RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN BOWDOIN NATIONAL WILDLIFE REFUGE AND ADJACENT AREAS OF THE MILK RIVER BASIN, NORTHEASTERN MONTANA, 1986-87

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U.S. GELOGICAL SURVEY

Water-Resources Investigations Report 87-4243

Prepared in cooperation with the

U.S. FISH AND WILDLIFE SERVICE and the

U.S. BUREAU OF RECLAMATION

Helena, Montana

1988

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

The following factors may be used to convert from inch-pound units in this report to metric (International System) units.

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter
acre-foot	1.233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot	0.3048	meter
inch	25.40	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

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

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

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

Trace-constituent concentrations in bottom sediment and biota are reported as weight per unit of weight, or micrograms per gram (μg/g) and micrograms per kilogram (μg/kg.) The results are equivalent to units of parts per million and parts per billion, respectively.

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ABSTRACT

Water, bottom sediment, and biota were sampled in 1986 at Bowdoin National Wildlife Refuge and adjacent areas of the Milk River basin in northeastern Montana. This report describes the results of a study conducted to determine concentrations of selected trace elements, radiochemicals, 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.

Concentrations of trace elements, radiochemicals, and pesticides in the refuge lakes generally were not substantially larger than those in the water supplied from Dodson South Canal or in irrigation drainage. Concentrations of arsenic (47 μg/L; micrograms per liter), uranium (43 μg/L), and vanadium (51 μg/L) in Dry Lake Unit, and boron (1,000 μg/L) in Lake Bowdoin were notably larger than at other sites. Zinc concentrations in an irrigation drain (56 μg/L) and two shallow domestic wells (40 and 47 μg/L) were elevated relative to other sites. Concentrations of gross alpha radiation (64 picocuries per liter) and gross beta radiation (71 picocuries per liter) were elevated in Dry Lake Unit. Pesticide concentrations at all sites were 0.08 μg/L or less. Water-use guideline concentrations for boron, cadmium, uranium, zinc, and gross alpha radiation were slightly exceeded at several sites. In general, trace-constituent concentrations measured in the water do not indicate any potential toxicity problems in Bowdoin National Wildlife Refuge; however, highwater conditions in 1986 probably caused dilution of dissolved constituents compared to recent dry years.

Trace-element concentrations in bottom sediment of the refuge lakes were generally similar to background concentrations in the soils. The only exception was Dry Lake Unit, which had concentrations of chromium (99 μg/g; micrograms per gram), copper (37 μg/g), nickel (37 μg/g), vanadium (160 μg/g), and zinc (120 μg/g) that were about double the mean background concentrations. The maximum selenium concentration in bottom sediment was 0.6 μg/g. Pesticide concentrations in bottom sediments were less than analytical detection limits at all sites.

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. Boron concentrations in two coot livers (140

μg/g dry weight) and in potential food items for waterfowl, including the vascular plant sago pondweed (810 μg/g dry weight) and plankton (750 μg/g dry weight), were at levels associated with adverse reproductive effects. Selenium concentrations in most organisms sampled were indicative of noncontaminated conditions; however, selenium concentrations in some samples of waterfowl dietary items such as macroinvertebrates (6.5 μg/g dry weight) and plankton (13 μg/g dry weight) were near levels producing 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 particular site or trophic level of biota consistently had unusually large concentrations. Pesticide concentrations in biota were small, relative to available toxicity data, at all sites.

INTRODUCTION

Background

During the past several years, concern has been increasing about the quality of irrigation drainage (surface and subsurface water draining irrigated land) and its potential effects on humans, fish, and wildlife. Elevated concentrations of selenium 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 Department of the Interior developed a management strategy 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. The Task Group subsequently prepared a comprehensive plan for reviewing irrigation-drainage concerns for which the Department of the Interior may have responsibility.

Initially, 19 locations in 13 States were identified that warrant reconnaissance investigations. These locations relate to three specific areas of Interior Department responsibility: (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 in 1986. These areas are:

Arizona-California: Lower Colorado-Gila River Valley area.
California: Salton Sea and Tulare Lake areas.
Montana: Sun River area.
Milk River 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.

Each reconnaissance investigation was 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 studies were directed toward determining whether irrigation drainage has caused or has the potential to cause significant harmful effects on human health, fish, and wildlife, or may decrease the suitability of water for other beneficial uses.

This report describes the results of the study in the Milk River area of Montana, which includes Bowdoin National Wildlife Refuge and adjacent areas of the Milk River basin. It's selection as one of the initial nine study areas was based on the geology and hydrology of the area, as well as limited data from the refuge that indicated relatively large concentrations of selenium in water and bottom sediment. In addition, large concentrations of selenium and other trace elements have been documented in water from Quaternary (glacial) and Cretaceous (marine origin) aquifers of north-central Montana, which includes the Milk River basin (Miller and others, 1980). Because irrigation drainage and saline seeps provide water to the refuge lakes, a potential exists for selenium accumulation.

Purpose and Scope

The purpose of this report is to describe concentrations of selected trace elements, radiochemicals, and pesticides in water, bottom sediment, and biota, and to compare the analytical results to available baseline information and to various guidelines for protection of environmental quality. The data from this report are intended to help the Department of the Interior determine whether irrigation drainage has caused or has the potential to cause harmful effects on humans, fish, and wildlife, or has impaired the suitability of the water for beneficial uses.

Fifteen sites were sampled within the study area; the sites included an irrigation canal, streams, lakes, an alluvial aquifer, and irrigation-return drains. Field work was conducted during the spring and summer of 1986. Samples of water and bottom sediment were collected by personnel of the U.S. Geological Survey; biota samples were collected by personnel of the U.S. Fish and Wildlife Service. Sample analyses were performed by laboratories of the respective agencies or laboratories contracted by the agencies.

Acknowledgments

Special thanks are given to Gene A. Sipe, refuge manager for the U.S. Fish and Wildlife Service at Bowdoin National Wildlife Refuge. Mr. Sipe's assistance with project planning, sample collection, and compilation of historical observations of wildlife at Bowdoin National Wildlife Refuge was of considerable benefit to this study.

GENERAL DESCRIPTION OF STUDY AREA

Location

The Milk River study area is centered around Bowdoin National Wildlife Refuge in northeastern Montana, about 7 miles east of the town of Malta (fig. 1). The refuge is located within the Milk River drainage, a tributary of the Missouri River.

The Milk River originates on the eastern slopes of the Rocky Mountains of northern Montana and Canada. The Milk River drains about 22,740 square miles, of which 15,100 square miles are in the United States. The river flows into Alberta, Canada, east of Glacier National Park and re-enters the United States at the international crossing about 100 miles to the east. Tributaries in the middle and downstream reaches of the Milk River basin drain low hills, isolated mountain ranges, and low-lying semiarid plateaus bordering the main valley.

Bowdoin National Wildlife Refuge is located near the middle of the agricultural valley served by the U.S. Bureau of Reclamation's Milk River Irrigation Project (fig. 2). Other water sources near the refuge that potentially may be affected by irrigation drainage include Nelson Reservoir, Beaver Creek, and shallow domestic wells.

History

Bowdoin National Wildlife Refuge is managed primarily as a sanctuary and breeding ground for migratory waterfowl. The refuge is located in the central flyway of a migration corridor extending from Canada to Mexico, and serves as a major resting area for waterfowl migrating to and from nesting areas in Canada. The 15,500-acre refuge was established in 1936, when the Milk River Irrigation Project made it possible to provide a reliable source of water to the area's lakes and ponds. The refuge is administered by the U.S. Fish and Wildlife Service.

Water diverted from the Milk River is the primary source of inflow to the refuge. In addition to supplied water, the refuge also receives irrigation drainage from adjacent farmlands. Natural runoff from surrounding land and ground-water seeps also contribute a small quantity of water to the refuge lakes.

The refuge contains four large, shallow lakes with adjoining marshland and numerous small, shallow ponds (fig. 3). Before the refuge was established, no dikes were available to retain the spring runoff; consequently, water levels in the lakes would decline substantially from evaporation during the hot, dry summer. The small amount of water that remained commonly became stagnant and hot, which was conducive to disease organisms. Botulism outbreaks killed thousands of birds almost every year.

In 1936, the U.S. Fish and Wildlife Service built a system of dikes and ditches to manage the water. In exchange for funds contributed by the U.S. Fish and Wildlife Service toward the construction of Fresno Dam (fig. 2), which created an upstream storage reservoir, the refuge was granted a water right of 3,500 acre-feet annually from the U.S. Bureau of Reclamation's Milk River Irrigation Project. This supplemental water, combined with spring runoff, is sufficient during most years to prevent serious disease problems and enables manipulation of water levels to encourage the growth of plants for food and shelter.

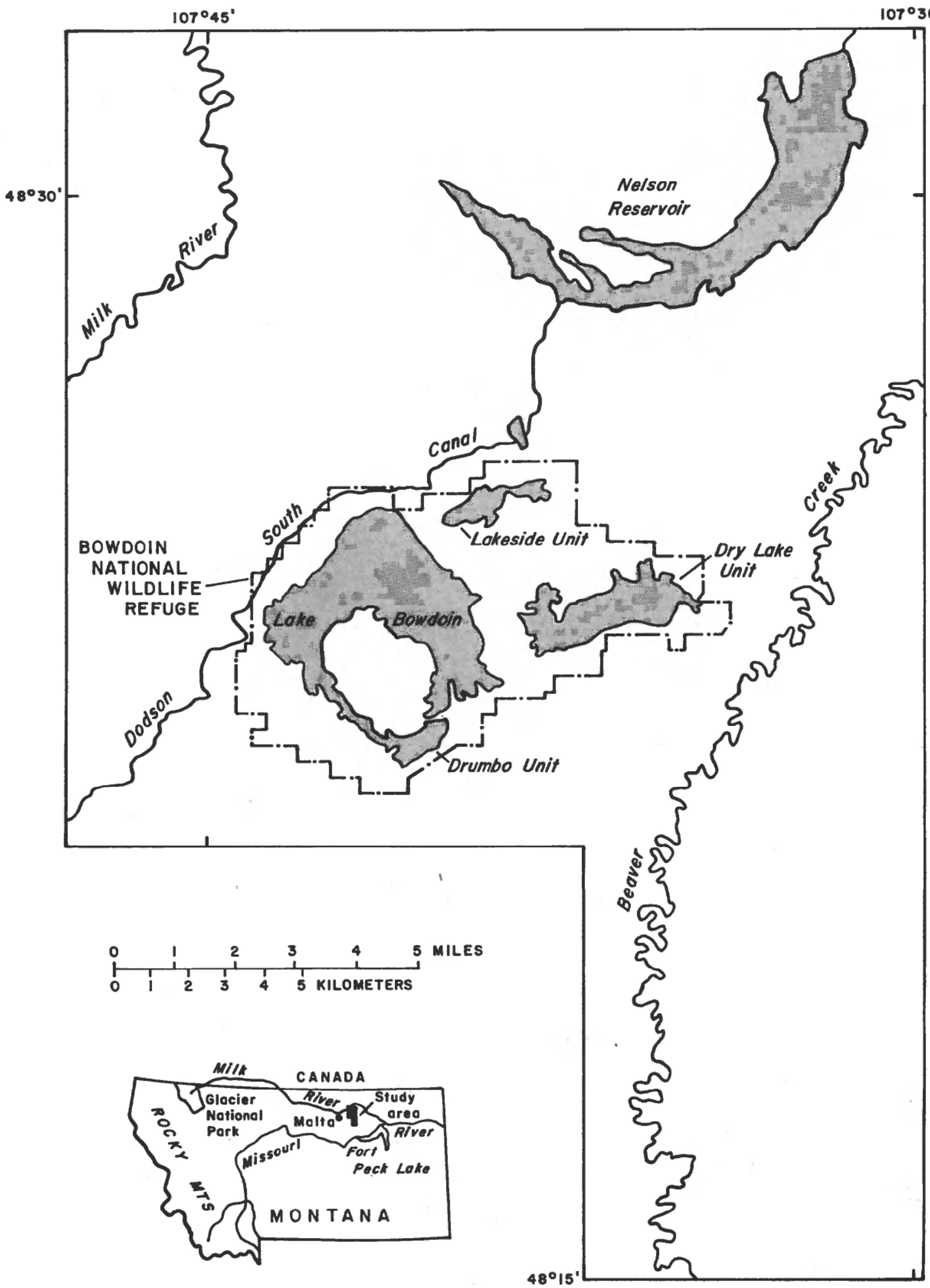

Figure 1.--Location of study area.

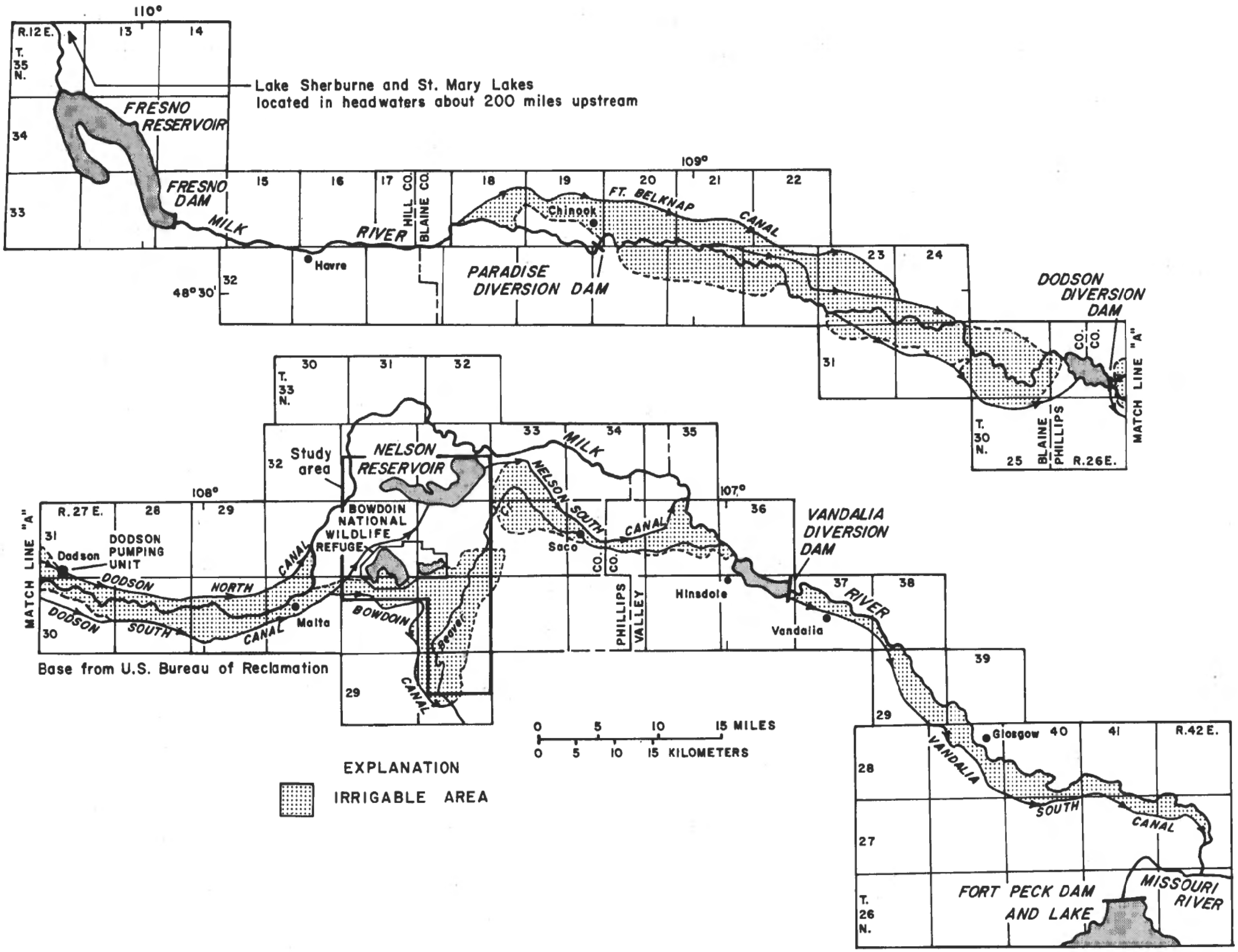

Figure 2.--Location of the Milk River Irrigation Project.

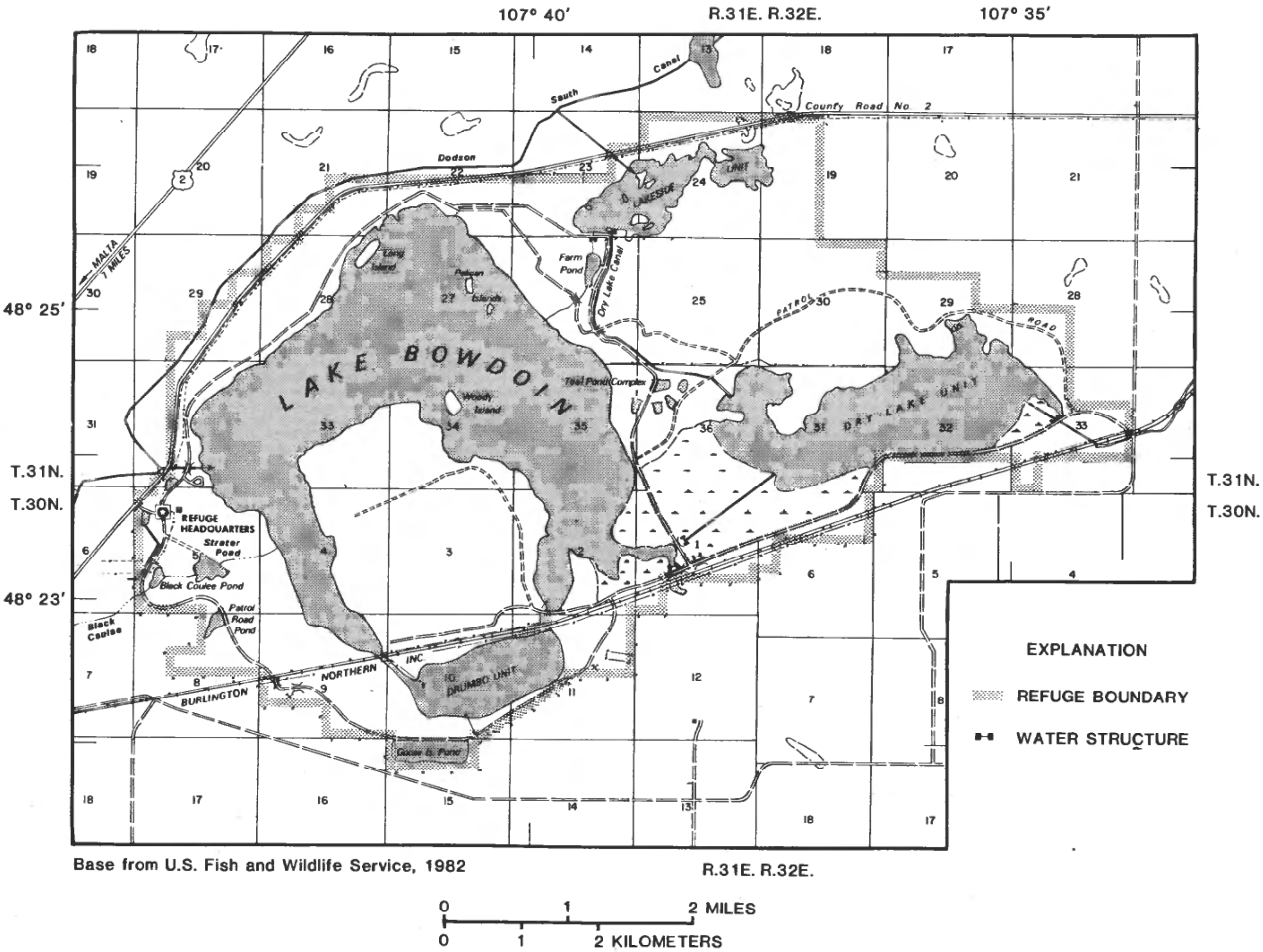

Figure 3.--Features of Bowdoin National Wildlife Refuge.

Historical Observations of Wildlife

Duck production in Bowdoin National Wildlife Refuge has gradually decreased during the past 25 years. The decrease is consistent with that observed across the "Prairie Pothole Region" of glacial lakes in the northern plains of the United States and Canada. Several factors are responsible for the decline.

The area has a long history of avian botulism. All losses from 1975 to 1986 were diagnosed as Type C botulism. From about mid-June to early September each year, routine patrols are made to monitor for a possible botulism outbreak. Although no studies have been specifically conducted to check for deformed birds, if a major problem existed, it is likely that some deformed birds would have been observed during these patrols. No such problem has been documented at the refuge.

Nesting success at the refuge indicates no hatchability problems. However, specific studies have not been conducted to assess whether any problems exist with embryo development.

Mortality of colonial nesting birds has been observed on several of the nesting islands over the years. Although the cause of the mortality has not been diagnosed, it has been presumed to be related to "natural" conditions. During the peak hatching period, these islands have several thousand young birds and mortality is common. However, no unusually large die-offs (compared to those commonly occurring) or gross deformities have been observed.

Climate

The climate of the Milk River study area is semiarid continental, which is characterized by a wide range of temperature extremes, low relative humidity, frequent winds, and small amounts of precipitation. Seasonal conditions include cold, dry winters; cool, moist springs; warm, dry summers; and cool, dry autumns. Recurring periods of drought or near-drought conditions have been common in recent years (1980-81 and 1983-84). Intense rainstorms of short duration may occur from spring through autumn and produce significant runoff. Severe cold periods are common during the winter, but are usually of short duration.

Mean annual air temperature in the study area averages about 42 °F. Average monthly temperatures range from about 8 °F in January to 70 °F in July. Seasonal extremes in temperature are large and can range from near -60 °F in winter to about 110 °F in summer.

Mean annual precipitation is about 12 inches, most of which occurs as rain from April to July. Average annual free-water-surface evaporation is about 38 inches (U.S. Department of Commerce, 1982); consequently, a water deficit exists for much of the year. In general, conditions during the study (1986) were much wetter than normal. Annual precipitation in 1986 was 21.4 inches, compared to the 6-year average of 11.3 inches during 1980-85.

Geology

Glaciation has been the predominant factor in the development of the soils and topography of the Milk River basin. Lake Bowdoin and the other smaller lakes and ponds in the area are natural lakes formed in topographic depressions scoured by glaciers. Continental glaciation extended into Montana south of the study area to approximately the present channel of the Missouri River.

After re-entry into the United States, the Milk River flows in north-central Montana across Cretaceous bedrock which has been covered by glacial debris ranging in depth from very thin strata to about 200 feet in some alluvial valleys. Glacial deposits in the Milk River basin consist of compacted mixtures of boulders, gravel, sand, silt, and clay of varying thickness, derived primarily from Cretaceous bedrock.

Bedrock underlying the glacial materials in and near the study area consists of, in ascending order, the Claggett Formation, Judith River Formation, and Bearpaw Shale, all of Cretaceous age (fig. 4). These sedimentary-rock formations consist

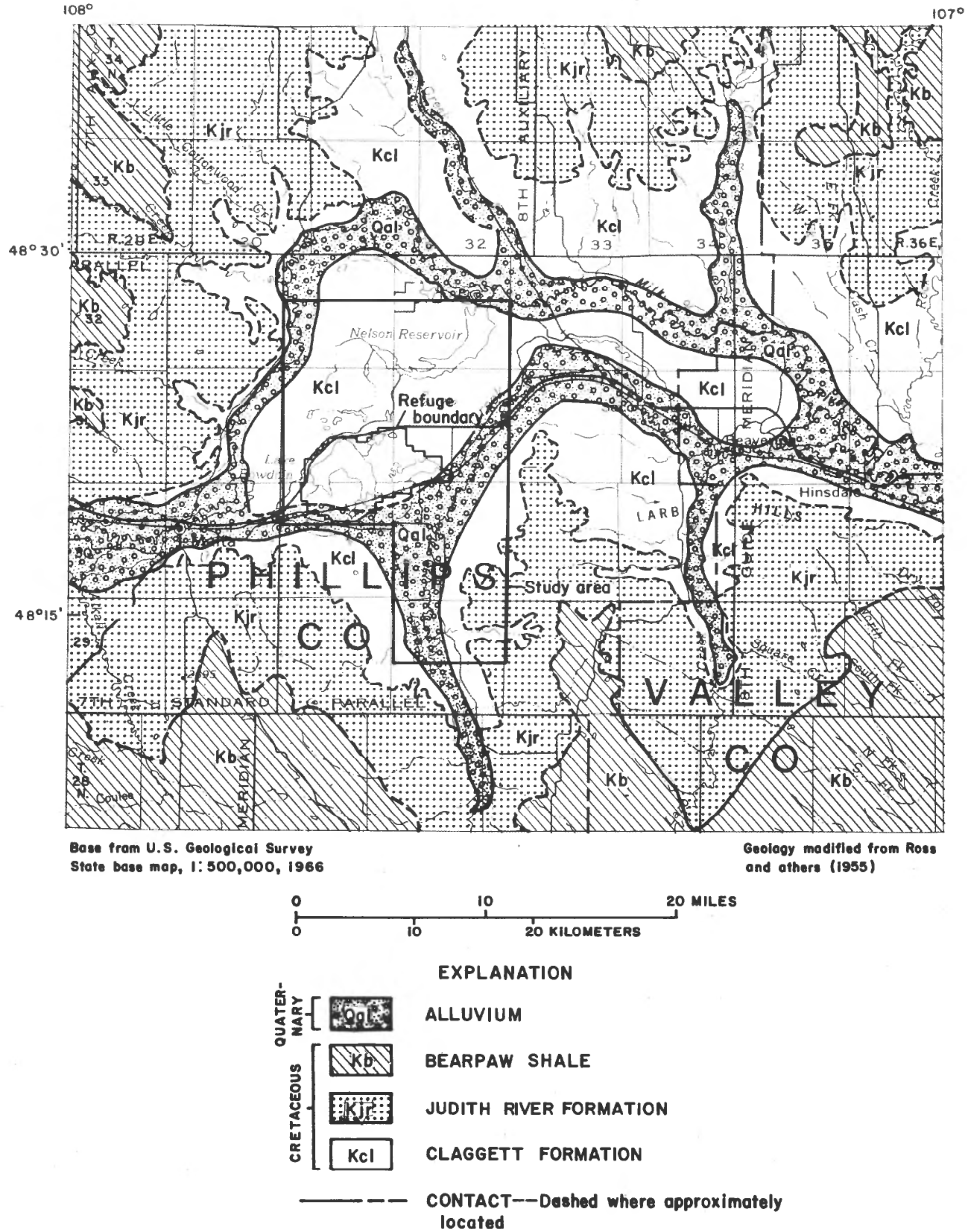

Figure 4.--Geology of the Milk River area. Surficial glacial deposits are not shown.

largely of nearly impermeable marine shale, alternating in places with sandstone beds. Similar shale formations in some areas are known to have a relatively large selenium content (Miller and others, 1980).

Although the refuge overlies Cretaceous shale, it is surrounded by alluvial deposits. Alluvium along the Milk River consists largely of sand, silt, and clay that thinly cover older glacial deposits.

Soils

Soils in the refuge and adjacent areas were formed from glacial till and alluvial parent materials derived primarily from Cretaceous shale. The soils that have developed on the glaciated plains of north-central Montana are of a fine to loamy texture and have a montmorillonite component (Montagne and others, 1982) that commonly contains a substantial amount of selenium. Selenium in the soil typically occurs as an insoluble compound of selenite or as a ferric-iron complex, but can be converted to the relatively soluble selenate form in alkaline soils.

Horizons of clay and clay loam are present throughout the soil profile. Soluble calcium and sodium salts are dispersed in much of the profile, and also tend to accumulate in subsoil horizons. The soils range from mildly to strongly alkaline.

Soils in the glaciated plains of Montana are depleted of plant-available soil moisture for most of the summer. Except in the irrigated valleys of the Milk River and major drainages, soil moisture is sufficient only for rangeland and some dryland farming.

Land Use

The largest land use within the study area and adjacent parts of the Milk River basin is rangeland for cattle grazing. Much of the rangeland is unsuitable for crop production.

Dryland farming occurs on nearly level to gently rolling upland areas, where the soil structure is suitable for cultivation. Grains and hay are the major dryland crops. Dryland grain farming commonly involves alternating cropped and fallow fields that are rotated on an annual basis.

Irrigated lands occur primarily along the main valley of the Milk River and along the downstream reaches of a few large tributaries. The primary irrigated crop is hay for forage and grazing.

Population is sparse in the Milk River basin (less than 5 persons per square mile). No major industries discharge to the Milk River and only small municipal sources of wastewater are present.

HYDROLOGIC SETTING

Milk River Irrigation Project

The Milk River Irrigation Project provides water for irrigation of about 121,000 acres of land in north-central Montana. The irrigated lands extend about 165 miles along the Milk River from near Havre, Mont., to several miles upstream from the confluence with the Missouri River (fig. 2). Major features of the irrigation project include Lake Sherburne and St. Mary Lakes in and near Glacier National Park, Fresno and Nelson Reservoirs (storage), several diversion dams and pumping units, and more than 700 miles of canals, laterals, and drains.

Fresno Reservoir, located about 14 miles west of Havre, Mont., provides storage of water for irrigation in the Milk River valley upstream from Bowdoin National Wildlife Refuge. Water that is used to irrigate lands in the vicinity of the refuge is diverted from the Milk River near Dodson, Mont. The Dodson South Canal (fig. 2) conveys water for irrigation on the south side of the Milk River. The canal also conveys water to Nelson Reservoir, an offstream storage reservoir, and to feeders supplying the refuge and the downstream reaches of Beaver Creek.

The Milk River Irrigation Project, by contract, delivers 3,500 acre-feet of water per year to Bowdoin National Wildlife Refuge. The water is delivered on a "when available" basis. During some years, as much as 10,000 acre-feet has been delivered. The irrigation project has significant water shortages an average of 4 years during every 10. At these times, diversions to the refuge are decreased to less than 3,500 acre-feet.

The refuge receives irrigation drainage from about 2,800 acres of irrigated land, plus unused water from one lateral canal. As much as 1,500 acre-feet of irrigation drainage can be contributed to the refuge during some years. This quantity represents about 15 to 40 percent of the refuge's water supply.

Hydrologic conditions during the study (1986) were not typical compared to the previous water-deficient conditions of 1980-85. Water levels in the refuge in the summer of 1985 were near an all-time low. Flows in the Milk River during the fall of 1985 and in 1986 were larger than normal; consequently, diversions to the refuge were increased. Total water volume supplied to the refuge during 1985 was about 9,600 acre-feet, compared to the normal supply by contract of 3,500 acre-feet. Of this total, about 95 percent was supplied in the fall of 1985, which restored the refuge lakes to near capacity (Robert Green, U.S. Bureau of Reclamation, oral commun., 1986). Above-normal flows again occurred in the Milk River early in 1986 prior to the current study. As a result, about 5,300 acre-feet of water was delivered to the refuge during 1986, which further raised the lake levels and enabled some partial flushing.

Bowdoin National Wildlife Refuge

The hydrology of the refuge is largely affected by available supplies of water diverted from the Milk River. Water levels in the lakes and ponds are managed by a system of dikes and canals to provide optimum conditions for waterfowl. During years of limited water supply, however, there is no outflow of surface water and the refuge is virtually a closed hydrologic system. Under such water-deficient conditions, the lakes and ponds recede to low levels as a result of evaporation.

During high-flow conditions in the Milk River, additional water can be supplied to inundate exposed mud flats and obtain some degree of dilution or possible flushing into Beaver Creek. A schematic diagram of water movement through the refuge is shown in figure 5.

The total water-surface area of lakes and ponds within the refuge is about 5,000 acres. An additional 1,500 acres consists of marshes and wetlands. The major lakes are Lake Bowdoin, Dry Lake Unit, Lakeside Unit, and Drumbo Unit (fig. 3). An interconnecting system of canals between the lakes and several smaller ponds enables the transfer of water for wildlife management. During water-deficient periods, the greatest priority for water supply is given to Lakeside Unit and Lake Bowdoin. Least priority is given to Dry Lake Unit.

Water drains from Lake Bowdoin and Dry Lake Unit into Beaver Creek when water levels in the lakes are sufficiently high. During high flows in Beaver Creek, water from Beaver Creek may flow into the refuge. Much of the land between Beaver Creek and the refuge is marshy, indicating a probable ground-water connection.

Natural surface-water runoff to the refuge is limited to a few small, intermittent stream drainages. The largest drainage contributing flow to the refuge is Black Coulee, which flows from the southwest into Black Coulee Pond and, eventually, Lake Bowdoin. Most of the flow in Black Coulee during the summer consists of both excess irrigation water and unconsumed irrigation drainage that has discharged into the channel.

Irrigation drainage enters Bowdoin National Wildlife Refuge via drain ditches, natural channels, and ground water. An estimated maximum of 1,500 acre-feet is contributed annually. Most of the irrigation drainage is from irrigated lands to the southwest and south of the refuge. Irrigation drainage flows primarily into Lake Bowdoin and Drumbo Unit.

Surficial glacial deposits and deeper Cretaceous shale in the area generally yield only small quantities of water that is commonly unsuitable for domestic use. The extent of ground-water contributions from the formations to the refuge is unknown.

Water in the alluvium surrounding the refuge is an important source of domestic supplies in the area. Ground-water levels in low-lying areas are generally near land surface and respond directly to water levels in the refuge lakes. Marshes typically develop in topographic depressions. Large water-level fluctuations are common in the alluvium as a result of seasonal recharge from the Milk River, applied irrigation water, canal leakage, and precipitation.

The glacial till and shale that underlie much of the Milk River basin contain relatively large quantities of soluble salts that can be readily dissolved and transported by ground water. Saline seeps have developed in many areas throughout the semiarid plains of the basin, either naturally or as a result of dryland-farming practices that utilize rotating fallow fields to artificially increase deep percolation of water. In addition to salts, numerous seeps discharge water containing large concentrations of selenium, boron, and several other potentially harmful trace elements (Miller and others, 1980).

Saline seeps, which are common in the northern part of the refuge, result from either canal leakage or precipitation percolating through the soil profile and

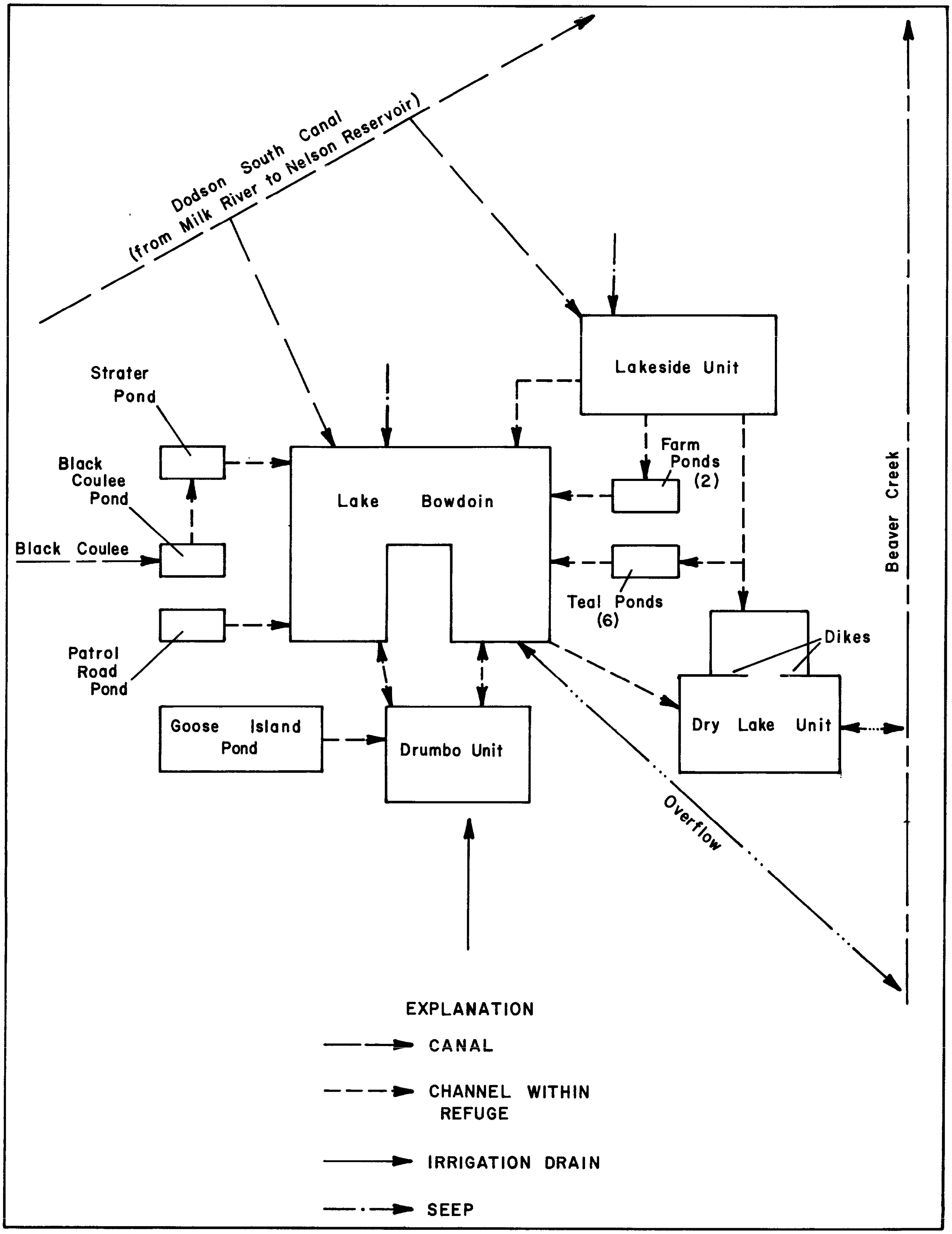

Figure 5.--Schematic diagram of water movement through Bowdoin National Wildlife Refuge.

glacial till to a relatively impermeable layer of clay or shale. The shallow ground water flows laterally towards Lake Bowdoin and Lakeside Unit, eventually discharging saline water near the shore of the lakes. The flows contributed by the seeps are typically negligible, but extensive salt deposits accumulate in areas of discharge.

PREVIOUS INVESTIGATIONS

The few investigations that have been conducted previously in or near the Milk River basin provide background and supplemental data to the current study. A brief summary of the results of those studies and the source of data are presented in the following sections.

Surface Water

A report by the Montana Department of Health and Environmental Sciences (1974) gives a general overview of water management and related issues in the Milk River basin. Water-quality data presented in the report are limited. Six samples, one from each of six sites located from the headwaters to the mouth on the Milk River, were analyzed for trace elements. The analyses are summarized in table 1.

Table 1.- *Statistical summary of trace-element concentrations measured at six sites on the Milk River, 1974*

[<, less than]

Element	Number of samples	Total recoverable concentration, in micrograms per liter		
		Minimum	Maximum	Median
Arsenic	6	<10	10	<10
Cadmium	6	<1	<10	<1
Copper	6	<10	10	<10
Iron	6	170	16,000	1,600
Manganese	6	40	520	70
Zinc	6	<10	80	20

Source of data: Montana Department of Health and Environmental Sciences (1974).

Selenium and boron concentrations were measured at six sites in Bowdoin National Wildlife Refuge, Nelson Reservoir, and adjacent streams in 1985 by students of Everett Pitt of Northern Montana College in Havre, Mont. Mr. Pitt emphasizes that the laboratory techniques used may not provide an accuracy that would be available from laboratories that routinely analyze water samples. The selenium and boron data are summarized in table 2.

Table 2.--*Statistical summary of selenium and boron concentrations in surface water at sites in and near Bowdoin National Wildlife Refuge, 1985*

[<, less than; --, no data]

Site	Selenium				Boron			
	Number of samples	Total concentration, in micrograms per liter			Number of samples	Total concentration, in micrograms per liter		
		Minimum	Maximum	Median		Minimum	Maximum	Median
Black Coulee	3	<10	20	<10	4	210	890	430
Lake Bowdoin	2	<10	30	--	4	1,210	4,540	3,260
Lakeside Unit	3	<10	30	20	4	500	580	580
Beaver Creek above Bowdoin National Wildlife Refuge	2	<10	100	--	3	500	730	500
Beaver Creek below Bowdoin National Wildlife Refuge	2	20	70	--	3	430	810	580
Nelson Reservoir at outlet	2	10	10	--	3	<100	360	360

Source of data: Everett Pitt, Northern Montana College, Havre, Mont., written commun., 1987.

The U.S. Geological Survey has operated four water-quality monitoring stations in the Milk River basin. Although several sites in and near the refuge were sampled in the past, only major constituents were analyzed for the purpose of describing salinity. Dissolved-solids concentrations from samples collected at these sites during water years 1980-85 are summarized in table 3. (Water year is the 12-month period from October 1 of one calendar year through September 30 of the next calendar year; the water year is designated by the ending calendar year.)

Samples for trace-element analysis have been collected routinely by the U.S. Geological Survey at one site on the Milk River about 145 river miles downstream from the study area. The station, Milk River at Nashua, Mont. (station 06174500), has been operated as a National Stream Quality Accounting Network (NASQAN) water-quality station since 1974. Trace-element concentrations are summarized in table 4.

Two water samples were collected in Bowdoin National Wildlife Refuge during the low-water conditions of 1985 by the U.S. Bureau of Reclamation and analyzed for trace elements. One site was in Lake Bowdoin and one was a well at the refuge headquarters near the west end of Lake Bowdoin. Concentrations of trace elements measured in samples from the two sites are listed in table 5.

Table 3.- *Statistical summary of dissolved-solids concentrations at U.S. Geological Survey water-quality stations in and near Bowdoin National Wildlife Refuge, water years 1980-85*

Station name	Station No.	Number of samples	Dissolved-solids concentration, in milligrams per liter		
			Minimum	Maximum	Median
Lake Bowdoin near Malta, Mont.	482250107391001	8	8,600	50,000	12,500
Dry Lake near Saco, Mont.	482425107350001	3	1,600	14,000	8,200
Milk River at Juneberg Bridge, near Saco, Mont.	06164510	68	170	1,200	710
Beaver Creek below Guston Coulee, near Saco, Mont.	06166000	24	140	2,600	520

Source of data: U.S. Geological Survey, issued annually.

Table 4.--*Statistical summary of trace-element concentrations at the NASQAN*[1] *station, Milk River at Nashua, Mont., water years 1974-87*

[<, less than]

Element	Number of samples	Dissolved concentration, in micrograms per liter		
		Minimum	Maximum	Median
Arsenic	52	<1	8	2
Barium	37	4	200	60
Cadmium	52	<1	5	<1
Chromium	52	<1	<10	<1
Copper	52	<1	13	3
Lead	52	<1	15	<2
Mercury	51	<.1	.6	.1
Molybdenum	16	<1	10	<10
Nickel	28	<1	12	4
Selenium	51	<1	10	1
Silver	37	<1	2	<1
Vanadium	16	<1	<6	<6
Zinc	52	<3	80	10

Source of data: U.S. Geological Survey WATSTORE computer retrieval for January 1974 to June 1987.

[1] National Stream Quality Accounting Network.

Table 5.--*Concentrations of trace elements in samples collected from Bowdoin National Wildlife Refuge, 1985*

[<, less than]

Element	Dissolved concentration, in micrograms per liter: Lake Bowdoin	Dissolved concentration, in micrograms per liter: Well at refuge headquarters
Aluminum	300	<100
Arsenic	31	<5
Barium	<500	<500
Boron	3,680	360
Cadmium	<2	<2
Chromium	80	<20
Copper	80	10
Iron	1,050	2,800
Lead	<20	<20
Manganese	210	1,460
Mercury	<1	<1
Molybdenum	<20	<20
Nickel	20	<10
Selenium	6	<5
Silver	<10	<10
Zinc	30	10

Source of data: U.S. Bureau of Reclamation.

Ground Water

Previous ground-water studies and data-collection programs that included analyses of trace elements are few in the Milk River basin. A regional saline-seep study and water-quality inventory of the Montana plains by Miller and others (1980) included some trace-element analyses of water samples from glacial drift and Cretaceous shale in the Milk River basin. Results of the study in the plains of northern and central Montana indicated that trace-element concentrations in the water samples were considerably larger in wells penetrating Quaternary (glacial) and Cretaceous (marine origin) aquifers than in wells penetrating Cretaceous (non-marine origin) and Tertiary aquifers. Of the 160 samples analyzed from throughout the Montana plains, more than 30 percent had selenium concentrations exceeding the U.S. Environmental Protection Agency (1986a) primary drinking-water standard of 10 μg/L (micrograms per liter). Many of the wells are used for domestic or stock-watering purposes.

Trace-element concentrations within the glacial drift and Cretaceous shale of the Milk River basin are summarized in table 6. The table was compiled from selected data for the part of the Milk River basin from Fresno Reservoir downstream to the vicinity of the Bowdoin National Wildlife Refuge.

Few ground-water samples have been collected by the U.S. Geological Survey in the Milk River basin. A computer retrieval of analytical results indicated that

12 samples had been analyzed for boron. Summary statistics for these analyses, in micrograms per liter, are: minimum, 650; maximum 3,600; median, 1,650.

Table 6.--*Statistical summary of trace-element concentrations in water from glacial drift and Cretaceous shale of the Milk River basin*

[<, less than]

Element	Number of samples	Dissolved concentration, in micrograms per liter		
		Minimum	Maximum	Median
Aluminum	20	<50	9,350	<50
Arsenic	20	<2	2.1	<2
Boron	20	60	4,700	640
Cadmium	3	<10	10	<10
Chromium	20	<10	20	<10
Copper	20	<10	180	10
Lead	19	<10	150	<50
Lithium	20	20	1,920	220
Mercury	20	<.3	.4	<.3
Nickel	20	<10	570	10
Selenium	20	<2	188	<2
Strontium	20	200	8,200	1,380
Tin	20	<50	1,270	330
Zinc	20	<10	5,500	180

Source of data: Modified from Miller and others (1980).

Soils and Bottom Sediment

The data base for trace-element concentrations in the soils and bottom sediment of streams or lakes is small for Bowdoin National Wildlife Refuge and the Milk River basin. Soil samples have been collected in the Milk River basin by the U.S. Bureau of Reclamation. However, because the analytical procedures used involve partial extraction rather than total digestion as used in the current study, results are not directly comparable to bottom-sediment analyses from the refuge lakes. Although the trace-element concentrations of soil samples analyzed by partial extraction are considerably less than "total" concentrations analyzed by complete digestion, the "partial-extraction" values may represent a more realistic quantity of trace element readily available for dissolution into water that contacts the soil or bottom sediment. "Total" concentrations, in contrast, represent the maximum contaminant potential of the soils and bottom sediments. "Partial-extraction" trace-element concentrations in the upper 60 inches of soils from 20 sites in the Milk River basin are summarized in table 7.

Table 7.--*Statistical summary of trace-element concentrations measured by partial-extraction analyses of soil samples collected in the Milk River basin*

[<, less than]

Element	Number of samples	Concentration, in micrograms per gram		
		Minimum	Maximum	Median
Arsenic	20	0.042	0.263	0.093
Barium	20	<.10	9.37	<.10
Boron	20	.19	2.27	.52
Cadmium	20	.01	.07	.04
Chromium	20	.28	.98	.38
Copper	20	.55	1.60	1.10
Lead	20	.71	1.42	.92
Mercury	20	.001	.007	.002
Nickel	20	.81	2.75	1.12
Selenium	20	<.002	.022	.006
Silver	20	<.01	.04	.02
Zinc	20	.97	4.51	2.26

Source of data: U.S. Bureau of Reclamation.

Additional data on trace-element concentrations in the soils and stream-bottom sediments of the northern Great Plains region of Montana, Wyoming, North Dakota, and South Dakota were published by the U.S. Geological Survey. Analytical methods used to measure trace-element concentrations were similar to those used in the current study and provide comparable results. Trace-element concentrations for the soils and stream-bottom sediments are summarized in table 8.

Table 8.--*Summary of mean trace-element concentrations in soils and stream-bottom sediment of the northern Great Plains*

[--, no data]

	Soils		Stream-bottom sediment	
Element	Number of samples	Concentration,[a] in micrograms per gram	Number of samples	Concentration,[a] in micrograms per gram
Arsenic	136	7.1	60	5.5
Barium	136	1,100	60	540
Boron	136	41	60	56
Chromium	136	45	60	72
Copper	136	19	60	22
Lead	136	16	60	5.9
Mercury	48	[b].026	60	.055
Molybdenum	136	3.8	60	4.8
Nickel	48	[b]22	60	24
Selenium	48	[b].47	60	.19
Silver	136	.14	--	--
Uranium	48	[b]2.0	60	3.4
Vanadium	48	[b]58	60	73
Zinc	136	63	60	71

Source of data: Modified from Ebens and Shacklette (1982).
[a]Concentrations are geometric means.
[b]Concentrations from analyses of samples collected only from glaciated areas.

Previous data for trace-element concentrations in lake-bottom sediment of Bowdoin National Wildlife Refuge are few. Bottom-sediment samples were collected from Lake Bowdoin in 1985 by personnel of the Sacramento Bee (Calif.) newspaper, U.S. Fish and Wildlife Service, and U.S. Bureau of Reclamation. Samples were analyzed for total concentration of selenium by independent laboratories. Results are presented in table 9.

Table 9.--*Concentrations of selenium measured in bottom sediment of Lake Bowdoin, 1985*

[<, less than]

Source of data	Number of samples	Total selenium concentration, in micrograms per gram
Sacramento Bee (Calif.) newspaper[1]	2	<0.1 - 3.1
U.S. Fish and Wildlife Service	7	All <2.0
U.S. Bureau of Reclamation	1	.35

[1]Edition of September 8, 1985; concentration reported as parts per million.

SAMPLE COLLECTION AND ANALYSIS

Objectives

The objective of the sampling plan used in this study was to describe concentrations of a broad spectrum of potentially toxic constituents in the water, bottom sediment, and biota throughout Bowdoin National Wildlife Refuge and adjacent areas. Efforts were made to sample at a sufficient number of locations to represent a wide range of environmental conditions. Of special importance was identification of any problem areas where constituent concentrations exceeded either guidelines for environmental quality or natural background concentrations.

A primary objective of the biological sampling was to identify possible contaminant bioaccumulation within various trophic levels. Biota selected from lower trophic levels represented a known diet item for consumer organisms (either fish or migratory birds). Consistency from site to site in the kind of organisms sampled was attempted so that areas could be compared. However, consistency could not be achieved in some instances because of inadequate biomass. Although diet items were selected, the intent of the investigation was not to establish food-chain relations.

Selenium was initially identified as the primary constituent of concern based on its known potential for toxicity to waterfowl. However, additional constituents were analyzed to address a greater range of possible effects of irrigation drainage on human health, fish, wildlife, and associated water uses. Three categories of potential contaminants were analyzed: trace elements, radiochemicals, and pesticides. A standard suite of trace elements and radiochemicals was designated by the Department of the Interior Task Group on Irrigation Drainage for consistency among all nine of the initial irrigation-drainage studies. The pesticides analyzed in water and bottom sediment varied between study areas and were selected based on the types of agricultural chemicals most commonly used in the drainage basins of the individual study areas. Pesticides analyzed in biota were a standard group of organochlorine compounds having a known potential for toxicity. Trace constituents analyzed in each of the sampling media are listed in table 10.

Table 10.--*Trace constituents analyzed in the water, bottom sediment, and biota*

Water (dissolved concentration)			Bottom sediment (total concentration)		Biota (total concentration)	
Trace elements	Radio-chemicals	Pesticides	Trace elements	Pesticides	Trace elements	Pesticides
Arsenic	Gross alpha radiation	2,4-D	Arsenic	2,4-D	Aluminum	p,p'-DDT
Barium	Gross beta radiation	2,4-DP	Barium	2,4-DP	Arsenic	p,p'-DDE
Boron	Radium-226	2,4,5-T	Boron	2,4,5-T	Barium	p,p'-DDD
Cadmium		Dicamba	Cadmium	Dicamba	Beryllium	PCB-1254
Chromium		Picloram	Chromium	Picloram	Boron	Oxychlordane
Copper		Silvex	Copper	Silvex	Cadmium	cis-Chlordane
Lead			Lead		Chromium	trans-Chlordane
Mercury			Mercury		Copper	cis-Nonachlor
Molybdenum			Molybdenum		Iron	trans-Nonachlor
Nickel			Nickel		Lead	Dieldrin
Selenium			Selenium		Manganese	Endrin
Silver			Silver		Mercury	
Uranium			Uranium		Molybdenum	
Vanadium			Vanadium		Nickel	
Zinc			Zinc		Selenium	
					Strontium	
					Tin	
					Vanadium	
					Zinc	

Sampling Sites

Sampling sites, types of constituents analyzed at each site, and schedule of sample collection are listed in table 11. Sampling sites were chosen to provide coverage of a diverse range of hydrologic, physical, chemical, and biological conditions within the study area. Because an important objective was to identify problem areas, water and bottom sediment were sampled where contaminants were most likely to accumulate or occur in the largest concentrations (such as lake bottoms and irrigation drainage). Representative species of biota were sampled in the refuge lakes and at Nelson Reservoir to provide indications of possible contaminant bioaccumulation. Samples from the lakes were collected at locations of greatest waterfowl use as well as at locations of limited use where conditions were thought to be stressful. The location of sampling sites within the study area is shown in figure 6.

All known major sources of surface-water inflows to Bowdoin National Wildlife Refuge were sampled. Dodson South Canal (site 1) served as a background site to reference the quality of supplied water entering the refuge. Black Coulee (site 2) and an irrigation return drain (site 4) provided an indication of the quality of irrigation drainage entering the refuge. Site 5, a flowing well locally known as "Lakeside Spring," presumably upwells from an abandoned gas well drilled into deep Cretaceous formations and discharges a minor quantity of water to Lake

Table 11.--*Sampling sites, types of constituents analyzed, and schedule of sampling for water, bottom sediment, and biota*

[Months in columns refer to times when samples were collected at the indicated site; N.F., no flow; N.F.C., no fish captured; --, no data]

Site No. (fig. 6)	Site name	Station number	Water			Bottom sediment		Biota	
			Trace elements	Radiochemicals	Pesticides	Trace elements	Pesticides	Trace elements	Pesticides
1	Dodson South Canal	482354107434801	June	--	June	--	--	--	--
			August	August	--	--	--	--	--
2	Black Coulee	482251107440601	August	August	--	--	--	--	--
3	Black Coulee Pond	--	--	--	--	--	--	N.F.C.	N.F.C.
4	Irrigation return drain	482131107393601	August	August	August	--	--	--	--
5	Flowing well ("Lakeside Spring")	482547107402701	June	--	--	--	--	--	--
6	Saline seep	--	N.F.	N.F.	N.F.	--	--	--	--
7	Lake Bowdoin (southwest arm)	482335107423501	--	--	--	--	--	June	June
			August	August	August	August	August	July	July
8	Lake Bowdoin (north)	482537107405301	--	--	--	August	--	July	July
9	Lake Bowdoin (central)	482430107404001	August	August	--	August	--	--	--
10	Lakeside Unit	482535107391501	--	--	--	--	--	June	June
			August	August	--	August	--	July	July
11	Dry Lake Unit	482430107350001	August	August	--	August	--	May	May
12	Drumbo Unit	482220107401501	August	August	--	August	--	July	July
13	Nelson Reservoir	482900107340001	--	--	--	--	--	July	July
14	Beaver Creek above Bowdoin National Wildlife Refuge	481504107343701	June	--	--	--	--	--	--
			August	August	--	--	--	--	--
15	Beaver Creek below Bowdoin National Wildlife Refuge	482633107304801	June	--	--	--	--	--	--
			August	August	--	--	--	--	--
16	Domestic well	482131107405501	August	August	August	--	--	--	--
17	Domestic well	482210107381501	August	August	August	--	--	--	--

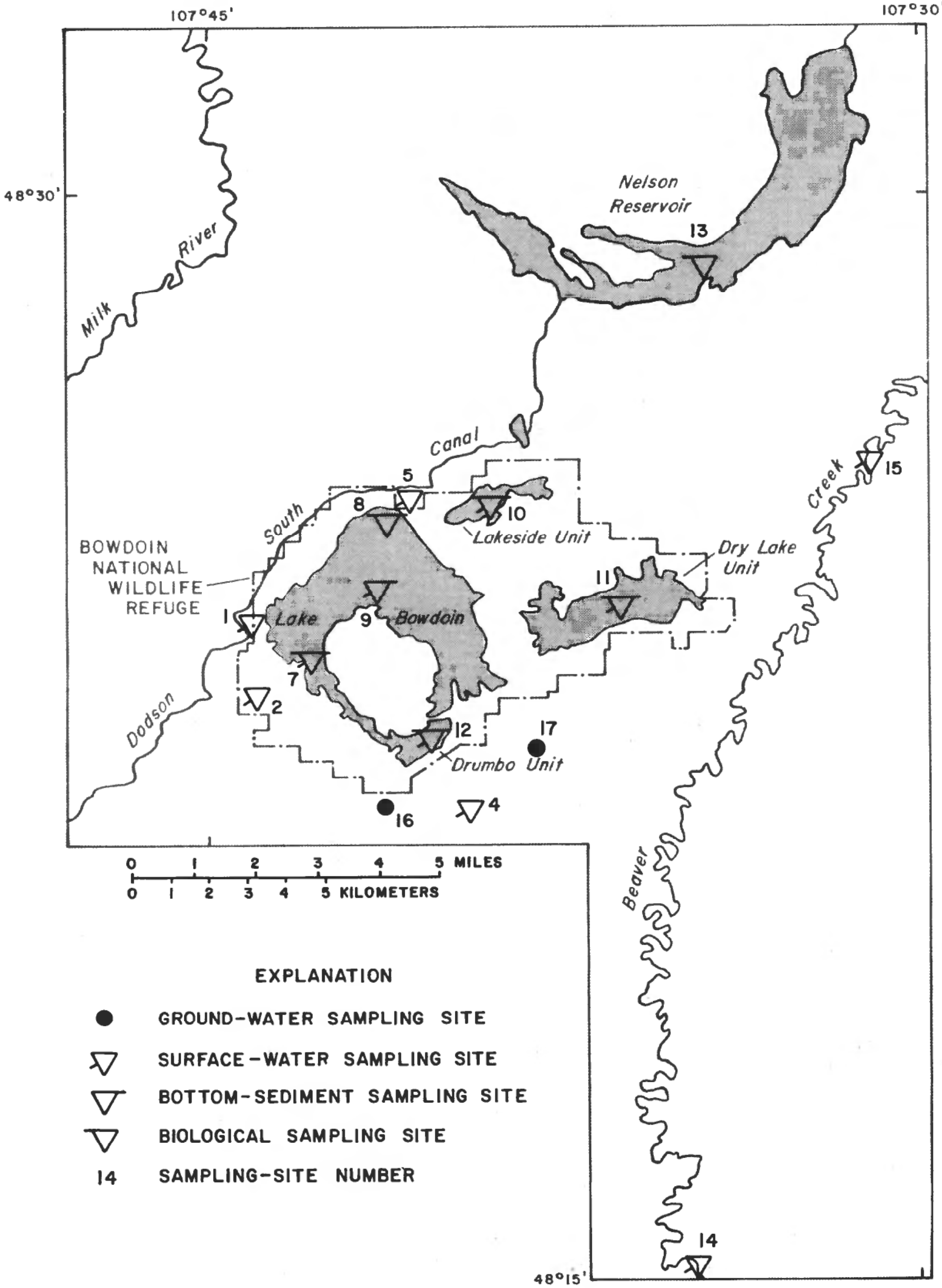

Figure 6.--Location of sampling sites.

Bowdoin. This site is not related hydrologically to the irrigation project, but was sampled for identification of contaminant potential. Site 6, a saline seep area near the shore of Lake Bowdoin, was dry at every sampling visit, as were other seeps in the area; therefore, the seep was not sampled.

Lake Bowdoin was sampled at three sites: a shallow section (site 7), near the outfall of the flowing well (site 8), and a deep-water section (site 9). Site 8, a bottom-sediment sampling site at the north shore of Lake Bowdoin is near where a mud sample was collected by personnel of the Sacramento Bee; the site was resampled during this study for comparison of results. The other lakes (sites 10, 11, and 12) were generally shallow and well-mixed by wind and were sampled at one point.

Sites 14 and 15 are located on Beaver Creek upstream and downstream from the refuge, respectively. Site 14 is upstream from irrigation effects, whereas site 15 receives some irrigation drainage contributed by irrigated lands along both sides of Beaver Creek. Site 15 also receives the outflow of surface water in some years, and presumably ground-water drainage in most years, from the refuge. The two sampling sites were selected to detect any significant changes in water quality between the sites as a result of either irrigation drainage or seepage from the refuge lakes.

Sites 16 and 17 are domestic wells completed in the alluvium south of the refuge. These sites were sampled to give an indication of water quality in the shallow aquifer that is recharged largely by deep percolation of irrigation water.

Six biological sampling locations were established in Bowdoin National Wildlife Refuge; however, no fish could be captured at site 3 so the site was subsequently omitted. The southwest arm of Lake Bowdoin (site 7) was selected because this is where avian botulism outbreaks generally are first observed on the refuge. It is also a major nesting area for coots, herons, and other waterfowl. The north end of Lake Bowdoin (site 8) is near alkali flats and seepage areas that are prominently visible on the uplands adjacent to the lake. Lakeside Unit (site 10) receives water directly from the Dodson South Canal. Based on the water management of the unit, however, the potential for evaporation and concentration of chemicals is less than in Lake Bowdoin. Accordingly, site 10 was considered as a possible background site. The unit also has good habitat for coot nesting and production. Dry Lake Unit (site 11) is used sparingly by waterfowl and sampling was limited to collection of avocet eggs. Drumbo Unit (site 12) was selected because it receives some irrigation drainage from irrigable lands south of the refuge and the chemistry of its water and bottom sediment was unknown.

Nelson Reservoir (site 13) was chosen as a biological sampling site because it receives water from Dodson South Canal and is a major impoundment that supports a sport fishery. Nelson Reservoir is also believed to be a major foraging area for white pelicans nesting on islands in Lake Bowdoin. Waterfowl nesting and production occur in wetland areas just east of the reservoir, but only a minor amount occurs in the habitat associated with the main lake.

Sampling Design

Water samples were collected to coincide with various stages of irrigation, application of agricultural chemicals, and biological productivity of aquatic organisms. In early June, inflow water from Dodson South Canal (site 1) was sampled to indicate the quality of initial diversions to Bowdoin National Wildlife Refuge, which generally constitute most of the annual water supply. Early June also corresponds to the time agricultural pesticides are applied and are most likely to be detected in streams receiving runoff from either irrigated or dryland fields. The two sites on Beaver Creek (sites 14 and 15) were sampled at this time to indicate early season runoff conditions prior to substantial contributions from irrigation drainage. Because many seeps become dry late in the summer, early June was believed to provide the best opportunity to sample a saline seep; however, all known seeps in the refuge had no observed flows during the 1986 study.

Water samples were collected at sites 1, 2, 4, and 14-17 in late summer (August). The lag between sampling periods allowed sufficient time for unconsumed irrigation water to move downgradient to the refuge through irrigation drains. Two channels (sites 2 and 4) conveying irrigation drainage were sampled during this late-season period to indicate the quality of irrigation drainage from farmlands adjacent to the refuge. Dodson South Canal (site 1) and the two sites on Beaver Creek (sites 14 and 15) were sampled again to identify any significant changes in water quality from late-season irrigation-drainage contributions. Two domestic wells (sites 16 and 17) were sampled during the seasonally high water-table conditions resulting from irrigation recharge.

Water and bottom sediment in the refuge lakes (sites 7-12) were sampled during late summer (August) when water levels had receded, water temperatures were high, and aquatic biological productivity was at a peak. Maximum trace-constituent concentrations, salinity, and diurnal oxygen depletion were assumed to occur at this time and to provide an indication of maximum environmental stress to aquatic organisms.

Biological samples were collected at sites 7, 8, and 10-13 during several periods from May through July based on desired growth stages and availability of organisms. Because fish are not present in most of the lakes or ponds of the refuge, fish samples were collected only in Nelson Reservoir (site 13). A detailed sampling plan for the various classes of biological organisms sampled in the Milk River study area is given in table 12.

Selection of the sampling periods for biota was based largely on availability of young-of-the-year birds and bird eggs. Because young-of-the-year birds generally are confined to a given local area until flight stage, the trace constituents observed in their tissue can be assumed to have been obtained from the food and water in the area where they were reared. An attempt was made to collect young-of-the-year birds as late in the prefledgling stage as possible. This late stage would allow maximum exposure of birds to any contaminant present and add some degree of certainty to the likelihood that any contaminant found in bird tissue also exists at that particular sampling locale. Consequently, birds were collected in late July. All bird-egg samples were obtained during the latter part of May and early June. Fish, macroinvertebrates, vascular plants, filamentous algae, and plankton were also collected during summer (July) when growth rates, water temperatures, and exposure to irrigation drainage would be at a maximum.

Young-of-the-year American coot (*Fulica americana*) and American avocet (*Recurvirostra americana*) were the primary age class and bird species chosen for collection of livers. The same species also were chosen for egg-sample collection. Bird liver is generally considered to be the best overall organ to use for a general trace-element analytical scan, even though other organs may have been better indicators for specific chemical parameters (such as, kidney for cadmium and bone for lead).

Table 12.--*Sampling plan for the various types of biota sampled*

[T, trace elements; P, pesticides as given in table 10; -, no sample]

Site No. (fig. 6)	Site name	Schedule	Birds Livers T	Birds Livers P	Birds Eggs T	Birds Eggs P	Fish T	Fish P	Macro-invertebrates T	Vascular plants T	Filamentous algae T	Plankton T
							Bowdoin National Wildlife Refuge					
7	Lake Bowdoin (southwest arm)	June	-	-	X	X	-	-	-	-	-	-
		July	X	X	-	-	-	-	X	X	X	X
8	Lake Bowdoin (north)	July	X	-	-	-	-	-	X	X	X	X
10	Lakeside Unit	June	-	-	X	X	-	-	-	-	-	-
		July	X	X	-	-	-	-	X	X	X	X
11	Dry Lake Unit	May	-	-	X	X	-	-	-	-	-	-
12	Drumbo Unit	July	-	-	-	-	-	-	X	X	X	X
							Nelson Reservoir					
13	Nelson Reservoir	July	-	-	-	-	X	X	X	X	X	X

[1]Biota: Birds: Livers--individual livers obtained from young-of-the-year waterfowl.
Eggs--individual eggs obtained from waterfowl or shore birds.
Fish--composite of whole body predator or forage fish.
Macroinvertebrates--Composites of free-swimming water-column or bottom-dwelling aquatic insects.
Vascular plants--composite of tubers, leaves, and seed heads from aquatic plants.
Filamentous algae--composite of green algae attached to substrate.
Plankton--composite of phytoplankton plus zooplankton.

For a screening survey, it was deemed unnecessary to identify organisms to a finer taxonomic classification than that which could be easily determined by macroscopic features. Several easily identifiable macroinvertebrate groups (damselfly and dragonfly naiads), however, were combined to achieve adequate biomass for analysis. Habitats used as collection sites for filamentous algae samples were typically those for green algae (Chlorophyta), although some samples may have contained some blue-green algae (Cyanophyta).

Whole-body fish (adult walleyes and white sucker fingerlings), macroinvertebrates (Hemiptera--corixids and notonectids; Odonata--dragonfly and damselfly naiads), vascular plants (sago pondweed), filamentous algae, and plankton were collected at Nelson Reservoir (site 13). Although all organisms representing a trophic level were collected from one locale, different collection sites had to be used to obtain samples for the various levels.

Sampling and Analytical Methods

Water

Water samples for chemical quality were collected according to methods described by the U.S. Geological Survey (1977). Sampling equipment for trace elements and radiochemicals was either nonmetal or coated with an approved epoxy paint to prevent trace-metal contamination of the sample. Pesticide samples were collected in glass containers to prevent organics contamination. Samples collected from natural streams or irrigation channels were depth integrated throughout the cross section. Water samples from lakes were collected at one point near middepth. Samples were split and duplicate samples analyzed for quality assurance at about 10 percent of the sites.

Water temperature, pH, and specific conductance were measured onsite at all water-sampling sites; dissolved oxygen was measured onsite at all lake sites. Streamflow was determined at stream or canal sites. Procedures for onsite water-quality determinations are described in Knapton (1985).

All samples for dissolved trace-element and radiochemical analyses were passed through a 0.45-micrometer filter to remove suspended material. Samples for total pesticides were unfiltered. Sample treatment and preservation were performed according to requirements of the U.S. Geological Survey (1985). Analyses of trace elements and pesticides were performed at the U.S. Geological Survey Water Quality Laboratory in Denver, Colo., according to methods described in Fishman and Friedman (1985) and Wershaw and others (1987), respectively. Analyses of radiochemicals were performed by a private laboratory under contract to the U.S. Geological Survey.

Bottom Sediment

Samples of bottom sediment were collected at six sites within the lakes of Bowdoin National Wildlife Refuge. Samples were collected from the upper 4 to 6 inches of sediment using a stainless-steel, handheld, coring device. Ten cores from each site were composited and mixed into a single sample, from which about 0.5 L (liter) of material was submitted for determination of total trace-element concentration. Bottom sediment from site 7 in Lake Bowdoin also was analyzed for total pesticides.

Total concentrations of trace elements in bottom sediment were determined by the analytical-geochemistry laboratory of the U.S. Geological Survey. Samples for trace-element analyses were air dried in the laboratory and then crushed and sieved through a 230-mesh (0.063 millimeter) nonmetal screen. The fraction of particles smaller than 0.063 millimeter diameter was retained and analyzed using methods described in Severson and others (1987). Pesticide analyses of bottom sediment were conducted by the water-quality laboratory of the U.S. Geological Survey using methods described in Wershaw and others (1987). The whole, unsieved sample was used for the pesticide analyses.

Biota

Biota samples were collected using standard equipment and techniques described in Hickey and others (undated). Young-of-the-year birds were shot using steel shot and the livers removed using stainless-steel dissecting equipment. Collecting apparatus was routinely cleaned prior to removal of each bird liver. For bird-egg samples, one egg was removed from individual nests until the desired number (generally three) was obtained. Fish were collected using gill nets or a seine, macroinvertebrates with a sweep net, aquatic vascular plants by uprooting with a tile spade, filamentous algae by hand-picking with forceps, and plankton with a Wisconsin-style plankton net (153-micrometer mesh diameter).

Onsite quality control consisted of assuring that the samples were representative of the trophic level and free of extraneous matter such as organic debris, sediment, and unrepresentative biota. Except for the eggs, all samples were frozen onsite and maintained in this condition until they were chemically analyzed at the laboratory.

All biota samples were analyzed at the U.S. Fish and Wildlife Service's Patuxent Analytical Control Facility (PACF), in Laurel, Maryland, according to methods described in the PACF Analytical Manual. Laboratory quality-control procedures included duplicate runs, spiked reference samples, and procedural blanks.

DISCUSSION OF RESULTS

The Department of the Interior's Task Group on Irrigation Drainage formed a committee to compile existing standards, criteria, and baseline values developed from previous research. The data are intended to be used as guidelines to assist in evaluation of the environmental significance of constituent concentrations measured during the reconnaissance investigations. The guidelines consist of either legally enforceable "standards" or recommended "criteria" for environmental protection. Baseline values represent available data on environmental conditions and can be used to indicate the occurrence of concentrations that are significantly greater than natural background levels. In some instances, direct comparison of measured concentrations to guidelines may not be appropriate if indicated water uses do not apply to the study area. In these situations, comparison of data among sites within the study area might be the most meaningful method for determining elevated concentrations.

Water Quality

A matrix of water-quality maximum guideline concentrations for several categories of water use is presented in table 13. Concentrations are given for the categories of human consumption, aquatic life, irrigation, and livestock watering, which are considered to be the most prevalent water uses in the study area. Most of the water-quality guidelines used in this study are concentrations adopted by the Montana Department of Health and Environmental Sciences (1986) for beneficial uses of water. Values listed generally reflect conditions relevant to Montana. Human-consumption guidelines refer to water-quality standards and criteria. Aquatic-life guidelines refer to freshwater aquatic organisms. Irrigation guidelines apply primarily to crops typically grown in Montana. Livestock-watering guidelines apply to livestock consumption of water and also may apply to wildlife watering.

Table 13.--*Water-quality maximum guideline concentrations for selected water uses*

[All concentrations are from Montana Department of Health and Environmental Sciences (1986), except where noted. Concentrations are in micrograms per liter, unless otherwise noted. Abbreviations: pCi/L, picocuries per liter; --, no guideline concentration available]

Constituent	Maximum guideline concentration for indicated water use			
	Human consumption	Aquatic life	Irrigation	Livestock watering
		Trace elements		
Arsenic	50	[a]190	100	200
Barium	1,000	--	--	--
Boron	--	--	750	5,000
Cadmium	10	[a]2	50	50
Chromium	50	[a]11	1,000	--
Copper	1,000	[a]21	5,000	500
Lead	50	[a]7.7	10,000	100
Mercury	2	[a].012, 4	--	10
Nickel	15	[a]160	2,000	--
Selenium	10	[a]35	20	50
Silver	50	[a]13, 4	--	--
Uranium	[b]35	--	--	--
Zinc	5,000	[a]47	10,000	25,000
		Radiochemicals		
Gross alpha radiation (pCi/L)	[c]15	--	--	--
Radium-226 (pCi/L)	[c]5	--	--	--
		Pesticides		
2,4-D	[d]100	--	--	--
Silvex	[d]10	--	--	--

[a]U.S. Environmental Protection Agency (1986a). Specific criteria for the protection of aquatic life are based on a water hardness of 200 milligrams per liter as calcium carbonate.

[b]National Academy of Sciences (1983)

[c]Montana Department of Health and Environmental Sciences (1982).

[d]U.S. Environmental Protection Agency (1986b).

Analytical results of water samples collected during the current study are presented in table 19 at the back of the report. Summary statistics for each of the constituents analyzed are presented in table 14.

Table 14.--*Statistical summary of trace-constituent concentrations in water, 1986*

[<, less than; pCi/L, picocuries per liter]

Constituent	Number of samples	Concentration, in micrograms per liter		
		Minimum	Maximum	Median
	Trace elements, dissolved			
Arsenic	16	<1	47	2.5
Barium	16	27	100	78
Boron	16	<10	6,000	120
Cadmium	16	<1	3	<1
Chromium	16	3	<10	<10
Copper	16	<10	10	<10
Lead	16	<5	7	<5
Mercury	16	<.1	.3	<.1
Molybdenum	16	<1	5	2
Nickel	16	1	9	2.5
Selenium	16	<1	1	<1
Silver	16	<1	<1	<1
Uranium	12	2.2	43	5.1
Vanadium	16	<1	51	2
Zinc	16	<3	56	14
	Radiochemicals, dissolved			
Gross alpha radiation (pCi/L)	12	<1.8	64	5.1
Gross beta radiation (pCi/L)	12	5.5	71	13
Radium-226 (pCi/L)	12	<.1	.3	.2
	Pesticides, total			
2,4-D	5	<.01	.08	.04
2,4-DP	5	<.01	<.01	<.01
2,4,5-T	5	<.01	<.01	<.01
Dicamba	5	<.01	.03	<.01
Picloram	5	<.01	.01	<.01
Silvex	5	<.01	<.01	<.01

Some general observations of water quality in the study area can be made from previous data (tables 1 through 6) and data collected during the current study (table 19). The Milk River near the study area contains predominantly a sodium sulfate type water (U.S. Geological Survey, issued annually), which typically has a small-to-moderate concentration of dissolved solids, depending on flow conditions.

Trace-element concentrations in the Milk River (table 1) are generally small relative to water-quality guidelines; however, the lack of surface outflows during low-water years may result in sufficient accumulation of salts and trace constituents that could impair aquatic life or other water uses as a result of the concentrating effect of evaporation. In addition, leaching and transport of soluble salts and trace constituents by irrigation drainage contribute an unknown, but possibly significant, load to the refuge lakes.

The limited previous data on water quality in Bowdoin National Wildlife Refuge indicate that much larger concentrations of dissolved solids exist during water-deficient years. Dissolved-solids concentrations during water years 1980-85 in Lake Bowdoin ranged from 8,600 to 50,000 mg/L (milligrams per liter), whereas the largest concentration in 1986 was 4,250 mg/L (tables 3 and 19). Similarly, most trace-element concentrations in Lake Bowdoin during 1985 (table 5) were several times larger than those measured during the high-water conditions of the current study. The extent of dilution in 1986 makes it difficult to identify potential threats to water quality that may exist during low-water conditions. The distribution of maximum trace-element concentrations measured in the Milk River study area during 1986 is illustrated in figure 7.

Comparison of concentrations among the sampling sites can indicate spatial variabilty and the existence of concentrations that are elevated with respect to the general range of values observed. The most notable occurrence of elevated trace-element concentrations was in Dry Lake Unit (site 11). Concentrations of arsenic (47 μg/L), uranium (43 μg/L), and vanadium (51 μg/L) were substantially larger at this site than at any of the other lakes or inflow waters. The cause of these large concentrations in Dry Lake Unit may be due to the quality of inflow water and the fact that this lake may serve as a sink for precipitated constituents during episodes of dessication. This lake is shallow and is well mixed by wind, providing the water with extensive contact with bottom material that could enhance dissolution of readily soluble constituents.

Overall, there appeared to be little difference between the quality of water delivered to Bowdoin National Wildlife Refuge from Dodson South Canal (site 1) and that of irrigation drainage conveyed in surface drains (sites 2 and 4). This similarity may indicate that water in the drains consisted largely of excess surface runoff of irrigation water or that the irrigation water moving through the soil profile had not leached a significant amount of soluble constituents. Trace-element concentrations measured in both sources were relatively small, with few exceptions. Uranium and zinc concentrations measured in the irrigation return drain (site 4) were substantially larger than those measured in the supply water (site 1). The large concentrations were not noted in the flow of Black Coulee (site 2), which consists of some natural flow plus excess applied irrigation water. The limited data on irrigation drainage are insufficient to determine whether increases in uranium and zinc concentrations are typical of irrigation drainage in the area.

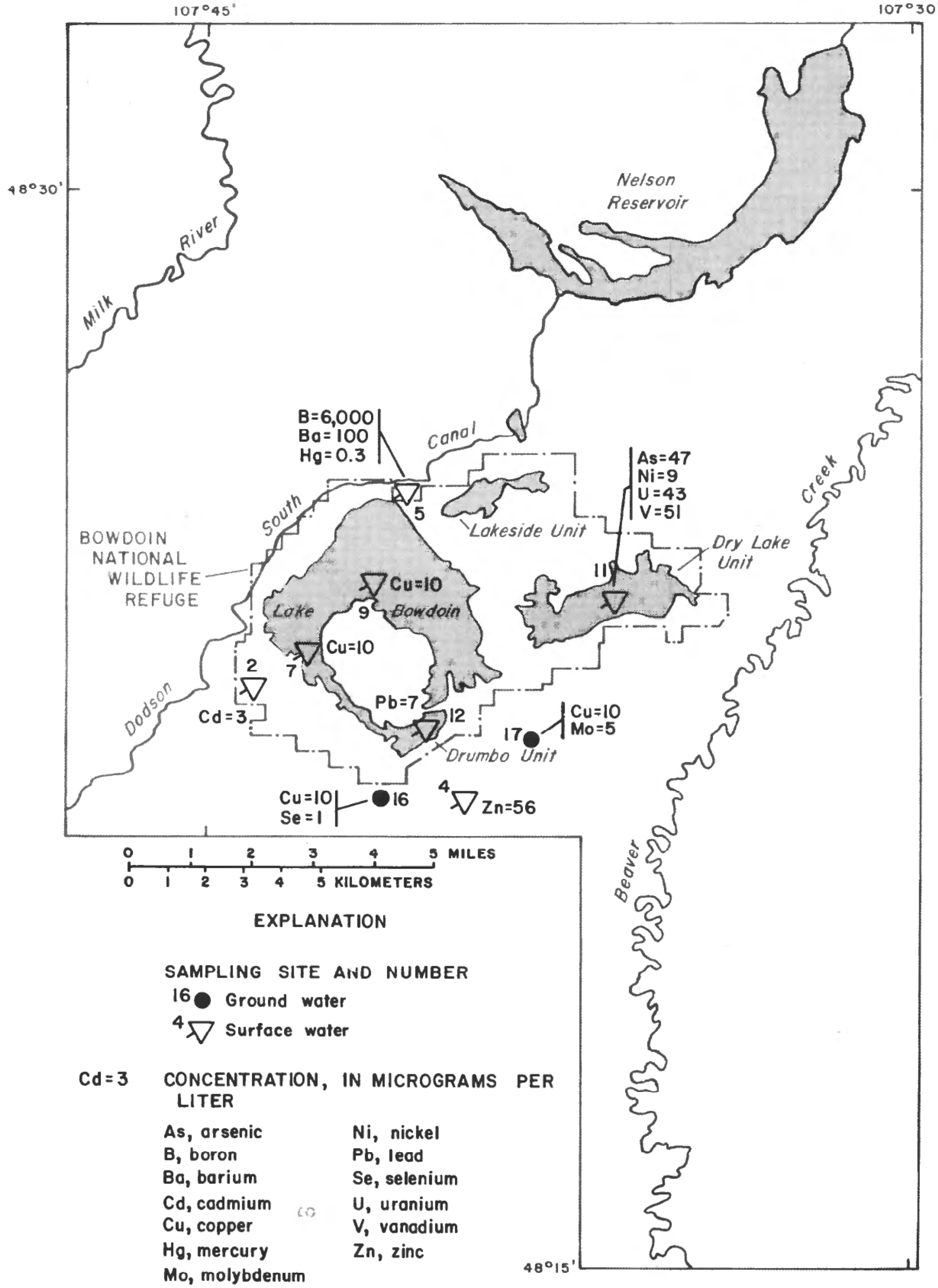

Figure 7.--Distribution of maximum trace-element concentrations in water, 1986.

Concentrations of most trace elements in the lakes of the refuge were not substantially larger than in the primary sources of inflow from Dodson South Canal (site 1) and irrigation drainage (sites 2 and 4). Some increase of concentrations in the lakes would be expected as a result of evaporation; this increase was noted for several trace elements. Examples of trace elements having at least a two-fold increase in one or more of the lakes compared to inflow water are arsenic, boron, uranium, and vanadium.

Arsenic concentrations were several times larger than inflow concentrations in all lakes, except Lakeside Unit (site 10). The arsenic concentrations were relatively small, however, with the exception of the maximum value of 47 μg/L measured in Dry Lake Unit (site 11).

Boron concentrations were substantially greater compared to those in inflow water only at site 7 (890 μg/L) and site 9 (1,000 μg/L) in Lake Bowdoin. The reason for this condition in Lake Bowdoin is uncertain, but there are several possibilities. One explanation could be the effect of inflow from the flowing well (site 5), which had the largest measured boron concentration in the study area (6,000 μg/L). However, the flow from this source is small and probably has a negligible effect on the water quality of Lake Bowdoin. Another possibility is that ground-water sources indicated by the numerous saline seeps along the north and east shores of Lake Bowdoin are contributing a significant quantity of boron. The prevalence of saline seeps in this area might be caused by subsurface leakage of water from the irrigation canal that parallels the lake shore near the seeps.

The concentrations of uranium (43 μg/L) and vanadium (51 μg/L) were substantially larger at Dry Lake Unit (site 11) in comparison to those at the other sites. The reason for these unusually large concentrations at this site is not certain, but may be related to the bottom-sediment chemistry of this shallow lake.

Water in the shallow alluvium south of Bowdoin National Wildlife Refuge (sites 16 and 17) generally was similar to water diverted from Dodson South Canal (site 1). Irrigation water from this canal is probably the primary source of recharge to the alluvial aquifer. Notable differences in the shallow ground water compared to the canal water included greater concentrations of boron (560 μg/L) and dissolved solids (1,790 mg/L) at site 17 and zinc at both wells (sites 16 and 17). The concentrations of zinc (47 and 40 μg/L) in water from the wells were similar to the value (56 μg/L) measured in the nearby irrigation return drain (site 4). The similarity of zinc concentrations in both the ground water and an irrigation return drain may indicate that zinc is readily mobilized from the soil by irrigation drainage.

Only minor differences were noted for most constituent concentrations between the two sites on Beaver Creek upstream from the refuge (site 14) and downstream from the refuge (site 15). However, some differences in concentration between the early season (June) and late season (August) sampling were substantial. Concentrations of dissolved solids, hardness, barium, and boron were smaller during August than June at site 15. Site 15 is located in a reach of Beaver Creek that receives irrigation drainage, and the decreased concentrations during August indicate that the irrigation water may be diluting concentrations. Concentrations of these constituents in August were also smaller at site 15 than at site 14, possibly as a result of flow depleted by evaporation in the upstream reaches.

Concentrations of radiochemical constituents in the water did not follow a consistent pattern throughout the study area. Although gross alpha and gross beta radiation had a similar pattern of concentration among most sites, concentrations of radium-226 (and the radiochemical element uranium) appeared to be unrelated. Dry Lake Unit (site 11) had the largest concentrations of gross alpha radiation (64 pCi/L; picocuries per liter) and gross beta radiation (71 pCi/L). Concentrations of radium-226 were small (less than or equal to 0.3 pCi/L) at all sites.

Pesticide concentrations in the water of the Milk River study area were small (less than or equal to 0.8 pCi/L) at all sites. No substantial increases of concentration were noted between the irrigation supply water of Dodson South Canal (site 1) and the irrigation drain water (site 4) or Lake Bowdoin (site 7). Concentrations of pesticides in both of the domestic wells (sites 16 and 17) were less than analytical detection limits.

A comparison of constituent concentrations measured in the study area to recommended maximum guideline concentrations (table 13) can indicate the existence of conditions that could impair beneficial uses of the water. Concentrations that equaled or exceeded maximum guideline concentrations are identified in table 15.

Table 15.--*Water-quality maximum guideline concentrations equaled or exceeded*

["X" denotes occurrence of a constituent concentration that equals or exceeds the maximum guideline concentration for the indicated water use; --, guideline not exceeded or not available]

		Water use			
Constituent	Site	Human consumption	Aquatic life	Irrigation	Livestock watering
		1985			
Boron	Lake Bowdoin[1]	--	--	X	--
Chromium	Lake Bowdoin[1]	X	X	--	--
Copper	Lake Bowdoin[1]	--	X	--	--
Nickel	Lake Bowdoin[1]	X	--	--	--
		1986			
Boron	5	--	--	X	X
	7	--	--	X	--
	9	--	--	X	--
Cadmium	2	--	X	--	--
Uranium	11	X	--	--	--
Zinc	4	--	X	--	--
	16	--	X	--	--
Gross alpha radiation	4	X	--	--	--
	9	X	--	--	--
	11	X	--	--	--

[1]Sample collected by U.S. Bureau of Reclamation; exact location not specified.

Concentrations measured during low-water conditions in Lake Bowdoin in 1985 by the U.S. Bureau of Reclamation (table 5) indicated exceedance of guideline concentrations for boron, chromium, copper, and nickel. Only chromium and copper exceeded the relevant aquatic-life guidelines; however, no guideline concentration is available to assess the relatively large boron concentration in Lake Bowdoin. Several other trace-element concentrations, including arsenic and selenium, were larger compared to 1986 concentrations. Although Lake Bowdoin was the only lake site sampled in the refuge in 1985, concentrations of trace constituents may have been generally larger in all refuge lakes compared to 1986, and may possibly have exceeded some guideline concentrations.

Of the few exceedances of water-quality guideline concentrations in the Milk River study area in 1986, most were minor. The few guidelines that were exceeded do not represent a relevant water use at every site and may not necessarily indicate any potential toxicity problem. Concentrations were not consistently large at any particular site. Median concentrations for all trace constituents were less than guideline concentrations.

Boron was in exceedance of guideline concentrations for both irrigation and livestock watering at the flowing well (site 5) in 1986. Even though water from this site is not used for irrigation, horses and wildlife graze in the vicinity and may drink the water. Although samples from sites 7 and 9 in Lake Bowdoin exceeded the irrigation guideline for boron, irrigation is not a relevant water use of the lake. Generally, boron concentrations at all sites, except site 5, were within a range of concentrations typical of eastern Montana.

The cadmium guideline concentration for aquatic life was slightly exceeded at Black Coulee (site 2), a natural channel with flow consisting largely of irrigation drainage. The concentration of cadmium measured in another source of irrigation drainage (site 4) was less than the guideline concentration.

The uranium concentration (43 μg/L) exceeded the guideline concentration for human consumption at Dry Lake Unit (site 11). Human consumption is not a relevant water use at this site and the significance of this relatively large uranium concentration to aquatic life is uncertain.

The zinc guideline concentration for aquatic life was equaled or exceeded at sites 4 and 16. However, the sites consist of an irrigation return drain and a domestic well for which an aquatic-life criterion is not directly applicable. The zinc concentrations at these sites were considerably less than guidelines for human consumption and irrigation.

Gross alpha radiation was extremely variable throughout the study area and exceeded the guideline concentration for human consumption at three sites. The exceedances included an irrigation return drain (site 4) and two of the refuge lakes (Lake Bowdoin, site 9; Dry Lake Unit, site 11). The significance of the exceedances is uncertain because none of the sites are drinking-water sources. Only Dry Lake Unit (site 11) had a value that exceeded the guideline concentration by a substantial margin. One domestic well (site 17) had gross alpha radiation of 13 pCi/L that was 2 pCi/L less than the guideline concentration.

Pesticide concentrations were small at all sites and commonly less than analytical detection limits. None of the concentrations measured during the current study exceeded the available pesticide guideline concentrations.

Concentrations of several constituents are worth noting because they approached guideline concentrations established by the U.S. Environmental Protection Agency and the State of Montana. The most notable concentrations, which were less than guideline concentrations referenced in this report, but substantially larger than other values measured in the study area, were arsenic, vanadium, and gross beta radiation at Dry Lake Unit (site 11). Because of the probability of dilution during the 1986 sampling period, any concentrations in the refuge lakes that approach guideline concentrations may represent a potential concern during low-water conditions.

Concentrations of trace elements, radiochemicals, and pesticides measured in the water of the Milk River study area in 1986 generally were small in comparison to water-quality guideline concentrations. The small data base developed from this study cannot prove conclusively that detrimental effects from potentially toxic constituents do not occur at times during low-water conditions. However, the few exceedances of water-quality guidelines and the generally successful waterfowl production during 1986 indicate that Bowdoin National Wildlife Refuge has the capacity to recover from possible adverse water-quality conditions that may exist during water-deficient years. As indicated by the relatively small constituent concentrations in 1986, periodic high-water conditions can dilute concentrations to nonharmful levels and enable some flushing of the lakes. As a result, toxicity from selenium or other trace constituents probably is not a persistent problem in Bowdoin National Wildlife Refuge.

Bottom Sediment

Specific criteria currently (1987) are not available for trace elements in bottom sediment. The effect of bottom-sediment chemistry on concentrations in the overlying water is extremely variable and dependent on factors such as water pH, dissolved-oxygen concentration, biological activity, temperature, and solubility of individual elements. The availability of trace elements for dissolution into the water column cannot be determined within the scope of the current study; however, analyses of bottom-sediment samples can indicate the occurrence of concentrations significantly greater than natural background levels.

Background concentrations of trace elements in the bottom sediment of Bowdoin National Wildlife Refuge were assumed to be represented by the mean of baseline concentrations measured in soils of the northern Great Plains (Severson and Tidball, 1979; Ebens and Shacklette, 1982). Although these soil samples were not specific to the study area, they represent similar geologic terrane and parent materials and are considered to be the best data available for identifying potentially elevated concentrations in the bottom sediment.

Analytical results of bottom-sediment samples collected during the current study are presented in table 20 at the back of the report. Summary statistics for each of the constituents analyzed are presented in table 16.

Baseline ranges and mean concentrations of trace elements in the soils of the northern Great Plains can serve as a reference for evaluating concentrations measured in bottom sediment from lakes in the refuge. Any significant increase in concentration compared to background levels in the soils could indicate accumulation of trace elements. Extensive accumulation might represent a potential for water-quality degradation if sediment-bound constituents were remobilized into solution. A comparison between trace-element concentrations in the soils of the northern Great Plains and lake-bottom sediment of Bowdoin National Wildlife Refuge is presented in table 17.

Table 16.--*Statistical summary of trace-element concentrations in bottom sediment, 1986*

[< = less than]

Constituent	Number of samples	Total concentration, in micrograms per gram: Minimum	Maximum	Median
Arsenic	6	4.7	8.6	6.6
Barium	6	500	940	760
Boron[1]	5	1.2	27	5.9
Cadmium	6	<2	<2	<2
Chromium	6	58	99	69
Copper	6	20	37	22
Lead	6	12	20	15
Mercury	6	<.02	.03	.02
Molybdenum	6	<2	<2	<2
Nickel	6	20	37	25
Selenium	6	.3	.6	.4
Silver	6	<2	<2	<2
Uranium	6	<100	<100	<100
Vanadium	6	70	160	82
Zinc	6	60	120	80

[1]Concentrations reported as extractable from bottom sediment.

Comparison of data for soils and bottom sediment indicates generally similar concentrations of trace elements. Median concentrations of trace elements in the bottom sediment were not substantially greater than mean concentrations in the soils of the northern Great Plains. With few exceptions, the ranges of concentration measured in the bottom sediment were within the baseline ranges of the soils and probably do not represent a significant accumulation of trace elements.

Concentrations of selenium in bottom sediment at all sites were relatively small and probably do not indicate a potential problem. The maximum selenium concentration in bottom sediment was 0.6 μg/g (microgram per gram) at site 10 (table 20). Both the median (0.4 μg/g) and maximum (0.6 μg/g) selenium concentrations in the bottom sediment of the refuge are similar to the mean concentration (0.5 μg/g) in the soils. Previous samples of bottom sediment analyzed by the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation (table 9), as well as samples analyzed in this study, could not verify the relatively large selenium concentration (3.1 μg/g)[1] reported by the Sacramento Bee newspaper. With the exception of the U.S. Geological Survey samples, all other samples were collected during the low-water conditions of 1985.

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[1]Reported as 3.1 parts per million.

Table 17.--*Comparison of trace-element concentrations between soils of the northern Great Plains and bottom sediment of Bowdoin National Wildlife Refuge*

[<, less than; --, no data available]

Element	Total concentration, in micrograms per gram: Soils: Geometric mean	Soils: Baseline range[1]	Bottom sediment: Median	Bottom sediment: Range
Arsenic	7.1	2.6-19	6.6	4.7-8.6
Barium	1,100	420-2,320	760	500-940
Boron [2]	41	18-96	5.9	1.2-27
Cadmium	--	--	<2	All <2
Chromium	42	15-120	69	58-99
Copper	19	8-43	22	20-37
Lead	15	5-47	15	12-20
Mercury	.026	.013-.051	.02	<.02-.03
Molybdenum	3.8	1.1-13	<2	All <2
Nickel	22	12-40	25	20-37
Selenium	.5	.2-1.1	.4	.3-.6
Silver	.14	<.22-.49	<2	All <2
Uranium	2.2	1.1-1.4	<100	All <100
Vanadium	64	33-120	82	70-160
Zinc	59	23-94	80	60-120

[1]Range is the range of concentrations within which 95 percent of sample concentrations would be expected to occur (Severson and Tidball, 1979).
[2]Boron concentrations in bottom sediment reported as extractable and are not directly comparable to total concentrations in soils.

Concentrations of most trace elements are clustered within a relatively narrow range of values. However, Dry Lake Unit (site 11) had the maximum concentration for 7 of the 11 trace elements occurring at detectable concentrations (fig. 8) in 1986. Of these elements, concentrations of chromium (99 μg/g), copper (37 μg/g), nickel (37 μg/g), vanadium (160 μg/g), and zinc (120 μg/g) were about double the respective mean background concentrations in the soils. The significance of these potentially elevated concentrations in the bottom sediment of Dry Lake Unit is uncertain, but there is some correlation with water chemistry in that this site also had the maximum concentrations of nickel and vanadium in water samples. Because uranium concentrations in the bottom sediment at all sites were less than the analytical detection limit of 100 μg/g, a correlation with the relatively large concentration in the water of Dry Lake Unit could not be identified.

The only other concentration of trace elements in bottom sediment that was large in comparison to the range of concentrations among the sites was boron (27 μg/g) at the north end of Lake Bowdoin (site 8). The relatively large boron concentration is not unexpected at this site because it is in the vicinity of numerous saline seeps and the discharge of the flowing well (site 5), which had the largest

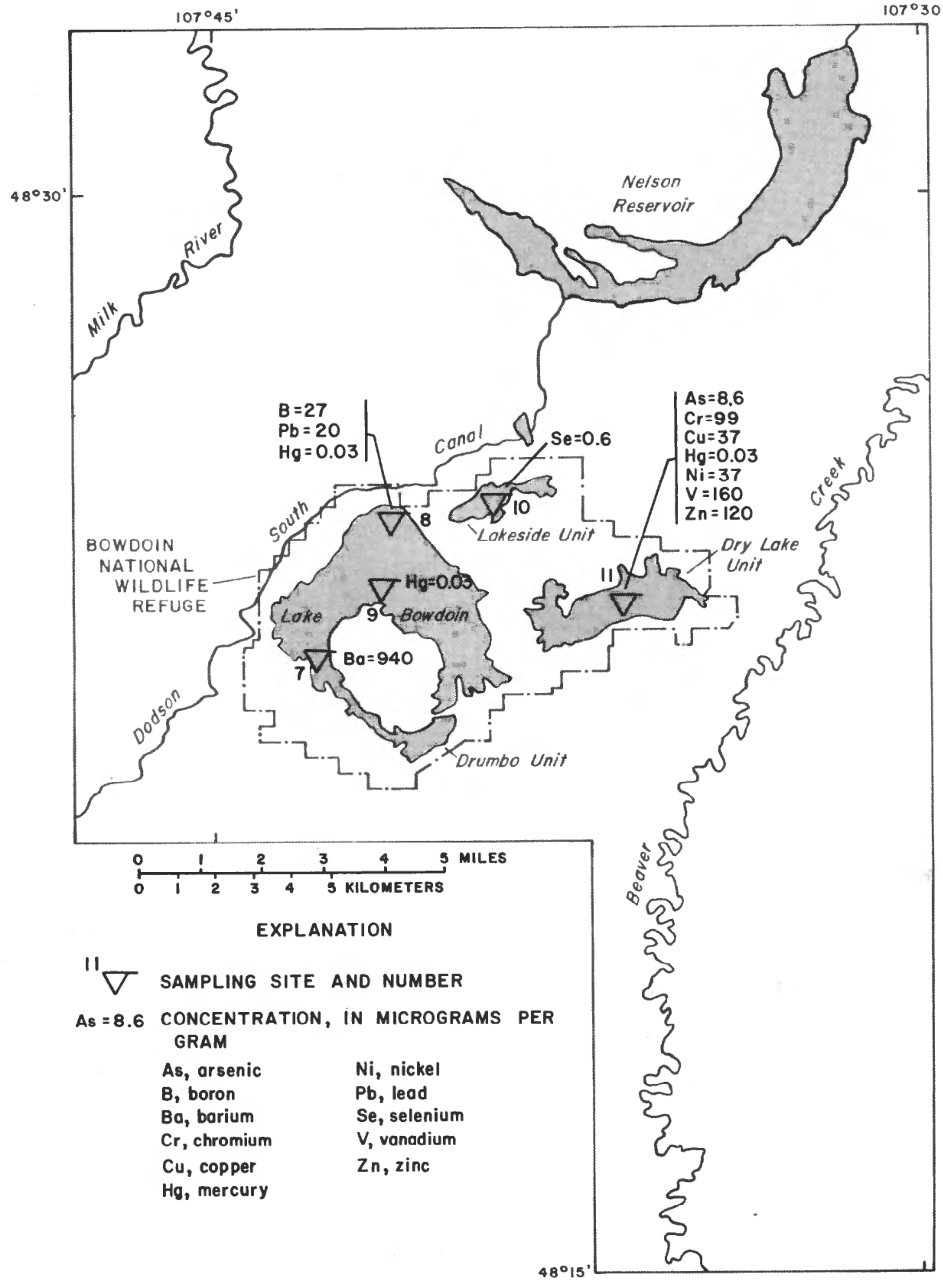

Figure 8.--Distribution of maximum trace-element concentrations in bottom sediment, 1986.

boron concentration (6,000 µg/L) measured in the water. Although the boron concentration in bottom sediment at site 8 is smaller than the mean boron concentration (41 µg/g) in the soils of the northern Great Plains (table 17), the boron data are not directly comparable because of differences in analytical methods of determination.

Pesticides were analyzed in bottom sediment from one site in Lake Bowdoin (site 7). Concentrations of all pesticides were less than the analytical detection limits.

Biota

In natural systems, no specific guidelines have been established for concentrations of trace elements or pesticides in waterfowl, fish, or lower aquatic organisms that can be used to indicate various degrees of toxicity. Because of the lack of guideline concentrations, toxicity information from controlled-diet studies and field studies from different areas have been referenced in this report to infer whether or not potentially harmful concentrations may exist in the biota of the study area. However, owing to the complexity and variability of biological responses in natural systems, chemical concentrations present in biota from one area or in a different species may not have the same effects on biota containing similar concentrations in another area. In addition, the composition of diets and duration of feeding on specific organisms are important factors in evaluating contaminant potential. All biological interpretations of the current study, therefore, are subject to the limitations of extrapolating the relatively sparse toxicity data.

Livers from young-of-the-year coots and coot eggs were collected in the refuge from sites 7 and 10. Livers were taken from two young-of-the-year avocets collected at the north end of Lake Bowdoin near site 8. Avocet eggs were the only biological samples collected from Dry Lake Unit (site 11). Macroinvertebrate groups (hemipterans--corixids and notonectids; and odonates--damselfly and dragonfly naiads), vascular plants (sago pondweed), filamentous algae, and plankton were collected at each site in the refuge, except site 11. Chironomid larvae were collected at site 8 because an adequate biomass of odonates could not be obtained. Plankton samples were collected from shallow, littoral areas, and a few organisms, that are not considered by definition as "true plankton," were observed in several of the samples. The effect on the analytical results, however, is considered to be minimal.

Two fish samples (adult walleyes and white sucker fingerlings) were obtained from Nelson Reservoir (site 13) and represent the only fish analyzed in the study area. Macroinvertebrate hemipterans and odonates, vascular plants (sago pondweed), and plankton also were collected from Nelson Reservoir.

Analytical results of biological samples collected during the current study are presented in tables 21 (dry-weight concentrations) and 22 (wet-weight concentrations) at the back of the report. Dry-weight concentrations in biota are calculated on the basis of percentage of moisture in the sample as determined from laboratory analyses of wet-weight concentrations.

In this study, the primary constituents of concern from a biological standpoint are arsenic, boron, mercury, and selenium. Summary statistics for arsenic, boron, mercury, and selenium for the various classes of organisms are presented in table 18. Generally, there is little information on the effects of these constituents among various trophic levels, but biological impairment has been noted in other contaminated areas. A brief discussion of their occurrence in the environment is given in the following paragraphs.

Arsenic in fish is absorbed primarily through food (Isensee and others, 1973; Woolson, 1975), but does not usually accumulate in freshwater fish or invertebrates (Moore and Ramamoorthy, 1984). Toxic inorganic arsenicals are rapidly transformed to organic arsenic in fish (Oladimeji and others, 1979). The chemical nature of arsenic normally present in bird tissues is not known (National Academy of Sciences, 1977).

Literature on boron is limited. The mode of uptake of boron in natural systems, whether primarily through water or diet, is unclear. However, much of the boron is presumed to be obtained through the diet.

Methylmercury is the most toxic, most readily accumulated, and the predominant form of mercury present in fish tissue (Phillips and others, 1980). Phillips and others (1980) concluded that planktivorous fish derive most of their methylmercury from water, but that both diet and water were sources in piscivorous fish. Little evidence is available to indicate what concentration of mercury in fish may be lethal (Armstrong, 1979). Methylated mercury also is presumed to be the dominant form in bird tissues and obtained mostly through diet.

It is speculated that selenium most likely occurs in the organic form in plants and animals that are diet items for fish and birds. Heinz and others (1987) reported that selenomethionine was much more readily absorbed by mallard ducks and passed into their eggs than was sodium selenite. Most authorities agree that most of the selenium present in higher consumer organisms, such as fish and birds, is obtained through consumption of selenium-contaminated food.

Arsenic

Arsenic concentrations generally were small in coot and avocet livers from Lake Bowdoin (sites 7 and 8), with the maximum concentration being 0.48 μg/g dry weight in an avocet liver from site 8 (fig. 9). Arsenic concentrations were less than the analytical detection limit in all six coot livers from Lakeside Unit (site 10). Arsenic concentration also was less than the analytical detection limit in bird eggs from the refuge.

The smallest concentration of arsenic in bird livers indicative of arsenic toxicity is unknown. However, the arsenic concentrations in coot livers from Lake Bowdoin (site 7) appear to be small (less than 0.40 μg/g dry weight; less than 0.10 μg/g wet weight) compared to the concentration of 16.7 μg/g in the liver (dry weight or wet weight not specified) of an osprey that was suspected of dying from arsenic poisoning in the eastern United States (Wiemeyer and others, 1980). Although the food habits of the coots and osprey are entirely different, a rather large concentration of arsenic appears to be required to be acutely toxic. Wiemeyer and others (1980) reported 0.23 to 1.02 μg/g arsenic (dry weight or wet weight not specified) in East Coast brown pelicans.

Arsenic concentration was less than the analytical detection limit in the sample of whole-body, adult walleyes from Nelson Reservoir. The sample of white

Table 18.--*Statistical summary of arsenic, boron, mercury, and selenium concentrations in biota, 1986*

[n, number of samples; <, less than; --, no data available]

Element	Concentration, in micrograms per gram					
	Bird livers		Bird eggs		Fish	
	Coot (n=12)	Avocet (n=2)	Coot (n=6)	Avocet (n=3)	Walleye (n=1)	White sucker (n=1)
Arsenic						
Dry weight						
Median	<0.20	--	<0.19	<0.18	--	--
Range	<.15-.39	0.39-.48	All <.19	All <.18	<0.16	0.30
Wet weight						
Median	<.05	--	<.05	<.05	--	--
Range	<.04-.09	<.10-.13	All <.05	All <.05	<.05	.05
Boron						
Dry weight						
Median	24	--	<9.6	<7.6	--	--
Range	<8.1-140	82-130	<7.9-11	<7.3-15	9.9	<12
Wet weight						
Median	6.0	--	<2.5	<2.0	--	--
Range	<2.0-33	22-32	<1.9-2.7	<2.0-4.0	2.7	<2.0
Mercury						
Dry weight						
Median	.99	--	.49	.44	--	--
Range	.29-1.3	<.37-.68	.37-1.2	.26-1.6	.80	.39
Wet weight						
Median	.23	--	.12	.12	--	--
Range	.08-.31	<.10-.17	.09-.28	.07-.41	.22	.06
Selenium						
Dry weight						
Median	3.2	--	1.4	2.9	--	--
Range	2.1-5.0	5.9-7.4	1.1-1.6	2.7-3.0	2.3	2.5
Wet weight						
Median	.76	--	.34	.78	--	--
Range	.51-1.2	1.6-1.8	.26-.42	.71-.79	.63	.42

Table 18.--*Statistical summary of arsenic, boron, mercury, and selenium concentrations in biota, 1986*--Continued

Element	Concentration, in micrograms per gram					
	Macroinvertebrates			Vascular plants (n=5)	Filamentous algae (n=5)	Plankton (n=5)
	Hemipterans (n=5)	Odonates (n=4)	Chironomids (n=1)			
Arsenic						
Dry weight						
Median	<1.0	<2.0	--	3.6	4.8	6.8
Range	<.37-<1.7	<.92-1.6	2.4	1.5-7.2	2.2-5.7	8.3-21
Wet weight						
Median	<.05	<.04	--	.27	.19	.05
Range	All <.05	<.04-.09	.06	.17-.70	.15-.39	<.04-.12
Boron						
Dry weight						
Median	<45	<92	--	420	240	<330
Range	<18-66	<38-92	160	210-810	65-300	<71-750
Wet weight						
Median	<2.0	<2.1	--	41	14	<1.9
Range	<1.9-1.9	<1.9-4.3	3.8	20-100	2.1-18	<1.9-3.0
Mercury						
Dry weight						
Median	<.97	<1.3	--	<.50	<.73	<8.3
Range	<.41-<1.6	<.77-<2.8	<1.7	<.40-<.68	<.59-<1.4	<1.6-<12
Wet weight						
Median	<.05	<.05	--	<.05	<.05	<.05
Range	All <.05	All <.05	<.04	All <.05	All <.05	All <.05
Selenium						
Dry weight						
Median	.59	<1.7	--	<.53	<.85	1.0
Range	<.50-2.6	<.92-6.5	2.3	<.41-.47	<.68-1.4	2.6-13
Wet weight						
Median	.06	.05	--	<.05	<.05	.05
Range	<.04-.09	<.05-.11	.06	<.05-.06	<0.4-.10	<.05-.07

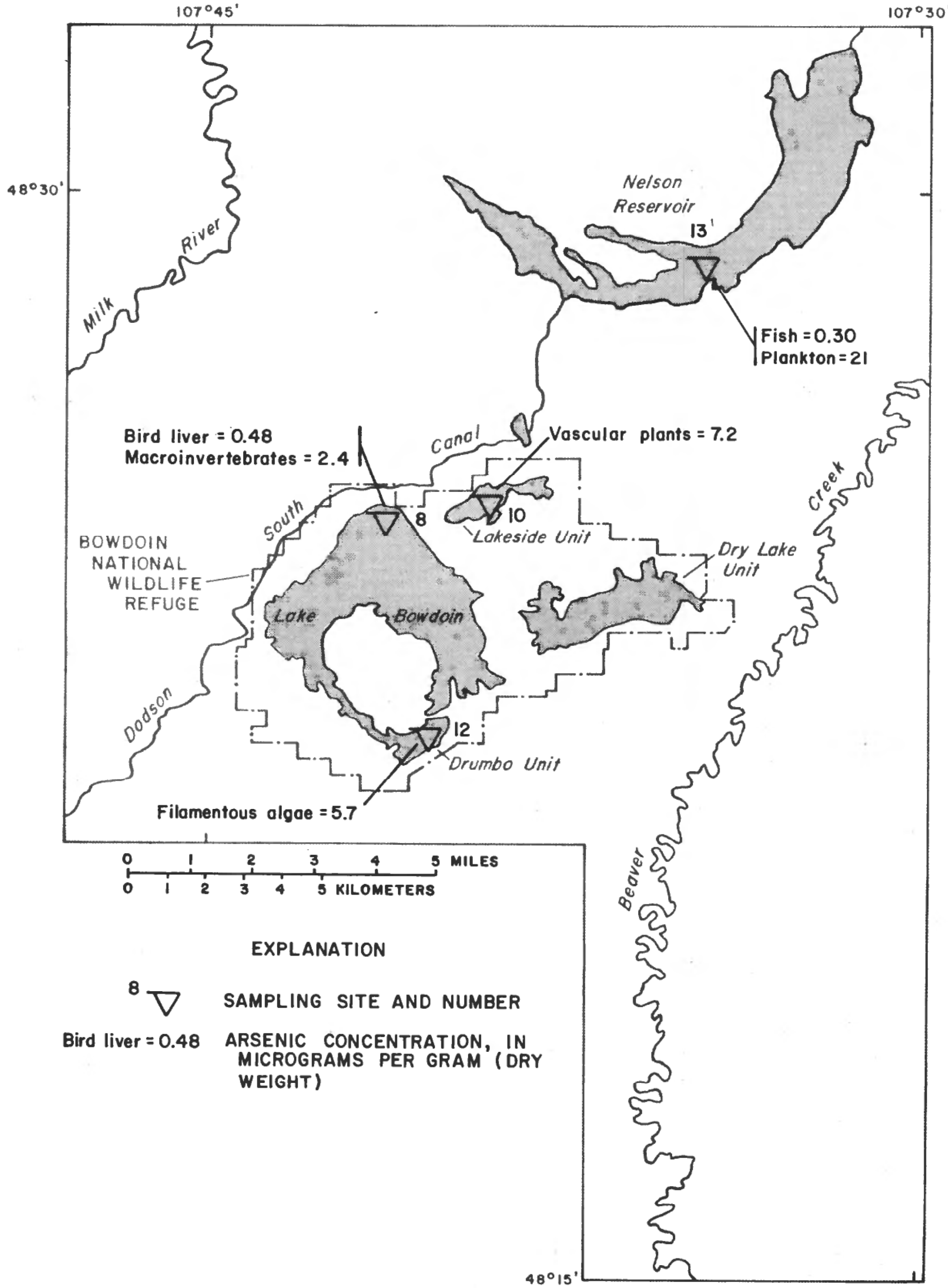

Figure 9.--Distribution of maximum arsenic concentrations in biota, 1986.

sucker fingerlings had an arsenic concentration of 0.30 μg/g dry weight (0.050 μg/g wet weight), which is much less than the 2.2 μg/g (wet weight) measured in the flesh of immature bluegills that showed poor growth and survival in a study by Gilderhus (1966). In the same study, arsenic residues of about 5.0 μg/g (wet weight) in adult bluegills were associated with severe weight loss and mortality, but some slowdown in growth rate occurred when residues in flesh were between 1.0 and 3.0 μg/g wet weight. (Residues in flesh averaged about 60 percent as large as those in whole fish.) Juvenile rainbow trout fed a diet containing 30 μg/g arsenic (dry weight basis) had a significant decrease in weight gain and contained arsenic residues in muscle of 1.52 μg/g dry weight in a study by Oladimeji and others (1984). Although different species of fish were used in the controlled and field studies referenced, an arsenic concentration in whole-body fish, in general, probably would need to be about 2 to 3 μg/g dry weight, in a sensitive species, to induce arsenic-related problems. These concentrations are significantly larger than the concentration found in the white sucker fingerlings from Nelson Reservoir. The concentration in the white sucker fingerling sample is also considerably less than 0.4 μg/g wet weight, which is considered indicative of unpolluted or slightly contaminated water (Moore and Ramamoorthy, 1984).

Arsenic concentrations in macroinvertebrates, vascular plants (sago pondweed), filamentous algae, and plankton were generally small in Bowdoin National Wildlife Refuge in 1986 (fig. 9). The maximum concentration among these groups of biota was 7.2 μg/g dry weight in sago pondweed at site 10. Based on these few data, none of the potential diet items in the refuge for juvenile coots, or other birds, contain as much as 30 μg/g dry weight of arsenic, which has been reported to result in lower body weights in 14-day-old mallard ducklings (Patuxent Wildlife Research Center, 1987).

Arsenic was detected in sago pondweed (5.0 μg/g dry weight), filamentous algae (3.9 μg/g dry weight), and plankton (21 μg/g dry weight) in Nelson Reservoir (site 13). The concentration in plankton was the largest arsenic value measured in any biota sample collected in the study area. At the time of collection, a blue-green algae (*Aphanizomenon flos aquae*) bloom was occurring and most of the plankton sample appeared to be composed of this algal species. This bloom condition may be partly responsible for the arsenic concentration being larger compared to other sites. The 21-μg/g dry weight concentration in the plankton of Nelson Reservoir is substantially larger than those measured in other tissues, but the concentration is less than the 30 μg/g dry weight which has been reported to decrease growth rates in mallard ducklings. Although arsenic concentrations in plankton were largest in Nelson Reservoir, arsenic concentrations in both filamentous algae and sago pondweed were largest in the refuge.

Boron

Maximum boron concentrations (140 μg/g dry weight) in two of the coot livers (fig. 10) from birds collected in the refuge at site 10, and an avocet liver from site 8 (130 μg/g dry weight) were about 1.5 times larger than the maximum concentration (89 μg/g) measured in a diet study (Patuxent Wildlife Research Center, 1987) identifying reproductive effects in mallards. The boron concentration in one coot liver from site 7 (73 μg/g dry weight) also was near this maximum value. Although boron occurred in the largest concentration in two coot livers from site 10, boron in another coot liver from the same general location was less than the analytical detection limit.

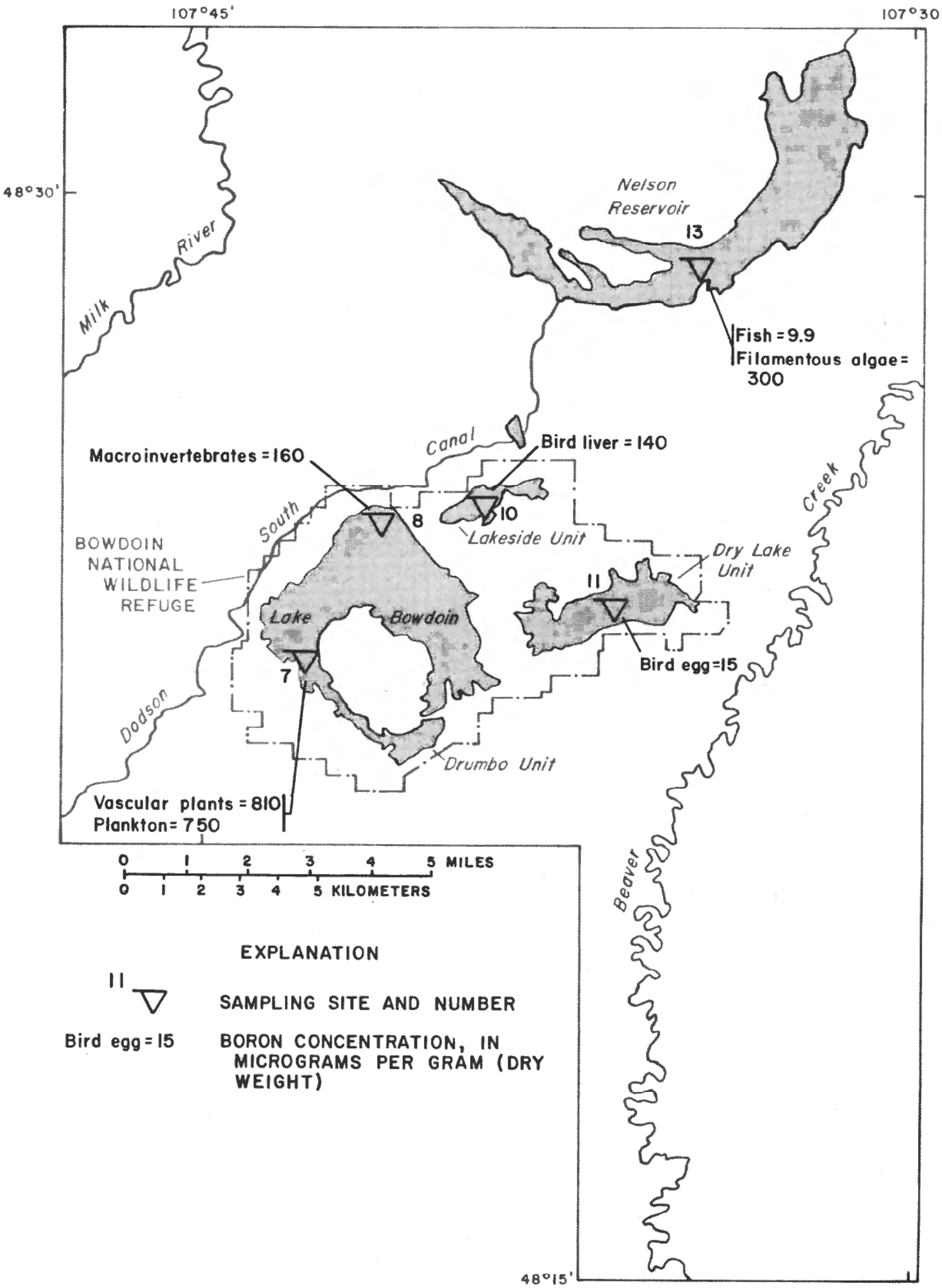

Figure 10.--Distribution of maximum boron concentrations in biota, 1986.

Boron concentration in eggs was variable. The maximum boron concentration in avocet eggs was 15 µg/g dry weight at site 11 and in coot eggs it was 11 µg/g at both sites 7 and 10. Maximum boron concentrations in avocet and coot eggs from Bowdoin National Wildlife Refuge were about one-half of those measured in the eggs from mallards fed the 1,000 µg/g dry weight boron diet in the study of the Patuxent Wildlife Research Center (1987) that observed reproductive effects.

Boron concentration in fish from Nelson Reservoir was less than the analytical detection limit in the sample of white sucker fingerlings, a potential prey species, but was 9.9 µg/g dry weight in the adult walleyes. The significance of the 9.9-µg/g dry weight boron concentration in the adult walleyes is unknown.

The macroinvertebrate sample of hemipterans from Drumbo Unit (site 12) had a boron concentration of 66 µg/g dry weight, whereas the other three hemipteran samples from the refuge had concentrations less than the analytical detection limit. Boron in odonates from the refuge ranged from less than the detection limit at site 7 to 92 µg/g dry weight at site 12. Boron concentrations in macroinvertebrate samples from Nelson Reservoir were less than the detection limit. The chironomid sample from Lake Bowdoin (site 8) had the maximum boron concentration of the macroinvertebrates in the study area--160 µg/g dry weight (fig. 10). Boron concentrations in macroinvertebrates are less than concentrations that caused reproductive effects in a diet study of mallards (Patuxent Wildlife Research Center, 1987).

Boron concentrations in all sago-pondweed samples in Bowdoin National Wildlife Refuge were larger than in either filamentous algae or plankton. The maximum boron concentrations in the study area for vascular plants and plankton occurred at site 7 in Lake Bowdoin (fig. 10). The maximum concentrations, in dry weight, were 810 µg/g in sago pondweed and 750 µg/g in the plankton. At all other sites in the refuge, boron concentrations in plankton were less than the analytical detection limit. A major zooplankton bloom (mostly the branchiopod *Daphnia*, but also containing significant numbers of copepods) was occurring during sampling at site 7. *Aphanizomenon flos aquae*, a blue-green algal species, also was prevalent in the sample. The bloom condition may have been a contributing factor to why the boron concentration in plankton was much larger at site 7 than at the other sites.

The significance of small levels of boron ingestion is unknown. However, the boron concentrations in some samples of sago pondweed and plankton from the refuge are between two diet concentrations (300 and 1,000 µg/g dry weight), which did not produce significant reproductive effects in mallard ducks at 300 µg/g dry weight, but which resulted in a decreased hatching success rate and produced fewer 21-day-old ducklings at 1,000 µg/g dry weight (Patuxent Wildlife Research Center, 1987).

In plants of Nelson Reservoir, boron concentrations were larger than analytical detection limits in sago pondweed and filamentous algae. The concentration in sago pondweed (210 µg/g dry weight) from Nelson Reservoir was less than in sago pondweed samples from the refuge; however, the maximum concentration in filamentous algae from Nelson Reservoir (300 µg/g dry weight) was slightly larger than the 270-µg/g dry weight concentration in algae samples from the refuge at site 7. The boron in filamentous algae was at a concentration at which no reproductive effects were observed in mallard ducks (Patuxent Wildlife Research Center, 1987).

Mercury

All bird livers from the refuge, with the exception of one avocet liver, contained mercury in concentrations larger than the analytical detection limit. However, these concentrations appear to be small. The maximum concentration of mercury measured in bird liver (fig. 11) was 1.3 μg/g dry weight (0.31 μg/g wet weight) from a coot at site 7. The largest mercury concentration in avocet liver was 0.68 μg/g dry weight (0.17 μg/g wet weight) at site 8. These concentrations generally are much less than mercury residues (wet weight) in livers from green herons (8.16 μg/g), mallard ducks (11.40 μg/g), and wood ducks (1.96 μg/g), respectively, from a known mercury-contaminated area (Powell, 1983). Finley and others (1979) concluded that mercury concentrations in excess of 20 μg/g wet weight in soft tissue would be considered extremely hazardous to passerine birds.

The maximum mercury concentration (0.31 μg/g wet weight) measured in coot livers from the refuge also is much less than the mercury residues (10.23 to 14.46 μg/g wet weight) measured in livers of dead black-duck ducklings maintained on a mash diet containing 3 μg/g mercury (Finley and Stendell, 1978). Likewise, the maximum mercury concentrations of 1.6 μg/g dry weight (0.41 μg/g wet weight) for avocet eggs at Dry Lake Unit (site 11) and 1.2 μg/g dry weight (0.28 μg/g wet weight) for coot eggs at Lake Bowdoin (site 7) are significantly less than the residue measured in black-duck eggs (average of 6.14 μg/g mercury wet weight) from the same study.

Mercury concentration in fish samples from Nelson Reservoir was 0.39 μg/g dry weight (0.065 μg/g wet weight) in the white sucker fingerlings and 0.80 μg/g dry weight (0.22 μg/g wet weight) in the adult walleyes. The difference in concentrations may be due to species differences, age, or size of fish. Mercury concentrations were shown to increase with increasing fish length in walleye (Glen Phillips and others, Montana Department of Fish, Wildlife and Parks, written commun., 1987). Detectable concentrations of mercury in walleye appear to be relatively common in reservoirs in the Missouri River basin. The concentration of mercury in the adult walleye from Nelson Reservoir appears consistent with data reported for whole-body walleyes (range of 0.09 to 1.70 μg/g wet weight) from Oahe Reservoir in South Dakota (U.S. Fish and Wildlife Service, written commun., 1984). Mercury concentrations in fish tissues from Nelson Reservoir are less than the range of 1.31 to 18.8 μg/g wet weight at which fathead-minnow larvae experienced 50-percent mortality (Snarski and Olson, 1982).

Mercury concentrations were less than the analytical detection limits in all macroinvertebrate, vascular-plant, filamentous algae, and plankton samples from the refuge and Nelson Reservoir. Mallards fed a diet of 0.5 μg/g dry weight mercury had abnormal egg-laying behavior and impaired reproduction, and produced ducklings with a slow growth rate (Heinz, 1979). None of the diet items collected from the study area had mercury concentrations larger than the analytical detection limits; however, the detection limits for mercury were commonly greater than 0.5 μg/g, which makes comparisons inconclusive.

Selenium

The average selenium concentration in coot livers was nearly the same at site 7 (3.3 μg/g dry weight) and at site 10 (3.2 μg/g dry weight). Maximum concentra-

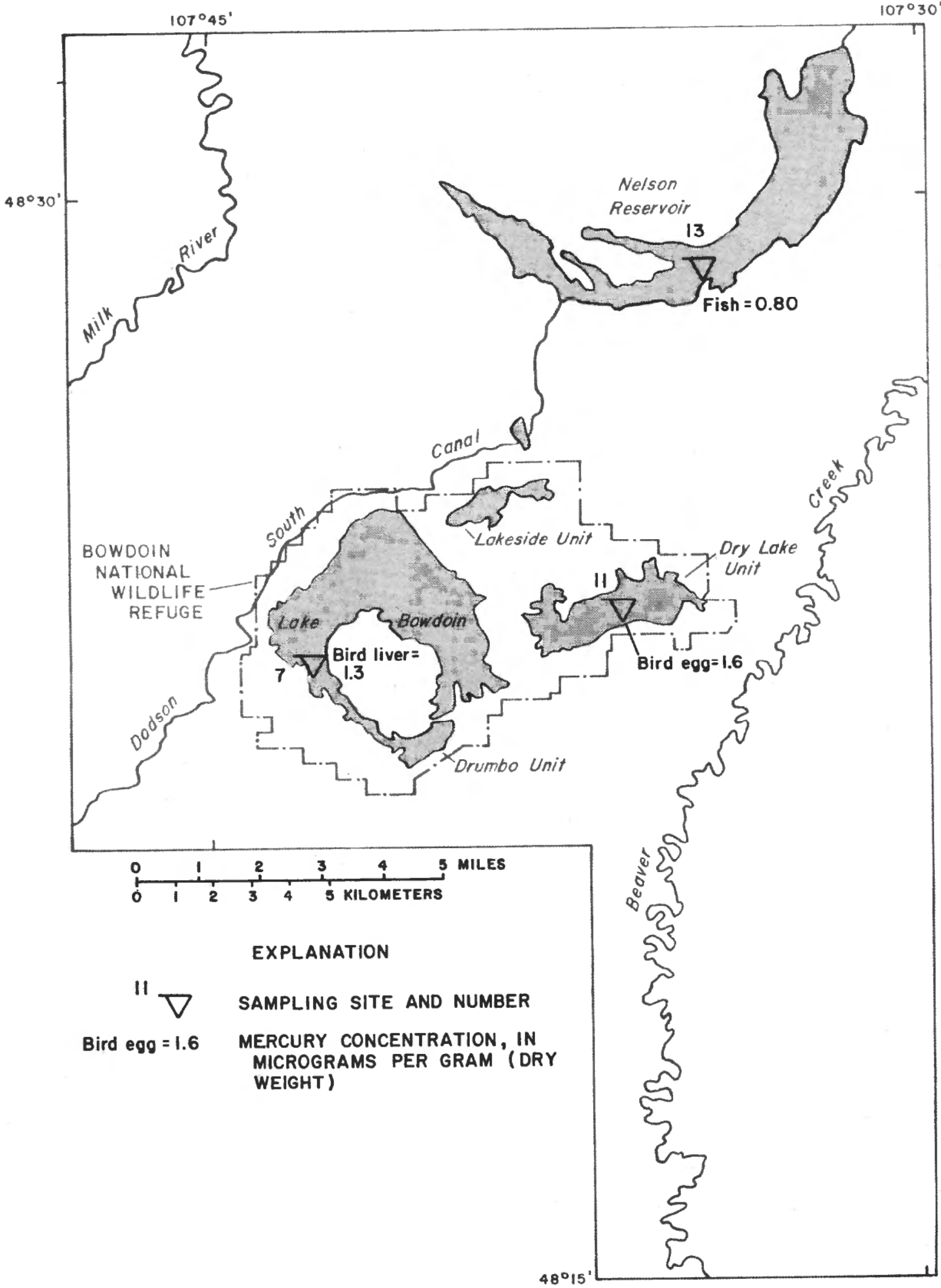

Figure 11.--Distribution of maximum mercury concentrations in biota, 1986.

tions of selenium at these sites were 4.0 μg/g dry weight (0.85 μg/g wet weight) at site 7, and 5.0 μg/g dry weight (1.2 μg/g wet weight) at site 10. The maximum concentration in bird livers from the study area (fig. 12) was 7.4 μg/g dry weight (1.8 μg/g wet weight) in an avocet liver at site 8 in Lake Bowdoin. These concentrations are less than concentrations measured in mallard livers (2.6-4.0 μg/g wet weight in females and 4.6-19 μg/g wet weight in males) of birds having reproductive problems associated with a diet containing 8 μg/g dry weight selenium (Patuxent Wildlife Research Center, 1987). The concentration of selenium in bird livers in nonselenium contaminated areas generally is less than 12 to 16 μg/g dry weight (Ohlendorf and others, 1986). If these selenium concentrations represent typical noncontaminated conditions, the livers taken from coots and avocets at Bowdoin National Wildlife Refuge would be indicative of a noncontaminated area.

The maximum selenium concentration in bird eggs was 3.0 μg/g dry weight (0.78 μg/g wet weight) in an avocet egg from site 11. Coot eggs from both Lake Bowdoin (site 7) and Lakeside Unit (site 10) had maximum concentrations of 1.6 μg/g dry weight (0.42 μg/g wet weight). Although selenium concentrations in the avocet eggs exceed those of coot eggs, all the concentrations are less than those measured in mallard eggs (4.9 to 14.0 μg/g wet weight) from females fed a diet containing 8.0 μg/g dry weight selenium that decreased duckling survival and caused physical abnormalities (Patuxent Wildlife Research Center, 1987). Selenium concentration in eggs from noncontaminated sites generally is less than 3 to 4 μg/g dry weight (Ohlendorf and others, 1986). On this basis, the selenium concentrations in coot eggs from Bowdoin National Wildlife Refuge would be considered typical of those found in noncontaminated sites. The maximum concentration in the avocet egg from Dry Lake Unit also is within the range expected for noncontaminated sites.

Selenium concentrations in fish samples from Nelson Reservoir were 2.3 μg/g dry weight (0.63 μg/g wet weight) in the whole-body adult walleye sample and 2.5 μg/g dry weight (0.42 μg/g wet weight) in the white sucker fingerling sample. Although the sample size is small, the values are much less than the concentration (2 μg/g wet weight) reported by Baumann and May (1984) as a level that could cause toxic effects in fish. The concentrations in fish from Nelson Reservoir also were substantially less than the selenium concentration, averaging 6.7 to 9.7 μg/g wet weight in adult bluegills (Gillespie and Baumann, 1986), which was associated with a decrease in numbers of adults and larval fish in a reservoir in the southeastern United States.

The largest selenium concentrations in macroinvertebrates sampled from Bowdoin National Wildlife Refuge were in hemipterans (2.6 μg/g dry weight) and odonates (6.5 μg/g dry weight) at site 7 in Lake Bowdoin. Site 7 was the only site in the study area where selenium was detectable in sago pondweed (0.47 μg/g dry weight), but filamentous algae at this site had concentrations less than the analytical detection limit. The maximum selenium concentration in potential food items of waterfowl also was measured at site 7 in the plankton (13 μg/g dry weight). A concentration nearly as large, however, was measured in plankton (10 μg/g dry weight) at site 10 in Lakeside Unit. A plankton bloom was occurring at both sites at the time of sampling, but the proportion of selenium that was incorporated in either phytoplankton or zooplankton is unknown. Selenium concentrations were substantially smaller in plankton samples from Lake Bowdoin (site 8, less than detection limit) and Drumbo Unit (site 12, 2.6 μg/g dry weight), where blooms were not observed. Based on these data, site 7 had more occurrences of maximum selenium concentrations in waterfowl diet items than any of the other sites sampled.

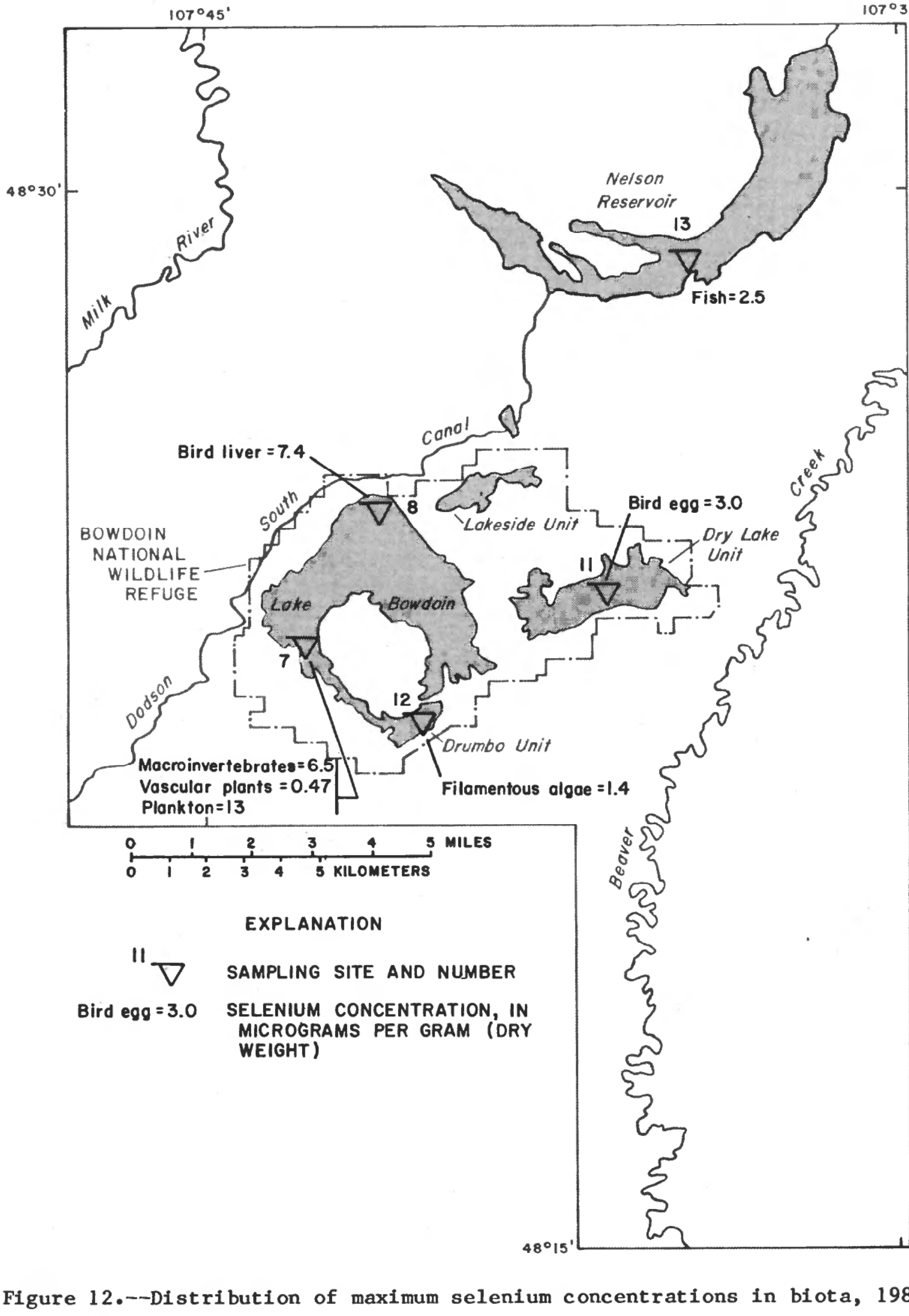

Figure 12.--Distribution of maximum selenium concentrations in biota, 1986.

Several of the food items at site 7 (odonates and plankton) had selenium concentrations near a level that has been demonstrated in controlled diet studies and reported in the literature as producing adverse effects on birds. Duckling survival was decreased and physical abnormalities were observed in mallards fed a diet containing 8 μg/g dry weight selenium (Patuxent Wildlife Research Center, 1987). Heinz and others (1987) reported that in birds fed a diet containing 10 μg/g dry weight selenium, 18 percent more abnormal embryos were found than for control birds. Survival of ducklings in that study also was significantly less than normal. In the same study, diets supplemented with selenium at concentrations of 10 and 25 μg/g dry weight also produced a significant number of abnormal embryos. Mallard ducklings fed diets containing 20 μg/g dry weight selenium had significantly lighter body weights and at 40 μg/g dry weight, decreased survival rates (Patuxent Wildlife Research Center, 1987). Although odonates and plankton are important components in the diets of juvenile coots and several species of waterfowl (Jones, 1940; Fitzner and others, 1980; and Swanson, 1985), a strict diet of either odonates or plankton is unlikely to be maintained for any extended period of time. Consequently, the amount of selenium consumed through the diet of waterfowl in the refuge would probably be less than that required to produce harmful effects demonstrated in controlled dietary studies.

Selenium concentrations in odonates, vascular plants, filamentous algae, and plankton in Nelson Reservoir were less than analytical detection limits. The only diet items sampled in Nelson Reservoir that had a detectable selenium concentration were the macroinvertebrate hemipterans (1.6 μg/g dry weight). Goettl and Davies (1978) reported 21 percent mortality in rainbow trout after 42 weeks of exposure to a diet containing a selenium concentration of 10 μg/g dry weight. These same authors also indicated a threshold effect for selenium in the diet of between 5 and 10 μg/g dry weight. Bluegill fed 54 μg/g dry weight selenium in a mayfly diet showed signs of selenosis within 13 to 20 days (Finley, 1985). By comparison, the potential diet organisms from Nelson Reservoir had selenium concentrations much less than levels shown to cause mortality or induce selenosis in fish.

Other Trace Elements

Information on potentially harmful concentrations of trace elements in biota for elements other than arsenic, boron, mercury, and selenium is limited. As a result, comparison of concentrations measured in this study to concentrations that possibly could cause adverse effects in biota is difficult. As an alternative to making comparisons to laboratory or onsite studies, the data on trace-element concentrations are compared among sites within each category of biota to identify any anomalously large concentrations that are not typical of the general trend of data. This type of comparison cannot identify potential impairment to biota, but might indicate concentrations elevated relative to the other samples. These potentially elevated concentrations may represent a concern if they are prevalent throughout various trophic levels or at a particular site (fig. 13).

Site 8 in Lake Bowdoin had the most occurrences of elevated concentrations, primarily in the chironomids, in which aluminum, barium, and iron concentrations were substantially larger than in other macroinvertebrate samples. Site 8 was the only site where chironomids were collected; consequently, no areal comparison can be made for this particular class of macroinvertebrate. In general, the chironomids had larger concentrations of most trace elements, compared to hemipterans and odonates. A plankton sample from site 8 also contained an elevated concentration of lead.

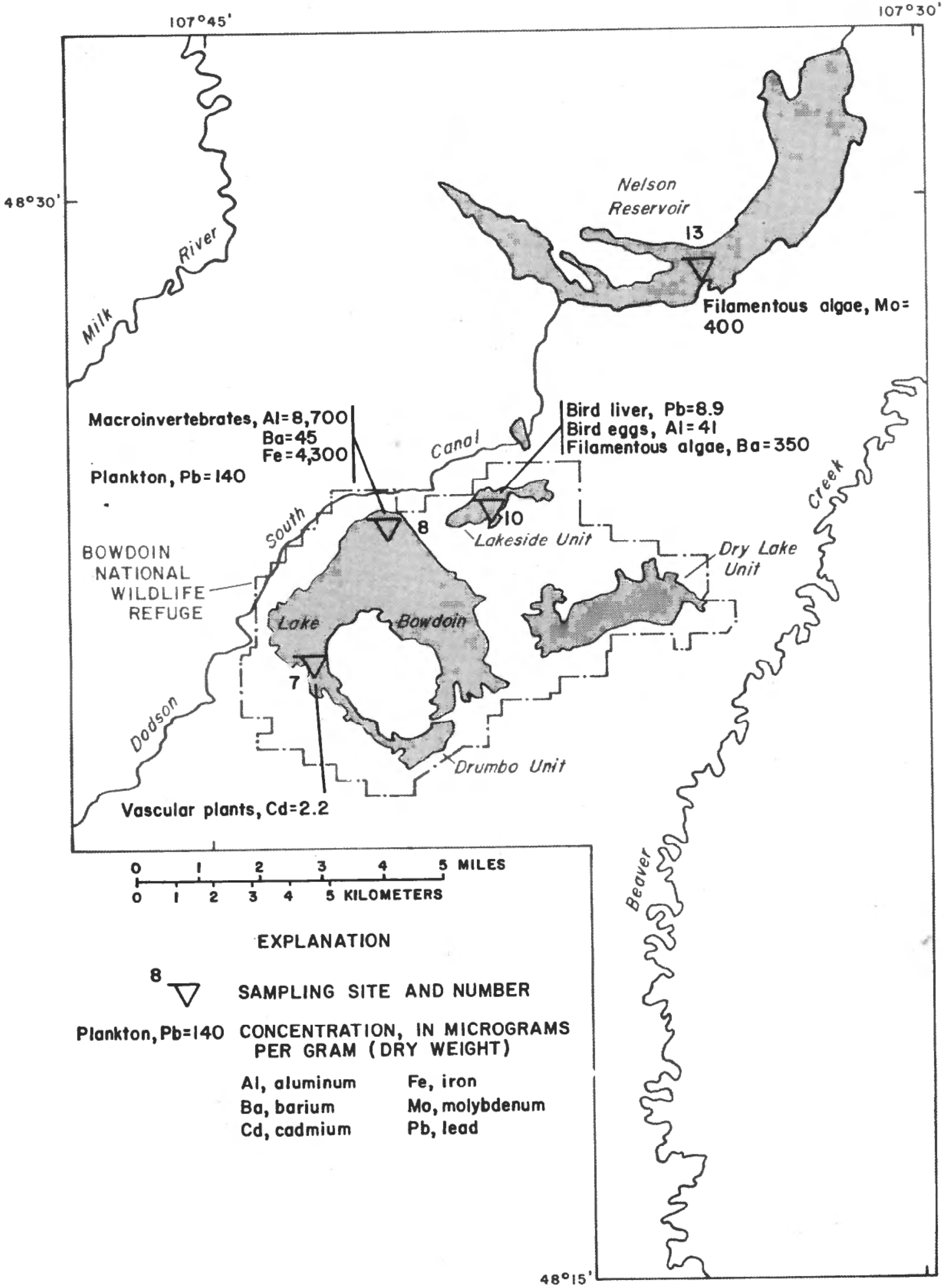

Figure 13.--Distribution of potentially elevated concentrations of trace elements in biota other than arsenic, boron, mercury, and selenium, 1986.

Site 10 in Lakeside Unit had several potentially elevated concentrations of trace elements in biota. Upper trophic-level tissues, including a coot liver and a coot egg, contained elevated concentrations of lead and aluminum, respectively. A sample of filamentous algae contained barium at a much larger concentration than at other sites in the study area.

Only two other biological samples contained notably larger concentrations in comparison to other sites. The molybdenum concentration was elevated in a sample of filamentous algae from site 13 in Nelson Reservoir and the vascular plant, sago pondweed, contained cadmium at a relatively large concentration at site 7 in Lake Bowdoin.

Potentially elevated concentrations of other trace elements occurred sporadically and generally were distributed uniformly among each group of biota, with the possible exception of chironomids. A cursory evaluation of concentrations among the sites indicates that unusually large concentrations were not prevalent at any particular site or within any specific trophic level.

Pesticides

One coot liver from Lake Bowdoin (site 7), two coot livers from Lakeside Unit (site 10), three coot eggs each from site 7 and site 10, one avocet egg from Dry Lake Unit (site 11), and the walleye and white sucker fish samples from Nelson Reservoir (site 13) were analyzed for pesticides. The pesticides analyzed are identified in table 10.

Liver samples from Bowdoin National Wildlife Refuge were analyzed because the birds contained inadequate fat. No organochlorine residues exceeded detectable concentrations in either the bird livers from the refuge or the fish samples from Nelson Reservoir. The only organochlorine pesticide detected at the refuge was p,p'-DDE in coot eggs (range of 0.09 to 0.74 μg/g wet weight) and in an avocet egg (1.7 μg/g wet weight). DDE concentrations ranging from 33.7 to 62.5 μg/g wet weight were measured in black-duck eggs from hens fed 10 μg/g DDE in their diet (Longcore and others, 1971). Effects of this diet included significant egg shell thinning and decreased survival of embryos and ducklings. After 2 years on untreated feed, hens produced eggs with residues averaging 6.2 μg/g wet weight and with egg shells that were 10 percent thinner than control eggs (Longcore and others, 1971). Blus (1982) reported that 3 μg/g fresh wet weight of DDE residue in brown-pelican eggs was associated with impaired reproductive success and that 4 μg/g wet weight was associated with total reproductive failure. The brown pelican is considered a sensitive species to organochlorine contaminants, particularly DDE and endrin. Blus (1982) defined the critical concentration of DDE in brown-pelican eggs to be 3 μg/g fresh wet weight. The maximum DDE concentration in eggs from the refuge is substantially less than this level.

SUMMARY

Reconnaissance-level studies were conducted by the Department of the Interior in 1986 to determine whether irrigation drainage from Federal water projects has caused or has the potential to cause harmful effects on the health of humans, fish, and wildlife, or may decrease the suitability of water for beneficial uses. Bowdoin National Wildlife Refuge in northeastern Montana, which receives most of its water supply from Milk River diversions, was designated for study on the basis of preliminary indications of large selenium concentrations. Samples of water, bottom sediment, and biota were collected from the refuge and adjacent areas of the Milk River basin.

The Milk River study area overlies Cretaceous marine shales, which are known to contain relatively large concentrations of selenium and other trace elements in some areas. Because Bowdoin National Wildlife Refuge is a hydrologically closed system during years of limited water supplies, accumulation of salts and trace elements from surface- and ground-water sources in the basin may potentially affect water quality, especially during water-deficient years when evaporation concentrates dissolved constituents.

In contrast to the low-water conditions prevalent during recent years, greater than normal streamflow in late 1985 and early 1986 raised the water levels in the refuge lakes and provided some partial flushing prior to the current study. As a result, concentrations of dissolved constituents analyzed in this study probably were diluted to some degree.

Previous data from water samples collected from the refuge during low-water conditions in 1985 prior to this study indicated that concentrations of boron, chromium, copper, and nickel slightly exceeded recommended water-quality guideline concentrations for various water uses. One sample of bottom sediment collected from Lake Bowdoin in 1985 had a large selenium concentration--3.1 μg/g.

Concentrations of trace elements in water at most sites in the refuge lakes in 1986 generally were not substantially larger than in the primary sources of inflow from Dodson South Canal and irrigation drainage. Dry Lake Unit had concentrations of arsenic (47 μg/L), uranium (43 μg/L), and vanadium (51 μg/L) that were notably larger compared to concentrations at the other sites. Boron concentrations were elevated (890 and 1,000 μg/L) only in Lake Bowdoin.

Results of the current study indicate that irrigation drainage sampled in 1986 had relatively small concentrations of most constituents. The only significant differences in water quality between the supplied water and irrigation drainage were zinc (56 μg/L) and uranium (13 μg/L) concentrations that were several times larger in one of the irrigation drains.

Only minor differences in water quality were measured between the two sites on Beaver Creek upstream and downstream from Bowdoin National Wildlife Refuge. There were some substantial differences in water quality between the early season (June) and late season (August) sampling periods at the downstream site. Concentrations of dissolved solids, hardness, barium, and boron were smaller in August than in June at the downstream site, possibly indicating dilution by irrigation drainage.

Water in the shallow alluvium south of the refuge was generally similar to water diverted from Dodson South Canal. Boron (560 μg/L) and dissolved-solids (1,790 mg/L) concentrations at one well were notably larger than in the canal water. Zinc concentrations (40 and 47 μg/L) measured in water from both sampled wells were several times larger than those in the water of Dodson South Canal. The elevated concentrations of zinc in a nearby irrigation drain and in the shallow ground water may indicate that zinc is readily mobilized from the soil by irrigation drainage.

Concentrations of radiochemical constituents in the water varied considerably throughout the study area, with the exception of radium-226 which was small at all sites (less than or equal to 0.3 pCi/L). Dry Lake Unit had the largest concentrations of gross alpha radiation (64 pCi/L) and gross beta radiation (71 pCi/L).

Pesticide concentrations in the water were small (less than or equal to 0.8 μg/L) at all sites. Compared to the supply water, neither Lake Bowdoin nor an irrigation drain had substantial increases in concentrations of pesticides. Concentrations in both of the domestic wells were less than analytical detection limits.

Few water-quality guideline concentrations were exceeded in the study area in 1986 and most exceedances were minor. The constituents exceeding guideline concentrations were boron, cadmium, uranium, zinc, and gross alpha radiation. The few guidelines that were exceeded do not represent a relevant water use at every site and may not necessarily indicate a potential toxicity problem. In general, constituent concentrations measured in 1986 were small; however, some degree of dilution probably resulted from the high-water conditions.

Trace-element concentrations in samples of bottom sediment from lakes in the refuge generally were within the ranges of background concentrations in soils of the northern Great Plains. Median concentrations in bottom sediments at most sites were similar to mean concentrations in the soils. With few exceptions, the concentrations measured in 1986 do not indicate extensive accumulation of trace elements in the bottom sediment. Bottom sediment of Dry Lake Unit generally had the largest trace-element concentrations relative to the other sites. Concentrations of chromium (99 μg/g), copper (37 μg/g), nickel (37 μg/g), vanadium (160 μg/g), and zinc (120 μg/g) were about double the respective mean background concentrations in the soils, which correlated with relatively large trace-element concentrations in the water at this site. The boron concentration (27 μg/g) in the bottom sediment at the north end of Lake Bowdoin was large relative to that at the other sites and also correlated to large boron concentrations in the water. The maximum selenium concentration in bottom sediment (0.6 μg/g) was similar to the mean concentration (0.5 μg/g) in the soils.

Pesticides were analyzed in bottom sediment from one site in Lake Bowdoin. Concentrations of all pesticides were less than analytical detection limits.

Arsenic concentrations were less than 0.50 μg/g dry weight in bird livers from Bowdoin National Wildlife Refuge and less than the analytical detection limit in bird eggs. Arsenic was not detected in the adult walleyes from Nelson Reservoir, but was detected in the white sucker fingerlings at a concentration of 0.30 μg/g, which is indicative of uncontaminated waters. With few exceptions, arsenic concentrations were small in macroinvertebrates, vascular plants, filamentous algae, and plankton. A relatively large arsenic concentration of 21 μg/g dry weight was measured in plankton from Nelson Reservoir, but this concentration may have resulted from a bloom of blue-green algae during sampling. Based on the few data, none of the potential diet items for waterfowl contain arsenic at concentrations having known detrimental effects.

Two coot livers and one avocet liver from Bowdoin National Wildlife Refuge had boron concentrations (130 to 140 μg/g dry weight) that exceeded concentrations in a study identifying reproductive effects. However, the maximum boron concentration in coot and avocet eggs was about one-half of that measured in eggs from the same study. Boron concentration in fish from Nelson Reservoir was less than the analytical detection limit in the white sucker fingerlings, but was 9.9 µg/g dry weight in adult walleyes. Boron concentrations in macroinvertebrates, vascular plants, filamentous algae, and plankton were variable, ranging from less than analytical detection limits in macroinvertebrates and plankton to 810 µg/g dry weight in vascular plants (sago pondweed) from Lake Bowdoin. Macroinvertebrate samples contained boron at concentrations less than levels causing reproductive effects in a diet study of mallards. Maximum concentrations measured in samples of sago pondweed (810 µg/g dry weight) and plankton (750 µg/g dry weight) are within a range that produced reproductive effects.

The maximum concentrations of mercury in bird livers (0.31 µg/g wet weight) and eggs (0.41 µg/g wet weight) were much less than concentrations measured in studies of known mercury contamination and mortality in waterfowl. Mercury was detected in the white sucker fingerlings and the adult walleyes in Nelson Reservoir at concentrations similar to those commonly measured in reservoirs in the Missouri River basin and were less than concentrations determined to cause mortality in fathead-minnow larvae. Mercury concentrations were less than analytical detection limits in all samples of macroinvertebrates, vascular plants, filamentous algae, and plankton.

Maximum selenium concentrations measured in bird livers (7.4 µg/g dry weight) from the refuge are indicative of a noncontaminated area and are less than concentrations reported to produce reproductive problems. The maximum selenium concentration in bird eggs (3.0 µg/g dry weight) is less than concentrations affecting duckling survival in dietary studies. Selenium concentrations in adult walleyes (0.63 µg/g wet weight) and white sucker fingerlings (0.42 µg/g wet weight) from Nelson Reservoir are much less than concentrations determined to cause toxic effects in fish. The largest selenium concentration in potential food items of waterfowl was measured in a plankton sample (13 µg/g dry weight) from Lake Bowdoin collected during a plankton bloom. The maximum concentration in macroinvertebrates (6.5 µg/g dry weight) occurred at the same site. Selenium concentrations in vascular plants and filamentous algae were small or less than analytical detection limits. Although some of the macroinvertebrate and plankton food items in Lake Bowdoin had selenium concentrations near levels producing detrimental effects in ducklings, the typical diet composition of waterfowl indicates that selenium intake probably would be less than that required to produce selenium toxicity.

The concentrations of several trace elements other than arsenic, boron, mercury, and selenium in biota were possibly elevated compared to the general trend of concentrations among the sampling sites. The concentrations appear to be atypical, but their actual significance is uncertain owing to the paucity of toxicity data. In general, no particular site or trophic level of biota consistently had unusually large trace-element concentrations.

Concentrations of organochlorine pesticides analyzed in biological samples generally were less than analytical detection limits. The only pesticide detected in the biota of the refuge was p,p'-DDE in coot eggs (0.09 to 0.74 µg/g wet weight) and in an avocet egg (1.7 µg/g wet weight). These concentrations are much less than those in eggs associated with impaired reproductive success.

REFERENCES CITED

Armstrong, F.A.J., 1979, Effects of mercury compounds on fish, *in* Nriagu, J.O., ed., The biogeochemistry of mercury in the environment: Elsevier/North Holland Biomedical Press, Chapter 24, p. 658-670.

Baumann, P.C., and May, T.W., 1984, Selenium residues in fish from inland waters of the United States, *in* The effects of trace elements on aquatic ecosystems: Electric Power Research Institute Workshop, Palo Alto, Calif., (Mar. 23-24, 1982), Proceedings, p. 7-1 to 7-16.

Blus, L.J., 1982, Further interpretation of the relation of organochlorine residues in brown pelican eggs to reproductive success: Environmental Pollution (Series A), v. 28, p. 15-33.

Ebens, J.E., and Shacklette, H.T., 1982, Geochemistry of some rocks, mine spoils, stream sediments, soils, plants, and waters in the western energy region of the conterminous United States: U.S. Geological Survey Professional Paper 1237, 173 p.

Finley, K.A., 1985, Observations of bluegills fed selenium-contaminated *Hexagenia* nymphs collected from Belews Lake, north California: Environmental Contamination and Toxicology Bulletin, v. 35, p. 816-825.

Finley, M.T., and Stendell, R.C., 1978, Survival and reproductive success of black ducks fed methylmercury: Environmental Pollution, v. 16, p. 51-64.

Finley, M.T., Stickel, W.H., and Christensen, R.E., 1979, Mercury residues in tissues of dead and surviving birds fed methylmercury: Environmental Contamination and Toxicology Bulletin, v. 21, p. 105-110.

Fishman, M.J., and Friedman, L.C., 1985, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 709 p.

Fitzner, R.E., Sipco, E.T., and Schreckhise, R.G., 1980, American coot nesting and feeding habits in southeastern Washington: Northwest Sciences, v. 54, p. 244-252.

Gilderhus, P.A., 1966, Some effects of sublethal concentrations of sodium arsenite on bluegills and the aquatic environment: American Fisheries Society Transactions, v. 95, no. 3, p. 189-296.

Gillespie, R.B., and Baumann, P.C., 1986, Effects of high tissue concentrations on reproduction by bluegills: American Fisheries Society Transactions, v. 115, p. 208-213.

Goettl, J.P., and Davies, P.H., 1978, Water pollution studies: Fort Collins, Colorado Division of Wildlife, Job Progress Report, Federal Aid Project F-33-R-13, 45 p.

Heinz, G.H., 1979, Methylmercury--Reproductive and behavioral effect on three generations of mallard ducks: Journal of Wildlife Management, v. 43, no. 2, p. 394-401.

Heinz, G.H., Hoffman, D.J., Krynitsky, A.J., and Weller, D.M.G., 1987, Reproduction in mallards fed selenium: Environmental Toxicology and Chemistry, v. 6, p. 001-011.

Hickey, John, and others, eds., undated, Field operations manual for resource contaminant assessment: Washington, D.C., U.S. Fish and Wildlife Service, Resource Contaminant Assessment Division, 2 sections and 12 appendixes, with various pagination.

Isensee, A.R., Kearney, P.C., Woolson, E.A., Jones, E.A., and Williams, V.P., 1973, Distribution of alkyl arsenicals in model ecosystems: Environmental Science and Technology, v. 7, p. 841-845.

Jones, J.C., 1940, Food habits of the American coot, with notes on distribution: U.S. Bureau of Biological Survey, Wildlife Research Bulletin 2, 52 p.

Knapton, J.R., 1985, Field guidelines for collection, treatment, and analysis of water samples, Montana District: U.S. Geological Survey Open-File Report 85-409, 86 p.

Longcore, J.R., Samson, F.B., and Whittendale, T.W., Jr., 1971, DDE thins eggshells and lowers reproductive success of captive black ducks: Environmental Contamination and Toxicology Bulletin, v. 6, no. 6, p. 485-490.

Miller, M.R., Bergantino, R.N., Bermel, W.M., Schmidt, F.A., and Botz, M.K., 1980, Regional assessment of the saline-seep problem and a water-quality inventory of the Montana plains *with a section on* Algal populations in seep-affected water, with an emphasis on salinity indicators and potentially toxic species by L.L. Bahls and P.A. Bahls: Montana Bureau of Mines and Geology Open-File Report 42, 379 p.

Montagne, Clifford, and others, 1982, Soils of Montana: Montana Agricultural Experiment Station Bulletin 744, 95 p.

Montana Department of Health and Environmental Sciences, 1974, Water quality inventory and management plan, Milk River basin, Montana: 119 p.

________1982, Administrative rules of Montana--Title 16, Chapter 20-Water Quality: Helena, 89 p.

________1986, Montana water quality 1986: Helena, 1986 Montana 306 (b) Report, 198 p.

Moore, J.W., and Ramamoorthy, S., 1984, Heavy metals in natural waters: New York, Springer-Verlag, 268 p.

National Academy of Sciences, 1983, Drinking water and health: Washington, D.C., v. 5, 157 p.

______1977, Committee on medical and biological effects of environmental pollutants: Washington D.C., Division of Medical Science, 332 p.

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

Oladimeji, A.A., Qadri, S.U, Tam, G.K.H., and deFreitas, A.S.W, 1979, Metabolism of inorganic arsenic to organoarsenicals in rainbow trout (*Salmo gairdneri*): Ecotoxicology and Environmental Safety, v. 3, p. 394-400.

_______1984, Long-term effects of arsenic accumulation in rainbow trout, *Salmo gairdneri*: Environmental Contamination and Toxicology Bulletin, v. 32, p. 732-741.

Patuxent Wildlife Research Center, 1987, Effects of irrigation drainwater contaminants on wildlife: Laurel, Md., U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Annual Report Fiscal Year 1986, 24 p.

Phillips, G.R., Lenhart, T.E., and Gregory, R.W., 1980, Relation between trophic position and mercury accumulation among fishes from the Tongue River Reservoir, Montana: Environmental Research, v. 22, p. 73-80.

Powell, G.V.M., 1983, Industrial effluents as a source of mercury contamination in terrestrial riparian vertebrates: Environmental Pollution, (Series B), v. 5, p. 51-57.

Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geological Survey, scale 1:500,000, 1 sheet.

Severson, R.C., Wilson, S.A., and McNeal, J.M., 1987, Analyses of bottom material collected at nine areas in the western United States for the DOI irrigation drainage task group: U.S. Geological Survey Open-File Report 87-490, 24 p.

Severson, R.C., and Tidball, R.R., 1979, Spatial variation of total element concentration in soil within the Northern Great Plains Coal Region: U.S. Geological Survey Professional Paper 1134-A, 18 p.

Snarski, V.M., and Olson, G.F., 1982, Chronic toxicity and bioaccumulation of mercuric chloride in the fathead minnow (*Pimephales promelas*): Aquatic Toxicology, v. 2, p. 143-156.

Swanson, G.A., 1985, Invertebrates consumed by dabbling ducks (*Anatinae*) on the breeding grounds: Minnesota Academy of Sciences Journal, v. 50, no. 3, p. 37-40.

U.S. Department of Commerce, 1982, Evaporation atlas for the contiguous 48 United States: National Weather Service Technical Report NWS 33, 26 p.

U.S. Environmental Protection Agency, 1986a, Quality criteria for water 1986: Washington, D.C., Office of Water Regulations and Standards, EPA 440/5-86-001.

______1986b, U.S. Code of Federal Regulations, Title 40: p. 141.12.

U.S. Geological Survey, issued annually, Water resources data, Montana, Volume I, Hudson Bay basin and Missouri River basin.

______1977, National handbook of recommended methods for water-data acquisition--Chapter 5, Chemical and physical quality of water and sediment: Office of Water-Data Coordination, 193 p.

______1985, 1985 Water quality laboratory services catalog: U.S. Geological Survey Open-File Report 85-171, 5 parts, with various pagination.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., 1987, Methods for determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A3, 80 p.

Wiemeyer, S.N., Lamont, T.G., and Locke, L.N., 1980, Residues of environmental pollutants and necropsy data for eastern United States ospreys, 1964-1973. Estuaries, v. 3, no. 3, p. 163-165.

Woolson, E.A., 1975, Bioaccumulation of arsenicals, *in* Woolson, E.A., ed., Arsenical pesticides: American Chemical Society Symposium, Serial No. 7, p. 97-107.

SUPPLEMENTAL DATA

Table 19.--*Water-quality data*

[Analyses by U.S. Geological Survey. Number in parentheses in column heading is parameter code identification. Gross alpha in picocuries per liter calculated from laboratory reporting unit of micrograms per liter. Abbreviations: ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; Cs-137, Cesium-137; Sr/Yt-90, Strontium-90/Yttrium-90; E, estimated. Symbols: <, less than; --, no data]

Site No. (fig. 6)	Station name	Date (month, day, year)	Time	Water level, in feet below land surface (72019)	Discharge, instantaneous (ft^3/s) (00061)	Specific conductance, onsite (µS/cm) (00095)
1	Dodson South Canal	06-11-86	1630	--	109	630
		08-26-86	1330	--	E1.0	550
2	Black Coulee	08-04-86	1600	--	2.0	630
4	Irrigation return drain	08-04-86	1900	--	.50	610
5	Flowing well (Lakeside Spring)	06-12-86	0900	--	.01	3,700
7	Lake Bowdoin, southwest arm	08-05-86	1030	--	--	4,500
9	Lake Bowdoin, central	08-05-86	0900	--	--	5,500
10	Lakeside Unit	08-05-86	1430	--	--	600
11	Dry Lake Unit	08-06-86	1000	--	--	9,200
12	Drumbo Unit	08-06-86	0845	--	--	2,350
14	Beaver Creek above Bowdoin National Wildlife Refuge	06-11-86	1800	--	34	1,580
		08-26-86	1830	--	.0	1,820
15	Beaver Creek below Bowdoin National Wildlife Refuge	06-11-86	2010	--	51	1,580
		08-26-86	2000	--	E22	675
16	Domestic well, 30N31E15CAA	08-26-86	1700	19.90	--	865
17	Domestic well, 30N31E12D	08-26-86	1500	13.70	--	2,750

Site No. (fig. 6)	pH, onsite (standard units) (00400)	Temperature, air (°C) (00020)	Temperature, water, onsite (°C) (00010)	Oxygen, dissolved (mg/L) (00300)	Oxygen, dissolved (percent saturation) (00301)	Hardness (mg/L as $CaCO_3$) (00900)	Solids, residue at 180 °C, dissolved (mg/L) (70300)	Nitrogen, NO_2+NO_3 total (mg/L as N) (00630)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N) (00631)
1	8.10	25.0	24.0	--	--	200	387	<0.10	--
	8.20	19.5	20.5	--	--	160	338	--	--
2	7.30	25.0	21.5	5.1	70	170	383	--	--
4	8.30	23.0	23.0	--	--	170	374	--	--
5	7.80	16.0	17.0	--	--	50	2,310	--	--
7	10.00	21.0	23.0	12.2	175	660	3,320	<.10	--
9	8.40	19.0	23.0	.7	10	900	4,250	<.10	--
10	9.50	25.0	25.0	11.2	165	130	364	<.10	--
11	9.60	17.5	18.5	5.3	70	640	7,230	--	--
12	9.20	16.0	17.5	3.4	43	350	1,580	--	--
14	8.00	23.0	23.5	--	--	550	1,160	--	--
	8.90	21.0	21.5	--	--	500	1,250	--	--
15	8.10	21.0	24.5	--	--	360	1,110	--	--
	8.70	19.0	19.5	--	--	170	383	--	--
16	7.40	21.0	12.5	--	--	310	487	--	.45
17	7.50	20.0	9.5	--	--	320	1,790	--	<.10

Table 19.--*Water-quality data*--Continued

Site No.	Phosphorus, total (mg/L as P) (00665)	Arsenic, dissolved (µg/L as As) (01000)	Barium, dissolved (µg/L) as Ba) (01005)	Boron, dissolved (µg/L as B) (01020)	Cadmium, dissolved (µg/L as Cd) (01025)	Chromium, dissolved (µg/L as Cr) (01030)	Copper, dissolved (µg/L as Cu) (01040)	Lead, dissolved (µg/L as Pb) (01049)	Mercury, dissolved (µg/L as Hg) (71890)
1	0.10	3	79	120	<1	<10	<10	6	--
	--	1	64	80	<1	<10	<10	<5	<0.1
2	--	2	61	90	3	<10	<10	<5	<.1
4	--	2	67	100	<1	<10	<10	<5	<.1
5	--	<1	100	6,000	<1	<10	<10	<5	.3
7	.16	10	<100	890	<1	<10	10	<5	<.1
9	.70	6	<100	1,000	<1	<10	10	<5	<.1
10	.09	3	44	100	<1	<10	<10	<5	<.1
11	--	47	78	<10	1	4	<10	<5	<.2
12	--	12	27	<10	<1	3	<10	7	<.2
14	--	2	93	290	<1	<10	<10	<5	<.1
	--	1	81	390	2	<10	<10	<5	<.1
15	--	6	84	330	<1	<10	<10	<5	<.1
	--	2	31	120	<1	<10	<10	<5	<.1
16	--	<1	37	120	<1	<10	10	<5	<.1
17	--	7	<100	560	<1	<10	10	<5	<.1

Site No.	Molybdenum, dissolved (µg/L as Mo) (01060)	Nickel, dissolved (µg/L as Ni) (01065)	Selenium, dissolved (µg/L as Se) (01145)	Silver, dissolved (µg/L as Ag) (01075)	Uranium, natural, dissolved (µg/L as U) (22703)	Vanadium, dissolved (µg/L as V) (01085)	Zinc, dissolved (µg/L as Zn) (01090)	Gross alpha, dissolved (pCi/L as U-nat)	Gross beta, dissolved (pCi/L as Cs-137) (03515)
1	1	6	<1	<1	--	2	15	--	--
	3	3	<1	<1	2.6	1	14	<1.8	5.5
2	1	3	<1	<1	2.5	2	<3	2.3	7.1
4	2	2	<1	<1	13	2	56	22	30
5	<1	2	<1	<1	--	14	30	--	--
7	4	1	<1	<1	3.1	6	20	3.1	6.7
9	4	2	<1	<1	2.5	4	30	34	37
10	<1	2	<1	<1	2.2	2	<3	2.8	6.9
11	2	9	<1	--	43	51	<3	64	71
12	1	5	<1	--	6.7	<6	<3	13	25
14	<1	7	<1	<1	--	<1	6	--	--
	3	1	<1	<1	5.2	1	23	<8.0	23
15	1	8	<1	<1	--	6	8	--	--
	3	3	<1	<1	4.0	3	9	3.6	9.5
16	3	2	1	<1	7.9	<1	47	6.2	10
17	5	2	<1	<1	8.2	<1	40	13	16

Site No. (fig. 6)	Gross beta, dissolved (pCi/L as Sr/ Yt-90) (80050)	Radium-226, dissolved, planchet count (pCi/L) (09510)	2,4-D, total (µg/L) (39730)	2,4-DP, total (µg/L) (82183)	2,4,5-T, total (µg/L) (39740)	Dicamba (mediben) (Banvel D), total (µg/L) (82052)	Picloram (Tordon) (Amdon), total (µg/L) (39720)	Silvex, total (µg/L) (39760)
1	--	--	0.08	<0.01	<0.01	0.01	0.01	<0.01
	4.3	0.2	--	--	--	--	--	--
2	5.6	.1	--	--	--	--	--	--
4	20	.1	.06	<.01	<.01	.02	<.01	<.01
5	--	--	--	--	--	--	--	--
7	5.2	.2	.07	<.01	<.01	.03	<.02	<.01
9	24	.2	--	--	--	--	--	--
10	5.3	.1	--	--	--	--	--	--
11	44	.2	--	--	--	--	--	--
12	16	.2	--	--	--	--	--	--
14	--	--	--	--	--	--	--	--
	15	.3	--	--	--	--	--	--
15	--	--	--	--	--	--	--	--
	7.2	<.2	--	--	--	--	--	--
16	7.7	<.1	<.01	<.01	<.01	<.01	<.01	<.01
17	11	.2	<.01	<.01	<.01	<.01	<.01	<.01

Table 20.--*Bottom-sediment data*

[Analyses by 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]

Site No. (fig. 6)	Date (month, day, year)	Trace-element concentration,									
		Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Lead	Mercury	Molybdenum	Nickel
7	08-05-86	6.6	940	6.1	<2	58	20	12	0.02	<2	22
8	08-05-86	4.7	500	27	<2	62	21	20	.03	<2	24
9	08-05-86	7.5	800	5.2	<2	76	21	16	.03	<2	26
10	08-05-86	5.4	780	1.2	<2	61	23	14	<.02	<2	20
11	08-06-86	8.6	730	--	<2	99	37	19	.03	<2	37
12	08-06-86	6.7	730	5.9	<2	80	35	12	<.02	<2	29

in micrograms per gram					Pesticide concentration, in micrograms per kilogram					
Selenium	Silver	Uranium	Vanadium	Zinc	2,4-D	2,4-DP	2,4,5-T	Dicamba	Picloram	Silvex
0.3	<2	<100	70	60	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
.4	<2	<100	80	95	--	--	--	--	--	--
.3	<2	<100	84	72	--	--	--	--	--	--
.6	<2	<100	71	83	--	--	--	--	--	--
.4	<2	<100	160	120	--	--	--	--	--	--
.3	<2	<100	97	77	--	--	--	--	--	--

Table 21.--*Biological data, in dry weight*

[Analyses by U.S. Fish and Wildlife Service. Concentration, in micrograms per gram. <, less than; --, no data]

Site No. (fig. 6)	Sample type	Taxa	Date (month, day, year)	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium
7	Liver	Coot	07-22-86	12	<0.15	0.51	<0.39	25	<0.39	6.3
7	Liver	Coot	07-22-86	11	<.46	.85	<.69	21	<.69	4.3
7	Liver	Coot	07-22-86	22	.39	<.65	<.65	73	<.65	3.2
7	Liver	Coot	07-22-86	7.3	.26	<.41	<.41	31	<.41	14
7	Liver	Coot	07-22-86	2.8	.22	<.43	<.43	21	<.43	<.43
7	Liver	Coot	07-22-86	<.45	.21	<.45	<.45	13	<.45	3.2
7	Egg	Coot	06-03-86	3.5	<.18	3.1	<.41	<8.3	<.41	<.41
7	Egg	Coot	06-03-86	10	<.18	1.4	<.37	9.6	<.37	<.37
7	Egg	Coot	06-03-86	3.1	<.16	1.5	<.40	11	<.40	.73
7	Macroinvertebrates	Odonates	07-22-86	140	<2.3	<5.6	<5.6	<110	<5.6	<5.6
7	Macroinvertebrates	Hemipterans	07-22-86	370	<1.3	5.0	<2.8	<56	<2.8	5.0
7	Vascular plants	Sago pondweed	07-22-86	630	2.2	16	<.81	810	2.2	14
7	Filamentous algae		07-22-86	3,100	2.2	56	<1.5	270	<1.5	47
7	Plankton		07-22-86	2,200	<11	<25	<25	750	<25	<25
8	Liver	Avocet	07-22-86	69	<.39	<1.4	<1.4	130	<1.4	<1.4
8	Liver	Avocet	07-22-86	99	.48	1.8	<.74	82	<.74	8.4
8	Macroinvertebrates	Chironomids	07-22-86	8,700	2.4	45	<4.2	160	<4.2	17
8	Macroinvertebrates	Hemipterans	07-22-86	140	<.37	1.9	<.91	<18	<.91	3.3
8	Vascular plants	Sago pondweed	07-22-86	2,400	3.6	25	<1.3	390	<1.3	16
8	Filamentous algae		07-22-86	5,400	4.8	27	<1.7	150	<1.7	210
8	Plankton		07-22-86	9,700	6.8	75	<12	<250	<12	<12
10	Liver	Coot	07-22-86	25	<.18	<.45	<.45	86	<.45	8.1
10	Liver	Coot	07-22-86	33	<.20	<.42	<.42	140	<.42	9.2
10	Liver	Coot	07-22-86	33	<.20	.47	<.40	140	.53	2.3
10	Liver	Coot	07-22-86	3.9	<.18	<.41	<.41	24	<.41	1.6
10	Liver	Coot	07-22-86	2.5	<.21	<.41	<.41	<8.1	<.41	<.41
10	Liver	Coot	07-22-86	20	<.18	<.41	<.41	24	<.41	2.1
10	Egg	Coot	06-04-86	41	<.19	1.9	<.40	<7.9	<.40	.63
10	Egg	Coot	06-04-86	2.1	<.19	2.0	<.40	<8.0	<.40	<.40
10	Egg	Coot	06-04-86	7.5	<.17	3.0	<.41	11	<.41	<.41
10	Macroinvertebrates	Odonates	07-24-86	100	1.6	4.3	<1.7	73	<1.7	15
10	Macroinvertebrates	Hemipterans	07-24-86	50	<.50	14	<1.1	<22	<1.1	7.8
10	Vascular plants	Sago pondweed	07-24-86	1,300	7.2	36	<1.0	420	<1.0	13
10	Filamentous algae		07-24-86	400	5.5	350	<2.9	65	<2.9	35
10	Plankton		07-24-86	160	<8.3	30	<17	<330	<17	<17
11	Egg	Avocet	05-20-86	8.6	<.17	1.4	<.36	15	<.36	<.36
11	Egg	Avocet	05-20-86	2.1	<.18	1.8	<.38	<7.6	<.38	<.38
11	Egg	Avocet	05-20-86	5.3	<.18	5.1	<.36	<7.3	<.36	<.36
12	Macroinvertebrates	Odonates	07-24-86	390	<1.7	<4.2	<4.2	92	<4.2	<4.2
12	Macroinvertebrates	Hemipterans	07-24-86	570	<1.7	7.6	<3.3	66	<3.3	<16
12	Vascular plants	Sago pondweed	07-24-86	5,300	1.5	63	<.88	560	<.88	23
12	Filamentous algae		07-24-86	7,100	5.7	53	<1.4	240	<1.4	19
12	Plankton		07-24-86	6,500	4.4	46	<3.6	<71	<3.6	<3.6
13	Fish	Walleye (adults)	07-23-86	9.9	<.16	2.2	<.35	9.9	<.35	12
13	Fish	White sucker (fingerlings)	07-23-86	180	.30	5.1	<.60	<12	<.60	17
13	Macroinvertebrates	Odonates	07-23-86	200	<.92	4.7	<1.9	<38	<1.9	20
13	Macroinvertebrates	Hemipterans	07-23-86	59	<1.0	2.6	<2.3	<45	<2.3	2.7
13	Vascular plants	Sago pondweed	07-23-86	1,500	5.0	42	<1.0	210	<1.0	27
13	Filamentous algae		07-23-86	4,600	3.9	72	<2.0	300	<2.0	240
13	Plankton		07-23-86	650	21	31	<25	<500	<25	<25

Table 21.--*Biological data, in dry weight*--Continued

Site No. (fig. 6)	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Tin	Vanadium	Zinc
7	69	2,000	<0.78	18	0.29	3.6	1.2	3.2	0.67	44	<0.39	170
7	49	1,900	<1.4	19	.87	3.6	2.2	4.0	.86	44	<.69	180
7	130	1,900	<1.3	23	1.1	3.9	1.3	2.6	1.1	43	<.65	210
7	50	1,800	<.82	15	1.3	3.0	7.4	3.8	<.41	36	<.41	140
7	94	300	<.85	22	1.0	2.5	<.43	2.6	.55	5.7	<.43	94
7	65	1,600	<.89	15	.70	3.5	3.3	3.4	.63	31	<.45	130
7	4.0	160	<.83	4.5	.37	--	.79	1.4	20	--	<.41	46
7	2.7	130	3.7	<3.7	.50	--	.51	1.6	13	--	<.37	21
7	3.1	140	<.81	<4.0	1.2	--	.89	1.1	9.7	--	<.40	43
7	10	210	<11	93	<2.8	<5.6	<5.6	6.5	10	<56	<5.6	98
7	17	340	<5.6	72	<1.2	<2.8	3.1	2.6	27	<28	<2.8	160
7	2.9	2,000	2.1	1,000	<.40	1.6	8.4	.47	120	44	1.9	9.5
7	3.2	1,700	<2.9	1,900	<.63	1.6	21	<.68	650	44	5.0	<15
7	38	1,600	<50	<250	<11	<25	<25	13	600	<250	<25	<250
8	28	940	<2.8	20	.68	<1.4	<1.4	7.4	2.1	21	<1.4	100
8	18	760	<1.5	14	<.37	1.3	3.7	5.9	3.4	18	<.74	76
8	18	4,300	<8.3	92	<1.7	<4.2	12	2.3	59	100	11	61
8	12	250	<1.8	12	<.41	<.91	2.4	.59	27	<9.1	<.91	110
8	11	4,700	<2.6	420	<.68	1.9	15	<.64	370	97	6.1	24
8	8.6	6,400	<3.4	660	<.73	3.3	110	<.85	200	140	11	20
8	30	7,500	140	160	<6.2	<12	<12	<5.8	1,100	190	20	<120
10	44	4,400	<1.89	14	1.0	4.2	4.6	3.2	1.1	98	<.45	210
10	85	410	<.84	13	.98	3.4	3.9	2.6	.60	9.2	<.42	180
10	63	4,000	8.9	15	.64	3.3	2.0	5.0	.70	97	<.40	160
10	59	1,400	<.83	9.9	1.0	3.4	1.2	2.6	.60	26	<.41	170
10	64	1,900	<.81	8.1	1.0	2.8	<.41	2.1	.63	37	<.41	150
10	48	930	<.83	12	.80	2.0	1.9	3.7	.58	16	<.41	120
10	3.5	120	<.79	<4.0	.48	--	1.0	1.6	15	--	<.40	47
10	3.6	96	<.80	<4.0	.47	--	<.40	1.4	27	--	<.40	41
10	2.9	98	<.81	<4.1	.63	--	<.41	1.3	17	--	<.41	49
10	18	170	<3.3	<17	<.77	2.0	7.8	1.1	33	<17	<1.7	83
10	16	160	<2.2	28	<.56	1.2	4.2	<.50	26	<11	<1.1	130
10	4.2	7,400	<2.0	380	<.50	2.3	8.4	<.52	220	150	5.8	14
10	3.5	650	<5.9	410	<1.4	<2.9	12	<1.5	110	<29	<2.9	<29
10	<17	400	<33	<170	<8.3	24	<17	10	110	<170	<17	<170
11	3.2	120	<.72	<3.6	.44	--	<.36	2.7	5.6	--	<.36	47
11	2.3	130	<.76	<3.8	1.6	--	.64	3.0	5.3	--	<.38	42
11	2.8	200	<.73	<3.6	.26	--	<.36	2.9	9.5	--	<.36	42
12	14	180	<8.3	45	<1.8	<4.2	<4.2	<1.7	14	<42	<4.2	100
12	13	570	<6.7	39	<1.6	<3.3	6.5	<1.7	45	<33	<3.3	120
12	3.9	2,500	<1.8	460	<.43	.93	11	<.41	440	61	8.4	11
12	5.8	3,700	<2.8	470	<.59	<1.4	12	1.4	310	83	12	16
12	24	4,400	24	160	<1.6	4.4	<3.6	2.6	220	110	13	140
13	1.4	28	<.70	3.5	.80	<.35	<.35	2.3	<.35	<3.5	.43	29
13	4.1	120	<1.2	7.7	.39	<.60	5.3	2.5	45	<6.0	.80	75
13	17	300	20	42	<.84	<1.9	9.2	<.92	7.3	<19	<1.9	81
13	20	170	<4.5	30	<.97	<2.3	4.3	1.6	12	<23	<2.3	180
13	4.0	2,100	2.1	160	<.50	2.3	13	<.53	270	52	3.3	11
13	9.2	3,500	<4.0	640	<.81	400	120	<.82	150	84	8.0	<20
13	27	650	<50	<250	<12	<25	41	<12	140	<250	<25	<250

Table 22.--*Biological data, in wet weight*

[Analyses by U.S. Fish and Wildlife Service. Concentration, in micrograms per gram. <, less than; --, no data]

Site No. (fig. 6)	Sample type	Taxa	Date (month, day, year)	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium
7	Liver	Coot	07-22-86	3.0	<0.039	0.13	<0.10	6.4	<0.10	1.6
7	Liver	Coot	07-22-86	2.3	<.096	.18	<.15	4.4	<.15	.91
7	Liver	Coot	07-22-86	5.3	.093	<.15	<.15	17	<.15	.77
7	Liver	Coot	07-22-86	1.7	.060	<.096	<.096	7.3	<.096	3.3
7	Liver	Coot	07-22-86	.65	.051	<.098	<.098	4.9	<.098	<.098
7	Liver	Coot	07-22-86	<.11	.051	<.11	<.11	3.2	<.11	.78
7	Egg	Coot	06-03-86	.81	<.042	.73	<.096	<1.9	<.096	<.096
7	Egg	Coot	06-03-86	2.7	<.046	.37	<.096	2.5	<.096	<.096
7	Egg	Coot	06-03-86	.76	<.038	.35	<.097	2.7	<.097	.18
7	Macroinvertebrates	Odonates	07-22-86	2.5	<.041	<.097	<.097	<1.9	<.097	<.097
7	Macroinvertebrates	Hemipterans	07-22-86	13	<.047	.18	<.10	<2.0	<.10	.18
7	Vascular plants	Sago pondweed	07-22-86	78	.27	2.0	<.10	100	.27	1.7
7	Filamentous algae		07-22-86	210	.15	3.7	<.098	18	<.098	3.1
7	Plankton		07-22-86	8.9	<.042	<.099	<.099	3.0	<.099	<.099
8	Liver	Avocet	07-22-86	17	<.098	<.34	<.34	32	<.34	<.34
8	Liver	Avocet	07-22-86	26	.13	.49	<.20	22	<.20	2.2
8	Macroinvertebrates	Chironomids	07-22-86	210	.056	1.1	<.10	3.8	<.10	.40
8	Macroinvertebrates	Hemipterans	07-22-86	15	<.040	.20	<.098	<2.0	<.098	.35
8	Vascular plants	Sago pondweed	07-22-86	170	.26	1.8	<.095	28	<.095	1.2
8	Filamentous algae		07-22-86	310	.27	1.5	<.099	8.5	<.099	12
8	Plankton		07-22-86	77	.053	.59	<.098	<2.0	<.098	<.098
10	Liver	Coot	07-22-86	5.4	<.040	<.097	<.097	19	<.097	1.8
10	Liver	Coot	07-22-86	7.6	<.047	<.098	<.098	33	<.098	2.1
10	Liver	Coot	07-22-86	7.9	<.047	.11	<.096	33	.13	.55
10	Liver	Coot	07-22-86	.89	<.041	<.095	<.095	5.5	<.095	.36
10	Liver	Coot	07-22-86	.61	<.050	<.098	<.098	<2.0	<.098	<.098
10	Liver	Coot	07-22-86	4.6	<.042	<.097	<.097	5.6	<.097	.50
10	Egg	Coot	06-04-86	10	<.047	.46	<.097	<1.9	<.097	.15
10	Egg	Coot	06-04-86	.51	<.048	.49	<.098	<2.0	<.098	<.098
10	Egg	Coot	06-04-86	1.8	<.040	.72	<.097	2.5	<.097	<.097
10	Macroinvertebrates	Odonates	07-24-86	5.9	.094	.26	<.098	4.3	<.098	.87
10	Macroinvertebrates	Hemipterans	07-24-86	4.5	<.044	1.2	<.097	<1.9	<.097	.70
10	Vascular plants	Sago pondweed	07-24-86	120	.70	3.5	<.097	41	<.097	1.3
10	Filamentous algae		07-24-86	13	.18	12	<.096	2.1	<.096	1.2
10	Plankton		07-24-86	.88	<.047	.17	<.093	<1.9	<.093	<.093
11	Egg	Avocet	05-20-86	2.3	<.045	.36	<.094	4.0	<.094	<.094
11	Egg	Avocet	05-20-86	.55	<.046	.47	<.099	<2.0	<.099	<.099
11	Egg	Avocet	05-20-86	1.4	<.048	1.4	<.098	<2.0	<.098	<.098
12	Macroinvertebrates	Odonates	07-24-86	9.1	<.040	<.097	<.097	2.1	<.097	<.097
12	Macroinvertebrates	Hemipterans	07-24-86	17	<.048	.22	<.097	1.9	<.097	.47
12	Vascular plants	Sago pondweed	07-24-86	600	.17	7.2	<.10	64	<.10	2.6
12	Filamentous algae		07-24-86	490	.39	3.7	<.096	17	<.096	1.3
12	Plankton		07-24-86	180	.12	1.3	<.097	<1.9	<.097	<.097
13	Fish	Walleye (adults)	07-23-86	2.7	<.045	.60	<.097	2.7	<.097	3.3
13	Fish	White sucker (fingerlings)	07-23-86	30	.050	.84	<.10	<2.0	<.10	2.8
13	Macroinvertebrates	Odonates	07-23-86	9.7	<.045	.23	<.095	<1.9	<.095	1.0
13	Macroinvertebrates	Hemipterans	07-23-86	2.6	<.045	.11	<.099	<2.0	<.099	.12
13	Vascular plants	Sago pondweed	07-23-86	150	.48	4.0	<.099	20	<.099	2.6
13	Filamentous algae		07-23-86	220	.19	3.4	<.096	14	<.096	11
13	Plankton		07-23-86	2.5	.083	.12	<.097	<1.9	<.097	<.097

Table 22.--*Biological data, in wet weight*--Continued

Site No. (fig. 6)	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Tin	Vanadium	Zinc
7	18	520	<0.20	4.6	0.075	0.92	0.30	0.81	0.17	11	<0.10	44
7	10	410	<.29	4.1	.18	.76	.47	.85	.18	9.4	<.15	38
7	30	450	<.31	5.6	.25	.93	.31	.63	.25	10	<.15	50
7	12	430	<.19	3.4	.31	.70	1.7	.88	<.096	8.4	<.096	33
7	22	69	<.20	5.1	.24	.57	<.098	.61	.13	1.3	<.098	22
7	16	400	<.22	3.7	.17	.85	.80	.82	.15	7.5	<.11	30
7	.92	37	<.19	1.0	.087	--	.18	.33	4.6	--	<.096	11
7	.71	34	.96	<.96	.13	--	.13	.42	3.5	--	<.096	5.4
7	.76	33	<.19	<.97	.28	--	.21	.26	2.3	--	<.097	10
7	.18	3.7	<.19	1.6	<.048	<.097	<.097	.11	.18	<.97	<.097	1.7
7	.60	12	<.20	2.6	<.043	<.10	.11	.094	.98	<1.0	<.10	5.8
7	.36	250	.26	120	<.049	.20	1.0	.058	15	5.4	.24	1.2
7	.21	110	<.20	130	<.042	.11	1.4	<.045	43	2.9	.33	<.98
7	.15	6.5	<.20	<.99	<.044	<.099	<.099	.050	2.4	<.99	<.099	<.99
8	6.9	230	<.69	4.9	.17	<.34	<.34	1.8	.52	5.1	<.34	26
8	4.7	200	<.39	3.6	<.098	.36	.98	1.6	.90	4.7	<.20	20
8	.42	100	<.20	2.2	<.040	<.10	.28	.055	1.4	2.4	.25	1.5
8	1.3	27	<.20	1.3	<.044	<.098	.26	.064	2.9	<.98	<.098	12
8	.78	340	<.19	30	<.049	.14	1.1	<.046	27	7.0	.44	1.7
8	.50	370	<.20	38	<.042	.19	6.6	<.049	12	8.3	.64	1.2
8	.24	59	1.1	1.2	<.049	<.098	<.098	<.046	8.7	1.5	.16	<.98
10	9.5	960	<.19	3.1	.23	.91	1.0	.70	.23	21	<.097	45
10	20	96	<.20	2.9	.23	.78	.90	.60	.14	2.1	<.098	41
10	15	950	2.1	3.5	.15	.79	.48	1.2	.17	23	<.096	38
10	13	330	<.19	2.3	.23	.79	.26	.60	.14	6.0	<.095	38
10	15	450	<.20	2.0	.24	.68	<.098	.51	.15	9.0	<.098	37
10	11	220	<.19	2.9	.19	.47	.44	.87	.14	3.7	<.097	29
10	.85	29	<.19	<.97	.12	--	.25	.39	3.7	--	<.097	11
10	.88	23	<.20	<.98	.12	--	<.098	.34	6.7	--	<.098	10
10	.70	23	<.19	<.97	.15	--	<.097	.30	4.1	--	<.097	12
10	1.1	10	<.20	<.98	<.045	.12	.46	.067	2.0	<.98	<.098	4.9
10	1.4	14	<.19	2.5	<.050	.10	.38	<.044	2.3	<.97	<.097	11
10	.41	720	<.19	37	<.049	.23	.81	<.050	21	15	.56	1.4
10	.12	21	<.19	13	<.045	<.096	.38	<.050	3.7	<.96	<.096	<.96
10	<.093	2.2	<.19	<.93	<.047	.13	<.093	.056	.64	<.93	<.093	<.93
11	.83	32	<.19	<.94	.12	--	<.094	.71	1.5	--	<.094	12
11	.61	34	<.20	<.99	.41	--	.17	.78	1.4	--	<.099	11
11	.75	53	<.20	<.98	.071	--	.098	.79	2.6	--	<.098	11
12	.33	4.3	<.19	1.1	<.042	<.097	<.097	<.040	.33	<.97	<.097	2.3
12	.37	16	<.19	1.1	<.047	<.097	.19	<.048	1.3	<.97	<.097	3.5
12	.44	290	<.20	52	<.049	.11	1.3	<.047	50	7.0	.96	1.3
12	.40	260	<.19	33	<.041	<.096	.85	.098	21	5.8	.81	1.1
12	.64	120	.64	4.3	<.044	.12	<.097	.071	6.0	2.9	.35	3.9
13	.39	7.8	<.19	.97	.22	<.097	<.097	.63	<.097	<.97	.12	7.9
13	.68	19	<.20	1.3	.065	<.10	.88	.42	7.4	<1.0	.13	12
13	.86	15	.97	2.1	<.042	<.095	.46	<.045	.36	<.95	<.095	4.0
13	.89	7.3	<.20	1.3	<.042	<.099	.19	.071	.53	<.99	<.099	7.7
13	.38	200	.20	15	<.048	.22	1.2	<.050	26	5.0	.32	1.1
13	.44	170	<.19	31	<.039	19	5.9	<.039	7.3	4.0	.38	<.96
13	.11	2.5	<.19	<.97	<.045	<.097	.16	<.046	.54	<.97	<.097	<.97