Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Malheur National Wildlife Refuge, Harney County, Oregon, 1988-89

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 91-4085

Prepared in cooperation with
U.S. FISH AND WILDLIFE SERVICE and
U.S. BUREAU OF RECLAMATION

Portland, Oregon
1992

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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Electrical conductivity is measured as specific electrical conductance, in units of microsiemens per centimeter ($\mu S/cm$) at 25 degrees Celsius (°C).

Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter ($\mu g/L$). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water, and is about the same as parts per million (ppm), by volume, unless concentrations are more than 7,000 mg/L. One thousand micrograms per liter is equivalent to 1 mg/L. One million nanograms per liter is equivalent to 1 mg/L. Chemical concentration in sediment and biological tissues is given in milligrams per kilogram (mg/kg) or micrograms per gram ($\mu g/g$) which are both equal to parts per million by mass. One percent by weight chemical concentration is equal to 10,000 $\mu g/g$.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$F = 1.8\ (°C) + 32.$$

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.

RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE MALHEUR NATIONAL WILDLIFE REFUGE, HARNEY COUNTY, OREGON, 1988-89

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By Frank A. Rinella and Carol A. Schuler

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ABSTRACT

A reconnaissance investigation of irrigation drainage was conducted during 1988-89 at the Malheur National Wildlife Refuge, southeastern Oregon. The study's objective was to determine if agricultural drainwater entering the Refuge was causing or had the potential to cause significant harmful effects to human health, fish and wildlife, or other beneficial water uses.

Concentrations of arsenic, boron, mercury, and selenium in some Refuge lake water and (or) biological tissues were sufficiently elevated to exceed recommended guidelines or criteria for the protection of the health of either humans, fish or wildlife, or to affect adversely other identified beneficial uses. However, these elevated concentrations were not consistently found in all sample mediums and were, therefore, probably not causing substantial adverse affects.

Small but detectable concentrations of dichlorodiphenyltrichloroethane (DDT) and metabolites, and endrin were found in lake bottom sediment. Most of the biota contained small or undetectable concentrations of organochlorine pesticides and polychlorinated biphenyls (PCBs).

Although lake levels were considerably above normal in 1988, lake concentrations of several water-quality constituents were found to be much higher than those concentrations observed historically. Lake levels have continued to decline in 1989 and 1990, thus further increasing speculation that these same constituents have continued to increase in concentration. It is projected that as the lake levels approach near-normal conditions, arsenic concentrations in the water could range from 300 to 350 μg/L (microgram per liter), and boron concentrations could range from 15,000 to 20,000 μg/L. These concentrations could result in conditions that would produce toxic effects in fish and wildlife at the Refuge. Current projections do not consider what conditions would result if below-normal lake levels are reached. The potential for these projected constituent concentrations to cause chronic and acute toxicity problems in the Refuge cannot be adequately assessed at this time.

Although elevated concentrations of some constituents were found in some sample mediums, none were thought to be associated with agricultural drainwater. Therefore, it was concluded that agricultural runoff to the Refuge in 1988 was not causing significant harmful effects to human health or to fish and wildlife resources.

INTRODUCTION

During the last several years, there has been increasing concern about the quality of irrigation drainage and its potentially harmful effects on human health, fish, and wildlife. Concentrations of selenium exceeding water-quality criteria for the protection of aquatic life (U.S. Environmental Protection Agency, 1986) have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley in California. In 1983, incidents 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 pesticides 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 (DOI) started a program in late 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the Western States. In October 1985, an interbureau group known as the "Task Group on Irrigation Drainage" was formed within the DOI. The Task Group subsequently prepared a comprehensive plan for reviewing irrigation-drainage concerns for which the DOI may have responsibility.

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

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

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

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

area, and the Kendrick Reclamation Project area. Eleven more reconnaissance investigations were started in 1988:

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

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

Background

In 1984-85, a collaborative water-quality investigation was conducted by the U.S. Geological Survey and the Oregon Department of Environmental Quality at the Refuge and in the Malheur River (Fuste' and McKenzie, 1987). One of the objectives of the study was to characterize water quality in the three Refuge lakes (Malheur, Mud, and Harney Lakes). Fuste and McKenzie (1987) noted concentrations of arsenic and boron in Harney Lake that exceeded recommended drinking-water and irrigation-water standards, respectively. In addition, the Oregon Department of Environmental Quality found mercury concentrations in fish tissues that exceeded the 85th percentile of the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program (NCBP) [Lowe and others, 1985]. Because the Refuge is located near agricultural land, and elevated concentrations of selected trace elements were detected in Refuge water and fish tissues, a potential existed for irrigation drainwater to affect the beneficial water uses of the Refuge.

Purpose and Scope

This report presents results of a reconnaissance investigation of the Malheur National Wildlife Refuge in 1988-89 to determine the potential for irrigation drainage water to adversely affect human health, fish and wildlife populations, and other beneficial water uses. To determine these potential environmental effects, a series of samples were collected in this study, which included (1) water from inflowing streams to the Refuge, (2) Refuge lake and spring water and bottom sediment, and (3) plants, invertebrates, fish, birds, and eggs within the Refuge. These samples were analyzed for concentrations of selected

major and minor elements, pesticides, and polychlorinated biphenyls (PCBs). These concentrations were compared with various water-quality standards or criteria, published literature values, concentrations naturally occurring in the area or from other locations, and concentrations found in contaminated locations.

On the basis of land- and water-management practices, the investigation was divided into three study areas. These areas were the Blitzen (which included south of Malheur Lake), the Silvies (which included north of Malheur Lake), and Silver Creek (which included north of Harney Lake) drainages. Timing for the collection of these samples took into consideration current irrigation practices and the bird breeding season.

Acknowledgments

The authors wish to thank George C. Constantino, Manager of the Malheur National Wildlife Refuge, and Refuge biologists David G. Paullin and Gary Ivey for providing logistical and field support and extensive background information on the Refuge. David G. Paullin deserves special appreciation in that his assistance and knowledge of the Refuge was critical for completing the field collections. The authors also wish to thank Bret Hodgson for his field assistance. The authors wish to acknowledge assistance of staff within their respective offices: Richard L. Roche for laboratory and field support, Jim W. Ball for geochemical workup and interpretation of the data, and Mark Hueber of the U.S. Geological Survey for performing the isotope analyses; Laura A. Gill for field and laboratory support and Marvin S. Yoshinaka and Charles D. Craig of the U.S. Fish and Wildlife Service for providing field support. The authors would like to also acknowledge reviews of this report by the National Irrigation Water-Quality Program and staff from the Malheur National Wildlife Refuge.

GENERAL DESCRIPTION OF THE MALHEUR NATIONAL WILDLIFE REFUGE

Description of the Basin

Malheur National Wildlife Refuge is located in Harney Basin, the largest hydrologically closed basin in Oregon (fig. 1). Harney Basin, draining an area of about 5,300 mi^2 (square miles) in southeastern Oregon, is one of the largest inland wetlands in the United States. The Refuge spans an area 40 miles long by 39 miles wide and is shaped like a lopsided "T." The Refuge covers approximately 184,000 acres of open water, marshes, wet meadows, riparian areas, irrigated meadows and grain fields, shrub uplands, grass uplands, alkali playas, and rimrock. The Refuge headquarters, located on the south side of Malheur Lake, is situated 32 miles southeast of the nearest town, Burns, Oregon. Harney Valley, a low flat area of about 600 mi^2, borders the Refuge, with about two-thirds of it lying to its north.

The Refuge was established in 1908 by an executive order of President Theodore Roosevelt for the production and maintenance of habitat for migratory water birds (U.S. Fish and Wildlife Service, 1985). Its area was expanded in 1935 with the inclusion of the 60,000-acre Blitzen Valley and in 1941 with the addition of the Double-O Unit

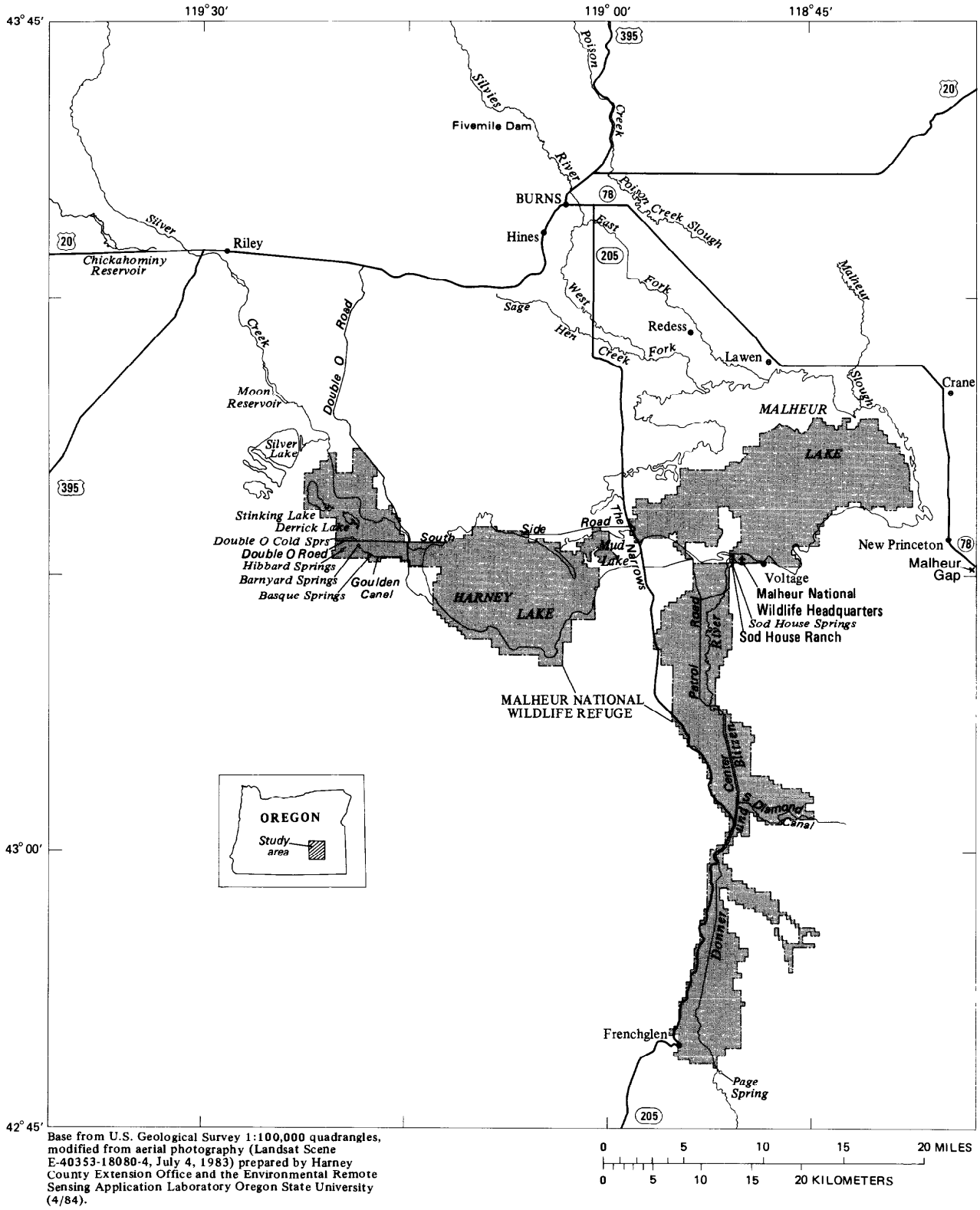

Figure 1.--Location of the Malheur National Wildlife Refuge.

acreage. Malheur, Mud, and Harney Lakes are the three major water bodies within the Refuge. Malheur Lake, in normal water years, is a shallow freshwater marsh, the largest in western North America.

The Refuge receives surface water from three principal sources. The Silvies River, whose headwater is in the Blue Mountains, drains 1,350 mi^2 in a southern direction and finally empties into Malheur Lake. Silver Creek to the northwest drains about 900 mi^2 and empties into Harney Lake. The Donner und Blitzen River, whose headwater is in the Steens Mountains located in the most southeastern part of the basin, drains 1,000 mi^2 and joins into Malheur Lake from the south. The area south of Malheur Lake that surrounds the Donner und Blitzen River is referred to as the Blitzen Valley. Malheur Lake is connected to Harney Lake through a channel called The Narrows (fig. 1). Harney Lake, the lowest point in the basin, is a natural sump. Evapotranspiration is the principal means of outflow from the lakes, accounting for 80 to 95 percent of lake water losses (Hubbard, 1975). Hubbard (1975) estimated evapotranspiration at about 40 inches per year and reported that groundwater losses were insignificant.

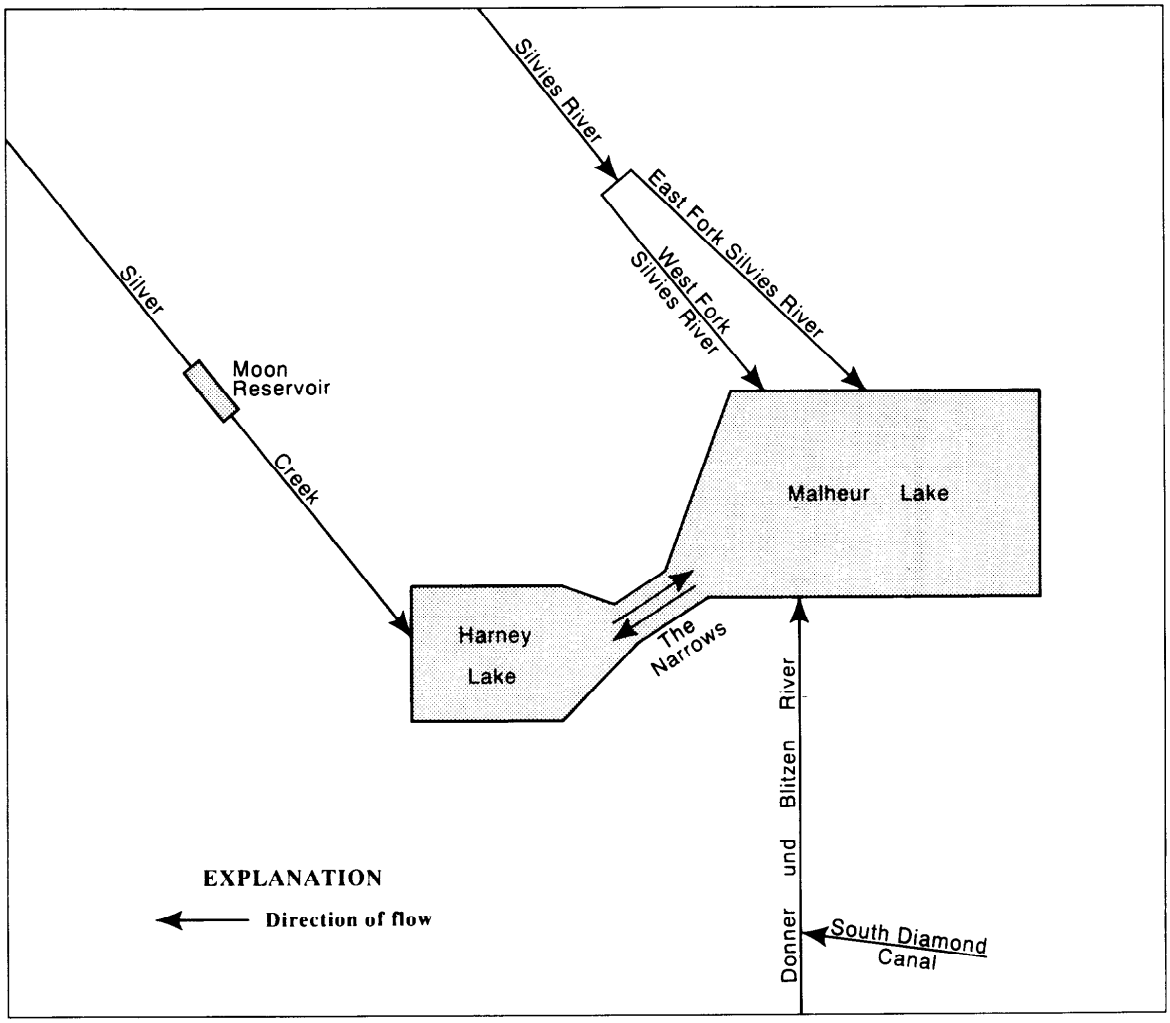

Figure 2.--Diagram of water movement through the Malheur National Wildlife Refuge.

The Refuge supports a variety of migratory and resident aquatic birds, raptor and passerine birds, resident game and nongame fish, and other resident wildlife. The productivity of the Refuge and its size and diversity of aquatic birdlife makes it an important part of the Pacific Flyway refuge system.

The area is an attractive tourist destination because of the rugged and varied nature of the terrain and the variety of wildlife that can be observed on the Refuge. The National Forests located north of the Refuge, the Refuge in the central part of the basin, and the Steens Mountains to the south are also important attractions. Three sites on the Refuge have been placed on the National Register of Historic Places; P-Ranch, Sod House Ranch, and Double-O Ranch. The sites include many of the original buildings and corrals. Parts of the Refuge are considered significant archaeological sites for American Indian artifacts. Stinking and Harney Lakes are designated as National Research Natural Areas. Grazing and recreational use have been excluded from these areas and each is managed for research, education, and related purposes.

Climate

The Harney Basin has a semi-arid climate with cold winters and short, relatively warm summers. The growing season averages 90 days. About 10 inches of precipitation fall in the valley annually, with about 50 percent of the total occurring between November and February; another 10 percent occurs during the driest months of July through September (Leonard, 1970). Most of the precipitation during November to March is in the form of snow.

The quantity of precipitation increases with altitude. Annual precipitation is about 19 inches in the Blue Mountains located north and northeast of Malheur Lake where the headwaters of the Silvies River, Sage Hen, Poison, and other creeks are located (Leonard, 1970). Annual precipitation can exceed 60 inches in the Steen Mountains, located south of Malheur Lake, which form the headwaters of the Donner und Blitzen River and numerous other creeks.

Temperature extremes in the Harney Basin are due largely to elevation and sun exposure. Winter daily temperature minimums in Harney Valley can average 20 °F less than the daily maximums, whereas summer (July - August) daily temperature can vary 35 °F throughout a day. Both Malheur and Harney Lakes commonly freeze over between December and February.

Geohydrology

The Refuge and surrounding area consists of alluvial and lake deposits, as well as aeolian sediment derived largely from volcanic rocks of adjacent uplands. Geologists infer that sedimentation of the Harney Basin occurred after a basalt extrusion dammed Malheur Gap (located near Princeton, Oregon), a former drainage outlet for the basin (Baldwin, 1976).

During Pleistocene time, increased precipitation and decreased evaporation resulted in a "pluvial" lake in Harney Basin. When at its highest level, the resulting expanded and deepened lake drained eastward

into the Malheur River. Drainage occurred first through a channel near Princeton and later through one near Crane, when lava flows blocked the former outlet (Baldwin, 1976). At the end of the Pleistocene glaciation period (about 10,000 years ago), warmer and drier conditions caused the pluvial lake to diminish until it no longer had an outlet and became a closed basin. Much of this former pluvial lake bottom is now brush-covered desert or is seasonally flooded grass-sedge meadowland. Malheur, Mud, and Harney Lakes are remnants of the Pleistocene lake (Duebbert, 1969).

Alluvial and lake deposits underlie the Harney Valley to depths approaching 250 feet. These deposits, in turn, are underlain by several hundred feet or more of older volcanic and sedimentary deposits (Leonard, 1970). The alluvial deposits consist predominantly of clay, silt, and fine sand in the central part of the valley, but sand and gravel predominate along the Silvies River fan near Burns and in other localities at the edge of the valley. The sand and gravel deposits gradually become finer southward, interfingering with silt and clay. Alluvial deposits in the Donner und Blitzen Valley south of Malheur Lake also are coarse grained and permeable but become finer grained northward.

Much of the ground water within the valley originates from recharge in the surrounding highlands. In addition, recharge also occurs during spring snowmelt runoff, when surface water floods parts of the valley. In Harney Valley, ground water generally moves southward toward Malheur Lake and either discharges to the atmosphere as evapotranspiration or discharges to Malheur and Harney Lakes. Ground water is similarly recharged in the Donner und Blitzen Valley, and ground-water movement is generally northward toward Malheur Lake (Leonard, 1970).

Some irrigation wells tap unconfined shallow alluvium northwest of Malheur Lake, but most irrigation wells are completed in semiconfined-to-confined aquifers in the deeper volcanic and sedimentary rocks. These deeper wells are located chiefly in the northwestern part of the valley and along the eastern edge.

Soils

The predominant soils surrounding the Refuge consist of fluvial and lacustrine deposits. The soils are light-colored and neutral or calcareous. Much of the area is poorly drained and has shallow hardpans. Soils in the surrounding valley are on lava plateaus or plains, which are shallow, stony, and light colored, containing clayey or loamy subsoils (Atlas of Oregon, 1977).

Most of the land surrounding the Refuge is suitable for livestock grazing, but not arable. The land is highly susceptible to erosion and contains alkali (evaporite deposits). Alkali is formed by evapotranspiration losses of shallow ground water in the arid climate. The area north of the Refuge has moderate to good arable land and requires some protection from erosion and improvement for drainage. Alkali soils can be found in some places south and east of the arable land (Atlas of Oregon, 1977).

Elemental concentrations of two soil samples collected in the study area (Boerngen and Shacklette, 1981) fall within a range of geochemical baseline concentrations of elements found in soils west of the 97th meridian within the conterminous United States (R. C. Severson, U.S. Geological Survey, written commun., 1987, based on data in Shacklette and Boerngen, 1984) [table 1].

Table 1.--Concentration range of elements found in two soil samples collected at the Malheur National Wildlife Refuge compared to the expected 95-percent confidence range for element concentrations in soils from the Western United States

[%-Wt = percent by weight; µg/g = micrograms per gram by weight; "--" = not analyzed]

Element	Unit of measure	Malheur Wildlife Refuge[1]	Western United States[2]
Aluminum	%-Wt	10 - >10	1.5 - 23
Arsenic	µg/g	5.5 - 7.8	1.2 - 22
Barium	µg/g	700 - 700	200 - 1700
Beryllium	µg/g	1.5 - 1.5	.13 - 3.6
Boron	µg/g	20 - 20	5.8 - 91
Calcium	%-Wt	1.16 - 1.60	.19 - 17
Chromium	µg/g	30 - 30	8.5 - 200
Copper	µg/g	30 - 30	4.9 - 90
Iron	%-Wt	3.0 - 5.0	.55 - 8.0
Lead	µg/g	10 - 15	5.2 - 55
Mercury	µg/g	.02 - .03	.0085 - .25
Magnesium	%-Wt	.5 - .7	.15 - 3.6
Manganese	µg/g	500 - 700	97 - 1500
Nickel	µg/g	15 - 20	3.4 - 66
Potassium	%-Wt	2.53 - 2.80	.38 - 3.2
Selenium	µg/g	<.1 - .3	.039 - 1.4
Sodium	%-Wt	1.5 - 3.0	.26 - 3.7
Strontium	µg/g	300 - 500	43 - 930
Uranium	µg/g	--	1.2 - 5.3
Vanadium	µg/g	70 - 70	18 - 270
Zinc	µg/g	50 - 99	17 - 180

[1] Boerngen and Shacklette, 1981.
[2] R. C. Severson, U.S. Geological Survey, written commun., 1987 based on data in Shacklette and Boerngen, 1984.

Agricultural Practices

The economy of the area surrounding the Refuge and in Harney County is based largely on agriculture and some forest products. Livestock, hay, and some grain crops are the chief products of agriculture. The hay crops are used extensively for raising beef cattle. Irrigation water for hay crops is derived mainly from spring snowmelt and is used to flood irrigate the fields. A 1982 census of agriculture lists 409 farms with an average size of 3,647 acres in Harney County (U.S. Army Corps of Engineers, 1987a). Of the farmland in use, 220,888 acres are in cropland, 28,365 acres are in woodland, 1,226,764 acres are in pasture and rangeland, and 15,488 acres are in houselots, roads, and other nonagricultural uses. About 145,700 acres are irrigated in Harney County. During normal years, combined irrigation diversions from the three drainages (Silvies, Donner und Blitzen, and Silver) amount to about 100,000 acre-feet/year (U.S. Army Corps of Engineers, 1987b).

Within the Refuge boundaries, sufficient lands are in production for haying and grazing to support up to 5,000 cattle annually (U.S. Fish and Wildlife Service, 1985). This is 40-60 percent less than was in production in the late 1960's and early 1970's when almost every available acre was used for cattle production. The large drop in acreage for haying and grazing is primarily due to management efforts to improve and increase bird nesting and brooding-rearing habitats.

Fish and Wildlife Resources

Malheur National Wildlife Refuge is managed by the U.S. Fish and Wildlife Service for the benefit of wildlife, particularly migratory birds. Management is designed to maintain the naturally occurring diverse mixture of habitats located within the Refuge boundaries (U.S. Fish and Wildlife Service, 1985). The broad goals of the Refuge are to preserve, restore, and enhance all threatened and endangered species; to perpetuate the migratory bird resource; and to preserve the natural diversity and abundance of flora and fauna. The Refuge also tries to provide the public with an understanding and appreciation of fish and wildlife ecology, and provide visitors with high quality and enjoyable recreational experiences oriented towards wildlife to the extent these activities do not interfere with the purposes for which the Refuge was established.

Management of the Refuge focuses on several key practices that include vegetation management, water management, farming, aquatic-plant production, predator management, reduction of human disturbances, and waterfowl-disease monitoring (U.S. Fish and Wildlife Service, 1985). Predation, primarily by ravens, coyotes, and raccoons plays a critical role in limiting success of breeding aquatic birds. Consequently, the Refuge has begun an effort to maintain predator populations at a level compatible with aquatic-bird populations.

Vegetation management is used on the Refuge to promote new growth for nesting cover, recycle nutrients, reduce brush, increase abundance of grasses, open up densely vegetated marshes, and create open feeding areas. This is accomplished by irrigation, haying, grazing, deferment from haying and grazing, prescribed burning, and noxious weed control.

The Refuge uses crop management to supplement the food supply for seasonal use by some aquatic birds. Crops are cooperatively farmed. The most common crops grown are barley, wheat, and oats. Production of aquatic plants in many areas of the Refuge is very low primarily because of the negative impacts of carp populations on the growth of these plants. Control of carp populations is difficult because the tremendous size of Malheur and Harney Lakes makes chemical-control cost prohibitive.

The value of the Refuge to migratory aquatic birds is largely dependent on adequate water resources. Refuge water supplies influence wildlife production by providing habitat for territories, nesting, and feeding, and for production of food plants and organisms. Water supplies are determined primarily by annual precipitation and evaporation rates in the Malheur-Harney Lakes area. The Refuge has limited control of water supplies by irrigation systems, such as dikes, canals, and other structures in the Blitzen Valley and the Double-O. Thus, its water supply is almost wholly dependent on natural water fluxes.

For management purposes, the Refuge is divided into four planning units: Double-O, Harney and Mud Lakes, Malheur Lake, and Blitzen Valley (U.S. Fish and Wildlife Service, 1985). The land- and water-management plan for Double-O and Blitzen Valley follows a developmental theme and is extensively developed with roads, dikes, ditches, water-control structures, ponds, nesting islands, farming, and irrigation. Management for Harney, Mud, and Malheur Lakes is nondevelopmental and emphasizes the use of natural ecosystem processes.

A diversity of fish and wildlife habitats occurs on the Refuge including warm water and cold water fish habitat, riparian areas, open water, marshes, nesting islands, irrigated meadows and grainfields, and uplands. The area serves as a major feeding, resting, and nesting area for migrating waterfowl, shorebirds, marsh birds, colonial nesting waterbirds, and raptor and passerine bird species in the Pacific Flyway. The marshes of the Refuge provide critical nesting and brooding habitat for diving ducks (redheads, canvasbacks, and ruddy ducks), geese and swans (Canada geese and trumpeter swans), colonial nesting species (eared and western grebes, white pelicans, double-crested cormorants, great blue herons, great egrets, bitterns, black-crowned night herons, and white-faced ibis), and other marsh and shorebirds. Malheur supports a crucial nesting population of greater sandhill cranes. Up to 90 percent of the California central valley population use the Refuge grainfields during fall migration. The shoreline sand and mudflat areas are important nesting and feeding habitat for snowy plovers, black-necked stilts, and American avocets. Large numbers of killdeer, long-billed curlews, Franklin's gulls, loggerhead shrikes, yellow warblers, willow flycatchers, and Brewer's sparrows are also produced annually. Several pairs of golden eagles are known to nest on the rimrocks in upland areas of the Refuge. Bald eagles frequent the area primarily during the winter and spring migration periods. Peregrine falcons periodically use the Refuge for feeding.

The Malheur-Harney Lakes area supports a variety of native and introduced game and nongame fish (Vorderstrasse and Garst, 1987). Game fish include Lahontan cutthroat, brook, rainbow, and redband trout;

whitefish; bluegill and pumpkinseed sunfish; brown bullhead; channel catfish; white crappie; yellow perch; and largemouth and smallmouth bass. Nongame fish include common carp, sucker, Tui chub, chiselmouth, shiner, dace, sculpins, and squawfish. Angling for game fish is prohibited on Malheur, Mud and Harney Lakes because of potential conflicts with migratory bird objectives.

Common carp provide a food source for large numbers of fish-eating birds, but have a destructive impact on submergent vegetation and aquatic-food resources. Consumption of plants and the turbid conditions created by their feeding and spawning actions prevents the growth of most aquatic plants. A lack of submergent vegetation has an adverse effect on bird production by limiting the availability of aquatic invertebrates which are necessary for food during the early development of many aquatic birds. The carp's activities also adversely effect migratory birds by depleting food resources. In 1978, Malheur Lake was treated with rotenone to reduce the carp population and allow recovery of submergent vegetation, particularly sego pondweed (Horton and others, 1983). The control program resulted in major increases in plant abundance which increased the use of the Refuge by migratory birds. However, since that time, carp numbers have substantially increased and sego pondweed is now virtually absent from the lakes.

The Refuge supports a large variety of resident wildlife species (Vorderstrasse and Garst, 1987). In upland regions, mule deer and pronghorn antelope are common. Mink, beaver, long-tailed weasels, and muskrat are abundant in wet meadows and other aquatic habitats. Rabbits, coyotes, and many species of rodents are common in most habitats. Evidence of bobcats is occasionally found in rocky upland habitats. Although the Refuge is not specially managed for upland game birds, it does support populations of ring-necked pheasant, chukar, quail, and mourning dove. A large variety of passerines also inhabit the area.

Approximately 57,000 acres of wildlife habitat on the Refuge was inundated during the high water period from record rainfall and heavy snowpacks in the early 1980's (U.S. Fish and Wildlife Service, 1984; Vorderstrasse and Garst, 1987). Increasing water levels have caused dramatic changes in habitats and in the abundance of some birds using the area. Prior to flooding, Malheur Lake was predominately islands and large shallow water areas dominated by emergent vegetation. With rising water levels, the lakes became too deep to support emergent vegetation and rose too rapidly to allow establishment of new wetland vegetation. Ice and wave action from the high water destroyed vegetation, brush, and numerous trees used for nesting. Thus, the loss of critical nesting habitat resulted in a reduction in the number of nesting pairs of some birds. Flooding also eliminated feeding habitats for numerous species that forage in shallow water, mudflats, sandy exposed areas, alkali playas, marsh vegetation, and emergent plant habitat. Duck nesting decreased after the loss of nesting and foraging habitat (fig. 3). Spring and fall waterfowl use also declined on the Refuge. Nesting and migrational use of Malheur by shorebirds decreased because of the loss of shallow water, mudflats, and alkali playas traditionally used for feeding and nesting.

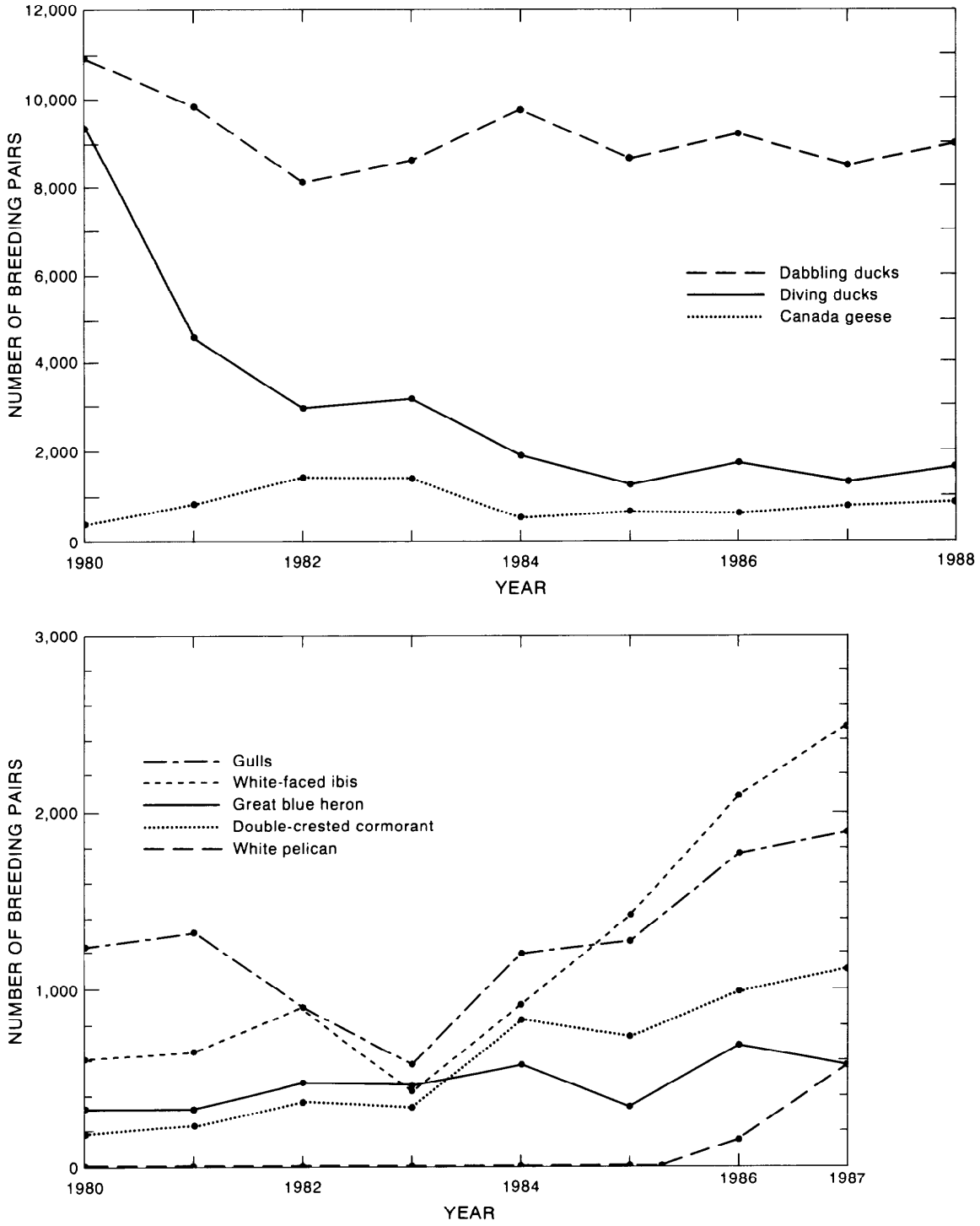

Figure 3.--Estimated number of nesting pairs of waterfowl and colonial birds using the Malheur-Harney Lakes area from 1980 to 1988 (U.S. Fish and Wildlife Service 1986, 1988).

The rising water levels also were disruptive to colonial nesting birds. The overall effect of flooding was the dispersal of birds from a few large colonies to numerous, small scattered colonies. Nesting pairs of several species of colonial nesting birds increased, including double-crested cormorants, great blue herons, white-faced ibis, California gulls, caspian terns, and white pelicans (fig. 3). With the onset of flooding, the deep open-water areas of the lakes were greatly increased, providing more foraging opportunities for fish-eating birds, such as double-crested cormorants and white pelicans. White pelicans nested on the Refuge in 1985 for the first time since 1960, and the number of nesting pairs has continued to increase (fig. 3). In the future, bird species and numbers on the Refuge can be expected to continue to change as the high water recedes to more normal conditions.

HYDROLOGIC SETTING

As previously noted, the Donner und Blitzen River and the Silvies River are the principal surface-water inflows to Malheur Lake, while Silver Creek flows directly into Harney Lake. The Silvies River and Silver Creek drain forested uplands rising to over 6,000 feet, while the Donner und Blitzen River drains the over 9,000-foot Steen Mountains. Spring snowmelt runoff is the principal source of streamflow and groundwater recharge to the area. Because the Silvies River and Silver Creek drainages are at lower elevations than the Donner und Blitzen River drainage, the duration and timing of their respective peak flows are different. As shown in figure 4, 1988 peak flow from the Donner und

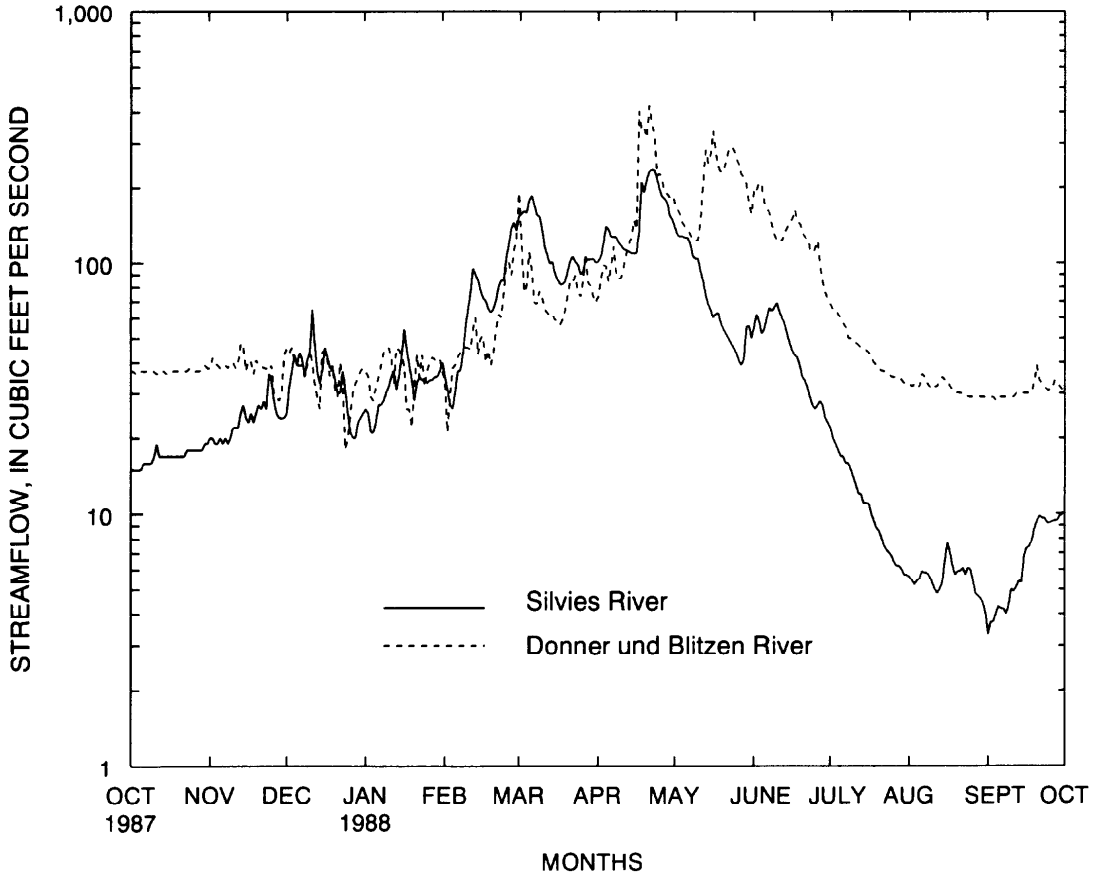

Figure 4.--Daily mean streamflow of the Silvies and the Donner und Blitzen Rivers, 1988 water year.

Blitzen River arrived a few weeks later than the flow from the Silvies River. The Donner und Blitzen River peak flow also is higher, and continues later in the season as the higher-level snow melts off (fig. 4). When Malheur lake-surface elevation reaches 4,092 feet, water flows from the main body of Malheur Lake through the Narrows into Mud Lake, and then into Harney Lake. Because Harney Lake has no outflow streams, the only source of water loss to the system is through evaporation. On an annual basis, the lowest levels in Malheur Lake occur typically in September or October. The highest levels occur generally in May or June, as a result of spring snowmelt runoff.

Hubbard (1975) estimated the contributions of ground water and precipitation (direct input to the lake surface) to Malheur Lake; estimates for Harney and Mud Lakes were not made. The only appreciable source of ground-water flow into Malheur Lake was Sod House Springs located near the mouth of the Donner und Blitzen River. During 1972 and 1973 water years, Sod House Springs estimated contribution was 4 and 12 percent, respectively of the inflow to Malheur Lake, while estimated inflow from precipitation to the lake was 13 and 25 percent, respectively (Hubbard, 1975). The remaining 63 to 83 percent of the inflow to Malheur Lake was surface-water contributions from the Donner und Blitzen and Silvies Rivers. Hubbard (1975) estimated that during 1972 and 1973 water years, evapotranspiration accounted for 80 and 96 percent, respectively, of the water outflow from Malheur Lake, with the remaining surface-water outflow through The Narrows.

Record snowfalls and unusually cool summers beginning in 1982 caused Malheur Lake surface elevation to rise dramatically (fig. 5). On June 27, 1984, Malheur Lake reached a lake-surface elevation of 4,102.4

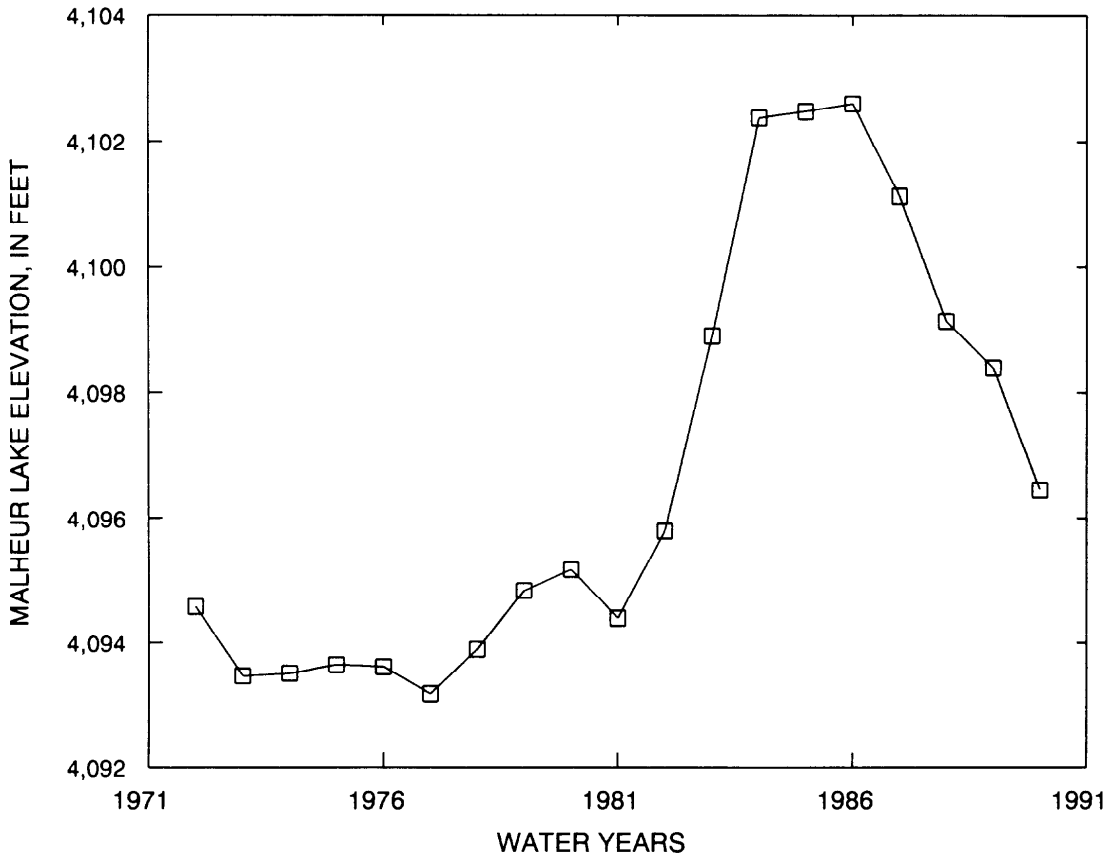

Figure 5.--Malheur Lake annual peak elevation, 1972-90 water years.

feet, the highest level for the period of record at that time (1903-84). More than 170,000 acres of land were inundated at this lake level (Hubbard, 1989). Prior to 1984, the previous maximum lake-surface areas ranged from 50,000 to 60,000 acres. The extensive enlargement of the lake system caused the joining of Malheur, Mud, and Harney Lakes into one large lake. In addition, rising lake levels flooded approximately 25 ranches (55,000 acres of agricultural land), the Union Pacific Railroad serving Burns, parts of two highways and two adjoining county roads, and large areas of wildlife habitat. The record lake-surface elevation was surpassed in 1985 (4,102.5 feet) and in 1986 (4,102.6 feet). Since 1987, below normal snow-precipitation patterns caused lake-surface elevation to recede slowly (maximum level of 4,101.1 feet in 1987, 4,099.1 feet in 1988, 4,098.4 feet in 1989, and 4,096.4 in 1990; fig. 5). The lake-surface elevation of 4,093 feet is considered to be a "normal" mean annual maximum for the period 1938-81 (National Weather Service, 1984).

PREVIOUS STUDIES

Several hydrologic and environmental studies have been done in the Malheur-Harney Lakes area. Both published and unpublished data from these studies provide supplementary information to the current reconnaissance study. Summaries of these studies follow.

Water and Bottom Sediment

Phillips and Van Denburgh (1971) did a study in the early 1960's to characterize the hydrology and geochemistry of closed-basin lakes in south-central Oregon. Among the basins studied was the Malheur-Harney Lake system (supplemental data table 24, at the back of this report). Of geochemical interest was the contrast in chemical analyses of water collected within the lakes in water years 1912 and 1962. The contrast was attributed to (1) year-to-year changes in the lakes' stored-solute tonnage due to varying increases and decreases of outflow, and (2) controls on calcium carbonate solubility due to evaporation. However, these factors did not explain the increase in relative amounts of sulfate from about 2 times the chloride concentration in 1912 to 11 times in 1961. Phillips and Van Denburgh (1971) believed that the increase in sulfate concentration in 1961 was due to agricultural application of gypsum (calcium sulfate) being used as an alkali-soil conditioner. For their closed-lake basin study, Phillips and Van Denburgh (1971) noted that sodium and potassium were by far the most abundant cations, while the combined amount of carbonate plus bicarbonate and chloride ranked first or second among the anions. Calcium-sodium-bicarbonate (Ca-Na-HCO_3) were the predominant ions found in Malheur Lake, whereas sodium-chloride-bicarbonate+carbonate (Na-Cl-HCO_3+CO_3) were the predominant ions in Harney Lake.

Calcium and magnesium, although usually the most abundant cations found in most water and rock-forming minerals in the area, were found in only relatively minor quantities in the saline lakes of the study area (Phillips and Van Denburgh, 1971). Calcium was believed to be depleted by precipitation of calcium carbonate minerals. Magnesium depletion could not be fully explained by carbonate precipitation. A part of the magnesium may have been combining with silica to form amorphous or

poorly defined montmorillonoid magnesium silicates (Phillips and Van Denburgh, 1971). Biological assimilation of significant amounts of calcium and magnesium also was thought to account for a part of the depletion (Phillips and Van Denburgh, 1971).

Hubbard (1975) did a study in the early 1970's to describe the hydrology of Malheur Lake. Chemical analyses were made from both water and bottom-sediment samples collected from major inflows and outflows, and from the lake (supplemental data table 24). These chemical data were used to supplement the description of the hydrology. Hubbard (1975) concluded that the quality of Malheur Lake differed greatly from one point in the lake to another, as well as from one point in time to another. Inflows from the Donner und Blitzen River, the Silvies River, and Sod House Springs were all low in dissolved solids relative to concentrations found within the lake. During summer months, water evaporation caused lake levels to recede and dissolved-solids concentrations to increase. Bottom-sediment samples showed only minor amounts of organochlorine pesticides and trace elements. Dichlorodiphenyldichloroethylene (DDE) was the only pesticide found in bottom sediment and ranged in concentration from 0.4 to 0.8 μg/kg (micrograms per kilogram). Using data from Hubbard (1975), Ca-HCO_3 was determined to be the predominant solute in Malheur Lake.

Fuste' and McKenzie (1987) characterized the water quality in Harney, Mud, and Malheur Lakes for 1984 and 1985. They noted that concentrations of sodium, potassium, chloride, sulfate, silica, dissolved solids, arsenic, beryllium, boron, bromide, iodide, molybdenum, and vanadium generally increased from Malheur to Mud to Harney Lakes (supplemental data table 24). The relatively high concentrations of these constituents in Harney Lake were derived from thermal springs surrounding the lake and by water evaporation. Calcium and magnesium did not show the same increases (a possible consequence of precipitation of calcium and magnesium minerals). In 1984, the predominant cations were Na>>Ca>K>Mg in Malheur Lake and Na>>K>Ca>Mg in Harney Lake. On the basis of Fuste' and McKenzie's data (1987), Na-HCO_3 were the predominant ions found in Malheur Lake, whereas Na-Cl-HCO_3+CO_3 were the predominant ions in Harney Lake. Concentrations of sodium, chloride, and arsenic, and specific conductance and sodium adsorption ratio in Malheur Lake increased significantly from 1984 to 1985. The increase of those ions with time could be from the inflow of saline water from Harney Lake and the dissolution of evaporite deposit surrounding Malheur and Harney Lakes as water levels rose. Fuste' and McKenzie (1987) also found that:

(1) compared with concentrations measured by Hubbard (1975) in Malheur Lake, the 1984-1985 data indicated that the lake was more homogeneous in composition;

(2) surface-water quality of streams flowing into Malheur Lake were similar to those observed in normal precipitation years; and

(3) boron concentrations in Mud and Harney Lakes, which ranged in concentration from 1,800 to 4,000 μg/L (micrograms per liter), exceeded the criterion for crop irrigation of 750 μg/L (U.S. Environmental Protection Agency, 1976).

Biota

In response to concerns of elevated concentrations of mercury in fish tissues and elevated concentrations of arsenic and boron in water from Harney County (Oregon Department of Environmental Quality, unpub. data, 1984; Fuste' and McKenzie, 1987), the U.S. Fish and Wildlife Service collected samples of aquatic birds and fish from Harney Lake and The Narrows in 1985 (U.S. Fish and Wildlife Service, unpub. data, 1985). Additional fish samples were collected in 1986 from near the Refuge headquarters, The Narrows, and Malheur River (U.S. Fish and Wildlife Service, unpub. data, 1986). Livers of the birds and whole body samples of fish were analyzed for trace elements. Concentrations of most elements were either below detectable concentrations or below concentrations suspected of being hazardous to fish and wildlife. Minor differences were observed in the chemical constituents of samples collected from the three sites on the Refuge and from Malheur River (tables 2 and 3). Samples from the Refuge had greater concentrations of zinc, mercury, and boron; whereas samples from Malheur River had higher concentrations of cadmium and lead, although most of these differences were not substantial.

One of the reasons for collecting biological samples in 1985 and 1986 was concern over concentrations of arsenic and boron in water; however, arsenic and boron did not appear to accumulate in fish or most bird tissues. Most concentrations of arsenic and boron were small or below reporting levels (tables 2 and 3). Fish contained smaller arsenic concentrations than the 85th percentile value for the National Contaminant Biomonitoring Program (NCBP) [Lowe and others, 1985; table 2]. Arsenic in bird tissues was below concentrations reported to cause reproductive problems or mortality (Eisler, 1988a; Goede, 1985). Boron concentrations were elevated in American coot livers (11 to 31 μg/g), but not in western grebes (<0.04 to 4.0 μg/g [micrograms per gram]). These values were lower than mean liver concentrations found associated with reproductive impairment in experimental feeding studies with mallards (Smith and Anders, 1989).

Cadmium, copper, mercury, selenium, and zinc were the only other elements in the 1985-86 data elevated in some fish and (or) bird samples (tables 2 and 3). Some of the fish tissue from the Refuge and Malheur River contained concentrations of cadmium, copper, mercury, and zinc that exceeded the 85th percentile value for the NCBP (Lowe and others, 1985; table 2). Geometric mean concentrations of mercury in livers of western grebes were as much as five times greater (table 3) than those found to be associated with reproductive impairment in nesting mallards (Heinz, 1979). Two samples contained mercury concentrations greater than 60 μg/g. Western grebes also had relatively large concentrations of selenium that ranged from 4 to 25 μg/g (table 3). Selenium threshold concentrations of 15 to 26 μg/g are known to cause teratogenicity and reduced hatching success in aquatic birds (Heinz and others, 1989; Ohlendorf and others, 1986a, Ohlendorf, 1989); two of the six western grebe samples exceeded these concentrations.

Table 2.--Concentrations of selected trace elements in fish from the Malheur National Wildlife Refuge and Malheur River, 1985-86, compared to concentrations in fish collected for the National Contaminant Biomonitoring Program (NCBP)

[Concentrations in micrograms per gram on a dry weight basis; geometric means reported when at least 50 percent of the samples contained detectable concentrations; one-half the reporting level was used in mean calculations; minimum and maximum range values in parenthesis; N equals the number of samples collected; -- indicates no samples analyzed; < (less than values) were less than the reporting level]

	NCBP[1/]		Malheur Refuge	The Narrows	The Narrows	Malheur River
	Mean	85th percentile	1986 (N=5)	1985 (N=5)	1986 (N=4)	1986 (N=8)
Arsenic	0.56	0.88	(<0.04-0.10)	0.22 (0.17-0.28)	0.12 (0.08-0.44)	0.24 (<0.04-0.70)
Boron	--	--	(<2-5.0)	4.1 (<3.5-8.0)	3.05 (<2-7.2)	(<2-<2)
Cadmium	.12	.24	0.03 (<0.03-0.19)	0.22 (<0.21-0.40)	0.067 (<0.05-0.19)	0.14 (0.087-3.2)
Chromium	--	--	(<0.7-<1.0)	1.8 (<1.7-4.1)	(<0.7-0.80)	0.73 (<0.7-2.0)
Copper	2.7	3.6	1.9 (0.92-4.3)	2.2 (<0.69-4.1)	1.8 (0.81-3.8)	3.0 (2.2-4.3)
Lead	.68	1.0	0.40 (0.40-0.40)	(<3-<3)	(0.30-<0.7)	0.63 (<3-3.1)
Mercury	.44	.72	1.2 (0.43-3.5)	0.33 (0.18-0.86)	0.62 (0.44-0.76)	0.33 (0.10-1.7)
Selenium	1.9	2.8	0.50 (0.2-1.0)	0.41 (0.26-0.69)	0.75 (0.62-1.1)	1.04 (0.47-2.8)
Zinc	95	160	91 (68-180)	99 (58-220)	101 (61-200)	72 (47-140)

1/ National Contaminant Biomonitoring Program (Lowe and others, 1985) concentrations (1980-81) converted to dry weight assuming 75-percent moisture.

Table 3.--Concentrations of selected elements in livers of aquatic birds from Harney Lake at the Malheur National Wildlife Refuge, 1985

[Concentrations in micrograms per gram on a dry weight basis; geometric means reported when at least 50 percent of the samples contained detectable concentrations; one-half the detection level was used in mean calculations; minimum and maximum range values in parenthesis; N equals the number of samples collected; < (less than values) were less than the reporting level]

Element	N	American coot	Western grebe
Arsenic	6	1.6 (0.97-1.8)	(<0.04-<0.04)
Boron	6	23 (11-31)	(<0.04-4.0)
Cadmium	6	0.36 (<0.23-1.5)	0.39 (0.13-1.1)
Chromium	6	(<1.8-<2.0)	(<1.8-<2.1)
Copper	6	29 (9.2-86)	11 (1.0-20)
Lead	6	(<3.2-<3.4)	(<3.2-<3.4)
Mercury	6	0.70 (0.45-0.87)	30 (9.6-75)
Selenium	6	2.5 (0.78-5.9)	11 (4.0-25)
Zinc	6	140 (107-220)	90 (70-140)

Concentrations of copper and zinc were elevated in some bird liver samples (table 3). Concentrations of copper in bird livers were less than those found in other monitoring studies (Ohlendorf and others, 1986b), whereas, zinc concentrations approached levels found in birds collected from zinc-contaminated sites (Lande, 1977). Copper and zinc concentrations were below concentrations believed to be acutely or subacutely toxic to avian species (Gasaway and Buss, 1972; Hapke, 1975). However, the chronic effects of these two elements are not well understood.

SAMPLE COLLECTION AND ANALYSIS

The sampling protocol for this study was designed to collect reconnaissance-level data at optimal times and locations for detecting selected chemical-constituent concentrations associated with irrigation drainage.

Site Selection

The study area was the Malheur-Mud-Harney Lakes system and the streams, springs, and irrigation flow that drain into the system. Sampling sites were selected to represent the types of water and habitats where irrigation drainage may have an impact. Thus, streams draining irrigated and wetland areas, springs supplying water to irrigated land and to the Refuge, lakes (Malheur and Harney Lakes)

receiving irrigation drainage, and sites in critical fish and wildlife habitat areas were sampled. In addition, sites located upstream of irrigated areas were sampled for comparison with sites downstream of or within irrigated areas. Locations of the water and bottom-sediment sampling sites are given in table 4 and figure 6.

Locations of biological sampling sites were not as clearly defined as those for collection of water and bottom sediment because of the mobility of fish and wildlife, the scarcity of desired organisms, and the location of suitable habitat. Thus, three general drainage sites were selected within the study area that correspond to west Harney Lake (inflow of Silver Creek), north Malheur Lake (inflow of Silvies River), and south Malheur Lake (inflow of Donner und Blitzen River) [fig. 7]. These sites will be referred to as Harney, North Malheur, and South Malheur sampling sites in this report. Sampling sites for biological samples roughly corresponded to selected sampling sites for water and bottom sediment. The north Malheur biological site (fig. 7) corresponded to water and bottom-sediment sites designated as sampling-site numbers 14 and 15 (fig. 6); the south Malheur biological site (fig. 7) corresponded to water and bottom-sediment sites designated as sampling-site numbers 13 and 15 (fig. 6); and the Harney biological site (fig. 7) corresponded to water and bottom-sediment sites designated as sampling-site numbers 12 and 16 (fig. 6).

Types of Samples Analyzed

Surface water, spring water, bottom sediment, aquatic plants, aquatic invertebrates, fish, birds, and bird eggs were analyzed for selected chemical elements (table 5) and organic compounds (table 6).

Twenty-two water samples were analyzed for dissolved major and minor elements and nutrients. Seven of the samples also were analyzed for additional elements necessary for geochemical interpretation. Nineteen water samples were analyzed for deuterium and oxygen-18 isotopic ratios. Unfiltered water samples from two sites (Malheur and Harney Lakes) were analyzed for triazine and chlorophenoxy-acid-herbicide compounds (table 6).

Bottom-sediment samples were collected from five sites and analyzed for total organic carbon, selected major and minor elements (table 5), and organochlorine pesticides and polychlorinated biphenyl compounds (table 6). The bottom sediment was separated into two size classes; the less than 63

Table 4.--Sampling locations and site descriptions for collection of water and bottom sediment from the Malheur-Harney Lake basin, 1988

[Abbreviations used for constituents are: ID = identification, WS = water sample, BS = bottom sediment, TE = trace elements, MI = major ions, RN = radionuclides, NU = nutrients, OC = organochlorine compounds, and HB = herbicides]

Map ID (figure 6)	Site ID	Station name	Constituents	Location
1	SRFD	Silvies River at Fivemile Dam	WS-TE+MI+RN+NU	Lat 43°39'08" Long 119°05'20"
2	EFSR	East Fork Silvies River nr Redess	WS-TE+MI+RN+NU	Lat 43°29'00" Long 118°53'56"
3	WFSR	West Fork Silvies River on Hwy 205 nr Mile Post 7	WS-TE+MI+RN+NU	Lat 43°28'52" Long 119°01'09"
4	DUBR	Donner und Blitzen River at Page Springs	WS-TE+MI+RN+NU	Lat 42°48'08" Long 118°52'01"
5	DUBV	Donner und Blitzen River nr Voltage	WS-TE+MI+RN+NU	Lat 43°15'04" Long 118°51'23"
6	SHSV	Sod House Springs nr Voltage	WS-TE+MI+RN+NU	Lat 43°16'05" Long 118°50'55"
7	SDCI	South Diamond Canal to Donner und Blitzen River	WS-TE+MI+RN+NU	Lat 43°02'48" Long 118°50'07"
8	SCNR	Silver Creek nr Riley	WS-TE+MI+RN+NU	Lat 43°41'30" Long 119°39'30"
9	DOCS	Double O Cold Springs nr Double O Station	WS-TE+MI+RN+NU	Lat 43°16'49" Long 119°19'08"
10	BHBS	Combined Basque, Hibbord, and Barnyard Springs	WS-TE+MI+RN+NU	Lat 43°15'32" Long 119°14'47"
11	HLSC	Harney Lake nr inflow of Silver Creek	BS-OC+TE	Lat 43°16'24" Long 119°12'32"
12	MLDB	Malheur Lake nr inflow of Donner Und Blitzen R	BS-OC+TE	Lat 43°16'14" Long 118°51'03"
13	MLSR	Malheur Lake nr inflow of Silvies River	BS-OC+TE	Lat 43°23'55" Long 118°52'14"
14	MLNC	Malheur Lake nr center	WS-TE+MI+RN+NU+HB BS-OC+TE	Lat 43°19'10" Long 118°46'20"
15	MLAN	Malhuer Lake outlet at Narrows	WS-TE+MI+NU	Lat 43°16'55" Long 118°57'50"
16	HLNC	Harney Lake nr center	WS-TE+MI+RN+NU+HB BS-OC+TE	Lat 43°14'44" Long 119°07'04"
17	HLNS	Harney Lake nr north shoreline	WS-TE+MI+NU	Lat 43°16'45" Long 119°11'34"

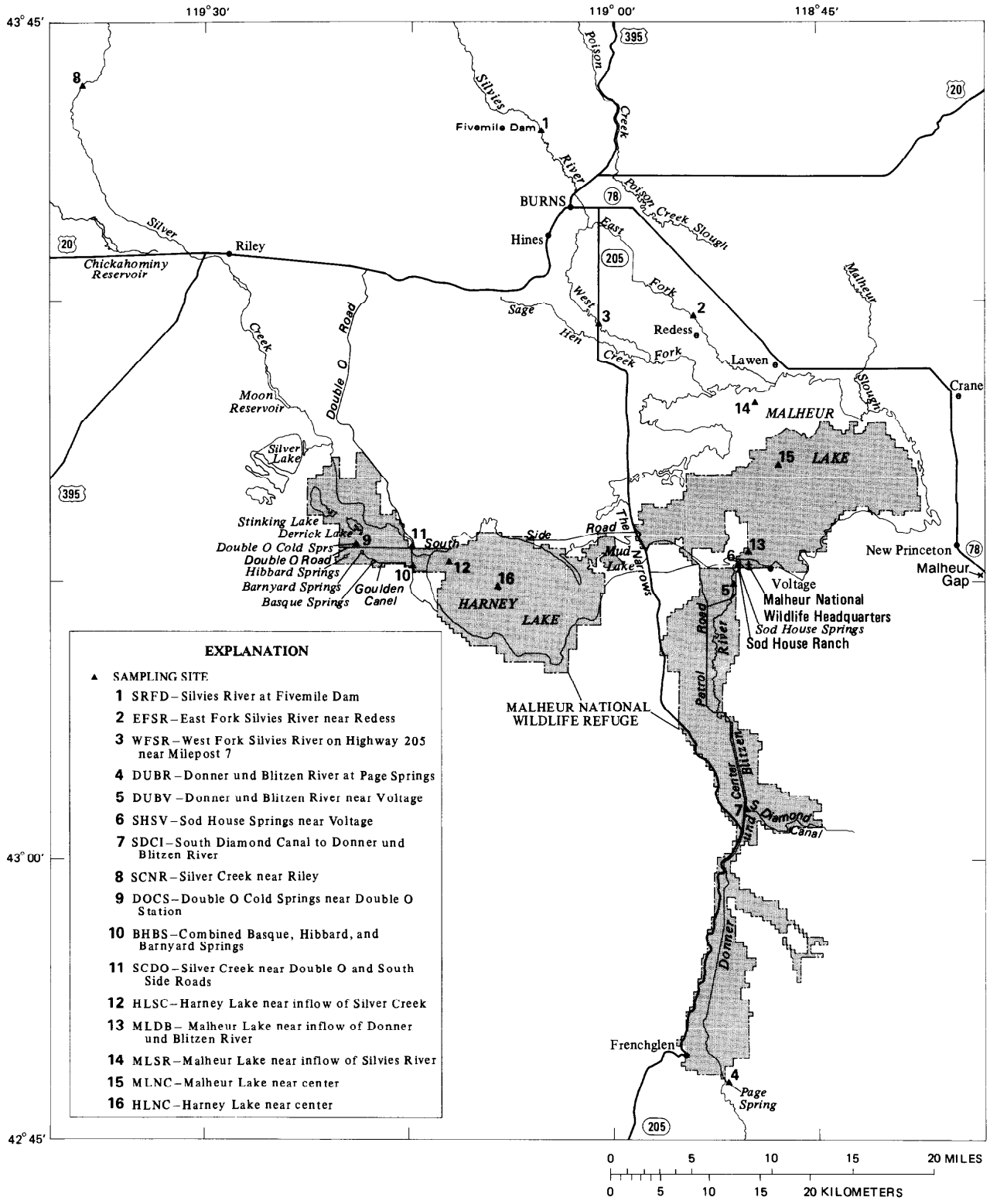

Figure 6.--Location of water and bottom-sediment sampling sites in the Malheur-Harney Lakes area, 1988.

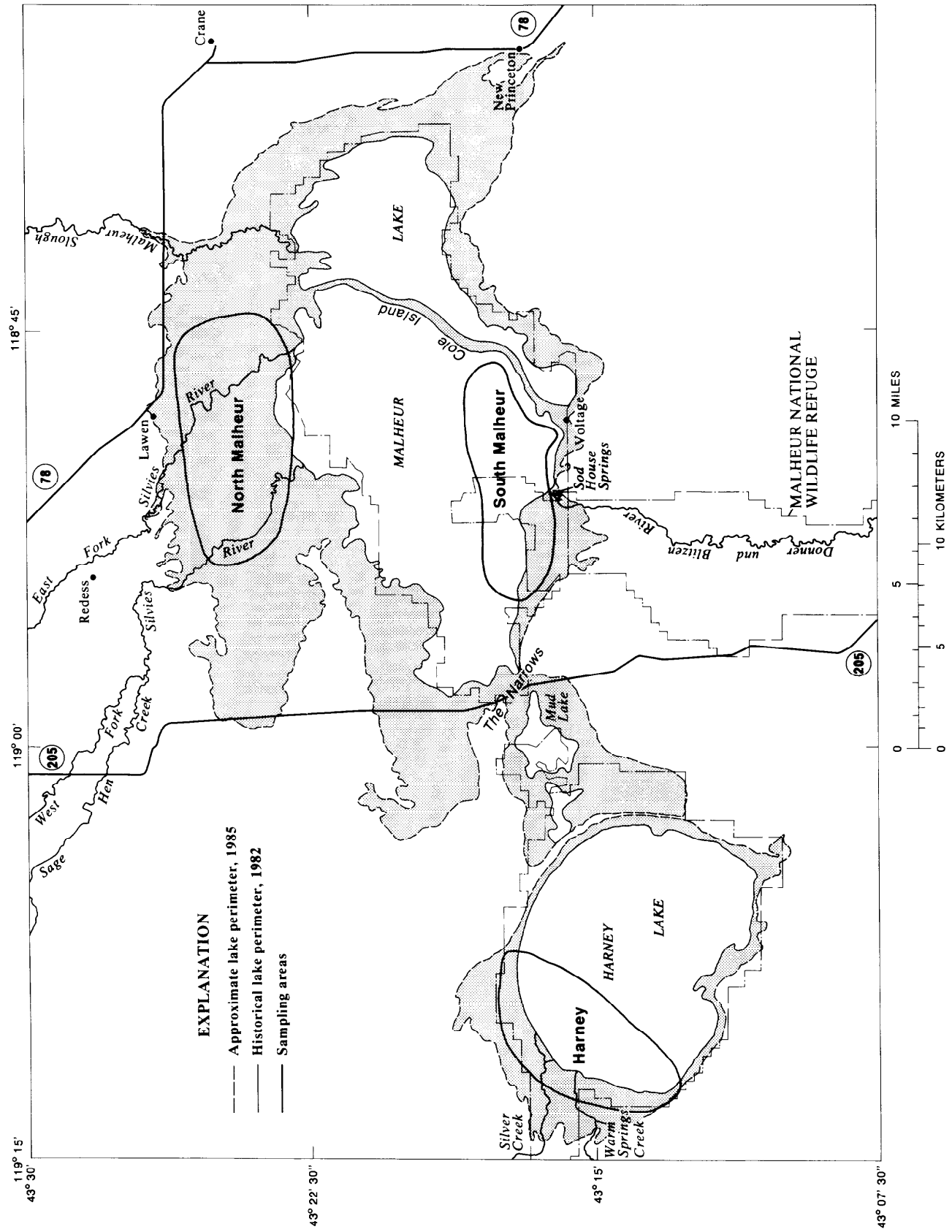

Figure 7.--Location of biological sampling areas at the Malheur National Wildlife Refuge, 1988.

Table 5.--Analytical reporting limits for selected elements in water, bottom sediment, and biota

[µg/L = micrograms per liter; µg/g = micrograms per gram dry weight; "--" = not analyzed]

Element	Analytical reporting limit		
	Water 1/ (µg/L)	Bottom sediment 2/ (µg/g)	Biota 3/,4/ (µg/g)
Aluminum	10	5	0.3 , 45
Antimony	--	--	-- , 0.1
Arsenic	1	0.1	.1 , .02
Barium	100	1	.1 , 23
Beryllium	--	1	.01 , 2
Boron	10	.4	2 , 23
Cadmium	1	2	.03 , .2
Chromium	1	1	.1 , .5
Copper	1	1	.02 , 11
Iron	10	5	.1 , 45
Lead	5	4	.4 , 5
Mercury	0.1	.02	.01 , .1
Magnesium	100	5	.1 , 450
Manganese	10	20	.02 , 7
Molybdenum	1	2	1 , 23
Nickel	--	2	.1 , 18
Selenium	1	.1	.05 , .5
Silver	--	2	2 , 23
Strontium	10	2	.1 , 5
Thallium	--	--	.6 , .5
Tin	--	10	-- , 23
Uranium	0.4	.2	-- , --
Vanadium	1	2	.3 , 23
Zinc 5/	3	4	.02 , 9

1/ Analysis done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory.
2/ Analysis done by the U.S. Geological Survey, Geologic Division, Analytical Laboratory.
3/ Analysis done by the Environmental Trace Substances Research Center.
4/ Analysis done by Hazelton Laboratories America, Inc. Analytical reporting limits were computed using wet-weight reporting values and an average moisture content of 78 percent.
5/ For saline water, the analytical reporting limit for zinc is 10 µg/L.

Table 6.--Analytical reporting limits for selected organic compounds in water, bottom sediment, and biota

[µg/L = micrograms per liter; µg/kg = micrograms per kilogram dry weight; µg/g = micrograms per gram wet weight; "--" = not analyzed]

Whole water			
Triazine herbicides 1/ (µg/L)		Chlorophenoxy acid herbicides 1/ (µg/L)	
Compound	Limit	Compound	Limit
Alachlor	0.10	2,4-D	0.01
Ametryne	.10	2,4-DP	.01
Atrazine	.10	Silvex	.01
Cyanazine	.10	2,4,5-T	.01
Metolachlor	.10	Dicamba	.02
Metribuzin	.10	Picloram	.01
Prometone	.10		
Prometryne	.10		
Propazine	.10		
Simazine	.10		
Simetryne	.10		
Trifluralin	.10		

Organochlorine compounds		
Compound	Bottom sediment 1/ (µg/g)	Biota 2/,3/ (µg/g)
Aldrin	0.1	-- , 0.05
BHC	--	0.01 , .05
Chlordane	1	.01 , .05
DDD	.1	.01 , .05
DDE	.1	.01 , .05
DDT	.1	.01 , .05
Dieldrin	.1	.01 , .05
Endosulfan	.1	-- , --
Endrin	.1	.01 , .05
Heptachlor	.1	-- , .05
Hept. Epoxide	.1	.01 , .05
Hexachlorobenzene	--	.01 , .05
Lindane	.1	-- , .05
Methoxychlor	.1	-- , --
Mirex	.1	.01 , .05
Nonachlor	--	.01 , .05
Oxychlordane	--	.01 , .05
PCB	1	.01 , .05
PCN	1	-- , --
Perthane	1	-- , --
Toxaphene	10	.01 , .05

1/ Analysis done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory.
2/ Analysis done by Mississippi State Chemical Laboratory.
3/ Analysis done by Texas A&M Research Foundation.

micrometer and the less than 2 mm (millimeter) size fractions. Both size fractions were analyzed for the selected elements. Only the less than 2 mm size fraction was analyzed for organic carbon, organochlorine pesticides, and polychlorinated biphenyls.

The biological samples analyzed from three study sites included 5 aquatic-plant samples, 7 aquatic-invertebrate samples, 11 fish samples, 15 bird samples, and 47 egg samples. The common and scientific species or families of organisms collected are shown in table 7. All biological samples were analyzed for selected trace elements (table 5). However, only selected samples of fish, bird eggs, and birds were analyzed for organochlorine pesticides and polychlorinated biphenyl compounds (table 6).

Table 7.--Common and scientific names of organisms collected from the Malheur National Wildlife Refuge, 1988

Common names	Scientific names
Plants	
Algae	Chlorophyta
Smartweed	*Polygonum sp.*
Sego pondweed	*Potamogeton pectinatus*
Invertebrates	
Damselflies	Zygoptera
Side swimmers	Amphipoda
Water boatmen	Corixidae
Mussels	Plecypoda
Fish	
Brown bullhead	*Ictalurus nebulosus*
Common carp	*Cyprinus carpio*
Largemouth bass	*Micropterus salmoides*
Sucker	*Catostomus sp.*
Tui chub	*Gila bicolor*
White crappie	*Pomoxis annularis*
Birds	
American avocet	*Recurvirostra americana*
American coot	*Fulica americana*
Double-crested cormorant	*Phalacrocorax auritus*
Gadwall	*Anas strepera*
Great blue heron	*Ardea herodias*
Mallard	*Anas platyrhynchos*
Western grebe	*Aechmophorus occidentalis*
White pelican	*Pelecanus erythrorhynchos*

Field Collection and Analytical Techniques

Water

Sampling times for the collection of water included: March to May 1988 (period of spring snowmelt, flood irrigation, and streamflow recession after snowmelt runoff), July 1988 (end of many surface-water diversions and beginning of irrigation with ground water), and September 1988 (period of surface-water low flows and maximum ground-water contributions to Malheur and Harney Lakes).

In the south Malheur area, surface and spring water (Sod House Springs) were sampled during peak irrigation (June - July). Samples were collected at the end of the irrigation season (September) when water in the Donner und Blitzen River is predominantly ground water. Surface water in the Silvies area was sampled in early spring (March) because the basin lacks sufficient water for sustained summer irrigation. The Silver Creek area was sampled in May because snowmelt historically occurs a little later than in the Silvies River drainage. Because of below normal snowpacks and water-storage practices in 1988, no water from the Silver Creek area reached Harney Lake. Double O Cold Springs in the Silver Creek area was resampled in September because it is extensively used for maintaining wildlife habitats during the drier months.

Field measurements of dissolved oxygen, pH, specific conductance, and temperature were made at 0.6 of depth from water surface at each sampling site. For the river and spring sites, measurements were made at one point in the cross section near the center of flow. Discharge measurements were made at all stream sites and at two spring locations using either a Price[1] AA type current meter or a Price pygmy meter using appropriate support equipment. Discharge measurements were considered to have an accuracy of ± 10 percent (Rantz, 1982).

Water samples analyzed for major and minor elements and nutrient concentrations were collected using depth-integrated or point samplers at multiple verticals (3-5) within the cross section, and composited into a churn splitter to obtain a representative sampling of the site. Depth-and width-integrated samples were collected using a US DH-48 suspended-sediment sampler. Point samples were collected using a Scott modified Van Dorn bottle at 0.6 of depth from water surface. The water samples were then filtered through a plastic filtration assembly containing a 0.45 micrometer-pore size, cellulose-acetate membrane filter. The filtered water was placed into appropriately labeled shipping bottles, and preserved according to the suite of chemical elements to be analyzed. Incremental alkalinity titrations were performed at each site using a portion of the filtered water.

The quality assurance of the water-chemistry data was determined by collecting duplicate samples for analysis from three water environments (Silver Creek, Double O Cold Springs, and Malheur Lake). Duplicate

[1] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

samples were analyzed for dissolved major and minor elements and nutrients. In addition, a standard reference sample was analyzed for the same chemical constituents. Analytical determinations for the major and minor elements and nutrients in water were made by the U.S. Geological Survey, National Water Quality Laboratory, located in Arvada, Colorado. Analyses were done according to procedures described by Fishman and Friedman (1985).

Water samples analyzed for pesticides were collected only from Malheur and Harney Lakes. These samples were collected using a 300-ml glass biological oxygen demand (BOD) bottle that was fitted into a weighted metal frame. The BOD bottles had been previously cleansed and baked in a 325 °C oven for 8 hours to remove organic residues. The sampling assembly containing the open BOD bottle was quickly lowered by rope through the water column until full. At each site, multiple samples were collected, composited into hexane-rinsed and baked 1-liter glass bottles fitted with teflon screw caps, and chilled below 4 °C. Analytical determinations for the pesticides in whole water were made by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory, located in Arvada, Colorado according to procedures described by Wershaw and others (1987).

Bottom Sediment

Bottom-sediment samples were collected in July after the irrigation season. Bottom sediment is an integrator of chemical constituents being transported with suspended sediment. Collection of bottom-sediment samples was made at the three major inflows to Malheur and Harney Lakes and within each lake. Lake samples were collected to determine whether differences in constituent concentrations exist between inflow areas and the lake centers.

Bottom-sediment samples were collected using a stainless steel Ponar sampler that was hand lowered to the stream or lake bottom. Because of sampler design and bottom conditions, depth of sediment penetration tended to be only a few inches. A minimum of seven subsamples were collected in a stream cross section, and a minimum of five subsamples were collected at each lake site. The subsamples were composited in a large stainless-steel pan and mixed thoroughly with a stainless-steel spoon. Composited bottom-sediment samples collected for inorganic elemental analysis were placed into pint-sized plastic shipping containers. Samples collected for pesticide analysis were first sieved though a stainless-steel sieve with 2 mm openings and then placed into quart, wide-mouth glass, shipping containers. All samples were iced in the field and shipped below 4 °C to the respective analytical laboratories. Quality assurance of the bottom-sediment data was determined by analyzing one duplicate sample collected from Malheur Lake. Samples for total digestion determinations of major and minor elements and organic carbon were sent to the U.S. Geological Survey, Geologic Division Analytical Laboratory, located in Denver, Colorado, and were analyzed by methods described by Severson and others (1987). Samples for determinations of organochlorine compounds were sent to the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory, located in Arvada, Colorado, and were analyzed according to methods described by Wershaw and others (1987).

Detailed interpretation of the elemental data was limited to the <63 μm (micrometer) size fraction because the <88 μm size fraction has been shown to be more readily ingested by some bottom-feeding, benthic organisms (Luoma, 1983). Although only the <63 μm size fraction elemental data were interpreted, few concentration differences were observed between the 63 μm and 2 mm size fractions.

Biota

Biological samples were collected from May to September 1988. Aquatic-bird eggs were collected during May and June, except for white pelican eggs which were collected from an abandoned colony in July. Adult birds were collected from June through August, and juvenile birds were collected in August. Plants, invertebrates, and fish were collected from July through September. Exact dates of sample collection are listed in supplemental data tables 25-27. Not all types of samples were available at each sampling site, because of differences in habitat type, loss due to predation, species availability, or changing water levels. All samples were placed in chemically cleansed jars (washed and rinsed in acetone and hexane), except for samples of large fish and bird carcasses that were wrapped in hexane-rinsed aluminum foil and then placed in plastic bags. Fish samples, not analyzed for organochlorine compounds, were stored in plastic bags. Immediately after collection, samples were placed on ice and later frozen to -13 °C. Samples were stored frozen at -13 °C for 3 to 7 months prior to chemical analysis.

Two species of aquatic plants, smartweed and filamentous algae were collected by hand. Plant samples were a composite of only the above ground portion of the plant. Neither species was available at all three sampling sites. A minimum of one composite, plant sample was collected from each sampling site where the species were available.

Aquatic invertebrates were collected with dip nets or handpicked from submerged rocks and logs. Invertebrates were separated from debris and sorted into families. Families collected included water boatmen, damselfly nymphs, side swimmers, and freshwater mussels. Invertebrate samples consisted of a composite of individuals. One sample of each available invertebrate family was collected from each sampling site, although not all families were found at every site.

Fish species collected from the Silvies and Blitzen sampling areas included white crappie, brown bullheads, and common carp. Common carp, white crappie, and tui chub were collected from the Harney sampling area. Fish were collected with gill nets, seines, and rod and reel. A minimum of two fish were pooled for each composite sample and then weighed. One composite sample of each species was collected from each study site for a total of nine samples. All species sampled were analyzed for major and minor elements. White crappie also were analyzed for organochlorine compounds.

Eggs were collected from great blue heron, double-crested cormorant, gadwall, American avocet, and American coot nests. One egg was collected from each randomly located nest. Each egg sample consisted of one egg. A replicate of three samples was collected from each sampling site for each species. Five eggs also were collected from

an abandoned colony of white pelicans. Eggs were cooled on ice immediately after collection and refrigerated until processed. Eggs were weighed and egg width and length were measured. Egg volume was calculated by multiplying 0.51 times the length times the width squared ($0.51 \times L \times W^2$) [O'Malley and Evans, 1980; Stickel and others, 1973]. Each egg was cut open around the equator; stage of embryo development was noted; observations of any gross deformities were made; the egg content was transferred to a chemically cleansed jar; and contents were weighed without the shell, and frozen. Shells of all eggs were rinsed with water and air-dried. Thickness of the egg shells, including membranes, was measured with a micrometer graduated in units of 0.001 mm (millimeter). Measurements were made at three sites around the equator and were averaged to determine a mean thickness for each shell. Average shell thickness was compared with measurements made on pre-1947 dated eggs of the same species.

Gadwall, American avocet, and American coot were the primary species collected for tissue analysis. Both male and female adults were collected because of the difficulties in determining the sexes of species that exhibit no chromatic sexual dimorphism. A replicate of three birds was collected from each sampling site. Pre-fledged gadwall juveniles also were collected from two of the sampling sites (south and north Malheur) to determine contaminant concentrations in birds that would have fed only in the study area. Juveniles were generally over 4 weeks old. One mallard was inadvertently collected from Harney Lake, but was still submitted for chemical analysis. Several western grebes were found dead on the shore of Harney Lake and were collected and submitted for chemical analysis. All birds, with exception of the grebes, were collected with steel shot and examined to determine their general condition the same day as collected. Livers were excised from all birds for analysis of minor inorganic elements. The livers from the three birds collected from each sampling site were pooled as a composite sample. One randomly selected adult and juvenile gadwall carcass from each study site was prepared for organochlorine analysis. Preparation included removal of feathers, bill, feet, and gastrointestinal tract prior to freezing and later analyses of the carcass.

Biological samples were analyzed for organochlorine compounds by Hand Chemical Laboratory (Mississippi State University), Mississippi State, Mississippi, and Geochemical and Environmental Research Group (Texas A & M), College Station, Texas. The minor elements were analyzed at the Environmental Trace Substances Laboratory (University of Missouri), Columbia, Missouri, and Hazleton Laboratories America, Inc., Madison, Wisconsin. Although the organochlorine compounds and minor elements were analyzed by two different laboratories, all laboratories have a stringent quality assurance-quality control program and undergo review by the U.S. Fish and Wildlife Service, Patuxent Analytical Control Facility to ascertain the accuracy and consistency of their analytical results. The use of different laboratories resulted in some discrepancies in minimum analytical reporting levels for the same elements.

Concentrations of most of the trace elements were measured after preconcentration to enhance detection using inductively-coupled plasma (ICP) scan. Boron concentrations were measured without preconcentration. Arsenic and selenium were analyzed using hydride

generation atomic-absorption methods and mercury by the cold-vapor technique. Selected samples were analyzed for organochlorine pesticides and polychlorinated biphenyls by methods using solvent extraction procedures and electron-capture gas chromatography.

Because livers, eggs, fish, plants, and invertebrates contain varying amounts of moisture, results for minor elements were expressed on a dry-weight basis for uniformity among sample types and with other published and unpublished results. Dry-weight concentrations can be converted to wet-weight concentrations by multiplying the dry weight by one minus the moisture fraction. Organochlorine concentrations were reported on a wet-weight basis for comparison with reporting procedures in the National Pesticide Monitoring Program (Schmitt and others, 1985) and other published literature.

Statistical analysis of the data was limited because of the small number of similar sample types analyzed. Generally, insufficient samples were collected to make valid spatial comparisons between study areas. Geometric means were calculated when three or more replications were collected, when samples from different sites could be combined, and (or) when at least 50 percent of the samples contained detectable concentrations. In these cases, concentrations were transformed to common logarithms to correct for skewed distributions (Sokal and Rohlf, 1981). Values below reporting levels were assigned a value of one-half the lower reporting level to enable computation of geometric means.

DISCUSSION OF ANALYTICAL RESULTS

Field Water-Quality Measurements

A comparison was made of water-quality measurements made in inflowing stream (omitting South Diamond Canal), spring, and lake water on the Refuge (table 8). Data pertaining to individual sampling sites can be found in supplemental data table 28. Comparison of minimum, median, and maximum values for temperature and dissolved-oxygen saturation indicate appreciable overlap between the stream, spring, and lake water (table 8). However, lake-water measurements for specific conductance, pH, and alkalinity were substantially different from the stream- and spring-water values (fig. 8 and table 8). These differences exist because of chemical, biological, and evaporative processes occurring in lake water, which represents the end of the hydrologic system.

Comparison of field measurements made in 1988 with those taken in 1984-85 (supplemental data table 24) indicate lake values for specific conductance and alkalinity were substantially larger in 1988. pH showed a similar tendency, but to a lesser extent. As will be discussed later, most of the 1988 increases for these and other elements can be attributed to the concentration effect resulting from lake-water evaporation.

At the time of sampling, pH in Harney Lake exceeded the MCL (recommended criteria level) of pH 6.5-9.0 that has been set for the protection of freshwater aquatic life from chronic toxicity (U.S. Environmental Protection Agency, 1986).

Table 8.--Selected field water-quality measurements from different sources at the Malheur National Wildlife Refuge, 1988

[Concentrations are listed as minimum/median/maximum values; μS/cm = microsiemens per centimeter; °C = degrees Celsius; mg/L = milligrams per liter; $CaCO_3$ = calcium carbonate; n = number of samples]

Constituent	Water class		
	Streams (n=12) Min/Med/Max	Springs (n=5) Min/Med/Max	Lakes (n=4) Min/Med/Max
Temperature (°C)	6.6/13.1/22.6	11.7/17.6/18.4	16.0/19.2/20.1
Specific conductance (μS/cm at 25 °C	91/ 157/ 436	286/ 421/ 650	1980/3610/8340
Oxygen, dissolved (percent saturation)	71/ 94/ 115	72/ 106/ 117	82/ 96/ 124
pH (units)	7.2/ 8.2/ 8.6	7.8/ 8.4/ 8.9	8.9/ 9.0/ 9.6
Alkalinity, dissolved (mg/L as $CaCO_3$)	48/ 77/ 163	100/ 186/ 248	718/ 962/1890

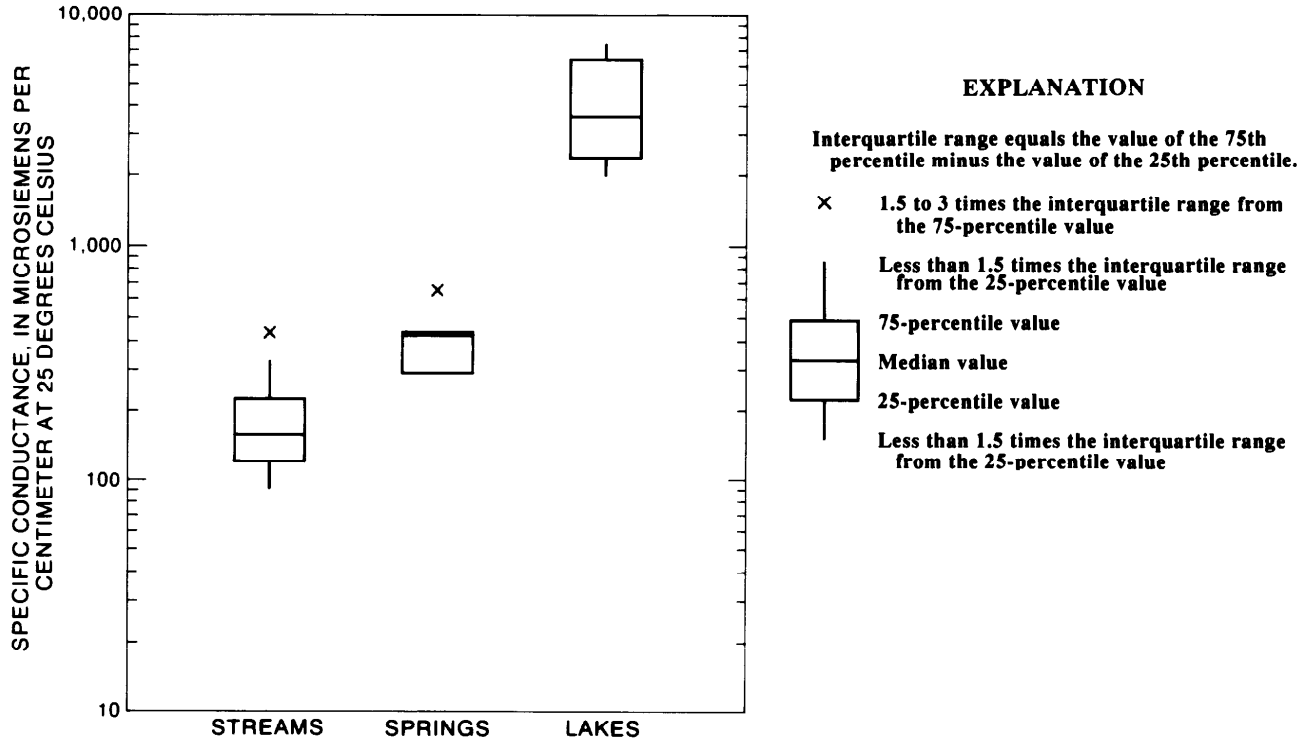

Figure 8.--Specific conductance values in Malheur National Wildlife Refuge water, 1988.

Harney Lake contained relatively high alkalinity ranging from 1,000 to 1,820 mg/L as $CaCO_3$ (table 28). Irrigation water with large alkalinity increases the relative proportion of sodium in soil water by precipitating calcium and magnesium ions as carbonates. As the percentage of sodium increases through this process, soil and plant damage can result (U.S. Environmental Protection Agency, 1986).

Major Dissolved Inorganic Constituents

Supplemental data table 24 lists the major dissolved inorganic constituent concentrations in stream-, spring-, and lake-water samples collected in 1988. The concentration of several constituents in the Silvies River increased in a downstream direction during the March sampling. Constituent concentrations at the East Fork of the Silvies River site had dissolved solids, calcium, magnesium, sodium, chloride, and sulfate concentrations that were, respectively, 1.9, 2.2, 2.1, 3.9, 3.7, and 4.8 times the values measured at the most upstream site (Silvies River at Fivemile Dam). About 86 percent of the Silvies River streamflow, at the most upstream location, was lost by the time it was remeasured at its two most downstream locations near Malheur Lake. Most of the water loss and increase in constituent concentrations were attributed to flood-irrigation practices and not to water evaporation, because of cool weather conditions found typically in March. Although many of the major constituent concentrations increased, the total surface-water dissolved-solids load entering Malheur Lake was only 16 percent of what was observed at the most upstream sampling site. No surface water from the Silvies River discharged into Malheur Lake during the September sampling.

Water from the Donner und Blitzen River, primarily used for wildlife habitat development, showed similar downstream increases in concentration of major inorganic constituents during the July and September samplings. During the July sampling, dissolved solids, calcium, magnesium, sodium, potassium, chloride, and sulfate concentrations at the most downstream site (Donner und Blitzen River near Voltage) were, respectively, 2.9, 3.3, 3.9, 4.3, 1.9, 4.2, and 13.3 times the values measured at the most upstream site (Donner und Blitzen River at Page Springs). The quantity of streamflow at the most downstream sampling location was only 13 percent of what was observed at the most upstream location. Streamflow diversion and return and water evaporation probably account for most of the water loss and constituent-concentration increases. The magnitude of the dissolved major constituent-concentration increases during the September sampling were not nearly as large as those occurring during the July sampling. In July, only 38 percent of the dissolved-solids load observed at the most upstream sampling site discharged into Malheur Lake, while in September 133 percent of the load discharged to the lake. A plausible reason for the downstream loading increase during the September sampling was release of water previously held in storage and an increase in the magnitude of the ground-water contribution.

The relative proportions of major ions found in stream, spring, and lake water collected during 1988 in the Malheur National Wildlife Refuge are shown in figure 9. The predominant major ions in streams were

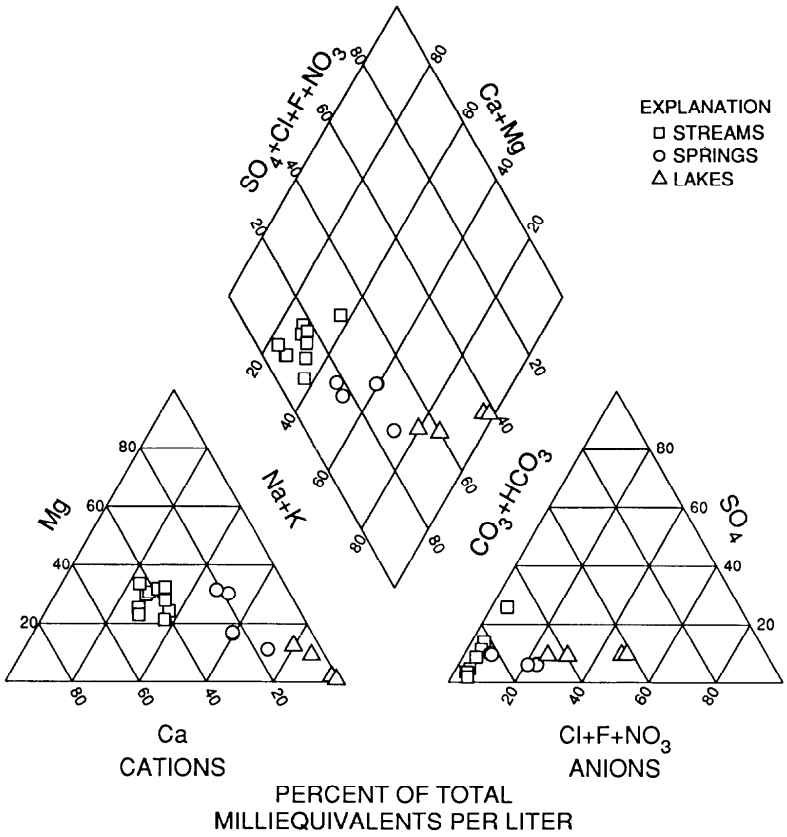

Figure 9.--Major ions in water from streams, springs, and lakes in the Malheur National Wildlife Refuge, 1988.

$Ca\text{-}HCO_3$, and $Na\text{-}HCO_3$in spring water. Lake water showed a shift in the predominant ions from $Na\text{-}HCO_3$ in Malheur Lake to $Na\text{-}Cl\text{-}HCO_3+CO_3$ in Harney Lake. This shift is due to water evaporation losses and mineral precipitation as lake water migrates from Malheur to Harney Lake.

The ratio of element concentrations in Malheur Lake to flow-weighted concentrations in streams flowing into Malheur Lake are shown in figure 10. In addition, the ratio of element concentrations in Harney Lake to those concentrations in Malheur Lake is portrayed in fig. 11. The 1988 annualized loads of spring-water and ground-water constituents to the lake system were minor when compared with the estimated stream loads, and are not included in figures 10 and 11. Magnesium, sodium, potassium, chloride, and sulfate concentrations in Malheur Lake were from 2 to almost 50 times the concentrations observed in the inflowing streams (fig. 10). This observation indicates that water evaporation greatly increases major ion concentrations in Malheur Lake. As lake levels rose in the early to mid-1980's, dissolution of many of the evaporite deposits surrounding the lake might have occurred, thus adding to the lakes' constituent loading. The increased constituent loading to the lakes would contribute to the concentration differences now observed between the inflowing stream and Malheur Lake. Concentrations of sodium, chloride, and sulfate in Harney Lake were two

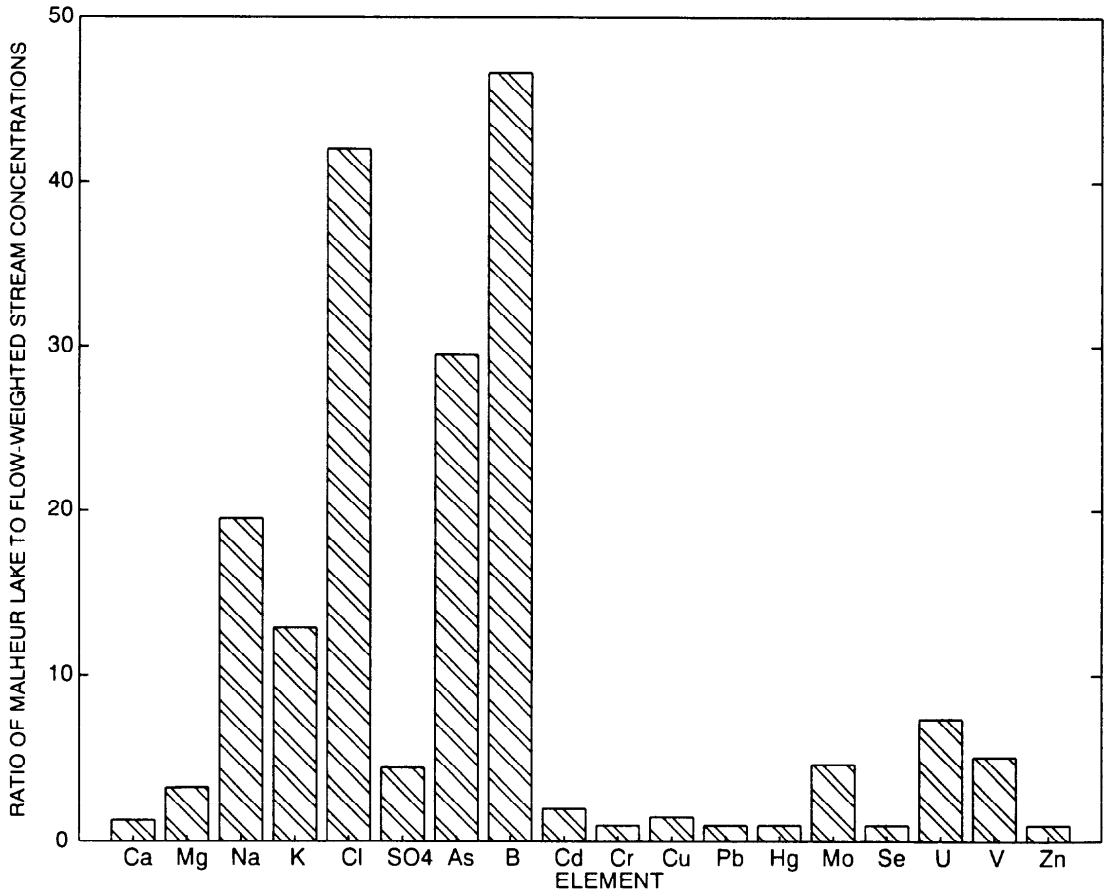

Figure 10.--Ratio of element concentrations in Malheur Lake to flow-weighted element concentrations of inflowing streams, 1988.

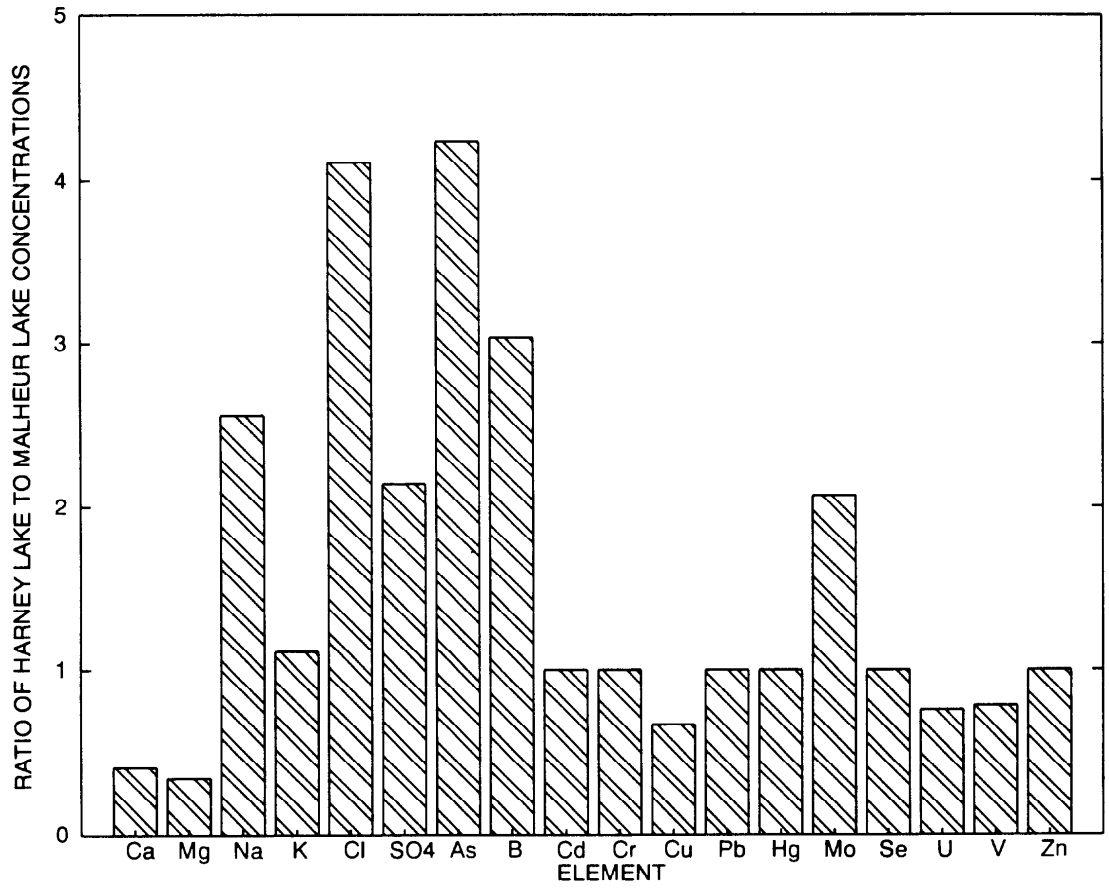

Figure 11.--Ratio of element concentrations in Harney Lake to element concentrations in Malheur Lake, 1988.

to four times the constituent concentrations found in Malheur Lake (fig. 11). These observations agree with previous observations made by Fuste' and McKenzie (1987) that indicate an increasing concentration gradient for a number of constituents from Malheur to Harney Lake. Calcium did not show an increasing concentration trend when comparing stream with lake or lake with lake water. Magnesium and potassium did not show an increasing concentration gradient when comparing Malheur and Harney Lake water.

Geochemical processes are important in controlling the water chemistry of the lakes and, in particular, the concentrations of calcium and magnesium ions. A geochemical model, WATEQ4F, was used to compute major and trace-element speciation and mineral saturation indices for Refuge water (Ball and others, 1987). The results indicated that calcium and magnesium were oversaturated in lake water, and that precipitation of carbonates would occur.

Relatively large dissolved-solids concentration and percentage of sodium in relation to calcium and magnesium (as defined by the sodium adsorption ratio, SAR) were found in Malheur and Harney Lakes (fig. 12). Dissolved-solids concentration in Malheur and Harney Lakes exceeded the 1,000 mg/L irrigation-water hazard criterion at which adverse effects to many crops occur (U.S. Environmental Protection Agency, 1986). Harney Lake exceeded the tolerance for sodium (SAR tolerance range 8-18, fig. 12) designated for irrigation-water use on general crops and forages (U.S. Environmental Protection Agency, 1986). Dissolved-solids concentration and the SAR showed an increasing concentration gradient from Malheur Lake to Harney Lake (supplemental data table 24), thus further substantiating that water evaporation is occurring in the lakes.

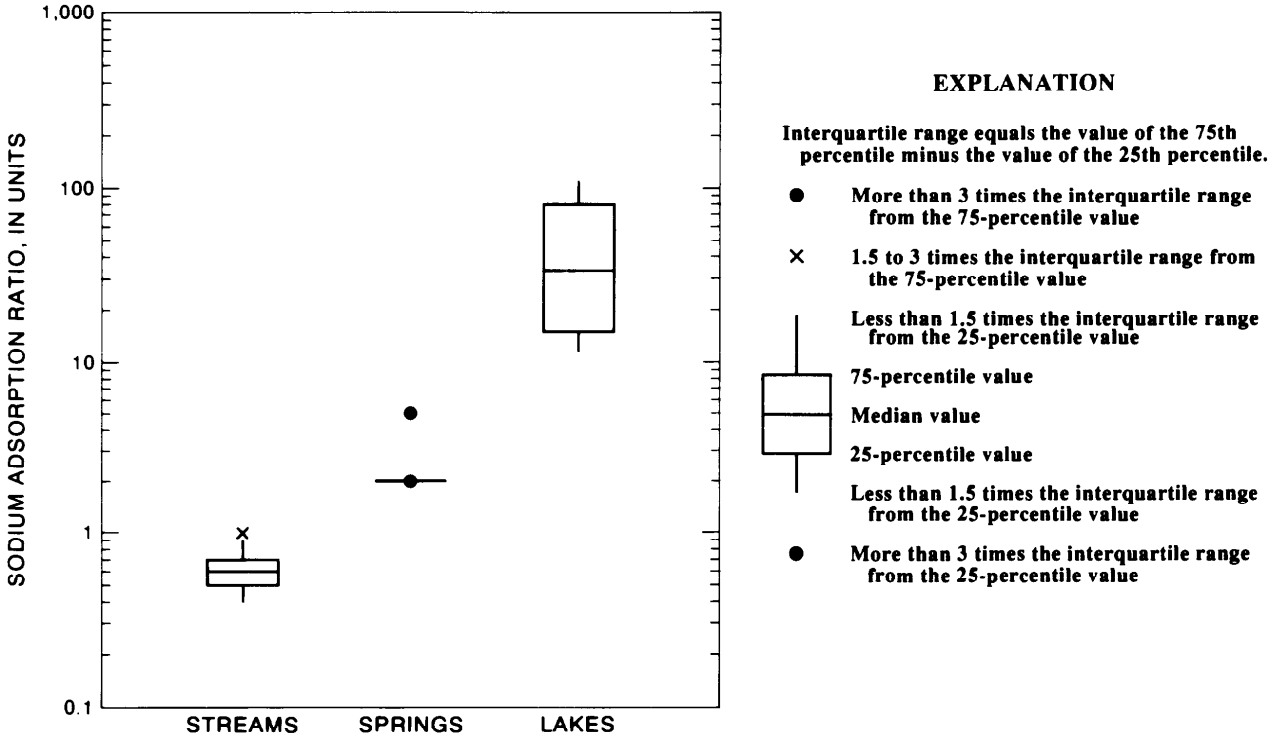

Figure 12.--Sodium adsorption ratios in Malheur National Wildlife Refuge water, 1988.

Dissolved Nutrients

Nitrogen and phosphorus are essential elements for aquatic-plant growth and, in sufficiently large concentrations, can alter water quality of a stream or a lake. Nutrient concentrations can affect water quality by causing excessive algal or aquatic-plant growth, and by causing acute or chronic toxicity to aquatic plants, fish, or animal life. Readily bioavailable forms of these nutrients include nitrate plus nitrite and orthophosphorus. Irrigation-return flow containing nutrients from fertilizers applied to agricultural land has been shown to affect downstream water quality (Wittenberg and McKenzie, 1980).

Research has shown that concentrations of nitrate as nitrogen (N) at or below 90 mg/L have no adverse effects on most warmwater fish nor does nitrite nitrogen when concentrations are at or below 5 mg/L (U.S. Environmental Protection Agency, 1986). The U.S. Environmental Protection Agency (1986) has set a maximum contaminant level for nitrate as N in domestic-drinking-water supplies of 10 mg/L. However, nitrate nitrogen has been known to cause algal blooms in lakes at concentrations as low as 1.0 mg/L (Wittenberg and McKenzie, 1980).

The U.S. Environmental Protection Agency (1986) has recommended that total phosphate concentration as phosphorus should not exceed 0.05 mg/L in any stream at the point where it enters any lake or reservoir, nor 0.025 mg/L within a lake, to prevent development of aquatic plants and to control accelerated or cultural eutrophication. No national maximum criterion level for phosphate phosphorus for the control of eutrophication has been established.

For this study, water-quality samples for nitrate-plus-nitrite analysis were collected at all sampling sites. Samples for orthophosphate phosphorus were collected only at selected sites because the objective for the collection of this constituent was to define the geochemistry of the study area with quantification of nutrient concentrations being a secondary concern. All Malheur-Harney Lake area concentrations of nitrate plus nitrite were less than 10 mg/L as N. Malheur and Harney Lakes, the Donner und Blitzen River, and Sod House Spring orthophosphorus concentrations exceeded U.S. Environmental Protection Agency guidelines for total phosphate phosphorus concentrations (supplemental data table 28).

Nitrate-plus-nitrite concentrations in samples collected for streams flowing into Malheur Lake during the runoff months, were all <0.1 mg/L as N and equaled those concentrations observed at sampling sites located upstream of the irrigated areas (supplemental data table 28). Concentrations of nitrate plus nitrite as N in springs feeding Malheur and Harney Lakes ranged from <0.1 to 0.54 mg/L. A sample collected in Malheur Lake had a nitrate plus nitrite concentration of about 0.70 mg/L as N, whereas concentrations found at The Narrows and in Harney Lake were all <0.1 mg/L as N. Based on field observations of extensive algal growths in Malheur and Harney Lakes during the summertime and the results of the nutrient analyses, the low nitrate plus nitrite concentrations in Malheur and Harney Lake water are believed to be due to biological assimilation.

Orthophosphorus data were collected only during the September low-flow period. Orthophosphorus concentrations in samples collected at headwater locations on the Silvies River and the Donner und Blitzen River were 0.05 and 0.01 mg/L, respectively (supplemental data table 28). The most downstream site on the Donner und Blitzen River had an orthophosphorus concentration of 0.14 mg/L, which was similar to the 0.15 mg/L concentration observed at the nearby Sod House Springs sites. A sample collected from Malheur Lake at the Narrows had an orthophosphorus concentration of 0.61 mg/L, exceeding the U.S. Environmental Protection Agency (1986) recommended value of 0.025 mg/L for total phosphate phosphorus. Concentrations of orthophosphorus, as observed in Malheur Lake, have been shown to cause the growth of nuisance plants (Schinder, 1971). Although suspended algal materials were high in the lakes, other biological or environmental factors appear to be retarding the growth of filamentous algae and submergent aquatic plants.

Isotopes of Hydrogen and Oxygen

Atoms of the same element that have different atomic weights are called isotopes. Most of the naturally occurring elements are mixtures of two or more stable isotopes. All of the isotopes of an element exhibit the same chemical properties, but their behavior to some kinds of physical, chemical, or biochemical processes may be influenced by their relative weights (Hem, 1985); and thus, the isotopic composition of an element within a water body may be useful as an index of its history (Hem, 1985). Deuterium (^{2}H) and oxygen-18 (^{18}O) are particularly important in hydrologic studies because they produce a significant proportion of water molecules that are isotopically heavier than normal water (Hem, 1985). The isotopically heavier water molecules are more abundant in water that has undergone evaporation, while the isotopically lighter water molecules are found more abundant in the vapor phase (or as rain or snow).

The amount of stable isotopes of hydrogen (deuterium, D) or (^{18}O) in a water sample is expressed as a deviation from a reference standard using a delta value, δ, in per mil (0/00 or parts per thousand) units:

$$\delta = [(R_{sample} / R_{standard}) - 1] \times 1000$$

where

δ = per mil (0/00) or parts per thousand for D or ^{18}O, and

R = D/H or $^{18}O/^{16}O$

The reference standard is SMOW (Standard Mean Ocean Water) as defined by Craig (1961a). Water containing a higher ratio in the sample when compared to the standard will give a positive δ (an isotopically "heavy" sample); a lower ratio will give a negative δ (an isotopically "light" sample). Refuge water samples were analyzed according to methods described by Bigeleisen and others (1952), and Epstein and Mayeda (1953). The analyses have analytical errors (standard deviations) of ± 1.5 per mil for δD and ± 0.1 per mil for $\delta^{18}O$.

Historically, the relation between δD and $\delta^{18}O$ has been found to be specific for different water sources. Craig (1961b) found that global δD and $\delta^{18}O$ in fresh (meteoric) water obey generally the following linear-regression equation:

$$\delta D = 8 \times \delta^{18}O + 10$$

This relation is in contrast to that obtained for stream, spring, and lake water sampled in the Malheur National Wildlife Refuge (fig. 13, supplemental data table 32). Refuge water observed the following linear-regression relation:

$$\delta D = 5.08 \times \delta^{18}O - 38.6 \qquad R^2 = 0.980$$

Typically, in water that has undergone considerable evaporation (like what is occurring in the Refuge), the $\delta D/\delta^{18}O$ ratio (slope of the linear-regression line) will be less than 8 and usually between 3 and 6 (Tyler B. Coplen, U.S. Geological Survey, Reston Virginia, written commun., 1989). Refuge water had a $\delta D/\delta^{18}O$ ratio of about 5 (fig. 13). The deviation from the meteoric water line occurred because water vapor from the lake surface was isotopically enriched in oxygen-16 (^{16}O) and hydrogen (H) and, in return, the water body becomes isotopically enriched in D and ^{18}O; this occurs because $H_2{}^{16}O$ has a higher vapor pressure than $H_2{}^{18}O$ or water molecules containing D.

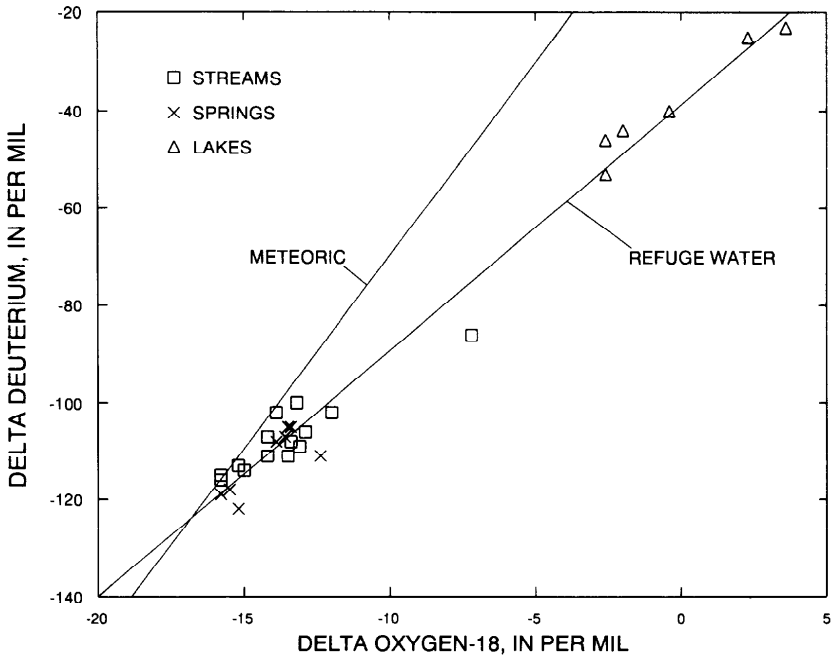

Figure 13.--Isotope composition of meteoric and Malheur National Wildlife Refuge water, 1988.

Values of δD and $\delta^{18}O$ for the lake water were significantly less negative (more positive) than those for the spring and stream water, thus indicating the high degree of evaporation that has occurred within the lakes (fig. 13).

Trace Elements

Of the trace elements analyzed in water, bottom sediment, and biological samples from the Malheur National Wildlife Refuge, only elevated concentrations of arsenic, boron, mercury, and selenium suggested some degree of hazard to human health, fish and wildlife, and (or) other water uses. The following sections individually address the these four elements and summarize the results of the remaining elements.

Arsenic

Water and bottom sediment

Arsenic is a highly undesirable element in water and is toxic to humans in small amounts. The U.S. Environmental Protection Agency (1987) has adopted 50 µg/L as the maximum contaminant level for arsenic in drinking-water supplies. Acute and chronic toxicity concentrations to fish and other organisms vary by species, life stage, exposure, and the form of arsenic. Arsenic(V) can affect freshwater aquatic plants at concentrations as small as 48 µg/L, whereas acute toxicity to freshwater aquatic animals can occur at concentrations as small as 850 µg/L (U.S. Environmental Protection Agency, 1986). The predominant form of arsenic in water from the Malheur National Wildlife Refuge was arsenic(V) [James Ball, U.S. Geological Survey, oral commun., 1988].

Arsenic concentrations in Refuge water show distinct differences among stream, spring, and lake water (fig. 14, table 9). Arsenic concentrations in streams flowing into Malheur Lake were low and ranged from 1 to 2 µg/L. Headwater stream concentrations were lower and ranged from <1 to 1 µg/L (supplemental data table 28). Although three of the nine arsenic concentrations grouped under stream category in figure 14 were less than 1 µg/L, only arsenic concentrations equal to or greater than 1 µg/L reporting level are shown. Because stream arsenic concentrations formed a tight population band, the solid line at 1 µg/L are arsenic concentrations which comprise the concentration range from the median to the 75-percentile value. The maximum arsenic concentration observed in streams flowing into Malheur Lake was 2 µg/L. Arsenic concentrations in spring water ranged from 5 to 9 µg/L. Water collected from a stream which had combined flows from three springs (Basque, Hibbard, and Barnyard) had an arsenic concentration of 47 µg/L. Concentrations of arsenic in lake water ranged from 55 to 330 µg/L. These lake concentrations exceeded the U.S. Environmental Protection Agency's MCL for drinking-water supplies (50 µg/L), and the lowest level known to affect freshwater aquatic plants (48 µg/L). As indicated in figure 11 and in supplemental data table 28, arsenic concentrations showed increasing concentration from Malheur Lake to The Narrows to Harney Lake. The Harney Lake arsenic concentration was more than four times the concentration observed in Malheur Lake. Malheur and Harney Lake arsenic values in 1988 were more than two times the concentrations reported for the same locations sampled in 1984-85 (supplemental data table 24).

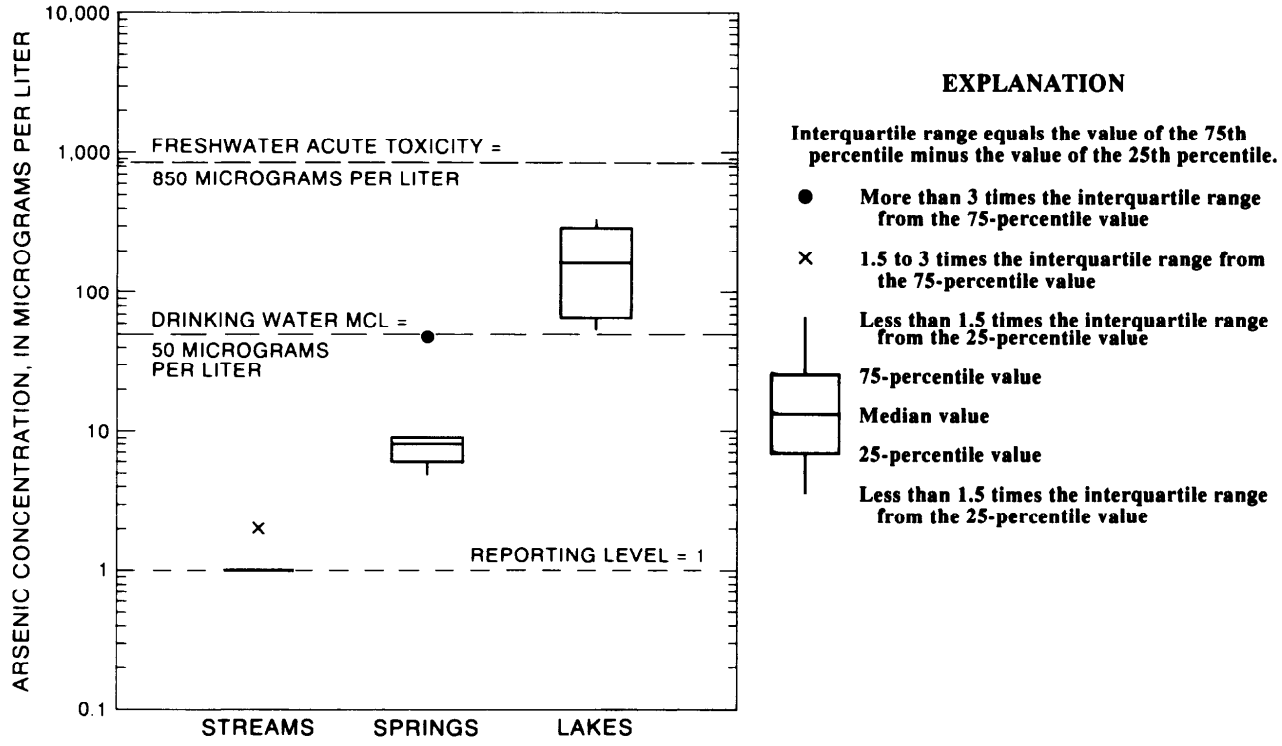

Figure 14.--Arsenic concentrations in Malheur National Wildlife Refuge water, 1988. The asterisk at 2 micrograms per liter is the maximum arsenic concentration observed in streams flowing into Malheur Lake.

Table 9.--Minimum, median, and maximum concentrations of selected elements at different locations in the Malheur National Wildlife Refuge, 1988

[Concentrations are listed as minimum/median/maximum values]

Constituent	Water, in micrograms per liter			Bottom sediment, in micrograms per gram
	Streams	Springs	Lakes	Lakes
	Min/Med/Max	Min/Med/Max	Min/Med/Max	Min/Med/Max
Arsenic	<1/1/2	5/8/47	55/160/330	2.2/6.1/11
Boron	<10/40/80	160/500/1100	2800/6400/16000	1/20/55
Mercury	<.1/<.1/<.1	<.1/<.1/<.1	<.1/<.1/<.1	.02/.02/.05
Selenium	<1/<1/<1	<1/<1/<1	<1/<1/<1	.1/.3/.6

A comparison was made between the range of arsenic concentrations found in five river and lake bottom-sediment samples (<63 μm size fraction) with the expected 95-percent baseline range for soils from the Western United States (table 1). Bottom-sediment arsenic concentrations were within this baseline range (table 9 and supplemental data tables 30-31).

Biota

Although elevated concentrations of arsenic were found in the lake water (table 9), biota collected from Malheur and Harney Lakes did not appear to accumulate arsenic. Biological samples generally contained less than 2 µg/g arsenic, with the exception of filamentous algae that had concentrations ranging from 3.7 to 14.7 µg/g (table 10). Overall, arsenic was lower than concentrations reported to cause "no observable effect" on vegetation (National Resource Canadian Council, 1978) and were within the range or lower than concentrations reported from areas with background levels of arsenic (National Academy of Science, 1977; Jenkins, 1980).

Table 10.--Concentrations of arsenic in aquatic plants, aquatic invertebrates, fish, and bird livers collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; < (less than values) were less than analytical reporting limit; -- indicates no analysis performed; * two samples were collected and analyzed; plant and invertebrate samples were a composite of individuals; fish samples were a composite of two to five fish; liver samples were a composite of two to three livers]

Species	Sampling sites		
	South Malheur	North Malheur	Harney
Plants			
Algae (Chlorophyta)	4.5	--	3.7-15*
Smartweed	1.7	0.87	--
Invertebrates			
Damselfly nymphs	.41	--	1.4
Mussels	.69	--	--
Sideswimmers	.50	--	--
Water boatmen	.77	.88	2.4
Fish			
Brown bullhead	.38	.39	--
Common carp	.25	.42	.36
Sucker	.23	--	--
Tui chub	--	--	.70
White crappie	.16	.28	.26
Bird livers			
American avocet	.17	.13	.072
American coot	.35	.37	.56
Gadwall, adult	.30	.30	0.22-0.45*
Gadwall, juvenile	.22	.18	--
Mallard	--	--	.24
Western grebe	--	--	<0.1-0.10*

Both plants and invertebrates from Harney Lake had higher arsenic concentrations than those from other sampling sites, a condition that was similar to patterns observed in the lake-water samples. Concentrations in invertebrates from Harney Lake ranged from 1.4 to 2.4 µg/g, whereas invertebrate concentrations in Malheur Lake ranged from 0.41 to 0.88 µg/g (table 10). There were no substantial differences between arsenic concentrations in the species sampled, but water boatmen contained the largest concentrations. Concentrations in water samples, ranging from 55 to 330 µg/L, exceeded levels reported to have caused adverse effects in aquatic organisms (19-48 µg/L) [Eisler, 1988a]. Concentrations of arsenic in both lakes could potentially inhibit survival and production of invertebrates, thereby, decreasing overall abundance and species composition.

Dietary uptake and direct uptake from the water have been identified as routes of arsenic accumulation in fish (Phillips and Russo, 1978). Thus, based on concentrations observed in water samples, fish on the Refuge could accumulate arsenic in their tissues. However, concentrations of arsenic were small and in the same range of values in all species of fish sampled (table 10). Concentrations in fish ranged from 0.16 to 0.70 µg/g, although most samples contained less than 0.45 µg/g. The largest concentration occurred in one sample of tui chub collected from Harney Lake. All fish samples contained lower arsenic levels than the 85th percentile (0.22 µg/g wet weight or about 0.88 µg/g dry weight) for the NCBP (Lowe and others, 1985) [fig. 15]. Furthermore, concentrations of arsenic were below tissue concentrations believed to be hazardous to fish or to fish-eating wildlife (National Academy of Science, 1977; National Resource Canadian Council, 1978; Johnson and Finley, 1980; Lima and others, 1984; Cockell and Hilton 1985).

Concentrations of arsenic in aquatic-bird livers ranged from less than 0.10 to 0.56 µg/g (table 10). Mean arsenic concentrations in bird eggs generally were at or below the analytical reporting level (<0.1 µg/g) [table 11]. Few differences were observed among the species or
between the sampling sites (tables 10 and 11). Goede (1985) reported that 2 to 10 µg/g arsenic in bird tissues is considered elevated and residues greater than 10 µg/g are indicative of arsenic poisoning. Residues found in birds on the Refuge were below concentrations that are indicative of arsenic poisoning or could impair reproductive success in aquatic birds (Woolson, 1975; National Academy of Science, 1977; Goede, 1985).

Although elevated concentrations of arsenic were found in water samples collected from Malheur and Harney Lake, these high concentrations did not appear to bioaccumulate in the biota. This observation appears to be consistent with results from studies in California (Hothem and Ohlendorf, 1989). Concentrations found in the biota appear to indicate that arsenic does not present a hazardous threat to fish and wildlife on the Refuge.

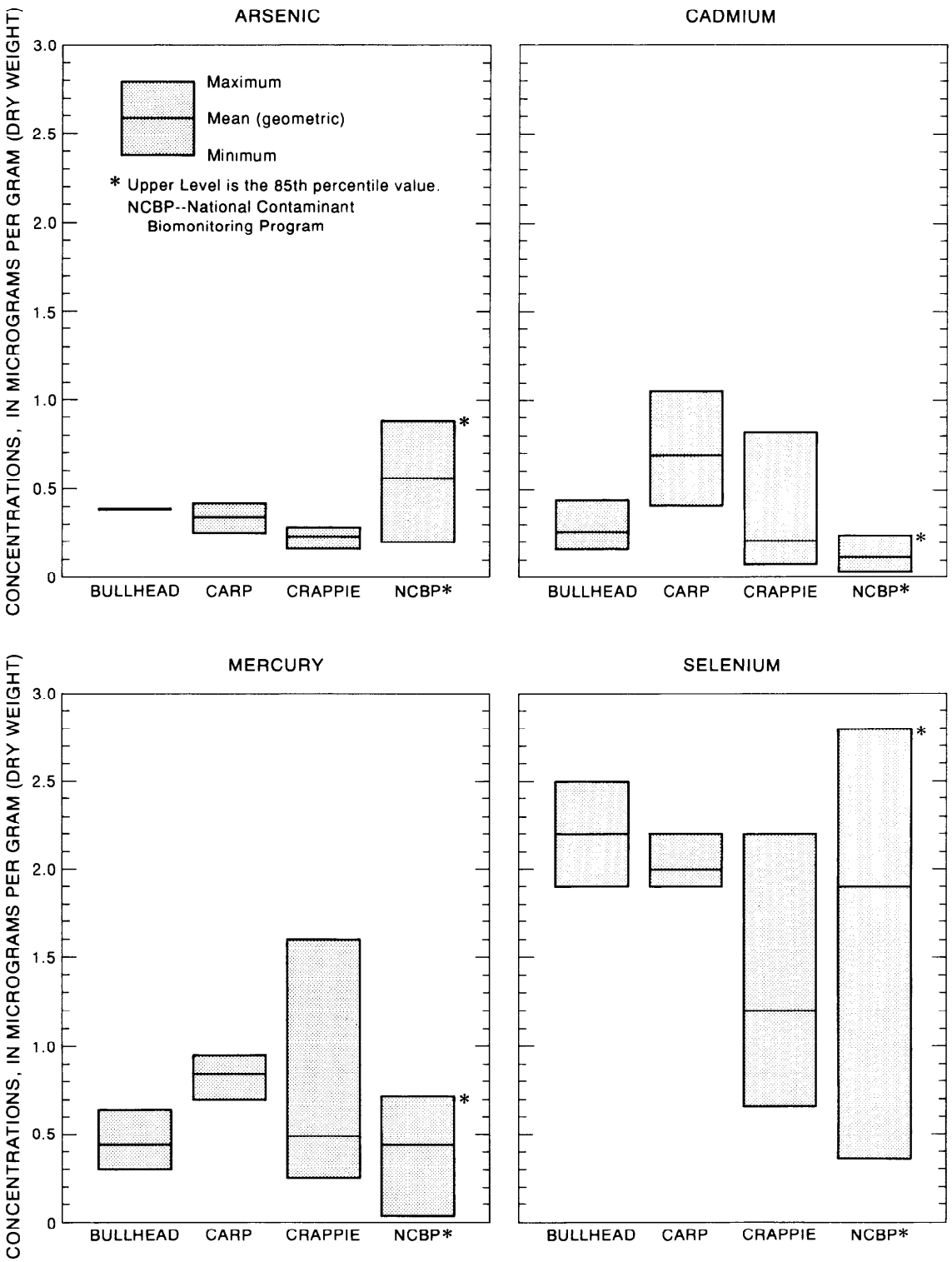

Figure 15.--Geometric mean and minimum and maximum range values (micrograms per gram dry weight) of selected minor elements in fish from the Malheur National Wildlife Refuge (1988) compared with concentrations in fish collected for the National Contaminant Biomonitoring Program (NCBP); Lowe and others, 1985.

Table 11.--Concentrations of arsenic in aquatic-bird eggs collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; geometric means reported when at least 50 percent of the samples contained detectable concentrations; one-half the detection level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit]

Species	N	Mean	Range
American avocet			
South Malheur Lake	4	0.10	<0.1-0.10
North Malheur Lake	4	.10	<0.1-0.10
Harney Lake	4	.40	<0.1-1.6
American coot			
South Malheur Lake	4	.10	<0.1-0.10
North Malheur Lake	4	.07	<0.1-0.10
Double-crested cormorant			
North Malheur Lake	3	.10	0.10-0.10
Harney Lake	3		<0.1-<0.1
Gadwall			
South Malheur Lake	3	.10	<0.1-0.20
North Malheur Lake	4	.08	<0.1-0.20
Harney Lake	3		<0.1-0.10
Great blue heron			
North Malheur Lake	3	.10	0.1-0.10
Harney Lake	3		<0.1-0.10
White pelican			
North Malheur Lake	5	.076	0.034-0.13

Boron

Water and bottom sediment

Boron is an essential element for plant growth, but the difference between the amount necessary for plant nutrition and for plant toxicity is small. The U.S. Environmental Protection Agency (1986) has adopted a boron criterion of 750 µg/L for the protection of sensitive crops subject to long-term irrigation.

Boron concentrations from the Refuge, like arsenic concentrations, show distinct differences when grouped according to stream, spring, and lake water (fig. 16, table 9). Boron concentrations in streams flowing directly into Malheur Lake ranged from 20 to 80 µg/L and were two times

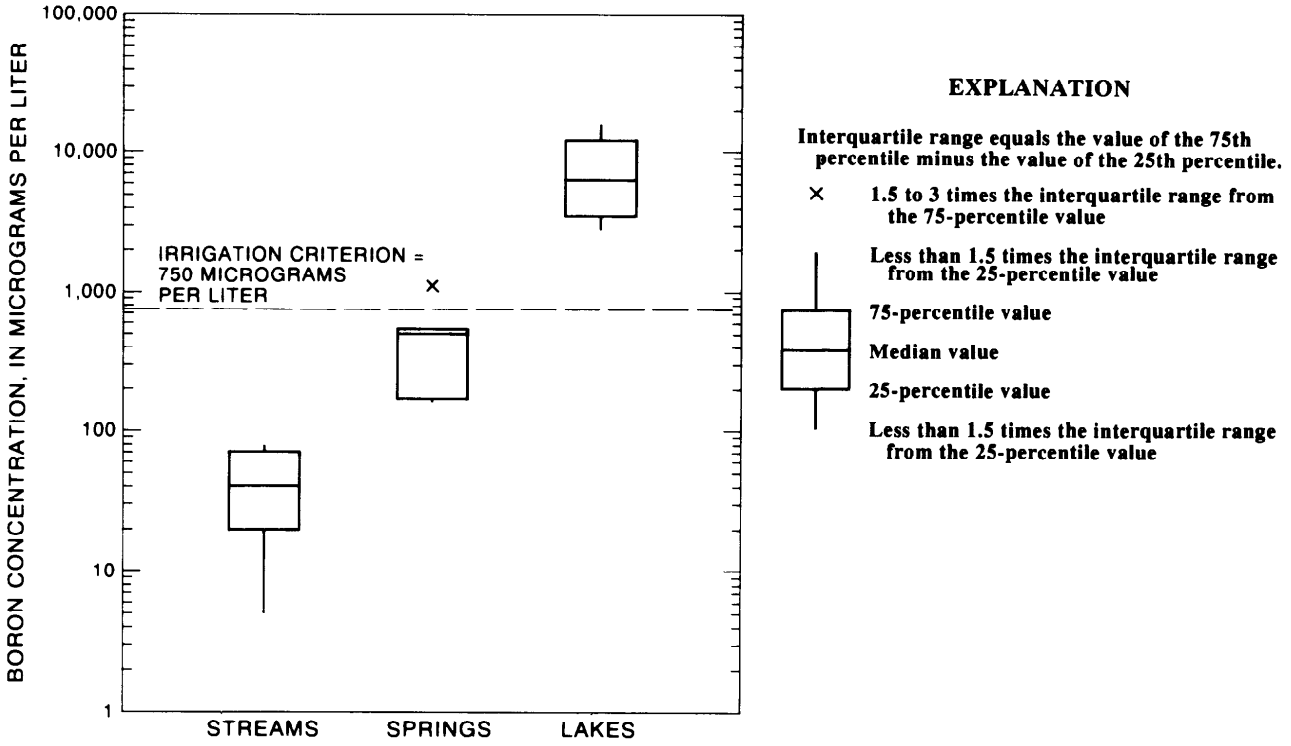

Figure 16.--Boron concentrations in Malheur National Wildlife Refuge water, 1988.

the values observed in their respective headwater. The <10 µg/L boron values were plotted as 5 µg/L in figure 16 to distinguish them from values greater than the analytical reporting limit. Boron concentrations in spring water ranged from 160 to 550 µg/L, with the exception of the combined small springs which had a concentration of 1,100 µg/L. Lake concentrations ranged from 2,800 to 16,000 µg/L and exceeded the U.S. Environmental Protection Agency's criterion for sensitive crops (750 µg/L). Like arsenic, boron showed a definite increasing concentration gradient when progressing from Malheur Lake through The Narrows and into Harney Lake. Harney Lake boron concentration was over three times the concentration observed in Malheur Lake. Malheur and Harney Lakes values were more than two times those reported for these same locations sampled in 1984-85, due to declining lake levels.

A comparison was made between the range of boron concentrations found in the five river and lake bottom-sediment Refuge samples (<63 µm size fraction) with the expected 95-percent baseline range for soils from the Western United States (see table 1). Bottom-sediment boron concentrations fell within the baseline range, with the exception of the boron concentration from the Donner und Blitzen River inflow site. At this site the boron concentration was less than the 95-percent baseline range. The comparison may not be completely valid, however, because boron in bottom sediment from this study represents water-extractable fraction of the total and in the soil baseline data represents total boron (Severson and others, 1987).

Biota

Large boron concentrations in water samples from Malheur and Harney Lakes (table 9) corresponded to larger concentrations in some biota collected from the Refuge, primarily from Harney Lake. The effects of boron at the Refuge were difficult to evaluate because high analytical reporting levels were used in analyzing about half the biota samples. Most samples did not have concentrations of boron that occurred above reporting limits; these samples included fish, bird livers, and some bird eggs.

Plant tissues contained concentrations of boron ranging from 60 to 380 µg/g (table 12). Algae contained the greatest concentrations, which were two to more than four times greater than those in smartweed. Boron

Table 12.--Concentrations of boron in aquatic plants, aquatic invertebrates, fish, and bird livers collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; < (less than values) were less than analytical reporting limit; -- indicates no analysis performed; * two samples were collected and analyzed; plant and invertebrate samples were a composite of individuals; fish samples were a composite of two to five fish; liver samples were a composite of two to three livers]

Species	Sampling sites		
	South Malheur	North Malheur	Harney
Plants			
Algae (Chlorophyta)	160	--	180-380*
Smartweed	60	80	--
Invertebrates			
Damselfly nymphs	5.0	--	94
Mussels	<2	--	--
Sideswimmers	4.0	--	--
Water boatmen	<30	<28	35
Fish			
Brown bullhead	<31	<25	--
Common carp	<25	<24	<28
Sucker	<27	--	--
Tui chub	--	--	<26
White crappie	<16	<28	<22
Bird livers			
American avocet	<17	<18	<19
American coot	<19	<18	<20
Gadwall, adult	<18	<19	<18-<26*
Gadwall, juvenile	<22	<18	--
Mallard	--	--	<18
Western grebe	--	--	<2-<2*

concentrations were detectable in only four of seven invertebrate samples analyzed (table 12). Detectable concentrations ranged from 4 to 94 µg/g. Concentrations in plants and invertebrates were considerably larger in Harney Lake than in Malheur Lake which corresponds with the increasing concentrations observed in water. Concentrations in plants and most invertebrates were considerably smaller than levels found in boron-contaminated sites in California (Schuler, 1987; Hothem and Ohlendorf, 1989). One sample of damselfly nymphs from the Refuge had a boron concentration (94 µg/g) similar to concentrations found in boron-contaminated sites (Schuler, 1987; Hothem and Ohlendorf, 1989). No concentrations of boron were found in fish above the analytical reporting limits which varied from 16 to 31 µg/g (dry weight) [table 12].

Although these data do not provide absolute concentrations of boron in food-chain organisms due to high analytical reporting levels, all concentrations were below approximately 400 µg/g in plants, 100 µg/g in invertebrates, and 30 µg/g in fish. These concentrations were below dietary levels reported to cause mortality or reproductive impairment in aquatic birds (Smith and Anders, 1989). Smith and Anders (1989) found that hatching success, duckling survival, and hatching weight gains of mallards were significantly reduced when adults were fed a diet containing 1,000 µg/g boron. At this concentration, boron did not affect adult survival or egg fertility nor was it teratogenic to mallards. Dietary concentrations of 300 µg/g boron did not have a significant effect on reproduction. Thus, the dietary threshold level for mallards is probably between 300 and 1,000 µg/g. Most all food-chain samples in this study had considerably smaller boron concentrations than 300 µg/g and only one sample of algae exceeded this concentration (380 µg/g). Liver samples also did not contain detectable boron concentrations and their reporting levels ranged from less than 2 to 26 µg/g (table 12). In Smith and Anders (1989) experimental feeding study, mallards fed a diet of 1,000 µg/g boron had mean liver concentrations of 33 µg/g. Thus, concentrations in bird livers from the Refuge were smaller than mean values found to be associated with reduced hatching success.

Analysis of eggs of aquatic birds used low analytical reporting levels (usually <2 µg/g) in most of the samples (table 13). Only 34 percent of the egg samples analyzed had detectable concentrations of boron. Concentrations ranged from less than 2 to 7.7 µg/g (6 samples had had concentrations above 20 µg/g). Smith and Anders (1989) found that adult mallards fed a diet of 1,000 µg/g produced eggs that contained 26-81 µg/g boron. Thus, it appears that concentrations in eggs from the Refuge were not elevated sufficiently to impair reproduction.

Mercury

Water and bottom sediment

Inorganic mercury, although a relatively rare element, is found throughout the earth's crust, occurring as sulfides, chlorides, or oxides at concentrations ranging from 10 to 500 µg/kg (micrograms per kilogram). Inorganic mercury in bottom sediment can be biologically converted to a more soluble organic form (methylmercury). Methylmercury

Table 13.--Concentrations of boron in aquatic-bird eggs collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; geometric means reported when at least 50 percent of the samples contained detectable concentrations; one-half the detection level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit]

Species	N	Mean	Range
American avocet			
South Malheur Lake	4		<2-<2
North Malheur Lake	4	1.6	<2-3.0
Harney Lake	4	4.1	3.0-7.7
American coot			
South Malheur Lake	4		<2-<2
North Malheur Lake	4	4.6	3.0-6.0
Double-crested cormorant			
North Malheur Lake	3		<2-<2
Harney Lake	3		<2-2.0
Gadwall			
South Malheur Lake	3	4.0	<2-8.4
North Malheur Lake	4		<2-5.0
Harney Lake	3		<2-12
Great blue heron			
North Malheur Lake	3		<2-<2
Harney Lake	3		<2-<21
White pelican			
North Malheur Lake	5		<26-<29

is readily bioconcentrated in organisms and will biomagnify through the food chain where it can be introduced to upper trophic-level consumers in a more concentrated form (Eisler, 1987). Bioconcentration factors for methylmercury in aquatic animals range from 4,000 to 85,000 (U.S. Environmental Protection Agency, 1986). Freshwater plants show a wide range of sensitivities to mercury, but, in general, appear to be less sensitive than freshwater animals. U.S. Environmental Protection Agency (1986) criteria for the protection of freshwater aquatic organisms states that the 4-day average water concentration should not exceed 0.012 µg/L of mercury more than once every 3 years on the average and that, the 1-hour average should not exceed 2.4 µg/L more than once every 3 years on the average. The U.S. Environmental Protection Agency's (1986) maximum contaminant level for mercury in drinking-water supplies is 2 µg/L.

Mercury concentrations in stream, spring, and lake water at the Malheur National Wildlife Refuge were all <0.1 μg/L (see table 9).

A comparison was made between the range of mercury concentrations found in the five river and lake bottom-sediment samples collected from the Refuge (<63 μm size fraction) with the expected 95-percent baseline range for soils from the Western United States (see table 1). Bottom-sediment mercury concentrations were within the baseline range.

Biota

Analytical reporting limits for the methods used for analysis of mercury in water were 0.1 μg/L (see table 5). However, concentrations of 0.1 to 2.0 μg/L in water are fatal to sensitive aquatic organisms, and concentrations of 0.03 to 0.1 μg/L are associated with significant sublethal effects (Eisler, 1987). For example, water concentrations as low as 0.04 μg/L mercury caused a reduction in growth of sensitive aquatic organisms (Kayser, 1976; U.S. Environmental Protection Agency, 1980; Thain, 1984). Analytical reporting levels used for water samples in this study were not sensitive enough to detect concentrations that could be hazardous to some aquatic organisms. Although mercury concentrations in water and sediment were below or slightly above reporting levels, mercury did appear to accumulate in some biological tissues.

Concentrations of mercury in aquatic plants and invertebrates were small, and no substantial differences in concentrations were observed between study sites. Concentrations in algae ranged from 0.01 to 0.13 μg/g (table 14). Aquatic invertebrates contained mercury concentrations that ranged from 0.056 to 0.26 μg/g (table 14). Little is known about mercury concentrations in invertebrates and how these levels relate to invertebrate productivity or bioaccumulation in the food chain. However, mercury concentrations in invertebrates from uncontaminated areas are generally below 0.2 μg/g wet weight (Powell, 1983; Eisler, 1987), which, when converted to a dry weight, is well above mercury levels observed in invertebrates collected from the Refuge.

Fish collected from the Refuge contained mercury concentrations that ranged from 0.25 to 1.6 μg/g (table 14). Concentrations varied between species and study sites, but none of the differences were consistent. Four of the 10 fish samples analyzed for mercury had concentrations that exceeded the 85th percentile in the NCBP (Lowe and others, 1985) [see fig. 15]. Nationwide background levels in freshwater fish are generally believed to be in the range of 0.01 to 0.2 μg/g (wet weight; approximately 0.04 to 0.8 μg/g dry weight) [National Academy of Science, 1972]. Although concentrations in Refuge fish were slightly elevated and exceeded background levels, they were not greater than the U.S. Food and Drug Administration's 1 μg/g (wet weight; approximately 4 μg/g dry weight) Action Level for human consumption. Furthermore, fish-eating birds should be protected if the total body burden of mercury in fish exceed 0.5 μg/g wet weight (approximately 2 μg/g dry weight) [National Academy of Science, 1972]. All fish collected from the Refuge had concentrations less than 2 μg/g.

Table 14.--Concentrations of mercury in aquatic plants, aquatic invertebrates, fish, and bird livers collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; < (less than values) were less than analytical reporting limit; -- indicates no analysis performed; * two samples were collected and analyzed; plant and invertebrate samples were a composite of individuals; fish samples were a composite of two to five fish; liver samples were a composite of two to three livers]

Species	Sampling sites		
	South Malheur	North Malheur	Harney
Plants			
Algae (Chlorophyta)	0.13	--	0.01-0.01*
Smartweed	<.16	<0.14	--
Invertebrates			
Damselfly nymphs	.091	--	0.080
Mussels	.056	--	--
Sideswimmers	.12	--	--
Water boatmen	.24	.26	< .14
Fish			
Brown bullhead	.64	.30	--
Common carp	.91	.70	.95
Sucker	.47	--	--
Tui chub	--	--	1.5
White crappie	1.6	.25	.61
Bird livers			
American avocet	.26	.72	2.3
American coot	.37	1.5	1.4
Gadwall, adult	.49	3.6	0.20-0.76*
Gadwall, juvenile	.90	.22	--
Mallard	--	--	.64
Western grebe	--	--	16-21*

Mercury concentrations are generally largest in birds that eat fish or other birds (Eisler 1987). Residues in Refuge birds were consistent with this observation. Larger concentrations were found in livers of western grebes (16-21 μg/g) than in livers of ducks and shorebirds (0.20-3.6 μg/g) [table 14]. As reported earlier, large mercury concentrations also were found in western grebes collected from the Refuge in 1985 (see table 3). Concentrations in 1985 were considerably larger than those found in 1988. Two of the 1985 birds had concentrations near 75 μg/g. Background mercury concentrations in most birds are usually less than 1 μg/g (wet weight; approximately 3 μg/g dry

weight) [Ohlendorf and others, 1978]. Signs of acute mercury poisoning can occur when concentrations in the liver exceed 30 μg/g wet weight (Stickel, 1971). Although 9 out of the 21 liver samples analyzed in 1985 and 1988 from the Refuge contained higher than background levels, none approached acutely lethal levels, however, the effects of mercury on avian reproduction and survival are not as well understood. Mercury concentrations in fish-eating birds collected from the Refuge were comparable to levels in the livers of mallards fed a diet containing 0.5 μg/g (wet weight) mercury for 3 years (Heinz, 1979). In that study, liver concentrations of 0.9 to 1.6 μg/g (wet weight; approximately 3-5.3 μg/g dry weight) were associated with reproductive problems in nesting mallards. If mercury is assumed to have similar reactions in fish-eating birds as in mallards, then the mercury concentrations found in livers of western grebes could potentially cause reproductive problems.

Patterns of mercury accumulation in egg tissues were similar to patterns in livers of adult birds. The largest mercury concentrations in eggs were found in fish-eating birds, including double-crested cormorants, great blue herons, and white pelicans (table 15). Concentrations of mercury in eggs of fish-eating birds ranged from 0.92 to 7.7 μg/g; whereas, concentrations of mercury in eggs of ducks and shorebirds ranged from 0.043 to 1.1 μg/g (table 15). Although mercury concentrations in eggs of fish-eating birds appeared elevated, only nine of the 17 eggs analyzed had concentrations comparable to levels in the eggs of mallards fed a diet containing 0.5 μg/g (wet weight) mercury for 3 years (Heinz, 1979). In that study, mercury concentrations in eggs were 0.8 μg/g (wet weight; approximately 2.5 μg/g dry weight). These concentrations were associated with decreased reproductive success in nesting mallards and altered behavior in their young. Impacts of mercury on reproduction of fish-eating aquatic birds is unclear because species sensitivity to mercury is known to vary (Haseltine and others, 1983). Herring gulls, brown pelicans, and common terns seem to be less sensitive to the effects of mercury on reproduction (Vermeer and others, 1973; Blus and others, 1974; Fimreite, 1974; Connors and others, 1975). Thus, great blue herons, white pelicans, western grebes, and double-crested cormorants also may be less sensitive to mercury than mallards in laboratory feeding studies.

Selenium

Water and bottom sediment

Selenium is an essential element in trace amounts for humans and some plants and animals, but there is only a small difference between the amount necessary for nutritional needs and the amount that causes chronic and acute toxicity (Eisler, 1985a). Selenium deficiency in fish, small laboratory animals, mammals, and livestock may be prevented by daily selenium amounts that range from 50 to 100 μg/kg (Eisler, 1985a). The U.S. Environmental Protection Agency (1987) has established the selenium criterion for the protection of freshwater aquatic life as 20 μg/L for a 1-hour average and 5 μg/L for a 4-day average. Laboratory studies have shown that selenium concentrations as small as 60 μg/L can be fatal to certain sensitive aquatic species (Eisler, 1985a). The drinking-water standard for selenium is 10 μg/L (U.S. Environmental

Table 15.--Concentrations of mercury in aquatic-bird eggs collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; geometric means reported when at least 50 percent of the samples contained detectable concentrations; one-half the detection level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit]

Species	N	Mean	Range
American avocet			
South Malheur Lake	4	0.20	0.055-0.57
North Malheur Lake	4	.29	0.18-0.38
Harney Lake	4	.25	0.12-0.42
American coot			
South Malheur Lake	4	.40	0.30-0.59
North Malheur Lake	4	.10	0.043-0.19
Double-crested cormorant			
North Malheur Lake	3	1.6	0.92-2.4
Harney Lake	3	2.2	1.5-2.7
Gadwall			
South Malheur Lake	3	.096	0.061-0.1
North Malheur Lake	4	.35	0.15-1.1
Harney Lake	3	.12	0.061-0.31
Great blue heron			
North Malheur Lake	3	1.7	1.2-2.6
Harney Lake	3	1.9	1.3-3.7
White pelican			
North Malheur Lake	5	4.4	2.6-7.7

Protection Agency, 1986). Selenium concentrations in stream, spring, and lake water at the Malheur National Wildlife Refuge were all <1 μg/L (see table 9).

A comparison made between the range of selenium concentrations found in the five river and lake bottom-sediment Refuge samples (<63 μm size fraction) and the expected 95-percent baseline range for soils from the Western United States (see table 1) showed bottom-sediment selenium concentrations to be within the baseline range.

Biota

Although selenium did not occur above reported levels in water or outside the baseline range for bottom sediment, it was detected in all biological samples collected from the Refuge. Analytical reporting levels for water and bottom sediment were 1 µg/L and 0.1 µg/g, respectively. Several studies have documented that some species of algae, invertebrates, and fish can bioconcentrate selenium from water concentrations as low as 0.15 µg/L (Eisler, 1985a).

Concentrations of selenium in algae, rooted aquatic plants (smartweed), and aquatic invertebrates were small (table 16), ranging from 0.3 to 0.99 µg/g. Aquatic invertebrates contained selenium concentrations that ranged from 0.93 to 2.2 µg/g. These levels were similar to concentrations reported from areas with normal background selenium levels (Schuler, 1987; Saiki and Lowe, 1987; Ohlendorf, 1989).

Fish collected from the Refuge contained concentrations of selenium ranging from 0.66 to 3.1 µg/g (table 16). Only one of the samples analyzed had selenium concentrations higher than the 85th percentile (0.70 µg/g wet weight or about 2.8 µg/g dry weight) in the NCBP (Lowe and others, 1985) [see fig. 15]. Concentrations were similar to background levels found in fish from areas not contaminated by selenium (Ohlendorf and others, 1987). All fish samples contained selenium concentrations that were below levels that reportedly cause toxic effects in fish (Hodson and others, 1980; Baumann and May, 1984; Gillespie and Baumann, 1986).

Food-chain samples from the Refuge, such as plants, invertebrates, and fish, consistently contained selenium concentrations near normal background levels. Normally, plants contain selenium concentrations of <1 µg/g, aquatic invertebrates contain <4 µg/g, and whole body samples of fish average about 2 µg/g (Eisler, 1985a; Ohlendorf, 1989). Animals generally accumulate high levels of selenium by consuming contaminated food (Sharma and Singh, 1983). In experimental feeding studies, concentrations of 25 µg/g in the diet have caused mortality in some bird species, while concentrations as low as 5 µg/g caused reproductive impairment (Ort and Latshaw, 1978, Heinz and others, 1987; Heinz and others, 1989). Selenium concentrations in food-chain items from this study were below dietary concentrations of 3 to 8 µg/g known to cause toxic effects in aquatic birds (Heinz and others, 1987, 1989; Lemly and Smith, 1987; Ohlendorf, 1989). Thus, birds consuming a diet of plants, invertebrates, or fish from the Refuge would not be exposed to selenium concentrations that would accumulate to hazardous levels in their tissues.

However, contrasting conditions were observed in the livers of several aquatic birds collected from the Refuge. Selenium concentrations were greater than 14 µg/g (dry weight) in livers of some birds of all species, with the exception of American coots (see table 16). Liver concentrations in adult aquatic birds ranged from 5.6 to 36 µg/g selenium, with one-half of the samples having selenium

Table 16.--Concentrations of selenium in aquatic plants, aquatic invertebrates, fish, and bird livers collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; -- indicates no analysis performed; * two samples were collected and analyzed; plant and invertebrate samples were a composite of individuals; fish samples were a composite of two to five fish; liver samples were a composite of two to three livers]

Species	Sampling sites		
	South Malheur	North Malheur	Harney
Plants			
Algae (Chlorophyta)	0.99	--	0.30-0.88*
Smartweed	.65	0.56	--
Invertebrates			
Damselfly nymphs	1.2	--	1.4
Mussels	1.8	--	--
Sideswimmers	.93	--	--
Water boatmen	1.2	2.2	1.7
Fish			
Brown bullhead	1.9	2.5	--
Common carp	2.0	1.9	2.2
Sucker	1.6	--	--
Tui chub	--	--	3.1
White crappie	.66	1.1	2.2
Bird livers			
American avocet	17	21	14
American coot	7.4	11	5.6
Gadwall, adult	14	36	21-22*
Gadwall, juvenile	14	3.9	--
Mallard	--	--	15
Western grebe	--	--	11-17*

concentrations larger than 14 μg/g. One juvenile gadwall liver also contained a high concentration of selenium, although not as high as most adult gadwalls (see table 16). Background selenium concentrations in wild birds from habitats not contaminated with selenium average between 4 and 10 μg/g (dry weight) [Koranda and others, 1979, Ohlendorf and others, 1986a, 1988; Presser and Ohlendorf, 1987]. Threshold concentrations of approximately 15 to 26 μg/g selenium (dry weight) have been reported to reduce hatching success and cause embryonic deformities (Ohlendorf and others, 1986b; Heinz and others, 1989; Ohlendorf, 1989). Concentrations of selenium in several species of birds would be considered sufficiently high to cause reproductive impairment of birds nesting on the Refuge.

Birds collected on the Refuge may have migrated from selenium-contaminated sites, thereby, accounting for their elevated selenium levels. However, Ohlendorf and others (1988) found that liver selenium concentrations decreased by 50 percent in 2 to 3 months after birds entered an uncontaminated site. In experimental feeding studies, Heinz and others (1990) concluded that birds quickly lose selenium once they leave a selenium-contaminated site. They found that selenium in birds was reduced by one-half after approximately 18 days of being off the selenium treated diet and was back to control levels after 71 days. In this study, birds collected in August and September would have migrated to the Refuge 3 to 4 months prior to collection. Other studies indicate that these birds should have had very low selenium levels in their livers unless a local source of selenium kept levels elevated. Accumulation of selenium in juvenile gadwall livers also indicates that birds may have been exposed to a local source of selenium. Although selenium found in these juvenile birds were not high enough to cause toxic reactions, they do indicate that some birds were accumulating selenium. Whether this condition would exist in other birds and other species is unknown because only two samples of juvenile birds (composite of two to three birds per sample) were analyzed.

Concentrations of selenium in eggs of the same bird species from the Refuge contrast with those concentrations found in bird livers. Eggs of aquatic birds from the Refuge contained selenium concentrations from 0.79 to 3.2 μg/g (table 17). The largest concentrations in eggs occurred in fish-eating birds, although differences between species were not substantial. Concentrations in all species were similar to normal selenium concentrations found in eggs from uncontaminated freshwater areas (1 to 3 μg/g dry weight or 0.4 to 0.8 μg/g wet weight) [King and others, 1980; Haseltine and others, 1981, 1983]. Selenium concentrations of 6 to 70 μg/g (dry weight) in eggs have been found in selenium-contaminated sites and were associated with reduced hatching success and high rates of embryo mortality and teratogenicity (Ohlendorf and others, 1986a; Hoffman and others, 1988). Similar concentrations caused embryo toxicosis in experimental feeding studies with mallards (Heinz and others, 1989). Based on these studies, the toxicity threshold level for selenium in eggs was estimated to be between approximately 9 to 30 μg/g dry weight (3.4-11 μg/g wet weight) [Heinz and others, 1989], well above selenium concentrations in eggs found at the Malheur Refuge.

A discrepancy exists in selenium concentrations found in biological samples and the potential hazards to aquatic birds nesting on the Refuge (fig. 17). Analyses of egg tissues and food-chain organisms indicate that selenium should not be a threat, but concentrations in bird liver tissues were at levels which have been associated with reproductive impairment. Selenium concentrations in eggs are generally believed a better indicator of contamination than selenium in liver tissues (Ohlendorf and others, 1986c). Concentrations in eggs indicate that selenium is unlikely to be a significant hazard to aquatic birds nesting on the Refuge. Small concentrations in food-chain materials support this contention. Similar results of elevated selenium concentrations in liver tissues with small concentrations in the eggs have been found in other studies (W.H. Mullins, U.S. Fish and Wildlife Service, oral commun., 1989; H.M. Ohlendorf, U.S. Fish and Wildlife Service, oral

Table 17.--Concentrations of selenium in aquatic-bird eggs collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry-weight basis; geometric means reported when at least 50 percent of the samples contained detectable concentrations; one-half the detection level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit]

Species	N	Mean	Range
American avocet			
South Malheur Lake	4	1.5	1.4-1.7
North Malheur Lake	4	2.0	0.87-3.1
Harney Lake	4	1.7	1.3-2.1
American coot			
South Malheur Lake	4	1.4	1.0-1.8
North Malheur Lake	4	1.5	1.4-1.8
Double-crested cormorant			
North Malheur Lake	3	2.4	2.2-2.6
Harney Lake	3	2.1	2.1-2.2
Gadwall			
South Malheur Lake	3	1.2	1.1-1.3
North Malheur Lake	4	1.4	1.2-1.5
Harney Lake	3	1.1	0.79-1.4
Great blue heron			
North Malheur Lake	3	2.3	2.0-2.6
Harney Lake	3	2.4	2.2-2.6
White pelican			
North Malheur Lake	5	2.8	2.3-3.2

commun., 1989; Goede and de Bruin, 1985). Experimental feeding studies and field studies have indicated that selenium concentrations in eggs and livers of adult birds can be predicted if the dietary concentration of selenium is known (Ohlendorf and others, 1986c; Heinz and others 1989; Ohlendorf, 1989). This relation appears to hold true for eggs in this study, but not for bird livers. Prediction of liver concentrations based on levels found in food-chain items would have been lower than actually found. Therefore, evaluation of hazards based only on liver tissue levels could be misleading.

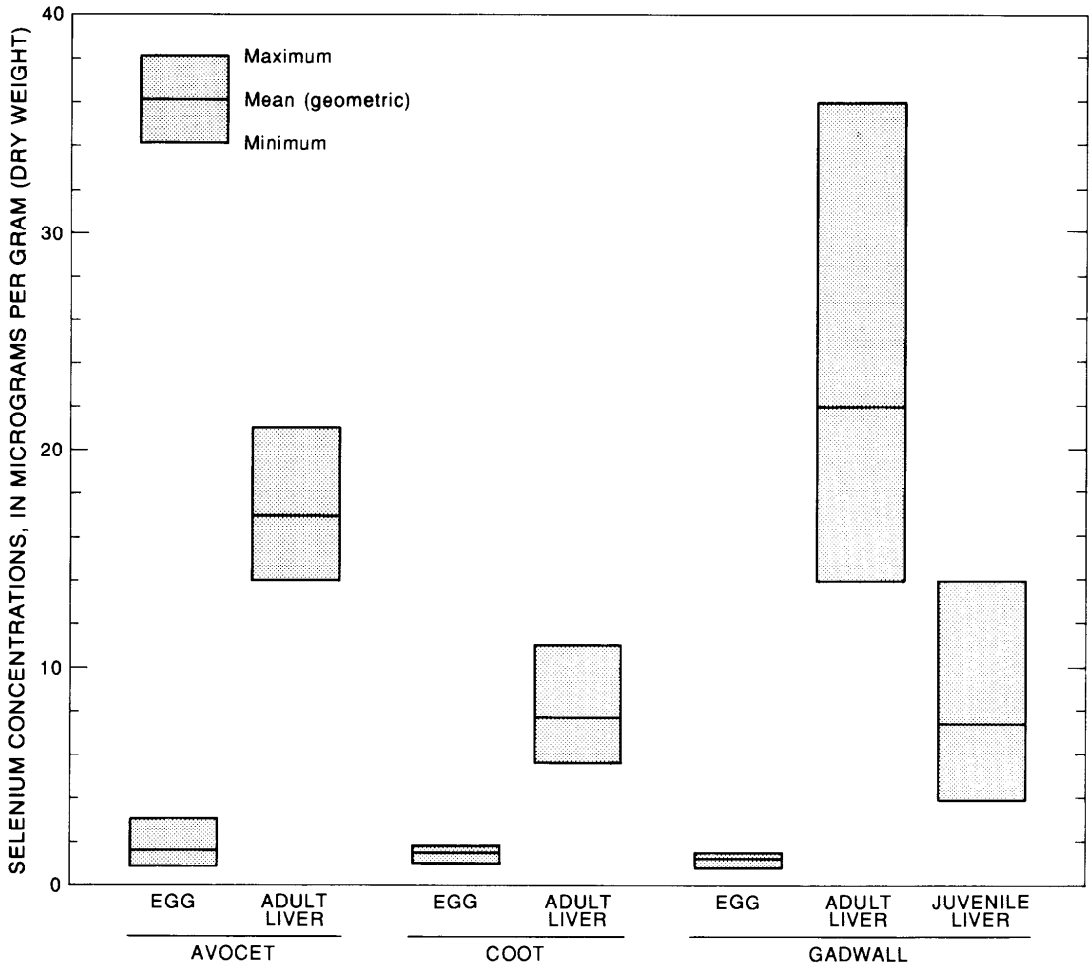

Figure 17.--Concentrations of selenium in aquatic-bird eggs and livers collected from the Malheur National Wildlife Refuge, 1988.

The reasons for high liver levels of selenium at the Refuge are not known. However, three possible explanations are (1) birds collected on the Refuge had migrated from selenium-contaminated sites prior to collection, thereby accounting for their elevated selenium levels; (2) the chemical form of selenium found on the Refuge may be different and behave differently than the form normally associated with selenium-contaminated sites; or (3) accumulation, retention times, and toxic effects of selenium were altered by the presence of other contaminants, such as mercury.

Other Elements

Water

Concentrations of cadmium, chromium, copper, lead, molybdenum, uranium, vanadium, and zinc analyzed in stream, spring, and lake water from the Malheur National Wildlife Refuge did not exceed the U.S. Environmental Protection Agency's criteria for the protection of freshwater-aquatic organisms, sensitive crops, or human health.

Comparison of element concentrations in stream and in spring water indicate few differences, with the exception of vanadium, uranium, and molybdenum. Vanadium concentrations in spring water were from two to three times those observed in stream water (supplemental data table 28). Malheur Lake concentrations of molybdenum, uranium, and vanadium were from 4.7 to 7.4 times those observed in inflowing streams (see fig. 10). Of these elements, only molybdenum showed an increasing concentration gradient when progressing from Malheur Lake to Harney Lake (see fig. 11). It is suspected but not verifiable that chemical precipitation processes were occurring that may limit some of the other elements from increasing in concentration from one lake to the other.

Bottom sediment

Stream and lake bottom-sediment samples collected from the five sampling locations were analyzed for 41 elements (supplemental data tables 30-31). Concentrations of 21 of these elements in the <63 μm size fraction were compared with the expected 95-percent baseline range for soils from the Western United States (see table 1). Concentrations of aluminum, barium, beryllium, calcium, chromium, iron, lead, manganese, nickel, potassium, sodium, strontium, vanadium, and zinc were within the baseline range. Concentrations of uranium from all five sites were less than the expected 95-percent baseline range. Concentrations of copper from the Blitzen River inflow site and magnesium from near the center of Harney Lake were greater than the expected 95-percent baseline range. Elevated copper and magnesium concentrations were only 33 percent larger than the maximum baseline values and were not considered extremes. A more definitive statement could be made as to whether these elements in bottom sediment are truly outliers if a bottom-sediment baseline database for the Western United States was constructed and used for the comparison (Severson, U.S. Geological Survey, written commun., 1987)

Several patterns emerged among the five sampling sites when comparing 41 element concentrations in the <63-μm size fraction. The Donner und Blitzen inflow site had the greatest number of elements in bottom sediment with the largest concentrations. The largest concentrations detected from the Donner und Blitzen River were for aluminum, iron, sodium, titanium, manganese, barium, cobalt, chromium, copper, europium, gallium, lanthanum, niobium, neodymium, nickel, scandium, thorium, uranium, vanadium, and yttrium. The elevated concentrations of these 20 elements may be related to the geology of the Steens Mountains which are predominantly basaltic volcanics. Basaltic rocks contain relatively larger concentrations of many of the elevated trace elements than rhyolytic ash deposits that predominate the geology of the areas upstream of the other two inflow sites (Richard Roche, oral commun., U.S. Geological Survey, 1988). The Malheur and Harney Lake sites were highest in concentrations for calcium, potassium, magnesium, phosphorus, arsenic, boron, mercury, lithium, selenium, and strontium. A plausible explanation for many of these elevated concentrations is geochemical and (or) sediment precipitation deposition of elements from the lake water.

Biota

Most elements analyzed in biological samples were below detectable levels or were at normal background concentrations (tables 18-20). Concentrations of aluminum, antimony, barium, beryllium, chromium, iron, magnesium, nickel, silver, strontium, thallium, tin, and vanadium were not significantly elevated or insufficient information was available to determine the biological significance. A few elements exceeding guidelines or background concentrations are briefly discussed in the following paragraphs.

Cadmium was detected in only about a third of the biota samples (see tables 18-20). Cadmium concentrations in fish were as much as four times larger than the 85th percentile (approximately 0.24 μg/g dry weight or 0.06 μg/g wet weight) determined in the NCBP (Lowe and others, 1985) [see fig. 15]. Concentrations in aquatic-bird food items were less than dietary levels shown to be toxic to birds in experimental feeding studies (Cain and others, 1983; White and Finley, 1978; White and others, 1978). Cadmium concentrations in most bird liver samples were below levels observed in other studies (Ohlendorf and others, 1986b; King and Cromartie, 1986), and the maximum level, 14 μg/g, was below concentrations known to be lethal to waterfowl (Eisler, 1985b; White and Finley, 1978).

Some of the invertebrates and birds, particularly gadwalls, from the Refuge appeared to have elevated concentrations of copper (see tables 18-20). Concentrations of copper in fish samples were two to 12 times greater than the 85th percentile value (approximately 3.6 μg/g dry weight or 0.90 μg/g wet weight) for the NCBP (Lowe and others, 1985). Although most species of birds did not accumulate copper, gadwalls had concentrations of 160-320 μg/g in liver tissues that approached levels found in birds collected from copper-contaminated sites in Norway (Lande, 1977). Normal background liver concentrations of copper for most species ranges from 10 to 50 μg/g (dry weight), but a few species, including ducks, contain concentrations that range from 100 to 400 μg/g (Underwood, 1971). Copper toxicosis is expected to occur when tissue concentrations reach 500 μg/g (Hapke, 1975). In an experimental feeding study with chickens, Bubien and others (1971) found that mortality occurred when the average copper content in the livers reached 1,000 μg/g. These studies indicate that concentrations in the livers of Refuge birds were well below levels that are believed toxic to avian species.

Because analytical reporting levels for lead were high, none of the biota contained detectable lead concentrations except for aquatic plants (see tables 18-20). Reporting levels used for analysis of invertebrates were similar to concentrations found in terrestrial invertebrates collected from a lead-contaminated site (Beyer and others, 1985). Reporting levels for fish exceeded the 85th percentile value (approximately 1.0 μg/g dry weight or 0.25 μg/g wet weight) for the NCBP (Lowe and others, 1985). This does not imply that lead could be a potential hazard to Refuge fish and wildlife, but only that reporting levels were too high to provide quantifiable data, although the reporting levels in food-chain organisms were below dietary levels reported to cause toxic reactions in avian species (Eisler, 1988b).

Table 18.--Geometric means and minimum and maximum concentrations for selected elements in plants, invertebrates, and fish collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry weight basis; geometric means reported when at least 50 percent of the samples contained reportable concentrations; one-half the reporting level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit; -- indicates no analysis performed]

Species	N	Aluminum	Antimony	Barium	Beryllium	Cadmium	Chromium	Copper	Iron	Lead
Algae	3	4500 (2300-8600)	(<0.12-0.50)	59 (38-93)	(0.20-<2.2)	(0.20-<0.25)	11 (9.2-14)	17 (11-39)	4400 (2200-7800)	8.0 (4-13)
Smartweed	2	520 (450-608)	(<0.14-<0.16)	33 (32-35)	(<2.8-<3.3)	(<0.28-<0.33)	(<0.56-<0.65)	(<14-<16)	650 (520-820)	(<5.6-6.5)
Damselfly nymphs	2	850 (600-1200)	--	5.8 (4.5-7.5)	(<0.1-<0.1)	0.85 (0.4-1.8)	1.0 (1.0-1.0)	15 (15-16)	800 (400-1600)	(<4-<4)
Water boatmen	3	240 (130-660)	(<0.14-<0.15)	(<28-<30)	(<2.8-<3.0)	1.2 (0.50-1.7)	(<0.55-<0.60)	38 (33-49)	240 (180-370)	(<5.5-<5.9)
Brown bullhead	2	(<62-130)	(<0.12-<0.16)	(<25-<31)	(<2.5-<3.1)	(<0.31-0.44)	(<0.49-<0.62)	(<16-36)	310 (310-320)	(<4.9-<6.2)
Common carp	3	60 (<55-120)	(0.12-<0.14)	(<24-<28)	(<2.4-2.8)	0.69 (0.41-1.05)	(<0.51-0.61)	(<12-44)	280 (190-470)	(<4.7-<5.5)
White crappie	2	(<43-<57)	(<0.082-<0.14)	(<16-<28)	(<1.6-<2.8)	(<0.16-0.82)	(<0.43-0.98)	(8.2-44)	92 (74-130)	(<3.3-<5.7)

Species	N	Magnesium	Molybdenum	Nickel	Silver	Strontium	Thallium	Tin	Vanadium	Zinc
Algae	3	9400 (8200-11000)	(<2-<25)	(11-<20)	(<2-<25)	180 (140-220)	(<0.45-<5)	(<22-<25)	(<22-<25)	25 (19-39)
Smartweed	2	5000 (4900-5030)	(<28-<33)	(<22-<26)	(<28-<33)	21 (91-107)	(0.56-<0.66)	(<28-<33)	(<28-<33)	25 (23-28)
Damselfly nymphs	2	1600 (1600-1700)	(<1-<1)	2.5 (2.0-3.0)	(<2-<2)	10 (9.1-11)	(<4-<5)	--	2.5 (1.7-3.8)	76 (71-81)
Water boatmen	3	1600 (1500-1700)	(<28-<30)	(<22-<24)	(<28-<30)	16 (12-24)	(<0.56-<0.60)	(<28-<30)	(<28-<30)	200 (170-270)
Brown bullhead	2	1900 (1700-2200)	(<25-<31)	(<20-<25)	(25-<31)	140 (89-220)	(<0.50-<0.63)	(<25-<31)	(<25-<31)	96 (84-110)
Common carp	3	1500 (1400-1700)	(<24-<28)	(<19-<22)	(<24-<28)	100 (93-109)	(<0.48-<0.56)	(<24-<28)	(<24-<28)	360 (305-406)
White crappie	2	904 (220-1700)	(<16-<28)	(<13-<23)	(<16-<28)	230 (130-450)	(<0.33-<0.57)	(<16-38)	(<16-<28)	86 (76-108)

Table 19.--Geometric means and minimum and maximum concentrations for selected elements in bird eggs collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry weight basis; geometric means reported when at least 50 percent of the samples contained reportable concentrations; one-half the reporting level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit; -- indicates no anaysis performed]

Species	N	Aluminum	Antimony	Barium	Beryllium	Cadmium	Chromium	Copper	Iron	Lead
Avocet egg	12	0.52	--	3.7			0.35	3.3	120	
		(<0.3-<3)		(1.7-7.9)	(<0.01-<0.1)	(<0.03-<0.2)	(<0.1-1.1)	(2.7-4.1)	(101-130)	(<0.4-<4)
Coot egg	8	0.55	--	2.6			0.21	2.5	90	
		(<0.3-<3)		(0.31-9.7)	(<0.01-<0.1)	(<0.03-<0.2)	(<0.1-<1)	(1.4-3.1)	(77-110)	(<0.4-<4)
Cormorant egg	6	0.53	--	0.3			.073	5.8	126	
		(<0.3-3.4)		(0.2-0.46)	(<0.006-<0.01)	(<0.01-<0.04)	(0.06-0.2)	(2.8-7.4)	(69-160)	(0.3-<3.5)
Gadwall egg	10	0.54	--	9.7		.026	.23	2.8	95	
		(0.70-<3)		(4.5-19)	(<0.006-<0.1)	(<0.01-0.04)	(0.08-3.4)	(1.3-4.0)	(56-140)	(<0.2-<4)
Heron egg	6	0.74	--	0.22				5.2	109	
		(0.40-1.7)		(0.1-0.44)	(<0.01-<0.01)	(<0.03-0.04)	(<0.1-0.46)	(4.5-6.0)	(90-130)	(<0.4-<0.5)
Pelican egg	5								95	
		(<52-<57)	(<0.13-<0.14)	(<27-<29)	(<2.6-<2.9)	(<0.26-<0.29)	(<0.52-0.57)	(<13-<14)	(82-107)	(<5.2-<5.7)

Species	N	Magnesium	Molybdenum	Nickel	Silver	Strontium	Thallium	Tin	Vanadium	Zinc
Avocet egg	12	420	0.33	0.33		9.2		--		49
		(350-480)	(<1-1.0)	(<0.1-0.70)	(<2-<2)	(5.1-15)	(<0.5-<4)		(<0.3-<0.3)	(36-60)
Coot egg	8	460				5.6		--		55
		(390-520)	(<1-<1)	(<0.1-<2)	(<2-<2)	(2.0-11)	(<0.6-<4)		(<0.3-<0.3)	(46-67)
Cormorant egg	6	560	0.90			5.3		--		46
		(550-603)	(<1-1.0)	(<0.04-0.20)	(<2-<2)	(4.6-6.0)	(<0.2-<0.6)		(<0.3-<0.3)	(22-62)
Gadwall egg	10	320		0.18		7.5		--		49
		(150-400)	(<1-<1)	(<0.09-<2)	(<2-<2)	(4.6-11)	(<0.2-<4)		(<0.3-<0.3)	(26-68)
Heron egg	6	580	0.80			3.4		--		48
		(500-660)	(<1-1.0)	(<0.1-0.43)	(<2-<2)	(2.1-6.2)	(<0.6-<0.6)		(<0.3-<0.3)	(42-55)
Pelican egg	5	440								45
		(550-630)	(<26-<29)	(<21-<23)	(<26-<29)	(<5.5-7.4)	(<0.53-<0.58)	(<26-<29)	(<26-<29)	(43-52)

Table 20.--Geometric means and minimum and maximum concentrations for selected elements in bird livers collected from Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry weight basis; geometric means reported when at least 50 percent of the samples contained reportable concentrations; one-half the reporting level was used in mean calculations; N equals the number of samples collected; < (less than values) were less than the analytical reporting limit; --indicates no anaysis performed]

Species	N	Aluminum	Antimony	Barium	Beryllium	Cadmium	Chromium	Copper	Iron	Lead
Avocet liver	3	(<35-<38)	(<0.092-0.10)	(<17-<19)	(<1.7-<1.9)	3.7 (2.6-5.9)	(<0.35-<0.38)	25 (22-28)	2020 (1400-2800)	(<3.5-<3.8)
Coot liver	3	(<37-<40.2)	(<0.098-0.11)	(<18-<20)	(<1.8-<2.0)	.67 (0.55-0.96)	(<0.37-<0.41)	37 (23-49)	2500 (1600-3500)	(<3.7-<4.0)
Gadwall liver (adult)	4	(35-<41)	(<0.088-<0.103)	(<18-<21)	(<1.8-11)	3.1 (1.6-14)	(<0.35-<0.41)	203 (160-308)	3300 (1800-11000)	(<3.5-<4.2)
Gadwall liver (juvenile)	2	(<35-<43)	(<0.088-<0.108)	(<18-<22)	(<1.8-<2.2)	.44 (0.35-0.56)	(<0.35-<0.43)	230 (170-320)	730 (520-1020)	(<3.5-<4.3)
Western grebe liver	2	(<3-<3)	--	0.20 (0.20-0.20)	(<0.09-<0.1)	2.4 (1.5-4.0)	(<1-<1)	40 (34-48)	16000 (14000-19000)	(<4-<4)

Species	N	Magnesium	Molybdenum	Nickel	Silver	Strontium	Thallium	Tin	Vanadium	Zinc
Avocet liver	3	790 (760-810)	(<17-<19)	(<14-<15)	(<17-<19)	(<3.5-<3.8)	(<0.36-<0.39)	(<17-<19)	(<17-<19)	108 (102-120)
Coot liver	3	760 (701-820)	(<18-<20)	(<15-<16)	(<18-<20)	(<3.7-<4.0)	(<0.37-<0.41)	(<18-<20)	(<18-<20)	160 (150-170)
Gadwall liver (adult)	4	901 (707-1400)	(<18-<21)	(<14-25)	(<18-<21)	(<3.5-6.6)	(<0.36-<0.42)	(<18-<21)	(<18-<21)	203 (180-240)
Gadwall liver (juvenile)	2	910 (810-1030)	(<18-<22)	(<14-<17)	(<18-<22)	2.7 (<3.5-4.3)	(<0.36-<0.44)	(<18-<22)	(<18-<22)	208 (180-240)
Western grebe liver	2	910 (850-980)	(<2-<2)	(<1-<2)	(<2-<2)	1.0 (0.93-1.1)	(<4-<4)	--	(<0.3-<0.3)	240 (230-250)

Furthermore, the reporting levels used for analysis of bird livers were lower than concentrations normally found in birds (Bagley and Locke, 1967) and all concentrations were less than these reporting levels. On the basis of this information, aquatic birds were probably not accumulating harmful levels of lead in their tissues.

Bioaccumulation of zinc appears to be common in plants, invertebrates, fish, and birds (see tables 18-20). Plants and invertebrates contained zinc concentrations less than concentrations found in zinc-contaminated habitats (Beyer and others, 1985). Concentrations of zinc in common carp (305-406 μg/g) were two to three times the 85th percentile value (approximately 160 μg/g dry weight or 40.1 μg/g wet weight) reported in the NCBP (Lowe and others, 1985), whereas other fish species had smaller concentrations. Other studies (Knapton and others, 1988; Lowe and others, 1985; Peterson and others, 1988; Stephens and others, 1988; Wells and others, 1988) also have shown that common carp concentrate zinc to a greater extent than do other species of fish.

Zinc concentrations (>200 μg/g) were found in some Refuge gadwalls and western grebes that approached levels in birds collected from zinc-contaminated sites in Norway (Lande, 1977). Zinc concentrations in bird livers also were greater than values found in other monitoring studies (Vermeer and Peakall, 1979; White and others, 1979; Ohlendorf and others, 1986b), but were two to three times lower than concentrations found in black-crowned night herons from contaminated sites (Custer and Mulhern, 1983). In experimental feeding studies, mallards fed a diet that contained 3,000 to 12,000 μg/g zinc had mean liver concentrations ranging from 401 to 483 μg/g (wet weight); whereas birds on a control diet had concentrations of 54 μg/g (Gasaway and Buss, 1972). These dietary concentrations caused a reduction in food intake and body weight followed by paralysis, diarrhea, anemia, and eventually death within 60 days. Dietary and liver concentrations of zinc on the Refuge were well below toxic levels to avian species found in laboratory feeding studies. However, the chronic effects of zinc and the concentrations that would be associated with chronic toxicosis are not clearly understood.

Organochlorine Pesticides and Polychlorinated Biphenyls

Water and Bottom Sediment

The reconnaissance nature of this study limited the analysis of pesticides and PCB compounds to sample media and locations where they would most likely exist. Because of their relatively high solubilities, triazine and chlorophenoxy acid herbicide compounds are found in water rather than partitioned into organic matter of sediment or in lipid of aquatic organisms. Therefore, only water samples from Malheur and Harney Lakes (the terminus of the hydrologic system) were analyzed for these herbicides. With the exception of a trace amount of dicamba (0.01 μg/L) in Harney Lake, all triazine and chlorophenoxy acid herbicides analyzed were at levels below their analytical reporting limits (supplemental data table 38). The U.S. Environmental Protection Agency has not established a criterion for dicamba in drinking water supplies, but the 48-hour LC50 for carp is 465 mg/L (The Royal Society of Chemistry, 1986).

Because organochlorine pesticides and PCBs tend to partition into organic matter of sediment and into biological tissues, these compounds are more likely found in bottom sediment and aquatic organisms. These compounds are highly resistant to chemical or biological transformations, and are extremely persistent in the environment (Smith and others, 1988). Concentrations of these compounds in bottom-sediment samples from the study area were, in most cases, below reporting limits (supplemental data table 29). Reportable amounts of DDT (dichlorodiphenyltrichloroethane), DDE (dichlorodiphenyldichloroethylene) and DDD (dichlorodiphenyldichloroethane) were found at four of the five sampling sites (fig. 18). Concentrations of DDT and its metabolites from all the sites ranged from <0.1 to 1.2 µg/kg (dry weight). In figure 18, <0.1 µg/kg DDT and metabolite concentrations were plotted as 0.05 µg/kg to differentiate them from those values equal to 0.1 µg/kg. DDE concentrations were highest in all areas and ranged from 54 to 82 percent of the total DDT and metabolite concentration. The only other organochlorine compound detected in bottom sediment was a trace amount of endrin (0.2 µg/kg) found at the Donner und Blitzen River inflow site. The concentrations of DDT and its metabolites and endrin did not exceed the U.S. Environmental Protection Agency's (1988) interim sediment values (interstitial water concentrations) determined for the protection of aquatic life from chronic toxicity.

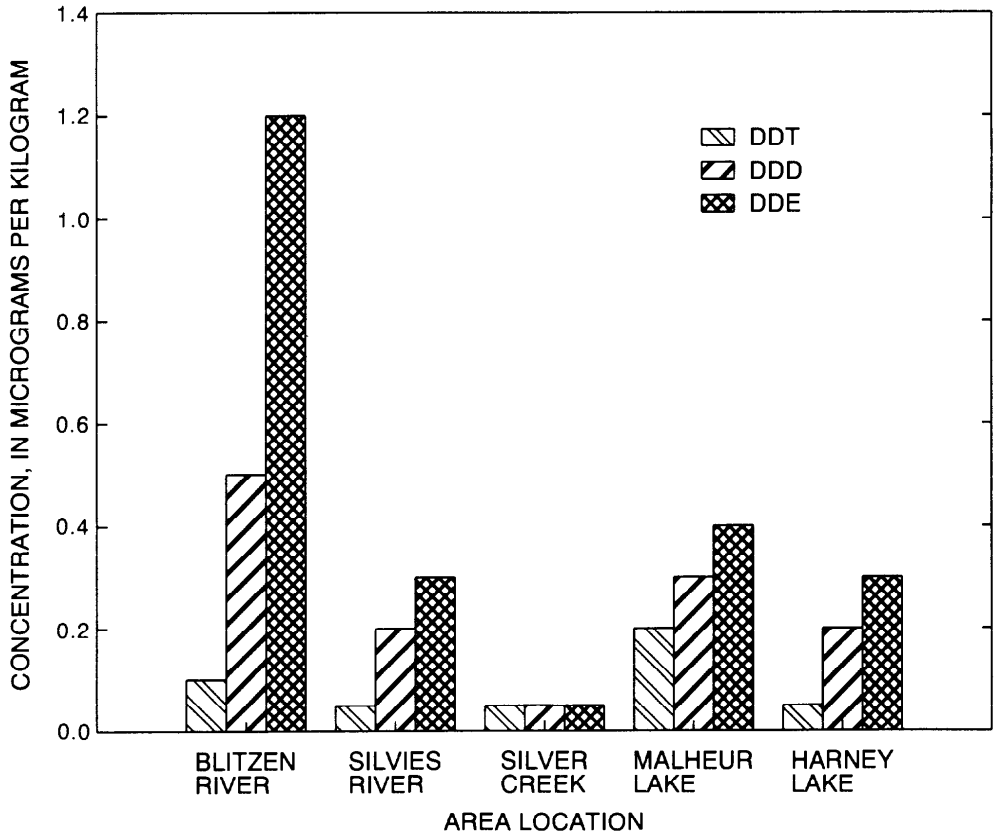

Figure 18.--Dry-weight concentrations of dichlorodiphenyltrichloroethane (DDT) and metabolites in Malheur National Wildlife Refuge bottom sediment, 1988. Bottom-sediment samples whose concentrations are less than the 0.1 microgram per kilogram reporting limit are plotted as 0.05 microgram per kilogram to distinguish them from those samples having concentrations equal to 0.1 microgram per kilogram.

Biota

Organochlorine pesticides and PCBs were analyzed in only 18 samples and only a few compounds were detected (supplemental data table 27). White crappie were the only fish species to be analyzed for organochlorines, and no detectable concentrations were found (supplemental data table 27). Only one gadwall sample had detectable concentrations of DDE, trans-nonachlor, and total PCBs (table 21). In contrast, all egg samples contained detectable concentrations of some organochlorines (table 22). Great blue heron eggs had the largest concentrations of most organochlorine compounds and had detectable levels of more compounds than the other bird species analyzed. Ohlendorf and others (1981) also found that fish-eating birds had the largest concentrations of organochlorine compounds. Concentrations of most compounds found in Refuge samples were below or near reporting levels. Compounds found in eggs included chlordane, DDT and metabolites, dieldrin, endrin, heptachlor epoxide, hexachlorobenzene, nonachlors, toxaphene, and PCBs (supplemental data table 27).

Table 21.--Concentrations of organochlorine pesticides and polychlorinated biphenyls (PCBs) in gadwalls from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a wet-weight basis; -- indicates no analysis performed; < (less than values) were less than the analytical reporting limit]

	Adult			Juveniles		
	South Malheur	North Malheur	Harney	South Malheur	North Malheur	Harney
beta 1,2,3,4,5,6-hexachlorocyclohexane (BHC)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
alpha-Chlordane	<.05	<.05	<.05	<.05	<.05	<.05
gamma-Chlordane	<.05	<.05	<.05	<.05	<.05	<.05
dichlorodiphenyldichloroethane (DDD)	<.05	<.05	<.05	<.05	<.05	<.05
dichlorodiphenyldichloroethylene (DDE)	<.05	.39	<.05	<.05	<.05	<.05
dichlorodiphenyltrichloroethane (DDT)	<.05	<.05	<.05	<.05	<.05	<.05
Dieldrin	<.05	<.05	<.05	<.05	<.05	<.05
Endrin	<.05	<.05	<.05	<.05	<.05	<.05
Heptaclor Epoxide	<.05	<.05	<.05	<.05	<.05	<.05
Hexachlorobenzene	<.05	<.05	<.05	<.05	<.05	<.05
trans-Nonachlor	<.05	.06	<.05	<.05	<.05	<.05
Oxychlordane	<.05	<.05	<.05	<.05	<.05	<.05
Total polychlorinated biphenyls (PCBs)	--	.61	--	--	--	--
Toxaphene	<.05	<.05	<.05	<.05	<.05	<.05

Table 22.--Concentrations of organochlorine pesticides and polychlorinated biphenyls (PCBs) in aquatic-bird eggs from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a wet-weight basis; egg concentrations were corrected for moisture loss by multipying reported data by the whole egg weight divided by the egg volume ($0.51 \times L \times W^2$); < (less than values) were less than the analytical reporting limit]

	Study sites and species									
	South Malheur			North Malheur				Harney		
	Avocet	Coot	Gadwall	Avocet	Coot	Gadwall	Heron	Avocet	Gadwall	Heron
beta 1,2,3,4,5,6-hexachlorocyclohexane (BHC)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
alpha-Chlordane	<.01	<.01	<.01	<.01	<.01	<.01	.03	<.01	<.01	.01
gamma-Chlordane	.01	<.01	<.01	<.01	<.01	<.01	.02	.01	<.01	.01
dichlorodiphenyldichloroethane (DDD)	.02	<.01	<.01	<.01	<.01	<.01	.09	<.01	<.01	.07
dichlorodiphenyldichloroethylene (DDE)	3.9	.19	.04	.14	.05	.28	5.3	1.7	.07	4.3
dichlorodiphenyltrichloroethane (DDT)	<.01	.01	<.01	<.01	<.01	<.01	<.01	.02	.01	.21
Dieldrin	.04	<.01	<.01	<.01	<.01	<.01	.10	.03	<.01	.02
Endrin	.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Heptaclor Epoxide	.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.02
Hexachlorobenzene	.06	<.01	<.01	<.01	<.01	<.01	.01	.03	<.01	.01
trans-Nonachlor	.03	<.01	<.01	<.01	<.01	<.01	.11	<.01	<.01	.03
Oxychlordane	.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.02
Total polychlorinated biphenyls (PCBs)	<.01	.18	<.01	<.01	<.01	<.01	.93	<.01	.07	.25
Toxaphene	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01

PCBs and DDE were the only compounds that were sufficiently elevated in eggs to warrant further discussion (see table 22). Total PCB concentrations ranged from 0.07 to 0.93 µg/g in three of the four species sampled, but they were not detected in all of the eggs. Great blue herons had the largest concentrations of 0.25 and 0.93 µg/g. These concentrations were below levels associated with lethal or sublethal effects in birds (Custer and Heinz, 1980; Eisler, 1986; Haseltine and Prouty, 1980; Heinz and others, 1984; Peakall and others, 1972).

DDE was detected in all egg samples analyzed, whereas DDT and DDD were detected in only a few samples as shown in table 22. Great blue heron eggs contained the largest DDE concentrations. However, the concentrations were considerably below levels associated with mortality or reproductive impairment in herons (Blus and others, 1980; Fitzner and others, 1988; Ohlendorf and others, 1979).

Mean eggshell thickness in the five aquatic-bird species sampled were reported in table 23. Mean thickness of eggs ranged from 0.249 mm (millimeters) for American avocets to 0.432 mm for double-crested cormorants. No eggshell thinning was found in double-crested cormorants; mean thickness was the same as the thickness measured in pre-1947 museum specimens (Henny and others, 1982). Eggshell thickness of pre-1947 eggs of gadwalls, American avocets, and American coots was unavailable for comparison to eggs collected from the Refuge in 1988 (L. Kiff, Western Foundation for Vertebrate Zoology, oral commun., 1989). Substantial eggshell thinning was measured in great blue herons; eggshell thickness was 8.5 percent less than pre-1947 museum specimens (Anderson and Hickey, 1972).

Table 23.--Arithmetic mean eggshell thickness of eggs collected from the Malheur National Wildlife Refuge, 1988

[Eggshell thickness in millimeters; percent thinning is based on comparison to pre-1947 eggshell thickness; N equals sample size; -- Pre-1947 data were unavailable for comparison; SD equals standard deviation]

Location	N	Mean ± SD	Pre-1947 Mean ± SD	Percent thinning[1]
Great blue heron	6	0.356±0.035	0.389±0.0032[2]	-8.5
Double-crested cormorant	6	0.432±0.025	0.432±0.0383[3]	0.0
American avocet	14	0.249±0.010	--	--
American coot	11	0.310±0.031	--	--
Gadwall	11	0.312±0.028	--	--

[1] Comparison of 1988 eggshell thickness to pre-1947 thickness.
[2] Data from Anderson and Hickey (1972).
[3] Data from Henny and others (1982).

This eggshell thinning corresponds to elevated DDE concentrations found in two heron eggs of 4.3 and 5.3 μg/g. However, great blue herons are not considered a species sensitive to the effects of DDT and its metabolites (Blus and others, 1980; Fitzner and others, 1988; Henny, 1972). In other studies, great blue herons had normal reproductive success with DDE concentrations up to 16 μg/g and 13 percent eggshell thinning (Blus and others, 1980). The threshold level for reproductive effects of DDT and metabolites in great blue heron eggs has not been established, but may be much higher than the threshold level of 3 μg/g (wet weight) established for brown pelicans (Blus and others, 1974).

Biological Observations

Much of the observed lack of biological activity at the Refuge in 1988 was attributed to the impact of the high-water conditions of the early 1980's. Aquatic plants and invertebrates were not found to be abundant on the Refuge. Submergent vegetation was not found in either Malheur or Harney Lake. Filamentous algae was only found in south Malheur Lake and in Harney Lake, whereas smartweed grew only in Malheur Lake on the south and north ends of the lake. Only a few aquatic- invertebrate families were observed, and the most abundant family encountered was water boatmen. Other invertebrates, such as damselfly nymphs, dragonfly nymphs, fly larvae, and beetle adults and larvae normally encountered in large abundance in habitats similar to the Refuge were uncommon.

A relation between contaminant concentrations and low invertebrate abundance could not be established in this study. Plausible explanations of why the Refuge appeared to be deficient of many aquatic organisms include high water levels, large carp populations, lack of appropriate substrate for food and cover, and elevated contaminant levels. Fluctuating water levels drowned out emergent vegetation on the Refuge and submergent vegetation could be limited by increasing water levels. Much of Harney and Malheur Lakes have become too deep to allow sufficient light to penetrate lower levels of the water column and could have limited plant propagation. However, the primary limiting factor to submergent vegetation is probably the large carp population in the lakes. The absence of submergent plant communities is also a limiting factor for aquatic invertebrates that normally utilize these communities for food, cover, and reproduction (Voigts, 1976). The submergent plant community is especially important during critical periods of the bird's life cycle, such as the breeding season when birds require an abundant invertebrate food source.

No evidence was seen of deformed bird embryos or juveniles on the Refuge. Most nests located on the Refuge were rechecked after the eggs had sufficient time to hatch. Most of the coot and avocet nests were lost to predators. Many of the coot nests had become accessible to predators by receding water levels. No coot nests were found on the periphery of Harney Lake, although a few nests were found in the Silver Creek drainage near the west end of Harney Lake. However, these few nests were later lost to predators. Few broods of coots, avocets, gadwalls, and mallards were observed on the Refuge and very few juvenile aquatic birds were seen during the breeding season of 1988. In contrast, young birds associated with adults after hatching are generally observed in other studies (Gullion, 1954; Ryder, 1961; Gould, 1974). This low production on the Refuge in 1988 is believed to be associated with the lack of suitable nest sites, high predation pressures, lack of an adequate food base (invertebrates and aquatic plants), and receding water levels. The low production cannot be directly attributed to elevated contaminant levels.

No significant health problems related to agricultural drainwater contaminants were noted in necropsied adult or juvenile birds. During August, a die-off of 15-20 western grebes was noted on west Harney Lake. All the grebes appeared to have died within a day or two of each other. Necropsy of four of these birds revealed no definitive evidence of the cause of death (R.K. Stroud, U.S. Fish and Wildlife Service, oral commun., 1988). Although mercury concentrations were elevated in the livers of these birds (see table 14), it is unlikely the cause of death.

Declining Lake Levels

From July 1985 to September 1988, Malheur and Harney Lake levels declined 4.5 feet, representing a 610,000 acre-foot (49 percent) loss in total lake volume. Because Harney Lake is shaped like a bowl in contrast to the platter shape of Malheur Lake, Harney Lake volume declined only 32 percent during the same time frame.

Increases in concentrations of various dissolved chemical constituents have occurred mainly as a result of declining lake levels. Arsenic, boron, vanadium, specific conductance, sodium, chloride, sulfate, total dissolved solids, sodium adsorption ratio, and alkalinity concentrations in Harney

Lake ranged from 1.4 to 2.1 times (median value 1.5 times) those in the 1984-85 study (Fuste' and McKenzie, 1987). These concentration increases correspond well with the 32 percent decline in Harney Lake volume.

Lake levels in 1988 were still considerably above normal, with additional lake level declines likely to occur before more normal lake level conditions were established. A Malheur Lake level of 4,093 feet is considered to be a more "normal" mean annual maximum. To reach that level, 1988 lake levels would need to decline an additional 5 feet, or about a 359,000 acre-foot (57 percent) loss in Malheur, Mud, and Harney lake volume; Harney Lake, alone, would experience a 50 percent reduction in lake volume. Various dissolved chemical constituents will increase in concentration as lake levels return to more normal conditions. Boron, specific conductance, sodium, chloride, sulfate, total dissolved solids, sodium adsorption ratio, and alkalinity are estimated to double in concentration in Harney Lake. Projected boron concentrations in Harney Lake could range from 15,000 to 20,000 μg/L. However, arsenic and vanadium concentrations would increase by only 30 percent because of possible geochemical considerations; projected arsenic concentrations in Harney Lake, at near normal lake conditions, could range from 300 to 350 μg/L.

A 50 percent increase in boron concentrations could significantly affect growth and survival of some aquatic plants. The projected boron concentrations could be potentially similar to levels found in boron contaminated sites in California (Schuler, 1987). These contaminated sites produced plants that had boron concentrations exceeding dietary levels shown to impair reproduction in nesting mallards (Schuler, 1987, Smith and Anders, 1989). Thus, increased boron concentrations in Harney Lake could potentially cause aquatic plants to bioaccumulate boron to levels that are toxic to aquatic birds. Arsenic concentrations found in Harney Lake water in 1988 were sufficiently elevated to affect survival of aquatic invertebrates (Eisler, 1988a; U.S. Environmental Protection Agency, 1985). Increases in arsenic concentrations by 30 percent could magnify hazards to aquatic invertebrates, possibly reducing their abundance and species composition. The potential for these projected lake-level constituent concentrations to cause acute and chronic toxicity problems to the health of human, animal, and aquatic life cannot be adequately assessed without a second reconnaissance investigation conducted at a time when maximum lake level is at near normal conditions or lower.

SUMMARY AND CONCLUSIONS

This report describes the results of a 1988-89 reconnaissance investigation of the Malheur National Wildlife Refuge. The objectives of the study were to determine if agricultural drainwater entering the Refuge: (1) had caused, or had the potential to cause, significant harmful effects on human health, fish, and wildlife, or (2) had adversely affected the suitability of the water for other beneficial uses. In a previous study conducted by the U.S. Geological Survey in 1984-85, elevated concentrations of arsenic and boron were found in Harney Lake (one of the three Refuge lakes) that exceeded drinking-water and irrigation-water standards, respectively. In addition, the Oregon Department of Environmental Quality found elevated mercury in fish tissues from the Refuge that exceeded the 85th percentile for concentrations of mercury in fish tissue analyzed in the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program

(NCBP). This study was initiated because the potential existed that irrigation-return-flow water was causing elevated elemental concentrations in Refuge water and fish tissues. This investigation was conducted by a team of scientists from the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the U.S. Bureau of Reclamation.

This study took place during a hydrologic time frame following a climatic period where Malheur Lake reached its highest lake-surface elevations in recorded history (1903-86). These record-high lake elevations were due to a combination of large snowfalls in the surrounding mountains and unusually cool summers. In 1988, tributary runoff to the Refuge was below average because of below normal snowpacks in 1987 and 1988, but Refuge lake levels in 1988 were still considerably above the long-term average. The combination of below normal tributary runoff and above average lake levels could mean that conclusions concerning the impacts of agricultural drainage to the Refuge may be different from conclusions that would have been reached if the study had been conducted during a normal hydrologic period.

The agricultural economy of the area is chiefly supported by a combination of livestock production, and the production of hay and some grain crops. Water used to irrigate the hay crops is predominantly derived from the spring snowmelt which is used to flood irrigate the land. Portions of the irrigation-return flows eventually reach the Refuge as tail water and ground-water seepage. Results of chemical analysis completed on surface water collected in March of 1988 showed that the concentrations of major ions collected at sites on the Silvies River located near Malheur Lake were from two to five times greater than concentrations observed at a site located upstream of where flood irrigation was occurring. In contrast, only 16 percent of the total dissolved-solids load measured at the upstream site was detected entering Malheur Lake. This seeming contradiction occurred because only 14 percent of the Silvies River streamflow at the upstream site actually was measured entering Malheur Lake. Most of the water loss and the increase in constituent concentrations were attributed to flood-irrigation practices and ground-water recharge, with water evaporation contributing only a minor role because of the cooler weather conditions typically experienced in March.

Flow-weighted concentrations of major ions in streams flowing into Malheur Lake were compared to concentrations for these same constituents observed in Malheur Lake. All major ions in Malheur Lake, with the exception of calcium, were from two to almost 50 times the concentrations observed in the inflowing streams. This observation indicates how, over time, water-evaporation losses occurring in Malheur Lake can greatly increase inflowing stream concentrations within Malheur Lake. It is also suspected, but cannot be substantiated, that as lake levels rose in the early to mid-1980's, dissolution of many of the evaporite deposits surrounding the lake occurred. Dissolution of these deposits, which are probably enriched in a number of major and minor elements, would add to the lakes' constituent loadings. The increased constituent loadings to the lakes would contribute to the concentration differences now observed between the inflowing stream and Malheur Lake. Major ion concentrations in Harney Lake, with the exception of calcium, magnesium, and potassium, were from two to four times the concentrations observed in Malheur Lake. This increase further illustrates how the continuing water-evaporation loss is occurring between the lakes, with the corresponding constituent-concentration effect

in progress as lake water migrated from Malheur to Harney Lake. Geochemical processes also played an important role in the water chemistry of the lakes and, in particular, the chemistry of calcium and magnesium.

A select number of water samples were collected and analyzed for nutrient concentrations. All Refuge concentrations of nitrate plus nitrite were less than the maximum contaminant level established by the U.S. Environmental Protection Agency for the protection of domestic drinking-water supplies. The largest nitrate-plus-nitrite concentration was observed in Malheur Lake, whereas concentrations found at The Narrows and within Harney Lake were less than the analytical reporting limit (<0.1 mg/L as N). The decrease in nitrate-plus-nitrite concentration proceeding from Malheur to Harney Lake is believed to be caused possibly by a combination of increased algal assimilation and denitrification processes. Orthophosphorus concentrations in some of the inflowing streams and springs, and within the lakes exceeded the U.S. Environmental Protection Agency's recommended total phosphate phosphorus concentrations established to prevent development of biological nuisances and to control accelerated or cultural eutrophication. Although the quantity of the suspended algal material appeared to be high within the lakes, other biological or environmental factors seem to be retarding the growth of filamentous algae and submergent aquatic plants.

Arsenic concentrations in Malheur and Harney Lakes exceeded the U.S. Environmental Protection Agency's maximum contaminant level established for the protection of domestic drinking-water supplies and the suggested chronic toxicity level for freshwater aquatic plants. Arsenic concentrations in Harney Lake were over four times the concentrations observed in Malheur Lake. These lake concentrations were more than twice the concentrations reported for the same locations sampled during a 1984-85 study. The increase in arsenic concentrations from 1984-85 to 1988-89 is possibly due to the concentration effect caused by water evaporation accompanying the decline in lake levels.

Although elevated concentrations of arsenic were found in water samples from Malheur and Harney Lakes, the biota sampled did not accumulate large concentrations of arsenic. Most biological samples contained less than 2 μg/g arsenic. Arsenic concentrations in fish tissues did not exceed the 85th percentile for the NCBP, and concentrations were below levels reported to be toxic to fish or fish-eating wildlife. Residues found in birds and their eggs were below concentrations that are indicative of arsenic poisoning or could impair productivity in avian species. Although all the biota contained small arsenic concentrations, the elevated water arsenic concentrations could have an indirect effect on biological populations. These elevated water concentrations exceeded concentrations known to be toxic to some aquatic organisms, thereby potentially limiting invertebrate abundance and composition, and reducing the availability of important foods for fish and aquatic birds.

Boron concentrations in Malheur and Harney Lakes exceeded the U.S. Environmental Protection Agency's criterion for irrigation of sensitive crops. Harney Lake boron concentrations were over three times the concentrations observed in Malheur Lake. These lake concentrations were more than two times the concentrations reported for the same locations sampled during a 1984-85 study. The increase in boron concentrations, like arsenic, from 1984-85 to 1988-89 is possibly due to the concentration effect caused by water evaporation accompanying the decline in lake levels.

Large boron concentrations in Malheur and Harney Lake water corresponded to large concentrations in some of the biota. Plant tissues, particularly algae, contained the largest concentrations of boron. One sample of aquatic invertebrates and algae contained boron residues that were similar to those found in boron-contaminated sites. However, concentrations in most biological samples were below levels found in boron-contaminated sites. In addition, boron concentrations in food-chain items did not exceed dietary levels reported to cause mortality or reproductive impairment in aquatic birds. Boron concentrations in both the bird livers and eggs were below levels found to be associated with reduced hatching success and indicates that boron would not directly impair the productivity of most avian species.

Mercury concentrations in stream, spring, and lake water at the Malheur National Wildlife Refuge were all less than the analytical reporting limit. Unfortunately, the analytical reporting limit was above the suggested U.S. Environmental Protection Agency's guidelines for the protection of freshwater aquatic organisms and their use. Thus, it is not possible to determine if mercury concentrations in some of the Refuge water were hazardous to any of the aquatic organisms. These concentrations were identical to concentrations reported for similar locations sampled during a 1984-85 study.

Although mercury concentrations in water and sediment were below or only slightly above reporting levels, mercury did accumulate in some biological tissues. Concentrations in plants and invertebrates were below concentrations normally found in uncontaminated areas. Slightly less than half the fish samples contained mercury concentrations that exceeded the 85th percentile in the NCBP. Several of the fish had concentrations that exceeded normal background levels, but did not exceed the U.S. Food and Drug Administration's Action Level for protection of human health, or exceed levels known to be toxic to fish-eating birds. The largest concentrations of mercury were found in the livers and eggs of fish-eating birds. Concentrations in some of these livers exceeded background levels, but did not approach lethal levels. Mercury concentrations in the livers of western grebes were similar to those found in mallards that exhibited reproductive deficiencies. Furthermore, about one-half the eggs of fish-eating birds contained mercury concentrations associated with reduced reproductive success in experimental mallard feeding studies. However, species sensitivity to mercury is known to vary. Fish-eating birds, such as herring gulls, brown pelicans, and common terns, appear to be less sensitive to mercury than mallards.

Selenium concentrations in stream, spring, and lake water at the Malheur National Wildlife Refuge were all less than the analytical reporting limit. These concentrations were identical to concentrations reported for similar locations sampled during a 1984-85 study. The selenium concentrations were smaller than U.S. Environmental Protection Agency's acute and chronic criteria for protection of freshwater aquatic life, but concentrations smaller than the reporting limits have been shown to bioconcentrate in aquatic organisms.

Selenium was detected in all biological samples collected from the Refuge. Concentrations in plants, invertebrates, and fish were small and similar to normal background levels. Only one fish sample had selenium concentrations greater than the 85th percentile for the NCBP. Eggs of aquatic birds also contained concentrations that were similar to levels normally found in aquatic birds. In contrast, elevated selenium concentrations were measured in the livers of most of the same bird species. About one-half the liver samples contained concentrations that exceeded threshold levels and were similar to levels known to reduce hatching success and cause developmental abnormalities. These birds would probably not retain selenium residues accumulated from selenium-contaminated sites on their wintering grounds because birds have been reported to rapidly lose selenium once they leave a contaminated site. Analysis of juvenile birds also indicates that birds were possibly exposed to a local source of selenium. Egg concentrations are generally a better indicator of selenium contamination than liver tissues. Thus, selenium probably would not pose a significant hazard to nesting aquatic birds, but more extensive research would be needed to clarify selenium conditions on the Refuge.

Of the other elements (cadmium, chromium, copper, lead, molybdenum, uranium, vanadium, and zinc) analyzed in stream, spring, and lake water from the Malheur National Wildlife Refuge, none exceeded the U.S. Environmental Protection Agency's criteria for the protection of (1) freshwater aquatic organisms, (2) sensitive crops, or (3) human health. Concentrations of these elements were in the range of those concentrations reported for similar locations sampled during a 1984-85 study, with the exception of molybdenum and vanadium concentrations in lake water. Malheur Lake molybdenum concentrations in 1988 were from 7 to 22 times those values reported in 1984-85; whereas, Malheur and Harney Lake vanadium concentrations in 1988 were from 1.5 to 9 times those values reported in 1984-85. The increase in molybdenum and vanadium concentrations, over time, also is thought to be due to the concentration effect caused by water evaporation accompanying the decline in lake levels. The other elements did not show lake concentration increases over the same time frame and are speculated to be involved in geochemical (precipitation), physical (adsorption onto particulate sediment), and biological processes which are removing them from the dissolved phase.

Most of the other elements analyzed in biological samples occurred below reporting levels or occurred at normal background concentrations. A few of the elements exceeded guidelines or were in excess of concentrations reported to be elevated. Cadmium concentrations in fish were up to four times greater than concentrations in the NCBP, but they and other food-chain materials were lower than dietary concentrations shown to be toxic to avian species. Concentrations in bird livers also were smaller than levels reported to be toxic. Elevated concentrations of copper occurred in most of the biota. Copper concentrations in fish exceeded the 85th percentile for the NCBP, and gadwalls had considerably larger concentrations than the other species of birds analyzed. However, all concentrations were below levels known to produce copper toxicosis. Lead concentrations in most of the biota were less than the analytical reporting limit, but high reporting limits were used in the analytical procedures for lead. In general, lead reporting limits for analysis of food-chain items were below dietary levels reported to cause toxic reactions in birds. Concentrations of zinc in most of the food-chain organisms were below levels found in zinc-contaminated habitats. Elevated zinc concentrations that approached levels found in zinc-

contaminated sites, occurred in gadwalls and western grebes collected from the Refuge. Experimental feeding studies indicate that dietary and liver concentrations on the Refuge were lower than levels that are lethal to birds, but those concentrations that will produce chronic effects are not as clearly understood.

Malheur and Harney Lake water were analyzed for triazine and chlorophenoxy acid herbicides. With the exception of a trace amount of dicamba found in Harney Lake, all other herbicides were at levels below their analytical reporting limits. Organochlorine pesticides and PCBs analyzed in Refuge bottom sediment were, in most cases, below their analytical reporting limits. Detectable concentrations of DDT and its metabolites (DDE and DDD) were found in a majority of the bottom-sediment samples; in addition, a trace amount of endrin was found in one sample. The concentrations of DDT and its metabolites, and endrin did not exceed the U.S. Environmental Protection Agency's interim sediment values (interstitial water concentrations) determined for the protection of aquatic life from chronic toxicity.

Most of the biota contained small or undetectable concentrations of organochlorine pesticides and PCBs. Concentrations in fish samples were all below the analytical reporting level. Organochlorines were detected in only one gadwall, whereas all egg samples contained detectable concentrations. Concentrations of DDT and its metabolites, and PCBs were the only compounds to occur consistently in egg samples. Although eggs contained slightly elevated levels of DDT and its metabolites and PCBs, most were below levels associated with mortality or reproductive impairment in aquatic birds. Moderately large concentrations of DDE were found in a few of the great blue heron eggs, but great blue herons
are thought to be less sensitive to the effects of DDE than other species. Measurements of egg shell thickness and comparison to pre-1947 museum specimens and productivity studies support this theory.

Aquatic plants and invertebrates were not abundant on the Refuge and may be limited by several physical and biological conditions, including high-water levels, increasing carp populations, and lack of appropriate substrate for invertebrate food and cover. No evidence was seen of deformed embryos or juveniles on the Refuge, but few juveniles of any species were observed. Low production of some species nesting on the Refuge is believed to be associated with lack of suitable nest sites, high predation pressures, lack of an adequate food base, and rapidly decreasing water levels.

As a result of declining lake levels which have occurred from July 1985 to September 1988, there has been dramatic increases in concentrations of a number of dissolved chemical constituents in the lake. Because 1988 lake levels were still considerably above normal, additional declines will occur over time before more normal lake levels are reached. Thus, additional increases in lake concentrations of a number of dissolved chemical constituents are projected to occur with time. It is estimated that at a more normal lake level, boron concentrations in Harney Lake could range from 15,000 to 20,000 μg/L, and that arsenic concentrations could range from 300 to 350 μg/L. These concentrations could result in conditions that would produce toxic effects in fish and wildlife at the Refuge. The potential for these projected lake-level constituent concentrations to cause chronic and acute toxicity problems to the health of human, animal, and aquatic life cannot be adequately assessed without a second reconnaissance investigation.

Although 1988-89 represented a hydrologic period of below normal tributary runoff to the Refuge and above average lake levels, there is no evidence that irrigation agricultural runoff to the Refuge in 1988 was causing significant harmful effects on human health, fish, and wildlife.

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SUPPLEMENTAL DATA TABLES

Table 24.--Historical and current water-quality data for the Malheur National Wildlife Refuge

[Concentrations are listed as minimum/median/maximum values if three or more observations available; minimum/maximum if only two observations available; and value if only one observation available. Historical data for 1912 and 1962 (Phillips and Van Denburgh, 1971), 1972-73 (Hubbard, 1975), and 1984-85 (Fuste' and McKenzie, 1987) are included for comparison. mg/L = milligrams per liter; µg/L = micrograms per liter; "--" = not analyzed]

Constituent	Year of sampling	Silvies River	Donner und Blitzen River	Sod House Springs	Malheur Lake	Malheur Lake at The Narrows	Harney Lake	Silver Creek
Temperature (°C)	1984	11.3/15.0	14.8	--	16/ 18/ 21	16/ 16/ 16	16/ 18/ 20	--
	1985	21.0/26.7	27.0	--	21/ 26/ 27	21/ 22/ 24	21/ 26/ 27	--
	1988	6.6/8.0/13.1	13.1/17.4/22.6	11.7/11.8	20.1	16.0	20.1	13.6
Oxygen, dissolved (percent sat.)	1984	--	--	--	11/116/160	87/ 90/100	96/ 97/103	--
	1988	73/ 94/100	71/ 96/115	72/76	82	98	93	107
pH (units)	1962	--	--	--	7.0	--	9.8	--
	1972-73	7.6/7.7/8.0	7.5/7.7/8.2	7.8	7.5/7.9/8.9	7.6/7.7/7.9	--	--
	1984	8.0/8.1	8.0	8.0	7.9/8.4/8.6	8.5/8.6/8.7	8.8/8.9/9.0	--
	1988	7.9/8.1/8.5	7.2/8.2/8.6	7.8/8.0	8.9	9.0	9.1	8.2
Specific Conductance (µS/cm at 25 °C	1962	--	--	--	409	--	47700	--
	1972-73	269/296/593	107/124/170	361	279/613/6770	442/ 555/ 893	--	--
	1984	220/310	129	451	505/610/ 794	1300/1360/1700	3150/3220/3250	--
	1985	--	--	--	759/778/1210	1730/1780/2050	3270/3290/3360	--
	1988	157/197/436	91/120/328	421/432	1980	2830	4390	120
Calcium, dissolved (mg/L)	1912	--	--	--	27	--	--	--
	1962	--	--	--	38	--	--	--
	1972-73	26/ 29/ 50	9.3/ 11/ 16	22	11/ 43/ 61	36/ 48/ 58	--	--
	1984	24/33	12	27	25/ 30/ 31	29	15/ 15/ 16	--
	1985	--	--	--	29/ 31/ 33	26/ 28/ 29	16	--
	1988	13/ 20/ 39	8.6/ 10/ 28	17/ 19	34	25	14	10
Magnesium, dissolved (mg/L)	1912	--	--	--	20	--	--	--
	1962	--	--	--	12	--	--	--
	1972-73	7.7/8.2/ 16	3.8/4.8/6.9	13	8.2/ 22/ 55	16/ 21/ 39	--	--
	1984	5.9/8.6	4.6	15	9.5/ 15/ 20	17	6.9	--
	1985	--	--	--	19/ 19/ 20	16/ 17/ 17	9.8	--
	1988	4.9/6.2/ 12	3.6/5.2/ 14	17/ 17	32	36	11	4.4
Sodium, dissolved (mg/L)	1912	--	--	--	117	--	8820	--
	1962	--	--	--	31	--	13200	--
	1972-73	15/ 23/ 59	6.3/9.2/ 11	35	14/ 54/1700	36/ 43/ 84	--	--
	1984	12.4/20.3	7.3	40	66/ 92/ 120	230	640/ 640/660	--
	1985	--	--	--	110/130/ 160	290/300/320	680	--
	1988	9.8/ 14/ 38	5.4/8.0/ 23	40/ 44	390	610	1000	8.6
Potassium, dissolved (mg/L)	1912	--	--	--	27	--	335	--
	1962	--	--	--	4.0	--	488	--
	1972-73	3.4/4.9/8.8	1.3/1.6/1.9	4.8	3.5/12 /130	8.9/ 9.9/ 18	--	--
	1984	3.3/3.5	1.6	6.5	12.3/16.5/ 22	26	40/ 41/ 43	--
	1988	0.6/2.6/3.5	1.3/1.4/2.5	14/ 18	18	34	20	2.2
Chloride, dissolved (mg/L)	1912	--	--	--	22	--	6800	--
	1962	--	--	--	4.5	--	11700	--
	1972-73	2.7/3.4/8.3	0.5/1.8/2.1	7.3	3.2/ 10/320	5.2/7.7/ 18	--	--
	1984	3.3/4.7	1.7	15	8.9/ 14/ 39	130	470/530/560	--
	1985	--	--	--	29 / 41/ 58	220/230/230	510	--
	1988	1.9/3.0/7.1	1.0/1.6/4.2	11/ 11	185	340	760	1.6
Sulfate, dissolved (mg/L)	1912	--	--	--	37	--	1930	--
	1962	--	--	--	51	--	2590	--
	1972-73	12/ 18/ 32	3.7/4.9/8.7	10	4.0/ 20/600	7.6/ 11/ 48	--	--
	1984	9.3/34	2.8	24	17/ 19/ 25	46	130/ 140/150	--
	1988	3.9/ 12/ 57	1.8/3.5/ 24	21/ 23	98	140	210	5.6
Alkalinity, dissolved (mg/L as $CaCO_3$)	1912	--	--	--	360	--	7370	--
	1962	--	--	--	145	--	10100	--
	1972-73	122/135/169	48/ 60/ 84	171	139/312/2250	218/290/438	--	--
	1984	110/139	68	182	246/300/ 336	615	575/ 600/625	--
	1988	77/ 92/163	48/ 61/147	186/200	718	925	1000/1820	61
Nitrate + Nitrite (mg/L as N)	1912	--	--	--	.54	--	.63	--
	1962	--	--	--	.74	--	--	--
	1972-73	.00/.00/.01	.05/.23/.29	.38	.00/.01/2.8	.00/.02/.17	--	--
	1984	<.02/<.02	.08	1.5	.02/.08/.90	.05	.11/.11/.14	--
	1988	<.1/<.1/<.1	<.1/<.1/<.1	.45/.54	.70	<.1	<.1	

Table 24.--Historical and current water-quality data for the Malheur National Wildlife Refuge--Continued

Constituent	Year of sampling	Silvies River	Donner und Blitzen River	Sod House Springs	Malheur Lake	Malheur Lake at The Narrows	Harney Lake	Silver Creek
Phosphorus, ortho, dissolved (mg/L as P)	1972-73	0.03/.04	0.03/.03/.05	--	0.00/.02/1.2	0.01/.01/.01	--	--
	1984	.03/.04	.03	.17	.01/.01/.12	.73	0.66/.68/.71	--
	1988	.05	.01/.14	.15	--	.61	--	--
Solids, dissolved (mg/L)	1912	--	--	--	484	--	22400	--
	1962	--	--	--	258	--	34300	--
	1972-73	178/206/377	82/ 98/120	237	166/374/4620	268/320/551	--	--
	1984	182/249	102	274	352/442/ 530	841	1950/1960/1980	--
	1988	127/160/288	74/150/235	273/296	1320	1840	2730	107
Sodium adsorption ratio (units)	1912	--	--	--	4.2	--	--	--
	1962	--	--	--	1.1	--	--	--
	1972-73	.8/ .8/1.9	.4/ .6/ .7	1.5	.6/1.9/ 65	1.2/ 1.4/ 2.1	--	--
	1984	.6/ .8	.4	1.8	2.5/3.2/ 4.2	8.4	30/ 32/ 33	--
	1985	--	--	--	3.8/4.3/ 5.6	11/11 /12	33	--
	1988	.5/ .7/ 1	.4/ .5/ .9	2/ 2	12	18	49	.6
Arsenic, dissolved (µg/L)	1972-73	--	--	8	0/9	--	--	--
	1984	--	--	5	4/ 6/ 9	9	120/120/120	--
	1985	--	--	--	11/ 15/ 22	63/ 70/ 81	140	--
	1988	<1/ 2/ 2	<1/ <1/ 1	5/ 6	59	78	250	1
Boron, dissolved (µg/L)	1984	200/300	300	210	500/700/1200	1100	3600/4600/6700	--
	1985	--	--	--	510/575/ 800	1800/1800/2100	4000	--
	1988	40/ 55/ 80	<10/ 20/ 40	160/170	2800	4300	8500	70
Cadium, dissolved (µg/L)	1972-73	--	--	0	0/0	--	--	--
	1984	--	--	<1	<1/ <1/ <1	<1	<1/ <1/ 1	--
	1988	<1/ <1/ <1	<1/ <1/ <1	<1/ <1	1/2	<1	1	<1
Chromium, dissolved (µg/L)	1972-73	--	--	0	0/0	--	--	--
	1984	--	--	<1	<1/ <1/ <1	<1	<1/ <1/ <1	--
	1988	<1/ <1/ <1	<1/ <1/ 1	1/ 1	<1	<1	<1	<1
Copper, dissolved (µg/L)	1972-73	4	7	5	3/ 8/ 18	17	--	--
	1984	--	--	2	2/ 4/ 5	21	3/ 5/ 9	--
	1988	3/ 4/ 4	2/ 4/ 8	1/ 2	6	4	4	<1
Lead, dissolved (µg/L)	1972-73	--	--	0	2/3	--	--	--
	1984	--	--	<5	<5/ <5/ <5	9	<5/ <5/ <5	--
	1988	<5/ <5/ <5	<5/ <5/ <5	<5/ <5	<5	<5	<5	<5
Mercury, dissolved (µg/L)	1972-73	--	--	0	2/3	--	--	--
	1984	--	--	<.1	<.1/<.1/<.1	<.1	<.1/<.1/<.1	--
	1988	<.1/<.1/<.1	<.1/<.1/<.1	<.1/<.1	<.1	<.1	<.1	<.1
Molybdenum, dissclved (µg/L)	1984	--	--	1	<1/ 1/ 2	<1	24/ 26/ 28	--
	1988	1/ 2/ 7	<1/ <1/ 3	2/ 3	14	22	29	2
Selenium, dissolved (µg/L)	1984	--	--	<1	<1/ <1/ <1	<1	<1/ <1/ <1	--
	1988	<1/ <1/ <1	<1/ <1/ <1	<1/ <1	<1	<1	<1	<1
Uranium, dissolved (µg/L)	1988	<.4/ .6/ .9	<.4/ .8	.9	3.7	--	2.8	<.4
Vanadium, dissolved (µg/L)	1984	--	--	19	7.5/8.0/8.8	5.4	24/ 27/ 27	--
	1988	6/ 7/ 9	5/ 10/ 17	20/ 33	51	48	40	6
Zinc, dissolved (µg/L)	1972-73	0	0	10	20/ 75/160	150	--	--
	1984	--	--	7	9/ 10/ 15	10	<10/<10/ <10	--
	1988	<3/ <3/ 4	<3/ <3/ 13	4/ 4	<10	<10	<10	<3

Table 25.--Concentrations of trace elements in plants, aquatic invertebrates, and fish collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in migrograms per gram on a dry weight basis; moisture content expressed as a percent; < (less than values) were less than the analytical reporting limit; -- indicates no samples analyzed; plant and invertebrate samples were a composite of individuals; fish samples were a composite of two to five fish]

Species	Sample	Site	Date	Moisture	Alumi-num	Anti-mony	Arse-nic	Bar-ium	Beryl-lium	Boron	Cad-mium
Algae	Plant	S Malheur	7/19/88	79.8	4500	<0.12	4.5	93	<2.5	160	<0.25
Algae	Plant	Harney	7/20/88	77.4	2300	.504	15.0	38	<2.2	380	<.22
Algae	Plant	Harney	8/31/88	77.2	8600	--	3.7	59	.2	180	<.2
Smartweed	Plant	S Malheur	7/19/88	84.7	608	<.16	1.7	35	<3.3	60	<.33
Smartweed	Plant	N Malheur	7/19/88	82.1	450	<.14	.87	32	<2.8	89	<.28
Sideswimmers	Invertebrate	S Malheur	8/31/88	81.1	820	--	.50	60	<.1	4	<.2
Damselfly nymphs	Invertebrate	S Malheur	8/31/88	79.7	1200	--	.41	7.5	<.1	5	.4
Damselfly nymphs	Invertebrate	Harney	8/31/88	86.6	600	--	1.4	4.5	<.1	94	1.8
Water boatmen	Invertebrate	S Malheur	7/19/88	83.2	170	<.15	.77	<30	<3.0	<30	1.7
Water boatmen	Invertebrate	N Malheur	7/21/88	81.9	660	<.14	.88	<28	<2.8	<28	.50
Water boatmen	Invertebrate	Harney	7/20/88	82.2	130	<.14	2.4	<28	<2.8	35	2.02
Mussels	Invertebrate	S Malheur	8/30/88	88.5	660	--	.69	114	<.1	<2	.3
Brown bullhead	Fish	S Malheur	8/31/88	84.0	<62	<.16	.38	<31	<3.1	<31	<.31
Brown bullhead	Fish	N Malheur	8/30/88	79.7	130	<.12	.39	<25	<2.5	<25	.44
Common carp	Fish	S Malheur	7/19/88	80.3	120	<.13	.25	<25	<2.5	<25	.41
Common carp	Fish	N Malheur	8/30/88	78.8	66	.12	.42	<24	<2.4	<24	.75
Common carp	Fish	Harney	9/01/88	81.9	<55	<.14	.36	<28	2.8	<28	1.05
Largemouth bass	Fish	S Malheur	8/15/88	76.1	8	--	<.2	1.8	<.1	<2	<.2
Sucker	Fish	S Malheur	7/19/88	81.4	54	<.13	.23	<27	<2.7	<27	<.27
Tui chub	Fish	Harney	9/01/88	80.6	<51	<.13	.70	<26	7.2	<26	<.26
White crappie	Fish	S Malheur	8/30/88	69.5	79	<.082	.16	<16	<1.6	<16	<.16
White crappie	Fish	N Malheur	8/30/88	82.4	<57	<.14	.28	<28	<2.8	<28	<.28
White crappie	Fish	Harney	9/01/88	76.9	<43	<.108	.26	<21	<2.2	<22	.82

Table 25.--Concentrations of trace elements in plants, aquatic invertebrates, and fish collected from the Malheur National Wildlife Refuge, 1988--Continued

Chromium	Copper	Iron	Lead	Mercury	Magnesium	Manganese	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Tin	Vanadium	Zinc
9.2	39	5100	13	0.13	11000	250	<25	<20	0.99	<25	200	<0.50	<25	<25	39
14	12	2200	9.7	<.11	8200	92	<22	<18	.88	<22	140	<.45	<22	<22	21
12	11	7800	4	.01	9300	210	<2	11	.3	<2	220	<5	22	22	19
<.65	<16	820	6.5	<.16	5030	240	<33	<26	.65	<33	107	<.66	<33	<33	23
<.56	<14	520	<5.6	<.14	4900	905	<28	<22	.56	<28	91	<.56	<28	<28	28
1.0	75	940	<4	.12	3000	39	<1	5.1	.93	<2	380	<4	--	3.1	56
1.0	16	1400	<4	.091	1600	77	<1	2	1.2	<2	9.1	<5	--	3.8	71
1.0	15	600	<4	.080	1700	17	<1	3	1.4	<2	11	<4	--	1.7	81
<.60	49	370	<5.9	.24	1500	31	<30	<24	1.2	<30	24	<.60	<30	<30	170
<.55	33	180	<5.5	.26	1700	24	<28	<22	2.2	<28	13	<.56	<28	<28	270
<.56	33	220	<5.6	<.14	1500	16	<28	<22	1.7	<28	12	<.57	<28	<28	170
4.1	11	1700	<4	.056	1600	2400	<1	3	1.8	<2	98	<4	--	2.9	106
<.62	<16	310	<6.2	.64	1700	27	<31	<25	1.9	<31	89	<.63	<31	<31	84
<.49	36	320	<4.9	.30	2200	38	<25	<20	2.5	<25	220	<.50	<25	<25	110
<.51	13	470	<5.1	.91	1700	18	<25	<20	2.0	<25	93	<.51	<25	<25	370
.61	<12	250	<4.7	.70	1400	8.5	<24	<19	1.9	<24	99	<.48	<24	<24	305
<.55	<14	190	<5.5	.95	1400	<8.3	<28	<22	2.2	<28	109	<.56	<28	<28	406
<1	3.5	94	<4	3.2	1600	2.7	<1	<1	.92	<2	110	<4	--	<.3	57
<.54	<13	260	<5.4	.47	1300	<8.1	<27	<21	1.6	<27	19	<.54	<27	<27	120
4.6	22	170	<5.1	1.5	1700	33	<26	<21	3.1	<26	57	.70	<26	<26	110
.98	<8.2	130	<3.3	1.6	220	7.2	<16	<13	.66	<16	205	<.33	<16	<16	76
<.57	<14	74	<5.7	.25	2400	22	<28	<23	1.1	<28	450	<.57	<28	<28	108
<.43	<11	82	<4.3	<.61	1400	<6.5	<22	<17	2.2	<22	130	<.44	38	<22	77

Table 26.--Concentrations of trace elements in aquatic-bird eggs and livers collected from the Malheur National Wildlife Refuge, 1988

[Concentrations in micrograms per gram on a dry weight basis; moisture in percent concentrations; < (less than values) were less than the analytical reporting limit; -- indicates no samples analyzed; liver samples consist of a composite of two to three livers; D.C. Cormorant is Double-Crested Cormorant]

Species	Sample	Site	Date	Moisture	Alumi-num	Anti-mony	Arse-nic	Bar-ium	Beryl-lium	Boron	Cad-mium	Chro-mium
American avocet	Egg	S Malheur	6/02/88	74.4	<3	--	<0.1	3.7	<0.1	<2	<0.2	<1
American avocet	Egg	S Malheur	6/02/88	73.5	.6	--	.1	6.1	<.01	<2	<.03	.67
American avocet	Egg	S Malheur	6/02/88	72.1	<.3	--	.1	3.5	<.01	<2	.04	<.1
American avocet	Egg	S Malheur	6/02/88	73.8	.4	--	.1	3.7	<.01	<2	.04	<.1
American avocet	Egg	N Malheur	6/03/88	74.8	<3	--	<.1	7.8	<.1	3	<.2	<1
American avocet	Egg	N Malheur	6/03/88	73.0	.8	--	.1	7.9	<.01	2	<.03	1.0
American avocet	Egg	N Malheur	6/03/88	72.4	<.3	--	.1	6.6	<.01	<2	<.03	.1
American avocet	Egg	N Malheur	6/03/88	73.3	<.3	--	.1	3.9	<.01	<2	<.03	.3
American avocet	Egg	Harney	6/01/88	72.3	<3	--	<.1	1.7	<.1	3	<.2	<1
American avocet	Egg	Harney	6/01/88	74.9	.7	--	1.6	2.2	<.01	4	<0.03	1.1
American avocet	Egg	Harney	6/01/88	73.8	.4	--	.1	2.1	<.01	7.7	0.03	.66
American avocet	Egg	Harney	6/01/88	74.8	.7	--	<.1	2.0	<.01	3	0.04	.73
American coot	Egg	S Malheur	6/02/88	73.5	<3	--	<.1	2.4	<.1	<2	<.2	<1
American coot	Egg	S Malheur	6/02/88	74.1	.6	--	.1	7.3	<.01	<2	<.03	.2
American coot	Egg	S Malheur	6/02/88	75.7	.6	--	.1	.31	<.01	<2	<.03	.55
American coot	Egg	S Malheur	6/02/88	76.0	.6	--	.1	1.2	<.01	<2	<.03	.2
American coot	Egg	N Malheur	6/03/88	73.7	<3	--	<.1	8.5	<.1	3	<.2	<1
American coot	Egg	N Malheur	6/03/88	75.3	.8	--	.1	9.7	<.01	6	.05	.3
American coot	Egg	N Malheur	6/03/88	73.9	<.3	--	<.1	2.8	<.01	5	.04	<.1
American coot	Egg	N Malheur	6/03/88	77.2	<.3	--	.1	1.2	<.01	5	.04	<.1
D.C. cormorant	Egg	N Malheur	5/03/88	83.1	2.3	--	.1	.37	<.01	<2	<.04	<.1
D.C. cormorant	Egg	N Malheur	5/03/88	83.7	3.4	--	.1	.36	<.01	<2	<.04	<.1
D.C. cormorant	Egg	N Malheur	5/03/88	83.6	.4	--	.1	.46	<.01	<2	<.03	.1
D.C. cormorant	Egg	Harney	5/04/88	83.5	<.3	--	<.1	.2	<.01	<2	.04	<.1
D.C. cormorant	Egg	Harney	5/04/88	83.9	<.3	--	<.1	.36	<.01	<2	.04	.2
D.C. cormorant	Egg	Harney	5/04/88	83.5	.3	--	<.1	.2	<.01	2	<.01	.06
Gadwall	Egg	S Malheur	6/02/88	69.2	.5	--	<.1	10.9	<.01	<2	.04	<.1
Gadwall	Egg	S Malheur	6/14/88	65.8	.5	--	.1	18	<.01	3	<.01	.08
Gadwall	Egg	S Malheur	6/14/88	69.6	1	--	.2	18	<.01	8.4	.04	3.4
Gadwall	Egg	N Malheur	6/28/88	68.9	<3	--	<.1	19	<.1	4	<.2	<1
Gadwall	Egg	N Malheur	6/22/88	67.8	.7	--	<.1	15	.01	<2	.04	.1
Gadwall	Egg	N Malheur	6/28/88	66.6	.4	--	.2	5.6	<.01	<2	.03	.2
Gadwall	Egg	N Malheur	6/22/88	68.4	.5	--	.1	6.7	<.01	5	.03	.2
Gadwall	Egg	Harney	6/16/88	69.5	.4	--	.1	5.4	<.01	12	<.03	.61
Gadwall	Egg	Harney	6/15/88	70.0	<.3	--	<.1	4.5	<.01	<2	<.03	.47
Gadwall	Egg	Harney	6/16/88	70.2	.7	--	<.1	7.9	<.01	<2	<.03	<.1
Great blue heron	Egg	N Malheur	5/03/88	82.6	1	--	.1	.33	<.01	<2	.04	.46
Great blue heron	Egg	N Malheur	5/03/88	81.4	.5	--	.1	.2	<.01	<2	<.03	<.1
Great blue heron	Egg	N Malheur	5/03/88	81.2	.6	--	.1	.44	<.01	<2	<.04	<.1
Great blue beron	Egg	Harney	5/04/88	82.1	.4	--	<.1	.1	<.01	<2	<.03	<.1
Great blue heron	Egg	Harney	5/04/88	84.3	.8	--	.1	.2	<.01	<2	.04	.3
Great blue Heron	Egg	Harney	5/04/88	82.3	1.7	--	<.1	.2	<.01	<2	<.04	<.1
White pelican	Egg	N Malheur	8/10/88	80.8	<52	<0.13	.062	<26	<2.6	<26	<.26	<.52
White pelican	Egg	N Malheur	8/10/88	81.7	<55	<0.14	.13	<27	<2.7	<27	<.27	<.55
White pelican	Egg	N Malheur	8/10/88	82.3	<56	<0.14	.034	<28	<2.8	<28	<.28	<.56
White pelican	Egg	N Malheur	8/10/88	81.1	<53	<0.13	.106	<26	<2.6	<26	<.26	<.53
White pelican	Egg	N Malheur	8/10/88	82.6	<57	<0.14	.086	<29	<2.9	<29	<.29	<.57
American avocet	Liver	S Malheur	6/28/88	71.5	<35	0.105	.17	<17	<1.7	<17	5.9	<.35
American avocet	Liver	N Malheur	6/28/88	72.9	<37	<0.092	.13	<18	<1.8	<18	2.6	<.37
American avocet	Liver	Harney	6/29/88	73.7	<38	<0.095	.072	<19	<1.9	<19	3.3	<.38
American coot	Liver	S Malheur	6/28/88	74.4	<39	<0.098	.35	<19	<1.9	<19	.56	<.39
American coot	Liver	N Malheur	6/28/88	72.9	<37	0.11	.37	<18	<1.8	<18	.55	<.37
American coot	Liver	Harney	6/29/88	75.1	<40.2	<0.10	.56	<20	<2.0	<20	.96	<.41
Gadwall (adult)	Liver	S Malheur	8/22/88	71.7	35	<0.088	.304	<18	<1.8	<18	1.7	<.35
Gadwall (adult)	Liver	N Malheur	6/30/88	72.6	<36	<0.091	.30	<18	<1.8	<18	14	<.36
Gadwall (adult)	Liver	N Malheur	8/24/88	73.6	<38	<0.095	.22	<19	<1.9	<19	2.3	<.38
Gadwall (adult)	Liver	Harney	8/22/88	75.7	<41	<0.103	.45	<21	11	26	1.6	<.41
Gadwall (juv.)	Liver	S Malheur	8/22/88	76.8	<43	<0.108	<.22	<22	<2.2	<22	.56	<.43
Gadwall (juv.)	Liver	N Malheur	8/24/88	71.6	<35	<0.088	.18	<18	<1.8	<18	.35	<.35
Mallard	Liver	Harney	7/20/88	72.2	<36	<0.09	.24	<18	<1.8	<18	1.8	<.36
Western grebe	Liver	Harney	7/01/88	76.1	<3	--	<.1	.2	<.1	<2	1.5	<1
Western grebe	Liver	Harney	7/01/88	76.1	<3	--	.1	.2	<.09	<2	4.0	<1

Table 26.--Concentrations of trace elements in aquatic-bird eggs and livers collected from the Malheur National Wildlife Refuge, 1988--Continued

Copper	Iron	Lead	Mercury	Magnesium	Manganese	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Tin	Vanadium	Zinc
3.5	120	<4	0.16	480	2.4	<1	<2	1.5	<2	11	<4	--	<0.3	54
3.01	130	<.4	.29	440	1.5	<1	.44	1.7	<2	10	<.6	--	<.3	48
2.9	110	1.9	.055	470	2.1	<1	<.1	1.4	<2	9.2	<.6	--	<.3	48
3.2	120	.6	.57	430	1.6	<1	.2	1.6	<2	8.4	<.6	--	<.3	54
3.3	130	<4	.18	440	2.9	<1	<2	3.1	<2	11	<4	--	<.3	46
3.1	110	<.4	.34	430	2.4	<1	.70	.87	<2	15	<.6	--	<.3	48
2.7	110	<.4	.38	409	2.0	<1	<.1	1.9	<2	7.4	<.5	--	<.3	46
3.0	105	<.4	.31	350	2.2	<1	.3	3.1	<2	5.1	<.6	--	<.3	36
3.7	130	<4	.42	430	.99	1	<1	1.3	<2	9.8	<4	--	<.3	53
4.1	110	<.4	.31	404	2.1	<1	.62	2.0	<2	7.8	<.6	--	<.3	60
3.1	130	<.4	.26	402	1.8	<1	.30	2.1	<2	8.5	<.6	--	<.3	44
3.7	101	<.4	.12	400	2.1	<1	.37	1.5	<2	10.6	<.6	--	<.3	54
2.7	89	<4	.44	520	3.7	<1	<1	1.3	<2	5.7	<4	--	<.3	67
2.7	110	<.4	.32	450	3.4	<1	<.1	1.0	<2	6.1	<.6	--	<.3	67
2.3	100	<.4	.30	390	4.4	<1	.3	1.8	<2	2.0	<.6	--	<.3	60
2.7	80	<.4	.59	520	3.3	<1	<.1	1.8	<2	3.7	<.6	--	<.3	49
3.0	84	<4	.043	460	1.3	<1	<2	1.8	<2	9.1	<4	--	<.3	52
3.1	94	<.4	.094	490	1.1	<1	.2	1.5	<2	11	<.6	--	<.3	56
2.4	92	<.4	.11	450	1.8	<1	.2	1.4	<2	6.7	<.6	--	<.3	50
1.4	77	<.4	.19	450	1.2	<1	<.1	1.5	<2	6.0	<.6	--	<.3	46
6.6	150	<.5	2.4	603	1.5	1	<.1	2.2	<2	5.6	<.6	--	<.3	49
6.5	110	<.5	1.7	560	1.4	1	<.1	2.6	<2	4.6	<.6	--	<.3	53
7.0	160	<.4	.92	560	1.6	1	.2	2.4	<2	5.9	<.6	--	<.3	57
7.4	160	<.4	2.6	550	1.6	<1	.2	2.2	<2	5.0	<.6	--	<.3	48
6.2	140	<.4	2.7	560	1.7	1	<.1	2.1	<2	6.0	<.6	--	<.3	62
2.8	69	.3	1.5	550	.70	1	<.09	2.1	<2	5.1	<.2	--	<.3	22
3.6	104	<.4	.12	400	1.7	<1	.1	1.1	<2	8.1	<.6	--	<.3	56
1.8	74	<.2	.061	320	1.2	<1	<.09	1.3	<2	8.7	<.2	--	<.3	36
3.4	140	<.4	.12	390	1.4	<1	1.8	1.1	<2	8.7	<.6	--	<.3	68
4.0	110	<4	.15	380	1.5	<1	<2	1.2	<2	11	<4	--	<.3	60
3.3	94	<.4	.48	360	3.1	<1	<.1	1.4	<2	7.1	<.6	--	<.3	57
2.9	100	<.4	1.1	340	2.4	<1	<.1	1.4	<2	7.0	<.6	--	<.3	49
3.3	96	<.4	.19	280	1.3	<1	.2	1.5	<2	6.5	<.6	--	<.3	52
3.8	94	.7	.31	390	.69	<1	.47	1.4	<2	7.3	<.6	--	<.3	53
1.3	56	<.4	.061	150	.56	<1	.2	.79	<2	4.6	<.6	--	<.3	26
2.3	110	<.4	.094	330	2.0	<1	.1	1.3	<2	8.2	<.6	--	<.3	53
4.5	110	<.5	2.6	500	1.7	<1	.2	2.0	<2	2.5	<.6	--	<.3	46
5.2	108	<.4	1.7	560	1.8	<1	<.1	2.3	<2	2.1	<.6	--	<.3	42
6.0	90	<.4	1.2	660	1.5	1	<.1	2.6	<2	2.4	<.6	--	<.3	55
5.2	101	<.4	1.3	530	1.3	1	<.1	2.4	<2	3.2	<.6	--	<.3	44
5.2	120	<.4	1.5	650	1.8	1	.43	2.7	<2	6.2	<.6	--	<.3	52
5.05	130	<.5	3.7	600	1.7	1	<0.1	3.0	<2	6.1	<.6	--	<.3	53
<13	99	<5.2	2.6	570	<7.8	<26	<21	3.1	<26	6.8	<.53	<26	<26	44
<14	82	<5.5	3.3	550	<8.2	<27	<22	2.7	<27	<5.5	<.55	<27	<27	43
<14	107	<5.6	7.7	<560	<8.5	<28	<23	2.8	<28	<5.6	<.57	<28	<28	43
<13	90	<5.3	5.8	630	<7.9	<26	<21	3.2	<26	7.4	<.53	<26	<26	52
<14	98	<5.7	4.3	<570	<8.6	<29	<23	2.3	<29	<5.7	<.58	<29	<29	45
22	2800	<3.5	.26	807	13	<17	<14	17	<17	<3.5	<.36	<17	<17	102
28	2100	<3.7	.72	810	11	<18	<15	21	<18	<3.7	<.37	<18	<18	102
24	1400	<3.8	2.3	760	14	<19	<15	14	<19	<3.8	<.39	<19	<19	120
23	2900	<3.8	.37	820	12	<19	<16	7.4	<19	<3.9	<.40	<19	<19	150
45	3500	<3.7	1.5	701	7.7	<18	<15	11	<18	<3.7	<.37	<18	<18	150
49	1600	<4.0	1.4	760	8.8	<20	<16	5.6	<20	<4.0	<.41	<20	<20	170
160	2500	<3.5	.49	707	11	<18	<14	14	<18	<3.5	<.36	<18	<18	180
164	1800	<3.6	<3.6	803	16	<18	<15	36	<18	<3.7	<.37	<18	<18	190
210	11000	<3.8	.20	830	12	<19	<15	22	<19	<3.8	<.38	<19	<19	205
308	2300	<4.2	.76	1400	53	<21	25	21	<21	6.6	<.42	<21	<21	240
320	1020	<4.3	.90	1030	11	<22	<17	14	<22	4.3	<.44	<22	<22	240
170	520	<3.5	.22	810	10	<18	<14	3.9	<18	<3.5	<.36	<18	<18	180
85	3300	<3.6	.64	750	14	<18	<14	15	<18	<3.6	<.36	<18	<18	130
34	14000	<4	21	850	25	<2	<2	11	<2	1.1	<4	--	<.3	230
42	14000	<4	16	980	29	<2	<1	17	<2	.93	<4	--	<.3	250

Table 27.--Concentrations of pesticides and polychlorinated biphenyls (PCBs) in fish, birds, and eggs collected from the Malheur National Wildlife Refuge, 1988

[Concentrations are in micrograms per gram on a wet-weight basis; -- indicates no analysis performed; < (less than values) were less than the analytical reporting limit; o,p' = ortho,para'; BHC = 1,2,3,4,5,6-hexachlorocyclohexane; DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene; DDT = dichlorodiphenyltrichloroethane; HCB = hexachlorobenzene]

Constituent	White Crappie			American Avocet			American Coot	
	South Malheur	North Malheur	Harney	South Malheur	North Malheur	Harney	South Malheur	North Malheur
Type of sample	Fish	Fish	Fish	Egg	Egg	Egg	Egg	Egg
Date collected	8/30/88	8/30/88	9/1/88	6/2/88	6/3/88	6/1/88	6/2/88	6/3/88
Percent moisture	85.4	93.4	84.5	70.5	73.0	70.5	73.0	74.5
Percent lipid	3.35	1.02	3.79	12.0	12.4	14.2	10.1	10.1
Aldrin	<0.05	<0.05	<0.05	--	--	--	--	--
Alpha-BHC	<.05	<.05	<.05	<0.01	<0.01	<0.01	<0.01	<0.01
Beta-BHC	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
Delta-BHC	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
Alpha-Chlordane	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
Gamma-Chlordane	<.05	<.05	<.05	.01	<.01	.01	<.01	<.01
o,p'-DDD	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
p,p'-DDD	<.05	<.05	<.05	.02	<.01	<.01	<.01	<.01
o,p'-DDE	<.05	<.05	<.05	<.01	<.01	.01	<.01	<.01
p,p'-DDE	<.05	<.05	<.05	3.9	.14	1.7	.19	.05
o,p'-DDT	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
p,p'-DDT	<.05	<.05	<.05	<.01	<.01	.02	.01	<.01
Dieldrin	<.05	<.05	<.05	.04	<.01	.03	<.01	<.01
Endrin	<.05	<.05	<.05	.01	<.01	<.01	<.01	<.01
Heptachlor	<.05	<.05	<.05	--	--	--	--	--
Heptachlor Epoxide	<.05	<.05	<.05	.02	<.01	<.01	<.01	<.01
HCB	<.05	<.05	<.05	.06	<.01	.03	<.01	<.01
Lindane	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
Mirex	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
cis-Nonachlor	<.05	<.05	<.05	<.01	<.01	<.01	<.01	<.01
trans-Nonachlor	<.05	<.05	<.05	.03	<.01	<.01	<.01	<.01
Oxychlordane	<.05	<.05	<.05	.01	<.01	<.01	<.01	<.01
Total PCBs	<.05	<.05	<.05	<.05	<.05	<.05	.18	<.05
Toxaphene	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05

Table 27.--Concentrations of pesticides and polychlorinated biphenyls (PCBs) in fish, birds, and eggs collected from the Malheur National Wildlife Refuge, 1988--Continued

Constituent	Gadwall			Great Blue Heron		Gadwall (Adult)			Gadwall (Juveniles)	
	South Malheur	North Malheur	Harney	North Malheur	Harney	South Malheur	North Malheur	Harney	South Malheur	North Malheur
Type of sample	Egg	Egg	Egg	Egg	Egg	Carcass	Carcass	Carcass	Carcass	Carcass
Date collected	6/14/88	6/22/88	6/16/88	5/3/88	5/4/88	7/19/88	6/30/88	6/29/88	8/22/89	8/24/89
Percent moisture	68.0	65.2	70.5	81.5	83.5	75.3	88.9	82.9	89.7	84.5
Percent lipid	15.7	17.4	14.1	5.71	4.73	13.7	6.59	3.23	1.25	1.09
Aldrin	--	--	--	--	--	<0.05	<0.05	<0.05	<0.05	<0.05
Alpha-BHC	<0.01	<0.01	<0.01	<0.01	<0.01	<.05	<.05	<.05	<.05	<.05
Beta-BHC	<.01	<.01	<.01	<.01	.05	<.05	<.05	<.05	<.05	<.05
Delta-BHC	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
Alpha-Chlordane	<.01	<.01	<.01	.03	.01	<.05	<.05	<.05	<.05	<.05
Gamma-Chlordane	<.01	<.01	<.01	.02	.01	<.05	<.05	<.05	<.05	<.05
o,p'-DDD	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
p,p'-DDD	<.01	<.01	<.01	.09	.07	<.05	<.05	<.05	<.05	<.05
o,p'-DDE	<.01	<.01	<.01	.06	.02	<.05	<.05	<.05	<.05	<.05
p,p'-DDE	.04	.28	.07	5.3	4.3	<.05	.39	<.05	<.05	<.05
o,p'-DDT	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
p,p'-DDT	<.01	<.01	<.01	<.01	.21	<.05	<.05	<.05	<.05	<.05
Dieldrin	<.01	<.01	<.01	.10	.02	<.05	<.05	<.05	<.05	<.05
Endrin	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
Heptachlor	--	--	--	--	--	<.05	<.05	<.05	<.05	<.05
Heptachlor Epoxide	<.01	<.01	<.01	<.01	.02	<.05	<.05	<.05	<.05	<.05
HCB	<.01	<.01	<.01	.01	.01	<.05	<.05	<.05	<.05	<.05
Lindane	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
Mirex	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
cis-Nonachlor	<.01	<.01	<.01	<.01	<.01	<.05	<.05	<.05	<.05	<.05
trans-Nonachlor	<.01	<.01	<.01	.11	.03	<.05	.06	<.05	<.05	<.05
Oxychlordane	<.01	<.01	<.01	<.01	.02	<.05	<.05	<.05	<.05	<.05
Total PCBs	<.05	<.05	.07	.93	.25	<.05	.61	<.05	<.05	<.05
Toxaphene	<.05	<.05	<.05	1.4	.31	<.05	<.05	<.05	<.05	<.05

Table 28.--Analysis of water-quality samples collected from the Malheur National Wildlife Refuge, 1988

[deg C = degrees Celsius, µS/cm = microsiemen per centimeter, mg/L = milligrams per liter, µg/L = micrograms per liter, " --" = not analyzed, < = less than]

Date	Station name	Time	Temperature water (deg C)	Barometric pressure (mm of Hg)	Discharge inst. cubic feet per second	Specific conductance (µS/cm)	Oxygen dissolved (mg/L)	Oxygen dissolved (percent saturation)	pH (standard units)	Alkalinity filtered (mg/L as $CaCO_3$)	Solids residue at 180 deg. C dissolved (mg/L)	Silica dissolved (mg/L as SiO_2)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium dissolved (mg/L as Na)	Potassium dissolved (mg/L as K)	Chloride dissolved (mg/L as Cl)	Sulfate dissolved (mg/L as SO_4)	Fluoride dissolved (mg/L as F)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorous ortho dissolved (mg/L as P)
Mar 22..	Silvies R at Dam	1700	7.4	650	87.6	171	9.6	94	8.0	77	155	--	18	5.8	9.8	3.3	1.9	12	--	<0.1	--
Sep 14...	Silvies R at Dam	0930	13.1	656	10.4	157	6.6	73	7.9	78	127	34	13	4.9	12	3.5	2.0	3.9	0.1	<.1	0.05
Mar 23...	E F Silvies R	1000	6.6	652	2.08	436	9.9	94	8.5	163	288	--	39	12	38	1.9	7.1	57	--	<.1	--
Mar 23...	W F Silvies R	1430	8.6	652	9.87	223	10.0	100	8.2	107	165	--	23	6.6	15	.6	3.9	13	--	<.1	--
Jul 18...	D und B at Page Sp	1230	18.6	659	48.7	91	9.0	111	8.2	48	74	--	8.6	3.6	5.4	1.3	1.0	1.8	--	<.1	--
Sep 17...	D und B at Page Sp	1315	13.1	654	31.3	98	10.4	115	8.6	50	87	28	9.0	4.0	6.0	1.3	1.1	1.8	.1	<.1	.01
Jul 21...	D und B nr Voltage	1045	22.6	662	6.40	328	6.1	82	8.2	147	214	--	28	14	23	2.5	4.2	24	--	<.1	--
Sep 16...	D und B nr Voltage	1545	16.1	655	15.4	142	6.0	71	7.2	72	235	32	12	6.5	11	1.6	2.0	9.2	.1	<.1	.14
Jul 21...	Sod House Sp	1400	11.7	660	--	432	7.2	76	7.8	200	296	--	17	17	44	18	11.	23	--	.54	--
Sep 16...	Sod House Sp	1030	11.8	655	--	421	6.7	72	8.0	186	273	41	19	17	40	14	11	21	.3	.45	.15
Jul 18...	S Diamond Canal	1600	27.0	661	0.24	186	13.5	197	9.3	101	126	--	19	9.0	11	1.2	.7	1.9	--	1.1	--
May 11...	Silver Cr	1045	13.6	651	26.4	120	9.4	107	8.2	61	107	--	10	4.4	8.6	2.2	1.6	5.4	--	<.1	--
11...	Silver Cr	--	--	--	--	--	--	--	--	--	--	--	10	4.4	8.7	2.3	1.7	5.8	--	<.1	--
May 10...	Double O Cold Sp	1115	17.6	661	15.1	290	9.6	117	8.9	100	196	--	14	5.9	38	5.2	22	9.0	--	.44	--
10...	Double O Cold Sp	--	--		--	--	--	--	--	--	--	--	14	5.9	37	5.1	22	8.8	--	.44	--
Sep 15...	Double O Cold Sp	1130	17.9	655	13.6	286	8.7	107	8.9	102	213	--	14	6.1	37	5.3	22	8.4	.2	.40	.01
May 10...	Combined Springs	1500	18.4	661	1.82	650	8.6	106	8.4	248	403	--	22	9.3	110	7.0	49	20	--	<.1	--
Jul 20...	Silver Creek Inflow	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Jul 20...	Silver Cr Inflow	1100	20.4	661	--	5570	6.2	82	--	--	--	55	--	--	--	--	--	--	--	--	--
Jul 21...	D und B R Inflow	1500	27.4	660	--	337	6.4	94	7.8	--	--	--	--	--	--	--	--	--	--	--	--
Jul 19...	Silvies R Inflow	1000	16.4	662	--	2440	6.9	82	9.2	--	--	--	34	32	390	20	180	98	--	.69	--
19...	Malheur L nr center	1130	20.1	662	--	1980	6.4	82	8.9	718	1320	--	34	33	390	15	190	98	--	.71	--
Sep 14...	Malheur L at Narrows	1315	16.0	658	--	2830	8.3	98	9.0	923	1840	49	25	36	610	34	340	140	1.1	<.1	.61
Jul 20...	Harney L nr center	0945	20.1	661	--	4390	7.3	93	9.1	1000	2730	--	14	11	1000	20	760	210	--	<.1	--
Sep 15...	Harney L nr N Shore	1430	18.3	654	--	8340	10.0	124	9.6	1820	5180	45	12	9.3	2000	64	1500	410	2.0	<.1	2.3

Table 28.--Analysis of water-quality samples collected from the Malheur National Wildlife Refuge, 1988--Continued

Date	Station name	Time	Molybdenum, dissolved (µg/L as Mo)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Aluminum, dissolved (µg/L as Al)	Lithium dissolved (µg/L as Li)	Selenium, dissolved (µg/L as Se)	Uranium natural dissolved (µg/L as U)	Mercury dissolved (µg/L as Hg)	Arsenic dissolved (µg/L as As)	Barium dissolved (µg/L as Ba)	Boron dissolved (µg/L as B)	Cadmium dissolved (µg/L as Cd)	Chromium dissolved (µg/L as Cr)	Copper dissolved (µg/L as Cu)	Iron dissolved (µg/L as Fe)	Lead dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)
Mar 22...	Silvies R at Dam	1700	1	--	8	4	--	--	<1	0.6	<0.1	<1	--	40	<1	<1	4	--	<5	--
Sep 14...	Silvies R at Dam	0930	1	82	6	3	600	<4	<1	--	<.1	1	31	40	<1	<1	4	81	<5	41
Mar 23...	E F Silvies R	1000	7	--	9	<3	--	--	<1	.9	<.1	2	--	80	<1	<1	3	--	<5	--
Mar 23...	W F Silvies R	1430	3	--	6	<3	--	--	<1	<.4	<.1	2	--	70	<1	<1	4	--	<5	--
Jul 18...	D und B at Page Sp	1230	<1	--	6	<3	--	--	<1	<.4	<.1	<1	--	20	<1	<1	5	--	<5	--
Sep 17...	D und B at Page Sp	1315	<1	55	5	13	10	<4	<1	--	<.1	<1	3	<10	<1	<1	2	24	<5	5
Jul 21...	D und B nr Voltage	1045	3	--	17	<3	--	--	<1	.8	<.1	1	--	40	<1	<1	3	--	<5	--
Sep 16...	D und B nr Voltage	1545	<1	64	15	4	1000	<4	<1	--	<.1	1	13	20	<1	1	8	1500	<5	200
Jul 21...	Sod House Sp	1400	2	--	33	4	--	--	<1	.9	<.1	6	--	170	<1	1	2	--	5	--
Sep 16...	Sod House Sp	1030	3	90	20	4	<10	<4	<1	--	<.1	5	2	160	<1	1	1	<3	<5	<1
Jul 18...	S Diamond Canal	1600	<1	--	28	9	--	--	<1	<.4	<.1	2	--	20	<1	<1	9	--	<5	--
May 11...	Silver Cr	1040	1	--	5	<3	--	--	<1	<.4	<.1	1	--	70	<1	1	<1	--	<5	--
11...	Silver Cr	1045	2	--	6	<3	--	--	<1	<.4	<.1	1	--	70	<1	<1	<1	--	<5	--
May 10...	Double O Cold Sp	1110	2	--	16	<3	--	--	<1	.6	<.1	8	--	540	<1	1	<1	--	<5	--
10...	Double O Cold Sp	1115	2	--	16	<3	--	--	<1	.5	<.1	8	--	550	<1	1	<1	--	<5	--
Sep 15...	Double O Cold Sp	1130	2	64	15	15	<10	18	<1	--	<.1	9	3	500	1	<1	2	4	<5	<1
May 10...	Combined Springs	1500	7	--	44	<3	--	--	<1	1.3	<.1	47	--	1100	<1	<1	1	--	<5	--
Jul 19...	Malheur L nr center	1130	15	--	51	20	--	--	<1	3.7	<.1	55	--	2800	1	<1	5	--	<5	--
19...	Malheur L nr center	1135	14	--	51	<10	--	--	<1	3.7	<.1	63	--	2800	2	<1	7	--	<5	--
Sep 14...	Malheur L at Narrows	1315	22	100	48	<10	20	20	<1	--	<.1	78	<100	4300	<1	<1	4	30.00	<5	<10
Jul 20...	Harney L nr center	0945	29	--	40	<10	--	--	<1	2.8	<.1	250	--	8500	1	<1	4	--	<5	--
Sep 15...	Harney L nr N Shore	1430	51	200	52	<10	20	40	<1	--	<.1	330	<100	16000	<1	<1	4	20.00	<5	<10

Date	Station name	Time	2,4-D total (µg/L)	Dicamba (Mediben) (Banvel D) total (µg/L)	2,4-DP total (µg/L)	Picloram (Tordon) (Amdon) total (µg/L)	Silvex total (µg/L)	2,4,5-T total (µg/L)	Alachlor total recover (µg/L)	Ametryne total (µg/L)	Atrazine total (µg/L)
Jul 19...	Malheur L nr center	1130	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	<0.10	<0.10	<0.10
20...	Harney L nr center	0945	<.01	.01	<.01	<.01	<.01	<.01	<.10	<.10	<.10

Date	Station name	Time	Cyanazine total (µg/L)	Metolachlor water whole tot.rec (µg/L)	Metribuzin water whole tot.rec (µg/L)	Prometone total (µg/L)	Prometryne total (µg/L)	Propazine total (µg/L)	Simazine total (µg/L)	Simetryne total (µg/L)	Trifluralin total recover (µg/L)
Jul 19...	Malheur L nr center	1130	<0.10	<0.1	<0.1	<0.1	<0.1	<0.10	<0.10	<0.1	<0.10
20...	Harney L nr center	0945	<.10	<.1	<.1	<.1	<.1	<.10	<.10	<.1	<.10

Table 29.--Analysis of bottom-sediment samples collected from the Malheur National Wildlife Refuge, 1988

[g/kg = gram per kilogram wet weight, µg/kg = microgram per kilogram wet weight, DDD = dichlorodiphenyldichloroethane, DDE = dichlorodiphenyldichloroethylene, DDT = dichlorodiphenyltrichloroethane, PCB = polychlorinated biphenyl, and PCN = polychlorinated napthalene]

Date	Station name	Time	Carbon, organic total in bottom sediment (g/kg as C)	Aldrin total in bottom sediment (µg/kg)	Chlordane total in bottom sediment (µg/kg)	DDD total in bottom sediment (µg/kg)	DDE total in bottom sediment (µg/kg)	DDT total in bottom sediment (µg/kg)	Dieldrin total in bottom sediment (µg/kg)	Endosulfan total in bottom sediment (µg/kg)	Endrin total in bottom sediment (µg/kg)
Jul 20...	Silver Cr inflow	1100	10	<0.1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Jul 21...	Blitzen R inflow	1500	20	<.1	<1.0	.5	1.2	.1	<.1	<.1	<.1
Jul 19...	Silvies R inflow	1000	38	<.1	<1.0	.2	.3	<.1	<.1	<.1	.2
Jul 19...	Malheur L nr center	1130	95	<.1	<1.0	.5	.5	.4	<.1	<.1	<.1
19...	Malheur L nr center	1135	94	<.1	<1.0	<.1	.4	<.1	<.1	<.1	<.1
Jul 20...	Harney L nr center	0945	42	<.1	<1.0	.2	.3	<.1	<.1	<.1	<.1

Date	Station name	Time	PCB total in bottom sediment (µg/kg)	PCN total in bottom sediment (µg/kg)	Heptachlor total in bottom sediment (µg/kg)	Heptachlor Epoxide total in bottom sediment (µg/kg)	Lindane total in bottom sediment (µg/kg)	Methoxychlor total in bottom sediment (µg/kg)	Mirex total in bottom sediment (µg/kg)	Perthane total in bottom sediment (µg/kg)	Toxaphene total in bottom sediment (µg/kg)
Jul 20...	Silver Cr inflow	1100	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Jul 21...	Blitzen R inflow	1500	<1	<1.0	<.1	<.1	<.1	<.1	<.1	<1.00	<10
Jul 19...	Silvies R inflow	1000	<1	<1.0	<.1	<.1	<.1	<.1	<.1	<1.00	<10
Jul 19...	Malheur L nr center	1130	<1	<1.0	<.1	<.1	<.1	<.1	<.1	<1.00	<10
19...	Malheur L nr center	1135	<1	<1.0	<.1	<.1	<.1	<.1	<.1	<1.00	<10
Jul 20...	Harney L nr center	0945	<1	<1.0	<.1	<.1	<.1	<.1	<.1	<1.00	<10

Table 30.--Analysis of total trace elements in the less than 63 micrometer size fraction in bottom-sediment samples collected from the Malheur National Wildlife Refuge, 1988

[%-Wt = percent by weight; µg/g = micrograms per gram by weight]

Station name	Date	Aluminum (%-Wt)	Calcium (%-Wt)	Iron (%-Wt)	Potassium (%-Wt)	Magnesium (%-Wt)	Sodium (%-Wt)	Phosphorus (%-Wt)	Titanium (%-Wt)
Silvies R inflow	07/19/88	6.0	6.5	2.8	1.4	2.2	1.4	0.11	0.35
Malheur L nr center	07/19/88	4.0	7.9	2.5	1.1	2.6	0.91	.14	.28
Blitzen R inflow	07/21/88	8.5	3.9	6.1	0.98	1.4	2.1	.11	1.1
Harney L nr center	07/20/88	4.5	7.7	2.7	1.6	4.8	1.7	.07	.31
Silver Cr inflow	07/20/88	4.8	4.3	2.6	1.3	2.3	1.6	.09	.33
				Split sample					
Malheur L nr center	07/19/88	4.0	7.9	2.5	1.1	2.6	.91	0.14	0.28

Station name	Date	Manganese (µg/g)	Silver (µg/g)	Arsenic (µg/g)	Gold (µg/g)	Boron (µg/g)	Barium (µg/g)	Berylium (µg/g)	Bismuth (µg/g)
Silvies R inflow	07/19/88	620	<2	3.5	<8	15	550	1	<10
Malheur L nr center	07/19/88	590	<2	6.1	<8	21	360	<1	<10
Blitzen R inflow	07/21/88	770	<2	2.2	<8	1.0	620	1	<10
Harney L nr center	07/20/88	520	<2	11.	<8	55	340	1	<10
Silver Cr inflow	07/20/88	410	<2	9.3	<8	34	350	1	<10
				Split sample					
Malheur L nr center	07/19/88	590	<2	6.1	<8	19	360	<1	<10

Station name	Date	Cadmium (µg/g)	Cerium (µg/g)	Cobalt (µg/g)	Chromium (µg/g)	Copper (µg/g)	Europium (µg/g)	Gallium (µg/g)
Silvies R inflow	07/19/88	<2	34	12	49	33	<2	14
Malheur L nr center	07/19/88	<2	28	11	32	36	<2	10
Blitzen R inflow	07/21/88	<2	33	28	90	120	2	22
Harney L nr center	07/20/88	<2	27	13	40	39	<2	11
Silver Cr inflow	07/20/88	<2	30	10	47	30	<2	12
				Split sample				
Malheur L nr center	07/19/88	<2	27	12	32	34	<2	9

Table 30.--Analysis of total trace elements in the less than 63 micrometer size fraction in bottom-sediment samples collected from the Malheur National Wildlife Refuge, 1988--Continued

Station name	Date	Mercury (µg/g)	Lanthanum (µg/g)	Lithium (µg/g)	Molybdenum (µg/g)	Niobium (µg/g)	Neodymium (µg/g)	Nickel (µg/g)	Lead (µg/g)
Silvies R inflow	07/19/88	0.04	20	25	<2	5	21	27	11
Malheur L nr center	07/19/88	.06	16	27	<2	<4	18	23	8
Blitzen R inflow	07/21/88	.02	22	17	<2	9	27	46	8
Harney L nr center	07/20/88	.02	15	110	<2	<4	19	26	8
Silver Cr inflow	07/20/88	.02	16	47	<2	<4	17	19	7
Split sample									
Malheur L nr center	07/19/88	0.04	15	27	<2	<4	18	23	8

Station name	Date	Scandium (µg/g)	Selenium (µg/g)	Strontium (µg/g)	Tantalum (µg/g)	Thorium (µg/g)	Uranium (µg/g)	Vanadium (µg/g)	Yttrium (µg/g)
Silvies R inflow	07/19/88	11	0.5	440	<40	4	0.70	80	20
Malheur L nr center	07/19/88	8	.6	430	<40	<4	.70	71	15
Blitzen R inflow	07/21/88	21	.1	430	<40	4	.75	220	24
Harney L nr center	07/20/88	10	.1	490	<40	<4	.60	110	16
Silver Cr inflow	07/20/88	9	.3	310	<40	<4	.55	78	16
Split sample									
Malheur L nr center	07/19/88	8	0.7	430	<40	<4	0.40	69	15

Station name	Date	Ytterbium (µg/g)	Zinc (µg/g)
Silvies R inflow	07/19/88	2	100
Malheur L nr center	07/19/88	2	69
Blitzen R inflow	07/21/88	2	97
Harney L nr center	07/20/88	2	60
Silver Cr inflow	07/20/88	2	54
Split sample			
Malheur L nr center	07/19/88	2	69

Table 31.--Analysis of total trace elements in less than 2 millimeter size fraction in bottom-sediment samples collected from the Malheur National Wildlife Refuge, 1988

[%-Wt = percent by weight; µg/g = micrograms per gram by weight]

Station name	Date	Aluminum (%-Wt)	Calcium (%-Wt)	Iron (%-Wt)	Potassium (%-Wt)	Magnesium (%-Wt)	Sodium (%-Wt)	Phosphorus (%-Wt)	Titanium (%-Wt)
Silvies R inflow	07/19/88	6.5	6.7	3.2	1.3	2.3	1.6	0.10	0.37
Malheur L nr center	07/19/88	3.8	7.6	2.4	1.1	2.5	.85	.14	.27
Blitzen R inflow	07/21/88	8.5	4.0	5.6	1.0	1.3	2.1	.11	.93
Harney L nr center	07/20/88	4.4	7.4	2.7	1.6	4.8	1.7	.06	.29
Silver Cr inflow	07/20/88	8.2	4.0	2.2	1.4	1.2	2.9	.05	.29
			Split sample						
Malheur L nr center	07/19/88	3.9	7.9	2.5	1.1	2.5	.88	0.14	0.28

Station name	Date	Manganese (µg/g)	Silver (µg/g)	Arsenic (µg/g)	Gold (µg/g)	Boron (µg/g)	Barium (µg/g)	Berylium (µg/g)	Bismuth (µg/g)
Silvies R inflow	07/19/88	670	<2	3.0	<8	13	520	1	<10
Malheur L nr center	07/19/88	570	<2	6.2	<8	21	340	<1	<10
Blitzen R inflow	07/21/88	720	<2	2.2	<8	1.2	630	2	<10
Harney L nr center	07/20/88	520	<2	11.	<8	51	320	1	<10
Silver Cr inflow	07/20/88	390	<2	4.5	<8	16	490	1	<10
			Split sample						
Malheur L nr center	07/19/88	590	<2	5.1	<8	19	350	<1	<10

Station name	Date	Cadmium (µg/g)	Cerium (µg/g)	Cobalt (µg/g)	Chromium (µg/g)	Copper (µg/g)	Europium (µg/g)	Gallium (µg/g)
Silvies R inflow	07/19/88	<2	31	17	75	38	<2	14
Malheur L nr center	07/19/88	<2	27	11	30	34	<2	9
Blitzen R inflow	07/21/88	<2	34	27	72	100	<2	22
Harney L nr center	07/20/88	<2	27	13	39	39	<2	10
Silver Cr inflow	07/20/88	<2	33	9	31	14	<2	17
			Split sample					
Malheur L nr center	07/19/88	<2	28	12	31	37	<2	10

Table 31.--Analysis of total trace elements in less than 2 millimeter size fraction in bottom-sediment samples collected from the Malheur National Wildlife Refuge, 1988--Continued

Station name	Date	Mercury (µg/g)	Lanthanum (µg/g)	Lithium (µg/g)	Molybdenum (µg/g)	Niobium (µg/g)	Neodymium (µg/g)	Nickel (µg/g)	Lead (µg/g)
Silvies R inflow	07/19/88	0.02	18	23	<2	5	20	39	10
Malheur L nr center	07/19/88	.04	15	26	<2	<4	16	22	8
Blitzen R inflow	07/21/88	.02	21	17	<2	8	26	43	7
Harney L nr center	07/20/88	.02	15	110	<2	<4	19	26	7
Silver Cr inflow	07/20/88	<.02	18	28	<2	8	20	13	8
Split sample									
Malheur L nr center	07/19/88	0.04	15	27	<2	<4	17	22	8

Station name	Date	Scandium (µg/g)	Selenium (µg/g)	Strontium (µg/g)	Tantalum (µg/g)	Thorium (µg/g)	Uranium (µg/g)	Vanadium (µg/g)	Yttrium (µg/g)
Silvies R inflow	07/19/88	13	0.4	420	<40	<4	0.35	96	22
Malheur L nr center	07/19/88	8	.7	410	<40	<4	.70	69	15
Blitzen R inflow	07/21/88	18	.2	460	<40	5	.80	180	25
Harney L nr center	07/20/88	9	.1	470	<40	<4	.75	110	15
Silver Cr inflow	07/20/88	8	.1	500	<40	<4	.40	50	22
Split sample									
Malheur L nr center	07/19/88	8	0.7	420	<40	<4	0.65	71	15

Station name	Date	Ytterbium (µg/g)	Zinc (µg/g)
Silvies R inflow	07/19/88	3	94
Malheur L nr center	07/19/88	2	67
Blitzen R inflow	07/21/88	4	85
Harney L nr center	07/20/88	2	59
Silver Cr inflow	07/20/88	3	46
Split sample			
Malheur L nr center	07/19/88	2	69

Table 32.--Analysis of oxygen and hydrogen isotopes in Malheur National Wildlife Refuge water, 1988

["/" = divided by, O = oxygen, H = hydrogen, D = deuterium]

Date	Station name	Time	$^{18}O/^{16}O$ stable isotope ratio per mil	$^{2}H/D$ stable isotope ratio per mil
May 09...	Silvies River at Dam	1805	-15.0	-114
Sep 14...	Silvies River at Dam	0930	-13.1	-109
May 09...	East Fork Silvies River	1730	-12.9	-106
May 09...	West Fork Silvies River	1715	-14.2	-110
Sep 14...	West Fork Silvies River	1200	-7.2	-86
May 09...	Donner und Blitzen River at Page Spring	1730	-15.8	-116
Sep 17...	Donner und Blitzen River at Page Spring	1315	-15.2	-113
May 09...	Donner und Blitzen River near Voltage	1625	-13.9	-102
Sep 16...	Donner und Blitzen River near Voltage	1545	-13.4	-108
Jul 21...	Sod House Springs	1400	-13.5	-105
Sep 16...	Sod House Springs	1030	-13.4	-105
May 09...	South Diamond Canal	1830	-14.2	-107
May 11...	Silver Creek	1040	-15.8	-115
11...	Silver Creek	1045	-15.0	-121
Sep 17...	Silver Creek	0845	-13.5	-111
May 10...	Double O Cold Springs	1110	-15.5	-124
10...	Double O Cold Springs	1115	-15.2	-122
Sep 15...	Double O Cold Springs	1130	-15.8	-119
May 10...	Combined Springs	1500	-12.4	-111
Sep 15...	Combined Springs	1330	-15.5	-118
May 09...	Donner und Blitzen River Inflow	1610	-12.0	-102
Sep 16...	Donner und Blitzen River Inflow	1245	-13.2	-100
Jul 19...	Malheur Lake near center	1130	-0.4	-40
May 09...	Malheur Lake at Narrows	1650	-2.0	-44
Sep 14...	Malheur Lake at Narrows	1315	2.3	-25
Jul 20...	Harney Lake near center	0945	-2.6	-53
May 10...	Harney Lake near North Shore	1700	-2.6	-46
Sep 15...	Harney Lake near North Shore	1430	3.6	-23

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