200	33	3	11
A-12	09-08-94	107	950	203	172	250	80	230	34	3	18
A-14	04-20-94	110	900	169	159	240	74	210	33	3	12
A-14	09-08-94	102	900	171	148	230	79	250	37	4	17

Table 10. Physical properties, and concentrations of major ions and selected trace elements for water samples collected from sites in or near the Angostura Reclamation Unit in 1994—Continued

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius; mm, millimeters; mg/L, milligrams per liter; µg/L, micrograms per liter; inst, instantaneous; TIT, titration; IT, incremental titration; ANC, acid neutralizing capacity; lab, laboratory; <, less than; --, no data available]

Site number	Date	Bicarbonate, filtered, IT, lab (mg/L as HCO_3) (00453)	Carbonate, filtered, IT, lab (mg/L as CO_3) (00452)	Chloride, filtered (mg/L as Cl) (00940)	Sulfate, filtered (mg/L as SO_4) (00945)	Solids, sum of constituents, filtered (mg/L) (70301)	Solids, residue at 180 deg C, filtered (mg/L) (70300)	Aluminum, filtered (µg/L as Al) (01106)	Arsenic, filtered (µg/L as As) (01000)	Boron, filtered (µg/L as B) (01020)	Cadmium, filtered (µg/L as Cd) (01025)
A-1	04-19-94	280	10	490	1,700	3,430	3,540	<10	<1	300	<1
A-1	09-08-94	405	0	540	3,300	--	6,220	20	<1	1,100	<1
A-5	04-19-94	166	1	96	790	1,400	1,490	<10	<1	160	<1
A-5	09-09-94	208	0	110	890	1,650	1,670	<10	2	180	<1
A-12	04-20-94	206	0	110	930	1,650	1,760	<10	<1	240	<1
A-12	09-08-94	248	0	130	1,100	1,930	2,010	30	1	340	<1
A-14	04-20-94	206	0	110	970	1,720	1,830	<10	<1	240	<1
A-14	09-08-94	208	0	140	1,100	1,920	2,000	20	<1	340	<1

Site number	Date	Chromium, filtered (µg/L as Cr) (01030)	Copper, filtered (µg/L as Cu) (01040)	Lead, filtered (µg/L as Pb) (01049)	Mercury, filtered (µg/L as Hg) (71890)	Molybdenum, filtered (µg/L as Mo) (01060)	Selenium, filtered (µg/L as Se) (01145)	Uranium, natural, filtered (µg/L as U) (22703)	Uranium, natural, 2 sigma, filtered, (µg/L) (75990)	Vanadium, filtered (µg/L as V) (01085)	Zinc, filtered (µg/L as Zn) (01090)
A-1	04-19-94	<1	<1	<1	<0.1	4	<1	16	2.5	9	<10
A-1	09-08-94	<1	<1	<1	<.1	4	--	25	3.7	15	<10
A-5	04-19-94	<1	1	<1	<.1	5	2	7.6	1.1	2	5
A-5	09-09-94	<1	<1	<1	<.1	8	4	9.2	1.4	3	<10
A-12	04-20-94	<1	<1	<1	<.1	7	2	11	1.6	2	<10
A-12	09-08-94	<1	<1	<1	<.1	8	3	13	2.0	4	<10
A-14	04-20-94	<1	<1	<1	<.1	7	2	11	1.7	2	<10
A-14	09-08-94	<1	<1	<1	<.1	6	2	13	1.9	4	<10

Table 11. Concentrations of selected major-ion and trace-element constituents in bottom-sediment samples collected from sites in or near the Angostura Reclamation Unit in 1994

[bot mat, bottom material; DS, dry sieved; µg/g, micrograms per gram; µm, micrometer; <, less than]

Station identification	Site number	Date	Time	Aluminum, bot mat, <62 µm DS, lab (percent) (34790)	Arsenic, bot mat, <62 µm DS, lab (µg/g) (34800)	Barium, bot mat, <62 µm DS, lab (µg/g) (34805)	Beryllium, bot mat, <62 µm DS, lab (µg/g) (34810)	Bismuth, bot mat, <62 µm DS, lab (µg/g) (34815)	Cadmium, bot mat, <62 µm DS, lab (µg/g) (34825)	Calcium, bot mat, <62 µm DS, lab (percent) (34830)
06395000	A-1	09-06-94	1425	3.7	<10	770	<1	<10	<2	0.76
06395000	A-1	09-06-94	1430	3.8	12	790	<1	<10	<2	.84
432121103252600	A-5	09-08-94	0830	3.8	12	920	<1	<10	<2	2.9
433012103042000	A-12	09-09-94	1030	4.6	19	1,100	<1	<10	<2	4.4
06403700	A-14	09-08-94	0800	3.5	<10	730	<1	<10	<2	1.1

Site number	Date	Cerium, bot mat, <62 µm DS, lab (µg/g) (34835)	Chromium, bot mat, <62 µm DS, lab (µg/g) (34840)	Cobalt, bot mat, <62 µm DS, lab (µg/g) (34845)	Copper, bot mat, <62 µm DS, lab (µg/g) (34850)	Europium, bot mat, <62 µm DS, lab (µg/g) (34855)	Gallium, bot mat, <62 µm DS, lab (µg/g) (34860)	Gold, bot mat, <62 µm DS, lab (µg/g) (34870)	Holmium, bot mat, <62 µm DS, lab (µg/g) (34875)	Iron, bot mat, <62 µm DS, lab (percent) (34880)	Lead, bot mat, <62 µm DS, lab (µg/g) (34890)
A-1	09-06-94	20	6	4	3	<2	7	<2	<4	1.7	23
A-1	09-06-94	20	7	4	2	<2	7	<2	<4	1.6	22
A-5	09-08-94	28	9	5	4	<2	8	<2	<4	1.9	28
A-12	09-09-94	48	30	8	10	<2	20	<2	<4	2.9	20
A-14	09-08-94	30	12	3	4	<2	6	<2	<4	1.3	17

Table 11. Concentrations of selected major-ion and trace-element constituents in bottom-sediment samples collected from sites in or near the Angostura Reclamation Unit in 1994—Continued

[bot mat, bottom material; DS, dry sieved; µg/g, micrograms per gram; µm, micrometer; <, less than]

Site number	Date	Lithium, bot mat, <62 µm DS, lab (µg/g) (34895)	Magnesium, bot mat, <62 µm DS, lab (percent) (34900)	Manganese, bot mat, <62 µm DS, lab (µg/g) (34905)	Molyb-denum, bot mat, <62 µm DS, lab (µg/g) (34915)	Nickel, bot mat, <62 µm DS, lab (µg/g) (34925)	Niobium, bot mat, <62 µm DS, lab (µg/g) (34930)	Phosphorus, bot mat, <62 µm DS, lab (percent) (34935)	Potassium, bot mat, <62 µm DS, lab (percent) (34940)	Scandium, bot mat, <62 µm DS, lab (µg/g) (34945)
A-1	09-06-94	4	0.09	490	<2	7	<4	0.03	2.7	<2
A-1	09-06-94	4	.09	420	<2	8	<4	.03	2.8	<2
A-5	09-08-94	8	.19	460	<2	8	<4	.05	2.5	2
A-12	09-09-94	20	.44	610	<2	18	<4	.06	2.2	5
A-14	09-08-94	6	.17	230	<2	7	<4	.03	2.4	<2

Site number	Date	Selenium, bot mat, <62 µm DS, lab (µg/g) (34950)	Sodium, bot mat, <62 µm DS, lab (percent) (34960)	Strontium, bot mat, <62 µm DS, lab (µg/g) (34965)	Tantalum, bot mat, <62 µm DS, lab (µg/g) (34975)	Thorium, bot mat, <62 µm DS, lab (µg/g) (34980)	Titanium, bot mat, <62 µm DS, lab (percent) (49274)	Uranium, bot mat, <62 µm DS, lab (µg/g) (35000)	Vanadium, bot mat, <62 µm DS, lab (µg/g) (35005)	Zinc, bot mat, <62 µm DS, lab (µg/g) (35020)
A-1	09-06-94	<1	1.0	120	<40	<4	0.03	<100	14	25
A-1	09-06-94	<1	1.0	120	<40	<4	.03	<100	13	25
A-5	09-08-94	<1	.93	170	<40	4	.06	<100	21	64
A-12	09-09-94	<1	.79	280	<40	7	.13	<100	75	64
A-14	09-08-94	<1	.75	110	<40	4	.08	<100	21	27

Table 12. Concentrations of selected constituents in composite fish samples collected from sites in or near the Angostura Reclamation Unit in 1994

[Concentrations in micrograms per gram dry weight]

Station identification	Site number	Sampling period	Sample number	Common name	Species	Age	Number of fish in sample
06395000	A-1	May 1994	CR-1-GS	Green sunfish	*Lepomis cyanellus*	subadult	10
	A-1	May 1994	CR-1-PK	Plains killifish	*Fundulus zebrinus*	adult	29
	A-1	September 1994	CR-1-XX	Green sunfish	*Lepomis cyanellus*	subadult	7
	A-1	September 1994	CR-1-XXX	Plains killifish	*Fundulus zebrinus*	adult	15
432121103252600	A-5	May 1994	CR-5-CC	Channel catfish	*Ictalurus punctatus*	subadult	4
	A-5	May 1994	CR-5-CS	White sucker	*Catostomus commersoni*	adult	3
	A-5	September 1994	CR-5-XX	Green sunfish	*Lepomis cyanellus*	subadult	8
	A-5	September 1994	CR-5-XXX	Rock bass	*Ambloplites rupestris*	adult	2
433012103042000	A-12	May 1994	CR-12-GE	Goldeye	*Hiodon alosoides*	adult	2
	A-12	May 1994	CR-12-NR	Shorthead redhorse	*Moxostoma macrolepidotum*	adult	2
	A-12	September 1994	CR-12-XX	Common carp	*Cyprinus carpio*	adult	3
	A-12	September 1994	CR-12-YY	Shorthead redhorse	*Moxostoma macrolepidotum*	adult	3
06403700	A-14	May 1994	FHC-14	Flathead chub	*Platygobio gracilis*	adult	29
	A-14	May 1994	GE-14	Goldeye	*Hiodon alosoides*	adult	2
	A-14	September 1994	FHC-XX	Common carp	*Cyprinus carpio*	adult	1
	A-14	September 1994	GE-XX	White sucker	*Catostomus commersoni*	adult	1

Site number	Sample number	Common name	Length (millimeters)	Percent moisture	Aluminum	Arsenic	Boron	Barium	Beryllium
A-1	CR-1-GS	Green sunfish	49 - 124	75.5	179	0.3	0.7	2.9	<0.03
A-1	CR-1-PK	Plains killifish	35 - 198	76.0	2,200	1.3	3.3	19.8	.12
A-1	CR-1-XX	Green sunfish	84 - 110	73.8	9,280	2.6	7.6	52.6	.26
A-1	CR-1-XXX	Plains killifish	48 - 72	75.7	68	.2	<2.0	1.3	<.03
A-5	CR-5-CC	Channel catfish	280 - 334	77.3	262	.3	1.0	3.2	<.03
A-5	CR-5-CS	White sucker	328 - 345	71.4	99	<.3	<.6	2.1	<.03
A-5	CR-5-XX	Green sunfish	80 - 160	76.8	120	.2	<2.0	3.1	<.03
A-5	CR-5-XXX	Rock bass	97 - 161	72.9	92	.4	<2.0	4.5	<.03
A-12	CR-12-GE	Goldeye	384 - 392	73.1	63	<.3	<0.6	1.1	.04
A-12	CR-12-NR	Shorthead redhorse	344 - 350	66.8	120	<.3	1.0	7.1	<.03
A-12	CR-12-XX	Common carp	415 - 470	76.8	170	.2	<2.0	2.8	<.03
A-12	CR-12-YY	Shorthead redhorse	170 - 316	70.3	32	<.1	<2.0	3.8	<.03
A-14	FHC-14	Flathead chub	85 - 198	72.7	908	1.8	2.0	12.5	<.03
A-14	GE-14	Goldeye	365 - 370	73.1	11	<.3	.6	.8	<.03
A-14	FHC-XX	Common carp	340	74.7	160	.7	<2.0	8.8	<.03
A-14	GE-XX	White sucker	327	67.2	43	.1	<2.0	3.3	<.03

Table 12. Concentrations of selected constituents in composite fish samples collected from sites in or near the Angostura Reclamation Unit in 1994—Continued

[Concentrations in micrograms per gram dry weight]

Site number	Sample number	Common name	Cadmium	Chromium	Copper	Iron	Mercury	Magnesium	Manganese
A-1	CR-1-GS	Green sunfish	0.067	1.96	11	244	0.22	1,740	80
A-1	CR-1-PK	Plains killifish	.110	9.62	8.9	1,770	.13	2,280	268
A-1	CR-1-XX	Green sunfish	.219	6.50	6.3	4,500	.12	2,780	1,210
A-1	CR-1-XXX	Plains killifish	.077	.27	1.9	78	.21	1,510	74
A-5	CR-5-CC	Channel catfish	.060	.62	5.0	236	.19	1,630	20
A-5	CR-5-CS	White sucker	.010	.28	3.0	167	.087	1,280	25
A-5	CR-5-XX	Green sunfish	.047	.24	3.0	92	.21	1,600	16
A-5	CR-5-XXX	Rock bass	.020	.26	3.4	78	.17	1,630	12
A-12	CR-12-GE	Goldeye	.054	.59	8.5	120	.48	1,390	6.8
A-12	CR-12-NR	Shorthead redhorse	.067	.53	3.5	148	.24	1,420	80
A-12	CR-12-XX	Common carp	.410	.59	5.0	292	.34	1,510	18
A-12	CR-12-YY	Shorthead redhorse	.056	.34	3.9	95	.26	1,630	70
A-14	FHC-14	Flathead chub	.067	.86	3.3	561	.13	1,530	34
A-14	GE-14	Goldeye	.047	.27	4.4	96	.50	1,490	7.6
A-14	FHC-XX	Common carp	.042	.60	4.3	211	.20	1,570	12
A-14	GE-XX	White sucker	.035	.34	1.8	86	.27	1,470	47

Site number	Sample number	Common name	Molybdenum	Nickel	Lead	Selenium	Strontium	Vanadium	Zinc
A-1	CR-1-GS	Green sunfish	<0.2	0.97	0.10	3.6	179	0.5	100
A-1	CR-1-PK	Plains killifish	.2	4.6	.90	3.4	190	4.0	146
A-1	CR-1-XX	Green sunfish	<1	3.9	2.2	2.3	244	15	122
A-1	CR-1-XXX	Plains killifish	<1	.08	.08	3.2	165	<.3	88.2
A-5	CR-5-CC	Channel catfish	.3	.28	.25	5.4	163	.7	81.6
A-5	CR-5-CS	White sucker	<.2	.2	.09	6.9	102	<.2	50.1
A-5	CR-5-XX	Green sunfish	<1	<.06	.06	7.7	172	<.3	90.5
A-5	CR-5-XXX	Rock bass	<1	<.06	<.05	10	175	<.3	68.9
A-12	CR-12-GE	Goldeye	.2	.2	<.07	3.7	76.3	<.2	118
A-12	CR-12-NR	Shorthead redhorse	<.2	.39	<.07	1.9	202	.7	53.6
A-12	CR-12-XX	Common carp	<1	.2	.27	7.2	166	.7	290
A-12	CR-12-YY	Shorthead redhorse	<1	<.06	<.05	4.1	242	.6	70.8
A-14	FHC-14	Flathead chub	<.2	.68	.27	4.4	148	2.6	107
A-14	GE-14	Goldeye	<.2	1.0	<.07	3.6	102	<.2	104
A-14	FHC-XX	Common carp	<1	.2	.27	4.9	171	.4	224
A-14	GE-XX	White sucker	<1	<.06	.09	3.3	206	.3	59.7

Table 13. Physical properties, and concentrations of major ions and selected trace elements for water samples collected from sites in or near the Belle Fourche Reclamation Project in 1994

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius; mm, millimeters; mg/L, milligrams per liter; µg/L, micrograms per liter; inst, instantaneous; TIT, titration; IT, incremental titration; ANC, acid neutralizing capacity; lab, laboratory; <, less than]

Station identification	Site number	Date	Time	Discharge, inst (cubic feet per second) (00061)	Specific conduct-ance (µS/cm) (00095)	pH, unfiltered, lab (standard units) (00400)	Tempera-ture, air (deg C) (00020)	Temper-ature, water (deg C) (00010)	Barometric pressure (mm of Hg) (00025)	Oxygen, dissolved (mg/L) (00300)
06428500	B-1	04-18-94	1020	131	1,410	8.2	21.0	14.8	684	8.5
	B-1	09-06-94	1430	41	1,510	8.6	26.5	20.9	674	9.6
06436760	B-12	04-18-94	1315	6.4	3,180	8.3	23.0	17.2	695	8.5
	B-12	09-06-94	1130	50	1,820	8.3	22.9	16.4	690	10.4
06437000	B-18	04-18-94	1515	198	1,440	8.4	24.0	18.5	700	10.1
	B-18	09-06-94	0840	230	1,840	8.3	11.7	15.4	690	8.6

Site number	Date	Oxygen, dissolved (percent saturation) (00301)	Hardness, total (mg/L as $CaCO_3$) (00900)	Alkalinity dissolved, total IT, lab (mg/L as $CaCO_3$) (39086)	ANC, unfiltered TIT to 4.5, lab (mg/L as $CaCO_3$) (90410)	Calcium, filtered (mg/L as Ca) (00915)	Magne-sium, filtered (mg/L as Mg) (00925)	Sodium, filtered (mg/L as Na) (00930)	Sodium (percent) (00932)	Sodium adsorp-tion ratio (00931)	Potassium, filtered (mg/L as K (00935)
B-1	04-18-94	94	660	174	173	180	51	56	15	0.9	7.1
B-1	09-06-94	123	550	165	170	140	48	130	34	2	9.1
B-12	04-18-94	98	1,100	205	210	190	150	370	42	5	9.7
B-12	09-06-94	118	820	175	174	200	78	110	22	2	10
B-18	04-18-94	118	630	163	157	150	63	80	21	1	6.1
B-18	09-06-94	96	850	167	168	210	78	100	20	1	9.6

Table 13. Physical properties, and concentrations of major ions and selected trace elements for water samples collected from sites in or near the Belle Fourche Reclamation Project in 1994—Continued

[µS/cm, microsiemens per centimeter; deg C, degrees Celsius; mm, millimeters; mg/L, milligrams per liter; µg/L, micrograms per liter; inst, instantaneous; TIT, titration; IT, incremental titration; ANC, acid neutralizing capacity; lab, laboratory; <, less than]

Site number	Date	Bicarbonate, filtered, IT, lab (mg/L as HCO_3) (00453)	Carbonate, filtered, IT, lab (mg/L as CO_3) (00452)	Chloride, filtered (mg/L as Cl) (00940)	Sulfate, filtered (mg/L as SO_4) (00945)	Solids, sum of constituents, filtered (mg/L) (70301)	Solids, residue at 180 deg C, filtered (mg/L) (70300)	Aluminum, filtered (µg/L as Al) (01106)	Arsenic, filtered (µg/L as As) (01000)	Boron, filtered (µg/L as B) (01020)	Cadmium, filtered (µg/L as Cd) (01025)
B-1	04-18-94	212	0	5.9	610	1,010	1,100	20	1	170	<1
B-1	09-06-94	202	0	20	620	1,070	1,090	30	<1	190	<1
B-12	04-18-94	236	6	180	1,400	2,420	2,610	<10	<1	430	<1
B-12	09-06-94	199	7	17	830	1,350	1,460	<10	1	290	<1
B-18	04-18-94	179	10	22	610	1,030	1,100	<10	10	160	<1
B-18	09-06-94	202	0	17	840	1,350	1,460	10	11	250	<1

Site number	Date	Chromium, filtered (µg/L as Cr) (01030)	Copper, filtered (µg/L as Cu) (01040)	Lead, filtered (µg/L as Pb) (01049)	Mercury, filtered (µg/L as Hg) (71890)	Molybdenum, filtered (µg/L as Mo) (01060)	Selenium, filtered (µg/L as Se) (01145)	Uranium, natural, filtered (µg/L as U) (22703)	Uranium, natural, 2 sigma, filtered, (µg/L) (75990)	Vanadium, filtered (µg/L as V) (01085)	Zinc, filtered (µg/L as Zn) (01090)
B-1	04-18-94	<1	1	<1	<0.1	1	2	6.6	1.0	1	7.0
B-1	09-06-94	<1	1	<1	<.1	2	<2	6.0	.9	<1	12
B-12	04-18-94	<1	1	<1	<.1	<1	4	17	2.5	3	<10
B-12	09-06-94	<1	2	<1	<.1	5	2	8.6	1.3	1	8.0
B-18	04-18-94	<1	1	<1	<.1	3	2	7.2	1.1	<1	8.0
B-18	09-06-94	<1	1	<1	<.1	4	4	10	1.5	1	<3.0

Table 14. Concentrations of selected major-ion and trace-element constituents in bottom-sediment samples collected from sites in or near the Belle Fourche Reclamation Project in 1994

[bot mat, bottom material; DS, dry sieved; µg/g, micrograms per gram; µm, micrometer; <, less than]

Station identification	Site number	Date	Time	Aluminum, bot mat, <62 µm DS, lab (percent) (34790)	Arsenic, bot mat, <62 µm DS, lab (µg/g) (34800)	Barium, bot mat, <62 µm DS, lab (µg/g) (34805)	Beryllium, bot mat, <62 µm DS, lab (µg/g) (34810)	Bismuth, bot mat, <62 µm DS, lab (µg/g) (34815)	Cadmium, bot mat, <62 µm DS, lab (µg/g) (34825)	Calcium, bot mat, <62 µm DS, lab (percent) (34830)
06428500	B-1	09-08-94	1430	3.1	24	1,300	2	<10	<2	0.53
06436760	B-12	09-06-94	1130	3.8	46	2,400	2	<10	<2	3.3
06437000	B-18	09-06-94	0840	3.2	170	810	<1	<10	<2	2.1

Site number	Date	Cerium, bot mat, <62 µm DS, lab (µg/g) (34835)	Chromium, bot mat, <62 µm DS, lab (µg/g) (34840)	Cobalt, bot mat, <62 µm DS, lab (µg/g) (34845)	Copper, bot mat, <62 µm DS, lab (µg/g) (34850)	Europium, bot mat, <62 µm DS, lab (µg/g) (34855)	Gallium, bot mat, <62 µm DS, lab (µg/g) (34860)	Gold, bot mat, <62 µm DS, lab (µg/g) (34870)	Holmium, bot mat, <62 µm DS, lab (µg/g) (34875)	Iron, bot mat, <62 µm DS, lab percent (34880)	Lead, bot mat, <62 µm DS, lab (µg/g) (34890)
B-1	09-08-94	48	21	17	12	<2	<4	<2	<4	8.2	29
B-12	09-06-94	47	37	15	20	<2	7	<2	<4	7.8	35
B-18	09-06-94	37	20	10	11	<2	7	<2	<4	3.8	22

Site number	Date	Lithium, bot mat, <62 µm DS, lab (µg/g) (34895)	Magnesium, bot mat, <62 µm DS, lab (percent) (34900)	Manganese, bot mat, <62 µm DS, lab (µg/g) (34905)	Molyb-denum, bot mat, <62 µm DS, lab (µg/g) (34915)	Nickel, bot mat, <62 µm DS, lab (µg/g) (34925)	Niobium, bot mat, <62 µm DS, lab (µg/g) (34930)	Phosphorus, bot mat, <62 µm DS, lab (percent) (34935)	Potassium, bot mat <62 µm DS lab (percent) (34940)	Scandium, bot mat, <62 µm DS, lab (µg/g) (34945)
B-1	09-08-94	14	0.24	2,800	6	43	<4	0.12	1.5	4
B-12	09-06-94	23	.72	960	5	41	<4	.25	1.7	6
B-18	09-06-94	12	.32	770	2	21	<4	.11	1.8	3

Site number	Date	Selenium, bot mat, <62 µm DS, lab (µg/g) (34950)	Sodium, bot mat, <62 µm DS, lab (percent) (34960)	Strontium, bot mat, <62 µm DS, lab (µg/g) (34965)	Tantalum, bot mat, <62 µm DS lab (µg/g) (34975)	Thorium, bot mat, <62 µm DS, lab (µg/g) (34980)	Titanium, bot mat, <62 µm DS, lab (percent) (49274)	Uranium, bot mat, <62 µm DS, lab (µg/g) (35000)	Vanadium, bot mat, <62 µm DS, lab (µg/g) (35005)	Zinc, bot mat, <62 µm DS, lab (µg/g) (35020)
B-1	09-08-94	<1	0.43	160	<40	6	0.120	<100	58	120
B-12	09-06-94	<1	.52	230	<40	6	.220	<100	120	120
B-18	09-06-94	<1	.54	200	<40	4	.080	<100	48	64

Table 15. Concentrations of selected constituents in composite fish samples collected from sites in or near the Belle Fourche Reclamation Project in 1994

[Concentrations in micrograms per gram dry weight]

Station identification	Site number	Sampling period	Sample number	Common name	Species	Age	Length (millimeters)	Number of fish in sample
06428500	B-1	May 1994	BFR-1-CS	White sucker	*Catostomus commersoni*	adult	112 - 172	2
	B-1	May 1994	BFR-1-FH	Flathead chub	*Platygobio gracilis*	adult	127 - 183	8
	B-1	September 1994	BFR-1-XX	Flathead chub	*Platygobio gracilis*	adult	91 - 162	11
	B-1	September 1994	BFR-1-YY	Shorthead redhorse	*Moxostoma macrolepidotum*	adult	152 - 243	4
06436760	B-12	May 1994	HC-12-FH	Flathead chub	*Platygobio gracilis*	subadult	62 - 127	6
	B-12	May 1994	H-12-GS	Green sunfish	*Lepomis cyanellus*	adult	89 - 105	2
	B-12	September 1994	HC-12-OO	Orangespotted sunfish	*Lepomis humilis*	subadult	105	1
	B-12	September 1994	HC-12-XX	Channel catfish	*Ictalurus punctatus*	adult	246	1
06437000	B-18	May 1994	BFR-18-FH	Flathead chub	*Platygobio gracilis*	adult	121 - 137	7
	B-18	May 1994	BFR-18-L	Longnose dace	*Rhinichthys cataractae*	adult	50 - 75	17
	B-18	September 1994	BFR-18-X	River carpsucker	*Carpoides carpio*	adult	55 - 95	9
	B-18	September 1994	BFR-18-Y	Sand shiner	*Notropis stramineus*	adult	60 - 72	26

Site number	Sample number	Common name	Percent moisture	Aluminum	Arsenic	Boron	Barium	Beryllium	Cadmium
B-1	BFR-1-CS	White sucker	77.7	847	0.5	2	8.4	0.05	0.730
B-1	BFR-1-FH	Flathead chub	77.2	86	<.3	<.6	2.4	<.03	.440
B-1	BFR-1-XX	Flathead chub	72.7	712	.4	<2	5.8	.03	.234
B-1	BFR-1-YY	Shorthead redhorse	71.4	387	.4	<2	29.9	.03	.880
B-12	HC-12-FH	Flathead chub	73.9	316	.6	1	6.0	<.03	.059
B-12	H-12-GS	Green sunfish	76.2	142	<.3	.9	3.8	<.03	.065
B-12	HC-12-OO	Orangespotted sunfish	73.6	51	.3	<2	4.2	<.03	.075
B-12	HC-12-XX	Channel catfish	74.0	1,050	.7	3	9.2	.03	.091
B-18	BFR-18-FH	Flathead chub	71.2	388	2.9	.7	8.1	<.03	.048
B-18	BFR-18-L	Longnose dace	71.9	241	1.5	.8	4.1	<.03	.056
B-18	BFR-18-X	River carpsucker	74.9	1,330	16	<2	35.6	<.03	.092
B-18	BFR-18-Y	Sand shiner	68.9	230	3.6	<2	9.1	<.03	.090

Table 15. Concentrations of selected constituents in composite fish samples collected from sites in or near the Belle Fourche Reclamation Project in 1994—Continued

[Concentrations in micrograms per gram dry weight]

Site number	Sample number	Common name	Chromium	Copper	Iron	Mercury	Magnesium	Manganese	Molybde-num
B-1	BFR-1-CS	White sucker	1.5	6.5	706	0.090	1,930	79.1	<0.2
B-1	BFR-1-FH	Flathead chub	.35	3.1	139	.15	1,110	11.9	.2
B-1	BFR-1-XX	Flathead chub	.62	3.2	411	.088	1,360	29.6	<1
B-1	BFR-1-YY	Shorthead redhorse	.45	3.5	712	.13	1,770	74.3	<1
B-12	HC-12-FH	Flathead chub	1.2	3.5	302	.13	1,330	10.9	<.2
B-12	H-12-GS	Green sunfish	.40	2.1	135	.17	1,580	27.6	<.2
B-12	HC-12-OO	Orangespotted sunfish	.35	7.4	73	.26	2,050	24.4	<1
B-12	HC-12-XX	Channel catfish	1.7	2.3	624	.30	1,410	23.6	<1
B-18	BFR-18-FH	Flathead chub	.81	8.3	390	.28	1,380	16.4	<.2
B-18	BFR-18-L	Longnose dace	.84	8.6	213	.19	1,360	18.5	<.2
B-18	BFR-18-X	River carpsucker	1.6	21	1,170	.28	1,880	65.6	<1
B-18	BFR-18-Y	Sand shiner	.30	2.1	207	.42	1,300	25.1	<1

Site number	Sample number	Common name	Nickel	Lead	Selenium	Strontium	Vanadium	Zinc
B-1	BFR-1-CS	White sucker	1.8	0.43	4.6	186	1.2	112
B-1	BFR-1-FH	Flathead chub	.22	.20	3.3	123	<.2	86.9
B-1	BFR-1-XX	Flathead chub	.44	.45	3.2	188	1.1	91.0
B-1	BFR-1-YY	Shorthead redhorse	.20	.09	3.4	263	.7	87.5
B-12	HC-12-FH	Flathead chub	.94	.28	6.3	148	.9	110
B-12	H-12-GS	Green sunfish	.36	<.07	6.1	151	.4	95.1
B-12	HC-12-OO	Orangespotted sunfish	<.06	.10	3.0	253	.7	129
B-12	HC-12-XX	Channel catfish	.84	.57	2.8	104	3.4	70.1
B-18	BFR-18-FH	Flathead chub	.45	.20	4.9	160	.8	91.9
B-18	BFR-18-L	Longnose dace	.48	.09	6.5	173	.5	140
B-18	BFR-18-X	River carpsucker	.88	.44	5.9	217	3.5	92.1
B-18	BFR-18-Y	Sand shiner	.10	.06	4.4	151	.6	141