RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE ANGOSTURA RECLAMATION UNIT, SOUTHWESTERN SOUTH DAKOTA, 1988-89

By Earl A. Greene, U.S. Geological Survey,

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CONVERSION FACTORS

For readers who may prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
inch	25.4	millimeter
square mile (mi^2)	2.590	square kilometer

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F = 9/5\ (°C) + 32$$
$$°C = 5/9\ (°F-32)$$

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

Trace-element concentrations in bottom sediment and biota are reported as weight per unit of weight, or micrograms per gram ($\mu g/g$) and micrograms per kilogram ($\mu g/kg$), which are units equivalent to parts per million (ppm) and parts per billion, respectively.

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ABSTRACT

A study was conducted during 1988 within the Angostura Reclamation Unit and adjacent areas in southwestern South Dakota to determine the concentrations of major ions, selected trace elements, and pesticides in water, bottom sediment, and biota, and to compare the analytical results to various guidelines for environmental protection and to available baseline information.

In general, water in the study area is a sodium sulfate type. Concentrations of major ions in water samples were relatively large and elevated in relation to national baseline values.

Concentrations of trace elements in water delivered to Angostura Reservoir appeared to be similar to irrigation drain water conveyed in return-flow drains, and in the Cheyenne River downstream of the irrigated lands. Arsenic concentrations were 4 μg/L (micrograms per liter) or less at all sample sites. The maximum concentration of boron (650 μg/L) was measured in Horsehead Creek, a background site. The maximum (16 μg/L) and second highest (13 μg/L) concentrations of selenium were measured in Cottonwood Creek, a background site. The maximum uranium concentration (44 μg/L) was measured in Iron Draw, an irrigation return flow drain, and was substantially greater than at the other sampling sites. Pesticide concentrations in water were small at all sites and most were less than analytical reporting limits.

In general, the study showed that toxic levels of selenium or other trace elements and pesticides in water probably is not a persistent problem within the project area or downstream of irrigation return flows.

Trace-element concentrations in bottom sediment were very similar to the geochemical baselines for soils of the western United States. The maximum measured concentration of selenium (14.0 μg/g (micrograms per gram)) was from Cottonwood Creek, which is a background site. Because the majority of trace-element concentrations were within baseline ranges, there probably is no significant accumulation of trace-element concentrations due to irrigation. Pesticide concentrations in all samples of bottom sediment were less than laboratory analytical reporting limits.

With few exceptions, concentrations of trace elements and pesticides in biota generally were less than values known to produce harmful effects on growth or reproduction. Maximum aluminum concentrations in fish (6,350 μg/g dry weight), invertebrates (7,150 μg/g dry weight), and plants (9,370 μg/g dry weight) were quite large; however, because of the lack of information on the correlation between aluminum concentrations and biological effects, it is difficult to make inferences in regard to toxicity. Selenium concentrations in the majority of whole-body fish tissue samples were greater than the baseline values. Selenium concentrations in eight fish samples and two invertebrate samples were near or exceeded levels that could cause detrimental effects. Several other trace elements were present in biota at

concentrations that were potentially elevated in comparison to the general range of values among the sampling sites, but no site or organism consistently had unusually large concentrations. At all sites, pesticide concentrations in biota were small relative to available toxicity data.

INTRODUCTION

Background

During the last several years, there has been increasing 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, 1986a) have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley in California. In 1983, incidences of mortality, birth defects, and reproductive failures in waterfowl were discovered by the U.S. Fish and Wildlife Service 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 Western States that receive irrigation drainage.

Because of concerns expressed by the U.S. Congress, the U.S. Department of the Interior started a program in late 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the Western States. In October 1985, an interbureau group known as the "Task Group on Irrigation Drainage" was formed within the Department of the Interior. The task group subsequently prepared a comprehensive plan for reviewing irrigation-drainage concerns in areas for which the Department of the Interior has responsibility.

The Department of the Interior developed a management strategy and the Task Group prepared a comprehensive plan for reviewing irrigation-drainage concerns. Initially, the Task Group identified 19 locations in 13 states that warranted reconnaissance-level field investigations. These locations relate to three specific areas of Department of the Interior responsibilities: (1) Irrigation or drainage facilities constructed or managed by the Department, (2) national wildlife refuges managed by the Department, and (3) other migratory-bird or endangered-species management areas that receive water from Department-funded projects.

Nine of the 19 locations were selected for reconnaissance investigations during 1986-87. The nine areas are:

Arizona-California:	Lower Colorado-Gila River valley area
California:	Salton Sea area
	Tulare Lake Bed area
Montana:	Sun River Reclamation Project area
	Milk River Reclamation Project area
Nevada:	Stillwater Wildlife Management area
Texas:	Lower Rio Grande-Laguna Atascosa National Wildlife Refuge area
Utah:	Middle Green River basin area
Wyoming:	Kendrick Reclamation Project area

In 1988, reports for seven of the reconnaissance investigations were published. Reports for the remaining two areas were published in 1990. On the basis of results of the first nine reconnaissance investigations, four detailed studies were initiated in 1988 in the Salton Sea area, Stillwater Wildlife Management area, Middle Green River basin area, and the Kendrick Reclamation Project area. Eleven more reconnaissance investigations were initiated in 1988:

California:	Sacramento Refuge Complex
California-Oregon:	Klamath Basin Refuge Complex
Colorado:	Gunnison and Uncompahgre River basins, and Sweitzer Lake
Colorado:	Pine River Project
Colorado-Kansas:	Middle Arkansas River basin
Idaho:	American Falls Reservoir
New Mexico:	Middle Rio Grande Project and Bosque del Apache National Wildlife Refuge
Oregon:	Malheur National Wildlife Refuge
South Dakota:	Angostura Reclamation Unit
South Dakota:	Belle Fourche Reclamation Project
Wyoming:	Riverton Reclamation Project

All studies are conducted by interbureau field teams composed of a scientist from the U.S. Geological Survey as team leader, with additional Geological Survey, U.S. Fish and Wildlife Service, and U.S. Bureau of Reclamation scientists representing several different disciplines. The investigations are directed toward determining whether irrigation drainage: (1) has caused or has the potential to cause significant harmful effects on human health, fish, and wildlife, or (2) may adversely affect the suitability of water for other beneficial uses.

Purpose and Scope

This report describes the results of a 2-year reconnaissance study to determine if potentially toxic constituents are present at concentrations sufficiently large to cause, or have the potential to cause, harmful effects on human health or on fish and wildlife within or immediately downstream from the Angostura Reclamation Unit. Concentrations of selected constituents were measured in water, bottom material, and biota; these concentrations were then compared to various standards, criteria, and to concentrations reported from other locations.

Whereas a reconnaissance study such as this may indicate whether potential contamination exists, it will not isolate the cause, source, or degree of contamination. The results of this study cannot support definitive conclusions about adverse effects, but rather can be used to assess the need for further investigations.

The study area included all of the irrigable lands within the irrigation unit. The return flows from the irrigable lands do not discharge to a wildlife refuge and are not a direct source of drinking water. Return flows drain to the Cheyenne River, which is a major drainage for western South Dakota and is a major tributary to Oahe Reservoir and the Missouri River water system.

Acknowledgments

The authors thank Bruce Laymon of the U.S. Bureau of Reclamation for helping gather data on the history, background, and land management of the study area.

This manuscript was reviewed by members of the Department of the Interior Task Group on Irrigation Drainage; many individuals of this group spent a large amount of time assisting in preparation of this document. Their assistance is greatly appreciated.

GENERAL DESCRIPTION OF STUDY AREA

Location and History

Angostura Reservoir, formed by the damming of the Cheyenne River, is located 9 mi southeast of Hot Springs, South Dakota. The Angostura Reclamation Unit 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 of South Dakota. The study area includes the Unit lands and surrounding vicinity as shown in figure 1.

The Angostura Reclamation Unit was authorized under the Water Conservation and Utilization Act of August 11, 1939, and was approved on March 6, 1941. The Unit was originally included in the Missouri River Basin Project, currently named the Pick-Sloan Missouri Basin Program.

Angostura Dam was constructed during 1946-49 and is a composite concrete gravity structure and an earth embankment. Irrigation water deliveries to the Unit lands began in 1956. A hydroelectric powerplant and switchyard with an installed capacity of 1,200 kilowatts was discontinued in 1960.

Land and Water Management

The Cheyenne River basin upstream from Angostura Dam has an area of approximately 9,100 mi^2 located in parts of three States--southwestern South Dakota, northwestern Nebraska, and east-central Wyoming. Although the Cheyenne River receives some flows that originate in the southern Black Hills, it predominantly drains semi-arid plains. Average annual net inflow to Angostura Reservoir is about 80,000 acre-ft.

Angostura Reservoir has a capacity of 130,700 acre-ft at the top of its conservation pool, a surface elevation of 3,187.2 ft above sea level, and inundates an area of approximately 4,600 acres.

The 12,200 acres of irrigated land are supplied by releases from Angostura Reservoir into Angostura Canal, a 30-mi-long canal with a design capacity of 290 ft^3/s. The canal extends from the reservoir along the south edge of the Unit and crosses the Cheyenne River through an inverted siphon to reach the north side of the river. Average annual releases to the Unit lands are approximately 40,000 acre-ft of water, which provide an average onsite farm delivery of 2.5 acre-ft per acre. Individual farms are served by 39 mi of laterals and a total of 34 mi of open and closed drains.

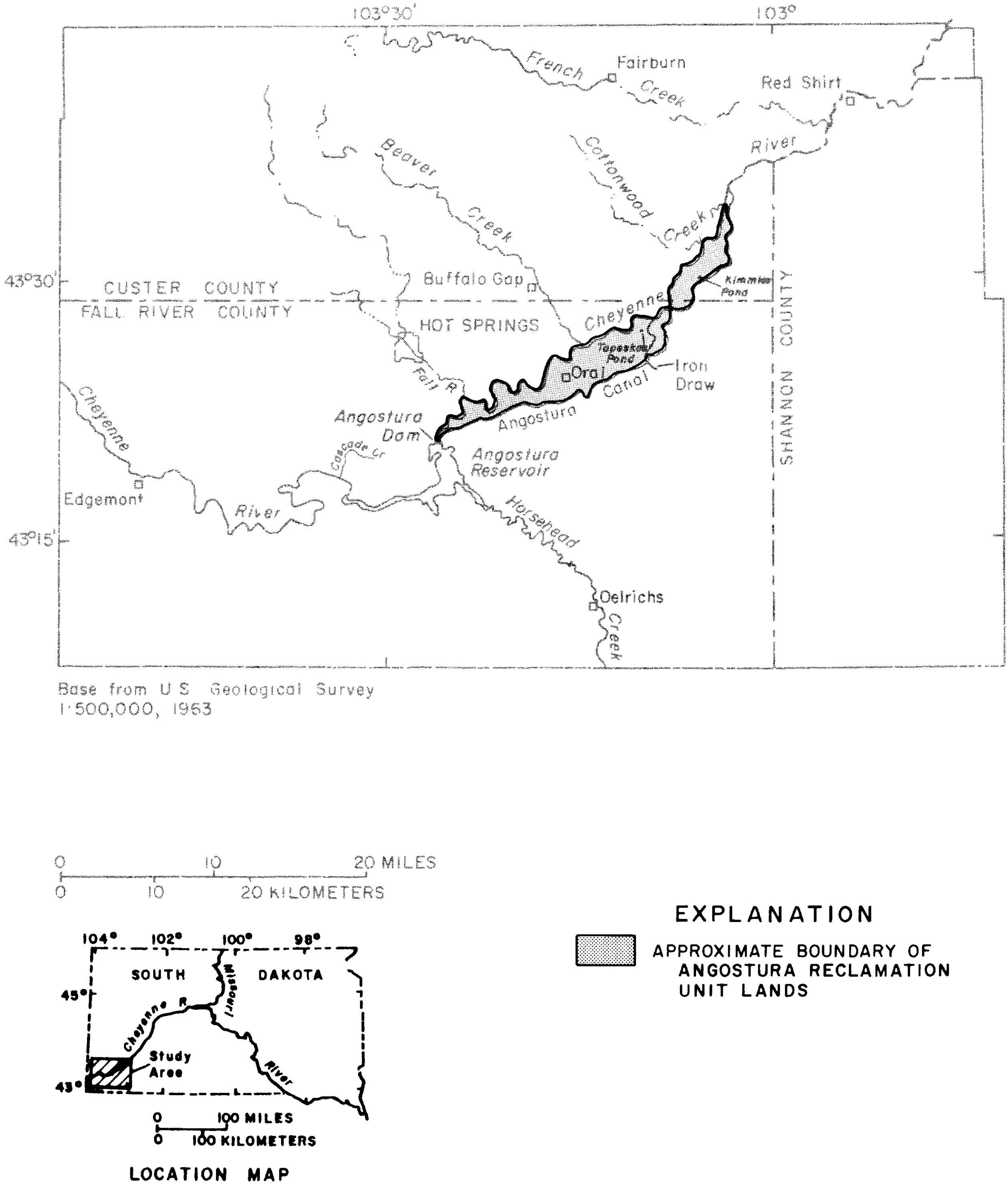


Figure 1.--Location of study area.

Irrigation return flows drain to the Cheyenne River throughout the length of the project and are not reused for irrigation. Except for flood-control releases during the spring and early summer runoff periods, there are usually no releases to the Cheyenne River from Angostura Reservoir during the irrigation season, which usually is from May through September. Therefore, most of the flow in the 4.5-mi reach of the Cheyenne River between Angostura Dam and the confluence with Fall River (fig. 1) during the irrigation season is composed of normal operational seepage from the dam and leakage from the radial gates.

There is no specific use of storage from Angostura Reservoir or use of irrigation return flow for public water supplies. Many farms and ranches within and immediately downstream of the project area use artesian springs and wells, which are several hundred feet in depth, as sources of domestic water. However, large concentrations of sulfate and dissolved solids are present in most of these sources. Many households utilize small distilling units, and many of the remaining users import their drinking water from the nearby community of Hot Springs.

Fish and Wildlife Use

Prior to construction of the Angostura Dam, small numbers of mule and white-tailed deer were present in the project area. Upland game birds present in the area were pheasant, sharp-tailed grouse, and Hungarian partridge. Other upland game animals included cottontail rabbits, jack-rabbits, and fox squirrels. As many as 2,000 ducks, primarily blue-winged teal, mallards, widgeons, and scaup, wintered in the area. Occasionally geese were seen. Furbearers included beaver, a few muskrat, and raccoon. Badger, mink, and striped skunk were present in the area in small numbers. Fish in the Cheyenne River were primarily channel catfish with fewer walleye pike, goldeye, carp, buffalo, bullhead, and largemouth bass (U.S. Fish and Wildlife Service, 1946).

A report on fish and wildlife changes due to the Angostura Reclamation Unit was completed by the U.S. Fish and Wildlife Service in 1964. The report indicated an increase in the numbers of mule and white-tailed deer, pheasant, and all fur-bearing animals. Waterfowl use increased from a few thousand ducks before construction in 1946 to more than 8,000 ducks in 1964. The species of fish in the Cheyenne River and Angostura Reservoir in 1964 were crappie, walleye pike, largemouth bass, bullhead, yellow perch, green sunfish, and rainbow trout (U.S. Fish and Wildlife Service, 1964).

Non-game use of the Angostura Reclamation Unit has not been investigated by the U.S. Fish and Wildlife Service. There are 377 bird species recognized in South Dakota, with 308 species regularly sighted. Thirty-four of these bird species occur primarily in the western part of South Dakota (South Dakota Ornithologists Union, 1978).

The pine forest and spruce stands of the Black Hills are the home of one endemic subspecies, the white-winged form of the dark-eyed junco, and are the eastern-most breeding area of many Rocky Mountain species. Federally threatened and endangered species that could occur in the area are the piping plover, bald eagle, peregrine falcon, least tern, and the black-footed ferret. Other species include the golden eagle, swift fox, Swainson's hawk, ferruginous hawk, and long-billed curlew. A number of small mammals and reptiles are present in the area.

Climate

The climate of the study area is semiarid continental, characterized by wide temperature ranges, low relative humidity, frequent high winds, and small amounts of precipitation. The study area typically is characterized by cold, dry winters; cool, moist springs; warm, dry summers; and cool, dry autumns. Recurring periods of drought and near-drought conditions have been common.

Average annual precipitation measured at Oelrichs is 16.35 inches (1951-80). Most of the annual precipitation occurs as rain from April to July; May is the wettest month. Site-specific evaporation data are unavailable, but average annual free-water-surface evaporation is about 47 inches (U.S. Department of Commerce, 1982).

In general, conditions during the data-collection phase of the study (1988) were drier than normal. Precipitation at Oelrichs during 1988 was 14.43 inches. During the 1988 irrigation season (May through September), precipitation at Oelrichs was 11.87 inches.

Geology

The study area is located in the Great Plains Region at the southern flank of the Black Hills uplift. The core of the uplift is composed of hard and erosion-resistant Precambrian igneous and metamorphic rocks along with Precambrian and Cenozoic intrusive rocks. Surrounding the Precambrian core are outcrops of Paleozoic strata, which are primarily bands of dipping limestones, interbedded sandstones, and shales.

A hogback ridge of Mesozoic strata composed of resistant sandstones form the outer rim of the uplift. The older sandstones and shales of the Mesozoic strata dip steeply into the surrounding plains, which are composed of younger Cretaceous marine shales that include the Pierre Shale (fig. 2). Geologic formations within each of the Eras (Precambrian, Paleozoic, Mesozoic, and Cenozoic) are shown in table 1. Younger outcrops of Cenozoic rocks are present in the plains. These Cenozoic formations are primarily of the White River Group.

The surficial deposits over the majority of the irrigated lands and vicinity are Late Cretaceous marine shales, mostly Pierre Shale, overlaid with small areas of alluvial deposits adjacent to the many streams. These alluvial deposits are located mainly along the flood plains of Cascade Creek, Fall River, Horsehead Creek, Beaver Creek, Cottonwood Creek, and the Cheyenne River (fig. 2).

The Pierre Shale is a thick, dark gray to black, fine-grained clayey rock with seams of bentonite and zones of limestone concretions. The Pierre Shale is a known source of selenium and other trace elements. Schultz and others (1980) studied the chemical composition of the Pierre Shale and equivalent rocks throughout the northern Great Plains Region. The maximum selenium concentration in 202 samples was 160 $\mu g/g$. The average concentration in 7 samples in Fall River County was 9 $\mu g/g$. Chemical concentrations for the Pierre Shale are summarized in table 2. Weathering of the shale will form a thin, relatively infertile, light-brown soil (Keene, 1973). This soil is found throughout the study area and is the primary soil type that is irrigated on the Unit lands.

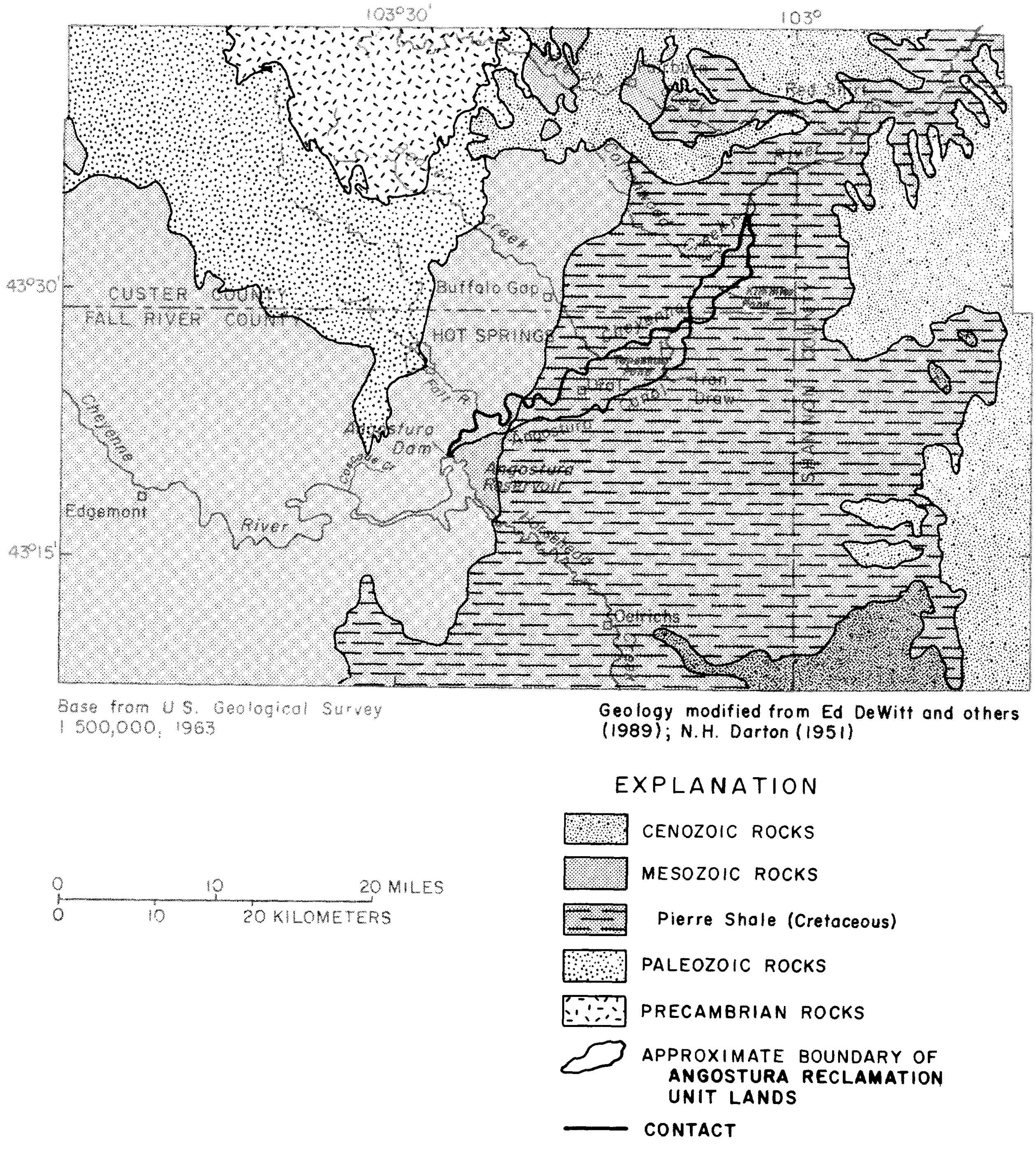


Figure 2.--Geology of the study area.

Table 1.--Geologic formations within the study area

Era	Formation
Cenozoic	White River Group
Mesozoic	Fox Hills Sandstone Pierre Shale Niobrara Formation Carlile Shale Greenhorn Limestone Belle Fourche and Mowry Shales, undivided Skull Creek Shale and Inyan Kara Group, undivided Sundance Formation Spearfish Formation
Paleozoic	Spearfish Formation Minnekahta Limestone and Opeche Shale, undivided Minnelusa Sandstone Madison Limestone and Englewood Limestone Formation, undivided Deadwood Formation
Precambrian	Undifferentiated igneous and metamorphic rocks

Table 2.--Summary of trace-element concentrations in 202 samples of Pierre Shale and equivalent rocks

[Source of data: Data modified from Schultz and others, 1980. Values are total concentration, in micrograms per gram, determined by chemical analysis except where noted; <, less than]

Element	Geometric mean	Minimum	Maximum	Median
Arsenic	9.2	1	490	9.3
Boron[1]	83	<20	410	100
Cadmium	.54	<.3	100	.5
Chromium[1]	66	4	260	71
Copper	28	6	150	29
Lead	20	7	44	22
Molybdenum	1.4	<1	350	1
Selenium	.74	<.5	160	.5
Uranium	4.5	1.3	28	3.0
Vanadium	136	25	740	140
Zinc	96	27	380	96

[1]Spectrographic analysis.

Soils and Agriculture

Soils in the study area are alluvial and aeolian in origin and are located in the "Chestnut Soils" zone of the Great Plains Region. Parent material and position with relation to the Cheyenne River cause a range of textures from heavy clay to fine sand. Sand and gravel usually are found from 4 to 10 ft below land surface.

The dominant soil series of the irrigable lands within the Unit are Ascalon fine sandy loam and Dailey fine sand. These soils are deep, well-drained to excessively drained, level to sloping, sandy and loamy soils on uplands. The soils on flood plains are Glenberg-Bankard or Lohmiller-Haverson loamy silty soils. These soils are deep, well to excessively drained on nearly level flood plains (Kalvels, 1982).

Most of the farms include both irrigated and nonirrigated lands. This integrated irrigation-dryland type farming operation includes dryland cattle grazing areas adjoining the irrigated land. Approximately 98 percent of the irrigated land is planted with corn and alfalfa. Other crops, on the remaining 2 percent of the irrigated land, include barley, oats, wheat, pasture, and silage. Fattened livestock also are produced in the Unit area. Gross crop value on Unit lands for 1988 was more than 2 million dollars.

Approximately 90 percent of the corn and 20 percent of the alfalfa is treated with a carbamate insecticide (carbofuran). Atrazine is applied to about 25 percent and parathion to 20 percent of the corn crop annually.

Hydrologic Setting

Principal hydrologic features of the Angostura Reclamation Unit are Angostura Dam, Angostura Reservoir, Angostura Canal, laterals and drains, the Cheyenne River, and tributaries. A schematic diagram of water movement through the Unit is shown in figure 3. Hydrologic and streamflow conditions during the data-collection phase of the study were not typical due to the drought conditions in western South Dakota during 1988. Streamflow in unregulated streams was less than normal, with many no-flow days in intermittent and ephemeral streams.

The Cheyenne River is the major inflow to Angostura Reservoir. Flow during 1988 for the Cheyenne River at Edgemont (station 06395000), which is upstream of the study area, was much less than average (fig. 4). Discharge at this site during 1988 was 8,720 acre-ft, compared to the long-term mean annual discharge of 68,540 acre-ft for water years 1929-32 and 1947-88.

Horsehead Creek is the second major source of inflow to the Angostura Reservoir. The 5-year mean annual discharge (water years 1984-88) for Horsehead Creek is 6,030 acre-ft. Streamflow was 99 acre-ft during water year 1988, with only 6 days of measurable flow from June 1 through September 30.

Cascade Creek, Fall River, Beaver Creek, and French Creek are the principal tributaries to the Cheyenne River in the study area. The source of these creeks are springs discharging from limestone outcrops (Paleozoic strata), usually in contact with a shale formation (fig. 2).

The source of Cascade Creek is Cascade Springs, the largest single spring in the Black Hills. Cascade Springs near Hot Springs, station 06400497, has a 10-year mean annual discharge of 14,710 acre-ft. Flow at station 06400497 during water year 1988 was 14,230 acre-ft.

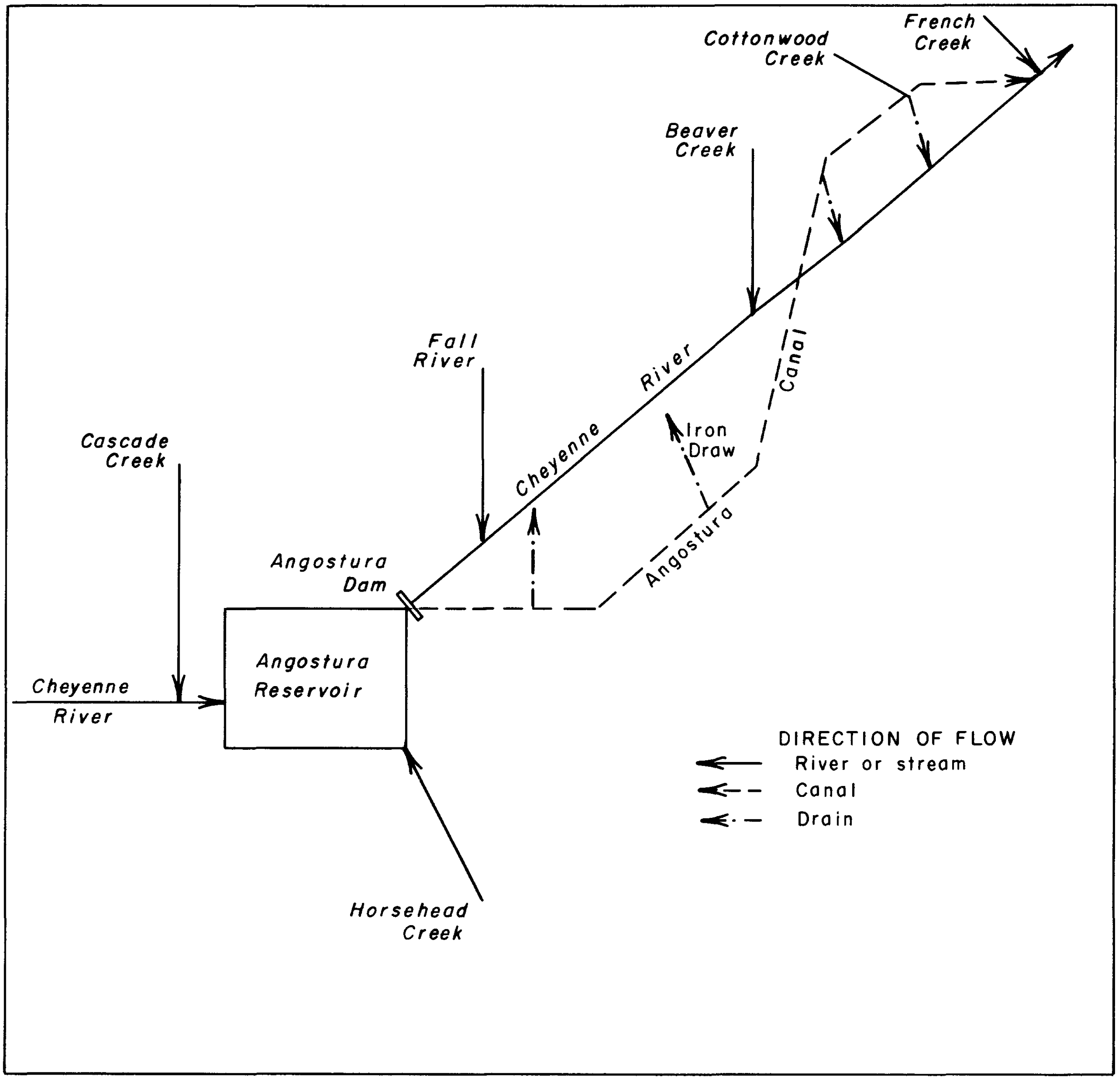


Figure 3.--Schematic diagram showing storage, diversions, and movement of water through the Angostura Reclamation Unit.

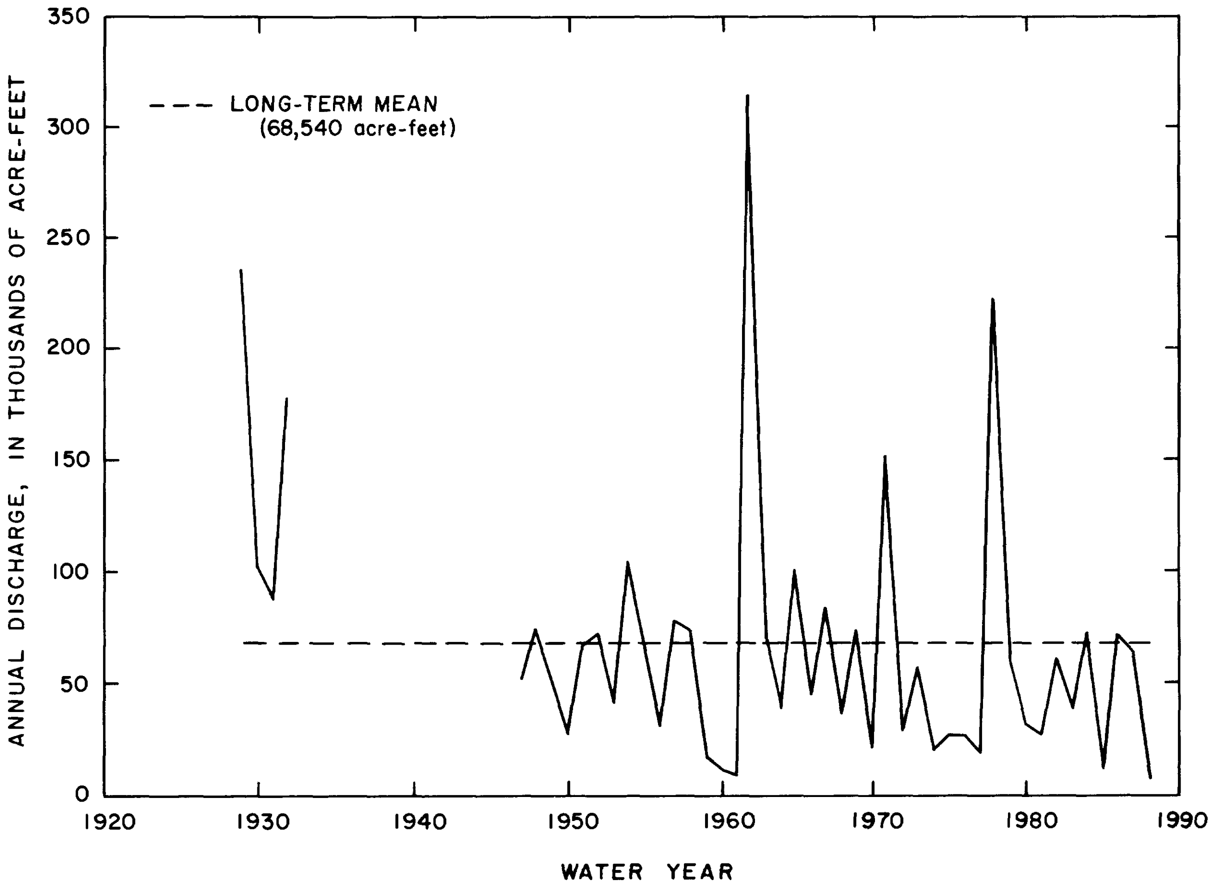


Figure 4.--Annual and long-term mean annual discharge of the Cheyenne River at Edgemont, water years 1929-32 and 1947-88.

The confluence of Fall River and the Cheyenne River is approximately 4.5 mi downstream from Angostura Dam. The source of Fall River is several large springs above and in the city of Hot Springs. The mean annual discharge for 51 years of record for Fall River at Hot Springs, station 06402000, is 17,820 acre-ft. Discharge of Fall River during water year 1988 was 15,470 acre-ft.

The confluence of Beaver Creek and the Cheyenne River is an additional 15.5 mi downstream from the confluence of Fall River (fig. 1). The mean annual discharge for 51 years of record for Beaver Creek near Buffalo Gap, station 06402500, is 5,140 acre-ft. Discharge of Beaver Creek during water year 1988 was 4,310 acre-ft.

The confluence of the Cheyenne River and French Creek is approximately 4.75 mi upstream from the northern edge of the study area and is downstream of all irrigation return flow. Mean annual discharge for 6 years of record (water years 1983-88) for French Creek above Fairburn, station 06403300, is 4,250 acre-ft. The discharge of French Creek during water year 1988 was 2,210 acre-ft.

Irrigation releases to Angostura Canal during the 1988 irrigation season (44,142 acre-ft) were larger than the 36-year average (39,824 acre-ft) (fig. 5).

The hydrogeology of the study area has been modified by irrigation farming. Flood irrigation is the most common method of irrigation, though a number of center-pivot irrigation systems have been installed. Surface-water return flow moves downgradient through the fields to surface drains, tributaries, and the Cheyenne River. Unconsolidated gravels readily transmit downward-percolating excess irrigation water, along with leakage from unlined reaches of canals and laterals, to the top of the nearly impermeable Pierre Shale. The shallow ground water forms a near-surface water table due to this recharge and is a source of water for domestic use. The shallow ground water discharges through hillside seeps as ground-water return flow (fig. 6).

PREVIOUS INVESTIGATIONS

Collection of surface-water data and investigations that have been conducted previously in and near the study area provided background and supplemental data for the current study. A summary of the data and/or results from these studies are presented in the following sections.

Surface-Water Quality

Past water-quality data have been collected by the U.S. Geological Survey at two sites on the Cheyenne River within the study area. These sites are the Cheyenne River below Angostura Dam (station 06401500), located 800 ft downstream from the dam, and the Cheyenne River near Buffalo Gap (station 06402600), located 12 mi east of Buffalo Gap. A statistical summary of selected water-quality data is presented for the Cheyenne River below Angostura Dam in table 3, and for the Cheyenne River near Buffalo Gap in table 4.

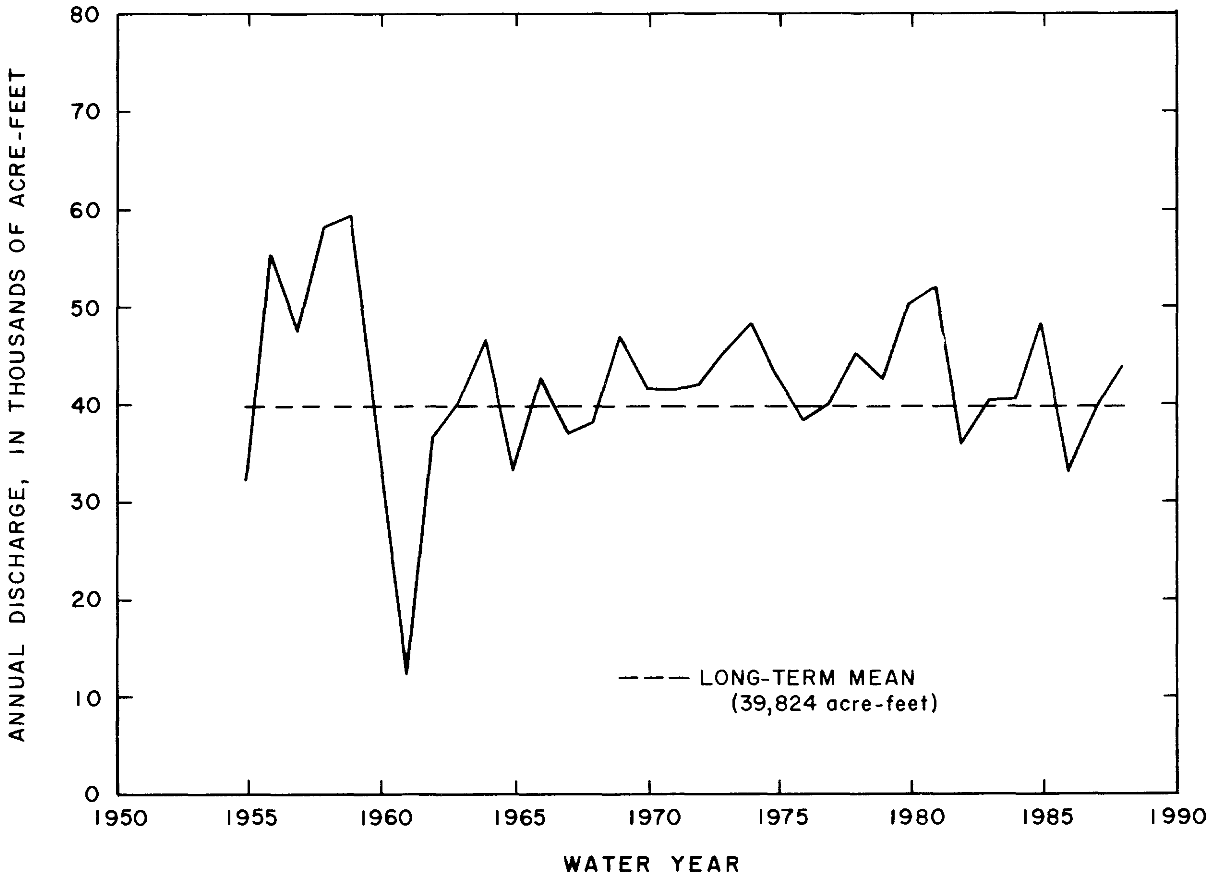
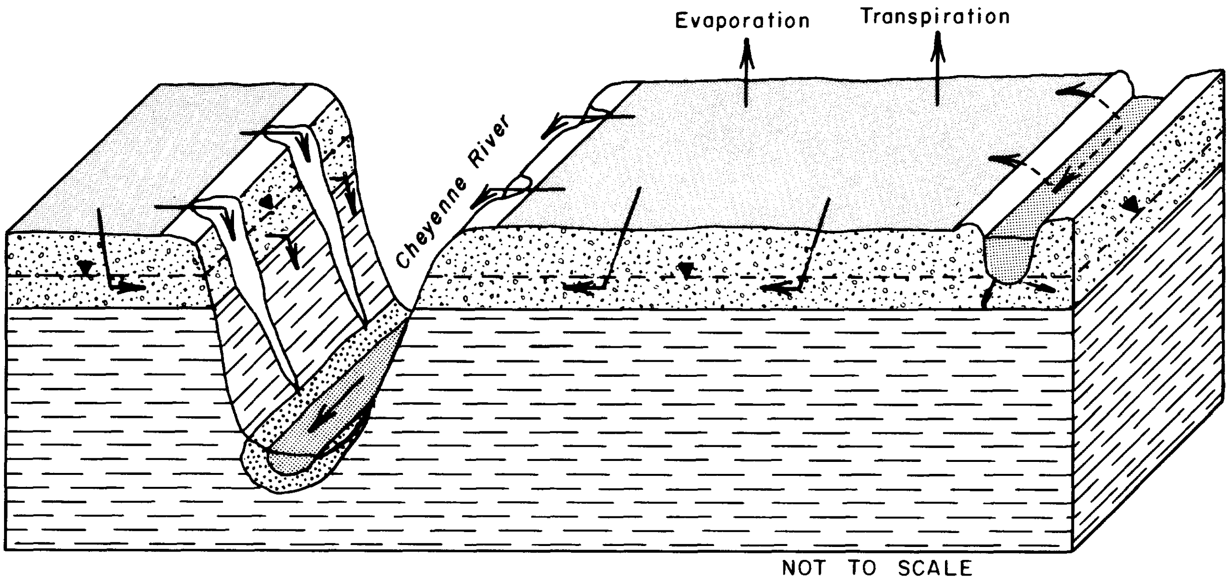


Figure 5.--Annual and long-term mean annual discharge of the Angostura Canal, 1955-88.



EXPLANATION

IRRIGATED CROPLAND

BENCH GRAVEL

ONFARM SUPPLY CANAL AND RIVER

CRETACEOUS SHALE (Pierre Shale and equivalent rocks)

ALLUVIUM

WATER TABLE

DIRECTION OF FLOW-- Irrigation water

DIRECTION OF IRRIGATION RETURN FLOW AND CANAL LEAKAGE

Figure 6.--Idealized diagram showing hydrogeology of irrigated land in the Angostura Reclamation Unit.

Table 3.--Statistical summary of selected water-quality data for the Cheyenne River below Angostura Dam (station 06401500), water years 1968-88

[Source of data: U.S. Geological Survey WATSTORE retrieval for September 1968 to September 1988. Major ions in milligrams per liter; trace elements in micrograms per liter; °C, degrees Celsius; <, less than]

Property or constituent	Number of samples	Value or concentration		
		Minimum	Maximum	Median
Specific conductance (microsiemens per centimeter at 25 °C)	221	690	4,100	2,100
pH (pH units)	152	7.3	8.5	8.0
Dissolved solids, residue on evaporation at 180 °C (milligrams per liter)	46	1,530	1,880	1,715
Major ions (dissolved)				
Calcium	158	130	300	210
Magnesium	158	36	95	70
Sodium	162	120	230	180
Potassium	158	1	17	10
Sulfate	162	540	1,200	900
Chloride	158	27	140	100
Fluoride	138	.3	6.0	.6
Silica	136	4	22	8
Trace elements (dissolved)				
Boron	157	20	860	160
Iron	16	<10	220	44
Manganese	16	<10	230	55

Table 4.--Statistical summary of selected water-quality data for the Cheyenne River near Buffalo Gap (station 06402600), water years 1968-80

[Source of data: U.S. Geological Survey WATSTORE retrieval for September 1968 to September 1980. Major ions in milligrams per liter; trace elements in micrograms per liter; °C, degrees Celsius; <, less than]

Property or constituent	Number of samples	Value or concentration		
		Minimum	Maximum	Median
Specific conductance (microsiemens per centimeter at 25 °C)	181	1,560	3,650	2,260
pH (pH units)	170	7.3	8.7	8.0
Dissolved solids, residue on evaporation at 180 °C (milligrams per liter)	54	1,120	1,950	1,805
Major ions (dissolved)				
Calcium	175	120	370	240
Magnesium	174	35	120	74
Sodium	180	130	300	200
Potassium	174	2	22	15
Sulfate	180	590	1,400	980
Chloride	175	1	160	110
Fluoride	147	.4	1	.6
Silica	147	4	17	10
Trace elements (dissolved)				
Boron	174	20	1,700	300
Iron	17	20	600	51
Manganese	17	<10	240	60

Ground-Water Quality

There are few previous ground-water studies and data-collection programs that characterize the ground-water quality of the shallow Quaternary alluvium and Cretaceous shales throughout the study area. Some ground-water samples have been collected by the U.S. Geological Survey in the study area. A statistical summary of data on the major ions and trace elements in samples from 19 wells completed in the Pierre Shale is presented in table 5. Selenium concentrations in all 19 samples were less than 1 μg/L (micrograms per liter).

Water-quality data were obtained from various lithologic units within the area of the Hot Springs 1° x 2° quadrangle in a study conducted by the U.S. Department of Energy (1979). A total of 340 ground-water samples was obtained: 78 samples were from alluvium; 95 samples were from the White River Group, Fox Hills Sandstone, and Pierre Shale; and the remainder of the samples were from deeper ground-water sources. A statistical summary of the data obtained from the study is presented in table 6.

Table 5.--Statistical summary of selected water-quality data for ground water from the Pierre Shale throughout the study area

[Source of data: U.S. Geological Survey WATSTORE retrieval. Major ions in milligrams per liter, trace elements in micrograms per liter; $CaCO_3$, calcium carbonate; mg/L, milligrams per liter]

Property or constituent	Number of samples	Value or concentration: Minimum	Maximum	Median
Specific conductance (microsiemens per centimeter at 25 °Celsius)	19	300	4,450	2,410
pH (pH units)	19	6.6	7.7	7.3
Hardness, total as $CaCO_3$ (mg/L)	19	10	2,200	650
Major ions (dissolved)				
Calcium	19	3	420	170
Magnesium	19	1	310	55
Sodium	19	1	500	190
Sulfate	19	15	1,700	550
Chloride	19	10	200	16
Silica	19	1	14	9
Trace elements (total)				
Arsenic	19	<1	<1	<1
Aluminum	19	<10	50	<10
Barium	19	<100	900	<100
Boron	19	20	1,800	620
Chromium	19	<10	24	<10
Cobalt	19	<2	10	<2
Copper	19	2	74	2
Iron	19	<10	40	30
Manganese	19	<10	640	<10
Molybdenum	19	4	15	4
Nickel	19	4	8	4
Selenium	19	<1	<1	<1
Silver	19	2	5	2
Strontium	19	280	9,600	2,900
Uranium	19	13	70	50
Zinc	19	<10	57	20

Table 6.--Statistical summary of ground-water-quality data for the Hot Springs 1° x 2° quadrangle

[Source of data: U.S. Department of Energy, 1979. Major ions in milligrams per liter; trace elements in micrograms per liter]

Property or constituent	Alluvium: Number of samples	Alluvium: 25th percentile	Alluvium: Median	Alluvium: 75th percentile	White River Group, Fox Hills Sandstone, and Pierre Shale, undivided: Number of samples	25th percentile	Median	75th percentile
Specific conductance (microsiemens per centimeter at 25 °Celsius)	79	1,384.9	2,380.2	3,567.3	95	1,279.9	2,177.5	3,355.6
pH (pH units)	78	7.1	7.3	7.6	95	7.1	7.4	7.7
<u>Major ions</u> (dissolved)								
Calcium	78	59.6	109.9	285.5	95	43.8	96.6	190.0
Magnesium	78	22.2	40.2	85.1	95	10.8	31.8	66.2
Sodium	78	47.6	156.0	306.7	95	114.2	194.3	290.4
Potassium	78	6.7	9.4	13.6	95	6.9	10.3	17.3
Sulfate	78	220.5	513.0	1,256.0	95	127.3	440.5	1,006.3
Chloride	77	5.0	14.0	41.8	95	5.0	21.5	65.3
Silica	78	4.5	6.8	8.4	95	4.5	6.9	10.5
<u>Trace elements</u> (dissolved)								
Boron	78	115.5	297.0	510.0	95	185.5	363.5	627.0
Iron	78	5.0	17.0	24.5	95	5.0	13.0	24.0
Lithium	78	68.0	111.0	213.0	95	69.0	116.0	201.5
Manganese	78	1.0	3.0	11.0	95	1.0	4.0	37.5
Molybdenum	78	2.0	4.0	9.0	95	2.0	2.0	9.0
Selenium	78	.3	.5	.7	95	.4	.6	.7
Vanadium	78	2.0	2.0	4.0	95	2.0	2.0	4.0
Uranium	78	8.0	12.4	28.6	95	6.1	15.0	31.8

Bottom Sediment

Previous data on trace-element concentrations in stream-bottom sediment are few for much of the study area. The U.S. Department of Energy (1979) collected stream sediment derived from the various lithologic units within the area of the Hot Springs 1° x 2° quadrangle. A total of 349 bottom-sediment samples were obtained: 79 samples were from the White River Group and alluvium, 119 samples from the Fox Hills Sandstone and Pierre Shale, 16 samples from the Niobrara Formation and Carlile Formation, and the remainder of samples from other geologic units. A statistical summary of geochemical data from the U.S. Department of Energy (1979) study for stream-bottom sediment is presented in table 7.

Existing Biota Data

No previous data are available for chemical analysis of waterfowl tissue, algae, or vascular plants from the study area. The U.S. Fish and Wildlife Service has analyzed a limited number of fish tissue from several locations in the Cheyenne River in the study area (table 8).

Seven fish tissue samples were collected in August 1985 and October 1986 (table 8) from the Cheyenne River near Edgemont, which is upstream of the irrigated land (fig. 1). Selenium dry-weight concentrations ranged from 2.0 to 4.1 $\mu g/g$ for the seven samples.

Selenium dry-weight concentrations in fish tissue from several locations in the Cheyenne River downstream of Angostura Dam and the irrigated land had levels of selenium ranging from 4.0 to 20 $\mu g/g$. All of these samples exceed the National Contaminant Biomonitoring Program 85th-percentile baseline value of 2.8 $\mu g/g$ dry weight. The greatest dry-weight concentration of selenium in fish tissue (20 $\mu g/g$) was from a location approximately three-fourths of a mile downstream from Angostura Dam. Water in this reach of the Cheyenne River is composed primarily of seepage from the dam and leakage from the radial gates. Three of eight fish tissue samples from the same location had selenium concentrations equal to or greater than 13 $\mu g/g$ (table 8), which may interfere with fish reproduction (Lemly and Smith, 1987).

Nine of 20 samples of fish tissue had copper concentrations that exceeded the National Contaminant Biomonitoring Program 85th-percentile baseline value of 3.67 $\mu g/g$ dry weight. The greatest dry-weight concentration of copper (21 $\mu g/g$) was from a location three-fourths of a mile downstream from Angostura Dam.

There have been no reported fish or wildlife dieoffs, failures in avian reproduction, or avian embryo deformities in the study area that can be directly attributed to selenium or other trace elements.

SAMPLE COLLECTION AND ANALYSIS

The objective of the sample collection and analysis was to determine if there are elevated concentrations of potentially toxic constituents associated with irrigation drainage and whether they may occur in the water, bottom sediment, or biota in the Angostura Reclamation Unit or adjacent areas. Efforts were made to obtain samples at a sufficient number of locations to characterize the environmental conditions of the study area. The sample locations were selected to identify any problem areas where constituent concentrations exceeded established standards and/or criteria, or natural background (baseline) concentrations.

Table 7.--Statistical summary of trace-element data in stream-bottom sediment for the Hot Springs 1° x 2° quadrangle

[Source of data: U.S. Department of Energy, 1979. Total concentration, in micrograms per gram]

	Source of stream-bottom sediment											
	Alluvium and White River Group, undivided				Fox Hills Sandstone and Pierre Shale, undivided				Niobrara Formation and Carlile Shale, undivided			
Element	Number of samples	25th percentile	Median	75th percentile	Number of samples	25th percentile	Median	75th percentile	Number of samples	25th percentile	Median	75th percentile
Arsenic	79	3.0	3.8	6.3	119	4.4	5.7	7.9	16	3.8	6.8	11.7
Chromium	79	23.0	29.0	42.3	119	40.0	46.5	55.0	16	43.0	57.0	64.0
Molybdenum	79	2.0	2.0	4.0	119	2.0	2.0	4.0	16	4.0	8.0	11.0
Selenium	79	.5	.7	.9	119	.8	.9	1.2	16	1.0	1.8	3.5
Zinc	79	45.0	63.0	82.3	119	81.0	93.0	107.3	16	75.0	100.0	143.0

Table 8.--Concentrations of trace elements in fish tissue from several locations along the Cheyenne River, 1985-86

[Analyses by U.S. Fish and Wildlife Service. Concentrations in micrograms per gram dry weight; <, less than; --, no data. Analyses performed by inductively coupled plasma-emission spectroscopy (ICP), no preconcentration unless otherwise noted]

Site name	Taxa	Collection date	Aluminum	Arsenic[2]	Beryllium	Cadmium	Cobalt	Copper
Cheyenne River at Edgemont	Fathead chub	08-03-85	--	<0.21	--	<0.21	16.0	2.8
	Flathead chub	08-03-85	--	<.21	--	<.21	28.0	2.8
	Channel catfish[1]	10-03-86	93	<.80	<0.07	.11	--	1.9
	Carp composite[1]	10-03-86	199	<.80	<.07	.16	--	8.9
	Flathead chub[1]	10-03-86	289	<.80	<.07	.13	--	6.8
	Plains killifish composite[1]	10-03-86	3,070	<.80	.15	.17	--	7.3
	River carpsucker[1]	10-03-86	1,200	<.80	.09	.13	--	2.8
Cheyenne River 3/4 mile downstream of Angostura Dam	Channel catfish	08-30-85	--	<.22	--	<.22	15.6	4.4
	Shorthead redhorse	08-30-85	--	<.20	--	<.24	51.8	3.0
	Smallmouth bass	08-30-85	--	<.21	--	<.21	8.6	2.5
	Black bullhead[1]	09-04-86	142	<.80	<.07	.14	--	2.2
	Black bullhead[1]	09-04-86	50	<.80	<.07	.07	--	3.8
	Carp[1]	09-04-86	319	<.80	<.07	.17	--	2.6
	Green sunfish composite[1]	09-04-86	75	<.80	<.07	.11	--	3.4
	White sucker[1]	09-04-86	137	<.80	<.07	.13	--	21
Cheyenne River near Oral	Carp[1]	09-04-86	62	<.80	<.07	.35	--	5.7
	Carp[1]	09-04-86	117	<.80	<.07	.32	--	4.6
	Shorthead redhorse[1]	09-04-86	18	<.80	<.07	.13	--	5.5
	Shorthead redhorse[1]	09-04-86	27	<.80	<.07	.15	--	2.4
	Shorthead redhorse[1]	09-04-86	60	<.80	<.07	.13	--	3.4

Site name	Collection date	Iron	Lead	Manganese	Mercury[2]	Molybdenum	Nickel	Selenium[2]	Thallium	Vanadium	Zinc
Cheyenne River at Edgemont	08-03-85	76	<0.42	--	0.19	<0.42	<0.25	3.1	<2	<0.17	138
	08-03-85	77	<.41	--	.23	<.41	<.25	4.1	<2	.21	120
	10-03-86	142	<.50	32	.30	--	.54	2.0	<5	--	70
	10-03-86	163	<.50	14	.15	--	.62	2.5	<5	--	108
	10-03-86	160	<.50	8.0	<.1	--	.65	3.0	<5	--	98
	10-03-86	1,520	.69	82	<.1	--	2.7	2.2	<5	--	80
	10-03-86	638	<.50	49	<.1	--	1.4	3.0	<5	--	62
Cheyenne River 3/4 mile downstream of Angostura Dam	08-30-85	218	<.45	--	.26	<.45	.36	4.9	<2	.40	87
	08-30-85	122	<.81	--	.11	<.40	<.28	20	<2	.36	77
	08-30-85	100	<.43	--	.22	<.43	<.26	17	<2	.43	56
	09-04-86	182	<.50	20	<.1	--	.79	4.5	<5	--	84
	09-04-86	134	<.50	11	.17	--	.25	4.2	<5	--	90
	09-04-86	398	<.50	35	.15	--	2.4	13	<5	--	170
	09-04-86	95	<.50	14	<.1	--	.34	7.2	<5	--	104
	09-04-86	156	<.50	38	<.2	--	2.2	6.6	<5	--	68
Cheyenne River near Oral	09-04-86	421	<.50	25	<.1	--	1.2	7.1	<5	--	242
	09-04-86	329	<.50	23	<.1	--	.45	7.4	<5	--	126
	09-04-86	63	.78	40	<.2	--	.65	4.4	<5	--	57
	09-04-86	74	<.50	40	<.1	--	.37	4.6	<5	--	46
	09-04-86	118	.79	53	<.1	--	.88	4.0	<5	--	56

[1] ICP preconcentration B, rather than ICP, no preconcentration, was performed for this sample.
[2] This element was scanned using atomic absorption methods.

A number of samples were analyzed for potentially toxic constituents to address the possible effects of irrigation drainage on human health, wildlife, and associated water uses. The constituents analyzed were major ions, trace elements, and pesticides. A standard list of major ions and trace elements was designated by the Department of the Interior Task Group on Irrigation Drainage for consistency among all irrigation drainage studies. The pesticides analyzed in water, bottom sediment, and biota varied among study areas and were selected based upon the common types of agricultural chemicals used on the irrigated lands. Major ions, trace elements, and pesticides analyzed in the water, bottom sediment, and biota are listed in table 9.

The objective of the biota sampling was to determine and compare the concentrations of elements and pesticides in several life forms upstream and downstream of the project area. Fish samples represented the larger trophic levels of the aquatic food chain, whereas aquatic plant and aquatic invertebrate samples represented the smaller trophic levels of the aquatic food chain. Bird eggs were collected to determine the concentrations in terrestrial animals associated with the aquatic environment.

Samples of aquatic plants and invertebrates were collected from the same sites as the fish samples to provide comparisons among the sites. Samples also were obtained from miscellaneous locations that were influenced by irrigation return flow. Timing of sample collection generally was for mid-summer periods after the rapid spring growth and exposure to irrigation return flow water.

Sampling Sites

Sampling sites, types of constituents analyzed at each site, number of samples collected (biota), and a schedule of sample-collection times are listed in table 10 for water and bottom sediment and table 11 for biota. Sampling sites were chosen to provide information for a diverse range of hydrologic, physical, and chemical conditions within the study area. Six biological sampling sites were located on or near the Cheyenne River to identify the presence of potentially elevated constituent concentrations in the biological community of the study area. The location of sampling sites within the study area is shown in figure 7.

Water and Bottom Sediment

The two major inflows to Angostura Reservoir, the Cheyenne River and Horsehead Creek, were sampled. The Cheyenne River near Hot Springs (site 2) served as a background site upstream of the Unit to determine water quality entering the reservoir. Horsehead Creek at Oelrichs (site 3) and Cottonwood Creek near Buffalo Gap (site 13) served as background sites to determine the influence that underlying geology has on water quality of the Unit.

Angostura Reservoir (site 4) was sampled in the deeper section for water-quality characteristics and near the delta of the Cheyenne River for bottom sediment. The reservoir stores all of the water for the Unit and is used extensively for fishing and recreation.

Angostura Canal near Hot Springs (site 6) was sampled because it is the outflow from Angostura Reservoir that conveys the irrigation water to the Unit lands. Fall River at the mouth near Hot Springs (site 7) is a major tributary to the Cheyenne River and contributes the majority of discharge in the Cheyenne River within the study area during most of the year.

Table 9.--Major ions, trace elements, and pesticides analyzed in water, bottom sediment, and biota for the Angostura Reclamation Unit

Water (dissolved concentration)			Bottom sediment (total concentration)		Biota (total concentration)	
Major ions	Trace elements	Pesticides	Trace elements	Pesticides	Elements	Pesticides
Alkalinity (bicarbonate plus carbonate)	Arsenic	1-Napthol	Arsenic	Atrazine	Aluminum	Aldrin
Calcium	Boron	3-Hydroxycarbofuran	Boron	Carbofuran	Antimony	Chlordane
Chloride	Cadmium	Alachlor	Cadmium		Arsenic	Dieldrin
Magnesium	Chromium	Aldicarb	Chromium		Barium	Endrin
Nitrogen	Copper	Aldicarb sulfone	Copper		Beryllium	Heptachlor epoxide
Potassium	Lead	Aldicarb sulfoxide	Lead		Boron	Hexachlorobenzene
Sodium	Mercury	Ametryne	Mercury		Cadmium	Lindane
Dissolved solids	Molybdenum	Atrazine	Molybdenum		Cobalt	Mirex
Sulfate	Selenium	Carbaryl	Selenium		Chromium	cis-Nonachlor
	Uranium	Carbofuran	Uranium		Copper	trans-Nonachlor
	Vanadium	Cyanazine	Vanadium		Iron	Oxychlodane
	Zinc	Methomyl	Zinc		Lead	PCB
		Metribuzin			Magnesium	Toxaphene
		Metolachlor			Manganese	o,p'-DDT
		Oxamyl			Mercury	p,p'-DDT
		Prometone			Molybdenum	o,p'-DDE
		Prometryne			Nickel	p,p'-DDE
		Propazine			Selenium	o,p'-DDD
		Propham			Silver	p,p'-DDD
		Sevin			Strontium	
		Simazine			Thallium	
		Simetryne			Tin	
		Trifluralin			Vanadium	
					Zinc	

Table 10.--Sampling sites, types of constituents analyzed, and schedule of sampling during 1988 for water and bottom sediment

[Months refer to the times when samples were collected at the indicated sites; NF, no flow; --, no data]

Site number (fig. 7)	Site name	Site location	Water			Bottom sediment	
			Major ions	Trace elements	Pesticides	Trace elements	Pesticides
2	Cheyenne River near Hot Springs	43°18'19" 103°33'43"	May June August November	May June August November	May June August November	-- -- -- November	-- -- -- November
3	Horsehead Creek at Oelrichs	43°11'17" 103°13'34"	May NF NF NF	May NF NF NF	May NF NF NF	-- -- -- October	-- -- -- --
4	Angostura Reservoir near Hot Springs	43°20'35" 103°26'15"	May June August November	May June August November	-- -- -- --	-- -- -- November	-- -- -- --
6	Angostura Canal near Hot Springs	43°21'08" 103°25'26"	May June August NF	May June August NF	-- -- -- --	-- -- -- November	-- -- -- --
7	Fall River at mouth near Hot Springs	43°23'12" 103°24'20"	May June August November	May June August November	-- -- -- --	-- -- -- November	-- -- -- --
8	Cheyenne River above Buffalo Gap	43°22'35" 103°17'16"	May June August November	May June August November	May June August November	-- -- -- November	-- -- -- November
10	Iron Draw near Buffalo Gap	43°26'55" 103°09'23"	May June August November	May June August November	May June August November	-- -- -- November	-- -- -- November
13	Cottonwood Creek near Buffalo Gap	43°31'36" 103°06'14"	May June August November	May June August November	-- June August November	-- -- -- November	-- -- -- November
14	Cheyenne River near Fairburn	43°42'00" 102°54'35"	May June August October	May June August October	May June August October	-- -- -- October	-- -- -- October

Table 11.--Sampling sites, types of constituents analyzed, number of samples collected, and schedule of sampling during 1988 for the various types of biota

[E, elements; P, pesticides as given in table 8; --, no sample]

Site number (fig. 7)	Site name	Site location	Schedule	Number of samples collected: Blackbird eggs[1] E	Blackbird eggs[1] P	Fish[2] E	Fish[2] P	Invertebrates[3] E	Vascular plants[4] E
1	Cheyenne River near Edgemont	43°18'20" 103°49'14"	April	--	--	10	--	--	--
			July	--	--	--	--	--	2
			September	--	--	10	--	--	--
5	Cheyenne River 0.75 mile downstream of Angostura Dam	43°21'21" 103°25'26"	July	--	--	--	--	--	1
			September	--	--	9	--	--	--
9	Tapeskas Pond	43°26'57" 103°10'00"	June	4	--	--	--	--	--
			July	--	--	--	--	1	1
11	Kimmies Pond	43°30'03" 103°05'28"	June	4	1	--	--	--	--
			July	--	--	--	--	1	1
12	Cheyenne River near Custer County 656 bridge	43°30'12" 103°04'20"	April	--	--	27	1	--	--
			July	--	--	--	--	1	1
			September	--	--	26	--	--	--
14	Cheyenne River near Fairburn	43°42'00" 102°54'35"	April	--	--	17	2	--	--
			July	--	--	--	--	1	2
			September	--	--	27	3	--	--
	Totals			8	1	126	6	6	8

[1]Bird eggs--Composite samples removed from the nests of red-winged blackbirds.
[2]Fish--Individual whole-body composites of available small fish species.
[3]Invertebrates--Composites of free-swimming water-column or bottom-dwelling aquatic insects.
[4]Vascular plants--Composite of tubers, leaves, and seed heads from aquatic plants.

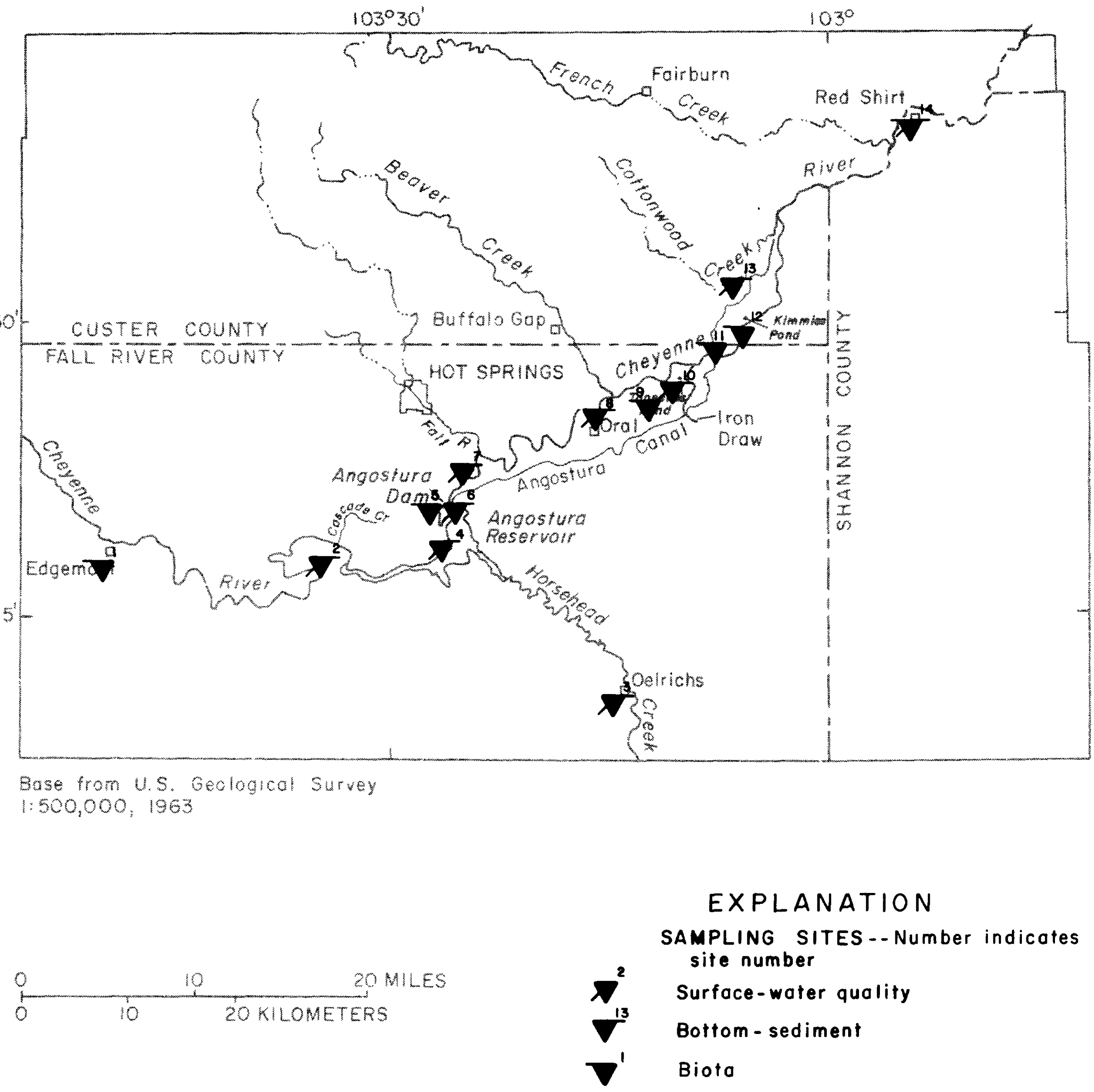


Figure 7.--Location of sample sites.

The Cheyenne River above Buffalo Gap (site 8) receives irrigation return flows from upstream irrigation. Iron Draw near Buffalo Gap (site 10) is a drain in which virtually all flow is due to surface-water and ground-water irrigation return flows.

The Cheyenne River near Fairburn (site 14) is downstream of the Angostura Reclamation Unit. This site was selected because it receives the composite of natural flow plus irrigation drainage from all irrigable land of the Unit.

Biota

The Cheyenne River near Edgemont (site 1) served as a background site upstream of the Unit lands to provide data on biota unaffected by irrigation drainage. Previous sampling of fish tissue had indicated elevated levels of selenium in the Cheyenne River below Angostura Dam; therefore, the Cheyenne River 0.75 mi downstream of Angostura Dam (site 5) was selected as a sampling site. The Cheyenne River at the Custer County 656 bridge (site 12) was selected because it receives additional irrigation drainage from the intervening lands downstream from site 5. The Cheyenne River near Fairburn (site 14), downstream of the Unit, was selected to compare spatial variability of constituent concentrations between biota within and downstream of the Angostura Reclamation Unit. This site also was sampled for water quality and bottom sediment.

Biological samples also were collected at Tapeskas Pond (site 9) and Kimmies Pond (site 11) because of their proximity to the Cheyenne River. Both of these sites are directly influenced by irrigation return water. Blackbird eggs, macroinvertebrates, and vascular plants were collected for analysis.

Sampling Design

Water samples were collected to coincide with the various stages of irrigation diversion, with the application of agricultural chemicals, and with the life-cycle changes in biological activity. Samples were collected in early May when natural flows were expected to be at a maximum due to snowmelt runoff and spring rains, irrigation return flows were at a minimum, and precrop pesticides had been applied.

Water samples were collected in June after crops were established and initial irrigation water had moved downgradient through surface- and ground-water return flow. In August, water samples were collected when irrigation diversion had reached a maximum and irrigation return flow comprised the largest proportion of instream discharge. Sites were sampled at this time to identify any changes in water-quality due to late-season irrigation contributions.

Water and bottom sediment were sampled in late October and November after irrigation diversion had ended and during the time of maximum ground-water return flow. This also coincided with low flow in the streams, and the expected time of maximum trace-element concentrations in water and bottom sediment.

Biological samples of whole fish were the primary tissue analyzed to investigate possible bioaccumulation of trace elements or pesticides in biota. Fish may accumulate chemical elements, nutrients, and synthetic organic compounds through oral ingestion, dermal contact, or through respiration across gill membrane. The bioconcentration factor in fish, accumulating elements or synthetic organic chemicals through the gill membrane, may result in a tissue concentration 100,000 times larger than concentrations in water. This is especially true of the chlorinated hydrocarbons and the polychlorinated biphenyls (PCBs), which often are incorporated into the lipid tissues.

Fish were collected at the same sampling sites during spring (April) and autumn (September) to compare seasonal concentrations of elements and pesticides in whole body tissue. Blackbird eggs, invertebrates, and aquatic plants generally were collected at the same sites as fish during the summer (June and July) when growth rates, water temperature, and exposure to irrigation drainage would be at a maximum. This also was the time when red-winged blackbirds were laying eggs and rearing young. A total of 155 samples were collected and submitted for laboratory analysis. Analysis of the various samples varied, but if there was adequate tissue, samples were analyzed for arsenic, boron, copper, selenium, and zinc. In addition, one or more types of inductively coupled plasma-emission spectroscopy (ICP) scans were conducted for additional elements.

Pesticide analysis of biological samples included organochlorine pesticides and polychlorinated biphenyls. Three fish samples from the spring collection, three fish samples from the autumn collection, and one sample of red-winged blackbird eggs from the summer collection were analyzed for pesticides.

Sampling Techniques and Analytical Methods

Water

Water samples for chemical quality were collected according to techniques recommended by the U.S. Geological Survey (1977). In flowing streams and canals, the water sample was a composite of depth-integrated subsamples collected in several vertical sections across the width of the stream. Samples collected from the reservoir were a composite sample obtained by subsampling each of the stratified layers of the reservoir.

Air temperature, water temperature, pH, field alkalinity, specific conductance, dissolved oxygen, and discharge were measured in flowing streams and canals. Temperature profile, depth of stratified layers, composite pH, field alkalinity, specific conductance, and dissolved oxygen were measured for the reservoir site.

Samples for analysis of dissolved major ions and trace elements were filtered through a 0.45-μm (micrometer) filter to remove suspended materials and isolate the dissolved fraction. Pesticide samples were unfiltered. Sample treatment and preservation were conducted by field personnel according to the requirements of the U.S. Geological Survey (1986). Analysis of major ions, trace elements, and pesticides were performed by the U.S. Geological Survey Water Quality Laboratory in Arvada, Colorado, according to methods described in Fishman and Friedman (1985) for inorganic constituents, and Wershaw and others (1987) for pesticides. In addition to the normal quality-assurance practices of the U.S. Geological Survey for the chemical analysis of water (Friedman and Erdmann, 1982), replicates, splits, and field blanks were processed for major ion and trace-element analysis. Overall, the replicates, splits, and field-blanks data indicated that there was no inadvertent gross contamination of the water samples from the field procedures or laboratory analytical procedures.

Bottom Sediment

Samples of bottom sediment were collected at nine sites within the study area. Samples were collected from streams and canals using a stainless-steel, Teflon[1]-coated scoop. At least nine evenly spaced subsamples from the upper 2 to 4 inches of sediment were collected along each cross section. These subsamples were composited and mixed into a single sample, from which 300 g (grams) were submitted for trace-element analysis and 200 g for organic analysis.

Bottom sediment from site 4 (Angostura Reservoir) was sampled by obtaining 5 equal-volume subsamples. These subsamples were composited into a single sample and treated similar to the stream and canal samples.

Total concentration of trace elements, and organic content were determined by a geochemistry laboratory of the U.S. Geological Survey in Lakewood, Colorado. The samples were submitted to the laboratory where they were air dried and sieved through screens with a 2-mm (millimeter) opening. The samples were then split, and one split passed through a 62-μm sieve. Both fractions (greater than 62 μm (micrometers) and less than 62 μm) were analyzed for trace elements and organic carbon content. Most elements were analyzed by inductively coupled argon-plasma atomic emission spectrometry (ICP) following complete mineral digestion with strong acids. Arsenic and selenium were determined by hydride generation atomic absorption, mercury by flameless cold-vapor atomic absorption, boron from hot-water extract, and uranium by ultra-violet fluoresence (Severson and others, 1987). Pesticide analyses of bottom material were conducted by the University Hygienic Laboratory of the University of Iowa, Iowa City, Iowa, using standard U.S. Environmental Protection Agency analytical methods (1986b).

Biota

Biota samples were collected using standard equipment and techniques (U.S. Fish and Wildlife Service, 1985a). Blackbird eggs were collected from individual nests and placed in jars cleaned to U.S. Fish and Wildlife specifications to preserve the integrity of the sample (U.S. Fish and Wildlife Service, 1985a). All samples were held on ice until they could be transported to a refrigerator or freezer for storage. Samples were shipped to the laboratory for analysis in insulated boxes packed with dry ice.

Fish were collected using electrofishing equipment. Invertebrates were collected with a Surber square foot bottom sampler, sweep net, or kicknet, and then sorted in petri dishes with distilled water and stored in chemically clean jars. Aquatic plants were pulled by hand to assure sampling of stems and roots. Plants were collected in the river channel or near the bank adjacent to the fish-collection sites.

Fish and plant samples were washed in water from which they were collected. Samples submitted for inorganic chemical analysis were double wrapped in plastic wrap or plastic bags. Samples analyzed for pesticides were double wrapped in aluminum foil and then wrapped in plastic bags. Samples to be analyzed by the laboratory were shipped in insulated boxes packed with dry ice.

[1]Use of the trade name Teflon in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

All biota samples were analyzed by the University of Missouri Environmental Trace Substances Research Center and the Mississippi State Chemical Laboratory according to analytical methods approved by the U.S. Fish and Wildlife Service's Patuxent Analytical Control Facility in Laurel, Maryland (U.S. Fish and Wildlife Service, 1985b). Trace-element analysis was done by ICP after a preconcentration treatment. Hydride-generation atomic-absorption spectroscopy was used for determination of arsenic and selenium levels in tissues. A cold-vapor reduction method was used for mercury. Quality-control procedures, including duplicate-sample analysis, spiked-reference samples, and procedural blanks, were conducted on all groups of biological samples according to quality-control standards established by the Patuxent Analytical Control Facility.

RESULTS OF ANALYSES

The data obtained from the reconnaissance investigation were used to evaluate the significance of constituent concentrations measured in water, bottom sediment, and biota. Data were compared to existing guidelines that consist of locally enforceable "standards" or recommended "criteria" for environmental protection, and baseline values where standards or criteria are not available. Baseline values represent the available data on background values for the environmental conditions in question and were used as the basis for indicating elevated concentrations of measured constituents. In some instances, comparison of measured constituent concentrations to the guidelines was not appropriate, and comparison of data among sites within the study area was the most meaningful method of determining elevated constituent concentrations.

Water Quality

Analytical results for water samples collected during the study are shown in table 21 in the Supplemental data section at the back of the report. A statistical summary of major ion and trace-element concentrations in surface water throughout the study area is presented in table 12. Major-ion concentrations in water in the study area were relatively large; calcium, magnesium, sodium, sulfate, and chloride concentrations were larger than the national baseline values (table 13). Sulfate generally exceeded the U.S. Environmental Protection Agency (1976) water-quality criterion of 250 mg/L (milligrams per liter) for domestic water supplies. Chloride did not exceed the U.S. Environmental Protection Agency (1976) water-quality criterion (250 mg/L) at any site.

In general, water in the study area was a sodium sulfate type. Chemical quality of water from samples collected during 1988 throughout the study area is illustrated in figure 8. The water was a calcium sulfate type at site 2, and a calcium bicarbonate type at site 7. The source of water at these two sites is springflow, probably originating from Paleozoic limestones. The chemical quality of water flowing over alluvium and the Pierre Shale (sites 3, 6, 8, 10, 13, and 14) was a sodium sulfate type.

Average dissolved-solids concentration was the largest in the Cheyenne River upstream of irrigation (site 2) and smallest in Fall River (site 7). Except for Fall River, which had an average dissolved-solids concentration of 952 mg/L, water in the study area generally had an average dissolved-solids concentration of greater than 1,000 mg/L (fig. 8). Concentrations of dissolved solids of 1,000 to 2,000 mg/L in irrigation water can adversely affect many crops (National Technical Advisory Committee to the Secretary of the Interior, 1968).

Table 12.--Statistical summary of major ions and trace-element concentrations in surface water throughout the study area, 1988

[Major ions in milligrams per liter; trace elements in micrograms per liter]

Constituent	Number of samples	Dissolved concentration		
		Minimum	Maximum	Median
Major ions				
Calcium	32	97	530	250
Magnesium	32	23	100	79
Sodium	32	67	510	250
Potassium	32	<.1	28	10
Bicarbonate plus carbonate (HCO_3+CO_3)	32	159	439	206
Sulfate	32	390	1,900	1,200
Chloride	32	42	170	130
Trace elements				
Arsenic	32	<1	4	1
Boron	32	180	650	255
Cadmium	32	<1	5	<1
Chromium	32	<1	4	2
Copper	32	<1	11	1
Lead	32	<5	11	<5
Mercury	32	<.1	[1]5.3	<.1
Molybdenum	32	<1	16	7
Selenium	32	<1	16	3
Uranium	32	3.9	44	9.9
Vanadium	32	<1	6	2
Zinc	32	<3	76	10

[1]Reported value is suspected to be inaccurate; next highest concentration measured was 0.7 micrograms per liter.

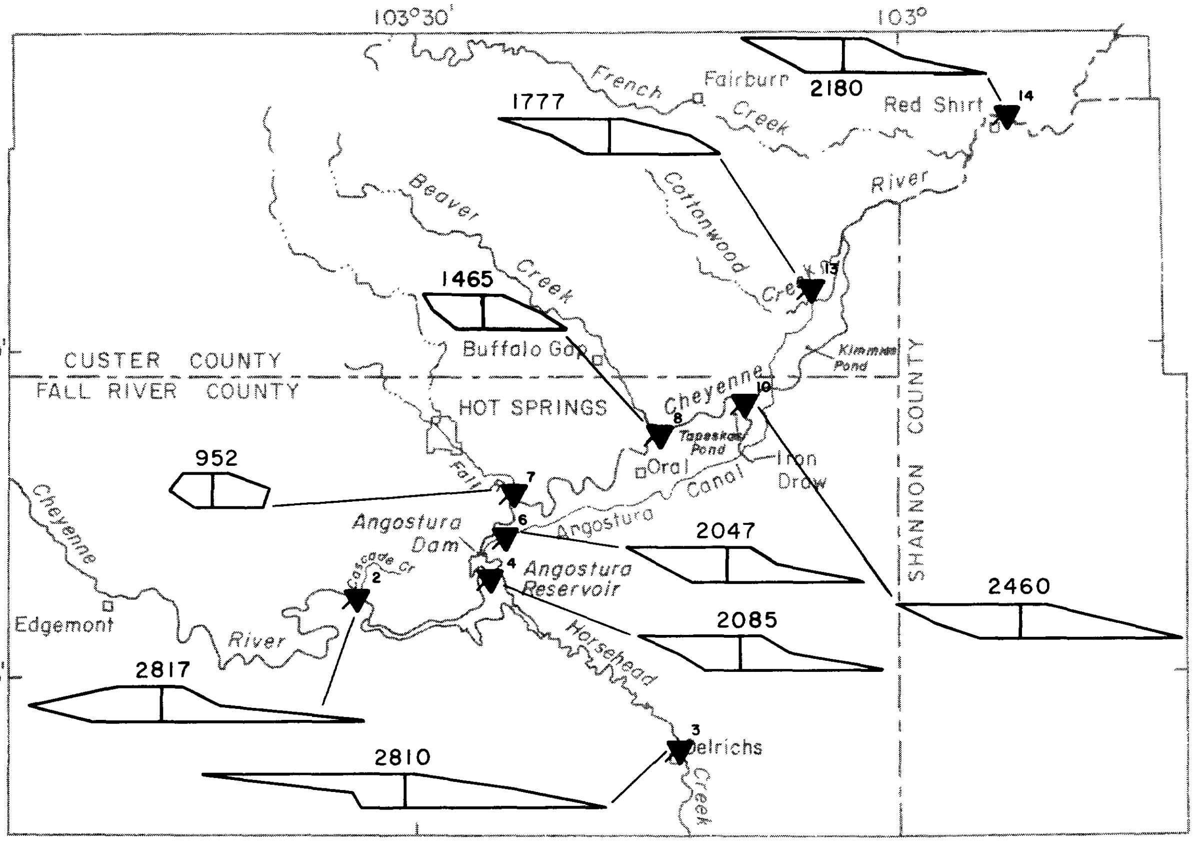
Table 13.--Comparison of major-ion and trace-element concentrations in surface water from the study area to national baseline values in water for United States rivers

[Source of data: Modified from Smith and others, 1987. Trace elements in micrograms per liter, major ions in milligrams per liter]

Water-quality property or constituent	National baseline values	Median value from study
Major ions		
Calcium	66.8	250
Magnesium	21.7	79
Sodium	68.9	250
Bicarbonate plus carbonate (HCO_3+CO_3)	[2]161.8	206
Sulfate as SO_4	116.9	1,200
Chloride	53.3	130
Trace elements		
Arsenic	3	1
Cadmium	<2	<1
Chromium	10	2
Lead	6	<5
Mercury	.3	<.1
Selenium	1	3
Zinc	21	10

[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]Reported as alkalinity ($CaCO_3$).



Base from U.S. Geological Survey
1:500,000, 1963

0 10 20 MILES
0 10 20 KILOMETERS

EXPLANATION

SURFACE-WATER-QUALITY SAMPLING SITE--Number indicates site number

WATER-ANALYSIS PATTERN--Number indicates average dissolved solids in milligrams per liter. Concentrations, in milliequivalents per liter, are plotted for sodium plus potassium (NA + K), calcium (Ca), magnesium (Mg), chloride (Cl), bicarbonate plus carbonate (HCO_3 + CO_3), and sulfate (SO_4). The anions are plotted to the right of the centerline, and the cations are plotted to the left. The area of the water-analysis pattern is an indication of the dissolved-solids concentration. The larger the area of the pattern, the greater the concentration of dissolved solids

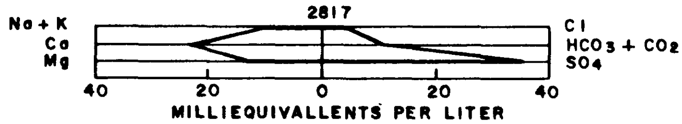


Figure 8.--Chemical quality of water and dissolved-solids concentration at sample sites, 1988.

The distribution of selected trace-element concentrations (fig. 9) show most were distributed near the analytical reporting limit, with the exception of molybdenum, selenium, and uranium. Uranium and zinc had the widest range of sample concentrations.

Concentrations of water-quality constituents from previous surface-water data (tables 3 and 4), which represented wet and dry years, are similar to concentrations of constituents that existed during 1988 (table 12), a water-deficient year. Comparisons of trace-element concentrations measured during the study showed the median selenium concentration was slightly larger than the national baseline value (table 13).

Overall, there appeared to be little difference between the concentration of trace elements in Cheyenne River water (site 2) delivered to the Angostura Reservoir, irrigation drainage conveyed in return flow drains (site 10), and the Cheyenne River downstream of the Unit lands (site 14). This similarity may indicate that irrigation return water consists largely of excess surface runoff from irrigation and shallow ground-water return flow moving downgradient through the alluvium. Except for a few instances, trace-element concentrations measured at sites 2, 10, and 14 were similar. The median value of molybdenum (14 μg/L) was slightly greater in water entering the study area (site 2) than at all other sites. The median values of uranium (14 μg/L) and zinc (20 μg/L) were slightly greater in water leaving the study area (site 14) than measured in the water entering the study area at site 2 (uranium = 7.1 μg/L, zinc = 10 μg/L). The median boron concentration of 480 μg/L in water sampled from a background site (site 13) was greater than the boron concentration of 215 μg/L in water entering the study area (site 2) and the boron concentration of 320 μg/L in water leaving the study area (site 14).

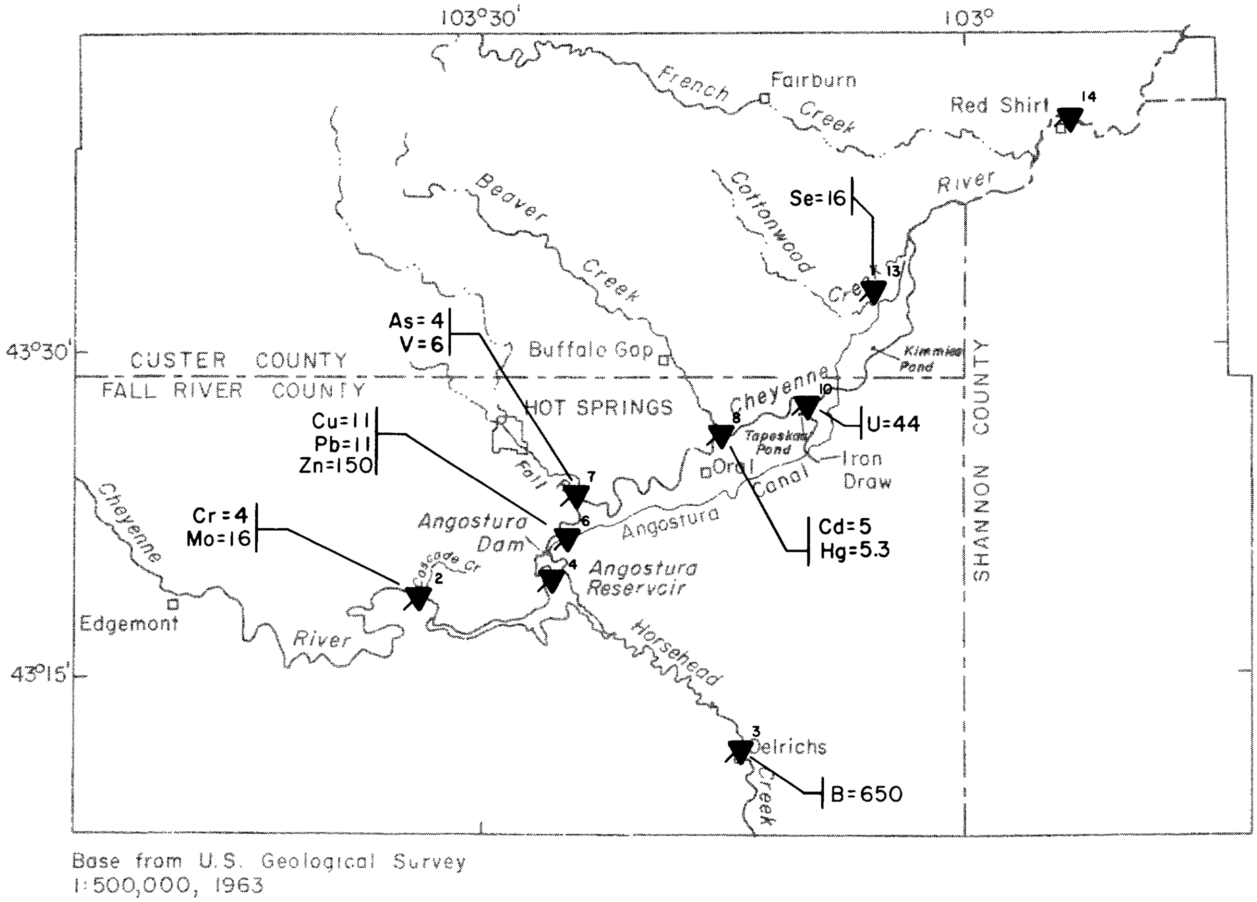
Concentrations of trace elements in Angostura Reservoir (site 4) were not substantially different from Cheyenne River water upstream (site 2). Concentrations of copper, mercury, and zinc decreased slightly during August and November from the early-season maximum values (table 21).

Comparisons of maximum trace-element concentrations in water among sites are illustrated in figure 10 to indicate spatial variability and elevated concentrations of individual constituents. Arsenic concentrations were relatively small at all the sample sites; the maximum concentration of arsenic (4 μg/L) was measured in Fall River (site 7).

Maximum concentrations of boron were greater in background site 3 (650 μg/L) and site 13 (560 μg/L) than at all the other sites (table 21), possibly because Horsehead Creek (site 3) and Cottonwood Creek (site 13) flow over Pierre Shale for most of their course.

The maximum concentration of selenium (16 μg/L) was greater at Cottonwood Creek (site 13), a background site, than at other sites (fig. 10). The second largest concentration of selenium (13 μg/L) also was measured at this site (table 21). The next largest selenium concentration (6 μg/L, table 21) was measured in the irrigation return drain, Iron Draw (site 10).

The maximum uranium concentration was 44 μg/L in Iron Draw (site 10, fig. 10), an irrigation return flow drain, and was substantially greater than the other sites. The second largest concentration of uranium (38 μg/L) also was measured at this site. Two other sites, Cottonwood Creek (site 13) and Cheyenne River near Fairburn (site 14), had uranium concentrations slightly elevated in comparison to other sites.



EXPLANATION

2 SURFACE-WATER QUALITY SAMPING SITE--Number indicates site number

Cd=5 TRACE ELEMENT--Number indicates concentration in micrograms per liter

As, Arsenic	Mo, Molybdenum
B, Boron	Pb, Lead
Cd, Cadmium	Se, Selenium
Cr, Chromium	U, Uranium
Cu, Copper	V, Vanadium
Hg, Mercury	Zn, Zinc

Figure 10.--Distribution of maximum trace-element concentrations in surface water for the study area, 1988.

The quality of water in the shallow alluvium within the area of the Hot Springs quadrangle (table 6) generally was similar to that from the Angostura Canal (site 6), and to the Cheyenne River water downstream of the reservoir (sites 8 and 14). Irrigation water from the canal is a source of recharge to the alluvial aquifer (fig. 6), which in turn discharges to the Cheyenne River. Differences in shallow alluvial water and canal water included a larger pH and chloride concentration in the canal water. The statistical summary for the alluvium within the area of the Hot Springs quadrangle (table 6) indicates that median concentrations of boron and uranium are similar to those in the canal, but 75th-percentile values are notably larger than canal values. This may indicate the occurrence of isolated areas of elevated boron and uranium concentrations of water in the alluvium.

Water in the Pierre Shale (tables 5 and 6) generally is similar to surface-water samples at the Horsehead Creek (site 3) and Cottonwood Creek (site 13) background sites, which flow over the Pierre Shale for most of their course. Ground water from the Pierre Shale probably reaches these streams from seepage. The major difference between the ground and surface water is the elevated concentrations of selenium in Cottonwood Creek compared to the water in the Pierre Shale or the water in Horsehead Creek.

There are only minor seasonal differences for most constituent concentrations between the May, June, August, and November samples. Generally, the seasonal maximums appear to be randomly distributed (table 21). However, maximum concentrations of uranium and selenium occurred in November.

Table 14.--Water-quality criteria, standards, or recommended limits of selected trace elements for human consumption, protection of freshwater aquatic life, irrigation, and livestock watering

[All concentrations are from U.S. Environmental Protection Agency (1986a). Concentrations are in micrograms per liter; --, no criteria or standard available]

	Maximum criteria or standards for water use			
Constituent	Human consumption	Aquatic life[1]	Irrigation[2]	Livestock watering[2]
Arsenic	50	[3]850	100	200
Boron	--	--	750	5,000
Cadmium	10	3.9	10	50
Chromium	50	[4]16	100	1,000
Copper	[5]1,000	18	200	500
Lead	50	82	5,000	100
Mercury	2	2.4	--	10
Selenium	10	20	20	50
Uranium	[6]35	--	--	--
Zinc	[5]5,000	120	2,000	25,000

[1]Specific criteria for the protection of freshwater aquatic life are based on acute criteria and a water hardness of 100 milligrams per liter.
[2]Recommended limits (National Academy of Sciences-National Academy of Engineering, 1973).
[3]As^{+5}.
[4]Cr^{+6}.
[5]Secondary Maximum Contaminant Level (SMCL).
[6]Suggested No Adverse Response Level (SNARL), National Academy of Sciences (1983).

Individual trace-element concentrations were compared to criteria, standards, or recommended limits to identify water-quality conditions that could impair beneficial uses of water. The water-quality criteria, standards, or recommended limits are listed in table 14. Only minor exceedances of criteria, standards, or recommended limits occurred in the study area during 1988. Concentrations were not particularly large at any one site. No constituent at any one site exceeded water-quality criteria or standards during all four sample periods. Median trace-element concentrations of all data for all sites (table 12) were less than the water-quality criteria or standards.

The cadmium acute criterion for freshwater aquatic life (3.9 $\mu g/L$) was exceeded in Fall River (site 7), a background site, and in the Cheyenne River at site 8, which receives irrigation return flow (table 21). These exceedances occurred during the November sample period when all irrigation releases had been discontinued, and ground-water return flow was presumably at a maximum.

One mercury concentration (5.3 $\mu g/L$ on June 21, 1988, at site 8) exceeded the mercury acute criterion for protection of freshwater aquatic life (2.4 $\mu g/L$). This reported value for mercury is suspected to be inaccurate and may be the result of sample contamination or laboratory analytical error.

Except for the Cheyenne River upstream of the Unit lands (site 2) and for Horsehead Creek (site 3), mercury concentrations exceeded the chronic mercury criterion (0.012 $\mu g/L$, U.S. Environmental Protection Agency, 1986b) for protection of freshwater aquatic life in at least one sample from all sampling sites (table 21). This may be of concern because of the fishery and recreational use of Angostura Reservoir and the Cheyenne River. However, because most of the samples had mercury concentrations less than the analytical reporting limit and most exceedances were at or only slightly greater than the reporting limit, the mercury data may be inconclusive.

Selenium concentrations (13 and 16 $\mu g/L$) exceeded the drinking water standards in two samples (May and November) in Cottonwood Creek (site 13), a background site. Water from this site is not used for human consumption. The U.S. Environmental Protection Agency (1988) has set a Federal selenium criterion for the protection of freshwater aquatic life of: (1) A 4-day average concentration not to exceed 5 $\mu g/L$ more than once every 3 years, or (2) a 1-hour average concentration not to exceed 20 $\mu g/L$ more than once every 3 years. For this investigation, 6 of 34 water samples, including spikes and replicates, equalled or exceeded 5 $\mu g/L$, and no water samples exceeded 20 $\mu g/L$ (table 21).

The Suggested No Adverse Response Level for uranium of 35 $\mu g/L$ for drinking water was exceeded in two samples (38 and 44 $\mu g/L$) collected in May and November in Iron Draw (site 10), an irrigation return flow drain. Water from this site is not used for human consumption, and the significance of this uranium concentration to aquatic life is unknown.

Pesticide concentrations in water were small at all sites and most were less than analytical reporting limits (table 15). None of the concentrations measured during the study exceeded available pesticide water-quality criteria or standards. The largest concentration of a pesticide was Prometone (1.0 $\mu g/L$) measured in the Cheyenne River at site 8, midway through the Unit lands.

Table 15.--Summary of pesticide concentrations in water for the study area, 1988

[Units in micrograms per liter; <, less than]

Pesticide	Analytical reporting limit	Number of sampling sites at which pesticides were detected	Maximum concentration
Carbamate insecticides			
3-Hydroxycarbofuran	<0.5	0	<0.5
Aldicarb	<.5	0	<.5
Aldicarb sulfone	<.5	0	<.5
Aldicarb sulfoxide	<.5	0	<.5
Carbaryl	<.5	0	<.5
Carbofuran	<.5	0	<.5
Oxamyl	<.5	0	<.5
Propham	<.5	0	<.5
Sevin	<.5	0	<.5
Triazine herbicides			
Alachlor	<.1	0	<.1
Ametryne	<.1	0	<.1
Atrazine	<.1	4	.2
Cyanazine	<.1	2	.1
Metribuzin	<.1	0	<.1
Metolachlor	<.1	1	.1
Prometone	<.1	2	1.0
Prometryne	<.1	0	<.1
Propazine	<.1	0	<.1
Simazine	<.1	2	.3
Simetryne	<.1	0	<.1
Other			
1-Naphthol	<.5	0	<.5
Methomyl	<.5	0	<.5
Trifluralin	<.1	0	<.1

Bottom Sediment

Trace elements may enter surface water from a variety of natural and human-related sources. Relation of water composition to source-rock type is complex, and is dependent on a number of factors. Some of these factors include water temperature and pH, biological activity, human activities, and solubility of individual constituents. The analyses of trace-element concentrations in bottom sediment for this study were used to indicate whether concentrations were elevated in comparison to background levels in soils.

Specific criteria or standards currently do not exist for assessing the toxic potential of trace-element concentrations in bottom sediment. However, background levels in the Unit lands and throughout the study area are assumed to be represented by geochemical baselines for soils of the western United States (R.C. Severson, U.S. Geological Survey, written commun., 1987; based on information in Shacklette and Boerngen, 1984). Although not specific to the study area, these baselines are one way of comparing study results to ambient conditions in the western United States. Analytical results from the bottom-sediment samples obtained during 1988 were compared to these baselines to determine possible elevated concentrations of trace elements in bottom sediment.

Analytical results of selected trace elements in the less than 62-μm and 2-mm fractions of bottom sediment from the study area are presented in tables 22 and 23 (Supplemental data at the back of the report). The distribution of selected trace-element concentrations in bottom sediment is illustrated in figure 11. The majority of trace-element concentrations were grouped fairly close to the median. Chromium, vanadium, and zinc had the widest range of concentrations among the data.

The smaller grain-size fractions usually contain the majority of trace-element concentrations (Horowitz, 1985). Concentrations of individual trace elements measured from the two size fractions were similar. The maximum concentrations of trace elements at each sample location generally were measured in the less than 62-μm fraction. Arsenic, barium, chromium, lead, and mercury had maximum concentrations greater in the less than 2-mm size fraction than in the less than 62-μm size fraction.

Trace-element concentrations in bottom sediment were very similar to the geochemical baselines for soils of the western United States (table 16). Some selenium concentrations were greater than the upper limit of the baseline range. Because the majority of trace-element concentrations were within baseline ranges, there probably is no significant accumulation of trace-element concentrations due to irrigation.

When comparing median trace-element concentrations of stream-bottom sediment from this study to data from the U.S. Department of Energy (1979) study (table 7), similar concentrations of elements are noted. Trace-element concentrations of bottom sediment derived from Fox Hills Sandstone and Pierre Shale surface exposures (table 7) were similar to values measured for this study.

Table 16.--Comparison of trace-element concentrations in the less than 62-micrometer fraction of bottom sediment in the study area, 1988, and geochemical baselines for soils from the western United States

[Total concentration, in micrograms per gram. <, less than; --, no data]

Element	Bottom sediment		Western soils[1]	
	Median	Range	Geometric mean	Baseline range[2]
Arsenic	8.6	6.2-15.0	5.5	1.2-22
Boron	2.1	1.2-7.3	23	5.8-91
Cadmium	<2	<2-2	--	--
Chromium	57	20-85	41	8.5-200
Copper	21	8-28	21	4.9-90
Lead	18	12-55	17	5.2-55
Mercury	.04	<0.02-0.04	.046	0.0085-0.25
Molybdenum	<2	<2-4	.85	0.18-4.0
Selenium	1.0	0.6-14.0	.23	0.039-1.4
Uranium	2.1	1.9-5.3	2.5	1.2-5.3
Vanadium	110	31-200	70	18-270
Zinc	90	39-140	55	17-180

[1]Modified from Shacklette and Boerngen, 1984.
[2]Range in which 95 percent of sample concentrations are expected to occur.

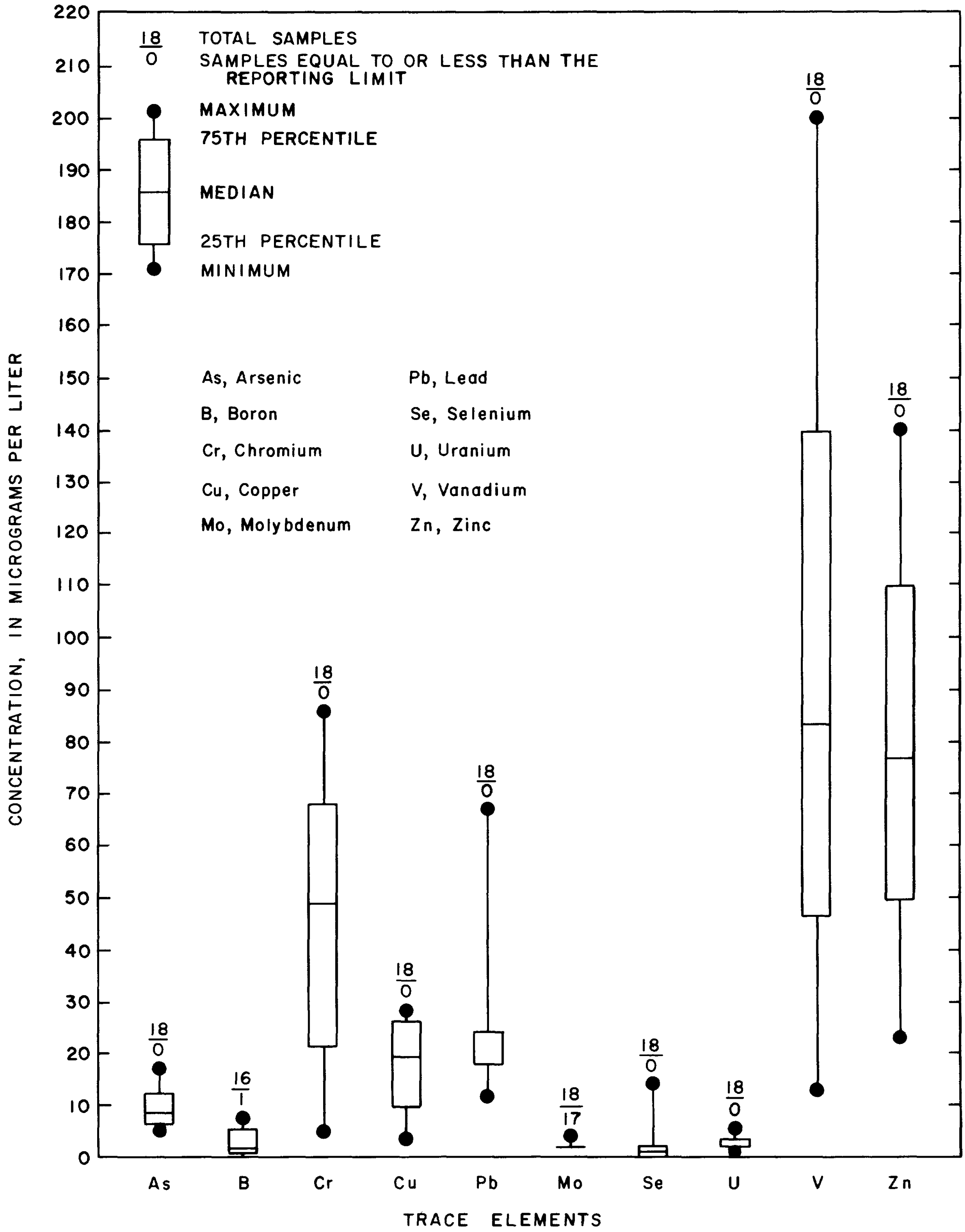


Figure 11.--Trace-element concentrations in the less than 62-micrometer and 2-millimeter fractions of bottom sediment for the study area, 1988.

The maximum trace-element concentrations of bottom sediment among sites are shown in figure 12. The occurrence of the majority of maximum trace-element concentrations are in the background stream Cottonwood Creek (site 13) and the Cheyenne River, midway through the irrigated area (site 8).

Selenium concentrations in bottom sediment at all sites generally were at the upper end of the baseline range. The maximum selenium concentration in bottom sediment of 14 μg/g (table 22) at site 13, a background site, was 10 times the upper end of the baseline range in soils (table 16). This relatively large concentration of selenium in bottom sediment at site 13 correlates with the highest concentrations of selenium in water that also were measured at this site.

Pesticides carbofuran and atrazine were analyzed in bottom sediment at sites 2, 8, 10, 13, and 14 (table 22). All samples of bottom sediment for pesticide concentrations had values less than the laboratory analytical reporting limit of 0.1 mg/kg (milligrams per kilogram).

Biota

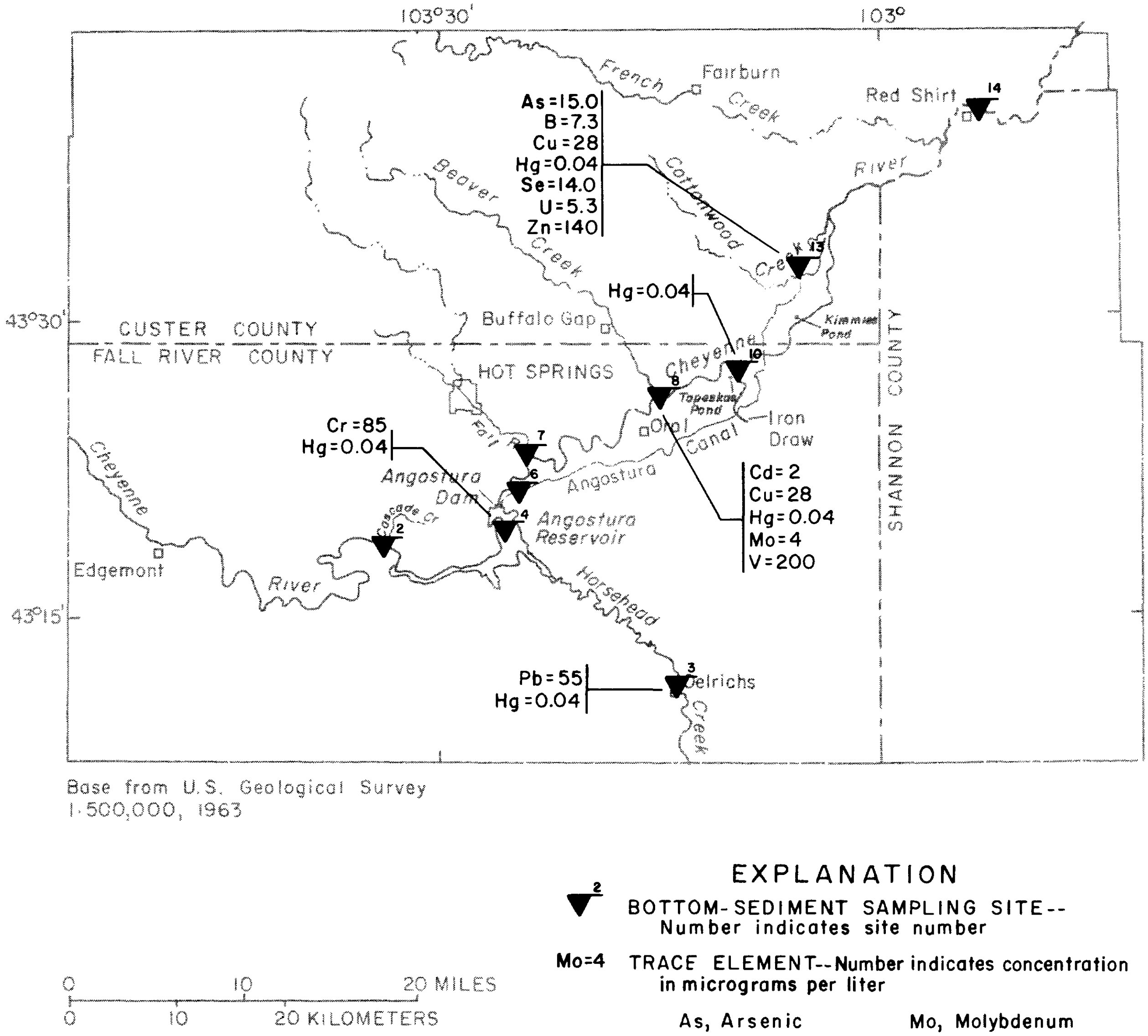
Very few precise or universal guidelines have been established for concentrations of elements or pesticides that can cause physiological harm in birds, fish, aquatic plants, or aquatic invertebrates. Tolerance for element and pesticide concentrations may vary among species as well as within the same species in different localities. Because of the complexity and variability of biological responses in natural systems to chemical concentrations in biota, no single or universal guidelines have been established to explain how an organism will respond to potentially toxic concentrations of chemicals in various aquatic habitats.

The U.S. Fish and Wildlife Service has been involved in the National Contaminant Biomonitoring Program (NCBP), formerly part of the National Pesticide Monitoring Program, since 1967. The Fish and Wildlife Service periodically analyzes residues of selected organocholorine contaminants and potentially toxic trace elements in samples of fish and wildlife collected from a nationwide network of stations (Lowe and others, 1985).

The National Contaminant Biomonitoring Program 85th-percentile values of trace-element concentrations in fish tissue are used in this study and other irrigation drainage reconnaissance studies as national baseline values (Hoffman and others, 1990; Setmire and others, 1990; and Radtke and others, 1988). The data from this study were compared to these baselines. Even if concentrations were elevated in relation to these baseline values, this does not necessarily mean detrimental biological effects will result.

Discussions of elements and pesticides sampled in biota are limited to those considered to be associated with irrigation drainage. Analytical results of biological samples collected during the current study are presented in table 24 (Supplemental data).

The following discussions of elements are limited to aluminum, arsenic, copper, selenium, and zinc because of their toxicity to fish and wildlife, the potential for these elements to occur at elevated concentrations compared to baseline values, and the large concentrations of elements at the sample sites. For each of these elements, residue found in specific taxa (fish, aquatic invertebrates, aquatic plants, and blackbird eggs) are discussed. When available, literature is cited to help explain the potential effects of the element concentrations on the biological organism or on the relation to other organisms in the aquatic system. The median and range of aluminum, arsenic, copper, selenium, and zinc concentrations in fish, invertebrates, plants, and blackbird eggs are presented in table 17.



EXPLANATION

2 BOTTOM-SEDIMENT SAMPLING SITE--Number indicates site number

Mo=4 TRACE ELEMENT--Number indicates concentration in micrograms per liter

As, Arsenic	Mo, Molybdenum
B, Boron	Pb, Lead
Cd, Cadmium	Se, Selenium
Cr, Chromium	U, Uranium
Cu, Copper	V, Vanadium
Hg, Mercury	Zn, Zinc

Figure 12.--Distribution of maximum trace-element concentrations in the less than 62-micrometer fraction of bottom sediment for the study area, 1988.

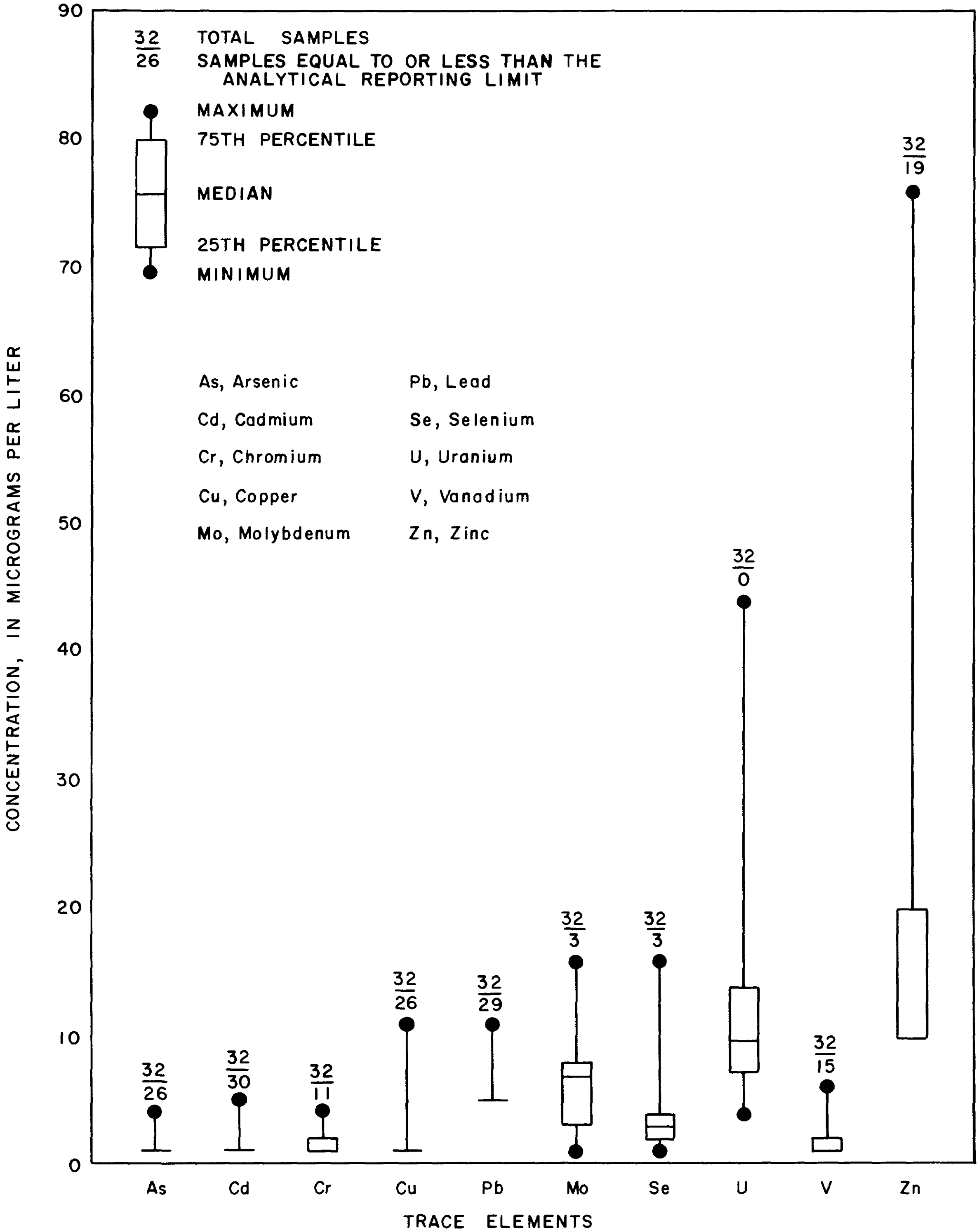


Figure 9.--Trace-element concentrations in surface water of the study area, 1988.

Table 17.--Median and range of aluminum, arsenic, copper, selenium, and zinc concentrations for all biota sampled in the study area, 1988

[Concentrations in micrograms per gram (dry weight); --, no data; N =, number of samples; <, less than]

Element		Fish	Invertebrates	Plants	Blackbird eggs
		N = 126	N = 6	N = 8	N = 4
Aluminum	Median:	200	1,815	2,140	4.0
	Range:	4.9 - 6,350	100 - 7,150	61 - 9,370	<3.0 - 9.9
Arsenic	Median:	0.2	1.4	1.3	0.1
	Range:	<0.1 - 2.3	0.5 - 2.7	0.1 - 7.3	<0.1 - 0.2
Copper	Median:	2.7	18	6.9	2.2
	Range:	0.94 - 16.1	5.8 - 25	1.8 - 9.1	1.0 - 2.8
Selenium	Median:	4	3.7	0.33	[1]2.4
	Range:	2.1 - 13	2.8 - 5.8	<0.1 - 2.9	1.5 - 3.0
Zinc	Median:	97	121	29	57
	Range:	45.2 - 401	92.7 - 224	9.5 - 37	36 - 64.7

[1]N = 8.

Aluminum

Fish

The concentration of aluminum in fish samples throughout the study area ranged from 4.9 to 6,350 μg/g dry weight (table 17). The median (50th-percentile) concentration of aluminum for all fish samples from sites 1, 5, 12, and 14 was 200 μg/g. The maximum concentration of 6,350 μg/g (table 24) was from a sample near Edgemont (site 1).

The median aluminum concentration of fish sampled upstream of the Angostura Reservoir (at site 1 near Edgemont) was larger than samples obtained downstream of the reservoir at sites 5, 12, and 14 (fig. 13). Median aluminum concentrations in fish samples collected in April decreased downstream from site 1 (352 μg/g) to site 12 (156 μg/g) to site 14 (73 μg/g) (table 18 and fig. 13). Median concentrations were less during September than during April at site 1 and greater during September than during April at sites 12 and 14 (fig. 13).

Aquatic invertebrates and plants

Median aluminum concentrations for all invertebrates and plants collected at sites 1, 5, 9, 11, 12, and 14 were 1,815 μg/g for invertebrate samples and 2,140 μg/g for plant samples (table 17). The largest aluminum concentrations for invertebrates (7,150 μg/g) and plants (9,370 μg/g) were from site 12. The second largest concentration of aluminum sampled in plants (9,250 μg/g) was from site 5, which is 0.75 mi downstream of Angostura Dam. The large aluminum concentrations for plants at sites 5 and 12 and invertebrates at site 12 were substantially larger than aluminum concentrations in biota at the other biological sampling sites (table 19).

Blackbird eggs

The aluminum concentrations in blackbird eggs collected at Tapeskas Pond (site 9) and Kimmies Pond (site 11) were relatively small in comparison to other biota (table 19). Aluminum concentrations of the three blackbird egg samples were <3, 3, and 4 μg/g at Kimmies Pond and the one sample from Tapeskas Pond had a concentration of 9.9 μg/g (table 19).

Arsenic

Fish

Arsenic values measured in the fish samples from the Cheyenne River (sites 1, 5, 12, 14) had a median of 0.2 μg/g and ranged from less than the analytical reporting limit of <0.1 to 2.3 μg/g (table 17). No significant downstream trends were observed. The maximum arsenic concentration in fish tissue (2.3 μg/g) was measured at site 14 (table 24). Percentile plots of arsenic concentrations in fish tissue showed the majority of samples were less than the National Contaminant Biomonitoring Program 85th-percentile baseline value of 0.81 μg/g dry weight (Lowe and others, 1985). Site 1, a background site, had the largest number of samples greater than the baseline value for arsenic residue in fish tissue (fig. 14). Gilderhus (1966) found that an arsenic residue level of 4.68 μg/g dry weight (effect level) in juvenile bluegills was associated with poor growth and survival. No samples had arsenic concentration in fish tissue greater than this level (fig. 14).

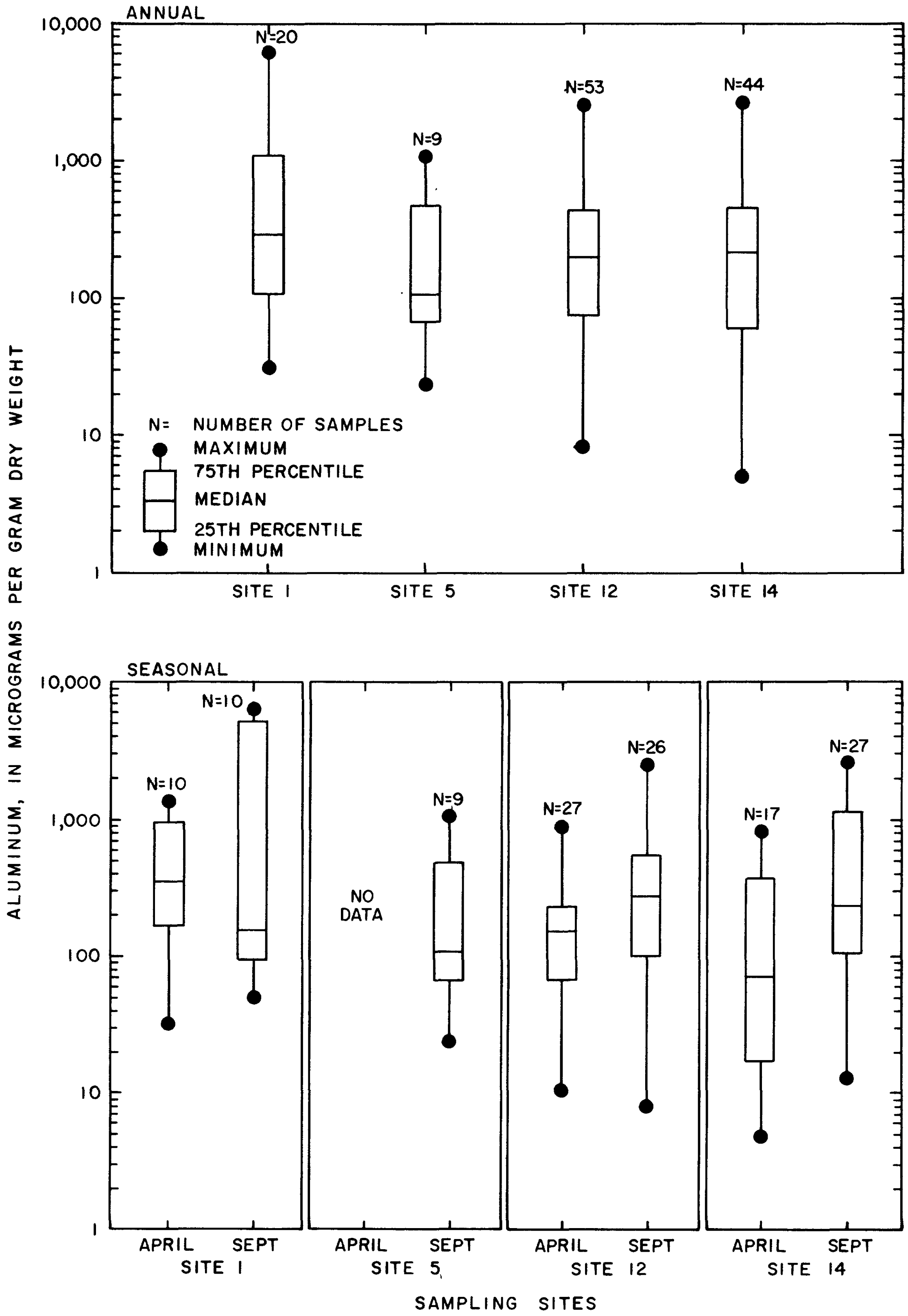


Figure 13.--Aluminum concentrations in fish tissue from sample sites, 1988.

Table 18.--Median and range of aluminum, arsenic, copper, selenium, and zinc concentrations in fish samples from four biological sampling sites in the Cheyenne River, 1988

[Concentrations in micrograms per gram (dry weight); --, no data; N=, number of samples; <, less than]

				Sampling site (fig. 7)			
				1	5	12	14
Elements	Biota	Month collected		April, N=10 September, N=10	-- September, N=9	April, N=27 September, N=26	April, N=17 September, N=27
Aluminum	Fish	April	Median:	352	--	156	73
			Range:	31 - 1,310	--	11 - 939	4.9 - 847
		September	Median:	157	110	282	240
			Range:	50.4 - 6,350	24 - 1,110	8 - 2,620	13 - 2,730
Arsenic	Fish	April	Median:	<0.2	--	0.2	0.1
			Range:	<0.2 - 1.2	--	<0.1 - 0.97	<0.1 - 0.79
		September	Median:	0.3	0.3	0.3	0.2
			Range:	<0.1 - 1.4	<0.1 - 0.6	<0.2 - 2.0	<0.1 - 2.3
Copper	Fish	April	Median:	4.3	--	2.94	2.74
			Range:	2.4 - 7.5	--	1.20 - 6.74	1.20 - 7.31
		September	Median:	2.9	2.4	2.3	2.6
			Range:	1.7 - 8.90	1.8 - 7.8	1.1 - 6.7	0.94 - 16.1
Selenium	Fish	April	Median:	3.0	--	5.2	3.5
			Range:	2.1 - 3.2	--	3.2 - 10	2.1 - 6.6
		September	Median:	3.2	11	5.2	4.0
			Range:	2.5 - 5.0	6.9 - 13	2.8 - 8.0	2.8 - 6.2
Zinc	Fish	April	Median:	139.5	--	98.4	102
			Range:	94.2 - 289	--	53.9 - 391	47.5 - 401
		September	Median:	127	91.1	85.3	88.5
			Range:	80.7 - 277	45.2 - 131	58.1 - 277	52.3 - 345

Table 19.--Aluminum, arsenic, copper, selenium, and zinc concentrations in aquatic plants, invertebrates, and blackbird eggs from individual biological sampling sites in the study area, 1988

[Concentrations in micrograms per gram (dry weight); --, no data; N=, number of samples; <, less than]

Element	Biota	Sampling site (fig. 7) 1	5	9	11	12	14
		N=2	N=1	N=1	N=1	N=1	N=2
Aluminum	Plants	1,940, 3,410	9,250	61	73	9,370	620, 2,340
Arsenic	Plants	0.59, 3.0	7.3	0.2	0.1	6.7	1.2, 1.4
Copper	Plants	6.8, 9.1	7.4	2.2	1.8	7.0	2.4, 7.71
Selenium	Plants	0.1, 0.2	2.9	<0.1	0.2	2.2	0.46, 0.80
Zinc	Plants	33, 37	31	14	9.5	37	11, 27.4
		N=2		N=1	N=1	N=1	N=1
Aluminum	Invertebrates	1,620, 1,670	--	1,960	100	7,150	4,230
Arsenic	Invertebrates	0.93, 1.2	--	1.9	0.5	2.7	1.5
Copper	Invertebrates	18, 18	--	25	5.8	17	17
Selenium	Invertebrates	3.0, 3.1	--	5.8	2.8	5.8	4.3
Zinc	Invertebrates	118, 140	--	224	92.7	120	121
				N=1	N=3		
Aluminum	Blackbird eggs	--	--	9.9	<3, 3, 4	--	--
Arsenic	Blackbird eggs	--	--	0.1	<0.1, 0.1, 0.2	--	--
Mercury	Blackbird eggs	--	--	2.2	1.0, 2.2, 2.8	--	--
Zinc	Blackbird eggs	--	--	64.7	36, 53.9, 60.1		
				N=4	N=4		
Selenium	Blackbird eggs	--	--	2.2, 2.3, 2.6, 3.0	1.5, 1.5 2.5, 2.9	--	--

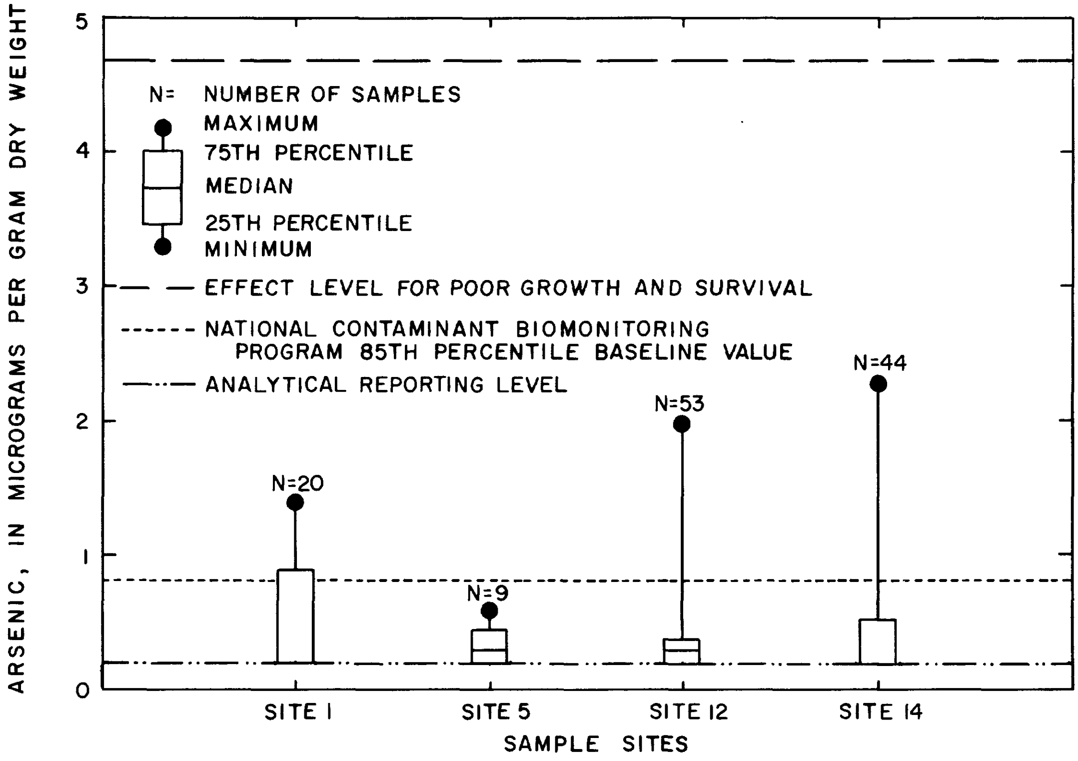


Figure 14.--Arsenic concentrations in fish tissue from sample sites, 1988.

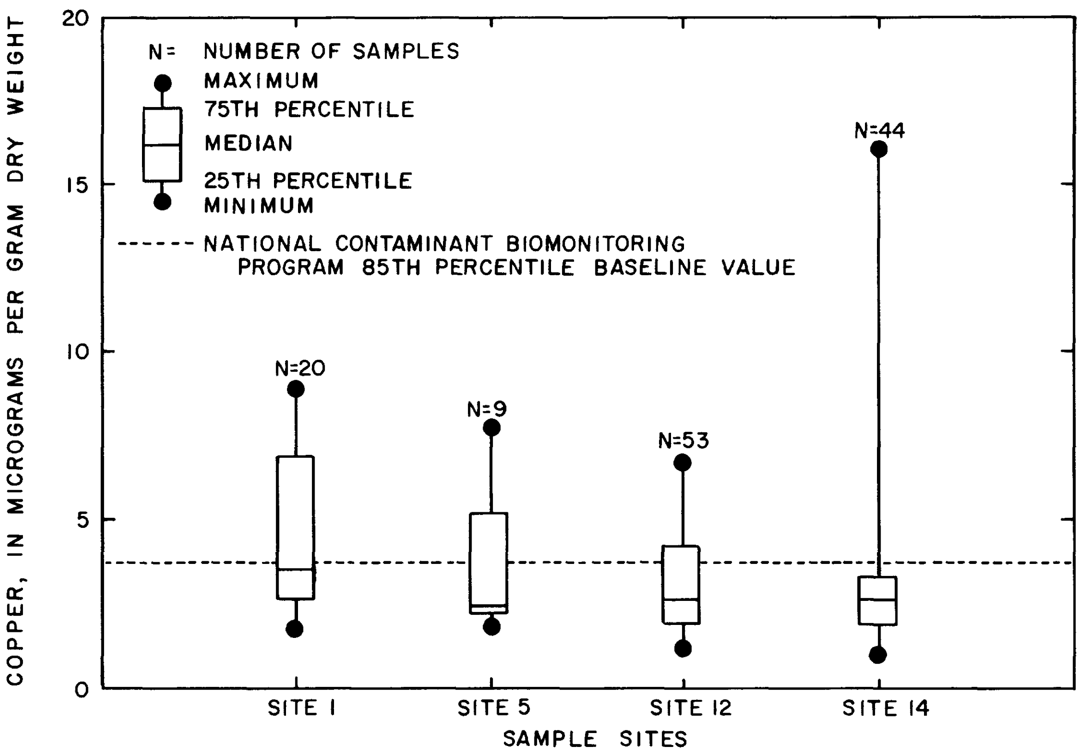


Figure 15.--Copper concentrations in fish tissue from sample sites, 1988.

Arsenic concentrations in fish throughout the study area were small and are not expected to impact the fishery resources in the Cheyenne River. The largest arsenic value (2.3 µg/g dry weight, 0.69 µg/g fresh wet weight) was significantly less than the 1.35 µg/g (fresh wet weight) in tissue residue of juvenile bluegills (Lepomis macrochirus) and 5 µg/g dry weight in adults considered elevated and potentially hazardous (Eisler, 1988).

Aquatic invertebrates

The median arsenic concentration of the six invertebrate samples was 1.4 µg/g, with individual samples ranging from 0.5 to 2.7 µg/g (table 17). The maximum arsenic concentration in invertebrates (2.7 µg/g) was measured at site 12 (table 19).

These levels of arsenic concentrations are not expected to cause harmful effects to other organisms that may feed upon them. Eisler (1988) reported that rainbow trout fed diets containing 90 µg/g or more of arsenic (as As^{+3} or As^{+5}), grew poorly, avoided food, and failed to metabolize food efficiently. No toxic effects were reported over 8 weeks of exposure to diets containing 1,600 µg/g as methylated arsenicals.

Aquatic plants

Median arsenic concentration in the eight plant samples (sites 1, 5, 9, 11, 12, 14) was 1.3 µg/g dry weight, with individual samples ranging from 0.1 to 7.3 µg/g (table 17). The maximum arsenic concentration in plants (7.3 µg/g) was measured at site 5, below Angostura Dam (table 19). The second largest arsenic concentration (6.7 µg/g) was measured at site 12. These two values, which were present in Sago pondweed, were significantly larger than those found at other sites, which ranged from 0.1 µg/g at Kimmies Pond (site 11) to 3.0 µg/g near Edgemont (site 1).

Blackbird eggs

The arsenic concentrations sampled in the blackbird eggs collected at Tapeskas Pond (site 9) and Kimmies Pond (site 11) were very small compared to other biota, ranging from <0.1 to 0.2 µg/g dry weight (table 19). The maximum concentration of 0.2 µg/g was measured at site 11.

Copper

Lowe and others (1985) show that the National Contaminant Biomonitoring Program 85th-percentile baseline value for copper in fish is 3.67 µg/g dry weight. Median concentrations of copper in fish tissue at sample sites 1, 5, 12, and 14 were less than this baseline value (fig. 15). Copper residues in fish tissue at site 1, a background site, generally were greater than at the other sample sites. Site 14, downstream of all irrigation return flow, had the least number of samples that exceeded the baseline value of 3.67 µg/g dry weight (fig. 15).

Selenium

Fish

The National Contaminant Biomonitoring Program 85th-percentile baseline value of selenium concentrations in fish tissue is 2.8 µg/g dry weight (Setmire and others, 1990; Lowe and others, 1985). Lillebo and others (1988) suggest that the level of selenium residue in whole fish tissue that will adversely impact fish growth or reproduction is 10.0 µg/g (effect level). The majority of selenium concentrations in fish tissue sampled were greater than the baseline value at the four sample sites (fig. 16). The largest median concentration (11 $\mu g/g$ dry weight) was at site 5 and is greater than the 10.0 $\mu g/g$ effect level for selenium concentrations in whole fish. The smallest selenium concentrations in fish were at site 1, a background site (fig. 16).

Seven of the nine fish samples collected in September at site 5 had selenium concentrations ranging from 10 to 13 $\mu g/g$ dry weight (table 24). One fish sample in April at site 12 had a selenium concentration of 10 $\mu g/g$ dry weight. These values are significant because they equal or exceed the effect level of 10.0 $\mu g/g$ dry weight selenium concentrations suggested to cause detrimental effects in fish (Lillebo and others, 1988). At site 5, where selenium concentrations were the greatest, smallmouth bass and green sunfish were abundant.

Aquatic invertebrates

The median selenium concentration of the six invertebrate samples collected in the study area was 3.7 $\mu g/g$ dry weight, with individual samples ranging from 2.8 to 5.8 $\mu g/g$ dry weight (table 17). The maximum selenium concentration (5.8 $\mu g/g$) was measured at sites 9 and 12 (table 19), which is slightly greater than the dietary level (5.0 $\mu g/g$ dry weight) for fish that may adversely impact growth or reproduction (Lemly and Smith, 1987). No invertebrate samples were available from site 5, 0.75 mi downstream of Angostura Dam.

Aquatic plants

The median selenium concentration for the eight plant samples collected from the biological sampling sites was 0.33 $\mu g/g$ dry weight, with individual samples ranging from <0.1 to 2.9 $\mu g/g$ dry weight (table 17). The maximum (2.9 $\mu g/g$ dry weight) was measured at site 5 (table 19). These concentrations are less than the 7.0 $\mu g/g$ dry weight dietary level that may adversely impact growth or reproduction of birds (Hoffman and others, 1990).

Blackbird eggs

The selenium concentrations in blackbird eggs collected at sites 9 and 11 ranged from 1.5 $\mu g/g$ at site 11 to 3.0 $\mu g/g$ dry weight at site 9 (table 19). These small residues are not likely to have harmful effects, based on a 9.0-$\mu g/g$ dry weight level in duck tissue that may adversely impact growth or reproduction of ducks (Lemly and Smith, 1987).

Zinc

The National Contaminant Biomonitoring Program 85th-percentile baseline value of zinc concentrations in whole-body fish tissue is 155 $\mu g/g$ dry weight (Lowe and others, 1985). The majority of samples collected at the biological sample sites had zinc concentrations less than this baseline value (fig. 17). The highest median concentration (131 $\mu g/g$ dry weight) was at site 1, a background site for biota data.

Pesticides

One sample of blackbird eggs from a nest at Kimmies Pond (site 11) and six fish samples from the Cheyenne River (sites 12 and 14) were analyzed for organochlorine pesticides and PCB residues (table 20). Pesticide concentrations in the blackbird eggs were less than analytical reporting limits. Pesticide concentrations in fish tissue that exceeded the analytical reporting limit were detected in 13 of 85 analyses from site 14, which is downstream of irrigation return flow (table 20). None of the organochlorine

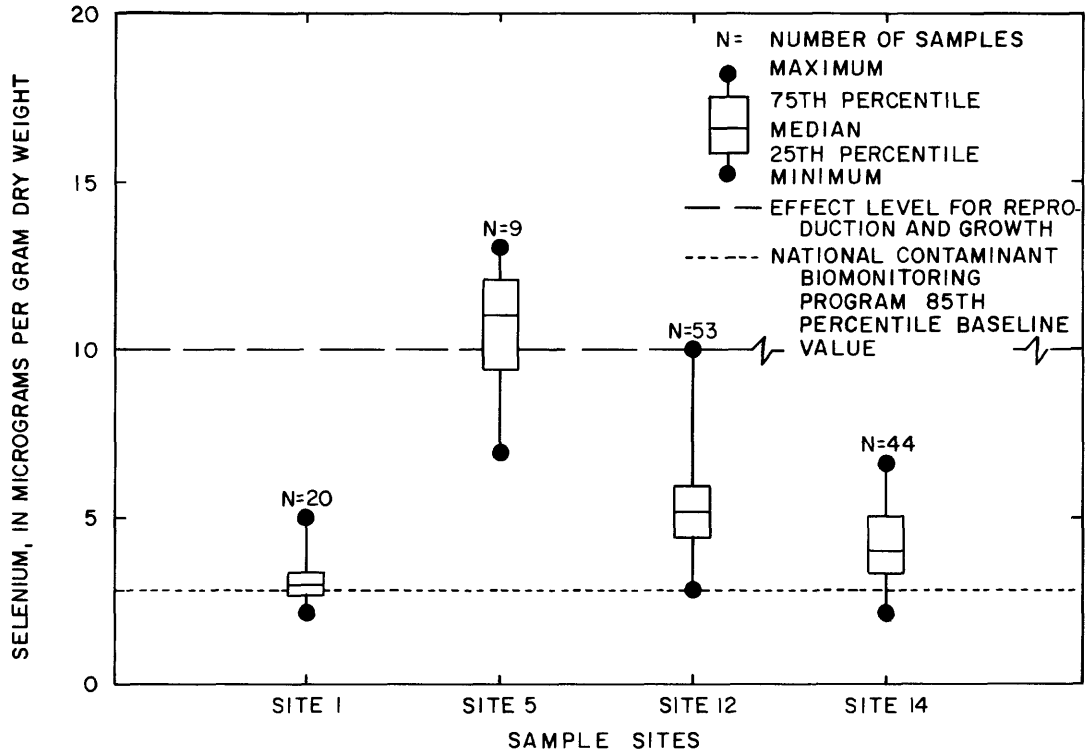


Figure 16.--Selenium concentrations in fish tissue from sample sites, 1988.

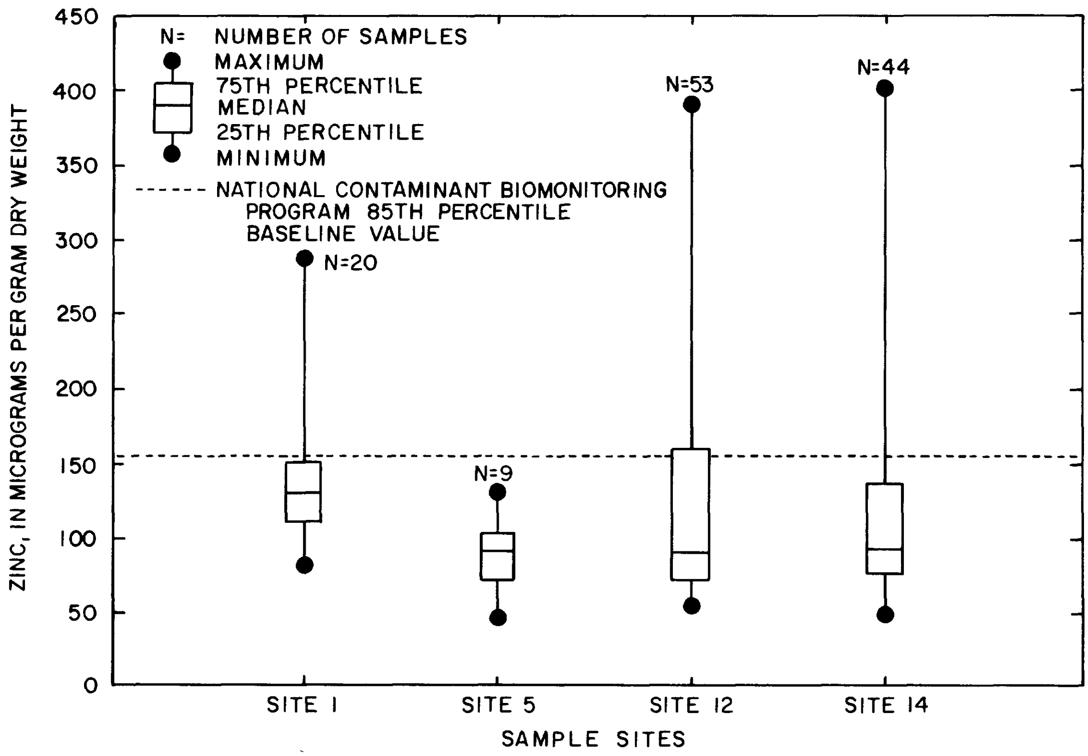


Figure 17.--Zinc concentrations in fish tissue from sample sites, 1988.

Table 20.--Concentrations of selected pesticides in biota, 1988

[Analyses by U.S. Fish and Wildlife Service. Concentrations in micrograms per gram, wet weight; PCB, polychlorinated biphenyls; mm, millimeters; <, less than; --, no date]

Site number (fig. 7)	Site name	Biota	Date	Est. Age (years)	Weight (grams)	Length (mm)	Percent moisture
11	Kimmies Pond	Blackbird eggs - 4	May 29		20	--	85.43
12	Cheyenne River near Custer County 656 Bridge	Carp	Apr. 20	5	1,400	483	77.2
14	Cheyenne River near Fairburn	Carp	Apr. 20	5	1,625	488	78.0
		Channel catfish	Apr. 20	7	1,750	584	75.8
		Carp	Sept. 7	3	591	361	75.6
		Sauger	Sept. 7	6	1,250	508	67.8
		Shorthead redhorse	Sept. 7	4	403	351	76.4

Site number (fig. 7)	Aldrin	Chlordane	Dieldrin	Endrin	Heptachlor epoxide	Hexachlorobenzene	Lindane	Mirex	cis-Nonachlor
11	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
12	--	<0.02	<0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01
14	--	<0.02	<0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01
	--	<0.02	<0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01
	--	<0.02	0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01
	--	<0.02	<0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01
	--	<0.02	<0.01	<0.01	<0.01	<0.01	--	<0.01	<0.01

Site number (fig. 7)	trans-Nonachlor	Oxychlordane	Total PCB's	Toxaphene	o'p'DDT	p'p'DDT	o'p'DDE	p'p'DDE	o'p'DDD	p'p'DDD
11	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
12	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
14	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	0.01	<0.01	0.02
	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	0.03	<0.01	0.01
	0.02	<0.01	0.39	<0.05	<0.01	<0.01	<0.01	0.05	<0.01	0.03
	0.02	<0.01	0.23	<0.05	<0.01	<0.01	<0.01	0.02	<0.01	0.01

pesticide concentrations in fish tissue exceeded the recommended limit of 1.0 μg/g wet weight established by the National Academy of Sciences-National Academy of Engineering (1973) for protection of fish.

The PCB content of two of the three fish samples collected in September from the Cheyenne River near Fairburn (site 14) was 0.23 and 0.39 μg/g wet weight. These concentrations are greater than the analytical reporting limits but less than the National Academy of Sciences-National Academy of Engineering (1973) recommended level of 2.00 μg/g wet weight for protection of any aquatic organism.

SUMMARY AND CONCLUSIONS

Reconnaissance studies were conducted by scientists of the U.S. Geological Survey, U.S. Fish and Wildlife Service, and U.S. Bureau of Reclamation during 1986-89 to determine whether irrigation drainage from U.S. Department of Interior irrigation projects has caused or has the potential to cause: significant harmful effects on human health, fish, and wildlife; or adverse effects on the suitability of water for other beneficial uses. The Angostura Reclamation Unit in southwestern South Dakota was chosen for a reconnaissance study because most of the irrigated land and surrounding area overlie Cretaceous marine shales which are known to contain large concentrations of trace elements, including selenium. The Angostura Reclamation Unit is a flow-through system with one storage site, Angostura Reservoir, used to supply water for 12,200 acres of irrigated lands.

Even though drought conditions prevailed during the sampling phase of the study (1988), concentrations of dissolved constituents in water from the Cheyenne River both upstream and downstream of the Angostura Reclamation Unit lands were not substantially greater than values measured in previous years. This probably is due to the fact that spring-fed tributaries, originating at limestone outcrops, contribute large amounts of flow to the Cheyenne River.

In general, water in the study area was found to be a sodium sulfate type. Dissolved-solids concentrations in water generally were greater than 1,000 mg/L, which may have adverse effects on some crops.

Results of the study indicate that irrigation return flow had relatively small concentrations of trace elements. Overall, there appeared to be minor differences between concentrations of trace elements in water of the Cheyenne River upstream of irrigated land and in water downstream from all irrigation return flow. The largest concentration of selenium (16 μg/L) was at Cottonwood Creek, a background site that drains a basin underlaid by Cretaceous shales. The largest concentration of uranium (44 μg/L) was in Iron Draw, an irrigation return flow drain. There were only minor differences for most constituent concentrations among the May, June, August, and November samples. Maximum concentrations of selenium and uranium occurred in November.

Concentrations of trace elements measured in water generally were small in comparison to water-quality criteria, standards, or recommended limits. The few instances in which water-quality guidelines for human consumption were exceeded occurred in water that is not used for domestic water supplies. The few instances in which water-quality guidelines for aquatic life were exceeded are minor and indicates that there probably are no adverse water-quality effects on aquatic life in the study area. There were no exceedances of recommended water-quality limits for irrigation use or livestock watering.

Pesticide concentrations generally were less than the analytical reporting limits. The largest pesticide concentration was 1.0 $\mu g/L$ of Prometone measured in the Cheyenne River at site 8, midway through the Unit lands.

Concentrations of most trace elements in stream-bottom sediment were similar to geochemical baselines for soils of the western United States. The maximum concentration of selenium (14 $\mu g/g$) in bottom sediment of Cottonwood Creek, a background site, was 10 times larger than the upper end of the baseline range in soils. The largest concentration of selenium measured in water (16 $\mu g/L$) also was at this site.

Pesticides, carbofuran and atrazine, were analyzed in samples of bottom sediment from sites where pesticides in water were sampled. Pesticide concentrations in all samples of bottom sediment were less than laboratory analytical reporting limits.

Biota samples for analysis of trace-element concentrations were collected upstream, within, and downstream of the Angostura Reclamation Unit lands. Fish samples were collected during the spring and fall to compare trace-element concentrations in fish influenced by ground-water seepage during the winter and by irrigation return flow during the irrigation season. Aquatic plants and aquatic invertebrates were collected at the same sites as the fish, when possible. Blackbird eggs and other biota were collected at two ponds near the Cheyenne River. All samples were collected in areas where irrigation return flow was most likely to have significant influence on the biota.

Median concentrations of aluminum in fish were larger upstream of the Angostura Reservoir than downstream of the reservoir. Median aluminum concentrations in fish samples collected in April decreased from 352 $\mu g/g$ at a background site upstream of the reservoir to 73 $\mu g/g$ at a site near Fairburn, which is downstream of all irrigation return flow. The maximum aluminum concentration in fish was 6,350 $\mu g/g$ in a sample from the Cheyenne River near Edgemont, upstream of the Angostura Reclamation Unit lands. Because of the lack of information on the toxicity of aluminum to fish, it is difficult to determine the significance of the large concentrations of aluminum in fish. The maximum aluminum concentrations in invertebrates (7,150 $\mu g/g$) and plants (9,370 $\mu g/g$) were from a site on the Cheyenne River, midway through the Unit lands, that receives irrigation return flow from upstream irrigated lands. Because of the lack of information on the correlation between aluminum concentrations and biological effects, it is difficult to make inferences in regard to toxicity.

Seven of the nine fish samples collected in September from the Cheyenne River 0.75 mi downstream of Angostura Dam had selenium concentrations ranging from 10 to 13 $\mu g/g$ dry weight. One fish sample collected in April from the Cheyenne River midway through the irrigation Unit had a selenium concentration of 10 $\mu g/g$ dry weight. These values are significant because they equal or exceed the selenium concentration of 10.0 $\mu g/g$ dry weight, which is suggested to cause detrimental effects in fish. The majority of individual fish tissue samples at the biological sample sites exceeded the baseline values for selenium concentrations.

Even though median concentrations of arsenic, copper, and zinc in fish were less than baseline values, the concentrations of all three elements exceeded their respective baseline values in a number of individual samples. The median concentrations of these elements during the April and September sampling periods generally were similar at all sites. Concentrations of most other elements in fish were low and are not expected to affect reproduction of fish.

The maximum selenium concentration for invertebrate samples was 5.8 μg/g dry weight in samples collected at Tapeskas Pond and in the Cheyenne River midway through the irrigation unit. Although only one sample was available from each of these two sites, this concentration is slightly greater than the dietary level for fish that may adversely impact growth or reproduction.

The six fish samples and one blackbird egg sample that were analyzed for organochlorine pesticides and PCB's had concentrations either less than analytical reporting limits or very low compared to levels of concern for human consumption. Data from the limited number of samples indicate that pesticide residues are not a problem in biota in the study area.

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SUPPLEMENTAL DATA

Table 21.--Field measurements and results of laboratory analyses of water samples from the Angostura Reclamation Unit study area, 1988

[Analyses by U.S. Geological Survey. Abbreviations: US/CM, microsiemens per centimeter at 25 °C; DEG C, degrees Celsius; MG/L, milligrams per liter; UG/L, micrograms per liter. Symbols: <, less than; --, no data]

SITE NUMBER (FIG. 7)	STATION NAME	DATE	TIME	TEMPER-ATURE WATER (DEG C)
2	CHEYENNE R NEAR HOT SPRINGS SD	05-04-88	1700	21.0
2	CHEYENNE R NEAR HOT SPRINGS SD	06-22-88	1300	28.0
2	CHEYENNE R NEAR HOT SPRINGS SD	08-22-88	1320	25.5
2	CHEYENNE R NEAR HOT SPRINGS SD	11-01-88	1500	15.5
3	HORSEHEAD CREEK AT OELRICHS	05-05-88	1800	19.0
4	ANGOSTURA RESERVOIR NEAR HOT SPRINGS SD	05-04-88	1200	12.0
4	ANGOSTURA RESERVOIR NEAR HOT SPRINGS SD	06-23-88	0930	21.5
4	ANGOSTURA RESERVOIR NEAR HOT SPRINGS SD	08-25-88	1030	22.0
4	ANGOSTURA RESERVOIR NEAR HOT SPRINGS SD	11-01-88	1000	10.0
6	ANGOSTURA CANAL NR HOT SPRINGS, SD	05-05-88	1430	14.0
6	ANGOSTURA CANAL NR HOT SPRINGS, SD	06-22-88	0800	23.0
6	ANGOSTURA CANAL NR HOT SPRINGS, SD	08-25-88	1400	23.0
6	ANGOSTURA CANAL NR HOT SPRINGS, SD	08-25-88	1405	23.0
6	ANGOSTURA CANAL NR HOT SPRINGS, SD	08-25-88	1410	23.0
6	ANGOSTURA CANAL NR HOT SPRINGS, SD	11-01-88	--	--
7	FALL RIVER AT MOUTH NR HOT SPRINGS, SD	05-05-88	1030	18.0
7	FALL RIVER AT MOUTH NR HOT SPRINGS, SD	06-23-88	1430	30.0
7	FALL RIVER AT MOUTH NR HOT SPRINGS, SD	08-24-88	1400	24.0
7	FALL RIVER AT MOUTH NR HOT SPRINGS, SD	11-03-88	0830	15.0
8	CHEYENNE RIVER AB BUFFALO GAP, SD	05-03-88	1500	15.5
8	CHEYENNE RIVER AB BUFFALO GAP, SD	06-21-88	0900	24.0
8	CHEYENNE RIVER AB BUFFALO GAP, SD	08-23-88	0915	18.0
8	CHEYENNE RIVER AB BUFFALO GAP, SD	11-02-88	0930	10.0
10	IRON DRAW NR BUFFALO GAP, SD	05-06-88	1030	18.0
10	IRON DRAW NR BUFFALO GAP, SD	06-21-88	1300	27.0
10	IRON DRAW NR BUFFALO GAP, SD	08-23-88	1245	21.0
10	IRON DRAW NR BUFFALO GAP, SD	11-02-88	1230	14.0
13	COTTONWOOD CREEK NEAR BUFFALO GAP, SD	05-03-88	1000	9.5
13	COTTONWOOD CREEK NEAR BUFFALO GAP, SD	06-24-88	0900	22.0
13	COTTONWOOD CREEK NEAR BUFFALO GAP, SD	08-24-88	1100	15.5
13	COTTONWOOD CREEK NEAR BUFFALO GAP, SD	11-02-88	1500	10.0
14	CHEYENNE RIVER NR FAIRBURN, SD	05-06-88	1600	20.5
14	CHEYENNE RIVER NR FAIRBURN, SD	06-20-88	1400	31.0
14	CHEYENNE RIVER NR FAIRBURN, SD	08-26-88	1000	19.5
14	CHEYENNE RIVER NR FAIRBURN, SD	10-31-88	1200	9.5

Table 21.--Field measurements and results of laboratory analyses of water samples from the Angostura Reclamation Unit study area, 1988--Continued

SITE NUMBER (FIG. 7)	DATE	TEMPER-ATURE AIR (DEG C)	DIS-CHARGE, INST. CUBIC FEET PER SECOND	SPE-CIFIC CON-DUCT-ANCE (US/CM)	OXYGEN, DIS-SOLVED (MG/L)	PH (STAND-ARD UNITS)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	CALCIUM DIS-SOLVED (MG/L AS CA)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)
2	05-04-88	16.0	31	3550	7.6	8.26	0.100	410	160	100	9.1
2	06-22-88	35.5	16	3050	7.2	8.00	0.150	460	130	92	8.0
2	08-22-88	30.5	16	2800	7.9	8.11	0.130	480	82	92	6.9
2	11-01-88	22.0	22	2890	8.8	8.21	0.170	530	94	96	6.8
3	05-05-88	20.0	0.1	3520	9.0	8.30	<0.100	190	42	93	14
4	05-04-88	17.0	--	2500	1.3	8.10	0.130	200	120	74	9.1
4	06-23-88	35.5	--	2560	7.6	8.02	<0.100	200	130	77	8.8
4	08-25-88	25.0	--	2550	--	8.00	<0.100	250	130	79	10
4	11-01-88	11.5	--	2700	9.1	8.39	0.100	260	140	79	10
6	05-05-88	25.0	69	2550	10.2	8.33	<0.100	200	140	75	9.3
6	06-22-88	30.0	207	2520	7.3	8.18	<0.100	250	130	79	10
6	08-25-88	28.5	162	2610	6.6	8.10	<0.100	270	140	80	9.0
6	08-25-88	28.5	162	2610	6.6	8.10	0.160	270	140	82	11
6	08-25-88	28.5	162	2610	6.6	8.10	<0.100	270	140	84	11
6	11-01-88	--	--	--	--	--	--	--	--	--	--
7	05-05-88	19.0	23	1290	9.9	8.51	0.180	150	92	38	8.4
7	06-23-88	32.5	24	1290	6.4	8.23	0.160	150	93	39	8.2
7	08-24-88	28.5	21	1360	8.4	8.40	0.180	160	99	41	8.5
7	11-03-88	15.5	25	1350	9.8	8.39	0.420	160	96	40	8.0
8	05-03-88	17.5	31	1810	9.8	8.26	0.960	180	95	59	10
8	06-21-88	32.5	23	1900	6.0	8.12	0.650	170	130	58	10
8	08-23-88	21.5	30	1980	7.9	8.10	0.960	160	120	67	11
8	11-02-88	21.0	35	2020	10.4	8.24	1.20	200	120	67	16
10	05-06-88	27.0	2.0	2990	8.5	8.32	4.30	280	130	81	28
10	06-21-88	--	1.4	3090	7.8	8.16	3.80	360	140	100	14
10	08-23-88	31.5	3.2	3000	8.0	8.13	2.40	300	140	90	20
10	11-02-88	24.0	2.5	2950	9.2	8.29	4.20	300	130	82	26
13	05-03-88	18.0	0.24	2660	10.1	7.95	0.450	200	130	61	<0.10
13	06-24-88	32.0	0.22	1180	2.8	7.80	<0.100	97	42	23	10
13	08-24-88	29.0	0.07	2850	3.1	7.66	<0.100	230	130	71	13
13	11-02-88	19.0	0.23	2660	7.2	7.88	0.440	250	130	62	13
14	05-06-88	20.0	78	2580	6.6	8.33	0.520	230	120	80	14
14	06-20-88	40.0	38	2670	9.4	8.18	0.230	260	170	91	10
14	08-26-88	27.5	66	2750	8.9	8.20	0.610	270	140	92	10
14	10-31-88	21.0	71	2660	11.2	8.25	1.30	270	130	82	10

Table 21.--Field measurements and results of laboratory analyses of water samples from the Angostura Reclamation Unit study area, 1988--Continued

SITE NUMBER (FIG. 7)	DATE	SODIUM, DIS- SOLVED (MG/L AS NA)	SULFATE DIS- SOLVED (MG/L AS SO4)	SOLIDS, RESIDUE AT 180 DEG. C DIS- SOLVED (MG/L)	ARSENIC DIS- SOLVED (UG/L AS AS)	BORON, DIS- SOLVED (UG/L AS B)	CADMIUM DIS- SOLVED (UG/L AS CD)	CHRO- MIUM, DIS- SOLVED (UG/L AS CR)	COPPER, DIS- SOLVED (UG/L AS CU)	LEAD, DIS- SOLVED (UG/L AS PB)	MERCURY DIS- SOLVED (UG/L AS HG)
2	05-04-88	320	1900	3160	<1	270	<1	<1	1	<5	<0.1
2	06-22-88	160	1600	2740	1	230	1	4	<1	<5	<0.1
2	08-22-88	100	1600	2640	<1	190	<1	3	1	<5	<0.1
2	11-01-88	110	1700	2730	<1	200	1	3	<1	<5	<0.1
3	05-05-88	510	1700	2810	1	650	<1	<1	1	<5	<0.1
4	05-04-88	240	1100	2000	<1	210	<1	<1	7	<5	0.4
4	06-23-88	250	1200	2040	<1	200	<1	2	1	<5	<0.1
4	08-25-88	270	1300	2090	2	200	<1	2	1	<5	0.2
4	11-01-88	260	1300	2210	1	230	<1	2	2	<5	<0.1
6	05-05-88	240	1100	2000	1	210	<1	<1	11	11	<0.1
6	06-22-88	250	1100	2020	1	210	1	2	2	<5	0.2
6	08-25-88	260	1300	2120	1	210	<1	3	1	10	0.1
6	08-25-88	260	1200	2120	1	210	<1	3	1	<5	<0.1
6	08-25-88	260	1200	2110	1	200	<1	2	2	5	<0.1
6	11-01-88	--	--	--	--	--	--	--	--	--	--
7	05-05-88	67	420	942	4	200	<1	2	<1	<5	<0.1
7	06-23-88	70	420	944	3	200	<1	2	1	<5	0.2
7	08-24-88	72	440	961	4	180	<1	2	<1	<5	<0.1
7	11-03-88	70	420	964	3	200	4	1	1	<5	<0.1
8	05-03-88	140	710	1380	1	230	<1	<1	1	<5	0.7
8	06-21-88	140	700	1400	1	280	<1	1	<1	<5	5.3
8	08-23-88	160	760	1520	<1	260	<1	2	1	<5	<0.1
8	11-02-88	150	780	1560	1	250	5	3	<1	<5	<0.1
10	05-06-88	300	1400	2450	<1	350	<1	<1	<1	<5	<0.1
10	06-21-88	300	1300	2480	1	360	1	2	<1	<5	<0.1
10	08-23-88	300	1400	2470	<1	320	<1	2	1	<5	<0.1
10	11-02-88	290	1400	2440	<1	330	1	2	1	<5	0.1
13	05-03-88	320	1100	2090	<1	490	<1	<1	<1	<5	<0.1
13	06-24-88	120	390	807	3	310	<1	2	3	<5	0.2
13	08-24-88	340	1200	2150	1	470	<1	2	<1	<5	<0.1
13	11-02-88	320	1100	2060	1	560	1	1	<1	<5	<0.1
14	05-06-88	260	1200	2110	1	320	<1	<1	1	<5	<0.1
14	06-20-88	260	1200	2170	1	370	<1	2	2	<5	<0.1
14	08-26-88	260	1300	2240	1	310	<1	2	1	6	<0.1
14	10-31-88	240	1200	2200	<1	320	1	2	<1	<5	0.2

Table 21.--Field measurements and results of laboratory analyses of water samples from the Angostura Reclamation Unit study area, 1988--Continued

SITE NUMBER (FIG. 7)	DATE	MOLYB-DENUM, DIS-SOLVED (UG/L AS MO)	SELE-NIUM, DIS-SOLVED (UG/L AS SE)	URANIUM NATURAL DIS-SOLVED (UG/L AS U)	VANA-DIUM, DIS-SOLVED (UG/L AS V)	ZINC, DIS-SOLVED (UG/L AS ZN)	ALA-CHLOR TOTAL RECOVER (UG/L)	AME-TRYNE TOTAL	ATRA-ZINE, TOTAL (UG/L)	CYAN-AZINE TOTAL (UG/L)	METHO-MYL TOTAL (UG/L)
2	05-04-88	12	3	12	3	10	<0.10	<0.10	<0.10	0.10	<0.5
2	06-22-88	14	3	6.5	2	20	<0.10	<0.10	<0.10	<0.10	<0.5
2	08-22-88	16	2	6.8	2	<10	<0.10	<0.10	<0.10	<0.10	<0.5
2	11-01-88	13	3	7.3	2	10	<0.10	<0.10	<0.10	<0.10	<0.5
3	05-05-88	3	1	11	<1	20	<0.10	<0.10	0.10	0.10	<0.5
4	05-04-88	8	2	9.5	<1	10	--	--	--	--	--
4	06-23-88	7	2	9.9	1	60	--	--	--	--	--
4	08-25-88	8	2	9.8	1	<10	--	--	--	--	--
4	11-01-88	6	2	11	2	20	--	--	--	--	--
6	05-05-88	10	2	8.9	1	<10	--	--	--	--	--
6	06-22-88	8	2	9.5	1	20	--	--	--	--	--
6	08-25-88	8	1	10	2	150	--	--	--	--	--
6	08-25-88	8	2	11	1	<10	--	--	--	--	--
6	08-25-88	8	2	10	1	10	--	--	--	--	--
6	11-01-88	--	--	--	--	--	--	--	--	--	--
7	05-05-88	10	3	5.1	6	5	--	--	--	--	--
7	06-23-88	7	3	5.3	5	50	--	--	--	--	--
7	08-24-88	8	2	5.6	6	5	--	--	--	--	--
7	11-03-88	10	2	6.1	5	7	--	--	--	--	--
8	05-03-88	6	3	9.0	2	76	<0.10	<0.10	0.10	<0.10	<0.5
8	06-21-88	8	4	8.5	3	<3	<0.10	<0.10	<0.10	<0.10	<0.5
8	08-23-88	7	3	10	2	<10	<0.10	<0.10	<0.10	<0.10	<0.5
8	11-02-88	4	<1	9.5	2	3	<0.10	<0.10	<0.10	<0.10	<0.5
10	05-06-88	4	6	38	<1	<10	<0.10	<0.10	0.10	<0.10	<0.5
10	06-21-88	3	6	22	2	20	<0.10	<0.10	0.10	<0.10	<0.5
10	08-23-88	3	4	28	1	12	--	--	--	--	--
10	11-02-88	<1	5	44	1	10	<0.10	<0.10	0.10	<0.10	<0.5
13	05-03-88	3	13	16	1	<10	--	--	--	--	--
13	06-24-88	1	5	3.9	1	48	<0.10	<0.10	<0.10	<0.10	<0.5
13	08-24-88	2	3	12	1	<10	<0.10	<0.10	<0.10	<0.10	<0.5
13	11-02-88	1	16	18	2	10	<0.10	<0.10	<0.10	<0.10	<0.5
14	05-06-88	8	4	14	1	<10	<0.10	<0.10	0.20	<0.10	<0.5
14	06-20-88	7	3	10	2	20	<0.10	<0.10	0.10	<0.10	<0.5
14	08-26-88	8	<1	14	2	20	<0.10	<0.10	0.10	<0.10	<0.5
14	10-31-88	6	3	15	<1	50	<0.10	<0.10	0.10	<0.10	<0.5

Table 21.--Field measurements and results of laboratory analyses of water samples from the Angostura Reclamation Unit study area, 1988--Continued

SITE NUMBER (FIG. 7)	DATE	METRI-BUZIN WATER WHOLE TOT.REC (UG/L)	METOLA-CHLOR WATER WHOLE TOT.REC (UG/L)	PROME-TONE TOTAL (UG/L)	PROME-TRYNE TOTAL (UG/L)	PRO-PAZINE TOTAL (UG/L)	PROPHAM TOTAL (UG/L)	SEVIN, TOTAL (UG/L)	SIMA-ZINE TOTAL (UG/L)	SIME-TRYNE TOTAL (UG/L)	TRI-FLURA-LIN TOTAL RECOVER (UG/L)
2	05-04-88	--	--	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
2	06-22-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
2	08-22-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
2	11-01-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
3	05-05-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
4	05-04-88	--	--	--	--	--	--	--	--	--	--
4	06-23-88	--	--	--	--	--	--	--	--	--	--
4	08-25-88	--	--	--	--	--	--	--	--	--	--
4	11-01-88	--	--	--	--	--	--	--	--	--	--
6	05-05-88	--	--	--	--	--	--	--	--	--	--
6	06-22-88	--	--	--	--	--	--	--	--	--	--
6	08-25-88	--	--	--	--	--	--	--	--	--	--
6	08-25-88	--	--	--	--	--	--	--	--	--	--
6	08-25-88	--	--	--	--	--	--	--	--	--	--
6	11-^1-88	--	--	--	--	--	--	--	--	--	--
7	05-05-88	--	--	--	--	--	--	--	--	--	--
7	06-23-88	--	--	--	--	--	--	--	--	--	--
7	08-24-88	--	--	--	--	--	--	--	--	--	--
7	11-03-88	--	--	--	--	--	--	--	--	--	--
8	05-03-88	<0.1	<0.1	1.0	<0.1	<0.10	<0.5	<0.50	0.30	<0.1	<0.10
8	06-21-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
8	08-23-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
8	11-02-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
10	05-06-88	--	--	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
10	06-21-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
10	08-23-88	--	--	--	--	--	--	--	--	--	--
10	11-02-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
13	05-03-88	--	--	--	--	--	--	--	--	--	--
13	06-24-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
13	08-24-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
13	11-02-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
14	05-06-88	<0.1	<0.1	0.2	<0.1	<0.10	<0.5	<0.50	0.10	<0.1	<0.10
14	06-20-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
14	08-26-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10
14	10-31-88	<0.1	<0.1	<0.1	<0.1	<0.10	<0.5	<0.50	<0.10	<0.1	<0.10

Table 21.--Field measurements and results of laboratory analyses of water samples from the Angostura Reclamation Unit study area, 1988--Continued

SITE NUMBER (FIG. 7)	DATE	1-NAPH-THOL (UG/L)	3-HYDROXY-CARBO-FURAN (UG/L)	ALDI-CARB (UG/L)	ALDI-CARB SULFONE (UG/L)	ALDI-CARB SULFOX-IDE (UG/L)	CAR-BARYL (UG/L)	CAR-BOFURAN (UG/L)	OXAMYL (UG/L)
2	05-04-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2	06-22-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2	08-22-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2	11-01-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
3	05-05-88	--	--	--	--	--	--	--	--
4	05-04-88	--	--	--	--	--	--	--	--
4	06-23-88	--	--	--	--	--	--	--	--
4	08-25-88	--	--	--	--	--	--	--	--
4	11-01-88	--	--	--	--	--	--	--	--
6	05-05-88	--	--	--	--	--	--	--	--
6	06-22-88	--	--	--	--	--	--	--	--
6	08-25-88	--	--	--	--	--	--	--	--
6	08-25-88	--	--	--	--	--	--	--	--
6	08-25-88	--	--	--	--	--	--	--	--
6	11-01-88	--	--	--	--	--	--	--	--
7	05-05-88	--	--	--	--	--	--	--	--
7	06-23-88	--	--	--	--	--	--	--	--
7	08-24-88	--	--	--	--	--	--	--	--
7	11-03-88	--	--	--	--	--	--	--	--
8	05-03-88	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5
8	06-21-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
8	08-23-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
8	11-02-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
10	05-06-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
10	06-21-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
10	08-23-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
10	11-02-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
13	05-03-88	--	--	--	--	--	--	--	--
13	06-24-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
13	08-24-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
13	11-02-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
14	05-06-88	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5
14	06-20-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
14	08-26-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
14	10-31-88	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Table 22.--Selected trace-element and pesticide concentrations in the less than 62-micrometer fraction of bottom sediment from the study area, 1988

[Analyses by the U.S. Geological Survey. Concentrations of trace elements are reported as total in bottom material, with the exception of boron, which is reported as extractable. Concentrations of pesticides are reported as recoverable from bottom material. <, less than; --, no data; µg/g, micrograms per gram; mg/kg, milligrams per kilogram]

Site number (fig. 7)	Site name	Date	Carbon (percent) Total	Organic	Inorganic	Trace-element concentration (µg/g) Arsenic	Barium	Boron	Cadmium	Chromium	Copper
2	Cheyenne River	11-01-88	4.20	0.37	3.83	11.0	510	--	<2	23	8
(split)	near Hot Springs		4.61	.29	4.32	7.6	700	--	<2	22	9
(replicate)			4.03	.25	3.78	6.6	480	--	<2	20	7
3	Horsehead Creek at Oelrichs	10-31-88	5.53	5.09	.44	8.6	720	5.5	<2	64	23
4	Angostura Reservoir near Hot Springs	11-01-88	1.71	1.07	.64	7.2	440	2.1	<2	85	26
6	Angostura Canal near Hot Springs	11-01-88	3.95	1.66	2.29	6.2	400	2.1	<2	47	19
7	Fall River at mouth near Hot Springs	11-03-88	3.54	.66	2.88	12.0	760	1.2	<2	50	20
8	Cheyenne River above Buffalo Gap	11-02-88	3.74	1.56	2.18	13.0	720	1.8	2	72	28
10	Iron Draw near Buffalo Gap	11-02-88	1.76	.47	1.29	8.9	930	--	<2	57	21
13	Cottonwood Creek near Buffalo Gap	11-02-88	3.47	2.84	.63	15.0	150	7.3	<2	67	28
14	Cheyenne River near Fairburn	10-31-88	2.41	.89	1.52	6.5	1,200	1.4	<2	35	16

Site number (fig. 7)	Site name	Trace-element concentration (µg/g) Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Uranium	Vanadium	Zinc	Pesticide concentration (mg/kg) Atrazine	Carbofuran
2	Cheyenne River	12	1,300	<0.02	<2	15	0.9	2.0	38	49	<0.1	<0.1
(split)	near Hot Springs	12	1,100	<.02	<2	15	1.0	1.9	39	49	--	--
(replicate)		12	780	<.02	<2	9	.6	2.0	31	39	--	--
3	Horsehead Creek at Oelrichs	55	470	.04	<2	26	1.0	2.0	110	96	--	--
4	Angostura Reservoir near Hot Springs	23	360	.04	<2	26	1.0	2.1	140	110	--	--
6	Angostura Canal near Hot Springs	28	730	<.02	<2	24	2.1	3.7	74	67	--	--
7	Fall River at mouth near Hot Springs	18	710	.02	<2	19	.9	1.9	84	76	--	--
8	Cheyenne River above Buffalo Gap	18	770	.04	4	35	4.3	3.8	200	120	<.1	<.1
10	Iron Draw near Buffalo Gap	18	860	.04	<2	23	1.6	3.4	110	90	<.1	<.1
13	Cottonwood Creek near Buffalo Gap	18	3,400	.04	<2	31	14.0	5.3	140	140	<.1	<.1
14	Cheyenne River near Fairburn	17	560	.02	<2	15	.6	2.1	67	58	<.1	<.1

Table 23.--Selected trace-element concentrations in the less than 2-millimeter fraction of bottom sediment from the study area, 1988

[Analyses by the U.S. Geological Survey. Concentrations of trace elements are reported as total in bottom material, with the exception of boron, which is reported as extractable. <, less than; --, no data; µg/g, micrograms per gram]

Site number (fig. 7)	Site name	Date	Carbon (percent) Total	Carbon (percent) Organic	Carbon (percent) Inorganic	Trace-element concentration (µg/g) Arsenic	Barium	Boron	Cadmium
2	Cheyenne River near Hot Springs	11-01-88	0.41	0.07	0.34	9.7	820	<0.4	<2
(split)			.44	.05	.39	6.2	820	<.4	<2
(replicate)			.35	.05	.30	8.6	810	<.4	<2
3	Horsehead Creek at Oelrichs	10-31-88	1.98	1.42	.56	9.0	420	5.3	<2
4	Angostura Reservoir near Hot Springs	11-01-88	1.55	.94	.61	6.7	440	1.6	<2
6	Angostura Canal near Hot Springs	11-01-88	2.76	1.16	1.60	5.8	570	1.8	<2
7	Fall River at mouth near Hot Springs	11-03-88	3.10	.39	2.7	14.0	770	.9	<2
8	Cheyenne River above Buffalo Gap	11-02-88	1.13	.45	.68	17.0	860	.7	<2
10	Iron Draw near Buffalo Gap	11-02-88	.32	.14	.18	5.6	730	.6	<2
13	Cottonwood Creek near Buffalo Gap	11-02-88	4.54	4.18	.36	11.0	280	6.4	<2
14	Cheyenne River near Fairburn	10-31-88	.97	.12	.85	12.0	1,700	.6	<2

Site number (fig. 7)	Site name	Trace-element concentration (µg/g) Chromium	Copper	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Uranium	Vanadium	Zinc
2	Cheyenne River near Hot Springs	6	3	18	360	<0.02	<2	4	0.2	1.1	13	23
(split)		5	4	19	350	<.02	<2	4	.2	1.1	14	22
(replicate)		6	4	18	300	<.02	<2	5	.3	1.5	12	21
3	Horsehead Creek at Oelrichs	65	24	67	520	.06	<2	25	1.0	1.9	100	97
4	Angostura Reservoir near Hot Springs	86	27	22	340	.04	<2	27	1.0	2.3	140	110
6	Angostura Canal near Hot Springs	31	14	29	540	<.02	<2	18	1.2	2.7	50	55
7	Fall River at mouth near Hot Springs	48	19	15	600	<.02	<2	20	.8	1.6	83	78
8	Cheyenne River above Buffalo Gap	20	10	19	530	<.02	2	15	1.6	2.2	56	51
10	Iron Draw near Buffalo Gap	12	5	15	220	<.02	<2	4	.4	1.2	26	25
13	Cottonwood Creek near Buffalo Gap	73	27	18	1,800	.02	<2	29	10.0	3.5	140	120
14	Cheyenne River near Fairburn	10	7	19	660	<.02	<2	8	.5	1.5	24	31

Table 24.--Field measurements and results of laboratory analyses of

[Analyses by U.S. Fish and Wildlife Service. Number in parentheses in micrograms per gram dry weight; Wt, weight, in grams; Lgth, Sb, antimony; As, arsenic; Ba, barium; Be, beryllium; B, boron; Mg, magnesium; Mn, manganese; Hg, mercury; Mo, molybdenum; Ni, V, vanadium; Zn, zinc; <, less than; --, no data. Analyses

Site number (fig. 7) and name	Taxa	Collection date	Est. Age (years)	Wt	Lgth	Mstr	Al[1]	Sb[2]	As[2]	Ba	Be[2]
1 Cheyenne River near Edgemont	Carp[4] (6)	09-07-88	0	5.5	71.0	80.3	306	<0.1	0.5	4.8	0.02
	Carp[3]	04-20-88	2	41.0	151.0	78.3	562	--	<.2	9.2	<.1
	Carp[3]	04-20-88	2	51.0	128.5	78.7	343	--	<.2	6.6	<.1
	Carp[3]	04-20-88	2	75.0	142.5	79.5	270	--	<.2	5.4	<.1
	Channel catfish[4]	09-07-88	2	46	195	75.0	106	<.1	.3	1.2	.02
	Flathead chub[3] (5)	09-07-88	2	5.0	84.6	76.9	110	--	.1	3.6	<.1
	Flathead chub[4] (4)	09-07-88	2	7.5	95.0	75.0	114	<.1	<.2	4.1	.03
	Flathead chub[3]	04-20-88	5	43.0	166.0	74.3	31	--	<.2	3.9	<.1
	Flathead chub[3]	04-20-88	3	68.0	118.4	71.9	360	--	.3	6.9	<.1
	Flathead chub[3]	04-20-88	3	70.0	117.4	72.1	877	--	.3	14.5	.1
	Green sunfish[3] (17)	09-07-88	--	3.2	53.4	79.8	200	--	.1	2.6	<.1
	Green sunfish[4]	09-07-88	2	22	102	74.9	50.4	<.1	<.2	2.0	.01
	Green sunfish[4]	09-07-88	2	25	112	75.9	53.3	<.1	.2	1.8	<.01
	Green sunfish[3]	04-20-88	2	40.0	80.8	68.3	88	--	<.2	2.9	<.1
	Green sunfish[3]	04-20-88	2	41.0	66.1	74.0	190	--	<.2	4.3	<.1
	Plains killifish[3] (17)	09-07-88	2	2.4	62.1	76.3	6,350	--	1.4	34.3	.2
	Plains killifish[3] (19)	09-07-88	2	2.5	64.8	76.4	6,150	--	1.1	32.3	.2
	Plains killifish[4] (16)	09-07-88	2	2.8	67.0	74.2	4,730	<.1	1.2	27.1	.16
	Plains killifish[3]	04-20-88	2	40.0	57.7	74.1	1,180	--	1.2	9.6	.1
	Plains killifish[3]	04-20-88	2	42.0	64.2	75.0	1,310	--	1.0	11.6	.1
	Gross invertebrate[3]	04-20-88		23.0	--	85.7	1,620	--	.93	18.7	<.1
	Odanata[3]	04-20-88		30.0	--	85.9	1,670	--	1.2	20.1	<.1
	Three square bulrush[3]	04-20-88		343.5	--	6.3	1,940	--	.59	15.3	<.1
	Softstem bulrush[3]	04-20-88		297.5	--	87.9	3,410	--	3.0	71.9	<.1
5 Cheyenne River 3/4 mile downstream of Angostura Dam	Green sunfish[3]	09-08-88	2	48	136	75.7	41	--	<.1	3.0	<.1
	Green sunfish[3]	09-08-88	3	74	157	77.2	95	--	.38	8.3	<.1
	Green sunfish[3]	09-08-88	3	77	156	76.2	110	--	.1	3.9	<.1
	Green sunfish[4]	09-08-88	3	72	151	73.5	24	<.1	<.2	5.7	<.01
	Smallmouth bass[3] (7)	09-08-88	0	6.0	74.0	75.0	110	--	.60	3.9	<.1
	Smallmouth bass[3] (8)	09-08-88	0	8.0	83.0	76.0	120	--	.4	4.2	<.1
	Smallmouth bass[4]	09-08-88	2	107	203	74.4	105	<.1	.3	3.5	<.01
	White sucker[4]	09-08-88	3	157	251	79.0	1,110	<.1	.3	19.2	.03
	White sucker	09-08-88	3	199	256	78.1	852	--	.5	16.8	<.1
	Sago pondweed[3]	07-27-88		429.5	--	88.5	9,250	--	7.3	135	.2
9 Tapeskas Pond	Gross invertebrate	07-27-88		12.0	--	89.3	1,960	--	1.9	15.5	<.1
	Softstem bulrush	07-27-88		175.5	--	85.6	61	--	.2	11.5	<.1
	Blackbird eggs	06-29-88		3.5	--	80.3	--	--	--	--	--
	Blackbird eggs	06-29-88		3.5	--	84.2	9.9	--	.1	2.0	<.1
	Blackbird eggs	06-29-88		3.5	--	83.1	--	--	--	--	--
	Blackbird eggs	06-29-88		3.5	--	83.7	--	--	--	--	--
11 Kimmies Pond	Gross invertebrate	07-27-88		10.0	--	58.8	100		.5	7.9	<.2
	Narrow leaf cattail	07-27-88		431.5	--	81.3	73		.1	2.9	<.1
	Blackbird eggs	06-29-88		3.5	--	79.9	--		--	--	--
	Blackbird eggs (3)	06-29-88		4.7	--	83.8	4		.2	1.1	<.1
	Blackbird eggs (4)	06-29-88		4.5	--	84.8	3		.1	2.0	<.1
	Blackbird eggs (4)	06-29-88		5.0	--	82.2	<3		<.1	.59	<.1

biological data from the Angostura Reclamation Unit study area, 1988

under taxa indicates number of fish or eggs. Concentrations,
length, in millimeters; Mstr, percent moisture; Al, aluminum;
Cd, cadmium; Cr, chromium; Cu, copper; Fe, iron; Pb, lead;
nickel; Se, selenium; Ag, silver; Sr, strontium; Tl, thallium;
performed by ICP, no preconcentration, unless otherwise noted]

B	Cd[1]	Cr[1]	Cu[1]	Fe[1]	Pb[1]	Mg	Mn[1]	Hg	Mo	Ni	Se	Ag	Sr	Tl	V	Zn
<3	0.46	<0.2	8.90	562	<0.5	1,580	47.1	0.19	0.42	0.9	2.7	0.076	220	<0.8	0.72	277
<3	.3	2	5.9	379	<4	2,130	50.9	.23	<1	<1	3.2	<2	384	<6	1.1	289
<3	.2	<1	6.4	318	<4	2,030	66.4	.20	<1	<1	2.4	<2	399	<6	.7	273
<3	.4	<1	4.8	263	<4	1,890	34.2	.21	<1	<1	2.8	<2	321	<6	.7	283
<3	.34	<.2	2.0	133	<.5	1,200	36.9	.28	1.0	4.3	3.3	.01	157	<.8	.82	80.7
<3	<.6	3	2.8	139	<5	1,540	33.7	.22	<1	<2	5.0	<2	242	<5	.4	133
<3	.39	.84	3.03	197	<.5	1,330	34.4	.15	.2	5.7	3.8	.02	230	<.8	.49	129
3	.2	<1	2.9	66	<4	1,490	12.0	.16	<1	<1	3.1	<2	222	<6	.3	94.2
<3	<.2	<1	2.4	263	<4	1,580	64.1	.11	<1	<1	3.0	<2	291	<6	.97	122
<3	<.3	4.2	3.2	559	<6	1,520	131	.091	3	18	2.1	<2	253	<6	1.7	99.1
<3	<.5	3	2.6	159	<5	1,700	48.2	.23	<1	3	3.9	<2	185	<5	.5	117
<3	.23	.57	1.7	202	<.5	1,580	32.6	.22	<.1	.4	3.1	<.01	206	<.8	.46	110
<3	.22	<.2	2.4	67.5	<.5	1,690	25.9	.37	.66	2.4	3.9	.02	201	<.8	.49	111
<3	<.2	<1	2.6	115	<4	1,390	29.5	.32	<1	<1	2.3	<2	244	<6	.5	102
<3	<.2	<1	3.8	162	<4	1,870	53.2	.28	<1	<1	3.2	<2	323	<6	.6	152
5	<.5	8.4	7.8	2,730	<5	2,410	601	.17	<1	5	2.8	<2	201	<5	9.7	137
5	<.6	7.4	7.1	2,630	<6	2,290	592	.17	<1	4	2.8	<2	190	<5	8.9	135
<3	.23	.64	7.08	2,220	2.1	1,980	440	.18	.32	<.3	2.5	.058	176	<.9	.32	125
3	<.2	3	6.0	616	<4	1,550	120	.12	<1	2	2.9	<2	141	<6	2.2	132
5	.2	2	7.5	650	<4	1,600	126	.17	<1	126	3.1	<2	160	<6	2.4	147
5	.6	2	18	1,240	<4	1,410	1,580	.09	<1	3	3.0	<2	32.4	<4	4.3	140
4	.3	2	18	1,280	<4	1,400	1,710	.091	<1	3	3.1	<2	27.5	<4	4.4	118
14	.3	10	6.8	1,420	<4	2,570	901	.005	<1	5.7	.1	<2	84.8	<4	3.4	37
15	.5	85	9.1	6,240	<4	3,090	738	.008	2.0	46	.2	<2	107	<4	6.8	33
<3	<.5	<2	2.1	56	<5	1,620	11	.14	<1	<2	8.8	<2	209	<5	<.3	96.6
<3	<.5	2	3.6	1,040	<5	2,080	26.4	.31	<1	<2	11	<2	318	<5	.8	131
<3	<.6	<2	2.3	97	<5	1,860	11	.19	<1	<2	10	<2	278	<5	.5	98.5
<3	.07	<.2	1.8	56.3	<.5	1,750	9.76	.25	.33	.7	6.9	.01	219	<.8	.41	108
<3	<.5	3	2.2	96	<5	1,570	40.9	.13	<1	<2	12	<2	186	<5	<.3	78.8
<3	<.6	<2	2.4	100	<5	1,630	42.8	.13	<1	<2	11	<2	201	<5	.6	81.0
4	.1	1.4	6.10	85.3	<.5	1,580	11.9	.15	.61	2.6	13	.02	233	<.9	.30	45.2
3	.1	1.6	4.28	643	<.6	2,010	80.6	.12	.2	.8	12	.02	221	<.9	1.5	91.1
<3	<.6	<2	7.8	949	<5	1,920	74.7	.13	<1	<2	11	<2	169	<5	1.9	63.1
210	<.3	29	7.4	19,300	5.0	5,240	1,230	.016	<2	22	2.9	<2	335	<4	16	31
5	<.3	2	25	1,930	<5	1,590	107	.075	<1	<1	5.8	<2	33.1	<5	5.2	224
11	<.2	3.4	2.2	90	<4	1,810	863	.005	<1	2.0	<.1	<2	66.7	<4	<.3	14
--	--	--	--	--	--	--	--	--	--	--	3.0	--	--	--	--	--
<2	<.2	<1	2.2	169	<4	419	6.5	.028	<1	<1	2.2	<2	12.9	<4	<.3	64.7
--	--	--	--	--	--	--	--	--	--	--	2.6	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	2.3	--	--	--	--	--
<4	<.5	<2	5.8	190	<8	1,080	24	.017	<2	<2	2.8	<4	24.1	<8	<.6	92.7
9.7	<.2	<1	1.8	113	<4	1,690	229	.005	<1	<1	.2	<2	70.3	<4	.4	9.5
--	--	--	--	--	--	--	--	--	--	--	1.5	--	--	--	--	--
<2	<.2	<1	2.2	189	<4	392	4.8	.120	<1	<1	2.9	<2	15.0	<4	<.3	60.1
<2	<.2	<1	2.8	182	<4	438	3.6	.250	<1	<1	2.5	<2	10.1	<4	<.3	53.9
<2	<.2	<1	1.0	91	<4	220	2.2	.058	<1	<1	1.5	<2	5.5	<4	<.3	36

Table 24.--Field measurements and results of laboratory analyses of biological

Site number (fig. 7) and name	Taxa	Collection date	Est. Age (years)	Wt	Lgth	Mstr	Al[1]	Sb[2]	As[2]	Ba	Be[2]
12 Cheyenne River near Custer County 656 Bridge	Black crappie	04-20-88	2	39	150.0	75.2	47.2	--	.3	5.7	<.01
	Black crappie	04-20-88	2	56	156.0	75.2	22	--	.2	1.7	<.01
	Black crappie	04-20-88	3	148	202.0	72.4	36.9	--	.31	1.3	<.01
	Carp	04-20-88	2	77	174.0	77.4	431	--	.50	9.5	.02
	Carp	04-20-88	2	82	186.0	77.8	184	--	.1	3.2	<.01
	Carp	04-20-88	2	115	207.0	78.3	178	--	.3	3.8	.01
	Carp	04-20-88	2	122	212.0	78.2	124	--	.2	3.4	.02
	Carp	04-20-88	2	126	212.0	77.0	747	--	.53	9.2	.03
	Carp	04-20-88	2	136	203.0	77.0	370	--	.4	14.5	.02
	Carp[4]	09-08-88	3	408	323	76.4	320	<.1	<.2	3.8	.01
	Carp	04-20-88	3	562	364.0	78.0	411	--	.3	8.1	.02
	Carp[4]	09-08-88	4	665	367	75.9	136	<.1	<.2	2.0	<.01
	Carp[3]	09-08-88	4	803	417	76.4	11	--	<.2	1.1	<.1
	Carp[3]	09-08-88	5	1,125	461	75.4	200	--	.3	8.0	<.1
	Carp[3]	09-08-88	5	1,175	450	75.5	1,000	--	.65	10.6	<.1
	Carp[3]	09-08-88	5	1,250	479	76.5	477	--	.3	4.9	<.1
	Carp	04-20-88	4	1,300	491.0	77.1	939	--	.34	13.3	.037
	Channel catfish[3]	09-08-88	1	55	193	73.6	260	--	.3	2.6	<.1
	Channel catfish	04-20-88	2	57	204.0	77.3	226	--	<.1	2.1	.02
	Channel catfish[3]	09-08-88	2	74	215	74.8	260	--	.71	5.2	<.1
	Channel catfish	04-20-88	2	91	242.0	75.4	177	--	<.1	3.9	.01
	Channel catfish	04-20-88	2	95	243.0	76.2	643	--	.1	9.0	.03
	Channel catfish[3]	09-08-88	2	98	237	76.6	710	--	.5	6.2	<.1
	Channel catfish	04-20-88	2	135	277.0	79.0	83.2	--	<.1	1.2	.02
	Channel catfish	04-20-88	3	180	300.0	80.6	203	--	.2	3.2	.02
	Channel catfish[4]	09-08-88	3	192	296	78.0	1,250	<.1	.4	7.4	.065
	Channel catfish[4]	09-08-88	3	220	297	79.0	938	<.1	1.0	9.1	.04
	Channel catfish[4]	09-08-88	3	276	318	79.2	981	<.1	.95	7.3	.040
	Flathead chub[3] (3)	09-08-88	3	19.0	127.0	71.2	2,620	--	2.0	21.1	<.1
	Goldeye	04-20-88	4	270	331.0	70.2	18	--	<.1	1.1	<.01
	Goldeye[3]	09-08-88	3	290	322	69.1	9.6	--	.3	.74	<.1
	Goldeye[4]	09-08-88	3	324	350	72.1	11	<.1	<.2	1.8	<.01
	Goldeye[3]	09-08-88	3	336	351	69.3	8	--	.4	.87	<.1
	Goldeye	04-20-88	4	377	366.0	71.5	11	--	<.1	.78	<.01
	Goldeye[3]	09-08-88	3	443	346	70.6	12	--	<.2	.65	<.1
	Goldeye[4]	09-08-88	4	456	368	69.5	16	<.1	<.2	.61	<.01
	Shorthead redhorse[3]	09-08-88	2	70	187	69.2	379	--	.2	6.4	<.1
	Shorthead redhorse[3]	09-08-88	2	70	194	70.7	250	--	.31	5.4	<.1
	Shorthead redhorse[3]	09-08-88	2	97	190	69.9	490	--	.2	7.1	<.1
	Shorthead redhorse	04-20-88	2	101	224.0	72.4	116	--	<.1	6.4	<.01
	Shorthead redhorse	04-20-88	2	120	236.0	72.9	69.5	--	.3	4.5	<.01
	Shorthead redhorse	04-20-88	3	124	237.0	72.9	188	--	.2	4.6	<.01
	Shorthead redhorse	04-20-88	2	133	242.0	69.7	88.9	--	<.1	4.4	<.01
	Shorthead redhorse	04-20-88	3	178	268.0	73.2	156	--	.1	10.0	<.01
	Shorthead redhorse[4]	09-08-88	3	246	302	70.2	303	<.1	<.2	5.4	<.01
	Shorthead redhorse[3]	09-08-88	3	246	286	71.1	230	--	.1	5.0	<.1
	Shorthead redhorse[4]	09-08-88	3	248	293	69.3	218	<.1	.2	5.0	<.01
	Shorthead redhorse[4]	09-08-88	3	314	321	68.3	475	<.1	.3	142	.02
	Shorthead redhorse	04-20-88	4	395	357.0	72.5	48.8	--	.1	4.3	.01
	Shorthead redhorse[4]	09-08-88	4	498	370	71.9	460	<.1	.6	8.6	.02
	Shorthead redhorse	04-20-88	4	538	377.0	67.2	92.3	--	.34	11.3	.02
	Shorthead redhorse	04-20-88	4	615	395.0	73.1	183	--	.67	161	.02
	Shorthead redhorse	04-20-88	5	769	403.0	68.3	111	--	.97	11.1	.02
	Gross invertebrate[3]	07-27-88		18.5	--	87.8	7,150	--	2.7	55.8	.2
	Sago Pondweed[3]	07-27-88		337.5	--	86.3	9,370	--	6.7	117	.3
14 Cheyenne River near Fairburn	Carp[4]	09-14-88	2	268	278	76.1	1,180	<.1	.4	17.2	.049
	Carp[4]	09-14-88	3	446	335	72.8	13	<.1	<.2	4.8	<.01
	Carp[4]	09-14-88	3	464	262	71.5	497	<.1	.2	7.6	.02
	Carp	04-20-88	3	479.0	338.0	79.0	396	--	.31	8.0	.02
	Carp	04-20-88	3	701.0	403.0	79.5	454	--	.79	18.0	.02
	Carp	04-20-88	4	1,300.0	468.0	82.8	847	--	.55	12.8	.03
	Channel catfish[3]	09-14-88	1	25	151	74.5	290	--	<.2	4.5	<.1
	Channel catfish (6)	04-20-88	1	28.7	167.5	81.2	369	--	.1	19.6	.02
	Channel catfish[4] 4	09-14-88	1	44	188	75.5	458	<.1	.4	5.6	.02
	Channel catfish	04-20-88	1	49.0	200.0	78.3	72.7	--	<.1	1.2	<.01
	Channel catfish[4]	09-14-88	1	70	216	74.1	112	<.1	.2	2.3	.02
	Channel catfish	04-20-88	2	131.0	277.0	76.3	129	--	.1	14.8	<.01
	Channel catfish	04-20-88	2	139.0	285.0	77.0	237	--	.1	3.9	.01

B	Cd[1]	Cr[1]	Cu[1]	Fe[1]	Pb[1]	Mg	Mn[1]	Hg	Mo	Ni	Se	Ag	Sr	Tl	V	Zn
3	<.03	1.4	1.40	145	<.5	1,890	33.7	.28	<1	.79	5.5	<.01	263	<.5	.5	107
<3	<.03	1.0	1.30	50.8	<.5	1,710	9.20	.28	<1	.46	5.7	<.01	239	<.5	.3	98.5
3	<.02	1.2	1.20	73.2	<.4	1,460	8.86	.25	<1	.60	4.6	<.01	172	<.5	<.3	71.1
3	.17	1.1	5.51	484	<.5	1,760	48.7	.12	<1	.70	5.2	.031	276	<.5	1.6	266
<3	.14	.87	4.60	201	<.4	1,800	27.8	.095	<1	.72	6.6	.02	259	<.5	.8	219
<3	.12	1.8	6.00	263	<.4	1,770	23.7	.11	<1	.97	6.4	.01	247	<.5	.7	212
<3	.15	1.1	5.32	179	<.5	1,820	23.1	.14	<1	.91	5.5	.02	278	<.5	.6	288
3	.15	1.8	4.73	591	<.5	1,860	42.8	.090	<1	1.1	5.4	.01	257	<.5	2.5	225
3	.11	1.2	4.89	367	<.4	1,880	43.9	.14	<1	.69	5.9	.01	261	<.5	1.3	222
<3	.1	<.1	3.97	295	<.5	1,500	21.7	.10	.1	<.3	5.2	.03	203	<.8	1.0	222
<3	.18	2.0	5.48	472	<.4	1,560	36.6	.23	<1	1.1	8.0	.01	195	<.5	1.7	391
<3	.1	<.6	1.9	129	<.5	1,630	13.0	.31	.1	<.4	3.6	<.01	176	<.9	.49	101
<3	<.5	3	4.5	208	<5	1,270	6.4	.29	<1	<2	7.7	<2	108	<5	<.3	234
<3	<.6	<2	5.4	320	<5	1,510	14	.919	<1	<2	8.0	<2	193	<5	.8	274
<3	<.6	<2	6.7	901	<5	1,530	6.7	.25	<1	<5	6.9	2	166	<5	3.3	266
<3	<.6	2	4.8	611	<5	1,390	20	.46	<1	<2	7.8	<2	138	<5	1.7	277
3	.23	2.7	5.98	1,100	<.5	1,650	37.9	.532	<1	1.6	10	.01	146	<.5	3.4	197
<3	<.6	<2	1.8	307	<6	1,310	22.3	.14	<1	<2	4.9	<2	104	<5	1.6	80.0
<3	.13	1.4	3.84	284	<.5	1,770	18.1	.33	<1	.70	6.5	<.01	170	<.5	1.2	123
<3	<.5	<2	1.8	467	<5	1,320	24.8	.18	<1	<2	5.1	<2	118	<5	1.5	78.2
<3	.094	1.8	2.20	263	<.5	1,610	18.8	.22	<1	1.0	3.4	<.01	172	<.5	1.1	98.4
4	.11	2.4	2.66	480	<.5	1,800	41.7	.23	<1	1.2	3.6	<.01	201	<.5	2.5	96.7
<3	<.6	<2	1.6	544	<6	1,700	37.1	.24	<1	<2	4.1	<2	163	<5	2.3	93.4
3	.14	.67	2.00	150	<.5	1,890	17.8	.23	<1	.40	4.3	<.01	221	<.5	.8	98.6
<3	.15	.98	1.90	250	<.5	1,720	28.7	.24	<1	.75	3.2	<.01	194	<.5	1.2	80.9
4	.23	<.2	2.3	727	<.5	1,630	51.9	.27	.3	<.3	4.0	<.01	163	<.8	4.6	89.9
7.7	.1	.80	1.9	617	.6	1,910	53.2	.26	.1	<.3	2.8	<.01	236	<.8	2.6	96.6
6	.16	.75	2.1	639	<.5	1,810	57.4	.32	.3	<.3	3.7	<.01	194	<.8	3.4	87.2
<3	<.5	5.4	3.2	1,660	<5	1,680	64.8	.11	<1	4	5.9	<2	144	<5	7.8	84.4
3	.082	1.2	2.05	117	<.4	1,320	7.39	.652	<1	.65	4.2	<.01	88.1	<.5	<.3	105
<3	<.6	<2	2.5	61	<5	1,230	5.3	.45	<1	<2	5.4	<2	102	<5	<.3	81.6
<3	.1	1.2	2.0	96.9	.6	1,440	6.86	.647	3.9	.6	4.4	.01	115	<.9	.2	106
<3	<.6	<2	1.1	86	<6	1,190	5.3	.624	1	3	4.8	<2	88.5	<5	<.3	80.2
<3	.08	.75	2.00	87.7	1.00	1,430	5.54	.49	<1	.46	4.6	<.01	105	<.5	<.3	93.3
<3	<.6	<2	1.4	93	<5	1,420	6.1	.791	<1	<2	6.6	<2	115	<5	.3	97.5
<3	.1	1.5	1.7	112	<.5	1,130	5.47	.619	.3	2.6	5.7	<.01	93.2	<.8	.2	86.2
<3	<.6	4	2.3	230	<6	1,440	73.2	.13	<1	<2	5.4	<2	194	<5	1.1	69.0
<3	<.5	3	1.8	165	<5	1,480	60.5	.14	<1	<2	5.9	<2	186	<5	1.1	64.8
<3	<.6	5	2.3	285	<6	1,470	89.3	.14	<1	7.4	5.8	<2	182	<5	1.7	67.9
<3	.05	3.2	2.75	171	<.5	1,620	82.7	.14	<1	3.2	5.2	<.01	231	<.5	.9	84.1
<3	.04	.56	3.74	106	<.5	1,720	60.5	.14	<1	1.0	4.1	<.01	249	<.5	.6	79.5
3	.05	1.4	2.65	199	<.5	1,670	63.8	.19	<1	.70	5.0	<.01	230	<.5	1.0	81.5
<3	<.06	4.2	2.63	129	<.5	1,520	57.9	.14	2	8.7	5.9	<.01	209	<.5	.7	71.2
3	.04	.57	2.94	196	<.5	1,630	63.2	.14	<1	.40	4.4	<.01	215	<.5	.93	70.9
<2	.1	1.6	2.3	234	<.5	1,380	63.1	.17	<.1	.8	5.5	<.01	187	<.8	1.1	65.8
<3	<.6	2	2.1	166	<5	1,360	47.8	.18	<1	5	5.1	<2	173	<5	1.0	58.1
3	.1	3.0	2.86	196	<.5	1,430	57.2	.21	<.1	1.5	5.2	<.01	176	<.8	1.1	64.3
4	.18	1.4	2.3	346	<.5	1,510	82.7	.19	<.1	1.7	4.7	<.01	226	<.8	1.3	59.6
<3	.07	1.4	6.74	161	<.5	1,550	38.2	.37	<1	1.7	3.4	<.01	220	<.5	.8	72.9
3	.2	1.5	3.0	789	<.7	1,470	97.0	.47	.2	1	5.1	<.01	212	<1	1.8	68.9
<3	.13	3.4	2.59	947	<.5	1,220	94.9	.25	1	5.4	3.8	<.01	170	<.5	.97	53.9
<3	.11	4.6	3.63	1,760	<.5	1,320	89.2	.37	<1	3.4	5.8	<.01	114	<.5	1.4	64.8
<3	.09	5.7	2.99	1,250	<.5	1,100	65.1	.30	2	11	4.7	<.01	92.1	<.5	.8	57.1
7.8	.3	9.1	17	5,690	5	1,810	502	.063	2.0	7.7	5.8	<2	90.2	<4	25	120
285	.3	21	7.0	8,740	<4	5,800	2,430	.016	3	21	2.2	<2	561	<4	33	37
<3	.17	.3	5.10	834	<.5	1,810	23.6	.16	<.1	.6	5.6	.01	240	<.8	3.6	307
<3	.24	<.1	3.69	88.3	<.5	1,450	14.7	.30	.31	<.3	3.5	.02	230	<.8	.51	345
<3	.17	2.2	4.49	449	<.5	1,530	15.5	.21	.1	.9	4.9	.02	194	<.8	1.4	312
4	.088	1.3	5.59	383	<.5	1,560	19.6	.16	<1	.83	5.3	<.01	191	<.5	1.0	401
<3	.40	1.6	5.98	916	.6	1,660	36.3	.48	<1	1.0	6.6	<.01	203	<.5	1.5	401
<3	.61	3.4	7.31	810	.7	1,780	25.9	.753	<1	1.7	6.6	<.01	207	<.5	2.1	248
<3	<.5	2	2.1	254	<5	1,420	17	.23	<1	<2	5.7	<2	125	<5	1.2	104
<3	.11	2.0	3.30	468	<.5	1,800	31.8	.24	<1	1.8	4.9	<.01	194	<.6	1.2	149
<3	.23	1.3	16.1	462	<.5	1,410	20.3	.12	.2	.8	6.2	.02	165	<.9	1.5	201
<3	.07	1.4	3.18	127	<.5	1,720	17.4	.22	<1	1.1	3.0	<.01	201	<.7	.9	134
<3	.29	<.2	1.8	189	<.5	1,510	15.5	.32	.65	2.6	3.3	<.01	160	<.8	.90	107
<3	.07	1.2	2.30	195	<.5	1,680	16.2	.32	<1	3.5	2.4	<.01	190	<.7	1.1	108
<3	.11	1.0	2.34	257	<.5	1,630	23.4	.35	<1	.60	2.9	<.01	192	<.6	1.1	102

Table 24.--Field measurements and results of laboratory analyses of biological

Site number (fig. 7) and name	Taxa	Collection date	Est. Age (years)	Wt	Lgth	Mstr	Al[1]	Sb[2]	As[2]	Ba	Be[2]
14 (Cont.)	Flathead chub[4] (7)	09-14-88	2	7.4	97.6	69.8	2,730	<.1	2.3	24.8	.099
	Flathead chub[4] (6)	09-14-88	3	12.5	115.0	67.8	2,060	<.1	1.6	20.3	.070
	Flathead chub[3]	09-14-88	4	21	142	74.1	81	--	.62	10.3	<.1
	Flathead chub[3]	09-14-88	4	26	148	71.5	2,040	--	1.8	28.2	.1
	Goldeye[4]	09-14-88	3	198	324	76.1	32	<.1	<.2	2.1	<.01
	Goldeye	04-20-88	3	264.0	327.0	67.7	8.3	--	.2	1.4	<.01
	Goldeye	04-20-88	4	279.0	355.0	77.0	26	--	<.1	2.0	<.01
	Goldeye	04-20-88	3	279.0	331.0	70.7	8.6	--	.2	1.1	<.01
	Goldeye	04-20-88	4	320.0	354.0	70.2	9.1	--	.1	1.4	<.01
	Goldeye[4]	09-14-88	3	325	357	70.7	106	<.1	.2	2.4	<.01
	Goldeye	04-20-88	4	344.0	353.0	74.7	58.7	--	<.1	2.9	<.01
	Green sunfish[4] (3)	09-14-88	2	8.3	83.7	75.1	165	<.1	<.2	2.9	.01
	Green sunfish[3]	09-14-88	1	19	102	75.5	14	--	<.1	1.5	<.1
	Green sunfish[3]	09-14-88	1	20	105	76.5	160	--	.1	3.1	<.1
	River carpsucker[3]	09-14-88	1	48	161	71.4	2,140	--	.96	33.9	.1
	River carpsucker[3]	09-14-88	1	60	167	72.9	1,830	--	1.0	31.0	<.1
	River carpsucker[3]	09-14-88	2	99	188	75.2	2,090	--	.96	35.2	<.1
	River carpsucker[3]	09-14-88	2	156	244	74.9	1,050	--	.6	18.1	<.1
	Sauger	04-20-88	3	443.0	382.0	67.4	65.5	--	.6	1.2	<.01
	Sauger	04-20-88	4	1,175.0	513.0	69.7	4.9	--	.52	.98	<.01
	Shorthead redhorse	04-20-88	2	93.0	220.0	70.3	411	--	.1	23.8	<.01
	Shorthead redhorse[3]	09-14-88	2	97	219	70.3	240	--	<.1	7.0	<.1
	Shorthead redhorse[3]	09-14-88	2	116	226	70.9	280	--	.3	9.8	<.1
	Shorthead redhorse[3]	09-14-88	2	141	249	71.2	210	--	.1	9.5	<.1
	Shorthead redhorse[3]	09-14-88	2	156	244	71.1	200	--	<.1	12.9	<.1
	Shorthead redhorse[4]	09-14-88	2	209	279	70.2	221	<.1	.3	11.3	.02
	Shorthead redhorse	04-20-88	2	230.0	240.0	73.0	154	--	<.1	7.5	<.01
	Shorthead redhorse	04-20-88	2	230.0	282.0	67.5	32	--	<.1	2.3	<.01
	Shorthead redhorse[4]	09-14-88	3	256	301	72.1	240	<.1	<.2	12.0	<.01
	Shorthead redhorse[4]	09-14-88	3	352	338	68.2	239	<.1	<.2	26.5	<.01
	Smallmouth bass[4]	09-14-88	1	90	182	67.8	13	<.1	.3	0.58	<.01
	Gross invertebrate[3]	07-27-88		17.5	--	87.9	4,230	--	1.5	51.9	.10
	Three square bulrush[3]	07-27-88		130.5	--	79.7	620	--	1.2	22.9	<.1
	Sago pondweed	07-27-88		497.5	--	90.5	2,340	--	1.4	103	<.1

[1] ICP, preconcentration B - pH 6 - was performed for this element.
[2] Individual Atomic Absorption was performed for this element.
[3] ICP, no preconcentration, was the only ICP scan performed on this sample.
[4] Molybdenum and vanadium were scanned by Atomic Absorption techniques for this sample.

data from the Angostura Reclamation Unit study area, 1988--Continued

B	Cd[1]	Cr[1]	Cu[1]	Fe[1]	Pb[1]	Mg	Mn[1]	Hg	Mo	Ni	Se	Ag	Sr	Tl	V	Zn
<3	.1	.62	3.0	1,550	1	1,550	55.1	.082	4.0	.4	3.9	.01	128	<.9	4.6	88.5
<3	.1	2.3	2.7	1,220	.7	1,430	45.6	.11	2.3	1.2	3.3	.02	130	<.9	3.7	93.2
<3	<.6	3	1.6	105	<5	1,570	15	.17	<1	4	4.0	<2	203	<5	.6	84.7
<3	<.6	6.0	3.1	1,200	<6	1,830	48.7	.12	<1	3	4.1	<2	212	<5	4.3	93.4
4	.1	.5	1.2	101	1	1,650	9.17	.618	<.1	<.4	3.9	<.01	170	<1	.36	144
<3	<.02	.73	1.20	56.3	<.4	1,250	8.28	.26	<1	.30	2.1	<.01	99.0	<.6	<.3	88.7
<3	.03	1.0	2.10	129	<.5	1,720	7.77	.46	<1	.41	3.6	<.01	133	<.6	<.3	138
<3	.04	.45	2.97	84.0	<.4	1,210	7.03	.745	<1	.20	2.3	<.01	83.5	<.6	<.3	92.3
<3	.03	.92	1.50	73.6	<.4	1,380	8.25	.35	<1	.52	3.0	<.01	97.0	<.6	<.3	90.4
<3	.1	1.4	1.7	119	<.5	1,470	8.31	.35	.34	.7	2.8	<.01	131	<.9	.3	99.5
<3	.093	1.7	3.33	124	<.5	1,750	9.55	.682	<1	2.1	3.0	<.01	148	<.6	.30	146
<3	.2	<.1	2.1	119	<.5	1,630	23.7	.25	.3	<.3	4.2	.01	190	<.8	.87	116
<3	<.5	<2	.94	44	<5	1,270	8.4	.24	<1	<2	5.2	<2	132	<5	.5	91.2
<3	<.5	2	1.8	130	<5	1,620	13	.31	<1	<2	5.0	<2	170	<5	.8	96.2
7.8	<.6	3	3.2	1,250	<5	1,780	50.1	.11	<1	<2	3.5	<2	215	<5	4.6	59.9
<3	<.6	4	3.5	1,180	<5	1,820	40.9	.11	<1	3	4.0	<2	214	<5	4.3	64.4
<3	<.6	4	3.3	1,250	<5	2,120	50.4	.14	<1	2	3.3	<2	258	<5	4.4	74.0
<3	<.6	3	2.8	641	<5	1,880	34.2	.599	<1	2	3.0	<2	240	<5	2.4	66.1
<3	<.02	1.6	1.30	85.0	<.5	1,150	6.31	.34	<1	1.0	3.5	<.01	69.2	<.6	<.3	49.2
<3	<.02	.87	1.20	47.1	<.5	1,080	4.60	1.3	<1	.51	4.2	<.01	56.2	<.6	<.3	47.5
<2	<.04	4.2	2.74	365	<.5	1,660	51.3	.13	<1	2.4	4.1	<.02	247	<.5	1.2	78.6
<3	<.5	3	2.0	185	<5	1,510	47.3	.22	<1	<2	5.3	<2	203	<5	.8	71.0
<3	<.6	2	2.2	260	<5	1,470	56.7	.22	<1	2	4.3	<2	211	<5	.8	67.6
3	<.4	<1	2.6	317	<4	1,680	40	.27	<1	<3	4.6	<2	206	<4	1	82
<3	<.6	2	2.0	176	<5	1,580	52.1	.22	<1	3	3.7	<2	248	<5	.8	77.5
3	.28	2.4	2.8	233	<.5	1,490	41.1	.35	1.7	5.1	4.5	<.01	195	<.9	.77	82.0
<3	.07	1.8	2.87	181	<.5	1,700	71.7	.13	<1	1.7	6.3	<.01	249	<.6	.8	84.5
<3	.03	.3	2.31	71.7	<.5	1,380	41.4	.13	<1	.41	3.5	<.01	165	<.6	.3	63.4
3	.19	1.6	2.4	226	<.5	1,620	70.3	.32	<.1	.8	3.8	<.01	233	<.9	.99	80.9
3	.20	1.0	2.6	211	<.5	1,510	73.4	.49	<.1	.6	3.5	<.01	193	<.9	.93	75.0
<3	.2	.85	1.2	40.4	<.5	1,240	13.4	.32	.62	1.2	5.6	<.01	101	<.8	.1	52.3
6.8	.3	4.4	17	2,690	<4	1,610	160	.078	2.0	4.2	4.3	<2	68.6	<4	12	121
14	<.2	5.9	2.4	954	<4	1,520	640	.005	<1	3.0	.46	<2	73.2	<4	1.5	11
294	.39	36	7.71	2,100	1.7	5,930	251	.01	4.7	24.9	.80	<.01	320	<1	7.43	27.4